Guide on

Climate Change Adaptation

for the Mining Sector

The Mining Association of Canada

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Guide on Climate Change Adaptation for the Mining Sector

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Natural Resources Canada
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Canada's Climate Change Adaptation Platform
Equipping Canadians for a Changing Climate

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Environment and Climate Change Canada
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Executive Summary

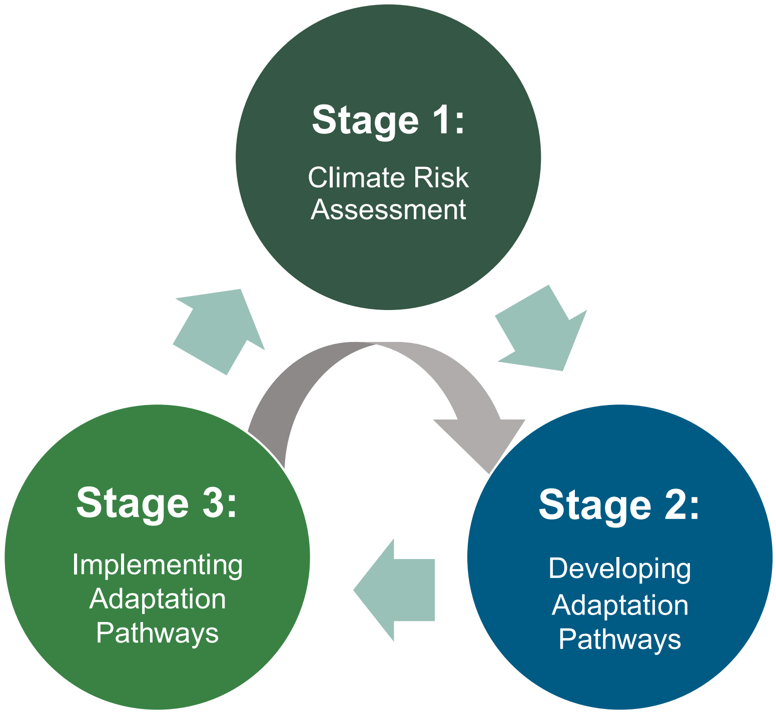
As part of the Mining Association of Canada's (MAC's) commitment to sustainable development, this document provides guidance on climate change adaptation for the mining sector. Climate change is already affecting the mining industry and projected changes to key climate variables such as temperature and rainfall have the potential to impact all aspects of the mining sector in the future. Mine Owners already have established processes in place to manage risks. Climate change acts as a modifier of these risks that could have physical, social, reputational, and economic impacts on the mining sector. Consistent with existing international guidance, this guidance provides tools that can be used by Owners to consider climate related risks and opportunities and incorporate climate change adaptation into their decision-making. This guidance describes a stepwise approach to:

- Increase the resilience of mines, reducing the potential for impacts and the need for more costly adaptation measures later in the life cycle.
- Take advantage of climate change opportunities for improved mine management, such as longer growing seasons that can help enhance revegetation and reclamation activities.

The incorporation of climate change considerations and the management of climate change-related liability is increasingly becoming a requirement by regulators. In parallel, there is a growing expectation from investors, lenders, insurers, and communities of interest (COI) that companies demonstrate how climate change-related risks are being managed. There is growing investor interest in the disclosure of the physical risks and opportunities posed by climate change, the potential operational, regulatory, financial, and reputational impacts, and corporate governance processes related to climate change adaptation. Implementing this guidance can help to inform disclosure of information related to climate change risk and support COI engagement, however, Owners should also consult specific guidance for environmental, social and governance disclosure through external reporting programs.

The guidance was developed with input from MAC members and subject matter experts and reflects the most up-to-date research in this area. The guidance specifically targets the Canadian mining sector but can be applied globally.

The guidance describes a three-stage process that Owners can apply to consider and incorporate climate change adaptation considerations into decision-making, as shown in the following figure.



Stage 1: Climate Change Risk Assessment

- Establish baseline climate conditions based on observed climate conditions for the site.
- Develop projected future climate conditions for the site using accepted modelling tools and approaches.
- Identify vulnerabilities by identifying infrastructure components, operations both on and off-site, ecosystem impacts and relationships to reclamation, and potential impacts on human health that interact with climate.
- Assess both direct and indirect risks associated with climate change for vulnerable infrastructure and operations.
- Identify potential opportunities that may arise from changing climate conditions.

Stage 2: Developing Adaptation Pathways

- Identify potential adaption measures to address risks or opportunities.
- Develop potential adaptation pathways that describe different options to address the risks or opportunities, including the timing (short, medium, or long-term) of implementation of adaptation measures such as upgrades to infrastructure, and the implementation of other adaption measures such as changes to operation, maintenance, or surveillance activities.
- Apply decision analysis tools to help inform the final selection of the preferred adaptation pathway, taking into account the potential benefits and costs (financial and non-financial) of each adaptation pathway assessed.

- Conduct sensitivity analysis to test the robustness and validity of the outcomes of the decision analysis against various biases and assumptions.
- Select the preferred adaptation pathways and identify the triggers and thresholds for further actions.

Stage 3: Implementing of Adaptation Pathways

- Design and implement the selected adaptation pathways.
- Conduct surveillance to inform future reviews of and potential updates to projections of future climate conditions, the climate change risk assessment, and the decision analysis of the selected adaptation pathway.
- Implement an adaptative management process to address uncertainty associated with climate change projections, to proactively respond to unexpected changes in climate conditions beyond those projected and to take additional action in response to observed threshold values.

These stages of the process are designed to be applicable to the incorporation of climate change adaptation into decision-making at existing sites and at new sites and can also be applied at the corporate level. It is important to emphasize that, as with all risk assessment and management processes, the outcomes and implementation are not static. The process is intended to be iterative, with vulnerabilities reconsidered, risks re-assessed, and adaptation pathways re-evaluated based on a range of information such as the results of surveillance activities, changes to infrastructure or operations at the mine site, changes in climate science, and updated projections of future climate conditions.

The process is also designed to be integrated into existing risk assessment and risk management practices, so that risks associated with climate change can be considered as part of the broader matrix of risks.

By implementing this guidance, Owners can integrate climate change considerations in their short, medium, and long-term plans, demonstrate to regulators, investors, insurers and COI what factors were considered, and steps that the Owner is taking to manage risks associated with climate change. A key output is the production of clear and concise documentation demonstrating the incorporation of climate change into decision-making, including the development and implementation, as appropriate, of adaptation measures.

Table of Contents

1 Introduction

Climate change is a global concern, and its impacts pose increasingly widespread risks to all industries and activities, including the mining sector. Changes in the climate have the potential to impact many aspects of the mining sector, such as physical impacts on mine sites and adjacent communities, social impacts, and impacts on Owners' reputations and economics.

This document provides guidance on assessing, selecting, and implementing measures to manage the risks and opportunities associated with climate change, including extreme weather events and long-term changes to climate conditions. By following this guidance Owners can strengthen resilience, reduce or eliminate impacts, minimize future modification costs, and create social and economic benefits for both public and private interests.

In 2016, the Mining Association of Canada's (MAC's) Community of Interest (COI) Advisory Panel issued a statement on climate change to MAC with "calls to action" in multiple areas including the disclosure of climate change risks and opportunities. The Panel proposed specific ideas and actions to assist MAC and its members in building on the progress already made in addressing climate change, and to help guide future endeavours with respect to planning, managing and operating mines and related activities in this changing global context. This document aligns with and reflects the advice provided by the COI Advisory Panel calls to action.

In addition to MAC's commitment to climate change adaptation, there is sector recognition of the issue at an international level, with the International Council on Mining and Metals (ICMM) releasing an updated report, *Adapting to a Changing Climate – Building Resilience in the Mining and Metals Industry* in 2019. This report notes a growing awareness of climate change and its potential impacts on the mining industry.

MAC would like to acknowledge the contributions from the Climate Change Adaption Steering Committee, formed to help guide and provide oversight to this process. MAC also acknowledges the support and financial contribution to the project provided by Natural Resources Canada.

1.1. Potential Impacts of Climate Change

Changing climate conditions could have a wide range of potential impacts on the mining sector. The direct impacts would be primarily physical in nature, such as an extreme precipitation event causing damage to a road crossing and could be on or off-site (e.g., damage to a road crossing on a publicly owned and maintained road used to access the mine site).

However, these direct, physical impacts could lead to a wide range of potential indirect impacts, such as:

- Health and safety of personnel on site.
- Health and safety on residents of nearby communities.
- Environmental impacts.
- Economic impacts on the Owner (e.g., short-term costs of remediation, longer-term costs of higher insurance rates).
- Legal liability and impacts.
- Reputational impacts.

1.2. Purpose

The intent of this guidance is to promote a sector-wide understanding of climate change-related risks and support the incorporation of climate change considerations in decision-making. More specifically, the guidance is intended to help mine Owners incorporate climate change adaptation into decision-making by providing tools to help Owners:

- Understand the historical and current climate.
- Project how the climate may change in the future.
- Identify site-level or corporate-level aspects of company operations (e.g., site water management, corporate supply chain) that are potentially vulnerable to changing climate conditions.
- Assess the risks associated with climate change for vulnerable infrastructure and activities and identify potential opportunities.
- Identify potential actions to manage risks or opportunities associated with climate change that may be implemented on a site-specific basis or at the corporate level (adaptation measures).
- Decide if, when, and how to implement adaptation measures (adaptation pathways).
- Implement the surveillance, management and continual improvement process that is necessary to monitor the changing climate and take appropriate actions in the future.

A key output is clear and concise documentation evidencing the integration of projected future climate conditions into an Owner's risk management approach.

The guidance is not meant to be prescriptive, and it describes a decision-making process that is consistent with, and builds on, the latest available guidance and best practices for climate change adaptation. It provides clear direction on the approach, information sources and documentation requirements to incorporate climate change considerations into decision-making, outlining decision-making processes at all stages of the mine life cycle.

Implementing this guidance can help inform corporate disclosure on the risks, opportunities, financial impacts, and governance processes related to climate change, including disclosure through initiatives such as:

- Canadian Securities Administrators (CSA) Staff Notice 51-358 *Reporting of Climate Change-Related Risks* (CSA 2019).
- Task Force on Climate-related Financial Disclosure's (TCFD) report on *Recommendations of the Task Force on Climate-related Financial Disclosures* (TCFD 2017).

It is important to note that implementing adaptation measures to increase resilience or mitigate potential impacts of climate change on a mine site or as a company, may be only one part of an Owner's overall climate change strategy. That strategy may also include measures to reduce greenhouse gas (GHG) emissions and adapting to other climate change related changes, such as carbon pricing, carbon capture and storage, emerging technologies and changing legal or taxation frameworks. This guidance focuses on adapting to the potential impacts of changing climate conditions on the mining sector. Other aspects related to climate change are outside the scope of this guidance.

1.3. Intended Audience

The guidance is intended primarily for mining companies, to allow them to incorporate consideration of climate change adaptation into current and closed mines as well as planned future operations. The guidance can also be applied by government agencies with responsibility for the management of orphaned and abandoned mines sites.

The guidance can be used by regulators to help improve their understanding of best practices related to climate change adaptation.

In addition, community organizations, non-government organizations and others that may be affected by mining can also use the guidance to help improve their understanding of best practices related to climate change adaptation so that they are better informed in their engagement with the mining sector.

While the guidance is written for the mining sector and illustrated with examples and case studies of relevance to the mining sector, the process described could be applied by a wide range of private and public sector activities. For example, a municipality could apply the process described in the guidance to help inform decisions about climate change adaptation, such as decisions about storm water management, even if the risks a municipality faces and the adaptation measures that would be considered to manage those risks may be quite different than for mining.

It is important to emphasize that while some aspects of this document are Canadian-specific, such the national projections of climate conditions described in Section 3, this guidance is intended to be applied globally.

For application in Canada, the guidance is consistent with legal requirements such as the Canadian *Impact Assessment Act*.

2 Overview

This section summarizes the concepts presented in the guidance and how those concepts are intended to be applied across the mining life cycle to incorporate climate change adaptation into decision-making. A discussion of how this guidance relates to other existing guidance documents is also provided.

It is important to have a common understanding of the mining and/or refining life cycle, and how each phase of the life cycle is defined. The life cycle typically consists of six phases: planning, design, construction, operations, closure, and post-closure. These phases are rarely linear, and planning, design and construction are recurring activities throughout the life cycle.

Definitions of the phases of the life cycle are adapted from MAC's *Guide to the Management of Tailings Facilities* (Tailings Guide) (MAC 2019b):

Planning is a recurring life cycle activity that applies to the planning of new (greenfield) developments, mine-life extensions, material changes in mine plan, re-opening of closed sites, and closure. Planning assesses a range of potential options in order to select the preferred option.

Design is a recurring life cycle activity that builds upon the planning phase. Once the preferred option has been selected, detailed design is undertaken.

Construction is a recurring life cycle activity that includes:

- For new mines and major expansions, the construction of mine infrastructure and facilities including transportation, power, ore processing, and management of water and mine waste.
- Ongoing construction during the Operation phase, particularly for tailings facilities (e.g., dam raises).
- Progressive reclamation (e.g., restoration of disturbed areas).
- Construction associated with closure plan implementation (e.g., installation of covers, removal of infrastructure).

Operation refers to the period in the life cycle when the mine is in production, ore is being processed (if there is a facility on site), and waste rock and tailings are being produced.

Closure occurs when the mine has permanently ceased commercial operations and the closure plan is implemented, including the removal of key infrastructure.

Post-closure occurs when the closure plan has been implemented and the remaining infrastructure, especially tailings and waste rock facilities, transition into a period of long-term ongoing maintenance and surveillance.

2.1. Overview of Process for Incorporating Climate Change Adaptation into Decision-Making

The guidance document describes a three-stage process that Owners can apply to incorporate climate change adaptation into decision-making (Figure 1):

Stage 1: Climate Change Risk Assessment

- Compile and analyze data sets on observed climate conditions for the site.
- Develop the projected future climate conditions for the site, based on baseline climate conditions, and using accepted modelling tools and different assumptions for future GHG emissions.
- Identify infrastructure components (e.g., stream crossings) and operations both on and off-site (e.g., access roads, port facilities used for shipping product) that are potentially vulnerable to changing climate conditions by considering:
  - How current or planned infrastructure components and site operations interact with the climate (e.g., mean annual temperature, extreme events such as rainfall).
  - Projected future climate conditions, and how interactions of infrastructure and site operations with the climate may change under changing climate conditions.
- Identify potential opportunities that may arise from changing climate conditions (e.g., longer growing season potentially enhancing reclamation activities), and changes that may arise due to climate change that are neither a vulnerability nor an opportunity (e.g., shift in growing conditions changing the preferred plants to use for reclamation), but which should be managed.
- Assess the risks associated with climate change for vulnerable infrastructure and operations, considering risks under current (baseline) climate conditions, and how those risks are expected to change under the projected future climate conditions.

Stage 2: Developing Adaptation Pathways

- Identify the objective and scope, including the risks to be managed and the factors to be considered, and identifying measurable performance objectives.
- Identify potential adaption measures that could be implemented to address risks or take advantage of opportunities, such as:
  - Physical modifications to existing infrastructure or construction of new infrastructure.
  - Revising operation, maintenance, and surveillance activities.
  - Providing support to third parties responsible for vulnerable off-site infrastructure.
  - Collaborating with suppliers on risks or opportunities associated with supply chains.
  - Enhancing governance structures related to climate change adaptation.
- Classifying and pre-screening the potential adaptation measures to eliminate from further consideration any that would have characteristics that would not be viable.
  - In some cases, it may be possible to make a decision at this point about adaptation pathways and measures to be implemented and timing of implementation and proceed to Stage 3.
  - In other cases, the process should continue to more detailed steps described below.

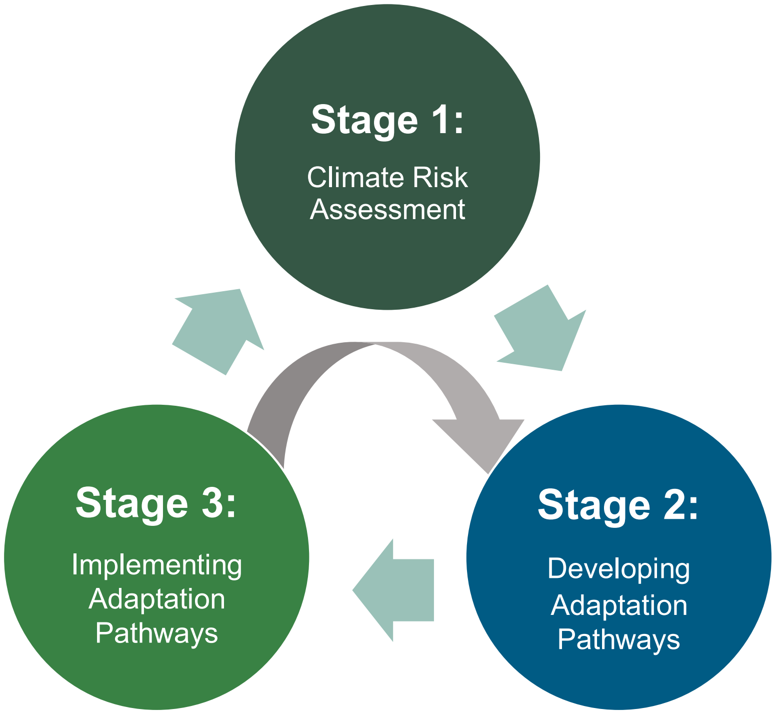
- Develop potential adaptation pathways that map out the sequence of possible implementation of adaptation measures to address risks or opportunities. Adaptation pathway options may include:
  - Business as usual in which the pathway does not include any adaptation measures and the Owner would respond if a climate event occurs.
  - Implementation of an adaptation measure in the short-term.
  - Defer implementation of an adaptation measure until a pre-defined threshold for relevant climate variables has been reached.
- Assess the potential adaptation pathways using decision analysis tools (e.g., multi-criteria analysis or cost-benefit analysis) to analyze potential adaptation pathways and inform the selection of the preferred pathway for each risk and/or opportunity to be managed.
- Conduct a sensitivity analysis to test the robustness and validity of the outcomes of the decision analysis against various biases and assumptions.
- Identify triggers and thresholds that may require a re-evaluation of the adaptation measure or require additional adaptation measures.
- Select the preferred adaptation pathway.

Stage 3: Implementing Adaptation Pathways

- Design and implement the selected adaptation pathways.
- Increase or revise surveillance activities to inform future reviews of and potential updates to:
  - Projected future climate conditions used in Stage 1.
  - Priorities identified in the climate change risk assessment.
  - Changes in the inputs or values used in the decision analysis of the selected adaptation pathway.
- Implement an adaptative management process across the mine life cycle to:
  - Address uncertainty associated with climate change projections.
  - Proactively respond to observed changes in climate conditions and incorporate updates to climate science.
  - Take the additional actions in response to observed threshold values as outlined in the adaptation pathway development process.

It is important to acknowledge that many Owners already have established, multi-disciplinary processes in place to identify, assess, and manage risks through risk management frameworks. Climate conditions are one potential source of risk considered in these processes. Where such processes already exist, climate change risks should be integrated as another potential source of risk to be considered, taking into account both the potential for direct impacts associated with climate change and the potential for climate change to be a modifier of other risks. Establishing a separate process specific to climate change risks is not recommended, and this guidance should be used to help facilitate the consideration of climate change risks using those existing processes. In other cases, the guidance can be applied as a stand-alone tool to identify and manage climate change risks.

Figure 1: Overview of the process for incorporating consideration of climate change into decision-making



2.2. Iterative and Scalable Approach

The three-stage process described above can be applied to the planning and design of new mine sites or infrastructure components and to help make new construction more resilient to climate change from the outset. It can also be applied to existing sites in the operations, closure, and post-closure phases, to help Owners make short-term and longer-term decisions about how best to respond to risks posed by climate change.

Iterative Approach

Regardless of the life cycle phase of the mine at which this process is being applied, it is important to emphasize that, as with all risk assessment and management processes, the outcomes and implementation are not static. The process is intended to be iterative, with vulnerabilities reconsidered, risks re-assessed, and adaptation pathways re-evaluated based on a range of information such as the results of surveillance activities and changes to infrastructure or operations at the mine site.

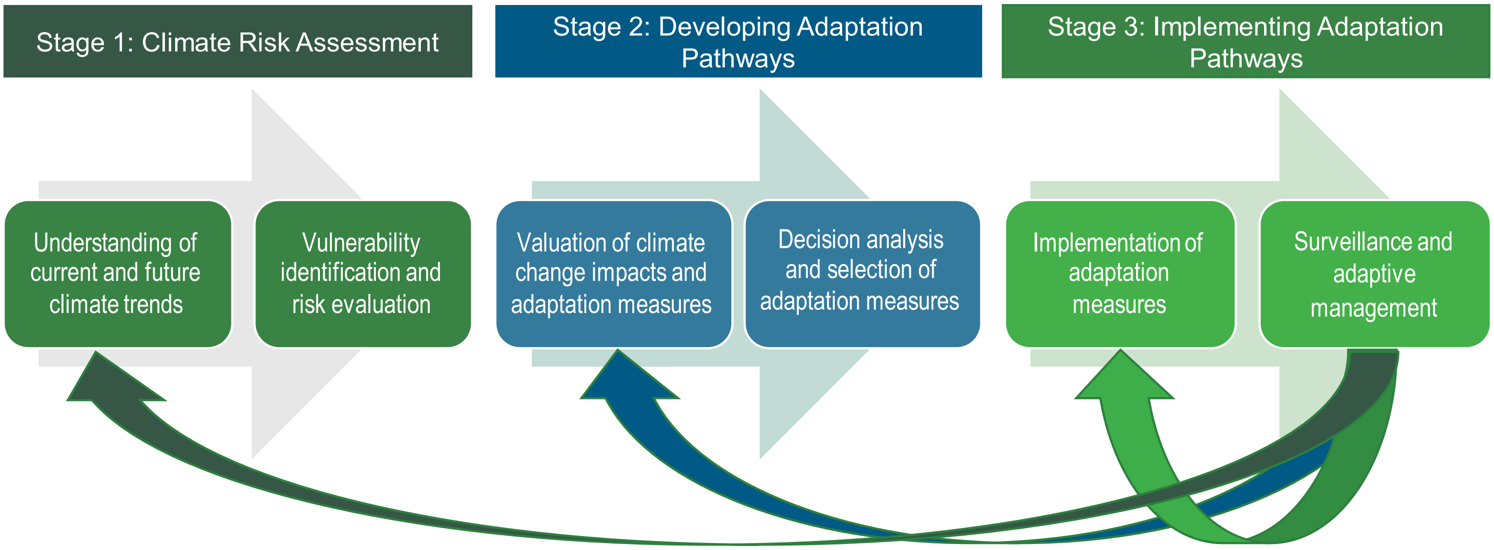
However, an iterative approach is all the more imperative when considering how to manage risks associated with climate change, given the uncertainty regarding projections of future climate conditions, the future refinement of these projections as the state of knowledge improves, and the potential emergence of shorter-term changes indicative of changing climate. Thus, it is recommended that Owners apply this guidance in an ongoing, iterative manner, informed by and considering:

- Updates to climate science, engineering codes and standards, or legal requirements that may alter vulnerabilities or risks.
- Changes to the operations of the mine, including infrastructure.
- Changes in policies, plans, business strategies and assets (e.g., maintenance and replacement time frames) (ISO 2019).
- Change in life cycle phase of the mine (i.e., a mine that is transitioning from operation to closure).
- Changes in future plans for the mine (e.g., a mine life extension).
- Changes to the external environment.
- Climate adaptation actions taken by third parties (ISO 2019).

As illustrated in Figure 2, changes such as those listed above could trigger review of the:

- Climate dataset and projected future climate conditions (Stage 1).
- Identification of vulnerabilities and opportunities (Stage 1).
- Climate change risk assessment (Stage 1).
- Adaptation pathways that have been selected (Stage 2).
- Implementation of adaptation pathways (Stage 3).
- Design and implementation of the surveillance program (Stage 3).

Figure 2: The iterative nature of the process for incorporating consideration of climate change into decision-making



Scalable Approach

The process is designed to be applied in a scalable manner, both across the life cycle, and through the process as more information is obtained. A scalable approach adjusts the level of detail needed based on the decision to be informed or the step in the process and allows the process to be started at the Planning stage when the initial mine plan is being developed.

In the context of climate change adaptation, a scalable approach involves primarily the degree of uncertainty and the efforts made to reduce that uncertainty. Uncertainty is inherent in the outcomes of any risk assessment, and uncertainty associated with projecting future climate conditions adds a further significant degree of uncertainty. Collection of more comprehensive datasets on observed climate conditions and the conduct of more comprehensive modelling of projected future climate conditions can help to reduce uncertainty. However, such a reduction in uncertainty is not always necessary or possible.

The following examples illustrate the different ways a scalable approach can be used.

- Scalable based on the objective of the decision-making process: a greater degree of rigor (smaller amount of uncertainty) is needed for inform some decisions compared to others, such as the decisions related to the detailed design of a new mine site, compared to a decision regarding a possible replacement of a stream crossing.
- Scalable through the life cycle: less detail and more uncertainty are tolerable during the planning phase of a new mine site or infrastructure component (e.g., water management infrastructure), but a more comprehensive observed climate dataset and modelling of projected future climate conditions may be required to inform detailed design based on the risk assessment results.
- Scalable through the stages of the process: for example, a less detailed climate dataset and projection of future climate conditions can be used to inform the identification of vulnerabilities, but the development and selection of adaption pathways may require additional information, such as information on critical climate variables (e.g., potential for drought conditions). Similarly, when implementing adaptation pathways (Stage 3), additional information may be needed to define trigger points for additional adaptation action.

Table 1 provides examples for one specific, scalable aspect – the level of detail of the climate dataset used to describe current and historical climate conditions. This dataset provides the basis for developing a site-specific projection of future climate conditions. Table 1 divides climate datasets into three categories: basic, intermediate, and detailed (Charron 2016). These categories apply not only to the potential application of the information but also to the formats the information may come in. Moving from the basic category through to the detailed category increases the complexity in the type of climate variables considered.

The planning and design phases are particularly important for new mines and for significant mine life extensions and closure planning. During the planning and design phases, climate change risks should be identified, assessed and incorporated into decision-making, helping to lead to more resilient operations and avoiding the need for mitigation in the future. However, as noted more detail is needed in the design phase. Both planning and design should consider a long timescale, including the length of the projected operating life of the mine and the closure and post-closure phases. During these phases, both extreme climate events (e.g., storms, high intensity precipitation events, wildfires) and long-term changes in climate (e.g., increasing temperatures) should be considered and incorporated into the design of the overall mine and into specific mine infrastructure components. Table 1 outlines how climate change may be refined over time for each phase of the mining life cycle.

Planning and design specific to the development of a closure plan may need to take an even longer-term view. Consistent with best practices for closure plan development, development should begin as early as possible in the life cycle, with the plan and associated design elements refined on an ongoing basis and finalized in the closing stages of the Operation phase. The ongoing development of the closure plan should be informed by projections of future climate and reflect updates to those projections over time, in addition to being informed by a range of other factors such as as-built conditions of the mine, changing legal requirements, improvements in technology, etc.

Table 1: Three Categories of Projected Climate Information (Adapted from Charron 2016)

Category	Characteristics			
	Purpose	Spatial Resolution	Climate Statistic	Mine Life Cycle Phase
Basic	■ Initial awareness ■ Preliminary risk analysis ■ Assessing alternatives ■ Corporate level disclosure (e.g., TCFD) ■ Identification of priority climate risk/ opportunities	■ Coarse scale (e.g., existing projections from government agencies, academic institutions, etc.)	■ Mean change (delta) from current climate	■ Planning ■ Conceptual closure planning
Intermediate	■ Identification of vulnerabilities ■ Impact assessments ■ Early development of "in-design" adaptation measures	■ Variable (e.g., national, provincial, regions within a country, watershed)	■ Range of projected future values for specific climate variables (e.g., mean annual temperature)	■ Conceptual design ■ Closure plan development through early life cycle phases
Detailed	■ Climate risk assessment ■ Support decision analysis tools ■ Inform surveillance and implementation of adaptation pathways ■ Site-level risk registers	■ Typically, fine scale (e.g., regional or tens of kilometres)	■ Extremes, including changing distribution of precipitation	■ Detailed design ■ Construction ■ Operation ■ Detailed closure design ■ Closure, post-closure

2.3. Existing Guidance on Incorporating Climate Change into Decision-Making

Prior to the development of this guidance, there was limited mining-specific guidance available that provided methods or procedures on incorporating climate change considerations in the Owner's decision-making process. A literature review was conducted that collected publicly available documentation from international agencies, academic institutions, and federal and provincial/territorial governments for guidance on incorporating climate change considerations for the mining industry.

Adapting to a Changing Climate: Building Resilience in the Mining and Metals Industry **(International Council on Mining and Metals (ICMM) 2019):** Provides a high-level update on the main challenges and opportunities the mining sector faces with respect to climate change adaptation. It provides an overview on why building resilience to climate change is important for mines and makes recommendations on how Owners can integrate climate considerations into existing risk management processes and sets out a step-wise process for building climate resilience. The report does not provide specific guidance on recommended adaptation options/practices. This guidance document is aligned with the guidance provided by ICMM.

Canada's Changing Climate Report **(Bush and Lemmen, ed. 2019):** Provides a national assessment of the state of knowledge on how and why Canada's climate has changed and what changes are projected for the future. Led by Environment and Climate Change Canada, it is the first report to be released as part of the *Canada in a Changing Climate: Advancing our Knowledge for Action* series of reports. This report includes an overview of climate models and how they are used to simulate historical climate and to make projections of future climate. It also includes a discussion of downscaling methods that transform General Circulation Model results into more detailed, local information better suited to impact studies. A summary of this information, including the observed and projected trends for a number of climate variables in Canada, is included as Appendix A and is described in more detail in Section 3.

More information about how to access and use observed and future climate data can be obtained from the Canadian Centre for Climate Services (CCCS), established by the Government of Canada so that Canadians have the information and support they need to understand and reduce the risks from climate change. The Centre's website includes basic information on climate change concepts, links to Canadian climate data portals, a library of resources relevant to considering climate information for decision-making, and a Support Desk.

The Support Desk helps answer questions to guide Canadians seeking to understand and use climate data. It provides direct access to climate experts, and can be reached through the Centre's website, by phone at 1-833-517-0376, or email at info.cccs-ccsc@canada.ca. Please check the CCCS website on a regular basis as new tools and resources become available.

Canadian guidance on how to use climate information to help inform adaptation decisions and how to decide what level of detail best supports adaptation and decision-making include the following:

- ***A Guidebook on Climate Scenarios*** **(Charron 2016):** Assists climate change adaptation practitioners when using climate information by providing a general introduction to climate science concepts.
- ***Dam Safety Guidelines, 2007*** **(Revised 2013; CDA 2013):** The Canadian Dam Association does not provide specific guidance on climate change considerations. For existing infrastructure, guidance recommends that climate change is to be considered when assessing whether existing

practices or plans need to be updated in the face of potential future changes, especially with respect to precipitation balances and extremes.

- ***Public Guideline: Principles of Climate Adaptation and Mitigation for Engineers*** **(Engineers Canada 2018):** Engineers Canada has developed guiding principles to outline the professional practice required for climate change adaptation and mitigation. These principles are designed to improve resiliency by understanding potential impacts and reducing the magnitude of these impacts. However, engineering planning, design, operations, and maintenance of infrastructure can no longer rely on historical trends projected into the future. For infrastructure maintenance in particular, engineers need to consider historical climate, weather trends over the short term (e.g., current climate), and climate projections over the long term (e.g., future climate). The long-term sustainability and resilience of infrastructure needs to be considered over its anticipated service life, with margins to accommodate climate adaptation measures. Engineers are to apply a reasonable standard of professional judgement in considering changing climate conditions, resilience, and mitigation opportunities within their professional practice.
- ***Government of Canada's Strategic Assessment of Climate Change*** **(2020):** The assessment provides guidance on how federal impact assessments will consider the mitigation and adaptation components of a project. The strategic assessment clarifies how the Impact Assessment Agency of Canada or other regulators will review information related to a project's GHG emissions and resiliency to climate change impacts. The guideline recommends that a description of the scope and timescale of the resilience assessment be prepared that considers all phases of a project. Projects are also to submit a description of the risk management framework and risk assessment process used to identify, evaluate, and manage climate risks.
- ***Climate Lens General Guidance Version 1.2*** **(Infrastructure Canada 2019):** Developed for projects looking to receive funding under the Investing in Canada Infrastructure Program (ICIP), Disaster Mitigation and Adaptation Fund and Smart Cities Challenge. Designed for future infrastructure, the assessment requires considering climate resiliency by examining the ability of a proposed project to respond to and recover from a climate change related event. Annex H of Version 1.2 includes references to national and regional climate service providers, climate data portals, and other sources of climate data and information across the country. Climate information is expanded in this version to address the needs of decision-making, in addition to an updated list of resources available for climate information and data.

2.4. Relationship with Climate Change Disclosure Initiatives

There is a growing interest from investors seeking improved disclosure on the risks, opportunities, financial impacts, and governance processes related to climate change. For example, two specific disclosure instruments have been developed:

- Canadian Securities Administrators (CSA) Staff Notice 51-358 *Reporting of Climate Change-Related Risks* (CSA 2019). There is a growing investor interest in Canada and internationally in the disclosure of risks, opportunities, financial impacts, and governance processes related to climate change. Canadian securities legislation requires the disclosure of material risks that affect mining companies and any associated financial impacts.

- Task Force on Climate-related Financial Disclosure's (TCFD) report on *Recommendations of the Task Force on Climate-related Financial Disclosures* (TCFD 2017). TCFD sets out a framework for the voluntary disclosure of climate-related risks and opportunities. It suggests climate-related opportunities for mining companies will stem from actions that improve operational efficiencies.

In addition, several multinational insurers and reinsurers have incorporated climate change adaptation when assessing their portfolio risks and have reduced underwriting capacity for certain exposures and have implemented new coverage exclusions and conditions.

Implementing this guidance can help inform disclosure related to these initiatives. However, this guidance document is not intended to provide guidance for disclosure through these programs. The results of a mine-specific climate risk assessment should be integrated into a company-wide risk management program or incorporated into corporate governance policy or strategy. This will help communicate and integrate climate-related risks and opportunities into a company's larger strategy or program and would demonstrate the need for capacity building and organizational learning. This would also allow all project risks and opportunities to be considered on a consistent basis and track the performance of adaptation measures.

3 Mining in a Changing Climate

This section presents concepts that help to inform the incorporation of climate change adaptation into decision-making. Although some of the details of this section provide an overview of how climate is changing and projected to change in Canada, the concepts described can be applied globally.

Mining has always required an understanding of climate variability and has established risk assessment and management practices and processes that consider climate-related risks and opportunities. For example, even without consideration of potential future changes in climate, it is common to design water management infrastructure and tailings facilities to accommodate extreme climate events, such as using probable maximum precipitation or flood conditions or a 1/10,000-year event, rather than shorter return periods.

However, climate change is now a modifier of these risks, and projected changes in climate may introduce additional risks as well as opportunities. Changes to the global climate have impacted and will continue to impact mines located in all environments and addressing climate change-related risks is a recognized priority for the mining sector (ICMM 2019).

This section introduces terminology used throughout the document:

Climate Variable: A weather parameter that can be measured and projected into the future (e.g., temperature, precipitation, wind, etc.) and that has the ability to interact with mine infrastructure and operations.

Climate Indicator: An index that can be quantified or measured to demonstrate changes of a Climate Variable (e.g., daily temperature, number of frost days, intensity and duration of rain events, wind speed and direction). The value of a Climate Indicator can change over time due to climate change.

Climate Event: An event (e.g., extreme rainfall event) that occurs when a Climate Variable is above a Climate Indicator value, resulting in unwanted impacts to infrastructure, mine operations or the surrounding environment.

Increases in GHG emissions have caused changes in trends for climate variables such as mean annual temperature and precipitation. These changes can be measured using climate indicators. Changes over time in climate variables can lead to climate change-related climate events such as: rise in sea level, permafrost degradation, extreme heat, extreme storm events, droughts, floods, and wildfires. Climate change acts as a modifier of risk by potentially altering the frequency and intensity of such events. Understanding changes in the observed conditions and how projected future changes in climate will have direct and indirect impacts on a mine, surrounding communities, and the environment is the first step in the overall process described in this guidance. The impacts of changes in climate variables will vary depending on many factors, particularly the location of the mine, the nature of the infrastructure, and the life cycle phase of the mine.

Key questions addressed in this section

What information is available to describe the current and future climate? Section 3.1 introduces the leading intergovernmental source of climate science and some key terms that help understand the accepted state of climate science research.

How is climate changing and projected to change in Canada? Section 3.2 provides an overview of the observed and projected trends in climate variables across Canada. This includes a description of past and future trends for a list of climate variables for Canada.

3.1. Introduction to Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is generally considered to be the definitive source of information related to past and future climate change, as well as climate science. The IPCC is a United Nations body dedicated to providing an objective, scientific assessment of climate change information, the potential natural, political, economic, and human impacts of climate change, and possible response options. The IPCC periodically releases Assessment Reports, each of which provides the current state of climate change science, where there is agreement within the scientific community. Each report undergoes a series of reviews to ensure objectivity and transparency. The IPCC does not conduct its own research and is considered neutral, policy-relevant but not policy-prescriptive.

Through this work, the IPCC provides a common source of information relating to emissions scenarios, provides third party reviews of climate models, and recommends approaches to document future climate projections. The IPCC issued its Fifth Assessment Report (AR5) in 2013, representing the most current synthesis of information regarding climate change. Assessment reports are updated every five to six years, and the Sixth Assessment Report (AR6) is planned to be released in 2021.

Climate modelling involves the mathematical representation of global land, sea, and atmosphere interactions over a long period of time. General Circulation Models (GCMs), also referred to as Global Climate Models and Earth System Models, have been developed by various modeling centres (including government agencies), and share many elements in common with the models described by the IPCC (IPCC 2013). Climate simulations produced by GCMs vary because different models use different ways to describe atmospheric, oceanic, and terrestrial processes and may employ different geographic (grid-box) resolutions.

General Circulation Models (GCMs) are numerical representations of the physical processes in the atmosphere, ocean, cryosphere, and land surface. They are the most advanced tools available for simulating the global climate system's response to changing GHG concentrations (IPCC 2019a). GCMs have coarse grid-box resolutions that vary between 1 and 4 degrees of latitude and 1 and 5 degrees of longitude over the entire planet (Charron 2016; European Network for Earth System Modelling 2019).

It is important to emphasize that all models have limitations and uncertainty, depending on the approach to overcoming model uncertainty applied in developing the models. As a result, projections based on any given model should not be viewed as completely accurate. The variation in climate projections is discussed in further detail in *A Guidebook on Climate Scenarios* (Charron 2016).

Therefore, when projecting future climate conditions to inform climate change assessments, a multi-model ensemble should be used to assess the range of projections. Guidance on developing a multi-model ensemble from data available from climatedata.ca, and how to use this data in the subsequent stages in the process described in this guidance, is provided in Appendix B.

Projections of future climate conditions also need to consider different potential future climate scenarios based on different assumptions about future GHG emissions and atmospheric concentrations. These future climate scenarios are expressed as Representative Concentration Pathways (RCPs). RCPs describe different scenarios of changing climate conditions by 2100. Specifically, RCPs describe the radiative forcing characteristics under each scenario (Charron 2016, IPCC 2019b). In AR5, the IPCC identified four scenarios, RCP2.6 (low emissions), RCP4.5, RCP6.0, and RCP8.5 (high emissions), that produce different outcomes for certain climate variables, which are described in Table 2 (van Vuuren *et al.* 2011). Figure 3 compares each of these RCP scenarios to the climate baseline, based on anticipated long-term global GHG emissions in gigatons of CO2-equivalents per year (IPCC 2014). The results (the shaded regions in Figure 3) help demonstrate the future range of uncertainty.

RCPs are used as inputs to GCMs when projecting future climate conditions. Rather than basing projections on a single RCP (e.g., using a worst-case scenario of RCP8.5) it is best practice to generate projections of future climate conditions under all four RCP scenarios, in addition to using multiple models.

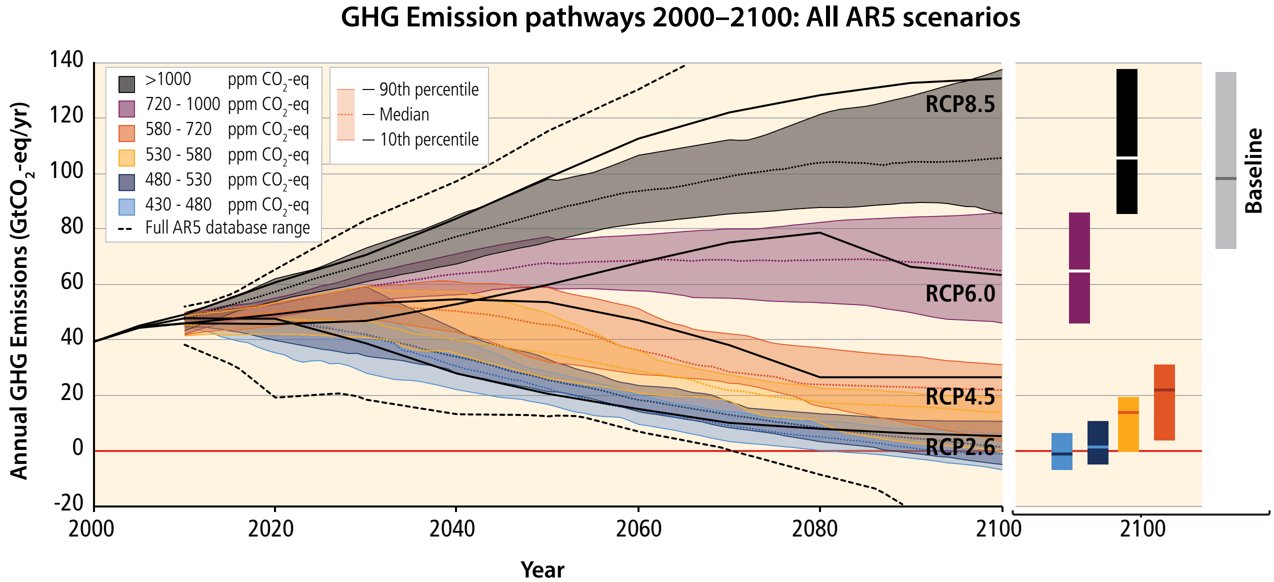
Radiative Forcing refers to the change in net downward minus upward irradiance in Watts per square metre (W/m^2) at the top of the atmosphere (IPCC 2019b; Charron 2016).

Table 2: Characterization of Representative Concentration Pathways (van Vuuren *et al.* 2011)

Name	Radiative Forcing in 2100	Global Characterization
RCP8.5 (high emissions scenario)	8.5 W/m^2	Increasing GHG emissions over time, with no stabilization, representative of scenarios leading to high GHG concentration levels.
RCP6.0	6.0 W/m^2	Total radiative forcing is stabilized shortly after 2100, by applying technologies and strategies for reducing GHG emissions.
RCP4.5	4.5 W/m^2	Total radiative forcing is stabilized shortly after 2100, without overshoot, by reducing GHG emissions over time through climate policy.
RCP2.6 (low emissions scenario)	2.6 W/m^2	"Peak and decline" scenario where the radiative forcing first reaches 3.1 W/m^2 by mid century and returns to 2.6 W/m^2 by 2100. This is achieved through a substantial reduction in GHGs over time through stringent climate policy.

RCP = representative concentration pathway; W/m^2 = Watt per square metre.

Figure 3: Global GHG emissions in gigatonnes of CO2-equivalents per year, for each RCP scenario based on long-term concentration levels compared to the baseline and mitigation scenarios for different long-term concentration levels (Reference: Figure SPM.11 (fragment) from IPCC 2014: Summary for Policymakers. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. *(https://www.ipcc.ch/report/ar5/syr/*).



A climate dataset is a collection of local climate observations and projected future conditions for Climate Variables of interest at a particular location or in a given region (e.g., temperature, precipitation). Such datasets are used to help inform the design specifications for infrastructure (e.g., a new stream crossing) and to inform how projections of future climate can be factored into design (Charron 2016).

Further guidance on developing climate datasets, that consider both the models that are part of the ensemble and the RCPs that inform the model outputs as recommended by the IPCC, Environment and Climate Change Canada and other scientific bodies, are included in Section 4.2 and more fully described in Appendix B. Climate datasets are generally site-specific and developed considering the characteristics of the site, including size, location, and geography, and must document the uncertainty associated with the projections.

3.2. Canada in a Changing Climate

The Government of Canada, led by Natural Resources Canada, prepares periodic assessments of the latest knowledge on climate change impacts and adaptation in Canada. These assessments provide a useful starting point for those working on climate change adaptation. The latest assessment, *Canada in a Changing Climate*, consists of a series of reports. The first to be released was Canada's Changing Climate (Bush and Lemmen 2019). It covers how and why Canada's climate has changed and what changes are projected for the future. The national and regional issues reports provide information about climate change impacts on society, natural environment and economy as well as adaptation actions being taken to address the impacts. The mining sector is specifically discussed in the national issues report.

Canada's Changing Climate Report shows that Canada has experienced changes in many climate variables, including air temperature, precipitation, and snow and ice cover. Compared to global averages, Canada has experienced more pronounced changes in mean annual temperatures, particularly in the North. Nationally, average annual temperatures have increased twice as much as the global average and are projected to continue increasing over the next century (Figure 4).

Average annual precipitation has also increased across all seasons, but trends are not uniform across the country (Figure 5). High-intensity precipitation events are projected to become twice as frequent for most of Canada by mid-century (Warren and Lemmen 2014). Moreover, projections show increases in the frequency and intensity of other extreme events including storms (wind, ice, snow), extreme heat, and wildfire.

Figure 4: Annual temperature change under a low emission (RCP2.6) and high emission (RCP8.5) scenarios, for the mid-century (2031 to 2050) and end of century (2080 to 2100) time horizons (Reference: Figure 4.8 (fragment) from Bush, E. and Lemmen, D.S., editors (2019): Canada's Changing Climate Report; Government of Canada, Ottawa, ON. 444 p.).

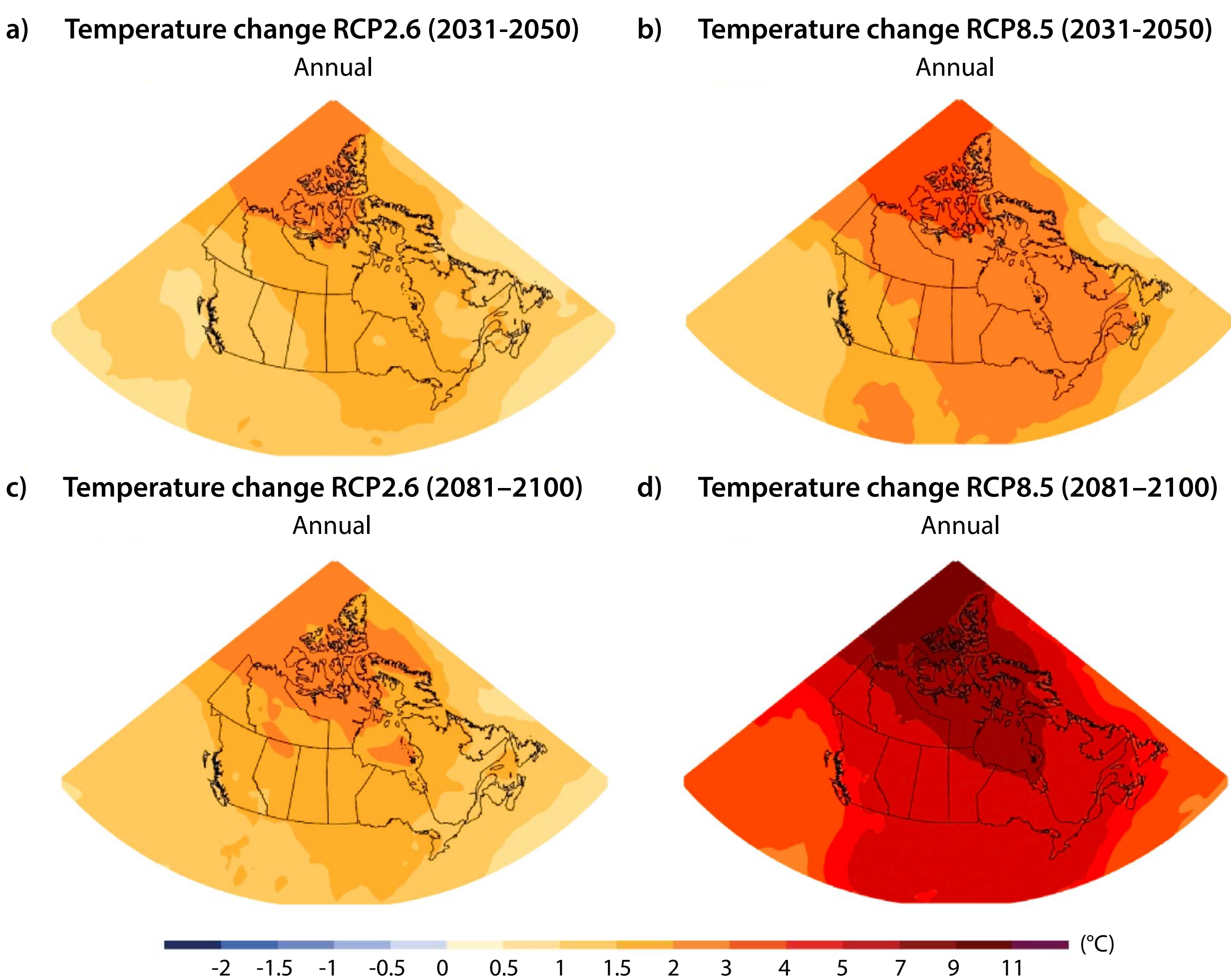
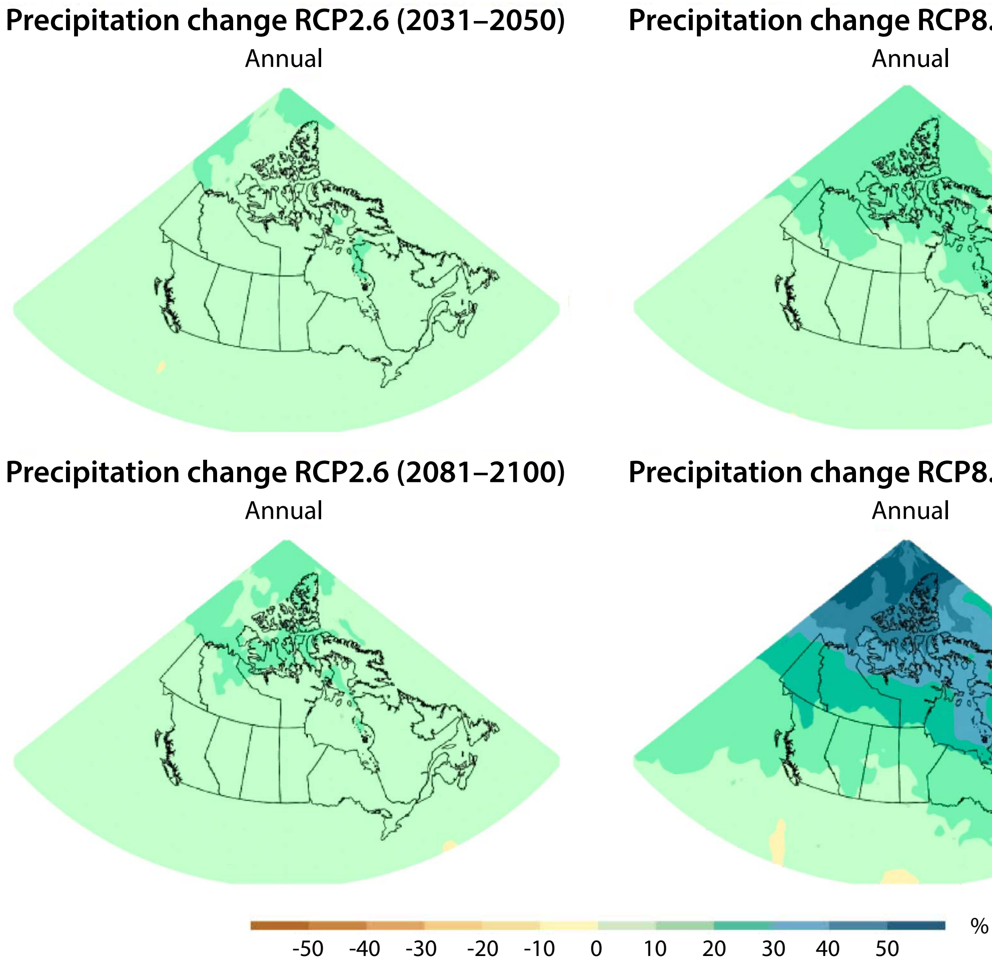


Figure 5: Annual precipitation change under a low emission (RCP2.6) and high emission (RCP8.5) scenarios, for the mid-century (2031 to 2050) and end of century (2080 to 2100) time horizons (Reference: Figure 4.19 (fragment) from Bush, E. and Lemmen, D.S., editors (2019): Canada's Changing Climate Report; Government of Canada, Ottawa, ON. 444 p.).



High level descriptions of historical and projected trends for climate variables in Canada from the peer-reviewed national assessment report *Canada's Changing Climate Report* produced by the Government of Canada (Bush & Lemmen 2019) and other sources as noted provide projections based on the most current climate projections available at the time of the release of this report and provide a general overview of how climate may change in Canada. Additional climate variables and associated events are included in Appendix A, Table 1. It is important to note that these descriptions provide estimates for large geographical areas of the country and may not capture local variations in climate. Appendix C provides guidance on data sources and methods that Owners can use to develop more site-specific projections of future climate conditions both in Canada and internationally.

Air temperature: Annual and seasonal mean temperatures for Canada have increased by 1.7°C between 1948 and 2016, and by 2.3°C for northern Canada (defined as the region north of 60° north latitude). By 2100, mean annual temperatures are projected to increase by about 2°C above the 1986 to 2005 baseline period for a low emission scenario (RCP2.6), and by more than 6°C in a high emission scenario (RCP8.5).

Annual mean precipitation: Annual mean precipitation has increased throughout Canada by about 20% from 1948 to 2012, with larger increases over northern Canada (Vincent *et al.* 2015; Bush and Lemmen 2019). By 2100, annual average precipitation is projected to increase across Canada by 7% under a low emissions scenario (RCP2.6) and up to 24% but with increasing seasonality under a high emissions scenario (RCP8.5) relative to the 1986 to 2005 baseline period. In particular, under a high emissions scenario, summer precipitation is projected to decrease over southern Canada by 2100.

Extreme precipitation events: Defined as a precipitation event that exceeds certain thresholds that has an associated impact or is considered extreme based on its rarity (percentile-based or based on return period) (WMO 2018). Observational evidence of changes in the magnitude of extreme precipitation events is lacking for Canada, and no detectable change has been found based on available station data. However, extreme precipitation events are projected to increase in frequency, with a return period of 20 years becoming a 1-in-10-year event by mid-century and a 1-in-5-year event by 2100 under a high emission scenario (RCP8.5). The amount of 24-hour extreme precipitation that occurs during a 1-in-20-year event is projected to increase as much as 25% by 2100 under a high emissions scenario.

Wind: Changes in wind patterns have been observed, and the severity and frequency of future wind gust events is expected to change late in the century (Warren and Lemmen 2014). The percentage increase in future daily wind gust events of more than 70 km/h could be 10% to 20% higher compared to the current conditions in most of the regions across Canada. Corresponding increases in future hourly wind gust events are projected to be 20% to 30% (Cheng *et al.* 2014).

Drought: There is low confidence in historical global-scale trends, but regional-scale trends in Canada towards increasing drought have been observed. Higher temperatures and changing frequency of precipitation, particularly in the summer, are projected to contribute to increasing drought occurrences.

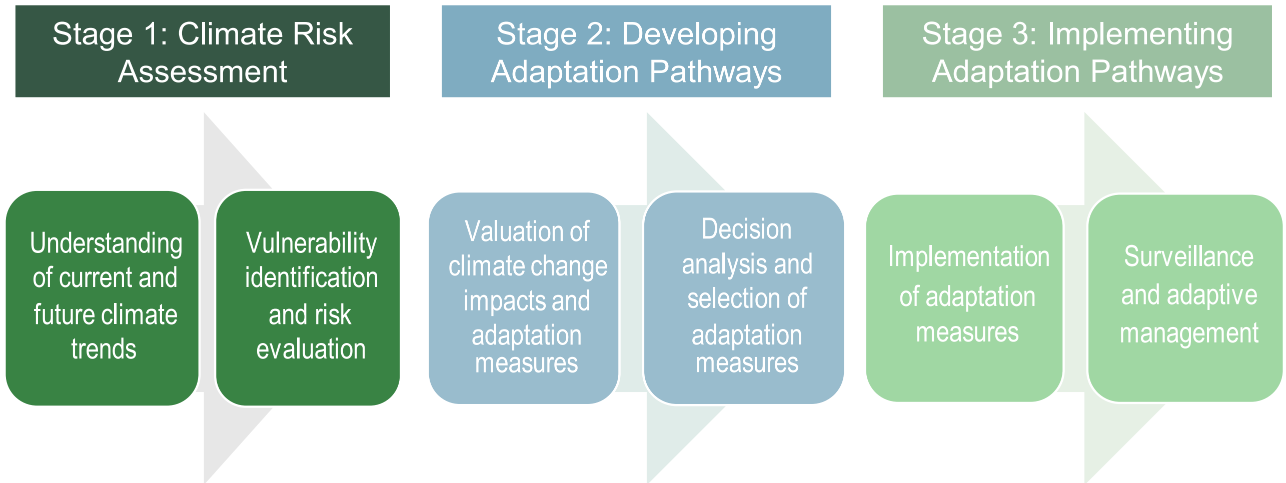
Humidity: The amount of water vapour in the atmosphere has increased since the 1970s, due to warmer air temperatures capable of holding more moisture. It is very likely that near-surface specific humidity will increase in the future as evaporation and air temperatures increase (IPCC 2013).

Canada's climate varies between regions, and while warming is observed across Canada, stronger trends can be found in northern and western Canada. These regional patterns can be attributed to shifts in large-scale atmosphere-ocean circulation patterns (Warren and Lemmen 2014). The effects of these changes are amplified in the northern regions of Canada, particularly shifting precipitation and temperature patterns. Warming of air and sea temperatures has occurred faster in these regions, leading to significant impacts on permafrost, sea ice, and glaciers. Observed decreases in sea ice extent and snowfall and the degradation of permafrost have been occurring and are projected to continue.

In addition to higher ocean temperatures and reduced sea ice, coastal regions are experiencing changing sea levels and coastal and inland flooding (Lemmen *et al.* 2016). The impacts associated with storms are complex for coastal regions, with storm surges representing a major hazard in some areas, most notably the Beaufort Sea coast and the Gulf of St. Lawrence and Atlantic coast. Maximum storm-surge heights exceeding 1 m already occur in all coastal regions of Canada. The frequency and magnitude of storm-surge flooding will increase in the future as relative sea levels continue to rise.

Global mean sea level has risen as a result of thermal expansion of ocean water due to warming and the addition of melting land ice from glaciers and ice sheets. Sea level is projected to increase by 28 to 98 cm during this century depending on the emission scenario, however, changes in sea-level vary significantly across Canada due to vertical land motion. Vertical land motion results in either the "uplift" of land upward or the "subsidence" of land downward as a response to the retreat of the last glacial ice sheet. In areas where land is experiencing land subsidence or sinking (e.g., parts of Atlantic Canada), sea level rise is occurring at much higher rates. Other areas are experiencing land uplift (e.g., Hudson Bay) where the sea level is decreasing as a result of the upward movement of the continental land. This land movement is occurring due to the delayed effects of the last continental glaciation (ice age) called glacial isostatic adjustment where the North American continental crust in areas close to the centre of the former ice sheets is lifting and regions that were originally near the edges of ice sheets are subsiding. Sea level is projected to rise not only in most of the Atlantic coast, but also in parts of the Pacific coast and the Beaufort coast in the Arctic (Bush & Lemmen 2019).

4 Stage 1: Climate Change Risk Assessment



This section provides guidance on describing and documenting how climate is changing in a way that will be useful when completing risk assessments and provides an overview of the process that can be used to identify climate change vulnerabilities, assess their risks, and identify potential opportunities that may arise from a changing climate.

Historically, potential climate impacts on mine sites have been addressed by relying on stationary design criteria based on historical information projected into the future. However, depending on the stationary design criteria used and magnitude of projected future changes for relevant climate variables, this approach may not be effective as climate changes. The following method describes a forward-looking approach of characterizing climate change that does not rely solely on forecasts based on historical information.

Mine-specific climate datasets should be developed considering the characteristics of the mine site including the size, location, geography, associated infrastructure and life cycle (including the life cycle of the mine itself and associated tailings and waste rock management). Following best practices, assessments should include:

1. A description of the baseline climate conditions, including mean and extreme events, and a sufficiently long observation record to capture long-term climate averages and a variety of extreme events.
2. Projections of future changes in climate conditions, including mean and extreme events, and also including an assessment of the uncertainties inherent in these projections.

Climatic data should be discussed in terms of climate normals (i.e., a climate baseline) and the future projected climate. Climate normals are defined as long-term averages used to describe the average climatic conditions of a location. In Canada, normals are defined by Environment and Climate Change Canada (ECCC) based on recommendations from the World Meteorological Organization (WMO), that use the most recent 30-year averages, and which are updated to the end of every decade (ECCC 2017). The climate baseline is grounded in both historical and current climate observations. The climate baseline is informed by the climate normal period but can be extended to include more historical information if needed depending on the application of the climate information. Appendix B provides guidance on how to establish a climate baseline.

Projected future climate is defined as the difference between the projections given by the outputs of climate models and the climate baseline. The future climate should be presented as a change relative to the climate baseline with respect to the climate normal period.

Based on the climate data, this section provides a step-by-step approach to identify potential changes that would occur as a result of climate change, the vulnerabilities, and the associated risks and opportunities. The process can be implemented in the planning and design of new greenfield sites and is also applicable to operating sites. As noted in the introduction, the overall process described in this Guide is an ongoing process of continual improvement. As part of this, assessments of vulnerabilities and risks should be updated regularly through the life cycle, in response to changes such as updates to the climate projections, observed climate conditions or the mine plan.

Key questions addressed in this section

How do you adequately describe the historical and current climate? How do you select and quantify the appropriate data? What climate data sources are available for historical/current climate? Section 4.1 outlines and recommends guidance for describing and documenting current climate, including minimum considerations for incorporating climate change, climate variables to consider, defining data completeness, historical/current climate data sources, and how to address data gaps.

How do you properly select and characterize future climate? How do you address uncertainty with climate projections? What climate data sources are available for future climate? Section 4.2 outlines and recommends guidance for describing and documenting future climate. Topics include scenarios to be considered (i.e., time horizons, emission scenarios), how to address uncertainty associated with future climate projections, future climate data sources, and additional refinements to better characterize uncertainty.

How is a changing climate expected to impact each phase of the mining life cycle? What off-site impacts are a changing climate expected to have? How would those impacts affect the mine? What opportunities may arise due to a changing climate? Section 4.3 discusses how climate change may impact all phases of the mining life cycle and what climate considerations are expected for each phase in terms of information. It also discusses how a changing climate will impact a mine's surrounding communities and environment, and possible opportunities as a result of a changing climate.

What are the climate-change vulnerabilities and risks for mining? What is the process to complete a climate-change risk assessment? Sections 4.4 and 4.5 outline a series of consecutive steps used in undertaking a climate risk assessment that can be scaled to different levels of detail for various phases of mine life.

What are some examples of climate-change risk assessments? Section 4.6 provides a risk assessment case study that can be used for further reference.

4.1. Establishing a Climate Baseline

A good understanding of historical and current climate conditions is essential to all other aspects of climate change adaptation, including providing inputs to projections of future climate conditions. Historical and current conditions are described by establishing a site-specific climate baseline which describes:

- Current climate normals
- Observed trends over the baseline period

When establishing the climate baseline, the Owner needs to determine the time period to be used for the baseline. Ideally, observations from the most recent time period should be used to create a long-term average that will depend on:

- The nature of decisions to be informed by the climate baseline (e.g., a shorter baseline period may be used for screening-type decisions, but a longer baseline period would be better for design of critical infrastructure).
- The availability of appropriate data.

The chosen baseline time period should be long enough to remove the influence of natural cycles (e.g., El Niño and La Niña cycles) from the observations so that the trend in climate is all that remains. Inter-annual variability in climate that is unrelated to climate change can disrupt the true trend in changes in climate. Local weather is influenced by many cycles that occur at different time scales (e.g., seasonal, diurnal, interannual). Increasing the length of this time period can help to remove the influence of these cycles if adequate data are available to establish the baseline. The time period used to establish the baseline should be as recent as possible to capture current climate conditions for comparison to projected future climate.

This section describes a method to establish a site-specific climate baseline using available climate datasets with further detail provided in Appendix B. The two key steps to establishing the climate baseline are:

- Selecting climate datasets for use in describing observed climate.
- Quantifying observed climate.

4.1.1 Selecting Climate Datasets

The climate baseline is established using existing climate datasets. Where available, the climate baseline should be based on observations from local weather stations. Weather or meteorological observations are short term (e.g., 1-year) collections of weather data such as wind and rain, whereas climate observations are a collection of meteorological observations and provide longer term trends in meteorological data.

However, the availability and suitability of climate datasets can vary considerably. The quality and suitability of datasets can be ranked as follows:

1. Climate datasets consisting of data from long-term meteorological observations from weather stations either on site or in close proximity to the mine.
2. Climate datasets consisting of data from more distant weather stations in the same region that can be considered representative of the site for which the baseline is being established (e.g., from national weather service providers or other industry sources such as other mines).

3. Climate datasets from other sources, such as data from climate data centres (e.g., provincial/territorial and local agencies), academic sources, scientific reports, relevant climate change assessments, governmental and intergovernmental publications, and databases.

Re-analysis data can be used to infill missing data and complete climate baselines by combining local observations with numerical weather prediction models as outlined in Appendix B.

Appendix C describes potential climate data sources with a focus on Canadian federal, provincial, and territorial resources.

The degree of representativeness and detail needed for a climate dataset depends on the decision to be made, and as described in Section 2.3, a scalable approach may be applied to establishing a climate dataset. A lower level of representativeness and detail may be used to develop a climate baseline and projected future climate to inform initial screening. On the other hand, a higher level of representativeness and detail may be used to refine the baseline and projection and inform detailed design. In order to develop a climate dataset with an appropriate level of detail, a climate risk-screening exercise can be conducted to identify which climate variables are of interest, the specific time periods, and return periods or durations, based on the decisions to be informed by the projected future climate conditions derived using the dataset. For example, a degree of dataset representativeness and detail that may be needed to inform the design of a new mine, as compared to a decision about whether to upgrade a small culvert.

Subsequent iterations of the development of the climate dataset, climate baseline, and projected future climate may also be informed by the outcomes of the assessment of climate vulnerability and risk.

4.1.2 Quantifying Climate Baseline

Based on the climate datasets and baseline period selected, the long-term averages (normals) and trends are calculated for climate variables to establish the climate baseline. Appendix B provides detailed guidance on trend analyses and statistical significance tests to help assess climate changes within the long-term observations, calculated as the average change in climate per specified period (e.g., change per decade or change per baseline period).The primary climate variables to consider are mean annual temperature and total precipitation as they are the focus of many climate studies and are typically observed for long periods of time and for many locations, which can help with the calculation of long-term climate averages. (e.g., IPCC AR5). Other indices, such as permafrost integrity in northern regions, should also be considered based on potential vulnerabilities associated with climate.

The intensity and return period of climate extremes (e.g., drought or extreme precipitation) should also be estimated as they pose risks at all phases of the mine life cycle. Any trends in extreme events, such as a decreasing return period for extreme precipitation events, should also be documented. Further discussion on calculating climate extremes is provided in Appendix B.

The box below provides a checklist of questions to consider in selecting data for use in established in the climate baseline.

Checklist for the Development of a Current Climate Dataset

- Based on the characteristics of the mine (i.e., life cycle phase and future plans, the age of the infrastructure, and region where the mine is located), is a rationale provided for the level of detail in the assessment of climate given?
- Is a detailed climate change dataset likely to be required in the future?
- What historical weather observations were considered and how were they selected?
- What weather observations were considered as part of the baseline climate period and how were they selected?
- How were missing weather observations from historical datasets addressed?

4.2. Projecting Future Climate Conditions

This section describes a recommended method for projecting future climate changes from the baseline conditions at a specific location or within a specific region, based on guidance accepted by the IPCC and other scientific bodies. More details are provided in Appendix B. In the IPCC's AR5, future climate projection data are available from about 30 GCMs covering four emission scenarios or RCPs. Climate projections used in AR5 are available from several sources, as discussed below and in more detail in Appendix C.

4.2.1 Selecting Future Climate Projection Sources

Projecting future climate for a given location is based on the climate baseline for that location, and then uses a combination of models and existing projections at larger spatial scale to develop projected site-specific future climate conditions. As described in Section 2.1, there are a range of models, existing projections and climate datasets that can be used. Selecting which models, existing projections, and datasets to use is site-specific, and is dependent on a range of factors such as:

- Objective of the risk assessment and the nature of decisions to be informed by the risk assessment
- Relevant climate variables
- Time scale to be considered
- Spatial resolution needed

As described in Section 3.2 these criteria will change over the life cycle depending on the nature of the decision to be informed by the projected future climate conditions.

Once these criteria are established, appropriate existing projections and datasets can be selected to the develop the projection of location-specific future climate conditions. When selecting models, existing projections, datasets, and other sources to use in developing projections of location-specific future climate conditions, the following factors should be considered:

- Climate science: Data sources are to be scientifically up to date.
- Number of GCMs: The use of as many models as possible (a multi-model ensemble).
- Spatial resolution: Finer spatial resolution may provide better site representation for detailed studies by using statistical or dynamical downscaling methods with Regional Climate Models (RCMs).
- Emission scenarios: Projections are to be available for a number of emission scenarios used in IPCC AR5 such as RCP2.6, 4.5, 6.0, and 8.5.

- Time period: Data should cover appropriate time periods used for risk assessments. For example, if the assessment covers the period until 2050, then climate projections should cover that time period and beyond (e.g., until 2080) to confirm the direction of change in climate and understand whether the magnitude of change over the extended time period (present to 2080) is different from the period of interest (present to 2050). It would be prudent to consider a longer time span to capture changes that may have impacts in the closure phase.
- Data format: Not all data formats are readily accessible for direct processing and some require some post-processing to extract the information of interest (i.e., NetCDF files require a set of software libraries to access the data).

Note that data sources have varying levels of review depending on whether they are provided by independent researchers or regulated organizations. Personnel with appropriate qualifications should assist in data source selection.

When selecting models, existing projections and datasets to use, it is important to consider the number of models used, the number of emission scenarios available, and the geographic coverage. Climate models are continually being improved and each has its own inherent biases and limitations. Thus, no one model, or climate scenario can be viewed as the most likely outcome or completely accurate. Therefore, IPCC (2013) and Charron (2016) recommend that climate change assessments use as many models and climate scenarios as possible, or a "multi-model ensemble." In addition, the mean of the results of an ensemble of models is generally closer to the observed values for past climate than any given individual model or scenario (Charron 2016). The suite of Canadian climate data portals outlined in Appendix C make climate projections (for temperature and precipitation variables, and derived indices) available at a variety of spatial scales, across different models and emission scenarios, and which can be displayed graphically or downloaded as values.

4.2.2 Understanding Uncertainty

Climate projection uncertainties stem from three main sources (Charron 2016):

- Natural variability in climate – most important for shorter timescales (decades)
- Climate model structural inaccuracies – important over all timescales
- Future trajectories of GHG emissions – important over longer timescales further in the future

Representing the Earth's climate system is difficult given the sensitivity of weather phenomena to small disturbances that cause natural variability. Climate model projections can vary because of differences in how they represent the earth system processes (Bush and Lemmen 2019). These can create biases in models and produce slightly different results (Charron 2016). For this reason, the multi model ensemble approach is typically used to delineate the probable range of results and will better capture the actual outcome (an inherent unknown). Uncertainties also arise when using different geographic resolutions of projections. Uncertainty in climate projections increases as global projections (usually provided at a scale of 100km or more) are downscaled into finer regional/local resolution.

In addition, to address uncertainty when considering long timescales, Owners should consider all plausible scenarios for future GHG emissions (i.e., RCP2.6, 4.5, 6.0, and 8.5), if available, since one RCP is not necessarily better or more correct to be used than the others. Each of the emission scenarios results in a future range (or cone) of uncertainty. It is uncertain what the exact conditions will be in the future, but conditions will likely fall within this range. A specific scenario or model output could be used as part of the risk assessment however, the uncertainty and bias in using one model should be considered when completing each of the following steps in this guidance.

4.2.3 Projecting Future Climate

Using the multi-model ensemble of existing future climate projections and datasets, models can be used to project future climate changes from the baseline for different time horizons. The most commonly used time horizons are:

- Near term or 2020s (e.g., 2011 to 2040)
- Mid-century or 2050s (e.g., 2041 to 2070)
- End-of-century or 2080s (e.g., 2071 to 2100)

The horizon of interest will depend on the phase of the mining life cycle. For example, if the timeframe of interest is 2030 to 2050, a range of years representative of the 2040s could be selected for the projection. Longer time horizons should be used for closure and post-closure. Projections of future climate should cover the same time duration as the current climate baseline. Thus, if the baseline is based on a 30-year period, then projections of future climate should be in 30-year increments.

Future extremes are projected using a similar method to the indices described in Section 3.2 and Appendix B, but the method should be applied to the selected multi-model ensemble. Daily temperature and precipitation projections from available downscaled data should be used for a climate assessment and considered during the planning and design phases of a mine and in developing adaptation pathways for existing mines (Section 6). Future climate extremes may be described in terms of a change from the baseline. As each model has a unique baseline, the calculations should be completed for each model and then assessed statistically to yield a range of projections across the multi-model ensemble.

At the time of completion of this guidance (late 2020), projections of future climate conditions related to permafrost degradation, percent loss of permafrost, or changes in the active layer thickness directly were not available from the sources provided in Appendix C, although each of these variables will be affected by mean annual temperatures, temperature extremes, and changes in ground and vegetation conditions. In addition, journal articles are available that describe research on projected percent loss of permafrost or the changes in active layer thickness. Bush and Lemmen (2019) present findings from studies which indicate increasing permafrost temperatures and reduced Canadian permafrost area. However, it is mentioned that confidence in projected permafrost degradation from climate model simulations is affected by inadequate representations of soil properties, uncertainties in understanding the response of deep permafrost layers, and interactions with changes in other climate variables such as increasing rainfall intensity. As climate science continues to advance, more information on permafrost related projections may become available.

Hydrological variations such as flood conditions can be projected by examining how the probable maximum precipitation (PMP), intensity-duration-frequency curves and rainfall statistics, snowpack and snowmelt, and evapotranspiration are projected to change under future climate conditions. The method for projecting both PMP and future potential evapotranspiration is the same as for the current climate but applied in this case to projections of future daily climate. The method for projecting future climate intensity-duration-frequency curves and rainfall statistics is described in Appendix B.

Unlike temperature projections, climate models are not yet able to fully resolve convective processes responsible for generating extreme precipitation amounts on finer spatial scales and contributing to extreme precipitation in larger scale synoptic systems (CSA 2019). For this reason, estimates of short-duration extreme precipitation for a selected location are unlikely to be robust. Methods outlined in Appendix B have been included to help increase the spatial extent of the analysis and capture more internal variability in the projections of precipitation. Any attempts to project future short-duration rainfall extremes should acknowledge the ongoing intense scientific research and debates on this subject.

As an extreme event that is often used as the basis of design of tailings facilities, the methodology for estimating PMP is particularly important and methodologies continue to be refined. However, Kappel (2019) did an assessment of Hurricane's Harvey and Florence, two of the most intense storms ever recorded in the United States in terms of both event duration and intensity. Kappel concluded that Harvey did not exceed the calculated PMP for the region and that the storm "provided a very beneficial real-time example that the PMP development process does appropriately envelope the processes which produce extreme rainfall." Thus, a PMP, if calculated properly, provides a very robust basis for the design of critical infrastructure such as tailings facilities. However, Kappel also concluded by stating that "Harvey also demonstrates the need to continually update the storm database and PMP estimates as new storms occur and the understanding of extreme rainfall mechanisms increases." This uncertainty should be acknowledged in the development of PMP projections.

Application of the multi-model ensemble approach to the variables described above produces a range of results. To help address uncertainty, it is necessary to calculate statistics that describe the range in projected relative change across the ensemble members as a whole (minimum, maximum, mean, median, and percentiles).

The box below provides a checklist of questions to help select and document models, existing projections and datasets used to develop projections of location-specific future climate.

Checklist for the Development of the Future Climate Dataset

Which climate models were used and how were they selected?

- How were the climate projections obtained?
- What future time periods (e.g., mid-century or end of century) were considered?
- Which scenarios were considered (e.g., RCPs)?

How is uncertainty in the future climate projections addressed?

What future climate variables were considered?

- What variables are available directly from the climate models (e.g., total precipitation)?
- What variables are based on analysis of the model projections (e.g., rainfall statistics)?
- What values are taken from literature?

4.3. Potential Impacts and Opportunities Associated with Climate Change

Climate change can have a wide range of potential impacts on the mining sector and could also present opportunities. The section presents a brief discussion, with examples, of the types of potential impacts and opportunities that should be considered in identifying climate change vulnerability and in subsequent risk assessments. The examples here are by no means exhaustive but are intended to provoke site-specific discussion about potential impacts, particularly off-site impacts which may not be as self-evident as potential on-site impacts. These potential impacts are outlined further in Appendix E.

Potential Impacts

The potential impacts of climate change on mining depend on a wide range of factors such as:

- Location of the mine:
- Geographical setting on how the local geography interacts with climate.
- Current climate and projected future climate.
- Size of the mine and the nature of mine-site infrastructure.
- Life cycle phase.
- Current risks being managed and how those risks could be modified by climate change.

Impacts that may affect mining activities may occur on or off-site. Impacts can also be direct or indirect. Appendix E provides examples of climate variables, climate events, and potential vulnerabilities categorized by mine life cycle phase (Table E-1).

Potential On and Off-Site Impacts

Potential on-site impacts include:

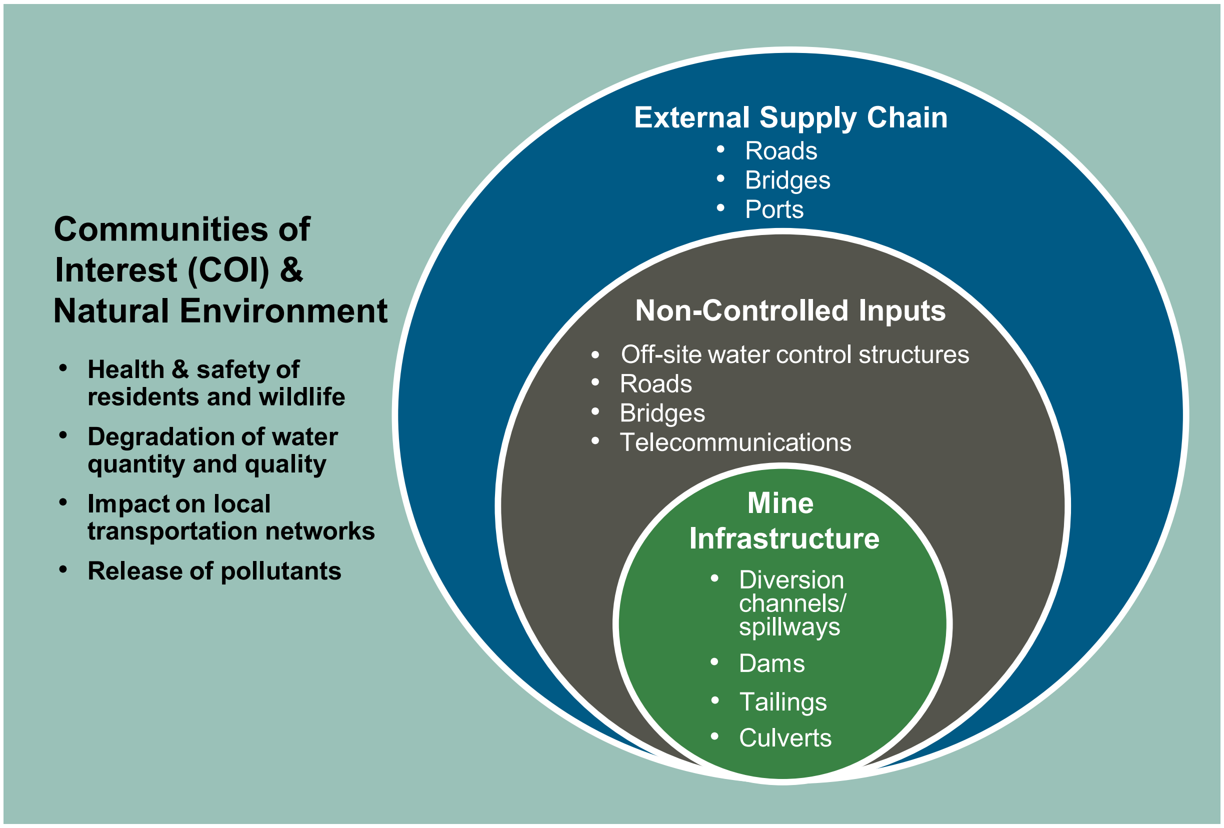
- Health and safety:
- Injury or loss of life due to fires, floods or other events.
- Injury or loss of life due to heat stress.
- Transportation infrastructure such as roads and airstrips:
- Damage to airstrips due to permafrost degradation.
- Water management infrastructure:
- Overtopping of diversion structures or spillways.
- Ineffective water treatment due to low water flow under drought conditions.
- Tailings facilities:
- Loss of water cover needed to maintain saturated condition and prevent oxidation of sulphide minerals.
- Higher than acceptable water levels.

Potential off-site impacts can be more challenging to identify and assess. Such impacts could lead to the inability to access the site, or disruption of supply chains, including the inability for supplies, personnel, or product to move to or from the site. Such impacts may also affect nearby communities, leading to environmental, economic and social impacts. Off-site impacts could include:

- Health and safety.
- Damage to or interruption of off-site transportation infrastructure.
- Early melting of winter roads.
- Impacts on port facilities due to sea level rise or extreme events.
- Interruption of air transportation due to extreme events such as storms of prolonged fog.
- Interruption of power supply for sites connected to the electrical grid.
- Extreme weather (e.g., windstorms or ice storms) could impact transmission lines.
- High temperatures can reduce transmission capacity.
- Reduced capacity to generate hydroelectricity due to drought.
- Interruption of telecommunications due to extreme weather events.
- Impacts on local or regional ecosystems, such as changes in habitat conditions leading to shifts in biodiversity or ecosystem structure and function (e.g., shifts in dominant vegetation types).
- These changes may have implications for closure planning and reclamation and expected post-closure land-use.

In identifying potential on and off-site impacts of climate change, it is helpful to consider the sphere of influence of a mine, which describes what impacts an Owner can influence, on or off-site (Figure 6). Impacts that are outside the sphere of influence cannot be controlled by the Owner. For example, an Owner can control aspects of its external supply chain by controlling the fuel usage, reagent acquisition and delivery, maintenance of vehicles, and contractors, but it cannot influence or control the off-site road conditions being used to transport goods to and from the site.

Figure 6: Spheres of influence of the Owner regarding climate change and adaptation.



Potential Direct and Indirect Impacts

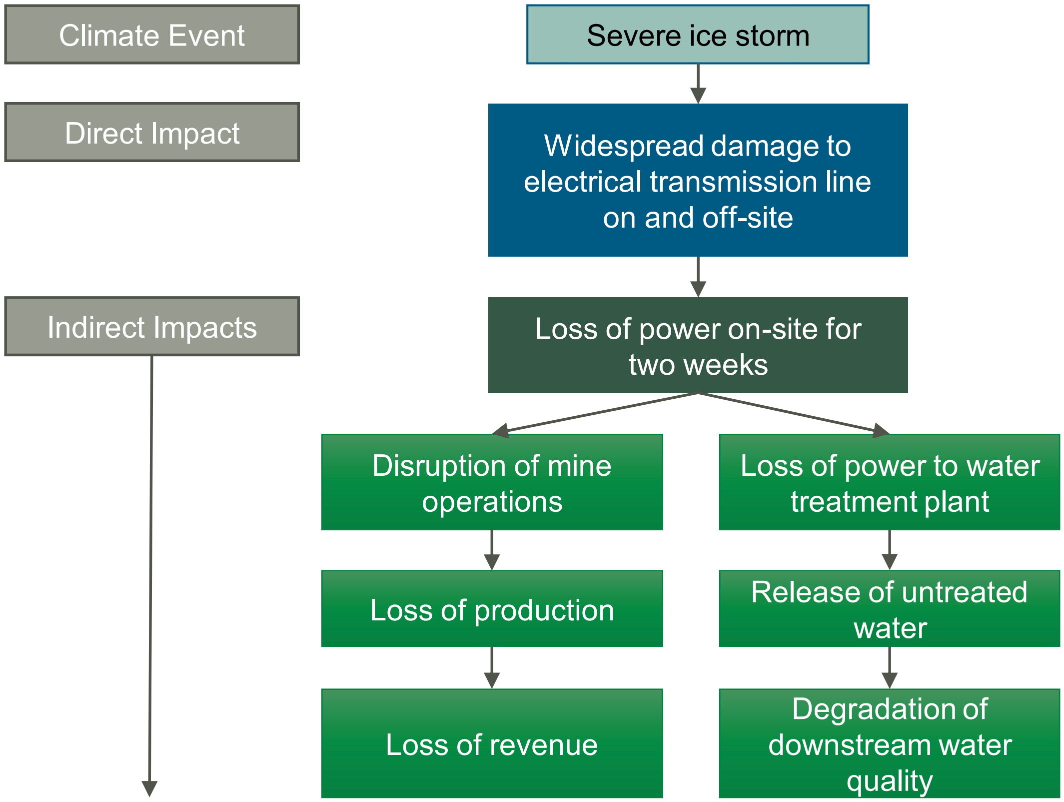
In addition to the potential for impacts to occur on or off-site, impacts can also be direct or indirect.

Direct impact: an impact (typically a physical impact) on a specific infrastructure component in response to a climate event.

Indirect impact: an impact that occurs as an outcome of a direct impact. An indirect impact may, in turn, lead to other indirect impacts.

Figure 7 helps to illustrate to difference between direct and indirect impacts.

Figure 7: How a climate event may cause both direct and indirect impacts.



The terms primary, secondary and tertiary, etc. may also be used to describe impacts. These terms are not intended to imply severity or priority, but rather the sequence of events that would lead to impacts. Indeed, as the example in Figure 7 illustrates, the potential consequences of indirect impacts may be significant.

Owners or operations with extensive global supply chains and operations that are dependent on a single transportation link that is not controlled directly by the Owner may be particularly vulnerable to indirect impacts of climate change. The need for resilience in supply chains should be considered in the development of potential adaptation measures.

Potential Opportunities

The mining industry must adapt and make decisions to manage risks associated with climate change. However, climate change may also present opportunities for the mining sector. Although it is essential to maintain a focus on understanding and managing risks, it is important to not overlook potential opportunities. In addition, some future changes to the climate may be neutral – neither risk nor opportunity, but changes that still need to be identified and understood.

Examples of changes in climate that could lead to opportunities, or to changes that pose neither risks nor opportunities include:

- Warmer winters and earlier spring melt may result in lower peak freshet flows, which could reduce flooding risks if peak flow risks are freshet related.
- As temperatures increase and sea ice melts, locations in the North that were previously inaccessible for mining may potentially be accessible.
- Rising temperatures may reduce overall energy consumption by decreasing winter heating demand, particularly at underground mines where ventilation air is heated in the winter.
- Increasing lengths of growing seasons would help enhance revegetation activities. In addition, changes in growing conditions could affect the optimal seed mixes for use in revegetation and increase carbon uptake of the biomass.
- Higher intensity snowmelts may provide an opportunity to obtain water from local sources as increased snowmelt will feed into these systems.

4.4. Vulnerabilities and Risks

Before describing the risk assessment approach, it is important to have a clear, consistent understanding of the concepts of vulnerability and risk.

Vulnerabilities

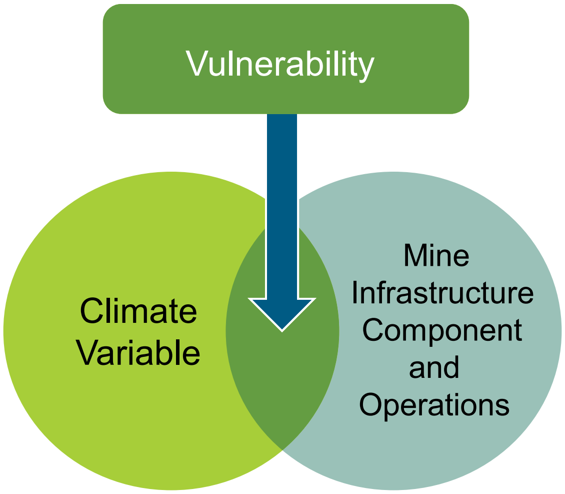
Vulnerabilities are present when a climate variable interacts with an entity such as mine infrastructure in a manner that has the potential to give rise to risk. Vulnerabilities are not limited to direct mine infrastructure but can also include off-site infrastructure and supply chains. The following examples illustrate the concept of vulnerabilities:

- If a road water crossing does not have the capacity to function if a climate event for which it was not designed occurs (e.g., high stream flows exceed the capacity of the water crossing), and there are no other adaptation measures in place (e.g., a diversion or stormwater retention pond), then that water crossing is vulnerable to a direct impact due to climate change.
- If the water crossing fails, there would be potential indirect impacts on:
  - Downstream ecosystems
  - Downstream infrastructure or communities
  - Transportation if the road is damaged
- If a mine accommodations complex is constructed on permafrost, then that accommodations complex is vulnerable to a direct impact if permafrost degrades.
- If the accommodations complex collapses or becomes unstable there would be potential indirect impacts on:
  - Health and safety if the failure is sudden or the building is considered unsafe.
  - Business continuity (e.g., if a portion of an accommodations complex fails, then the Owner's capacity to house personnel on site is reduced, leading to reductions in workforce and production rate).

All potential direct and indirect impacts should be identified, and vulnerabilities identified accordingly. Similarly, the identification of vulnerabilities should take into account potential on and off-site impacts.

Figures 8 and 9 illustrate the concept of vulnerabilities in different ways.

Figure 8: Vulnerabilities exist when a climate variable interacts with a mine infrastructure component and/or operation.

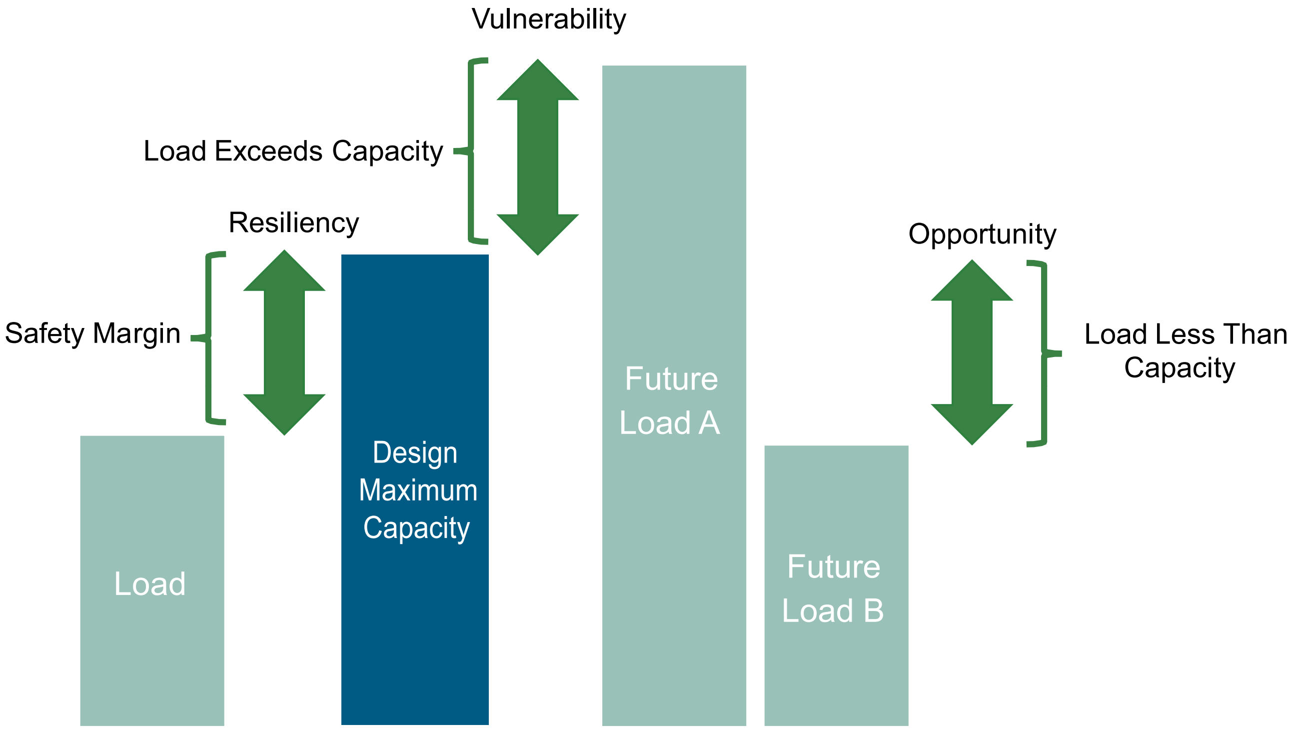


Vulnerabilities and associated risks will change over the mine life cycle and are dependent on a range of factors such as:

- Location (e.g., coastal vs. inland, arid vs. temperate).
- Geographic extent of the mine and its infrastructure and operations.
- Changing climate conditions, particularly if conditions exceed the projected future conditions.
- Nearby communities and ecosystems.
- Local or regional changes, such as:
- New infrastructure
- New commercial or recreational activities
- Expansions of communities
- Changing land use
- Changes in regional water management.
- Implementation of adaptation measures by third parties.
- Lifespan of the mine and required lifespan of infrastructure.
- Mine closure and post-closure conditions.
- Mine itself, the infrastructure components on site, and the operations taking place.

Examples of climate change vulnerabilities and how they may change throughout the mine life cycle are provided in Appendix E.

Figure 9: If the future load may exceed the design maximum capacity, a vulnerability exists (adapted from Engineers Canada). If the future load may be less then an opportunity exists.



Risks

Risk is defined as a potential negative impact, detrimental to operations, a facility, the environment, public health or safety, that may arise from some present process or future event (MAC 2019b). When assessing risk, both the potential severity and consequence of the impact and its probability of occurrence are considered.

The concept of risk is often misunderstood, and the term is often misused. In conducting risk assessment and communicating risk and risk-related activities, it is important to be clear about what risk means, and in particular, be clear that risk considers both the potential consequence or severity of an event, and the probability or likelihood of that event occurring. For example, in comparing the personal risk of driving a car versus commercial air travel, the potential consequence is the same in both cases – catastrophic. However, the likelihood of you being killed in a fatal car crash is higher than the likelihood of you being killed in a fatal plane crash. Therefore, your personal risk associated with driving a car is higher than your risk associated with commercial air travel, even if some people may perceive commercial air travel to be riskier.

Risk can be expressed qualitatively, semi-quantitatively, or quantitatively, depending on the objective of estimating risk and the degree of certainty associated with various parameters involved in the estimate. This is discussed further in Section 4.5.

4.5. Risk Assessment Framework

Completing a climate change risk assessment helps Owners build an evidence base and provides a more complete picture of their climate-related vulnerabilities and risks. A risk assessment will help Owners make decisions about potential implementation of climate change adaptation measures (ICMM 2019).

As previously noted, mining companies are experienced in managing risks and in many cases have existing enterprise and operational risk management programs that can be tailored to support or include a climate risk assessment. This section describes a risk assessment framework that is intended to add a climate lens to an already existing risk management program, or it can serve as the basis for a risk management program for Owners that may not already have one in place.

A risk assessment is used to identify climate change vulnerabilities and risks, assess the magnitude of the risks, and rank the risks identified. Climate change can pose a range of potential risks at the site and corporate-level, associated with potential impacts (consequences) on health and safety of personnel on-site and residents of local communities, infrastructure, mine operations, local/regional environment, Owner economics, Owner reputation, and potential for social or labour unrest. In planning and conducting a climate change risk assessment, this broad range of potential consequences should be considered in addition to other potential modifiers of risk such as changing legal requirements, and changing expectations of investors, insurers and communities. The risk assessment focuses on the inherent risk in the absence of adaptation measures and Stage 2 looks at the residual risk after the development of adaptation pathways.

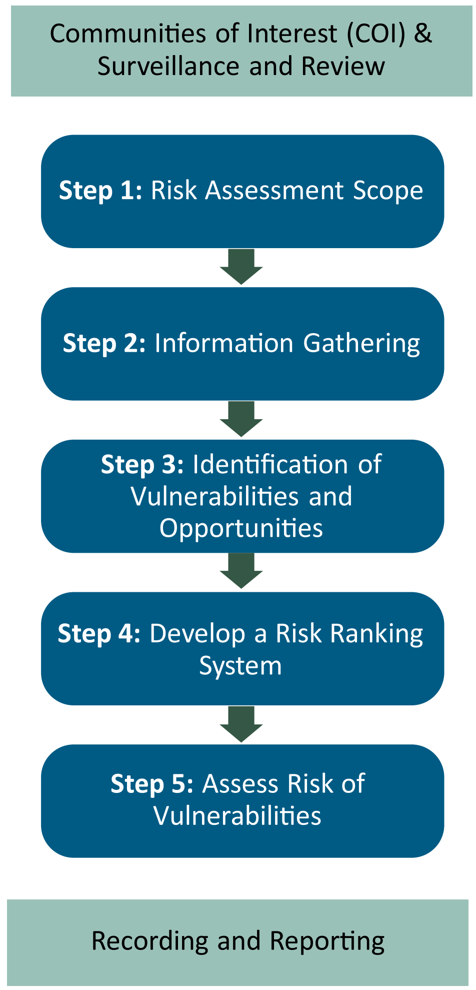
The following climate change risk assessment framework is aligned with the ISO 31000 Risk Management Standard (ISO 2018) and incorporates mining-specific issues based on existing guidance documents (Section 2.3). The framework considers the following overarching principles of assessing climate change risk:

- Vulnerabilities and risks are expected to occur throughout the mine life cycle, and therefore the framework considers vulnerabilities and risks that could occur in all phases of the life cycle.
- The risk assessment is based on the currently available information.
- The risk assessment is customized to the specific mine site in consideration of the risk assessment objectives.
- The risk assessment provides supporting information to assist the decision-making process (Section 5.0).

The steps of a climate change risk assessment framework are shown in Figure 10, and detailed descriptions for each step are provided below. The framework outlines a series of actions as well as overarching components (e.g., COI engagement, surveillance and review, recording and reporting) that can be used to undertake a site-specific climate risk assessment. It can also be used to undertake a regional climate risk assessment should multiple operations be located in the same region, or if an Owner collaborates with local communities or other industries in conducting a risk assessment. This framework can be scaled to different levels of detail at different phases of mine life, in accordance with the needs of decision makers.

A site-level climate risk assessment would include specific definitions in terms of vulnerability and risk that could be different than definitions at the enterprise (portfolio) level, which are broader and may prioritize risks across multiple mine sites. When translating site-level climate risks onto an enterprise-wide risk matrix, site-level risks may not necessarily be applicable. For example, climate risks identified at the site level can be underestimated if consequence categories used at the enterprise level, which are typically larger than at the site level, are used. This would likely occur when using matrices for larger companies that consider multiple assets and consequence rankings/scaling may need to be adjusted moving from the enterprise assessment to site-specific assessments.

Figure 10: Climate change risk assessment framework.



Overarching Elements of the Risk Assessment Framework

Communities of Interest (COI) Engagement

Throughout all steps of the risk assessment, an important aspect is ongoing communication and engagement with COI, including Indigenous communities/groups. COI are becoming concerned about the potential impacts of climate changes on their health and safety, environment, communities, and livelihoods, and the presence of a mine close to their communities may compound these concerns. Owners should explore this through existing COI engagement frameworks, including MAC's TSM Indigenous and Community Relationships Protocol.

COI engagement can help support the decision-making process by providing feedback and information from people with different expertise and experience across multiple areas. In particular, COI engagement can:

- Inform the process of identifying vulnerabilities and assessing risk.
- Facilitate knowledge sharing, including traditional knowledge, that can help the Owner to better understand:
- How the climate has been changing.
- The applicability and accuracy of the climate baseline developed by the Owner.
- The potential effectiveness of proposed climate change adaptation measures.
- Help avoid "maladaptation" where adaptation actions of one group may have negative consequences for others (ICMM 2019).
- Help COI have a better understanding of the climate change risks identified, and the actions that the Owner is taking to manage those risks.
- Help COI better understand potential impacts of climate change in their own communities.

Surveillance and Review

Consistent with the iterative approach described in Section 2.3, the risk assessment process should be iterative. This is true of all risk assessment processes but is particularly important given the uncertainties associated with climate change.

Owners should review their risk assessment on a regular basis (e.g., annually, or when a material change to the operation or business occurs) to confirm that the assessment is still valid and up to date. The result of this review could trigger an update to the risk assessment as necessary based on significant changes. As described in Section 2.3, changes in vulnerabilities and risks could be triggered by factors such as:

- Updates to climate science, projected future climate conditions, or other factors (e.g., legal requirements) that may alter vulnerabilities or risks.
- Changes to the operations of the mine, including infrastructure.
- Changes in corporate policies, plans, business strategies and assets.
- Change in life cycle phase of the mine.
- Changes in future plans for the mine.
- Changes to the external environment.
- Climate adaptation actions taken by third parties.

Recording and Reporting

The risk assessment process and outcomes should be documented and reported. Risk management activities and outcomes for decision-making should be communicated to appropriate internal stakeholders and COI. Reporting should be compiled in common and simple terms that can be understood by senior management, regulators, and COI.

Assembling the Team

Prior to initiating the risk assessment process, Owners should establish a multidisciplinary team that can provide a diverse level of skills and knowledge that will help to complete the assessment. The team should include people who are knowledgeable of:

- Local historical and current climate.
- Design and/or operation of the different infrastructure components of the mine.
- Future climate projections and climate impacts.
- Site-specific risk register and risk assessment process.

The composition of the team will depend on the Owner's organizational structure but would typically include representatives from the following functions: mine operations, environment, community and government relations, water management, tailings management, procurement, and mine management. Additional expertise such as risk assessment, climatology and health and safety professionals may also be required.

STEP 1: Risk Assessment Scope

Defining the scope of the risk assessment is required to identify the level of effort needed to conduct the assessment and will be informed by Owners' internal requirements.

The level of effort will depend on the project size, geographic extent (i.e., does this cover the whole mine, or just one component?), potential impacts beyond the mine property, criticality (i.e., is this a critical piece of infrastructure?), and vulnerabilities. The risk assessment scoping should consider the following:

- Objective(s) of the risk assessment.
- Boundaries of the assessment referred to as the domain, considering the geographic extent, infrastructure components, operations, and level of design that are to be included.
- Existing risk registries or risk management programs that have already identified risks, to be referenced or integrated with the climate risk assessment.
- Temporal boundaries of the assessment – what phase of the mine life cycle the assessment considers, what the life span of the mine or infrastructure component is.
- Human and financial resources needed to carry out the risk assessment, and any time constraints.
- COI that need to be engaged, and at what point in the process they need to be engaged.
- Linkages to existing risk assessment practices and procedures (i.e., existing risk registers).
- How the climate change risk assessment will be integrated into the overall decision-making process at both the operational and enterprise level.

STEP 2: Information Gathering

Obtaining baseline information will help develop an inventory of data, identify existing tools, and other relevant and up-to-date resources necessary to complete the assessment. The level of information required will vary, but typically includes:

- Information from existing risk assessment practices and reviews. This could include the enterprise or mine-specific risk criteria already used by the Owner to assess risks.
- Traditional and Indigenous knowledge.
- Climate adaptation measures already taken by third parties.
- A list of mine equipment, infrastructure components, operations, and design parameters that will be used to identify vulnerabilities (Step 3) – this list can vary in the level of detail and will depend on the phase in the mine life cycle, and may include:
- Construction:
    - Water management and treatment
    - Dust management
    - Land preparation
- Operations and Ongoing Construction:
    - Tailings management
    - Waste rock management
    - Water management and treatment
    - Dust management
    - Transportation infrastructure
    - Processing plant
- Closure and Post-closure:
    - Water management and treatment
    - Tailings management
    - Waste rock management
    - Dust management
    - Reclamation and revegetation
- Information on the current designs of infrastructure and closure plans, including climatic assumptions considered for design purposes (e.g., storm return periods used, intensity-duration-frequency estimates), as well as any codes, standards, permit requirements, or guidelines followed in the design process.
- Operational data for equipment and infrastructure, including surveillance results, operational experience (e.g., how a specific infrastructure responded during similar past climate events?), anticipated resiliency, and incident reports.

A document register should be established to identify and track source documents for the baseline information to be used to inform the assessment of vulnerabilities and risk.

STEP 3: Identification of Vulnerabilities and Opportunities

This step involves:

1. Identifying and describing the potential interactions between a range of relevant climate indicators and infrastructure components, operations, communities, and the surrounding environment.
2. Based on these potential interactions and the projected future climate conditions developed in Stage 1, identify the climate change vulnerabilities.

Potential direct and indirect impacts and associated vulnerabilities both on and off-site should be identified, and relationships between direct and indirect vulnerabilities should be described. Identification of vulnerabilities should be done in a comprehensive manner with both internal and external input. Having as complete a listing of vulnerabilities as possible, and a clear understanding of the relationships between direct and indirect vulnerabilities is essential since this will form the basis for the risk assessment. Anything missed here will be left out of the risk assessment.

During this step, any opportunities or climate change outcomes that would be neutral (neither negative nor opportunity) should also be identified. Opportunities do not need to be assessed or evaluated through the risk assessment process but should be considered in subsequent development of adaption pathways (Section 5) and implementation (Section 6).

STEP 4: Define a Risk Ranking System

As described in Section 4.3, risk is the product of the likelihood and the consequence of a potential unwanted event. Ranking the likelihood and consequence of each vulnerability being assessed facilitates categorization of risk, for example as low, medium, or high. To assess risk using the approach described in this guidance, it is necessary to develop a risk ranking system or scale and associated risk criteria for both likelihood and consequence.

Risk criteria for consequence can be described qualitatively or quantitatively. For example, a range of categories that represent severity of financial consequences can quantitatively describe the potential financial cost of a risk. Other consequence categories that can be used include health and safety, structural design, operational, reputational (public exposure), environmental, and social risks. Table 3 provides examples of qualitative and quantitative risk criteria for consequence.

Table 3: Qualitative and quantitative examples of consequence categories.

Consequence Category/ Risk Scoring	Qualitative	Capital Loss per event
1	Insignificant	<$250,000
2	Minor	$250,000 – $500,000
3	Moderate	$500,000 – $1 million
4	Major	$1 million – $2 million
5	Catastrophic	>$2 million

Risk criteria for likelihood can also be described qualitatively or quantitatively. Which approach to use depends, in part, on the degree of uncertainty. Assigning quantitative probabilities to an event without adequate information to justify those probabilities can be misleading. Table 4 provides examples of qualitative and quantitative risk criteria for likelihood.

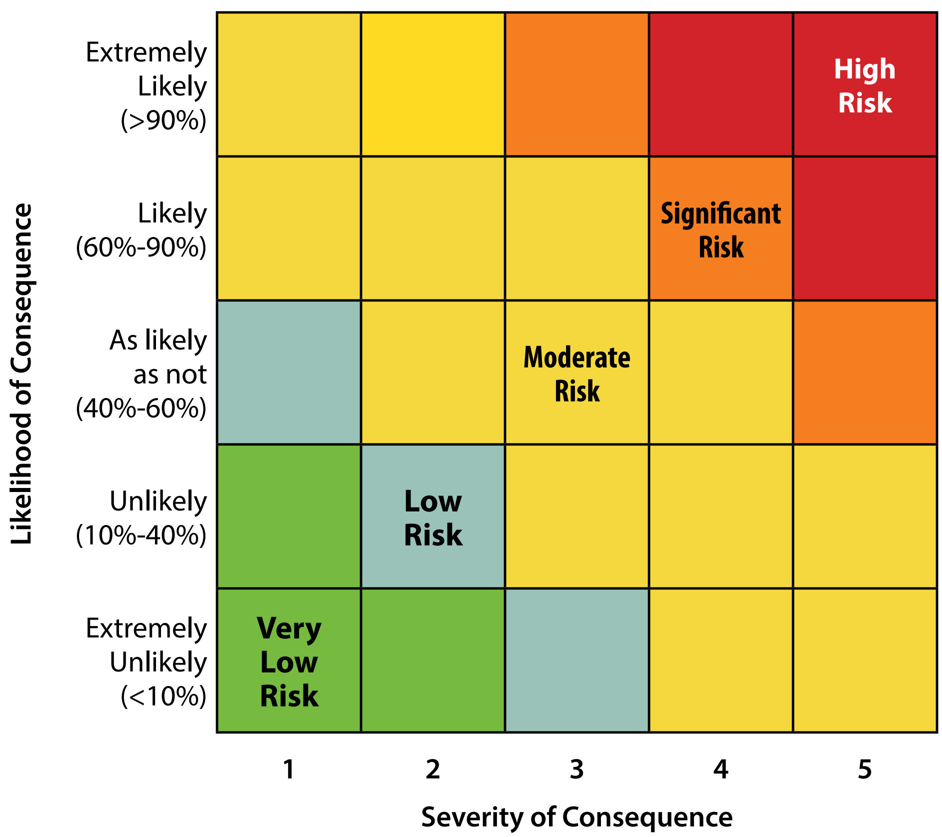
Table 4: Qualitative and quantitative examples of likelihood categories.

Likelihood Category/Risk Scoring	Qualitative	Annual Probability
1	Rare	<1%
2	Unlikely	1-10%
3	Possible	10-50%
4	Likely	50-100%
5	Almost Certain	100%

When conducting qualitative risk assessments, a matrix approach can be used to categorize risk for each vulnerability assessed. In this approach a grid or matrix is developed, with consequence on one axis and likelihood on the other. The risk categorization is determined by the likelihood and consequence, and where in the matrix those intersect for a given vulnerability.

This is illustrated in Figure 11, which is an example of a matrix, also referred to as a heat map, representing a risk ranking system. The consequence (x-axis) and likelihood (y-axis) have both been divided into five categories for a 5 by 5 matrix and can be used to plot each vulnerability to categorize the risk.

Figure 11: Example matrix or heat map for a risk ranking system.



Many Owners have existing risk ranking systems that may be applied to climate change risks – with or without modification. If a ranking system is not already being applied, a system should be developed and applied that includes climate risk and considers:

- Developing appropriate criteria to allow the climate risks to be differentiated (i.e., so all risks do not end up in the same category).
- Developing criteria that align with existing terminology used by the Owner (e.g., does the Owner refer to "high probability" or "extremely likely", does the Owner define terms such as "likelihood" or "consequence").
- Relevant policies or objectives that define acceptable levels of risk (e.g., those outlined in sustainability reports). The acceptable level of risk should be defined in the context of the mine site and for its specific life cycle phase, taking into account the likelihood and consequence, and perspectives of the Owner, regulators and COI (MAC 2019b).

STEP 5: Assess Risk of Vulnerabilities

The risk ranking system developed in Step 4 is applied to the vulnerabilities identified in Step 3, and the risk associated with each vulnerability is assessed. Each vulnerability to be assessed is assigned a consequence score and likelihood score. The consequence and likelihood scores may be plotted on the matrix/heat maps.

One notable difference in the methodology for assessing climate change risks, compared to assessing other risks, is that for each vulnerability, the risk is categorized under both current and projected future climate conditions, to be able to understand how the risk may change (e.g., greater likelihood and/or consequence) as a result of climate change. Alternatively, if other approaches are being used, the risk can be calculated by the consequence and likelihood but should similarly be calculated for both current and projected future climate conditions. The resulting risk associated with climate change is the delta or change in the risk between the current and future climates.

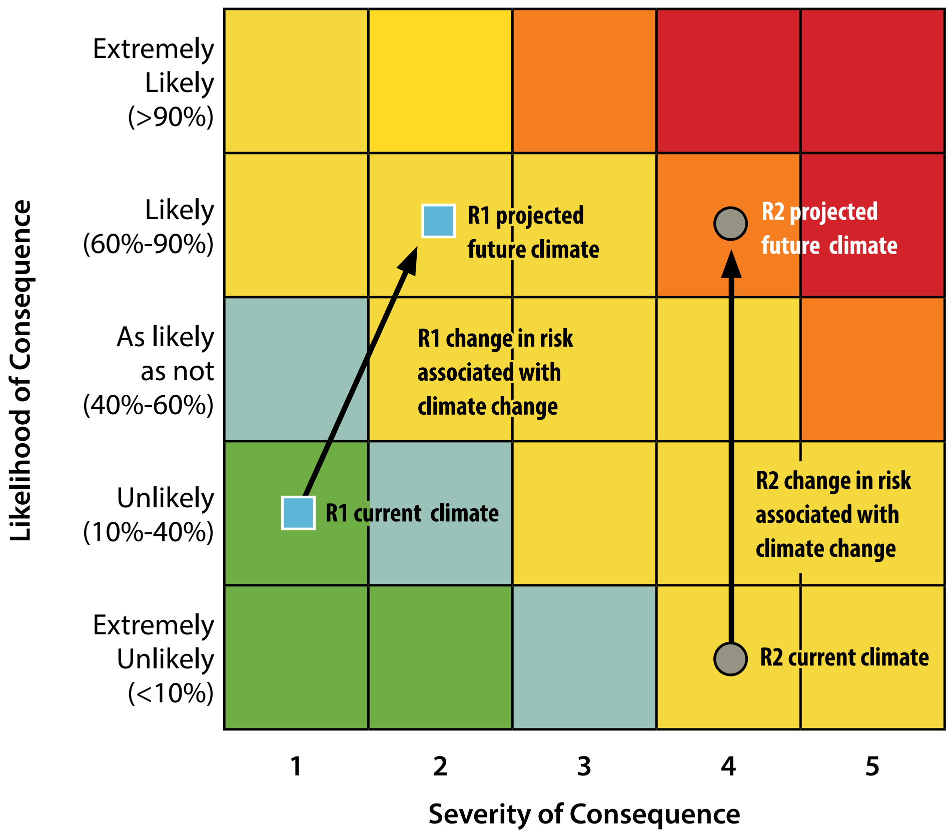
Figure 12 provides an illustration of this using two risks:

- R1: the risk of overtopping of a spillway as a result of a high intensity precipitation event.
- Under current climate conditions, R1 is categorized as very low risk.
- Under projected future climate conditions, assuming no additional management action is taken between current and future conditions, the likelihood of an overtopping of the spillway is higher, and the consequence if overtopping does occur is also higher.
- Therefore, under projected future climate conditions, R1 is categorized as a moderate risk.
- The risk associated with climate change for R1 is moderate, since it would change by two categories of risk, from very low to moderate.
- R2: the risk of failure of a containment structure as a result of increasing temperature leading to permafrost degradation, leading to a reduction in structural stability.
- Under current climate conditions, R2 is categorized as a moderate risk.
- Under projected future climate conditions, assuming no additional management action is taken between current and future conditions, the likelihood of failure of the containment structure is higher, but the consequence if failure does occur is unchanged.

- Therefore, under projected future climate conditions, R2 is categorized as a significant risk.
- The risk associated with climate change for R2 is low, since it would change by one category of risk, from moderate to significant.

Thus, the risk associated with climate change for R1 is higher than for R2. However, under both scenarios, the risk associated with R2 is higher. Both of these factors would need to be considered in prioritizing these risks for decision-making.

Figure 12: Example matrix/heat map with plotted consequence and likelihood scores for each vulnerability under current and future climate conditions.



The risk assessment can be conducted at varying degrees of detail, through qualitative, semi-quantitative, or quantitative methods, or a combination of these methods. Risk assessment is an iterative process and Owners should consider the following:

- Uncertainties associated with the vulnerabilities that give rise to risks including the quality and completeness of the data that the risk assessment is based on.
- Uncertainties associated with assessing the likelihood and consequence of risks, particularly the likelihood.
- Results of surveillance or additional data collection.
- Adaptation measures already in place and their effectiveness in reducing the risk.
- More detailed analysis of climate projections can be done as climate science improves to improve the understanding of climate risks.

Results from the risk analysis of all vulnerabilities assessed are compared, ranked, and prioritized to inform decision-making and determine whether additional action is required. Ranking and prioritization should consider both the change in risk associated with climate change, as well as the absolute risk for each vulnerability assessed. In the example above, R2 would likely be considered a higher priority, even though the change in risk associated with climate change is higher for R1.

In addition, it is important to consider giving high priority to high or extreme consequence events due to the severity of the potential impacts, even if the likelihood is very low.

Checklist for Climate Change Vulnerability and Risk Assessment

- What are the objectives of the climate change risk assessment?
- What level of information is required to complete the assessment? Has the appropriate level of information been obtained?
- Have all potential vulnerabilities been identified and described for all stages of the mine life cycle?
- Have the risk ranking criteria been clearly defined? Are there any existing risk ranking systems in place that may be applied to climate change risks?
- How have uncertainties been considered in the assessment?

4.6. Case Study

The following case study is an example of a vulnerability and risk assessment that has been completed by a mining company. Appendix D provides more detailed information.

Agnico Eagle – Using Climate Datasets to Reduce Risks and Inform Cover Design

Agnico Eagle is a Canadian gold mining company operating three mines in the Nunavut territory in Canada – Meadowbank, Meliadine and Whale Tail. Their mine proposals have been subjected to an Environmental and Social Impact Assessment (ESIA), a requirement of the Nunavut Impact Review Board (NIRB). NIRB requires project proponents to take into consideration the potential effects of a changing climate through the life cycle of a proposed project. NIRB asks proponents to consider the question "How will potential changes in climate affect the infrastructure associated with the Project?"

In the case of Agnico Eagle's projects in Nunavut, the level of detail in the submissions to NIRB, NIRB's subsequent Information Requests, and the available future climate projections used to support the assessment evolved from the time that the original Meadowbank project was initiated in 2005, to the more recent Whale Tail approval in in 2020.

Each mine's climate change assessment included a detailed characterization of the historical climate in the region, and more locally at the project site. For projecting future climate, the approach used was:

- Use existing, publicly available climate change projections.
- Analyze those projections using applicable tools and protocols.
- Provide the projections in a format that was meaningful to both a non-climate scientist and other disciplines completing sections of the ESIA who were relying on the data for technical applications.

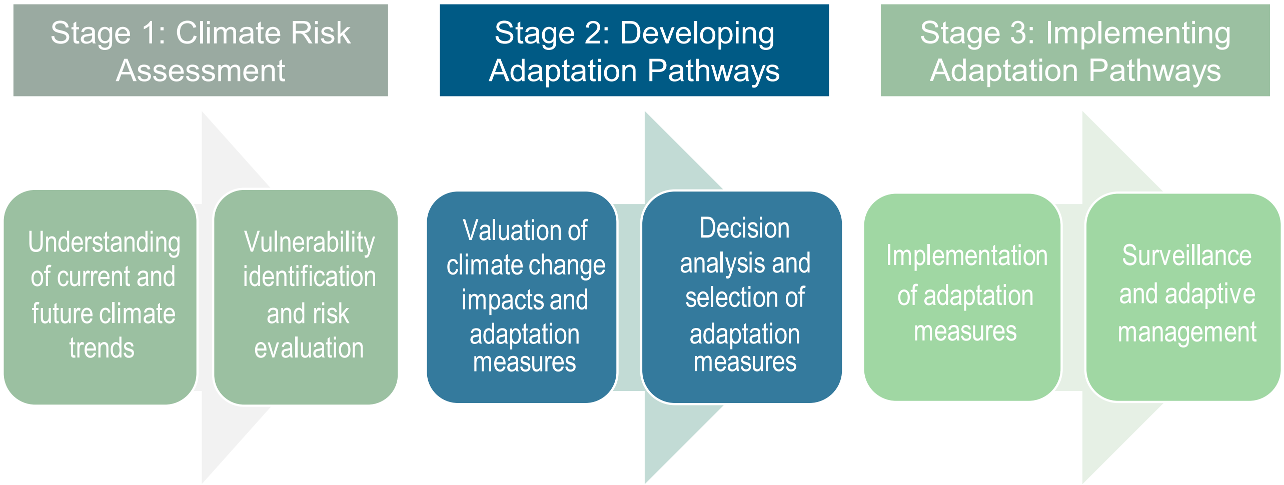
This information was then provided in a format that supported further analysis and provided a basis for identification of potential climate-infrastructure interactions and the design of adaptation measures to reduce project risks. The level of detail required to document the adaptation options became more detailed with each subsequent assessment. NIRB, their technical reviewers and stakeholders focused on the potential adaptation options and how they related to the project design.

A key vulnerability identified as part of the Whale Tail project was the vulnerability of the Waste Rock Storage Facility (WRSF) to increasing temperatures. The WRSF is designed to ensure that the waste rock remains frozen to prevent the oxidation of sulphide minerals in the waste rock, thus preventing acidic drainage from occurring and impacting the quality of groundwater and surface water. To account for seasonal thawing of the permafrost active layer, the potentially acid generating waste rock would be covered with a layer of non-potentially acid generating rock. If this cover is not thick enough, and the depth of the active layer were to extend below the cover into the waste rock, then acidic drainage could occur.

Thus, demonstrating that climate change, specifically degradation of permafrost, would not impact the WRSF and compromise the protection of groundwater and surface water was identified as a key consideration in the NIRB review process and was addressed by Agnico Eagle in the design of the WRSF.

To address this vulnerability, Agnico Eagle assessed the minimum cover thickness required for the WRSF under changing climate conditions. The first step in this assessment was to develop a climate dataset that incorporated information from the surveillance program for the existing Meadowbank WRSF (about 50 km southwest of Whale Tail) and provide a summary of the future projected monthly mean temperatures for the Whale Tail location. This climate dataset was then used as input in a thermal modelling study to evaluate seasonal freeze-thaw conditions and estimate future changes in the depth of the active layer. The outputs were used to assess the thickness of cover that would be needed to ensure that the potentially acid generating waste rock remains frozen below the active layer under the different projections of future climate conditions. The outputs of this assessment were then used to develop the final design for the WRSF, which received NIRB approval.

5 Stage 2: Developing Adaptation Pathways



This section provides guidance on how to develop adaptation pathways that describe future actions to respond to risk and opportunities posed by climate change.

Mining companies typically already have mechanisms in place to manage risk, such as management systems, risk assessment, development and implementation of risk management plans and implementation of surveillance programs, and they typically review and update these mechanisms throughout the life cycle.

However, climate change and the uncertainty associated with projections of future climate pose additional challenges. The optimum decision taken today may not remain the optimum decision a decade from now based on the change in the observed climate conditions or may not remain the optimum decision when the next IPCC Assessment Report is released, and projections of future climate are updated. Thus, climate change adaption adds an increased level of uncertainty and flux to existing mechanisms for risk assessment and management. Due to this uncertainty, decisions on how to best adapt to changing climate conditions are challenging.

This section provides guidance on making decisions about climate change adaptation in the face of such uncertainty, and it recommends the development of adaptation pathways as a tool to evaluate, develop, and potentially implement adaptation measures. The adaptation pathways approach is a "planning approach addressing the uncertainty and challenges of climate change decision-making. It enables consideration of multiple possible futures and allows analysis/exploration of the robustness and flexibility of various options across those multiple futures" (South West Climate Change Portal 2020).

Adaptation measures are actions taken to manage risks or opportunities associated with climate change. Adaptation measures may include actions to either prevent or reduce the likelihood of the occurrence of an adverse impact due to climate change or reduce or mitigate the consequences of an adverse impact due to climate change. They may be implemented on a site-specific basis or at the corporate level and include a wide range of potential actions such as:

- Modifications to existing infrastructure or construction of new infrastructure.
- Revising plans, practices, and procedures such as:
  - Operating practices such as water management.
  - Maintenance practices such as maintenance of permafrost dependent infrastructure.
  - Surveillance practices related to climate and climate change vulnerabilities.
  - Closure plans to reflect projected future climate conditions.
- Developing improved projections of future climate conditions.
- Enhancing governance structures related to climate change adaptation.

Key questions addressed in this section

How can Owners most appropriately respond to risks associated with climate change, given the uncertainty? Section 5.1 discusses how risks may change over time and how that influences the selection of adaptation pathways.

What are the key elements of a decision-making framework? Section 5.2 outlines the framework for developing adaptation pathways that can be used to help Owners decide how and when to consider climate change.

What are some examples of decision-making tools used when integrating climate change? Section 5.3 provides a case study that used decision-making tools to evaluate adaptation measures and can be used for further reference.

5.1. Timing Considerations in Decisions about Adaptation

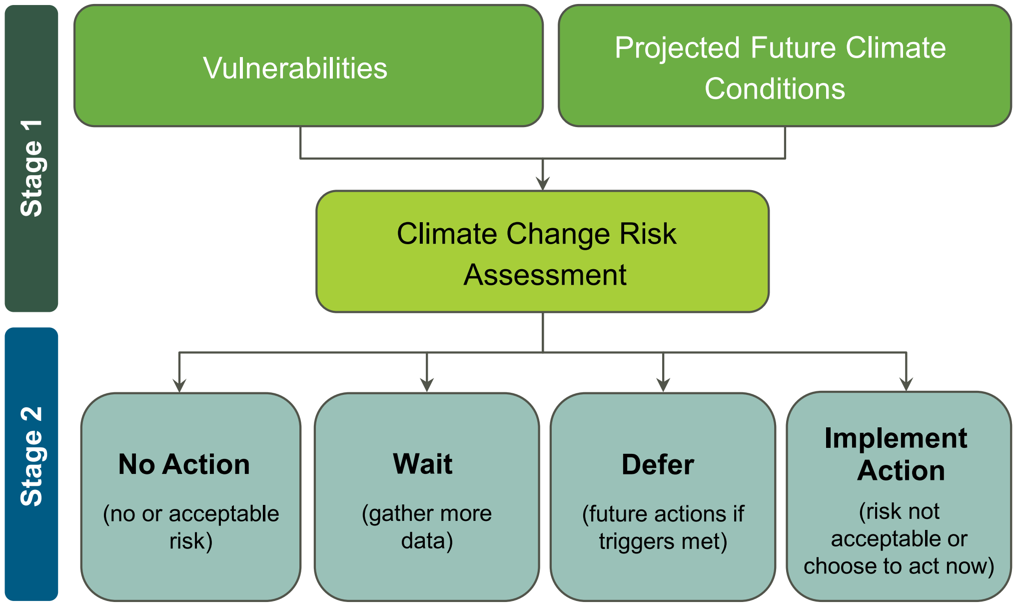
There are many different adaptation measures that can be implemented, as outlined in Section 5.2, to manage risk or opportunities. However, a key part of this challenge in selecting adaptation measures is making decisions about when to implement adaptation measures that may not be tested by a climate event for many years, versus accepting the increasing risk as a result of changing climate conditions, and potentially incurring impacts and associated costs if a climate event happens before adaptation measures have been implemented.

To help address this challenge, adaptation pathways may be developed that present several potential pathways or approaches to respond to risks and opportunities posed by climate change. Considering the projected future climate conditions and the outcomes of the climate change risk assessment, options for an Owner to consider are (Figure 13):

- **No action required:** The climate change risk is acceptable now and under the projected future climate conditions.
- **Wait:** There is currently insufficient information to make a decision. Conduct additional assessment, periodically update projected future climate conditions and re-assess risk. If, in the future, the risk is unacceptable or projected to become unacceptable, then adaptation measures would be identified, assessed, and implemented.

- **Defer, with pre-defined triggers for action:** The risk is currently acceptable and short-term action is not needed but changing climate may necessitate future action. Performance indicators (triggers) are defined, surveillance is implemented, and if those triggers are exceeded in the future, then adaptation measures will be implemented.
- **Implement action in the short term:** Proceed with implementation of adaptation measures.

Figure 13: Decision-making: if and when to implement adaptation measures.



This process can be used to inform a range of decisions about potential adaptation pathways, such as:

- Site-wide decisions about which adaptation pathways are to be prioritized for implementation.
- Decisions about adaptation pathways related to a specific infrastructure component such as a building foundation.

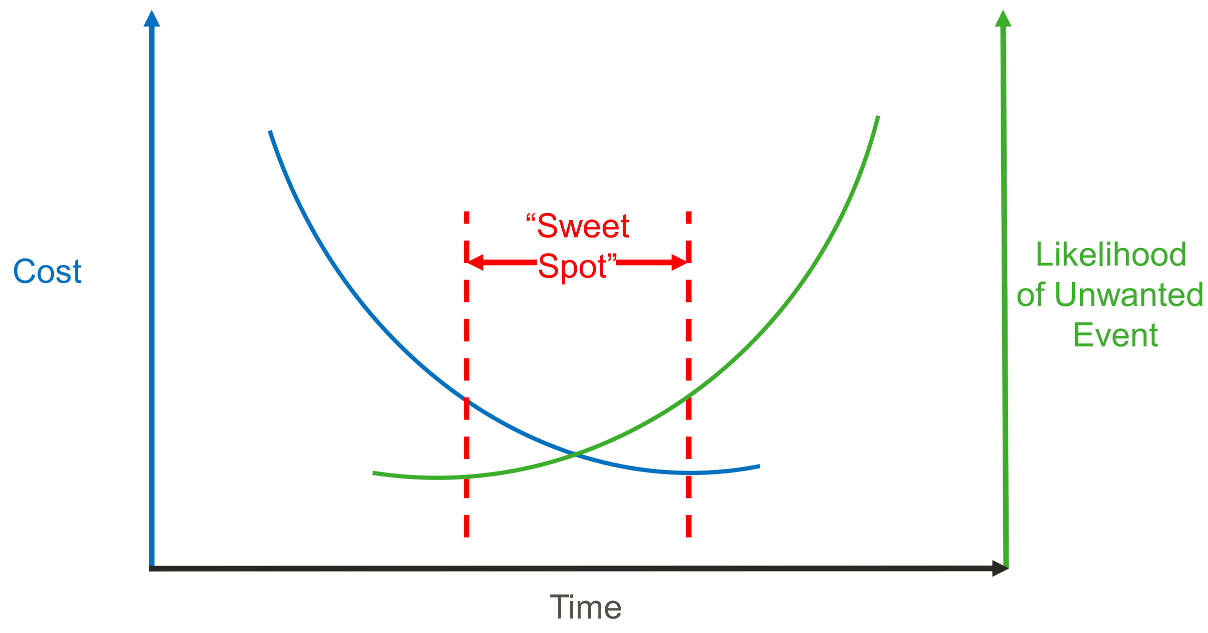
For a given mine site or Owner, there may be a wide range of climate change risks and opportunities. The process described in this section should be followed to make decisions on how to address each risk and opportunity. However, Owners also need to consider that, for any given climate change risk or opportunity, the potential adaptation measures may be:

- Independent of the management of other risks or opportunities.
- Complementary to the management of other risks or opportunities (e.g., help to increase the effectiveness of management of other risks).
- Applicable to multiple risks or opportunities (i.e., one potential adaptation measure would address several different risks).
- At odds with the management of other risks or opportunities (i.e., management of one risk may conflict with or reduce the effectiveness of management of a different risk).

When implementing the process described in this section, and making decisions about adaptation pathways and measures, it is important that Owners take a wholistic approach, and consider these possible relationships between different adaptation measures, in order to help ensure the optimum outcomes and avoid unintended consequences.

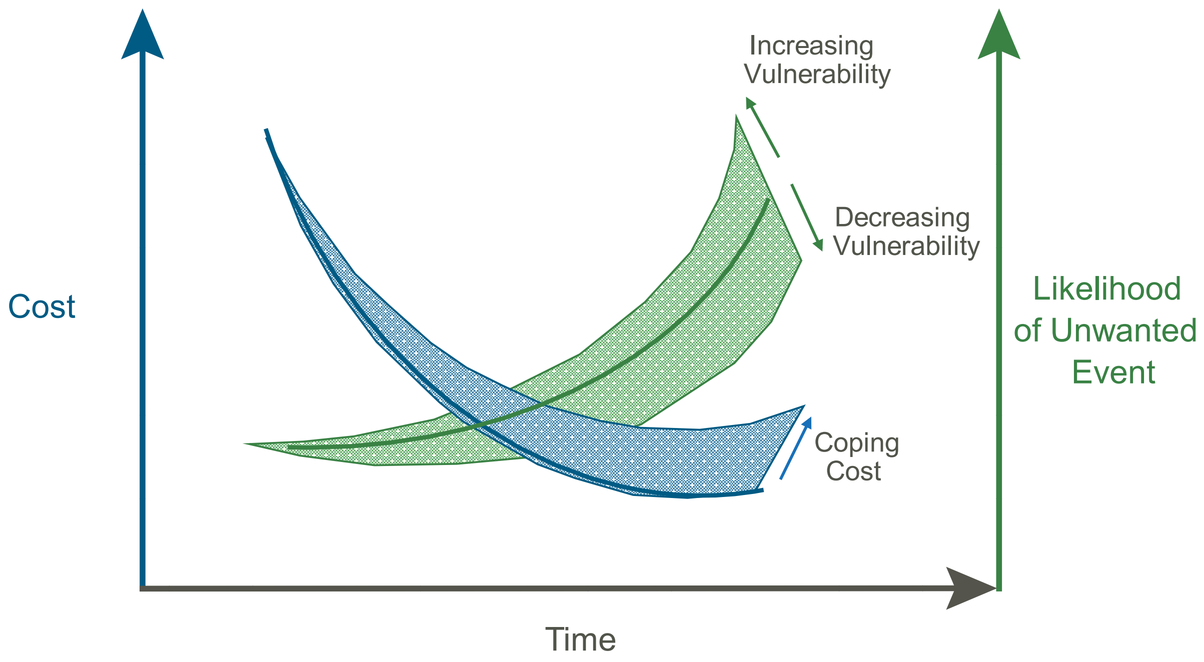
When developing adaptation pathways and making decisions about implementation of adaptation measures, Owners should carefully consider the timeframe for implementing adaptation measures, the nature of those measures, and the associated costs. The term 'cost' is used here to be inclusive of non-financial costs such as environmental or social factors, as well as financial costs. When considering financial costs in such decisions, conventional accounting wisdom would suggest that deferring 'costs' to the future is the less costly option due to discounting of future 'costs'. However, conventional engineering wisdom suggests that the longer the adaptation measure is deferred, the more likely the occurrence of the unwanted event (e.g., damage due to permafrost degradation) that the adaptation measure is intended to address. In addition, over time, the options for implementation of adaptation measures may be reduced, decreasing the Owners flexibility to manage risk: the longer one waits, the fewer options they have to address a given risk. Therefore, as depicted in Figure 14, there is a recognized optimum timeframe for such decisions that balances costs with the implementation of adaptation measures.

Figure 14: A decision analysis will help Owners decide when is the most effective time to implement adaptation measures.



Given the uncertainty of projections of future climate conditions, the costs and likelihood of an unwanted event (the blue and green lines on Figure 14) should be considered as ranges. The further into the future, the larger the uncertainty, hence the uncertainty has been represented as a wedge shape, as shown by the shaded regions in Figure 15.

Figure 15: How the optimum changes when considering future uncertainty.



5.2. Adaptation Pathways Framework

This section provides guidance on how to identify potential adaptation measures and develop and select adaptation pathways to be implemented. This process builds upon projected future climate conditions and climate change risk assessment developed in Stage 1 and includes[1]:

1. Identifying the objective and scope, including the risks to be managed and the factors to be considered, and identifying measurable performance objectives.
2. Identifying potential adaptation measures.
3. Classifying and pre-screening the potential adaptation measures to eliminate from further consideration any that would have characteristics that would not be viable.
4. Developing potential adaptation pathways based on the objective and scope and incorporating the remaining potential adaptation measures.
5. Assessing the potential adaptation pathways using decision analysis tools.
6. Conducting a sensitivity analysis to test the robustness and validity of the outcomes of the decision analysis against various biases and assumptions.
7. Selecting the preferred adaptation pathway.

1. Process is adapted from guidance on assessing alternatives for tailings management presented in MAC's Tailings Guide (MAC 2019b).

5.2.1 Identify the Objective and Scope

Prior to developing potential adaptation pathways, the objective and scope, including the risks to be managed and the factors to be considered, should be determined. The objective and scope help identify the level of effort needed, also considering the level of risk the Owner is willing to accept. This will depend on the geographic extent (i.e., are adaptation pathways being developed for the whole mine, or just one aspect such as the tailings facility), and the vulnerabilities and risks to be addressed. In determining the scope, the Owner should consider similar factors as those considered in determining the scope of the risk assessment (Section 4.5).

The objective and scope will also determine the composition of the team to be involved in the development and selection of adaptation pathways. As with the team assembled to conduct the risk assessment, this team should be multi-disciplinary, and include members with roles, responsibilities, and knowledge relevant to the objective and scope. The team may include personnel who were also involved in the risk assessment. The exact team will depend on the Owner's organizational structure, but will typically include the operations team, water management specialists, and upper mine management. In some cases, external expertise may be required.

In addition to describing the overall objective, measurable performance objectives should be defined. Performance objectives are related to the risk to be managed and the scope and should be defined accordingly. Performance objectives should be applicable to relevant life cycle phases and, as appropriate to the overall objective and scope, they should address:

- Protection of employee and public health and safety.
- Design objectives and criteria for adaptation measures.
- Mitigation of adverse direct and indirect impacts due to climate change.

In developing performance objectives, Owners should also consider:

- Corporate policies
- Existing management systems
- Existing performance objectives, standards, and guidelines
- Legal requirements
- Commitments to COI
- Inputs from external reviews
- Sound engineering and environmental practices

5.2.2 Identify Potential Adaptation Measures

Once Owners have identified vulnerabilities and opportunities, and assessed and prioritized the associated risks, the next step is to identify potential adaptation measures.

The objectives of potential adaptation measures are to identify means to:

- Manage direct and indirect, on and off-site risks associated with climate change:
    - Eliminate climate change-related risks where possible.
    - Reduce residual risks to acceptable levels.

  - Develop contingency plans and mitigation plans to be implemented to mitigate impacts of a future climate change-related event.
- Take advantage of potential opportunities posed by climate change.
- Adapt to projected changes in future climate conditions that are neither risk nor opportunity but should be addressed to optimize future performance.

The objective at this step is not to pass judgement on potential adaptation measures, but rather to develop a list of candidates. This exercise should be multi-disciplinary and should involve personnel involved in conducting the risk assessment as well as personnel involved in different aspects of mine and corporate operations who have roles and responsibilities related to the vulnerabilities and risks identified.

Adaptation measures can take a range of forms and can be incorporated into all areas of an Owner's business (ICMM 2019).

Examples of adaptation measures related to specific risks or opportunities include:

- Physical modifications to existing infrastructure, such as replacing or upgrading to ensure that the infrastructure is adequate for projected future climate conditions.
- Construction of new infrastructure, such as new water management infrastructure.
- Revising the closure plan to ensure the longer-term risks are addressed in the closure and post-closure period (e.g., adopt more resilient cover systems for mine waste).
- Revising operation, maintenance, and surveillance practices to improve management of climate change risks or opportunities, such as:
  - Revising existing operating practices or introducing new practices, such as improved water management and re-use to reduce vulnerability to drought conditions or extreme precipitation.
  - Revising existing maintenance practices or introducing new practices associated with infrastructure that is vulnerable to climate change, such as increased frequency of removing debris from culverts.
  - Revising surveillance activities associated with climate change vulnerabilities, to inform improved understanding of risk, evaluate performance under changing climate conditions, and inform short, medium, and long-term decision-making.

Examples of site-wide or corporate-level adaptation measures include:

- Enhancing monitoring of weather conditions or developing more detailed projections of future climate conditions to better understand vulnerabilities and risks and reduce uncertainty.
- Reducing reliance on seasonal or winter roads by decreasing fuel consumption through increased energy efficiency of operations or increasing the use of alternative energy sources (e.g., wind turbines).
- Revising corporate policies, standards, or guidelines to reflect the need to conduct climate change risk assessment and development of adaptation measures.
- Enhancing governance structures related to climate change adaptation, including assigning accountability and delegating responsibility for climate change adaptation, and implementing a management systems approach.
- Collaborating with suppliers on risks or opportunities associated with the potential disruption of supply chains.

- Implementing strategic actions such as changes to business practices or extending insurance coverage.
- Engaging third parties (e.g., regulators, COI, investors, insurers, subject matter experts) on climate change adaptation to improve risk assessment inputs, refine the potential adaptation options and the overall understanding of the acceptability of the residual risks.

5.2.3 Classify and Pre-Screen Potential Adaptation Measures

Potential adaption measures identified can be classified, based on the categories below. This can aid in decision-making, particularly in cases where several potential adaption measures are identified for a particular risk. Categorizing potential adaptation measures can also help with communications internally, including to senior management, and to COI, regulators, and other external parties.

- **No regrets adaptation:** Adaptation measures that are justified under current climate conditions and would produce benefits no matter how the climate changes (will benefit under all plausible future scenarios). These measures are less vulnerable to uncertainties in risk (Mason *et al.* 2013).
- **Low-regrets adaptation:** Adaptation measures that have relatively low costs that will increase adaptive capacity to cope with future climate risks. Measures are relatively easy or inexpensive to modify if needed (Mason *et al.* 2013).
- **Win-win adaptation:** Adaptation measures that not only help to reduce climate risks but have other associated benefits (Mason *et al.* 2013).
- **Flexible adaptation:** Adaptation measures that can provide an iterative approach for managing uncertainty (e.g., New York Climate Resiliency Design Guidelines). For example, building a dyke that has a broader foundation base so that a higher dyke can be built onto the existing base in future if required.
- **Critical adaptation:** Adaptation measures that have to be implemented regardless of cost (e.g., potential significant loss of life if not implemented).
- **Other:** Adaptation options that are not feasible due to constraints of cost, technical ability, time, etc.

Once classified, potential adaptation measures should be pre-screened to eliminate any measures which are not viable. The Owner should establish a set of minimum specifications (e.g., performance objectives) and eliminate potential adaptation measures that do not meet those specifications. This will reduce the number of potential adaptation measures to be considered in the development and selection of adaptation pathways.

Consistent with the scalable approach (Section 2.2), it may, in some cases, be possible to make a decision at this point about adaptation measures to be implemented and timing of implementation, depending on the:

- Climate change risk or opportunity to be addressed.
- Potential adaptation measures considered.
- Results of the classification and pre-screening of potential adaptation measures.

In such cases, it is possible to proceed to Stage 3. In other cases, the process should continue to more detailed steps described below.

5.2.4 Identify Potential Adaptation Pathways

Once potential adaption measures have been identified and pre-screened, potential adaptation pathways should be identified that map out different options for possible adaptation measures and possible timing of implementation for each risk and opportunity to be addressed.

The adaptation pathways approach was first developed in the Netherlands in the early 2000s, and it is a "planning approach addressing the uncertainty and challenges of climate change decision-making. It enables consideration of multiple possible futures and allows analysis/exploration of the robustness and flexibility of various options across those multiple futures" (South West Climate Change Portal 2020).

The adaptation pathways approach supports strategic, flexible, and structured decision-making, and allows decision makers to plan for, prioritise and stagger investment in adaptation measures (CoastAdapt 2017). Adaptation pathways can be developed to:

- Schedule implementation of adaptation measures and associated decisions.
- Identify the decisions that need to be taken in the short-term and those that can be deferred to the longer-term.

Adaptation pathways can be developed at different scales, from a specific vulnerable infrastructure component, to a mine site, to the corporate level. They should be developed with multi-disciplinary input, input from different operational units, and senior management, and may also be developed with external input such as from regulators and COI.

Development of adaptation pathways should consider:

- Projected future climate conditions.
- Outcomes of the climate change risk assessment.
- Opportunities identified.
- Status of implementation of existing adaptation measures.
- Potential adaptation measures identified and the classification of those adaptation measures.

Working through multiple scenarios for the future is a fundamental strength of the adaptation pathways approach to sequence decision points and recognize when existing risk management or adaptation measures may no longer be effective. By developing a range of scenarios, a range of possible adaptation measures for can be assessed to determine the potential:

- Effectiveness, including robustness and flexibility of adaptation measures considered under the various scenarios.
- Implications of implementing adaption measures within different time periods.

Consistent with Figure 13, potential adaptation pathways to address a given climate change risk may include:

- No action required: The Owner considers risk to be acceptable now and under the projected future climate conditions, and the adaptation pathway does not include any additional adaptation measures. The Owner would respond if a climate event occurs (e.g., replace a stream crossing damaged by a flood).

Even if the Owner would not consider this approach to be a potential adaptation pathway, then a business as usual or base-case scenario should be described in all cases to provide a point of comparison for the selection of the adaptation pathway to be implemented. This includes:

- Assigning a cost to current risks.
- Defining the repair/remediation costs associated with future climate events.
- Comparing the base case to each potential adaptation pathway using decision analysis tools (described below).

- **Wait:** There is currently insufficient information to make a decision. Conduct surveillance, periodically update projected future climate conditions, and re-assess risk. If, in the future, the risk is unacceptable or projected to become unacceptable, then adaptation measures would be identified, assessed, and implemented. Operations or maintenance activities may be revised as a "low-regrets" adaptation measures to help improve risk management in the interim.
- **Defer with pre-defined triggers for action:** The risk is currently acceptable and short-term action is not needed but changing climate may necessitate future action. An adaptation measure is identified, performance indicators (triggers) are defined for the vulnerability, and surveillance is implemented to ensure that the Owner understands the performance against the indicators. If the triggers are exceeded in the future, then the adaptation measure would be implemented. Operations or maintenance activities may be revised as a "low-regrets" adaptation measure to help improve risk management in the interim.
- **Implement action:** Depending on the risk and the nature of the adaptation measure to be implemented, the Owner may decide to implement an adaptation measure in the short-term, such as a capital project to replace a vulnerable infrastructure component.

Each adaptation pathway may include one or more adaptation measures, such as upgrades to infrastructure, and changes to operation, maintenance, or surveillance activities.

This final option, including the development of pre-defined thresholds and triggers, is a key characteristic of the adaptation pathways approach that facilitates effective decision-making regarding deferred implementation of adaptation measures. It is further described below.

5.2.5 Climate Thresholds and Triggers

Thresholds or tipping points describe the climate conditions for a specific climate variable (e.g., mean annual precipitation) beyond which further changes in climate would result in the existing risk management or adaptation measures no longer being able to meet performance objectives and potentially failing (e.g., the maximum capacity of a spillway) (Buurman and Babovic 2016).

A trigger describes a smaller deviation from current conditions for the climate variable associated with a threshold. Triggers are established to provide the Owner an early warning of the approach of a threshold, with adequate time to implement adaptation measures and manage risk before the threshold is reached. This approach enables implementation to be proactive and strategic, rather than reactive and ad hoc (Buurman and Babovic 2016).

Defining thresholds and associated triggers is tool that can be used in developing adaptation pathways in which implementation of an adaptation measure would be deferred.

A trigger can be related to a specific acute extreme event or to a chronic change in a climate variable. Identification of triggers can involve review of similar systems that operate in climate analogue locations (i.e., a location where the present climate is similar to what the climate will be in the future at the site) and ask the following questions: How will the vulnerability be impacted? How has the vulnerability responded to historical climate trends and extreme events in the past?

For specific infrastructure components the triggers and thresholds would be defined based on the design parameters for that infrastructure. For example, if a water crossing is designed for a flood event of a specific magnitude with a return period of 1/1000 years, then that event may be defined as the trigger, while the threshold could be defined as a flood event of equal magnitude at a more frequent return period.

Figures 16 and 17 provide examples of how short and long-term climate changes can result in a threshold or trigger being exceeded.

In Figure 16, long-term changes in mean annual air temperature cause an increase in ground temperature, leading to permafrost degradation. A threshold can be defined based on a mean annual temperature or ground temperature beyond which permafrost degradation would result in significant infrastructure damage (an unacceptable risk). A trigger – a lower ground temperature than the threshold – can be defined. For this risk, the adaptation pathway would take into account the threshold and trigger. If the trigger is reached, the Owner may decide to implement adaptation measures as per the adaptation pathway or may decide to further defer implementation, depending on their risk tolerance.

In Figure 17 acute climate events such as extreme precipitation will always have a probability of occurring, however, the increasing probability of these events is much harder to measure and it is more difficult to assign a trigger point for action in an adaptation pathway. Given this uncertainty, the Owner may opt to set a lower (more conservative) trigger point, and the adaptation pathway may include other adaptation measures such as increased surveillance or maintenance activities.

Figure 16: As air temperatures continue to increase, this will cause ground temperatures to increase leading to the thawing of permafrost, reaching a threshold beyond which damage to infrastructure is expected to occur under two representative concentration pathways.

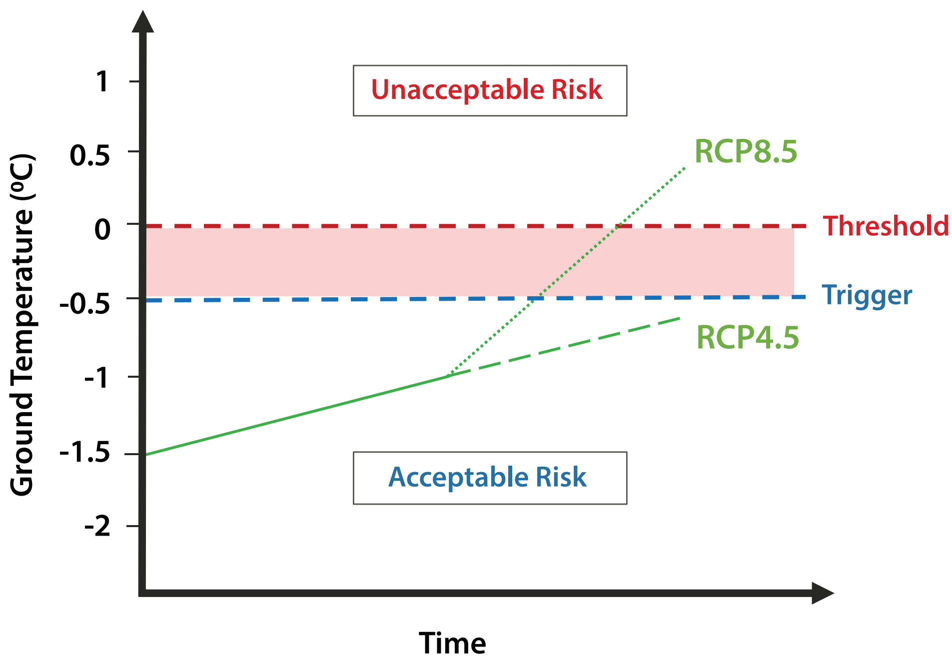


Figure 17: The probability of extreme precipitation events is projected to increase (previous intensities with a 1-in-100 year return period are becoming more frequent), under two representative concentration pathways triggering potential the implementation of adaptation measures according to the adaptation pathway, to mitigate unacceptable risks.

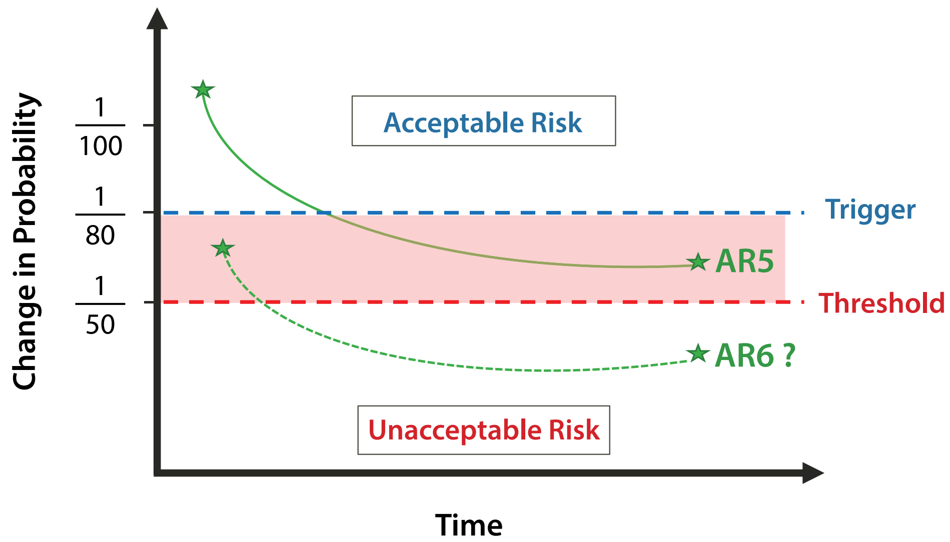
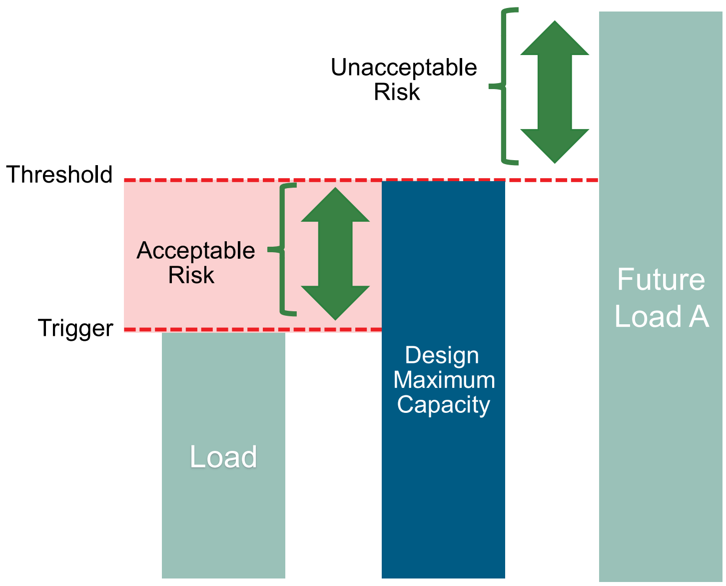


Figure 18 revisits the concepts of climate change risk assessment shown in Figure 9 and provides a different demonstration of the concept of threshold and trigger. In this figure, the trigger is based on the design load for an infrastructure component, while the threshold is based on the design maximum capacity. A load exceeding the trigger but less than the threshold would be considered an acceptable risk, and according to the adaptation pathway would trigger implementation of adaptation measures to mitigate unacceptable risk.

Figure 18: An unacceptable risk occurs when a threshold is exceeded.

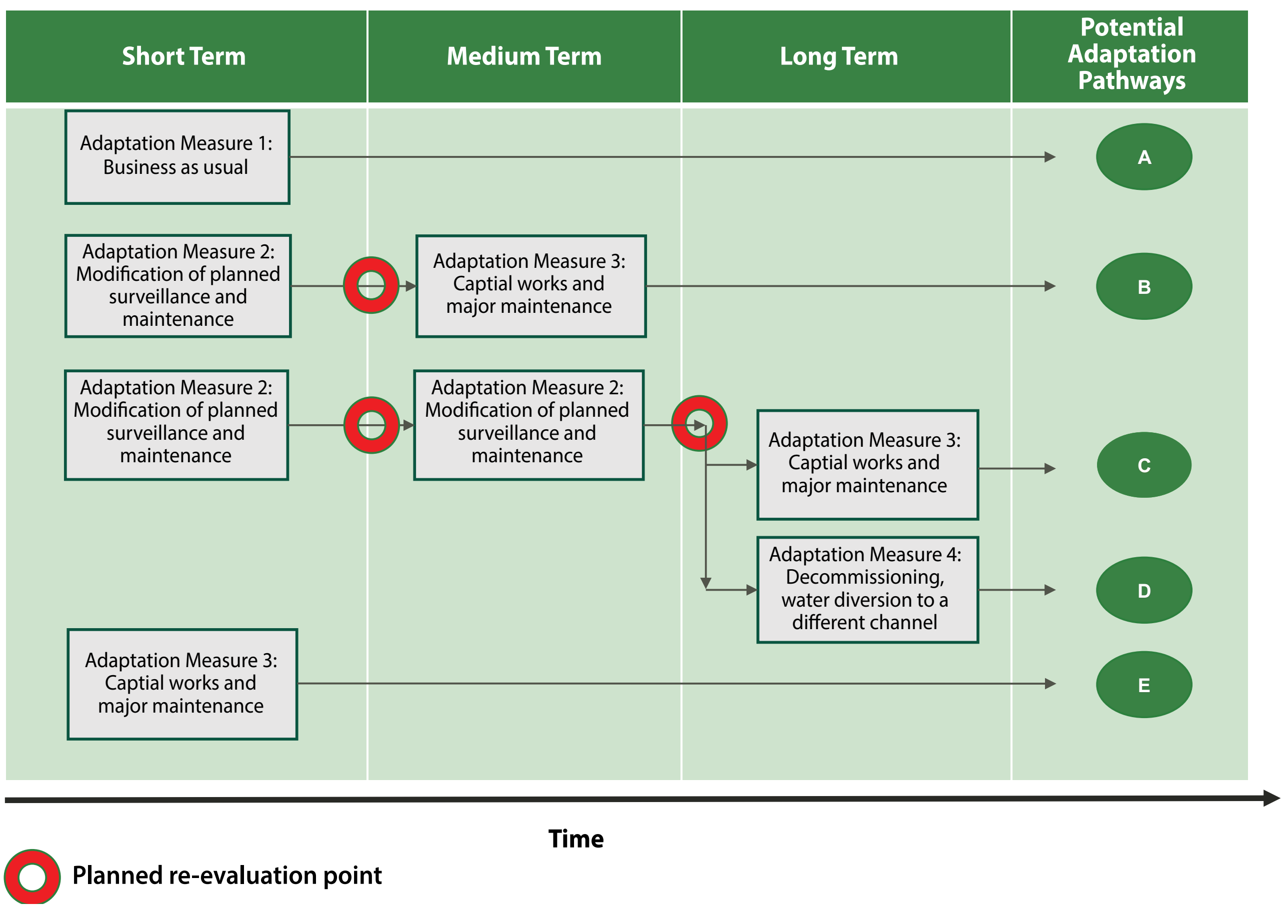


5.2.6 Documenting Potential Adaptation Pathways

For the purpose of communication, pathways can be depicted as a map that sequences possible implementation of potential adaptation measures. Figure 19 shows potential adaptation pathways for a surface water culvert. Adaptation pathways consider alternative adaptation options, and also what additional adaptation may be required at some point in the future if trigger levels are met. The figure considers the following adaptation options for the example of a vulnerable culvert:

- **Option 1:** Business as usual. This case assumes that no additional adaptation measures are required. This coping approach may have already been discounted as an option if the risk assessment identified this vulnerability had an unacceptable risk.
- **Option 2:** Modification of planned surveillance and maintenance. This could mean additional maintenance to clean out the culvert more frequently.
- **Option 3:** Capital works/major maintenance to upgrade the culvert.
- **Option 4:** Decommissioning and water diversion to different infrastructure. In practice this may only be an option in the mine closure phase.

Figure 19: Example potential adaptation pathways map for a surface water culvert.



Once the potential adaptation pathways have been developed, decision analysis tools can be used to evaluate the potential pathways to determine which adaptation pathway to implement.

5.2.7 Decision Analysis of Potential Adaptation Pathways

Once potential adaptation pathways have been identified, the Owner needs to select the preferred pathway to implement. The selection should consider a wide range of factors such as:

- Projected future climate conditions and associated uncertainties.
- Climate change risk assessment.
- Existing risk management measures or adaptation measures.
- Life cycle phase of the mine.
- Potential direct and indirect impacts and costs if a climate event occurs that exceeds the capacity of existing risk management measures or adaptation measures.
- Estimated costs (capital and operating) of implementing the adaptation pathway.
- Expected direct and indirect benefits of implementing the adaptation pathway (e.g., reduced risks, reduced liability, lower insurance premiums).
- Interdependency between different climate change risks (e.g., multiple vulnerabilities on-site related to extreme precipitation events).
- Relationships between different adaptation measures and pathways.

To select the preferred pathway to implement, the potential pathways for each risk or opportunity to be addressed should also be compared to a base-case scenario or status quo scenario in which no action is taken. The factors above should also be considered for the base-case, together with the estimated coping costs of responding to a climate event.

Rigorously and meaningfully assessing potential adaptation pathways, given such a diverse range of factors to consider, is challenging. However, there are a range of decision analysis tools available to support this process and help Owners make decisions to achieve an optimal balance between costs (financial or non-financial) and risk.

Decision analysis tools focus on understanding the benefits, impacts, costs, and risks of implementing adaptation pathways in the short-term versus deferring implementation or responding to climate change events if they occur at some time in the future.

It is important to note that these tools assume that potential adaptation measures associated with each adaptation pathway would be effective in addressing climate change events, which eliminates an important variable from consideration. Other methods need to be used to assess the expected effectiveness of potential adaptation measures.

The approach described using these tools is primarily geared to decision-making for existing infrastructure. However, these tools could also be applied in the planning and design phases for new infrastructure (e.g., new mine or expansions of an existing mine) or for closure design.

For each potential adaptation pathway, the impacts of the residual risks involves:

- Quantifying the costs (e.g., financial, social, environmental) of implementing the adaption pathway, to the extent possible.
- Describing the benefits of implementing the adaptation pathway and quantifying those benefits to the extent possible.

- Estimating the financial liabilities and other costs of not implementing the adaptation pathway, and the impact of implementing the adaption pathway on those liabilities and costs.
- Conducting an economic assessment to estimate the financial liabilities of not adapting, and to identify the most cost-effective adaption pathways to manage the risk.

However, there are some challenges when evaluating climate change impacts and adaptation pathways that accompany economic assessments, as discussed in Rodgers and Douglas (2015a) and GIZ (2013), including:

- Uncertainty about projected future climate conditions, including the magnitude of changes in normal and extreme conditions, timing, and frequency. Consideration of different future climate scenarios, and scenario analysis, can help reduce this uncertainty.
- Uncertainty regarding the adaptive capacity of a region/mine (i.e., the long-term resources).
- A bias may arise when assigning costs to adaptation measures since there is a tendency to focus on "hard" adaptation measures (e.g., replace a vulnerable water crossing) rather than "soft" adaptation measures (e.g., improvements to governance or green infrastructure such as a dike design that promotes habitat creation versus a concrete lined dike) since they are easier to quantify. However, "softer" adaptation measures may be better suited and more effective when addressing a specific climate change impact. These "soft" adaptation measures should not be overlooked simply because they are more difficult to quantify, natural adaptation can result in more resilient and less costly measures.
- Underestimation of future costs.

There are several different types of decision analysis tools that can be used to rank and prioritize potential adaptation pathways.

The three most commonly used tools are (Rodgers and Douglas 2015b):

- Multi-criteria/multi-actor analysis (MCA) or multiple accounts analysis (MAA)
- Cost-benefit analysis (CBA)
- Cost effectiveness analysis (CEA)

All three tools can be used to analyze and prioritize potential adaptation pathways but vary according to which variables can be monetized.

If both the costs and benefits of potential adaptation pathways being assessed cannot be expressed in monetary terms or if non-monetary considerations such as environmental or social factors are the priority in the decision, then an MCA is usually most appropriate, and it is recommended that the MAA tool described in the MAC Tailings Guide (MAC 2019b) be used.

If the costs and benefits of potential adaptation pathways being assessed can be monetized, a CBA is advantageous. In this case, a decrease in the Owner's market capitalization could be used as a proxy estimate of "cost" of an environmental or social factor.

If the benefits of potential adaptation pathways being assessed can be quantified but not expressed in monetary terms, while costs can be quantified in monetary terms, a CEA is preferred, and the MAA approach described in the MAC Tailings Guide can also be used. In all other cases, an economic approach is very difficult to apply, and other approaches may need to be considered, such as an MAA.

To inform the selection of adaptation pathways, Owners should select the decision analysis tool(s) to be used based on the objectives and scope and the availability of information needed to apply these different tools.

5.2.8 Sensitivity Analysis

The use of decision analysis tools involves making certain assumptions or assigning values or weights to different aspects being considered. For example:

- In a cost-benefit analysis, a discount rate may be applied to future capital or operating costs.
- In a multi-criteria or multiple accounts analysis, values and weights are applied to compare very different aspects, such as environmental impact and cost due to business disruption.

This is one of the strengths of applying these tools. Assumptions and biases are inherent in all decisions, but when using these tools these assumptions and biases are documented and transparent. It also means that the outcomes of these decision analyses can be tested, to test the robustness of the final decision (i.e., selection of the adaption pathway), under different assumptions and biases. For example:

- What are the outcomes of the cost-benefit analysis if a different discount rate is applied? How sensitive is the outcome to this particular aspect of the analysis?
- What are the outcomes of an MAA if different weights are applied (e.g., increase the weight given to environmental impacts vs. business disruption) or if certain factors, such as capital and operation cost, are removed from consideration? Would the outcome change? How robust is the outcome, or how sensitive is it to small changes in the weightings applied?

To test the sensitivity of the outcomes of decision analysis to different values and biases, sensitivity analyses should be done. In the case of tools such as an MAA, this would include re-running the analysis with different weights assigned to different factors considered.

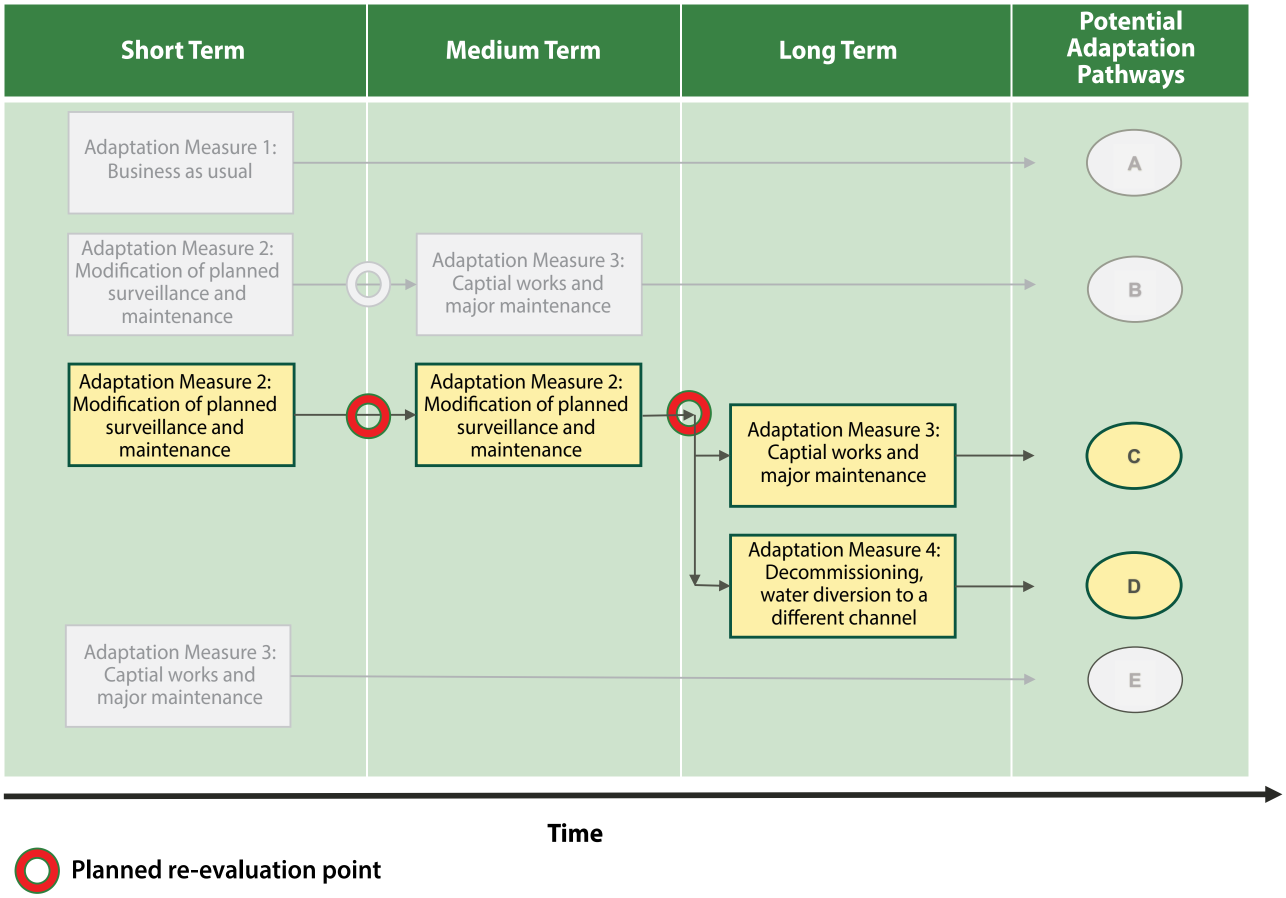
The level and type of sensitivity analysis conducted should be determined site-specifically, and the outcomes should be carefully considered by the Owner in the final selection of adaption pathways.

5.2.9 Select the Preferred Adaptation Pathway

Once all analyses are complete, the Owner selects the preferred adaptation pathway from the potential pathways identified, as illustrated in Figure 20. This decision should be based on the results of the decision analysis and the sensitivity analysis but may also take into consideration other factors that may be not have been possible to incorporate into decision analysis, such as the relationships between different adaptation measures or pathways.

The outcomes of the process, including the adaption pathway selected, should be documented and reported. The results should be communicated to the appropriate internal and external stakeholders using common and simple terms that can be understood by all involved.

Figure 20: Example of a projected chosen adaptation pathway map for a surface water culvert.



Checklist for Developing Adaptation Pathways

- What are the objectives and scope for the adaptation measures that are being evaluated?
- How have the possible adaptation measures been classified and screened?
- What are the thresholds and triggers for each adaptation pathway?
- Which decision-making tool has been used to prioritize and rank the impacts and benefits of the potential adaptation pathways?
- How have the impacts and benefits associated with the preferred adaptation pathways been calculated (i.e., direct, indirect, and coping costs)?
- What are the key sensitivities of the preferred adaptation pathway?

5.3. Case Studies

This case study provides an example of a cost-benefit analysis, one type of decision-making tool, that has been completed by a mining company. Appendix D: Case Studies provides more detailed information.

Glencore – Sudbury Integrated Nickel Operations

Glencore is a global mining and metallurgical company that operates over 150 mining and metallurgical sites around the world. Their Sudbury Integrated Nickel Operations (Sudbury INO) started the development of a Climate Change Plan in response to corporate Sustainable Development Goals in 2009.

Using the site's risk register, Glencore held an initial internal risk assessment working session with key members of operations, engineering, capital, and other departments. The session raised awareness of the impacts of extreme weather and climate change on operations, specifically infrastructure, and solicited measures to cope with the impacts. The risk assessment revealed several areas that are affected by extreme weather and climate change for the Sudbury INO. The session also allowed Glencore to identify and prioritize site-specific climate challenges and results were incorporated into their existing risk registry. The climate risk assessment process also helped to engage management teams and technical experts in the process of identifying climate risks and proposing adaptive measures to reduce risks.

One of the key recommendations from the working group meetings was to develop a decision-making process to help prioritize the potential adaptation measures identified in the risk assessment and decide when the measures should be implemented. In response to this recommendation a cost-benefit analysis (CBA) approach was developed and used to analyze and prioritize adaptation options in consideration of the costs of implementing each adaptation option.

The first stage of the CBA developed a baseline scenario that looked at infrastructure and operational information that would be included in the assessment, vulnerabilities that could affect the water management system and result in priority risks, analysis of the consequences of each vulnerability, and the estimated cost related to each vulnerability. Both direct costs for reclamation from a vulnerability, and indirect costs such as reputational impact were estimated.

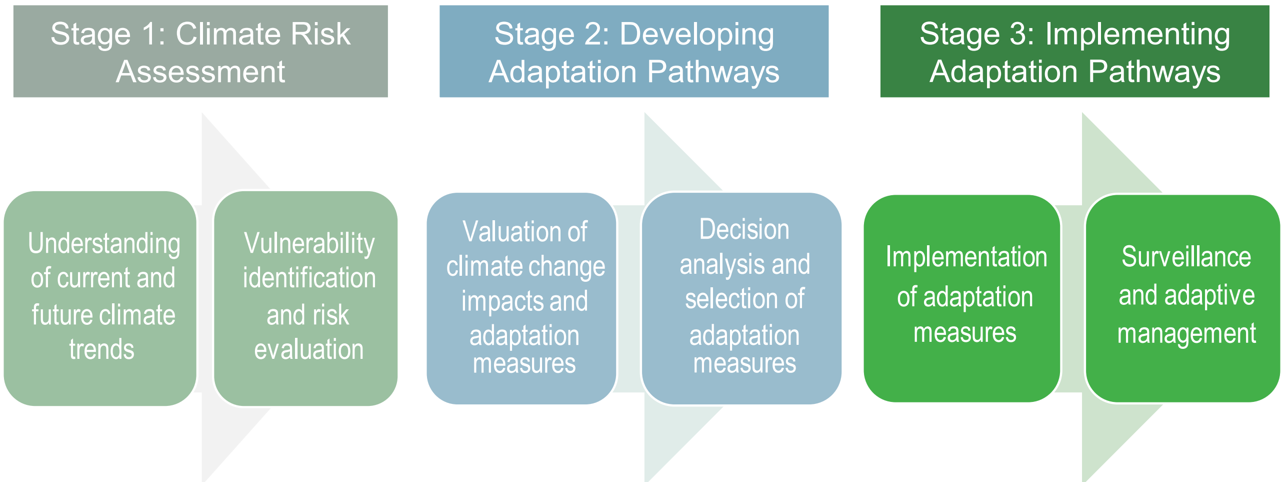
Using this information, the project team developed estimates of risk for each vulnerability under current climate conditions and normal operating conditions, and then combined these estimates with cost information to establish an economic baseline. Vulnerabilities included dealing with:

- High water level conditions in spring
- Low water level conditions in summer/fall
- A significant rainfall event
- Localized flooding in low-risk and high-risk areas

Historical climate trends and site-specific hydrologic models that considered infrastructure and operational thresholds were used to characterize the likelihood of an environmental vulnerability occurring under current climate conditions. To evaluate how the economic risk could change under future climate conditions, changes to the likelihood of each vulnerability were estimated.

Adaptation options were identified for each risk that would decrease the consequence or the likelihood of occurrence of the event. Two time periods were assessed, a period of 10 years and a period of 39 years, and the costs versus benefits were assessed assuming the adaptation option was implemented at the start of each period versus a business-as-usual approach. A stochastic assessment of each time period was assessed under the current and future climate conditions. The outputs of the assessment were presented in a tabular format to visually represent when estimated financial costs of the business-as-usual scenario, also referred to as coping costs, were outweighed by the reduction in costs from implementing the adaptation measures. This summary was used to show how investing in adaptation would result in reduced costs in the future.

6 Stage 3: Implementation of Adaptation Pathways



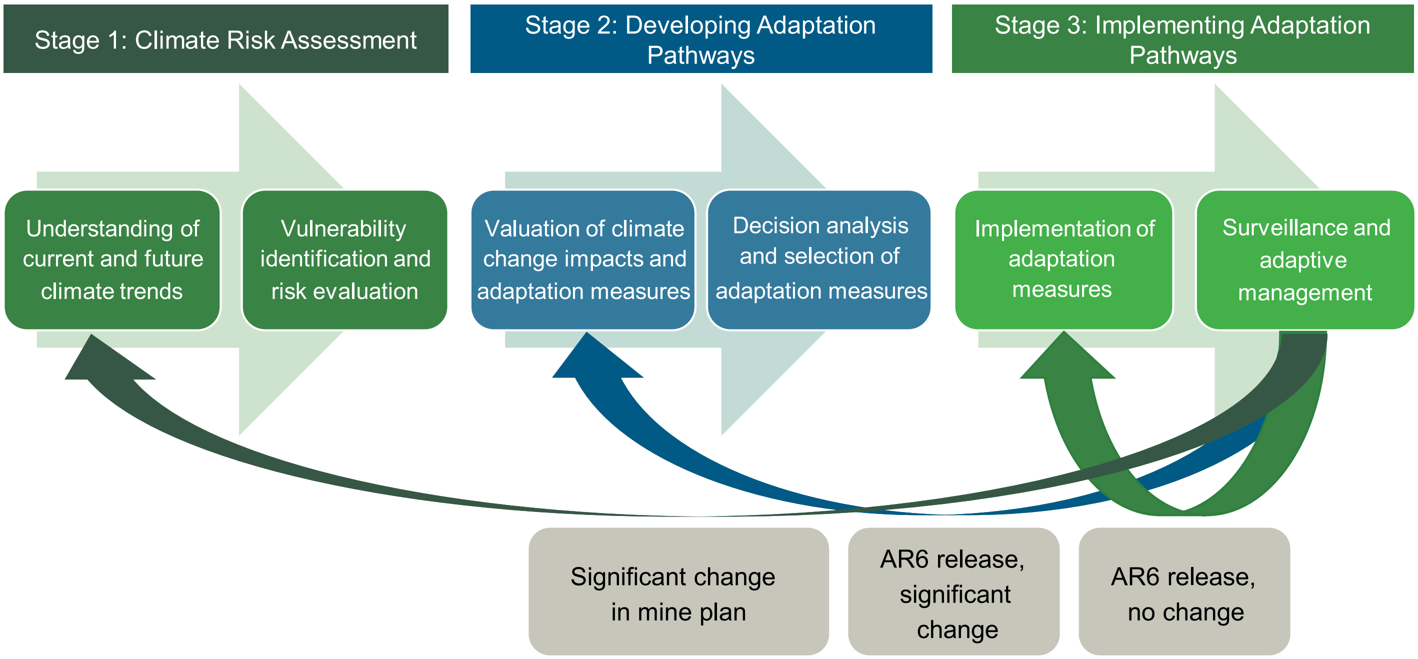
This section provides guidance on implementing adaptation pathways and the ongoing surveillance and management that form an adaptive management plan, a holistic approach to managing the risks and uncertainty associated with climate changes during the mine life cycle.

Key actions used to implement adaptation pathways and effectively manage risk include:

- Design and implementation of the selected adaptation pathways.
- Surveillance.
- Adaptative management to identify and address the uncertainty in the process and help drive continual improvement.

Stage 3 supports the iterative and continual improvement approach to incorporating consideration of climate change adaption into decision-making, as described in Section 2.2, and illustrated in Figure 21.

Figure 21: Schematic of the iterative nature of the process and continual improvement.



Key questions addressed in this section

What actions must an Owner take to implement the selected adaptation pathway? Sections 6.1 and 6.2 describe how the implementation should be linked to a surveillance program so that emergence signals (triggers and thresholds) can be tracked to identify when to revisit decisions or actions.

How can governance be improved by implementing adaptive management? Section 6.3 outlines the key principles describing the minimum requirements recommended for a continual improvement process and documentation.

What are some examples of implementation of adaptation pathways? Section 6.4 provides case studies that have used a continuous improvement process to address climate change uncertainty and can be used for further reference.

Surveillance includes the inspection and monitoring (i.e., collection of qualitative and quantitative observations and data) of activities and infrastructure. Surveillance also includes the timely documentation, analysis, and communication of surveillance results, to inform decision-making and verify whether performance objectives and risk management objectives, including critical controls, are being met (adapted from MAC 2019b).

6.1. Design and Implementation of Adaptation Pathways

Once adaptation pathways have been selected as an outcome of Stage 2, the adaptation pathway and associated adaptation measures should be designed and implemented.

What design and implementation will entail depends on the specifics of each pathway, and may include:

- Preparing and documenting detailed designs for:
  - Modifications of existing infrastructure to be implemented in the short-term.
  - Construction of new infrastructure to be initiated in the short-term.
- Implementing modifications to existing infrastructure or constructing new infrastructure as per short-term plans, and documenting:
  - Any deviations from the design.
  - Final as-built conditions.
- Preparing and documenting preliminary designs for:
  - Modifications of existing infrastructure to be implemented in the medium-term.
  - Construction of new infrastructure to be initiated in the medium-term.
- Defining, documenting, and implementing changes to existing operating, maintenance or surveillance practices or new practices to be implemented.
- Revising the closure plan as appropriate.

6.2. Surveillance

As part of design and implementation of adaptation pathways, surveillance programs should be designed and implemented, or existing surveillance programs should be revised appropriately, so that there is ongoing collection of site-specific climate data and to inform the assessment of:

- Current climate conditions, including how the observed conditions compare to the projected future climate conditions used in Stage 1. This could include changes in flora and fauna, ecosystem integrity, changes in resource availability (i.e., water), and effects on regional stressors such as water availability or, conversely, flooding.
- Effectiveness of existing risk management measures and adaptation measures that have been implemented.
- Performance against defined thresholds and triggers to assess the need for future implementation of adaptation measures.
- Performance of vulnerabilities for which the risk is considered acceptable.

Results from surveillance should be used to inform future reviews of and potential updates to:

- Projected future climate conditions used in the risk assessment.
- Priorities resulting from the climate change risk assessment.
- The decision analysis used to select the preferred adaptation pathway.

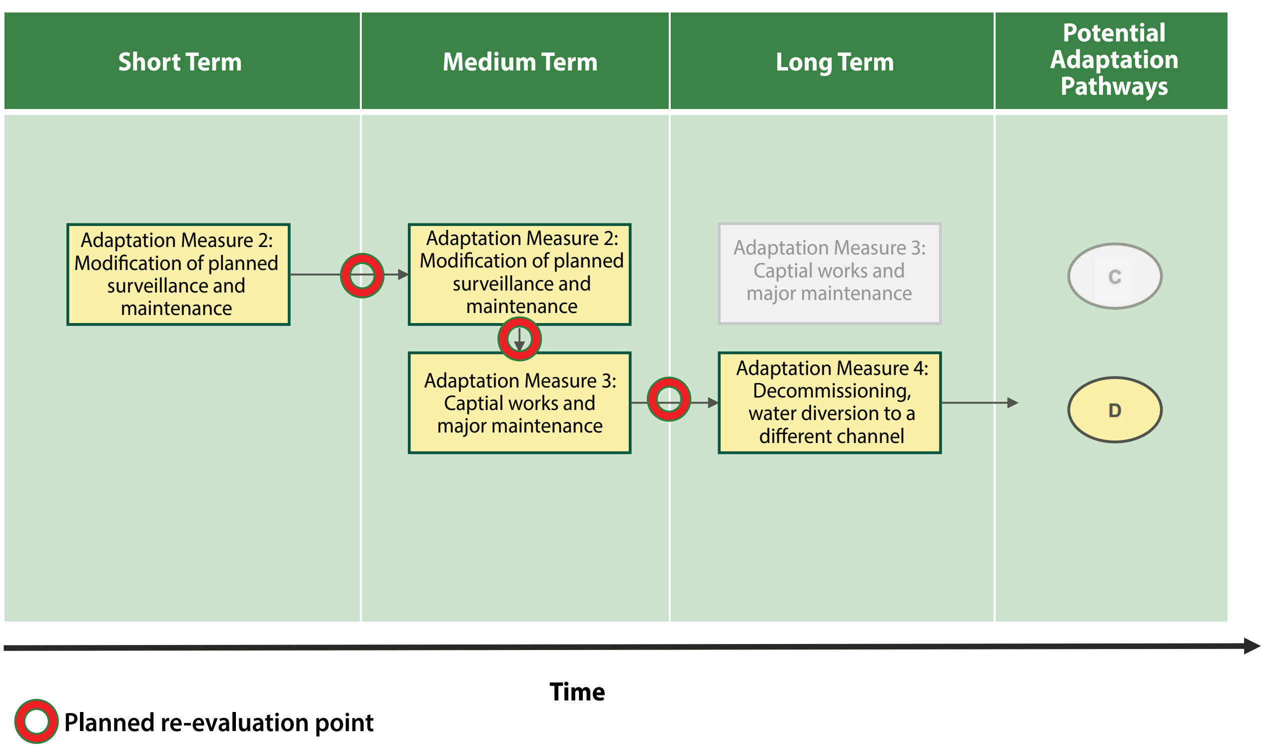
6.3. Developing and Implementing an Adaptive Management Process

Adaptive management is a process of iteratively planning, implementing, and modifying strategies to address the impacts of a changing climate. It involves adjusting approaches in response to observations of their effects and changes in the system brought on by resulting feedback effects and other variables (adapted from ISO 14090).

Uncertainties are inherent in projections of future climate conditions and are compounded over the long time scales of the mine life cycle. Furthermore, updates in knowledge (i.e., updates in climate science or surveillance information) may not keep pace with changing conditions. Applying adaptive management provides Owners with an additional tool to manage uncertainty and risks associated with climate change and incorporates new knowledge/information as it becomes available or responds proactively to changing conditions. In this regard, adaptive management facilitates implementation of the iterative approach described in Section 2.2 which is a key characteristic of this guidance.

Building on the adaptation pathways example in Section 5 the selected pathway illustrated in Figure 20 will be re-evaluated a number of times over the mine life. Based on the observed climate conditions, updates to climate science and the results of the surveillance program the pathway that is implemented may differ from the planned pathway. This example is illustrated in Figure 22 that shows how the adaptation measures could have been implemented based over the life of the mine where Planned Adaptation Measure 3 was implemented earlier in the mine life than what was originally planned.

Figure 22: Illustrative example of how the planned adaptation pathway may changed over the life of the mine based on continual improvement.



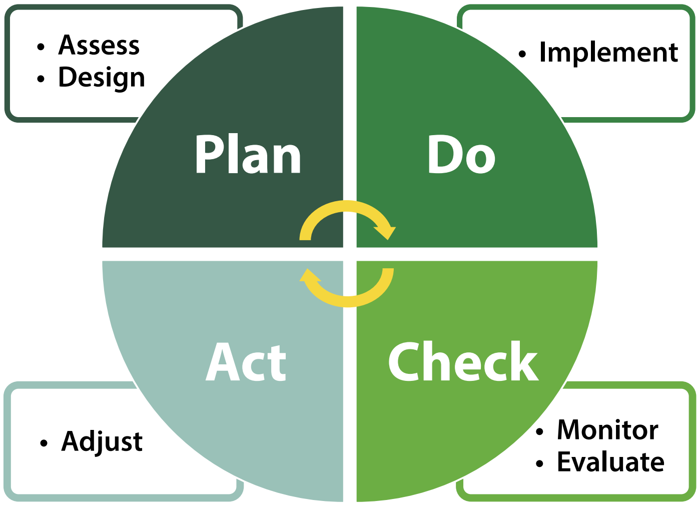
Adaptative management can also help to improve the effectiveness of the adaptation pathways approach by providing a governance and decision-making framework for their implementation. Integration of surveillance results, as well as defined thresholds and triggers for adaption measures into the adaptive management process helps ensure that appropriate future actions will be taken. Adaptive management also helps inform future reviews of adaptation pathways.

Adaptive management considers the current mine site conditions and future plans, current climate conditions and state of knowledge, evolving projections of future climate conditions, and uses surveillance results to confirm whether objectives have been met and identifies deficiencies or opportunities for continual improvement. Adaptive management can be used during any phase of the life cycle to address uncertainty associated with climate change projections, or to proactively respond to unexpected changes in climate conditions beyond those projected.

Adaptive management should also consider the cross-cutting (systemic) issues of the operation/business by examining the internal and external interdependencies and linkages (ISO 2019). This approach takes into account all aspects of upstream and downstream impacts of a facility's processes. For example, for water management, Owners should consider not only on-site water management, but also changes to the water availability, quality, and withdrawal at a watershed/catchment basin-level for competing user needs (e.g., agriculture in the area). Such interdependencies need to be considered in Stage 1 when identifying vulnerabilities and assessing risk. However, these interdependencies may not be static, and additional interdependencies or linkages may emerge over time. Adaptative management can help ensure that such changes are recognized and accounted for in future updates.

This section describes the main principles of adaptive management and provides guidance for developing and implementing an adaptive management process. The principles are consistent with other Plan-Do-Check-Act management systems models and are aligned with the tailings management framework outlined in the MAC Tailings Guide (MAC 2019b) and the ISO 14001 *Environmental Management Systems* (2015) (Figure 23).

Figure 23: Principles of the adaptive management approach based on *A Guide to the Management of Tailings Facilities* and the ISO 14001 *Environmental Management Systems* (MAC 2019b; ISO 2015).



Plan

Planning involves establishing objectives for adaptive management, synthesizing existing knowledge and developing processes and plans necessary to meet and implement adaptation pathways, including thresholds and triggers for implementation of adaptation measures.

Planning relies on the results of the vulnerability and risk assessment (Section 4), and the adaptation pathways developed and selected for implementation (Section 5). Planning should address the following:

- Accountability, responsibilities, and roles for implementing adaptation pathways and the adaptive management process and making decisions related to climate change adaptation.
- Integration of adaption pathways into existing policies, plans, procedures, and schedules (e.g., water management plan).
- Identification and development of performance indicators based on the performance objectives, to measure and assess the performance for specific adaptation measures.
- Identification of any uncertainties or constraints.
- Design of adaptation measures as described in Section 6.1.
- Development of the surveillance program or revision of the existing surveillance program as described in Section 6.2.
- Development of a training plan to ensure that personnel understand their roles and responsibilities related to climate change adaptation, and, where relevant, understand changes associated with implementation of adaptation pathways.
- Ensure that the necessary resources and tools for implementation are in place.

Do

This step involves the implementation of the adaptation pathways and the surveillance program, and other plans developed as part of the adaptive management process (e.g., training). This step would also include implementing adaptation measures as per the adaption pathways (e.g., if defined thresholds have been met).

Check

This step involves reviewing the results of implementation, particularly surveillance, to assess and document performance. Key activities are to assess the performance of existing adaptation measures, and to assess performance against defined thresholds and triggers for implementation of adaptation measures. In addition, this step should also include identifying:

- Periodic review of the design basis for adaptation measures related to equipment and infrastructure and monitor climate science updates to confirm that the climatic assumptions used as the original design basis are still valid.
- Deficiencies or non-conformances that have been encountered during the implementation of adaptation pathways and measures.
- Opportunities for continual improvement.
- Changes (e.g., observed conditions vs climate projections, changes to the mine plan) that may be relevant to future development and implementation of adaptation pathways.

Act

This step involves a review of the results from the Check step and is integral to the iterative approach described in Section 2.3. Owners should review and potentially make updates to Stages 1 and 2 described in this guidance, including:

- Reviewing any updated climate science, engineering codes and standards, COI perspectives, and legal requirements.
- Reviewing and potentially updating the:
  - Governance structures for the adaptive management process and implementing adaptation pathways.
  - Climate dataset and climate baseline and associated uncertainties and gaps.
  - Projection of future climate conditions and associated uncertainties.
  - Identification of vulnerabilities and opportunities.
  - Climate change risk assessment and associated uncertainties.
  - Performance objectives and indicators.
  - Thresholds and triggers for implementation of adaptation measures.
  - Surveillance program.
- Reviewing the adequacy and effectiveness of adaptation measures that have been implemented.
- Developing action plans to address deficiencies and opportunities for continual improvement.

Ultimately, this step informs the review and potential updates to adaptation pathways.

Checklist for Developing and Implementing Adaptive Management

- How are all triggers and thresholds being monitored?
- What performance indicators are used to measure the performance of the adaptation measures?
- How does the surveillance program track changes to the mean frequency and magnitude of extreme events and comparison to triggers and thresholds?
- How are uncertainties being addressed?
- How is the adaptation management plan integrated into corporate policies, management and operational systems and procedures?
- What is the review cycle?

6.4. Case Studies

The following case studies are examples of adaptive management that have been implemented by mining companies. Appendix D provides more detailed information for each of the case studies listed.

Giant Mine Rehabilitation – Climate Change Thresholds

Giant Mine is a historic gold mine that is undergoing remediation and closure, located 5 km north of the city centre in Yellowknife, Northwest Territories. A key objective, and focus of the remediation project, is the long-term containment and management of historical mining waste at the site. One challenge associated with the Giant Mine Remediation Project is the prevalence of arsenic trioxide (arsenic) containing material that was produced as a result of processing gold ore. Approximately 237,000 tonnes of arsenic containing material is currently stored on-site in underground chambers with the old mine workings. A long-term management plan for the arsenic containing material was developed to prevent release of arsenic and potential impacts on the residents of Yellowknife and water quality in Great Slave Lake. It was decided that the most effective way to manage the arsenic containing material would be to allow the underground chambers to freeze via the "frozen block method."

Given the location of the mine and the current knowledge of climate change in the North, a key challenge in the management of the containment facility will be to maintain the temperature so that the underground chambers remain frozen. Climate change projections were developed for future changes in mean annual temperature to inform the design and management of the containment facility. Specifically, the knowledge will be used to support the detail design of the freeze block so that the appropriate equipment and monitoring procedures can be implemented, and adjustments can be made to maintain the frozen block over time. In essence, the climate projections will inform triggers and thresholds, steps in the adaptive management plan and specifically decision points when management actions must be taken.

Suncor's Millennium Mine – Adaptive Management for Fluid Tailings

Suncor Energy Ltd. (Suncor) is a Canadian energy company that specializes in the production of synthetic crude from oil sands in Alberta. In 2016 Suncor submitted a Fluid Tailings Management Plan (TMP) for Base Plant Application and concurrently submitted the Millennium Operational Amendment (MOA) Application including details with respect to mine and closure plans. The proposed TMP will result in over 70 per cent of its tailings being managed through a new, unproven technology – Passive Aquatic Storage System (PASS) – which uses the addition of chemicals to dewater the tailings and reduce the mobility of contaminants. Water will be placed on top of treated tailings after the end of mine life creating an aquatic closure outcome in dedicated disposal area 3 (DDA3), (also known as water capping). This new PASS in intended to also manage the uncertainties and risks related to a changing climate, specifically uncertainties related to water levels.

To manage and decrease liability and environmental risk resulting from the accumulation of fluid tailings the Government of Alberta issued the Tailings Management Framework for the Mineable Athabasca Oil Sands (TMF) in 2015. As part of the implementation of the TMF, the Alberta Energy Regulator (AER) released Directive 085: Fluid Tailings Management for Oil Sands Mining Projects which sets out new requirements for fluid tailings management plans. Given Suncor's new approach to tailings management the AER needed assurances that the TMP would meet the requirements under both the framework and the Directive.

Suncor provided information regarding the rationale, data, and assumptions related to the risks and uncertainties for the PASS and DDA3. This information included mitigation measures, contingency plans, and milestones for reclamation, including information relevant to climate change. Suncor found that climate change could pose a risk to the Upper Pit Lake (UPL) and that current predictions show a warmer and wetter future. If the opposite were true, the viability of the UPL could be compromised if it was not appropriately managed.

Suncor provided information to the AER regarding its adaptive management plan to address the risks, including:

- The ability to change the outlet elevation of the lake.
- Changing this littoral zone elevation.
- Adapting the approach over the next 26 years as Suncor gains a better understanding of long-term hydrology and climate conditions.
- Cap the treated fluid tailings in some form once completed, ensuring that even in a scenario where the lake periodically dries up, there is some barrier between the treated fluid tailings and the environment.
- Modify the closure landscape and drainage to supply more/less water to the UPL.

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Glossary

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>Acceptable Risk</td><td>The level of risk deemed acceptable to an Owner, considering legal requirements, internal policy, business factors and societal acceptance.</td></tr>
<tr><td>Adaptive Capacity</td><td>The capacity of a mine to absorb stresses on the system due to changes in the climate. A mine with high adaptive capacity can cope with and even benefit from a changing climate. A mine has increased climate resiliency when its vulnerabilities have decreased.</td></tr>
<tr><td>Adaptive Management</td><td>The iterative process of planning, implementing, monitoring, and modifying strategies that address the uncertainty of a changing climate. The process adjusts approaches in response to changes in the system that occur as a result of a feedback effects and other variables (ISO 2019).</td></tr>
<tr><td>Adaptation Measures</td><td>Adaptation measures are actions taken to manage risks or opportunities associated with climate change. Adaptation measures may include actions to either prevent or reduce the likelihood of the occurrence of an adverse impact due to climate change; or reduce or mitigate the consequences of an adverse impact due to climate change. They may be implemented on a site-specific basis or at the corporate level and include a wide range of potential actions such as:
Modifications to existing infrastructure or construction of new infrastructure.
Revising plans, practices, and procedures such as:
Operating practices such as water management.
Maintenance practices such as maintenance of permafrost dependent infrastructure.
Surveillance practices related to climate and climate change vulnerabilities.
The closure plan to reflect projected future climate conditions.
Developing improved projections of future climate conditions.
Enhancing governance structures related to climate change adaptation.</td></tr>
<tr><td>Climate Change</td><td>Refers to a change in the mean and/or variability of climate that persists for an extended period, typically for decades or longer (IPCC 2013).</td></tr>
<tr><td>Climate Change Adaptation</td><td>The process of adjusting to the current and projected climate and its effects (ISO 2019).</td></tr>
<tr><td>Climate Change Impact</td><td>The consequence of a climate-related event that affects a mining companies' objectives.</td></tr>
<tr><td>Climate Data</td><td>Measurements of weather/climate variables (i.e., minimum and maximum temperature, total precipitation) collected at varying durations (i.e., hourly, daily, annually) used to help identify trends in climate (Roy et al. 2017).</td></tr>
</table>

Term	Definition
Climate Event	An event (e.g., extreme rainfall event) that occurs when a Climate Variable is above a Climate Indicator value, resulting in unwanted impacts to infrastructure, mine operations or the surrounding environment.
Climate Indicator	An index that can be quantified or measured to demonstrate changes of a Climate Variable (e.g., daily temperature, number of days frost days, intensity and duration of rain events, wind speed and direction). Climate Indicators may change as a result of climate change.
Climate Models	Mathematical representations of climate system processes between the atmosphere, lithosphere, hydrosphere, cryosphere, and biosphere under external forces (i.e., solar radiation, natural and anthropogenic greenhouse gases) over a long period of time. (Roy *et al.* 2017).
Climate Variable	A weather parameter that can be measured and projected into the future (e.g., temperature, precipitation, wind, etc.) and that has the ability to interact with mine infrastructure and operations.
Communities of Interest (COI)	COI include all individuals and groups who have an interest in, or believe they may be affected by, decisions respecting the management of operations. COI may include, but are not restricted to: ■ Indigenous peoples ■ Community members ■ Under-represented groups ■ Employees ■ Contractors/suppliers ■ Neighbours ■ Local environmental organizations and other non-governmental organizations (NGO) ■ Local governments and institutions Other COI may include: ■ Suppliers ■ Customers ■ Regional or national environmental organizations and other non-governmental organizations (NGO) ■ Governments ■ The financial community ■ Shareholders Definition from MAC's *TSM Indigenous and Community Relationships Protocol*
Consequence	The outcome of an event or through cascading and cumulative effects, affecting the Owner's objectives (ISO 2018). It can have a positive or negative direct or indirect effect on objectives and can be expressed qualitatively or quantitatively. Consequence is commonly described as the severity of the event and is used to calculate/define risk: Risk = Consequence × Likelihood

Term	Definition
Cost-Benefit Analysis (CBA)	A procedure to compare the costs and benefits of an adaptation option over time and is recommended if the costs and benefits of adaptation options can be expressed in monetary terms.
Cost Effectiveness Analysis (CEA)	A procedure similar to a CBA, can be used to rank and prioritize adaptation options if a monetary value can be assigned to costs but cannot be assigned to the benefits of adaptation options.
General Circulation Models (GCMs)	Numerical representations of the physical processes on Earth. They are the most advanced tools available for simulating the global climate system's response to changing GHG concentrations (IPCC 2019a). GCMs have coarse grid-box resolutions that vary between 1 and 4 degrees of latitude and 1 and 5 degrees of longitude over the entire planet (Charron 2016; European Network for Earth System Modelling 2019)
Impact	Also referred to as consequence, describes the effects a changing climate, including extreme weather and climate events, has on natural and human systems (ICMM 2019).
Legal Requirement	Any law, statute, ordinance, decree, requirement, order, judgment, rule, or regulation of, and the terms of any license or permit issued by, any governmental authority.
Likelihood	The chance of something happening, commonly described as the probability or frequency of occurrence.
Multi-Criteria Analysis (MCA)	A procedure similar to a CBA used to rank and prioritize multiple adaptation options; however, prioritization is also based on qualitative assessment criteria including feasibility, cost-effectiveness, co-benefits, ease of implementation and resources required. It can also be used when benefits cannot be quantitatively measured, or if multiple benefits cannot be aggregated (Rodgers & Douglas 2015a).
Owner	Refers to the company, partnership, or individual who has legal possession or is the legal holder of a mine under the law in the applicable jurisdiction where the mine is located (adapted from MAC 2019).
Probable Maximum Precipitation (PMP)	Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year (WMO 2009).
Radiative Forcing	Refers to the change in net downward minus upward irradiance in Watts per square metre (W/m^2) at the top of the atmosphere (IPCC 2019b; Charron 2016).

Term	Definition
Risk	Risk represents the potential inability of infrastructure/facility/communities/environment to withstand negative effects or benefit from any positive effects of changes in climate. Risk is a function of the magnitude of the changes in the climate, the sensitivity of an entity to those changes, and their adaptive capacity. The potential severity or consequence of the impact and its probability or likelihood of occurrence are both considered when evaluating risk. Risk = Consequence × Likelihood.
Risk Criteria	The factors used to categorize risk. Risk criteria include consequence and likelihood and may include confidence and other risk modifiers.
Surveillance	Includes the inspection and monitoring (i.e., collection of qualitative and quantitative observations and data) of activities and infrastructure. Surveillance also includes the timely documentation, analysis, and communication of surveillance results, to inform decision-making and verify whether performance objectives and risk management objectives, including critical controls, are being met (adapted from MAC 2019b).
Time of Emergence Triggers/Signals	For climate change impacts on climate sensitive components of a mine, triggers arise when a mine component has reached its threshold where it can either fail or be damaged. Within adaptive management, triggers or time of emergence signals will help to provide decision points identifying how and when management actions are to be taken.
Vulnerability	Vulnerability defines the extent to which a mine infrastructure component is susceptible to, or unable to cope with climate change. Vulnerabilities are present when a climate variable can interact with mine infrastructure, and that interaction has the potential to give rise to risk.

Appendix A: Trends in Climate Variables and Events

The following table provides the historical and projected trends for a number of climate variables in Canada based on Canada's Changing Climate Report (Bush and Lemmen 2019). The high-level trends for the climate variables can help to characterize historical, current, and future climate. If a detailed analysis of observations is not required (e.g., at the early planning stages of mine life), a literature review expanding on these trends of available climate information for the region may be sufficient to characterize the historical and future climate.

Table 1: Historical and projected trends of climate variables for Canada and associated climate events (Bush and Lemmen 2019 except as noted).

Climate Variables and Associated Events	Historical Trend	Projections
Air Temperature	Annual (seasonal) mean temperatures for Canada have increased by 1.7°C (1.5°C to 3.3°C) between 1948 and 2016, and by 2.3°C (1.6°C to 4.3°C) for northern Canada specifically.	Annual mean temperatures are projected to increase by about 2°C above the 1986 to 2005 reference period for a low emission scenario, and by more than 6°C in a high emission scenario by the end of the century.
Extreme Temperatures	Extreme warm temperatures have become hotter, and extreme cold temperatures have become less cold, consistent with observed warming temperature trends.	Observed changes in extreme temperatures are projected to continue in the future with a magnitude of change proportional to the magnitude of mean temperature change.
Annual Mean Precipitation	Annual mean precipitation has increased throughout Canada by about 20% from 1948 to 2012, with larger increases over northern Canada (Vincent *et al.* 2015; Bush and Lemmen 2019).	Annual precipitation is projected to increase by about 7% under a low emissions scenario (RCP2.6) and up to 24% under a high emission scenario (RCP8.5) by the end of the century across Canada. However, under a high emission scenario, summer precipitation is projected to decrease over southern Canada by the end of the century.
Extreme Precipitation	No consistent changes in short-duration precipitation extremes have been identified in Canada (Bush and Lemmen 2019). More stations have experienced an increase than a decrease in the highest amount of one-day rainfall each year, but the direction of trends appears to be random over space.	Extreme precipitation average across Canada is projected to increase in frequency, with a return period of 20 years becoming a 1-in-15 year event by the end of the century with a low emission scenario, and a 1-in-10-year event by mid-century and a 1-in-5-year event by the end of the century under a high emission scenario. The amount of 24-hour extreme precipitation that occurs once in 20 years is projected to increase as much as 25% by the end of the century under a high emission scenario.

Climate Variables and Associated Events	Historical Trend	Projections
Sea Level	Global mean sea level rose by an estimated 0.19 m between 1901 and 2010 (IPCC 2013). For most of the 20th century sea level rose at a rate of nearly 1 mm/year but has tripled since 1993 with recent rates showing approximately 3 mm/year globally (Bush and Lemmen 2019). In Canada, varied sea level rise rates are attributed mainly to glacial isostatic adjustments (uplift near the centre of former ice sheets and subsidence on the edges), sediment consolidation (east coast), and tectonic activity (west coast) (Bush and Lemmen 2019). In Canada, relative sea level rise has been observed by millimetres per year on the Atlantic and Beaufort Sea coasts, with lower amounts along the Pacific coast. However, sea level fall has been observed around Hudson Bay where land is rising due to post-glacial rebound (Warren and Lemmen 2014).	Global sea level is expected to continue rising in response to warmer ocean temperatures (thermal expansion) and as glaciers and sea ice continue to melt (Government of Canada 2009). The global mean sea level rise estimates were developed by combining Representative Concentration Pathway (RCP) based studies of global sea level rise which examined the modelled effects on ocean thermal expansion, Greenland and Antarctic ice sheet dynamics, changes in land-water storage, and melting of glaciers and the Greenland and Antarctic ice sheets (NOAA 2017). For the intermediate-high to extreme scenarios, the potential for rapid Antarctic ice sheet collapse is included. Overall, the scenarios provide a range of 0.16 m to 0.63 m in global mean sea level rise by the year 2050 and 0.3 m to 2.5 m by the year 2100 relative to the base year 2000 on a global scale (NOAA 2017). Due to land subsidence parts of Atlantic Canada are projected to experience sea-level change higher than the global average during the coming century (Bush and Lemmen 2019). Relative sea level rise estimates by 2100 for a median high emission scenario (RCP8.5) range from 75 to 100 cm in Nova Scotia, 25 to 50 cm in Vancouver, and -50 to -90 cm around Hudson Bay and the Canadian Artic Archipelago (Bush and Lemmen 2019).

Climate Variables and Associated Events	Historical Trend	Projections
Wind	Changes in wind patterns have been observed across Canada (Warren and Lemmen 2014). Homogenized wind speed records from 1953 to 2006 for 117 stations across Canada revealed generally increasing wind speeds in the north and eastern regions and decreasing wind speeds in the south and west regions (Wan *et al.* 2010).	The severity and frequency of future wind gust events is expected to change late in the century. Percentage increase in future daily wind gust events of more than 70 km/h could be 10% to 20% higher compared to the current conditions in most of the regions across Canada, corresponding increases in future hourly wind gust events are projected to be 20% to 30% (Cheng *et al.*, 2014).
Sea Ice and Glaciers	The area of summer sea ice has decreased across the Canadian Arctic by 5% to 20% per decade since 1968 and the area of winter sea ice has decreased by 8% per decade in eastern Canada. Sea ice thickness has also decreased by 65% in the Arctic during the period of 1975 to 2012 (AMAP 2017). Canadian glaciers have thinned over the last five decades due to increasing temperatures. Recent warming has resulted in a shortening of the ice road season by several weeks due to enhanced freeze-thaw cycles (Boyle *et al.* 2013). In the Northwest Territories, the average opening date for the Mackenzie River ice road has been delay by more than 3 weeks since 1996 (Hori *et al.* 2018)	Increases in temperature will result in continued reduction in sea ice area across the Canadian Artic in the summer and fall, and in the winter on the eastern coast of Canada. It is with medium confidence that global glacier volume is projected to decrease by 15% to 55% under a low emission scenario (RCP2.6) and by 35% to 85% under a high emissions scenario (RCP8.5) by the end of the century (IPCC 2013). Glaciers across the Western Cordillera are projected to lose 74% to 96% of their volume by the end of the century, decreasing the glacial meltwater supply to rivers and streams by mid-century.

Climate Variables and Associated Events	Historical Trend	Projections
Snow Cover	Snow cover and accumulation has decreased across most of Canada by between 5% and 10% per decade since 1981 as a result of delayed snow onset and earlier spring melts.	Snow cover duration will decrease across Canada as air temperatures continue to increase across all emissions scenarios.
Permafrost	Permafrost temperatures have increased by 0.1°C per decade in the central Mackenzie Valley and by 0.3°C to 0.5°C per decade in the high Arctic. Active layer thickness has increased by approximately 10% since 2000 in the Mackenzie Valley.	Further increases in mean surface temperatures are projected to result in continued permafrost thawing by mid-century. Low and medium emissions scenarios project areas with deeper permafrost in Canada will decline by 16% to 20% by 2090 relative to a 1990 baseline.
Flood	There is low confidence in global-scale trends, but regional-scale increasing trends have been observed.	Changing frequency and intensity of extreme rainfall events are projected to contribute to increasing flooding events.
Drought	There is low confidence in global-scale trends, but regional-scale increasing trends have been observed.	Higher temperatures and changing frequency of precipitation are projected to contribute to increasing drought occurrences over southern interior regions of Canada.
Humidity	It is very likely that the amount of water vapour in the atmosphere has increased since the 1970s, due to warming air temperatures capable of holding more moisture.	It is very likely that near-surface specific humidity will increase in the future as evaporation and air temperatures increase (IPCC 2013).
Wildfire	Changes in temperature and precipitation have increased the likelihood of extreme events, including wildfire.	Higher temperatures and changing frequency of precipitation are projected to contribute to increasing wildfire potential and increase the length of the fire season.

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Appendix B: Detailed Methodology for Developing Baseline and Projected Climate Datasets

This methodology appendix is a summary of a general framework that can be used when developing a climate data set. This approach for developing climate datasets is developed based on recommended guidance accepted by the Intergovernmental Panel on Climate Change (IPCC) and other scientific bodies as referenced in the sections below. Climate analyses should be performed by experts in the field and the info presented here is intended to educate Owners on what to ask for and what to expect from a consultant (expert) and could be used as a basis for a standard scope of work.

Climate datasets should be project specific and developed considering the characteristics of the mine site including the size, location, geography, and lifespan. For example, the lifespan of a mine will determine which time horizon(s) should be included in the future climate dataset (e.g., near, mid, end of century). The climate data set will differ between mines at different stages of the mine life cycle as discussed in the main report. Not all mines will require the same depth of climate data, and this will depend on the type of risks present. Mines with a higher vulnerability to significant/severe risks should ensure all available data required to address these risks have been acquired.

In the following methodology, the current climate is defined as the current climate normal (used to describe the average climatic conditions of a location) and may extend to the most recent observation years. The historical climate is defined as observations recorded prior to the normal period. Climate projections are used to estimate change from current climate conditions into the future at the mine.

Current Climate Baseline Development

Understanding the historical and current climate and trends is important when evaluating design parameters. Where available, the climate baseline is grounded in observations from local weather or meteorological stations. Weather or meteorological observations refer to atmospheric conditions at a given time and location. Collections of weather data include atmospheric variables such as wind speed and direction, rain, temperature, etc. Climate refers to the prevailing weather conditions over a longer time frame at a given location. This methodology provides guidance on establishing current climate baseline conditions given meteorological observations at the mine. If no long-term on-site observations are available, the baseline can be established by using data from publicly available local and regional weather stations. Section 1.1 outlines the data selection criteria to consider when selecting between weather stations, as well as guidance on data completeness requirements when establishing the climate baseline.

If the observations are not sufficiently complete, the data can be infilled with reanalysis data (Section 1.2) that has been compared and correlated to the available regional weather stations.

Data Selection Criteria

Ideally, historical and current climate should be characterized based on available long-term daily meteorological observations from a station either on-site or close in proximity with similar geographic/climatic influences as the mine. For example, if a mine is located next to a large body or water then the closest or most representative station should also be adjacent to a large body of water (ideally the same body of water). Based on available data sources, continuous long-term on-site weather station data is always preferred to best capture the local influences. Any changes to the on-site weather station that could potentially affect the recordings should be noted and taken into account (e.g., moving the station, even just a short distance, can cause a change in the recorded values which are not due to the weather). For any given location, there can be noticeable changes in the weather from year to year due to natural variability. To isolate climate trends from this variability, observations must be averaged over long periods of time, preferably 20 to 30 years (Charron 2016).

To establish a climate baseline, the observations should cover the currently accepted climate normal period (e.g., 1981 to 2010 at the time of finalization of this guidance (late 2020)) which are used to describe the average climatic conditions of a location and may extend to the most recent observation years. In Canada, the normal period is defined by Environment and Climate Change Canada based on recommendations from the World Meteorological Organization (WMO). The recommendations are for 30-year averages updated to the end of every decade (ECCC 2017).

A quality assurance and maintenance program should be developed for any on-site weather stations for use in climate change dataset development by the meteorology/climate expert responsible for the installation and maintenance of the station. This expert should consider both the station siting and quality management recommendations from WMO (2008). Like any weather station maintained by ECCC, on-site stations need to undergo calibration, quality assurance and quality control before the observations should be considered for a climate change dataset.

The following selection criteria should be considered to identify the station which best represents a mine site's climate:

- The length of record (minimum of 20 years, ideally 30 years of data)
- Availability of a continuous record (e.g., no consistent missing days, months, or seasons)
- Proximity to the area of interest
- Age of observations compared to the currently accepted normal period
- Latitude
- Elevation of station
- Geographic setting
- Monthly data availability threshold of 90% valid data for all years.

The data availability threshold is applied to avoid including months with incomplete data in establishing baseline statistics for precipitation and temperature. WMO (1989) recommends using the "3/5" rule, where if a month has either 3 consecutive days or 5 random days missing, then that month should not be used in establishing climate normal. The 90% monthly data availability criterion is a simplification of this rule, in that if more than 3 in 30 days are missing, the month is not used regardless of if the missing days are consecutive or not.

In a given region the selected station(s) may be located at a variety of elevations and may not match the elevation of the mine of interest. Multiple station data can be used to help adjust the most representative station data and help inform what the current climate is in the region. As temperature and precipitation both vary with elevation, adjustment factors may be applied, creating more representative datasets for elevation of the mine.

The available climate data from each station should be compared to, and meet, the selection criteria outlined above for the historical and current climate baseline period. Data from many weather stations is constrained by low numbers of observations or a limited life span for the station (data quantity), and varying data quality. Therefore, the station which matches the most selection criteria, with the first three criteria bearing the most weight, should be selected.

Infilling Missing Data – Reanalysis Data

Meeting the monthly data availability is often a challenge over the desired, long observation period. When available climate observations are representative of a mine based on the majority of selection criteria but fail to meet the required data completeness, the expert should develop a method to be used to infill the missing data. Reanalysis is one method; this process combines observations with numerical weather prediction models or data assimilation systems to provide a dynamically consistent estimate of the state of climate during the historical period of interest (NOAA 2019). The National Aeronautics and Space Administration's (NASA's) Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) is an example of an atmospheric reanalysis dataset using the Goddard Earth Observing System Model, along with its atmospheric data assimilation system. For more information on MERRA-2 and other reanalysis data sources, refer to Appendix D.

Reanalysis data is gridded, meaning it captures a larger spatial resolution (e.g., covers a larger area and may not capture local influences) than weather station observation data that represents local conditions with influences. When using reanalysis data, the closest grid square should be used in most cases, however, if a station is located near the border of a grid square then the adjacent grid square should also be considered. The grid square most representative of the local observations should be used.

Due to the gridded nature of reanalysis data, bias exists as it can capture trends not necessarily representative of a specific location, but that represents the larger grid square. The reliability of reanalysis data may also be impacted due to observational constraints and changing observational networks (UCAR 2019). A bias correction can be completed to remove this bias through a correlation analysis with available weather stations observations. It should be noted that not all reanalysis data includes weather station observations and can be generated entirely through models. A bias correction should be completed to remove the potential impact of observational constraints or model bias.

Quantifying Current Climate

Quantifying Current Climate Normals and Trends

The current climate normal and trends should be calculated using the selected station data (or infilled station data) for the chosen baseline period (consider covering the current climate normal and extending to the most recent observations). When calculating the annual and monthly current climate normals and trends, mean temperature and total precipitation should be considered. Definitions are provided for calculating these normals and trends in Table 1.

Table 1: Definition of Current Climate Indices

Climate Indices	Definition	Units
Average Annual Total Precipitation	Calculated as the sum of all the observed total precipitation during the selected annual period. Each annual value is averaged over the period of the climate normal.	mm
Monthly Precipitation	Calculated as the sum of all the observed total precipitation during the selected month in an annual period. Each monthly value is averaged over the period of the climate normal.	mm
Average Annual Temperature	Calculated as the average of all the observed daily mean temperatures during the selected annual period. Each annual value is averaged over the period of the climate normal.	°C
Monthly Temperature	Calculated as the average of all the observed mean temperatures during the selected month in an annual period. Each monthly value is averaged over the period of the climate normal.	°C

The compiled data can then be used to calculate selected climate normals and trends, using a trend analysis methodology (e.g., linear regression analysis) to assess observed changes in long term climate observations. The climate normal should be calculated as the average of a given climate parameter over the selected baseline period, and the climate trend should be calculated as the average change in the climate parameter per desired period. For example, the climate trend may be calculated per decade (i.e., the decadal trend or change) or per year (i.e., the annual trend or change). The statistical significance of the observed trends can be calculated through appropriate statistical tests that are not influenced by seasonal or other cycles, such as the Mann Kendall test. It may be helpful to represent normal and trend results graphically with the observations to better communicate the variability between the observations and results (i.e., normals and trends).

Quantifying Current Climate Extremes and Trends

In addition to the annual and monthly current climate indices discussed above, climate extremes should be calculated. Climate extremes pose risks for a mine at all phases of its life cycle, influencing the planning, design, operation, and post-closure and closure. For example, climate extremes such as heavy precipitation events can impact infrastructure and interrupt operations due to resulting flooding or inability to deal with the excess water as part of the existing water management plan. Climate extremes are also important to consider when evaluating design parameters, especially any climate extremes that have been previously experienced. An example of climate extremes that may be calculated include the 27 indices developed by Expert Team on Climate Change Detection and Indices (ETCCDI). These indices use daily precipitation and temperature data to evaluate different extreme events including (but not limited to) hot and cold spell durations, warm and cold days and nights above threshold percentiles, maximum 1 and 5 day precipitation, and wet and dry spell durations (WMO 2009). Other forms of extreme value analysis may be carried out to estimate recurrence intervals for extreme events by analyzing the tails of climate variable probability distributions (Charron 2016).

Quantifying Current Climate Precipitation and Rainfall

Changing precipitation patterns are often a concern for the mining industry as it changes when, what type, and how much water the mine must manage. Precipitation patterns may evolve over the current climate baseline considered and may differ from the historical data used to develop the climatic assumptions applied in mine infrastructure design. Mines may consider changing precipitation patterns through quantifying precipitation variables and indices such as:

- Probable Maximum Precipitation (PMP)
- Intensity-Duration-Frequency (IDF) curves and rainfall statistics (annual, monthly, and daily max distributions)
- Snowpack and snowmelt
- Evapotranspiration and/or evaporation

Probable maximum precipitation (PMP) is defined as "the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends" (WMO 2009). The PMP is a theoretical value that represents the greatest amount of rain possible in a given area as opposed to a design storm that represents the amount of rain associated with a specific probability of occurrence. The WMO acknowledges that there is significant uncertainty regarding PMP calculations and recommends that a comparison of reported values is conducted. There are two widely accepted approaches (meteorological and statistical) to estimate the PMP. The meteorological approach compares measured rainfalls against measured and maximum moisture content or precipitable water while the statistical approach utilizes the statistics of historical annual maximum rainfall events to estimate the PMP.

Extreme rainfall events for a range of durations and return periods can be calculated using rainfall statistics. The results are published as Intensity-Duration-Frequency or IDF curves. There are multiple methods available to estimate IDF curves. The Method of Moments is used to estimate parameters to fit the Gumbel Distribution to the 1 day duration annual maximum rainfall events. The fitted distribution is then used to extract rainfall amounts for selected return periods to estimate the 1-day IDF curves, similar to ECCC's methodology at select monitoring stations (EC 1990). When referring to daily IDF curves and rainfall statistics it should be clear whether the duration is 24-hour (based on hourly observations) or 1-day (based on hourly or daily observations). The 24-hour rainfall is calculated as the maximum rainfall during a moving block of 24 hours while the 1-day rainfall is calculated as the maximum rainfall during a fixed period (typically from midnight of one day to midnight of the next). Due to the differences in the method of calculation, there are typically differences in the values, with the 24-hour rainfall being higher (since the moving block allows for greater capture of storms).

Sub-daily IDF curves and rainfall statistics can be estimated using hourly observations if available. Sub-daily running totals for precipitation for the desired durations (1-hour to 24-hour) are derived and then a similar methodology to the daily IDF curves and statistics can be applied. Multi-day IDF curves and rainfall statistics can be estimated using hourly or daily observations by deriving multi-day running totals for precipitation for the desired durations (e.g., 2-day to 120-day) and then applying the same methodology as for the daily duration. Additionally, ECCC provides sub-daily IDF curves at some weather stations for selected return periods (EC 1990).

Unlike rainfall, snowfall does not necessarily produce an immediate effect. An individual snowfall may be smaller than a rainfall event (based on equivalent depth of water), however an accumulation of snowfalls over a long period may melt relatively quickly and produce an effect larger than any single rainfall event. It is thus important to understand the probability of occurrence for large snowpacks and associated melt events. Where snowpack is measured, this can be done in a similar fashion to the IDF curves (using maximum annual values for snowpack and snowmelt fitted to Gumbel distributions); where snowpack is not measured, estimates of snow accumulation and melt based on precipitation and temperature (EC 1983) must be used to obtain annual maximum values for snowpack and snowmelt.

Evaporation and transpiration can occur simultaneously. Evapotranspiration is useful to define runoff and is used in hydrology studies and it is also a key parameter to understand as evaporation from pit lakes and ponds can be a significant loss of water. The principal weather parameters affecting evapotranspiration are air temperature, solar radiation, humidity and wind speed, with air temperature typically being the dominant independent variable. For many locations, observations of solar radiation, humidity and wind speed may not be available. Pan evaporation can be used to estimate lake evaporation but observations for this parameter may also be limited. Methods are available to estimate evapotranspiration based on air temperature alone, such as the Hargreaves equation (Food and Agriculture Organization [FAO] 2006) and the Thornthwaite Equation (EC 1983). Experts should describe how evapotranspiration is observed or calculated as part of the baseline.

Projecting Future Climate

Future climate projections are important for understanding how climate is projected to change from the selected climate baseline period. Future climate is typically projected using climate models that involve the mathematical representation of land, sea, and atmosphere interactions over a long period of time.

The Fifth Assessment Report (AR5) is the most current complete synthesis of information regarding climate change at the time of finalization of this guidance (late 2020). Climate projections should be performed using the most up to date IPCC Assessment Reports (ARs).

Future climate projection data are available from about 30 Global Climate Models (GCMs), which encompass the entire globe, covering four representative concentration pathways (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) in AR5. The Coupled Model Intercomparison Project 5 (CMIP5) promotes a standard set of model simulations to facilitate comparison of model runs and provides a data portal where GCM outputs can be obtained. Future climate projection data is also available on a global scale for the GCMs and emission scenarios (SRES scenarios) used in AR4 but are not discussed here beyond linking the emission scenarios in AR4 to the RCPs in AR5.

The model projections are summarized for magnitude of change from the climate regime baseline for different time horizons, most commonly for simulated current conditions, mid-century or 2050s (2041 to 2070) and end-of-century or 2080s (2071 to 2100) time horizons.

All climate models are based on the same physical principles and each simulates a plausible response to the imposed change in radiative forcing. Given uncertainty in how future emissions will evolve, it is necessary to consider a number of options which give us information about the possible range of future climate. Because of these uncertainties, the IPCC recommends that climate change assessments use as many models as possible, or a "multi-model ensemble". For this reason, the multi model ensemble approach is typically used to delineate the probable range of results and better capture the actual outcome (an inherent unknown) improving the confidence in the range the potential future climate projections. A list of future climate projection sources is included in Appendix C with a detailed description of each.

Regional Climate Change Projections

Although climate change is a global phenomenon, its effects are felt differently between and across regions. For a detailed climate assessment, regional climate change projections should be used as the availability of high spatial resolution (on the order of 10 km instead of 100 km in GCMs) may provide better site representation for detailed studies. In addition, the availability of daily downscaled data allows for better characterization of the climate extremes, especially for precipitation.

Regional climate change projections are available from many data sources as listed in Appendix C.

Uncertainty of Climate Change Downscaling Methods

The spatial and temporal resolution mismatch between GCMs outputs and the data requirements of climate change risk assessment is a key consideration when analyzing projected climate for a mine site on the local scale. It is therefore necessary to perform some post-processing to reconcile this mismatch or clearly communicate its presence in the results of the climate risk assessment. Consequently, dynamic downscaling (regional climate models) and statistical downscaling have been developed to meet these requirements (Chen *et al.* 2011). Dynamical downscaling requires high-resolution regional climate models that are driven by GCMs simulations to dynamically simulate regional or local scale climate processes. Regional climate models have a higher spatial resolution which allows them to better represent the underlying topography and some of the regional and local physical processes, with the highest resolution models able to include convection schemes. Dynamical downscaling can be sensitive to large-scale biases however and can be expensive. Statistical downscaling uses statistics-based techniques to determine the relationship between local observed climate variables and large-scale climate predictors/patterns from GCMs (NCAR 2019; Princeton University 2019). These relationships are then applied to GCM outputs to estimate a regional or local climate.

Each approach has advantages and constraints However, both methodologies produce comparable results in simulating current climate and should thus be considered complementary approaches for downscaling regional climate (Canadian Standards Association 2010).

Projecting Future Climate Extremes

Climate models often misrepresent climate extremes especially with regards to precipitation due to limitations in the spatial and temporal resolutions needed to represent them. Because of this, extremes may not be fully captured and are often described in terms of a change from the baseline to minimize potential bias in absolute values from the climate model projections. Future climate extremes are projected using daily temperature and precipitation projections from available data. As each model has a unique baseline, the calculations should be completed for each model and then statistics provided to describe the range of projections over the multi-model ensemble.

Projecting Future Climate Precipitation and Rainfall

The Canadian Standards Association (2010) noted that "In an effort to derive quantitative future short-duration rainfall estimates to better suit the needs of design, water resource and storm water management practitioners, a number of various statistical downscaling and analysis techniques have been developed. However, there is no standard or accepted research methodology to determine how future sub-daily extreme rainfall could change in intensity and frequency at point locations or over a small area in the future climate".

Nonetheless, consistent with the current climate methodology, changing precipitation can be considered by examining how the PMP, IDF curves and rainfall statistics, snowpack and snowmelt, and evapotranspiration are projected to change under future climate conditions. The future climate methodology for projecting the PMP and future potential evapotranspiration is the same as the current climate methodology but applied to the future daily climate projections. The methodology for projected future climate IDF curves and rainfall statistics is slightly more challenging.

Climate models are not yet able to fully resolve convective processes responsible for generating extreme precipitation amounts on finer spatial scales and contributing to extreme precipitation in larger scale synoptic systems (CSA 2019). For this reason, estimates of short-duration extreme precipitation for a selected location are unlikely to be robust (Li *et al.* 2019). Li *et al.* (2019) recommends that a pooling method be used to increase the spatial extent of the analysis and capture more internal variability in the projections of precipitation. Projections of extreme precipitation statistics should be done by analyzing the percentage changes in precipitation amounts between the downscaled modelled baseline period and future period. The changes should then be applied to the observed precipitation statistics to minimize bias and preserve the observed distribution of precipitation (Luo *et al.* 2018). Any attempts to project future short-duration rainfall extremes should acknowledge the ongoing scientific research on this subject.

For downscaled daily future climate projections, properly accounting for the local rainfall distributions is essential to capture extreme rainfall events that are critical to the construction of the IDF statistics. An additional analysis step should be taken to address these uncertainties in the downscaling approaches with regards to local rainfall distributions. This additional analysis step is intended to remove bias in the projections or normalize the projections to observations to address the uncertainties in accounting for local rainfall distributions.

Future projections of daily (1-day) duration IDF curves and rainfall statistics may be estimated using the downscaled daily projections for the desired return periods. Similarly, the same approach will be used for multi-day durations for the desired return periods. Projecting sub-daily duration IDF curves and rainfall statistics requires hourly future projections of precipitation, which are not readily available, especially for statistically downscaled projections. As a starting point, the same relationships between daily and sub-daily IDF curves and rainfall statistics can be assumed to apply under future climate conditions, however, this does not allow for a changing precipitation patterns in the distribution of rainfall in the future.

An ensemble approach should be used for all the precipitation variables and indices described above to help address uncertainty in the projections, as explained above. Statistics for projected changes should be calculated across the ensemble to describe the range in projected anomalies across the ensemble members (min, max, mean, median and percentiles). Uncertainty may also be examined by performing sensitivity analyses on the future projections. For example, in Metro Vancouver (2018) a sensitivity analysis was performed on rainfall projections by grouping the projected changes by RCP scenarios, downscaling methods, statistical distributions, and PDO indices ("cool", "warm", or "all" years). The result of the analysis presents the uncertainty in each step of the process used to project future climate.

Using the Results

The nature of the quantifying the current climate and project the future climate includes substantial inherent uncertainly that must be considered in a changing climate. The range of projected values comes from three main sources: (1) unknown human emissions of greenhouse gases, (2) natural climate variability, and (3) imperfect climate model projections. The range of plausible climate projections increases for projected periods farther in the future and is subject to future developments. Therefore, work should be updated as new climate science is developed and after the release of the latest AR by the IPCC.

One way to acknowledge this uncertainty is to provide future projections considering the range of projections rather than just one. Selecting one or a subset of models can increase bias and narrow the range of projections. Rather, projections for the ensemble median can be assumed to represent the climate conditions with natural variability averaged out if the ensemble size is large enough as well as the middle of the range of climate model uncertainty. The projections at the 95th percentile among a large ensemble can be considered to represent a cautious approach in terms of both natural variability and climate model uncertainty (for a specified level of assumed GHG emissions). When considering the impact of future projected climate on current design parameters, the level of acceptable risk tolerance should inform what parts of the range of future conditions are considered. Selection of future projections for climate change risk assessment should be based on the balance between the extra investment and consequential risks.

Therefore, it is recommended that the results be used as follows:

- Ensemble mean or median projections should be selected as the starting point in regard to risk assessment and undertaking planning and engineering design applications of infrastructure in the future.
- Consideration should be given to the "project life & future level of service requirements" and selection of the appropriate planning horizon for each infrastructure component (i.e., 2050s and 2080s).
- For critical infrastructure, selection of future projections at the higher end of the range should be considered. For example, for critical infrastructure, whose failure is considered unacceptable, a 90th or 95th percentile could be considered over the typical 50th percentile.
- If a risk is identified for an infrastructure component for the area, then a more refined analysis should be performed further define the risks considering the projected range of values.
- When considering action to address an identified potential risk consideration should be given to selection from the projected range of values through a decision-making analysis. There are different analysis methods that can be used for decision-making purposes. If costs and benefits of adaptation options can be monetized, a cost-benefit analysis is preferred. If benefits of adaptation options can be quantified but not expressed in monetary terms, while costs can be quantified in monetary terms, cost-effective analysis is preferred. If both costs and benefits cannot be expressed in monetary terms or if non-monetary criteria such as environmental or social factors are the priority, multi-criteria/multi-actor analysis is recommended. In all other cases, an economic approach is very difficult to apply, and other approaches may need to be considered.
- If a subset of models or RCPs are used then the reason, bias and the impact on the assessment be documented.

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Appendix C: Climate Change Data Sources

Acronyms

Acronym	Definition
ADAS	Atmospheric Data Assimilation System
AR	Assessment Report *Published by the IPCC composed of the full scientific and technical assessment of climate change*
AR4	Fourth Assessment Report Published by the IPCC
AR5	Fifth and current Assessment Report Published by the IPCC
BCSD	Bias Correction Spatial Disaggregation
BCCAQ	Bias Correction/Constructed Analogues with Quantile mapping reordering
CCCS	Canadian Centre for Climate Services
CCDP	Canada Climate Change Data Portal
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRIM	Computer Research Institute of Montreal
ECCC	Environment and Climate Change Canada
ETCCDI	Expert Team on Climate Change Detection and Indices
GCM	Global Climate Models
GHCN	Global Historical Climatology Network
GEOS-5	Goddard Earth Observing System Model Version 5
HadGEM2-ES	Hadley Global Environment Model 2 Earth System
IDF Curves	Intensity-Duration-Frequency curves
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NRCan	Natural Resources Canada
OCDP	Ontario Climate Data Portal
PCC	Prairie Climate Centre
PCIC	Pacific Climate Impacts Consortium
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SNAP	Scenarios Network for Alaska and Arctic Planning
SSHRC	Social Sciences and Humanities Research Council of Canada
WCRP	World Climate Research Program

Current and Historical Climate Data Sources

As discussed in Appendix B: Detailed Methodology for Developing Baseline and Projected Climate Datasets, in order to establish a climate baseline, continuous long-term daily meteorological observations from climate stations on-site or in the same region of the mine must be obtained. Tables 1 and 2 include a list of publicly available observed climate data sources, with a focus on Canadian-specific federal, provincial, and territorial resources. The data sources provided are the most relevant data sources and may not capture all available sources. In addition to the observed climate sources, two sources of gridded regional reanalysis data have also been included. Reanalysis data assimilates a large number of observations from multiple sources to produce a long-term picture of climate in a given area. This data can be used if a chosen weather station does not meet the data completion criteria described in greater detail in Appendix B.

As outlined in Appendix B, when selecting a data source for observed climate data, the following factors should be considered to ensure the most appropriate observations are used:

- Availability of observations (length of record, a minimum of 20 years is suggested but 30 years is preferrable when possible)
- Availability of a continuous record
- Geographic area available
- Temporal resolution (i.e., daily, monthly, annual)
- Variables available (i.e., temperature, precipitation)

It is important to note that the availability of observations may vary considerably between weather stations within a given data source, and further selection criteria should be considered when selecting weather stations and has been provided in Appendix B.

Additionally, Table 3 provides a list of observed data sources for permafrost data in North America. This information is important to consider if a mine is located in permafrost regions, particularly if the structural integrity of infrastructure is reliant on permafrost.

Table 1: Canadian and International Observed Climate Data Sources

Details	National Climate Data and Information Archive (Government of Canada)	Adjusted and Homogenized Canadian Climate Data (AHCCD) Dataset	ClimateData.ca	National Oceanic and Atmospheric Administration (NOAA)	Engineering Climate Datasets (Government of Canada)
Description	■ Provides historical climate data from present and past weather stations throughout Canada.	■ Adjusted and homogenized Canadian climate data (AHCCD) are climate station datasets that incorporate adjustments (derived from statistical procedures) to the original historical station data to account for discontinuities from non-climatic factors, such as instrument changes or station relocation. ■ AHCCD was developed for use in climate research, including climate change studies.	■ Online data portal that provides access to ECCC daily weather data and climate normals	■ Provides publicly available historical climate data through the Global Historical Climatology Network (GHCN)-Daily database of weather stations.	■ Provides historical engineering climate datasets from present and past weather stations throughout Canada.
Variables	Hourly: ■ Temperature (°C) ■ Dew point temperature (°C) ■ Relative humidity (%) ■ Wind direction (10's deg/tens of degrees) ■ Wind speed (km/h) ■ Visibility (km) ■ Station pressure (kpa) ■ Humidex ■ Windchill Daily/Monthly: ■ Max temperature (°C) ■ Min temperature (°C) ■ Mean temperature (°C) ■ Heat degree days ■ Cools degree days ■ Total rain (mm) ■ Total snow (cm) ■ Total precipitation (mm) ■ Snow on the ground (cm) ■ Direction of maximum gust (10's deg/tens of degrees) ■ Speed of maximum gust (km/h)	Daily: ■ Max, min, and mean surface air temperature (°C) ■ Rainfall, snowfall, and total precipitation (mm) Monthly/Seasonal/Annual/Trends: ■ Max, min, and mean surface air temperature (°C) ■ Rainfall, snowfall, and total precipitation (mm) ■ Sea level pressure (hPa), ■ Surface wind speed (m/s)	Hourly: ■ Temperature (°C) ■ Dew point temperature (°C) ■ Relative humidity (%) ■ Wind direction (10's deg/tens of degrees) ■ Wind speed (km/h) ■ Visibility (km) ■ Station pressure (kPa) ■ Humidex ■ Windchill Daily/Monthly: ■ Max temperature (°C) ■ Min temperature (°C) ■ Mean temperature (°C) ■ Heat degree days ■ Cools degree days ■ Total rain (mm) ■ Total snow (cm) ■ Total precipitation (mm) ■ Snow on the ground (cm) ■ Direction of maximum gust (10's deg/tens of degrees) ■ Speed of maximum gust (km/h)	Over 40 meteorological elements available including: ■ Min temperature (°F or °C) ■ Average temperature (°F or °C) ■ Max temperature (°F or °C) ■ Precipitation (mm or inches) ■ Snowfall (mm or inches) ■ Evaporation (mm or inches) ■ Wind speed (m/s or miles/hour) ■ IDF curves	■ IDF Curves (updated every two years depending on data availability) ■ Canadian Weather Energy and Engineering Datasets (CWEEDS) ■ Canadian Weather Year for Energy Calculation (CWEC)

Details	National Climate Data and Information Archive (Government of Canada)	Adjusted and Homogenized Canadian Climate Data (AHCCD) Dataset	ClimateData.ca	National Oceanic and Atmospheric Administration (NOAA)	Engineering Climate Datasets (Government of Canada)
Variables Cont'd	Normals include 19 variables available including: ▪ Daily average temperature (°C) ▪ Daily max temperature (°C) ▪ Daily min temperature (°C) ▪ Precipitation (mm)		▪ Normals include 19 variables available including: ▪ Daily average temperature (°C) ▪ Daily max temperature (°C) ▪ Daily min temperature (°C) ▪ Precipitation (mm) IDF curves are also provided from ECCC/MSC		
Geographic Area	Canada	Canada	Canada	Global (U.S. focused)	Canada
Time Period[1]	▪ Search allows for 1840 – Present ▪ Climate normals available for 1981 – 2010	1840 – Present	▪ 1840 – Present ▪ MSC climate normals available for 1981-2010	▪ Daily Summaries available from 1900 – Present ▪ Climate normals available for 1981-2010	Varies between variables
Temporal Resolution	Hourly, Daily, Monthly, Normals (30-year averages)	Daily, Monthly, Seasonal	Daily, Hourly, Monthly, Normals (30-year averages)	Hourly, Daily, Monthly, Seasonal, Annual, Normals	Not Applicable
Spatial Resolution	Not Applicable – monitoring station data	Not Applicable – monitoring station data	No, station data are point locations	Not Applicable – monitoring station data	Not Applicable
Data Format	▪ CSV ▪ XML	▪ CSV ▪ GeoJSON	▪ CSV ▪ JSON	▪ Interactive Map ▪ CSV ▪ Note: Data may not be in a standardized format	▪ PDF ▪ Text Document ▪ PNG File
Developed by	Government of Canada	ECCC	Collaboration between: ▪ ECCC ▪ Computer Research Institute of Montreal (CRIM) ▪ Ouranos ▪ Pacific Climate Impacts Consortium (PCIC) ▪ Prairie Climate Centre (PCC) ▪ HabitatSeven	Department of Commerce, Government of the United States of America	Government of Canada
Link	*http://climate.weather.gc.ca/historical_data/search_historic_data_e.html*	*http://climate-scenarios.canada.ca/?page=homogenized-data*	*https://climatedata.ca/*	*https://www.ncdc.noaa.gov/cdo-web/datasets*	*http://climate.weather.gc.ca/prods_servs/engineering_e.html*

1 Availability of observations may vary considerably between weather stations.

Table 2: Reanalysis Data Sources

Details	North American Regional Reanalysis (NARR)	Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)
Description	Provides gridded regional reanalysis data for North America.	A NASA gridded atmospheric reanalysis database using the Goddard Earth Observing System Model Version 5 (GEOS-5) with its Atmospheric Data Assimilation System (ADAS) Version 5.12.4.
Variables	List of variables available include: ■ Temperature (K) ■ Specific humidity (kg/kg) ■ Wind (m/s) ■ Total precipitation (kg/m^2)	List of variables available include: ■ Temperature (°C) ■ Precipitation (mm) ■ Wind speed (m/s) ■ Snow cover (both total snow storage on land (kg/m^2) and fractional area of land) ■ Snow depth (m)
Geographic Area	North America	Global
Time Period[1]	1979 to Present	1980 to Present
Temporal Resolution	Sub-daily, Daily	Sub-daily, Daily
Spatial Resolution	~32 km	50 km
Data Format	NetCDF	NetCDF
Developed by	■ National Oceanic and Atmospheric Administration ■ Department of Commerce, Government of the United States of America	■ National Aeronautics and Space Administration (NASA) ■ Global Modeling and Assimilation Office
Link	*https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/north-american-regional-reanalysis-narr*	*https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/*

1 Availability of observations may vary considerably between weather stations.

Table 3: Provincial/Territorial Observed Climate Data Sources

Details	BC Station Data Portal (Pacific Climate Impacts Consortium)	Current and Historical Alberta Weather Station Data Viewer	IDF Curve Lookup (Ontario Ministry of Transportation)
Description	■ The portal provides raw data from a variety of sources for current and historical data. ■ Sources include: ● BC Ministry of Environment, Agriculture, Transportation and Infrastructure ● BC Hydro ● ECCC	Current and historical data provided by Alberta Agriculture and Forestry and Environment and Parks.	The IDF Curve Lookup tool is a web-based application for retrieving IDF curves.
Variables	List of variables available include: ■ Min temperature (°C) ■ Mean temperature (°C) ■ Max temperature (°C) ■ Precipitation (mm) ■ Mean wind speed	List of variables available include: ■ Precipitation (mm) ■ Accumulated precipitation (mm) ■ Temperature (°C) ■ Min temperature (°C) ■ Max temperature (°C) ■ Relative humidity at 2m (%) (Hourly only) ■ Wind speed at 2 and 10m (km/h) ■ Wind direction at 2m (deg) ■ Wind speed at 10m (km/h) ■ Corn heat units ■ Potato heat units ■ Growing degree days (5°C) ■ Reference evapotranspiration (mm) ■ Frost probability 0°C (%)	■ IDF curves ■ Rainfall intensity (mm/hour) ■ Rainfall depth (mm)
Geographic Area	British Columbia	Alberta	Ontario
Time Period[1]	Daily Summaries available from 1870 to Present	Search allows for 2004 to Present	Varies based on location
Temporal Resolution	Hourly, Daily, Semi-Daily	Hourly (from 2008), Daily, Monthly, Yearly	2-year, 5-year, 10-year, 25-year, 50-year, 100-year durations for 5-min, 10-min, 15-min, 30-min, 1-hour, 2-hour, 6-hour, 12-hour, 24 hour

Details	BC Station Data Portal (Pacific Climate Impacts Consortium)	Current and Historical Alberta Weather Station Data Viewer	IDF Curve Lookup (Ontario Ministry of Transportation)
Spatial Resolution	Not Applicable	Not Applicable	30-arc seconds
Data Format	Interactive Map NetCDF, CSV/ASCII, MS Excel 2010	CSV	Data cannot be downloaded, only shown on web page
Developed by	Pacific Climate Impacts Consortium (PCIC)	Alberta Climate Information Service (ACIS)	Ontario Ministry of Transportation 2016
Link	*https://data.pacificclimate.org/portal/pcds/map/*	*https://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp*	*http://www.mto.gov.on.ca/IDF_Curves/terms.shtml*

1 Availability of observations may vary considerably between weather stations.
Note: Datasets that are provided by other provinces and territories rely on ECCC

Table 4: Permafrost Observed Data Sources

Details	Arctic Portal	Nunavut Permafrost Databank	National Snow and Ice Data Centre (NSIDC)	Scenarios Network for Alaska and Arctic Planning (SNAP) Data
Description	Covers a wide range of environmental conditions including permafrost monitoring observed in the Arctic and sub-Arctic regions.	Contains permafrost information for Nunavut, presenting research that has been conducted for specific areas throughout the territory.	The centre provides data for many regions, with variables specific to the cryosphere.	Data portal includes datasets on permafrost depth and active layer thickness through the Alaska LandCarbon Project.
Variables	■ Permafrost extent ■ Permafrost classification (continuous, discontinuous) ■ Sea ice extent	■ Temperature ■ Depth of permafrost	Many variables are available depending on the region, including: ■ Permafrost thickness ■ Active layer ■ Air temperature ■ Snow depth	■ Permafrost thickness ■ Active layer thickness
Geographic Area	Global	Nunavut, Canada	North America	Alaska
Time Period	Varies between research	Varies between research	January 1, 1965 to December 31, 1997	Varies between research
Temporal Resolution	Varies between research	Varies between research	Not Specified	Varies between research
Data Format	Interactive Maps, Shapefile, KML	Interactive Map	ASCII Text	IMG
Developed by	International Permafrost Association	Nunavut Climate Change Centre	National Snow and Ice Data Centre	Scenarios Network for Alaska and Arctic Planning
Link	*https://gtnp.arcticportal.org/*	*http://climatechangenunavut.ca/en/climate-change/nunavut-permafrost-databank*	*https://nsidc.org/data/search/#keywords=permafrost/sortKeys=score,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25* *https://nsidc.org/data/GGD503/versions/1*	*http://ckan.snap.uaf.edu/dataset/depth-to-permafrost-alaska-landcarbon-project* *http://ckan.snap.uaf.edu/dataset/active-layer-thickness- alaska-landcarbon-project*

Future Climate Data Sources

Future climate projections are important for understanding how climate is projected to change from the climate baseline. Tables 6 through 10 list future climate change data sources for Canada at national and provincial levels, as well as international examples. Similar to the current and historical data sources, selection of data sources for future climate should consider criteria listed in Table 5.

Table 5: Considerations when selecting future climate data sources.

Considerations	Description
Climate Science	Data sources should be using the most up to date climate science. For example, the IPCC's AR5 is the most current synthesis of climate change information and projections at the time of printing.
Number of Models	The use of a multi-model ensemble to avoid bias within individual model (IPCC 2013; Charron 2016).
Spatial Resolution	Finer resolution may allow for better capture of terrain, but downscaling may not provide additional information (Charron 2016). The inclusion of downscaled datasets adds another layer of uncertainty associated with the downscaling method used.
Emission Scenarios	The data should be available for a number of emission scenarios such as RCP2.6, 4.5, 6.0, or 8.5 based on IPCC's AR5.
Time Period	Data available should cover the appropriate time periods, depending on the lifespan of a mine, how long the mine will be in operation until post-closure. Future time periods should match the length of the climate baseline period (Charron 2016).
Data Format	Not all data formats are readily accessible for direct processing and require some post-processing to extract the information of interest (i.e., NetCDF files require a set of software libraries to access the data).

As discussed in Appendix B, the Intergovernmental Panel on Climate Change's (IPCC) is generally considered to be the definitive source of information related to past and future climate change as well as climate science. The IPCC provides a common source of information relating to emission scenarios, assessment, and attribution of observed and projected changes in climate and recommends approaches to document future climate projections. The IPCC issues assessment reports summarizing the most current state of climate science. The Fifth Assessment Report (AR5) was released in 2013 and is the most current complete synthesis of information regarding climate change, and therefore, it is recommended that data sources use AR5 projections.

When selecting a future climate data source, it is important to consider the number of models used, the number of emission scenarios available and the geographic coverage. All climate models are based on the same physical principles and each simulates a plausible response to the imposed change in radiative forcing. Given uncertainty in how future emissions will evolve, it is necessary to consider a number of options which give us information about the possible range of future climate. Because of these uncertainties, the IPCC recommends that climate change assessments use as many models as possible, or a multi-model ensemble. For this reason, the multi model ensemble approach should be used to delineate the probable range of results and better capture the actual outcome (an inherent unknown).

For example, the Canadian Centre for Climate Services has used data prepared by the Pacific Climate Impacts Consortium (PCIC) to provide decision makers with access to statistically downscaled Canada-wide climate scenarios. The downscaled outputs for future climate projections are based on Global Climate Model (GCM) projections from Coupled Model Intercomparison Project Phase 5 (CMIP5) for a multi-model ensemble of 24 GCMs. They provide climate variables (minimum and maximum temperature, and precipitation) for a simulated period between 1950 to 2100 for RCP2.6, 4.5 and 8.5.

It is important to note that the data sources listed below have varying levels of review depending on whether they are provided by independent researchers or regulated organizations. The environmental champion or the meteorology/climate subject matter expert should be involved to help complete the data source selection.

Table 6: Canadian Future Climate Change Data Sources – National

Details	Canadian Climate Data and Scenarios (CCDS)	ClimateData.ca	Pacific Climate Impacts Consortium (PCIC)
Description[1]	■ An interface provided by the Government of Canada offering a range of products including multi-model ensemble scenarios based on 29 CMIP5 global climate models, statistically downscaled scenarios based on 24 models, and derived datasets. ■ Statistical downscaling is based on the Bias Correction/Constructed Analogues with Quantile mapping version 2 (BCCAQv2). ■ A range of percentiles are made available for multi-model ensembles offered on the site, including the 25th, 50th, and 75th percentiles. ■ Can be accessed through the Canadian Centre for Climate Services (CCCS).	■ Online data portal that provides interactive data viewing and extraction tools and datasets from ANUSPLIN and BCCAQv2. ANUSPLIN is a gridded observational dataset produced by Natural Resources Canada. ■ The BCCAQv2 method is developed by PCIC for downscaling daily climate model projections of temperature and precipitation. ■ Results are from an ensemble of 24 climate models and include extreme indices, 10th and 90th percentiles, and a 50th percentile of 30-year averages for each variable.	■ Provides statistically downscaled Canada-wide climate scenarios. ■ Two downscaling methods are used: ● Bias Correction Spatial Disaggregation (BCSD) ● Bias Correction/ Constructed Analogues with Quantile mapping reordering (BCCAQ) ■ The downscaled outputs are based on GCM projections from CMIP5 and historical gridded climate data for up to 27 GCMs. ■ A subset is provided which captures 90% of the range in projected temperature and precipitation variables consisting of 12 GCMs.

Details	Canadian Climate Data and Scenarios (CCDS)	ClimateData.ca	Pacific Climate Impacts Consortium (PCIC)
Variables	GCM data: ▪ Temperature (°C) ▪ Total precipitation (%) ▪ Snow depth (%) ▪ Sea ice thickness (%) ▪ Sea ice concentration (%) ▪ Near surface wind speed (%) Downscaled data: ▪ Mean temperature (°C) ▪ Daily min temperature (°C) ▪ Daily max temperature (°C) ▪ Total precipitation (%)	▪ Hottest day (highest maximum temperature) (°C) ▪ Coldest day (lowest minimum temperature) (°C) ▪ Frost days ▪ Mean temperature (°C) ▪ Min temperature (°C) ▪ Max temperature (°C) ▪ Cooling degree days ▪ Days with Tmin < -15°C and < -25°C ▪ Days with Tmax >25°C, >27°C, >29°C, >30°C, >32°C ▪ Growing degree days (10°C, 5°C, 0°C) ▪ Heating degree days ▪ Ice days ▪ Max 1-day total precipitation ▪ Wet days (>1mm, >10mm, >20mm) ▪ Total precipitation (mm) ▪ Tropical nights (days with Tmin >18°C, >20°C, >22°C)	▪ Min temperature (°C) ▪ Max temperature (°C) ▪ Precipitation (mm/day) ▪ Wind (available for PBCmet 2010 and PNWNAmet 2015 only)
Geographic Area	Global	Canada	Canada
Time Period	Reference Period: 1986-2005 Future Period: ▪ 2021-2040 ▪ 2041-2060 ▪ 2061-2080 ▪ 2081-2100	1950-2100	Daily gridded Reference Period: 1950-2013 Statistically Downscaled GCM: 1950-2100
Temporal Resolution	Daily (for downscaled), Seasonal, Annual	Daily, Annual	Daily
Spatial Resolution	10 km resolution	10 km (300 arc-seconds) resolution	10 km (300 arc-seconds) resolution

Details	Canadian Climate Data and Scenarios (CCDS)	ClimateData.ca	Pacific Climate Impacts Consortium (PCIC)
Emission Scenarios	RCP2.6, 4.5, 8.5	RCP2.6, 4.5, 8.5	RCP2.6, 4.5, 8.5
Data Format	Interactive Map GeoTIFF or NetCDF	CSV or JSON	Interactive Map NetCDF, ASCII, Arc/Info ASCII Grid
Developed by	Government of Canada 2018	Collaboration between: ■ ECCC ■ Computer Research Institute of Montreal (CRIM) ■ Ouranos ■ Pacific Climate Impacts Consortium (PCIC) ■ Prairie Climate Centre (PCC) ■ HabitatSeven	University of Victoria
Link	*https://climate-scenarios.canada.ca/?page=main*	*https://climatedata.ca*	*https://www.pacificclimate.org/data*

Table 7: Canadian Future Climate Change Data Sources – National, Continued

Details	Climate Atlas of Canada	Canada Climate Change Data Portal (CCDP)	IDF_CC Tool 3.5
Description	■ Provides maps of statistically downscaled climate variables using an ensemble of 24 GCMs from PCIC, downscaled with the BCCAQv2 method. ■ The source of historical observed data is Natural Resources Canada.	■ Data derived from dynamically downscaled climate projections using the regional climate models RegCM and PRECIS. ■ RegCM was developed by the National Center for Atmospheric Research (NCAR). ■ PRECIS was developed at the Met Office Hadley Centre. ■ Both RCMs were driven by the GCM Hadley Global Environment Model 2 Earth System (HadGEM2-ES).	■ Computerized web-based tool for the development of IDF curves under climate change (Version 3.5) using a Geographic Information System (GIS). ■ Provides precipitation accumulation depths for a variety of return periods (2, 5, 10, 25, 50, and 100 years) and durations (5, 10, 15, and 30 minutes, and 1, 2, 6, 12, and 24 hours). ■ The tool allows users to generate IDF curve information based on historical data as well as future climate conditions. ■ The tool uses operated rain gauges from Environment and Climate Change Canada (ECCC). ■ The IDF curves require a minimum of 10 years worth of data as recommended by Environment Canada.

Details	Climate Atlas of Canada	Canada Climate Change Data Portal (CCDP)	IDF_CC Tool 3.5
Description Cont'd			■ Users can also create and share their own rain station information. ■ The tool allows users to select multiple RCPs and applies the results from 24 GCMs and 9 downscaled GCMs (developed by PCIC from CMIP5) that simulate various climate conditions to local rainfall data. ■ Additional guidance for updating IDF curves for climate change, with special considerations for sub-daily durations can be found in the CSA (2019) guidance document.
Variables	25 variables available including: ■ Max temperature (°C) ■ Min temperature (°C) ■ Total precipitation (mm/day) ■ Cooling degree days ■ Corn heat units ■ Freeze-thaw cycles	■ Mean temperature (°C) ■ Max temperate (°C) ■ Min temperature (°C) ■ Precipitation (mm/day)	IDF Curves
Geographic Area	Canada	Canada	Canada
Time Period	Baseline Period: 1976-2005 Future Period: ■ 2021-2050 ■ 2051-2080 Note: 2095 was used as a cut off since some models did not have data beyond this date	Baseline Period: 1986-2005 Future Period: ■ 2020-2039 ■ 2040-2069 ■ 2070-2099	1950-2100
Temporal Resolution	Annual	Monthly, Seasonal, Annual	N/A
Spatial Resolution	1:250,000 and 1:50,000	50 km resolution	10 km (300 arc-seconds)
Emission Scenarios	RCP4.5 and 8.5	RCP4.5 and 8.5	RCP2.6, 4.5, 8.5

Details	Climate Atlas of Canada	Canada Climate Change Data Portal (CCDP)	IDF_CC Tool 3.5
Data Format	Interactive Map Data available for download (CSV)	Interactive Map Data available for download (CSV)	Text file
Developed by	■ Prairie Climate Centre ■ Social Sciences and Humanities Research Council of Canada ■ Government of Manitoba ■ ECCC 2018	University of Regina 2019	■ Western University ■ Institute for Catastrophic Low Reduction
Link	*https://climateatlas.ca/*	*http://canadaccdp.ca/*	*https://www.idf-cc-uwo.ca/*

Table 8: Canadian Future Climate Change Data Sources – Provincial

Details	Ontario Climate Data Portal (OCDP)	Ontario Climate Change Data Portal (Ontario CCDP)	The BC Climate Explorer
Description	■ Provides access to climate data over the Province of Ontario. ■ Based on a large ensemble of climate projections from GCMs, as well as dynamically (RCMs) and statistically downscaled outputs (total of 209 ensemble members). ■ Downscaled by York University, PCIC, NA-CORDEX, University of Toronto, and University of Regina. ■ The range of percentiles included for each variable are 5% to 95%.	■ Data derived from dynamically downscaled climate projections over Ontario using the regional climate models RegCM and PRECIS. ■ RegCM was developed by the National Center for Atmospheric Research (NCAR). ■ PRECIS was developed at the Met Office Hadley Centre. ■ Both RCMs were driven by the GCM Hadley Global Environment Model 2 Earth System (HadGEM2-ES).	■ Climate data used were downloaded from ClimateBC that uses a set of PRISM maps. ■ Ensemble of global climate models, ClimateBC provides downscaled time series for model runs of 6 GCMs.

Details	Ontario Climate Data Portal (OCDP)	Ontario Climate Change Data Portal (Ontario CCDP)	The BC Climate Explorer
Variables	■ Mean temperature (°C) ■ Max temperature (°C) ■ Min temperature (°C) ■ Precipitation (mm/day) 27 Climate Extreme Indices (defined by the Expert Team on Climate Change Detection and Indices, ETCCDI) and 11 others	■ Mean temperature (°C) ■ Mean air temperature at 2 m (°C) ■ Max air temperature at 2 m (°C) ■ Min air temperature at 2 m (°C) ■ Precipitation (mm/day) ■ Specific humidity at 2 m (10-3) ■ Surface air pressure (hPa) ■ Wind speed at 10 m (m/s) ■ Total cloud fraction (unit: 1) ■ Surface net downward shortwave flux (w/m^2) ■ Surface net upward longwave flux (w/m^2) ■ IDF curves	Provides a list of variables available including: ■ Mean annual temperature (°C) ■ Annual precipitation (mm) ■ Growing season (mm)
Geographic Area	Ontario	Ontario	British Columbia
Time Period	Reference Period: 1986-2005 Future Period: ■ 2050s (2040-2069) ■ 2080s (2070-2099)	Baseline Period: 1986-2005 Future Period: ■ 2020-2039 ■ 2040-2069 ■ 2070-2099	Climate Normals available for 1971-2000 Time Series available from 1900-2100
Temporal Resolution	Daily, Monthly, Seasonal, Annual	Hourly, Daily, Monthly, Seasonal, Annual	Monthly, Seasonal, Annual, Climate Normals
Spatial Resolution	10 km resolution	25 km resolution	60 km resolution
Emission Scenarios	RCP2.6, 6.0, 4.5, 8.5	AR4: A1B AR5: RCP4.5 and 8.5	RCP2.6, 4.5, 8.5
Format	CSV	Interactive Map Data available for download (CSV)	Interactive Map
Developed by	York University	Institute for Energy, Environment and Sustainable Communities, University of Regina 2019	Colin Mahony and Joey Lee Data from ClimateBC Through Biogeoclimatic Ecosystem Classification (BEC) and Ecology Research program of the British Columbia Ministry of Forests, Lands and Natural Resource Operations
Link	*http://lamps.math.yorku.ca/OntarioClimate/index_v18.htm*	*http://www.ontarioccdp.ca/*	*http://www.bc-climate-explorer.org/*

Table 9: Canadian Future Climate Change Data Sources – Provincial Continued

Details	Scenarios Network for Alaska and Arctic Planning (SNAP)	New Brunswick's Future Climate Projections	Newfoundland and Labrador Climate Data and Tools
Description	■ Provides downscaled, gridded historical and projected climate data for sub-Arctic and Arctic regions of Alaska and Canada. ■ SNAP uses downscaled projected data from one of 5 top ranked GCMs or calculated as a five-model average. ■ For statistical and dynamical downscaling, the CMIP3 and CMIP5 model outputs are used. ■ SNAP uses gridded Parameter Elevation Regression on Independent Slopes Model (PRISM) temperature and precipitation data. ■ The University of East Anglia's Climatic Research Unit (CRY) provides the monthly climate data, and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis for model selection methods and ERA-Interim for dynamical downscaling work.	■ Provides climate datasets for the Province of New Brunswick based on the CMIP5 model outputs. ■ The range of percentiles included for each variable are the mean, 10th, 25th, 75th, and 90th percentile for each climate station.	Provides climate datasets for the Province of Newfoundland and Labrador.
Variables	More than 50 variables are available for dynamical downscaling including: ■ Temperature ■ Rainfall ■ Snowfall ■ Wind speed and direction ■ Heat fluxes (radiative and turbulent) ■ Snow depth Statistical downscaling: ■ Mean annual temperature ■ Precipitation Interactive maps include: ■ Temperature (°F and °C) ■ Precipitation (in and mm) ■ Extreme weather (temperature and wind) ■ Sea ice coverage ■ Wind ■ Wildfire	Includes 29 climate indices including: ■ Mean temperature (°C) ■ Total precipitation (mm) ■ Annual cooling degree days ■ Annual freeze-thaw days	■ Daily mean temperature (°C) ■ Daily mean precipitation (mm) ■ Cooling degree days ■ Number of frost-free days

Details	Scenarios Network for Alaska and Arctic Planning (SNAP)	New Brunswick's Future Climate Projections	Newfoundland and Labrador Climate Data and Tools
Geographic Area	Sub-Arctic and Arctic regions of Alaska and Canada	New Brunswick	Newfoundland and Labrador
Time Period	Reference Period: ■ 1961-1990 ■ 2019-2019 Future Period: ■ 2040-2049 ■ 2060-2069 ■ 2090-2099	Baseline Period: 1980-2010 Future Period: ■ 2020 ■ 2050 ■ 2080	Future Period: ■ 2041-2070 ■ 2071-2100
Temporal Resolution	Daily, Monthly, Seasonal, Decadal Averages	Seasonal, Annual	Seasonal
Spatial Resolution	■ 2 km resolution (Statistical downscaling, PRISM) ■ ~80 km resolution (Reanalysis)	Provided for 64 weather stations in New Brunswick	Provided for 29 locations in the province
Emission Scenarios	AR4: B1, A1B, A2 AR5: RCP4.5, 6.0, 8.5	AR4: A2 and B1 AR5: RCP4.5 and 8.5	Not Specified
Format	Interactive map available Data available for download (GeoTiff format)	Interactive map available (for AR4 data) Data available for download (CSV)	CSV
Developed by	International Arctic Research Center at the University of Alaska Fairbanks	Government of New Brunswick	Government of Newfoundland and Labrador
Link	*https://www.snap.uaf.edu/*	*http://acasav2.azurewebsites.net/*	*https://www.turnbackthetide.ca/tools-and-resources/climate-data-and-tools.shtml*

Table 10: Global/International Climate Change Data Sources

Details	North America Coordinated Regional Climate Downscaling Experiment (NA-CORDEX)	The Mining Climate Assessment (MiCA) Tool	Climate Change Knowledge Portal (CCKP)
Description	■ Provides regional climate downscaled projections worldwide using dynamical methods for North America. ■ Considers 6 GCMs from CMIP5. ■ CORDEX is available for other regions with varying variables, time periods, temporal resolution, and spatial resolution.	■ Provides climate projection data from an ensemble of 15 GCMs associated with CMIP5 and provides information directly relevant to the metals and mining industry. ■ The future climate projections are calculated as change values from the equivalent baseline (as opposed to absolute future values). ■ For each variable, additional statistical analysis of median, quartiles, and standard deviation results for each month, across all climate models is calculated. ■ A membership is required to access this tool.	■ Provides climate-related information, tools and data. ■ Historical and future climate data are provided, with future climate projections from CMIP3. ■ Consists of 16 models. ■ Provides statistically downscaled data from 9 GCMs from CMIP3, using BCSD. ■ Model ensembles depict ensemble median, highest 10th percentile, and lowest 90th percentile.
Variables	30 variables listed for the NA-CORDEX, the following listed as essential: ■ Near-surface air temperature (K) ■ Daily max near-surface air temperature (K) ■ Daily min near-surface air temperature (K) ■ Precipitation (kg m-2 s-1)	■ Daily max temperature (°C) ■ Daily min temperature (°C) ■ Rainfall (mm) ■ Wind speed (note: only available for 8 GCMs)	Historical: ■ Temperature ■ Rainfall Future: ■ Near surface monthly mean air temperature ■ Near surface mean daily min temperature ■ Near surface mean daily max temperature ■ Monthly precipitation sums
Geographic Area	■ NA-CORDEX (North American CORDEX program) ■ Other regional CORDEX data banks include South Asia, East Asia and the Mediterranean	Global	Global

Details	North America Coordinated Regional Climate Downscaling Experiment (NA-CORDEX)	The Mining Climate Assessment (MiCA) Tool	Climate Change Knowledge Portal (CCKP)
Time Period	Reference Period: 1950-2005 Future Period: 2006-2100	Baseline Period: 1986-2005 Future Period: 20-year period centred on 2035, spanning between 2025 to 2045	Reference Period: 1901-2015 Future Period: ■ 2020-2039 ■ 2040-2059 ■ 2060-2079 ■ 2080-2099 Downscaled Period: ■ 1961-1999 ■ 2046-2065 ■ 2081-2100
Temporal Resolution	Hourly, Daily, Monthly, Seasonal	Monthly, Annual	Monthly, Annual
Spatial Resolution	12.5-25 km resolution 25 km or 50 km for North America	100 km resolution	50 km resolution
Emission Scenarios	RCP4.5 and 8.5	RCP8.5	RCP2.6, 4.5, 6.0, 8.5
Format	netCDF	CSV	CSV
Developed by	World Climate Research Program (WCRP) 2019	The International Council on Mining and Metals 2018	The World Bank Group
Link	CORDEX: *http://www.cordex.org/* NA-CORDEX: *https://na-cordex.org/*	*https://icmm-mica-live.azurewebsites.net/Home/About*	*https://climateknowledgeportal.worldbank.org/*

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Appendix D: Case Studies

Sudbury Integrated Nickel Operations – Glencore

Background

Glencore is a global mining and metallurgical company that operates over 150 mining and metallurgical sites around the world. Their Sudbury Integrated Nickel Operations (Sudbury INO) employs approximately 1,200 permanent employees at its four locations with an annual production capacity of over 70,000 tonnes of nickel matte. The Strathcona Mill receives ore from the two Sudbury mines and produces a stream of nickel-copper concentrate that is smelted by Sudbury smelter and shipped to other Glencore locations. The facility started the development of a Climate Change Plan in response to corporate Sustainable Development Goals in 2009.

Climate Risk Assessment

Using the site's risk register Glencore held an initial internal risk assessment working session with key members of operations, engineering, capital, and other departments. The session raised awareness of the impacts of extreme weather and climate change on operations, specifically infrastructure, and solicited measures to cope with the impacts. The risk assessment revealed several areas that are affected by extreme weather and climate change for the Sudbury INO including:

- Water management issues including flooding
- Employee Safety (especially in extreme events)
- Transportation of product during variable weather
- Curtailment of production due to weather factors
- Energy security
- Infrastructure safety and operation
- Non-compliance with regulations due to changing climate trends (for example: higher levels of wastewater discharge due to climate change can put companies at risk of not meeting their discharge targets, per provincial or federal regulation)

Workshop attendees were at first unclear on how climate change would affect their operations. The workshop was useful in overcoming this hesitancy by addressing the questions in the context of "how does weather affect your work?" and talking about "weather variability". Climate change was initially viewed by some as an event/occurrence that would occur in the distant future, well beyond the end of the mine life in Sudbury. However, the acceptance that climate change has already impacted operations was realized through both data on historic trends and the sharing of impacts that have been experienced at the Sudbury operations by the workshop participants. Putting climate change into the existing risk vocabulary allowed for project team member buy-in and advanced the discussion.

The climate change risk assessment working session also allowed Glencore to identify and prioritize site-specific climate challenges. Risk results were easily incorporated into the company's existing risk registry. Driven by internal champions, the climate risk assessment process also helped to engage management teams and technical experts in the process of identifying climate risks and proposing adaptive measures to reduce risks.

Since the initial workshop, annual working group meetings have been held with a focused project team to review updated climate data and in-depth engineering assessments to gather more information. The follow-up studies focused on:

- Management of onsite water (including water balance studies)
- Impacts of changing meteorology on operations (curtailment and heat stress)
- Snow moisture content, and rain on snow run-off assessments.

This work was written up as a Case Study with the support of Golder Associates and Natural Resources Canada available at: *http://climateontario.ca/doc/casestudies/mining_case_study_glencore.pdf*

Decision Analysis

One of the key recommendations from the working group meetings was to develop a decision-making process to help prioritize the potential adaptation measures identified in the risk assessment, and understand when the measures should be implemented, e.g., now, or at some point in the future. In response to this recommendation a Cost-Benefit Analysis (CBA) approach was used. A CBA approach was used to analyze and prioritize adaptation options in consideration of the costs of implementing each adaptation option. The CBA also assisted with capital planning regarding water management risk.

The first stage of the assessment was to develop a baseline scenario that looked at:

- Infrastructure and operational information that would be included in the assessment.
- Vulnerabilities that could affect the water management system and result in the priority risks.
- Analysis of the consequences of each vulnerability.
- The estimated cost related to each vulnerability.

This information was confirmed in a focused workshop that included environment and safety specialists, engineers, and members of the finance team. Both direct costs for reclamation from a vulnerability, and indirect costs such as reputational impact were estimated. Using this information, the project team first developed estimates of risk for each vulnerability under current climate conditions and normal operating conditions, and then combined these estimates with cost information to establish an economic baseline. The following five vulnerabilities were identified:

- Dealing with high water level conditions in spring
- Dealing with low water level conditions (in Summer/Fall)
- Dealing with a significant rainfall event
- Dealing with localized flooding in low-risk areas
- Dealing with localized flooding in high-risk areas

Historical climate trends and site-specific hydrologic models that considered infrastructure and operational thresholds, were used to characterize the likelihood of an environmental vulnerability occurring under current climate conditions. To evaluate how the economic risk changes under future climate conditions, changes to the likelihood of each vulnerability was estimated. A Climate Generator developed for the GoldSIM site water balance for the smelter area was used to process data from the Future Climate Dataset. At this time data from the IPCC Fourth Assessment Report (AR4) was used to obtain monthly predictions for future temperature and precipitation. Using the stochastic feature of the generator a range of future climate conditions were characterized for each of the five vulnerabilities.

Adaptation options were identified for each risk that would decrease the consequence of the event or reduce the probability of occurrence of the vulnerability. Two time periods were assessed, a period of 10 years and a period of 39 years and the costs verses benefits were assessed assuming the adaptation option was implemented at the start of each period versus a business-as-usual approach. A stochastic assessment of each time period was assessed under the current and future climate conditions. The outputs of the assessment were presented in a tabular format to visually represent when estimated financial costs of the business-as-usual scenario, also referred to as coping costs, were outweighed by the reduction in costs from implementing the adaptation measures. This summary was used to show when investing in adaption at this time will likely result in reduced costs in the future. Glencore continues to assess the adaptation options and will include an updated assessment as part of the capital planning process for recommended adaptation options.

An overview of the development approach and results of the assessment were written up as a Case Study with the support of Golder Associates and Natural Resources Canada available at:
http://climateontario.ca/doc/casestudies/SINO_CaseStudy-FINAL.pdf

Adaptive Management

The annual working group meetings referenced above include Sudbury INO's risk champion and EMS (ISO) champion, who track the recommendations and action items from the working group meetings as part of the operations Risk Register and Environmental Monitoring System continuous improvement process. This process is documented in an overall plan for the operations.

One area of continuous improvement has been the update of the climate data that supports the risk assessment. As noted above the assessment started when the current available data was based on the AR4 results, Glencore has since updated the data to incorporate the AR5 results available from climatedata.ca and has completed detailed climate statistical analysis to develop projections for changes in rainfall intensity, temperature and precipitation extremes and Probable Maximum Precipitation. These updated projections are being incorporated in the process as triggers for adaptation planning.

Additional Resources

Link to Glencore Sustainability Climate Change responsibilities, objectives, and initiatives:
https://www.glencore.com/sustainability/climate-change

Agnico Eagle Mines – Using Climate Datasets to Reduce Risks and Inform Cover Design

Background

Agnico Eagle Mines Ltd. (Agnico Eagle) is a Canadian gold mining company that has produced precious metals since 1957. Its mines are located in Canada, Finland and Mexico, with exploration activities in each of these countries as well as in the United States and Sweden. The company has significant operations in the Kivalliq District of Nunavut Territory, these include:

- Meadowbank open-pit gold mine, approximately 300 km west of Hudson Bay and 110 km by road north of Baker Lake
- Meliadine mine, approximately 25 km north of Rankin Inlet and 290 km southeast of Meadowbank
- Whale Tail (Amaruq mine) 50 km northwest from the Meadowbank mill that will extend the operations of the Meadowbank facilities after production at the site is completed

These projects developed since 2006 now represent Agnico Eagle's largest gold deposits in terms of mineral resources.

Climate Vulnerability and Risk Assessment

An Environmental and Social Impact Assessment (ESIA) is required by the Nunavut Impact Review Board (NIRB) prior to NIRB issuing a Project Certificate that will allow a project to proceed to the approvals process and operation. The NIRB requires the project to take into consideration the effects of a changing climate.

The initial guidance was to follow an approach outlined by the Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (FPTCCCEA) in 2003. The FPTCCCEA guidance document asks the question, "How will potential changes in climate affect the infrastructure associated with the

Project". The answer to this question was used as a basis for a series of climate change assessments to address climate vulnerabilities for all stages of the projects for consideration by NIRB. However, the level of detail in the submissions to NIRB, their subsequent Information Requests and the available future climate projections used to support the assessment evolved from the time that the original Meadowbank project was initiated in 2005, to the more recent Whale Tail approval in in 2020.

Consistent to each climate change assessment a detailed characterization of the historical climate in the region, and more locally at the project site was completed. For future climate the approach was to take existing, publicly available climate change projections, analyze them using developed tools and protocols, and then provide the projections in a format that is meaningful to both a non-climate scientist and other disciplines completing sections of the ESIA who are relying on the data for technical applications. This information was then provided in a format that supports further analysis and provide a basis for identification of potential climate-infrastructure interactions and design of adaptation measures to reduce project risks. For all projects, publicly available information from Environment Canada and Climate Change (ECCC) was used to analyze current climate trends and future climate projections. The following table summarizes the future climate data used in the assessments, and the key vulnerabilities identified.

Project	Data Source	Climate Variables Considered	Key Vulnerabilities
Meadowbank	Global projections from the Third Assessment Report (2001) from the IPCC	Projections of annual mean temperature for the arctic	Changing temperatures impacting major infrastructure due to permafrost degradation
Meliadine Mine	Global projections from the Fourth Assessment Report (2007) from the IPCC provided by ECCC	Projections of monthly mean temperature and total precipitation extracted from the grid cell closest to the mine site for an ensemble of climate models (all available models, all emission scenarios)	Identifying potential impacts of climate change on the project through climate-infrastructure interactions following required guidance for completing an ESIA
Whale Tail (Amaruq Mine)	Global projections from the Fifth Assessment Report (2013) from the IPCC provided by ECCC	Projections of monthly mean temperature and total precipitation extracted from the grid cell closest to the mine site for an ensemble of climate models (all available models, mid-range and high emission scenario)	Changing temperatures impacting freeze-back thickness in waste rock storage piles forming the cover system of acid generating rock.

IPPC = Intergovernmental Panel on Climate Change

ECCC = Environment and Climate Change Canada

Decision-Making Incorporating Climate Change

The level of detail required to document the adaptation options also became more detailed with each subsequent assessment. NIRB, their technical reviewers and stakeholders focused on the potential adaptation options and how they related to the project design. This case study will focus on the most recent assessment for the Whale Tail project.

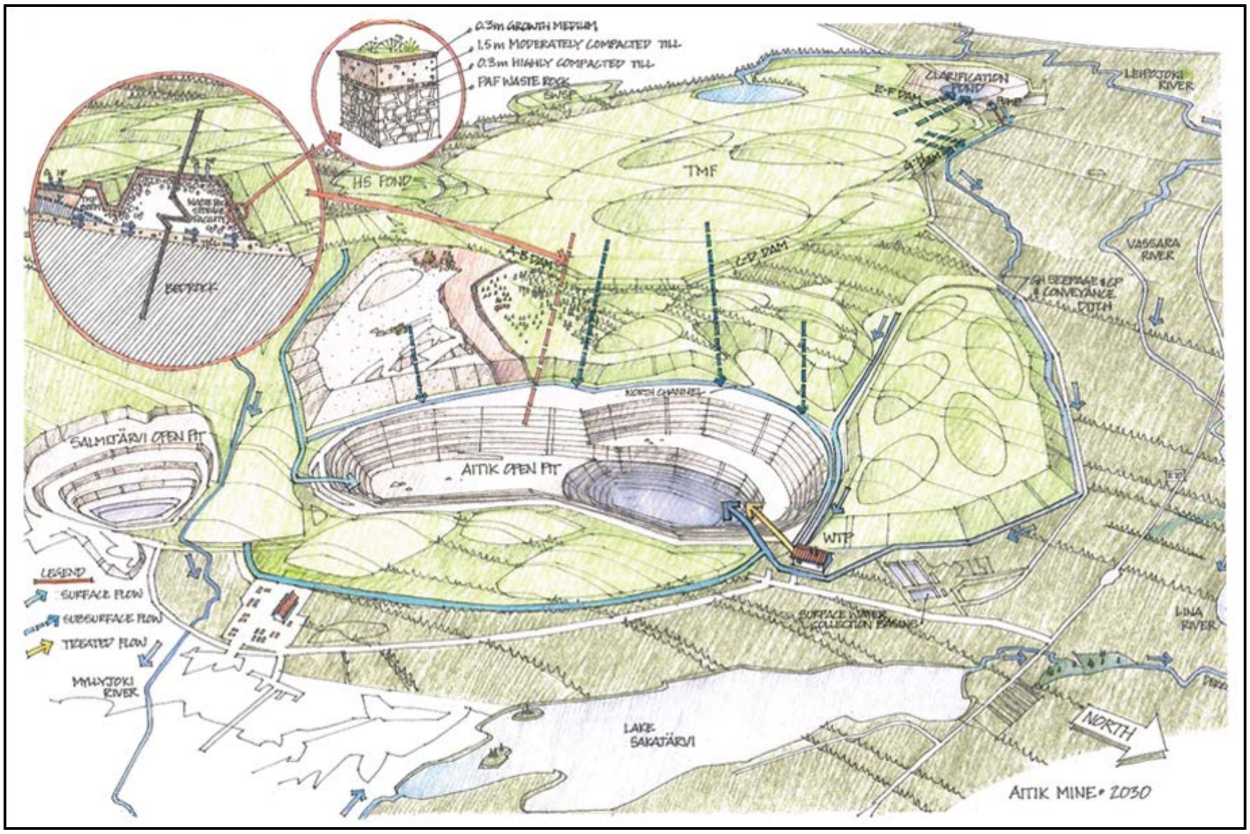
As noted above a key vulnerability identified as part of the Whale Tail project was the vulnerability of the Waste Rock Storage Facility (WRSF) to increasing temperatures. The Whale Tail WRSF will be covered with non-potentially acid generating (NPAG) and non-metal leaching waste (NML) rock to promote freezing as a control strategy against acid generation and migration of contaminants from the potentially acid generating (PAG) and metal leaching waste (ML) rock contained in the WRSF. The design of the WRSF will maintain the existing water quality in the area and prevent contamination of ground and surface water. If freeze-back does not occur due to rising temperatures, then sulphide mineral oxidation or acid generating reactions can occur and affect water quality. Demonstrating that climate change will not impact the protection of ground and surface water was a key consideration during the review of the application by the NIRB, this was also highlighted in technical comments from federal government including the department of Crown-Indigenous Relations and Northern Affairs Canada and Natural Resources Canada. To address this vulnerability, an assessment of the minimum cover thickness was conduced.

The first step of the cover assessment was to develop a climate dataset that incorporated information from the ongoing Meadowbank Mine Waste Rock Storage Facility monitoring program and provide a summary of the future projected monthly mean temperature for the Whale Tail location. This climate data was then used as inputs in a thermal modelling study to evaluate freeze-back times and estimate changes in the depth of the active layer. The outputs were used to assess the thickness of NPAG/NML rock that would be required to maintain the PAG/ML materials frozen below the active layer under the selected climate change conditions. The outputs of this assessment were then incorporated into the final design drawings and received NIRB approval.

Adaptation Pathways

In addition to the thermal modelling assessment the NIRB approval required that ground temperature probes, known as thermistors, be installed at different locations to monitor the ground temperatures throughout the mine operations. In addition to confirming the inputs into the thermal modelling assessment and monitor freeze back over time to refine the model, data on variables that could not be included in the initial assessment were also required. This included the addition of thermistors at locations that could provide data on the potential active layer variations due to sun and dominant wind exposure, as well as effects of slope vs. plateau and an on-site meteorological station. The observed meteorological conditions, the recorded thermal data and updated future climate projections will be used to determine the climate related parameters for the final cover design and will be communicated to the public through the Nunavut Water Board during the final closure application.

Aitik Mine, Base Case Design and Closure Plan



Conceptual Drawing – Aitik Mine, Year 2030

Background

Boliden AB (Boliden) is a Swedish mining and smelting company focusing on production of copper, zinc, lead, gold, and silver resources at properties in Sweden, Finland, Norway and Ireland. Since 1968, the company has extracted copper, gold, and silver at Aitik Mine in Northern Sweden using open pit mining methods. The Aitik Mine is undergoing an expansion that will increase mining and processing capacity from 36 to 45 million tonnes per year (Mt/y). In support of the proposed expansion, Boliden assessed potential liabilities and developed a Base Case Design and Plan for Closure. Closure footprints and site infrastructure at the property include: a tailings storage facility (TMF) and clarification pond, potentially acid forming (PAF) and non-acid generating waste rock storage facilities (WRSFs), the Aitik and Salmijärvii open pits, clean and contact water diversion ditches, storage ponds and a water treatment plant.

Climate Vulnerability and Risk Assessment

Technical assessments scoped under the Aitik Mine Closure Plan include:

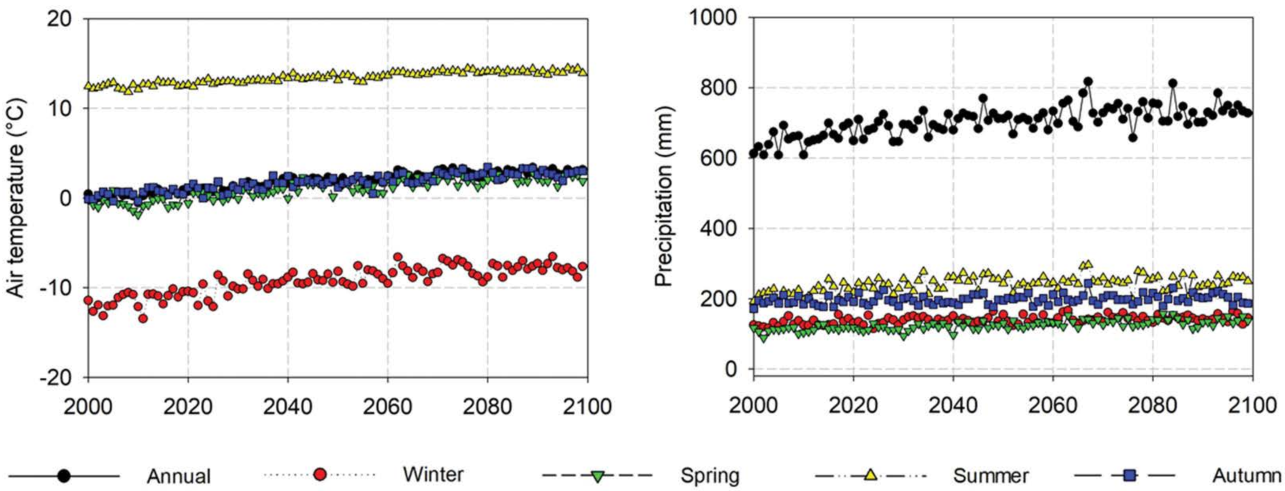
- A hydrogeochemical evaluation of waste rock storage facilities (WRSFs)
- A hydrogeochemical assessment of the tailings storage facility (TSF)
- A pit lake water balance and water quality modelling study
- Water quality/aquatic resources effects assessments for receiving water courses below the mine site.

All of these evaluations require climate data to drive hydrological and/or geochemical models, and therefore, in order to ensure consistency and coordination within and between the various modelling teams, a long-term, daily- climate dataset was first developed that accounted for predictions of climate change for the local region.

Two long-term (multi-decadal) climate stations operated by the SMHI (Swedish Meteorological and Hydrological Institute) are located within 15 km of the Aitik Mine. Inspection of past and recent data indicates the project site experiences a continental subarctic or boreal climate, characterized by a cold winter and short, cool summer. Mean annual temperature at the property is 0.1°C with typical July and January temperatures being 14.7°C and -13.1°C, respectively. Mean annual precipitation for the project site is estimated to be 600 mm. On average, 50% of annual precipitation reports as rainfall in June, July, August, and September.

Climate change scenario data confirms the following for the project site (Figure 1): 1) future climate conditions will be warmer and wetter at the mine site, with mean annual temperature (T) increases of ~3 °C and precipitation (P) increase of 25% expected by 2100; 2) T increases are anticipated for all seasons, but greatest changes are expected for winter months (December, January, February); 3) increases in P are likely to be greatest for summer (June, July, August) and autumn (September, October, November) as compared to winter (December, January, February) and spring (March, April, May).

Figure 1. Example Climate Change Scenario Data for Aitik Mine (RCP4.5, 50 km gridded). The data shown are derived by averaging monthly climate data outputs from nine GCMs.



For the most recent iteration of the Aitik Mine Closure Plan, a daily climate record was assembled for a 200-year closure timeline (i.e., 2025 to 2225). The generation of the climate database entailed the compilation of site-specific and regional climate data to characterize existing mine conditions and utilization of daily climate change scenario data (SMHI 2014) to represent future conditions. Technical details of the climate database and its assembly are summarized in Fraser *et al.* (2011, 2017).

RCP4.5 was ultimately selected as a basis for the Closure Plan, with the main rationale for the scenario selection being to maintain consistency with prior closure work and regulatory submissions that were informed by the now superseded A1B storyline. Of note, the Closure Plan timeline extends to 2225, but climate change scenario data are only available to 2100. Accordingly, a 35-year portion of the climate database, the period spanning 2065-2099, was looped several times to represent the 2100-2225 time period.

Decision-Making Incorporating Climate Change

A warmer and wetter future climate regime at Aitik Mine is expected to translate to changes such as: 1) progressive and earlier onset of freshet, later occurrence of autumn freeze-up, and a longer ice-free season; 2) shifts with time and changes in the proportions of rain versus snowfall realized on an annual basis; 3) increases in winter baseflow conditions and likelihood of mid-winter or shoulder season melt events; and 4) progressive increases in receiving environment flow with time. Additionally, these climate-sensitive water balance changes are in turn expected to impart changes on the hydrogeochemical behaviour of mine facilities (i.e., TMF, WRSFs and the open pits), as well as downstream receiving streams.

A key component of the Closure Plan is the use of low-permeability till cover systems to minimize gas exchange and sulphide mineral oxidation in potentially-acid generation WRSFs. In this regard, wetter conditions and changes to the cover water balance will afford a more effective barrier to gas exchange. For the Aitik open pit, modelling confirms that warmer and wetter conditions result in a shorter fill time for the Aitik open pit (by ~15 years) owing mainly to increased amounts of runoff generated by contributing areas adjacent to the facility. Pit lake modelling also shows that a decrease in pit filling duration will: 1) decrease the subaerial exposure time and loadings from pit walls; and 2) affect the timing and duration of various water management and mitigation measures invoked under the Closure Plan, including active water treatment.

Adaptation Pathways

A comprehensive Failure Mode and Effect Analysis (FMEA) of the Base Case Design and Closure Plan was conducted to identify potential failure modes, effects/pathways, and mitigation measures to reduce the likelihood and/or consequences for a given failure pathway. As part of this evaluation, risks and opportunities related to future climate change were assessed. Overall, the FMEA approach was proven to be effective as the process informs on managing risks, such as climate change, in parallel to competing components of the total risk profile, while also providing opportunities to optimize and refine base case design through additional study and iteration.

Additional Resources

Fraser C.J.D., Martin A.J., Pedersen T.F. (2011) Climate-scaled water balance development for mine closure planning. Proceedings of the 6th International Conference on Mine Closure. September 18-21, 2011, Lake Louise, Canada: 357-366.

Fraser C, Martin A, Mueller S and Scott J (2017) Incorporating Climate Change Scenarios into Mine Design and Permitting Studies. 13th Annual Mine Water Association Congress, Rauha-Lappeenranta, Finland, June 25-30, 2017.

SMHI (2014). CORDEX scenarios for Europe from the Rossby Centre regional climate model RCA4. Report Meteorology and Climatology No. 116, Swedish Meteorological and Hydrological Institute, SE 601 76 Norrköping, Sweden. 84 pp.

Giant Mine Rehabilitation – Climate Change Triggers

Photo: Giant Mine: The Freeze Optimization Study
(Source: Mackenzie Valley Environmental Impact Review Board 2013)

Background

Giant Mine is a historic gold mine that is undergoing remediation and closure. The mine is located 5 km north of the city centre in Yellowknife, Northwest Territories. The Giant Mine Remediation Project, co-managed by the Governments of Canada and the Northwest Territories (GNWT), includes components such as physical and chemical stability, surface remediation, water treatment, and monitoring of the mine site for human health and safety and the surrounding communities for environmental effects. A key objective, and focus of the remediation project, is the long-term containment and management of historical mining waste at the site.

Climate Vulnerability and Risk Assessment

One challenge associated with the Giant Mine Remediation Project is the prevalence of arsenic trioxide (arsenic) containing material that was produced as a result of processing gold ore. Approximately, 237,000 tonnes of arsenic containing material is currently stored on-site in underground chambers (GNWT & INAC 2010). As the mine is located close to a populous area and on the shores Lake Athabasca, a long-term management plan for the arsenic containing material must be developed. After extensive research and consultation, it was decided that the most effective way to manage the arsenic containing material would be to allow the chambers and stopes to freeze via the "frozen block method." The design criterion is as follows:

> The criterion for the initial containment is to lower the ground temperature to -10°C over a distance of at least 10 m around and below all mining workings where arsenic trioxide dust is present. The 10 m zone at -10°C will be extended to the top of the chamber and stope following the saturation of the arsenic trioxide… (T)he criterion would then be shifted to the second stage, where it will target specifically the arsenic trioxide dust. The proposed criterion in that stage is to maintain the temperature within the dust to -5°C or colder. (Mackenzie Valley Environmental Impact Review Board 2013)

Given the location of the mine and the current knowledge of climate changing in the North, a key challenge in the management of the containment facility will be to maintain the temperature so that the block remains frozen. Climate change projections were developed to provide information on the region's increasing future average temperature (GNWT 2019), and ultimately to inform the design and management of the containment facility. Specifically, the knowledge will be used to support the detail design of the freeze block so that the appropriate equipment and monitoring procedures can be implemented, and adjustments can be made to maintain the frozen block over time. In essence, the climate projections will inform triggers and thresholds, steps in the adaptive management plan and specifically decision points when management actions must be taken.

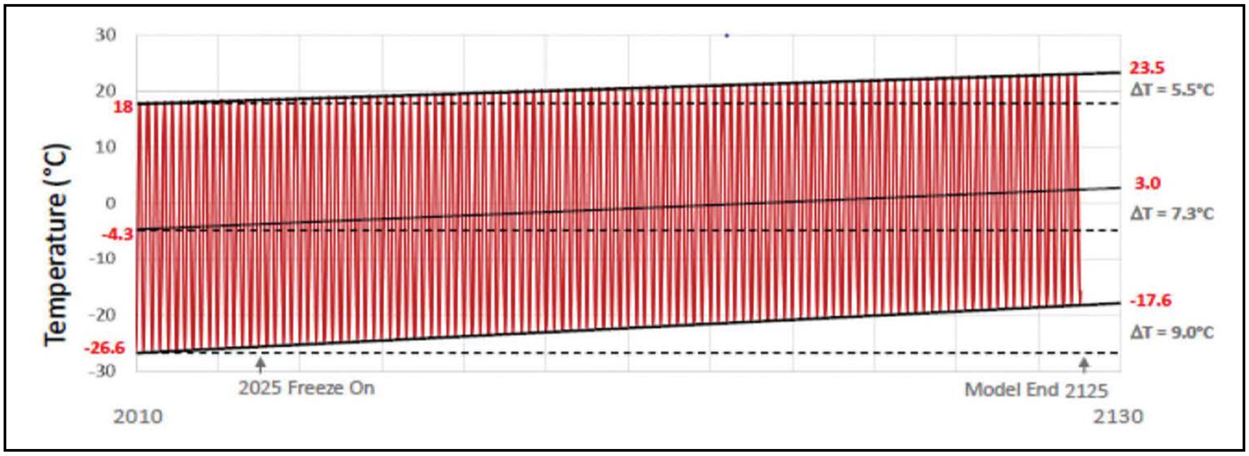
A description of the current climate over the past 48 years (1971–2018) was provided based on observed measurements from the Yellowknife A climate station, approximately 5 kilometres away from Giant Mine. The climate station observations were infilled with reanalysis data (based on satellite and ground observations) to achieve the data completeness required for the analysis and adjusted to account for siting and wind undercatch impacts on observations. These observations were used as a climate baseline which provided context for the current climate and how it is changing.

The future climate was described using the projections from Global Circulation Models (GCMs) included as part of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). There is uncertainty with the projections, however, this uncertainty is reduced by using multiple projections from multiple models and scenarios (multi-model ensemble), as recommended by the IPCC (IPCC 2013). The future projections are provided in terms of percentiles or exceedance probabilities, allowing for different levels of acceptable risk. This assessment is being used by the surface water and mine closure teams to assess the impacts of climate change on their design packages.

Decision-Making Incorporating Climate Change

The above climate assessment updated the original design projections that identified the most economical and best technology for performance. The more recent data confirmed previous climate change projections developed to provide insights on warming trends between the years 2025 through 2130 using Scenario Network for Alaska & Arctic Planning (SNAP) models available from the NICO Mine (GNWT 2019). Using the highest and lowest projections to the year 2130, a greater warming was observed in the winter (+9.0°C) than in the summer (+5.5°C). By incorporating the climate warming model into the strategic design, the performance of the frozen block can be modelled for the same temporal span (100-year projection).

Figure 2: Climate warming Projections Applied Between 2025 and 2125 (GNWT/CIRNAC 2019)



A Freeze Optimization Study (FOS) is being conducted to evaluate and mitigate risks, and to determine the most effective strategy to achieve the frozen block method (GNWT & INAC 2010). The FOS includes the summary of results of the implementation of the freeze block method on one containment chamber, using active and passive (hybrid) thermosyphons. The study presents that the passive thermosyphons showed signed of decreased performance in May (2011), when the air temperature became too warm, therefore these thermosyphons were switched to hybrid mode. Monitoring the passive operations allowed for a further understanding of how the climate can influence what is happening in the ground. The major findings of the study are summarized as follows:

- Ground freezes faster than anticipated, hence, the conceptual design presented is conservative.
- Freezing is fast enough that full passive cooling might be reasonable (assuming today's climate conditions); therefore,
- Active freezing with an energy intensive refrigeration unit may not be required.

An additional environmental assessment was conducted to evaluate the risk of a wet or dry method for the initial freeze. The assessment concluded that the dry method worked just as well as the wet at reaching the target freeze temperature (GNWT 2018), therefore the additional risk associated with the wet method can be avoided. The dry freeze is also easier to reverse than the wet freeze, therefore on the occasion a better technology for arsenic remediation is available, the freeze block can be easily reversed. The design projections were also used in the adaptation design, particularly in relation to the thermal syphons. Maintenance of the thermosyphons in perpetuity is expected as their efficiency reduces with time (e.g., loss of charge gas pressure). Without maintenance, the frozen block could warm and thaw if the cooling system is not monitored and maintained.

Adaptation Pathways

As previously mentioned, the success of the freeze block method is reliant on the surrounding climate of the mine. The initial freeze to achieve the frozen shell around the arsenic chambers, is the most critical. If periods where the ambient air temperature is consistently above the freeze pipe temperature, then an active heat removal method would need to be incorporated to achieve the desired permafrost. In addition, if future technologies provide a better option for managing the arsenic dust, the flexibility to adapt to other options should be available. The objective of the FOS is to provide background information for successful implementation of the freeze block and allow the Governments to identify areas that require potential adaptation measures and monitoring to make sure the freeze block is successful at containing the arsenic storage chamber. The FOS also provides an opportunity to identify any uncertainties and constraints, as well as develop contingencies based on unforeseen events that may arise.

During the initial and operational freeze stages of the freeze program, a monitoring procedure will be implemented to observe whether the freeze block is meeting the design criteria temperature. A contingency plan has also been developed to account for uncertainties that may arise during the freeze operation. This includes investigating causes, replacing defective components if necessary, extent the duration of the active/hybrid freeze, and/or installing more hybrid thermosyphons and freeze piping (GNWT & INAC 2010).

The following monitoring procedures are planned to examine the performance of the freeze block. The primary instruments will include the following:

- Ground temperature monitoring system (GNWT & INAC 2010)
- Devices for measuring ground movement in areas where stability is a concern (GNWT & INAC 2010)
- Monitoring of fluid temperatures, flow rates, and pressures in hybrid system piping (GNWT & INAC 2010)
- Checks of gas pressure and monitoring of heat loss from the radiators of passive thermosyphons (GNWT & INAC 2010)

If monitoring during the long-term passive freeze maintenance phase indicates unexpected warming in or around the frozen blocks, the available contingency measures will include:

- Investigate causes.
- Replace defective components.
- Install additional thermosyphons to counteract surface warming (GNWT & INAC 2010).

A critical threshold is set when the ground temperature 10 m from the chamber reaches -2°C, while a trigger is set for when this temperature reaches 0°C (GNWT 2019). A worst-case scenario was assessed for defective thermosyphons that go unnoticed and unmitigated. Once the frozen block is achieved and the 10 m zone is at -10 °C, it was predicted to take 10 years before the outer limits of dust thawed to -5 °C, therefore providing sufficient time to react and adapt before the threshold is exceeded (GNWT & INAC 2010).

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Suncor's Millennium Mine – Adaptive Management in Tailings Management

Background

Suncor Energy Ltd. (Suncor) is a Canadian energy company that specializes in the production of synthetic crude from oil sands in Alberta. It has been operating commercial oil sands in Alberta since 1967 and currently operates several oil sands mines in northern Alberta.

In 2016 Suncor submitted a Fluid Tailings Management Plan (TMP) for Base Plant Application and concurrently submitted the Millennium Operational Amendment (MOA) Application including details with respect to mine and closure plans. The proposed TMP will result in over 70 per cent of its tailings being managed through a new, unproven technology – Passive Aquatic Storage System (PASS) – which uses the addition of chemicals to dewater the tailings and reduce the mobility of contaminants. Water will be placed on top of treated tailings after the end of mine life creating an aquatic closure outcome in DDA3, (also known as water capping). This new PASS in intended to also manage the uncertainties and risks related to a changing climate, specifically uncertainties related to water levels.

The Alberta Energy Regulator (AER) applies a risk-based approach to regulating industry, meaning higher-risk activities receive greater attention. Given the nature and scale of fluid tailings generated by oil sands mine operations and the ongoing research and development of tailings treatment technology, fluid tailings management is considered one of Alberta's higher-risk industrial activities. To manage and decrease liability and environmental risk resulting from the accumulation of fluid tailings the Government of Alberta issued the Tailings Management Framework for the Mineable Athabasca Oil Sands (TMF) in 2015. As part of the implementation of the TMF, the AER released Directive 085: Fluid Tailings Management for Oil Sands Mining Projects, which sets out the new requirements for fluid tailings management plans. For the Suncor TMP Application, this means that the AER needed to have the appropriate assurances that Suncor's fluid tailings will meet TMF outcomes on time and that the approvals' conditions are clear and enforceable under Directive 085.

Climate Vulnerability and Risk Assessment

Suncor provided information regarding the rationale, data, and assumptions related to the risks and uncertainties for the PASS and DDA3. This information included mitigation measures, contingency plans, and milestones for reclamation, including information relevant to climate change. Suncor found that climate change could pose a risk to the Upper Pit Lake (UPL) and that current predictions show a warmer and wetter future. If the opposite were true, the viability of the UPL could be compromised if it was not appropriately managed. Suncor provided information to the AER on the levers at its disposal to manage this risk, including:

- The ability to change the outlet elevation of the lake.
- Changing this littoral zone elevation.
- Adapting our approach over the next 26 years as we gain a better understanding of long-term hydrology and climate conditions.
- Cap the treated fluid tailings in some form once completed, ensuring that even in a scenario where the lake periodically dries up, there is some barrier between the treated fluid tailings and the environment.
- Modify the closure landscape and drainage to supply more/less water to the UPL.

Decision-Making Incorporating Climate Change

Under Directive 085 the AER include conditions in approvals that are outcomes based, manage risk and uncertainties, support flexibility and adaptive management, and are enforceable. At a minimum, approval conditions will address:

- Project-specific thresholds for both new and legacy fluid tailings
- Tailings deposit performance and milestones
- Mitigation measures and contingency plans
- Monitoring and reporting requirements

Therefore, the AER included research, monitoring, evaluation and reporting requirements to Suncor's TMP approval to provide the information needed to verify the technology and deposit performance assumptions, including requirements related to climate change monitoring and evaluation.

Adaption Pathways

Climate change scenarios could have a number of potential impacts to closure and closure outcomes. To manage uncertainties in future climate conditions Suncor modelled a range of expected conditions based on the best information available. In general, these predictions indicate that the temperature will increase and so will the amount of precipitation (warmer and wetter). However, it remains possible that there could be less precipitation in the future. The modeling conducted to date shows that under expected climate change conditions the UPL will be viable. Should there be less water than expected Suncor has the ability to effectively modify DDA3 to still achieve a viable lake.

As background, the closure drainage plan achieves a 9:1 ratio of watershed to lake area and fall within the acceptable range for a viable pit lake. In the absence of a hydrological model, using watershed to lake surface area ratio as a general approach for lake size viability is considered acceptable. However, Suncor has a hydrological model (which is the basis for the MOA application) which it used to determine if there is sufficient watershed to support the size of the proposed lake given a range of climate change scenarios. The approach of using a hydrological model is preferred to a generic watershed/lake ratio and provides better information to help manage uncertainties.

Suncor has two key levers available to manage the impacts of climate change scenarios on the viability of the planned pit lake for DDA3:

1. Suncor has the ability to change the outlet elevation of lake. The tailings plan for DDA3 has a conservative settlement/consolidation assumption for the treated tailings during operations from 2018 to 2043; therefore, it is expected that more settlement will occur in DDA3 over the operational period. This means that the final elevation of treated tailings in DDA3 could be lower. This provides Suncor with flexibility to move the outlet elevation higher or lower depending on the case.
2. Suncor has the ability to change the littoral zone elevation. The littoral zone for the UPL is created by excavating in Sand Dump 9. This means the littoral zone elevation can be changed to accommodate a smaller or larger lake size.

The time from now until the planned completion of DDA3 (2043) provides additional opportunities for risk assessment and mitigations. This time will allow for additional ongoing work in tailings treatment technology, model improvements and climate change understanding. In conclusion, these potential mitigations provide Suncor with the flexibility to adapt the closure plan as we improve our understanding of long-term hydrology over the next 20+ years.

Additional Resources

Alberta Energy Regulator Decision 20171025A: Suncor Energy Inc., Applications for Millennium Operational Amendment and Base Plant Tailings Management Plan. *https://www.aer.ca/documents/decisions/2017/20171025A.pdf*

Alberta Energy Regulator. 2017. Directive 085: Fluid Tailings Management for Oil Sands Mining Projects. *https://www.aer.ca/documents/directives/Directive085.pdf*

Government of Alberta. 2015. Lower Athabasca Region: Tailings Management Framework for the Mineable Athabasca Oil Sands (TMF). *https://open.alberta.ca/publications/9781460121740*

Appendix E: Climate Change Vulnerabilities – Mine Life Cycle

As discussed in Section 4, climate change risks vary based on which life cycle phase a mine is in. Climate risks are dependent on the mine's location (e.g., coastal vs. inland, arid vs. temperate), geographic extent, and physical infrastructure components.

Following the first two steps of the risk assessment process (Step 1: Risk Assessment Definition and Step 2: Information Gathering), Step 3: Vulnerability Identification requires the identification of a site's climate change vulnerabilities and risks. Climate risks are site specific; therefore, the list of potential risks developed under Step 3 is expected to vary between sites. The following is a non-exhaustive list of potential climate vulnerabilities that may pose risks to a mine and have been included in the table below. The vulnerabilities are divided by the climate change variables that will influence the projected change in each vulnerability (i.e., increasing temperatures will cause an increase in permafrost degradation).

- Increasing Temperatures
- Extreme Heat
- Drought
- Changing Winds
- Changing Precipitation
- High Intensity Precipitation Events
- Changes in Snowfall
- Higher Intensity Snowmelt
- Glacial Retreat
- Changing Growing Seasons
- Permafrost Degradation
- Sea Level Rise
- Storms (e.g., ice, lightening, wind, hurricanes)
- Coastal Erosion
- Flooding
- Wildfire
- Humidity/ Evapotranspiration
- Biological Communities

Table E-1 provides examples of potential risks that may occur as a result of climate change vulnerabilities during each phase of the mine life cycle.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Increasing Temperatures	■ May impact the location of the mine site, as water availability may be impacted by hazards driven by increasing temperatures (i.e., extreme heat and drought). ■ During the planning phase the Owner should consider potential impacts of projected future changes in temperature, based on risks identified in other phases.	■ May impact the underlying climatic assumptions used in the design of mine infrastructure, including ventiliation system networks. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Higher temperatures can reduce the capacity of thermal generators and transmission lines. ■ Higher temperatures may mean a longer ice-free season in the Arctic, shortening supply seasons for mines that rely on winter ice roads for supply. ■ Seasonal variability in energy use requirements may be observed (e.g. less heating energy required in the winter but more requried for cooling in the summer. ■ May lead to more operational shutdowns due to higher underground temperatures ■ May impact ventilation energy costs (likely to increase as a result). ■ May increase dust generation and impact dust mitigation activities. ■ May create unsuitable working conditions for personnel.	■ Changes in temperature may affect successful growth of flora/ vegetation species for closure activities. ■ Higher temperatures may damage infrastructure remaining on sites after closure. ■ May increase dust generation and impact dust mitigation activities.
Extreme Heat	■ During the planning phase the Owner should consider potential impacts of projected future extreme heat, based on risks identified in other phases. ■ May need to plan for transmission loss of electricity from generation source to site.	■ May impact the design of infrastructure and mine if not designed to withstand extreme heat. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Extreme heat may have impacts on water availability (see Drought section) and may cause site water imbalance. Reduction in water resources needed for cooling water may impact operations or lead to turbine inefficiencies. For example, water is needed for mining and metal operations for cooling, crushing, grinding, milling ore, slurry transport, tailings storage and dust mitigation activities.	■ Extreme heat may damage infrastructure remaining on sites after closure. ■ Extreme heat may result in vegetation die-back. ■ Extreme heat may impact the effectiveness of closure strategies for mine waste (e.g., performance of cover systems).

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Extreme Heat Cont'd			■ Water availability is critical for hydroelectric power production. ■ Higher temperatures may cause health and safety concerns for employees. Heat waves may cause chronic heat fatigue and heat stress can exacerbate cardiovascular and respora-tory disease. ■ Reduced efficiency of infrastructure under high temperatures. ■ May increase dust genera-tion and impact dust miti-gation activities. ■ May create unsuitable working conditions for personnel.	■ May increase dust generation and impact dust mitigation activ-ities.
Drought	■ May impact the water ballance. Specifically, if a mine requires a certain amount of water to maintain operations, the mine plan may need to consider future changes in temperature and precipitation, as drought events are projected to increase in frequency.	■ May impact the design of infrastructure and mine if not designed to withstand periods with little to no water. ■ May impact the underlying climatic assump-tions used in the development of the closure plan.	■ May impact water availabil-ity and site water balance. ■ May increase the cost of water supply. ■ May impact groundwater supply as recharge rates decrease. ■ Increased drought condi-tions may increase the likelihood of fires in the surrounding areas (see Wildfire section). ■ May increase dust genera-tion and impact dust miti-gation activities. ■ May impact the effec-tiveness of mine waste management strategies (e.g., need to maintain saturated conditions to prevent acidic drainage), which may in turn impact water management and treatment needs.	■ Long-term effective-ness of covers for tailings and waste rock may decrease in areas under water stress. ■ Increased frequency of drought events may lead to vegetation die-back. ■ May impact the effec-tiveness of mine waste management strategies (e.g., need to maintain saturated conditions to prevent acidic drain-age), which may in turn impact water manage-ment and treatment needs. ■ May impact water stress on local commu-nities.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Changing Winds	■ During the planning phase the Owner should consider potential impacts of projected future changes in wind, based on risks identified in other phases.	■ The design of infrastructure may need to consider an increase in winds that may lead to damage. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Increasing winds may damage on-site infrastructure (e.g., extreme winds may damage building roofs or other infrastructure). ■ Increasing winds may contribute to dust generation and associated dust management requirements. ■ Energy transmission pathways may be disrupted.	■ Potential for long-term infrastructure to be damaged as a result of increased winds. ■ Increasing winds may elevate risks of dust migration off-site.
Changing Precipitation	■ During the planning phase the Owner should consider the potential impacts of projected future changes in preciptation, based on risks identified in other phases.	■ May impact the underlying climatic assumptions used in the design of mine infrastructure. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Changes in seasonal precipitation will affect hydrology and soil moisture which may impact the ability of waste containment structures to prevent contamination of surrounding land and groundwater. ■ Increased precipitation and high temperatures may accelerate the weathering of acid-generating waste rock and cause earlier onset and increased volume of acidic drainage. ■ Changes to the flow of water through mine sites as a result of changes in precipitation may cause failures with slope stability, potentially damaging containment structures. ■ Changes to the flow of water through the site may impact water management including site drainage.	■ Changes in seasonal precipitation may affect rehabilitation of flora/ vegetation for closed sites. ■ Changes in seasonal precipitation will affect hydrology and soil moisture which may impact the ability of waste containment structures to prevent contamination of surrounding land and groundwater. ■ Increased precipitation and high temperatures may accelerate the weathering of acid-generating waste rock and causing earlier onset and increased volume of acid mine drainage. ■ Changes to the flow of water through mine sites as a result of changes in precipitation may cause failures with slope stability, potentially damaging containment structures.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Changing Precipitation Cont'd				■ Changes to the flow of water through the site may impact water management including site drainage, and may impact surrounding Communities of Interest.
High Intensity Precipitation Events (Mason *et al.* 2013)	■ During the planning phase the Owner should consider potential impacts of projected future high intensity precipitation events, based on risks identified in other phases.	■ May consider construction and design standards that consider climate change. ■ The design of future dams, tailings facilities, water management systems (e.g., culverts, pipelines and treatment plants) should consider future climate change, specifically for changes in precipitation and extreme events that may be outside the historical design values. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ High intensity precipitation events may damage infrastructure, disrupt operations and supply chains. ■ May result in localized or downstream flooding (see Flooding section). ■ Heavy precipitation events may impact water management stuctures that have not been designed to withstand these events. ■ Intense precipitation events may cause road washouts, limiting access to mine sites and interrupting supplies and services. ■ Increased precipitation may cause wall movement and pit wall failure related to the dewatering of the pit. ■ May increase energy requirements for increased dewatering and water movement (pumping) activities. ■ Heavy precipitation events may impact tailings facilities that have not been designed to withstand these events. ■ May have impacts on site drainage. ■ May cause contamination downstream from releases of untreated water.	■ Final water management structures may overflow and downstream structures may be overwhelmed as a result of extreme rain events. ■ May result in localized or downstream flooding (see Flooding section). ■ Intense precipitation events may cause road washouts, limiting access to mine sites and interrupting supplies and services. ■ Heavy precipitation events may impact tailings facilities that have not been designed to withstand these events. ■ May have impacts on site drainage. ■ May cause contamination downstream from releases of untreated water.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Changes in Snowfall	▪ During the planning phase the Owner should consider potential impacts of projected future changes in snowfall, based on risks identified in other phases. ▪ Refer to applicable building codes for structures (e.g., snow load on buildings).	▪ The design of infrastructure (e.g., building roofs) may be damaged or may fail if snowloads increase and exceed design thresholds. ▪ May impact the underlying climatic assumptions used in the development of the closure plan.	▪ Changes to the flow of water through mine sites as a result of changes in snowfall may damage water management infrastructure and containment structures. ▪ Increased equipment and energy requirements for increased snow removal activities. ▪ Decreases in snowfall may lead to increased erosion of tailings facilities. ▪ Changes in snowfall patterns and increased frequency of winter thaws and "rain-on-snow" events by increase the risk of avalanches and may also increase the risk associated with high flows and excessive run-off during the winter.	▪ Potential for long-term infrastructure to be damaged as a result of increased snowloads. ▪ Changes to the flow of water through mine sites as a result of changes in snowfall may damage water management infrastructure and containment structures. ▪ Decreases in snowfall may lead to increased erosion of tailings facilities. ▪ Changes in snowfall patterns and increased frequency of winter thaws and "rain-on-snow" events by increase the risk of avalanches and may also increase the risk associated with high flows and excessive run-off during the winter. ▪ May also impair supply chains / cause supply chain interruptions.
Higher Intensity Snowmelt	▪ During the planning phase the Owner should consider potential impacts of projected future changes in snowmelt, based on risks identified in other phases.	▪ The design of infrastructure may need to consider an increase in snowmelt that may lead to damage. ▪ May impact the underlying climatic assumptions used in the development of the closure plan.	▪ May provide an opportunity to draw from local lakes as increased snowmelt will feed into these systems. ▪ May have implications for site water balance and water availability in the summer if the water management systems are overwhealmed during freshet and the Owner is not able to store sufficient water for use in the summer	▪ Greater intensity freshet may overwhelm water management on site and disrupt operations (see high intensity precipitation section). ▪ May have implications for site water balance. ▪ May result in localized or downstream flooding (see Flooding section).

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Higher Intensity Snowmelt Cont'd			■ High intensity snowmelt events may damage infrastructure, disrupt operations and supply chains. ■ May result in localized or downstream flooding (see Flooding section).	
Glacial Retreat	■ During the planning phase the Owner should consider potential impacts of projected future glacial retreat, based on risks identified in other phases.	■ The design of infrastructure may need to consider an increase or decrease in water availability and changes in water balance if downstream from a retreating glacier. ■ May impact the underlying climatic assumptions used in the development of the closure plan. ■ May impact future mine design and potential ore reserves and mine life if glacial retreat exposes areas not previously accessible to mining.	■ Retreating glaciers may impact water management on site. ■ May impact future mine design and potential ore reserves and mine life if glacial retreat exposes areas not previously accessible to mining.	■ May impact water management on site for remaining infrastructure.
Changing Growing Seasons	■ During the planning phase the Owner should consider potential impacts of projected future changes in growing season on progressive reclamation and closure plan development and implementation.	■ Owner should consider potential future changes in growing season and impacts on progressive reclamation and closure plan development and implementation.	■ Changes in the length of growing season may impact the progressive rehabilitation and dust emissions.	■ The length of growing season may impact the species selection and rehabilitation of flora/vegetation which may impact Communites of Interest.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Changing Growing Seasons Cont'd	■ Owner should consider the potential impacts to surrounding Communities of Interest that may rely on local agriculture.	■ Owner should consider impacts to surrounding Communities of Interest that may put stress on local agriculture.		
Permafrost Degradation	■ During the planning phase the Owner should consider potential impacts of projected future permafrost degradation, based on risks identified in other phases.	■ Thawing permafrost could impact the design of mining infrastructure whose structural integrity may rely on it. ■ May impact the climatic assumptions used in closure design.	■ Degrading permafrost can cause land instability and may impact infrastructure that relies on the permafrost including tailings facilities, water management infrastructure, mine access roads, haul roads, building and plant foundations, and other subsurface structures. ■ May impact the effectiveness of mine waste management strategies (e.g., need to maintain frozen conditions to prevent acidic drainage), which may in turn impact water management and treatment needs.	■ Potential for long-term infrastructure, particularly tailings facilities and water management infrastructure, to be damaged as a result of permafrost degradation. ■ May impact the effectiveness of mine waste management strategies (e.g., need to maintain frozen conditions to prevent acidic drainage), which may in turn impact water management and treatment needs.
Sea Level Rise	■ During the planning phase the Owner should consider potential impacts of projected future sea level rise, based on risks identified in other phases. ■ Should be considered in the selection of locations for key mine site components for sites close to sea level.	■ May impact the design of infrastructure when considering sea level rise. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Salt water intrusion into freshwater supplies may impact water quality. ■ May affect port availability and may disrupt operations due to delays or interruptions of transport. ■ May impact on-land infrastructure built close to sea level.	■ May damage infrastructure if close to sea level.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Storm Events (lightning, ice, snow) (Mason *et al.* 2013)	■ During the planning phase the Owner should consider potential impacts of projected future changes in storm events, based on risks identified in other phases.	■ May impact the design of infrastructure when considering higher frequency of lightning and increases in snow and ice loads. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Can damage infrastructure, disrupt operations and supply chains. ■ Increasing storm events may damage on-site infrastructure due to ice or lightning strikes. ■ Transmission pathways for energy may be disrupted as a result of ice accretion or damaged power lines. ■ Storm events may impact the ability for employees to do business, due to unsafe work environments or blocked site access. ■ May increase dust generation and impact dust mitigation activities. ■ May increase stressors for local Communities of Interest.	■ Potential for long-term infrastructure to be damaged as a result of storm events post closure. ■ May increase dust generation and impact dust mitigation activities.
Coastal Erosion	■ During the planning phase the Owner should consider potential impacts of projected future coastal erosion, based on risks identified in other phases. ■ Should be considered in the selection of locations for key mine site components for sites close to sea level.	■ The design of infrastructure may need to consider and account for unstable slopes as a result of erosion. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Climate change exacerbates coastal erosion due to higher water levels and wave action which may cause unstable slopes or can lead to salt water intrusion. ■ Coastal erosion may damage transportation and other infrastructure located in the near-shore environment.	■ May impact long-term infrastructure if the stability of slopes are compromised.
Flooding	■ During the planning phase the Owner should consider potential impacts of projected future increases in flooding, based on risks identified in other phases.	■ Stormwater infrastructure may be impacted if not designed to meet projected increases in extreme precipitation events.	■ Energy transmission pathways may be disrupted. ■ May damage infrastructure on and off-site, including water management infrastructure and transportation infrastructure.	■ May damage infrastructure on and off-site, including water management infrastructure and transportation infrastructure. ■ May cause contamination downstream from releases of untreated water.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Flooding Cont'd	■ Should be considered in the selection of locations for key mine site components to prevent impacts from future flooding and how this will impact neighbouring communities.	■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Flooding may impact the ability for employees to do business due to unsafe work environments or blocked site access. ■ May cause contamination downstream from releases of untreated water.	
Wildfires	■ During the planning phase the Owner should consider potential impacts of projected increases in wildfires, based on risks identified in other phases. ■ Should be considered in the selection of locations for key mine site components to prevent or limit impacts from wildfires.	■ May impact the design of infrastructure to consider using fire resistant materials on site if wildfire is a potential vulnerability.	■ Lightning may increase the likelihood of fires in the surrounding areas. ■ Damage due to wildfire may include the disruption of energy transmission, limit access to operations, and can cause damage to communications and power infrastructure. ■ Wildfires may impact the ability for employees to do business due to unsafe work environments or blocked site access. ■ Wildfires may lead to temporary suspensions of operations which may have implications for water management (e.g., power for pumps and other equipment) and may result in disruptions to maintenance and surveillance activities (e.g., distruption of tailings facility surveillance).	■ May cause damage to long-term infrastructure post closure. ■ Wildfires may lead to temporary interruptions of power supply, site access, and other resources which may have implications for water management (e.g., power for pumps and other equipment) and may result in disruptions to maintenance and surveillance activities (e.g., distruption of tailings facility surveillance).
Humidity/ Evapotranspiration	■ During the planning phase the Owner should consider potential impacts of projected changes in humidity/ evapotranspiration, based on risks identified in other phases.	■ May impact the design of infrastructure to consider changes in humidty and evapotranspiration. ■ May impact the underlying climatic assumptions used in the development of the closure plan.	■ Changes in humidity may impact water balance during operations ■ May impact the effectiveness of closure strategies for mine waste (e.g., performance of cover systems). ■ May impact dust generation and impact dust mitigation activities. ■ May impact progressive reclamation activities, especially revegetation. ■ May affect working conditions at site.	■ May impact the effectiveness of closure strategies for mine waste (e.g., performance of cover systems). ■ May impact dust generation and impact dust mitigation activities ■ May impact revegetation.

Climate Variables and Events	Planning	Design	Construction and Operations	Closure and Post-closure
Biological Communities	■ During the planning phase the Owner should consider potential impacts of projected changes in biological communities, based on risks identified in other phases. ■ May cause a shift or loss of available habitat for species, change community composition, shift the assimilative capacity of receiving environment, and drive effluent criteria. ■ Change in biological communities may affect livelihood of local communities	■ May cause a shift or loss of available habitat for species, change community composition, shift the assimilative capacity of receiving environment, and drive effluent criteria.	■ May cause a shift or loss of available habitat for species, change community composition, shift the assimilative capacity of receiving environment, and drive change in legal requirements.	■ May cause a shift or loss of available habitat for species, change community composition, shift the assimilative capacity of receiving environment, and drive change in legal requirements.

Note: The information presented in this table has been inferred based off several sources including but not limited to;

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