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NUNAVUT REGIONAL ADAPTATION COLLABORATIVE (RAC)

Vulnerability Assessment of the Mining Sector to Climate Change Task 1 Report

REPORT

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Executive Summary

Introduction

With federal funding support through Natural Resources Canada's Regional Adaptation Collaborative Program, IMG-Golder Corp. (IMG-Golder) was contracted by the Government of Nunavut (GN) to collect and compile information to assess the vulnerability of Nunavut's mining industry to climate change and describe potential adaptation strategies.

Studies carried out across the Arctic provide evidence that the climate is changing. In Nunavut, climate change adaptation scenarios for various communities have been developed and adaptive planning has been started, but no detailed studies have been completed that assess potential adaptation measures that could be employed to deal with the impacts that a changing climate can have on the mining sector and mining-related large infrastructure in the territory

Some studies have been carried out to assess the vulnerability of the Canadian mining sector to the effects that climate change may have on mine development in southern areas; however, the issues faced in the south are not necessarily similar to the issues faced in the Arctic. Given the mining sector's importance in Nunavut's regional economy and its contribution to the territory's development through job creation, supporting economic activities and promoting educational opportunities, the need for an assessment of northern mining issues is warranted. The vulnerability of these activities to climate change has regional significance in Nunavut because of the dominant economic role the mining activities play on a regional basis (*e.g.,* creation of training and employment opportunities and infrastructure development).

The mining sector has demonstrated that infrastructure can be designed and operated in the North; however, it is particularly vulnerable to climate variability and change because its associated development activities are dependent on the natural environment.

Therefore, a changing climate will present challenges for the planning, design and operation of mining infrastructure in Nunavut which will in turn affect economic and community development. In order to determine how a changing climate can cause impacts to mining infrastructure, and identify adaptation measures that can be employed to limit those impacts, the following steps were undertaken in the development of this *Regional Adaptation Collaborative (RAC): Vulnerability Assessment of the Mining Sector to Climate Change Task 1 Report*:

- describe climate trends and climate forecast models for three areas in Nunavut;
- describe existing Traditional Knowledge on climate change in Nunavut;
- identify existing and proposed mining infrastructure components in Nunavut;
- provide an overview to known impacts of development on permafrost;
- identify vulnerabilities of mining infrastructure components to climate change;

- identify existing knowledge on adaptation measures to be implemented in the planning of mining infrastructure (see below); and
- organize, facilitate and summarize a Vulnerability Assessment Workshop to identify priorities for the RAC.

Climate Trends / Forecasts

There is general agreement that in the future the average, annual temperature will increase across Nunavut. There is less agreement regarding the amount or type of precipitation; however more intense storms are expected. The actual effects of a changing climate are influenced by the significant geographic variability of Nunavut. Historical observations demonstrated local differences in climate change trends. An assessment of three locations in Nunavut (Iqaluit, Baker Lake, and Cambridge Bay) showed a general warming trend, slight decrease in precipitation, and significant increase in freeze-thaw cycles for all three communities since 1971. The type and quantity of precipitation is expected to change in the future, and an increase in extreme weather events (e.g., hot and cold extremes, more frequent /intense precipitation events) is anticipated.

Existing and Proposed Mining Infrastructure Components in Nunavut

There is currently only one operating mine in Nunavut (Agnico-Eagle Mines Ltd.'s Meadowbank Mine, located 75 kilometers (km) north of Baker Lake). However, there are several large mining projects planned, e.g., the Mary River project on Baffin Island (by Baffinland Ironmines Corp.) and the Kiggavik Project, 75 km of Baker Lake (by AREVA Resources Canada Inc.). Existing and proposed mines require access through roads, airstrips, railways and ports. If the companies process the excavated rock at the site, they also need Tailings Management Facilities or TMFs. Mining related infrastructure components and their respective vulnerabilities to climate change discussed in this report are: roads, airstrips, railways, ports and TMFs.

Development Practices on Permafrost

The common issue in the development of mining and large infrastructure is the potential degradation of permafrost due to climate change. The presence of permafrost is accounted for when designing and constructing infrastructure. Improper construction activities in permafrost zones can result in changes to ground surface properties which can in turn impact the ground thermal regime and cause permafrost degradation. Proper design can help to overcome these issues; however, changes to the climate in the future may lead to permafrost degradation. The local conditions and the design practices have an equal or greater effect on the adaptive capacity of the infrastructure.

Examples of currently implemented development practices in Arctic climates that can increase the adaptive capacity of infrastructure are:

- avoid building on thaw-sensitive (e.g., ice-rich) soils;
- leave vegetation in place to regulate ground temperatures (e.g., construct embankments on top of it);
- minimize disturbances to permafrost by maintaining existing ground thermal regime;

- accept changes to ground thermal regime or modify permafrost before construction;
- use conventional foundation construction methods if soils are thaw stable (*i.e.,* contain a minimum of ice);
- design infrastructure to limit heat penetration into the ground (increase embankment thickness, use insulation, use sunsheds / snowsheds, use reflective surfaces);
- design infrastructure to enhance winter heat extraction (use air ducts, thermosyphons, air convention embankment, or heat drains);
- design infrastructure using reinforcement techniques to minimize impact on permafrost (use geotextile / geogrids, use berms and gentle slopes, use pre-thawing strategies, excavate / replace ice-rich soil, remove snow); and
- incorporate site-specific climate data / climate change predictions into infrastructure planning.

Vulnerabilities of Mining Infrastructure to Climate Change and Adaptation Measures

The following table summarizes the information on identified vulnerabilities of infrastructure components to climate change and currently applied Adaptation Measures described in this report.

Environmental Issues Resulting from Climate Change	Impacts to Infrastructure	Currently Implemented Adaptation Measures
Road, Airstrips and Railways		
Increased permafrost degradation Increased frost heave and freeze-thaw settlement in permafrost Changing transitions between continuous / extensive / sporadic / isolated permafrost zones	Threats to structural integrity of pile foundations, dikes, bridges. Increased embankment failures. Damage to infrastructure overlying frost heave / freeze-thaw areas. Increased maintenance / repair costs for infrastructure (e.g., repairing road surfaces).	Conduct geotechnical investigations to qualitatively assess permafrost sensitivity (e.g., assess soil type / ground ice content); avoid constructing infrastructure on areas of high sensitivity to temperature changes. Plan to flatten sideslopes and widen shoulders to reduce snow accumulation on embankments. Plan to use porous rock in construction to reduce risks on ponding on sideslopes. Plan construction methods that minimize disturbances to vegetation. Leave vegetation in place and construct on top. Plan to avoid cuts into the ground, instead increase amount of fill material for embankments.
Changes to precipitation patterns and extreme weather events	Increased embankment damage / washouts, increased soil / rock slides; therefore increased road / airstrip / railway closures. Decreased weather predictability decreasing dust suppressant applications.	Assess local topography / seasonal drainage patterns and design infrastructure to incorporate culverts / bridges to accommodate extreme weather events (e.g., freshet flows). Incorporate site-specific climate data / climate change predictions into road / airstrip / railway planning. Use permafrost adaptation measures as described above.
Increased air temperatures	Decreases in the length of operational times for winter roads / ice bridges. Increases in freezing rain / frosting affecting airstrip safety. Increase of permafrost temperature, shift in permafrost distribution, and thickening of active layer.	Plan for transportation systems using ice roads to be shifted to open-water, air-based or land-based systems. Develop operational plans to lengthen operating seasons for winter roads / ice bridges (e.g., spray with water to thicken ice, plow snow off to enhance freezing, restrict hauling to hours of darkness at end of transportation season). Use permafrost adaptation measures as described above.

Environmental Issues Resulting from Climate Change	Impacts to Infrastructure	Currently Implemented Adaptation Measures
Ports		
■ Increased coastal permafrost / subsea permafrost degradation	■ Increased erosion rates along coastlines (see below, coastal erosion). ■ Increased maintenance / replacement costs for port / coastal infrastructure (e.g., breakwaters). ■ Decreased infrastructure stability / integrity (e.g., reduced foundation strength of docks / pilings).	■ Plan for coastal erosion protection strategies (see below, coastal erosion) ■ Rebuild dock infrastructure / incorporate new designs to account for melting permafrost conditions.
■ Sea level rise	■ Reduced top clearance between ships and overhead structures (e.g., bridges, loading facilities). ■ Increased elevation at which wave forces attack a structure, potentially increasing the vulnerability of the structure. ■ Increased exposure of dock decks. ■ Increased corrosion rate and the degradation over time of materials that were specifically designed for a particular range of sea level conditions. ■ More wave action / sea spray on navigational installations. ■ Increases in absolute low sea levels allowing greater under-keel clearance for vessels, (e.g., reducing the need for dredging in low sedimentation areas).	■ Conduct site-specific assessments to determine if sea level rise at a certain port is actually an issue (*i.e.,* determine if it is counteracted by the rising of coastal areas due to melting glaciers). ■ Account for sea level rise of at least 5 mm/yr during planning and design phases for ports. ■ Plan to have the lowest point in buildings in coastal areas at higher elevations. ■ Implement coastal erosion measures as described below.

Environmental Issues Resulting from Climate Change	Impacts to Infrastructure	Currently Implemented Adaptation Measures
■ Increased storm events and wave energy	■ Degradation of port infrastructure. ■ Loss of viable industrial land around ports. ■ Reduced regularity of port services (e.g., availability / use). ■ Permanent loss of offshore and onshore sediments (e.g., sand). ■ Retreat of coastal landscapes (*i.e.,* erosion; see below - coastal erosion). ■ Disruptions to shipping routes during increased wind events (e.g., increased danger manoeuvring through narrow channels).	■ Construct sea defence structures such as breakwaters and jetties to limit damage from storm events / wave action. ■ Plan for increased heights for sea defence structures (e.g., breakwaters, jetties). ■ Incorporate site-specific climate data / climate change predictions into port planning.
■ Sea ice diminishment	■ Increased expanses and duration of open water. ■ Increased opportunities for marine shipping; therefore increased demands on Northern port infrastructure / services. ■ Larger expanses and longer durations of open water, increases impacts of storm events (see above, storm events).	■ Plan for ports to accommodate increases in traffic due to a longer open-water shipping season. ■ Conduct ice studies to determine appropriate dock locations and shipping lanes. ■ Design docks to withstand the impacts of sea ice (e.g., use systems to break up or minimize the development of sea ice around docks to enable marine shipping in winter). ■ Implement measure as described above for storm events.
■ Ocean current shifts	■ Changes to coastal hydrodynamics (e.g., narrowing or widening of channels, changed dredging requirements, erosion or accretion of beaches, changes to ocean current velocities).	■ Study shifts to currents to plan for infrastructure placement. ■ Minimize littoral drift using breakwaters / jetties.
■ Coastal erosion	■ Altered dredging requirements. ■ Disturbance or possible required removal / reinforcement / reconstruction / moving of onshore port structures. ■ Decreased structural stability / integrity of port infrastructure.	■ Protect coastlines from erosion by using sandbags, sunken vessels, rocks and gravel to reduce the impacts of erosive wave action. ■ Incorporate near-shore protective structures in port design to protect against coastal erosion (e.g., rubble mounds or vertical walls to absorb or reflect wave energy.

Environmental Issues Resulting from Climate Change	Impacts to Infrastructure	Currently Implemented Adaptation Measures
Tailings Management Facilities		
■ Increased permafrost degradation	■ Foundation instability / unstable embankment slope conditions / settlement of structures (see examples below). ■ Settlement of dam foundations; resulting in reduced elevation between normal water levels and the top of a dam (i.e., less freeboard) / reducing impoundment capacity / increasing risk of dam overtopping and dam failure. ■ Thawed soils with lower geotechnical shear strength parameters; potentially resulting in decreased slope stability. ■ Thawing of frozen embankment fill or permafrost foundations; potentially resulting in increased seepage and impacts to downstream water quality. ■ Limited ability to rely on freezing for tailings management strategies. ■ Potential increase in landslides around an impoundment; resulting in increased risk of overtopping of tailings dams.	■ Conduct site-specific risk assessments to determine potential concerns at TMFs and identify adaptation measures. ■ Conduct studies to acquire environmental conditions (e.g., air / ground / permafrost temperatures) for mine site planning. ■ Plan to locate mine infrastructure where permafrost will cause the least risks. ■ Assume that permafrost will thaw and encourage it to thaw / incorporate future surface settlement into structural designs. ■ Incorporate plans to control Acid Rock Drainage (ARD) for permafrost environments (e.g., freeze control, climate control, engineered dry covers, subaqueous disposal, blending, segregation, co-disposal of tailings and waste rock, surface disposal of thickened tailings, collection and treatment of leachates). ■ Monitor ground temperature and water pressure in TMF dams and foundations with thermistors and piezometers. ■ Plan to use thermosyphons to maintain frozen core dams / permafrost foundation conditions.
■ Increased frost action (e.g., thicker active thaw layer resulting from increased air temperatures) and decreased ice	■ Increased freeze-thaw action; resulting in changes to soil stability, reduced hydraulic conductivity of dam materials, and potential dam instability. ■ Increased freeze-thaw action increasing the permeability of soil covers; resulting in increased infiltration into underlying tailings and discharge of contaminated seepage. ■ Thawing of ice entrapped in tailings impoundments; resulting in increased in water to be managed / treated / discharged.	■ Plan to establish vegetation covers to minimize erosion / insulate permafrost. ■ Plan to install thermosyphons to maintain freezing ground temperatures. ■ Reduce ice entrapment in tailings by dewatering tailings prior to deposition and appropriate beach management / operational strategies. ■ Monitor active layer depth with thermistors. ■ Increased importance to monitor water levels in tailings impoundments and discharge from TMFs.

Environmental Issues Resulting from Climate Change	Impacts to Infrastructure	Currently Implemented Adaptation Measures
Changes to precipitation and impoundment water levels	Increased precipitation during increased storm events; potentially resulting in water flow into tailings impoundments exceeding storage capacity and overtopping of dam / erosion of dam surface / release of contaminated water. Increased drought potentially causing reduced efficiency of impoundment water covers. Increased snow pack potentially increasing ground insulation from cold temperatures and reducing the reliability of tailings impoundments relying on permafrost.	Plan water diversion channels / outflow channels / spillways to reduce and manage precipitation / storm water inflows / runoff. Design water covers to ensure that minimum water levels are maintained during droughts. Design TMFs to reduce erosion from precipitation (e.g., use flatter slopes, erosion protection measures such as rip-rap, use vegetation covers, construct diversion channels for inflow / runoff). Increased importance to monitor water levels in tailings impoundments and ground temperature in frozen dams / foundations.
Changes to wind patterns	Increased winds during increased storm events; potentially resulting in increased wind erosion (e.g., of soil). Increased winds causing increases in wave height on tailings impoundments / increased risk of dam overtopping / increased risk of turbulence in tailings water cover potentially causing re-suspension and oxidation of tailings particles.	Conduct site-specific assessments of wind directions and speeds to account for potential wind impacts. Incorporate plans to minimize wind erosion at TMFs (e.g., use gravel / cobbles or vegetation covers to dissipate the wind's energy). Plan to use soil covers over exposed tailings to minimize surface erosion.
Increased extreme weather events	As above for changes to precipitation and wind. Increased damage to vegetation covers that were established to reduce erosion.	Design TMFs to withstand more frequent / intense storm events (e.g., larger spillways that are capable of passing larger storm events). Monitor and incorporate site-specific climate data / climate change predictions into TMF planning and designs.

Vulnerability Assessment Workshop

A Vulnerability Assessment Workshop was held in Iqaluit and involved the participation of 16 representatives from the mining sector, territorial and federal government agencies and other involved organizations. The purpose of the workshop was to engage the stakeholders and obtain necessary feedback to identify the primary areas of concern with regards to climate change and mining infrastructure. Workshop participants assessed TMFs as the most important infrastructure, followed by port infrastructure. These two areas are assessed in more detail in the Task 2 Report.

Plain Language Summary

Past studies have shown that the climate in the Canadian Arctic is changing. This *Regional Adaptation Collaborative (RAC): Vulnerability Assessment of the Mining Sector to Climate Change Task 1 Report* was completed to describe how changes in the climate can affect infrastructure in Nunavut, particularly infrastructure used in the mining sector such as: roads, airstrips, railways, ports and tailings impoundment areas. This infrastructure must meet the demands of an Arctic climate today but must also be able to withstand changes in the future. Actions can be taken now or in the design phase for new infrastructure that will increase the ability to withstand possible changes in climate. These actions, called adaptation measures, can be used to reduce impacts on Nunavut's infrastructure. A review of current northern design practices provided in this report.

There is general agreement that in the future the average annual temperature in Nunavut will increase. There is less agreement regarding the amount or type of precipitation; however more intense storms are expected. The actual effects of a changing climate are expected to be different at different locations in Nunavut. A review of climate trend information for three Nunavut communities (Iqaluit, Baker Lake and Cambridge Bay) since 1971 revealed that air temperature and freeze-thaw events show increasing trends, while precipitation patterns have changed and the amount of precipitation has slightly decreased over the past decades. These trends may become more significant in the future.

There is currently only one operating mine in Nunavut (Agnico-Eagle Mines Ltd.'s Meadowbank Mine, located 75 kilometers (km) north of Baker Lake). However, there are several large mining projects planned, e.g., the Mary River project on Baffin Island (by Baffinland Ironmines Corp.) and the Kiggavik Project, 75 km of Baker Lake (by AREVA Resources Canada Inc.). Existing and proposed mines require access through roads, airstrips, railways and ports. If the companies process the excavated ore at the site, they also need facilities to store the remaining rock products after the processing (tailings) that are generated during the processing. These facilities are called Tailings Management Facilities or TMFs.

In many Arctic regions, the existence of permafrost (persistent subzero temperature for at least two years) is accounted for when designing and constructing infrastructure. However, climate change can cause changes in the environment (particularly, it can increase permafrost temperature and decrease the distribution) and therefore impact infrastructure such as roads, airstrips, railways, ports and TMFs. Local conditions and the design practices influence the way the infrastructure can adapt to the environment.

A brief summary of some of this report's findings on potential climate change impacts on infrastructure, and adaptation measures that can be used to minimize those impacts, include the following:

- **permafrost** – thawing of permafrost increases the active layer (the layer of the ground on top of the permafrost that thaws annually) thickness; adaptation: minimize disturbances to permafrost (e.g., protect it from heat through technical design) or design infrastructure to accommodate changes in permafrost (e.g., settling from a deepening active layer);
- **air temperature** – general warming trends at locations across Nunavut; adaptation: conduct site-specific studies to determine climate trends at proposed mine developments; account for impacts of air

temperature on permafrost in mine design; revise construction, maintenance and use patterns of winter roads and ice bridges;

- **precipitation patterns and extreme weather events** – changes in the type and quantity of precipitation and increases in extreme weather events (e.g., floods, droughts, storms); adaptation: account for changes in the intensity / duration of precipitation events and consequences (e.g., flooding, droughts); incorporate plans to handle changes into infrastructure design (e.g., erosion protection measures on slopes, storm defence structures on coastlines, adequate inflow / outflow channels for runoff in TMFs);
- **sea ice** – a diminishing extent of sea ice coverage and a shorter duration of sea ice cover resulting in an increased open water season; adaptation: plan for ports to handle an increased demand for port infrastructure and services due to increased marine shipping in the North;
- **sea level** – sea level rise (e.g., due to melting of polar ice caps and expansion of ocean water as it warms); impacts are localized due to the land's rising (caused by melting glaciers); in some areas, sea levels may not rise; adaptation: conduct site specific studies to assess local potential for seal level rise; plan port infrastructure to account for potential rises in sea levels (e.g., construct buildings at higher onshore locations; install coastal erosion measures); and
- **coastal erosion** – increased open water season and extreme events can increase wave action and coastal erosion; adaptation: plan to protect port infrastructure from erosion (e.g., protect shorelines from waves, protect coastal permafrost from degrading forces).

A Vulnerability Assessment Workshop was held in Iqaluit and involved the participation of 16 representatives from the mining sector, territorial and federal government agencies and other involved organizations. The purpose of the workshop was to involve stakeholders and get necessary feedback to identify the primary areas of concern with regards to climate change and mining infrastructure. Workshop participants assessed TMFs as the most important infrastructure possibly impacted by a changing climate, followed by port infrastructure. These two areas are assessed in more detail in the Task 2 Report.

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1.0 INTRODUCTION

There is widespread scientific evidence that the climate is changing and that human emissions are contributing to it (Intergovernmental Panel on Climate Change [IPCC] 2007). Worldwide, research is underway to understand climate change implications for human activities, including resource extraction and associated developments.

It is important to identify and characterize potential vulnerabilities to climate change for individual development sectors because changing environmental conditions are believed to have major implications for economic development and social and cultural well-being (Arctic North Consulting 2009). However, a detailed understanding of the direct implications of climate change for major industrial activities appears to be limited By identifying potential vulnerabilities, stakeholders, developers and regulators can develop and implement pro-active approaches to reducing future uncertainties referred to as Adaptation Measures.

Amongst other development activities, mining is particularly vulnerable to climate change because associated development activities depend on the natural environment (Arctic North Consulting 2009). The potential vulnerability of these activities to climate change has regional significance because of their dominant economic role they play on a regional basis (*e.g.,* creation of training and employment opportunities and infrastructure development).

Climate is an important component to be considered in mine development. Mines across Canada have been affected by climate change related hazards (Pearce *et al.* 2011). The mining sector needs to develop strategies to be able to mitigate mining related environmental impacts and at the same time adapt to climate variability and change to minimize consequences for affected communities and the environment. Pearce *et al.* (2011) discuss five key findings:

- mines are affected by climate events that are indicative of climate change, with examples of negative impacts over the past decade;
- most existing mine infrastructure has been designed assuming that the climate is not changing;
- most industry stakeholders interviewed view climate change as a minor concern;
- limited adaption planning for future climate change is underway; and
- significant vulnerabilities exist in the post-operational phase of mines.

The expected lifetime of any infrastructure is critical in determining the vulnerability to climate variability and to climate change. Many mining-related infrastructure components are temporary (i.e., required for a few years) compared to infrastructure expected to perform for several decades (i.e., permanent). A temporary access road or air strip for example may only be required during the operation of a single mine site and is required for only a few years (e.g., less than 20 years). However if a road is utilized to access several mines (that may be developed over several years or decades) from a common port then this road and the port are considered more permanent in nature and expected to operate for several decades (e.g. 50 years and more). Similarly, long-term mine waste containment facilities must function into the future. The same applies to mine closure infrastructure such as spillways.

Weather variability (i.e., year-to-year, more short-term changes in local conditions) may impact temporary infrastructure such as mining-related roads. However, long-term changes in climatic conditions and trends (i.e., climate change) may affect long-term infrastructure components. Both long-term and short-term developments have to be engineered to adequately perform over their life time (for example, roads design to prevent regular washed out during the spring). The focus of this Report is the long-term components and their vulnerability to Arctic climate and climate change.

From a business perspective it is assumed that climate change impacts could lead to increased costs for mining development. Northern mines are already experiencing high costs for their operations related to remote and isolated locations and associated transportation logistics, harsh climate conditions, and biophysical parameters. Today, few Canada-wide studies have been conducted describing the vulnerability of the Canadian mining sector to climate change (e.g., Arctic North Consulting 2009), and several climate change adaptation scenarios for communities in Nunavut have been developed (e.g., Ford *et al.* 2007) but no detailed study exists outlining potential impacts and adaptation measures for mining development in the Arctic.

As a start to address this gap in our knowledge, this Nunavut *Regional Adaptation Collaborative* (RAC) Task 1 Report identifies and describes the vulnerability of the Nunavut mining sector to climate change, based on the following infrastructure components:

- roads;
- airstrips;
- railways;
- ports; and
- tailings management facilities.

Infrastructure such as roads, airstrips, port facilities that have been constructed to directly service mines are considered in this Report rather than existing infrastructure in communities that mining companies may utilize in the shipment of goods to and from the mine. Infrastructure constructed specifically for mines may be of a more temporary nature than the more permanent facilities associated with communities.

With federal funding support through Natural Resources Canada's Regional Adaptation Collaborative Program, IMG-Golder Corp. (IMG-Golder) was contracted by the Government of Nunavut (GN) to collect and compile information to assess the vulnerability of Nunavut's mining industry to climate change and describe potential adaptation strategies. The project was divided into two tasks which are briefly outlined as follows:

Task 1

- describe climate trends for three areas in Nunavut and summarize climate forecast model projections;
- describe existing Traditional Knowledge on climate change in Nunavut;
- identify existing and proposed mining infrastructure components in Nunavut
- provide an overview to known impacts of development on permafrost;
- identify vulnerabilities of mining infrastructure components to climate change;
- identify existing knowledge on adaptation measures to be implemented in the planning of mining infrastructure; and
- organize, facilitate and summarize a Vulnerability Assessment Workshop.

Task 2

- describe existing policies / regulations and the environmental assessment process as it pertains to the planning for mining projects in Nunavut with special emphasis on climate change;
- provide an overview of existing Good Environmental Practices as they relate to the phases of mine development in the North that could be most effected by climate change; and
- develop two case studies that document considerations for implementation by stakeholders for planning and development of mining reated infrastructure in Nunavut.

This Report covers Task 1 objectives.

2.0 PROJECTED CLIMATE CHANGE

Nunavut experiences very cold winters and short summers that are too cool to permit the growth of trees or other vegetation seen in southern climates of Canada. Average monthly temperatures are below freezing for eight months of the year. Continuous permafrost underlies virtually the entire territory with areas of discontinuous permafrost in the south-western area (Section 3.1). Nunavut consists of an island archipelago and land to the west of Hudson Bay. The local geography significantly influences the climatic conditions.

The Arctic climate is a complex system and has multiple interactions with the global climate system. The sensitivities of snow and ice regimes to small temperature increases and of cold oceans to small changes in salinity, both of which can lead to subsequent amplification of the signal, are processes that could contribute to unusually large and rapid climate change in the Arctic (Huntington *et al.* 2005).

2.1 Historical Observed Conditions

Given the significant geographical variability it is expected that the local climate will also vary across Nunavut, so the climate observed in one location is not necessarily indicative of the climate in another location. For example, Figure 1 presents the average annual temperature observed in Baker Lake (BL), Cambridge Bay (CB) and Iqaluit (IQ).

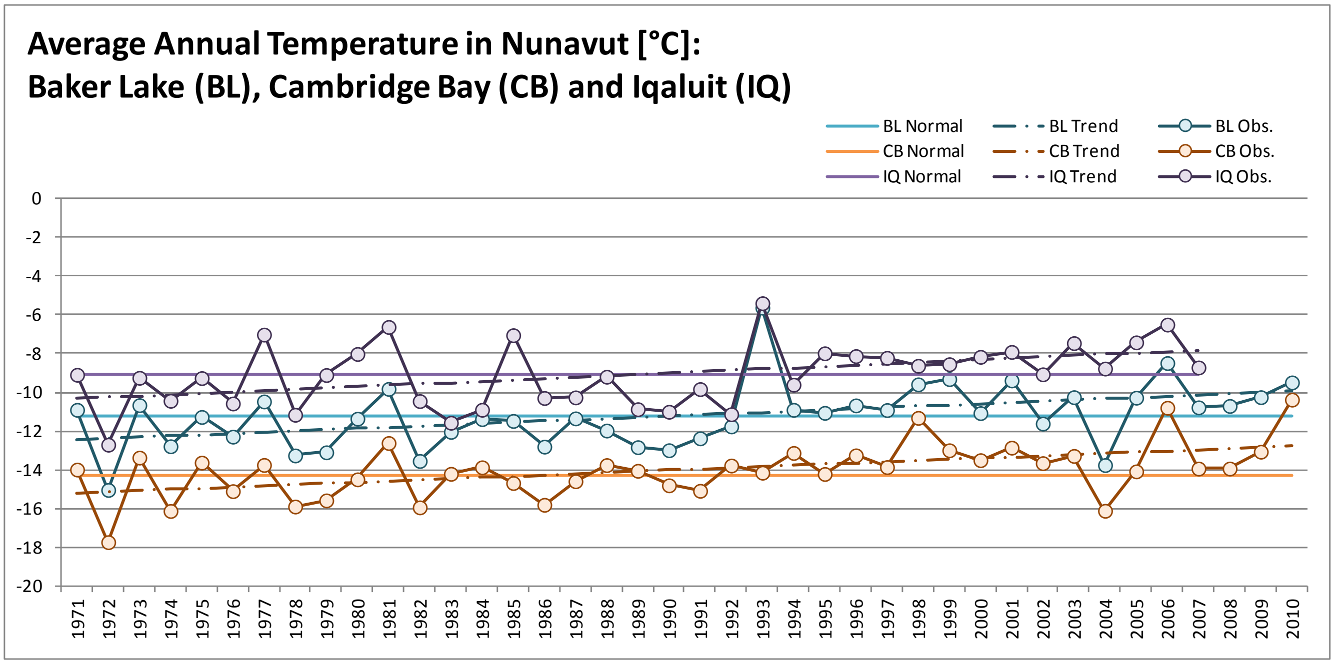

Figure 1: Variation in Average Annual Temperature in Nunavut (modelled after Environment Canada 2011)

This figure shows a general warming trend at all three locations. The temperature trends are more prominent in Baker Lake and Cambridge Bay than in Iqaluit. Although the general direction of trends may be similar across a region, locally the magnitude of the trend and variation in observed values can be very different in any given year.

Iqaluit and Cambridge Bay temperatures are largely moderated by near-by ocean waters and currents, somewhat typical of a maritime climate. The temperature in Cambridge Bay is colder than the other two locations, despite its maritime climate. This is due to is more northern location. Baker Lake is slightly colder than Iqaluit in the winter due to the continental land effects (colder in winter, slightly warmer in summer). Land masses usually warm up quicker in summer and cool off more in winter, the typical effects of a continental climate (modelled after Environment Canada 2011).

Iqaluit's precipitation averages just over 400 mm annually, much wetter than many other localities in the Canadian Arctic Archipelago, with the summer being the wettest season. Baker Lake has a drier climate, again due to the continental land effects (drier in general). A historical analysis of precipitation showed a slight downward trend in precipitation for all three locations. Baker Lake indicated more robust precipitation trends than Cambridge Bay and Iqaluit (modelled after Environment Canada 2011). In addition, the climate analysis of all stations showed a statistically significant increase in number of the freeze and thaw cycles.

Based on these observations it is important to closely monitor and study climate at a local scale when considering the climate vulnerability of local infrastructure.

2.2 Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) was formed by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to assess the latest climate change information (research papers and other publications). The IPCC has released a series of reports that indicate that global temperatures are increasing and precipitation trends are changing. These conclusions are derived from historical observations and scenarios of future climate (or future climate trends) are based on the output of global climate models (GCM's) published by international research groups and universities. Changes in the Arctic are expected to be greater than projections in more southern areas (Huntington *et al.* 2005).

Using the outcomes for available GCM specifically for the Baker Lake area for the projection time horizon of 2041 to 2070 the future projections indicate an increase in annual temperatures compared to the historic record. The overall range of the projections is larger than, the range of the historic observations indicating a warmer future.

A similar increase in the total annual precipitation was not projected. The future projections indicate that annual precipitation will not change dramatically in the future relative to the historic observed climate. The range of future projections encompasses nearly all of the past observations. However the GCM's cannot currently take into account the influence of local geography as noted in the historical observations.

Although the total annual precipitation is not projected to increase the type and quantity of precipitation is likely to change in the future. There is general acknowledgment that extreme events are likely to increase in the future (Canadian Meteorological and Oceanographical Society [CMOS] 2007) that includes:

- higher and more frequent hot extremes and fewer cold extremes;
- longer and more frequent heat waves; and
- more frequent, higher intensity precipitation events.

The implications to mining and related infrastructure (as discussed further below in this report) in Nunavut can include:

- melting of sea ice and glaciers are a contributing factor to sea level rise along with thermal expansion of the ocean, both of which may result in more open water, leading to greater wave action and ultimately to increased coastal erosion. Melting of sea ice may also allow increased year round shipping;
- decreased sea ice and increasing wave action coupled with increased intensity of storms could impact the use of port facilities;
- increased temperatures could lead to a degradation of permafrost and increase in the active layer that could impact existing infrastructure and impact the design requirements for new infrastructure;
- increase in subsurface flow that occurs as permafrost thaws may alter groundwater flow pathways which may impact transport of contaminants;
- decreased snow cover could mitigate the impacts of the increased temperatures due to a removal of the insulating snow layer;
- increase in intense precipitation events could increase erosion of embankments and other structures;
- increase in intense precipitation events could have implications for water resource management and flooding that could impact impoundment and tailings facilities;
- increased wind and summer drought conditions could cause dusting problems at tailings management facilities and gravel roads; and
- increased risk of summer drought, particularly in regions where the stream-flow is provided by spring and summer runoff, due to a decrease in snow-pack that could impact water cover tailings facilities.

2.3 Traditional Knowledge in Nunavut

Inuit Traditional knowledge (TK), also known as Inuit Qaujimajatuqangit (IQ), has been fundamental to the survival of aboriginal people in the Arctic for thousands of years. Knowledge of weather and climate patterns and animal resource availability has been passed from generation to generation and has been instrumental in adaptation to environmental changes that affect harvesting activities such as hunting, trapping and fishing (Nuttall *et al.* 2005). Inuit throughout Nunavut have also observed changes in temperature, precipitation, the length of season, prevailing wind strength and direction, and weather predictability (Government of Nunavut [GN] 2005a; GN 2005b; GN 2005c; GN 2005d Huntington et. al. 2005). Additionally, the qualitative information that the Inuit of Nunavut possess on biophysical systems such as sea ice, permafrost, river hydrology, slopes and terrestrial and marine ecosystems has contributed to scientific understanding of the extent of climate change in the Arctic by acting as a counterpart to quantitative information (Bonny and Berkes 2008; Ford and Smit 2004). Changes in biophysical systems can have a negative effect on infrastructure in the Arctic. For example, thawing of permafrost can lead to significant damage of inland structures, such as roads and airstrips (Instanes *et al.* 2005; United States [U.S.] Arctic Research Commission Permafrost Task Force 2003). Also, the erosion of coastal permafrost areas produces ice blocks loaded with sediment, which poses a threat to vessels travelling in Arctic waters (Instanes *et al.* 2005).

The Government of Nunavut (GN) has produced reports of TK of climate change in the Baffin region, Kivalliq region and Kitikmeot region. The reports found that detailed TK studies of climate change in Nunavut have not been performed. Rather, studies of TK on topics such as monitoring and environmental protection included some information of climate change. Observations of increases in temperature, thinning and roughness of sea ice, changes in wind patterns, changes in animal behaviour and a reduction in snow cover have been reported. However, these observations were collected from a small sample population. It was noted that more observations from more Inuit are required to complete a comprehensive account of TK on climate change. Therefore it was recommended that detailed studies that specifically address TK on climate change and adaptation are performed (GN 2005a; GN 2005b; GN 2005c; GN 2005d).

Changes in climatic variable in the Arctic, such as temperature, the length of season, and precipitation, observed by Inuit contribute to the projection of future climate scenarios (Riedlinger and Berkes 2001). The full extent of change expected in climate is uncertain (Christensen *et al.* 2007), and in addition to scientific knowledge, TK of the Arctic environment is an important resource in assessing what effect climate change may have on Nunavut's infrastructure.

2.4 Space Weather

Though not related to climate change, space weather is a concern in northern areas. Geomagnetic storms (i.e., space weather) are more pronounced in higher geographic latitudes than in lower latitudes (CENTRA Technology Inc. 2011). Geomagnetic storms are caused by changes in solar activity, which causes variations in the electrical currents of the Earth's magnetosphere and ionosphere. This results in fluctuations in the magnetic field of the Earth and is manifested on the surface in geomagnetically induced current (GIC). Because geomagnetic storms are more pronounced in higher latitudes, northern areas are more susceptible to GIC (CENTRA Technology Inc. 2011; Pirjola 2008).

GICs interfere with cathodic protection systems, which are used in metallic structures, such as buried pipelines to prevent corrosion. GICs involves current flowing from metallic substances into electrolyte such as soil and water (*i.e.*, corrosion), whereas cathodic protection systems are utilized to prevent this from occurring. GICs can result in current flowing from metallic substances into electrolyte despite the presence of a cathodic protection system. In effect, this shortens the lifetime of buried pipelines (Pirjola 2008; Bushman 2001; Gummow 2000).

3.0 CURRENT STATE OF MINING AND LARGE INFRASTRUCTURE IN NUNAVUT

Agnico-Eagle Mines Ltd.'s Meadowbank Mine, located 75 kilometres (km) north of Baker Lake, is currently the only operational mine in Nunavut. Construction of the Meadowbank Mine began in 2008 and operations commenced in early 2010. Extraction will take place in three open pits, beginning with current extraction operations in the Portage pit, to be followed by the Goose Island pit and Vault pit, with operations expected to continue until 2019 (Nunavut Geoscience 2011a; Agnico-Eagle Mines Ltd. 2010).

During 2010, there were 85 active mine-related exploration projects across Nunavut. These included 35 in the Kitikmeot region, 33 in the Kivalliq region and 17 in the Qikiqtaaluk region (Nunavut Geoscience 2011b). These projects are described, along with the operating Meadowbank mine, in Table 1. Dimension and/or size of infrastructure, where known, are indicated.

For the mining projects listed in Table 1 with no known infrastructure listed, it is assumed that many if not all of these sites are accessed by aircraft. Therefore, it is possible that many of these sites may have gravel airstrips. A scan of available literature resulted in the list of known infrastructure components (Table 1), but the listed information is not considered exhaustive.

Additionally, Table 1 includes information on planned or proposed mining-related infrastructure development in Nunavut that was identified during the scan of available literature.

Notes *- Table 1 describes known permanent infrastructure (e.g., airstrips, roads, camps, etc.), not temporary (e.g., seasonal) ones. It is acknowledged that the term "permanent" may refer to more short-term infrastructure (e.g., roads servicing one particular mine site) or longer-term infrastructure (e.g., roads that service several mine sites).*

All projects have been given the status of "Exploration" in accordance with the Nunavut Geoscience (2011a) website's title as "Exploration Overview" for exploration and mining activities in 2010 unless further research revealed a different status (e.g., closed mine).

Exploration projects are those that Nunavut Geoscience had listed on its exploration activities map for 2010 (even if a previously existing mine was located at the site).

Table 1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components *

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Kitikmeot					
Amaruk Diamonds; Diamonds	Exploration	40 km south-west of Kugaaruk	Diamonds North Resources Ltd.		
Amaruk Gold; Gold	Exploration	40 km south-west of Kugaaruk	Diamonds North Resources Ltd.		
Amaruk Nickel; Nickel-copper PGE's	Exploration	40 km south-west of Kugaaruk	Diamonds North Resources Ltd.		
Anuri; Gold	Exploration	265 km south of Kugaaruk	North Country Gold Corp.		
Arcadia Bay; Gold	Exploration	155 km east-south-east of Kugluktuk	Alix Resources Corp.		
Blue Caribou; Base Metals	Exploration	191 km south of Bathurst Inlet	Skybridge Development Corp.		
Boston (Hope Bay Project); Gold	Postponed indefinitely	130 km south-west of Cambridge Bay	Hope Bay Mining Ltd.	Proposed infrastructure included a mill at Boston, expanded port, camps, roads and airstrips to support these future mining activities as part of Hope Bay Project.	
Contwoyto IOL Concession; Gold	Exploration	160 km south-west of Bathurst Inlet	Golden River Resources Corp.		
Coppermine Project; Uranium	Exploration	96 km south-south-west of Kugluktuk	Hornby Bay Mineral Exploration Ltd.		2010 completed significant upgrades to the camp and exploration facilities.
Doris (Hope Bay Project); Gold	Postponed indefinitely	130 km south-west of Cambridge Bay	Hope Bay Mining Ltd.	Proposed infrastructure included a mill at Boston, expanded port, camps, roads and airstrips to support these future mining activities as part of Hope Bay Project.	

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
George Lake (Back River Project); Gold	Exploration	372 km south-east of Cambridge Bay	Sabina Gold & Silver Corp.		
Gondor; Base Metals	Exploration	225 km south-west of Bathurst Inlet	MMG Resources Inc. (Minmetals)		
Goose Lake (Back River Project); Gold	Exploration	400 km south-east of Cambridge Bay	Sabina Gold & Silver Corp.		
Hackett River; Base metals	Exploration	104 km south-south-west of Bathurst Inlet	Sabina Gold & Silver Corp.		
Halkett Inlet; Gold	Exploration	85 km north-west of Kugaaruk	Diamonds North Resources Ltd.		
Hammer; Diamonds	Exploration	142 km south-east of Kugluktuk	Stornoway Diamond Corporation		
Hepburn Base Metals; Base metals	Exploration	150 km south-west of Kugluktuk	Diamonds North Resources Ltd.		
Hepburn Diamonds; Diamonds	Exploration	170 km south-south-west of Kugluktuk	Diamonds North Resources Ltd.		
High Lake; Base metals	Project on hold, was undergoing environmental assessment	190 km east-south-east of Kugluktuk	MMG Resources Inc. (Minmetals)	Proposed infrastructure included a 53 km all- weather gravel road, a port at Grays Bay and 2,000 metre (m) airstrip at Sand Lake	
High Lake East; Base metals	Exploration	225 km east-south-east of Kugluktuk	MMG Resources Inc. (Minmetals)		
Hood; Base metals	Exploration	220 km south of Kugluktuk	MMG Resources Inc. (Minmetals)		
Hood River IOL Concession; Gold	Exploration	125 km west of Bathurst Inlet	Golden River Resources Corp.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Inuk (Committee Bay Gold Project); Gold	Exploration	135 km south of Kugaaruk	North Country Gold Corp.		
Izok Lake; Base metals	Exploration	255 km south-west of Kugluktuk	Minerals and Metals Group (MMG) Resources Inc. (Minmetals)		
Jericho Mine; Diamonds	Mine, closed; Operational 2006-2008	255 km south-south-east of Kugluktuk	Shear Diamonds Ltd.	All-weather roads at the site. Year-round 1,125 m airstrip; 568 km winter road from Yellowknife.	2010 purchase of Jericho included main mine site, all equipment, camp and plant facilities. Processing plant and facility that accommodates 225 people at the site.
Lupin Mine; Gold	Mine, closed; Operational 1982-2003 and 2004-2005	287 km south-south-east of Kugluktuk	MMG Resources Inc. (Minmetals)	568 km winter road road from Yellowknife.	Production plant under care and maintenance in 2010.
Madrid (Hope Bay Project); Gold	Postponed indefinitely	130 km south-west of Cambridge Bay	Hope Bay Mining Ltd.	Proposed infrastructure included a mill at Boston, expanded port, camps, roads and airstrips to support these future mining activities as part of Hope Bay Project.	
MIE; Nickel-copper PGE's	Exploration	110 km south-south-west of Kugluktuk	MIE Metals Corp.		
Raven (Committee Bay Gold Project); Gold	Exploration	260 km south-west of Kugaaruk	North Country Gold Corp.		
Rockinghorse IOL Concession; Gold	Exploration	185 km south-east of Kugluktuk	Golden River Resources Corp.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Three Bluffs (Committee Bay Gold Project); Gold	Exploration	220 km south of Kugaaruk	North Country Gold Corp.		
Ulu; Gold	Mine, closed; Operational 1982-1998 and 2000-2005	202 km south-east of Kugluktuk	MMG Resources Inc. (Minmetals)	Support road and airstrip.	Under care and maintenance in 2010.
West Plains (Committee Bay Gold Project); Gold	Exploration	247 km north-east of Baker Lake	North Country Gold Corp.		
Wishbone; Base metals	Exploration	415 km south-east of Kugluktuk	Sabina Gold & Silver Corp.		
Yava; Base metals	Exploration	395 km south-east of Kugluktuk	Savant Explorations Ltd.		
Kivalliq					
Aberdeen; Uranium	Exploration	85 km west of Baker Lake	Cameco Corporation		
Aura; Gold	Exploration	355 km west of Whale Cove	Uranium North Resources Corp.		
Cache; Gold	Exploration	105 km west of Whale Cove	Alix Resources Corp.		
Chesterfield Inlet; Diamonds	Exploration	15 km west of Chesterfield Inlet	Shear Diamonds Ltd.		
Churchill; Diamonds	Exploration	45 km north of Rankin Inlet	Shear Diamonds Ltd.		
Churchill West; Diamonds	Exploration	45 km north of Rankin Inlet	Shear Diamonds Ltd.		
Ferguson Lake Diamonds; Diamonds	Exploration	160 km south of Baker Lake	Thanda Resources Ltd.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Ferguson Lake Ni-Cu-PGM; Nickel-copper PGE’s	Exploration	160 km south of Baker Lake	Starfield Resources Inc.		
Greyhound Lake; Base metals	Exploration	38 km north of Baker Lake	Aura Silver Resources Inc.		
Judge Sissons (North Thelon); Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		
Kiggavik North; Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		
Kiggavik Project (Including Kiggavik, Sissons, St. Tropez Claims); Uranium	Undergoing environmental assessment	75 km west of Baker Lake	AREVA Resources Canada Inc. (ARVEA)	Airstrip; all-season road under consideration to replace planned winter-access road	
Kiggavik South (North Thelon); Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		
Lac Cinquante (Angilak); Uranium	Exploration	235 km south-west of Baker Lake	Kivalliq Energy Corp.	2010 program consisted of new camp construction.	
Mallery Lake Project; Gold	Exploration	132 km west-south-west of Baker Lake	Uranium North Resources Corp.		
Meadowbank Mine; Gold	Mine; Operational 2010, ongoing	75 km north of Baker Lake	Agnico-Eagle Mines Ltd.	Airstrip; All-season road from Baker Lake (110 km) Camp.	Open pits (3 to be completed; 1 being excavated in 2010) Camp Processing plant (mill).
Meliadine; Gold	Exploration	25 km north-east of Rankin Inlet	Agnico-Eagle Mines Ltd.	Plans to construct an all-weather access road from Rankin Inlet (second half 2011) and upgrade camp facilities.	
Muskox; Gold	Exploration	95 km north-north-east of Baker Lake	Agnico-Eagle Mines Ltd.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Nanuq; Diamonds	Exploration	225 km north-east of Baker Lake	Peregrine Diamonds Ltd.		
Nanuq North; Diamonds	Exploration	300 km north-east of Baker Lake	Indicator Minerals Inc.		
Nueltin Lake; Uranium	Exploration	325 km west of Arviat	Cameco Corporation		
Nutaaq; Rare earth elements	Exploration	65 km west of Baker Lake	Forum Uranium Corp.		
Parker Lake; Gold	Exploration	130 km south-east of Baker Lake	Agnico-Eagle Mines Ltd.		
Qilalugaq; Diamonds	Exploration	10 km north of Repulse Bay, extending across the Rae Isthmus	Stornoway Diamond Corp.		
Schultz Lake (North Thelon); Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		
Southampton; Nickel-copper PGE's	Exploration	55 km north of Coral Harbour	Vale Inco Ltd.		
Southampton Island [a]; Nickle-copper PGE's	Exploration	85 km north-north-west of Coral Harbour	Anglo American Exploration (Canada) Ltd.		
Southampton Island [b]; Nickel-copper PGE's	Exploration	55 km west of Coral Harbour	Anglo American Exploration (Canada) Ltd.		
SY Project; Gold	Exploration	250 km west of Whale Cove	Corsa Capital Ltd.		
Tanqueray Block (North Thelon); Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		
Turqavik; Uranium	Exploration	85 km west of Baker Lake	Cameco Corporation		
Ukalik (North Thelon); Uranium	Exploration	50 km east of Baker Lake	Forum Uranium Corp.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Yathkyed (Angilak); Uranium	Exploration	235 km south-west of Baker Lake	Kivalliq Energy Corporation	2010 program consisted of new camp construction.	
Qikiqtaaluk					
Aviat; Diamonds	Exploration	72 km west-south-west of Igloolik	Stornoway Diamond Corporation		
Bravo Lake (Baffin Island Gold); Gold	Exploration	220 km south of Clyde River	Commander Resources Ltd.		
Chidliak Diamonds; Diamonds	Exploration	115 km north-north-east of Iqaluit	Peregrine Diamonds Ltd.		
Chidliak Ni-Cu-PGM; Nickel-copper PGE’s	Exploration	115 km north-north-east of Iqaluit	Peregrine Diamonds Ltd.		
Cumberland; Diamonds	Exploration	60 km east of Pangnirtung	Peregrine Diamonds Ltd.		
Kimmirut; Uranium	Exploration	75 km north of Kimmirut	Peregrine Diamonds Ltd.		
Mary River; Iron	Final Environmental Impact Statement (EIS) submitted in February 2012	160 km south of Pond Inlet	Baffinland Iron Mines Corp. (Baffinland)	Airstrip; Winter access road; Bulk sampling program in 2008 involved making a 120 km all-weather access road from mine / camp area to Milne Port to the north-west.	Plans to preferably develop a 143 km railway and a port at Steensby Inlet (port including a rail loading / unloading facilities; rail service / maintenance facilities; worker accommodations; ore loading, freight and tug docks; ore stockpile and ship loading facilities, and an airstrip
Melville Gold; Gold	Exploration	140 km north-east of Repulse Bay	AngloGold Ashanti Holdings Plc.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Polaris Mine; Base metals	Mine, closed; Operational 1981-2002	Little Cornwallis Island, 95 km north-west of Resolute Bay	Teck Resources Ltd.		Underground mine; (Processing plant, power plant, workshop built on a barge); Reclamation 2002-2004; Infrastructure to be buried in nearby quarry; Environmental monitoring to continue until end of 2011.
Qilaq; Diamonds	Exploration	110 km east-north-east of Iqaluit	Peregrine Diamonds Ltd.		
Qimmiq (Baffin Island Gold); Gold	Exploration	250 km south of Clyde River	Commander Resources Ltd.		
Roche Bay; Iron	Exploration	72 km south-west of Hall Beach	Advanced Exploration Inc.		
SQ-05 [a]; Base metals	Exploration	25 km south-east of Sanikiluaq	McKinnon Prospecting Ltd.		
SQ-05 [b]; Base metals	Exploration	60 km south-east of Sanikiluaq	McKinnon Prospecting Ltd.		
Storm; Base metals	Exploration	120 km south-south-east of Resolute Bay	Commander Resources Ltd.		
Tuktu; Oron	Exploration	72 km west of Hall Beach	Advanced Exploration Inc.		

Table1: Mining and Exploration Activities in Nunavut during 2010 and Known, Associated Permanent Infrastructure Components * (continued)

Project & Commodity Group	Status of Project	Location	Operator	Airstrip / Road / Port	Other Infrastructure / Notes
Nanisivik Base metals	Mine, closed; Operational 1976-2002; reclamation began 2003	28 km east-northeast of Arctic Bay	Breakwater Resources Ltd.	Airstrip 7 km to the south-west; still used by community of Arctic Bay; Road 21 km west to Arctic Bay; Former community being reclaimed; Port 2.7 km to the north.	

* Sources: Canadian Broadcasting Corporation (CBC) News 2012; Baffinland 2008; 2011; 2012; Nunavut Geosciences 2011a; Nunavut Geosciences 2011b; Agnico-Eagle Mines Ltd. 2010; Nuna Logistics Ltd. 2010a and 2010b; AREVA 2011; 2008; Wolfden Resources Inc. 2006.

3.1 Current Practices for Development on Permafrost

Ground (*i.e.,* soil, rock, sediment) that has remained below 0°C for two or more consecutive years is defined as permafrost (Walsh *et al.* 2005). There are four categories of permafrost in Canada: continuous, extensive discontinuous, sporadic discontinuous and isolated patches. Zones of continuous permafrost are areas completely underlain by permafrost (with the exception of large lakes and rivers). In Canada, areas where permafrost underlies between 90% and 100% of the surface are considered continuous (Transportation Association of Canada [TAC] 2010; Natural Resources Canada [NRCan] 2007; Walsh *et al.* 2005). Areas where permafrost underlies between 50% and 90% of the surface are considered extensive discontinuous, and areas where permafrost underlies between 10% and 50% of the surface are considered sporadic discontinuous. Isolated patches are those where permafrost underlies less than 10% of the surface (TAC 2010; NRCan 2007). Permafrost can be further distinguished by temperature. Permafrost is considered "cold" if ground temperature is below -5°C and "warm" if ground temperature is between -2°C and 0°C. Continuous permafrost is generally considered cold and extensive discontinuous, sporadic discontinuous, and isolated patches are considered warm (TAC 2010; Walsh *et al.* 2005).

During 2007-2009, as part of the International Polar Year (IPY) the extent of permafrost monitoring in Nunavut was expanded with the drilling of boreholes and installation of monitoring equipment. The majority of permafrost monitoring sites in Nunavut occur on Baffin Island and there are few in the Kivalliq region. Most of the sites are located near developments (*e.g.* roads and settlements; Ednie and Smith 2010; Smith *et al.* 2010). Permafrost in Nunavut is mostly cold and continuous with the exception of areas of discontinuous permafrost in the south-western part of the territory (Ednie and Smith 2010; Smith *et al.* 2010; NRCan 2003).

The common issue in the development of mining and large infrastructure is the potential degradation of permafrost due to climate change. Climate change is expected to result in changes in permafrost coverage. An increase in air temperature in the Arctic is expected to reduce the extent of permafrost, increase active layer thickness, and result in transitions between zones of cold and warm continuous permafrost, and continuous and discontinuous permafrost (Instanes *et al.* 2005; Walsh *et al.* 2005).

The presence of permafrost is accounted for when designing and constructing infrastructure. Improper construction activities in permafrost zones can result in changes to ground surface properties which can in turn impact the ground thermal regime and cause permafrost degradation. Proper design can help to overcome these issues; however, changes to the climate in the future may lead to permafrost degradation. The local conditions and the design practices have an equal or greater effect on the adaptive capacity of the infrastructure.

Permafrost Thaw

Permafrost remains frozen because the ground thermal regime and local climate (*e.g.,* air temperature) are in balance (TAC 2010; Instanes *et al.* 2005; Walsh *et al.* 2005). The balance of temperature is controlled by climatic and terrestrial conditions (TAC 2010; Instanes *et al.* 2005). Climatic factors with the greatest effect on permafrost are air temperature and the insulating property of snow cover (TAC 2010). The terrestrial conditions that have the greatest impact are directly related to the geothermal properties of the ground (capacity to conduct heat) as influenced by water (ground and surface), soil organic matter, and surface vegetation, as well as the ability of the ground surface to absorb or reflect solar radiation (TAC 2010; Instanes *et al.* 2005).

Based on past experience any construction activity (*e.g.,* cutting or filling) in permafrost areas that results in a change in ground surface properties will change the ground thermal balance (Fortier *et al.* 2011; TAC 2010; Instanes *et al.* 2005). For example, clearing vegetation from the ground surface can lead to permafrost thaw. Vegetation reduces heat ground penetration in the summer, which keeps permafrost temperatures cool. When vegetation is cleared, heat transfer into the ground from the air is less inhibited and ground temperatures increase (TAC 2010; Instanes *et al.* 2005). Additionally, removing vegetation exposes soils to solar radiation. The heat absorbed from solar radiation can also contribute to an increase in ground temperature (TAC 2010; Instanes *et al.* 2005). In the winter, the area cleared of vegetation will be covered in snow. Snow has an insulating effect and so the cooling of ground temperatures is reduced. The net effect is usually a change in the ground thermal balance such that the heat flow in to the ground is greater than the heat flow out, which results in an increase in ground temperature and can lead to an increase in the active layer and permafrost thaw (TAC 2010; Instanes *et al.* 2005).

Permafrost thawing and increased active layer thickness can result in settlement (i.e., subsidence) of overburden soils. Thawing of ice-rich soil (and related settlement) can result in ponding of surface water and changes in surface water drainage. Increased active layer thickness can also increase seasonal groundwater flow through shallow overburden soils (Walsh *et al.* 2005). Changes in surface water drainage and groundwater flow are particularly relevant to TMF's designed to protect water quality by containment of waste materials and impacted water (e.g., where containment is provided by permafrost). Furthermore, ponding of surface water (e.g., from permafrost thawing) and/or impoundment of water (e.g., within a TMF) contributes to increased permafrost thawing and related impacts (Stratos Inc. 2011; Dawson and Morin 1996; Mining and Mineral Science Laboratories 1996).

Ground Ice

The formation of ground ice (freezing) can also cause changes to the ground surface. Frost heave describes the upward or outward movement of the ground surface that is caused by the formation of ice in the soil (U.S. Arctic Research Commission Permafrost Task Force 2003).The term "freeze-thaw" refers to the formation and thawing of ground ice (U.S. Arctic Research Commission Permafrost Task Force 2003).

The impact that thawing permafrost may have on infrastructure is correlated to ice content. Ice can exist in permafrost in three ways: as small crystals within soil pores, as lenses parallel to the ground surface, and as intrusive masses (*e.g.,* ice wedges; Instanes *et al.* 2005; Walsh *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003). The distribution of ice in permafrost is related to soil texture, where silts and clays tend to be high in water content. Soil with a volume of ice that exceeds the volume of available pore space is considered "ice-rich". Excess ice content is a determining factor in attributing thaw sensitivity in permafrost (TAC 2010; Instanes *et al.* 2005; Walsh *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003). The thawing of ice-rich soil leads to ground subsidence because water has a higher volume when in solid (frozen) phase than in liquid phase. This process is termed "thaw settlement" (U.S. Arctic Research Commission Permafrost Task Force 2003). Ice-rich soils are therefore considered thaw sensitive (TAC 2010; Instanes *et al.* 2005; Walsh *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003).

Permafrost is often used as a foundation for infrastructure. Consequently, the melting of ice-rich permafrost can result in infrastructure damage (TAC 2010; Instanes *et al.* 2005; Walsh *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003).

Ground Vegetation and Embankment Construction

The construction of infrastructure such as embankments (for roads, railways or airstrips) does not necessarily require that vegetation be cleared from the ground surface. Rather, it is recommended practice to construct embankments on top of vegetation wherever feasible (TAC 2010). This buried layer of vegetation helps regulate temperature, but not to the same extent as if it was on the surface (TAC 2010). In any case, embankment construction results in mineral soil exposure at the ground surface. This complicates the preservation of permafrost, particularly under the embankment slopes because:

- less thermal protection at the slopes because granular fill is not as thick as in the embankment;
- less cooling of ground temperature in the winter due to the insulation effect of snow accumulating on embankment slopes; and
- warming of ground temperature due to heat from water flowing and accumulating at the toe of the embankment slopes (Fortier *et al.* 2011; TAC 2010).

Permafrost Engineering and Design

Generally, there are three design approaches for infrastructure in permafrost soils to accomplish structural stability and integrity:

- disturb permafrost as little as possible by maintaining existing ground thermal regime (referred to as the passive method in North America and as Principle I in Russia);
- accept changes in ground thermal regime that are caused by construction and operation, or modify permafrost before construction (referred to as the active method in North America and as Principle II in Russia); and
- if soils are thaw stable, use conventional foundation methods (Instanes *et al.* 2005).

The success of designs following the passive and active method approaches largely depends on properly estimating changes in active-layer thickness and the ground thermal regime to which a structure will be exposed during its lifetime. Expected changes in ground conditions can often be accounted for through design, construction, operation and maintenance methods (TAC 2010; Instanes *et al.* 2005).

Though not always feasible, the most effective way to limit the impact of freeze-thaw settlement on transportation infrastructure is to avoid building on thaw-sensitive soils (*e.g.,* soils with high ice content; TAC 2010; Instanes *et al.* 2005). If thaw-sensitive soils cannot be removed or avoided, cuts, high fills and sideslope alignments should not be used for structures built in these areas (TAC 2010).

In addition, a number of techniques have been developed to offset the warming effect that construction activities have on permafrost. Table 2 lists techniques that have been applied and/or tested in northern Canada and/or Alaska according to three categories: "limit heat penetration", "enhance winter heat extraction", and "reinforcement techniques".

Table 2 Currently Applied or Tested Permafrost Protection Techniques *

Technique	Description
Limit Heat Penetration	
Increasing embankment size	Increasing embankment thickness / width and flatness can be effective in cold or moderately cold regions of permafrost, but may not be practical in warm permafrost conditions because active layer might be too thick. It can reduce heat penetration underneath embankment.
Insulation	Polystyrene and peat can be used as insulation to reduce heat penetration underneath embankments.
Sunsheds / showsheds	Sunsheds / showsheds are bracket-like structures installed along the side of embankments. In the winter, these structures act as snowsheds. Snowsheds prevent snow accumulation on the side of embankments, thereby allowing cold air circulation along embankment slopes. In the summer, they act as sunsheds and prevent direct solar radiation on embankment sides.
Reflective surface	Pavement surfaces that have a high albedo (the reflectivity of a surface) *i.e.,* lighter colour reduce the heating effect of solar radiation.
Enhance Winter Heat Extraction	
Air ducts	Air ducts are placed under embankments to allow for heat extraction using natural convection.
Thermosyphons	Thermosyphons are composed of a pipe that includes refrigeration gas, which can be used to extract heat beneath embankments. Thermosyphons are costly for long linear structures (*e.g.,* roads and railways) and are only used in areas where there is potential for severe permafrost degradation.
Air convection embankment	Air convection embankments involve the use of clean, coarse, poorly-graded rock as fill to create embankments. Using fill of this composition will result in large interconnected voids that will facilitate air convection, which in effect results in heat extraction from beneath the embankment.
Heat drain	Heat drains consist of highly permeable geocomposite (*i.e.,* membrane) placed in the shoulder or underneath the embankment and an air intake at the foot of the embankment. Heat from underneath the embankment is extracted through convection.
Reinforcement Techniques	
Geotextile and geogrid	Geotextile and geogrid are site specific applications that are typically used in areas that are poorly drained, have deep active layers, taliks, and/or have soft or organic soils at depth. They subgrade from mixing with embankment fill, and provide reinforcement by restricting the spread of embankment fill over soft soil.
Berms and gentle slopes	Berms and gentle slopes limit snow accumulation on embankment slopes. A minimum sideslope ratio of 6 horizontal:1 vertical is recommended.
Pre-thawing	Pre-thawing involves thawing permafrost to reduce effects of freeze-thaw settlement by stabilizing foundations.
Excavation / replacement	Excavation / replacement involves the excavation of ice-rich (thaw sensitive) permafrost and replacement with fill.
Snow removal	Snow removal is a maintenance practice and is often a regular operating procedure. Snow accumulation on embankment sideslopes restricts heat loss, and snow removal reduces this effect.

* Source: TAC 2010.

Infrastructure developments constructed on ice-rich permafrost have utilized these techniques in efforts to reduce the frequency of failures and closures. For example, air convection embankments have been tested in Alaska, Nunavik and Yukon with positive results, but are costly to implement (TAC 2010; Reimchen *et al.* 2009; Maynard 2007; Saboundjian and Goering 2003). Thermosyphons have also demonstrated success in maintaining low temperatures under embankments and limiting freeze-thaw settlement in northern Manitoba and Alaska, but are also costly to implement (TAC 2010; Maynard 2007). Sound choice of which technique to implement is largely affected by knowledge of soil characteristics as well as past experience (TAC 2010). Section 3.5 (Potential Adaptation Measures to Address Impacts on Northern Roads, Airstrips, and Railways) provides a detailed discussion of permafrost engineering to mitigate climate change impacts.

3.2 Roads and Proposed Roads in Nunavut

Nunavut has a limited road network that is typically concentrated within communities; there are no roads connecting the territory's communities, and no all-weather roads connecting Nunavut to the rest of Canada. There is only one paved road in Nunavut, located in Iqaluit (Aboriginal Affairs and Northern Development Canada [AANDC] 2011).

Aside from community road systems, there are a number of roads that extend out of Nunavut's communities to mining sites, such as a highway that stretches from Arctic Bay to the former mine site of Nanisivik (21 km in length; the mine closed in 2002). There is one winter ice road, the Tibbitt to Contwoyto winter ice road, which links mine sites in western Nunavut (*i.e.,* not associated with communities) with the NWT during the early spring (WorldLingo 2011; Bathurst Inlet Port and Road [BIPAR] Joint Venture Ltd. 2007).

A 110 km all-weather gravel road, the Tehek Road, was constructed from the community of Baker Lake north to Agnico-Eagle's Meadowbank gold mine. The Tehek Road provides an access and re-supply route to the mine. Road construction began in October 2006 and required over 1.7 million cubic metres (m^3) of materials. Road construction was completed in April 2008 (Agnico-Eagle Mines Ltd. 2010; Nuna Logistics 2010c).

In 2008, the Milne Inlet Tote Road was upgraded from a winter road to an all-season road. The road is 100 km in length and connects the Baffinland Mary River project site to Milne Inlet. The Tote Road was established in 1965 and will require upgrades so that mine-related traffic can be accommodated during the construction and operation phases of the project (Baffinland 2012; Knight Piesold Consulting Ltd. [Knight Piesold] 2010). Iron ore will not be transported in volume by truck using the Tote Road to Milne Inlet from the mine site to Milne Inlet, which was an option considered in the Draft EIS. In consideration of the volume of iron ore to be transported, it was now (in the final EIS; see below) determined that transporting ore from the mine site to Steensby Port by rail is more practical (Baffinland 2012).

Newmont Mining Corporation (Newmont) worked towards developing three gold deposits in the Hope Bay area (Doris, Madrid and Boston). Newmont has recently postponed the development in the Hope Bay area indefinitely (CBC News 2012). In April 2010, a 5-km all-weather road was constructed, and in 2010 construction was underway to complete an all-weather road (Windy Road) to Windy Camp on Windy Lake (Chadwick 2011; Hanks 2011; Newmont 2010).

Table 3 lists mine associated road systems that are known to currently exist in Nunavut.

Table 3: Existing Roads in Nunavut in 2010 *

Location / Road	Description	Comments	Known Length
Arctic Bay to Nanisivik Highway	Gravel; all-weather	Connects town of Arctic Bay to former mining town of Nanisivik; also used for midnight sun marathon run.	21 km
Baker Lake to Meadowbank Mine	Gravel; all-weather	Connects Baker Lake to Agnico-Eagle's Meadowbank gold mine.	110 km
Hope Bay area	Gravel; all-weather roads	Locations / lengths of roads at / between mine sites / camps unknown.	Unknown
Milne Inlet Tote Road	Gravel; all-weather	Connect Baffinland Mary River project site to Milne Inlet.	100 km
Tibbitt to Contwoyto Winter Road	Winter ice road (February-March)	Only route from Nunavut to the South; services mines in the south-western part of Nunavut and connects them to mines in the NWT; in Nunavut the road extends from the inactive Jericho mine towards the south-east for over 100 km, crosses the Nunavut-NWT border, and carries on towards the south-west through numerous mine sites until it reaches Yellowknife.	568 km (including NWT portion)

* Sources: Tibbett to Contwoyto Winter Road Joint Venture 2011; WorldLingo 2011; Knight Piesold2010; BIPAR Joint Venture Ltd. 2007.

Examples of Proposed Roads

Bathurst Inlet Port and Road - The 211 km all-weather BIPAR Project, a 50/50 joint venture project between the Kitikmeot Corporation and Nuna Logistics Ltd., includes plans for a road to connect Bathurst Inlet (*i.e.,* the mine sites and proposed port there) to the existing Yellowknife to Contwoyto Winter Road. In effect, the proposed project would also link NWT to the Bathurst Inlet Port facility. Although it would be designed and constructed as an all-weather road, its proposed operational period would be from January to April (Nuna Logistics Ltd. 2010a; BIPAR Joint Venture Ltd. 2007).

A Draft EIS for the project was submitted to the Nunavut Impact Review Board (NIRB) in 2008, but their technical review of the project was suspended later that year and has been on hold since (Quenneville 2011; Nuna Logistics Ltd. 2010a). It should be noted that the Mackenzie Valley Environmental Impact Review Board (MVEIRB) was involved in the environmental assessment of the project with respect to NWT-Nunavut transboundary considerations. MVEIRB and NIRB cooperate in the review of projects of mutual concern (Dowlatabadi *et al.* 2003) and have signed a Memorandum of Understanding (2004) to this effect.

After consideration of a recently completed pre-feasibility study, Minerals and Metals Group (MMG) Resources Inc., previously the major backer of the project, decided that the project was too complex and expensive when compared to two other options to access the company's Izok Lake base metals project site. The alternative direct-to-the-coast, all-weather route options would not have to cross Contwoyto Lake to access the company's property which is located 250 km south-east of Kugluktuk (George 2011; Quenneville 2011; CBC News 2011).

Road from Manitoba to South-west Nunavut - Studies have been initiated to assess the potential construction of a highway from Manitoba north to Rankin Inlet (WorldLingo 2011). In November of 2010, Manitoba Premier Greg Selinger and Nunavut Premier Eva Aariak signed a Memorandum of Understanding to undertake a feasibility study of the all-weather road that would start in Gillam, Manitoba, and link to Nunavut's communities along Hudson Bay's western shore (*i.e.,* Arviat, Whale Cove and Rankin Inlet) and potentially Baker Lake (White 2011). This would be the first all-weather road connecting Nunavut with the south.

Additional proposed roads are described in Table 1 for specific mine sites (*e.g.,* for Baffinland's Mary River Project).

3.3 Airstrips in Nunavut

There are only two paved runways in Nunavut: one at the Iqaluit Airport and one at the Rankin Inlet Airport (NAVCan 2011; Government of Nunavut [GN], Department of Economic Development and Transportation [EDT] 2009). Table 4 provides details of the airstrips.

Table 4: Paved Runways in Nunavut *

Location	Alignment Direction	Elevation (m)	Year Constructed
Iqaluit	South-east to north-west	22 (south-east end) to 34 (north-west end)	Originally constructed as Frobisher Bay Air Force Base 1940s - 1950s; converted for civilian use 1963
Rankin Inlet	South-east to north-west	27 (north-west end) to 29 (south-east end)	1978

* Source: NAVCan 2011.

Mine and exploration sites with known airstrips are listed in Table 1 (Section 3.0). It can be assumed that most of the mine and exploration sites listed in Table 1, as well as other previously active exploration and/or mine sites, are or were accessed by aircraft on remote gravel airstrips.

In 2010, a feasibility study was carried out to explore the options of paving the airstrip at the Cambridge Bay Airport as part of the Cambridge Bay Airport Improvements Project. The feasibility study included geotechnical investigations, permafrost thermal modeling, engineering evaluation and constructability assessment. Four runway paving options and one runway extension option without paving were evaluated to complete the feasibility study. Climate change was considered in the feasibility assessment by incorporating climate warming in thermal modeling simulations and in design recommendations. The feasibility study recommended a runway paving option with which to proceed if paving the runway will of the Cambridge Bay Airport will be the outcome of the Improvements Project (WorleyParsons Canada Ltd. 2010).

It is assumed that any proposed mine-related development activity in Nunavut would include plans to develop one or more airstrips. For example, the Baffinland Mary River project includes plans for three gravel airstrips. Two of the airstrips exist (one at Milne Port and another at the Mine Site; Table 1) but will require upgrades to accommodate project development. Plans exist to build the third airstrip at Steensby Port (Knight Piesold 2010).

Remote sites may alternatively have been accessed by temporary aircraft-capable ice airstrips which are not considered part of Nunavut's permanent infrastructure and are therefore not discussed in this report (Nuna Logistics Ltd. 2010d), or they may have been accessed through ports (Section 3.7) or beach landings.

3.4 Railways and Proposed Railways in Nunavut

There are currently no railway systems in Nunavut. However, an approximately 149 km long railway is currently proposed by Baffinland for its Mary River project south of Pond Inlet. The railway would extend from their Mary River project site to Steensby Inlet. It would be used to deliver iron ore from Mary River to a port in the inlet and also to transport supplies from the port to Mary River. The port (Section 3.7) would include rail loading and unloading facilities and rail service and maintenance facilities (Knight Piesold 2010; Baffinland 2008).

Note – The Draft EIS for the Mary River project was submitted in December 2010 (Knight Piesold 2010)*, and the final EIS (Baffinland 2012) for the project was submitted in February 2012, after the submission of the Task 1 and Task 2 Draft Reports. Throughout this Report, references are made to the Draft EIS and only if development plans have changed, the changes are described and the final EIS is cited.*

The proposal includes 24 bridges, 2 tunnels and over 200 culvert crossings along the railway. The design of the railway has been adjusted to the local permafrost and ground conditions. The ground over which the railway will be built has continuous permafrost, with an active layer between 1 and 3 m in thickness. Ground conditions vary along the railway and site investigations have been undertaken to define areas with thaw-sensitive soils so that the railway can be routed to avoid these areas where possible. Thaw-sensitive soils that cannot be avoided will be addressed through embankment design with the following methods (to the extent possible):

- use quarry-run fill that allows embankments to self ventilate to maintain ground thermal regime;
- place additional fill when aligning structures rather than cutting into the ground;
- maintain current water drainage patterns, which can change the thermal regime of the ground if altered; and
- excavate thaw-sensitive and ice-rich soils in select instances (Knight Piesold 2010).

3.5 Identified Vulnerabilities of Roads, Airstrips, and Railways in Nunavut to Climate Change

3.5.1 Permafrost

There are recognized challenges in designing infrastructure on permafrost. In particular, processes such as frost heave and freeze-thaw settlement in permafrost can damage overlying structures such as roads, airstrips and railways (i.e., embankments; Section 3.1; TAC 2010; ArcticNorth 2009; Dillon Consulting Ltd. 2007; Instanes *et al.* 2005). Permafrost degradation often reduces slope stability, resulting in slope movement such as creep (downslope displacement of soil) and slumping, which can threaten pile foundations, dikes, and bridges (TAC 2010; Dillon Consulting Ltd. 2007; Instanes *et al.* 2005). Freeze-thaw damage is highest in areas of thaw sensitive ground, *i.e.,* ice-rich soils (Section 3.1; Kiggiak-EBA Consulting Ltd. 2011; Knight Piesold 2010; Instanes *et al.* 2005; US Arctic Research Commission Permafrost Task Force 2003).

In terms of climate change, increase in air temperature is expected to reduce the extent of permafrost and increase active layer thickness, which will likely result in changes in transitions between permafrost zones of continuous, extensive discontinuous, sporadic discontinuous, and isolated patches (Section 3.1; Instanes *et al.* 2005; Walsh *et al.* 2005). Although infrastructure damage due to frost heave and freeze-thaw settlement often occurs when the current permafrost design and engineering principles outlined in Section 3.1 have not been carefully followed, it is expected that climate change may significantly contribute to infrastructure failure and require additional adaptive measures (Fortier *et al.* 2011; Kiggiak-EBA Consulting Ltd. 2011; TAC 2010; Instanes *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003).

In areas of continuous permafrost, the permafrost layer and surface conditions are generally colder than in the extensive discontinuous and sporadic discontinuous permafrost zones (Section 3.1). In cold conditions, seasonal thawing is usually effectively mitigated by increasing embankment thickness, which shields underlying permafrost from heat gain (Kiggiak-EBA Consulting Ltd. 2011; TAC 2010; Instanes *et al.* 2005). However, embankments on thaw-sensitive soils (Section 3.1) in zones of continuous permafrost are vulnerable to increases in air temperature, and this must be considered in its design (TAC 2010; Instanes *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003). Embankment failures due to permafrost thawing in these areas are likely to occur more frequently as air temperature increases (TAC 2010; Instanes *et al.* 2005; Humlum *et al.* 2003). This will result in higher maintenance costs as more frequent repairs will be required (Fortier *et al.* 2011; TAC 2010; Dillon Consulting Ltd. 2007; Instanes *et al.* 2005; Humlum *et al.* 2003). It is more costly to construct and repair paved surfaces than unpaved surfaces. As such, the increase in cost of repairing paved surfaces will be more pronounced than that for unpaved surfaces as the occurrence of embankment failures increase (TAC 2010).

3.5.2 Precipitation / Extreme Weather Events

Snow and rain can lead to embankment damage in permafrost areas. Embankments can act as a snow fence, where snow accumulates on embankment shoulders and toes (Fortier *et al.* 2011). Snow cover has a thermal insulation effect preventing heat loss thereby reducing the cooling of permafrost in the winter. As a result heat is gained, which can result in permafrost thaw (Fortier *et al.* 2011). Upon snowmelt, standing water can also accumulate on the sides of embankments and have the same insulation effect (Kiggiak-EBA Consulting Ltd. 2011; TAC 2010).

Embankment washouts are common in northern Canada during snowmelt, especially when combined with intense rain (*i.e.,* flash freshets; Kiggiak-EBA Consulting Ltd. 2011; TAC 2010). Drainage structures, such as culverts and bridges, are used to accommodate extreme weather events such as freshet flows, but their success is limited by knowledge of local drainage patterns. Background studies are required to determine proper placement and type and/or size of culvert (Kiggiak-EBA Consulting Ltd. 2011; TAC 2010).

Increases in these extreme weather events, as potentially expected to occur across Nunavut (Section 2.2 and 2.3) can potentially decrease slope stability resulting in an increase of slides of soil and rock (*e.g.*, landslides; Instanes *et al.* 2005; Welsh *et al.* 2005). Factors such as ground water regime, erosion from surface water flow and freeze-thaw can increase the occurrence of landslides. Intense periods of rainstorms or rapid melting of snow and ice can lead to an increase in pore water pressure and erosion, which reduce slope resistance resulting in slope failure (Instanes *et al.* 2005). Consequently, an increase in extreme weather events is likely to result in an increase in road, airstrip and railway closures (Instanes *et al.* 2005).

Rain is also an important aspect in unpaved infrastructure maintenance, such as dust suppression during summer months. Dust produced from roads can impact health, safety and the environment (GN, Department of Sustainable Development, Environmental Protection Service 2002). In Nunavut, three approved dust suppressants are used but they are ineffective if applied in or before rain. Rain can wash away the suppressants, and potentially into water bodies. If concentrated in water bodies, the suppressants are toxic and will impact wildlife and habitat (Kiggiak-EBA Consulting Ltd. 2011; GN, Department of Sustainable Development, Environmental Protection Service 2002). Weather predictability is expected to decrease in the Arctic (Section 2.3; Welsh *et al.* 2005), which may complicate dust suppressant application.

3.5.3 Air Temperature

Besides the impact of air temperature increases on permafrost (Section 3.5.1), one consequence of a warming trend is that the length of operation time for winter roads and ice bridges may shorten. Consequently, it may be required that dependence of transportation systems on ice routes be shifted to open-water, air-based and/or land-based systems (Rawlings *et al.* 2009; Infrastructure Canada, Research and Analysis Division 2006; Instanes *et al.* 2005). In a study of winter roads and ice bridges in the NWT by Rawlings *et al.* (2009), it has been observed that in most cases the mean length of operation time for winter roads and ice bridges has decreased over the past years, and the decrease in the length of operation time corresponds to increases in global average air and ocean temperature. But in some cases, the recorded length of season has actually *increased* over time (Section 3.6.1).

Increases in air temperature can also result in an increase in the occurrence of freezing rain and frosting, which raises airstrip safety concerns (Section 2.1; Dillon Consulting Ltd. 2007). Freezing rain and frost on airstrips is likely to decrease friction between aircraft tires and runway. Consequently, airplanes may experience issues in braking and may result in airplanes sliding off airstrips (LPS Aviation Inc. 2007).

3.6 Adaptation Measures to Address Potential Climate Change Impacts on Northern Roads, Airstrips, and Railways

In the TAC publication *Guidelines for Development and Management of transportation Infrastructure in Permafrost Regions* (2010), a risk-based approach is recommended for incorporating climate change considerations into infrastructure design on permafrost. The objective is to find a fiscally responsible solution to balance between initial costs and future costs (TAC 2010). The context of the approach is formed in consideration of:

- the likelihood and severity of permafrost degradation potentially resulting from construction activities and climate warming; and
- the related consequences on the performance of the road, rail and/or airstrip and degradation of the surrounding environment (TAC 2010).

Assessing Permafrost Sensitivity

Permafrost sensitivity to temperature can be qualitatively assessed by considering soil type and ground ice content, where ice-rich soils are the most thaw-sensitive. To obtain this information, thorough geotechnical investigations of the study area must be completed (TAC 2010). Table 5 outlines the sensitivity of soil types according to different permafrost temperature zones. Note that Zones 3 and 4 coincide with continuous and Zones 1 and 2 with discontinuous permafrost.

Table 5: Classification of Sensitivity by Soil Type and Permafrost Temperature *

Type of Soil	**Permafrost Temperature Zone**			
	Zone 4 (T<-7°C)	**Zone 3** (-7°C≤T<-4°C)	**Zone 2** (-4°C≤T<-2°C)	**Zone 1** (-2°C≤T<-0°C)
Any soil containing massive ice	M	H	H	H
Peat and organic	L	M	H	H
Lacustrine (silt or clay)	M	M	M	H
Glacial tills	L	L	L	M
Marine soils with salinity	M	M	H	H
Alluvial and glaciofluvial (sand or gravel)	L	L	L	M
Frost-shattered rock	L	L	M	M

L - Low sensitivity; M - Medium sensitivity; H - High sensitivity.

* Source: Etkin 1998 as cited by TAC 2010.

Ideally, areas of high sensitivity to temperature changes should be avoided. If it is not feasible to avoid these thaw-sensitive areas, adaptation measures can be considered to reduce damage to infrastructure (Section 3.1). It is apparent that warmer permafrost temperatures (Zones 1 and 2) possess a higher sensitivity to temperature changes and that therefore temperature increases should be mitigated through engineering design wherever possible.

Assessing Consequences of Infrastructure Failure

Infrastructure failure refers to deformations (*e.g.,* cracks, settlements and potholes) that require rehabilitation. Rehabilitation refers to repairs beyond regular maintenance procedures that have not been planned to occur during the life-time of the structure (TAC 2010).

To assess the consequences of road, airstrip and railway failure, the severity of damage can be considered in a relative sense. For example, permafrost related infrastructure failures, such as settlements, may not force a road closure. However, similar settlements in an airstrip can force closure (TAC 2010). The consequences of impact are higher in remote areas where access is restricted to limited airstrips and roads.

The availability of knowledge on infrastructure and permafrost conditions may differ between locations, so site-specific information is critical in accurately assessing risk and consequence (TAC 2010). Figure 2 shows the relative consequences of permafrost degradation to roads, airports and railways in different permafrost conditions.

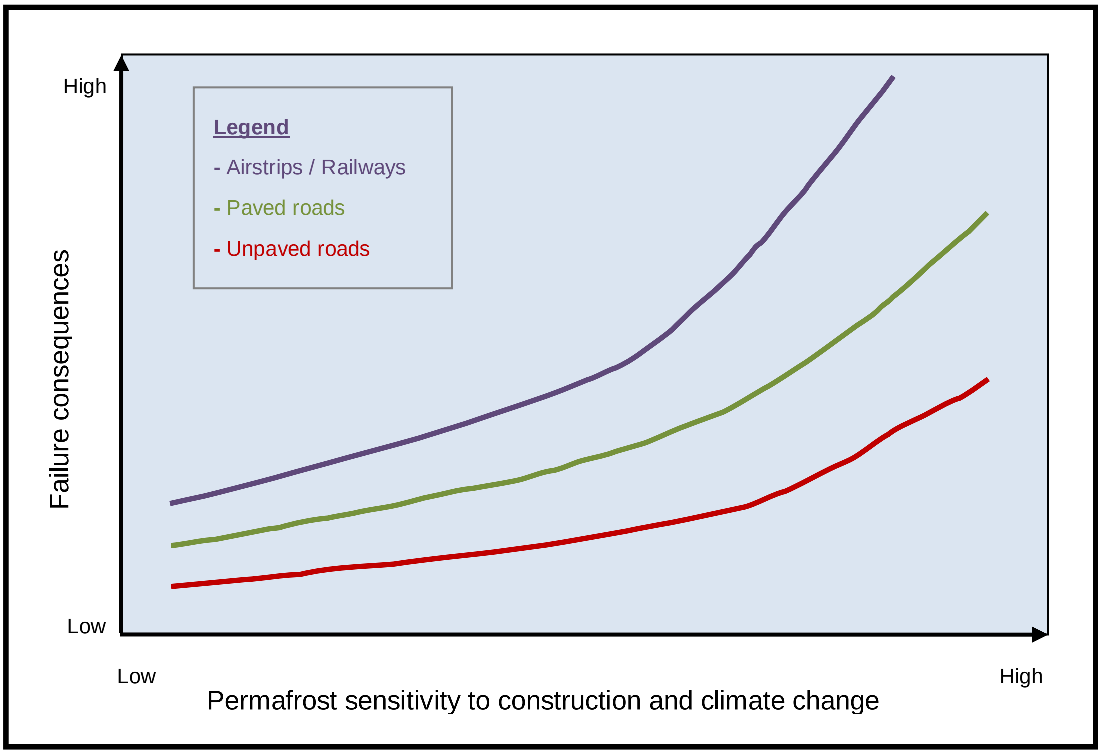

Figure 2: Relative Consequences of Permafrost Degradation on Different Transportation Facilities (Modified from TAC 2010)

Adaptation

Design, construction, operation and maintenance methods have a significant effect on embankment stability. The following are recommended measures to incorporate into embankment design to manage uncertainty in future climate change scenarios in permafrost regions (TAC 2010):

- construction of thick embankments that insulate and stabilize the active layer;
- flattening sideslopes and widening shoulders, which will reduce snow accumulation on embankments and push ponded water further from the embankment toe (Section 3.1);
- use of porous rock (*e.g.,* quarried-run rock) in construction to reduce the risk of ponding on sideslopes (because they facilitate drainage);
- utilization of construction methods that minimize disturbance of vegetation, soil exposure, and avoids cuts into ground before fill material (for embankment) is placed;
- use of passive methods and protection techniques (*e.g.,* limiting heat penetration, enhancing winter heat extraction and/or reinforcement; Section 3.1) to retain permafrost and improve embankment integrity; and
- in mountainous terrain, permafrost related terrain hazards must be carefully acknowledged when designing highway embankments and drainage structures.

Increasing embankment thickness is generally effective in regulating the subsurface thermal regime and is the most commonly used measure in mitigating temperature increase of permafrost (Kiggiak-EBA Consulting Ltd. 2011; TAC 2010; Instanes *et al.* 2005). It is possible that thickening embankments alone may be inadequate in shielding continuous permafrost areas, where active layer thickness is expected to increase due to air temperature increases (Instanes *et al.* 2005). Changes in embankment design and maintenance will likely be required to adapt to the expected change in permafrost regime (Section 3.1; Instanes *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003).

In zones of warm permafrost (Zones 1 and 2), there is a lack of economically feasible methods to mitigate embankment failure due to high costs and because it is more difficult to maintain freezing temperatures than in cold permafrost (Instanes *et al.* 2005). Some techniques, such as thermosyphon, air duct, heat drain, and air convection cooling have demonstrated success in a limited number of cases in maintaining freezing ground temperatures by facilitating ground heat loss (*i.e.,* heat extraction) to mitigate frost heave and thaw settlement (Section 3.1; TAC 2010; Instanes *et al.* 2005). The high cost of operating these measures has discouraged their use in embankment failure prevention (Instanes *et al.* 2005; U.S. Arctic Research Commission Permafrost Task Force 2003; Table 6).

Alternatively, construction of berms can flatten sideslopes to reduce snow accumulation and ponding. Snowsheds or sunsheds can serve a dual purpose in mitigating permafrost temperature increase: in the winter, snowsheds reduce snow accumulation on embankment slopes and in the summer, sunsheds prevent direct solar radiation on embankment slopes (Section 3.1; TAC 2010).

Table 6 lists techniques to mitigate increases in permafrost temperature and associated relative costs. The relative costs of the techniques are subject to change because site-specific factors (*e.g.,* availability of materials, expertise and equipment) will affect implementation costs of the different adaptation methods. All techniques are described in Section 3.1.

Table 6: Applicability and Relative Cost of Adaptation Techniques *

Technique	Continuous (Cold) Permafrost	Discontinuous (Warm) Permafrost	Sporadic Permafrost	Maintenance Requirement	Comments
Embankment thickening	$	$$	$$$	N/A**	Applicability and cost depends on material availability.
Insulation (polyurethane and peat)	$$$	$$$ [a]	N/R***	Low	Bulky material needs to be imported. [a] More effective if used in combination with heat extraction methods.
Sunsheds / showsheds	$$$	$$$	N/R	High	High level of maintenance.
Reflective surface	$$$	$$$	N/R	High	High level of maintenance.
Air ducts	$$$$	$$$$	N/R	Moderate	Possible solution if well designed to avoid water accumulation in ducts.
Thermosyphons	$$$$$	$$$$$	N/R	Moderate	More suitable for severe localized problems.

Table 6: Applicability and Relative Cost of Adaptation Techniques * (continued)

Technique	Continuous (Cold) Permafrost	Discontinuous (Warm) Permafrost	Sporadic Permafrost	Maintenance Requirement	Comments
Air convection embankment	$$$$	$$$$	N/R	Low	Promising technique. Requires competent rock and capacity to produce specified material near construction site.
Heat drain	$$$$	$$$$	N/R	Low	Bulky material needs to be imported. Promising technique.
Geotextile and geogrid	$$$$	$$$$	$$$$	Low	Likely to reduce settlement and cracking problems.
Berms	$$$	$$$ [b]	N/R	Low	[b] More effective if used in combination with heat extraction methods. Granular material needs to be available.
Pre-thawing	$$$	$$$	$$$	N/A	Possible solution if time permits.
Excavation / replacement	$$	$$$	$$$$	N/A	Availability of granular material.
Snow removal	$$$	$$$	$$$	N/A	Labour intensive solution. Requires a service center near the site to be protected.

░	Suggested application.
▓	Application possible but not optimal.

* Source: Beaulac *et al.* 2004 as cited by TAC 2010.

** N/A: not applicable.

*** N/R: not recommended.

NOTE - $, $$, $$$, $$$$, $$$$$ is a relative scale, where $ presents the lowest relative cost and $$$$$ the highest.

Water drainage is also a concern in regulating permafrost temperature. Topographical analyses of local seasonal drainage patterns must be completed to ensure bridges and culverts are designed and placed in areas best to withstand extreme weather events associated with precipitation, such as flash freshets (TAC 2010).

3.6.1 Winter Roads and Ice Bridges

Rawlings *et al.* (2009) point out that operational considerations (*i.e.,* maintenance) and changes in precipitation may over-ride trends in temperature resulting in an increase in operating season length. Drier conditions over the operating season and/or drier winters may lead to longer operating seasons. Current operational practices that may help lengthen operating seasons include:

- spraying ice roads and ice bridges with water to thicken ice structure;
- monitoring ice sheet thickness with ground penetrating radar;
- plowing snow off the road to enhance the freezing effect (snow has an insulating effect); and
- restricting hauling to hours of darkness towards the end of the season when the ice sheet is stronger.

These techniques could be applied to other roads and ice bridges in the North to adapt to the changing climate. Additional studies of operational practices and climatic parameters are required to further adaptation techniques of ice roads and ice bridges to climate change (Rawlings *et al.* 2009).

3.6.2 Suggested Research and Policy Action

There is little consensus on the changes in depth of the active layer above permafrost due to climate change. One study suggested that the active layer is very likely to increase by more than 50% by 2050 (Walsh *et al.* 2005). A number of climate change models have projected a reduction in the extent of continuous permafrost, up to a 41% reduction by 2080 (Walsh *et al.* 2005). Data used in the models do not necessarily reflect regional or local conditions, namely soil characteristics and vegetation, and there is uncertainty associated with these projections (Walsh *et al.* 2005). Improving knowledge of regional soil and vegetation characteristics would help to improve localized model projections of changes in permafrost conditions (Walsh *et al.* 2005).

An important issue is the lack of on-site climate data, particularly precipitation. This is crucial for flood analysis and in determining design floods. Furthermore, there are generally short-term records for stream flow in project areas. The commonly accepted approach is to utilize information from other stations within the region or in adjacent regions to extrapolate to site conditions. However, it is recognized that there are uncertainties related to this method and it is suggested to collect data on-site for a longer period of time.

3.7 Ports and Proposed Ports in Nunavut

This section of the report on ports in Nunavut primarily addresses docks, breakwaters and other infrastructure that intrudes into or is adjacent to the coastline. These structures could be impacted directly or indirectly by the marine environment as well as climate change. Climate change could also have impacts on the marine environment and therefore have additional impacts on ports. Discussions of other types of onshore port infrastructure that could be impacted directly or indirectly by the terrestrial environment (*e.g.,* roads, airstrips, railways) are presented elsewhere in this report (Section 3.5 and Section 3.6).

Existing Ports and Breakwaters

NRCan's Atlas of Canada's Marine Transportation map lists 28 ports in Nunavut, including one at the former Nanisivik mine site. These ports and their classifications as a Regional / Local Port or a Remote Port (NRCan 2008) are summarized in Table 7. Further information on each port includes: the open water season, the conditions of community landing beaches, and whether there is a push-out and/or public dock available (GN, Department of Economic Development and Transportation [EDT] 2009).

The list of ports presented below is included in this report because mining and other development activities taking place in Nunavut may utilize existing infrastructure, or potentially select these locations for further port development activities. These ports could be vulnerable to potential impacts that climate change could have on the coastal environment. These potential impacts include permafrost disturbance, sea level rise, changing sea ice duration and changing length of open water season, each of which is described further below.

Table 7: Existing Ports in Nunavut *

Location	Type of Port	Current Open Water Season	Landing Beach Type	Public Dock
Arctic Bay	Regional / Local Port	Aug-Sept	Gravel	No
Arviat	Regional / Local Port	Jul-Oct	Gravel / rock	Yes
Baker Lake	Regional / Local Port	Jul-Oct	Gravel	Push out
Bathurst Inlet	Not specified	Aug-Oct	Sand / gravel	No
Cambridge Bay	Remote Port	Jul-Sept	Coarse gravel	Yes
Cape Dorset	Regional / Local Port	Jul-Oct	Sand / gravel	Yes
Chesterfield Inlet	Regional / Local Port	Jul-Oct	Sand / gravel	Yes
Clyde River	Regional / Local Port	Jul-Sept	Sand / gravel	No
Coral Harbour	Regional / Local Port	Jul-Oct	Gravel	Push-out and dock
Gjoa Haven	Not specified	Jul-Oct	Soft sand	Yes
Grise Fiord	Regional / Local Port	Aug-Sept	Sand / gravel	No
Hall Beach	Regional / Local Port	Aug-Sept	Sand / gravel	No
Igloolik	Regional / Local Port	Aug-Oct	Sand / shingle	No
Iqaluit	Regional / Local Port	Jul-Oct	Rock / shale / mud / sand	Yes
Kimmirut	Regional / Local Port	Jul-Nov	Clay / gravel	No
Kugaaruk	Not specified	Aug	Clay / gravel	No
Kugluktuk	Not specified	Jun-Oct	Dock	Yes
Nanisivik	Remote Port	Jul-Oct	Dock	Yes
Pangnirtung	Regional / Local Port	Jul-Sept	Gravel	Yes
Pond Inlet	Regional / Local Port	Aug-Sept	Sand / gravel	No
Qikiqtaarjuaq	Regional / Local Port	Jul-Oct	Sand	No
Rankin Inlet	Regional / Local Port	Jul-Oct	Gravel	Push-out and dock
Repulse Bay	Regional / Local Port	Aug-Sept	Gravel	No
Resolute Bay	Regional / Local Port	Aug-Sept	Sand / gravel	Push-out
Sanikiluaq	Not specified	Jul-Oct	Gravel	Push-out
Taloyoak	Regional / Local Port	Jul-Sept	Sand / gravel	Yes
Umingmaktok	Not specified	No data	Sand / gravel	No
Whale Cove	Regional / Local Port	Jul-Oct	Boulders / gravel	Push-out and dock

* Sources: NRCan 2008; GN, EDT 2009.

Breakwater structures which serve to protect harbours, boats and equipment from rough ocean waters (Ganley 2008) also exist in several Nunavut communities (*e.g.,* Iqaluit, Kugluktuk, and Pangnirtung).

Note – This Report addresses oceanic ports only. It is acknowledged that freshwater ports do exist in Nunavut which may be used for mining-related purposes, e.g. port infrastructure exists at the community of Baker Lake *on the water body of Baker Lake, which is used by the Meadowbank project. This section focuses on the impacts of climatic parameters on marine coastal port infrastructure only.*

Proposed Ports and Breakwaters

Iqaluit

During the 2005-2006 federal election, it was announced that a military / civilian deep-water port would be possibly constructed in Iqaluit. Three armed naval, heavy icebreakers would be based at this port. The aim of this project was to enhance Canada's Arctic defences with a deep-water port, where large vessels could directly reach the shore. In 2007, it was announced that the deepwater port would be built in Nanisivik rather than Iqaluit (see below; CASR 2007).

In January 2010, the GN developed several design options for a deep-water port which it presented at a city council meeting in Iqaluit. The options included one layout located on Polaris Reef which would have good access for ships, but only a launch ramp for boaters. Another option was for the deep-water port to be built on top of the community's old causeway. This option would include a small craft dock but would be less suitable for cargo ships (Ridlington 2010; Windeyer 2010).

There are also three design options for expanding the small craft harbour at the municipal breakwater in Iqaluit. Two of the designs are at the existing breakwater site, and the third option is at the city's old causeway (Ridlington 2010).

Nanisivik

In August 2007, it was announced that a deep-water port would be constructed at the location of the existing port facility at Nanisivik; the existing port facility was associated with a former mine site. The Nanisivik port has existing dock and refueling infrastructure (*i.e.,* fuel tank storage facilities; CBC News 2007; CASR 2007).

A contract was awarded to an engineering firm in 2009 to help design the deep-water (naval) port at Nanisivik on behalf of the Canadian Forces, with work to include planning and design developments and the preparation of construction estimates for the port (BC News 2009). Construction is expected to begin in 2013 and the port is estimated to be operational by 2016 (Lytvynenko 2011).

Bathurst Inlet Port and Road (BIPAR Project) - A deep-water port project has been proposed for Bathurst Inlet, as part of the BIPAR Project (Section 3.2). The port would be located 35 km south of the community of Bathurst Inlet. It would include a dock, barges, a camp (large enough for up to 200 people), a truck maintenance shop, diesel fuel tank facility (with 18 large fuel storage tanks), and a 1,200 m airstrip (George 2011; Quenneville 2010). However, the BIPAR Project was recently halted (Section 3.2).

Milne Inlet and Steensby Inlet (Mary River Project)

Baffinland submitted a Draft EIS to the NIRB in December 2010 and a final EIS in February 2012. These documents provide details on Baffinland's proposed Mary River Project, located on Northern Baffin Island, which aims to extract and ship iron ore to international markets. To facilitate this, Baffinland is intending to construct two ports (Baffinland 2012; Knight Piesold 2010):

- Milne Port (in Milne Inlet) – accessible from the mine site by the Milne Inlet Tote Road (Section 3.2); the port would operate during the open water season only; and
- Steensby Port (in Steensby Inlet) – accessible from the mine site by a newly constructed railway (Section 3.4); the port would operate year-round, requiring the use of vessels with ice breaking capabilities.

Milne Port

Milne Inlet is a narrow fjord with deep waters (100+ m deep) and steep surrounding headlands with primarily rock cliff shorelines. Portions of the shoreline of the fjord consist of alluvial fans and raised beach ridges. Milne Port would be located at the southern tip of the inlet on a fjord-head delta. The port would operate during the open water season only (Baffinland 2012; Knight Piesold 2010).

Many of the existing facilities at the Milne Port would be utilized and expanded early in the construction phase. Existing facilities include a personnel camp, water supply and treatment facilities, mobile diesel generators, a sewage treatment plant, an incinerator, fuel bladder tanks, borrow areas, rock quarries, a laydown area, an airstrip, and a temporary bulk sampling ore stockpile area. Additionally, ore stockpile areas, an ore dock and loading facilities would be constructed to facilitate project operations at the port. A permanent freight dock would also be constructed, but prior to its completion, early shipments would use barges that would be beached and offloaded. The ore and freight docks would be constructed approximately 80 m apart from each other to facilitate safe port operations (Knight Piesold 2010).

Characteristics of the two proposed dock options at Milne Inlet include (Knight Piesold 2010):

- <u>one freight dock</u> – this dock would be used to handle freight and fuel during construction and operation. Tug berths are proposed for both ends of the dock. Proposed construction requires dredging and levelling of the seabed, placement of a gravel pad, installation of precast concrete cribs / caissons transported to site and sunk in place on the prepared seabed then backfilling them with dredged material or sand (*i.e.,* all dredged materials expected to be used as fill for the cribs or backfill for the freight dock). Additional infrastructure include civil, electrical and mechanical utilities, sub-base, base & finishing surface; and fenders, bollards, docking aids and environmental monitoring systems; and
- <u>one ore dock</u> – this dock would be used to load ore onto ore transport vessels. The ore dock is comprised of permanent structures which will remain in the seabed and onshore year round and of floating structures for use in open water season which will be removed in winter. The facility incorporates sunken barges to support floating infrastructure and floating barges to support ore conveyors and shiploaders. Proposed construction requires dredging and levelling of the seabed, placement of gravel pad, installation of sheet piles, and backfilling of the ore dock with dredged material (excess materials to be used to backfill the freight dock). Additional infrastructure includes civil, electrical and mechanical utilities, sub-base, base & finishing surface, fenders, bollards and mooring buoys.

The docks at Milne Port may be particularly vulnerable to changing oceanic conditions due to climate change, due to their direct exposure to fluctuating sea levels, currents and coastal erosion (Section 3.8). To protect against the erosive forces of the ocean, both docks would utilize riprap (a foundation of broken stones supplied from a nearby quarry) for scour protection in their construction. Additionally, the ore dock would have breakwaters on either side of it (Knight Piesold 2010).

It was determined not feasible to transport ore by road to Milne Inlet and an ore dock at Milne Inlet is currently not considered in the final EIS. Instead, transporting ore by rail from the mine site to Steensby Port is the planned delivery option (Baffinland 2012).

Steensby Port

Steensby Inlet is a wide bay with shallow waters (typically less than 100 m deep) and surrounding low-relief terrain. Shorelines include wide tidal flats, lagoon complexes, and mixes of bedrock and coarse, sedimentary, alluvial materials. Steensby Port would be located on the inlet's eastern shore, approximately 50 km into the inlet. Facilities at the port would be located in Steensby Inlet as well as on nearby Steensby Island. It is anticipated that the port and associated railway would take four years to construct, and then once the railway was operational, the port would be used for year-round shipping operations, with ore being transported from the mine site to Steensby Port on the railway. Stockpiled ore would be stored at the port (*i.e.,* on Steensby island) until loaded onto the ore carriers (Knight Piesold 2010).

A dedicated fleet of ice-breaking cape-size (*i.e.,* cargo ships too large to traverse the Panama Canal; Maritime Connector 2011) ore carriers will transport most of the ore from Steensby Port to market, with the additional use of supplementary ships chartered on the open market during the open water season. Resupply sealifts would likely be delivered to Steensby Port during the open water season only (*e.g.,* mid-July through mid-October) with supplies then moved from the port to the mine site on the railway. However, various freight and oversized equipment that would not be able to move through the tunnels on the railway would be directed to Milne Port (see above; Knight Piesold 2010).

The Steensby Port site is proposed to include temporary construction docks, a freight dock, ore management and port site facilities. The ore management facilities include a rotary rail car dumper, ore stockpiles, a rail-mounted stacker / reclaimer system, a secondary screening plant, and an ore loading dock. The port site facilities include a power generating station, communications system, service / administration / accommodation buildings, a maintenance shop / main office, portable water treatment system, wastewater treatment system, tank farm, incinerator, airstrip, navigational aids, site roads, railway maintenance facilities and offices, and a rail yard; (Knight Piesold 2010).

With respect to docks, the Steensby Port facilities would initially include two temporary construction docks - one on Steensby Island (to facilitate construction of the ore dock and ore handling systems) and one on the mainland (to support all other construction activities at the port). During the construction phase, Baffinland would build the permanent port infrastructure, including a freight dock on the mainland and an ore dock on Steensby Island (Knight Piesold 2010).

Characteristics of the proposed docks at Steensby Inlet include (Knight Piesold 2010):

- <u>two temporary construction docks</u> – these docks would be used to handle freight during the construction phase. Concrete caissons would be built into temporary docks for use during construction and these would be pre-positioned during the open water season before construction to enable material and equipment unloading during the first year of construction, prior to the arrival of major sealift deliveries;

- one freight dock – this dock would be used to receive and handle freight and fuel during the operation phase. Proposed construction would not require underwater blasting, but would be require the placement of fill to form level pads, installation of caissons on the pads and backfilling them with locally quarried aggregate; and
- one ore dock – this dock would be used during the operation phase to receive the ice-breaking ore carriers and non ice-breaking class ships during the open water season. Proposed construction requires blasting / dredging and levelling the seabed, installation of discrete caissons to be backfilled with dredged / excavated materials and local aggregate, followed by completion of the dock superstructure and trestle to the island.

Additionally, Baffinland would require a crossing to access Steensby Island. A combination bridge-causeway structure would be constructed to link infrastructure on the mainland to the island. The crossing would allow access for vehicles and also support conveyors that would move ore from the railway car dumper on the mainland to the ore stockpiles on the island. It would require no blasting in its construction, and would be built from both directions by placing fill (appropriately sized to withstand ice loading) during the open water season (Knight Piesold 2010).

Hope Bay (Hope Bay Project) – Newmont's Hope Bay project, which has been postponed indefinitely (Section 3.2), has limited port facilities in Roberts Bay (in Hope Bay). The bay has a shallow shelf that extends out (*e.g.,* to an estimated 4 m depth at 100 m distance from the shoreline at the jetty), and the bay is surrounded by gently rolling rocky terrain and a rocky shoreline (S. Martin, Bargemaster of accommodations barge on site, pers. comm., November 2011).

At Roberts Bay, the only existing port-related infrastructure is the Roberts Bay Jetty which is used to facilitate supply barge loading and unloading. The jetty was constructed in 2008 and is oriented north-westly extending about 100 m out into the bay with a 12 m wide crest. It is comprised of gravel and an embedded steel mesh for structural strength and resistance to coastal erosion (S. Martin, Bargemaster of accommodations barge on site, pers. comm., November 2011; NIRB 2010; SRK Consulting Inc. [SRK Consulting] 2009a). In 2010, two land-based mooring points were established, with plans to set up more (NIRB 2010). In March 2009, two sets of thermostat cable and temperature logger units were installed in the Roberts Bay Jetty to monitor the permafrost regime under the jetty (NIRB 2010). Results from the monitoring are expected to provide knowledge on the current status of the coastal and subsea permafrost and forecast long-term changes.

One resupply vessel arrives at Roberts Bay each year to provide the mine site with machinery, equipment and necessities. These large vessels moor approximately 800 to 1000 m offshore and then smaller barges ferry the supplies in stages to the jetty where the materials are offloaded (*e.g.,* using ramps and/or cranes). The bay is too shallow to enable the larger vessels to get closer to shore (S. Martin, Bargemaster of accommodations barge on site, pers. comm., November 2011).

There were plans to enhance the end of the jetty in winter 2011 with the addition of dock sheet piling along its side. This would facilitate the easier off-loading of materials from the ferrying vessels (S. Martin, Bargemaster of accommodations barge on site, pers. comm., November 2011; NIRB 2010) and presumably provide more stability to the jetty while protecting its end from erosive forces.

As part of Phase 2 of its Hope Bay Project, Newmont planned for new infrastructure components, including the development of an expanded port.

3.8 Identified Vulnerabilities of Northern Ports to Climate Change

Canada has the world's longest coastline for any single country, with a total 243,042 km of coastline including the mainland and offshore islands (Statistics Canada 2011). Of this, approximately 200,000 km of coastline is found in the Canadian Arctic (Instanes *et al.* 2005), with Nunavut having approximately 45,000 km (or 18.5%) of coastline (Nunavut Tourism 2011; Noweczek 2010).

Although most of the Arctic's coastline is uninhabited, coastal development is important to Northern residents, with natural resource development often concentrated along the coastline (Instanes *et al.* 2005). Ports are currently located and/or planned to be constructed across Nunavut, with port infrastructure including docks, jetties, breakwaters and causeways that extend from the shoreline into the marine environment. These structures, and the potential impacts of a changing climate are addressed in the following sections.

Additional onshore infrastructure that could be located at and/or around ports may include buildings, stockpile areas, loading and unloading facilities, tank farms and fuel storage areas, airstrips, roads, and railways. These infrastructure components are addressed if their presence is within the direct or indirect influence zone of the marine and coastal environment. The potential impacts of climate change on infrastructure components located in terrestrial environments are described elsewhere in this Report.

In addition to the protection of infrastructure, it is important that the natural coastal dynamics are well understood to minimize environmental impacts of port developments. Coastal environments may be characterized as including sediment source areas and sediment sink areas connected by transport zones. The development of port infrastructure (e.g. groynes, breakwater and jetties) may interfere or alter the natural sediment transport environment such that natural rates of erosion or deposition of sediment are impacted. Alteration of the natural coastal processes may result in environmental impacts at or nearby to the port facility. The potential for impacts by structures on natural processes which may be changing as a result of changing climate should be evaluated to assess the environmental implications of a proposed development.

3.8.1 Permafrost

All of Nunavut's coastline areas are within the zone of continuous permafrost (TAC 2010). Terrestrial continuous permafrost development is described in Section 3.1.

Coastal permafrost refers to geologic materials that have remained below 0°C for two years or longer and are found at or below sea level. They include onshore and offshore areas of permafrost that are impacted (directly or indirectly) by marine processes (Walsh *et al.* 2005).

Subsea permafrost is formed because of a negative mean annual sea-bottom temperature or through the inundation of terrestrial permafrost. The thermal regime of subsea permafrost is controlled by seawater temperature. Subsea permafrost is similar to terrestrial permafrost in that it may be covered by an active layer (Walsh *et al.* 2005). The distribution of subsea permafrost in the Arctic Ocean is not well known and it is likely that there are several areas of Nunavut's seabed that are underlain by permafrost (U.S. Arctic Research Commission 2003).

Coastal (and subsea) permafrost can be subdivided into four zones, as shown in Figure 3. The zones are based mainly on water depth and the dominant processes that operate in those depths. Zone 1 is the inter- and supra-tidal environment of beaches and flats. Zone 2 is seaward of Zone 1, and is the area where seasonal ice cover freezes to the seabed. Zone 3 is the area where the sea ice does not freeze to the seabed because it is too deep, but under-ice circulation may be restricted, resulting in higher salinities and lower seabed temperatures. Zone 4 is considered to have primarily 'normal' seawater salinity and temperatures (Walsh *et al.* 2005). Permafrost located in Zone 1 is referred to as coastal and permafrost located in Zones 2 and 3 is considered subsea permafrost (Walsh *et al.* 2005).

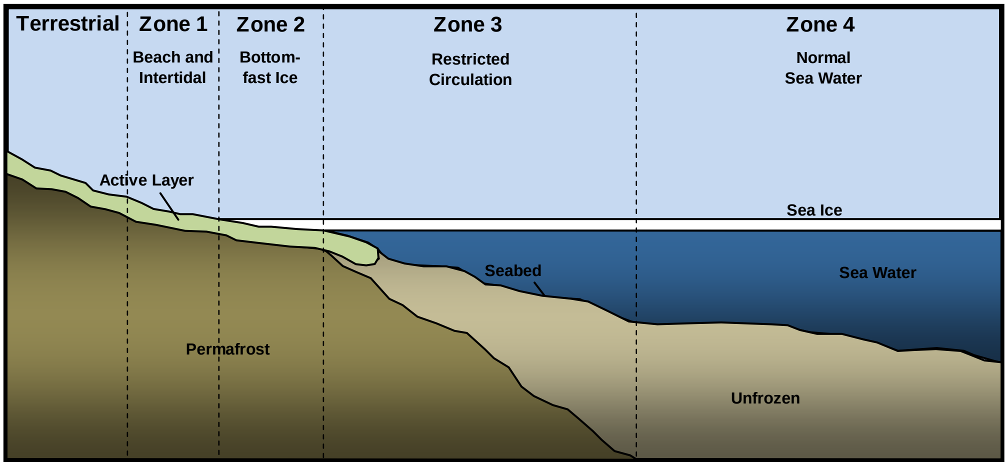

Figure 3: Coastal and offshore permafrost zones (redrawn from Walsh et al. 2005)

Climatic and Environmental Impacts on Permafrost

Coastal dynamics in the Arctic are often impacted (directly or indirectly) by the presence of permafrost (Instanes *et al.* 2005). Where terrestrial permafrost transitions to subsea permafrost, it is influenced by various intermediary environments that impact its distribution and conditions (Walsh *et al.* 2005).

The freezing point of sediments can be depressed below 0°C (*e.g.,* by the presence of salt or by capillary effects in fine-grained materials), so coastal and subsea permafrost may not be technically in a solid state (Walsh *et al.* 2005). In marine environments, the definition of frozen permafrost includes either ice-bonded (mechanically cemented by ice), ice-bearing (permafrost or seasonally frozen sediments containing some ice), or a mixture of both. The ice content of permafrost can consist of pore or interstitial ice in soil pore spaces, or it can consist of larger forms referred to as massive ice. Unfrozen fluids can be present in soil pore spaces in both ice-bonded and ice-bearing materials (Walsh *et al.* 2005).

In general, coastal permafrost conditions are impacted directly by oceanographic (*e.g.,* sea-ice thickness) and meteorological (*e.g.,* storm-surge frequency) processes (Walsh *et al.* 2005).

Direct influences on coastal permafrost include (Walsh *et al.* 2005):

- seawater temperature;
- sea-ice action;
- storm surges;
- wave action; and
- tides.

Indirect influences on coastal permafrost include (Walsh *et al.* 2005):

- erosion (*e.g.,* of cliffs and bluffs); and
- sea level rise (e.g. resulting lateral migration of Zone 2 and 3 permafrost).

As erosive processes degrade coastal permafrost areas, the ice along the shoreline is exposed to warmer air and water, causing it to melt. The thawing of permafrost typically results in thaw subsidence as the ice content of soils is lost. This thaw subsidence allows wave action to affect erodible materials, particularly in the Arctic's low-lying, ice-rich permafrost coasts (Instanes *et al.* 2005).

Coastal permafrost is vulnerable to climate change. Its stability is directly dependent on the magnitude of changes in water temperature and salinity, air temperature, sea-ice thickness, and coastal and seabed stability (Walsh *et al.* 2005).

Impacts of Permafrost on Ports

Coastal infrastructure can be impacted by decreases in coastal and subsea permafrost stability. Near-shore thaw subsidence can contribute to increased erosion rates and ground level subsidence, impacting infrastructure that is located close to the coast. Therefore docks can be vulnerable to warming and/or thawing permafrost due to the reduced foundation strength of the docks and associated pilings (*i.e.,* docks with structure components in Zone 1; Walsh *et al.* 2005). Additionally, the rebuilding or incorporation of new design elements for land-based port infrastructure in the Arctic may be required because of melting permafrost conditions (The World Association for Waterborne Transport Infrastructure [PIANC] 2008).

Baffinland discussed climate change effects to permafrost in its Draft EIS, noting that climate-induced changes to average snow cover could impact permafrost by increasing soil temperature, increasing active layer depths, increasing surface runoff, changing drainage patterns as a result of subsidence and thermokarst formations, and increasing sediment loadings and mass wasting on slopes (Knight Piesold 2010). In the coastal environment, these potential changes could contribute to shoreline erosion processes and impact port-related infrastructure. Baffinland predicts that its Mary River project will remain within the zone of continuous permafrost for the life of the project, but that the area's active layer depth will increase up to 50% and with that the permafrost thickness decreases (Knight Piesold 2010).

Further descriptions of permafrost impacts and associated coastal erosion rates are provided in Section 3.8.6 below.

3.8.2 Sea Level

Changes in sea levels and the vertical movements of land change the characteristics of entire coastlines. Holocene (10,000 to 12,000 years ago) changes in sea level have had a strong influence on coastal development worldwide. During the Pleistocene (2 million years ago), the growth and decay of ice sheets in the Northern hemisphere caused large fluctuations in sea levels; typically 100+ m along the coasts of Canada. Many factors contributed to these fluctuations; for example, sea levels were impacted as growing ice sheets reduced the amount of water in the oceans, but also land heights were impacted as the weight of ice sheets caused the depression of the land (followed by the rebound of the land when the ice sheets retreated, *i.e.,* isostatic rebound). Over geologic history, sea levels have rarely been where they are today, changing by different amounts and at different times around the world (Trenhaile 1998).

During the twentieth century, the global sea level has been estimated to rise an average of 1.7 millimeters per year (mm/yr), with rates slightly increasing since the 1960s. Climate model projections indicated that this rate could increase to 2.5 mm/yr during the twenty-first century for a rise of mean sea level of 0.2 to 0.6 m, accounting for both thermal expansion of the oceans and melting of the Antarctic and Greenland ice sheets, but estimates of a rise of up to 1 m have been proposed (PIANC 2008).

Climatic and Environmental Impacts on Sea Levels

It is expected that higher temperatures resulting from a warming climate will continue to cause higher sea levels. Contributors to higher sea level include increased melting of polar ice, ice caps and mountain glaciers as well as the thermodynamic expansion of warmer sea water (Instanes *et al.* 2005; Trenhaile 1998).

It is important to acknowledge that sea level rise can be a highly localized phenomenon, and that isostatic rebound plays a significant role in the relativity of sea level rise versus increasing land elevations. In general, in Northern Canada, glacial rebound can be up to a meter a century, demonstrating that the land is rising faster than the sea level (PIANC 2008) and therefore potentially decreasing or neutralizing rates of sea level rise.

As mentioned in the previous section, thaw of coastal permafrost may result in subsidence of the land as the ice content of soils is lost. In areas where shoreline fringe ice is reducing through increased temperatures, the insulating properties of the shore fringe ice are being reduced which may increase thaw subsidence. The combination of sea level rise and thawing of permafrost in coastal regions may result in locally enhanced rates of sea level rise.

Impacts of Rising Sea Levels on Ports

Rising sea levels could cause a diversity of impacts to coastal areas. These may include (PIANC 2008; Trenhaile 1998):

- tidal flooding / intensification of coastal flooding / increased overtopping and lowland flooding / inundation of marshes and coastal plains;
- intrusion of salt water into estuaries, rivers and groundwater / increased salinity of bays, rivers and groundwater;

- impacts to tidal range, oceanic currents, upwelling patterns, salinity levels;
- increases in and/or changes to runoff;
- increased penetration of wave energy to the coastline and into harbours, increasing coastal erosion (particularly in coastlines composed of soft sediments);
- increases in and/or changes to erosion patterns (*e.g.,* accelerated beach erosion, increased land-mass erosion such as landslides); and
- increased sedimentation at river outlets / reduced tidal flows in narrow straits and bay inlets.

A rise in sea level could have major impacts on harbour and port infrastructure, as well as the standard of service of coastal structures (Hesterman 2011; PIANC 2008). Impacts to ports could include (PIANC 2008):

- reduced top clearance between ships and overhead structures (*e.g.,* bridges, loading facilities);
- increased elevation at which wave forces attack a structure, potentially increasing the vulnerability of the structure;
- increased exposure of dock decks;
- increased corrosion rate and the degradation over time of materials that were specifically designed for a particular range of sea level conditions;
- more wave action / sea spray on navigational installations; and
- an increase in absolute low sea levels allowing greater under-keel clearance for vessels, possibly reducing the need for dredging in low sedimentation areas.

Baffinland discussed changes in sea levels in its Draft EIS, noting that sea levels have risen approximately 120 m over the past 20,000 years and that currently sea levels are estimated to be rising at 2 mm/yr (Knight Piesold 2010).

It is acknowledged that climate change could impact sea levels at Milne Port, but that changes to sea levels would not be an issue to the floating structures proposed for Milne Port. The fixed docks at Milne Port would also be designed to accommodate tide changes, storm surges and predicted sea level rises over the design life of the facility (Knight Piesold 2010).

The port facilities at Steensby Inlet are situated in an area of recognized falling sea levels because isostatic rebound in the area is greater than the rate of sea level rise. Studies for that port have predicted that when considering maximum isostatic rebound and minimum sea level rise, the sea level would fall by 1.39 m by the year 2100, and when considering minimum isostatic rebound and maximum sea level rise, the sea level would rise by 0.17 m by 2100. The design of the docks at Steensby Inlet will account for these potential changes in sea levels by ensuring sufficient clearance for the shipping route and clearance at the dock (Knight Piesold 2010).

3.8.3 Storm Events and Waves

Climate change is projected to lead to increasing storm frequency in the Arctic. Increased storm frequency and intensity due to climate change can add to greater wave energy issues, such as increased erosion along Arctic's shorelines (Perrie 2007; Instanes *et al.* 2005).

Wave energy is a function of wind speed, wind duration, extent of fetch (open water areas) and water depth (Instanes *et al.* 2005). In areas of sea level rise and where coastal permafrost undergoes thaw subsidence, wave energy issues can be exacerbated (PIANC 2008). Wave characteristics can be impacted by a variety of climate-related parameters, including (PIANC 2008; Instanes *et al.* 2005):

- changes in temperature affecting winds, causing shifts to the seasonal distribution of wind speeds and direction which may impact the frequency, pathways and durations of storm and hurricane events;
- increases in the expanse of open water in the Arctic, and increase in the duration of the open water period, resulting in a corresponding increase in available wave energy (*e.g.,* due to increased fetch), and consequently increased rates of wave-induced coastal erosion;
- changes in climate affecting the seasonal distribution of wave heights, periods and directions;
- changes in climate affecting the frequency and pathway of high wave events; and
- changes to the location, duration and extent of the shore ice fringe could cause changes to the wave regime experienced by the shoreline over the course of a year (e.g. more exposure to waves in the shoulder season, less robust protection in winter leading to ice push/thrust effects at the shoreline, reduced shorefast ice).

In general, Arctic storms have an effect on sediments, erosion rates, wave characteristics and oceanic surges (Perrie 2007).

Climatic and Environmental Impacts on Storm Events and Waves

The influences of climate change on storms result from the alteration of open water areas and sea ice cover. Open surface flows modify storm development and direction, and also marine winds (*i.e.,* increased open water in the Arctic impacts the region's weather; Perrie 2007).

Changes in storm events may be realized through shifts in the overall distribution of wind, wave and precipitation conditions, and through shifts in the seasonal or spatial distribution of storm occurrences. Such changes may adversely affect the capacity of natural systems to recover from storm-induced erosion, and potentially lead to the permanent loss of offshore sediments (*e.g.,* sand). The loss of offshore sediments may lead to the retreat of coastal landscapes and the reduction of viable land for industrial use (PIANC 2008). Additionally, disruption of existing erosional shorelines may adversely affect depositional shorelines that rely on the transfer of terrestrial sediments from the eroding areas.

Impacts of Storm Events and Waves on Ports

More frequent storms resulting from climate change may have major impacts on coastal infrastructure (Hesterman 2011). During storm events, waves may interact with the shoreline at higher water levels (e.g. due to storm surge), potentially increasing the energy of the waves reaching the shoreline, and increasing the vulnerability of exposed structures in ports and along coasts. Changes in the magnitude and duration of storm surges can result in oceanic water overtopping sea wall structures, resulting in low land flooding around ports and throughout coastal areas. Increases in the elevation and subsequent inland extent of storm surges and associated increased coastal flooding, spray zones and erosion patterns can cause the degradation, failure and required maintenance or replacement of port infrastructure. Dredging requirements can be altered around port areas by storm influenced sediment transport. Specifically related to ports, reduced calm weather may increase berthing time for ships at terminals and delay their departures, both of which can result in longer anchoring time for waiting vessels and potentially affect shipping in general (PIANC 2008).

The frequency, duration and intensity of storms and associated wave action may have adverse impacts on ports and coastal areas. An increase in storm activity in the Arctic may have a more significant impact on Nunavut's ports and port infrastructure than an increase in storm activity in areas further south, because storms have the potential to intensify the erosive actions of waves. Arctic ports might be more sensitive to climate change because (PIANC 2008; Perrie 2007; Instanes *et al.* 2005):

- an increased duration of open water throughout the year would allow increased storm wave action and associated coastal erosion processes for longer periods throughout the year; and
- storm wave impacts could also be intensified as a loss of fringe ice protection decreases coastline protection from wave action.

In general, changes in the characteristics of storms can result in (PIANC 2008):

- degradation of structures;
- loss of viable industrial land around ports;
- reduced regularity of port services (*e.g.,* availability / use);
- the permanent loss of offshore and onshore sediments (*e.g.,* sand);
- retreat of coastal landscapes (*i.e.,* erosion); and
- reduced capacity of natural systems to recover.

In the Arctic, the proportion of winds with speeds above 15 m/s is projected to increase, resulting in higher waves and affecting navigation and potentially shipping routes (*e.g.,* because manoeuvring through narrow channels would be more difficult; PIANC 2008).

3.8.4 Sea Ice

The dominant feature of Arctic marine ecosystems is ice, and it plays an important role in sculpting the coastal landscape of Nunavut. Two distinct Arctic zones are recognized: the Arctic Basin marine region with year-round sea ice cover, and other Arctic subregions with open-water periods of one to four months each year. Currently approximately 10% of the Earth's surface is permanently covered by ice, but the volume and extent of ice (and snow) cover appears to be decreasing, and that trend is expected to continue, with recent studies showing that changes in the Arctic Ocean's sea ice are happening more quickly than previously observed (PIANC 2008).

Sea water is saline, so it does not freeze until its temperature drops to around -2°C. Decreased air temperatures cause the seawater to form minute floating ice needles before it is cold enough to freeze into a slushy mixture which accumulates up to a 1 m thickness. As entrapped pockets of brine (salty seawater) move downwards with gravity and accumulate in the lower layers, the surface slush becomes less saline, increasing its freezing point and promoting the development of solid ice (*i.e.,* sea ice freezes solid from the top down). When it is frozen solid into pack ice it forms a vast continuous sheet which remains until spring or summer, when it retreats and breaks up (PIANC 2008).

Climatic and Environmental Impacts on Sea Ice

Sea ice consists of both pack ice and fringe ice. Pack ice is ice that is free floating in the ocean. Fringe ice is ice that develops along the coastal margin and may be both shorefast (frozen to the ground) or free floating if the water is deep enough (e.g. an ice shelf).

Pack ice in the Arctic is either annual ice which melts in the spring and freezes in the fall, or multiyear ice, which remains frozen throughout the summer (*i.e.,* the polar ice cap of the Arctic Ocean) or breaks up in summer (*i.e.,* the broken pieces of the ice pack surrounding the polar pack which block many of the channels between Nunavut's islands year-round [PIANC 2008]).

Fringe ice in the Arctic is typically seasonal ice that is associated with shorelines. It tends to be seasonal, breaking up in the summer. Fringe ice can provide some measure of erosion protection to shoreline areas that are exposed to open water in the winter.

It is anticipated that climate change will result in thinner, less extensive sea ice (and thereby improving navigation along Northern shipping routes; PIANC 2008). Zone 3 (Figure 3) is particularly likely to be impacted by changes in the thickness and extent of sea ice because there may be less restriction of circulation in shallow waters, relaxing controls on brine formation in bays and reducing rates of permafrost thawing. Changing sea-ice regimes may also affect pressure-ridge development, changing under-ice circulation (Walsh *et al.* 2005).

Baffinland discussed sea ice conditions in its Draft EIS, noting that with increasing global temperatures, sea ice is expected to form later and clear earlier in the year. It is speculated that the loss of sea ice could increase atmospheric humidity, cloudiness and precipitation, and also alter marine mammal habitats (Knight Piesold 2010).

Impacts of Sea Ice on Ports

It is anticipated that large parts of the Arctic Ocean will no longer have permanent ice cover by 2100 (PIANC 2008). As the climate changes, increases in the expanses and duration of open water in the Arctic are expected to increase opportunities for commercial shipping, the transportation of mineral resources, and tourism (Knight Piesold 2010; PIANC 2008), which would in turn increase the use of and pressures on Northern ports and their infrastructure.

With anticipated increased navigation in the North, ports and other coastal infrastructure would likely be required to supply increased services such as ice-breaking assistance and improved emergency response capabilities (*e.g.,* for oil cleanup; Instanes *et al.* 2005), increasing the use of and stresses upon port infrastructure.

As climate change is expected to result in the reduction of ice-cover thickness, it can be assumed that the resulting ice loading on support structures in the water (*e.g.,* bridge piers, dock pilings) would be diminished. However, it has been noted that until such correlations are observed, engineers would be unlikely to incorporate reflective changes into the designs of such structures (Instanes *et al.* 2005).

Mary River Project

With respect to ports and port access, Milne Inlet is ice-covered most of the year, with only a three-month open-water season in summer (*i.e.,* the only time the port would be used). Steensby Inlet is ice-covered for most of the year, with an approximate three-month open-water season in summer (but its port would be used year-round; Knight Piesold 2010).

Proposed year-round shipping at the Steensby Port would require that vessels break the sea ice, approach the ore dock and depart from the dock independently (*i.e.,* they would be unassisted by ice-breaking tugs). The ice around the dock would also be disturbed during the ships' time at the dock, potentially through the use of a bubbler system (if one were utilized to minimize ice build-up at the dock) and through ballast water discharge. Baffinland has determined that because ballast-water discharge would be collected in the North Atlantic, it would have higher density (due to temperature and salinity differences) than the Steensby Inlet water and would therefore sink upon discharge, causing little or no effect on sea ice beyond the immediate vicinity of the dock (Knight Piesold 2010).

Impacts on Shipping

Baffinland is proposing to use two shipping routes for its Mary River project. Ship access to Milne Inlet would be from the North Atlantic through Davis Strait and Baffin Bay, and ship access to Steensby Inlet would be through Hudson Strait and Foxe Basin. Concerns related to sea ice and actual shipping activities include freeze-up and thaw times, open water leads in ice, and the movement of pack ice (*e.g.,* due to strong winds and currents in Hudson Strait; Knight Piesold 2010).

Baffinland did not anticipate that changes in sea ice cover due to climate change would significantly affect its shipping operations in the Foxe Basin (the report does not address potential sea ice impacts on the project's proposed Northern shipping route; Knight Piesold 2010).

3.8.5 Currents

Currents refer to the circulation systems of oceans as they move water. Gravity, wind, tide and different ocean temperatures around the world contribute to current movements. For large-scale ocean currents, temperature is the greatest influence in deepwater (i.e. non coastal waters, typically open ocean), with warming water causing water to expand and lose density, causing it to rise to the surface where in warm climates it evaporates, increasing salinity and density, and causing it to sink again. This causes cooler water to rise, which is then warmed by the sun, repeating the cycle. These cycles, in combination with the Earth's rotational forces, govern current directions. In the northern Hemisphere, currents move clockwise (Heberts 2010).

Large areas of the Arctic Ocean are ice-covered year-round, with seasonally open waters in the remaining areas. This ocean is relatively isolated from the rest of the world's oceans (Woods Hole Oceanic Institute 2006).

The Arctic's deeper waters are saline and dense, and are more resistant to flow (viscous) when compared with oceanic waters further south. The presence of submarine ridges also minimizes movement deeper water movement, with very cold water (approximately -1°C) remaining relatively stagnant at the bottom of the Arctic Ocean (Heberts 2010).

However, the surface water (*i.e.,* water to a depth of approximately 46 m) are less saline and in the Arctic Ocean circulate in a large rotational pattern (*i.e.,* a gyre) from east to west around the polar ice cap. This is referred to as the Beaufort Gyre, and it is caused by the clockwise winds in the region. The Beaufort Gyre slowly swirls the surface waters in the Arctic Basin, and it turns the polar ice cap along with it, completing one rotation approximately every four years (Heberts 2010).

Inflows into the Arctic Ocean (and Beaufort Gyre) include water moving in from the North Atlantic Current (moving North between Greenland and Europe), water moving in from the Bering Sea and the Pacific Ocean (moving North through the Bering Strait) and also freshwater discharges from rivers, including the dominant Mackenzie River in the NWT (Heberts 2010).

Outflows from the Arctic Ocean's Beaufort Gyre system include water exiting by winding through the NWT's and Nunavut's islands and down into and out of Hudson's Bay, as well as water exiting along the western coast of Greenland and through the Davis Strait (*i.e.,* the Labrador Current) into the Atlantic Ocean (Heberts 2010; Woods Hole Oceanic Institute 2006). Rates of evaporation in the Arctic are very low, so evaporation is not a significant process for removing water from the region's oceans (Hebert 2010).

A large additional Northern current, the Transpolar Drift, carries water from Siberia, across the North Pole, and down the East coast of Greenland, pushing Arctic surface water eastward into the Atlantic. This current is not likely to influence Nunavut's coastal waters. Figure 4 shows the major currents influencing Nunavut and its surrounding ocean waters.

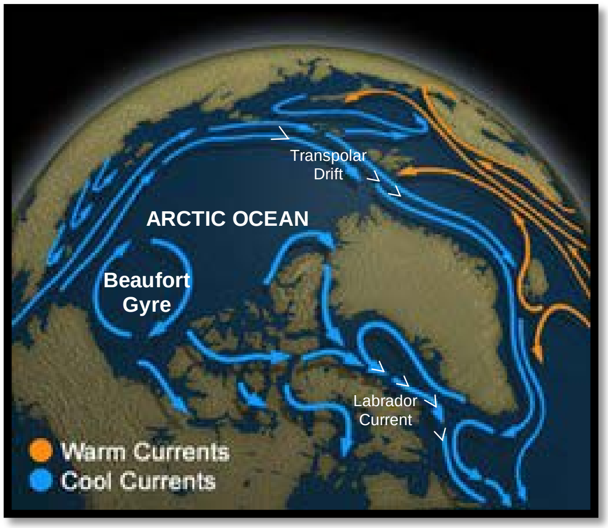

Figure 4: Ocean currents through Nunavut (modified from Heberts 2010)

In near-shore and shallow water environments, tidal and wind effects on currents become dominant. Temperature and density variations can also be important in areas where there is significant quantity of freshwater discharge (e.g. near river mouths). The near-shore currents tend to be smaller in geographic extent than the oceanic currents described above but may have larger velocities than the generally low velocities of the oceanic currents (Herbert 2010).

Climatic and Environmental Impacts on Currents

Oceanic circulation could be impacted by climate change, either suddenly or gradually, but how this affects coastal hydrodynamics through changes in wave height, wave direction, or sea level would vary from one location to another, and may only properly assessed through site-specific modeling (PIANC 2008). A potential outcome of the interaction of climate change and currents may be changes in the drift direction of pack ice and icebergs and the duration of either (see section on Sea Ice above). Reduction in sea ice may also have a corresponding influence on currents as the ocean waters are subject to wider temperature ranges through direct exposure to the atmosphere instead of through the insulating characteristics of ice and also to greater wind stress.

Impacts of Currents on Ports

It is possible that coastal hydrodynamics could change as a result of shifting currents in response to climate change, but such changes would likely be unique to the location. Changes could include the narrowing or widening (or potentially closing or opening) of channels, changing dredging requirements, the erosion or accretion of beaches that protect port structures, and/or changes in ocean current velocities (PIANC 2008).

3.8.6 Coastal Erosion

Coastal erosion rates vary across the Arctic and are influenced by numerous processes including climatic parameters, environmental forcing (*i.e.,* wave exposure), sedimentology, geocryology characteristics (*i.e.,* frozen rocks, soil and ground), geochemistry, and also anthropogenic disturbances along coastlines. Coastal erosion rates vary with sediment type, with select examples of environmentally-induced erosion rates in the Arctic including (Instanes *et al.* 2005):

- 1 to 3 meters per year (m/yr) in fine-grained icy silty-clayey sediments;
- 10 to 15 m/yr in silty-sandy sediments with high ice content when directly exposed to waves and storm surges and extreme weather;
- as low as 0.1 m/yr in frozen sediments with low ice content; and
- limited erosion in rock.

Anthropogenic influences can either increase erosion rates (through disturbances) or slow erosion rates (through using shoreline protection strategies; Instanes *et al.* 2005).

Climatic and Environmental Impacts on Coastal Erosion

It is predicted that the Arctic's coastal conditions will be altered as a result of climate change (Instanes *et al.* 2005), but the actual impact that climate change has on coastal morphology can be difficult to assess because, as an example, although climate change can affect waves and currents (which modify coastlines), localized bathymetry then causes variations to those waves and currents, making impacts to coastal morphology a site-specific phenomenon (PIANC 2008). A variety of other climatic parameters can directly and indirectly cause changes to the stability of coastal and subsea permafrost, and influence coastal erosion types and rates, including air temperature, sea-level increases, longer open-water seasons, and freshwater discharge into the marine environment.

Air temperature – Anticipated increases in air temperatures may increase backshore thermokarst development (Walsh *et al.* 2005). Thermokarst is defined as hummocky, irregular relief caused by the melting of permafrost containing excess ice, subsidence of the ground, and thermal and mechanical erosion by flowing water (Trenhaile 1998). Increased thermokarst development can increase the rate at which materials are moved to the coastal environment, and increase sediment deposition. Increased air temperatures can also increase the instability of the permafrost in Zone 1, and likely result in increased coastal water temperatures. These influences, in combination with decreased sea-ice thickness, can cause more rapid permafrost warming in Zones 1 and 2 (Figure 3; Walsh *et al.* 2005).

Sea-level increases – Increases in sea levels can shift the locations of Zones 1 and 2 to higher elevations. This can increase the erosion rates and instability of coastal permafrost (Walsh *et al.* 2005).

Longer open-water seasons – As sea ice cover decreases, longer open-water seasons are expected. Coastal environments would be exposed to more storm action, increasing rates of backshore erosion and leading to increased rates of near-shore deposition and possible permafrost expansion by the insulating properties of deposition of sediment layers (aggradation). Backshore erosion can also increase the rate that terrestrial permafrost is exposed to coastal conditions and increase the rate of warming of terrestrial permafrost in the backshore environment (Walsh *et al.* 2005).

Freshwater discharge (fluvial inflow patterns) – Shifts in freshwater discharge into the Arctic Ocean (*e.g.,* lower flow rates, different timing and duration of flooding) can impact the near-shore and coastal salinity and temperatures regimes. Increased salinity can contribute to permafrost thaw, and increased temperatures can cause increased permafrost destabilization, contributing to coastal erosion rates (Walsh *et al.* 2005).

Other factors - As coastal permafrost decreases in stability, rates of near-shore thaw subsidence and coastal erosion are likely to increase, thereby increasing sediment loads to coastal systems and potentially higher levels of suspended sediment and shifting depositional patterns (Walsh *et al.* 2005). Shifts in deposition may result in redirection or focusing of erosion in order to maintain open waterways: for example deposition of sediment at the mouth of a river in a narrow channel may result in increased velocities as tidal exchange has to pass through a narrower and narrower opening, the growth of the delta also deflecting current towards the opposite shore.

Increased erosion rates can lead to increased carbon dioxide emissions from coastal and near-shore areas, and increased methane emissions from terrestrial permafrost. In the long-term, destabilizing intra-permafrost gas hydrates could lead to enhanced climate change (Walsh *et al.* 2005) and increased rates of subsidence and or erosion

Uncertainties in the future impacts of sea-level rise and storm activities make it difficult to predict coastal bluff erosion (Instanes *et al.* 2005).

Impacts of Coastal Erosion on Ports

Changes in near-shore sediment deposition patterns can alter dredging requirements at ports (PIANC 2008; Walsh *et al.* 2005). The sediment regime at the start of a project may be significantly different by 2100 if sediment sources within the littoral cell containing the port are activated by erosion, sea level rise or thawing permafrost.

The inland movement of eroding shorelines can cause the disturbance and potentially the required removal, reinforcement, reconstruction or moving of onshore port structures (PIANC 2008; Deduce 2007). While less of a potential impact on bedrock shorelines, ports located on erodible soils or soils subject to thaw could be impacted by the shoreline changing shape or location to accommodate the new climate and oceanic regime.

The foundations and structural strength of port infrastructure along coastlines may be subject to erosion and deterioration, considering environmental parameters such as coastal permafrost stability and thaw subsidence, and the vulnerabilities of structural components to warming and/or thawing permafrost (PIANC 2008; Walsh *et al.* 2005).

3.9 Adaptation Measures to Address Potential Climate Change Impacts on Northern Ports

In general, climate-induced impacts to port infrastructure operations and maintenance can cause inconvenience and/or increase costs for port operations. Examples include increased maintenance and replacement costs for port and coastal infrastructure, increased maintenance due to increased storm damage impacts on coastal protection infrastructure (*e.g.,* seawalls, breakwaters), and increased dredging requirements due to increased sedimentation at river outlets (Naruse 2011; PIANC 2008).

Worldwide, the International Association of Ports and Harbours (IAPH) has conducted assessments of potential climate change impacts on ports, but work completed in the past focused more on GHG reduction (mitigation) measures rather than on adaptive measures. This is due in part to the fact that ports have unique natural conditions for which individual climate change vulnerability assessments would be required to determine their specific vulnerabilities (Naruse 2011).

In 2009, a survey was distributed to members of the IAPH and American Association of Port Authorities; it was the first worldwide survey of port authorities aimed to address climate change adaptation. The majority of survey respondents from 93 agencies representing major seaports around the world indicated that sea level rise and increased storm events were their primary concerns associated with climate change, but only 6% indicated that they intended to build hurricane barriers within the next 10 years, and fewer than 18% had plans to build storm protection structures (Hesterman 2011). Respondents more often discussed mitigation measures versus adaptation measures, and survey results showed that (Naruse 2011):

- most ports prepare port plans for a 5 to 10 year period;

- most port designs account for 50 year (or more) historic flood / storm events, but not climate change; and
- approximately half of the ports addressed in the survey were not addressing climate change issues in 2009.

In July 2011, the IAPH produced a document entitled Seaports and Climate Change: An Analysis of Adaptive Measures. The document addresses potential restrictions to managing sea ports with regards to climate change (*e.g.,* due to a lack of relevant knowledge, financial restraints), climate change impacts on ports, climate change sensitivity of port assets and adaptation measures for basic port structures (*e.g.,* port entrances, shore protection structures), operational port structures (*e.g.,* quay walls, mooring buoys), and port superstructures (*e.g.,* tank farms, service buildings; IAPH 2011). Naruse (2011) notes that, although the document provides a good description of adaptive measures for ports, it is deficient in defining best practices for ports.

Permafrost

Measures that design engineers can use to manage uncertainty related to future climate change associated issues with the terrestrial permafrost potentially encountered throughout onshore port areas are described in Sections 3.1 and 3.6.

In the marine / coastal environment, non-frozen materials are not expected to present serious problems for engineering activities (*e.g.,* port infrastructure; Walsh *et al.* 2005). A significant concern with the stability of coastal permafrost is its vulnerability to erosion (*e.g.,* from increased wave action), so measures to prevent coastal erosion would work to preserve the integrity of coastal permafrost. As described in more detail below (see below, Coastal Erosion), the use of protective near-shore structures (*e.g.,* jetties, breakwaters, seawalls) are important means of protecting shorelines from the erosive forces of the ocean (Nysigh 2001) so long as they do not adversely affect the natural sediment transport regime or significantly alter the nearshore wave climate such that erosion is enhanced on adjacent shorelines.

Additional methods of protecting against erosion, and changes of coastal permafrost, have been employed in Tuktoyaktuk, NWT, where erosion rates are high and threaten port and other land-based infrastructure in the community. Erosion protection strategies which have been used or considered include (Wolfe *et al.* 1998):

- the use of sandbags (or geotextile tubes) placed on the beach to protect against wave action (these are vulnerable to undermining and breakage, although the sand can serve to nourish the beaches; see below, Coastal Erosion);
- the use of fill at a coastline to rebuild, maintain and regrade coastal bluffs and shorelines;
- the use of sunken vessels such as barges to act as breakwaters (this was determined to be relatively ineffective at reducing wave energy during storm surges); and
- the deposition of rocks and gravel on the beach to dissipate wave energy (can be ineffective unless there is adequate protection of the toe of the beach).

The protection of coastal permafrost can help enhance the stability of coastal infrastructure such as ports. Adaptation measures to address impacts associated with permafrost changes (*e.g.,* warming and/or thawing) should be identified at the planning and design phases for port infrastructure.

Collecting information on shoreline changes can help predict future changes and enable the preparation and development of adaptation measures that would help address climate change impacts (Deduce 2007).

Sea Level

Port planners must consider the impacts that rising sea levels could have on ports, and incorporate future potential sea level heights into port designs (Stephan 2009). In the absence of any site-specific guidance, it is recommended to use an allowance for sea level rise of at least 5 mm/yr during the planning and design phases (and construction) phases for port infrastructure (PIANC 2008).

As an adaptive measure to minimize impacts from rising sea levels, the lowest point in buildings in coastal areas (*e.g.,* onshore port structures) should be placed at higher elevations (PIANC 2008).

Storm Events and Waves

The design of a port should incorporate sea defences that would help limit damage caused by storm events and wave action (Stephan 2009). Adaptation measures concerning storm events and associated increases in wave energy can be incorporated into port design, planning and construction. Measures can include increasing the heights of quay levels, sea wall structures and connected areas behind them to address the anticipated increased frequency of overtopping those structures and to decrease associated lowland flooding (PIANC 2008).

Breakwaters and jetties serve to reduce wave forces in the near-shore zone (Nysigh 2001). The proactive development of breakwaters and jetties with appropriate structural strength and size can be used to dissipate wave energy and minimize erosive issues associated with storm events and wave action, thereby protecting port infrastructure (PIANC 2008; Nysigh 2001; see below, Coastal Erosion). Breakwater orientation should be assessed in the planning stages (PIANC 2008). Breakwater and jetty design should consider sea level rise to ensure that they remain effective over the life of the Port.

Sea Ice

Anticipated repercussions of climate change include the diminishment of sea ice and opening of new and/or longer seasonal maritime transportation routes in the Arctic. This would require that ports in Northern region develop adaptive strategies for dealing with the increased use of those new routes, and the subsequent use of the port infrastructure in proximity to these routes (Naruse 2011). Additional capacity in Northern ports is considered essential to the success of Arctic shipping strategies related to Northern resource development and a changing climate (Instanes *et al.* 2005).

Port docking facilities can be designed to limit damage caused by sea ice. Considerations for developing, constructing and maintaining port infrastructure and associated dock facilities to withstand sea ice stresses could include (Knight Piesold 2010):

- completing bathymetric work during the planning phase to determine safe and sensible transportation routes when considering ice conditions;

- completing ice studies and other marine assessments to determine the most appropriate dock locations considering expected ice conditions, define shipping lanes, and determine what ice class of vessel would be appropriate for use in the area (as required);
- designing docks using caissons instead of solid structures to allow ice to accumulate between the caissons and help ice move past dock structures;
- using ice-reinforced vessels such as tug-boats to break up ice around docks for subsequent removal;
- using bubbler systems around docks to minimize the development of sea ice in the area; and
- using warmed ballast water discharge from vessels to minimize the development of sea ice or help reduce the thickness of already developed sea ice around docks.

Currents

As an adaptation measure to address the impacts of currents, breakwaters and jetties can function to minimize littoral drift in the near-shore zone caused by currents (Nysigh 2001; see below, Coastal Erosion). However, these must be carefully planned and should not result in adverse effects upcoast or downcoast within the littoral zone.

Coastal Erosion

The incorporation of near-shore protective structures in port design can help to minimize climate-induced impacts that affect coastal erosion (*e.g.,* wave energy). Coastal near-shore structures can be formed by dumping construction materials in a mound shape on the seabed. They are gravity structures, dependent on their own weight for stability rather than on foundation preparation. With suitable engineering, these mounds are effective at attenuating wave energy through run-up on their sloped faces and energy dissipation within the voids of their rough surfaces. Mound types and the potential advantages of their use to protect port infrastructure in Nunavut could include (Nysigh 2001):

- rubble mounds – rubble mounds comprised of graded layers of natural (*e.g.,* quarried) rock are common structural configurations of breakwaters; advantages to using rubble mounds are that they may be adapted to any water depth and most foundation conditions; settlement of the rubble mound under wave action typically causes the readjustment of the rock components to a more stable configuration (*i.e.,* rather than structure failure), and the rubble surface generally absorbs rather than reflects wave energy; any structural damage that does occur is likely to be progressive (rather than sudden and catastrophic), and damages are typically easily repaired;
- gabions – gabions are rock-filled wire baskets and mattresses, and they are often formed into mounds and incorporated into rubble mounds to provide coastal defence works; advantages of using gabions are that they are flexible (*e.g.,* adjust to differential settlement caused by undermining from wave / current scour), they can be filled and placed underwater, and hydrostatic heads do not develop behind the permeable structures; wave energy is absorbed within the interstices of the stones and the stones remain securely encased; however, they tend to corrode, have a very short life in seawater and are generally avoided; and

- engineered mounds – engineered mounds are constructed out of pre-cast structures (e.g. dolostones) and built similarly to rubble mounds; the primary difference is that the construction material are manmade and not naturally derived.

Near-shore structures can also be formed by straight vertical or near-vertical walls which work to reflect wave energy. The reflected wave moves out to sea at the same velocity as the incoming wave and in the same phase so that wave heights are doubled and wave energy quadrupled. Walls are vulnerable to failure or severe damage from single waves that exceed design proportions and from excess scour at the toe caused by increased wave energy through reflection. Wall configurations can include single walls for small structures in low-wave areas, to double walls for more massive structures with more extreme environmental exposures. Walls can be formed by sheet pile structures (*e.g.,* lines of piles interlocking into a continuous wall), with pilings materials including steel, timber and concrete (*e.g.,* concrete caissons, cribs). When designing wall structures, considerations of the foundations are important, as wall structures cause waves to generate scouring currents that can erode unconsolidated foundation materials and cause undermining. Piles must be deep enough to attain structural stability against overturning (Nysigh 2001) and the effect of the seawall on the near-shore seabed and adjacent areas must be considered to minimize environmental degradation of near-shore habitats.

As an adaptation measure, the construction of harbours and protective hard structures can help protect ports and coastlines against erosion (Deduce 2007). Alternatively, as a mitigative measure, beaches and foreshore areas can be nourished with materials (*e.g.,* sand) to replinish those lost to erosion, but this strategy may require ongoing regular periods of maintenance (Deduce 2007). Beach nourishment can also be used to address disruptions to littoral transport caused by port structures. Ports themselves can cause disturbances to the natural flow of sediments in coastal areas. Port structures can generate new erosion and accretion processes where breakwaters act as a barrier to sediment transport and then force the flow of sediments further offshore. Adaptation measures to prevent this should involve planning for port locations that take into account their influences on sediment dynamics, and ensure the incorporation of preventative measures and mitigative solutions (Deduce 2007).

3.9.1 Suggested Research and Policy Action

Although changes in the Arctic’s air temperatures are documented, and studies have been conducted on how those changes impact terrestrial permafrost, there are no comparable multi-year studies to investigate how air temperature changes will impact coastal permafrost (Walsh *et al.* 2005).

There is currently a lack of monitoring projects for coastal and subsea permafrost (although efforts are being made to monitor forcing variables and coastal erosion, Section 3.8.6), resulting in knowledge gaps in the understanding of coastal stability in the Arctic. The absence of monitoring programs results from the difficulty of working in coastal Arctic environments (particularly in Zones 1 and 2) because installing and maintaining equipment (*e.g.,* to measure temperature) throughout the year requires placing it so that the equipment and mooring gear (such as cables) are not vulnerable to storms and sea ice. Such deployments are typically both challenging and expensive (Walsh *et al.* 2005).

Future research on coastal and subsea permafrost could help engineers gain a comprehensive understanding of coastal permafrost processes. Potential studies could include (Walsh *et al.* 2005):

- the interaction between storms and permafrost;
- heat convection in coastal permafrost thawing during storms after the thawed overlying material is eroded;
- thaw subsidence rates and their contributions to coastal erosion and/or ground level subsidence;
- brine exclusion and convection in enhancing coastal and subsea permafrost degradation; and
- gas hydrates in coastal and subsea permafrost to assess their stability throughout future climate change circumstances.

A better understanding of coastal permafrost processes and effects of a changing climate would provide more specific knowledge on the associated impacts to infrastructure components at Nunavut's ports.

In general, coastal erosion rates in the Arctic are not readily quantifiable (except on a site specific basis) and are less significant in the eastern Arctic versus the western Arctic, but have increased over the past 30 years; satellite imagery will help assess these rates in the future and increase the understanding of coastal dynamics and appropriate mitigation measures required to protect port infrastructure (Instanes *et al.* 2005).

Collecting information on historic and ongoing shoreline changes can help predict future changes and enable the preparation and development of adaptation measures that would help address climate change impacts (Deduce 2007).

3.10 Tailings Management Facilities in Nunavut

The following terms and definitions are used throughout this section of the report (EC 2011; Bjelkevik 2005):

- tailings – mine waste material resulting from mineral processing; after mineral processing when the valuable metal content is removed, the remains are silt and sand-size waste materials (tailings);
- tailings dam (or tailings embankment) – a structure designed to contain, settle and store tailings and process water; solids settle out and water is typically recycled; wide range of designs (*e.g.,* upstream, downstream and centreline constructions);
- tailing impoundment – storage space / volume created by the tailings dams where tailings are deposited and stored;
- tailings pond – supernatant water stored in the tailings impoundment; and
- Tailings Management Facility (TMF) – comprised of all structures required to handle and store tailings; starts where tailings leave the process plant and ends where they are deposited (includes dams, impoundments, reclaim ponds, spillways, decant structures, tailings pipelines, polishing ponds); can include mined out open pits used for tailings storage, lakes used for tailings storage, and underground mines backfilled with tailings.

3.10.1 Design and Closure of Tailings Management Facilities

Some mineral processing separates valuable concentrate from sand-sized tailings. Tailings are typically transported in the form of hydraulic slurry at a solids content of about 30% (by weight). Slurry tailings are pumped from the process plant with centrifugal pumps to a designated area for sedimentation and storage. Perimeter dams can be used to create an impoundment area for tailings storage (Bjelkevik 2005). Over time, the solids (sand and silt-sized particles) consolidate (*i.e.,* settle) and the water is collected in a retaining pond where it can be recovered for reuse in the process plant, treated for release into a receiving water body (*e.g.,* a river) or evaporate (*i.e.,* in arid climates).

Tailings can be dewatered or thickened to a solids content of 60% or even 70% (by weight) for underground backfill or surface disposal. In a cold climate like Nunavut it may be difficult to reclaim water from a tailings impoundment during the winter because it will freeze. Dewatering tailings to achieve a high solids content allows water to be recovered at the process plant and reduces the volume of water that is pumped out to the TMF with the tailings. This limits the potential for ice entrainment in the TMF and reduced tailings storage capacity. Thickened tailings typically require piston or positive-displacement pumps to transport the tailings by pipeline. Thickened tailings are typically non-segregating with minimal bleed water reducing water management requirements (*i.e.,* only precipitation runoff must be managed). Co-disposal of thickened tailings with waste rock is another emerging trend that offers many operational and environmental advantages in a cold climate. Coarse tailings can be stored in a dry disposal facility (*e.g.,* coarse rejects from some metal or mineral recovery processes; Witt *et al.* 2004).

TMFs are in essence impoundments that allow for the deposition of solids and collection of fluids where contained residues are stored over the long-term. Typically a TMF is also designed to isolate the tailings from the surrounding environment and minimize the discharge of contaminants. Closed tailings facilities must store those residues over geological periods, requiring the TMF design and construction be reliable over the very long-term to ensure ongoing environmental protection (Witt *et al.* 2004).

Typically, as tailings fill an impoundment area, the surrounding dams are continuously raised (Bjelkevik 2005). Tailings are discharged and may form layers as the TMF is enlarged or raised. Tailings dam construction around the deposited materials is typically an ongoing process, with the dams being raised in stages because the size and capacity of a tailings impoundment must increase with the mine's production of tailings. As a result, the tailings dam design and impoundment characteristics may change significantly over the mine operating period typically resulting in heterogeneous conditions that must be considered for closure design. Therefore tailings dams require considerable planning and attention over the operating period and for closure (Bjelkevik 2005; Witt *et al.* 2004).

Typically the most significant environmental risk that tailings closure must address is the potential for acid generation and metal leaching to impact water quality. This is also an important consideration for other mine waste including waste rock. Covering tailings with a rock or soil cover for closure helps reduce erosion and dispersion of tailings, acid generation. It may assist preventing infiltration resulting in discharge of contaminated surface water or groundwater. Alternatively, tailings can be flooded or submerged under water to reduce oxidation of sulphide tailings and acid generation. There are two main categories of tailings covers for closure: dry covers (*e.g.,* low permeability soil covers, capillary break covers, or store-and-release covers) and wet covers (*e.g.,* water covers; Bjelkevik 2005; Holubec 2004; Witt *et al.* 2004). Freezing tailings (and waste rock) in permafrost by placing a thick layer of non-acid generating cover material over the acid generating waste (i.e., permafrost aggradation) is also an effective mitigation measure for acid generation and metal leaching (Section 3.10.4).

3.10.2 Types of Tailings Management Facilities in Nunavut

Three main different types of TMFs have been utilized and/or are planned to be used in Nunavut:

- above ground tailings impoundments (*e.g.,* dams);
- natural tailings impoundments (*e.g.,* lakes); and
- underground tailings storage (*e.g.,* mine backfill).

Tailings impoundment areas can be constructed above ground using topographic relief and perimeter containment dams. The selection, approval and development of a TMF are subject to regulatory processes (Task 2 Report).

Section 5 of the Metal Mining Effluent Regulations (MMER; 2002; Task 2 Report) allows for the deposition of waste rock or effluent (with an approved exemption under the *Fisheries Act*) that contains any concentration of a deleterious substance of any pH into natural lakes to function as tailings impoundment areas as described in Schedule 2 (which was amended in February 2011 by the *Regulations Amending the Metal Mining Effluent Regulations)*. Examples of tailings deposition in natural waterbodies in Nunavut include:

- Garrow Lake (south end of Little Cornwallis Island);
- the dammed north-west arm of Second Portage Lake (north of Baker Lake); and
- a dammed section of Tail Lake (south-west of Cambridge Bay; Fisheries and oceans Canada [DFO] 2012).

In addition to the use of man-made and natural tailings impoundment areas, there is the option of disposing of tailings underground in underground mine voids. Using tailings as backfill provides ground support to help stabilize mined-out areas. This disposal strategy also has the advantage of minimizing the requirement for surface tailings disposal areas and with that minimize the footprint of the mine (Global InfoMines 2009).

Isolation of the tailings waste from the hydrologic system reduces flow pathways that could lead to contaminant transport. Freezing of the mining waste is also utilized to prevent or minimize acid rock drainage (ARD) and leaching along with other techniques.

Although natural lakes may be utilized, there is often an increase in water level as outflow from the lake is restricted (dams constructed to limit outflow).

3.10.3 Examples of Tailings Management Facilities in Nunavut

Closed Mines

Nanisivik Mine (Artificial Impoundment)

Nanisivik was a lead-zinc-silver mine located in an area of continuous permafrost at the north end of Baffin Island. The Nanisik tailings are considered Potentially Acid Generating (PAG) and were discharged subaqueously at a solids content of 35% into a small, deep lake. As the lake began to fill with tailings and the ore reserves increased, an internal dyke was constructed to partition the lake so that tailings could be stacked up to 12 m above the natural lake level. Thermistors indicated that tailings below a 5 m wide rockfill causeway were frozen to a depth of 10 m a few years after the causeway was constructed. The internal dyke was raised in 2 m lifts using crushed and saturated shale that was allowed to freeze before constructing the next lift. Tailings were discharged upstream of the frozen internal dyke to provide insulation from the impounded water and help it remain frozen. The cold climate and minimal thaw during the summer months at Nanisivik allowed the mine to economically construct impermeable frozen dams for the tailings disposal facility during operations (Cassie and Gilchrist 1996).

When the mine closed in 2002, plans were submitted to bury the tailings under layers of shale and gravel, so that permafrost would encapsulate the tailings. However, stakeholders were concerned that the proposed cover thickness for the tailings would be insufficient to ensure long-term permafrost encapsulation and prevent seepage from the tailings (Rideout 2002).

The mine's final site closure plan (2004) placed soil and rockfill cover over the tailings. The covers were designed to account for climate change by considering a rise in average air temperature of 5°C every 100 years. The 10 million m^3 of covered sulphidic tailings should remain encapsulated in permafrost and isolated from the atmosphere to minimize the risk of ARD (Cassie *et al.* 2007). Soil covers for tailings and waste rock were constructed using approximately 1.7 million m^3 of local gravel. Soil covers were designed to encapsulate the mine waste in permafrost, and therefore minimizing potential negative environmental impacts. Monitoring is continuing to assess the physical condition of constructed reclamation measures, the performance of thermal barrier covers, water quality aspects of the freeze-back of taliks (thawed zones in continuous permafrost) located within tailings impoundments, and water quality of runoff from the covered tailings areas (Cassie *et al.* 2007).

Polaris (Natural Impoundment)

Polaris was a lead-zinc mine located at the south end of Little Cornwallis Island in an area with continuous permafrost. Tailings at Polaris were thickened to a solids content of 60% and discharged subaqueously to the bottom of a deep, meromictic lake (Garrow Lake) with high salinity and minimal vertical mixing (Kuit and Gowans 1983). Marine and land tailings disposal options were also evaluated but Garrow Lake was selected because it had ideal environmental and hydrological features for tailings disposal with minimal environmental impact. Because tailings were discharged to the bottom of the lake and there was no vertical mixing, overflow from Garrow Lake was discharged to the ocean without any containment required.

However, in 1985 a tailings line break caused discharge of the tailings into the surface layer of the lake and zinc concentrations in the surface layer increased. In 1990 and 1991 an impervious frozen core dam was constructed across the outlet of Garrow Lake so that discharge from the lake could be halted until zinc concentrations stabilized (Donald 2005). The dam allowed the mine to contain and discharge water from the Garrow Lake tailings disposal facility in a controlled manner. In 1992 discharge from the lake was resumed by siphoning over the dam and from 1999 to 2003 the water level in Garrow Lake was gradually decreased to its original (i.e., pre-mining) elevation so that the dam could be decommissioned. The centre portion of the dam was removed in March and April of 2004 and later that summer Garrow Lake was discharging naturally through its original creek channel (Donald 2005). Therefore long-term maintenance of a frozen core dam is not required for the closed Polaris TMF.

Active Mines

Meadowbank Mine (Natural Impoundment)

The tailings management plan for the Meadowbank Mine is to use a portion of the dewatered north-west arm of Second Portage Lake for the deposition of approximately 20 million tonnes of tailings, requiring dike construction and dewatering activities, with the tailings impoundment area situated between an attenuation pond and the tailings dike. The lake's size will be significantly reduced through the construction of the dike that separates the tailings deposition area from the rest of the lake (Cumberland Resources Ltd. [Cumberland] 2004).

The Second Portage TMF will be bounded by a series of dikes including the Central Dike, Stormwater Dike, and Saddle Dams. The Central Dike and Saddle Dams will be permanent structures. Whereas the Stormwater Dike acts to divide the TMF north to south for a four year time period. The perimeter dikes will be constructed primarily from materials generated during mining. All three dike designs include a downstream rockfill, a filter zone, and an upstream impermeable element (Golder 2007). The tailings will be capped for closure and permafrost is expected to freeze the tailings and talik below the Second Portage Lake Arm minimizing the potential for downward movement of contaminants (Cumberland 2004).

Approved Mine Projects

Hope Bay Mine (Natural Impoundment)

Originally, 21 tailings disposal alternatives were identified and evaluated for the Doris North Project at Hope Bay, which is now postponed indefinitely (Section 3.2). After a pre-screening assessment, eleven of those alternatives remained and were carried through further assessments. The evaluation results identified subaqueous tailings disposal in Tail Lake as the preferred tailings disposal alternative for the project (mill operations have not commenced at the mine site and therefore tailings have not yet been produced; SRK Consulting 2006).

The placement of tailings underground was considered for the Doris North Project but waste rock was selected for underground mine backfill because of the large volume of tailings (compared to the available storage underground), geochemical stability and swell characteristics of the tailings (Global InfoMine 2009).

Proposed Mine Projects

High Lake (Natural Impoundment)

Zinifex Ltd. had intentions to use High Lake as a tailings impoundment but in 2008, the company announced its decision to put a multi-year delay on its planned zinc and copper mining project near Kugluktuk (CBC News 2008).

Kiggavik Project (Underground Storage)

Note – The description of the Kiggavik Project in this Report is mainly based on the 2008 Project Proposal. The Draft EIS was submitted in December 2011, after the submission of the Task 1 and Task 2 Draft Reports.

Throughout this Report, references are made to the Project Proposal (AREVA 2008) and only if development plans have changed, the changes are described and the Draft EIS (AREVA 2011) is cited.

AREVA has submitted its project proposal for milling and mining operations on its two properties, Kiggavik and Sissons (collectively called the Kiggavik Project) west of Baker Lake, the first uranium mine and mill facility within the continuous permafrost zone of Canada. The tailings are planned to be deposited in two mined-out open pits (located in permafrost) that will be converted for use as TMFs. Storage of radioactive tailings below ground in the mined-out open pits reduces the risk of wind spreading these materials. The in-pit TMFs would be constructed in the mined-out Centre Zone and Main Zone open pits at Kiggavik. In order to ensure that there will be sufficient volume to manage tailings, the mining plan proposes mining and stockpiling ore at Kiggavik early in the project schedule and delaying the start-up of the mill for approximately two to three years, until the first of the two TMFs is available (to be located in the Centre Zone). Approximately 10.7 million tonnes of tailings are estimated to be produced from the Kiggavik Project (AREVA 2011).

The tailings management approach for the Kiggavik Project is modeled after AREVA's McClean Lake operation in northern Saskatchewan. As such, the Kiggavik Project is designed to eliminate the need for engineered surface tailings impoundment facilities. In addition, the design of the TMFs does not rely on frozen ground. The advantages of the in-pit disposal method for tailings (versus above-ground disposal strategies) include (AREVA 2008):

- better isolation and security;
- lower hydraulic gradients below the water table within natural systems than those that develop in surface tailings impoundments; the lower hydraulic gradients result in a lower flux of contaminants leaving the facility; and
- greater depths of tailings in a pit should become more consolidated, lowering hydraulic conductivity.

Decommissioning of the Kiggavik TMF is planned to involve the placement of a cover layer (waste rock and low-permeability soil) and an erosion barrier of waste rock over the tailings mass, with the cover extending to the natural ground surface and graded to blend into the area's topography. The cover is expected to enhance the consolidation of the tailings, lowering the tailings hydraulic conductivity, and eliminating potential concerns associated with the quality of overlying pond water for the decommissioned facility. A diversion ditch or berm will be constructed around the pit's boundaries to prevent surface runoff from entering the pit areas (AREVA 2008).

AREVA anticipates that even if permafrost should disappear completely in the vicinity of the TMFs in the long-term as a consequence of climate change (*e.g.,* over 500 years), then the unfrozen host rock surrounding the TMFs has a low enough hydraulic conductivity (along with the low hydraulic conductivity of the tailings) to limit the potential for the long-term movement of contaminants out of the tailings management area.

Mary River Project (No Tailings Impoundment)

Baffinland's Mary River Project will not involve the processing of ore on-site (*i.e.,* no generation of tailings) and will therefore require no TMFs (Knight Piesold 2010).

3.10.4 The Use of Permafrost in Tailings Management Facilities

Permafrost can play an important role in the management of tailings (and other mine waste materials including waste rock) at mine sites. The presence, distribution, ground ice content and temperature of permafrost are important considerations when planning Northern mine sites. In cold climates like Nunavut, permafrost can be used to freeze tailings and mitigate potential contaminant migration out of the tailings impoundment area. Tailings impoundment design can take advantage of freezing during the winter months and the limited thaw period during the summer months to the freeze tailings (International Network for Acid Prevention [INAP] 2011; Cassie *et al.* 2007; Meldrum *et al.* 1998; Dawson and Morin 1996). Tailings can be covered by a capping layer (*e.g.,* soil, rock, gravel) to promote the freeze-back of tailings from permafrost below and to help preserve the underlying permafrost. The more quickly freeze-back of tailings (or waste rock) occurs, the less acid generation potentially resulting in release of metal contaminated leachate discharged from a mine waste disposal facility. In this case, the capping layers become the active thaw layer, freezing and thawing seasonally while the underlying tailings remain permanently frozen (EBA 2004; Dawson and Morin 1996).

The strategy of using permafrost to freeze tailings and mitigate environmental impact has been successfully carried out at several mines in Nunavut (INAP 2011; Cassie *et al.* 2007; Cumberland 2004; Holubec 2004; Meldrum *et al.* 1998):

- Rankin Inlet - 48,000 m^3 of tailings were placed into a drained pond and allowed to freeze resulting in reduced environmental impact and risk to human health; the tailings were covered with a gravel layer (*e.g.,* 1 to 1.5 m thick) that was designed to act as the active thaw layer;
- Nanisivik - reclamation of tailings areas involved capping them to promote freeze-back of the mine waste materials; and
- Meadowbank Mine - the closed tailings storage area will have a 2 m thick cover layer of non-acid generating rockfill; it is anticipated that the active thaw layer will be confined within the rockfill cover to maintain the underlying tailings in a frozen state; the cover layer will be contoured to direct runoff off the tailings area; performance of the tailings area cover will be assessed over time to determine if it is performing as designed with potential climate change; strategies to reduce runoff from the cover could involve increasing the moisture content of the capping soil to reduce the active layer thickness; performance monitoring with ground temperature measurements during operations and closure will help analyze freeze-back conditions; thermal modeling indicates that the tailings will freeze in the long-term, and that the talik below the Second Portage Arm will freeze preventing seepage from the tailings impoundment discharging to groundwater below the permafrost (Cumberland 2004).

Freezing mine waste specifically to control acid generation is a management strategy that can be employed at mine sites with continuous permafrost. Encapsulation of tailings in permafrost minimizes the movement of contaminants out of the tailings impoundment. For example, at Rankin Inlet, a study was conducted to determine if the encapsulation of sulphide tailings in permafrost has kept them in a chemically inert state. Results indicate that at lower temperatures, sulphide oxidation rates are substantially reduced indicating that tailings disposal in permafrost is a promising method of reducing ARD at mine sites located in continuous permafrost zones (Meldrum 1998).

Potential control strategies to reduce ARD in permafrost environments include (EBA 2004; Witt *et al.* 2004; Dawson and Morin 1996):

- freeze control – freezes and immobilizes fluids controlling ARD reactions and migrations can be accomplished through freezing thin layers while filling or total freezing once the impoundment area is filled; TMF that are designed to encourage permafrost aggradation during operations can promote tailings are fully frozen in the impoundment at the end of mine operations;
- climate control – use of low precipitation levels and the cold characteristics of permafrost to act as natural buffers to ARD production;
- engineered dry cover – uses a cover of dry soil and rock material; restricts water and oxygen from entering tailings below; reduces infiltration into the tailings to minimize discharge of contaminated seepage to the environment (e.g., covering an impoundment [such as with clay material] helps prevent seepage from tailings ponds);
- subaqueous disposal – uses a water cover; restricts oxygen from entering materials;
- blending - blends acidic and alkaline materials to produce a net neutral waste product (*i.e.,* a non-acidic leachate);
- segregation –segregates acidic and alkaline materials to segregate waste products;
- co-disposal of tailings and waste rock – storage of tailings and waste rock in the same facility can reduce total storage requirements because tailings fill the voids of the waste rock and reduce environmental impact;
- surface disposal of thickened tailings – dewatering tailings to a solids content higher than 60% solids can help reduce oxidation of tailings, decrease infiltration, reduced water management and reduced environmental impact; or
- collection and treatment – involves the collection and treatment of leachate; requires perpetual operation of the collection and treatment system after closure of the mine; significant long-term post-closure liability.

Another strategy considered practical in areas of continuous permafrost is the construction of frozen core dams to impound mine waste materials. Frozen core dams contain a central saturated soil zone that is allowed to freeze and become a hydraulic barrier. The frozen core is keyed into a frozen foundation and supported by upstream and downstream granular shells that support and insulate the frozen core. Thermosyphons (*e.g.,* vertical pipes that conduct heat) may be included in the design of frozen core dams to help freeze the core. Design considerations must ensure that the core, foundation and seepage barriers remain frozen (EBA 2004).

The BHP Ekati Mine in NWT uses frozen core dams to contain tailings and water. Frozen core dams at Ekati have a central zone of frozen, saturated gravel that is expected to remain below – 2°C over the life of the structure, with consideration of a range of possible climatic conditions, including a warming trend due to climate change (EBA 2004).

3.10.5 Vulnerabilities of Northern Tailings Management Facilities to Climate Change

Mine tailings interact with the environment during their transport, sedimentation, deposition and after closure. The release of pollutants must be restricted during these activities, with governmental regulations defining the allowable limits for the levels of physical, chemical and radioactive containments released (Witt *et al.* 2004).

Climate change could impact TMFs if frozen materials (*e.g.,* tailings encapsulated in permafrost) become unfrozen many years later, releasing excess water and contaminants. Increasing air temperatures, due to climate change, have the potential to significantly increase the rate of ground thawing (Stratos Inc. 2011; Instanes *et al.* 2005).

The structural failure of a tailings dam can cause the release of tailings solids and contact water from the impoundment. This can be particularly problematic if the tailings are acid generating and saturated, resulting in the uncontained flow of tailings traveling considerable distances (Stratos Inc. 2011; Witt *et al.* 2004).

As water levels increase due to impoundment of water, this will result in permafrost warming and thawing around and beneath the tailings lake. This is an issue for not only dam stability but also groundwater flow pathways, talik formation etc. Other issues can include slumping, shoreline erosion and increased sediment loads which can have effects on water quality and also need to be considered in the mine's water management strategy.

The following sections describe some potential impacts that permafrost, frost action and ice, precipitation and water, winds, and extreme weather events and changes in these parameters could have on TMFs.

3.10.5.1 Permafrost Degradation

Where tailings facilities have been designed with impoundment dams that are dependent on permafrost, problems may occur over the long-term if permafrost is not maintained in the embankment or foundation. Thawing of frozen embankment fill or permafrost foundation can result in unacceptable seepage, settlement, and unstable embankment slope conditions. Increased seepage from a tailings facility may result in downstream water quality impacts (Andersland and Ladanyi 2004). Settlement of dam foundations can result in loss of freeboard (distance between normal water level and the top the dam), reduced impoundment capacity, risk of dam overtopping and dam failure. Thawed soil typically has lower geotechnical shear strength parameters resulting in decreased slope stability. Increased seepage, settlement and reduced soil strength all contribute to decreased slope stability and may result in embankment dam failure. Furthermore, impounded water adjacent to a TMF dam can contribute to increased permafrost thawing and must be considered during design of dams that rely on a frozen core or foundation (SRK Consulting 2009b).

Permafrost encapsulation of tailings (described above) requires an annual mean air temperature of approximately -8º Celsius. Climate change associated warming trends may limit the ability to rely on freezing for tailings management strategies (INAP 2011). Potential engineering consequences of permafrost warming include (Esch and Osterkamp 1990):

- increase in annual thaw or active layer depth;
- warming of permafrost at depth; and
- development of new or larger thaw zones (taliks).

Permafrost degradation (*i.e.,* due to air temperature increases; Section 3.1) can affect tailings dams (Bjelkevik 2005). Permafrost thaw can cause the settlement of structures (EBA 2004), and permafrost degradation beneath a dam in permafrost zones can result in both settlement and foundation instability (MAC 1998). Permafrost ground can be considered either "thaw-stable" or "thaw-unstable". Thaw-stable soils typically do not contain ice and will not settle excessively upon thawing. Whereas, thaw-unstable soils contain significant amounts of ice that, when thawed, can lead to unacceptable settlement and loss of strength (Indian and Northern Affairs Canada [INAC] 2003). Dam instability caused by permafrost thaw can cause considerable challenges for mine operators (EBA 2004).

Pore Water Pressure and Seepage

The thawing of permafrost can increase pore water pressure in dams and increase seepage from a tailings impoundment (EBA 2004). Increased pore water pressure and seepage as a result of permafrost thaw can impact tailings impoundments as follows (Mining Association of Canada [MAC] 1998):

- increased pore water pressure in dams can cause slope and foundation instability, and even liquefaction of foundation materials and impounded tailings;
- seepage through a dam can cause piping and the movement of soil particles, potentially resulting in dam instability; and
- seepage from a tailings impoundment can impact surface water and groundwater quality.

Increased seepage from tailings impoundments as a result of permafrost thawing is a potential concern for mine operators (Stratos Inc. 2011; SRK Consulting 2009b; EBA 2004).

Piping and Internal Erosion

Thawing of frozen core dams or a dam foundation can increase seepage through a dam and increase the potential for piping (Bjelkevik 2005; EBA 2004). Piping is a form of internal erosion that, in tailings dams, involves the transport of particles within the pores of the dam construction materials. Over time, the continuous loss or movement of materials in a dam can result in sinkholes at the dam's surface or internal erosion; and in severe cases can lead to dam failure (Bjelkevik 2005).

In general, the initiation of internal erosion in a dam requires (Bjelkevik 2005):

- small soil particles directly adjacent to larger soil particles that can be transported through the voids between the larger particles without being trapped between the larger particles;
- hydraulic pressure that is strong enough to initiate internal erosion by moving finer particles from their original position in the particle structure; and
- the absence of a properly designed filter zone between different material zones to trap and prevent the movement of particles.

Piping and internal erosion can be prevented, even with potential thawing of permafrost, if a dam is designed with compatible zones and filters that prevent the movement of particles or internal erosion. Therefore piping and internal erosion should not be a risk for properly designed dams.

Landslides

Landslides can occur as a result of permafrost thaw on slopes around a tailings pond. A large landslide into a tailings impoundment with ponded water adjacent to a dam could cause waves to overtop the dam. A landslide in a tailings impoundment could block a spillway and combined with a precipitation event could also lead to dam overtopping (MAC 1998).

3.10.5.2 Frost Action and Ice

Frost and ice can impact TMFs with the potential to affect their long-term stability (SRK Consulting 2010; Witt *et al.* 2004). An increase in mean annual air temperature is expected to increase the thickness of the active thaw layer subjected to repetitive freeze-thaw cycles. When water freezes it expands and then when it thaws it reduces in volume. This expansion and contraction of water in tailings, dam fill and foundation materials can impact a tailings impoundment as follows (Bjelkevik 2005):

- repetitive freeze-thaw action can split soil particles, change the soil structure, increase hydraulic conductivity of dam materials and impact performance (*e.g.,* increased seepage) or lead to dam failure;
- repetitive freeze-thaw of foundation and dam fill materials can result in cracks in dams and impact performance (*e.g.,* increased seepage) or lead to dam failure; and
- repetitive freeze-thaw and ice lens development can result in consolidation of tailings and may decrease hydraulic conductivity of the tailings.

Other potential frost and freeze-thaw related impacts on TMFs include:

- frost weathering can cause the physical breakdown of rock and soil into smaller particles, and in cold climates, this process may increase rates of acid generation (EBA 2004);
- thawing of frozen, saturated soil releases excess water, reducing the strength of the soil mass, and increasing the likelihood of slope failures, even on gentle slopes (Witt *et al.* 2004);
- frost or thaw creep can result in slow, downward movement of soil on a slope and eventually lead to slope instability or failure; and
- freeze-thaw action can increase the permeability of soil covers resulting in increased infiltration into underlying tailings and increased discharge of contaminated seepage from a tailings impoundment (Witt *et al.* 2004).

Potential Impacts of Ice on TMFs

In cold climates, ice accumulation at tailings impoundment outlets, can increase the risk of dam overtopping (Bjelkevik 2005). Tailings impoundments in a cold climate may not be able to reclaim water if it becomes frozen and permanently entrapped as ice. Tailings impoundment design in a cold climate should allow for ice to consume some of the available storage volume. At the Meadowbank Mine, it is estimated that the volume of ice trapped in the tailings impoundment could be up to 30% of the total storage volume and increase the height of the facility by approximately 3 m relative to the height expected if there was no ice entrapped (Cumberland

2004). Future thawing of entrapped ice in a tailings impoundment has the potential to increase available storage but an increased volume of water will have to be managed and/or treated prior to discharge.

3.10.5.3 Precipitation and Water

Effective management of precipitation events and water are important considerations at TMFs. Precipitation events (and changes in their pattern) can impact water levels in tailings impoundments. The use of water covers is a method to reduce acid generation in tailings, and the appropriate maintenance of the water cover is essential. Increased precipitation can also cause various forms of erosion. These considerations are described in the following paragraphs.

Impoundment Water Levels

Precipitation events increase water flow into a tailings impoundment area, potentially exceeding their design storage capacity and causing overtopping of dams (MAC 1998). When precipitation and other inflow sources of water at a tailings facility exceed the rate of evaporation and other outflows, water must be discharged to the environment in a controlled manner (Witt *et al.* 2004). If the spillway or discharge facilities cannot handle increased flows then overtopping of dams. Overtopping of a dam can result in dam failure and release of tailings and contaminated water to downstream areas. The uncontrolled release of water from a tailings impoundment can also contribute to erosion of downstream areas. To prevent the uncontrolled release of water, a water balance should be carried out that account for expected storm events. Diversion channels can also be incorporated into tailings impoundment design to reduce runoff into the facility (Witt *et al.* 2004).

Impoundment Water Covers

Water covers are regarded as a cost-effective method to mitigate potentially acid-generating mine tailings. Benefits include low cost, low maintenance and no dust problems. Drawbacks include the required construction of dams and long-term stability issues for the dams (Bjelkevik 2005). If tailings are covered with water to reduce acid generation, a minimum water level must be maintained in the tailings impoundment at all times, even during periods of extreme drought. Maintaining a water cover requires a sufficiently large catchment area and water retaining dams that are stable in the long-term. In addition, water covered TMF must have spillways or discharge facilities that can handle design storm events (Bjelkevik 2005).

As an example, in Nunavut, Meadowbank Mine is planning to use a water cover for a portion of its natural TMF (Cumberland 2004; Section 3.10.3).

Erosion

Storm events can result in increased water flow into an impoundment and erosion at spillway outlets. Precipitation can cause erosion of exposed tailings surfaces or dam slopes with insufficient erosion protection. Surface water runoff can become concentrated into channels forming erosion rills (up to 0.3 m deep) and erosion gullies (over 0.3 m deep; Bjelkevik 2005). Rain intensity cannot be controlled, but slope length, slope angle, and erosion protection measures can be designed to resist erosion during design storm events (Bjelkevik 2005).

Effects of Climate Change

Potential changes in seasonal precipitation patterns in Nunavut (Stratos Inc. 2011; Section 2) could lead to changes in duration, amount, and intensity of rainfall, which are the primary causes of soil erosion. As precipitation infiltrates the soil, it increases the soil weight and pore water pressure in the soil while reducing the shear strength of the soil which can cause slope instability.

Increased snow pack depth can insulate the ground from cold winter air temperatures that help maintain permafrost in frozen embankments and foundations. Whereas, extended periods of cold air temperatures in the fall prior to significant snow accumulation help to refreeze active thaw zones and maintain permafrost. Changes in the climate that result in warmer air temperatures in the fall before snow accumulation or early snow accumulation can threaten tailings impoundments that were designed to rely on permafrost (*e.g.,* frozen core dams or foundations; Andersland and Ladanyi 2004).

Where embankments impound water during the summer months, extended periods of deep water ponding can thaw frozen embankments and foundations. Increased rainfall and runoff accumulation within tailings impoundment facilities can increase ground thaw, increase seepage from the impoundment and threaten the stability of perimeter dams that rely on permafrost for seepage cut-off or stability (Andersland and Ladanyi, 2004).

TMFs that impound water with low-permeability dams typically are designed with a spillway to convey the design storm. If climate change increases storm intensity or flows associated with the design storm, the size of the spillway may be inadequate and there may be a future risk of dam overtopping and dam failure.

3.10.5.4 Wind

Wind erosion at TMFs can lead to the dusting and migration of tailings particles from the impoundment. For example, orange-coloured dust (*e.g.,* wind-blown tailings) had been observed in the community of Rankin Inlet which created public pressure to remediate the tailings (Meldrum 1999). There are concerns that wind-blown tailings at the Meadowbank Mine in Nunavut could impact the water quality of nearby lakes (Cumberland 2004).

Wave action from wind can cause erosion of upstream dam slopes with inadequate erosion protection and even overtopping of the dams (MAC 1998; Bjelkevik 2005). Wave action can cause turbulence in a tailings water cover, increasing the oxygen concentration, re-suspending tailings particles, and allowing oxidation of sulphide tailings (Bjelkevik 2005).

Changed wind patterns due to climate change could result in changes to prevailing wind directions and speeds. Planning and design of TMFs should account for potential wind impacts (*e.g.,* erosion and wave action). On-site wind monitoring equipment can aid in establishing trends and observing changes in wind pattern.

3.10.5.5 Extreme Weather Events

Some of the greatest concerns of climate change may be associated with the change in frequency and severity of extreme weather events, although the exact rates and magnitudes of expected regional climate change are not known (Brennan *et al.*, 2001). It is anticipated that the frequency of extreme weather events (*e.g.,* floods, droughts, high winds) will increase over the long-term (Bjelkevik 2005).

Extreme weather events can cause damage to mitigative measures that are employed to minimize environmental impacts from a TMF. For example, floods, high winds, or extremely cold weather can damage a vegetation cover that was put in place to reduce erosion (Bjelkevik 2005). Extreme storm events (e.g., flooding) can exceed the discharge capacity of an impoundment spillway and result in dam overtopping and possibly dam failure.

3.10.6 Review of Existing Tailing Management Guidelines

The primary objective of tailings facilities management is to achieve public and worker safety, and result in an acceptable environmental impact (Engels and Dixon-Hardy 2010). The following is a summary of Canadian guidelines and manuals that aim at supporting mining companies in implementing safe design, construction and operating procedures for TMFs (beyond regulatory requirements discussed in Section 2 of the Task 2 Report).

The Mining Association of Canada (MAC) published *A Guide to the Management of Tailings Facilities* (1998). A second edition was started in 2009 but is currently still in draft format (MAC 2009). This guide was designed to assist mine operators with design and operation of a successful TMF. The guide describes all phases involved in tailings management from design to construction, operation and finally closure (MAC 1998; 2009). The guide provides:

- methods of safe and environmentally responsible management of tailings facilities;
- environmental and safety criteria to help mining companies to develop tailings management systems; and
- methods to improve the consistency of engineering and tailings management principles (MAC 1998).

Principles and approaches from sources such as mining company manuals, workshops, and international guidelines and standards were incorporated into the guide. The second edition (MAC 2009) incorporates the lessons learned since the release of the first edition (MAC1998), particularly comments and suggestions from public and private shareholders in the mining sector. Since the release of the first edition of the guide, the MAC has developed two companion guides:

- *Developing an Operation, Maintenance and Surveillance (OMS) Manual for Tailings and Water Management Facilities* (2003); and
- *A Guide to Audit and Assessment of Tailings Facility Management* (2009).

The OMS Manual was developed by tailings experts within the Canadian mining industry and was designed to complement the 1998 guide by adding all aspects of day-to-day operations of a tailings facility (MAC 2003). The manual is based on sound industrial practice and procedures and was developed to address the need for additional guidance at the operational level of a mine, specifically for guidance in the development of procedural manuals for safe operation, maintenance and surveillance (OMS) of mine site tailings and water management facilities. OMS manuals are site-specific to ensure that it is applicable at all stages of a mine's life cycle, from commissioning to abandonment. OMS manuals must be revised on a regular basis to ensure continual improvement and to maintain applicability at all stages of a mine's life cycle. The OMS Manual provides a practical approach of how to:

- prepare a site specific OMS manual;
- define the roles, responsibilities and required competency at all levels within the management structure;
- provide a detailed overview of tailings and water management facilities;
- define operating standards and procedures;
- develop a maintenance program;
- inspect and monitor tailings and water management facilities; and
- develop and define emergency preparedness and response plans.

In addition to safety and environmental responsibility, OMS manuals can be beneficial to a company in areas such as:

- compliance with government regulation and corporate policy;
- demonstration of voluntary self-regulation and due diligence;
- continual improvement; and
- employee, environmental and public protection.

The document incorporates industry practices and procedures, and was developed in consideration of the different priorities of the variety of stakeholders involved in tailings and water management facilities.

Standardized guidelines for tailings dams were developed by MAC and other mining professionals and included in the 1999 *Dam Safety Guidelines* developed and published by the Canadian Dam Association (CDA; Engels and Dixon-Hardy 2010). These guidelines address in detail the responsibility for dam safety, scope and frequency of dam safety reviews, the need for an operating manual and emergency planning.

The above described MAC documents and the CDA guidelines were developed with the intention to complement existing territorial, provincial and federal government regulations in Canada and at the same time to promote due diligence in the mining industry. The overall goal of these documents is to provide a tool to protect the environment and the public from the potential hazards associated with tailings facilities (Engels and Dixon-Hardy 2010). They constitute the main guidance for establishing a universal framework for managing TMFs in Canada.

Additionally, independent organizations, such as the International Commission on Large Dams (ICOLD), the United Nations Environmental Programme (UNEP) and the International Council on Metals and the Environment (ICME) have addressed tailings facilities safety and raised awareness among regulators (ICOLD 2011).

ICOLD and their over 50 member countries (including Canada) have worked to address tailings safety and management concerns over the last 30 years. ICOLD established a committee on tailings and waste rock lagoons in 1976 and have since published 12 bulletins specific to tailings storage (ICOLD 2011) and one specific to permafrost.

Even though there is a long list of ICOLD bulletin publications on tailings facilities none of them addresses permafrost environments. One bulletin addresses dam construction on permafrost:

- **133** *Embankment Dams on Permafrost* (2008; note: this bulletin is not specific to tailings facilities but addresses standard practices for constructing dams on permafrost)

There is an ongoing liaison between ICOLD and UNEP to determine what lessons can be learned from past failures, to evaluate current regulatory instruments and their effectiveness (Engels and Dixon-Hardy 2010). UNEP is working with interested governments around the world to establish an ongoing *Regulators Forum* – with the safety and environmental performance of tailings facilities and approaches to their regulation as some of their main aspects.

Adaptation measures for TMFs involve incorporating best practices (such as the documents described above) into the planning and construction, operations and closure phases of a mine. The environmental best practices for mine sites as determined by EC (2012) are described in the Task 2 Report, and include details on how tailings facilities should be managed, including considerations for mining in a northern environment (*e.g.,* closure planning for tailings structures in permafrost conditions).

3.10.7 Risk Assessment

It is important to assess risk and undertake precautionary actions to reduce identified risks related to TMFs, including the incorporation of measures to adapt to changes in climate over time (Brennan *et al.*, 2001)

MAC's 1998 *Guide to the Management of Tailings Facilities* identified four phases of a tailings impoundment life cycle: design, construction, operation and closure (as described above). The guide proposed that a risk assessment be undertaken for each phase (MAC 1998). The risk assessment procedure is described in this section of the Report because of the high, long-term risks associated with the management of tailings.

As part of the environmental assessment process, a risk assessment is conducted to identify potential concerns with a facility and its associated plans and procedures (*e.g.,* hazards or failure modes, their probabilities, and their consequences; MAC 1998). Risks may be considered the product of a combined measure of the probability and severity (consequence) of an adverse event (Bjelkevik 2005).

Risk assessments are standardized (*i.e.,* formalized) methods of review which help identify hazards, although not eliminate them. Risk assessments can be considered management support tools that enable mine operators to develop risk-based decision making; these assessments do not replace sound engineering or knowledgeable tailings management practices (Bjelkevik 2005; Bruce and Oboni 2000). As such, risk assessments are used to develop risk management strategies (MAC 1998).

Methodologies for risk assessment include attempting to determine parameters which pose potential threats to a tailings management facility (including ones specifically relating to climate-induced risks; MAC 1998). Tailings management systems are complex and process-specific, and include man-made components (*e.g.,* dams, pipelines and ponds) interacting with natural components (*e.g.,* permafrost, slopes, seismically active faults, precipitation, runoff), and tailings containment risk assessments are therefore unique to each mine (Bruce and Oboni 2000).

In conducting a risk assessment for a TMF, potential triggers and failure modes related to climatic and environmental parameters need to be considered, such as (MAC 1998):

- reservoir overtopping,

- dam instability,
- foundation instability; and
- structural failure.

Upon completion of identifying potential triggers and failure modes, the probability of each potential failure must be determined, and the estimated consequences of the failure for each potential failure mode (including environmental impacts). Then operating, maintenance, inspection and incident response procedures can be developed to reduce the identified potential risks (MAC 1998).

When designing a TMF, climatic and environmental considerations should include (to be compiled from literature surveys and field / laboratory investigation programs (MAC 1998):

- hydrology and hydrogeology (*e.g.,* water balance, catchment runoff and diversion arrangements, erosion management plan);
- foundations, geology and geotechnical engineering;
- construction materials including engineering characteristics of tailings and borrow materials, grout / concrete or other natural or synthetic liner material (*e.g.,* shear strength, permeability, acid generating potential, wind and water erosion potential);
- special environmental considerations (*e.g.,* climatic conditions including extreme values to be expected, wind and wave actions, permafrost effects, frost action); and
- seepage (*e.g.,* establish maximum allowable seepage objectives for environmental and structural requirements; develop a seepage management plan).

Through completing risk assessments, the potential triggers and failure modes associated with the phases of a mine's life cycle, as well as the probability and consequences of any failures, should have been identified. Then adaptation measures can be implemented to mitigate the impacts that those identified failures could have on components of a mine, such as its TMFs.

When assessing risks, thermal modelling can also be utilized to determine whether frozen conditions will be maintained.

In the following, adaptation measures to mitigate potential impacts from climate change on TMFs in Nunavut are identified. More details are provided in the Task 2 Report.

3.10.8 Adaptation Measures to Address Potential Climate Change Impacts on Tailings Management Facilities

The management of tailings is a significant long-term issue that mine operators must address well beyond the mine's operational period. Studies looking at the long-term perspectives of tailings management have suggested that most existing tailings management practices are likely inadequate in the context of addressing long-term climate change projections (Bjelkevik, 2005).

3.10.8.1 Permafrost

When planning for mining projects it is imperative to account for potential changes in climatic trends and with that minimizing the impacts that changes in the permafrost regime have on infrastructure. Approaches to limiting the impacts to permafrost at mine sites include (EBA 2004):

- locating mine infrastructure where degradation of permafrost will cause the least risks (*e.g.,* removing overburden and constructing infrastructure directly on bedrock);
- assuming permafrost will thaw and encouraging it to thaw (*e.g.,* by stripping insulating vegetation) or incorporating the predicted future surface settlement into structural designs;
- remove the permafrost (*e.g.,* in areas of thin permafrost); or
- take adaptive measures to preserve the permafrost (*e.g.,* in areas of thick, stable permafrost).

As described earlier, permafrost can be incorporated into strategies for controlling ARD from tailings and waste rock. In Nunavut, strategies for preventing ARD are variable, and require careful consideration for the most appropriate applications at specific mine site locations.

The design, construction and closure of mining activities on temperature-sensitive permafrost should consider the potential for future climate change (EBA 2004). Current engineering practice for tailings facility design now considers potential climate warming with thermal analyses for structures located in permafrost zones. Moreover, it is important that tailings facility designs assess climatic trends are using long-term historical records from meteorological stations in the area.

Cold regions dam designs can either attempt to preserve frozen conditions or accommodate future thaw by removing thaw-unstable soils (INAC 2003). The preferred approach to minimize potential impacts of climate warming is to either design tailings facilities with unfrozen embankments or design embankments that are thaw-stable. Thaw-stable embankments remain stable (*i.e.,* have a sufficient slope factor of safety) with thawed soil strength parameters and potential thaw settlement will not threaten the safety or function of the embankment or tailings facility. Dams on permafrost should be constructed on rock or thaw-stable foundations and incorporate traditional seepage control measures such as geomembrane liner or bedrock foundation grouting so that dam performance is not impacted by permafrost degradation (SRK Consulting 2009b; INAC 2003).

The use of frozen core dams is not recommended at sites with discontinuous permafrost or where climate change may result in the disappearance of permafrost (INAC 2003). Frozen core dams that relied on permafrost may require supplemental cooling by installation of thermosyphons to maintain frozen core and foundation conditions (INAC 2003). Thermosyphons are vertical pipes with fins that extend above ground surface and use a fluid to transfer heat from (*i.e.,* freeze) the ground during the winter months. Thermosyphons are typically equipped with valves that are closed during the summer so that the thermal transfer fluid does not circulate and thaw frozen ground during summer months. If future air temperatures are not sufficiently cold to maintain a frozen core dam then thermosyphons could theoretically be modified with a refrigeration system to maintain frozen conditions. Although a thermosyphon is essentially a passive system requiring only minimal maintenance and monitoring, a refrigeration system would be an active system with significant energy requirements to operate which may not be a desirable long-term requirement. Other modifications to maintain frozen conditions include adding insulation or increasing cover (INAC 2003). Tailings facilities that impound water should be designed to be drained prior to winter, if practicable, so that cold air temperatures can maintain permafrost in the embankment and foundation soils. However, maintaining frozen ground conditions for structures that have been designed using that strategy may be a challenge with climate warming (INAC 2003). Once seepage flow is initiated through a dam structure or foundation, it is very difficult to control by refreezing due to the convective heat transfer of water (INAC 2003).

Preventing unplanned events, such as dam failures, requires the early detection of permafrost degradation. The use of monitoring devices (*e.g.,* temperature sensing instrumentation) can act as an early warning system of permafrost degradation (EBA 2004). In a warming climate, the use of temperature monitoring instrumentation could help mine operators in Nunavut to identify and respond to changes that pose risks to the integrity of TMFs. Temperature sensing equipment that can be used to measure and monitor ground temperatures and water pressures at TMFs include (EBA 2004):

- thermistors – temperature sensors that can be used to monitor changes in permafrost, frozen core dams, or dam foundations; and
- piezometers - monitor changes in pore water pressure in soil, rock or tailings.

Additionally, periodic ground surveys are important aspects of monitoring any earth structures in order to recognize deformations and identify trends that could be caused by thaw-settlement or frost heave (EBA 2004).

In general, the development of adaptation measures for dealing with changes to permafrost at mine sites will require a good knowledge of the environmental conditions at the site, and the following information should be gathered prior to mine construction to aid in mine site planning and design (EBA 2004):

- daily mean and monthly air temperatures;
- amplitude of ground temperature variation within the active layer and depth of the active layer;
- stable permafrost temperature distribution at depth; and
- precipitation and snow cover measurements.

The role of permafrost and potential changes in its regime after mine closure should also be considered early in the planning stages for a mine to provide planners with a good understanding of the appropriate choices for tailings disposal options and methodologies (EBA 2004), taking into account methods for understanding how a changing climate could impact permafrost and therefore TMFs, and developing adaptation strategies to deal with anticipated impacts.

It needs to be considered whether a site that may currently be in a cold permafrost region will remain under those conditions for the design life which for TMF is often 100-200 years. Similar to adaptation strategies discussed earlier (e.g., Section 3.6; Table 2), utilization of contingency technologies (e.g., extraction of heat or artificially maintain frozen conditions) may be required if conditions become warmer. Frozen conditions should not be relied upon for long-term structures such as TMFs.

3.10.8.2 Frost Action and Ice

Climatic (*e.g.,* temperature) and geotechnical (*e.g.,* soil material properties) parameters that affect frost action need to be considered when planning tailings management facility structures such as dams in order to minimize damage due to frost heave, thaw creep, thaw settlement and other ice-related processes. Frost and ice control measures could include:

- establishing a vegetation cover to minimize erosion and insulate permafrost (e.g., through natural revegetation);
- installation of thermosyphon, air duct or convention cooling systems to maintain freezing ground temperatures to mitigate frost heave and thaw settlement (Instanes *et al.* 2005; United States Arctic Research Commission Permafrost Task Force 2003; Section 3.1); or
- entrapment of ice into tailings can be minimized by dewatering tailings prior to deposition, effective beach management and employing appropriate operational strategies to reduce ice entrapment (*e.g.,* developing a detailed deposition plan; Cumberland 2004).

3.10.8.3 Precipitation and Water

Mine planners and operators require the ability to adapt to potential changes in precipitation events (*e.g.,* their duration, intensity and frequency; Section 2). Mitigation measures should aim to handle increased storm inflow volumes. Additionally, mitigation measures that reduce the impact of increased water flow, such as erosion, should be considered.

Water Levels

Climate change may require that water retaining dams be designed with more conservative assumptions regarding maximum water levels and extreme storm events resulting in increased crest elevations (INAC 2003). The use of clean water diversion channels to reduce storm inflows to a tailings impoundment and prevent the overtopping of dams and erosion during heavy rainfall events should be considered (Witt *et al.* 2004). Spillways and outflow channels should be adequately sized to pass storm flows and, if possible, excavated into bedrock so they are not suspectible to erosion (Bjelkevik 2005).

Water Covers

Water cover design should be designed so that minimum water levels are maintained during drought periods by evaluating minimum precipitation and maximum evaporation scenarios over the long-term (Bjelkevik 2005).

Erosion

The erosive weather forces of precipitation can be minimized through the appropriate design of TMFs. Adaptation measures that can be incorporated into the design of TMF structures (*e.g.,* dam slopes) to reduce erosion (Bjelkevik 2005; Witt *et al.* 2004):

- flatter slopes;
- erosion protection (*e.g.,* gravel, boulders or rip-rap) that is sized for the design storm flows;

- vegetation covers to shield surfaces from precipitation impacts and minimize surface erosion; and
- constructing diversion channels to reduce runoff and inflow to the TMF.

3.10.8.4 Wind

Considering the anticipated increase in storm events in the Arctic (Section 2), it can be proposed that concerns related to wind erosion at TMFs may increase in the future, requiring planning and adaptive strategies to deal with increased wind speeds and dusting of tailings.

The reduction of wind erosion effects can be accomplished with properly designed tailings covers (Witt *et al.* 2004). Wave break structures can be built across flooded tailings impoundments to reduce wave heights, minimize tailings re-suspension and maintain low oxygen concentrations in water covers.

Wind erosion of exposed tailings surfaces can be reduced by (Bjelkevik 2005):

- placement of discontinuous layers of gravel, cobbles, rockfill or boulders to dissipate the wind's energy and minimize wind erosion;
- vegetation covers to shield surfaces from the wind and minimize surface erosion; and
- granular or soil covers over exposed tailings to minimize surface erosion.

3.10.8.5 Extreme Weather Events

A potential increase in extreme weather events in the Arctic (Section 2) requires that TMF designers identify and include adaptation measures that can extreme weather events could have.

As described above, TMFs should be designed to withstand more frequent and intense storm events. For example, larger spillways capable of passing larger storm flows.

Changes in the seasonal timing of extreme weather events should also be considered. For example, warmer spring weather could result in early thawing of snow and ice and increased spring runoff volumes. Alternatively, less snow accumulation during the winter could result in lower spring runoff volumes. Site-specific climate data and climate change predictions should be considered.

3.10.9 Suggested Research and Policy Action

The Canadian Nuclear Safety Commission (CNSC) recently secured funding for research to predict mining related permafrost degradation within the continuous permafrost zone to gain knowledge needed to support the technical review of AREVA's Kiggavik project (Permafrost Degradation within Continuous Permafrost Zones, CNSC 2011). The multi-year assessment will involve the assessment of permafrost degradation behaviour beneath TMFs at the Kiggavik site near Baker Lake. This will facilitate the development of long-term predictions of how the thermal regime under TMFs may react under climate change conditions, providing a critical assessment of the potential adverse environmental effects of mining-related projects in Arctic and sub-Arctic regions (CNSC 2011).

Making information from mining projects more publicly available including the on-site environmental data (including climate data) and information collected from monitoring programs would assist stakeholders (regulators, decision makers, developers and affected communities) in gaining an understanding of the local environment, changes that are happening and impacts that may be occurring . This would improve knowledge of regional baseline conditions, provide input data for models to aid engineering design and also help to build best practices.

There is a gap in assessing long-term chemical stability of mine wastes in a changing climate and development of potential adaptation strategies through an integrated approach to mining, mineral processing and mine waste management largely unexplored. This gap could be addressed trough targeted studies.

4.0 VULNERABILITY ASSESSMENT WORKSHOP

A Vulnerability Assessment Workshop (the Workshop) was held in Iqaluit with 16 participants from the mining industry, territorial and federal government agencies and others. The Workshop was held on June 21, 2011 at the Government of Canada Building.

4.1 Workshop Overview

The purpose of the Workshop was to engage the stakeholders in the vulnerability assessment designed to obtain necessary feedback from the stakeholders to identify the primary areas of climate change adaption concern. Prior to the Workshop, climate parameters were used to prepare a framework (climate-infrastructure assessment matrix) to discuss the probability and consequence of climate events affecting mining operations and infrastructure that have been outlined in this Report.

The Workshop was designed to appeal to attendees from a variety of backgrounds, all of which have an interest in the changing climate of the North. The governments of Nunavut and the Northwest Territories, NRCan, several mining companies, the NWT & Nunavut Chamber of Mines, AANDC (formerly INAC), the Qikiqtani Inuit Association and the Nunavut Research Institute sent representatives to attend the Workshop.

The Workshop was designed to be an interactive exercise between the subject matter experts and the stakeholders. The Workshop provided a venue to discuss vulnerabilities with the subject matter experts during “tabletop” exercises. The first portion of the Workshop focused on providing the necessary background information required to perform the exercises. The second portion of the Workshop focused on identifying the key climate / mining interactions and explaining the relationships between the two. Missing infrastructure components and climate events were then identified by the attendees. The third portion of the Workshop focused on assigning probability and consequences to all the climate-infrastructure interactions identified previously. Finally, a summary of the vulnerability assessment was given, along with a list of potential areas for further investigation.

4.2 Summary of Workshop Results

The climate-infrastructure matrix is a critical tool used in the vulnerability assessment. Within the matrix, the climate-infrastructure interactions that are discussed in Section 3 were identified, building a common understanding of the vulnerabilities of climate change.

During the Workshop, attendees were given the opportunity to recommend any missed climate-infrastructure components. Encouraging dialogue between the participant’s aids in the understanding of concerns across different sectors and backgrounds, providing a more complete view of the concerns associated with the vulnerabilities of climate change.

The results of the Workshop interaction and review of the climate-infrastructure interactions were summarized within the climate-infrastructure matrix. Four key pieces of information were identified in the matrix:

- infrastructure components;
- identification and description of potential impact of climate change on infrastructure components;
- identification and description of perceived environmental health and safety consequence of climate change on a given infrastructure; and
- identification and description of perceived economic consequence of climate change on a given infrastructure.

Once the climate-infrastructure matrix was complete, the information was used to guide the participants in the ranking of consequence and probability associated with each area of vulnerability presented in the matrix. Each participant was asked to rank four components associated with an area of vulnerability:

- environmental health and safety consequences;
- probability of environmental health and safety consequences occurring;
- economic consequences; and
- probability of economic consequences occurring.

Each participant ranked the four components associated with an area of vulnerability on a scale of 1 to 7 with one being mild consequence or not likely and seven being severe consequence or highly likely. The risk associated with each area of vulnerability is assessed by combining (multiplying) the ranking of the consequence and probability. Risk scores are provided for both environmental health and safety concerns, as well as economic concerns. The ranking was first performed based on perceived vulnerability under current climate conditions. The participants then repeated the probability ranking using the information on climate projections for the 2050s presented earlier in the Workshop.

Each participant provided an individual assessment of the consequence and probability, combined into a risk score for each area of concern. Responses from all individuals are summarized, providing a range of assessed risk. The minimum, maximum and average risk score are identified and compared between infrastructure components are summarized in Figures 5 and 6. TMFs were divided into two categories: existing or abandoned ones and new TMFs currently proposed or potentially proposed in the future.

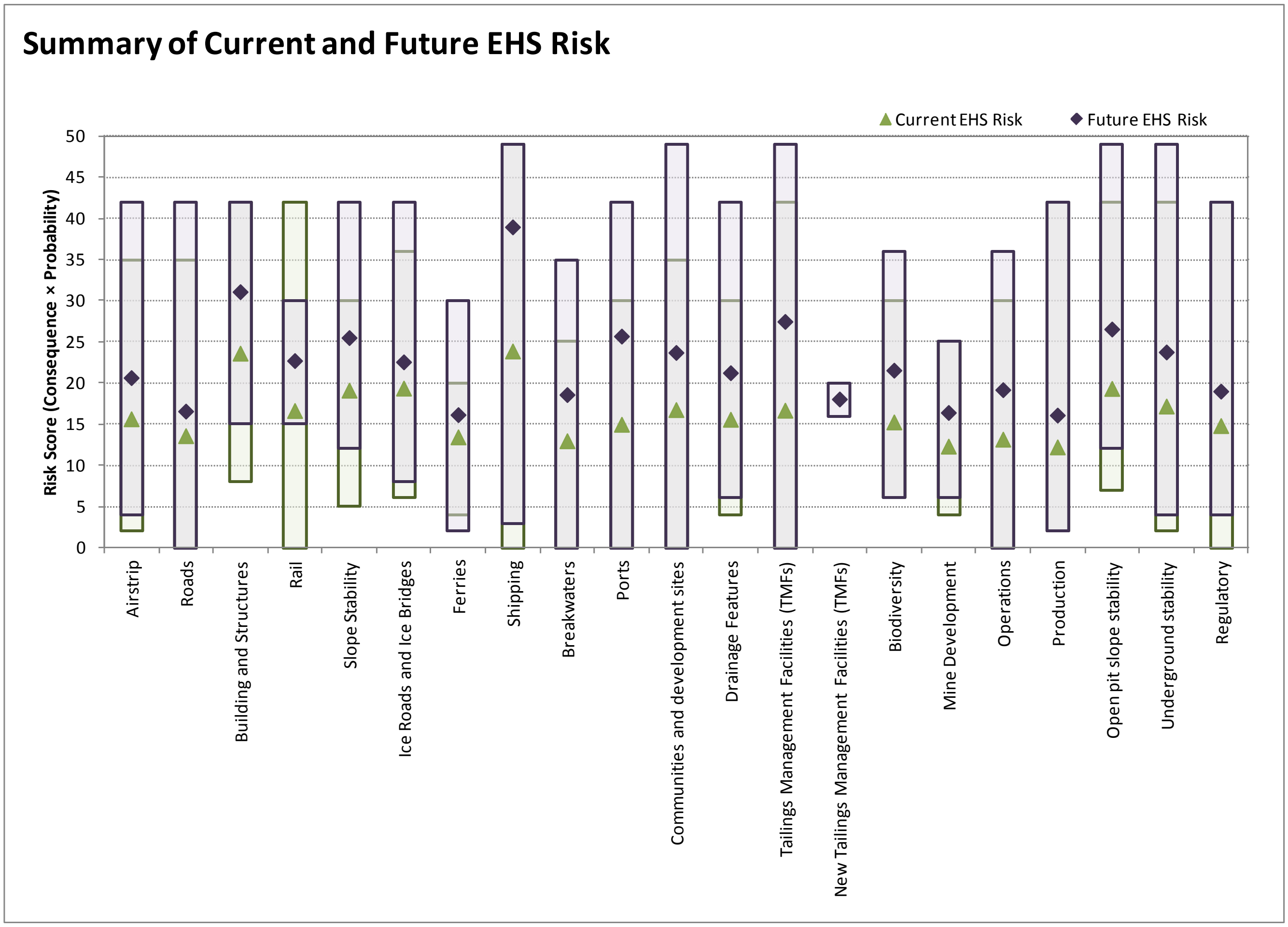

Figure 5: Summary of Current and Future Environmental Health and Safety (EHS) Risk

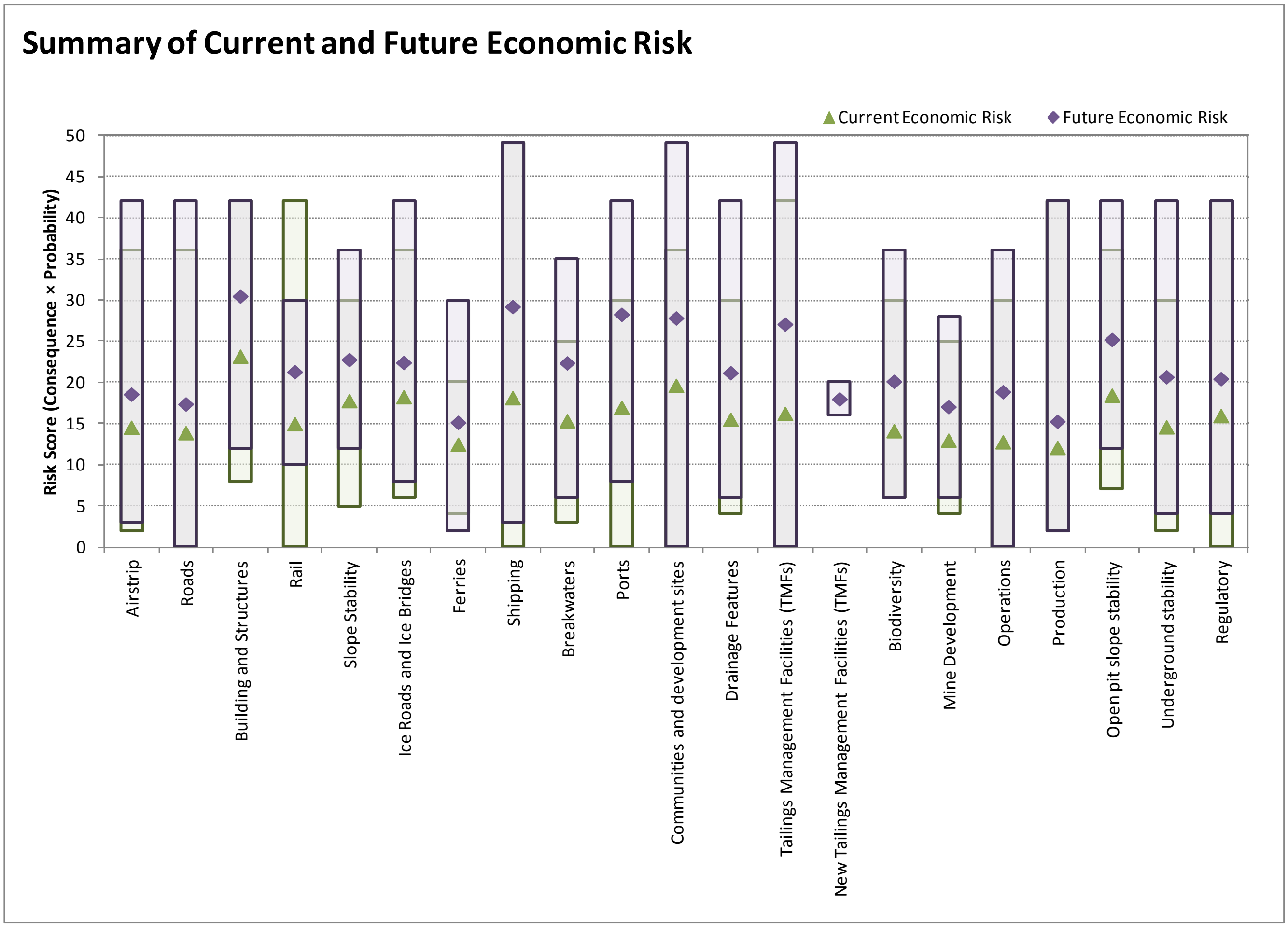

Figure 6: Summary of Current and Future Economic Risk

From the figures it is apparent that Workshop participants assessed TMFs and ports as the most important mining-related infrastructure. These infrastructure components are the focus of the Task 2 Report.

5.0 SUMMARY OF IDENTIFIED ADAPTATION MEASURES

Through periodic assessments of the scientific literature, the IPCC has shown that the climate is changing in Canada's Arctic regions. A changing climate can have impacts on the natural environment. Documented and anticipated changes to environmental parameters in Nunavut include the following:

- permafrost – permafrost degradation (e.g., thermokarst development) and increases in active layer thickness;
- air temperature – general warming trends at locations across Nunavut;
- precipitation and weather patterns – changes in the type and quantity of precipitation and increases in extreme weather events (e.g., floods, droughts, storms);
- sea ice – a diminishing extent of sea ice coverage and a shorter duration of sea ice cover resulting in an increased open water season;
- sea level – sea level rise (e.g., due to melting of polar ice caps and thermodynamic expansion of ocean water as it warms); impacts localized due to the land's isostatic rebound; and
- coastal erosion – increased open water season and extreme events exacerbating wave action and coastal erosion.

As the climate changes, it is causing impacts to the Northern environment and infrastructure. The Vulnerability Assessment Workshop in Iqaluit (in June, 2011) was designed to gather input from the mining sector and other stakeholders on the perceived vulnerability of infrastructure components in Nunavut to climate change. Through the development of a climate-infrastructure matrix, participants of the workshop were able to rank the consequence and probability associated with each area of vulnerability presented in the matrix:

- environmental health and safety consequences;
- probability of environmental health and safety consequences occurring;
- economic consequences; and
- probability of economic consequences occurring.

The impacts from climate change on mining-related infrastructure in Nunavut can be limited through the use of good design practices, adaptive planning and the implementation of mitigative measures. Participants assessed TMFs and ports as the most vulnerable mining infrastructure components. Consequently, TMFs and ports are the focus of the case studies provided in the Task 2 Report and are followed by a detailed list of design, construction and maintenance recommendations

5.1 Roads, Airstrips and Railways

Recognized techniques exist for infrastructure development in the north. Additional adaptation measures to reduce the impacts of climate change on roads, airstrips and railways in regions of thaw-sensitive permafrost in Nunavut were identified and include:

- **increasing embankment thickness** to reduce heat penetration from the air into the soil and permafrost;
- **insulating** permafrost with polystyrene or peat to reduce heat penetration underneath embankments;
- installing **sunsheds / snowsheds** to reduce exposure to solar radiation (sunshed) in the summer, and to prevent snow accumulation on the side of embankments (snowsheds) in the winter;
- using **reflective surfaces** (*i.e.,* high albedo) to reduce the heating effect of solar radiation;
- installing **thermosyphons** to extract heat from beneath embankments;
- utilizing **air convection embankments** to enhance heat extraction from within and underneath embankments;
- installing **heat drains** to extract heat from within and underneath embankments;
- using **geotextile and geogrid** fabric in the construction of an embankment to provide reinforcement;
- constructing **berms** to limit snow accumulation on embankment slopes;
- **pre-thawing** ice-rich permafrost before construction to reduce the effects of freeze-thaw settlement;
- **excavation** of ice-rich permafrost and **replacement** with fill (e.g., gravel); and
- **snow removal** to reduce the insulating effect of snow on embankments.

Changes in precipitation patterns can also impact roads, airports and bridges. Site investigations to define surface water flow must be performed so that **culverts and bridges** are placed in areas where flooding and or high water flow occur to prevent washouts. Culverts and bridges are essential in protection against extreme weather events, such as flash freshets, which occur during spring in the Arctic.

On-site climate data, particularly precipitation should be collected. Furthermore, more long-term data on stream flow in project areas should be collected in order to address uncertainties.

5.2 Ports

Climate change affecting factors such as costal permafrost, sea level, storm events and waves, sea ice, currents, and coastal erosion have the potential to impact ports in Nunavut.

Permafrost

Measures to protect against erosion of coastal permafrost include:

- construction of **jetties** to protect against wave action;

- construction of **breakwaters** to protect against wave action;
- construction of **seawalls** to protect against wave action;
- use of **sandbags** or **geotextile tubes** placed on the beach to protect against wave action (these are vulnerable to undermining and breakage, although the sand can serve to nourish the beaches; see below, Erosion);
- use of **fill** along the coastline to rebuild, maintain and regrade coastal bluffs and shorelines; and
- the **deposition of rocks and gravel** on the beach to dissipate wave energy (can be ineffective unless there is adequate protection of the toe of the beach).

Sea Level

In the planning and design of ports, it is generally recommended to use an allowance for **sea level rise of at least 5 mm/yr** (in the absence of site-specific information).

Storm Events and Waves

The design of a port should incorporate sea defences to help the damage caused by storm events and wave action. Adaptation measures include **increasing the heights** of quay levels and any protective structures (jetties, breakwaters, seawalls – as described above) and connected areas behind them

Sea Ice

Considerations for developing, constructing and maintaining port infrastructure and associated dock facilities to withstand sea ice stresses include, but are not limited to:

- completing **bathymetric work** during the planning phase to determine safe and sensible transportation routes when considering ice conditions;
- completing ice studies and other marine assessments to **determine the most appropriate dock locations** considering expected ice conditions, define shipping lanes, and determine what ice class of vessel would be appropriate for use in the area (as required);
- designing docks using **caissons instead of solid structures** to allow ice to accumulate between the caissons and help ice move past dock structures;
- using **bubbler systems** around docks to minimize the development of sea ice in the area; and
- using **warmed ballast water discharge** from vessels to minimize the development of sea ice or help reduce the thickness of already developed sea ice around docks.

Currents

Currents can cause littoral drift in near-shore zones. The impact of littoral drift can be minimized by breakwaters and jetties.

Coastal Erosion

Near-shore structures can be incorporated in port design to help minimize climate-induced impacts that affect coastal erosion (e.g., wave energy). These structures include:

- **rubble mounds** comprised of graded layers of natural rock to absorb wave energy;
- **gabions** composed of rock-filled wire baskets and mattresses that are formed into mounds to absorb wave energy;
- **engineered mounds** constructed out of pre-cast structures to absorb wave energy;
- straight vertical or near-vertical **seawalls** to reflect wave energy; and
- **fill materials** (e.g., sand) deposited along beaches and foreshore areas.

5.3 Tailings Management Facilities

TMFs in the North are designed to take advantage of climate-related factors such as permafrost and precipitation and can be impacted by changes in the climate such as frost action, water, wind, and extreme weather events.

Permafrost

Measures to manage uncertainty related to future climate change associated issues with permafrost that can impact tailings management facilities are described above for roads, airstrips and railways. In particular, ground temperature should be monitored during operations and post-closure where maintaining frozen conditions is an important aspect of TMF design.

Frost Action and Ice

Frost and ice control measures include:

- establishing a **vegetation cover** to minimize erosion and insulate permafrost;
- installation of **thermosyphons, air ducts or conventional cooling systems** to maintain frozen ground temperatures to mitigate frost heave and thaw settlement; and
- **minimizing entrapment of ice in tailings** by dewatering tailings prior to deposition, effective beach management and employing appropriate operational strategies to reduce ice entrapment.

Precipitation and Water

Measures to adapt tailings facilities to potential changes in precipitation events (*e.g.,* their duration, intensity and frequency) include:

- the use of **clean water diversion channels** to reduce storm inflows to a tailings impoundment and prevent the overtopping of dams and erosion;

- the design of **water covers** to ensure that minimum water levels are maintained during drought periods; and
- the incorporation of **flatter slopes**, **erosion protection** (e.g., gravel, boulders or rip-rap), **vegetation covers**, and **diversion channels** to reduce erosion.

Wind

Wind erosion of exposed tailings surfaces can be reduced by:

- placement of discontinuous **layers of gravel, cobbles, rock or boulders** to dissipate the wind's energy and minimize wind erosion;
- **vegetation covers** to shield surfaces from the wind and minimize surface erosion; and
- **granular or soil covers** over exposed tailings to minimize surface erosion.

Extreme Weather Events

Considerations that can be incorporated into tailings facilities design include larger storm events. For example, designing a **larger spillway** will accommodate larger storm flows.

Risk Assessment

Identify / determine parameters which pose potential threats to a TMFs. Tailings management systems are complex and process-specific, and include man-made components (*e.g.,* dams, pipelines and ponds) interacting with natural components (*e.g.,* permafrost, slopes, seismically active faults, precipitation, runoff), and tailings containment risk assessments are therefore unique to each mine. Assessing particular site-specific risks is instrumental in developing appropriate Adaptation Measures.

5.4 Monitoring and Availability of Monitoring Information

The common issue in the development of mining and large infrastructure is the potential degradation of permafrost due to climate change. The presence of permafrost is accounted for when designing and constructing infrastructure. Improper construction activities in permafrost zones can result in changes to ground surface properties which can in turn impact the ground thermal regime and cause permafrost degradation. Proper design can help to overcome these issues; however, changes to the climate in the future may lead to permafrost degradation. The local conditions and the design practices have an equal or greater effect on the adaptive capacity of the infrastructure

Monitoring programs should be designed and implemented to ensure that mine closure activities and any potential environmental impacts are mitigated and ensure that mine closure objectives are met. Aquatic and terrestrial ecosystem monitoring should continue until mine closure work is completed, but also carried out post-closure to ensure that rehabilitation measures meet relevant regulatory requirements and comply with targeted end land uses.

Making information from mining projects more publicly available including the on-site environmental data (including climate data) and information collected from monitoring programs would assist stakeholders (regulators, decision makers, developers and affected communities) in gaining an understanding of the local environment, changes that are happening and impacts that may be occurring . This would improve knowledge of regional baseline conditions, provide input data for models to aid engineering design and also help to build best practices.

Additionally to ensuring public availability of baseline data collected at mine sites, regularly updated maps would facilitate the review process for specific developments. Environmental parameters such as the distribution of permafrost temperatures, air temperatures and precipitation could be mapped in conjunction with past, current and planned development projects. These maps should be made available to stakeholders and the interested public.

There is a gap in assessing long-term chemical stability of mine wastes in a changing climate and development of potential adaptation strategies through an integrated approach to mining, mineral processing and mine waste management largely unexplored. This gap could be addressed trough targeted studies.

Mining companies, regulators, scientists and other industry stakeholders should increase their efforts to collaborate to develop practical adaptation strategies that can be integrated into existing and new mine operations, including in the post-operational phase. Adaptation strategies should be monitored closely and results, such as successes and failures should be shared.

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