THE CITY OF IQALUIT'S CLIMATE CHANGE IMPACTS, INFRASTRUCTURE RISKS & ADAPTIVE CAPACITY PROJECT

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TABLE OF CONTENTS

SECTION 5

SECTION 6

SECTION 7

Executive Summary

Although the world's understanding of the full impacts of global warming is in its infancy, most scientists believe that the Arctic is one area of the world which will be most dramatically affected by climate change. The Intergovernmental Panel on Climate Change concluded that the Arctic is highly vulnerable to the impacts of a warming climate and has low adaptive capacity. Currently, communities throughout Nunavut are experiencing the social, environmental and economic impacts of climate change.

Infrastructure is a critical component of communities: it supports most local activities and sustains important social and economic services with housing, roads, schools, hospitals, power and communication facilities and municipal services. As climate becomes more variable and extreme, communities and the infrastructure upon which they rely are increasingly vulnerable. In the last two decades, escalating damage to infrastructure from weather-related impacts has raised the question of its durability in the face of climate change.

As climate change impacts become more evident, municipalities recognize the need to build their adaptive capacity. With funding from Indian & Northern Affairs Canada, the City of Iqaluit undertook the *Climate Change Impacts, Infrastructure Risks & Adaptive Capacity Project,* the aim of which was to identify risks to its infrastructure (including buildings, roads, and water supply, wastewater treatment and waste disposal systems) and develop adaptation options. The project methodology involved synthesizing existing research about local climatic conditions, projected trends in future climate, probable impacts to infrastructure and adaptation options for an arctic community. Consultations with community leaders, municipal staff, climate change experts and those who design, build and service infrastructure provided information on current risks to infrastructure, which was used to identify pertinent impacts and develop adaptation options for the City of Iqaluit.

Arctic Climate Conditions & Trends

Over the last century, arctic climate has been characterized by a warming trend unprecedented in the last 10,000 years. This has caused ground temperatures to rise (bringing about changes in the permafrost layer), sea ice to diminish, glaciers to retreat and sea level to rise. Most current and ongoing studies indicate arctic weather will be warmer and wetter, and changes manifested in the 20th century will very likely be larger the 21st. Changes will be seen in all four seasons, but most prominently during the winter. Studies also indicate that the intensity and frequency of extreme weather events will increase.

Iqaluit's Climate

Iqaluit's daily mean air temperature is -9.8^{o} Celsius, with a daily mean in July of 7.7^{o} Celsius and -28^{o} Celsius in February. Total annual precipitation is 412.1 mm, comprising 198.3 mm of rain between June and September and 235.8 cm of snow between October and April.

To develop climate scenarios for the City of Iqaluit, 29 temperature and precipitation scenario runs from seven General Circulation Models were used. Because each model distinguishes the climate in somewhat different ways, the Intergovernmental Panel on Climate Change suggests using output from all models to develop a regional projection. All scenarios reviewed for Iqaluit project increases in mean annual and seasonal temperatures (for example, a mean annual increase of 1. 7^{o} Celsius is projected for 2010-2039 over baseline climate).

Climate Change & Infrastructure

Like most arctic communities, Iqaluit's infrastructure has been designed and built using standards based on past climate data. Recent changes in climate have cause significant damage to infrastructure, as it is exposed to conditions it was not originally designed to withstand. With projected increases in climate variability and extreme events, damage to infrastructure is expected to increase exponentially. Of particular concern for arctic infrastructure are changes in permafrost, the frequency and severity of extreme weather events, precipitation, the coastal environment and ultraviolet radiation levels.

Changes in Permafrost

Since most arctic infrastructure relies on the properties of frozen ground for stability, a decrease in the permafrost layer is the most pronounced climate change impact for northern regions. Permafrost is very sensitive to long-term warming temperatures and studies show that even small increases in temperature will cause soils to lose their bearing capacity. A warmer climate will reduce the permafrost layer and cause ground instability, which will damage roads, buildings and pipelines. Although historical data on the performance and maintenance of Iqaluit's infrastructure is very limited, changes in the depth of the active layer have been observed, affecting the stability of some buildings in the area.

An Increase in Extreme Weather Events

With extreme weather events on the rise, property damage costs and losses in Canada are now measured in the billions. Current research provides growing evidence of significant correlation between warmer temperatures and extreme weather. Studies show small changes in average temperatures can significantly increase extreme events, which may result in greater infrastructure damage.

Another effect of warmer temperatures is an increase in the intensity and frequency of windstorms. In 2007, a February blizzard in Iqaluit brought higher-than-usual winds that caused extensive damage to houses and buildings in the area. Some studies indicate that even small increases in peak wind speeds will cause disproportionate increases in building damage.

Changes in Precipitation

Climate scenarios project an increase in precipitation in the form of heavier rains and snowfalls, which may expose infrastructure to conditions it was not designed to endure. Projected increases in snowfall may cause loading on buildings that could lead to structural failure. The insulating properties of snow may increase the active layer and put infrastructure in areas prone to snow accumulation at risk of thaw settlement. Significant changes in rainfall may alter runoff patterns and disrupt drainage systems. More intense rainfall and snow accumulation may affect slope stability and increase the probability of slides.

Changes to the Coastal Environment

A community's vulnerability to the impacts of climate change and sea-level rise is affected by the regional characteristics of ocean processes, the nature of its shoreline and the vertical movements of the Earth's crust that cause land masses to rise or sink. Tectonic movement is causing some coasts to rise relative to sea level or subside, depending on location. The central Arctic and Hudson Bay are experiencing emergence, while peripheral regions of the Arctic, including eastern Baffin Island, are submerging. As a result, Baffin Island will be very vulnerable to sea-level rise, and even more to the particular coastal processes associated with this rise, such as coastal flooding, erosion, and storm surges.

Increased Ultraviolet Radiation

Increased exposure to ultraviolet radiation will negatively affect many building materials, including synthetic polymers used in paints and plastics, and natural polymers found in wood. Ultraviolet-induced deterioration has been observed in the Arctic and due to significant ozone depletion, it is expected to increase throughout the 21st century.

Climate Change Impacts

For the scope of this project, the City of Iqaluit's buildings, roads, and water supply, wastewater treatment and waste disposal systems were reviewed to identify possible impacts from projected changes in climate.

Buildings

A number of factors will determine a building's vulnerability to climatic risks, including its condition, foundation type, location and age. The foundation system is one of the most important elements in determining a building's ability to withstand projected changes in climate. Most foundation systems in the Arctic elevate structures off the ground to protect the permafrost layer below and rely on the frozen ground for stability. If rising temperatures cause a decrease in the permafrost layer, foundations may lose their bearing capacity and settle significantly. These changes will affect a building's performance and possibly shorten its operating life.

Buildings need air-tight, moisture-free and well-insulated envelopes to reduce their vulnerability to climate change impacts. Studies indicate that $^2/_3$ of all damage to a building is related to the design and construction of its enclosure. With projected increases in precipitation, buildings without tight envelopes will risk damage from the ingress of rain and melted snow.

Because buildings deteriorate overtime with damage from ongoing and seasonal climatic processes, such as freeze-thaw cycles, regular maintenance is critical in providing long-term protection from premature weathering and more resilience in the face of future climate variability and extremes.

Roads

Warmer air temperatures will amplify seasonal frost effects, causing differential settlement, embankment deformation and slope instability on roads. Loss of permafrost may increase the likelihood of embankment failure for roads in steep areas.

Water Supply & Wastewater Treatment Systems

Since failure of water supply and wastewater treatment facilities has the potential to cause significant consequences and because they are designed to last longer than the average building (i.e., more than 60 years), these facilities warrant particular consideration to reduce their vulnerability to climatic risks. Changes in the permafrost layer may lead to thaw subsidence and compromise the integrity of these facilities, which could affect their performance and lead to interruption in water supply and wastewater treatment services for residents.

Water and sewer pipes may also be vulnerable to changes in climate. Above-ground piping will be more susceptible to the impacts of weather extremes and deterioration from freeze-thaw cycles. Buried piping, which relies on the frozen nature of permafrost, will be vulnerable to an increase in the active layer and warmer ground temperatures.

A warming climate could impact the quantity and quality of the City of Iqaluit's water supply. Warmer air temperatures may increase surface evaporation in the reservoir, lowering the water level. Increase in water temperatures could allow the growth of algae and other micro-organisms, which would compromise the City's water quality. Projected increases in precipitation in the form of intense rainfalls may put water quality at risk by washing contaminants into the reservoir.

Waste Disposal System

Most arctic landfills rely on the frozen state of permafrost to contain leachate and impede decomposition. If temperatures continue to warm and the loss of permafrost becomes substantial, the City may need to take remedial measures to prevent its landfill and former waste disposal sites from leaching into the ground below and becoming a serious hazard to public safety.

Climate Change Impacts on Infrastructure

Based on research and consultation, a decrease in the permafrost layer was identified as the most significant climate-related concern for Iqaluit's infrastructure. The following may be particularly at risk: buildings with shallow foundations; buildings, roads and buried pipes along steep south-facing slopes and/or in areas of high snow accumulation; any building or road in areas of poor drainage where water may pool; and the landfill and former waste disposal sites.

The following infrastructure may be vulnerable to other climate change impacts: buildings or piping in poor condition due to age, absence of regular maintenance, out-dated design or over-extended use; infrastructure located along the coast which may be susceptible to damage from flooding or storm surges; the drainage system which may be impacted by changes in precipitation; and the City's water supply.

Responding to Climate Change Through Adaptation

Adaptation is a relatively new concept in the field of climate change research: in the past, communities have typically responded to climate change through mitigation efforts. However, rising greenhouse gas emission levels indicate that even the most effective mitigation efforts are unlikely to decelerate changes in climate. As a result, adaptation is becoming a very critical response option to climate change.

A community's ability to cope within a certain range of climatic conditions defines its *coping range*. Its vulnerability increases as it is exposed to climatic conditions that fall outside this range. Studies show that communities are better able to cope with changes in long-term mean climatic conditions than with climate change-related variability. The severity and frequency of extreme events have the potential to increase a community's vulnerability exponentially.

A complex blend of economic, social, technological, political and biophysical circumstances will determine a community's ability to adapt to climate change. Adaptive capacity is defined by the following characteristics: availability of economic resources, access to technology, ability to transfer information and skills, conditions and availability of physical and social infrastructure, institutional support and equity.

As an arctic community, Iqaluit is challenged by competing priorities unrelated to climate change which may act as barriers to adaptation, such as social and economic issues. Because the magnitude and timing of climate change is uncertain, it may be difficult to rationalize expensive adaptation measures in the face of seemingly more immediate concerns. Conditions influencing the design and construction industries may also constrain adaptive capacity. For example, short-term financial considerations have, historically, influenced planning and building decisions more than long-term adaptability needs.

Adaptation Options for the City of Iqaluit

Adaptation options can take may forms, such as educational or awareness-raising programs, infrastructure retrofits, policy changes or additions and building standard amendments. Since adaptation planning is a continuous and iterative process, options identified for the City of Iqaluit today will need to be revised as the community is exposed to future climatic conditions, and as new information and technologies become available.

The aim of adaptation options identified for the City of Iqaluit is to ensure that its infrastructure can continue to operate effectively and provide essential services to its residents within a range of projected changes in climatic conditions. Options have been identified under the following headings: *Changes in Permafrost*, *Increases in Extreme*

Weather Events & Precipitation, Changes to the Coastal Environment, Changes to Water Quality & Quantity, and Interconnected Issues. Adaptation options under each heading are placed in the following categories: *Actions, Partnerships & Collaborative Initiatives, Awareness-raising, and Research, Data Collection & Monitoring* (see Section 6 for a full listing of adaptation options).

POLICIES

In addition to adaptation options, incorporating climate-related policies into the City of Iqaluit's decision-making and planning process is an important mechanism for reducing its vulnerability. Their effectiveness will be enhanced if they are incorporated into existing policies with similar planning goals and objectives; for example, the City's *General Plan* contains physical development policies for Iqaluit, some of which reflect its commitment to environmental responsibility and sustainability. Existing policies that foster sustainable development, if enforced, will provide some resilience to climate change risks.

Through a review of existing policies and consultations, a number of climate-related policies have been identified to help guide future planning decisions, which include:

- *Require all new municipal infrastructure to be designed and constructed to specifications that withstand projected changes in climate over their expected design life and meet sustainable development standards;*
- *Restrict development in areas prone to the impacts of sea-level rise, including, flooding and storm surges;*
- *Ensure future landfills are designed and sited with consideration for projected changes in permafrost;*
- *Require all new developments and major refurbishment projects to implement best practices in water efficiency and conservation technologies; and*
- *Regulate culvert size in new developments to ensure they have the capacity to cope with projected increases in precipitation.*

Prioritizing Adaptation Options

After reviewing a range of choices, community stakeholders and municipal staff identified the following criteria for prioritizing the City of Iqaluit's adaptation options: addresses a high-priority impact; addresses long-term planning decisions for significant structures; provides benefits in the absence of climate change; and provides information that further enhances the City's understanding of infrastructure vulnerabilities and climate change risks.

Using these criteria, adaptation options were prioritized as *High, Medium or Low*. The following adaptation options were designated as high-priority for implementation:

- *Inventory existing infrastructure to determine which structures may be most vulnerable to climate change impacts.*
- *Install gauges to record ground temperature in areas representing the City's various ground conditions (including at the landfill and former waste disposal sites) and monitor for changes.*
- *Map permafrost conditions using ground temperature data to identify areas most susceptible to thaw subsidence and monitor for changes.*
- *Coordinate a community waste management program that encourages waste reduction.*
- *Explore best practices in landfill siting, design, construction and closure to determine whether present practices will need to be modified to compensate for changes in permafrost.*
- *Revise the City's disaster management plan to include procedures for extreme weather events.*
- *Examine the drainage system's capacity to cope with projected increases in precipitation.*
- *Develop an anti-littering campaign aimed at reducing litter in ditches that may cause blockages.*
- *Educate residents on emergency procedure for extreme weather events.*
- *Develop a Coastal Area Protection Plan that sets out guidelines for managing development and activities within the coastal area.*
- *Develop a contingency plan to ensure that vital municipal functions are maintained in times of extremely low water supply.*

- *Develop a leak detection and maintenance program to reduce water loss and energy consumption.*
- *Create the Impacts & Adaptation Information Database to house all information related to climate change and infrastructure.*
- *Prepare a guide on development standards that incorporates climate change considerations.*

NEXT STEPS

To ensure that the adaptation planning process continues, next steps for immediate implementation have been identified: seek funding for a climate change coordinator to implement adaptation planning initiatives; seek funding to develop action plans for high-priority adaptation options; identify external stakeholders and work in partnership with them to implement high-priority adaptation options; and include climate-related policies in the City's *General Plan* when it is revised for 2008.

Besides these immediate next steps, the City can implement ongoing initiatives to build its adaptive capacity. The following will help prepare the City for a range of conditions: maintain awareness of climate change issues, develop partnerships and initiate collaborative programs, monitor climate and future scenarios, be advised of and encourage changes to building standards, codes and practices; revise the City's disaster management plan to include climate change considerations; utilize local and Inuit traditional knowledge, and incorporate climate change considerations into all long-term planning decisions.

CONCLUSION

The adaptation options presented in this report provide a starting point for a more detailed exploration of conditions that may facilitate or constrain the City's adaptive capacity. Uncertainty surrounding climate change and gaps in information and research should not delay adaptation planning efforts. It is imperative to make incremental steps now in planning procedures and continue to gather information which will make it easier for future generations to cope with inevitable change.

SECTION 1

1.1 INTRODUCTION

The international scientific community agrees that increased levels of carbon dioxide will cause a rise in the average global temperature throughout the 21st century (IPCC, 2001). Environmental impacts of climate change will have serious implications for municipal infrastructure, affecting its performance and shortening its operating life. Increased air temperatures will diminish the extent and thickness of permafrost, causing ground disturbances which will adversely affect structures, roads and pipes. A rise in sea level will erode landmass where homes, buildings and municipal facilities are located. Extreme weather events will cause extensive damage and destroy some structures. These changes will impact the health and safety of community residents and have serious financial implications for municipalities in northern regions.

Communities in Nunavut have already reported weather-related impacts on infrastructure. According to a survey report prepared by Nunavut Research Institute, several communities have observed alterations to building foundations from changes in the permafrost layer. In 2003, a large hole in the asphalt of Iqaluit's air strip was discovered, raising concerns about the stability of the underlying permafrost (Shirley, 2005).

The City of Iqaluit has recognized the need to address local priorities for supporting adaptation planning. Like other arctic communities, it is currently unprepared for projected changes in climate. With increases in population and development predicted, the City recognizes the importance of building its adaptive capacity through actions, partnerships, awareness-raising and information gathering to integrate climate-related considerations into its existing planning and decision-making processes.

1.2 PROJECT PURPOSE

The City of Iqaluit received funding from Indian & Northern Affairs Canada's *Impacts & Adaptation Funding Program* to undertake the *Climate Change Impacts, Infrastructure Risks & Adaptive Capacity Project*. The purpose of this project was to assess the vulnerability of its infrastructure to climate change impacts and build its adaptive capacity through research and consultation. In partnership with Nunavut Research Institute, the City identified impacts and developed adaptation options to reduce risks to its infrastructure.

1.3 METHODOLOGY

The project methodology relied, in part, on research. An extensive literature review provided information on regional climatic conditions, projected trends for future climate, and probable impacts and adaptation options for an arctic community. Research sources for some components of the project were limited so additional information was gathered by consulting with experts in meteorology, risk management and climate change, and with former and present municipal staff.

To determine pertinent climate change risks and adaptation options for Iqaluit, the project methodology also sought community consultations. The consultative process used elements of a vulnerability assessment model based on the assumption that understanding how future climate change will affect communities depends on identifying past and present experiences of and response to climate variability, determining how the community currently copes with these risks, and whether existing coping mechanisms will be sufficient for projected future climatic conditions (Ford & Smit, 2004).

It is essential that observations provide insight into risks and adaptation options specific to a community's unique circumstances. For this project, individuals who design, build and service infrastructure in Iqaluit were interviewed to determine what climatic or environmental hazards currently pose risk to infrastructure. This information was used to complement the literature review and appears throughout the report.

1.4 PROJECT SCOPE

The scope of this project is to examine one component of the community: Iqaluit's built infrastructure. The research and recommendations compiled in this report could be integrated into a community-wide adaptation plan dealing with other areas, such as health, transportation and traditional subsistence, or stand alone as an overview of potential infrastructure risks.

1.5 LOCAL CONTEXT

Formerly named Frobisher Bay, Iqaluit is located on the southeastern tip of Baffin Island along Koojesse Inlet. Created in 1999, it is the capital city of Nunavut, Canada’s newest territory. Iqaluit is the smallest capital city in the nation with approximately 6200 residents, although it is the largest of Nunavut’s 28 communities. It is one of the fastest growing communities in the country and experienced an 18.1 percent increase in population between 2001 and 2006 (Statistics Canada, 2007). It is a culturally diverse city and Inuit represent approximately 60 percent of the population.

As the capital of Nunavut, Iqaluit represents all of the communities in the Territory. It has most of the amenities of a capital city, including the Legislative Assembly and Government of Nunavut and Government of Canada offices, as well as a hospital, college campus, museum, visitor centre, research facilities, hotels, restaurants and an airport. Beyond the city centre and residential areas lie parks and undeveloped hinterland where traditional activities occur. The municipality encompasses a total area of approximately 52 square kilometres.

The City of Iqaluit is responsible for providing all basic municipal services to its residents, including the delivery of water, disposal of sewage and solid waste, snow removal and road maintenance. The municipality operates 30 buildings, which include office buildings, garages, recreational facilities, an emergency services building, staff residences, a dog pound, and all facilities associated with water supply and wastewater treatment services.

1.6 SURFICIAL GEOLOGY

Iqaluit is at the edge of the Hall Upland and Davis Physiographic regions (AMEC, 1997). Metamorphic and igneous bedrock underlie the area and are predominantly granitic gneiss. The surficial cover is unconsolidated glacial deposits and is thickest in the southern and western portions of the community. The northern and eastern parts of the community have either a thin of cover of glacial deposits or exposed bedrock. The predominant surficial material is glaciomarine deposits of sand, with varying amounts of gravel, clay and silt. It contains locally derived boulders and cobbles. Hodgson (2005) reports that areas covered with till in the region are typically well-drained and contain only pore ice below the frost table. Poorly-drained till may contain ice lenses, especially at the base of slopes.

Photo Credit: J. Lavallée

Soils in the region are cryosols, a typical soil type for cold climate areas. These soils developed on sandy morainal material that was deposited by glaciers. Most wetlands in the area have no more than a few centimetres of peat. Iqaluit's dominant vegetation is *Salix* (willow) and *Ericaceae* (heath), and extensive areas are covered by mosses, grasses and sedges (Hodgson, 2005).

Geotechnical investigations were conducted at various sites around Iqaluit by AMEC Earth and Environment and provide some information about the subsurface conditions in the area. Drillings found the glaciomarine sand in some areas to be ice-rich; it contained excess water when thawed. These reports suggest that during seasonal thaw, groundwater may be found perched above the permafrost table 1.5 to 2 metres below existing grade (AMEC, 1997).

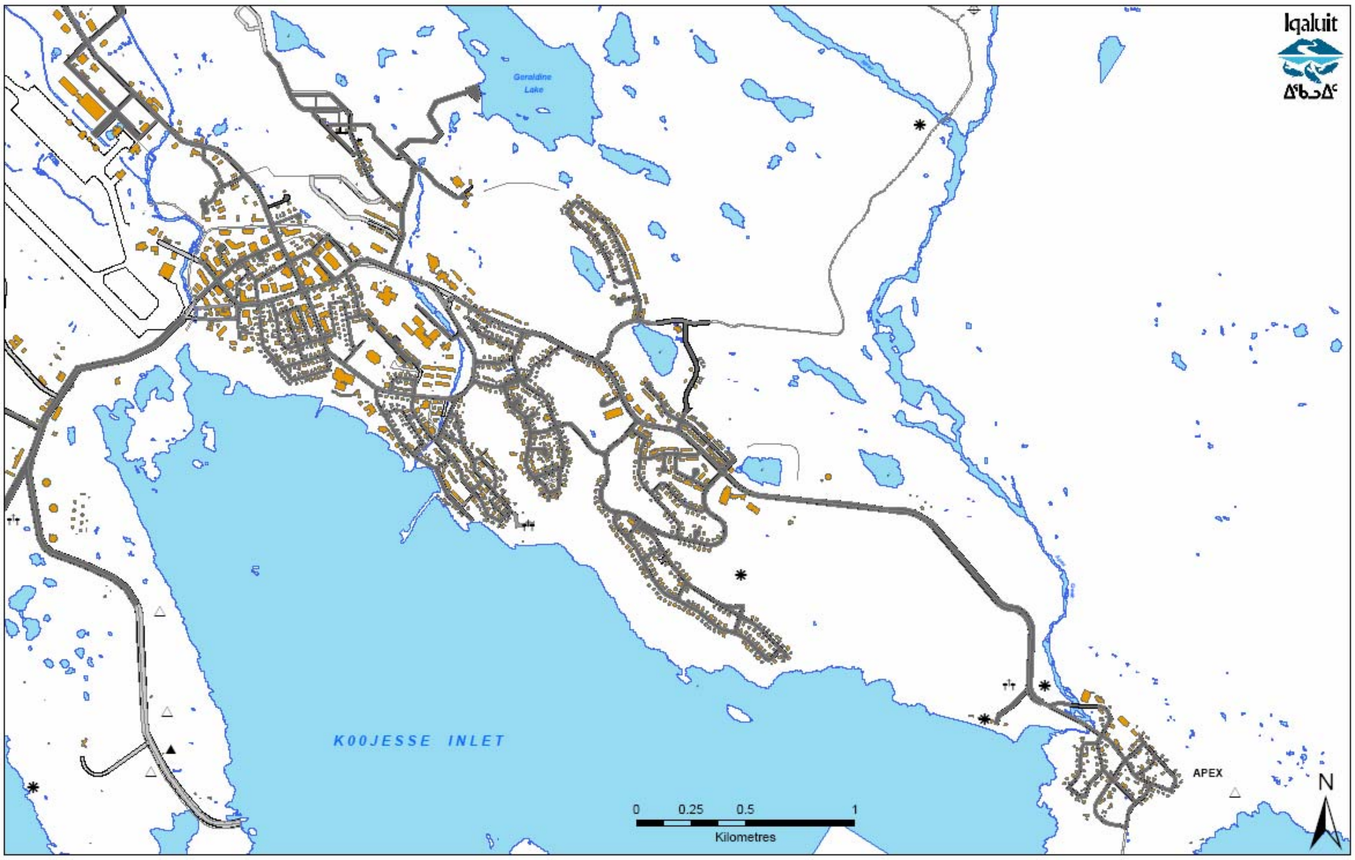
Iqaluit is located in a zone of continuous permafrost. Ground temperature data taken from different sites throughout the community for geotechnical investigations suggest the mean ground temperature is approximately -5° Celsius at a depth of about 10 metres. The depth of the active layer varies from 1 to 2 metres depending on the level of surface disturbance and vegetative cover. In areas of paved ground surface, the active layer is estimated to reach 3 metres (AMEC, 1998). Ground temperature data from northern Quebec, which has metamorphic and igneous bedrock similar to the Iqaluit area, suggest a 300 metre maximum depth of permafrost near the coast in southern Baffin Island (Hodgson, 2005).

Most rivers in Iqaluit drain into Koojesse Inlet. Glacial erosion has created cliffy valleys and numerous basins, which are now lake-filled. Land that rises up from the

Inlet is characterized by ridges of rock separated by valleys of varying width. Inner Frobisher Bay is estimated to have a maximum depth of 272 metres (Hodgson, 2005).

1.7 MAP OF THE CITY OF IQALUIT

The following map depicts the Iqaluit's city limits, roads, buildings and housing units.



Map prepared by FoTenn Consultants Inc., www.fotenn.com.

SECTION 2

2.1 CLIMATE CHANGE TRENDS

The international scientific community supports the theory that climate change has been almost exclusively the result of human activity, primarily the combustion of fossil fuels and secondarily deforestation (Battle et al., 1997 and IPCC, 2007). Industrialized nations use fossil fuel in almost every aspect of daily life. Since the turn of the 20th century, atmospheric levels of carbon dioxide have increased by 35% and global average temperature has risen by about 0.6^{o} Celsius (ACIA, 2005). Canada, a nation with harsh climate and considerable transportation needs, is one of the world's biggest consumers of energy; in fact, its emissions are growing faster than any other leading industrial nation. Rising levels of greenhouse gases in the atmosphere are expected to bring about significant and persistent changes in climate (Tanaka, 2006).

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

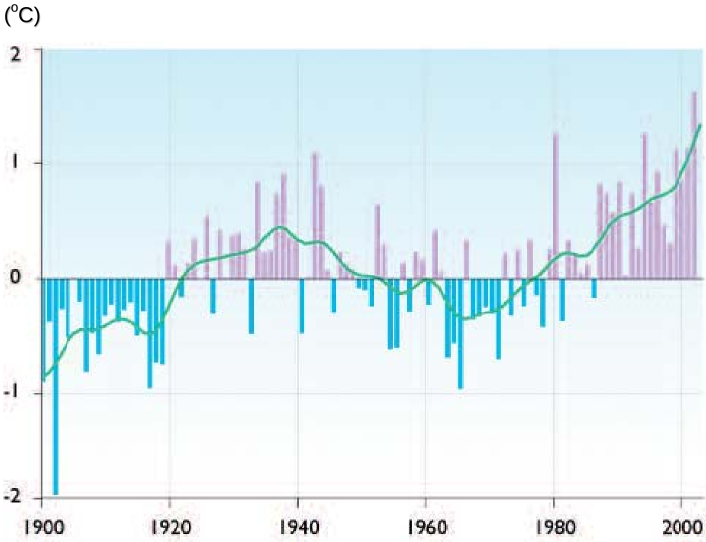
IPCC, page 5, 2007

The degree to which rates of carbon dioxide accumulate in the atmosphere will determine the severity of regional effects. At the current rate of fossil fuel use, carbon dioxide levels could double in the world's atmosphere as early as 2020 and even triple by the end of this century. A tripling of carbon dioxide would have catastrophic effects and likely lead to a collapse of the world's communities (Battle et al., 1997).

Scientists agree that it is too late to evade the effects of climate change, since carbon dioxide remains in the atmosphere for hundreds of years after it is released (ACIA, 2004). Today it is estimated that world-levels of carbon dioxide emissions will need to be reduced by as much as 60% in order stabilize levels of greenhouse gases in the atmosphere (Tanaka, 2006). Immediate mitigation of atmospheric levels of carbon dioxide and adaptation planning to prepare for the impacts of long-term and complex changes in climate are essential.

A one or two-degree increase in temperature may not seem significant or dire; however, the interconnectedness of oceans, atmosphere and land will make the implications of warmer temperatures far-reaching, multi-faceted, and even contradictory (Tanaka, 2006). Changes in global temperatures will vary – some regions will experience warmer temperatures, some colder. Wind and rainfall patterns will shift at unprecedented rates. Extreme weather events and natural disasters will be on the rise.

OBSERVED ARCTIC TEMPERATURES, 1900 TO PRESENT



Annual average changes in temperature for regions from 60 to 90° North.

Source: ACIA, 2005

Science confirms that the world is currently experiencing the effects of climate change. While it is unclear how climate variables will interact and influence human and natural communities, it is almost certain that changes affecting communities today portend much more serious changes in the future (UK Climate Impacts Programme, 2003).

2.2 ARCTIC CLIMATE IN THE 20TH CENTURY

Typically, Canada's Arctic has long, cold winters (average temperatures range from -18° Celsius in the south to -37° Celsius in the north) and short, cool summers (average temperatures range from 16° Celsius in the south to 6° Celsius in the north) (Environment Canada, 2007). Precipitation amounts are relatively low, with higher precipitation rates over Baffin Island.

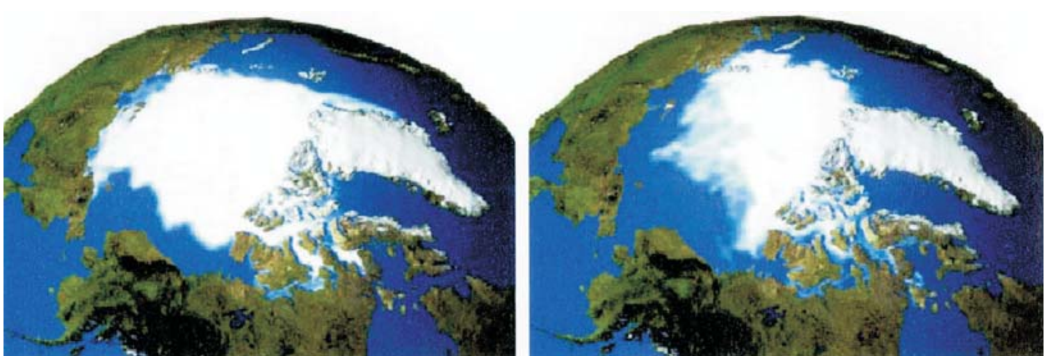
Since data are very limited for the first part of the 20th century, the following is an overview of changes in climate for the period between 1950–1998 (McCarthy et. al., 2001):

- There has been a warming trend in air temperature in the western Arctic (3 to 4° Celsius) and a cooling in the extreme northeast (-1° Celsius), with rates over land much higher than those over sea ice.
- Precipitation has increased by about 8%.

- Sea ice has receded and thinned at an approximate rate of 3% per decade.
- Ground temperatures and permafrost have warmed by about 2^{o} Celsius, causing the depth of the active layer to increase.
- Snow cover has decreased by about 10% in the last 30 years.
- The temperature of Atlantic water flowing into the Arctic Ocean has increased.
- Glaciers and ice sheets are melting and numerous small, low-altitude glaciers have disappeared.
- Sea level has risen approximately 10 – 20 cm in the last century.
- Ocean salinity and density has been reduced.

Over the last century, arctic warming has resulted in permafrost melting, retreat of glaciers and reduction in sea ice; the rate and nature of these changes has been unprecedented in the last 10,000 years. With greenhouse gas emissions on the rise, the rate of the warming trend is expected to continue throughout the 21st century (Kattsov & Kallen, 2005).

OBSERVED SEA ICE FOR SEPTEMBER 1979 & 2003



1979 2003

Constructed from satellite data, these images compare sea ice concentrations in September 1979 (the first year this data was available in meaningful form) and 2003.

Source: ACIA, 2005

2.3 PROJECTING FUTURE CLIMATE TRENDS IN THE ARCTIC

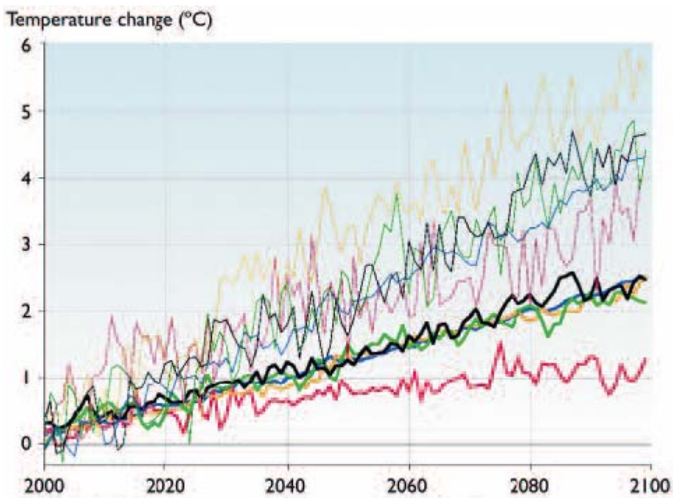
Using estimated changes in greenhouse gas emission concentrations, climate models can project future changes in temperatures and precipitation. These projections will help communities prepare for changes and are an integral component of adaptation planning; however, climate processes in the Arctic are complex which poses challenges for climate modeling in northern regions. As climate-change science improves, climate projections are likely to be more accurate. There will always be some level of uncertainty because scientists cannot be sure all physical processes relevant to climate change will be included in model simulations (ACIA, 2004).

According to Arctic Climate Impact Assessment (ACIA) and the Intergovernmental Panel on Climate Change (IPCC) reports, forecasted climate scenarios parallel many documented changes in climate in the 20th century. A 2001 assessment prepared by IPCC makes the following projections for the Arctic throughout the 21st century.

- It is very likely that nearly all land areas will warm more rapidly than the global average, particularly during the cold season in northern high latitudes.
- There will be a decrease in the diurnal temperature range in many areas, with night-time low temperatures increasing more than day-time highs.
- Models project a decrease in Northern Hemisphere snow cover and sea-ice extent, and continued retreat of glaciers and ice caps.
- Mean precipitation is likely to increase and lead to greater yearly variability.
- Precipitation extremes will increase beyond the global mean and the intensity of precipitation events is projected to increase.
- Rises in lowest daily minimum temperatures are projected to occur over nearly all land areas and will be greatest in areas where snow and ice retreat.
- Frost days and cold waves are likely to decrease.

Even with the variability of projected scenarios and uncertainty of future climate, projections are that Arctic weather will be warmer and wetter throughout the 21st century. Changes will occur during all seasons, but will be most prominent during the winter, with significantly warmer temperatures and substantially increased rain and snowfall (Anisimov & Fitzharris, 2001).

PROJECTED SURFACE AIR TEMPERATURE CHANGE



This graph shows average temperatures projected from five ACIA climate models. The thinner lines at the top are projected arctic temperature increases and the heavy lines at the bottom are global temperature increases.

Source: ACIA, 2005

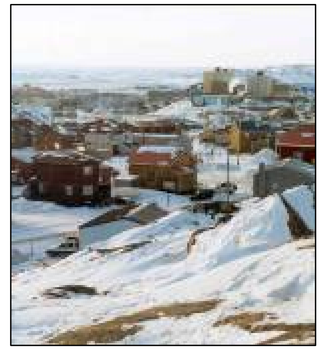
2.4 REPORTS OF CHANGING CLIMATE IN NUNAVUT

Observational reports of changing climate and extreme weather events are on the rise in Nunavut, such as the following:

In 2006, Resolute Bay experienced its warmest October in 59 years - seven degrees higher than normal average temperatures for that time of year. An Environment Canada meteorologist reported the higher-than-usual land temperatures are a sign that the atmosphere is warming significantly because of more open water and cloud coverage and less sea ice (Nunatsiaq News, November 10, 2006).

On a trip from Kugluktuk to Iqaluit in November 2006, a Canadian Coast Guard icebreaker found no ice to break as far north as 72 degrees. Approximately 250 scientists use this floating laboratory to study the impacts of climate change in the Arctic and one scientist reported the lack of sea ice for that time of year was unprecedented (Nunatsiaq News, November 3, 2006).

In February, 2006, warm temperatures and rain showers fell across south Baffin Island, breaking records in Nunavut. Since 1946, south Baffin Island has only received rain in February on three other occasions. Temperatures reached 6.8^{o} Celsius in Pangnirtung and 4.2° Celsius in Iqaluit (breaking a 60-year monthly record), compared to the normal high of -21° Celsius. Icy conditions on runways grounded planes in Iqaluit and 125 km/h winds destroyed one building and broke windows in Pangnirtung (Nunatsiaq News, March 3, 2006 and CBC North, 2006).



Environment Canada reported the summer of 2006 was the second-warmest since national records began in 1948. The greatest warming occurred along Northwest Territories and Nunavut's border, where temperatures reached more than 2.5° Celsius above normal. The winter of 2006-07 was also the second-warmest winter recorded since 1948 (Environment Canada, 2007).

2.5 Climate Change Impacts in the Arctic

Many scientists believe that the Arctic will experience the most severe and rapid changes in climate (ACIA, 2004). Currently, northern regions are experiencing warming at unprecedented rates (US Arctic Research Commission (USARC), 2003), and twice the speed of the rest of the world. The Arctic warms faster than lower latitudes because as average temperatures rise, snow and ice melt and expose darker land. The exposed land and open ocean surfaces absorb more solar energy and increase warming (ACIA, 2004).

An assessment report by IPCC (2001) concluded that the Arctic is highly vulnerable to the impacts of climate change and has low adaptive capacity. Projected warming temperatures and increases in precipitation will cause significant changes throughout the Arctic. Weather will become more variable and a rise in temperatures is expected to generate more extreme weather events, causing more frequent and intense storms. These combined changes will have severe economic, social and ecological consequences for communities in northern regions.

The key concerns associated with climate change in the Arctic are:

1. Melting of ice sheets and polar glaciers is expected to continue; they will retreat and thin throughout the century. Increased melting will contribute to rising sea

levels. Increased sea-level rise in the Arctic is expected to be greater than the global average (IPCC, 2001).

2. Loss of sea ice will continue. If carbon dioxide levels double, as they are projected to do as early as 2020 (Battle et al., 1997), summer ice could shrink by 60%.
3. Large areas of permafrost will thaw resulting in a thickening of the active (seasonally thawed) layer. This will cause erosion and changes in drainage. It may also lead to landslides and slumping, which will alter landmasses (USARC, 2003 and Anisimov, et al., 2001).
4. Arctic hydrology will change due to melting snow and ice. Impacts will include a change in runoff regimes, pooling of water and a weakening of the ocean's circulation.
5. Arctic vegetation zones will shift and the distribution, migration, diversity and abundance of some animal species will change. As ranges shift northward, new species will be introduced and some existing Arctic species will decline. Loss of sea ice will decrease habitat for animals such as polar bears, walrus and seals.
6. Human communities will face economic, social and cultural impacts. Changes in sea ice, weather patterns, and species diversity and habitat will be particularly disruptive for Inuit who practice traditional lifestyles. Community infrastructure will be impacted by changes in both average climate and climatic extremes.
7. Increased levels of ultraviolet radiation will affect people and arctic ecosystems. The effects of climate change in the upper atmosphere will maintain high ultraviolet radiation levels in the Arctic over the next few decades (ACIA, 2004).
8. Ocean surface water will warm as air temperatures rise, affecting marine plants and animals, as warmer surface water mixes with deeper water to raise the overall temperature of oceans (Tanaka, 2006).

Changes in the Arctic's atmosphere will translate into significant changes for the rest of the world. For example, melting glaciers and river runoff will change the salinity and density of the world's oceans, resulting in a prolonged slowing of oceanic circulation and ventilation, and significant changes in regional climate around the world (Anisimov & Fitzharris, 2001). Since many migratory species depend on arctic feeding and breeding grounds, the impacts of climate change in northern regions will have world-wide implications for biodiversity (IPCC, 2001).

2.6 OVERVIEW OF IQALUIT'S CLIMATE

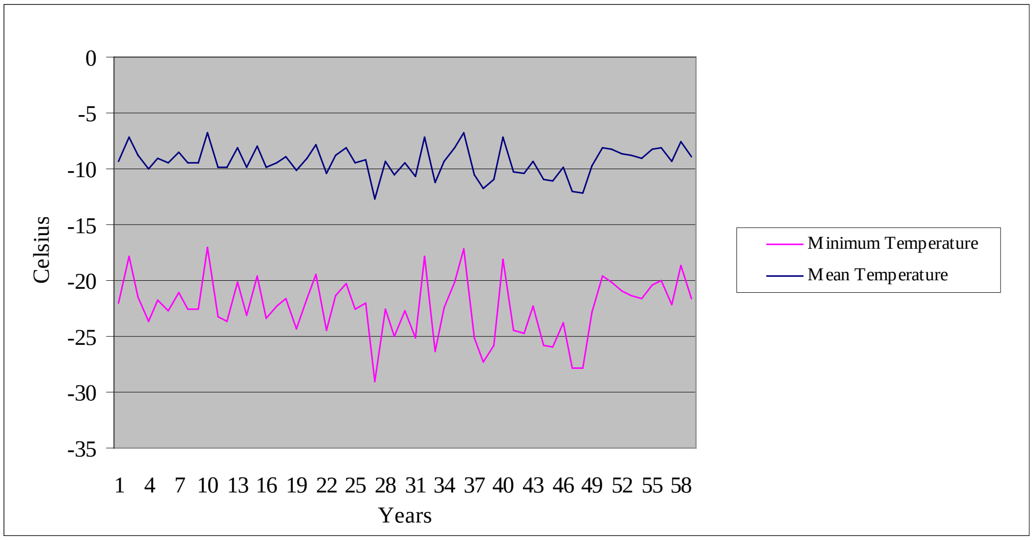
Iqaluit is located at 63^{o}45' north latitude and 68^{o}32' west longitude. Based on *Canadian Climate Normals for Iqaluit Station A, 1971-2000*, its daily mean air temperature is -9.8^{o} Celsius, with a daily mean in July of 7.7^{o} Celsius and -28^{o} Celsius in February (see *Appendix A* for *Climate Normals, 1971-2000* table). Total annual precipitation is 412.1 mm. This comprises 198.3 mm of rain, of which 95% falls between June and September, and 235.8 cm of snow, which falls between October and April (Environment Canada, 2007).

Comparative climate records show summer temperatures in Iqaluit are anomalously low for its latitude and precipitation is relatively high. Williams and Bradley (1995) concluded that three factors contribute to these anomalies: 1) frequent cyclonic activity between Baffin Bay and the North Atlantic Ocean, 2) the cool waters of western Davis Strait and Labrador Sea, and 3) year-round open water of the Labrador Sea (as cited in Hodgson, 2005).

Homogenized data from 1946 to 2004 for Iqaluit's mean and minimum* temperatures (http://www.cccma.bc.ec.gc.ca/hccd/) illustrates a slight warming from approximately 1996 to 2004. However, based on the relatively short time frame for this warming, it is difficult to characterize it as a trend.

* *A maximum temperature data set for Iqaluit was not available.*

IQALUIT'S MEAN & MINIMUM TEMPERATURES, 1946-2004



2.7 PROJECTING REGIONAL CLIMATE

State-of-the-art climate models have limitations and projecting regional climate remains the greatest challenge for climate modelers (Hengeveld, 2000). Most regional climate scenarios are derived using projections from global models which cannot compensate for all local variations. As a result, it is difficult to project regional and local anomalies, and projections based on global models come with a relatively high degree of uncertainty. The following contribute to limited detail and a high level of uncertainty in regional climate projections:

1. NATURAL VARIATION: Changes in climate can be the result of natural variability, as well as changes in greenhouse gas concentrations in the atmosphere;
2. FUTURE EMISSIONS: Climate scenarios are based on projected atmospheric levels of greenhouse gas emissions, assumptions about future human activities, and demographic and technological changes;
3. UNCERTAINTY IN SCIENCE: The scientific understanding of regional climate systems is still limited; and
4. DOWNSCALING: Developing regional projections from global models introduces uncertainty that limits the confidence in the magnitude of projections (Mukheibir & Ziervogel, 2007).

2.8 PROJECTING IQALUIT'S FUTURE CLIMATE

To develop climate scenarios for the City of Iqaluit, 29 temperature and precipitation scenario runs from seven General Circulation Models (GCM) were used (see *Appendix B* for temperature and precipitation model outputs). The data for these scenario runs are from grid points of each model that contain Iqaluit. *Climate Normals for Iqaluit Station A, 1961-1990* are the baseline data for these scenario runs (see *Appendix A* for *Climate Normals, 1961-1990* table). Each of the seven models used is highly-regarded and well-reported, but distinguishes the climate in somewhat different ways (see *Appendix C* for the list of GCM used). The most important difference among the models is the special resolution of the grid cells used to map the Earth's surface (Burn et al., 2004). In other words, the area (km^2) and the width (latitude and longitude) vary for each grid cell. Despite the differences, IPCC (2001) confirms that information from these models can be used to obtain estimates of potential regional climate change.

"Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century."

IPCC, page 10, 2007

Studies were conducted to test the ability of climate models to provide accurate projections using past climate data. Results showed that GCM provided temperature simulations that were closer to the climate data than precipitation, seasonal and regional simulations (Bonsal et al., 2006). Based on these results, it is recommended that all scenario runs from the various GCM be used to provide a range of temperature and precipitation scenarios for consideration.

Environment Canada's *Climate Change Scenarios Network* (www.ccsn.ca) provides baseline climate information for three future intervals: 2010-2039, 2040-2069, 2070-2099. For the purpose of this project, data from the first two intervals (2010-2039 and 2040-2069) were reviewed for temperature. Because precipitation projections are not as reliable as temperature projections, only precipitation data for the 2010-2039 interval were reviewed. As more information becomes available to assess the projections, data from the temperature interval 2070-2099 and precipitation intervals 2040-2069 and 2070-2099 can be reviewed (see *Appendix D* for tables summarizing data for these intervals).

To develop climate scenarios representing a range of conditions, the 29 runs were ranked according to annual changes for both temperature and precipitation. For a distribution of ranges, the upper and lower estimates were selected at ranks 4 and 26, and the median at rank 15. The changes indicated by each rank can be used to provide a low to high range for future climate over the recorded 1961-1990 baseline climate.

2.8.1 Climate Change Scenarios for Temperature

Table A provides scenarios for changes in temperature (^{o}C) by 2010 – 2039. The median projection for temperature is an annual increase of 1.8^{o} Celsius, with a lower and upper range of 1.3 – 2.4^{o} Celsius over baseline climate. The greatest seasonal increase in temperature is projected for winter.

Table A: Climate Change Scenarios for Temperature, 2010 – 2039*

Rank	**Winter (DJF)**	**Spring (MAM)**	**Summer (JJA)**	**Fall (SON)**	**Annual**
4th	1.3	0.2	0.8	1.1	1.3
15th (Median)	2.3	1.5	1.5	1.8	1.8
26th	3.2	2.4	2.1	2.8	2.4
Mean	2.2	1.4	1.5	1.8	1.7

Table B provides scenarios for changes in temperature (^{o}C) by 2040 – 2069. The median projection for temperature is an annual increase of 3.1^{o} Celsius, with a lower and upper range of 2.5 – 4.3^{o} Celsius over baseline climate. The greatest seasonal increase in temperature is projected for winter.

Table B: Climate Change Scenarios for Temperature, 2040 – 2069*

Rank	**Winter (DJF)**	**Spring (MAM)**	**Summer (JJA)**	**Fall (SON)**	**Annual**
4th	3.3	0	1.4	2.1	2.5
15th (Median)	4.9	2.6	2.5	3.3	3.1
26th	5.8	4	3.4	4.6	4.3
Mean	4.6	2.2	2.6	3.3	3.2

**Data are ranked by changes in annual mean temperature (^{o}C) and are for projected increases over baseline climate for the time period indicated.*

2.8.2 Climate Change Scenarios for Precipitation

Table C provides scenarios for changes in total precipitation (%) by 2010 – 2039. The median projection for precipitation is an annual increase of 6%, with a lower and upper range of 0 – 9% over baseline climate. The lower limit of the range forecasts a decrease in precipitation for all four seasons; however, the upper limit projects an annual increase of 9%. Winter has a greater median increase in precipitation than all other seasons.

Table C: Climate Change Scenarios for Precipitation, 2010 – 2039**

Rank	**Winter (DJF)**	**Spring (MAM)**	**Summer (JJA)**	**Fall (SON)**	**Annual**
4th	-3	-5	-4	-3	0
15th (Median)	9	3	5	8	6
26th	27	9	18	13	9
Mean	10	1.9	6	6.2	5.2

***Climate change scenarios are ranked on the basis of change in annual mean precipitation (%). Data are for projected changes in mean precipitation as a percentage over baseline climate for the time period indicated.*

SECTION 3

3.1 CLIMATE CHANGE & INFRASTRUCTURE

Infrastructure supports community activities and sustains important social and economic services such as housing, roads, schools, hospitals, power and communication facilities, and water, sewage and waste management. Over the last several decades, increasing damage to and failure of infrastructure has raised the question of its durability in the face of unpredictable climate (Auld & MacIver, 2005). *The Norwegian Building Research Institute* has recorded building damage for close to 50 years. It estimates that the cost of damage to structures now accounts for approximately 5% of the annual investment cost for new construction. In the face of future climate pressures, damage to infrastructure is expected to increase exponentially (Liso et al., 2003(b)). To reduce vulnerability, communities must adjust their social, economic and ecological systems to present and projected changes in climate (Smit & Pilifosova, 2002).

For more than 50 years, northern engineering standards and design practices have been directed by permafrost depth and distribution, thickness of the active layer, air temperature, and wind and snow loads (Etkin, 1998). Like most arctic communities, Iqaluit's infrastructure has been engineered to standards based on past climate conditions. Impacts to infrastructure which previously remained unscathed by harsh weather conditions indicate that existing structures are increasingly vulnerable to changing climate. To ensure the stability and longevity of Iqaluit's infrastructure, it is imperative to examine future climatic risks and incorporate provisions into current land-use planning practices (Auld & MacIver, 2005).

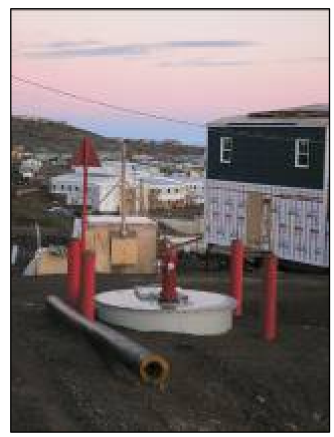


Photo Credit: C. Lo

Changes in climate patterns and an increase in extreme weather events will bring about human, ecological and economic losses. Historically, arctic communities have adapted well to local conditions; however, increases in the frequency and intensity of events may fall outside their usual coping range. Community vulnerability will intensify as populations rise, natural ecosystems are disrupted and development continues to encroach on precarious areas (Etkin et al., 2004). A community's adaptive capacity will depend largely on how it is designed, the state of its infrastructure and its ability to adapt to new climatic conditions. Ideally, through proper planning and preparedness, communities can expand their coping range to accommodate projected changes in climate (Ford & Smit, 2004).

Research shows that spending rates to replace infrastructure are declining (IPCC, 2001). As a result, aging and over-extended infrastructure is an issue in many communities and puts them at increasing risk to climatic hazards. Infrastructure will need to be inventoried and assessed before accurate decisions can be made regarding levels of vulnerability.

Relatively few studies have focused on the implications of failing infrastructure within communities (Liso, 2001). If structures are to remain stable for at least sixty years and meet future climate challenges, immediate research is needed to determine regional climatic impacts and design requirements, and communities will have to continually identify ways to increase their resiliency as more information becomes available (Auld & MacIver, 2005).

3.2 The Physical Environment & Processes Related to Infrastructure

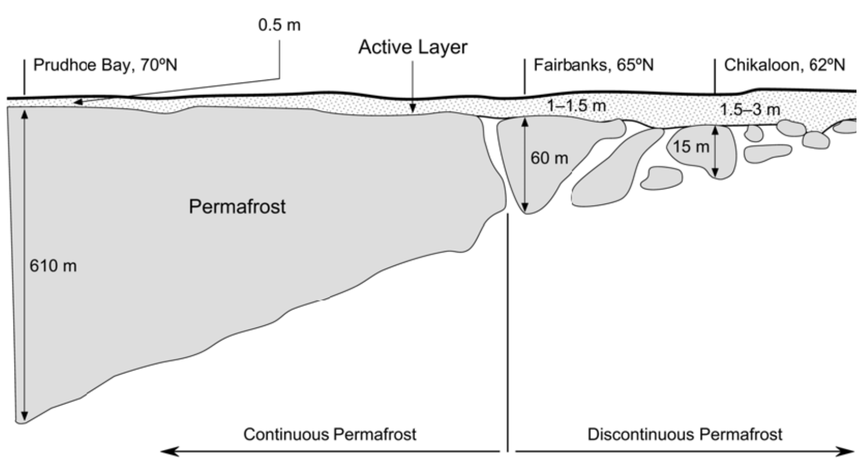
Future climate may increase damage to arctic infrastructure, as structures are exposed to more frequent and intense environmental stresses (Anisimov & Fitzharris, 2001). Impacts of particular concern are: changes in permafrost, increase in extreme weather events, changes in precipitation, changes in the coastal environment, and increased ultraviolet radiation.

3.2.1 Changes in Permafrost

Permafrost is defined as the subsurface layer that remains below freezing (0^{o} C) continuously for two years (USARC, 2003). Covering approximately 50% of Canada's landmass, permafrost underlies most of the terrestrial surfaces in the Arctic (Couture et al., 2002 and Anisimov & Fitzharris, 2001). Permafrost ranges in thickness from a few metres in southern areas of the Canadian Arctic to several hundred metres in northern regions. The extent of permafrost is affected by soil type and water content, as various types of soil and rock conduct heat at different rates. Above the permafrost lies the active layer, which freezes and thaws annually and is most susceptible to changes in air temperatures.

A continuous permafrost zone describes an area where permafrost occurs everywhere except below newly-emerged land or large waterbodies deeper than 3m that do not freeze to the bottom in the winter (USARC, 2003). In a discontinuous zone, permafrost is thinner and eventually becomes absent from parts of the land surface. The boundary between continuous and discontinuous zones usually corresponds with the northern tree line (Woo et al., 1992). A sporadic zone refers to an area of isolated patches of permafrost (USARC, 2003).

PERMAFROST ZONES



Latitudinal profile through permafrost zones in Alaska.

Source: USARC, 2003

A pronounced impact of climate change in northern regions will be increases in permafrost temperatures and the active layer depth (Anisimov & Fitzharris, 2001). A warmer climate throughout the Arctic will reduce the thickness and extent of permafrost, increase the active layer, and cause changes in the frequency and character of the freeze-thaw cycle (Couture et al., 2002). Since most arctic infrastructure relies on the properties of frozen ground for stability, the loss of permafrost will very likely cause significant settling and considerable rates of failure (USARC, 2003).

If typically ice-rich permafrost thaws, the ground subsides. The ground is displaced downward inconsistently over an area, resulting in uneven terrain. The loss of ground stability may cause damage to or loss of roads, buildings and pipelines. The integrity of infrastructure in coastal zones will be further compromised if the sea encroaches subsided areas.

Permafrost is very sensitive to long-term warming trends (USARC, 2003). Even small increases in temperature substantially affect the integrity of permafrost, causing soils and foundation systems to lose their bearing capacity as previously frozen ground thaws (Couture et al., 2002). In the Arctic, a building foundation's stability decreases sharply with rising temperatures (Instanes et al., 2005). For example, a 2^{o} Celsius rise in soil temperature led to a 50% loss of bearing capacity of the frozen ground in Yakutsk, Russia. Scientists predict that this city is at risk of losing most of its buildings by 2030 unless substantial adaptation measures are implemented (Anisimov & Beloloutskaia 2003). Continuous infrastructure maintenance plays an important role in avoiding or delaying structural failure. In Yakutsk, thaw-induced settlement damaged more than 300 structures, including a power station, airport runway and numerous residential buildings. Much of this loss might have been avoided if affected infrastructure had undergone regular maintenance and repairs (Instanes et al., 2005).

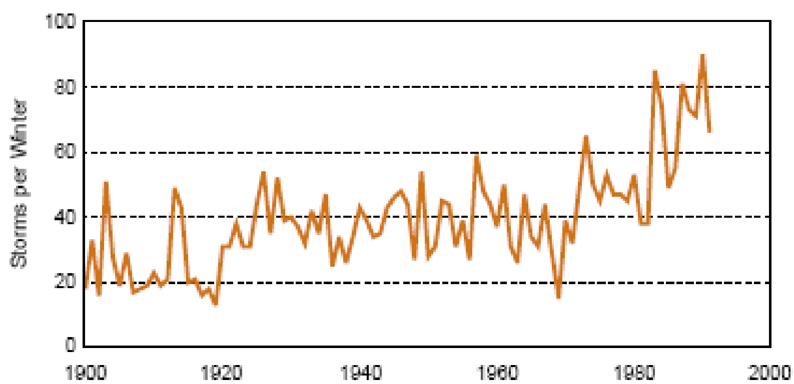
In Nunavik, permafrost thawing has caused roads, airport runways and foundations to buckle and split (Nunatsiaq News, September 8, 2006). Permafrost temperature in this region has risen an estimated 1^{o} Celsius since 1988. The Nunavik Transport Department predicts that if temperatures continue to warm, all transportation infrastructure in the area will be in jeopardy.

Loss of permafrost could cause significant and costly stability problems for Iqaluit's existing infrastructure. Historical data on its infrastructure's performance and maintenance is very limited; however, recently observed changes in the depth of the active layer have affected the stability of some local buildings. A representative of Canadrill Ltd., an Iqaluit-based company that installs and maintains foundation systems throughout Nunavut, observed a four-to-six foot increase in the active layer in some areas of Iqaluit over a period of eight years. In 1998, the active layer was estimated to be six feet deep; 2006's estimated depth in some areas was 10 – 12 feet. During the summer of 2006, Canadrill repaired nine house foundations and estimates that approximately 50 additional foundations need restoration. Long-term warming may exacerbate the number of foundations affected by differential shifting. Buildings with shallow foundation systems will be particularly at risk.

3.2.2 Increase in Extreme Weather Events

The economic and human losses to extreme weather events are severe and considered the most costly of all natural disasters (Environment Canada, 2003). Costs from weather-related incidents have increased five-fold between 1990 and 2003 (Girard & Mortimer, 2006) and severe winter storms have nearly doubled in the Northern Hemisphere since the 1970s (Boyd, 2003).

Frequency of Winter Storms in the Northern Hemisphere



Source: Adapted by Francis & Hengeveld, 1998 from original source, Lambert, 1996

According to studies reviewed by the IPCC (2001), global warming will increase storm frequency in some regions of the Arctic. Although not all extreme weather events can be attributed to climate change, research confirms that a warmer climate will make extreme weather events more probable

(Tanaka, 2006 and Francis & Hengeveld, 1998). The two main effects of climate change on the frequency and intensity of extreme weather events are:

1. Rising temperatures change the flow of heat and energy within the climate system, which alters atmospheric and oceanic circulation patterns. As a result, many of the world's major storm tracks may shift significantly.

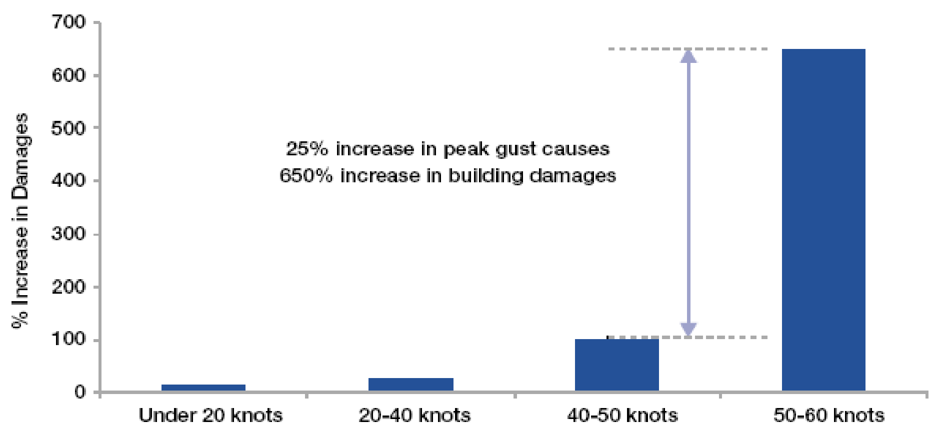
2. A rise in global temperature increases the amount of water that is moved through the hydrological cycle, which creates more available moisture in the atmosphere to fall as rain or snow. GCM project that increases in precipitation will cause more intense snow and rain events, rather than an increase in snow or rain days (Bruce et al., unpublished).

Studies show that small changes in average temperatures can cause significant changes in extreme weather events. Even small long-term increases in extreme events may cause a significant rise in infrastructure damage, which will increase exponentially in infrastructure that is poorly-constructed and maintained (Francis & Hengeveld, 1998 and Auld & MacIver, 2005). A recent British study revealed that approximately a million buildings could be damaged by an increase in average wind speed of only six percent, at a cost of up to two billion pounds (Graves & Philipson, 2000).

As temperatures increase, the intensity and frequency of windstorms will also rise (IPCC, 2001). In 2003, Hurricane Juan caused eight deaths in Halifax and over $200 million in insurable damages (Fogarty, unpublished). A February 2007 blizzard in Iqaluit brought winds that gusted up to 141 km per hour and caused extensive damage to the high school and the *8th Storey Building* by blowing off entire sections of their roofs. According to a report commissioned by the Insurance Australia Group, a small increase in peak wind speeds is causing disproportionate increases in building damage costs. This report predicts that a 25% increase in peak wind speed can cause a 6.5-fold increase in damage claims to buildings (Coleman, 2002). Although projecting future increases in wind speeds from climate models is very challenging, the construction of more wind-resistant structures is an important adaptation option to reduce potential damage (UK Climate Programme, 2003).

Researchers from the *Centre for Earth Observation Science* (www.umanitoba.ca/ceos) at the University of Manitoba will lead a study on extreme arctic weather to gain an understanding of severe weather systems in southeastern Nunavut. Beginning in the fall of 2007, this four-year project aims to develop more accurate models for predicting major storm events around Iqaluit, an area characterized by frequent and severe winter storms.

BUILDING DAMAGE CLAIMS VERSUS PEAK WIND GUST SPEEDS



Small increases in peak wind gust speeds can cause disproportionate increases in buildings damage. Source: Coleman, 2002.

3.2.3 CHANGES IN PRECIPITATION

Each year, the impacts of precipitation cause substantial damage to the built environment (Liso et al., 2003(b)). IPCC (2001) projects that throughout the 21^{st} century more intense precipitation days are likely, and the timing and regional patterns of precipitation will change with a warmer climate. For every one degree Celsius of warming, precipitation is likely to increase by one percent. This is expected to bring heavier rains and more snowfall, and may expose infrastructure to conditions that it was not originally designed to withstand (Tanaka, 2006).

Projected increases in snowfall may cause loading on buildings that will require modifications in existing building codes to prevent significant damage (Maxwell, 1997). A number of communities in Nunavut have experienced unusually high snowfall that has impacted infrastructure and services. For example, Coral Harbour exceeded its 2005 snow removal budget and had to seek additional funds. A storm later that year caused snow accumulation that restricted road access to the airport, delaying an emergency medical evacuation (Shirley, 2005).

High snow accumulation insulates underlying soil, particularly on south-facing slopes, increasing the temperature and depth of the active layer. Infrastructure in areas prone to snow accumulation and warming from the sun may be at a greater risk to thaw settlement.

Based on climate model simulations, the return period of extreme rainfall events is expected to be reduced by a factor of two (Kharin & Zwieres, 2000). For example, a current 10-year rainfall event could occur every 5 years under projected changes in climate. As a result, the durability of existing infrastructure will be compromised as structures are exposed to more frequent extreme precipitation events.

Significant changes in rainfall are likely to alter runoff patterns and disrupt drainage systems. They may also alter ice-water balances in the active layer that will affect the bearing capacity of soils and foundations (Anisimov & Beloloutskaia, 2003). Existing drainage systems may need to be upgraded to allow for the possibility of increased and more intense rainfall.

Changes in precipitation may affect slope stability and increase the probability of slides. Slope stability is affected by runoff patterns, freeze-thaw processes, human disturbance and erosion. The amount of water infiltration caused by the intensity and duration of rain and snowmelt can increase the probability of slope failure.

3.2.4 CHANGES IN THE COASTAL ENVIRONMENT

Historically, coastal communities have been vulnerable to climatic and environmental hazards; however, their vulnerability may be exacerbated by a warmer climate and rise in sea level (Hengeveld et al., 2005). The main threats to communities from sea-level rise are flooding, storm surges (which can force sea-ice movement and potentially damage nearby infrastructure) and coastal erosion.

The extent of a coastal community's vulnerability to climate change impacts is affected by the regional characteristics of ocean processes, the nature of its shoreline and the vertical movements of the Earth's crust that cause land masses to rise or sink (Hengeveld et al., 2005). Like other areas of the world, the Arctic is experiencing tectonic movement, which is causing the coast to rise relative to sea-level (emergence), as well as subside (submergence), depending on location. The central Arctic and Hudson Bay are experiencing emergence, while peripheral regions of the Arctic, including eastern Baffin Island, the Beaufort Sea and the northwest fringe of the Arctic Islands are submerging. Andrews' study (as cited in Maxwell, 1997) suggests that the outermost coast of eastern Baffin Island is submerging at a rate of approximately 0.5m per century. IPCC (2001) suggests sea level will rise on average about 0.5m by 2100. Based on these projections, the Beaufort Sea region will be highly sensitive to sea-level changes. Baffin, Ellesmere, Devon and Bylot Islands will only be slightly less vulnerable to change, but will be particularly susceptible to the coastal processes associated with sea-level rise (Maxwell, 1997).

"The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea-level rise."

IPCC, page 8, 2007

Coastal erosion rates across the Arctic vary significantly, depending partly on the physical make-up of the area and degree of human disturbance or settlement. Studies show that erosion rates have increased in the last 30 years, causing concern for residents in arctic coastal communities (Anisimov & Fitzharris, 2001). Climate change is expected to increase wave-induced coastal erosion, as the extent of sea ice decreases and creates greater areas and longer periods of open water. With less ice on and off shore, coastal areas will be prone to more severe wave action that will alter their profiles.

The shores of Baffin Island are underlain by continuous permafrost and characterized by tidewater glaciers. Due to their composition, these shores will be prone to substantial changes as warmer air and water may cause significant coastal thaw subsidence and subsequent wave-induced erosion (IPCC, 2001 and Maxwell, 1997). These processes will affect coastal stability and may accelerate erosion rates.

Sea-level rise and changes in coastal processes will have significant consequences for infrastructure located in coastal areas. Warmer temperatures are projected to cause an increase in more extreme and frequent storm surges. These storms will bring higher winds that may induce greater water levels and higher waves at the coast. More intense rainfall will increase runoff, which will amplify sediment levels in coastal waters (IPCC, 2001). Reinforcing coastal areas where infrastructure is found can reduce risks; however, care should be taken not disrupt adjacent coastal areas. Land-use planning decisions that consider potential climate change impacts will help to protect coastal areas from climatic risks.

Flooding over Iqaluit's breakwater, September, 2007

Photo Credits: B. Malloy (L) and R. Armstrong (R)

In Tuktoyaktuk, Northwest Territories, combined challenges of sea-level rise, increased wave action, erosion and thawing permafrost have resulted in the loss of several buildings and threats to important cultural and heritage sites (ACIA, 2004). Erosion rates are expected to increase in the area, and efforts to control it may become increasingly expensive, eventually making Tuktoyaktuk uninhabitable (Couture et al., 2002).

3.2.5 INCREASED ULTRAVIOLET RADIATION

Exposure to ultraviolet radiation negatively affects many building materials, including synthetic polymers used in paints and plastics, and natural polymers found in wood. Ultraviolet-induced deterioration has been observed in the Arctic, and due to ozone depletion, is expected to increase throughout the 21st century. The impacts on infrastructure exposed to ultraviolet radiation are compounded in northern regions by extended hours of sunlight during summer months and the high surface reflectivity of ice and snow (Anisimov & Fitzharris, 2001). Increased exposure to ultraviolet radiation will decrease the quality of certain materials and may cause early degradation. Ultraviolet radiation damage could be exacerbated by other climatic stresses, such as freeze-thaw cycles and high winds.

SECTION 4

The following section provides an overview of potential risks to Iqaluit's infrastructure under projected climate scenarios for the 21st century. For the scope of this project, the City of Iqaluit's buildings, roads, and the water supply, wastewater treatment and waste disposal systems were reviewed.

4.1 BUILDINGS

In addition to its water supply and wastewater facilities, the City of Iqaluit maintains 15 buildings, including two arenas, a curling club, the Elders' Centre, City Hall, garages and warehouses. Climate change impacts on Iqaluit's buildings will vary depending on their size, condition, foundation type, location and age. At present, neither a comprehensive building inventory nor records of past or recent building performance exist.

Photo Credit: C. Lo

A building's foundation system is one of the most important elements in determining its stability and resilience to withstand climatic variations. Arctic foundation systems are typically designed to ensure that heat from the structure does not induce permafrost thawing. Most buildings in the Canadian Arctic are built on pile foundations that elevate structures off the ground to protect the permafrost layer below.

If temperatures continue to warm and cause a significant increase in the active layer, a foundation may experience a loss of bearing capacity, resulting in structural damage which could affect the building's performance and shorten its operating life. Buildings with shallow foundations will be most vulnerable to increases in the active layer (Couture et al., 2002).

A number of foundation systems is currently in use for large industrial and equipment buildings. Often these facilities have slab-on-grade foundations to protect the underlying permafrost by combining insulation below the floor and a cooling system to remove heat from beneath the structure. Research suggests that these foundations will also be at risk from rising temperatures because an increased thaw season may require a thicker insulating buffer below the structure and warmer temperatures may decrease the capacity of the cooling system to refreeze the buffer layer during the winter (Anisimov & Fitzharris, 2001).

An air-tight, moisture-free and well-insulated envelope can reduce a building's vulnerability to climate change impacts. Studies indicate that $^{2}/_{3}$ of all damage is related to the building enclosure's design and construction (Liso et al., 2003(b)). Besides providing structural support, a building envelope prevents heat loss and the entry of moisture. According to studies conducted by the *Norwegian Building Research Institute*, more than 75% of all building damage is caused by climatic conditions, mainly moisture damage (Liso et al., 2003(a)). Increased driving rains could affect external structures and lead to water penetration around openings (UK Climate Impacts Programme, 2003). Ultraviolet radiation can also deteriorate sealants and paints, and affect the building envelope's integrity.

Buildings will deteriorate over time from damage caused by daily weather conditions and climatic processes, such as freeze-thaw cycles. If this damage is not repaired, the structure's durability will be compromised (Auld & MacIver, 2005 and Boyd, 2003). Maintaining buildings throughout their lifecycle is an important adaptive practice to protect them from climate change impacts and premature weathering. Lifecycle assessments for new building designs can increase their durability and reduce the cumulative costs of repairing future long-term deterioration.

It should be noted that climate change will also impact positively on buildings and construction in Iqaluit. For example, warmer air temperatures will decrease heating requirements, reduce insulation needs and extend the construction season (Maxwell, 1997). Those interviewed who design and build infrastructure in Iqaluit noted that the construction season (defined by the length of time the harbour remains unfrozen, allowing sealifts to bring supplies) has increased over the last decade. They estimated that the construction season has been extended by as much as eight weeks, as the harbour thaws and freezes a month earlier on average than in previous years.

Seal lift dock full of supplies from the South

Photo Credit: C. Lo

4.2 ROADS

The City of Iqaluit maintains approximately 40 kilometres of roads, of which seven kilometres are paved. From the time the ground thaws in the summer, roads need continuous grading until they freeze again in the fall. As a result, road repairs are very costly for the City and account for almost $^{1}/_{3}$ of the Department of Public Works' operating and maintenance budget.

Road construction and maintenance alters ground surfaces and increases their vulnerability to a warmer climate. Studies show paved and ploughed roads, and airstrips will have a mean annual temperature of 1 to 2^{o} Celsius higher than the original undisturbed surface (Maxwell, 1997). Warmer air temperatures may also amplify seasonal frost effects and cause differential settlement, embankment deformation and slope instability (Anisimov & Fitzharris, 2001 and Couture et al., 2002). Studies show paved roads are less tolerant to differential settlement than unpaved roads (Maxwell, 1997).

Photo Credit: C. Lo

An increase in the depth of the active layer may cause a rise in embankment failures in steep areas. Depending on solar exposure, embankments prone to significant snow cover in the winter tend to experience a higher surface temperature (3 to 6^{o} Celsius) because snow insulates the underlying surface (Maxwell, 1997). These areas will become particularly vulnerable to a warmer climate, and may experience significant thaw settlement and loss of stability (Instanes et al., 2005 and Couture et al., 2002).

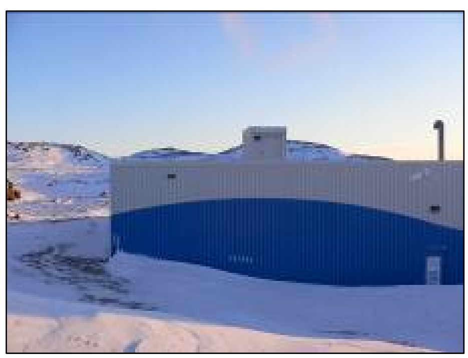
4.3 WATER SUPPLY & WASTEWATER TREATMENT SYSTEMS

Projected changes in permafrost could cause structural damage, compromising the integrity of water supply and wastewater treatment facilities and potentially affecting their performance, causing interruption in services and leading to costly repairs. Because they have the potential to cause significant problems upon failure and are designed to last longer than the average building (i.e., more than 60 years), these facilities warrant particular consideration to reduce their vulnerability to climatic risks.

4.3.1. WATER SUPPLY SYSTEM

Lake Geraldine is the raw water source for the City of Iqaluit. Surficial water flow fills the reservoir during the spring and summer. Since there is no surficial water flow during the winter, the City must store a sufficient supply for over-winter consumption (from mid-October to June). Water from the reservoir is treated by sand filtration, chlorination and lime stabilization at the water treatment plant and is stored in tanks before entering the main distribution system. Stored water is required for flow equalization, fire protection and emergency allowances. Water is distributed to residents by trucks or via a network of watermains and recirculation lines.

The amount of runoff that supplies Lake Geraldine is currently unknown. A water and sewer study commissioned by the City of Iqaluit in 2002 indicated that current demand was reaching the watershed's limit and recommended a dam extension for more raw water storage. In the summer of 2006, the level of the dam was raised 2 metres to increase storage in Lake Geraldine. The study also revealed that more treated water storage was required to satisfy a demand of 400 litres per person per day through to year 2023 (Trow Consulting Engineering Ltd., 2002). An additional 2.3 million litre tank for treated water storage will be installed in the summer of 2007 and the City plans to install a pipe network from a second raw water source to supplement Lake Geraldine's recharge requirement as early as 2016.



Water Booster Station & Water Distribution Plant

Photo Credits: C. Lo

The City of Iqaluit maintains approximately 27,400 metres of water distribution pipes. Most of these pipes are buried; however, the system also includes some above-ground piping, initially cheaper to build, but requires more long-term maintenance than buried piping. The City has plans to eventually replace all above-ground with buried piping.

Historical information shows very few breakages in buried pipes, so their deterioration is not currently a concern; however, buried piping in Iqaluit relies on the constant temperature of the permafrost, approximately 10 feet below ground. Changes in permafrost will have implications for the buried pipe distribution system.

Backhoe installing under-ground piping.

Photo Credit: C. Lo

In addition to impacts on infrastructure, climate change has the potential to affect the quantity and quality of the City of Iqaluit's water supply. Warmer air temperatures could increase surface evaporation, lowering the reservoir's water level. Permafrost thawing could have harmful effects on the quality of drinking water in some northern communities (Instanes et al., 2005). Water in the reservoir could eventually reach temperatures that allow algae and other micro-organisms to grow, compromising water quality. Increased precipitation in the form of more intense rainfalls could put municipal water quality at risk by washing contaminants and soil into the reservoir.

4.3.2 Wastewater Treatment System

The majority of the City's sewage and wastewater is collected and transferred via sewers, forcemains and pumping stations. The remainder is collected by trucks and discharged at the dumping station. The City maintains approximately 19,100 metres of sewers and forcemains, two sewage pumping stations, and one operational sewage dumping station. The City does not have a piped storm water system: all drainage is surficial.

Wastewater Treatment Plant

Photo Credit: C. Lo

The refurbished wastewater treatment facility was commissioned in May of 2006. Currently the plant is operational; however, sewage is diverted back to the sewage lagoon when the facility requires maintenance adjustments. It is a primary treatment facility that screens solids and discharges effluent into Koojesse Inlet. The sewage lagoon and wastewater treatment facility are located in the southwest limits of the City's boundary, along the inlet.

As with the water distribution system, the sewer system includes a combination of buried and above-ground piping. A section of above-ground piping is made with asbestos cement and is therefore, susceptible to failure if frozen. Another section is made of corrugated steel and is in need of continual maintenance. The remaining piping is considered to be in relatively good condition.

The wastewater treatment system warrants particular consideration because failure of any part of it will have significant consequences for the surrounding environment. Measures should be taken to ensure that projected increases in precipitation, in the form of heavy downpours, do not overwhelm the system and cause failure or overflow which could contaminate adjacent waterbodies. The facility's foundation system should be monitored to prevent any significant settlement.

Photo Credit: C. Lo

4.4 WASTE DISPOSAL SYSTEM

The City is responsible for the collection, diversion and disposal of all municipal solid waste. Currently, waste is transported to the landfill site, dumped in an active cell, compacted and covered with shredded mulch material. The City separates household hazardous waste, tires and certain metals from the regular waste stream. Although there are approximately 100 households participating in a composting program, organics are not generally diverted from the landfill and the City does not operate a recycling program. Besides the landfill, the City has seven former waste disposal sites under its jurisdiction.

Historically, arctic landfills have been designed and sited with little consideration of effects on the environment or potential hazards if the permafrost layer thawed. The active layer is very fragile and susceptible to damage when disturbed, especially during summer months. As the frozen ground thaws in the summer, landfills typically become a quagmire of garbage mixed with water (Magee & Rice, 2002). If part of the active layer is removed or disturbed to build an operating cell, this may cause the permafrost to thaw and disrupt the ground's thermal balance. There are three main impacts associated with disturbing the permafrost around landfill sites:

1. Ice mounds may form where the ground has been disturbed. These mounds freeze and thaw each year, which expands the disturbed area. Soil is brought to the surface with the freeze-thaw cycle and mixes with ice to form a frost heave.
2. If the permafrost melts and leaves behind water, it creates an ice bulb. When the ice bulb melts a pond is formed. As wind pushes water to the sides of the pond, the warmer water melts the permafrost and expands the size of the pond.
3. In areas where ponds are not formed, the ground can become very wet during the summer. The excess water saturates the ground, forming a quagmire, or muddy swamp (Zender Environmental Engineering and Services, 2001).

Studies show that thawing permafrost can cause settlement of up to 25 percent of the original frozen depth, depending on the composition of the land surface (Magee & Rice, 2002). Over time, this may disrupt drainage and water flow around the landfill. The City of Iqaluit recently altered drainage around its operating landfill to keep "clean" surficial runoff from mixing with landfill runoff.

Since most arctic landfills do not have a lining or collection system, they rely on the frozen state of the permafrost to contain leachate and impede decomposition. Typically, decomposing waste produces a significant amount of methane, a major contributor to global warming; however, communities have relied on perennial frozen ground to hinder this process. With projected changes in permafrost, it is critical to design and operate future landfills to minimize thawing and divert surficial runoff away from sites (Magee & Rice, 2002). In the meantime, the City may need to take remedial measures to prevent its landfill and former waste disposal sites from posing serious hazards to public safety in the event of substantial permafrost loss.

4.5 Summary of Impacts

The literature search and consultations identified changes in permafrost as the most significant climate-related concern for Iqaluit's infrastructure. The following infrastructure will be particularly at risk:

- Buildings with shallow foundations (since immediate warming will be near-surface); deep foundations could later experience instability;
- Buildings, roads and buried pipes along steep south-facing slopes and/or in areas of high snow accumulation;
- Buildings and roads in areas of poor drainage where water may pool; and
- The landfill and former waste disposal sites that rely on the frozen state of permafrost to impede decomposition.

The following list summarizes infrastructure that may be vulnerable to other climate change impacts:

- Buildings or piping in poor condition due to age, absence of regular maintenance, or over-extended use which will be particularly vulnerable to damage from extreme weather events;
- Buildings with flawed building envelopes which will be susceptible to moisture damage from the ingress of precipitation;
- Buildings with structurally weak roofs which will be susceptible to damage from snow loading;
- Infrastructure located along the coast which will be susceptible to damage from flooding, storm surges and erosion, such as the *Sewage Pumping Station 2* and the cemetery;
- Above-ground piping made of asbestos cement and steel; and
- The drainage system which may be impacted by changes in precipitation.

Iqaluit's cemetery along the coast

In addition to the infrastructure, climate change is expected to impact the quality and quantity of the City's water supply.

SECTION 5

5.1 RESPONDING TO CLIMATE CHANGE THROUGH ADAPTATION

Since climate is not static, the world will always experience climatic variations, both spatially and temporally. However, human-induced changes in the atmosphere are altering climate regimes and average conditions, and increasing the frequency and magnitude of weather-related events. These changes are beginning to have significant physical, ecological and socio-economic impacts on communities around the world and are expected to increase in intensity throughout the century (Smit & Pilifosova, 2001).

In response, many countries, including Canada, are attempting to improve their scientific understanding of climate variability and change. They are also beginning mitigation initiatives and steps to build their adaptive capacity (Smit, 1993). *Mitigation* refers to reducing greenhouse gas emissions to abate changes in climate. *Adaptation* involves implementing measures to diminish, cope with, or take advantage of the consequences of climatic events (Smit & Pilifosova, 2001).

Photo Credit: J. Lavallée

Adaptive capacity is defined as a community's ability to cope with or adjust to climate change impacts and risks. In building adaptive capacity, communities develop practical means to cope with climatic uncertainties, reduce vulnerability and in some cases, support sustainable development. A community's social, economic, and technological conditions affect its adaptive capacity (Smit & Pilifosova, 2001).

Adaptation is a relatively new concept in the field of climate change research, although more familiar in the fields of natural hazards, resource management and sustainable development. Typically, government and communities have responded to climate change through mitigation but because greenhouse gas emission levels continue to rise and research shows that even the most effective mitigation efforts are unlikely to decelerate changes in climate, adaptation is becoming a more critical response option to climatic risks (Ford, 2006 and Smit & Pilifosova, 2001). A community's ability to cope within a certain scope of climatic conditions is termed its *coping range*. As climate change and variability create conditions that fall outside this rage, it becomes vulnerable. The degree to which climatic conditions deviate from the norm will determine the community's level of vulnerability (Smit et al. 2003).

Impacts may manifest gradually or acutely as temperatures rise. Research indicates that communities are better able to cope with changes in long-term mean climatic conditions than with climate change-related variability and extreme events. It is therefore important to consider interannual variations and extremes, as well as changes in mean climate when developing adaptation options (Smit & Pilifosova, 2001).

5.2 Types of Adaptation

Many forms of adaptation exist: spontaneous or anticipatory, localized or regionalized and long or short-term. *Autonomous or spontaneous adaptation* takes place in response to climatic stimuli without deliberate intervention and is usually reactive in nature. *Planned adaptation* can be both reactive and proactive, and responds strategically to the awareness that climate is changing (Conway, 2004 and Smit & Pilifosova, 2001). For example, communities that anticipate climate stimuli and develop strategies to reduce risks are practicing proactive planned adaptation.

Planned adaptation is not a substitute for mitigation but a complementary response. Because implementing adaptation options can enhance sustainability as well as reduce vulnerability, planned adaptation can generate numerous benefits. Burton (1996) outlines six reasons for pursuing planned adaptation:

1. Climate change cannot be completely evaded.
2. Proactive, planned adaptation is more effective and less costly than spontaneous adaptation.
3. Climate change impacts may manifest faster and be more pronounced than projections propose; unanticipated events are possible.
4. Adaptation can produce immediate benefits to counter climate variability and extreme events.
5. Removing maladaptive practices can also produce immediate benefits.
6. Climate change can bring opportunities as well as threats.

5.3 DETERMINANTS OF ADAPTATION

A community's ability to adapt to climate change is determined by a combination of economic, social, technological, political and biophysical circumstances. Based on conditions that affect a community's adaptability in the areas of hazards, resource management and sustainable development, Smit et al. (2001) identify characteristics which determine adaptive capacity:

"The benefits of strong, early action on climate change outweigh the costs."

Stern, page 9, 2007

1) ECONOMIC RESOURCES: Financial strength increases a community's ability to cope with environmental hazards and is a strong determinant of adaptive capacity. Communities with sufficient economic resources will be in a better position to carry the costs associated with adaptation. In contrast, poverty has been linked to vulnerability and disadvantaged groups within a community are particularly susceptible to climatic hazards.

2) TECHNOLOGY: Due to the complexity of climate change issues, implementing most adaptive options depends on the ability to access technology. Its availability or accessibility will determine a community's capacity to project future climate scenarios, identify impacts, implement adaptation options, and monitor progress. The absence of technology will limit the range of adaptation options available to a community.

3) INFORMATION & SKILLS: Communities need to have some level of scientific understanding of climate change and pragmatic skills to identify appropriate adaptation options. Trained and skilled personnel are needed to facilitate adaptation planning and coordinate initiatives at various levels within the community. High staff turnover impedes the transfer of information and skills.

4) INFRASTRUCTURE: Lack of sufficient infrastructure to carry out the daily functions of a society will reduce its capacity to adapt to changing environmental conditions. Community residents need access to resources, such as safe and adequate housing and a reliable energy source.

5) INSTITUTIONAL SUPPORT & EQUITY: Political, social and economic institutions determine entitlements and access to resources. Effective institutions

within a community have a greater capacity to ensure equity. Equitable distribution of resources and power contribute to adaptive capacity. A community's entitlement to resources and its ability to access them influences it ability to cope with environmental risks.

Conditions for adaptive capacity vary widely among nations and groups, and can change over time, depending on the availability of resources. As an arctic community, Iqaluit is challenged by unique conditions which may act as barriers to adaptation: for example, competing priorities unrelated to climate change, such as social and economic issues, may be more of a concern for decision-makers and community leaders (Ford, 2006 and Burton et al., 2004). It may be difficult to justify expending human and financial resources on measures to abate future climate conditions when there appear to be more immediate issues to address. Because the magnitude and timing of climate change is uncertain at local levels, it may be difficult to rationalize expensive adaptation measures in the present (Dore & Burton, 2001). Although communities may be reluctant to invest in options with deferred payback, studies show that making structures resilient to climate change impacts now is more cost-effective than adapting them after they have been constructed (Niang-Diop & Bosch, 2005).

Conditions influencing the design and construction industries may also constrain adaptive capacity. Typically, short-term financial gains have had more influence on planning and building decisions than long-term adaptability requirements (Auld & MacIver, 2005). Burton (2003) states that forces within these industries encourage risk-taking and growth, despite probable hazards. Some developers ignore restrictions and codes and take risks when the amenity value of property is high, as it is in coastal areas. Such risks may exacerbate the vulnerability of those developments in the long-term and reduce a community's adaptive capacity.

Photo Credit: J. Lavallée

SECTION 6

6.1 ADAPTATION OPTIONS FOR THE CITY OF IQALUIT'S INFRASTRUCTURE

Developing adaptation options involves collecting information, planning, designing, implementing, monitoring, evaluating and revising. It requires a wide spectrum of approaches, such as educational or awareness-raising initiatives, infrastructure retrofits, policy changes or additions, and building standard amendments. Because adaptation is an ongoing process, communities need to revise adaptation options as new and unfamiliar climatic conditions that lie outside their existing experience evolve (Auld & MacIver, 2005). Adaptation options will change with the development of new technologies and research (Burton et al., 2004).

The aim of the following adaptation options is to ensure that the City's infrastructure can continue to operate properly and provide essential services to residents, despite changes in climatic conditions. They are organized in conjunction with the main climatic risks for the City under the headings: *Changes in Permafrost, Increases in Extreme Weather Events & Precipitation, Changes to the Coastal Environment, Changes to Water Quality & Quantity, and Interconnected Issues.* Adaptation options under each heading are placed in the following categories: *Actions, Partnerships & Collaborative Initiatives, Awareness-Raising, and Research, Data Collection & Monitoring*.

Note: Adaptation options marked with an asterisk (*) were designated by municipal staff as a high priority. For the methodology on determining priority rankings, see Section 7.1.

6.1.1 Adaptation Options Related to Changes in Permafrost

	Priority Ranking
Actions	
▪ Inventory existing infrastructure to determine which structures may be most vulnerable to climate change impacts; the inventory should detail approximate age, condition, maintenance, repair and retrofit history, foundation type and location.	***High***
▪ Evaluate the road system to identify areas at high risk to ground subsidence and/or slope failure.	***Medium***
▪ Identify and map areas where snow typically accumulates around foundations and remove it regularly.	***Low***
Partnerships & Collaborative Initiatives	
▪ Install gauges to record ground temperature and monitor for changes; gauges can be installed at 1, 6 and 10 metres when drilling for new developments; gauges should be installed in areas representing the City's various ground conditions.	***High***
▪ Install temperature gauges at the landfill and former waste disposal sites to record ground temperatures and monitor changes in permafrost.	***High***
▪ Map permafrost conditions using ground temperature data to identify areas most susceptible to thaw subsidence and monitor for changes.	***High***
▪ Coordinate a community waste management program that encourages waste reduction.	***High****
Research, Data Collection & Monitoring	
▪ Explore best practices in landfill siting, design, construction and closure to determine whether present practices will need to be modified to compensate for changes in permafrost.	***High***
▪ Record incidence of infrastructure subsidence and any remedial action taken.	***Medium***
▪ Explore best practices in road construction and maintenance to determine whether present practices will need to be modified to compensate for changes in climatic conditions.	***Medium***

6.1.2 Adaptation Options Related to Increases in Extreme Weather Events & Precipitation

	Priority Ranking
Actions	
▪ Revise the City's disaster management plan to include procedures for extreme weather events.	***High***
▪ Examine the drainage system's capacity, including ditches and culverts, to cope with projected increases in precipitation.	***High****
▪ Identify critical infrastructure and develop contingency plans to protect against and prepare for weather-related hazards.	***Medium***
▪ Review maintenance regime for drains, culverts and ditches to establish whether more frequent clearing is required.	***Low***
Partnerships & Collaborative Initiatives	
▪ Develop an anti-littering campaign aimed at reducing litter in ditches that may cause blockages.	***High****
▪ Collaborate with government departments, local businesses and organizations to establish criteria and procedures for closing City operations in response to extreme weather events.	***Medium***
▪ Promote new building materials and practices that can withstand projected changes in climate such as increased ultraviolet radiation.	***Medium***
▪ Promote new roof designs that can withstand projected increases in precipitation and wind speeds.	***Medium***
▪ Promote best practices for building envelopes which prevent the ingress of moisture during periods of intense rainfall.	***Medium***
Awareness-Raising	
▪ Educate residents on emergency procedures for extreme weather events.	***High***
Research, Data Collection & Monitoring	
▪ Record costs for repairing and/or replacing infrastructure damaged by extreme weather events; develop a new code on yearly budget statements for reporting these costs.	***Low***

6.1.3 Adaptation Options Related to Changes in the Coastal Environment

	Priority Ranking
Actions	
▪ Record any damage to infrastructure and/or changes in the coastline from flooding, storm surges and erosion.	***Medium***
▪ Develop a flood and storm surge recovery plan for infrastructure in vulnerable areas and incorporate it into the City's disaster management plan.	***Medium***
Partnerships & Collaborative Initiatives	
▪ Develop a *Coastal Area Protection Plan* that sets out guidelines for managing development and activities within the coastal area.	***High***
▪ Install tide gauges for collecting sea-level data.	***Medium***
▪ Collaborate with a geomatics research group to conduct *LiDAR* mapping of Iqaluit's coastline to identify areas prone to flooding and erosion.	***Medium***
▪ Research and record storm surge and flooding events that have impacted Iqaluit's coastal area.	***Medium***

Flooding in Iqaluit, September, 2007

Photo Credit: R. Armstrong

6.1.4 Adaptation Options Related to Changes in Water Quantity & Quality

	Priority Ranking
Actions	
▪ Develop a contingency plan to ensure that vital municipal functions are maintained in times of extremely low water supply; incorporate this information into the City's disaster management plan.	***High****
▪ Increase local water storage reservoirs to offset potential losses of precipitation.	***Medium***
Partnerships & Collaborative Initiatives	
▪ Develop a leak detection and maintenance program to reduce water loss and energy consumption.	***High****
▪ Participate in Natural Resources Canada's *Geoscience Information for Modeling Water Resources in Northern Communities Program* to determine the sustainability of the City's potable water supply such as reservoir volume and recharge rates.	***Medium***
▪ Collaborate with developers to encourage the installation of water-saving devices and appliances in all new developments.	***Medium***
▪ Explore the feasibility of establishing a jointly-funded rebate scheme for residents to purchase and install water-saving devices and appliances.	***Low***
▪ Collaborate with developers to create a program that trains plumbers in water conservation technologies.	***Low***
Awareness-Raising	
▪ Develop and implement a water conservation program for residents, businesses, government and developers to promote sustainable water use.	***Low***
Research, Data Collection & Monitoring	
▪ Monitor drainage patterns and water quality around landfill and former waste disposal sites to ensure that landfill and surficial runoff are not mixing.	***Medium***
▪ Increase the level of water quality monitoring in the reservoir to maintain quality standards in the face of projected changes in temperature and precipitation.	***Medium***

6.1.5 Adaptation Options for Interconnected Issues

	Priority Ranking
Actions	
▪ Create the *Impacts & Adaptation Information Database* to house all information related to climate change and infrastructure.	***High***
▪ Conduct audits on existing buildings to assess their performance and determine specific and technical measures to reduce energy consumption.	***Medium***
▪ Develop a plan for and schedule of preventive and remedial maintenance for infrastructure; keep maintenance records for all structures (Note: The Government of Nunavut uses the *Maintenance Management Operating System* software to record maintenance information).	***Medium***
▪ Develop master plans for the water supply, wastewater treatment and waste disposal systems to address local implications of climate change and projected increases in population.	***Medium***
Partnerships & Collaborative Initiatives	
▪ Prepare a guide on development standards that incorporates climate change considerations.	***High***
▪ Meet annually with representatives from the engineering, design and building communities to communicate new findings or changes in climate that affect infrastructure; this information can be used to update standards, codes and building practices.	***Medium***
▪ Collaborate with Nunavut Research Institute to develop a community-based monitoring program to engage residents in recording and identifying changing climatic conditions, weather hazards and incidences of damage to infrastructure.	***Medium***
▪ Stay informed of design and construction practices that incorporate climate change considerations and post this information on the City's website.	***Medium***
▪ Review future climate projections for Iqaluit every 3-5 years.	***Medium***
▪ Support efforts that require developers to address climate change risks as part of any Environmental Impact Assessment.	***Medium***
▪ Conduct a cost-benefit analysis for implementing adaptation options versus not adapting to climate change.	***Low***
Awareness-Raising	
▪ Seek opportunities to communicate the success of the City's adaptation planning initiatives locally, regionally and nationally to raise awareness of climate change issues.	***Low***

RESEARCH, DATA COLLECTION & MONITORING	
▪ Record significant changes to infrastructure to track impacts from climatic hazards (this may provide a better understanding of infrastructure vulnerabilities and thresholds to risks).	***Medium***
▪ Review existing adaptation options every 2 -3 years to determine whether they provide sufficient protection against climate change impacts and revise as necessary.	***Medium***
▪ Review existing policies every 2 – 3 years to ensure that they are effective in responding to climate change impacts and revise as necessary.	***Medium***

6.2 DEVELOPING CLIMATE CHANGE POLICIES

Incorporating climate-related policies into the decision-making and planning process is an important mechanism for increasing adaptive capacity; however, the uncertainty associated with climate change has inhibited the development of these policies in most communities. Climate-related policies increase resilience to projected climate scenarios and reduce vulnerability to extreme events unrelated to climate change (CFC Consultants Ltd. & CBCL Ltd., 2005). Therefore, developing these policies to guide future planning decisions is an integral component of adaptation planning.

Rather than address climate change as an isolated issue, it is important to build adaptive measures into existing policies that support similar planning goals (Berkhout, 2005). Currently, the *General Plan* contains physical development policies for Iqaluit which blends social, economic and environmental considerations and show commitment to environmental responsibility and sustainability. Policies that foster sustainable development also provide some resilience in the face of climatic risks. Examples of these policies found in the *General Plan* (2003) include:

Housing units in the Plateau, Iqaluit's sustainable subdivision.

1. *Council shall continue to protect the Lake Geraldine water supply by designating the watershed a Watershed Protection Area in accordance with the provisions in Section 4.2.*
2. *Council shall encourage developers of new residential buildings to pursue a lot layout and building orientation to maximize solar exposure and energy-efficient building designs.*

3. *Council will encourage water conservation methods, such as water recycling systems, to reduce per capita water consumption.*

These policies aim to change existing practices; however, their effectiveness lies in the City's ability to enforce them. For example, the *National Building Code of Canada* includes guidelines for protecting structures from environmental risks, although they have no legal power until adopted by municipal, territorial or provincial governments. Such policies and standards could greatly increase infrastructure resiliency, whereas poor construction and lack of enforcement could exacerbate vulnerability. Among other options, the City could give preference to development plans that pursue water conservation methods and energy-efficient building designs.

Photo Credit: C. Lo

6.3 Suggested Polices for the City of Iqaluit

After reviewing the *General Plan* and consulting with community stakeholders, the following climate change policies were developed for the City of Iqaluit:

	Priority Ranking
▪ Restrict development in areas prone to the impacts of sea-level rise, including flooding and storm surges.	***High***
▪ Require future landfills to be designed, sited, constructed and closed with consideration for projected changes in permafrost.	***High***
▪ Require that all new municipal infrastructure be designed and constructed to specifications that withstand projected changes in climate over their expected lifecycle and meet sustainable development standards.	***Medium***
▪ Require all new developments and major refurbishment projects to implement best practices in water efficiency and conservation technologies, including low-flow toilets and showerheads, and the installation of water-saving appliances.	***Medium***
▪ Regulate culvert size in new developments to ensure they have the capacity to cope with projected increases in precipitation.	***Low***

SECTION 7

7.1 PRIORITIZING ADAPTATION OPTIONS

Numerous criteria exist for prioritizing adaptation options and their relevance is different for every community. Smith & Lenhart (1996) suggest adaptation options that will be significantly less effective or ineffective if implemented in reaction to climate change (such as a catastrophic impact that could lead to extensive damage), and yield net benefits in the absence of climate change (such as water conservation programs that provide immediate benefits under both current and future climate conditions) should be considered high-priority.

Photo Credit: J. Lavallée

Because of the substantial gaps in research and data available, adaptation options that provide climate change-related information should be considered a priority for Iqaluit. These options will provide a context for projected impacts and help the City identify infrastructure most vulnerable to climatic risks. For example, although loss of permafrost is identified as a significant impact for northern infrastructure, limited information on the condition of the City's buildings makes it difficult to identify which structures are most vulnerable. Furthermore, since ground temperature monitoring has yet to be done, it is not feasible to develop accurate or even probable projections as to the degree or speed of permafrost change. The City needs these data to prioritize which structures are at the greatest risk to changes in permafrost.

Base on these criteria, priority adaptation options for the City of Iqaluit are those which:

1. Address a high-priority impact;
2. Address long-term planning decisions for significant structures;
3. Provide benefits in the absence of climate change; and
4. Provide information to further enhance the City's understanding of infrastructure vulnerabilities and climate change risks.

Adaptation options and policies were prioritized based on their potential impact as *High, Medium or Low* priority (see *Sections 6.1.1 – 6.1.5* for priority designations for each option). In addition to prioritizing adaptation options using the above criteria, municipal staff designated additional options high-priority based on current land-use planning goals. These adaptation options are marked with an asterisk (*) in *Sections 6.1.1 – 6.1.5.*

7.2 Next Steps

This project is intended to be a working document to guide the adaptation planning process and will evolve as new information becomes available to inform decisions. The following initiatives are recommended for immediate implementation. They will help the City fill important information and research gaps and serve to build its adaptive capacity through the process.

- Seek funding to hire a climate change coordinator to implement adaptation planning initiatives;
- Seek funding to develop action plans for high-priority adaptation options;
- Identify external stakeholders and work in partnership with them to implement high-priority adaptation options that lie out of the direct scope of the City of Iqaluit; and
- Include climate-related policies in the City's *General Plan* when it is revised for 2008.

7.3 Ongoing Initiatives to Build Adaptive Capacity

The following initiatives are broad strategies to build on the adaptation options outlined in *Section 6.* By further building adaptive capacity, they will help prepare the City for a range of conditions. Their implementation should be an ongoing process and will focus the City's efforts on gathering information and collaborating on initiatives that are integral to the adaptation planning process.

7.3.1 Maintain Awareness of Climate Change Issues & Initiatives

To ensure that adaptation planning remains a key issue for the City of Iqaluit, it is important to maintain awareness of ongoing climate change issues and initiatives. Community awareness will help increase participation in programs aimed at reducing risks and help ensure their success. As general awareness increases, so does the likelihood that other organizations and communities will engage in adaptation planning.

7.3.2 Develop Partnerships & Initiate Collaborative Programs

"There is still time to avoid the worst impacts of climate change if strong collective action starts now."

Stern, page 27, 2007

Developing partnerships with organizations that conduct climate change-related research and monitoring programs will provide relevant data that is beyond the City's capacity to collect, yet key to developing appropriate adaptation options. Partnerships and collaborative efforts among various levels of government, community leaders, local businesses, organizations and residents are critical to the success of the City's adaptation planning efforts.

7.3.3 Monitor Climate & Future Scenarios

Monitoring climate conditions is an important component of adaptation planning. Climate modeling provides some insight into future climate scenarios; however, the complexity of climate regimes and the many human-induced variables that affect climate, such as doubling of carbon dioxide levels, increases the probability of climate surprises (Conway, 2004). The accumulation of more information and better climate modeling techniques may increase the accuracy of future projections. The City will need to monitor projections for local conditions and decide whether additional or different adaptation measures will be required to reduce risks. By working closely with the climate community and recording local conditions and changes to infrastructure, the City will increase its knowledge base for making more informed decisions.

7.3.4 Be Advised of & Encourage Changes to Standards, Codes & Practices

Historically, engineering standards, building codes and land-use planning policies have been slow to change (Auld & MacIver, 2005), but revision efforts to reflect recent and projected changes in climate are underway. For example, the Canadian Council of Professional Engineers (CCPE) recently launched a national committee, known as the *Public Infrastructure Engineering Vulnerability Committee*, to coordinate a national assessment of infrastructure vulnerability. The CCPE plans to work with engineers, policymakers and scientists to determine precautionary design levels that safeguard infrastructure from climatic risks and promote sustainability.

The Canadian Standards Association (CSA) is also working to revise standards to accommodate future projections in climate change. Its report, entitled *The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change,* discusses how standards and codes can bring adaptation measures into mainstream practice through a coordinated national standards strategy. Recognizing the complexity of the regulatory jurisdictions related to laws, codes and standards, it called for coordinated outreach to identify needs for the development of new national standards (the vulnerability of northern infrastructure was identified as a high priority), and access to high-quality, reliable climate data (Girard & Mortimer, 2006).

The City of Iqaluit can play an important role in encouraging and informing changes to standards, codes and practices. Through communication and cooperation on initiatives, the City can facilitate sharing of information to bring about change. Providing information on local climate and its impact on infrastructure will help organizations like CCPE and CSA determine precautionary levels for planning, designing and building infrastructure in the North.

7.3.5 MONITOR INFRASTRUCTURE FOR CHANGES

It is important to monitor the condition of infrastructure as it is exposed to variable and extreme climate over time. Climate change may alter timelines required for upgrading and maintaining infrastructure, and shorten the lifespan of existing structures (Auld & MacIver, 2005). Recording damages and losses, and keeping maintenance and upgrade records will provide the City with important information to assess the vulnerability of structures, identify compromised infrastructure, and plan retrofits and replacements as needed.

7.3.6 Utilize Local & Inuit Traditional Knowledge

Abundant local and Inuit traditional knowledge within the community can provide important information for designing appropriate adaptation options. Inuit Qaujimajatuqangit (IQ) is a set of cultural beliefs which embody healthy and sustainable community development, information sharing, capacity building, community participation, resourcefulness and environmental protection. These principles should be considered in revising and developing adaptation options.

7.3.7 Work with the Community to Revise the City of Iqaluit's Disaster Management Plan

Because research indicates communities will be exposed to more extreme weather events throughout the 21st century, the City and community should collaborate to revise the disaster management plan. Auld & MacIver. (2005) suggest that a community can reduce its vulnerability to weather hazards or disasters with planned and timely responses to weather warnings, proper land-use planning, sound engineering designs and practices, well-maintained structures, and self-sufficient energy options, such as renewable energy.

Its harsh winter conditions, lack of alternate energy sources and remote location make Iqaluit very vulnerable to climate-related disasters that could significantly damage critical infrastructure, such as the power generating plant, airport and hospital. Collaborative efforts will be required to safeguard critical infrastructure and increase emergency preparedness by developing a comprehensive plan to manage risks associated with climatic events.

7.3.8 Incorporate Climate Change Considerations into All Long-term Planning Decisions

Infrastructure planning decisions made today will likely be affected by future climatic risks, so all long-term planning decisions should incorporate climate change considerations (Smith & Lenhart, 1996). Depending on its design life (whether the infrastructure's typical expected lifecycle is 30 or 100 years, for example) structures will be affected by different future climate conditions (Auld & MacIver, 2005). Regardless of lifecycles, all long-term planning decisions will be impacted by climate change to some degree: proper planning and preparedness will enhance the ability of future generations to cope with the results.

7.4 CONCLUSION

The work presented in this report is the first component of an adaptation plan for the City of Iqaluit and provides a foundation for facilitating its adaptive capacity. Because climate change is unavoidable, the City must continue to be proactive in limiting infrastructure risks. The vulnerability of its infrastructure will be affected by both changing climatic conditions and a significant increase in population and development. Its ability to respond to these changes will depend on a number of conditions, but in particular, its ability to coordinate efforts among organizations to share resources in preparation for an uncertain future. Further information and research are needed to designed new buildings and adapt existing ones to improve their resilience to projected changes in climate. This will require collaboration among the engineering, design and construction professionals to update standards, codes and building practices. The City will need to be persistent in researching, collecting data and monitoring progress to better understand local climatic risks, and be willing to revise its adaptation planning efforts as new information becomes available. By doing so, it will prepare itself for future changes and will benefit from being a more environmentally responsible and sustainable arctic community.

Photo Credit: J. Lavallée

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APPENDIX A: CLIMATE NORMALS FOR IQALUIT STATION A

The following tables summarize data recorded at the Environment Canada *Iqaluit Station A* (63^{o} 45'N, 68^{o} 33' W, elevation 33.5 m) *Canadian Climate Normals* for temperature, precipitation and wind values (www.climate.weatheroffice.ec.gc.ca).

I. CLIMATE NORMALS FOR 1961-1990

MONTH	**MEAN TEMPERATURE (^{o}C)**	**MEAN RAINFALL (mm)**	**MEAN SNOWFALL (cm)**	**MEAN PRECIPITATION (mm)**	**MAXIMUM GUST SPEED**
ANNUAL	-9.5	192.9	256.8	424.1	126.4
JANUARY	-25.8	0	24.4	21.8	146
FEBRUARY	-26.8	0	21.4	19	114
MARCH	-23.5	0	25.3	22	156
APRIL	-14.7	0.2	32.5	28.4	153
MAY	-4.2	2.3	28.2	29.6	103
JUNE	3.4	24.3	11.7	36.5	89
JULY	7.7	57.8	0.3	58.2	117
AUGUST	6.8	62.8	0.7	63.5	109
SEPTEMBER	2.3	38.1	14.4	51.9	126
OCTOBER	-4.9	6.7	38.8	42.4	137
NOVEMBER	-12.7	0.4	35.5	30.9	126
DECEMBER	-22.1	0	23.9	19.8	141

II. Climate Normals for 1971-2000

Month	Mean Temperature (°C)	Mean Rainfall (mm)	Mean Snowfall (cm)	Mean Precipitation (mm)	Maximum Gust Speed
Annual	-9.8	198.3	235.8	412.1	126.8
January	-26.6	0.1	22.8	21.1	146
February	-28	0	16.8	15	114
March	-23.7	0	25.3	21.8	156
April	-14.8	0.2	32.4	28.2	153
May	-4.4	2.8	25.1	26.9	103
June	3.6	24.7	9.8	35	93
July	7.7	59.2	0.1	59.4	117
August	6.8	64.8	0.8	65.7	109
September	2.2	41.5	13.7	55	126
October	-4.9	4.5	34.9	36.7	137
November	-12.8	0.5	32.4	29.1	126
December	-22.7	0	21.7	18.2	141

Appendix B: Model Outputs For Climate Scenarios
I. Annual Outputs

GCM	Grid Cells		Temperature Change (°C) 2010-2039	Precipitation Change (Percent of Baseline) 2010-2039	Temperature Change (°C) 2040-2069	Precipitation Change (Percent of Baseline) 2040-2069	Temperature Change (°C) 2070-2099	Precipitation Change (Percent of Baseline) 2070-2099
	Latitude	Longitude						
cgcm2 a21	65.3049°N	67.5°W	2.4	9	4.3	0	6.5	15
cgcm2 a22	64.9419°N	67.5°W	1.7	3	3.8	7	5.9	11
cgcm2 a23	64.9419°N	67.5°W	2.4	4	3.9	8	6.3	9
cgcm2 b21	65°N	67.5°W	2.2	6	3.8	4	5.1	7
cgcm2 b22	63.6786°N	67.5°W	1.6	5	3.5	12	4.1	11
cgcm2 b23	64.9419°N	67.5°W	2	0	3.6	4	4.7	5
csiromk2b a11	65°N	67.5°W	1.8	10	4.3	18	6.3	29
csiromk2b b11	64.9419°N	67.5°W	1.8	-1	3.8	16	4.7	20
csiromk2b a21	62.7874°N	67.5°W	1.9	8	3.5	22	6.6	25
csiromk2b b21	65.3049°N	67.5°W	2.5	6	4.3	16	5	22
hadcm3 a21	65°N	67.5°W	1.4	11	3.7	14	5.8	29
hadcm3 a22	65°N	67.5°W	1.9	10	3.4	21	6.1	24
hadcm3 a23	63.6786°N	67.5°W	2.4	0	3.2	12	5.9	22
hadcm3 b21	63.7245°N	67.5°W	2.1	7	3	12	4.5	23
hadcm3 b22	65.3049°N	67.5°W	1.9	9	2.5	14	4.4	23
hadcm3 b11	65.3049°N	67.5°W	1.8	9	2.7	12	3.4	15
hadcm3 a1fi	65°N	67.5°W	1.7	9	4.5	22	7.1	37
ccsrnies a21	64.9419°N	67.5°W	1.9	9	2.3	6	7.2	19
ccsrnies b21	65°N	67.5°W	2.4	6	3	8	5.9	14
ccsrnies a11	63.6786°N	67.5°W	1.7	8	3.1	10	7	18
ccsrnies b11	62.7874°N	67.5°W	0.5	5	1.7	7	5	10
ccsrnies a1fi	64.9419°N	67.5°W	1.3	-1	2.9	7	8.4	18
ccsrnies a1t	63.7245°N	67.5°W	1.4	1	2.8	11	6.7	21
echam4 a21	65°N	67.5°W	0.2	2	1.4	15	4.2	26
echam4 b21	63.6786°N	67.5°W	0.4	4	3	17	3.6	22
gfdlr30 a21	63.6786°N	67.5°W	1.9	-2	2.9	15	4.9	20
gfdlr30 b21	63.6786°N	67.5°W	1.5	3	2.8	14	3.7	3
ncarpcm a21	62.7874°N	67.5°W	1.7	6	2.7	9	4.6	20
ncarpcm b21	62.7874°N	67.5°W	2	5	2.9	12	4	17

II. Model Outputs for Winter

GCM	Grid Cells		Temperature Change (°C) 2010-2039	Precipitation Change (Percent of Baseline) 2010-2039	Temperature Change (°C) 2040-2069	Precipitation Change (Percent of Baseline) 2040-2069	Temperature Change (°C) 2070-2099	Precipitation Change (Percent of Baseline) 2070-2099
	Latitude	Longitude						
cgcm2 a21	64.9419°N	67.5°W	3.2	-10	6.5	-12	10.6	7
cgcm2 a22	64.9419°N	67.5°W	2.3	-2	5.7	3	9.2	0
cgcm2 a23	64.9419°N	67.5°W	3.1	4	5.3	0	9.3	-1
cgcm2 b21	64.9419°N	67.5°W	3	1	6.6	-3	8.5	4
cgcm2 b22	64.9419°N	67.5°W	2.2	-4	5.8	7	6.2	8
cgcm2 b23	64.9419°N	67.5°W	2.4	0	5.2	10	8	-1
csiromk2b a11	65.3049°N	67.5°W	2.2	34	5	28	7.7	65
csiromk2b b11	65.3049°N	67.5°W	2.5	24	5.3	54	5.8	42
csiromk2b a21	65.3049°N	67.5°W	2.5	27	4.8	42	7.8	55
csiromk2b b21	65.3049°N	67.5°W	3	29	5.3	49	5.8	43
hadcm3 a21	65°N	67.5°W	1.3	8	4.1	19	7.9	29
hadcm3 a22	65°N	67.5°W	1.6	31	4.5	48	7.4	36
hadcm3 a23	65°N	67.5°W	2	-3	3.4	0	7	13
hadcm3 b21	65°N	67.5°W	1.8	9	3.3	17	5.8	32
hadcm3 b22	65°N	67.5°W	1.4	18	2.9	30	5.1	46
hadcm3 b11	65°N	67.5°W	1.7	21	3.6	33	2.9	16
hadcm3 a1fi	65°N	67.5°W	1.8	18	5.8	27	10.4	64
ccsrnies a21	63.6786°N	67.5°W	3.5	8	3.6	7	11.5	2
ccsrnies b21	63.6786°N	67.5°W	3.3	13	3.8	3	9.9	-5
ccsrnies a11	63.6786°N	67.5°W	2.7	17	4.5	-2	12.1	3
ccsrnies b11	63.6786°N	67.5°W	0.2	9	0.7	8	8.1	-3
ccsrnies a1fi	63.6786°N	67.5°W	1.9	3	4.9	-3	13.8	-4
ccsrnies a1t	63.6786°N	67.5°W	2.9	11	4	5	11.1	1
echam4 a21	62.7874°N	67.5°W	0.3	-9	3	0	10	40
echam4 b21	62.7874°N	67.5°W	0.5	-1	6.6	26	8.2	29
gfdlr30 a21	63.7245°N	67.5°W	3.4	10	5.1	12	8.6	23
gfdlr30 b21	63.7245°N	67.5°W	2	-3	4.6	-3	6.1	-2
ncarpcm a21	62.7874°N	67.5°W	2.7	12	4.9	19	8.2	32
ncarpcm b21	62.7874°N	67.5°W	3.2	14	4.9	30	6.8	46

III. Model Outputs for Spring

GCM	Grid Cells		Temperature Change (°C) 2010-2039	Precipitation Change (Percent of Baseline) 2010-2039	Temperature Change (°C) 2040-2069	Precipitation Change (Percent of Baseline) 2040-2069	Temperature Change (°C) 2070-2099	Precipitation Change (Percent of Baseline) 2070-2099
	Latitude	Longitude						
cgcm2 a21	64.9419°N	67.5°W	1.8	5	2.8	-6	4.6	-1
cgcm2 a22	64.9419°N	67.5°W	1.4	10	3.2	-2	5	-6
cgcm2 a23	64.9419°N	67.5°W	2.3	1	3.2	4	5.4	-5
cgcm2 b21	64.9419°N	67.5°W	1.2	-12	2.4	-5	3.4	-2
cgcm2 b22	64.9419°N	67.5°W	1.5	0	2.9	8	3.1	-5
cgcm2 b23	64.9419°N	67.5°W	2.2	4	3	-2	3.1	-4
csiromk2b a11	65.3049°N	67.5°W	1.5	-2	5.8	33	8.6	51
csiromk2b b11	65.3049°N	67.5°W	1.6	5	4	21	5.6	39
csiromk2b a21	65.3049°N	67.5°W	2.1	-5	4.2	24	9.3	47
csiromk2b b21	65.3049°N	67.5°W	2.9	10	5.3	28	6.3	37
hadcm3 a21	65°N	67.5°W	0.7	-13	2.9	6	4.5	6
hadcm3 a22	65°N	67.5°W	1.8	7	3.1	27	5.2	20
hadcm3 a23	65°N	67.5°W	2.7	3	2.5	5	5.3	15
hadcm3 b21	65°N	67.5°W	2.4	6	2.2	-6	4	2
hadcm3 b22	65°N	67.5°W	1.5	1	1.5	-3	3.7	20
hadcm3 b11	65°N	67.5°W	1.9	12	1.6	7	3	6
hadcm3 a1fi	65°N	67.5°W	1.7	-3	3.3	11	5.2	9
ccsrnies a21	63.6786°N	67.5°W	0.4	-7	-0.7	0	3.7	0
ccsrnies b21	63.6786°N	67.5°W	1.7	8	0.5	-1	1.5	2
ccsrnies a11	63.6786°N	67.5°W	0.3	-2	-0.2	-5	2.5	-8
ccsrnies b11	63.6786°N	67.5°W	-0.2	2	0	-5	0.6	0
ccsrnies a1fi	63.6786°N	67.5°W	0.2	-1	0	-9	4.4	-4
ccsrnies a1t	63.6786°N	67.5°W	-0.4	-4	0.3	4	2.5	2
echam4 a21	62.7874°N	67.5°W	0.1	-1	0.6	2	3	15
echam4 b21	62.7874°N	67.5°W	0.5	5	1.5	6	2.3	15
gfdlr30 a21	63.7245°N	67.5°W	0.6	8	0.8	-3	3	26
gfdlr30 b21	63.7245°N	67.5°W	1.4	5	2.6	12	2.7	13
ncarpcm a21	62.7874°N	67.5°W	2.3	9	2.6	8	4.8	17
ncarpcm b21	62.7874°N	67.5°W	2.8	4	3.3	11	4.2	21

IV. Model Outputs for Summer

GCM	Grid Cells		Temperature Change (°C) 2010-2039	Precipitation Change (Percent of Baseline) 2010-2039	Temperature Change (°C) 2040-2069	Precipitation Change (Percent of Baseline) 2040-2069	Temperature Change (°C) 2070-2099	Precipitation Change (Percent of Baseline) 2070-2099
	Latitude	Longitude						
cgcm2 a21	64.9419°N	67.5°W	2.5	23	4.9	17	6.4	34
cgcm2 a22	64.9419°N	67.5°W	1.6	20	3.4	24	5.7	47
cgcm2 a23	64.9419°N	67.5°W	2.4	2	4	10	6.3	20
cgcm2 b21	64.9419°N	67.5°W	2.8	23	3.4	22	4.9	28
cgcm2 b22	64.9419°N	67.5°W	1.3	10	2.5	32	3.8	40
cgcm2 b23	64.9419°N	67.5°W	2	0	3.1	-2	4.4	14
csiromk2b a11	65.3049°N	67.5°W	1.5	2	2.4	2	3.6	0
csiromk2b b11	65.3049°N	67.5°W	1	10	2.7	6	3.4	3
csiromk2b a21	65.3049°N	67.5°W	1	0	1.9	15	3.3	-5
csiromk2b b21	65.3049°N	67.5°W	1.9	1	3.2	6	3.5	6
hadcm3 a21	65°N	67.5°W	1.3	4	3	10	4.4	34
hadcm3 a22	65°N	67.5°W	1.5	10	2.5	15	5.2	28
hadcm3 a23	65°N	67.5°W	2.1	13	2.9	20	5	20
hadcm3 b21	65°N	67.5°W	1.5	16	2.6	15	3.4	23
hadcm3 b22	65°N	67.5°W	1.7	5	2.5	15	3.4	18
hadcm3 b11	65°N	67.5°W	1.6	8	2.1	9	3.2	20
hadcm3 a1fi	65°N	67.5°W	1.6	8	3.7	28	5.6	37
ccsrnies a21	63.6786°N	67.5°W	1.6	-6	2.5	-2	4.8	17
ccsrnies b21	63.6786°N	67.5°W	2.1	-5	2.8	-2	4.1	3
ccsrnies a11	63.6786°N	67.5°W	1.7	1	2.7	7	4.5	19
ccsrnies b11	63.6786°N	67.5°W	1.1	-4	2.5	5	3.9	5
ccsrnies a1fi	63.6786°N	67.5°W	1.3	-10	2.3	11	5.4	18
ccsrnies a1t	63.6786°N	67.5°W	1.3	2	2.4	11	4.6	12
echam4 a21	62.7874°N	67.5°W	0.4	18	0.9	27	1.2	27
echam4 b21	62.7874°N	67.5°W	0.4	6	1.7	14	1.7	28
gfdlr30 a21	63.7245°N	67.5°W	1.1	6	1.8	26	2.6	20
gfdlr30 b21	63.7245°N	67.5°W	0.8	3	1.4	18	2.2	-7
ncarpcm a21	62.7874°N	67.5°W	0.7	-1	1.2	12	2.1	15
ncarpcm b21	62.7874°N	67.5°W	0.8	10	1.3	9	1.6	10

V. Model Outputs for Fall

GCM	Grid Cells		Temperature Change (°C) 2010-2039	Precipitation Change (Percent of Baseline) 2010-2039	Temperature Change (°C) 2040-2069	Precipitation Change (Percent of Baseline) 2040-2069	Temperature Change (°C) 2070-2099	Precipitation Change (Percent of Baseline) 2070-2099
	Latitude	Longitude						
cgcm2 a21	64.9419°N	67.5°W	1.9	-3	3.1	2	4.3	21
cgcm2 a22	64.9419°N	67.5°W	1.5	8	2.7	6	3.9	5
cgcm2 a23	64.9419°N	67.5°W	1.7	10	3.1	17	4.4	22
cgcm2 b21	64.9419°N	67.5°W	1.6	-10	2.9	3	3.6	0
cgcm2 b22	64.9419°N	67.5°W	1.2	-10	2.6	5	3.3	4
cgcm2 b23	64.9419°N	67.5°W	1.5	-6	3.1	10	3.2	12
csiromk2b a11	65.3049°N	67.5°W	1.8	16	4.2	29	5.5	38
csiromk2b b11	65.3049°N	67.5°W	2.1	1	3.2	8	4	24
csiromk2b a21	65.3049°N	67.5°W	1.9	13	3.3	22	5.9	39
csiromk2b b21	65.3049°N	67.5°W	2.2	9	3.2	4	4.6	26
hadcm3 a21	65°N	67.5°W	2.4	9	4.6	22	6.5	41
hadcm3 a22	65°N	67.5°W	2.8	6	3.5	9	6.5	18
hadcm3 a23	65°N	67.5°W	2.8	8	4.1	15	6.5	35
hadcm3 b21	65°N	67.5°W	2.8	7	4	18	4.8	33
hadcm3 b22	65°N	67.5°W	3	17	3	16	5.2	19
hadcm3 b11	65°N	67.5°W	2.2	3	3.3	7	4.2	14
hadcm3 a1fi	65°N	67.5°W	1.7	3	5.3	19	7.3	41
ccsrnies a21	63.6786°N	67.5°W	2.2	9	3.6	21	9	52
ccsrnies b21	63.6786°N	67.5°W	2.5	11	4.9	30	8.2	53
ccsrnies a11	63.6786°N	67.5°W	2.1	17	5.3	36	8.9	52
ccsrnies b11	63.6786°N	67.5°W	1.1	9	3.8	22	7.5	36
ccsrnies a1fi	63.6786°N	67.5°W	1.5	6	4.4	24	10	51
ccsrnies a1t	63.6786°N	67.5°W	1.5	7	4.3	21	8.6	62
echam4 a21	62.7874°N	67.5°W	0.1	8	1.1	22	2.4	23
echam4 b21	62.7874°N	67.5°W	0.4	12	2.1	21	2.2	18
gfdlr30 a21	63.7245°N	67.5°W	2.4	6	4	16	5.1	15
gfdlr30 b21	63.7245°N	67.5°W	1.7	-1	2.8	19	3.6	9
ncarpcm a21	62.7874°N	67.5°W	0.9	8	2	1	3.4	25
ncarpcm b21	62.7874°N	67.5°W	1.4	7	2.1	10	3.3	17

Appendix C: Global Circulation Models

The following GCM were used to develop Iqaluit's scenario runs for temperature and precipitation.

Model	**Group**	**Width (Degree Latitude)**	**Width (Degree Longitude)**	**Area (km2)**
CSIROMk2B	Australian	3.2	5.6	95,000
HADCM3	British	2.5	3.75	50,000
CGCM2	Canadian	3.75	3.75	74,000
ESCHAM4	German	2.8	2.8	41,000
CCSR98	Japanese	5.6	5.6	168,000
NCARPCM	American	2.8	2.8	41,000
GFDLR30	American	2.2	3.75	44,000

APPENDIX D: CLIMATE CHANGE SCENARIOS

CLIMATE CHANGE SCENARIOS FOR TEMPERATURE, 2070 – 2099*

RANK	WINTER (DJF)	SPRING (MAM)	SUMMER (JJA)	FALL (SON)	ANNUAL
4th	5.8	2.5	2.1	3.3	4
15th (Median)	8.1	4	3.9	4.8	5.1
26th	11.1	5.6	5.6	8.6	7
MEAN	8.3	4.2	3.9	5.4	5.4

**Data are ranked by changes in annual mean temperature (°C) and are for projected increases over baseline climate for the time period indicated.*

CLIMATE CHANGE SCENARIOS FOR PRECIPITATION, 2040 – 2069**

RANK	WINTER (DJF)	SPRING (MAM)	SUMMER (JJA)	FALL (SON)	ANNUAL
4th	-3	-5	2	4	6
15th (Median)	10	4	12	17	12
26th	42	24	26	24	18
MEAN	15.6	5.9	13.1	15.6	11.9

CLIMATE CHANGE SCENARIOS FOR PRECIPITATION, 2070 – 2099**

RANK	WINTER (DJF)	SPRING (MAM)	SUMMER (JJA)	FALL (SON)	ANNUAL
4th	-2	-5	3	9	9
15th (Median)	16	6	19	24	20
26th	46	37	34	52	26
MEAN	21.3	11.3	18.4	27.7	18.4

***Climate change scenarios are ranked on the basis of change in annual mean precipitation (%). Data are for projected increases in mean precipitation as a percentage over baseline climate for the time periods indicated.*