



Transport Canada

MIKE ZUBKO AIRPORT – CLIMATE CHANGE VULNERABILITY ASSESSMENT

Final Report

May 17, 2016



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PIEVC CLIMATE CHANGE VULNERABILITY ASSESSMENT

INUVIK AIRPORT

FINAL

PROJECT NO.: 0727-004
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DATE: May 17, 2016

May 17, 2016
Project No.: 0727004

Janice Festa, Senior Policy Advisor
Transport Canada
330 Sparks Street
Ottawa, ON, K1A 0N5

Dear Mrs. Festa,

Re: PIEVC Climate Change Vulnerability Assessment: Inuvik Airport - FINAL

Please find attached the final version of our above-referenced report. Thank you for the opportunity to work on this assessment. Should you have any questions, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC ENGINEERING INC.
per:



Lukas Arenson, Dr.Sc.Techn.ETH, P.Eng.
Senior Geotechnical Engineer

EXECUTIVE SUMMARY

BGC Engineering Inc. (BGC) was retained by Transport Canada (TC) to carry out an assessment of northern airports and their vulnerability to climate change. The assessment follows a standardized protocol prepared by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) of Engineers Canada. As part of this work a climate change vulnerability assessment was carried out for Inuvik's Mike Zubko Airport located in the continuous permafrost zone of the Northwest Territories in Canada. The assessment looked at a 30-year projected trend in climate conditions for the Inuvik region, which are based on historic data and climate projections using climate models. Key trends are:

- Mean annual air temperature is increasing at about 0.8 °C per decade with warming rates greatest in winter and fall (high confidence);
- The number of annual freeze/thaw cycles is decreasing by about 4 cycles per decade (high confidence);
- Annual rainfall is decreasing by 25 mm per decade with the maximum number of intense rainfall days to occur in the months of July and August (medium confidence);
- Annual total snowfall decreased by about 60 cm in the last decade with significant seasonal variability (medium – low confidence);
- No trend data for rain on snow events are available;
- The number of freeze-thaw cycles has slightly decreased in recent years;
- First snow days are occurring later in the season, whereas last snow days show no statistically significant trend (medium – low confidence); and
- No statistically significant trend was identified for changes in wind direction and intensity.

Using these trends, the vulnerability assessment, during which 465 climate event – infrastructure component combinations were assessed, identified no infrastructure element that would be at high risk due to climate change and 65 combinations at medium risk. The infrastructure components likely to be most vulnerable to climate change are the drainage system and winter/summer flight operations.

Due to the low to medium risks to climate change associated with the infrastructure at Mike Zubko Airport in Inuvik, no immediate engineering action is recommended. The assessment identified frost on runways, taxiways and aprons, and poor visibility as the two main climate events that may become problematic for safe airport operation in the future. However, currently there is insufficient historic climate data available and future projections do not exist that would allow for a confident assessment on how these climate events may affect the airport infrastructure in the future. The lack of data has therefore been identified as another potential risk as it may result in inappropriate decisions on future adaptation and mitigation strategies. Available baseline environmental and maintenance data are inadequate for carrying out a detailed engineering assessment. Therefore, it is recommended to evaluate current environmental monitoring programmes, standard operational procedures and airport maintenance efforts to support future decisions and the design of mitigation and adaptation strategies if those were needed. Specifically, this includes:

- *Collect data on frost formation* to assess conditions during which, and to what degree, frost-related challenges occur;
- *Evaluate the capacity of drainage systems* to assess the resiliency of culverts and ditches;
- *Systematically collect information on the visibility (fog & cloud ceiling)* to identify potential trends that help in deciding if upgrades in the current instrumentation is required;
- *Monitor local snow accumulation, including spatial (re-)distribution* to assess current snow management plans and plan future requirements;
- *Carry out procedural review* by assessing current operation and maintenance practices, and standard operational procedures, and evaluate their robustness against future climatic conditions;
- *Document maintenance and repair efforts in a systematic manner* to note changes and highlight infrastructure performance in response to those; and
- *Reassess the climate change vulnerability in five years* with several stakeholders that include the airport operators, the owners and users of the airport, as more baseline data, infrastructure performance information, and improved climate models become available.

The changing climate will likely result in increased maintenance and repair efforts for which resources must be provided. Because the currently available data is insufficient, additional baseline data should be collected for at least three years, specifically tailored towards infrastructure – climate combinations that are potentially at risk in the future. These additional data will help make informed decisions in the near future on where available resources are best allocated and if additional ones are required.

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LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Transport Canada. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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1.0 INTRODUCTION

1.1. Background

In August 2005, Engineers Canada established a national committee known as the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee the planning and execution of a broad-based national engineering assessment of the vulnerability of Canadian public infrastructure to climate change. This is a continuing priority for the engineering profession because of the uncertainties caused by a changing climate that may influence the validity of climatic design parameters, which are generally based on historical data.

The PIEVC developed a vulnerability assessment method that follows a structured risk assessment protocol known as the PIEVC Engineering Protocol (the Protocol). The Protocol has been tested on more than 40 projects since 2007¹. The Protocol is structured in such a way that the infrastructure vulnerability is evaluated in a staged process. The observations, conclusions and recommendations derived from the Protocol are intended to provide information for the decision-maker about design, construction, operation, maintenance, planning and development.

Transport Canada (TC), in collaboration with the Departments of Transportation of the Northwest Territories, selected Mike Zubko Airport in Inuvik to be assessed with the PIEVC Protocol. The airport is founded on permafrost. Recently-observed instabilities, including runway settlement, has been attributed to permafrost degradation initiated by climate change. The objective of this assessment is to identify potential vulnerabilities of the airport to future climate change. The results of this assessment will be used to develop substantiated engineering and planning recommendations for management and remedial action to address those components of the airport infrastructure that are at the highest risk of failure, damage or deterioration to future changes in local climate.

1.2. Purpose and Scope

BGC Engineering Inc. (BGC) was retained by TC to carry out an assessment of Mike Zubko Airport and identify its vulnerability to climate change. The contract (No. T8080-140109) was awarded to BGC on March 24, 2015. The infrastructure of Mike Zubko Airport in Inuvik, NWT that is included under the scope of the vulnerability assessment following the PIEVC Protocol comprises of:

- Structural elements (e.g., runway structures and signals);
- Policies and procedures (e.g., emergency preparedness and response plans, asset management, operations and maintenance practices); and
- Support equipment (e.g., HVAC, backup power and control systems)

The assessment does not include non-structural building elements or accessory equipment, such as seating in the terminal or signage. In addition, the scope of the assessment encompasses the

¹ <http://pievc.ca/>

current design, construction, operation and management of this infrastructure as well as any planned upgrades or major rehabilitation projects in the planning stages.

In detail, the scope of work included the following:

1. Define the infrastructure components for the airport runway and associated structures that encompass its physical infrastructure, supporting systems, maintenance and operation, and other considerations;
2. Determine the likely effects of climate change on individual components of the infrastructure;
3. Undertake consultations with Transport Canada and airport management, planning, engineering, operations and maintenance staff;
4. Provide recommendations to address the engineering vulnerabilities; and
5. Prepare a report and presentation slides.

1.3. PIEVC Protocol for Climate Change Vulnerability Assessment

The PIEVC developed a generalized step-by-step protocol to assess the vulnerability of infrastructure to climate change. BGC used Revision PG-10 (Canadian Council of Professional Engineers, 2012) of the Protocol for the assessment. The Protocol provides a structured framework that can be used for any infrastructure. It has been successfully used to assess the following categories:

- Various types of buildings;
- Roads, bridges and associated structures e.g. culverts;
- Stormwater and wastewater treatment and collection systems; and
- Water resource systems and other water management infrastructure.
- Energy transmission and distribution systems
- Airports

The Protocol structures the climate change vulnerability assessment into five main steps:

- Step 1 – Project Definition
- Step 2 – Data Gathering and Sufficiency
- Step 3 – Risk Assessment
- Step 4 – Engineering Analysis
- Step 5 – Recommendations

The development of these steps is shown in Figure 1-1 and described in the subsections that follow. Additional information is available in PIEVC (2012).

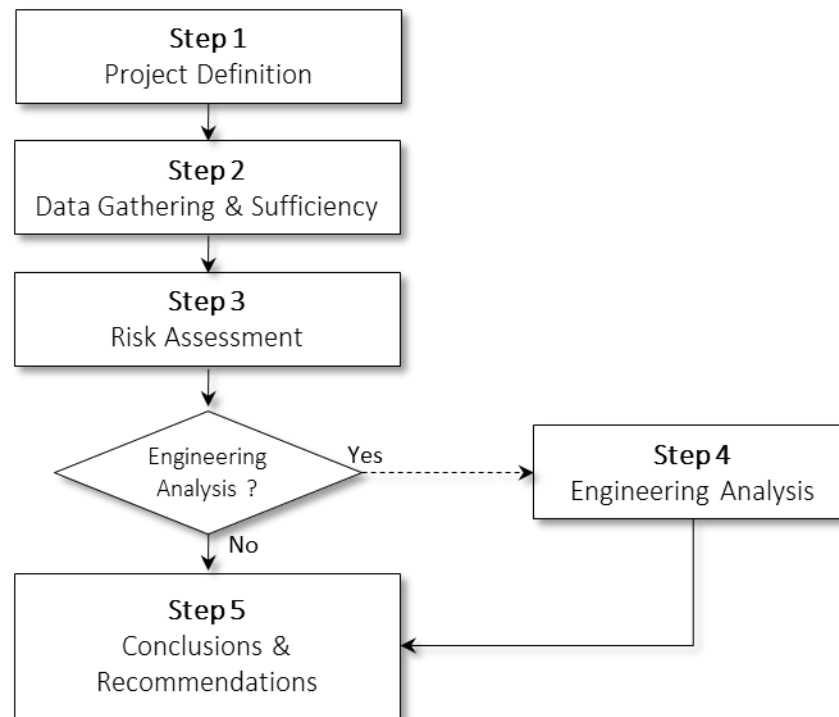


Figure 1-1. Overview of the PIEVC Protocol flow chart (after Canadian Council of Professional Engineers, 2012).

1.3.1. Step 1 – Project Definition

In the first step of the vulnerability assessment protocol, global project parameters and boundary conditions are defined. This step includes the definition of the following:

- Infrastructure to be assessed
- Its location
- Climatic and geographic considerations
- Uses of infrastructure.

The goal of this step is to narrow the focus and allow for an efficient data acquisition.

1.3.2. Step 2 – Data Gathering and Sufficiency

Further details regarding the infrastructure and the particular climate effects that are being considered are evaluated in this second project step. The sufficiency of the gathered data due to: i) poor quality; ii) high levels of uncertainties; or iii) lack of data altogether, is assessed. This step further focuses on evaluating and starting initiatives to counter these insufficiencies.

Specifically, Step 2 defines the following for the project:

- Infrastructure components;
- Climate baseline;
- Climate change assumptions;
- Time frame;

- Geography;
- Jurisdictional considerations; and
- Other potential changes that may affect the infrastructure

1.3.3. Step 3 – Risk Assessment

During the risk assessment, the infrastructure's response to climate events is evaluated. The protocol uses a spreadsheet to examine the interaction between the infrastructure and climate events. Therefore, lists are developed of relevant climate events and relevant infrastructure components.

An essential component of Step 3 is the holding of a workshop with the infrastructure operations, management and engineering staff, and other relevant individuals. At the workshop, results of the initial risk assessment are reviewed. The workshop participants then assess the probabilities and severities of the interactions identified. The risk assessment worksheet is then updated based on the input from the workshop participants.

Ideally, participants at the workshop include the following:

- The practitioner team;
- Representatives from the infrastructure management team;
- Representatives from the infrastructure engineering team;
- Representatives from the infrastructure operations team;
- Local expertise/knowledge regarding severe climatic events in the region and climatic events that may have affected the infrastructure;
- Representatives from the organization providing climate information;
- Representatives from any advisory groups or technical experts who may be supporting the vulnerability assessment; and
- Others deemed necessary by the infrastructure owner or practitioner team.

1.3.4. Step 4 – Engineering Analysis

In Step 4, a focused engineering analysis is conducted on the interactions requiring further assessment, as identified in Step 3 (risk assessment). The engineering analysis requires a numerical assessment of:

The total load on the infrastructure, comprising:

- Current load on the infrastructure;
- Projected change in load arising from climate change effects on the infrastructure; and
- Projected change in load arising from other change effects on the infrastructure.

The total capacity of the infrastructure, comprising:

- Existing capacity;
- Projected change in capacity arising from aging/use of the infrastructure; and
- other factors that may affect the capacity of the infrastructure.

One final data availability and quality assessment is carried out. If the data quality or statistical error does not support clear conclusions from this step, the Protocol directs to revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for more robust engineering analysis.

At the end of this step, recommendations based on analysis are made (Step 5) and the need for additional/refined risk assessments is evaluated (Step 3).

1.3.5. Step 5 – Recommendations

Recommendations are developed from the work completed in the previous steps. Generally, the recommendations will fall into five major categories:

- Remedial action is required to upgrade the infrastructure;
- Management action is required to account for changes in the infrastructure capacity;
- Continue to monitor performance of infrastructure and re-evaluate at a later time;
- No further action is required; and
- There are gaps in data availability or data quality that require further work.

Additional conclusions or recommendations may be identified regarding the veracity of the assessment, the need for further work, or areas that were excluded from the current assessment.

1.4. Project Team

The climate change vulnerability assessment was executed by the following BGC project team:

- Jack Seto, M.Sc., P.Eng., P.E.
- Lukas Arenson, Dr.Sc.Techn.ETH, P.Eng.
- Midori Telles-Langdon, B.A.Sc., E.I.T., G.I.T.

In addition to participants of the workshop (see Section 2.10), input was provided by:

- Jenna Craig, Transport Canada
- Nemanja Jevtovic, Transport Canada
- Janice Festa, Transport Canada
- Darren Locke, Government of the Northwest Territories

1.5. Report Layout

The case study has been executed following the process defined in the Protocol. This report describes how the Protocol was implemented and presents the results obtained. Recommendations for the Inuvik Airport are also included. This document is laid out as follows:

- Section 2: Project Definition. Following Step 1 of the Protocol, the infrastructure, climate history and identification of resources are identified.
- Section 3: Data Gathering and Sufficiency. Following Step 2 of the Protocol, more details are presented on the infrastructure parts assessed and the particular climate factors / projections being considered.

- Section 4: Risk Assessment. Following Step 3 of the Protocol, an overview of the risk assessment is described, as are the results of the consultation workshop.
- Section 5: Engineering Analysis. Following Step 4 of the Protocol, the capacity for infrastructure to accommodate projected climate changes is assessed.
- Section 6: Recommendations. Following Step 5 of the Protocol, the results from the previous steps are reviewed and recommendations for further actions are summarised.
- Section 6: Conclusions. Conclusions drawn from the vulnerability assessment are summarized.
- Appendix A: Climate Data Analysis. An analysis for historical and projected climate trends for the Inuvik area.
- Appendix B: Climate Change Vulnerability Matrix for Inuvik Airport following the Protocol.
- Appendix C: Recommendation matrix for Inuvik Airport summarizing measures to be implemented.
- Appendices D and E provide slides of the workshop presentation and a non-technical summary of the work performed, respectively.

2.0 STEP 1 – PROJECT DEFINITION

This section describes the global project parameters and provides background information on the infrastructure, potential climate factors, and boundary conditions of relevance. It also assesses the data sufficiency. This first step is intended to narrow the focus to allow for an efficient engineering vulnerability assessment.

2.1. Permafrost and Infrastructure

Permafrost is defined as ground (soil, peat, rock) that remains below 0 °C for more than two consecutive years (National Research Council Canada, 1988). Within the Canadian context of permafrost distribution, the areas which contain permafrost include alpine regions and northern Canada (Figure 2-1). In the more northerly regions, permafrost is generally continuous over the landscape. Progressing southward, permafrost becomes discontinuous, with a decreasing proportion of the landscape containing permafrost. In the most southerly instances of permafrost, isolated pockets of permafrost are encountered in a landscape largely devoid of permafrost, which is referred to as sporadic permafrost.



Figure 2-1. Permafrost extents in Canada (Natural Resources Canada, 1995).

Factors which influence the distribution and temperature of permafrost include:

- Air temperature, which is in turn influenced by:
 - Latitude;
 - Elevation;
 - Topography;
 - Proximity to water bodies; and

- Weather patterns;
- Thermal properties of the soil or rock;
- Heat required to convert water into ice when freezing (or ice into water when thawing) termed latent heat;
- Presence of insulative material on the ground surface (muskeg, snow, vegetation);
- Presence of infrastructure (e.g., embankment, building foundation type);
- Exposure to convective air movement (i.e., wind);
- Exposure to radiative energy (i.e., direct sunlight);
- The reflective/absorbance of radiative energy due primarily to the color of the surface (light colors reflecting more energy, dark colors absorbing more energy) referred to as the albedo of the surface;
- Vegetation;
- Precipitation; and
- Surface water.

The special and extreme environment requires unique engineering and infrastructure solutions that account for severe climate conditions, presence of potentially ice-rich permafrost and various cryogenic processes. The strength and deformation characteristics of frozen soils are dependent on soil type, temperature, density, ice content, unfrozen water content, salinity, stress state, and strain rate (Arenson et al., 2014). Changes in temperature and in particular the thawing of frozen soil, may lead to significant changes in the strength and deformation characteristics, resulting in accelerated settlement and possible foundation failure.

In consequence, foundation design must include an evaluation of the maximum active layer (seasonal thaw) thickness and permafrost temperature that may occur in the foundation soils during the lifetime of the structure.

2.2. Climate Change Effects on Infrastructure in Permafrost

As outlined by Instanes et al. (2005), the potential effects of increasing mean annual ground surface temperature on permafrost will be very different for continuous and discontinuous permafrost zones. In the continuous zones, increasing air temperatures are very likely to increase permafrost temperatures and possibly increase the depth of the active layer. In the discontinuous zone, the effects of a few degrees increase in the mean annual permafrost temperature are very likely to be substantial (Harris, 1986). Since the temperature of most of this permafrost is presently within a few degrees of the melting point, the permafrost is likely to disappear. However, except for the southernmost zone of sporadic permafrost, many centuries will likely be required for the frozen ground to disappear entirely. But, increases in active layer depths and thawing of the warmest permafrost from the top are already ongoing in response to current warming.

Construction activities on their own affect the surface conditions, and ultimately the ground temperatures due to anthropogenic changes in the insulation cover, snow distribution, hydrology, vegetation and Albedo. The thermal and mechanical response of the foundation to the constructed infrastructure, such as accelerated creep or thaw consolidation, may be very slow.

Additionally, changes in permafrost are induced due to climate change. Due to the superposition of anthropogenic and climate change induced changes in the ground thermal regime and the associated time lags, it may be difficult to clearly identify the source of the induced changes.

If the infrastructure has not been designed to account for potential climate change, it may not have sufficient capacity in the future.

2.3. Identifying the Infrastructure

2.3.1. General Description

This report concerns the Mike Zubko Airport in Inuvik, Northwest Territories. The airport is located 12 km east of the community of Inuvik (Figure 2-2), and was constructed by Transport Canada between 1956 and 1958. The airport has a single asphalt runway (Runway 06/24, 6001 ft (1830 m) long and 150 ft (45 m) wide), and offers daily scheduled flights as well as charter services. The Inuvik Airport is a very important regional hub airport within the NWT - Department of Transportation's airports system that supports both commercial and military flight operations across the Western Arctic. The airport consists of the runway, five taxiways, the commercial buildings and the military base (Figure 2-3).

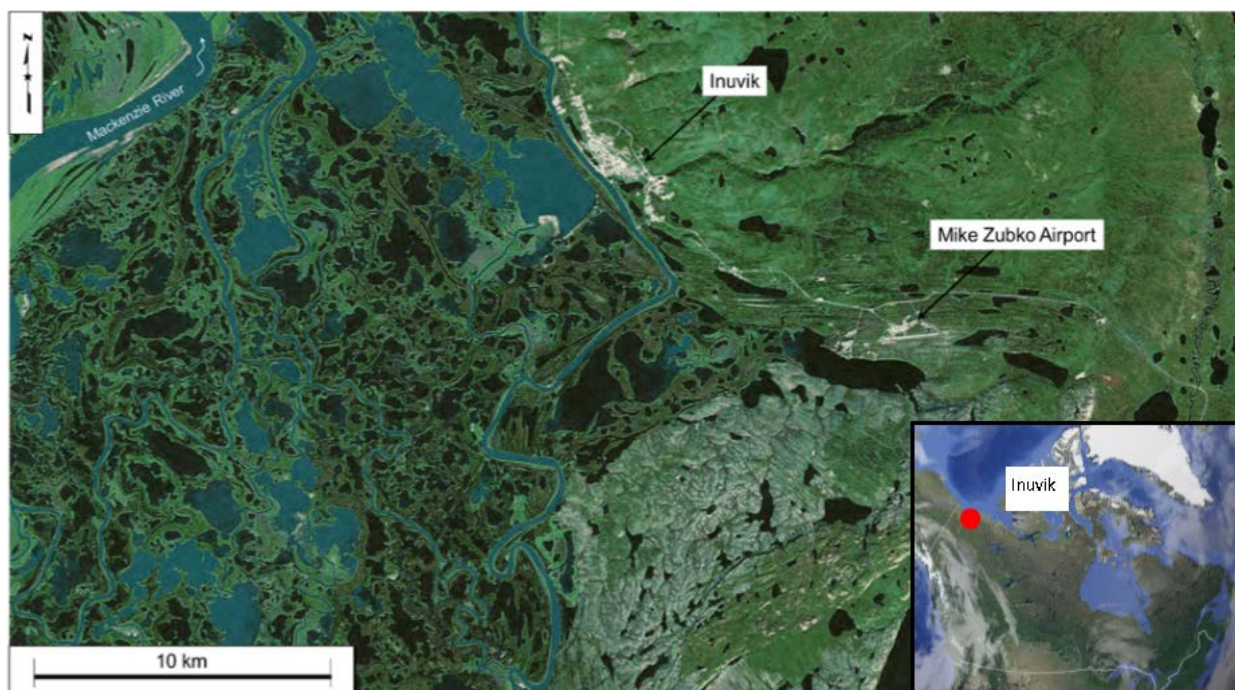


Figure 2-2. Location of Inuvik's Mike Zubko Airport (source: Digital Globe).

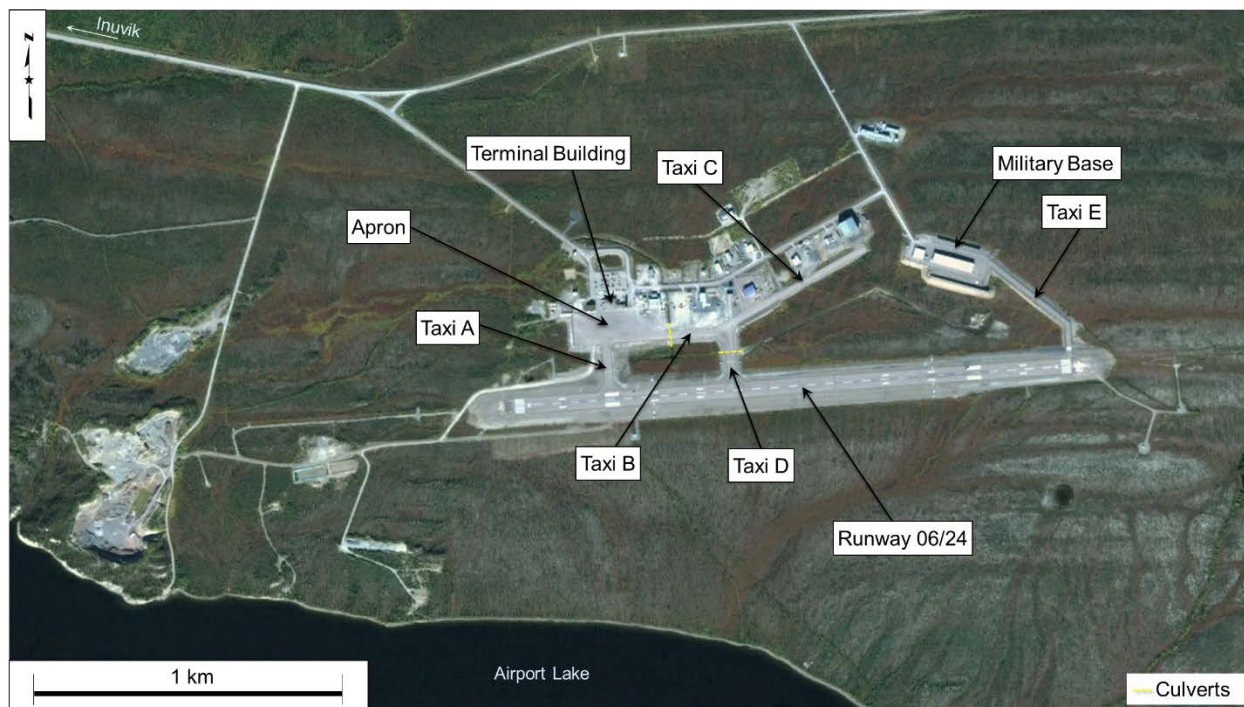


Figure 2-3. Inuvik's Mike Zubko Airport (source: Google Earth, 2007).

Trends in total aircraft movement, defined as aircraft take-offs and landings by Statistics Canada, and passengers are shown in Figure 2-4 below.

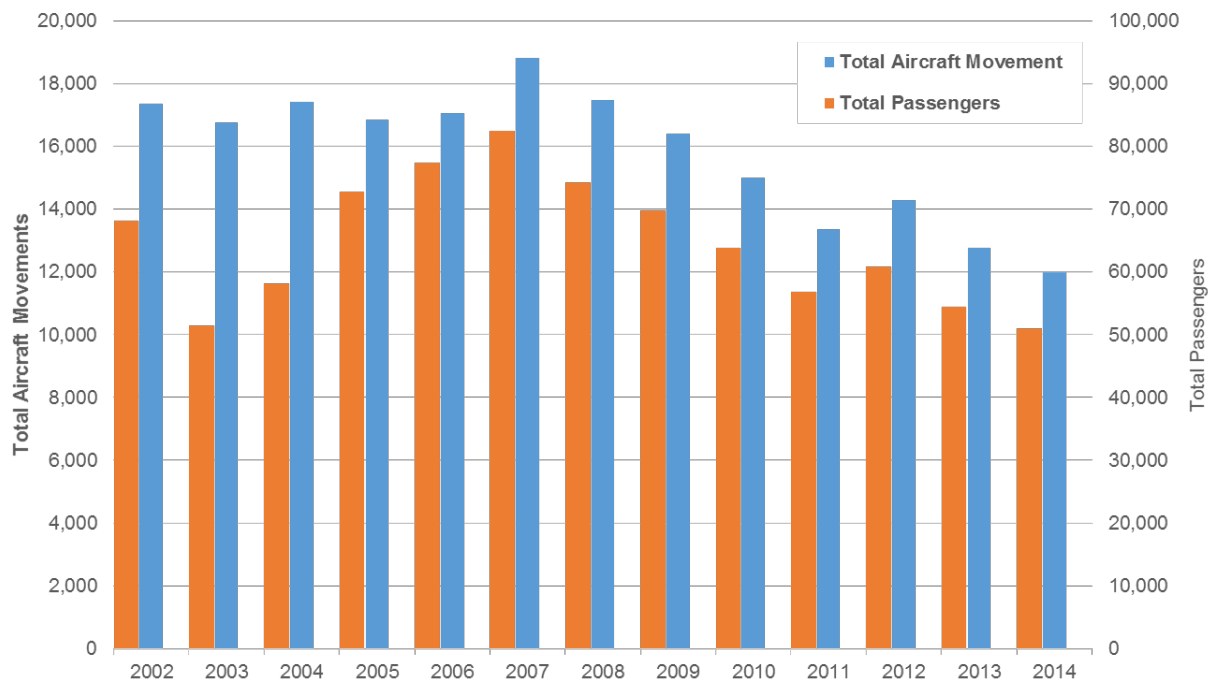


Figure 2-4. Total Aircraft movement and total passengers 2002 - 2014 (Data provided by GNWT).

A 3000 ft (914 m) extension of runway 06/24 is proposed (Figure 2-5) that would support larger aircraft movement in the region, as well as supporting the Royal Canadian Air Force's CC-150T tanker aircraft for extending the range of CF-18 High Arctic missions. The runway expansion would further allow for larger aircraft to land safely in adverse conditions (rain, ice, mechanical failures).

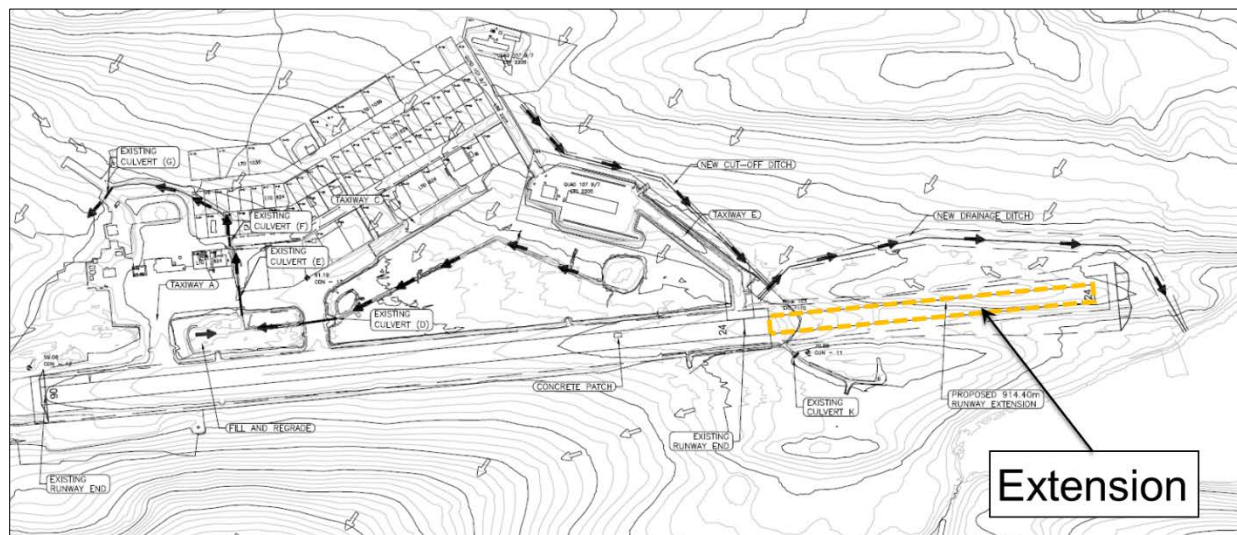


Figure 2-5. Layout of Inuvik's Mike Zubko Airport including proposed runway extension.

2.3.2. Site Description

Inuvik is located about 200 km north of the Arctic Circle and nearly 100 km south of the Beaufort Sea. The population is 3,463 (2011 Census), which is the second largest community of the Northwest Territories. The Inuvik Airport is located on morainal deposits composed of till veneer over bedrock and associated gravel and sand, varying in thicknesses of 2 to 5 m thick (Rampton, 1987). The terrain slopes gently to the south towards Dolomite Lake (also known as Airport Lake), which forms part of the southern boundary of the airport property and is located approximately 1000 m south of the terminal. The terrain is locally overlain by fluvial, lacustrine and organic deposits (Tunncliffe and Burn, 2011; Tetra Tech EBA, 2014). The low topographic gradients result in poor drainage and potentially intermittent flow. As reported in Tetra Tech EBA (2014), streams flow into a wide wet area and reappear further down-gradient in some areas.

The entire site is located on continuous permafrost with high ground ice content (>20%) in the upper 10 to 20 m of the ground (Figure 2-1; Natural Resources Canada, 1995). To prevent thawing of underlying permafrost, a runway embankment with a gravel surface would be required to be at least 3.6 m thick, and a runway embankment with an asphalt surface would be required to be at least 4.2 m thick (Johnston, 1974). However, at the time of construction, these requirements were considered too costly, particularly since an asphalt surface would not be constructed for several years. Any potential thawing or surficial settlement could be remediated by regular maintenance of the gravel surface (Johnston, 1982). In the end, embankments were designed with a thickness ranging from 2.4 m to 4.2 m and averaging 3.0 m (Johnston, 1974).

Originally designed to be 1,520 m long in 1957, the runway was extended to the current length of 1,830 m in 1958. Run of quarry rock fill was used to construct the embankment, and a 230 mm thick layer of 40 mm crushed gravel was placed as a surface layer. The apron was enlarged and surfaces paved in 1969. Between 1970 and 1974 approximately 0.5 m of settlement occurred at the intersection of the apron and Taxiway A and was attributed to impeded drainage through the fill. As mitigation, additional fill was placed and a drainage ditch was constructed (Hoeve and Hayley, 2015).

Structural problems with the runway that have been noticed by airport staff include differential settlement, sudden subsidence, sloughing, ponding and drainage issues. Hoeve and Hayley (2015) reported the two following main issues developing between 2005 and 2010:

- Subsidence above an infilled thermokarst pond on the north side of the runway, approximately 300 m from the east end (Figure 2-6).
- Settlement on Taxiway E at the intersection with the runway, where the infrastructure was blocking the natural surface drainage. In 2008, mitigation methods, including installation of insulation and construction of a concrete pavement, were implemented.



Figure 2-6. Runway 06/24 subsidence (Tetra Tech EBA, 2013).

Airport maintenance staff noted the presence of the previously unidentified subsidence approximately 12 metres north of the runway centreline and 325 metres west of the east end of the runway on September 19, 2013 (Tetra Tech EBA, 2013). Within hours the initial subsidence had developed into a depression approximately 20 cm deep, several meters wide and 5 to 10 metres long. When the settlement was surveyed on September 24, 2013 it had settled further with the deepest point of the depression being approximately 0.5 m (Figure 2-6). The pavement surface had not cracked, but was pulling apart at pre-existing seams and thermal cracks. The

only flight affected was Canadian North (Boeing 737-200) flight from Yellowknife that Wednesday afternoon (CBC, 2015).

2.3.3. Elements of Infrastructure Assessed

An overview of the infrastructure elements considered in the vulnerability assessment is provided below. Detailed descriptions and rationales for the sub-component grouping can be found in Section 3.1.

- Physical Components
 - Runway
 - Taxiways (A, B, C, D, E)
 - Apron
 - Drainage System
 - Access Roads
 - Service Roads
 - Heterogeneity in Natural Foundation/Permafrost
- Supporting Infrastructure
 - Operation and maintenance personnel
 - Snow clearing
 - Crack filling
 - Winter flight operation
 - Summer flight operation
 - Winter maintenance
 - Summer maintenance
 - Lighting systems
 - Surface markings and signals
 - Weather station
 - Environmental monitoring
 - Nav aids
 - Vegetation
 - RCAF BAK-12 Aircraft Arresting System (ARS) for CF-18 interceptors
 - Security systems
 - Data availability
- Others
 - Emergency procedures and Medevac
 - Wildlife
 - Future development/Airport Master Plan

2.3.4. Data Sources

The following technical documents were available for the Inuvik Airport and provided by the GNWT:

- Drainage Improvements Study by Stantec, June 18, 2014.
- Reduced Graded Area at the Inuvik Mike Zubko Airport, Hazard Identification, Risk Assessment, and Control (HIRAC) by DOT, May 29, 2014.
- Integrated Geophysical Methods Applied to Geotechnical and Geohazard Engineering by Koichi Hayashi, 2014.
- Integrated multi-instrument geophysical surveys of permafrost conditions under a runway, Inuvik, NWT, Canada by Koichi Hayashi, Jon Tunnicliffe, Alex Becker, Patrick Finlay, Lothar Schrott, and Chris Burn, 2011.
- Initial Summary, Geophysical Survey, Settlement Location, North of Centreline Approximate Drainage Technical Memo by EBA Engineering Consultants, September 30, 2013.
- “Our Surfaces” Presentation by DOT Division.
- 400-1506.dwg, most recent Inuvik Airport contour data with some planimetric and electrical data.

Note: Operational records were not available that would allow to correlate weather interruptions or longer down times with specific infrastructure components.

2.4. Identifying Climate Factors

Weather data from meteorological station Inuvik A, operated by Environment Canada were used. Station Inuvik A (IATA ID YEV) is located just south of the Inuvik airport. Daily records for this station date back to 1958. The mean annual air temperature for the climate normal period of 1981-2010 is -8.2 °C, with July typically being the warmest month and January the coldest. Average daily air temperatures remain above freezing from May to September. Inuvik experiences on average 240 mm of precipitation in a year, with the majority of precipitation falling from July to October. Snowfall occurs between the months of September to May, with occasional snowfall during June and August. The climate normals for Inuvik over the period of 1981 to 2010 are summarised in Figure 2-7, and Table 2-1 to Table 2-3.

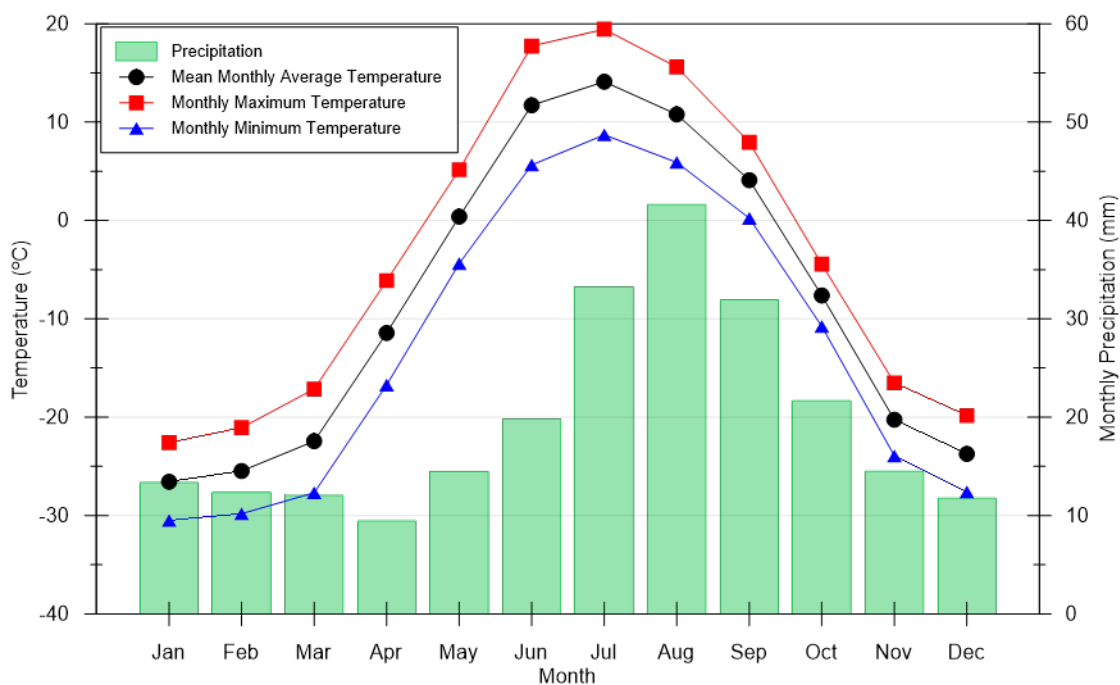


Figure 2-7. Mean monthly air temperature and precipitation totals, Inuvik (1981-2010) (Environment Canada, 2016).

Table 2-1. Average annual climate conditions, Inuvik (1981-2010) (Environment Canada, 2016).

Parameter	Value	Parameter	Value
Daily Average Temperature	-8.2 °C		
Daily Maximum Temperature	-3.5 °C	Daily Minimum Temperature	-12.9 °C
Rainfall	114.5 mm	Snowfall	158.6 cm
Precipitation	240.6 mm		
Wind Speed	9.4 km/hr	Most Frequent Direction	East
Average Station Pressure	100.7 kPa		

Table 2-2. Thawing and freezing days, Inuvik (1981-2010) (Environment Canada, 2016).

Degree Days:	> 24 °C	> 18 °C	> 15 °C	> 10 °C	> 5 °C	> 0 °C
	0.4	25.3	87.1	323	754.5	1365.3
Degree Days:	< 0 °C	< 5 °C	< 10 °C	< 15 °C	< 18 °C	
	4331.6	5546.7	6941	8530.9	9564.6	

Table 2-3. Visibility and cloud cover, Inuvik (1981-2010) (Environment Canada, 2016).

Hours with Visibility:	< 1 km	1 to 9 km	> 9 km
	80	887.4	7798.6

Hours with Cloud Cover:	0 to 2/10	3/10 to 8/10	8/10 to 1
	2464	1619.9	4682.1

Appendix A presents a more detailed analysis of the historical climate records and climate projections for the Inuvik area. The following lists the potential change factors associated with each climate element considered in the vulnerability assessment:

- Air Temperature
 - Rate of change
 - Mean values
 - Extremes (highs during summer/lows during winter, incl. duration)
 - Freezing and thawing indices
- Ground Temperature
 - Rate of change
 - Freezing and thawing indices
- Frost
 - Freeze/thaw cycles
- Rainfall
 - Frequency
 - Duration
 - Intensity
 - Total annual/seasonal
 - Rain on snow
 - Freezing rain
- Snowfall
 - Frequency
 - Duration
 - Total annual
 - First/last snow day
- Wind
 - Gusts
 - Directional
 - Seasonal
- Storms
 - Blizzards/White-outs
 - Ice storms
 - Hail
 - Lightning/electrical storms
- Wildfires
- Visibility

- Fog
- Cloud cover/solar radiation
- Cloud ceiling height

2.5. Climate Extremes

There has been a steady decrease in the number of extreme cold days ($<35^{\circ}\text{C}$) and an increase in the number of warm days ($>25^{\circ}\text{C}$). The increase in number of warm days on started in recent years, whereas the decrease in the number of cold days started in the 1980'ies.

No trend has been identified in the number of extreme snowfall or rainfall event, nor wind directions and wind gusts.

2.6. Identifying Time Factors

This project identifies climate projections from 2015 to 2045, a 30-year projection. This time frame was decided upon by the project team as a suitable planning time frame for airport decision makers.

2.7. Permafrost Conditions

The Inuvik Airport is located in an area of ice-rich permafrost. The thickness of permafrost in the area is approximately 90 m (Burn et al., 2009). The site is underlain by varying thickness of organic material (0.1 to 2.4 m), brown silt, and silty gravel. Site investigations completed prior to construction of the airport reported active layer thickness ranging from 0.45 m to 1.20 m. Below the active layer, occasional ice lenses and masses 0.15 m to 0.4 m in thickness were observed in the organic layer. At the top of the silt unit, layers of ice ranging up to 0.6 m thickness were observed. Ice contents were generally low in the underlying silty gravel. Ground temperature monitoring from 1958 to 1974 showed that the permafrost table initially aggraded 0.6 m into the embankment fill following construction. Mean ground temperatures at a depth of 4.6 m beneath the runway (the maximum depth instrumented) were -5.0°C to -5.5°C (Johnston, 1974).

Tunncliffe et al. (2011) discuss geophysical surveys performed at the site using three different geophysical instruments: ground penetrating radar (GPR), capacitively-coupled resistivity (OhmMapper), and multichannel analysis of surface waves (MASW). Surveys were performed along the runway, taxiway A, and the Forward Operating Location (FOL) taxiway. These surveys showed a clear area where subsidence occurred at the 1000 ft. marker on the north edge of the runway (Figure 2-8), consistent with site observations noted in Section 2.3.1.

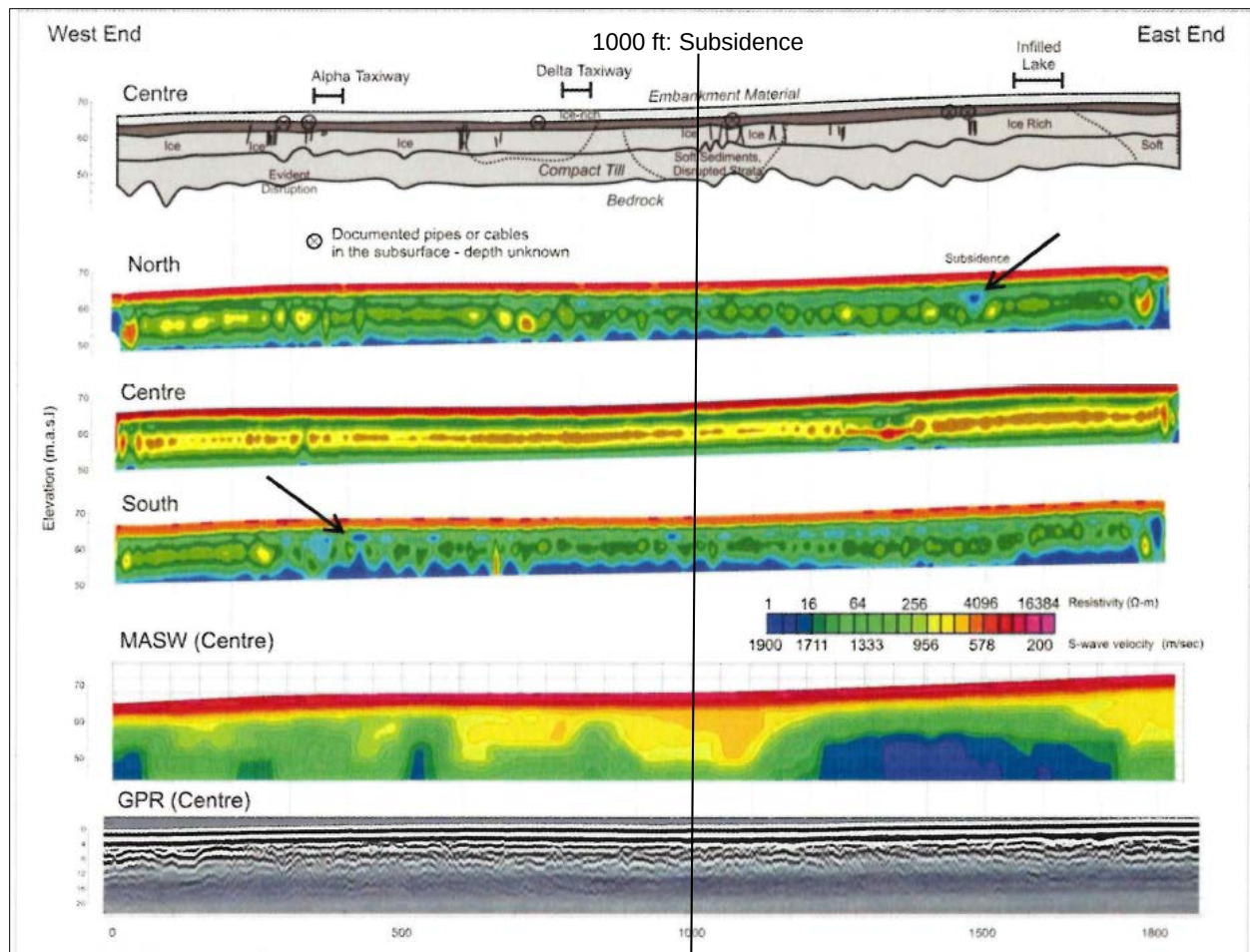


Figure 2-8. Ohm mapper, MASW and GPR processed survey records, running from West to East (Turniccliffe et al., 2011).

More recently, Hoeve and Hayley (2015) present ground temperature profiles for six months of thermistor data collected in 2014 along the edge of the runway (Figure 2-9). These data show ground temperatures at a depth of 10 m below grade ranging from -1.0°C to -1.4°C.

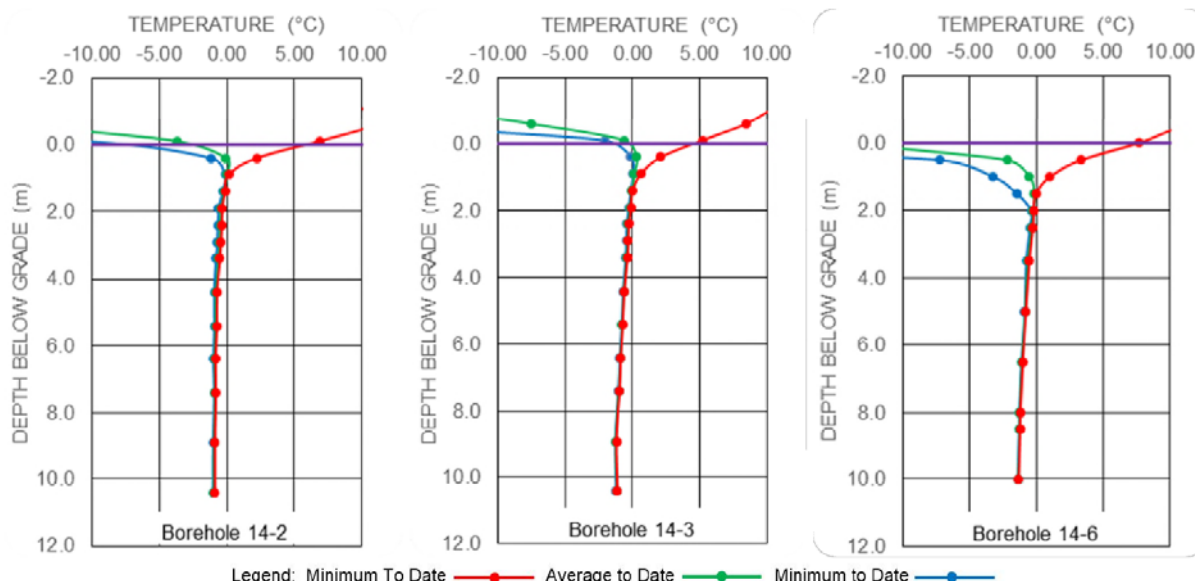


Figure 2-9. Ground temperature profiles for the edge of the runway, data collected in 2014 (Hoeve and Hayley, 2015)

2.8. Identifying Jurisdictional Considerations

The agencies with jurisdiction include Transport Canada and the Government of Northwest Territories, Department of Transportation. Information on the standards used for initial design of the various components was not available for the assessment.

The following standards have been considered:

- Transport Canada: Aerodrome Standards and Recommended Practices, TP312 4th Edition, March 1993.
- ICAO Annex 14, Aerodromes, Volume I - Aerodrome Design and Operations, 6th Edition.
- National Standard of Canada CAN/CSA-S503-15. Community drainage system planning, design, and maintenance in northern communities, January 2015.
- National Standard of Canada CAN/CSA- S501-14. Moderating the effects of permafrost degradation on existing building foundations, December 2014.

2.9. Assessment of Data Sufficiency

2.9.1. Infrastructure Data

Infrastructure data and technical documents, including runway layout and infield topography, were provided to BGC by the Government of the Northwest Territories Department of Transportation. However, no specific information on the current conditions were available that would allow to assess how far into the life cycle the components are. Nevertheless, the data are considered sufficient for the assessment.

2.9.2. Climate Data

Climate data used for design and input into climate change predictions are based on the historical observations from the Environment Canada climate station at Inuvik Airport. Daily recorded data from January 1958 to December 2014 was used in the assessment. Some data gaps exist, notably rainfall and snowfall data for the period from 2008 to 2014, and wind data for the period from 1997 to 2007. Reasons for the missing data are unknown.

2.9.3. Subsurface Data

Subsurface and permafrost data was collected from various sources including published reports from the Geological Survey of Canada on permafrost monitoring in the Mackenzie Corridor and site specific studies performed in 1974 (Johnston, 1974). Hoeve and Hayley (2015) provide ground temperature profile data collected from boreholes along the edge of the runway. Tunnicliffe et al. (2011) presents cross sections developed from multi-instrument geophysical surveys of the runways and taxiways.

2.10. Summary of Risk Assessment Workshop

A risk assessment workshop was held at the Mike Zubko Airport from July 22nd to 24th, 2015. The purpose of this workshop was to collect information regarding the condition of airport infrastructure and discuss potential and previous issues with this infrastructure. The end product of these discussions was a draft risk assessment matrix, presented in the memo entitled, Inuvik Airport PIEVC Risk Matrix: Draft for Review, submitted to TC on August 25th, 2015.

The workshop sessions included participants from the Government of Northwest Territories Department of Transportation, Transport Canada, National Defense Canada, and Engineers Canada. The following people attended and participated in the workshop (location of primary residence in parentheses):

- Transport Canada:
 - Jenna Craig (Ottawa)
 - Nemanja Jevtovic (Ottawa)
 - Janice Festa (Ottawa)
 - Luc-Alexandre Chayer (Ottawa)
- Engineers Canada: Guy Felio (Ottawa)
- Government of Northwest Territories:
 - Darren Locke (Yellowknife)
 - Patrice Ngu Ndiangang (Inuvik)
 - Gurdev Jagpal (Inuvik)
 - Jason MacNail (Inuvik)
 - Terry Brookes (Yellowknife)
 - Ted Nestor (Yellowknife)
- National Defense Canada: Lance Gelinas (Winnipeg)

- BGC Engineering Inc.: Lukas Arenson (Vancouver)

During discussions with the participants, the following concerns regarding operation and maintenance of the airport were raised:

- Frost on the runway surface;
- Drainage conditions, in particular beneath the Apron and Taxiway C;
- Increased variability in weather conditions; and
- Major structural problems related to the dip in the runway (sinkhole), which is thought to be related to thawing of the ice rich permafrost foundation, and which is currently being repaired by improving drainage conditions.

The workshop was divided into five sessions: introduction, site visit, climate parameters, infrastructure components, and summary. The focus of the sessions was to discuss and assign probabilities (P) for a number of climate events that affect infrastructure components and then to assign severities of the consequences (S) to these climate events on the infrastructure components. Both parameters were assigned a value of 0 to 7, with the lower values representing low probability / consequence and the higher values representing high probability and severe consequences, in accordance with the PIEVC Protocol. The risk, R, is computed as the product of the probability and the severity. The values discussed during the workshop were incorporated into an initial risk matrix delivered for review. Feedback received on the initial risk matrix was incorporated into the final version of the matrix presented in this report.

3.0 STEP 2 – DATA GATHERING AND DATA SUFFICIENCY

The goal of this step was to narrow the infrastructure components and relevant climate parameters to make the risk assessment more efficient, and to assess the sufficiency of these data with respect to the climate change vulnerability.

3.1. Infrastructure Components

The infrastructure was grouped into components that are considered as a structural unit in its capacity and response to changes in the climate conditions. For example, the drainage system was not disassembled into individual components, such as culverts, ditches or ponds during the initial stage of the vulnerability assessment. If a component (or system) is highlighted as being of medium or high risk, an in-depth assessment that looks at individual elements of that particular component would be carried out.

3.1.1. Physical Infrastructure

The physical infrastructure considered includes:

- Runway
- Taxiways
- Apron
- Drainage System
- Access and Service roads
- Heterogeneity in natural foundation and permafrost conditions

For the runway, taxiways and apron the sub-elements considered are surface/pavement, base/subbase (fill), subgrade, and foundation (natural). In addition, structural aspects, including stability, runway friction, surface roughness and deflections are considered in the assessment.

The drainage system considerations include culverts, ditches, and ponds. For the assessment, the capacity of the drainage system to safely convey water so that it does not impact the structural stability of the infrastructure or its functionality is assessed.

3.1.2. Supporting Systems/Infrastructure

Supporting infrastructure components include the following elements:

- Operation and maintenance personnel
- Snow Clearing
- Crack Filling
- Winter Flight Operation
- Summer Flight Operation
- Summer Maintenance
- Winter Maintenance
- Lighting Systems
- Surface Marking and Signals

- Weather Station
- Environmental Monitoring
- Nav aids
- Vegetation
- RCAF BAK-12 Aircraft Arresting System
- Security Systems
- Data availability

Comments related to maintenance elements and other supporting elements that are either non-structural or have a supporting role are provided in Table 3-1 and Table 3-2, respectively.

Table 3-1. Overview of maintenance elements.

Element	Comments
Operation and maintenance personnel	Availability and qualifications of airport operations and maintenance personnel
Winter flight operation	General airport operations during winter
Winter maintenance, including snow clearing	Maintenance activities required for safe operation during winter
Summer flight operation	General airport operations during summer
Summer maintenance, including crack filling and surface markings	Maintenance activities required for safe operation during summer

Table 3-2. Overview of supporting systems and infrastructure.

Element	Comments
Environmental Monitoring	Additional environmental monitoring, such as reports on glycol use (used by airlines for de-icing)
Lighting Systems / Nav aids	Consider lighting systems, including navigational aids such as instrumented landing systems and windsock, required for safe operation
Security Systems	Components required to maintain security for safe operation, such as fences and gates
Data Availability	Quality and quantity of data available for a satisfactory evaluation of climate related vulnerabilities

3.1.3. Other

Other elements considered include:

- Emergency Procedures and Medevac
- Wildlife
- Future Developments/Airport Master Plan

3.2. Performance Response

Performance response factors were identified to assess the potential impact of climate change effects on the infrastructure components. The performance response categories selected for this assessment are summarised in Table 3-3.

Table 3-3. Performance response considerations.

Performance Response	Description
Structural Design	Conformity to the original structural design of the infrastructure and potential risk of failure.
Functionality	The ability to keep up the state of repair required to ensure a specified level of service of infrastructure.
Serviceability	The ability of infrastructure to fulfil its intended purpose.
Watershed, Surface Water & Groundwater	The risk of impacting the original hydrology and water cycle in a significant way
Operations, Maintenance & Materials Performance	The effort required to provide a specified level of service for infrastructure.
Emergency Response	The risk of interference with the use of infrastructure in the provision of emergency response services (incl. Medevac).
Economic Considerations	The financial impacts (both public and private) resulting from changes in the functionality of infrastructure of interest.
Policy Considerations	Changes in methods or standards used to design, construct, operate, or maintain the infrastructure.
Social Effects	Impacts on social and socioeconomic aspects resulting from changes or complete loss in the functionality of, or the operations and maintenance efforts associated with the infrastructure.
Environmental Effects	The environmental impacts resulting from changes in the functionality of, or the operations and maintenance efforts associated with the infrastructure.

3.3. Climate Baseline

At the time of airport construction, weather records from the community of Aklavik, located 55 km west of Inuvik, were used to estimate climate conditions for design. The mean annual air temperature was estimated to be -9 °C with a thawing season of approximately 140 days. The average wind speed was estimated to be 14 km/hr (Johnston, 1974). Dominant wind direction at the Inuvik Airport at the time of design was N and NE at the time of construction.

3.4. Climate Change Assumptions

Environment Canada's climate station at the Inuvik Mike Zubko Airport shows a clear trend of increasing air temperatures and decreasing precipitation over the past 56 years (1958-2014). Mean annual air temperatures have increased by 0.8 °C per decade over the past 30 years. The warming has occurred mostly during the fall and winter, with spring and summer temperatures

remaining relatively stable. Conversely, average annual precipitation totals have been decreasing by about 10 mm per decade, with the largest decline occurring during the winter. Modest declines in precipitation are evident in the spring and fall, while an increase in summer precipitation has been observed.

A detailed analysis of the historical climate record for Inuvik Airport is provided in Appendix A. Also contained in the appendix is an overview of climate change projections for the Inuvik area based on regional climate models. The following section summarizes the climate elements potentially impacting the vulnerability of the airport infrastructure (Table 3-4), the relevant historical climate trends (Table 3-5), and the projected climate changes for the Inuvik area (Appendix A).

Table 3-4. Climate Effects and potential change factors and impacts.

Climate Element	Potential Change Factor	Affected Infrastructure and Potential Impacts
Air Temperature	• Rate of change • Mean values • Extremes (high summer/low winter) • Freezing and thawing indices	Ground temperatures are strongly influenced by air temperatures. The depth of influence depends on the period (freezing / thawing degree-days), with daily temperatures affecting the runway surface, seasonal temperatures affecting the top of the foundation soils and long-term (annual, decadal) trends influencing ground temperatures at depth (typically 10 m depth and greater). Ground temperature changes that can cause frost heaving or permafrost thaw may result in embankment instabilities through differential movements, shoulder rotation, or sloughing. The majority of infrastructure founded on permafrost soils is influenced by changes in seasonal and longer-term air temperature trends.
Ground Temperature	• Rate of change • Freezing and thawing indices	Similar effect to air temperature changes. In warm permafrost environments, long-term trends (rate of change) in ground temperatures differ from changes in air temperature because of latent heat effects at the permafrost table.
Frost	• Freeze/thaw cycles	Frost is strongly related to air temperatures. However, elements such as the runway surface or culverts can be structurally affected by changing number in frost cycles due to deformations associated with the volumetric changes when water freezes to ice and vice-versa. Freeze-thaw cycles can affect runway friction and surface roughness. It may further affect runway puddling and therefore require more maintenance. Inuvik airport does not have a specific de-icing bay or a Central Deicing Facility (CDF). De-ice procedure is to taxi to the west side of the apron adjacent to taxiway A where de-icing is undertaken prior to re-start and taxi for departure.

Climate Element	Potential Change Factor	Affected Infrastructure and Potential Impacts
Rainfall	- Frequency - Duration - Intensity - Total annual/seasonal - Rain on snow - Freezing rain	Rainfall affects the surface hydrology and, to a lesser degree, the ground thermal regime. Intense rain events may exceed the design flow capacities for culverts and ditches, resulting in water ponding and flooding of infrastructure. Water that accumulates to develop ponds could form a heat sink that alters the geothermal regime. Water ponding on the runway can result in aquaplaning and create unsafe conditions for take-off and landing. Freezing rain is a significant hazard to aircraft as it may reduce runway friction and surface roughness. Rain on snow events may cause floods and hazards.
Snowfall	- Frequency - Duration - Total annual - First/last snow day	Snow storms reduce visibility and affect maintenance and operation of the airport. Furthermore, thick snow cover acts as a thermal insulator, preventing cold winter air temperatures from penetrating the ground and resulting in ground warming. On the other hand, reduced snow cover could result in ground cooling. Total annual snow accumulation may further influence drainage conditions and culvert capacities during freshet.
Wind	- Gusts - Direction - Seasonal	Wind affects safe approaches for airplanes, i.e. main airport operations all year. It also influences the maintenance and operation of the airport by causing disruptions to flights, visibility issues, and wind-swept debris. Snow drifts may further affect ground thermal conditions across the road embankment by reducing the insulating snow cover on one side slope and thickening the layer on the other.
Storms	- Blizzards/White-Outs - Ice storms - Hail - Lightning/Electrical storms	Storms affect operation and maintenance of the airport through disruption to flights, visibility issues, and potential damage to vital infrastructure. In northern communities, airport shutdowns may have major social and economic impacts since air traffic may be the only means of transportation and provides vital connections to other communities.
Visibility	- Fog - Cloud cover/solar radiation - Cloud ceiling height	Changes in weather effects to visibility such as fog, cloud cover, and cloud ceiling height can cause disruptions to flights and other airport operation issues.
Wildfires	- Frequency - Intensity	Wildfire significantly affect visibility and cause disruptions to flights and other airport operation issues, including impacts on permafrost.

Table 3-5. Historical climate trends, Inuvik (1985-2014).

Climate Element	Best-Fit Linear Trends
Air Temperature	• Mean annual air temperature is increasing 0.8 °C per decade • Rate of warming is greatest in winter and fall • Extreme cold days occur most frequently from January and February and extreme warm days occur most often in July and August.
Freezing and Thawing Indices	• Freezing index decreasing by 215 degree-days per decade • Thawing index increasing by 16 degree-days per decade
Freeze/Thaw Cycles	• Annual freeze/thaw cycles are decreasing by about 4 cycles per decade • Fall freeze/thaw cycles are decreasing more rapidly than spring freeze/thaw cycles
Rainfall	• Annual rainfall is decreasing by 25 mm per decade • The rate of decrease is highest in summer and lowest in winter • Heavy rainfall events occur most frequently during July and August
Snowfall	• Annual snowfall was stable until the mid-1990's but was decreasing by about 60 cm during the last decade • Significant annual variability in total snowfall • The rate of decrease is consistent in spring, winter, and fall
Snow Depths	• Snow depths are increasing in April and May, and decreasing in November, December, and March
First/Last Snow Day	• First snow days are occurring later in the season • Last snow days show no statistically significant trend
Wind	• No statistically significant trend

3.5. Changes in Climate Parameters

Detailed description on climate change projections and assumptions used are provided in Appendix A. Climate change projections were estimated using the CanESM2 and CanRCM4 models in the RCP4.5 and RCP8.5 experiments, respectively². For the Inuvik area, all models show an increase in air temperature of about 3 °C by 2045 compared to the 1986-2005 average daily air temperature. The models differ more for the projected changes in precipitation. Depending on the scenario and the model, mean precipitation rates are expected to increase by 5 – 20% by 2045, which is contrary to the recent historical long-term trends.

A level of confidence (High, Medium, and Low) was assigned to each parameter listed below, based on a combination of observed trends, projected trends, and observations from locals as discussed during the workshop. The assignment is mainly based on data availability for climate model calibration and historic trends.

² Canadian Centre for Climate Modelling and Analysis(CCCma):
<http://ec.gc.ca/ccmac-cccma/default.asp?lang=En&n=4596B3A2-1>

3.5.1. Air Temperature

With regards to air temperatures, trends in the mean annual air temperatures as observed in recent history and projected in the near-future (i.e., next thirty years) are considered to not significantly affect airport infrastructure and operations. However, other parameters related to air temperatures are more significant for the assessment. Those are briefly discussed in Table 3-6.

Table 3-6. Climate parameters related to air temperatures.

Parameter	Comments and expected trends	Confidence
Maximum Air Temperature	Increase in the maximum air temperature as well as an increase in the frequency of extreme warm air temperatures	M
Minimum Air Temperature	Decrease (warming) in extreme cold air temperatures and decrease in the occurrence of extreme cold air temperatures	M
Freezing Index	Decrease in degree days, i.e., warming in winter	H
Thawing Index	Increase in degree days, i.e., warming in summer	H
Freeze – Thaw Cycles	Increase in the number of freeze-thaw cycles per season	M
Heat Waves	Increase in extended periods of warm air temperature	L
Cold Waves	Decrease in extended periods of cold air temperature	L

3.5.2. Frost

Maintenance staff at the airport indicate that increased effort has been required to control frost on the runways. The climate data available from Environment Canada do not provide sufficient evidence that would confirm or disprove the local observations. A medium confidence for this trend is used herein.

3.5.3. Precipitation

Climate parameters related to precipitation are listed in Table 3-7.

Table 3-7. Climate parameters related to precipitation.

Parameter	Comments and expected trends	Confidence
Rainfall Frequency	More frequent rainfall events	M
Rainfall Duration	Duration of rainfall events increase	M
Rainfall Intensity / Storms	The intensity of the rainfall increases	M
Rainfall in Fall	Increased number of rain days in fall	L
Freezing Rain	Increase in days of freezing rain	M
Rain on Snow	Increase in rain on snow events during the winter months	M
Total Snowfall	Increase in total amount of snow during the winter	L

Parameter	Comments and expected trends	Confidence
Snowfall Duration	Duration of snowfall events increase	M
Snowfall Frequency	More frequent snowfall events	M
First Snow Day	Snow starts staying on the ground later in the year	L
Last Snow Day	Snow has completely thawed earlier in the year	L
Blizzards / White-outs	Increase in the number of blizzards	L
Ice Storms	Increase in the number of ice storms	L
Hail	Increase in the number of hail events	L

3.5.4. Others

Additional climate parameters that are included in the assessment are summarized in Table 3-8.

Table 3-8. Other climate parameters.

Parameter	Comments and expected trends	Confidence
Wind Gusts	Increase in the velocity (strength) of wind gusts	L
Wind Direction	Change in predominant wind directions	L
Wind in Winter	Change in wind regimes (strength and direction) during the winter months. Winter conditions are separated from the rest of the year as it impacts snow drift	M
Ground Freezing Index	Decrease in degree days, i.e., ground temperature increase in winter	H
Ground Thawing Index	Increase in degree days, i.e., ground temperature increase in summer	H
Cloud Cover	Decrease in cloud cover and increase in solar radiation	L
Cloud Ceiling Height	Decrease in cloud ceiling height	L
Fog / Visibility	Increase in days with fog and decrease in visibility	L
Lightning / Electrical Storms	Increase in lightning activity (thunderstorms) and electrical storms	L
Flooding	The airport is located at an elevation where flooding will not affect the infrastructure.	-
Forest Fires	Airport infrastructure is located predominantly on tundra such that forest fires are not expected to directly affect the physical infrastructure.	-

3.5.5. Wildfires

Wildfires have been reported in the Inuvik area, but no records are available that would provide evidence of significant changes in wildfires close to the airport. However, Sanford (2015) showed clear evidence for a dramatic increase in wildfires in Alaska since 1990. As such a medium level of confidence was selected for the assessment.

3.5.6. Climate Variability

The annual changes in various climate parameters seems to have increased and based on input from locals, seasonal weather has become less predictable. Therefore, it seems that the variability in the climate parameters listed above has increased (Medium Confidence).

3.5.7. IDF Curves

The online IDF CC Tool, developed at the University of Western Ontario, was used to assess IDF climate change projections. Results provided in Appendix A show that for the RCP4.5 scenario, the historical IDF curve falls within the range of projected IDF, and for the RCP8.5 scenario, the historical IDF curve falls at the lower bound or below the predictions.

3.6. Historical Climate Extremes

Often it is not the overall trend or the average conditions that influences infrastructure performance, but the extreme climate event. The historical trends and potential changes of these events, as presented in Appendix A, can be summarized as follows:

- Decrease in the number of extreme cold days ($\leq -35^{\circ}\text{C}$).
- No significant change in extreme warm days ($\geq 25^{\circ}\text{C}$).
- A decreasing trend in the number of days with rainfall of more than 10 mm is noted over the last 30 years.
- The maximum number of intense rainfall days ($\geq 10\text{ cm}$) occurs in the months of July and August.
- A decreasing trend in the number of days with snowfalls of more than 10 cm is noted over the last 30 years.
- Large snowfall days ($\geq 10\text{ cm}$), most frequently occurs during the month of October.
- No long-term trend is noted for changes in the number of freezing precipitation days.
- Freezing precipitation days most frequently occurs during the month of October.
- No trend data for rain on snow events are available. These events most frequently occur in May.
- The most “strong wind days” occur in the months of January and December.

3.7. Time Frame

A fixed 30 year time frame (2045) was chosen for this analysis (see Section 2.6).

3.8. Geography & Permafrost

Geography considerations are identified in Step 1 (see Section 2.3.1). Permafrost conditions are identified in Section 2.7.

3.9. Jurisdictional Considerations

Agencies and departments at the federal, provincial and municipal levels have jurisdictional control and influence on various elements / sections of the airport. These are identified in Step 1 (see Section 2.8).

3.10. Potential Changes that May Affect the Infrastructure

In addition to the climate-related effects, the runway, taxiways, and aprons are subjected to other loads that may affect its performance (Table 3-9).

Table 3-9. Potential changes that may affect the airport infrastructure.

Change	Comments
Travel Frequency	As number and frequency of flights to the airport increases more wear and tear of infrastructure components may occur.
Aircraft Type	Changes in the type of aircraft serving the airport, both civil and military, may impact the wear and tear on infrastructure components.
Aging	Regular aging of the infrastructure is ongoing and may affect performance.
Runway Expansion	Proposed runway expansions would affect existing infrastructure.

4.0 STEP 3 – RISK ASSESSMENT

The vulnerability assessment component of the Protocol identifies where an interaction, relationship or direct dependency between an infrastructure component and a climate event exists. By ranking the probability of the interaction occurring (P) and the severity resulting from the interaction (S), a risk value (R) is calculated. The determination of the probability and severity factors are based on experience and professional judgment. Different personnel are involved in this process to provide an objective rating.

The following steps were undertaken for the risk evaluation:

1. Determine which performance factors are applicable to each infrastructure component;
2. Indicate in the matrix if there is a relationship between each infrastructure component and the climate event (Y/N);
3. For each climate event, assign a probability scale factor P (0-7);
4. For each climate event – infrastructure component relationship, assign a severity scale factor S (0-7);
5. Calculate the risk of the infrastructure component/climate event relationship as the product of probability and severity: $R = P \times S$.

The final risk value determines future actions, as summarized in the table below.

Table 4-1. Risk tolerance thresholds used for this assessment adapted from the Protocol (Canadian Council of Professional Engineers, 2012).

Risk Range	Threshold	Response
<15	Low Risk	No immediate action necessary
15-25	Medium-Low Risk	Action may be required
25-35	Medium-High Risk	
>35	High Risk	Immediate action required

4.1. Performance Response of the Infrastructure Component

The performance response factors described in Section 3.2 are assessed qualitatively with respect to their potential impact on an infrastructure component, as summarized in Table 4-2.

Table 4-2. Performance response prioritization methodology.

Infrastructure Component	Performance Response (✓ if yes)									
	Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Economic Considerations	Policy Considerations	Social Effects	Environmental Effects
Physical Infrastructure										
Runway	✓	✓	✓		✓	✓	✓	✓	✓	✓
Taxiways (A, B, C, D, E)	✓	✓	✓		✓	✓	✓	✓	✓	✓
Apron	✓	✓	✓		✓	✓	✓	✓	✓	✓
Drainage	✓	✓	✓	✓	✓			✓		✓
Access Roads	✓	✓	✓		✓	✓		✓		
Service Roads	✓	✓	✓		✓	✓		✓		
Heterogeneity in Natural Foundation/Permafrost	✓	✓	✓		✓	✓	✓	✓	✓	✓
Supporting Infrastructure										
Operation and Maintenance Personnel		✓	✓		✓	✓	✓	✓	✓	
Snow Clearing		✓	✓	✓	✓	✓	✓	✓		✓
Crack Filling		✓	✓		✓	✓	✓	✓		
Winter Flight Operation					✓	✓	✓	✓	✓	
Summer Flight Operation					✓	✓	✓	✓	✓	
Summer Maintenance		✓	✓		✓	✓	✓	✓		✓
Winter Maintenance		✓	✓		✓	✓	✓	✓		✓
Lighting Systems		✓			✓	✓		✓		

Infrastructure Component	Performance Response (✓ if yes)									
	Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Economic Considerations	Policy Considerations	Social Effects	Environmental Effects
Surface Markings / Signals		✓			✓	✓		✓		
Weather Station	✓	✓	✓		✓	✓		✓		✓
Environmental Monitoring	✓	✓	✓		✓	✓		✓		✓
Nav aids		✓			✓	✓	✓	✓		
Vegetation				✓	✓			✓		✓
Aircraft Arresting System	✓	✓	✓		✓			✓		
Security Systems	✓	✓	✓		✓			✓		
Data Availability	✓	✓	✓	✓	✓			✓		✓
Others										
Emergency Procedures and Medivac					✓	✓		✓	✓	
Wildlife									✓	✓
Future Developments/Master Plan					✓		✓		✓	✓

4.2. Potential Climate Events

The risk assessment uses a screening tool to identify infrastructure components that are critically affected by climate change. Therefore, only climate events that affect the performance response of one or more infrastructure components are considered. In total, 32 climate events, listed below, were considered.

- Maximum Air Temperature
- Minimum Air Temperature
- Air Freezing Index
- Air Thawing Index
- Freeze – Thaw Cycles
- Heat Waves
- Cold Waves
- Frost
- Rainfall Frequency
- Rainfall Duration
- Rainfall Intensity (Rain Storms)
- Rainfall in the Fall
- Freezing Rain
- Rain on Snow
- Total Snowfall
- Snowfall Duration
- Snowfall Frequency
- First Snow Day
- Last Snow Day
- Blizzards/White-outs
- Ice Storms
- Hail
- Wind Gusts
- Wind Direction
- Wind in Winter
- Ground Freezing Index
- Ground Thawing Index
- Cloud Cover/Solar Radiation
- Cloud Ceiling Height
- Fog/Visibility
- Lightning/Electrical Storms
- Wildfire
- Climate Variability

4.3. Probability Estimation

The Protocol defines the probability scale factor, P , as the probability of an infrastructure component to lose its functionality or have its performance adversely affected if it is exposed to a certain climatic condition. Two methods are proposed in the Protocol to rank this probability, as shown in Figure 4-1. For this study, Method A was chosen as the most appropriate because there was insufficient data to conduct a quantitative assessment.

Score	Probability	
	Method A	Method B
0	Negligible Not Applicable	< 0.1 % < 1 in 1,000
1	Highly Unlikely Improbable	1 % 1 in 100
2	Remotely Possible	5 % 1 in 20
3	Possible Occasional	10 % 1 in 10
4	Somewhat Likely Normal	20 % 1 in 5
5	Likely Frequent	40 % 1 in 2.5
6	Probable Often	70 % 1 in 1.4
7	Highly Probable Approaching Certainty	> 99 % > 1 in 1.01

Figure 4-1. Methods to estimate the probability scale factors according to Canadian Council of Professional Engineers (2012). Method A was chosen for this assessment.

4.4. Severity Estimation

The Protocol also defines the severity scale factor, *S*, to express the severity of the consequences of loss in performance or functionality of an infrastructure component. The Protocol provides two methods for selecting the severity (see Figure 4-2). Method E, a qualitative assessment, was selected for reasons similar to the selection of the probability scale factor.

Score	Severity of Consequences and Effects	
	Method D	Method E
0	No Effect	Negligible Not Applicable
1	Measurable	Very Low Some Measurable Change
2	Minor	Low Slight Loss of Serviceability
3	Moderate	Moderate Loss of Serviceability
4	Major	Major Loss of Serviceability Some Loss of Capacity
5	Serious	Loss of Capacity Some Loss of Function
6	Hazardous	Major Loss of Function
7	Catastrophic	Extreme Loss of Asset

Figure 4-2. Methods to estimate the severity scale factors according to Canadian Council of Professional Engineers (2012). Method E was chosen for this assessment.

4.5. Summary and Discussion of Risk Assessment Matrix

In the risk assessment matrix presented in Appendix B, a total of 465 infrastructure component/climate event combinations were assessed (Figure 4-3). Of these event combinations, 86% (400) were evaluated as Low Risk, 12% (56) were Medium-Low Risk, and less than 2% (9) were Medium-High Risk. The Medium-High Risk and Medium-Low Risk combinations are summarized in Table 4-3 and Table 4-4 and further discussed in the sections below.

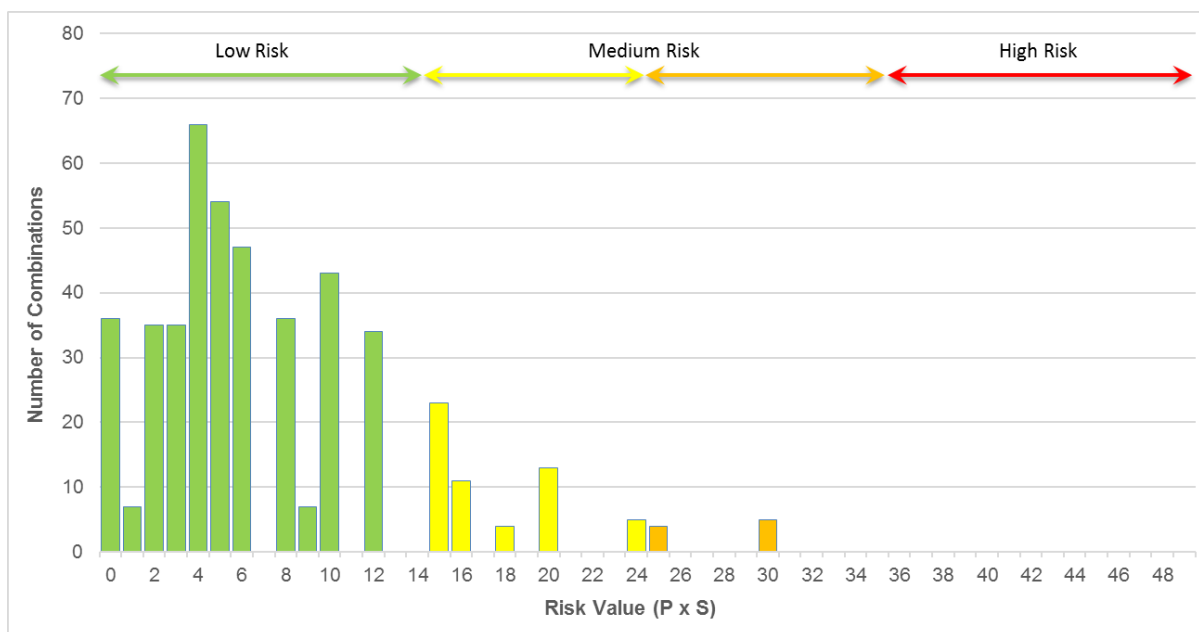


Figure 4-3. Distribution of risk values evaluated for Inuvik Airport.

The evaluation did not identify high risk combinations ($R > 35$) for which immediate actions would be required. The reason for the lack of high risk combinations assessed is the limited severity of consequences and effects. According to the protocol, hazardous or catastrophe conditions must occur associated with loss of function or asset in response to a projected change in climate parameter. For example, permafrost warming due to climate change that could result in reduced bearing capacity or runway settlement is expected to be a slow process that can be managed through monitoring and maintenance, thereby reducing the need for immediate action.

The failure of the runway that was observed in 2013 (see Section 2.3) occurred in response seepage through the runway fill and thermal degradation of ice rich soil. While the failure of the embankment structure occurred relatively fast, the development of the actual problem was slow and could likely have been identifying with proper monitoring.

Table 4-3. Medium-High Risk combinations.

Infrastructure Component	Climate Event
Data Availability	- Maximum Air Temperature - Air Thawing Index - Fog/Visibility - Climate Variability
Drainage	Rainfall Duration¹
Winter Flight Operation	Fog/Visibility
Summer Flight Operation	Fog/Visibility
Emergency Procedures and Medevac	Fog/Visibility

¹ Rainfall intensity, duration and frequency are typically considered in combination (e.g., IDF), the three parameters were assessed individually and the duration was considered to be the element most critical for the drainage system.

Table 4-4. Medium-Low Risk combinations.

Infrastructure Component	Climate Event
Data Availability	• Minimum Air Temperature • Air Freezing Index • Freeze/Thaw Cycles • Heat Waves • Rainfall Duration and Intensity • Total Snowfall • Snowfall Duration and Frequency • Ground Freezing and Thawing Index • Cloud Cover
Runway	• Maximum Air Temperature • Freeze/Thaw Cycles • Heat Waves • Frost • Rainfall Duration and Intensity • Ground Freezing and Thawing Index • Cloud Cover/Solar Radiation
Taxiways (A, B, C, D, E)	• Heat Waves • Frost
Apron	• Frost
Drainage	• Rainfall Intensity (Rain Storms) • Total Snowfall • Ground Thawing Index • Cloud Cover/Solar Radiation • Wildfires
Heterogeneity in Natural Foundation/Permafrost	• Freeze/Thaw Cycles • Ground Thawing Index • Cloud Cover/Solar Radiation • Wildfires
Operation and Maintenance Personnel	• Wildfires
Snow Clearing	• Total Snowfall • Snowfall Duration and Frequency
Winter Flight Operation	• Frost
Summer Maintenance	• Climate Variability
Winter Maintenance	• Frost • Climate Variability
Lighting Systems	• Fog/Visibility • Wildfires

Infrastructure Component	Climate Event
Weather Station	• Wildfires
Environmental Monitoring	• Wildfires
Nav aids	• Fog/Visibility • Wildfires
Aircraft Arresting System	• Ground Freezing and Thawing Index • Wildfires
Security Systems	• Ground Freezing and Thawing Index
Emergency Procedures and Medivac	• Climate Variability • Wildfires

4.5.1. Medium – High Risk

Nine infrastructure components in combination with six climate events were identified with risk values of 25 and higher.

The drainage system is potentially critical in combination with projected changes in precipitation. The changes in the IDFs together with changes of the pools and channels, such as the area in-between the runway and taxiway A, B and D, may result in drainage that overwhelms the design capacity. Proper drainage is all the more important as it has significant impacts on the permafrost, potentially accelerating permafrost degradation. Inuvik Airport, as part of their ongoing improvement efforts, has realized the importance of proper drainage and is currently implementing an area-wide upgrade in surface drainage, which includes the construction of new berms and culverts.

The availability of data has been identified as the component affected by the most climate events resulting in Medium-High risk values. Having reliable data on the climate events, but also on the response of the infrastructure is critical as it allows for guiding future design and management decisions. In the absence of adequate data, it is challenging to make informed decisions. The risk related to data availability is therefore to not make appropriate decisions on improvements, operation and maintenance efforts.

The remaining three medium-high risk combinations are all related to potential changes in visibility. As the climate is warming and moisture is increasing, days of poor visibility and fog may increase, resulting in negative impacts on flight operations in winter and summer, as well as on emergency procedures. However, the confidence in such trends is low and the uncertainty range large and therefore, it is unclear what will happen. Nevertheless, these are combinations worth considering.

4.5.2. Medium – Low Risk

As shown in Table 4-4, 18 infrastructure elements are affected by 18 different climate events that result in the lower end of the medium risk category. Data availability, frost and the ground thawing index are the three climate events with the highest counts that may affect infrastructure. Changes in frost events, i.e. the deposition of ice crystals on a surface directly from the water vapour in the atmosphere, is expected to increase due to warmer days and an increase in atmospheric moisture. The impact on the infrastructure due to frost is mainly a reduction in friction of road, taxiway, and runway surfaces, which could result in operational challenges and increased maintenance efforts. The consequences of a change in frost, however, are not severe and can typically be managed as part of ongoing maintenance.

The consequence of an increase in the ground thawing index is ground warming, active layer thickening and permafrost degradation. While these processes may lead to instabilities, these tend to occur at a relatively slow rate, allowing environmental monitoring, as initiated at Inuvik Airport, to identify trends and provide input for implementing adaptation measures.

Other climate events that fall in this category and are worth highlighting are maximum air temperature, freeze-thaw cycles, snow fall and wildfires.

4.5.3. High Consequence Elements

Three infrastructure elements are discussed in this section for which the climate – infrastructure combinations resulted in a low risk, but are considered worthwhile to be highlighted.

4.5.3.1. Runway and Foundation

Failure of the runway and its foundation can potentially result in major consequences. However, within the climate change vulnerability assessment, high severity values were not assigned in response to changes in climate events. The main reason for this is that the changes do occur slowly over time and mainly manifest in smaller differential settlements. While such settlements need to be repaired, they are not expected to result in a major loss of the infrastructure capacity and can be managed as part of regular maintenance activities.

4.5.3.2. Snow Clearing

Efforts required for snow management seem to have increased in response to different factors. Based on the available climate projections, it is possible that the total annual amount of snowfall decreases, but it may increase during the warmer months in spring. As such, the snow may be heavier and require more effort for clearing. In addition, a persistent snow pack during the warmer months increases the possibility for rain on snow events, which could impact operation and require additional maintenance efforts. The vulnerability assessment did not flag snow clearing as a major problem, but together with additional data, potential changes in snow characteristics should be considered in the acquisition of maintenance equipment if replacements are required.

4.5.3.3. Winter Maintenance

There are no reliable data available on trends in the occurrence of major snow storms. However, if snow storms were to increase in frequency and severity, additional resources and equipment may have to be procured. Proper winter maintenance is the key to maintaining access to and from Inuvik.

5.0 STEP 4 – ENGINEERING ANALYSIS

According to the Protocol, Step 4 requires that the infrastructure and its capacity be assessed in the light of projected climate change loads. *Vulnerability* exists when infrastructure has insufficient capacity to withstand the projected or anticipated loads that may be placed on it. *Resiliency*, on the other hand, exists when the infrastructure has sufficient capacity to withstand increasing loads resulting from climate change. An engineering analysis is recommended for elements that fall in the Medium Risk category (Table 4-3 and Table 4-4), mainly to decide whether immediate action (similar to a High-Risk combination) is required or not.

An engineering analysis requires information on the various factors that affect the load and capacity of all infrastructure components. For the Inuvik Airport, such data are unavailable, hence professional judgement was used to qualitatively rank the relative vulnerability or resiliency of the infrastructure.

In total, 64 combinations fell into the Medium Risk category (i.e., initial risk values between 15 and 34). Since the initial assessment was already carried out using professional judgement, no significant change in the risk value was anticipated. Therefore, only those seven combinations with initial risk values greater than 20 were considered having potential to be re-ranked as High Risk. The combinations that fell into the Medium Risk category and were further analysed are summarised in Table 5-1 and discussed in the following subsections.

Table 5-1. Infrastructure component - climate event combinations considered in Step 4 (engineering analysis).

Infrastructure Component	Climate Event	Initial Risk Value	Section
Data Availability	- Maximum Air Temperature - Air Freezing Index - Air Thawing Index - Frost - Rainfall Intensity (Rain Storms) - Fog / Visibility - Natural Variability	30 24 25 30 24 30 25	5.2
Runway	Frost	24	5.3
Drainage	- Rainfall Duration - Rainfall Intensity (Rain Storms)	25 24	5.4
Winter Flight Operation	- Frost - Fog / Visibility	24 30	5.5.1
Summer Maintenance	Fog / Visibility	30	5.5.2
Emergency Procedures and Medevac	Fog / Visibility	25	5.5.3

5.1. Methodology

For each infrastructure component listed in Table 5-1 current loading conditions, changes in these loading conditions due to projected climate change, and expected changes in the capacity were analysed. If data were available, the vulnerability ratio was calculated by dividing the total projected load by the total projected capacity. If this ratio exceeded 1.0, the infrastructure component was considered vulnerable, otherwise it was considered to have adaptive capacity. However, since no quantitative data were used during this assessment, the vulnerability ratio was estimated from assumed changes in load and capacity via professional judgement only. The sufficiency of data was then assessed and the need to conduct a revised risk assessment (Step 3) evaluated. Detailed recommendations are provided in Section 6.0.

5.2. Data Availability

5.2.1. Current Situation

In order to understand change in environmental loads and the response of the infrastructure to these changes, data are needed. The changes in the foundation conditions, which are considered to be the most critical elements for the infrastructures assessed at Inuvik Airport, are expected to occur slowly and in a manner that is neither abrupt nor catastrophic. Therefore, monitoring structural behaviour helps in assessing the infrastructure's resilience and guides mitigation measures.

5.2.2. Vulnerability

Accurate data is required in order to plan mitigation strategies, which may be of structural, management or operational nature. If the data available are incomplete or not appropriate, the proposed measures may not be accurate.

5.2.3. Data Sufficiency

During the assessment of the infrastructure vulnerability to climate change, it was identified that insufficient information is available for correlating structural behaviour and airport operations with climate trends or extreme weather events.

5.2.4. Evaluation of Need for Additional Risk Assessment

Considering the risk of making uninformed decisions based on insufficient or inadequate data, immediate action is recommended without an additional risk assessment regarding data sufficiency.

5.3. Runway

5.3.1. Current Load

The critical climate event is the frost forming on the runway surface affecting roughness and safety. Currently, sanding is the preferred strategy to increase surface roughness during frost events, and the use of pre-wetted sand when wind and frost prevail.

5.3.2. Climate Change Load

Based on anecdotal evidence, supported by historic temperature and humidity data, an increased number of frost events is likely. This increases the load on the runway.

5.3.3. Expected Change in Existing Capacity

Runway surface roughness may decrease with time together with increased maintenance efforts. This decrease and increase, respectively, is expected to occur at a slow rate that does not materially affect the safe operation of the airport.

5.3.4. Vulnerability

Based on the available information, runway and maintenance crews currently have sufficient adaptive capacity.

5.3.5. Data Sufficiency

Not enough data are available to assess how changes in frost events affect runway operations and safety.

5.3.6. Evaluation of Need for Additional Risk Assessment

No immediate action or additional risk assessment is required.

5.4. Drainage

Surface water management structures include ditches, culverts, ponds and flow channels. The dimensions of these structures vary as do capacities, which in response to climate change can be affected by erosion, ground deformations, and changes in the surface vegetation and local hydrology.

5.4.1. Current Load

The hydro-climatic events for which the drainage structures and the water management system were designed are unknown. Based on discussion with GNWT-DOT staff, some drainage-related problems currently observed include poor drainage from the infield and washouts under the runway, which has led to the formation of a sinkhole in the runway. Ponding and poor-draining ditches were also observed during the inspection (see Photo Sheets).

5.4.2. Climate Change Load

Based on historical data and projected changes in precipitation, a moderate increase in rain volumes and intensities during the summer months is possible. In addition, freshet volumes may increase due to a potentially slight increase in spring snow volumes.

5.4.3. Expected Change in Existing Capacity

It is expected that the existing capacity decreases in response to changes in the IDFs. Also, increases in spring snow may affect the capacity of the system during freshet. However, increases in total and short-term volumes are expected to not exceed current capacities but reduce resilience.

5.4.4. Vulnerability

The existing surface water management system is considered vulnerable because climate change may create loads that exceed the original design parameters.

5.4.5. Data Sufficiency

Insufficient data are available to quantify potential changes in surface runoff. In particular, surface flow measurements are currently lacking and future flows will be difficult to predict. Furthermore, the grades and dimensions of current drainage structures are unknown.

5.4.6. Evaluation of Need for Additional Risk Assessment

No immediate action or additional risk assessment is required.

5.5. Supporting Infrastructure

The remaining components are supporting elements for which the vulnerability and resilience cannot be evaluated as systematically as for physical infrastructure. Fog and visibility are the main parameters affecting the different elements, as discussed below.

5.5.1. Winter Flights

Potential increases in fog and reduced visibility as well as increases in frost days may affect winter operations. However, there are currently insufficient data to project how these may change in the future. Hence, no immediate action or additional risk assessment is required.

5.5.2. Summer Maintenance

Potential increases in fog and reduced visibility in response to higher moisture may affect summer operations. However, as for winter fog, there are insufficient data to project how these may change in the future and no immediate action or additional risk assessment is required.

5.5.3. Emergency Procedures and Medevac

Potential increases in fog and reduced visibility may influence emergency procedures and Medevacs. As stated above, there are insufficient data to project how these may change in the future and no immediate action or additional risk assessment is required.

6.0 STEP 5 – RECOMMENDATIONS

6.1. Limitations

Recommendations are developed from the work completed in the previous stages of the Protocol. Generally, the recommendations will fall into five major categories:

- Remedial action is required to upgrade the infrastructure;
- Management action is required to account for changes in the infrastructure capacity;
- Continue to monitor performance of infrastructure and re-evaluate at a later time;
- No further action is required; and/or
- There are gaps in data availability or data quality that require further work.

The four climate events associated with the highest risk values are:

- Frost;
- Rainfall Duration;
- Ground Thawing Index; and
- Fog Visibility.

Future trends of air temperature change can be reasonably projected but it is more challenging to project changes in the intensity and duration of precipitation events, let alone project for second and third order effects, such as frost, ground and water temperatures or visibility. Therefore, such projections have large uncertainties associated. For example, the limitations for rainfall projections should be noted as stated in the Climate Data Analysis (Appendix A): “Current climate models are unable to predict rainfall intensity at the short durations (e.g., <24 hours) required to generate IDF curves. Consequently, modeled rainfall projections cannot be used directly to generate projected IDF curves for future conditions.”

While these limitations are considered acceptable for the purposes of this study, they were included in the development of the recommendations.

6.2. Overview of Recommendations

The recommendations related to the climate change vulnerability of infrastructure elements of medium to high risk values ($R > 12$) are summarised in Appendix C. In total, 114 combinations out of the total of 465 were judged as requiring some action and were further analyzed. Recommendations and priorities are provided for each combination of infrastructure component, climate element and factor, and performance response. The priority levels of the various performance responses are distributed by:

- High priority: 4 (1%) recommendations;
- Medium priority: 27 (6%) recommendations;
- Low priority: 83 (19%) recommendations; and
- No priority (none): 326 (74%).

As per the Protocol, actions were assigned to each recommendation as per its respective priority:

- Remedial action (engineering) is required;
- Management action is required;
- No further action is required; or
- Additional study or the acquisition of more data is required.

Recommendations for further observations and monitoring are presented. It's worth noting that additional monitoring and observations are recommended for all 114 combinations. This highlights the importance of having sufficient data available for making informed decisions. The distribution of recommended actions is summarised in Table 6-1. Some infrastructure elements have multiple recommended actions (e.g., remedial, management, and further study).

Table 6-1. Number of individual recommended actions by elements.

Priority	Remedial Action	Management Action	Additional Studies	Monitoring / Observations
High	-	4	-	4
Medium	9	24	9	27
Low	48	52	40	79
No	1	-	1	1
TOTAL	58	80	50	111

Note: More than one action could be assigned to a single element.

Remedial actions can be divided into four tasks:

- Climate data gathering and analysis;
- Subgrade investigations and analysis;
- Infrastructure capacity analysis; and
- Operation and maintenance record analysis.

Currently, no immediate remedial action is recommended that would require significant engineering work. This is because the different runway instabilities cannot be explained by one unique mechanism and because there is insufficient baseline subsurface information available to assess whether such repairs can arrest or slow down future instabilities. Therefore, the recommendations focus on collecting baseline information for the components that are thought to be most vulnerable to climate change. Such information would be useful for reassessing the vulnerability and designing adaptation and mitigation measures.

Therefore, it is recommended that a detailed environmental monitoring program in combination with infrastructure and operations performance monitoring and a review of current procedures be initiated. Highest risks are associated with differential settlements that form slowly in response to permafrost degradation. As such, infrastructure behaviour can be monitored via detailed deformation monitoring, such as LiDAR or photogrammetry, and specific forms developed for their

assessment, for example. The results from regular surveys can be reviewed to assess deformations or drainage problems, which may be correlated with specific climate events.

In parallel to the monitoring program, specific thresholds should be developed for critical climate parameters defining conditions that may be key for a specific infrastructure element. For example, an acceleration in the ground thawing index increase may result in deformations that can no longer be maintained using current practice. This also requires the development of an asset management system in which a specific design life is defined for the infrastructure component.

Inuvik Airport initiated a ground temperature monitoring network. As shown in the recommendation matrix (Appendix C), this important data gap has already been addressed and improved assessments will be possible in the future when sufficient data are available. It is, however, important that the monitoring continues for many years.

Finally, surface water management has also been identified as an issue for current operation and structural improvements are currently being implemented. This will also increase the resilience against changes in runoff due to climate change.

6.3. Specific Recommendations

The specific recommendations are listed below, in order of decreasing importance.

1. *Collect data on frost formation* to assess conditions during which and to what degree frost related challenges occur;
2. *Evaluate the capacity of drainage systems* to assess the resiliency of culverts and ditches;
3. *Systematically collect information on the visibility (fog & cloud ceiling)* to identify potential trends that help in deciding if upgrades in the current instrumentation is required;
4. *Monitor local snow accumulation, including spatial (re-)distribution* to assess current snow management plans and plan future requirements;
5. *Carry out procedural review* by assessing current operation and maintenance practices, and standard operational procedures, and evaluate their robustness against future climatic conditions;
6. *Document maintenance and repair efforts in a systematic manner* to note changes and highlight infrastructure performance in response to those; and
7. *Reassess the climate change vulnerability every five years* with several stakeholders that include the airport operators, the owners and users of the airport, as more baseline data, infrastructure performance information, and improved climate models become available.

None of these recommendations require immediate engineering action.

6.4. Runway Extension

As shown in Figure 2-5 an extension of runway 06/24 is planned to the west. The vulnerability assessment highlighted that a good understanding of the changes in the foundation conditions and the surface hydrology help in reducing risks of infrastructure failure due to changing climate in the future. The construction of this extension should be used to carefully record the foundation conditions and to initiate performance monitoring that include ground temperature and moisture

content monitoring in and under the runway embankment fill, that would be challenging to install later. Special attention must be turned toward the drainage conditions in order to avoid the formation of a sinkhole under the new runway but also the existing runway as surface runoff may change in response to the extension. Detailed monitoring of the performance of the drainage system, which includes the monitoring of potential icing in culverts and erosions along the drainage ditches will allow for evaluating the resilience of the system in the context of climate change during a future vulnerability assessment.

7.0 CONCLUSIONS

Following the standardized protocol prepared by the Public Infrastructure Engineering Vulnerability Committee (PIEVC), a climate change vulnerability assessment was carried out for Inuvik's Mike Zubko Airport located in the continuous permafrost zone of the Northwest Territories in Canada. Within the Protocol the 30-year projected climate change trends for the Inuvik region, which are based on historic data and climate models are considered. Key trends are:

- Mean annual air temperature is increasing at about 0.8 °C per decade with warming rates greatest in winter and fall;
- The number of annual freeze/thaw cycles is decreasing by about 4 cycles per decade;
- Annual rainfall is decreasing by 25 mm per decade with the maximum number of intense rainfall days to occur in the months of July and August;
- Annual total snowfall decreased by about 60 cm during the last decade with significant seasonal variability;
- No trend data for rain on snow events are available;
- The number of freeze-thaw cycles has slightly decreased in recent years;
- First snow days are occurring later in the season whereas last snow days show no statistically significant trend; and
- No statistically significant trend was identified for changes in wind direction and intensity.

Using these trends, the vulnerability assessment, during which 465 climate event – infrastructure component combinations were assessed, identified no infrastructure element that would be at High Risk due to climate change. In total, 56 combinations were at Medium-Low Risk, 9 were at Medium-High Risk and the rest (86%) fell within the Low Risk category. The infrastructure components likely to be most vulnerable to climate change are the drainage system and winter/summer flight operations. Further, interactions of runway, taxiways and aprons with frost may be vulnerable.

Due to the low to medium risks to climate change associated with the infrastructure at Mike Zubko Airport in Inuvik, no immediate engineering action is recommended. The assessment clearly identified frost and poor visibility as the two main climate events that may become problematic in the future. However, currently there are not sufficient detailed data available and future projections do not exist that would allow for a confident assessment on how climate events may affect airport operations in the future. As a result, the lack of data (i.e., data availability) has been identified as medium to high risk for the airport. Hence, current environmental and maintenance baseline data are inadequate for carrying out a detailed engineering assessment. Therefore, it is recommended to evaluate current environmental monitoring programmes, standard operational procedures and airport maintenance efforts to support future decisions and the design of mitigation and adaptation strategies if those were needed. Specifically, this includes:

- Collection of data related to frost formation;
- Evaluation of the drainage systems and its maintenance efforts;
- Collection of information on visibility;
- Monitor local snow accumulation and protocol current snow management plans;

- Carry out review of maintenance and operational procedures;
- Keep records of various maintenance activities in a systematic way; and
- Reassess the climate change vulnerability in five years with several stakeholders that include the airport operators, the owners and users of the airport, once more baseline data, infrastructure performance information, and improved climate models become available.

The changing climate will likely result in increased maintenance and repair efforts for which resources must be provided and standard procedures adapted. Because the currently available data are insufficient, additional baseline data should be collected, specifically tailored towards infrastructure – climate combinations that are potentially at risk in the future. These additional data help making informed decisions in the near future on where available resources are best allocated and if additional ones are required.

8.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

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PHOTOGRAPHS



Photo 1.
Sinkhole on runway (June 2011).



Photo 2.
Sloughing and water ponding at toe of Taxiway E embankment looking North (June 2011).



Photo 3.
Subsidence on Taxiway E (June 2011).



Photo 4.
Tension cracks along the runway embankment looking West (June 2011).



Photo 5.
Water ponding in diversion ditch West of Taxiway E looking towards the runway (July 2015).



Photo 6.
Water ponding in diversion ditch East of Taxiway E (July 2015).



Photo 7.
Double culvert installed under access road on east end of the runway (July 2015).



Photo 8.
New diversion ditch on the south of runway (July 2015)



Photo 9.
Water ponding in the infield between runway and Taxiways A, B and D (July 2015).



Photo 10.
Inlet for culvert under Taxiway D (July 2015).



Photo 11.
Outlet for culvert under Taxiway D (July 2015).



Photo 12.
Inlet for culvert under Taxiway B (July 2015).



Photo 13.
Outlet for culvert under Taxiway B
(July 2015).



Photo 14.
Embankment of Taxiway B sloughing,
looking towards Taxiway D (July 2015)



Photo 15.
Fixed sinkhole (see Photo 1; Report,
Figure 2-6) on runway (July 2011).



Photo 16.
Settlements under air terminal building (July 2015)



Photo 17.
Water ponding next to hangar building looking towards air terminal building (July 2015).



Photo 18.
Water ponding on apron between air terminal building and hangar, looking north (July 2015).



Photo 19.
Northeast end of apron showing
differential settlements and water
ponding (July 2015).



Photo 20.
Thermistor installation on east end of
runway (July 2015).



Photo 21.
Thermistor installation on east end of
runway (July 2015).

APPENDIX A

CLIMATE INFORMATION ANALYSIS

A.1. INTRODUCTION

As part of BGC Engineering Inc. (BGC)'s vulnerability assessment of the Inuvik airport to future climate change, the current state of knowledge of climate change in the Canadian North (with special reference to the western continental Canadian arctic) was reviewed, the historical climate record from Environment Canada's meteorological station at Inuvik Airport was compiled and assessed, and publicly-available climate change projections for the Inuvik region were reviewed. This appendix summarizes the main findings.

A.2. EVIDENCE OF CLIMATE CHANGE IN THE ARCTIC

In a phenomenon known as Arctic amplification, arctic temperatures have increased at a rate nearly double the global average. Warmer temperatures have affected sea ice and snow cover to an extent not previously predicted by climate models (Cohen et al., 2014). The following sections summarize the observed changes in air temperature and precipitation and their significance to the cryosphere in the Canadian Arctic, with specific emphasis on recent work relevant to the project area.

A.2.1. Air Temperature

The following observations have been reported with respect to temperature trends in the western Arctic for the period since the 1950s (Zhang et al., 2000; Bonsal et al., 2001; McBean et al., 2005; Prowse et al., 2009; Cohen et al., 2014):

- the warmest temperatures in the Arctic on record have occurred since 2005;
- northern hemisphere high latitudes have experienced temperature increases at twice the rate of lower latitudes;
- Arctic amplification is strongest in the fall and winter months; and
- warming during the past 150 years has been unprecedented since the onset of the current interglacial period.

Overall, arctic temperatures have increased at unprecedented rates and to unprecedented levels since the mid-20th century (IPCC, 2013). This is in line with predictions from global climate circulation models.

A.2.2. Freezing and Thawing Index

The air freezing index (AFI) and air thawing index (ATI) are two climate parameters widely used to quantify the "severity" of a winter or summer with respect to freezing or thawing effects on pavements (Doré and Zubeck, 2008). It is also a useful indicator of air temperatures over a season.

The freezing index is defined as the number of negative degree days between the highest and lowest points on a curve of cumulative degree days versus time. The thawing index is the number of degree days between the minimum in the spring and the maximum the next autumn. Since ground surface temperatures are generally not available for most locations, air temperatures can be used as a surrogate.

Work by Frauenfeld et al. (2007) demonstrated that in recent decades, no significant changes in freezing and thawing index were observed in Russian permafrost regions. However, seasonally frozen ground areas were found to be experiencing significant warming trends. Over North America, including the Canadian and Alaskan permafrost regions, a decrease in the freezing index has been observed. Coastal areas and eastern Canada have experienced significant increases in the thawing index.

The International Arctic Science Committee (2009) described projected changes in freezing and thawing indices calculated using output from the Arctic Climate Impact Assessment (ACIA)-designated climate models. An analysis for the community of Coppermine (Kugluktuk), Nunavut, showed that the 30-year mean AFI is projected to decrease from approximately 4850 degree-days in 1960 to 3850 degree-days in 2100. This represents an average increase in winter (October–March) temperatures of approximately 5 to 6°C. The 30-year mean ATI was projected to increase from approximately 720 degree-days in 1960 to 1430 degree-days in 2100, representing an increase in average summer (April–September) temperatures of approximately 4°C. Instanes and Mjureke (2005) analysed the effects of these changes at an airport at Svalbard, Norway using observed air temperature data from 1930 to 2000 and future air temperature projections. Their work suggested that the average thaw depth is projected to increase by as much as 50 percent between 2000 and 2050 and that ground temperatures at 2 m depth are projected to increase by 4°C over this same period. Even at 40 m depth, ground temperatures were projected to increase by approximately 2°C by 2050.

Mills et al. (2009) reported that over the next fifty years, low-temperature pavement cracking will become less problematic, structures will freeze later and thaw earlier with correspondingly shorter durations in the freezing season. However, higher extreme in-service pavement temperatures will increase the potential for rutting, which will lead to earlier maintenance, rehabilitation and reconstruction in the design life of the paved surfaces.

A.2.3. Precipitation

With respect to precipitation, the following observations have been made for the period of 1948 to 2005 (Mekis and Hogg, 1999; Zhang et al., 2001b, Prowse et al., 2009):

- annual precipitation totals have increased throughout northern Canada, with the largest increases observed in the Arctic Tundra (+25%) and Arctic Mountain (+16%);
- precipitation changes occurred most notably during the fall, winter and spring;
- heavy precipitation events increased through the period of record; and
- decadal increase in the frequency of heavy snowfall events occurred in northern Canada.

Brown (2000) reported that snow cover extent has significantly decreased over most of Canada, especially during late-winter and early-spring. This was found to also influence the timing of snowmelt and freshwater ice breakup (Lacroix et al., 2005; Duguay et al., 2006).

A.2.4. Permafrost Temperatures and Active Layer Thickness

Recent warming of permafrost has been observed across the Canadian permafrost region, although the magnitude and rate of change has varied, depending on the region. Smith et al. (2005) reported that since the 1980s, the central and northern Mackenzie Valley has warmed the most in the Canadian Arctic. The authors found that changes in snow cover may have enhanced or decreased the magnitude of the response of permafrost temperature to changes in air temperature. The Intergovernmental Panel on Climate Change (2013) notes that permafrost temperature increases of up to 3°C have been observed in Northern Alaska from the early 1980s to the mid-2000s. Permafrost extents in the near surface are projected to decrease by at least 37% by the end of this century (IPCC, 2013).

Tarnocai et al. (2004) reported on active layer monitoring from thirteen undisturbed sites along the Mackenzie Valley. They found that maximum thaw penetrations did not strongly correlate with summer air temperatures (i.e., thawing index) but depended also on a number of other factors, including vegetation cover, snow cover, and near-surface soil moisture.

During the International Polar Year (2007-2008), a comprehensive permafrost temperature monitoring network was initiated. Data were presented in Smith et al. (2010) and Romanovsky et al. (2010). The data are now available from the Global Terrestrial Network for Permafrost, GTN-P (<http://gtnpdatabase.org>) that recently established the new, dynamic database (Biskaborn et al., 2015). Within the northern hemisphere polar region, ground temperatures are currently being measured in about 575 boreholes in North America, the Nordic region and Russia. These measurements show that in the discontinuous permafrost zone, permafrost temperatures fall within a narrow range, with the mean annual ground temperature (MAGT) at most sites being warmer than -2°C. A greater range in MAGT is present within the continuous permafrost zone, from above -1°C at some locations to as low as -15°C. Permafrost temperature warming rates are much smaller for permafrost already at temperatures close to the melting point compared with colder permafrost, especially for ice-rich permafrost, where latent heat effects dominate the ground thermal regime (Smith et al., 2010; Ednie and Smith, 2015). Colder permafrost sites are warming more rapidly.

A.3. ANALYSIS OF HISTORICAL CLIMATIC DATA FOR INUVIK AIRPORT

Historical climate data was obtained from Environment Canada's Inuvik A climate station located at the Inuvik Airport (TC ID YEV). The climate station is located at 68°18'14" N and 133°28'59" W at an elevation of 67.70 m above sea level.

The 57 year (1958 to 2014) climate record was analyzed with respect to changes in temperature and precipitation. The reference climate period used is the thirty-year normal period from 1981 to 2010. Recent long-term trends have been determined for the thirty-year period of 1985 to 2014.

A.3.1. Data Gaps

Of the data compiled from Environment Canada, any year missing more than 5% (18 days) of the daily data values have been excluded from the figures. Figure A-1 shows the data availability for temperature, precipitation, rainfall, snowfall, snow on ground, and wind data.

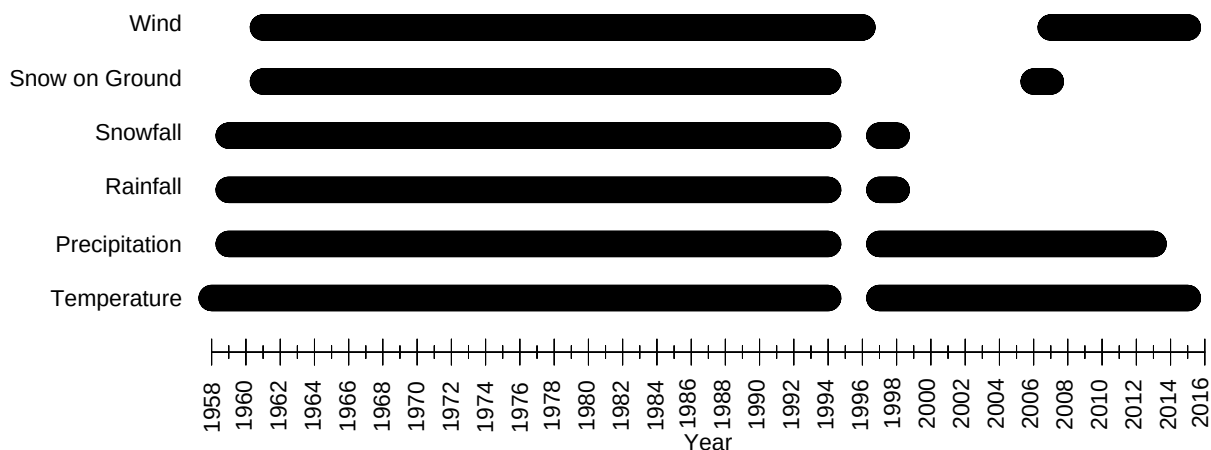


Figure A-1. Inuvik climate data availability.

A.3.2. Air Temperature

A.3.2.1. Mean Annual Air Temperature (MAAT)

Figure A-2 (see attached Figures section) shows the mean, maximum and minimum annual air temperatures for the period of record. Figure A-3 compares the annual deviations in mean annual air temperature from the reference mean (averaged from 1958 to 1987). From these two figures, the following observations have been drawn:

- Annual air temperatures have been steadily increasing over the past 30 years at an average rate of 0.8°C/decade.
- Temperatures are rising more during the winter than during the summer.
- 4 of the 5 warmest years on record have occurred in the past 25 years: 1998 (-4.8°C), 2010 (-5.9°C), 2014 (-6.1°C), 1993 (-6.1°C).
- The majority of deviations from the mean annual temperature has been positive since the 1990s in comparison to the reference period.
- Temperature changes are significantly related to the Pacific Decadal Oscillation (PDO) Index with positive PDO indices being correlated to positive temperature anomalies and negative PDO indices correlated with negative temperature anomalies. Over the past decade, this correlation has waned, perhaps explaining the increasing dominance of other climate-forcing mechanisms (see Figure A-3).

A.3.2.2. Maximum and Minimum Annual Air Temperatures

As shown in Figure A-2, the minimum annual air temperatures have been increasing at an average rate of 2.6°C/decade, but the maximum annual air temperatures show no overall trend.

A.3.2.3. Seasonal Air Temperatures

Figure A-4 shows the mean and seasonal yearly air temperatures for the period of record. Table A-1 summarizes the average annual and seasonal air temperature trends over the past thirty years (1985 to 2014).

Table A-1. Seasonal Air Temperature Trends from 1985 to 2014, Inuvik Airport.

Period	Best-Fit Trend in Mean Annual Air Temperature (°C/decade)
Annual	0.8
Winter (December to February)	1.1
Spring (March to May)	0.5
Summer (June to August)	-0.1
Fall (September to November)	1.5

A.3.2.4. Freezing and Thawing Indices

Figure A-5 presents the historical mean annual air temperature, freezing index and thawing index. The following observations have been drawn from this figure:

- The general long-term trend is of decreasing freezing index and increasing thawing index, reflecting the long-term warming trend.
- Over the past thirty years, the freezing index has declined at an average rate of 250 degree-days/decade and the thawing shows no overall trend. In other words, subfreezing temperatures have been warming at a greater rate than above-freezing temperatures, reflecting the seasonal trends described in Section A.3.2.3.

A.3.2.5. Freeze-Thaw Cycles

Premature deterioration of pavements is related to high frequencies of freeze-thaw cycles, particularly where subgrades are composed of fine-grained, saturated material. In permafrost areas, pavement structures stay strong throughout the winter because the subgrade remains frozen until spring. However, milder winters, with more freeze-thaw cycles, would accelerate road deterioration and increase maintenance costs.

The historical air temperature record was examined to determine historical trends for the occurrence of freeze-thaw cycles. For this analysis, a freeze/thaw cycle was defined as a day where the maximum temperature exceeded 0°C and the minimum temperature was less than -1°C. The historical occurrence of freeze-thaw cycles at Inuvik Airport is shown in Figure A-6. From this figure, the following observations have been drawn:

- Annually, the number of freeze/thaw cycles are declining at an average rate of 4.5 cycles/decade.

- Decreasing trends in freeze/thaw cycles are similarly distributed through the spring and fall (2.1 and 1.9 cycles/decade respectively).

A.3.3. Precipitation

A.3.3.1. Precipitation Totals

Figure A-7 presents the historical annual and seasonal precipitation records. Figure A-8 presents the historical annual precipitation, rainfall, and snowfall records. Figure A-9 shows the count of days with precipitation, rainfall, and snowfall. Table A-2 summarizes the average annual and seasonal precipitation trends over the past thirty years.

Table A-2. Seasonal precipitation trends from 1985 to 2014, Inuvik Airport.

Period	Best-Fit Trend in Total Precipitation (mm/decade)
Annual	-16
Winter (December to February)	-11
Spring (March to May)	-6
Summer (June to August)	9
Fall (September to November)	-7

The following observations have been drawn from these figures and Table A-2:

- Over the period of record, annual precipitation totals have been decreasing over time.
- Over the past thirty years, annual precipitation totals have been decreasing at an average rate of 16 mm/decade.
- Precipitation totals underlie strong seasonal controls. Generally, in a given year, most precipitation falls during the summer. Summer precipitation totals have increased in the past 30 years. Conversely, precipitation totals in all other seasons have shown decreasing trends.
- The four wettest years occurred prior to 1972, whereas the four driest years on record have occurred since 1995 (apart from 1957).

A.3.3.2. Rainfall Totals

Figure A-10 presents the historical annual and seasonal rainfall record. The following observations have been drawn from this figure over the past 30 years:

- Annual rainfall totals show a slight increasing trend.
- The majority of rainfall occurs during the summer months.

A.3.3.3. Snowfall Totals

Figure A-11 presents the historical annual and seasonal snowfall record. The following observations have been drawn from this figure:

- Annual snowfall shows a decreasing trend.
- Trends of decreasing snowfall are consistent across the seasons: winter, spring, and fall.

A.3.3.4. Snow Depth and Timing

Figure A-12 presents the historical mean monthly snow depth record. Figure A-13 presents the first and last snow days of the year. The following observations have been drawn from these figures:

- Monthly snow depths show few discernible trends, with the months of April and May showing an increase in snow depths and March and December showing a slight decrease in snow depths over the past 30 years.
- First snow day of the year has occurred later in the year and last snow day of the year has occurred earlier over the past 30 years.

A.3.4. Extreme Climatic Events

Extreme climatic events can last for a period of minutes or hours (e.g., hailstorms, high winds, blizzards, heavy snowfalls or rainfalls), days or weeks (e.g., warm or cold waves), or months, seasons and years (e.g., drought, warm or cold summer, winter, or years). Table A-3 summarizes extreme daily air temperatures, rainfall and snowfall in addition to extreme monthly rainfall and snowfall totals.

Table A-3 shows that the highest daily rainfall on record occurred during the month of July. The greatest daily snowfall on record occurred during the month of October. Extreme minimum daily air temperatures have reached temperatures colder than -50°C from December through March and have been subfreezing (colder than 0°C) for all months. Extreme maximum daily temperatures have been above freezing (warmer than 0°C) for all months of the year.

Table A-4 summarizes the extreme climate events and the corresponding figures that have been prepared showing how these events have been distributed monthly and annually.

Table A-3. Extreme Climatic Events, Inuvik Airport, 1981 to 2010.

Month	Max Daily Rainfall (mm)		Max Daily Snowfall (cm)		Min Daily Temperature (°C)		Max Daily Temperature (°C)	
	Year	Value	Year	Value	Year	Value	Year	Value
Jan	1981	1.8	1963	11.4	1975	-54.4	1981	5.4
Feb	1982	0.2	1962	13.7	1968	-56.7	1989	5.2
Mar	1989	0.8	1967	13.0	1964	-50.6	1965	6.1

Month	Max Daily Rainfall (mm)		Max Daily Snowfall (cm)		Min Daily Temperature (°C)		Max Daily Temperature (°C)	
	Year	Value	Year	Value	Year	Value	Year	Value
Apr	2002	10.0	1961	17.8	1971	-46.1	1995	13.8
May	1961	19.3	1966	24.9	1961	-27.8	1998	25.0
Jun	1972	19.1	1970	10.2	1959	-6.1	1999	32.8
Jul	1998	41.0	1974	4.8	1966	-3.3	2001	32.8
Aug	1970	33.0	1969	22.6	1966	-6.1	1994	32.5
Sep	1976	22.9	1957	12.2	1983	-20.1	1989	26.2
Oct	1964	13.2	1971	44.2	1965	-35.0	2003	20.9
Nov	1967	0.8	1994	22.0	1963	-46.1	1970	10.6
Dec	1988	0.4	1986	18.6	1964	-50.0	1973	5.0

Table A-4. Extreme Climate Events at Inuvik Airport.

Extreme Climate Event	Figure Number	Comment
Snowfall (>= 10 cm)	A-14	No strong trend in the magnitude or annual occurrence of heavy snowfall days. Heavy snowfall events have most frequently occurred during May and October.
Rainfall (>= 10 mm)	A-15	No strong trend in the magnitude or annual occurrence of heavy rainfall days. Heavy rainfall events have most frequently occurred during July and August.
Rain on snow	A-16	At least one rain on snow event has been recorded for all months except August. Rain on snow days occur most frequently during the month of May.
Fog	A-17	Fog has typically been observed during every month of the year but most frequently in January and June.
Freezing precipitation	A-18	Freezing rain days have been observed from September through June, and most frequently during May and October. There has been no observable trend in its annual occurrence.
Wind gusts	A-19	Days with heavy gusts (>= 63 km/hr) have been recorded during all months, and most frequently in January and December. No annual long term trend in wind gusts is discernible.
Extreme temperatures	A-20 A-21	Extreme cold days occur most frequently from January to March. Extreme warm days occur most often from June to August. In recent years, the occurrence of extreme cold days has decreased. No discernible trend in extreme warm days was observed.
Wind Gusts	A-22 A-23	Percent of wind gusts per year shows a slight increase over the past ten years. Predominant wind direction for all seasons is northwest.

A.3.4.1. Rainfall Intensities

Rainfall Intensity-duration-frequency (IDF) curves are graphical representations of the probability that a given average rainfall intensity will occur at various event return periods. They are routinely used in water management and form the basis for runoff estimates and sizing of culverts, drain pipes and other water management infrastructure.

Figure A-24 shows Environment Canada's IDF curves for short duration rainfall at Inuvik Airport (obtained from ftp://ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/). These curves are based on data collected from the Inuvik Airport climate station from 1972 to 1994. This provides a baseline for IDF values in the area. Climate change impacts on IDF curves will be discussed in Section A.4.2.

A.3.5. Summary

In general, the following long-term trends have been observed at Inuvik Airport:

- A strong warming trend has been observed that is seasonally variable with fall and winter increases accounting for the majority of the annual air temperature increases.
- The air freezing index has been decreasing with time, reflecting the long-term warming trend.
- There has been an overall slight decrease in the seasonal and annual occurrence of freeze-thaw cycles.
- Precipitation totals have been decreasing with time.
- No clear trends in extreme climatic events were observed.

A.4. CLIMATE CHANGE PROJECTIONS

A.4.1. Long-Term Changes

Typically two approaches are used in engineering design to project climate change: i) extrapolating recent historical climatic trends into the future, and ii) using complex global circulation models (GCMs) that simulate the complex interaction between greenhouse gas and aerosol emissions and their impact on the dynamic and physical processes, interactions, and feedbacks of the climate system. Extrapolation of historical climate data works best when the data record is continuous and over a long period and when projecting not too distant into the future (e.g., ten to twenty years as opposed to fifty years or more). Extrapolation of the most recent climate trend can be subjective, as different rates can be obtained depending on the timing and period of the data set being projected. Climatologists typically consider “normal” climate based on thirty-year averages.

Representative Concentration Pathways (RCP) are greenhouse gas concentration trajectories which provide input to climate change models based on four possible scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). The four scenarios are defined by their respective radiative forcing values for the year 2100: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (IPCC, 2013). For this analysis, RCP4.5 and RCP8.5 were selected as moderate and conservative estimates, respectively.

Climate change projections from the Canadian Centre for Climate Modelling and Analysis (CCCma), obtained from <http://www.cccma.ec.gc.ca>, were considered for projected trends in mean annual air temperature and mean annual precipitation. The CanESM2 and CanRCM4 models were considered in the RCP4.5 and RCP8.5 experiments for the previously listed climate parameters. The resulting climate change projections for the Inuvik region are summarized in Table A-5.

Table A-5. Climate change projections for the region around Inuvik for 2045 relative to 1986-2005 values (Environment Canada).

Model	Change in Mean Annual Air Temperature (°C)	Change in Mean Annual Precipitation (%)
CanESM2 RCP4.5	3-4	10-20
CanESM2 RCP8.5	3-4	20-40
CanRCM4 RCP4.5	3-4	5-10
CanRCM4 RCP8.5	3-4	10-20

Projections provided by the Community Earth System Model (CESM¹), which is a fully-coupled, global climate model that provides state-of-the-art simulations of the Earth's past, present, and

¹ <http://www2.cesm.ucar.edu>

future climate states, are provided by the National Science Foundation (NSF) and the U.S. Department of Energy (DOE). The model allows for seasonal projections using the RCP8.5 scenario.

Table A-6. Annual and seasonal climate change projections for 2036-2055 relative to 1986-2005 values (Climate Reanalyzer).

Climate Parameter	Annual	Winter	Spring	Summer	Fall
Mean Temperature (°C)	2.8-3.0	4.0-4.25	2.0-2.25	1.25-1.5	3.5-3.75
Precipitation (m)	0	0	0	0	0
Freezing Days (°C)	No data available				
Thawing Days (°C)	200-225	0	50-100	100-150	50-100

A.4.2. Extreme Rainfall Events

IDF curves are based on historical precipitation data at a particular climate station. As such, the information conveyed will be invalid for future conditions if precipitation characteristics are predicted to follow a long-term trend, as is the case for this study area. For example, with a trend of increasing precipitation, a current 100-year rainfall event might become a 50-year rainfall event (i.e., twice as frequent). As this might lead to the under-design of drainage systems, development of IDF curves that take into account projected changes in rainfall intensity become an important objective.

For the Inuvik Airport, the online IDF CC Tool, a computerized tool for the development of IDF curves under climate change conditions, was used to generate IDF climate change predictions (<http://www.idf-cc-uwo.ca/>). The tool was developed at the University of Western Ontario in collaboration with the Canadian Water Network, and draws on Environment Canada's IDF dataset.

Climate change projections for Inuvik from the following sources were considered:

- HadGEM2-ES, Met Office Hadley Centre, UK
- IPSL-CM5A-MR, Institute Pierre Simon Laplace, France
- GFDL-CM3, National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory, USA
- NorESM1-M, Norwegian Climate Centre, Norway
- BNU-ESM, College of Global Change and Earth System Science, China
- FGOALS_g2, Institute of Atmospheric Physics and Tsinghua University, China

Of the above projections, the maximum values for RCP4.5 were represented by the GFDL-CM3 projection and the minimum values were represented by the IPSL-CM5A-MR projection. Of the RCP8.5 projections the maximum values were represented by the GFDL-CM3 and FGOALS_g2 projections. The minimum values for RCP8.5 were represented by the BNU-ESM, HadGEM2-ES, and NorESM1-M projections.

Figure A-25 and Figure A-26 present the current IDF values (determined from precipitation data for the period of 1972 to 1994) for each return period, as represented by solid coloured lines, in addition to projected ranges, as represented by coloured shaded areas, for the RCP4.5 and RCP8.5 scenarios, respectively. For the RCP4.5 scenario, the historical values fall within the range of predictions. For the RCP8.5 scenario, the historical values fall at the lower bound or below the range of predictions.

A.5. SUMMARY

Over the last half century, the Canadian Arctic has experienced a significant increase in temperature and a decrease in precipitation. Analysis of 57 years of climate data from Inuvik Airport demonstrates both these trends. Over the thirty-year period from 1986 to 2015, air temperatures in the area have been warming at an average rate of 0.8°C/decade. Temperature anomalies appear to be associated with the Pacific Decadal Oscillations (PDO), although the correlation has waned over the past decade. Most of the warming has occurred during the fall and winter. Over the same thirty year period, precipitation totals in the area have been decreasing at an average rate of about 16 mm/decade. Most of the decrease in precipitation has occurred during the winter while precipitation totals have been increasing during the summer.

All global climate models project increases in temperature and precipitation over the Canadian Arctic, including the study area. Projected changes in air temperature for the area are consistent with the average trend from the past thirty years. Projected changes in precipitation show an overall increase, contrary to the decreasing trend observed over the past thirty years.

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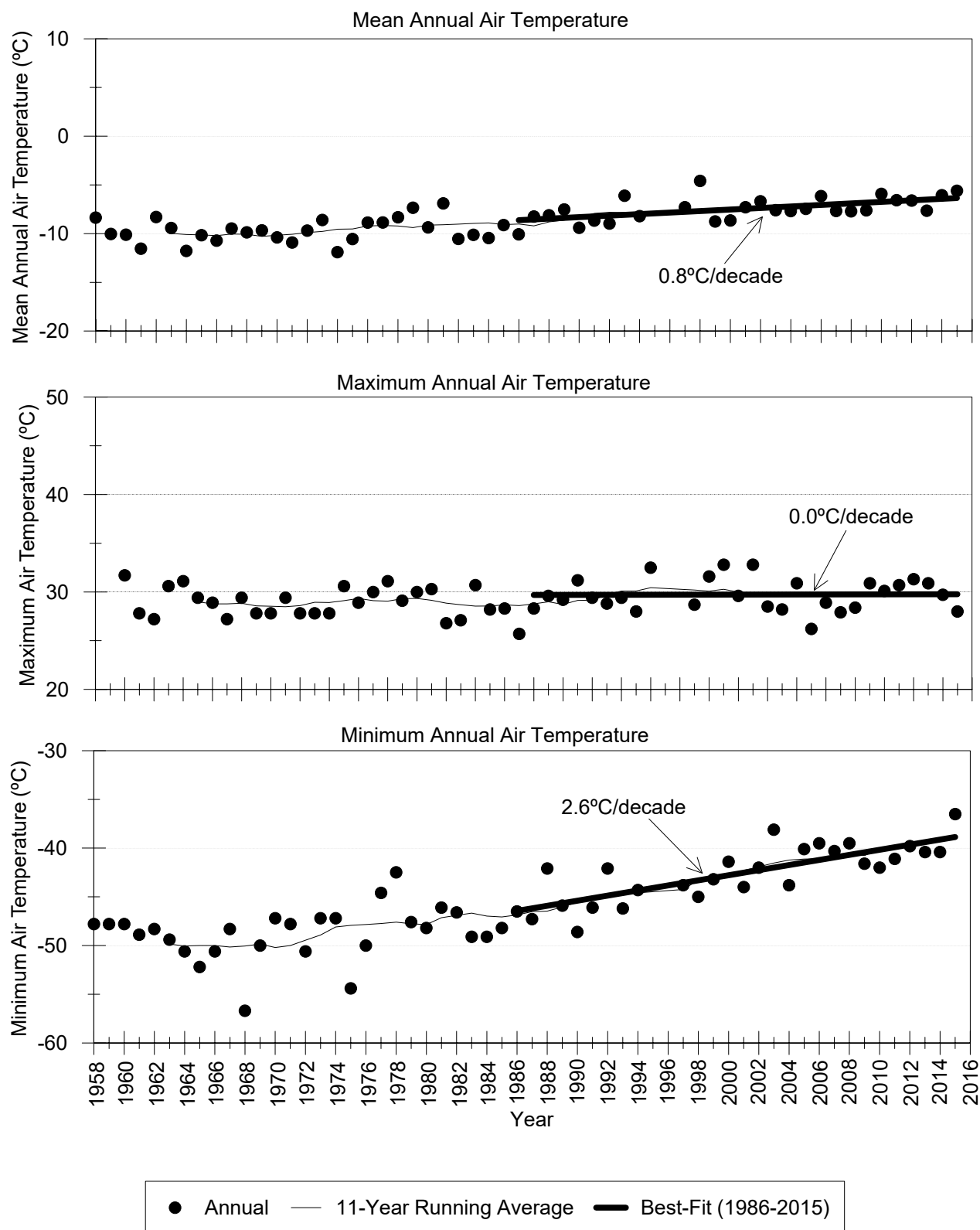
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FIGURES



Note: Sufficient data to calculate annual values not available for 1995-1996.

Figure A-2 Inuvik Annual Mean, Maximum, & Minimum Temperatures

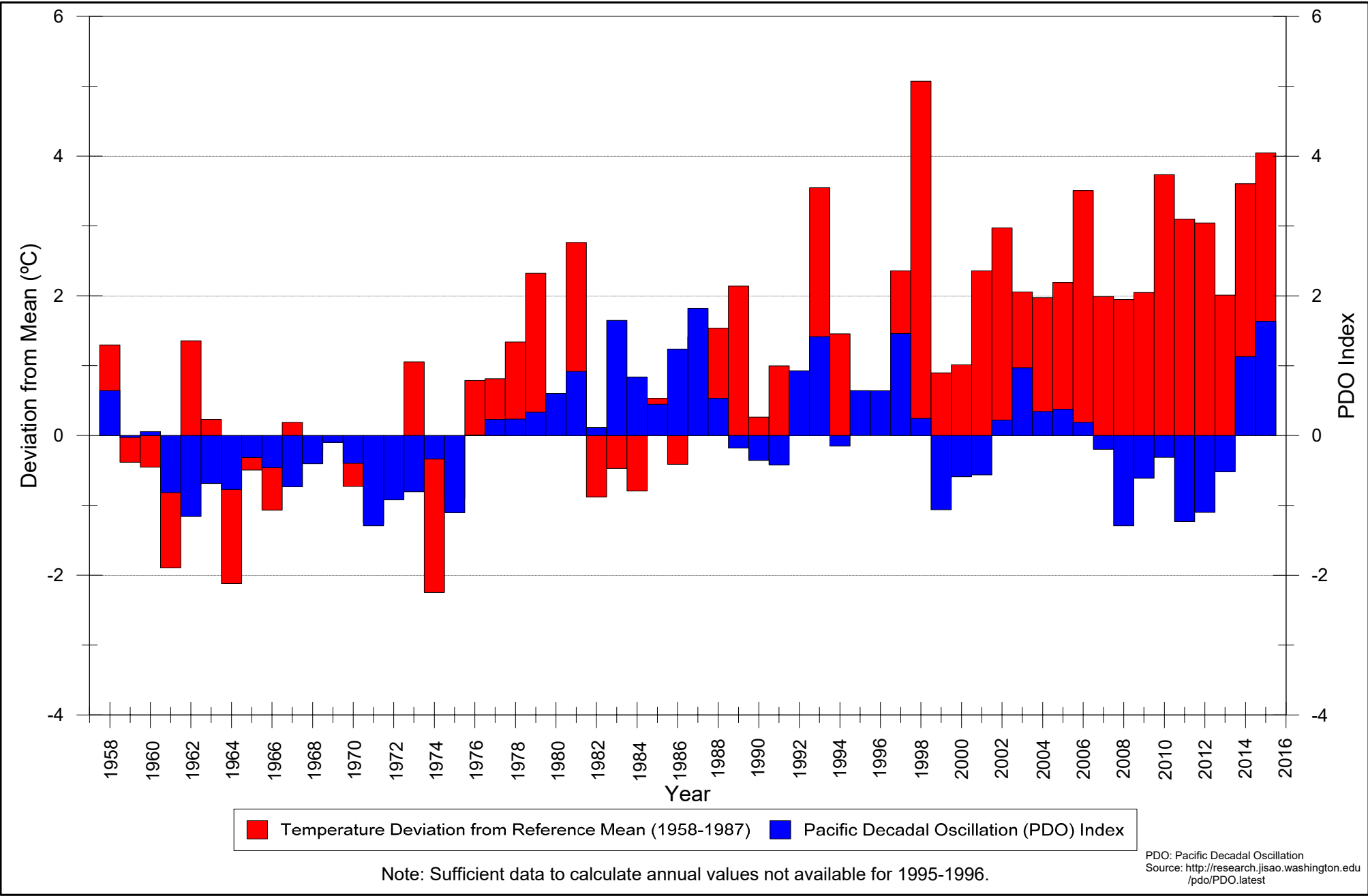
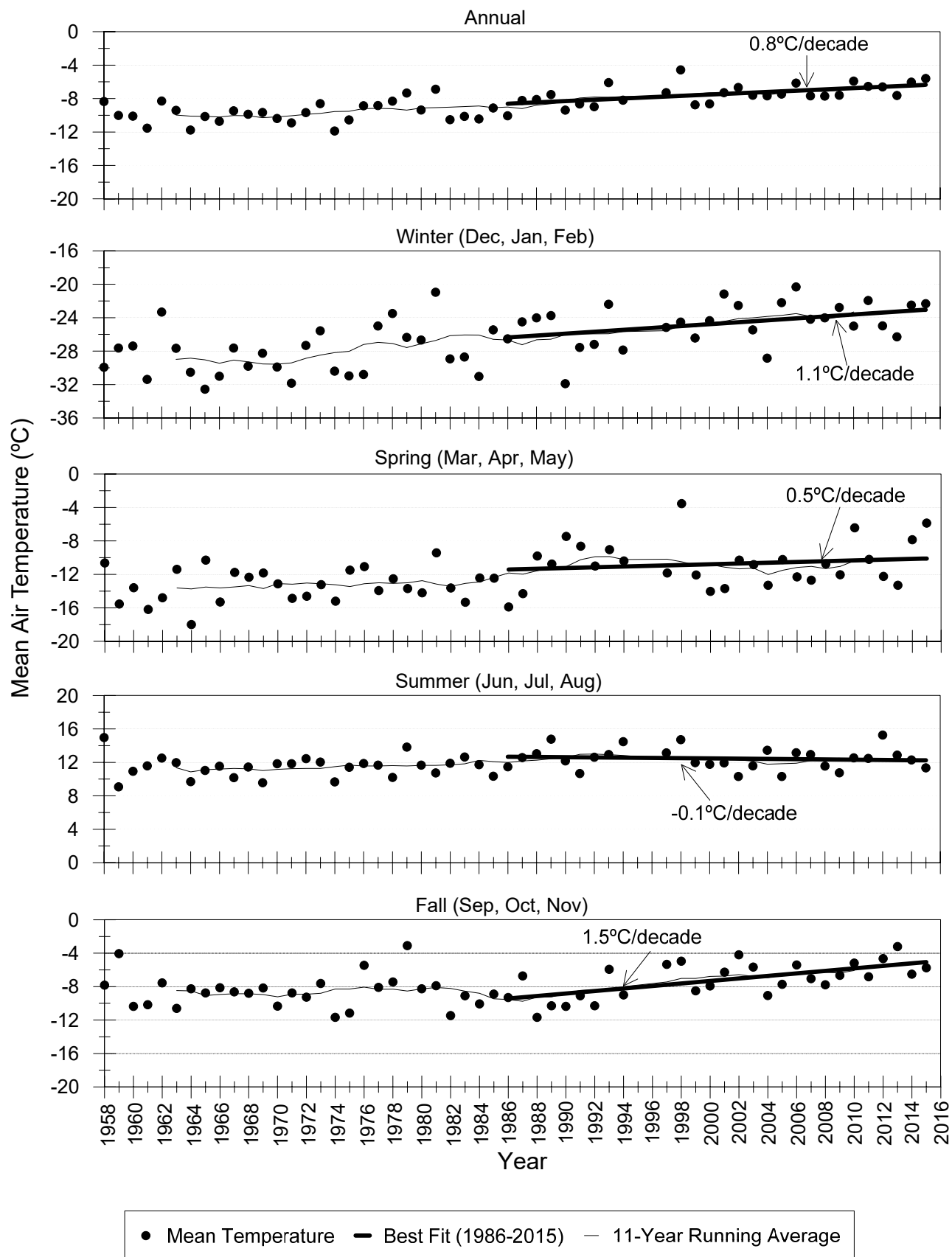
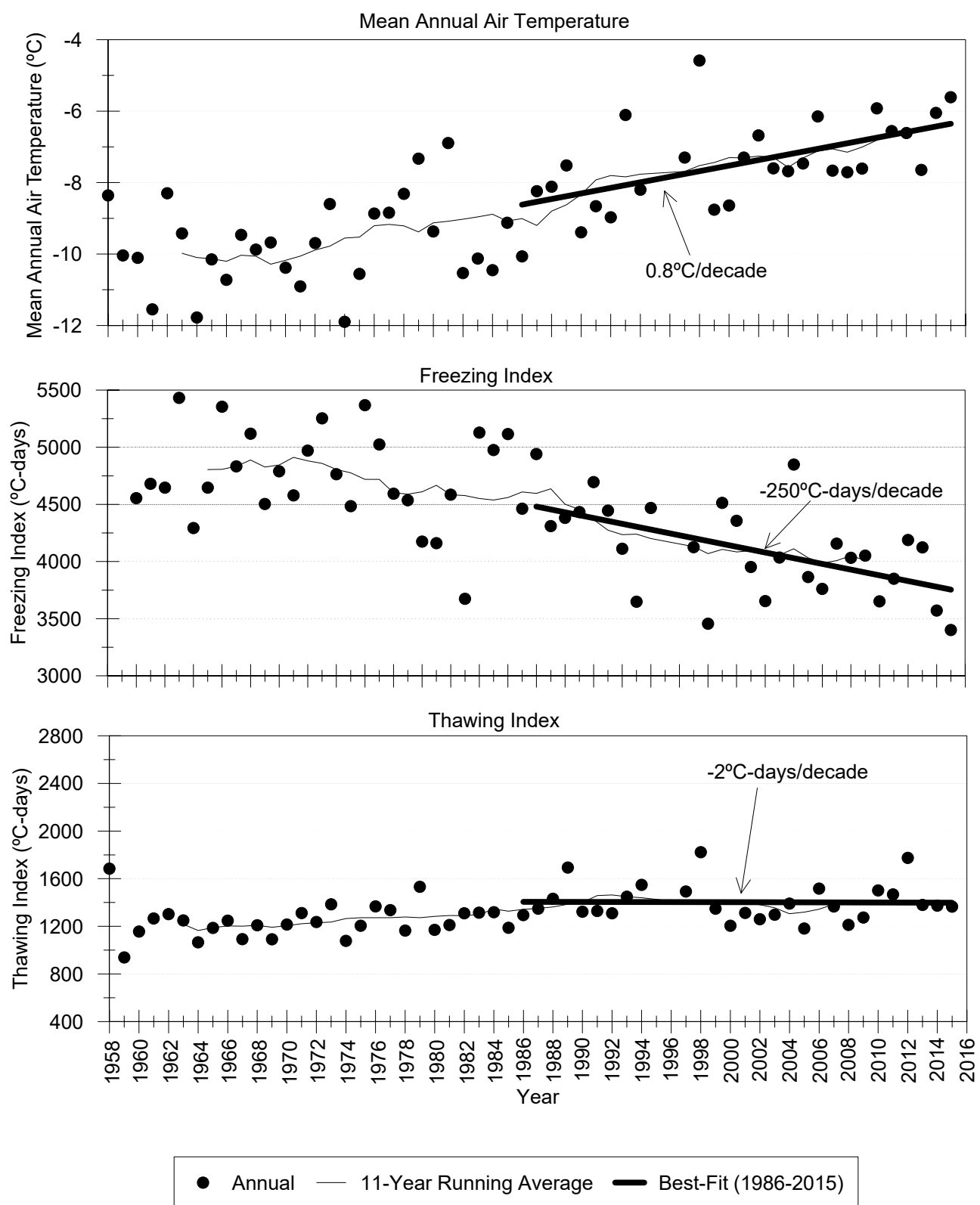


Figure A-3 Inuvik Temperature Deviations from Reference Mean and PDO Index



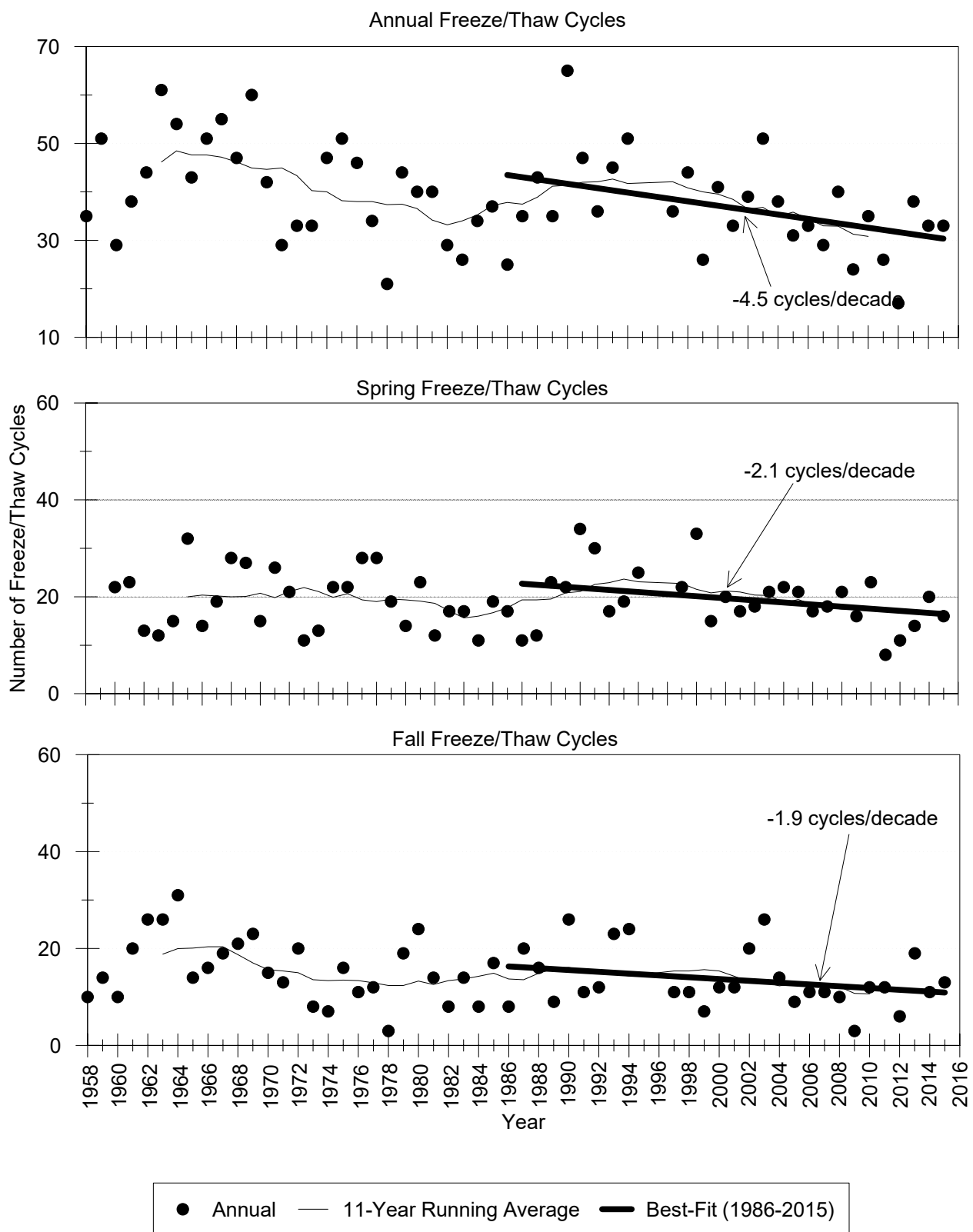
Note: Sufficient data to calculate annual values not available for 1995-1996.

Figure A-4 Inuvik Annual and Seasonal Air Temperatures



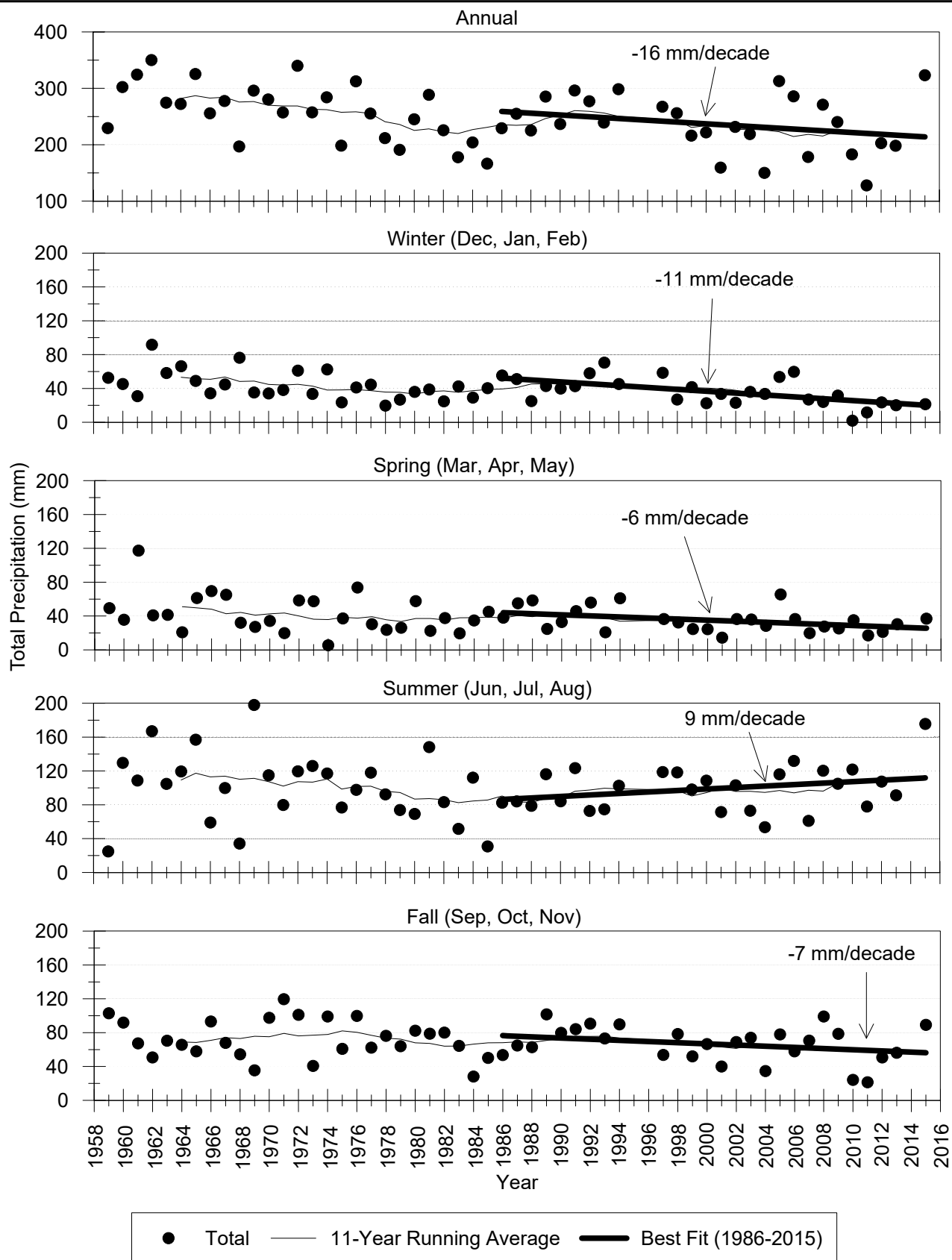
Note: Sufficient data to calculate annual values not available for 1995-1996.

Figure A-5 Inuvik Historical Freezing and Thawing Indices



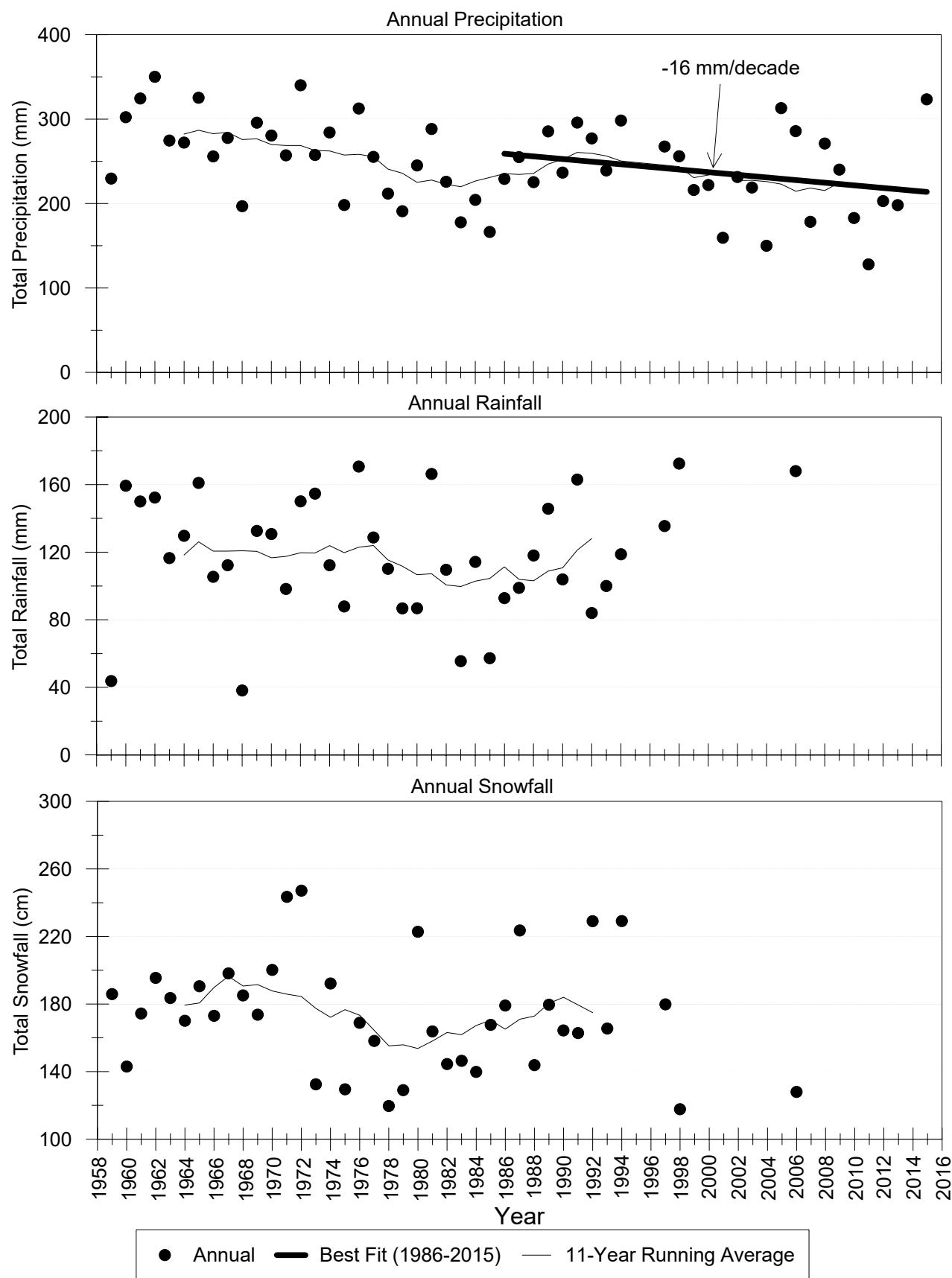
Note: A freeze/thaw cycle is considered as having a maximum daily air temperature above 0°C and minimum daily air temperature below -1°C. Sufficient data to calculate annual values not available for 1995-1996.

Figure A-6 Inuvik Historical Freeze/Thaw Cycles



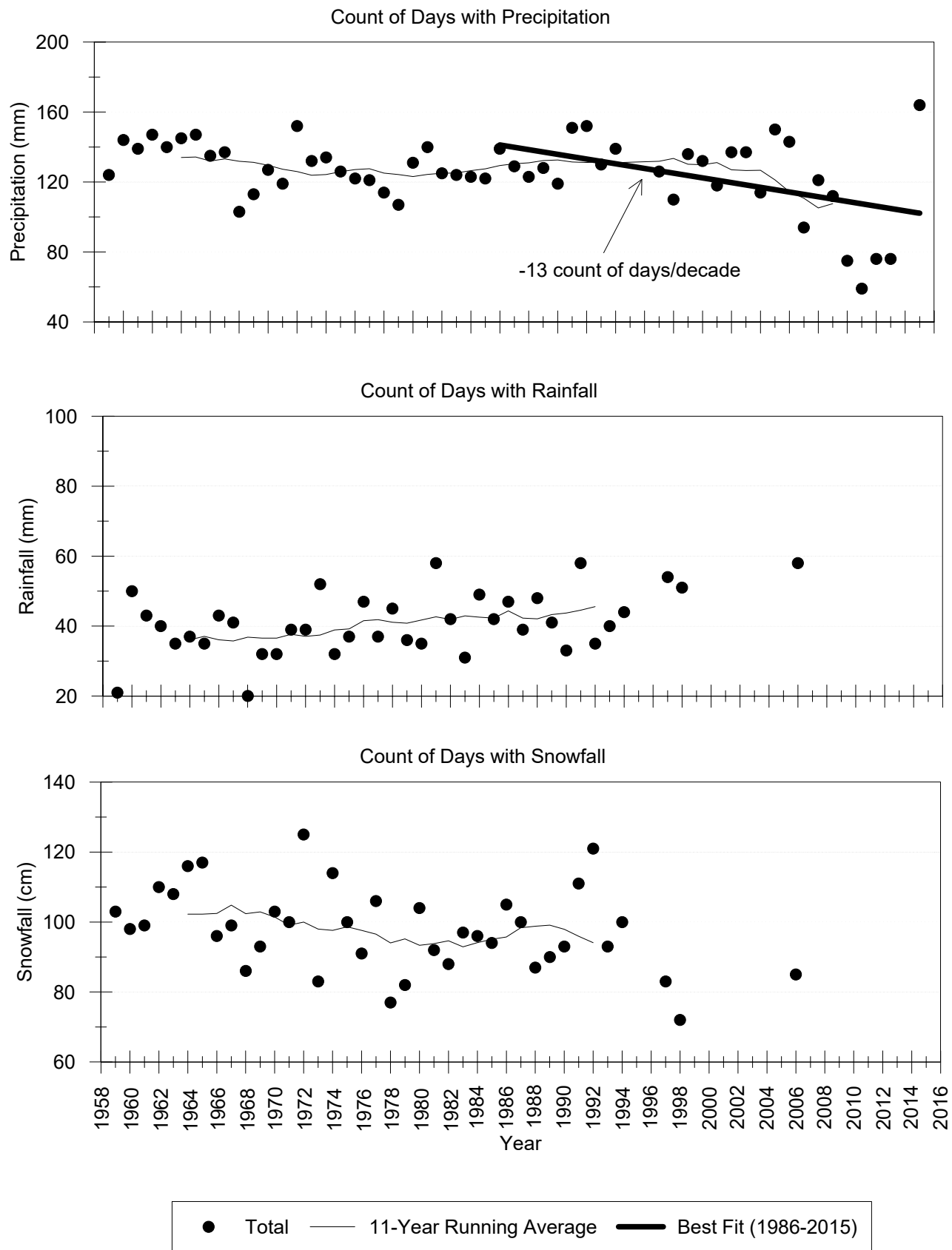
Sufficient data to calculate annual values not available for 1958, 1995-1996, and 2014.

Figure A-7 Inuvik Seasonal Precipitation



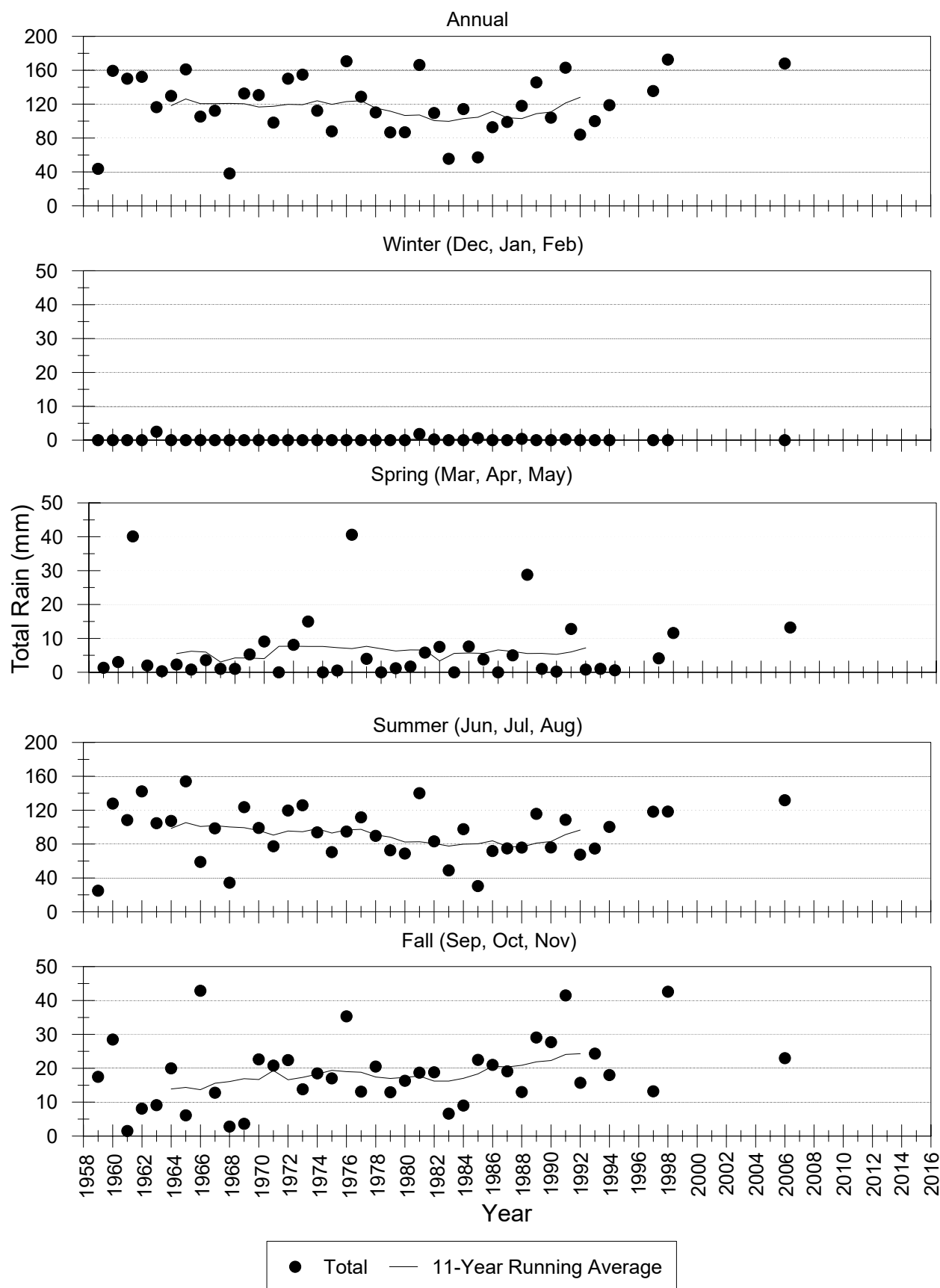
Note: Sufficient data to calculate annual precipitation values not available for 1958, 1995-1996, and 2014. Sufficient data to calculate annual rain and snow values not available for 1958-1960, 1995-1996, 1999-2005, and 2007-2015.

Figure A-8 Inuvik Annual Precipitation



Note: Sufficient data to calculate annual precipitation values not available for 1958, 1995-1996, and 2014. Sufficient data to calculate annual rain and snow values not available for 1958-1960, 1995-1996, 1999-2005, and 2007-2015.

Figure A-9 Inuvik Count of Days with Precipitation



Note: Sufficient data to calculate annual values not available for 1958-1960, 1995-1996, 1999-2005, and 2007-2015.

Figure A-10 Inuvik Seasonal Rainfall

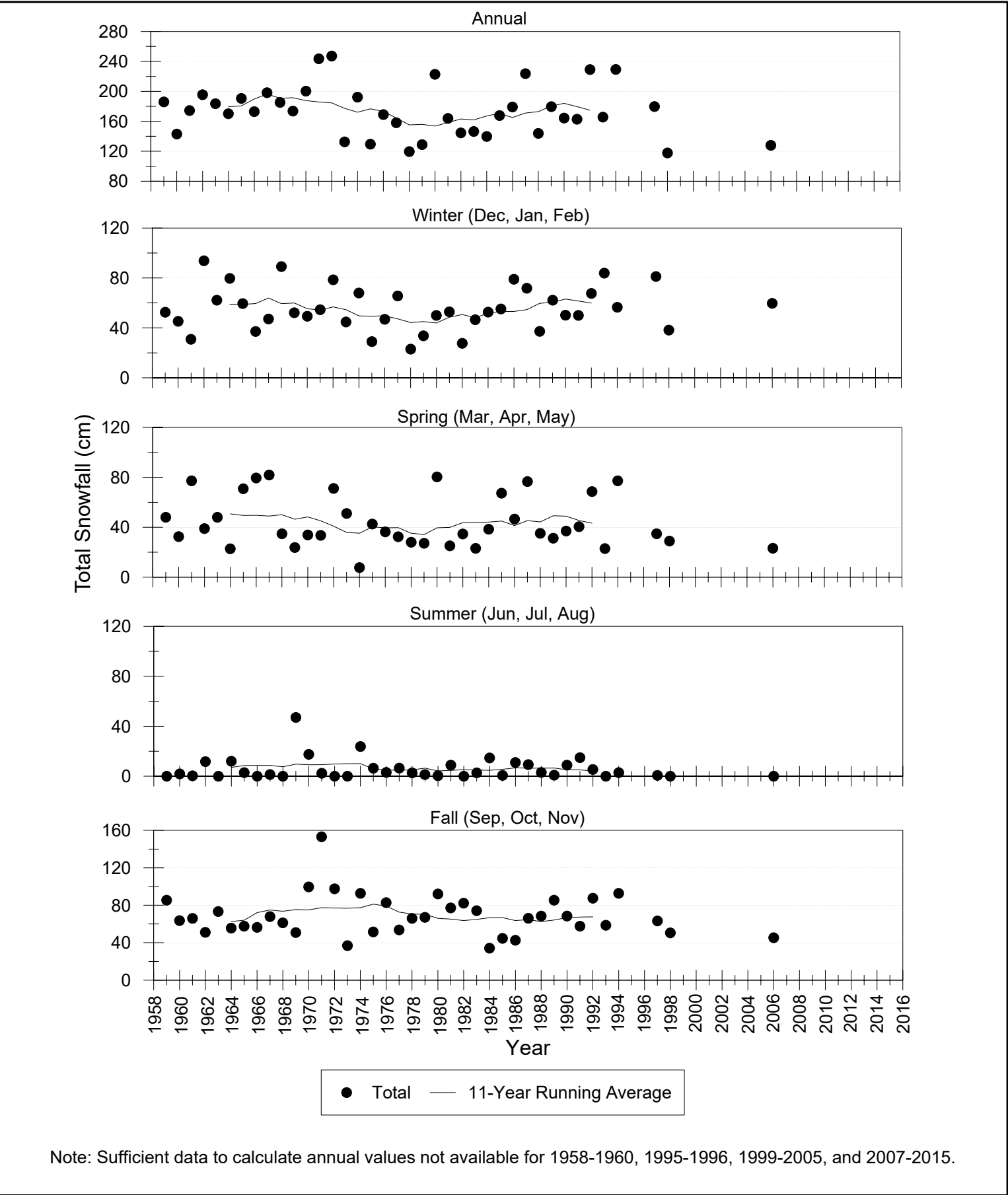


Figure A-11 Inuvik Seasonal Snowfall

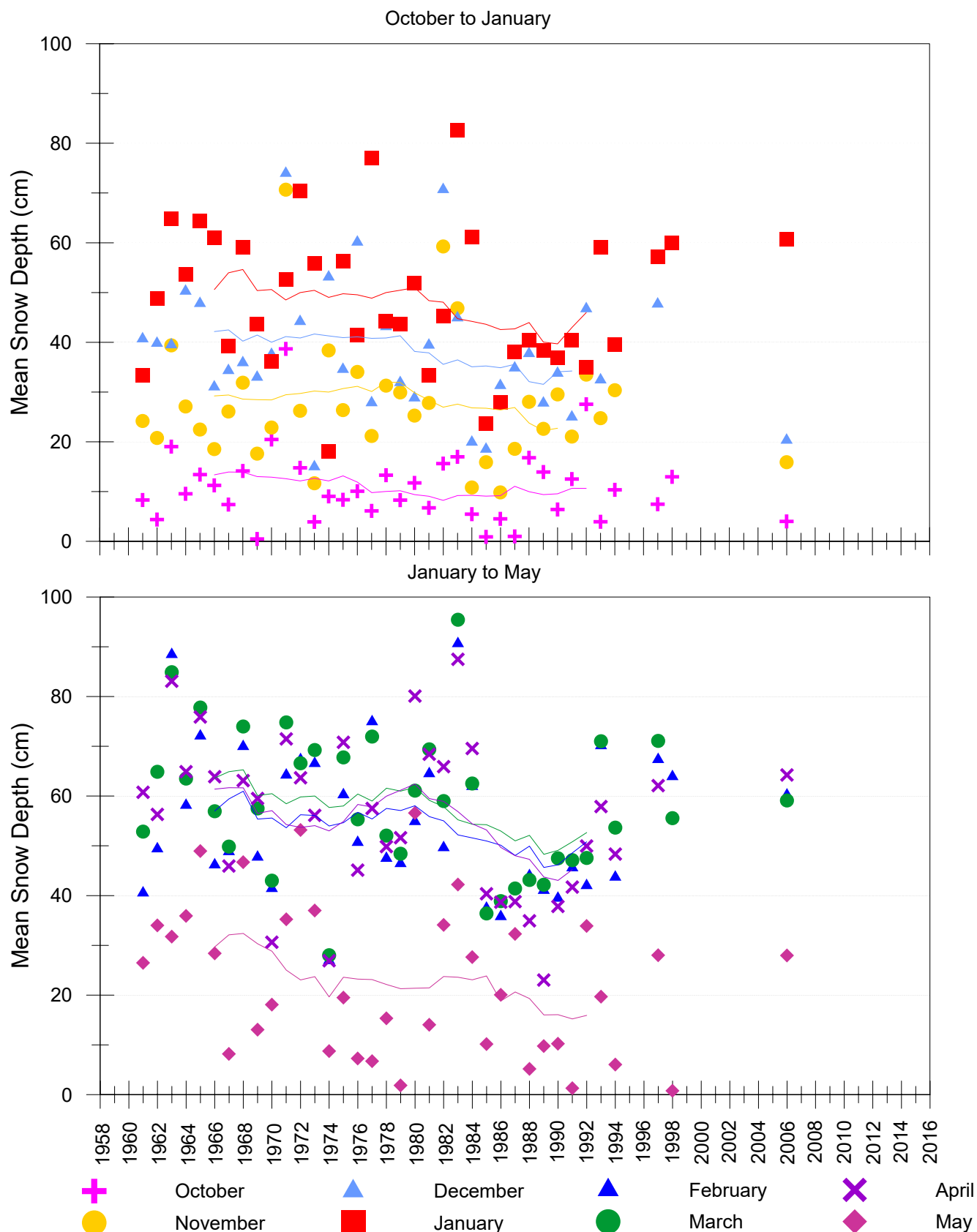
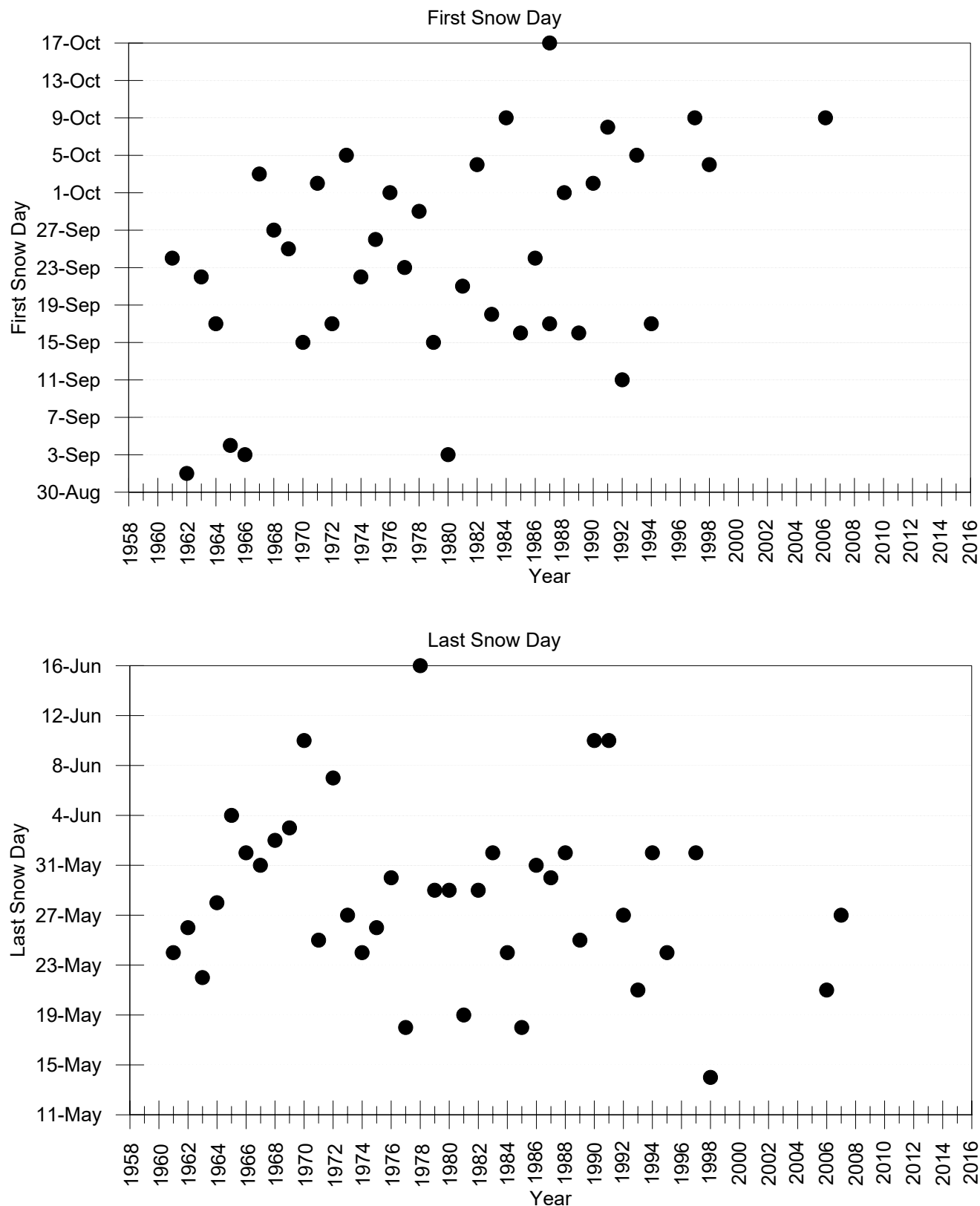


Figure A-12 Inuvik Historical Monthly Snow Depths



Note: Sufficient data to calculate annual values not available for 1958-1960, 1995-1996, 1999-2005, and 2007-2015.

Figure A-13 Inuvik First and Last Snow Days

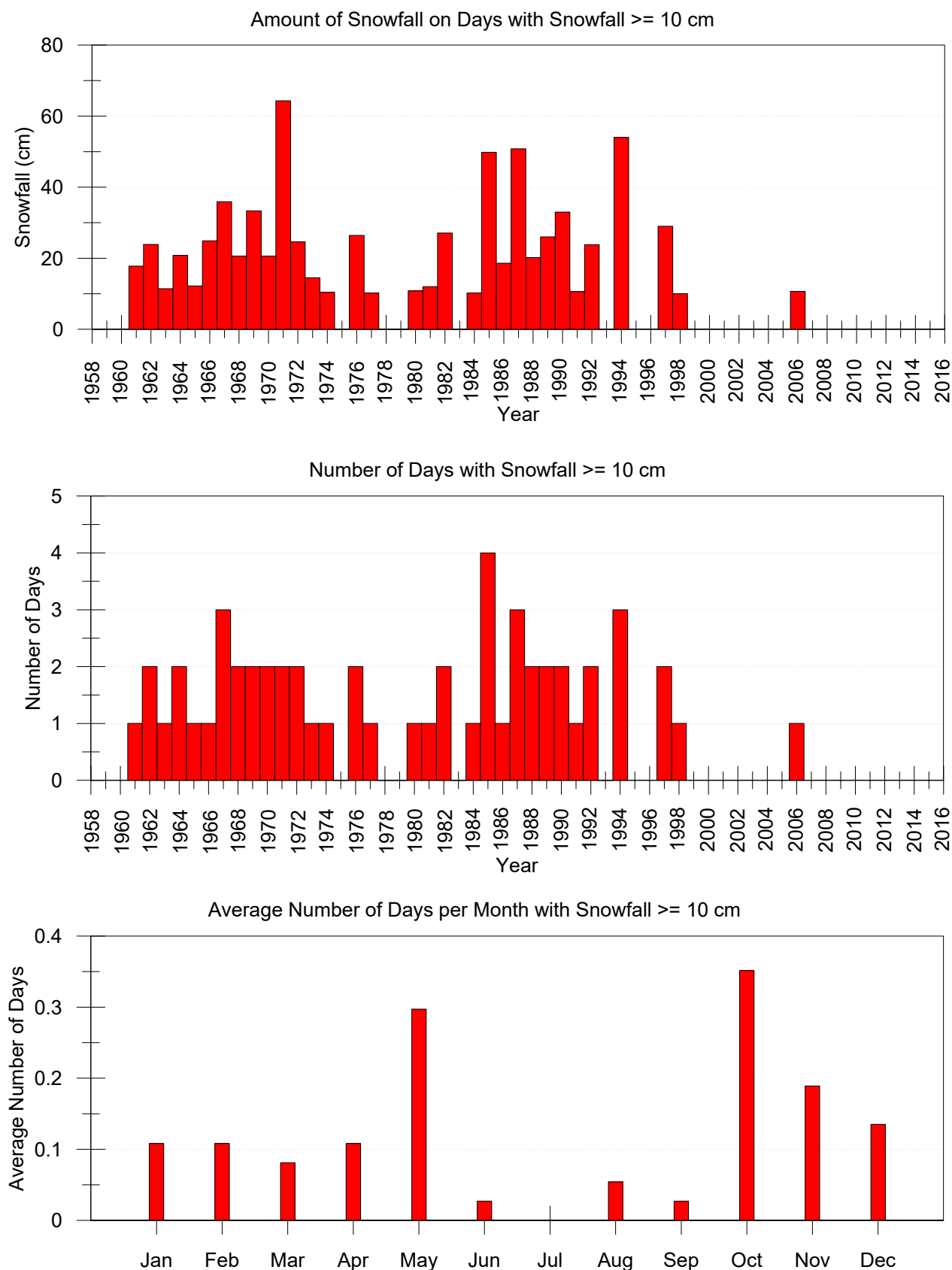


Figure A-14 Inuvik Snowfall Overview

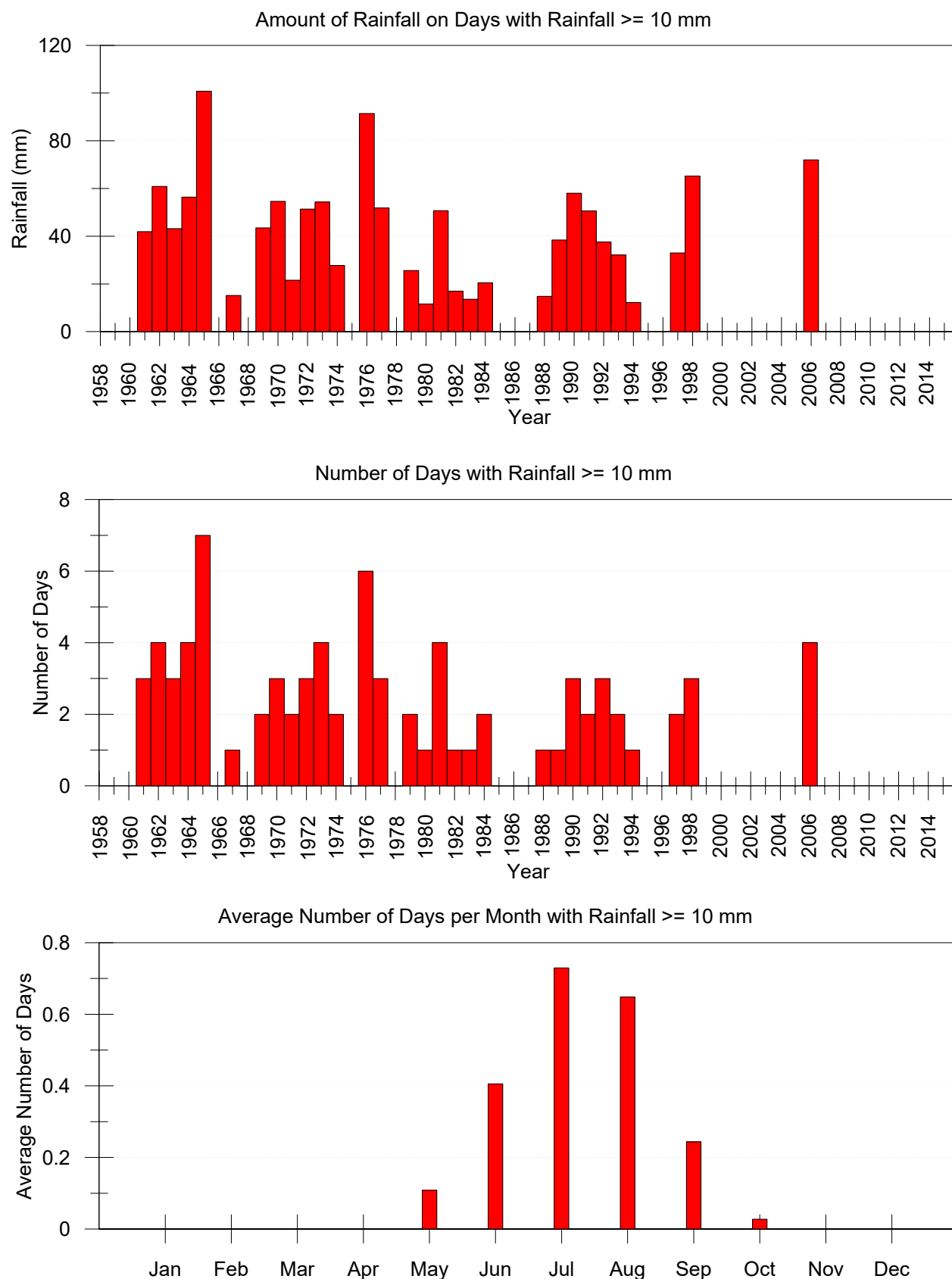


Figure A-15 Inuvik Rainfall Overview

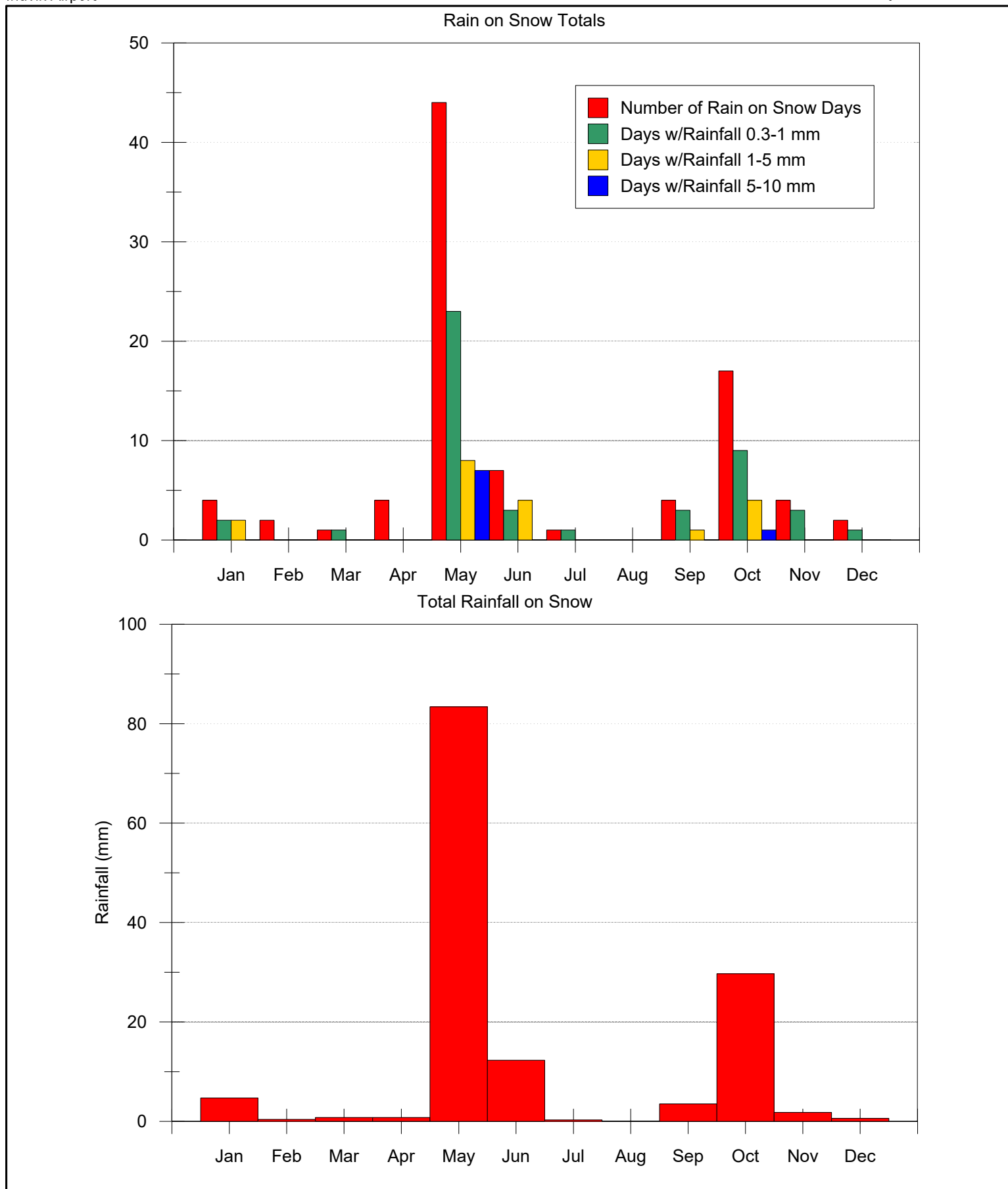


Figure A-16 Inuvik Historical Rain on Snow Overview (1958-2006)

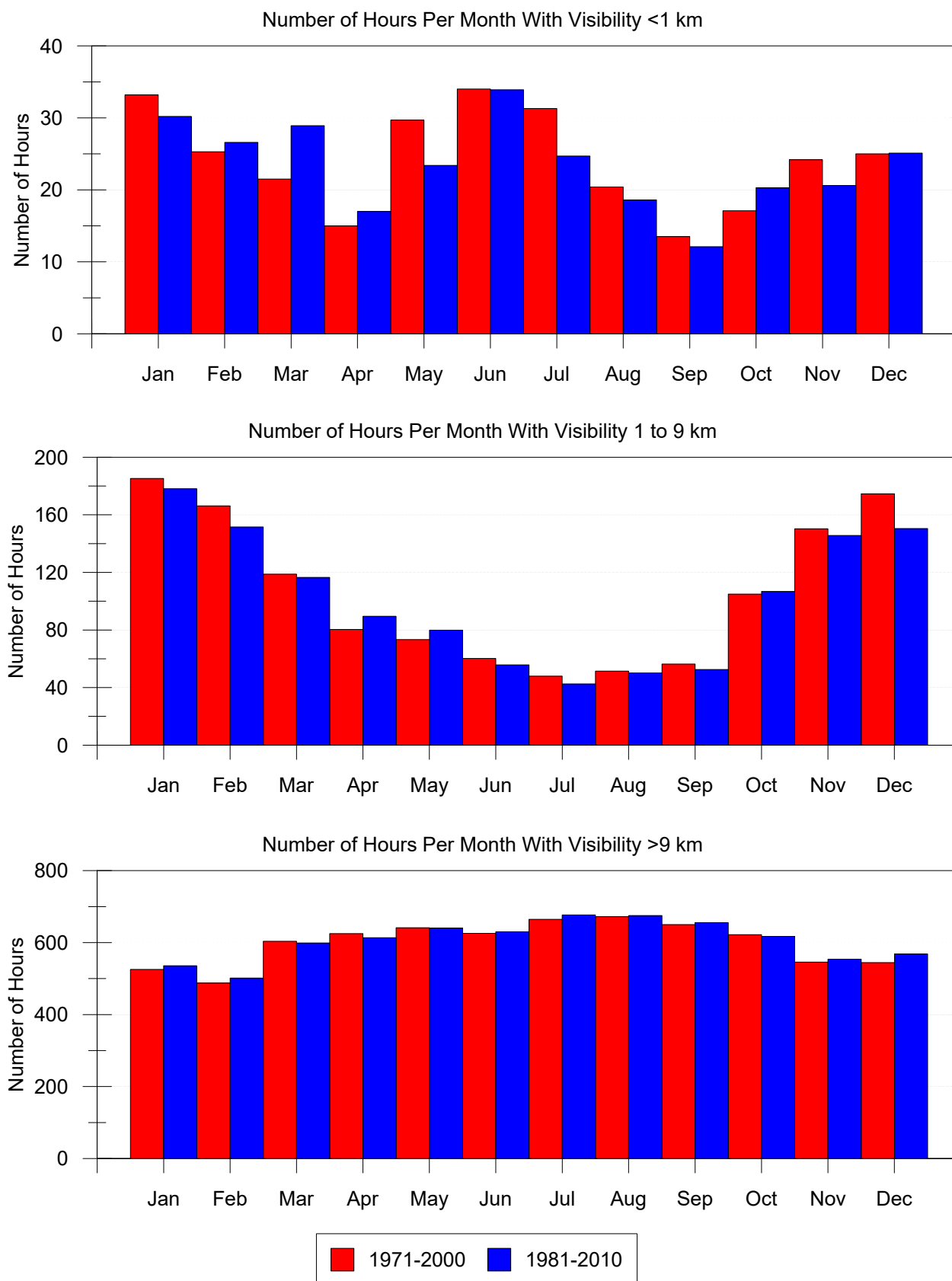
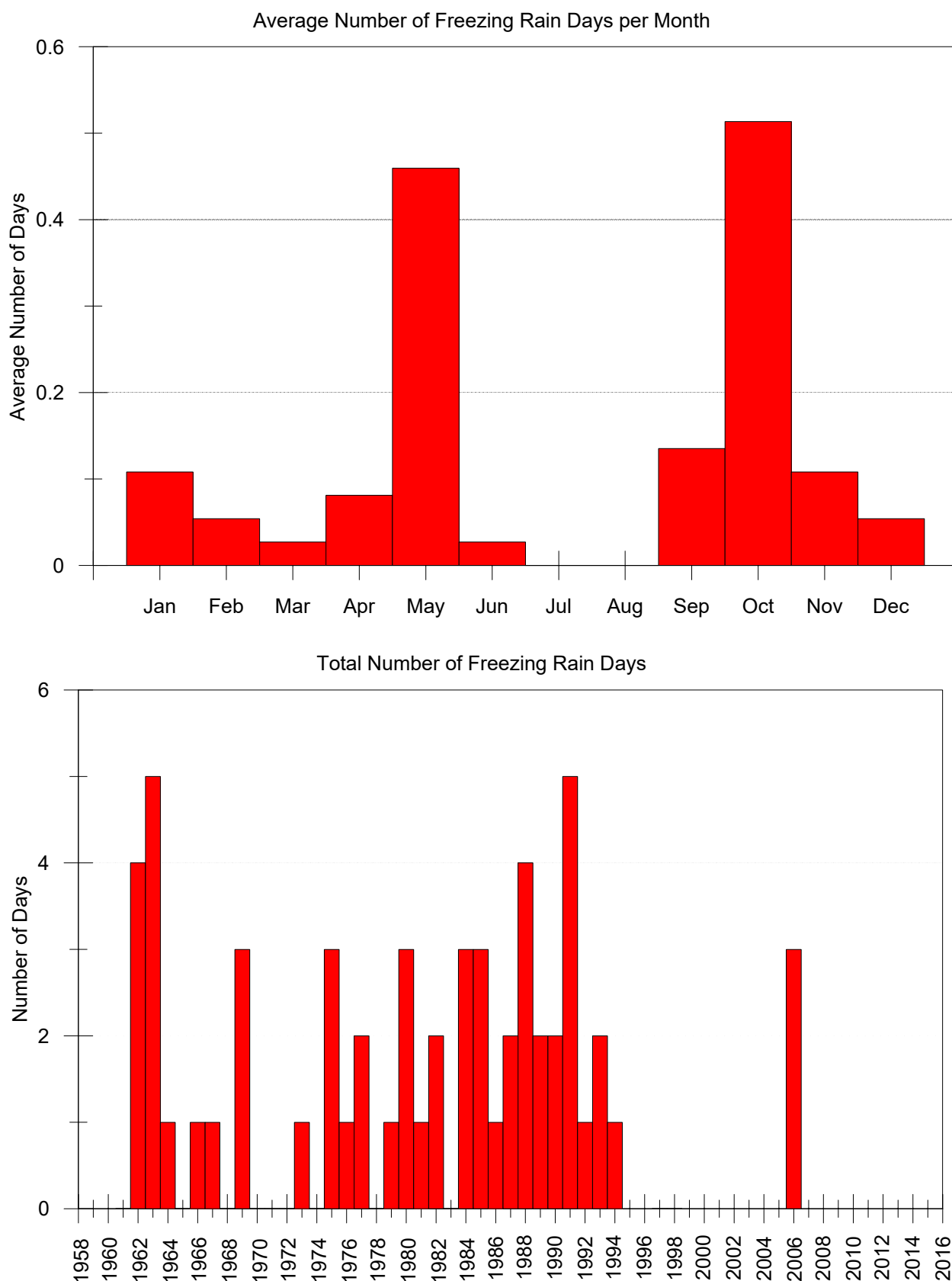
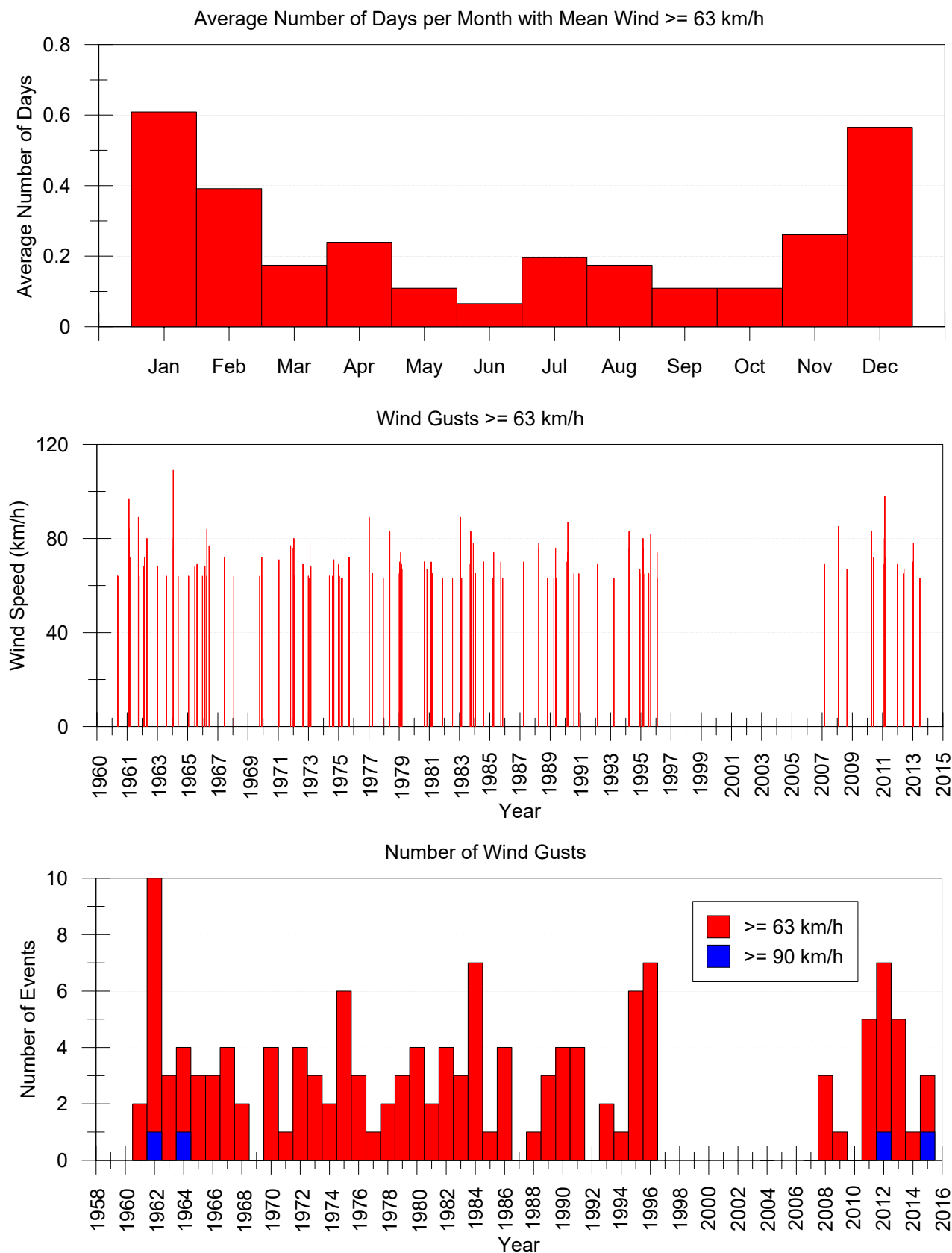


Figure A-17 Inuvik Historical Fog and Visibility



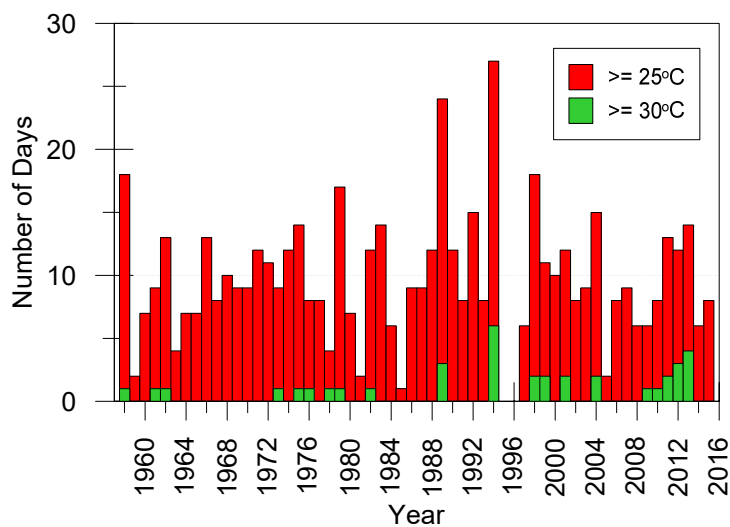
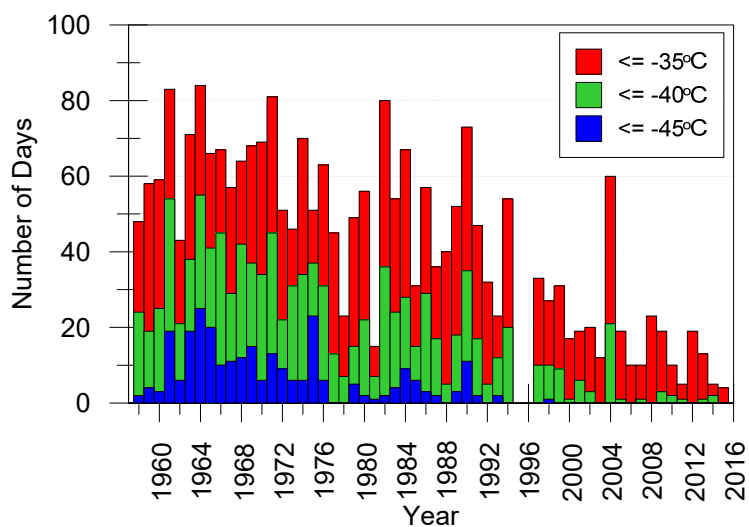
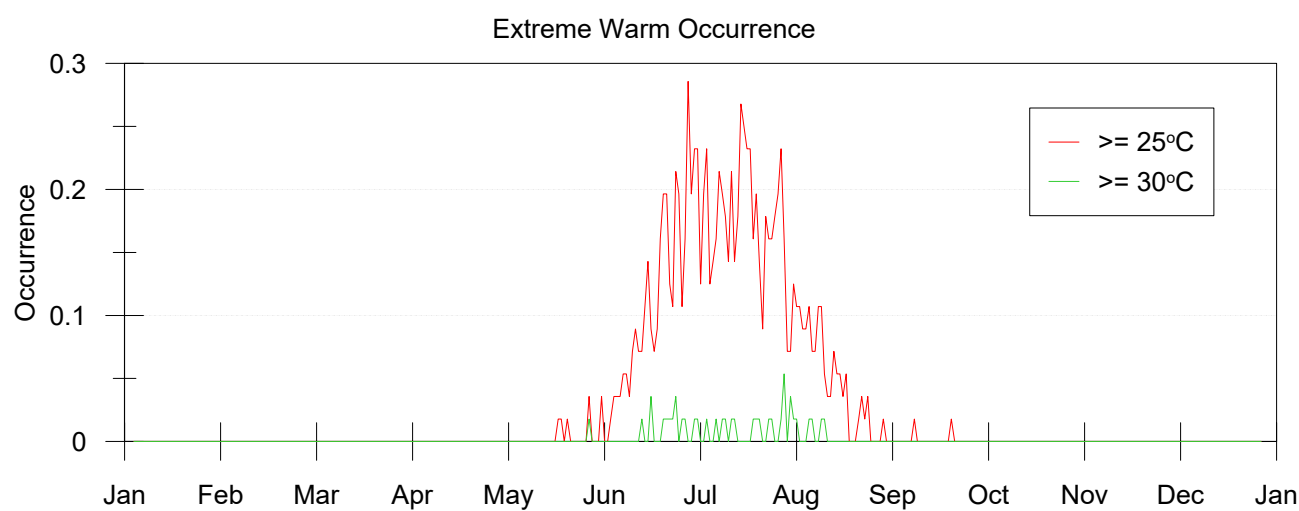
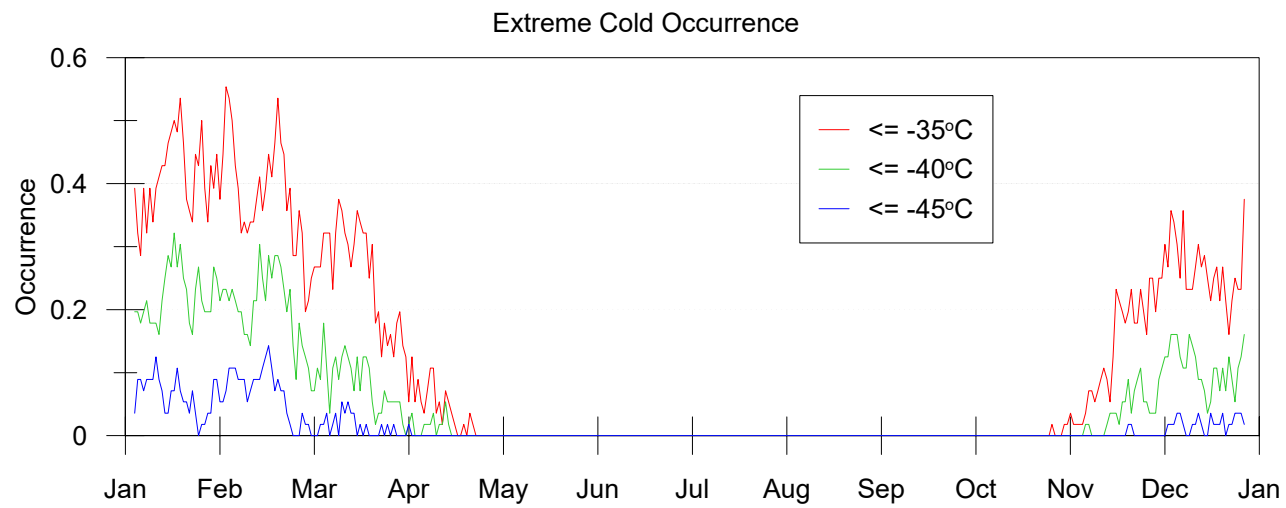
Note: Sufficient data to calculate annual values not available for 1958-1960, 1995-1996, 1999-2005, and 2007-2015.

Figure A-18 Inuvik Historical Freezing Precipitation Overview



Note: Sufficient data to calculate annual values not available for 1958-1960, 1997-2003, and 2005-2006.

Figure A-19 Inuvik Historical Wind Gusts Overview



Note: Sufficient data to calculate annual values not available for 1995-1996.

Figure A-20 Inuvik Extreme Temperatures Overview

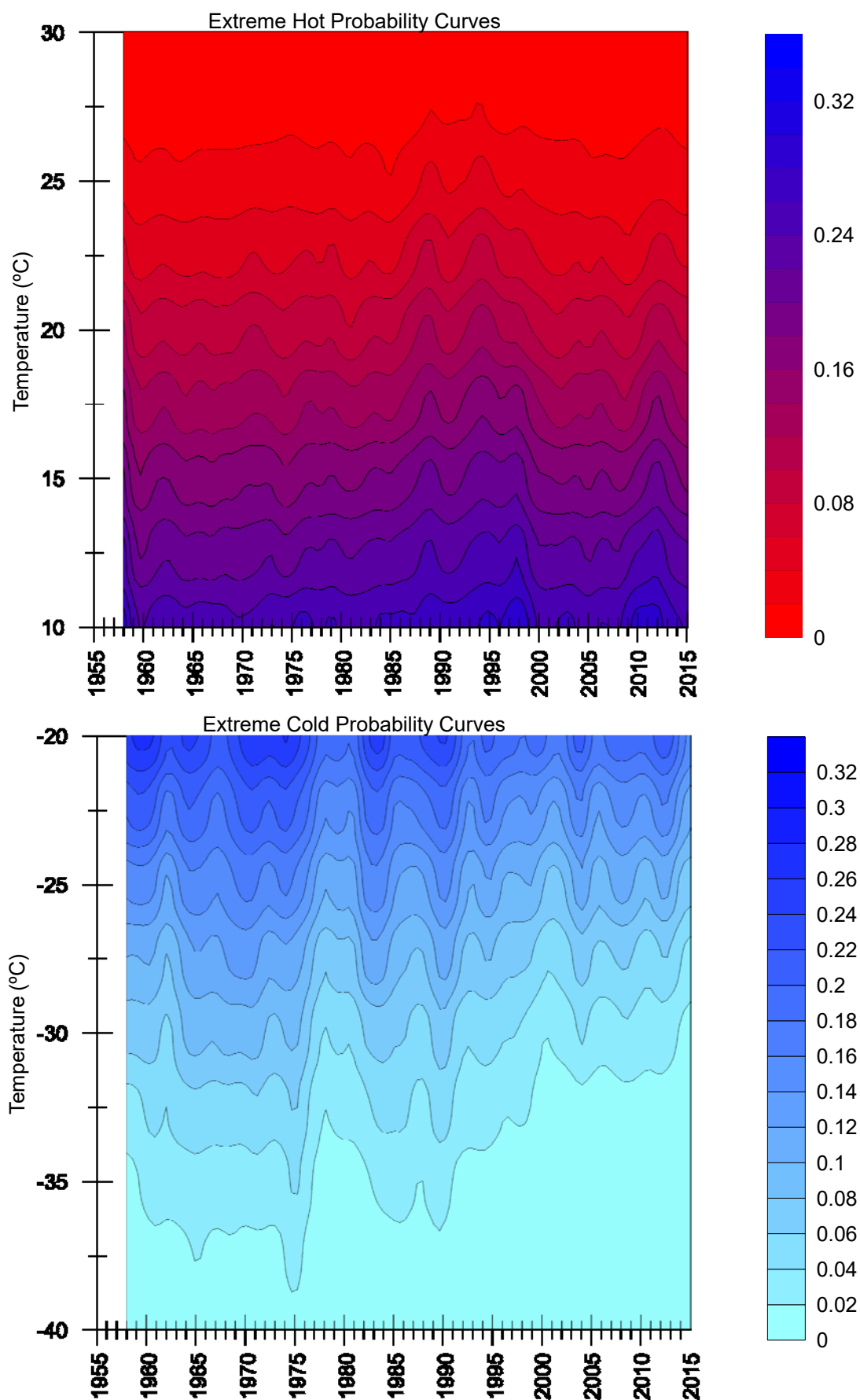
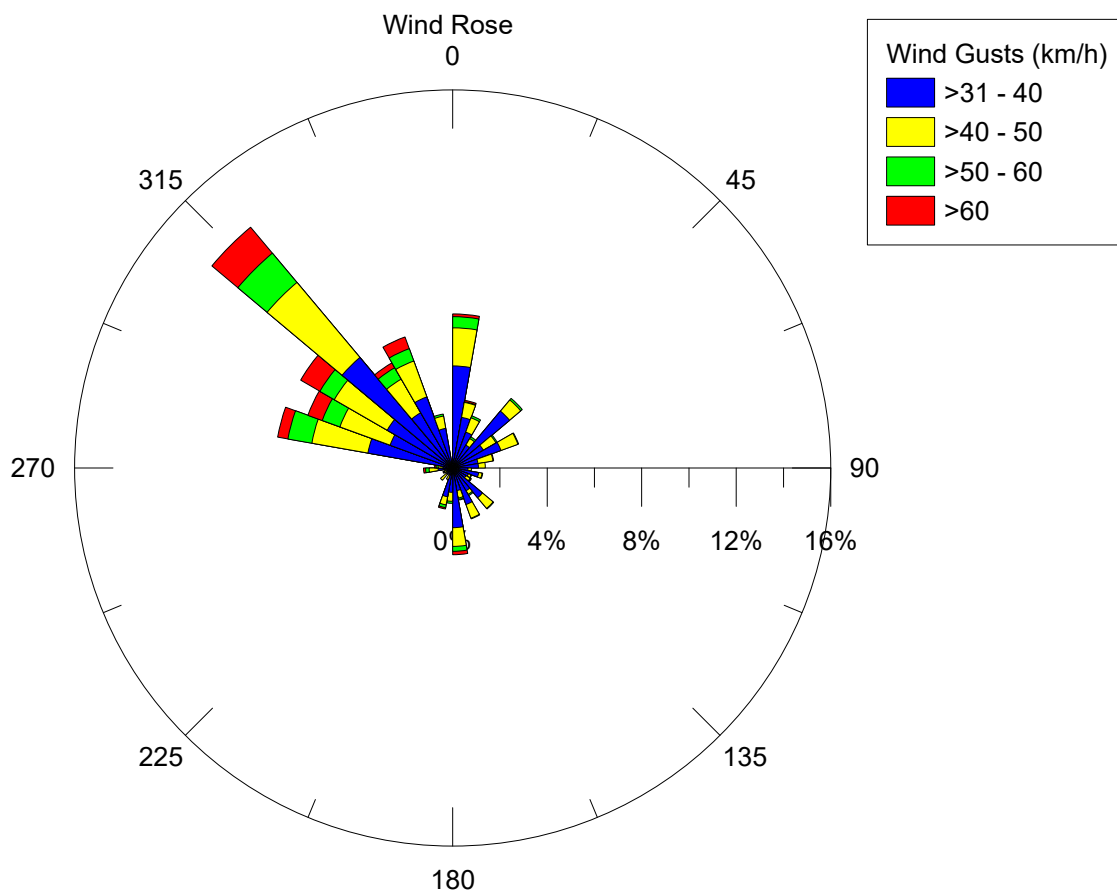
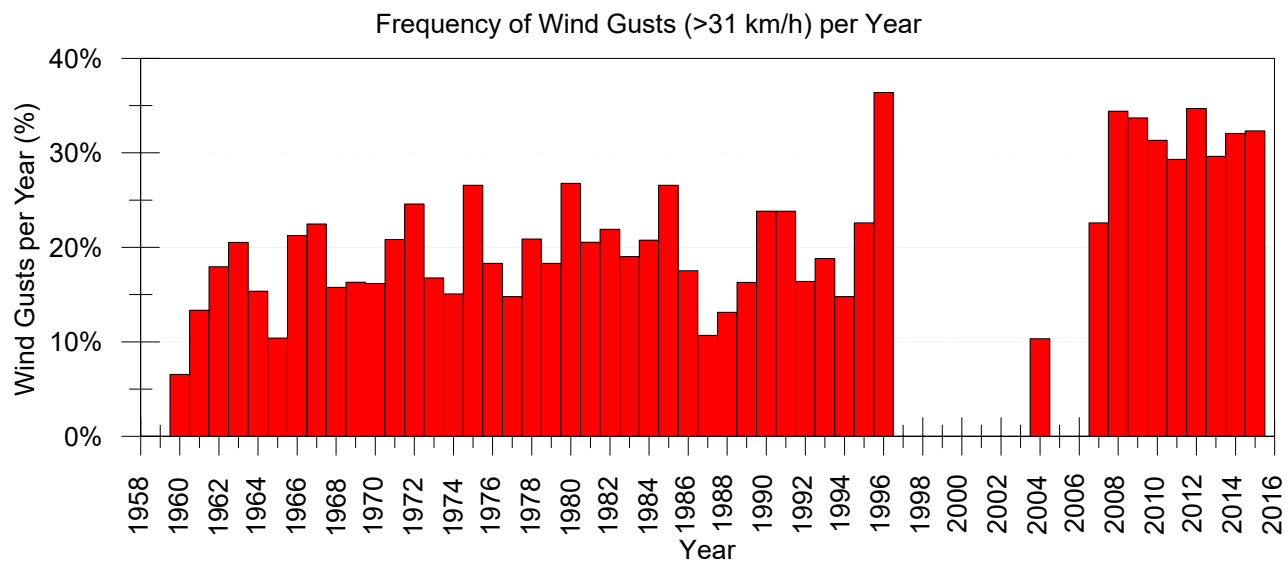


Figure A-21 Inuvik Historical Temperature Probability Curves



Note: Sufficient data to calculate annual values not available for 1958-1960, 1997-2003, and 2005-2006.

Figure A-22 Inuvik Historical Wind Rose and Gusts Per Year

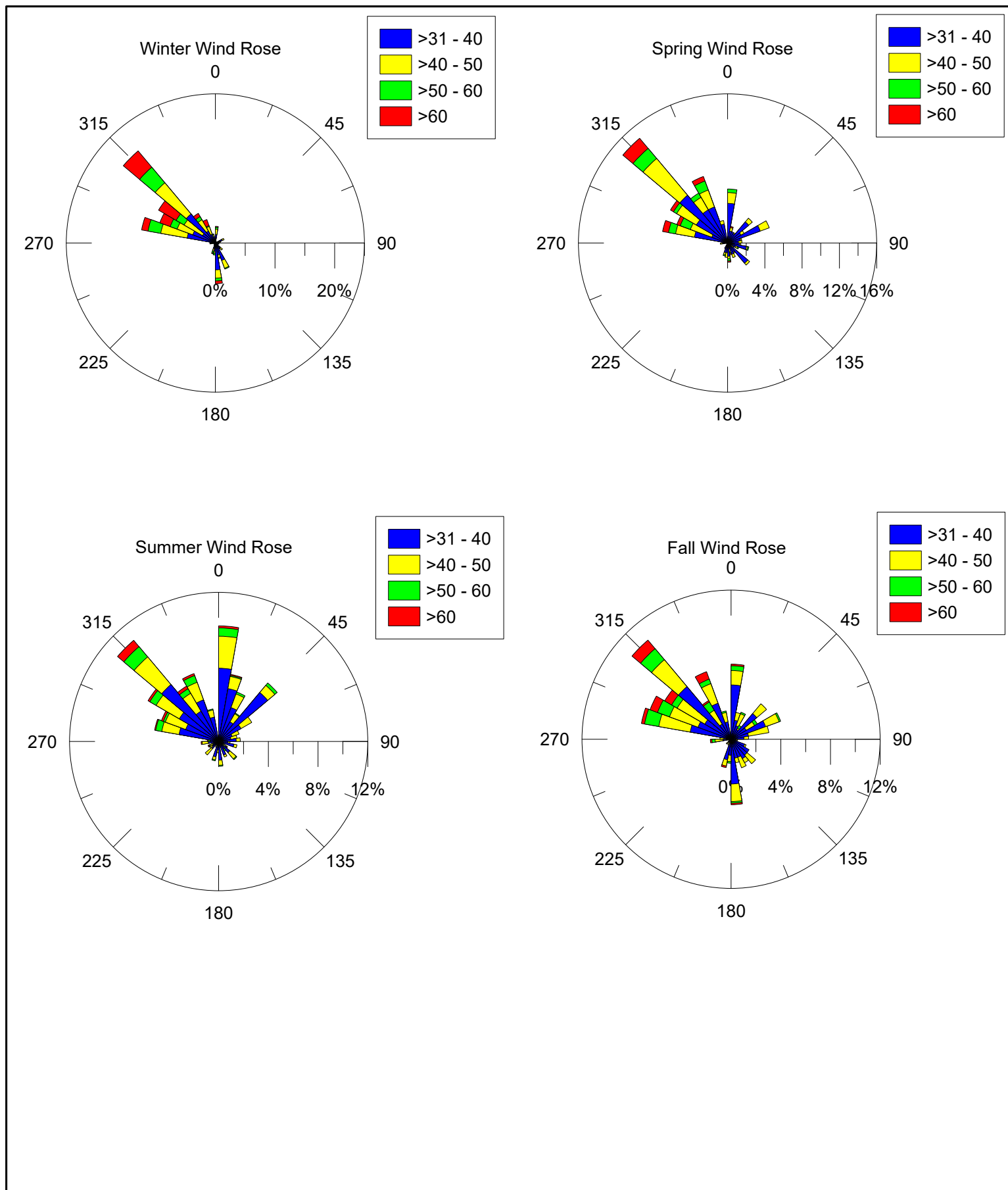


Figure A-22 Inuvik Historical Seasonal Wind Roses

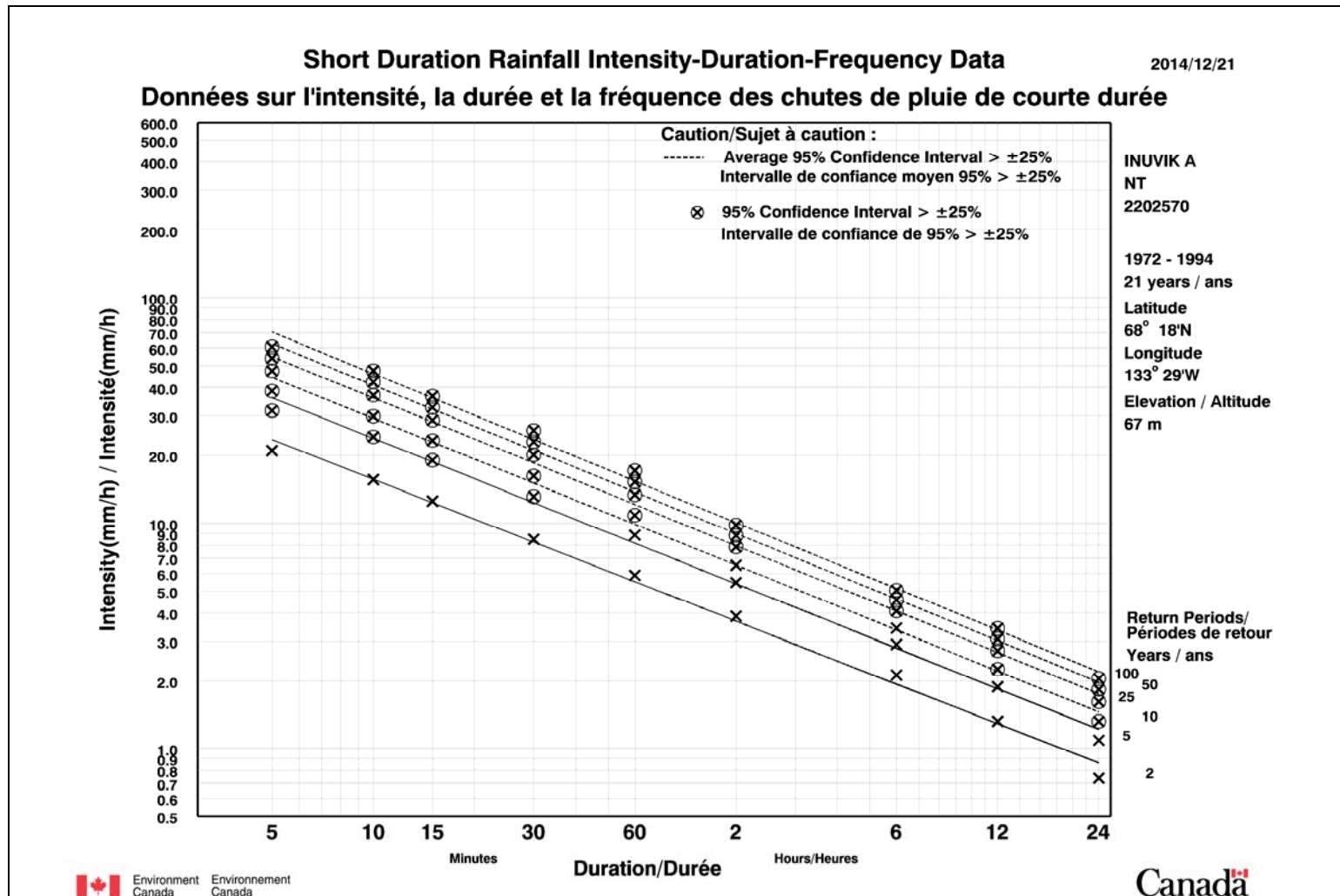
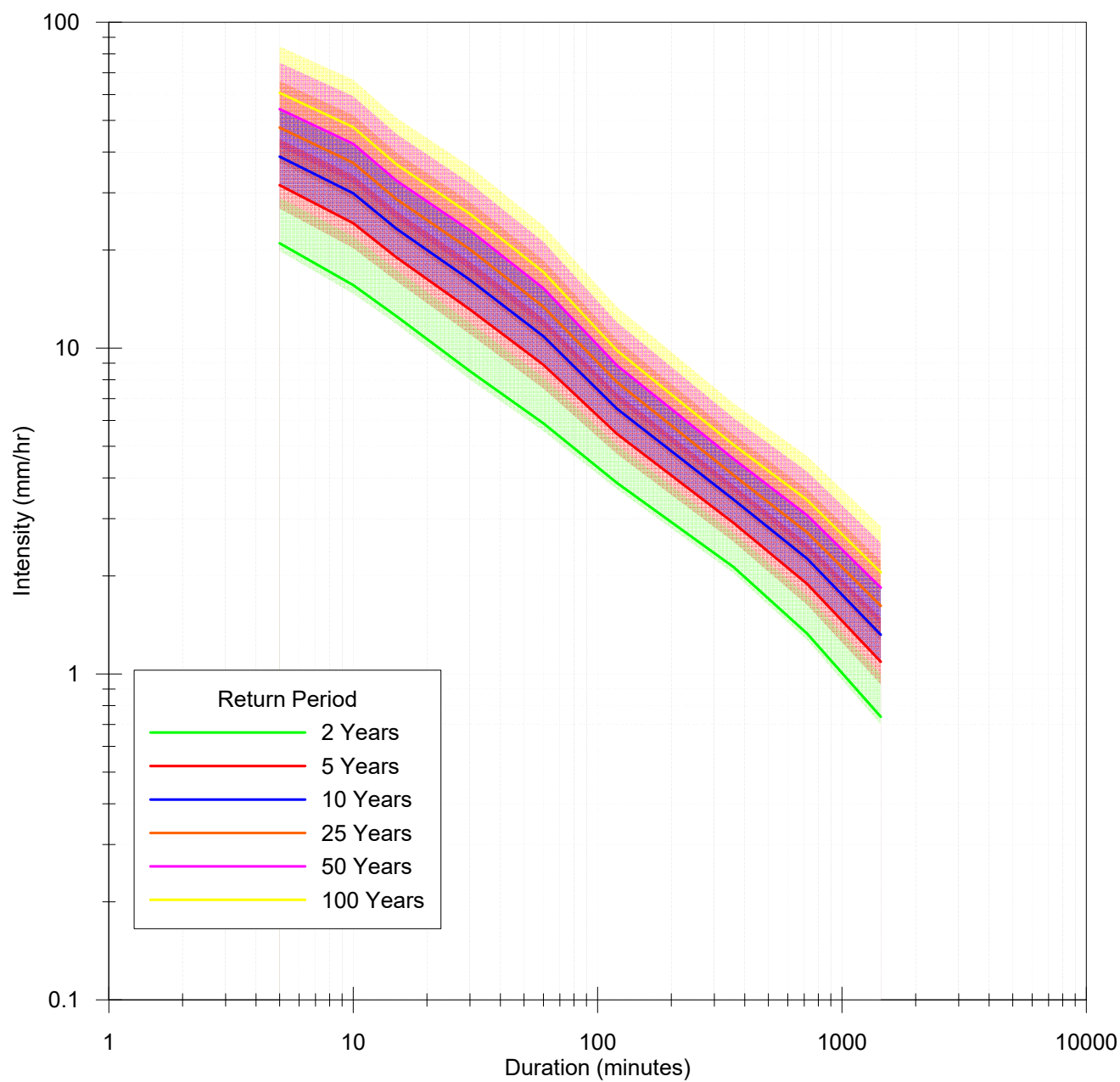


Figure A-24 Inuvik Intensity-Duration-Frequency Data (1972-1994) (Environment Canada)

BGC ENGINEERING INC.



Shaded areas represent climate change predictions from 2015-2045

Figure A-25 Inuvik RCP 4.5 IDF Projections

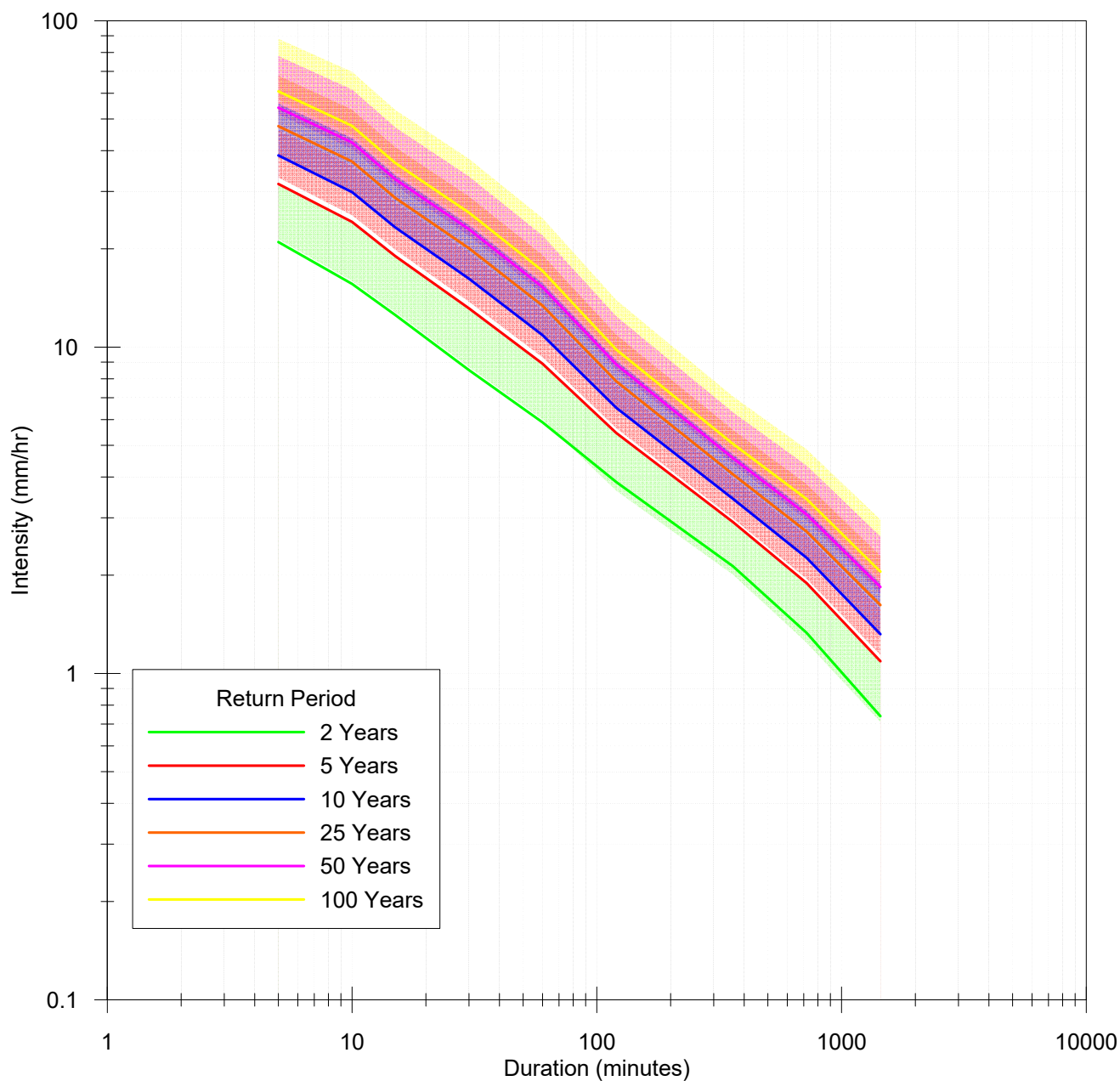


Figure A-26 Inuvik RCP 8.5 IDF Projections

APPENDIX B

CLIMATE CHANGE VULNERABILITY ASSESSMENT MATRIX

Infrastructure Components		Infrastructure Response Considerations										1				2				3				4				5				6				7				8				9			
												Air Temperatures																																			
												Maximum Air Temperature				Minimum Air Temperature				Air Freezing Index				Air Thawing Index				Freeze - Thaw Cycles				Heat Waves				Cold Waves				Frost				Rainfall Frequency			
												Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here			
		Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Economical Considerations	Policy Considerations	Social Effects	Environmental Effects	Mark Relevant Responses with ✓																																			
												Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R				
	Physical Infrastructure																																														
1	Runway	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	6	3	18	Y	5	1	5	Y	6	2	12	Y	5	1	5	Y	5	3	15	Y	5	4	20	Y	5	1	5	Y	6	4	24	Y	4	2	8
2	Taxiways (A, B, C, D, E)	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	6	1	6	Y	5	1	5	Y	6	1	6	Y	5	1	5	Y	5	2	10	Y	5	3	15	Y	5	0	0	Y	6	3	18	Y	4	1	4
3	Apron	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	6	2	12	Y	5	1	5	Y	6	1	6	Y	5	1	5	Y	5	2	10	Y	5	3	15	Y	5	0	0	Y	6	3	18	Y	4	1	4
4	Drainage	✓	✓	✓	✓	✓			✓		✓	N				N				Y	6	1	6	Y	5	1	5	Y	5	2	10	N				Y	5	1	5	Y	6	1	6	Y	4	3	12
5	Access Roads	✓	✓	✓		✓	✓		✓			Y	6	1	6	Y	5	1	5	Y	6	0	0	Y	5	0	0	Y	5	1	5	Y	5	0	0	Y	5	0	0	Y	6	1	6	Y	4	1	4
6	Service Roads	✓	✓	✓		✓	✓		✓			Y	6	1	6	Y	5	1	5	Y	6	0	0	Y	5	0	0	Y	5	1	5	Y	5	0	0	Y	5	0	0	Y	6	1	6	Y	4	1	4
7	Heteo. in Natural Foundation / Permafrost	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	6	2	12	Y	5	1	5	N				N				Y	5	3	15	Y	5	2	10	Y	5	0	0	N				N			
	Supporting Infrastructure																																														
8	Operation and Maintenance Personnel		✓	✓		✓	✓	✓	✓	✓		Y	6	2	12	Y	5	1	5	N				N				N				Y	5	2	10	Y	5	2	10	N				N			
9	Snow clearing		✓	✓	✓	✓	✓	✓	✓		✓	N				Y	5	1	5	Y	6	1	6	N				N				N				Y	5	0	0	Y	6	2	12	N			
10	Crack filling		✓	✓		✓	✓	✓	✓			Y	6	1	6	N				N				Y	5	1	5	Y	5	2	10	Y	5	2	10	N				N				Y	4	1	4
11	Winter flight operation					✓	✓	✓	✓	✓		N				N				N				N				N				N				Y	5	1	5	Y	6	4	24	N			
12	Summer flight operation					✓	✓	✓	✓	✓		N				N				N				N				N				Y	5	1	5	N				N				Y	4	1	4
13	Summer maintenance		✓	✓		✓	✓	✓	✓		✓	Y	6	1	6	N				N				Y	5	1	5	Y	5	2	10	Y	5	1	5	N				N				Y	4	3	12
14	Winter maintenance		✓	✓		✓	✓	✓	✓		✓	N				Y	5	0	0	Y	6	1	6	N				N				N				Y	5	1	5	Y	6	3	18	N			
15	Lightning systems		✓			✓	✓		✓			N				N				N				N				N				N				N				Y	6	1	6	N			
16	Surface marking / Signals		✓			✓	✓		✓			N				N				N				N				Y	5	1	5	Y	5	0	0	Y	5	0	0	Y	6	2	12	N			
17	Weather station	✓	✓	✓		✓	✓		✓		✓	Y	6	0	0	Y	5	0	0	N				N				N				Y	5	1	5	Y	5	0	0	Y	6	1	6	Y	4	1	4
18	Environmental monitoring	✓	✓	✓		✓	✓		✓		✓	Y	6	0	0	Y	5	0	0	N				N				N				Y	5	1	5	Y	5	0	0	Y	6	1	6	N			
19	Nav aids		✓			✓	✓	✓	✓			N				N				N				N				N				N				N				N				N			
20	Vegetation				✓	✓			✓		✓	Y	6	1	6	Y	5	2	10	Y	6	1	6	Y	5	1	5	Y	5	0	0	Y	5	2	10	Y	5	2	10	Y	6	1	6	Y	4	1	4
21	Aircraft arresting system	✓	✓	✓		✓			✓			N				N				N				N				N				N				N				Y	6	2	12	Y	4	1	4
22	Security systems	✓	✓	✓		✓			✓			N				N				N				N				N				N				N				N				N			
23	Data availability	✓	✓	✓	✓	✓			✓		✓	Y	6	5	30	Y	5	4	20	Y	6	4	24	Y	5	5	25	Y	5	3	15	Y	5	3	15	Y	5	2	10	Y	6	5	30	Y	4	4	16
	Others																																														
24	Emergency procedures and medevac					✓	✓		✓			N				N				N				N				N				Y	5	2	10	Y	5	0	0	Y	6	1	6	Y	4	1	4
25	Wildlife									✓	✓	Y	6	1	6	Y	5	1	5	Y	6	1	6	Y	5	1	5	N				Y	5	1	5	Y	5	1	5	N				Y	4	1	4
26	Future developments / Masterplan					✓		✓		✓	✓	N				N				N				N				N				N				N				N				Y	4	1	4

Infrastructure Components		Infrastructure Response Considerations										10				11				12				13				14				15				16				17				18																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
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												Rainfall Duration				Rainfall Intensity (Rain Storms)				Rainfall in the Fall				Freezing Rain				Rain on Snow				Total Snowfall				Snowfall Duration				Snowfall Frequency				First Snow Day																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
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1	Runway	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Infrastructure Components		Infrastructure Response Considerations										19				20				21				22				23				24				25				26				27							
												Last Snow Day				Blizzards / White-Outs				Ice Storms				Hail				Wind Gusts				Wind Direction				Wind in Winter				Ground Freezing Index				Ground Thawing Index							
												Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here							
		Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater	Operations, Maintenance & Materials Performance	Emergency Response	Economical Considerations	Policy Considerations	Social Effects	Environmental Effects	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R												
		Mark Relevant Responses with ✓																																																	
	Physical Infrastructure																																																		
1	Runway	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	3	1	3	N				Y	2	5	10	N				Y	2	1	2	Y	1	3	3	Y	1	4	4	Y	5	3	15	Y	4	4	16				
2	Taxiways (A, B, C, D, E)	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	3	1	3	N				Y	2	3	6	N				Y	2	0	0	Y	1	1	1	Y	1	2	2	Y	5	2	10	Y	4	3	12				
3	Apron	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	3	1	3	N				Y	2	3	6	N				Y	2	1	2	Y	1	1	1	Y	1	2	2	Y	5	2	10	Y	4	3	12				
4	Drainage	✓	✓	✓	✓	✓			✓		✓	Y	3	3	9	Y	2	4	8	Y	2	2	4	Y	2	2	4	Y	2	2	4	N				N				Y	5	2	10	Y	4	4	16				
5	Access Roads	✓	✓	✓		✓	✓		✓			N				N				Y	2	1	2	N				Y	2	0	0	Y	1	1	1	Y	1	1	1	Y	5	1	5	Y	4	1	4				
6	Service Roads	✓	✓	✓		✓	✓		✓			N				N				Y	2	1	2	N				Y	2	0	0	Y	1	1	1	Y	1	1	1	Y	5	1	5	Y	4	1	4				
7	Heteo. in Natural Foundation / Permafrost	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	3	3	9	N				N				N				N				N				N				Y	5	2	10	Y	4	5	20				
	Supporting Infrastructure																																																		
8	Operation and Maintenance Personnel		✓	✓		✓	✓	✓	✓	✓		Y	3	1	3	Y	2	4	8	Y	2	4	8	Y	2	4	8	N				N				N				N				N							
9	Snow clearing		✓	✓	✓	✓	✓	✓	✓		✓	Y	3	1	3	Y	2	3	6	Y	2	4	8	Y	2	4	8	Y	2	1	2	Y	1	2	2	Y	1	3	3	N				N							
10	Crack filling		✓	✓		✓	✓	✓	✓			Y	3	2	6	N				N				N				N				N				N				Y	5	1	5	Y	4	2	8				
11	Winter flight operation					✓	✓	✓	✓	✓		Y	3	1	3	Y	2	5	10	Y	2	6	12	N				Y	2	3	6	Y	1	4	4	Y	1	4	4	N				N							
12	Summer flight operation					✓	✓	✓	✓	✓		Y	3	1	3	N				N				Y	2	4	8	Y	2	4	8	Y	1	3	3	N				N				N							
13	Summer maintenance		✓	✓		✓	✓	✓	✓		✓	Y	3	1	3	N				N				Y	2	4	8	N				Y	1	1	1	N				N				N							
14	Winter maintenance		✓	✓		✓	✓	✓	✓		✓	Y	3	2	6	Y	2	6	12	Y	2	5	10	N				N				N				Y	1	2	2	N				N							
15	Lightning systems		✓			✓	✓		✓			N				Y	2	3	6	Y	2	3	6	Y	2	1	2	Y	2	1	2	N				N				Y	5	2	10	Y	4	3	12				
16	Surface marking / Signals		✓			✓	✓		✓			N				N				Y	2	3	6	Y	2	0	0	N				N				N				N				N							
17	Weather station	✓	✓	✓		✓	✓		✓		✓	N				Y	2	2	4	Y	2	2	4	Y	2	1	2	Y	2	2	4	N				N				N				N							
18	Environmental monitoring	✓	✓	✓		✓	✓		✓		✓	N				Y	2	1	2	Y	2	1	2	Y	2	1	2	Y	2	0	0	N				N				Y	5	1	5	Y	4	1	4				
19	Nav aids		✓			✓	✓	✓	✓			N				Y	2	3	6	Y	2	2	4	Y	2	1	2	N				N				N				N				N							
20	Vegetation				✓	✓			✓		✓	Y	3	1	3	N				Y	2	1	2	Y	2	3	6	Y	2	1	2	N				N				Y	5	2	10	Y	4	3	12				
21	Aircraft arresting system	✓	✓	✓		✓			✓			N				Y	2	2	4	Y	2	4	8	Y	2	1	2	N				N				N				Y	5	4	20	Y	4	5	20				
22	Security systems	✓	✓	✓		✓			✓			N				Y	2	1	2	Y	2	2	4	Y	2	1	2	N				N				N				Y	5	4	20	Y	4	5	20				
23	Data availability	✓	✓	✓	✓	✓			✓		✓	Y	3	3	9	Y	2	6	12	Y	2	3	6	Y	2	5	10	Y	2	6	12	Y	1	5	5	Y	1	5	5	Y	5	3	15	Y	4	5	20				
	Others																																																		
24	Emergency procedures and medevac					✓	✓		✓			N				Y	2	6	12	Y	2	5	10	Y	2	1	2	N				Y	1	2	2	Y	1	3	3	N				N							
25	Wildlife									✓	✓	N				N				N				N				Y	2	1	2	N				N				N				N							
26	Future developments / Masterplan				✓		✓		✓	✓		N				N				N				N				N				N				N				Y	5		0	Y	4		0				

Infrastructure Components		Infrastructure Response Considerations										28				29				30				31				32				33			
												Cloud Cover / Solar Radiation				Cloud Ceiling Height				Fog / Visibility				Lightning / Electrical Storms				Wildfires				Climate Variability			
												Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here				Enter Infrastructure Threshold Value Here			
		Mark Relevant Responses with ✓										Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
Physical Infrastructure																																			
1	Runway	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	4	5	20	N				N				N				Y	5	2	10	N			
2	Taxiways (A, B, C, D, E)	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	4	3	12	N				N				N				Y	5	2	10	N			
3	Apron	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	4	3	12	N				N				N				Y	5	2	10	N			
4	Drainage	✓	✓	✓	✓	✓			✓		✓	Y	4	4	16	N				N				N				Y	5	3	15	Y	5	2	10
5	Access Roads	✓	✓	✓		✓	✓		✓			Y	4	2	8	N				N				N				Y	5	2	10	N			
6	Service Roads	✓	✓	✓		✓	✓		✓			Y	4	1	4	N				N				N				Y	5	1	5	N			
7	Heteo. in Natural Foundation / Permafrost	✓	✓	✓		✓	✓	✓	✓	✓	✓	Y	4	4	16	N				N				N				Y	5	3	15	N			
Supporting Infrastructure																																			
8	Operation and Maintenance Personnel		✓	✓		✓	✓	✓	✓	✓		N				N				Y	5	2	10	Y	2	2	4	Y	5	3	15	N			
9	Snow clearing		✓	✓	✓	✓	✓	✓	✓		✓	N				N				N				N				N				Y	5	1	5
10	Crack filling		✓	✓		✓	✓	✓	✓			Y	4	2	8	N				N				N				N				Y	5	2	10
11	Winter flight operation					✓	✓	✓	✓	✓		N				Y	3	4	12	Y	5	6	30	Y	2	1	2	N				Y	5	2	10
12	Summer flight operation					✓	✓	✓	✓	✓		Y	4	2	8	Y	3	4	12	Y	5	6	30	Y	2	4	8	Y	5	3	15	Y	5	2	10
13	Summer maintenance		✓	✓		✓	✓	✓	✓		✓	Y	4	2	8	N				N				N				Y	5	2	10	Y	5	3	15
14	Winter maintenance		✓	✓		✓	✓	✓	✓		✓	Y	4	1	4	N				N				N				N				Y	5	3	15
15	Lightining systems		✓			✓	✓		✓			N				N				Y	5	3	15	Y	2	1	2	Y	5	3	15	N			
16	Surface marking / Signals		✓			✓	✓		✓			N				N				N				N				Y	5	2	10	N			
17	Weather station	✓	✓	✓		✓	✓		✓		✓	N				N				N				Y	2	0	0	Y	5	3	15	N			
18	Environmental monitoring	✓	✓	✓		✓	✓		✓		✓	Y	4	1	4	N				Y	5	2	10	Y	2	1	2	Y	5	3	15	N			
19	Nav aids		✓			✓	✓	✓	✓			N				Y	3	3	9	Y	5	3	15	Y	2	1	2	Y	5	3	15	N			
20	Vegetation				✓	✓			✓		✓	Y	4	1	4	N				N				N				Y	5	2	10	N			
21	Aircraft arresting system	✓	✓	✓		✓			✓			N				N				N				N				Y	5	3	15	N			
22	Security systems	✓	✓	✓		✓			✓			N				N				Y	5	1	5	Y	2	1	2	Y	5	2	10	N			
23	Data availability	✓	✓	✓	✓	✓			✓		✓	Y	4	4	16	Y	3	3	9	Y	5	6	30	Y	2	3	6	Y	5	1	5	Y	5	5	25
Others																																			
24	Emergency procedures and medevac					✓	✓		✓			N				Y	3	2	6	Y	5	5	25	Y	2	2	4	Y	5	3	15	Y	5	3	15
25	Wildlife									✓	✓	N				N				N				N				Y	5	1	5	N			
26	Future developments / Masterplan					✓		✓		✓	✓	N				Y	3	2	6	Y	5	2	10	N				N				Y	5	1	5

APPENDIX C

RECOMMENDATION MATRIX

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
	Factor	Priority		Engineering	Management				
Runway	Temperature	Maximum Air Temperature	18	low	✓	✗		Yes	Warmer maximum air temperature conditions may result in changes of the runway flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in runway surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
		Minimum Air Temperature	5	no	✗	✗			No action needed
		Air Freezing Index	12	no	✗	✗			No action needed
		Air Thawing Index	5	no	✗	✗			No action needed
		Freeze-Thaw Cycles	15	low	✓	✗		Yes	Potential increase in freeze-thaw cycles in combination with increase moisture availability may result in more rapid cracking and weathering of the runway surface. Monitoring of changes in runway surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
		Heat Waves	20	low	✓	✓	Yes	Yes	Warmer maximum air temperature conditions may result in changes of the runway flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in runway surface is recommended in order to evaluate potential mitigation measures if these were required in the future. New surface mixtures or increased patching may be required.
		Cold Waves	5	no	✗	✗			No action needed
		Frost	24	medium	✓	✓	Yes	Yes	Increase in humidity is resulting in increased frost accumulation on the runway surface, which reduces friction. Monitoring is recommended to better understand the conditions when frost forms and if the changes are significant. Depending on future changes in frost, structural measures may be required, which could include increase in asphalt roughness or installation of a runway heating system.
	Rain	Frequency	8	no	✗	✗			No action needed
		Duration	15	low	✓	✗	Yes	Yes	Additional studies are required to understand changes in rain intensity, duration and frequency. Projections and historical trends are currently not conclusive. Structural measure may include increase in drainage capacity and changes in the overall drainage system by diverting the majority of the incoming runoff round the airport infrastructure. Additionally, water should be prevented from flowing under or through any embankment (runway, taxiways and aprons) if practical.
		Intensity	16	low	✓	✗	Yes	Yes	
		Rainfall in the Fall	6	no	✗	✗			No action needed
		Freezing Rain	6	no	✗	✗			No action needed
		Rain on Snow	8	no	✗	✗			No action needed
	Snow	Total	4	no	✗	✗			No action needed
		Duration	8	no	✗	✗			No action needed
		Frequency	12	low	✓	✓		Yes	Increase snow accumulation can affect the structural stability of the runway structure due to its insulating effect. Additional studies are required to better understand changes in snow frequency, including an assessment of available clearing equipment. Measures that prevent negative impacts from increasing snow accumulation on the runway include the removal of snow to areas where permafrost stability and increased freshet is not an issue.
		First Snow Day	3	no	✗	✗			No action needed
		Last Snow Day	3	no	✗	✗			No action needed
	Storms	Ice Storms	10	no	✗	✗			No action needed
	Wind	Wind Gusts	2	no	✗	✗			No action needed
		Wind Direction	3	no	✗	✗			No action needed
		Wind in Winter	4	no	✗	✗			No action needed
	Ground Freezing Index		15	low	✓	✗	Yes	Yes	Warmer winters and warmer summers result in ground temperature increase and active layer thickening. This may lead to thaw consolidation and other structural instabilities of the runway embankment. Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential hazards. Further, studies are recommended that identify areas along the runway that are specifically susceptible to warming and thaw.
	Ground Thawing Index		16	low	✓	✗	Yes	Yes	
	Cloud Cover/Solar Radiation		20	low	✓	✓		Yes	Increased solar radiation may result in warmer runway surface temperatures and changes of the runway flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in runway surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
	Wildfires		10	no	✗	✗			No action needed
	Taxiways	Temperature	Maximum Air Temperature	6	no	✗	✗		
Minimum Air Temperature			5	no	✗	✗			No action needed
Air Freezing Index			6	no	✗	✗			No action needed
Air Thawing Index			5	no	✗	✗			No action needed
Freeze-Thaw Cycles			10	low	✓	✗		Yes	Potential increase in freeze-thaw cycles in combination with increase moisture availability may result in more rapid cracking and weathering of the surface. Monitoring of changes in the taxiway surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
Heat Waves			15	low	✓	✓		Yes	Warmer maximum air temperature conditions may result in changes of the surface flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in the taxiway surface is recommended in order to evaluate potential mitigation measures if these were required in the future. New surface mixtures or increased patching may be required.
Cold Waves			0	no	✗	✗			No action needed
Frost			18	low	✓	✓		Yes	Increase in humidity is resulting in increased frost accumulation on the taxiway surfaces, which reduces friction. Monitoring is recommended to better understand the conditions when frost forms and if the changes are significant. Depending on future changes in frost, structural measures may be required, which could include increase in asphalt roughness or installation of a runway heating system.
Rain		Frequency	4	no	✗	✗			No action needed
		Duration	10	no	✗	✗			No action needed
		Intensity	8	no	✗	✗			No action needed
		Rainfall in the Fall	3	no	✗	✗			No action needed
		Freezing Rain	5	no	✗	✗			No action needed
		Rain on Snow	6	no	✗	✗			No action needed
Snow		Total	4	no	✗	✗			No action needed
		Duration	4	no	✗	✗			No action needed
		Frequency	4	no	✗	✗			No action needed
		First Snow Day	3	no	✗	✗			No action needed
		Last Snow Day	3	no	✗	✗			No action needed
Storms		Ice Storms	6	no	✗	✗			No action needed
Wind		Wind Gusts	0	no	✗	✗			No action needed
		Wind Direction	1	no	✗	✗			No action needed
		Wind in Winter	2	no	✗	✗			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
	Element	Factor		Priority	Engineering	Management			
	Ground Freezing Index		10	low	✓	✖	Yes	Yes	Warmer winters and warmer summers result in ground temperature increase and active layer thickening. This may lead to thaw consolidation and other structural instabilities of the taxiway embankments. Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential hazards. Further, studies are recommended that identify areas along the taxiways that are specifically susceptible to warming and thaw.
	Ground Thawing Index		12	low	✓	✖	Yes	Yes	
	Cloud Cover/Solar Radiation		12	low	✓	✓		Yes	Increased solar radiation may result in warmer taxiway surface temperatures and in changes of the surface flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in the taxiway surfaces is recommended in order to evaluate potential mitigation measures if these were required in the future.
	Wildfires		10	no	✖	✖			No action needed
Apron	Temperature	Maximum Air Temperature	12	low	✓	✖		Yes	Warmer maximum air temperature conditions may result in changes of the runway flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in the taxiway surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
		Minimum Air Temperature	5	no	✖	✖			
		Air Freezing Index	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	10	low	✓	✖		Yes	Potential increase in freeze-thaw cycles in combination with increase moisture availability may result in more rapid cracking and weathering of the surface. Monitoring of changes in the apron surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
		Heat Waves	15	low	✓	✓		Yes	Warmer maximum air temperature conditions may result in changes of the surface flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in the apron surface is recommended in order to evaluate potential mitigation measures if these were required in the future. New surface mixtures or increased patching may be required.
		Cold Waves	0	no	✖	✖			No action needed
		Frost	18	low	✓	✓		Yes	Increase in humidity is resulting in increased frost accumulation on the taxiway surfaces, which reduces friction. Monitoring is recommended to better understand the conditions when frost forms and if the changes are significant. Depending on future changes in frost, structural measures may be required, which could include increase in asphalt roughness or installation of a runway heating system.
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	8	no	✖	✖			No action needed
		Rainfall in the Fall	3	no	✖	✖			No action needed
		Freezing Rain	5	no	✖	✖			No action needed
		Rain on Snow	6	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
		Duration	4	no	✖	✖			No action needed
		Frequency	4	no	✖	✖			No action needed
		First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Ice Storms	6	no	✖	✖			No action needed
	Wind	Wind Gusts	2	no	✖	✖			No action needed
		Wind Direction	1	no	✖	✖			No action needed
		Wind in Winter	2	no	✖	✖			No action needed
	Ground Freezing Index		10	no	✓	✖	Yes	Yes	Warmer winters and warmer summers result in ground temperature increase and active layer thickening. This may lead to thaw consolidation and other structural instabilities of the apron foundation. Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential hazards. Further, studies are recommended that identify areas under the apron that are specifically susceptible to warming and thaw.
	Ground Thawing Index		12	low	✓	✖	Yes	Yes	
	Cloud Cover/Solar Radiation		12	low	✓	✓		Yes	Increased solar radiation may result in warmer surface temperatures and changes of surface flexibility and thermal expansion, which can lead to cracks or deformations. Monitoring of changes in the apron surface is recommended in order to evaluate potential mitigation measures if these were required in the future.
	Wildfires		10	no	✖	✖			No action needed
Drainage	Temperature	Air Freezing Index	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	10	no	✖	✖			No action needed
		Cold Waves	5	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Frequency	12	low	✓	✖	Yes	Yes	Additional studies are required to understand changes in rain intensity, duration and frequency. Projections and historical trends are currently not conclusive. Structural measure may include increase in drainage capacity and changes in the overall drainage system by diverting the majority of the incoming runoff round the airport infrastructure. Maintenance of the drainage system, which includes opening of clogged channels and culverts, de-icing, steaming or installation of redundancies may provide sufficient capacity mainly for short duration and high intensity events.
		Duration	25	medium	✓	✖	Yes	Yes	
		Intensity	24	medium	✓	✖	Yes	Yes	
		Rainfall in the Fall	12	low	✓	✖		Yes	No action needed
		Freezing Rain	3	no	✖	✖			
		Rain on Snow	12	low	✓	✖		Yes	
	Snow	Total	20	medium	✓	✓	Yes	Yes	Additional snow may affect the drainage system by clogging and reducing the capacity. Additional studies are required to better understand changes in snow frequency, including an assessment of available clearing equipment. Measures that prevent negative impacts from increasing snow accumulation may likely be related to changes in snow clearing and deposition.
		Duration	8	no	✖	✖			
		Frequency	8	no	✖	✖			
		First Snow Day	6	no	✖	✖			
		Last Snow Day	9	no	✖	✖			
	Storms	Blizzards/White-Outs	8	no	✖	✖			No action needed
		Ice Storms	4	no	✖	✖			No action needed
		Hail	4	no	✖	✖			No action needed
	Wind	Wind Gusts	4	no	✖	✖			No action needed
	Ground Freezing Index		10	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
		Factor		Priority	Engineering	Management			
	Ground Thawing Index		16	low	✓	✖		Yes	Warmer summers result in ground temperature increase and active layer thickening. This may lead to thaw consolidation and other structural instabilities of components of the drainage system. Water ponding, in result to increases precipitation during the summer can accelerate the increase in the ground thawing index and further permafrost degradation. Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential hazards. Further, studies are recommended that identify sections along the drainage system that are specifically susceptible to warming and thaw.
	Cloud Cover/Solar Radiation		16	low	✓	✖		Yes	Increased solar radiation may result in warmer surface temperatures and changes of surface conditions, including warmer water in the ponds. Monitoring of changes in the drainage system is recommended in order to evaluate potential mitigation measures if these were required in the future.
	Wildfires		15	medium	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
	Climate Variability		10	no	✖	✖			No action needed
Access and Service Roads	Temperature	Maximum Air Temperature	6	no	✖	✖			No action needed
		Minimum Air Temperature	5	no	✖	✖			No action needed
		Air Freezing Index	0	no	✖	✖			No action needed
		Air Thawing Index	0	no	✖	✖			No action needed
		Freeze-Thaw Cycles	5	no	✖	✖			No action needed
		Heat Waves	0	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	8	no	✖	✖			No action needed
		Rainfall in the Fall	3	no	✖	✖			No action needed
		Freezing Rain	3	no	✖	✖			No action needed
		Rain on Snow	6	no	✖	✖			No action needed
	Snow	Total	6	no	✖	✖			No action needed
		Duration	6	no	✖	✖			No action needed
		Frequency	6	no	✖	✖			No action needed
	Storms	Ice Storms	2	no	✖	✖			No action needed
	Wind	Wind Gusts	0	no	✖	✖			No action needed
		Wind Direction	1	no	✖	✖			No action needed
		Wind in Winter	1	no	✖	✖			No action needed
	Ground Freezing Index		5	no	✖	✖			No action needed
	Ground Thawing Index		4	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		8	no	✖	✖			No action needed
	Wildfires		5	no	✖	✖			No action needed
Heterogeneity in Natural Foundation/Permafrost	Temperature	Maximum Air Temperature	12	low	✓	✖	Yes	Yes	Warmer maximum air temperature conditions may result in different responses to the permafrost foundation primarily depending on its ice content. Studies are recommended that identify areas of the airport infrastructure that are specifically susceptible to warming and thaw.
		Minimum Air Temperature	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	15	low	✓	✖		Yes	Potential increase in freeze-thaw cycles in combination with ground temperature warming and active layer thickening may result in non-uniform changes in the characteristics of the foundation. Monitoring of ground temperatures is recommended in combination with evaluating susceptible sections in order to evaluate potential mitigation measures if these were required in the future.
		Heat Waves	10	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
	Snow	Total	12	low	✓	✓	Yes	Yes	Potential increase in snow thickness in spring can result in ground temperature warming and active layer thickening. Monitoring of snow thicknesses and ground temperatures is recommended in combination with evaluating susceptible sections in order to evaluate potential mitigation measures if these were required in the future.
		Duration	8	no	✖	✖			No action needed
		Frequency	8	no	✖	✖			No action needed
		First Snow Day	9	no	✖	✖			No action needed
		Last Snow Day	9	no	✖	✖			No action needed
	Ground Freezing Index		10	no	✖	✖			No action needed
	Ground Thawing Index		20	medium	✓	✖	Yes	Yes	Ground warming, also via ground surface warming induced by increase in solar radiation, can result in active layer thickening and differential degradation in response to heterogeneous permafrost conditions. Monitoring ground temperatures is recommended in combination with evaluating susceptible sections in order to evaluate potential mitigation measures if these were required in the future.
	Cloud Cover/Solar Radiation		16	low	✓	✖		Yes	
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Operation and Maintenance Personnel	Temperature	Maximum Air Temperature	12	no	✖	✖			No action needed
		Minimum Air Temperature	5	no	✖	✖			No action needed
		Heat Waves	10	no	✖	✖			No action needed
		Cold Waves	10	no	✖	✖			No action needed
	Rain	Freezing Rain	2	no	✖	✖			No action needed
	Snow	Total	12	low	✖	✓	Yes	Yes	Currently, trends regarding total snow, duration of snow fall events and their frequency are inconclusive. Snow monitoring, including an evaluation of spatial distribution and impacts of drifting snow is recommended. Changes in the snow management, such as changes in snow deposition or acquisition of additional / alternative equipment and personnel are to be evaluated pending assessment of potentially negative impact in the future.
		Duration	12	low	✖	✓	Yes	Yes	
		Frequency	12	low	✖	✓	Yes	Yes	
		First Snow Day	3	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
		Factor		Priority	Engineering	Management			
	Storms	Last Snow Day	3	no	✖	✖			No action needed
		Blizzards/White-Outs	8	no	✖	✖			No action needed
		Ice Storms	8	no	✖	✖			No action needed
		Hail	8	no	✖	✖			No action needed
	Fog/Visibility		10	low	✖	✓	Yes	Yes	Currently, trends regarding visibility are unclear. Monitoring is recommended. Changes in visibility are to be evaluated and equipment update for working under poor visibility to be evaluated pending assessment of potentially negative impact in the future.
	Lightning/Electrical Storms		4	no	✖	✖			No action needed
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Snow Clearing	Temperature	Minimum Air Temperature	5	no	✖	✖			No action needed
		Air Freezing Index	6	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	12	low	✖	✓		Yes	Frost may result in response to snow clearing activities. Currently, not sufficient data are available to assess how snow clearing and frost are interacting. Monitoring is recommended and depending on the existence of a correlation changes in snow management, sanding or even structural changes, such as increase in asphalt roughness or installation of a runway heating system should be evaluated.
	Rain	Freezing Rain	5	no	✖	✖			No action needed
		Rain on Snow	12	low	✖	✓		Yes	Rain on snow can affect drainage system. Changes in the snow management, such as changes in snow deposition are to be evaluated pending future changes in precipitation. Currently, trends are inconclusive and additional snow and rain monitoring is recommended, including the effect of snow management / redistribution.
	Snow	Total	16	low	✖	✓	Yes	Yes	Currently, trends regarding total snow, duration of snow fall events and their frequency are inconclusive. Snow monitoring, including an evaluation of spatial distribution and impacts of drifting snow is recommended. Changes in the snow management, such as changes in snow deposition are to be evaluated pending assessment of potentially negative impact in the future.
		Duration	16	low	✖	✓	Yes	Yes	
		Frequency	16	low	✖	✓	Yes	Yes	
		First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	6	no	✖	✖			No action needed
		Ice Storms	8	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
	Wind	Wind Gusts	6	no	✖	✖			No action needed
		Wind Direction	2	no	✖	✖			No action needed
		Wind in Winter	3	no	✖	✖			No action needed
	Climate Variability		5	no	✖	✖			No action needed
Crack Filling	Temperature	Maximum Air Temperature	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	10	no	✖	✖			No action needed
		Heat Waves	10	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	10	no	✖	✖			No action needed
		Intensity	8	no	✖	✖			No action needed
	Snow	Total	8	no	✖	✖			No action needed
		First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	6	no	✖	✖			No action needed
	Ground Freezing Index		5	no	✖	✖			No action needed
	Ground Thawing Index		8	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		8	no	✖	✖			No action needed
	Climate Variability		10	no	✖	✖			No action needed
Winter Flight Operation	Temperature	Cold Waves	5	no	✖	✖			No action needed
		Frost	24	medium	✓	✓	Yes	Yes	Depending on future changes in frost, structural measures may be required, which could include increase in runway surface friction or installation of a runway heating system.
	Rain	Freezing Rain	6	no	✖	✖			No action needed
		Rain on Snow	8	no	✖	✖			No action needed
	Snow	Total	8	no	✖	✖			No action needed
		Duration	4	no	✖	✖			No action needed
		Frequency	8	no	✖	✖			No action needed
		First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	10	low	✖	✓		Yes	Currently, trends regarding blizzards and ice storms are not available. Additional monitoring data and model improvements are required before specific adaptation measures can be recommended. Augmenting maintenance crew and equipment may have to be considered.
		Ice Storms	12	low	✖	✓		Yes	
		Lightning/Electrical Storms	2	no	✖	✖			No action needed
	Wind	Wind Gusts	6	no	✖	✖			No action needed
		Wind Direction	4	no	✖	✖			No action needed
		Wind in Winter	4	no	✖	✖			No action needed
	Cloud Ceiling Height		12	low	✓	✓	Yes	Yes	Projections and historical trends on cloud ceiling and visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Fog/Visibility		30	medium	✓	✓	Yes	Yes	

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element	Factor	Risk Value	Priority	Engineering	Management	Additional Study Required	Observations / Monitoring	Comments
	Climate Variability		10	low	✓	✓		Yes	It is likely that climate variability and the occurrence of extreme weather conditions increase. To be better prepared, it is recommended to improve short- to mid-range weather forecasts via developing new and specific models for the area.
Summer Flight Operation	Temperature	Heat Waves	5	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	4	no	✖	✖			No action needed
		Rainfall in the Fall	3	no	✖	✖			No action needed
	Snow	First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Hail	8	no	✖	✖			No action needed
		Lightning/Electrical Storms	8	no	✖	✖			No action needed
	Wind	Wind Gusts	8	no	✖	✖			No action needed
		Wind Direction	3	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		8	no	✖	✖			No action needed
	Cloud Ceiling Height		12	low	✓	✓	Yes	Yes	Projections and historical trends on cloud ceiling and visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Fog/Visibility		30	medium	✓	✓	Yes	Yes	
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
	Climate Variability		10	low	✓	✓		Yes	It is likely that climate variability and the occurrence of extreme weather conditions increase. To be better prepared, it is recommended to improve short- to mid-range weather forecasts via developing new and specific models for the area.
Summer Maintenance	Temperature	Maximum Air Temperature	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	10	no	✖	✖			No action needed
		Heat Waves	5	no	✖	✖			No action needed
	Rain	Frequency	12	low	✓	✓	Yes	Yes	Additional studies are required to understand changes in rain intensity, duration and frequency. Projections and historical trends are currently not conclusive. Summer maintenance of the drainage system, such as ditch cleaning, culvert replacements may be required more frequent to provide sufficient capacity in the drainage system.
		Duration	10	low	✓	✓	Yes	Yes	
		Intensity	12	low	✓	✓	Yes	Yes	
		Rainfall in the Fall	3	no	✖	✖			No action needed
	Snow	First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Hail	8	no	✖	✖			No action needed
	Wind	Wind Direction	1	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		8	no	✖	✖			No action needed
	Wildfires		10	no	✖	✖			No action needed
	Climate Variability		15	low	✓	✓		Yes	It is likely that climate variability and the occurrence of extreme weather conditions increase. To be better prepared, it is recommended to improve short- to mid-range weather forecasts via developing new and specific models for the area.
Winter Maintenance	Temperature	Minimum Air Temperature	0	no	✖	✖			No action needed
		Air Freezing Index	6	no	✖	✖			No action needed
		Cold Waves	5	no	✖	✖			No action needed
		Frost	18	low	✓	✓	Yes	Yes	Increase in humidity is resulting in increased frost accumulation on airport surfaces. Monitoring is recommended to better understand the conditions when frost forms and if the changes are significant. Additional maintenance equipment, such as sanders, including the sand, may be required if additional data confirm current assumptions
	Rain	Rainfall in the Fall	3	no	✖	✖			No action needed
		Freezing Rain	4	no	✖	✖			No action needed
		Rain on Snow	6	no	✖	✖			No action needed
	Snow	Total	12	low	✖	✓		Yes	Potential increase in snow thickness may result in more winter maintenance. Monitoring of snow events and maintenance efforts is recommended in order to evaluate potential mitigation measures, such as change in equipment.
		Duration	8	no	✖	✖			No action needed
		Frequency	8	no	✖	✖			No action needed
		First Snow Day	6	no	✖	✖			No action needed
		Last Snow Day	6	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	12	low	✖	✓		Yes	Currently, trends regarding blizzards and ice storms are not available. Additional monitoring data and model improvements are required before specific adaptation measures can be recommended. Augmenting maintenance crew and equipment may have to be considered.
		Ice Storms	10	low	✖	✓		Yes	
	Wind	Wind in Winter	2	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		4	no	✖	✖			No action needed
	Climate Variability		15	low	✖	✓		Yes	It is likely that climate variability and the occurrence of extreme weather conditions increase. To be better prepared, it is recommended to improve short- to mid-range weather forecasts via developing new and specific models for the area.
Lighting Systems	Temperature	Frost	6	no	✖	✖			No action needed
	Rain	Freezing Rain	3	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	6	no	✖	✖			No action needed
		Ice Storms	6	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	2	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
		Factor		Priority	Engineering	Management			
	Wind	Wind Gusts	2	no	✖	✖			No action needed
	Ground Freezing Index		10	no	✖	✖			No action needed
	Ground Thawing Index		12	no	✖	✖			No action needed
	Fog/Visibility		15	low	✓	✖	Yes	Yes	Projections and historical trends on visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Surface Marking	Temperature	Freeze-Thaw Cycles	5	no	✖	✖			No action needed
		Heat Waves	0	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	12	low	✓	✓	Yes	Yes	Frost may affect surface marking. No data are currently available indicating that an impact exists. Additional monitoring is recommended.
	Storms	Ice Storms	6	no	✖	✖			No action needed
		Hail	0	no	✖	✖			No action needed
	Wildfires		10	low	✖	✖			No action needed
Weather Station	Temperature	Maximum Air Temperature	0	no	✖	✖			No action needed
		Minimum Air Temperature	0	no	✖	✖			No action needed
		Heat Waves	5	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	4	no	✖	✖			No action needed
		Rain on Snow	4	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	4	no	✖	✖			No action needed
		Ice Storms	4	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	0	no	✖	✖			No action needed
	Wind	Wind Gusts	4	no	✖	✖			No action needed
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Environmental Monitoring	Temperature	Maximum Air Temperature	0	no	✖	✖			No action needed
		Minimum Air Temperature	0	no	✖	✖			No action needed
		Heat Waves	5	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Rain on Snow	2	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	2	no	✖	✖			No action needed
		Ice Storms	2	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	2	no	✖	✖			No action needed
	Wind	Wind Gusts	0	no	✖	✖			No action needed
	Ground Freezing Index		5	no	✖	✖			No action needed
	Ground Thawing Index		4	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		4	no	✖	✖			No action needed
	Fog/Visibility		10	no	✖	✖			No action needed
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Naveed's	Storms	Blizzards/White-Outs	6	no	✖	✖			No action needed
		Ice Storms	4	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	2	no	✖	✖			No action needed
	Cloud Ceiling Height		9	no	✖	✖			No action needed
	Fog/Visibility		15	low	✓	✓	Yes	Yes	Projections and historical trends on visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Vegetation	Temperature	Maximum Air Temperature	6	no	✖	✖			No action needed
		Minimum Air Temperature	10	no	✖	✖			No action needed
		Air Freezing Index	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Freeze-Thaw Cycles	0	no	✖	✖			No action needed
		Heat Waves	10	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
		Factor		Priority	Engineering	Management			
		Cold Waves	10	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	4	no	✖	✖			No action needed
		Rainfall in the Fall	0	no	✖	✖			No action needed
		Rain on Snow	2	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
		First Snow Day	3	no	✖	✖			No action needed
		Last Snow Day	3	no	✖	✖			No action needed
	Storms	Ice Storms	2	no	✖	✖			No action needed
		Hail	6	no	✖	✖			No action needed
	Wind	Wind Gusts	2	no	✖	✖			No action needed
	Ground Freezing Index		10	no	✖	✖			No action needed
	Ground Thawing Index		12	no	✖	✖			No action needed
	Cloud Cover/Solar Radiation		4	no	✖	✖			No action needed
	Wildfires		10	low	✖	✖			No action needed
Aircraft Arresting System	Temperature	Frost	12	low	✓	✖	Yes	Yes	Frost may affect the aircraft arresting system, however, currently there are No reports available indicating frost having been an issue on the system. Potential impacts of frost on the system may be evaluated. Alternatively, system use may be ceased during frost events or the system could be heated.
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	8	no	✖	✖			No action needed
		Freezing Rain	4	no	✖	✖			No action needed
		Rain on Snow	4	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
		Duration	4	no	✖	✖			No action needed
		Frequency	4	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	4	no	✖	✖			No action needed
		Ice Storms	8	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
	Ground Freezing Index		20	low	✓	✖	Yes	Yes	Warmer winters and warmer summers result in ground temperature increase and active layer thickening. This may lead to decrease in strength, thaw consolidation and other structural instabilities . Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential effects on the aircraft arresting system.
	Ground Thawing Index		20	low	✓	✖	Yes	Yes	
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Security Structures	Rain	Freezing Rain	2	no	✖	✖			No action needed
		Rain on Snow	2	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	2	no	✖	✖			No action needed
		Ice Storms	4	no	✖	✖			No action needed
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	2	no	✖	✖			No action needed
	Ground Freezing Index		20	low	✓	✖		Yes	Warmer winters and warmer summers result in ground temperature increase and active layer thickening. This may lead to decrease in strength, thaw consolidation and other structural instabilities . Additional monitoring of ground temperatures is required to better understand changes in ground temperatures and potential effects on the security system.
	Ground Thawing Index		20	low	✓	✖		Yes	
	Fog/Visibility		5	no	✖	✖			No action needed
	Wildfires		10	low	✖	✖			No action needed
Data Availability	Temperature	Maximum Air Temperature	30	high	✖	✓		Yes	Air temperatures and related parameters are expected to change significantly with climate change. In order to assess how various infrastructure reacts to climate change, it is not only critical to collect information on temperature, but to further record infrastructure response, management decisions and operations to climate events in a systematic way (database).
		Minimum Air Temperature	20	medium	✖	✓		Yes	
		Air Freezing Index	24	medium	✖	✓		Yes	
		Air Thawing Index	25	medium	✖	✓		Yes	
		Freeze-Thaw Cycles	15	medium	✖	✓		Yes	
		Heat Waves	15	medium	✖	✓		Yes	
		Cold Waves	10	no	✖	✖			No action needed
		Frost	30	high	✖	✓		Yes	Frost can have significant impact on various infrastructure elements and air traffic operations. It is recommended that a system is developed to properly record frost and how it may affect infrastructure elements as well as air traffic operations and management.
	Rain	Frequency	16	medium	✖	✓		Yes	Changes in rain and its related parameters are uncertain in response to climate change. However, in order to assess if changes occur and how various infrastructure reacts to climate change, it is not only critical to collect information on rain, but to further record infrastructure response, management decisions and operations to climate events in a systematic way (database).
		Duration	20	medium	✖	✓		Yes	
		Intensity	24	medium	✖	✓		Yes	
		Rainfall in the Fall	12	medium	✖	✓		Yes	
		Freezing Rain	3	no	✖	✖			No action needed
		Rain on Snow	4	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



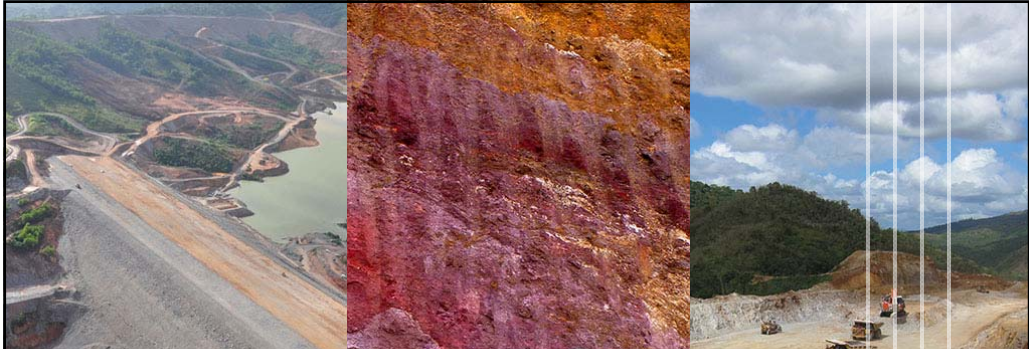
Infrastructure Component	Climate Element		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
		Factor		Priority	Engineering	Management			
	Snow	Total	20	medium	✖	✓		Yes	Changes in snow and its local response to the permafrost are uncertain in response to climate change. However, in order to assess if changes occur and how various infrastructure reacts to climate change, it is not only critical to collect information on snow, but to further record infrastructure response, management decisions and operations to climate events in a systematic way (database).
		Duration	16	medium	✖	✓		Yes	
		Frequency	20	medium	✖	✓		Yes	
		First Snow Day	9	no	✖	✖			No action needed
		Last Snow Day	9	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	12	medium	✖	✓		Yes	No action needed
		Ice Storms	6	low	✖	✖		Yes	
		Hail	10	low	✖	✓		Yes	
	Wind	Wind Gusts	12	medium	✖	✓		Yes	Changes in wind are uncertain in response to climate change. However, in order to assess if changes occur and how various infrastructure reacts to climate change, it is not only critical to collect information on wind, including major wind gusts, but to further record infrastructure response, management decisions and operations to climate events in a systematic way (database).
		Wind Direction	5	low	✖	✓		Yes	
		Wind in Winter	5	low	✖	✓		Yes	
	Ground Freezing Index		15	medium	✖	✓		Yes	Ground temperatures are expected to change at a different rate than air temperature and those changes depend on several factors.. In order to assess how the ground temperatures change in response to climate change, and to assess the response of the infrastructure on changes in permafrost conditions it is not only critical to collect information on ground temperature, but to further record infrastructure response, management decisions and operations to climate events in a systematic way (database).
	Ground Thawing Index		20	medium	✖	✓		Yes	
	Cloud Cover/Solar Radiation		16	medium	✖	✓		Yes	Solar radiation is likely changing due to climate change. The changes are widely uncertain and it is unclear how this may further affect changes in the permafrost. A systematic (database) collection of solar radiation, cloud cover and infrastructure response is recommended.
	Cloud Ceiling Height		9	low	✖	✓		Yes	
	Fog/Visibility		30	high	✖	✓		Yes	Visibility is likely changing due to increase in moisture as (fog) in response to climate change. The changes are widely uncertain and it is unclear how this may further affect changes in airport operations . A systematic (database) collection of visibility data and related airport operations activities is recommended.
	Lightning/Electrical Storms		6	no	✖	✖			No action needed
	Wildfires		5	no	✖	✖			No action needed
	Climate Variability		25	high	✖	✓		Yes	Changes due to climate change can only be evaluated if the signals from climate variability are known. A better understanding of the climate variability further helps improving any local climate and weather models that may be needed in order to plan mitigation and future management options.
Emergency Procedures and Medivac	Temperature	Heat Waves	10	no	✖	✖			No action needed
		Cold Waves	0	no	✖	✖			No action needed
		Frost	6	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	10	no	✖	✖			No action needed
		Intensity	12	no	✖	✖			No action needed
		Freezing Rain	5	no	✖	✖			No action needed
		Rain on Snow	6	no	✖	✖			No action needed
	Snow	Total	8	no	✖	✖			No action needed
		Duration	8	no	✖	✖			No action needed
		Frequency	8	no	✖	✖			No action needed
	Storms	Blizzards/White-Outs	12	low	✖	✓		Yes	Currently, trends regarding blizzards and ice storms are not available. Additional monitoring data and model improvements are required before specific adaptation measures can be recommended. Augmenting maintenance crew and equipment may have to be considered.
		Ice Storms	10	low	✖	✓		Yes	
		Hail	2	no	✖	✖			No action needed
		Lightning/Electrical Storms	4	no	✖	✖			No action needed
	Wind	Wind Direction	2	no	✖	✖			No action needed
		Wind in Winter	3	no	✖	✖			No action needed
	Cloud Ceiling Height		6	no	✖	✖			No action needed
	Fog/Visibility		25	medium	✓	✓	Yes	Yes	Projections and historical trends on visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Climate Variability		15	no	✖	✖			No action needed
	Wildfires		15	low	✖	✓	Yes	Yes	Wildfires may become more frequent in the area. Additional studies are required to understand the potential and design adequate adaptation and mitigation measures.
Wildlife	Temperature	Maximum Air Temperature	6	no	✖	✖			No action needed
		Minimum Air Temperature	5	no	✖	✖			No action needed
		Air Freezing Index	6	no	✖	✖			No action needed
		Air Thawing Index	5	no	✖	✖			No action needed
		Heat Waves	5	no	✖	✖			No action needed
		Cold Waves	5	no	✖	✖			No action needed
	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	0	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed
	Wind	Wind Gusts	2	no	✖	✖			No action needed
	Wildfires		10	low	✖	✖			No action needed
Future Developments/Masterplan	Rain	Frequency	4	no	✖	✖			No action needed
		Duration	5	no	✖	✖			No action needed
		Intensity	4	no	✖	✖			No action needed
	Snow	Total	4	no	✖	✖			No action needed

Inuvik Airport - Recommendation Matrix



Infrastructure Component	Climate		Risk Value	Action Recommendations			Additional Study Required	Observations / Monitoring	Comments
	Element	Factor		Priority	Engineering	Management			
	Ground Freezing Index		0	no	✖	✖			No action needed
	Ground Thawing Index		0	no	✖	✖			No action needed
	Cloud Ceiling Height		6	no	✖	✖			No action needed
	Fog/Visibility		10	low	✓	✓	Yes	Yes	Projections and historical trends on visibility are currently not conclusive and additional monitoring is recommended. Potential adaptation measures are upgrades on the automatic landing system.
	Climate Variability		5	no	✖	✖			No action needed

APPENDIX D WORKSHOP PRESENTATION



PIEVC Vulnerability Assessment

Inuvik Mike Zubko Airport

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Workshop Overview

Wednesday, July 22	
Introduction	2:30 pm – 5:00 pm
Thursday, July 23	
Site Visit	8:00 am – 10:00 am
Break-out Session I	10:30 am – 12:00 pm
Lunch	12:00 pm – 1:00 pm
Break-out Session II	1:00 pm – 2:30 pm
Break	2:30 pm – 3:00 pm
Break-out Session III	3:00 pm – 5:00 pm
Friday, July 23	
Wrap-up	8:00 am – 11:00 am

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Presentation Overview

- Welcome
- Introduction of Participants and Project
- Presentation by Engineers Canada
- Climate Change Vulnerability Assessment Protocol
- Inuvik Airport Background (GNWT Presentation)
- Climate Change and Inuvik Airport
- Overview of Workshop
- Site Visit

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Introduction

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Inuvik Mike Zubko Airport



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Inuvik Mike Zubko Airport



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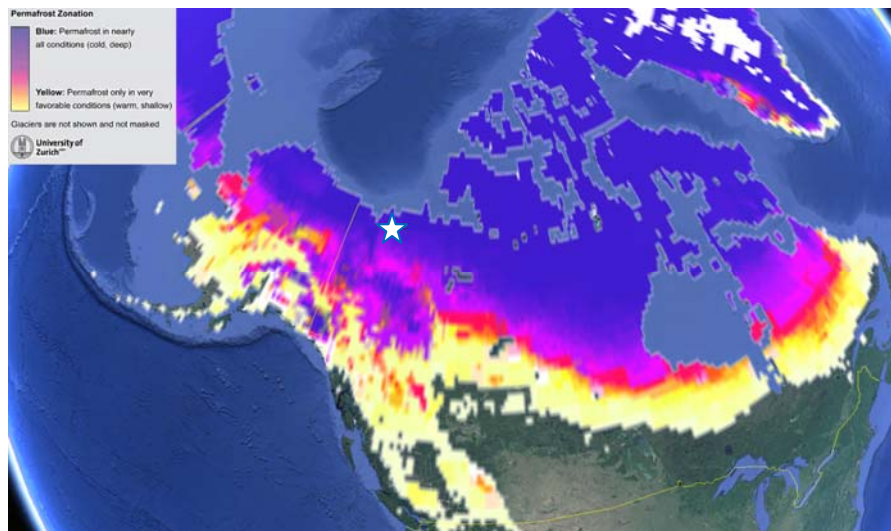
Inuvik Mike Zubko Airport

- Airport originally constructed in 1956-1958
- Located 12 km east of the community of Inuvik
- 2012 aircraft movement: 14,284
- Asphalt runway, 45 m wide by 1829 m (6000 feet) long
- Located in continuous permafrost

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Inuvik Mike Zubko Airport



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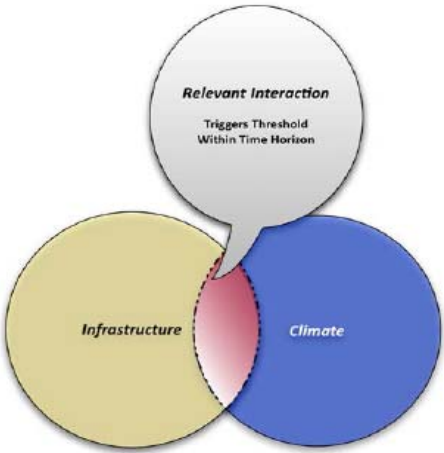
Engineers Canada Presentation



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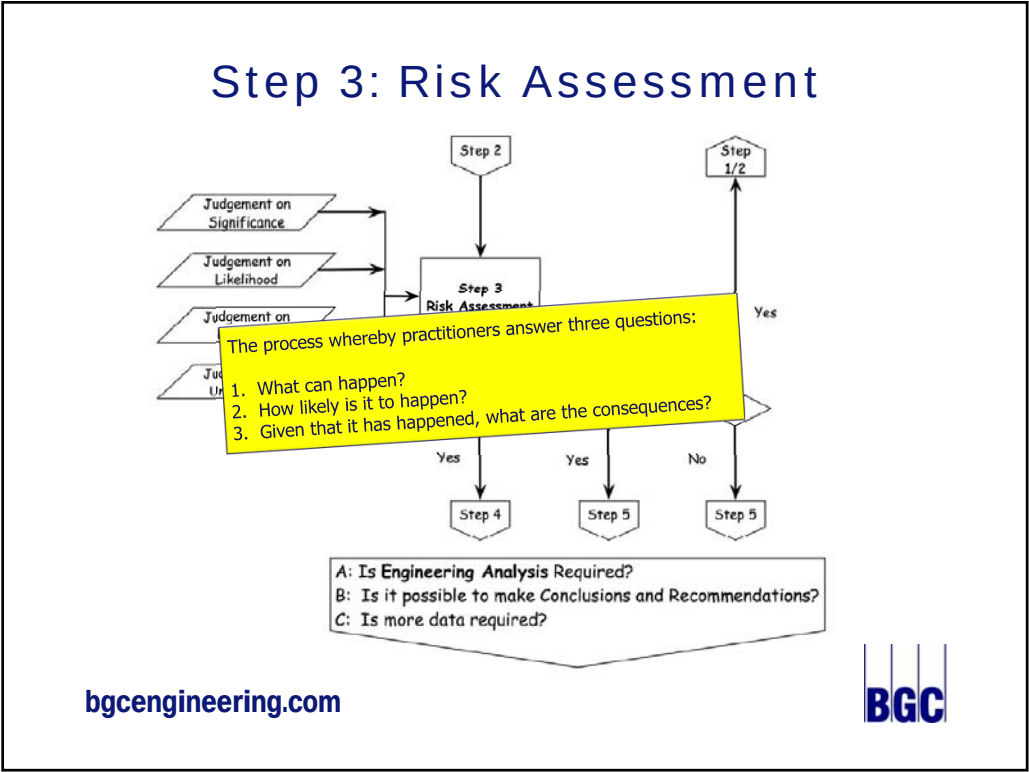
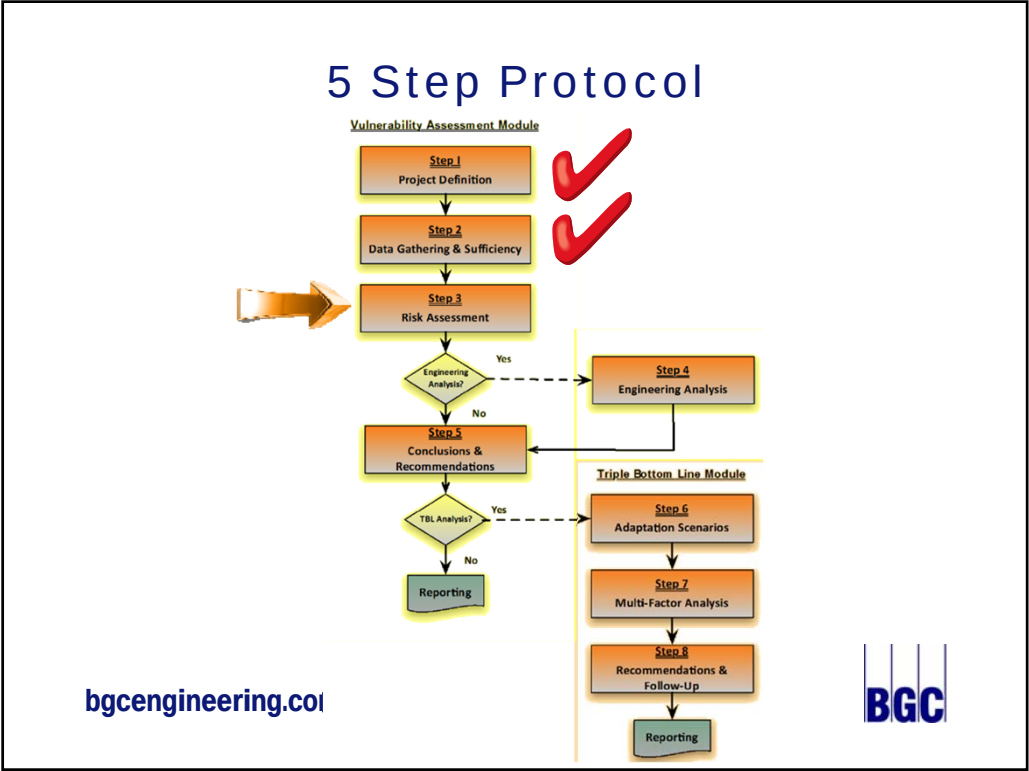


PIEVC Protocol for Climate Change Vulnerability Assessment



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Risk

The possibility of injury, loss, or negative environmental impact created by a hazard. The significance of risk is a function of the **probability** of an unwanted incident and the **severity** of its consequence. In mathematical terms:

$$R = P \times S$$

Where:

- R = Risk
- P = Probability of a negative event
- S = Severity of the event, given that it has happened

Probability, P

Score	Probability	
	Method A	Method B
0	Negligible Not Applicable	< 0.1 % < 1 in 1,000
1	Highly Unlikely Improbable	1 % 1 in 100
2	Remotely Possible	5 % 1 in 20
3	Possible Occasional	10 % 1 in 10
4	Somewhat Likely Normal	20 % 1 in 5
5	Likely Frequent	40 % 1 in 2.5
6	Probable Often	70 % 1 in 1.4
7	Highly Probable Approaching Certainty	> 99 % > 1 in 1.01

Probability Scoring

		Will the Interaction Change Over Time Horizon of Assessment?	More-Same-Less?	Projected Change in Magnitude?	Projected Change in Frequency	Robustness of Forecast?	Professional Judgment	Probability Score
		Y/N	+ 0 -	H M L	H M L	H M L	Comments	0-7
High Temperature	Number of Days with maximum temperature exceeding 30°C	Y	+	H	H	H	Regional climate modeling forecast suggests that both frequency and magnitude will increase from an average of 0.6 to ~ 3 days per year. The climate specialists have a high level of confidence in the projection. This is a significant change. The projection is consistent with other predictions. This suggests that the likelihood of change is relatively high.	6

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Severity, S

Score	Severity of Consequences and Effects	
	Method D	Method E
0	No Effect	Negligible Not Applicable
1	Measurable	Very Low Some Measurable Change
2	Minor	Low Slight Loss of Serviceability
3	Moderate	Moderate Loss of Serviceability
4	Major	Major Loss of Serviceability Some Loss of Capacity
5	Serious	Loss of Capacity Some Loss of Function
6	Hazardous	Major Loss of Function
7	Catastrophic	Extreme Loss of Asset

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Risk Tolerance Thresholds

Risk Range	Threshold	Response
< 12	Low Risk	No action necessary
12 – 36	Medium Risk	- Action may be required - Engineering analysis may be required
> 36	High Risk	Action required

Low Risk interactions represent no immediate vulnerability. In the professional judgment of the practitioner, there is very low potential changing climate vulnerability associated with the infrastructure component. No further action is necessary.

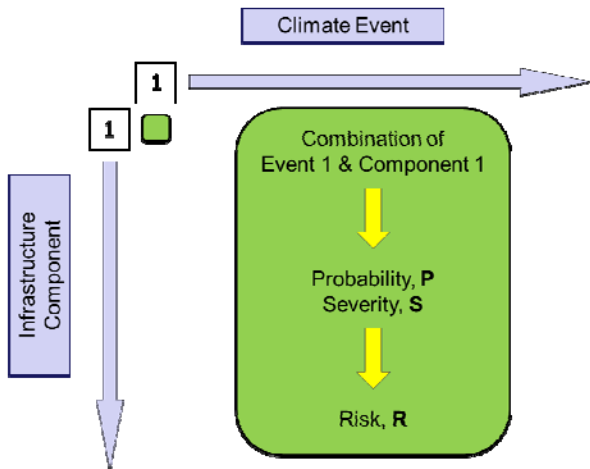
Medium Risk interactions represent a potential vulnerability. In the professional judgment of the practitioner, there is potential changing climate vulnerability associated with the infrastructure component. Further Engineering Analysis may be necessary since the practitioner may not be able to provide a clear, unambiguous, determination of the vulnerability.

High Risk interactions represent an identified vulnerability. In the professional judgment of the practitioner, there is identifiable changing climate vulnerability associated with the infrastructure component. Immediate action may be required.

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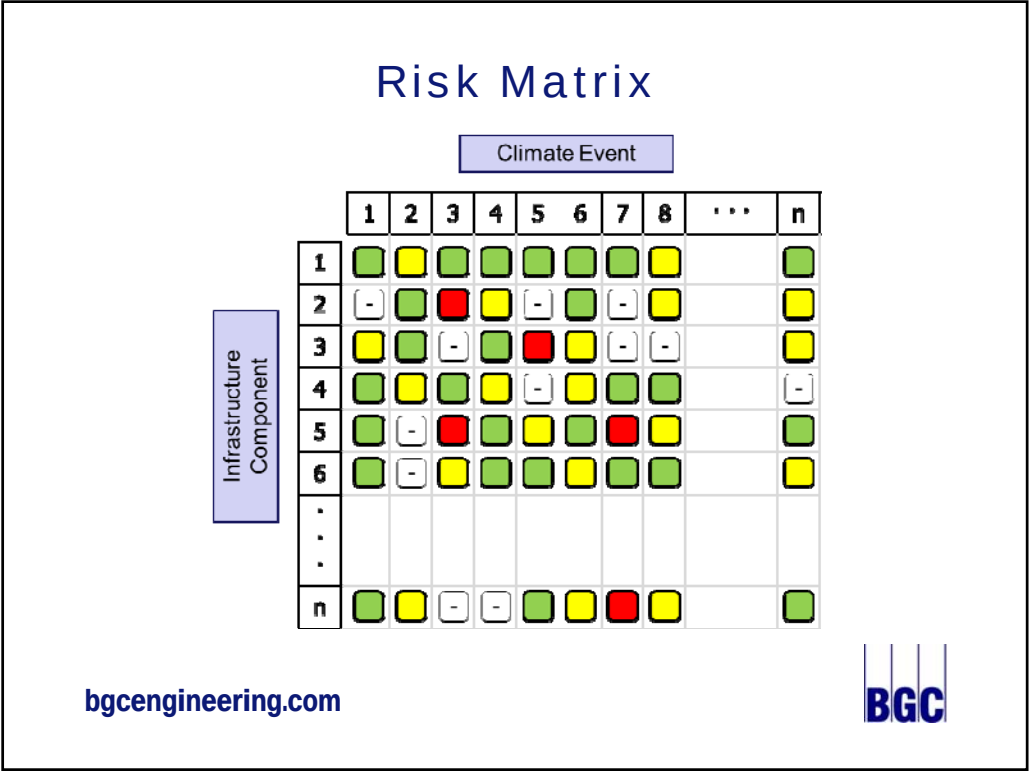


Risk Matrix



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Climate Events and Change Factors I

Suggested Climate and Infrastructure Threshold Parameters	
Climate Parameter	Infrastructure Threshold Parameter
Temperature	▪ Rate of change ▪ Mean values ▪ Extremes ○ High summer ○ Low winter
Precipitation as Rain	▪ Frequency (One-Day, Short Duration Less than 24 hours, Multi-Day) ▪ Total annual/seasonal precipitation and rain ▪ Intensity of rain events (One-Day, Short Duration Less than 24 hours) ▪ Proportion of annual and seasonal precipitation as rainfall ▪ Drought conditions
Precipitation as Snow	▪ Frequency ▪ Total annual/seasonal precipitation and snow ▪ Magnitude of snow events ▪ Proportion of annual and seasonal precipitation as snowfall ▪ Frequency and intensity of rapid snow melt events ▪ Rain on snow events
Wind Speed	▪ Mean values (one hour mean winds) ○ Monthly ○ Seasonal ○ Annual ▪ Extremes/gusts ▪ Thunderstorm winds ▪ General wind patterns/gradients ▪ Changes in hurricane and/or tornado event frequency/intensity



Climate Events and Change Factors II

Suggested Climate and Infrastructure Threshold Parameters	
Climate Parameter	Infrastructure Threshold Parameter
Sea (Water) Level Elevation	▪ Change in mean value ○ Available from Intergovernmental Panel on Climate Change (IPCC) reports
Fog	▪ Frequency ▪ Visibility
Ice	▪ River or lake ice build up ▪ Sea ice build up
Hail	▪ Frequency of events ▪ Magnitude of events
Frost	▪ Freeze thaw cycles ▪ Change in frost season
Ice Accretion	▪ Change in frequency/intensity of ice storm events ▪ Ice build up on infrastructure components
Other	▪ Other climate factors as relevant to the infrastructure under consideration

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Performance Response Consideration I

1. Structural Design

 - Safety
 - Load carrying capacity
 - Overturning
 - Sliding
 - Fracture
 - Fatigue
 - Serviceability
 - Deflection
 - Permanent deformation
 - Cracking and deterioration
 - Vibration
 - Foundation Design
 - Permafrost
2. Functionality

 - Effective Capacity of the infrastructure
 - Short term
 - Medium term
 - Long term
 - Equipment – Component Selection
 - Design, process and capacity considerations

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Performance Response Consideration II

3. Serviceability

- Ability to conduct routine and/or planned maintenance and refurbishment activities
 - Short term
 - Medium term
 - Long term
- Equipment – Component Replacement frequencies
 - Design, process and capacity considerations

4. Watershed, Surface Water, and Groundwater

- Erosion scour of associated or supporting earthworks
- Slope stability of embankments
- Sediment transport and sedimentation
- Channel realignment/meandering
- Water quality
- Water quantity
- Water resource demands
 - Public, hydro, industrial, agricultural use of water resources
 - Groundwater recharge characteristics
- Run off
- Recharge
- Thermal characteristics of the water resource

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Performance Response Consideration III

5. Operations, Maintenance, and Materials Performance

- Occupational safety
- Access to worksite
- Structural integrity
- Equipment performance
 - Maintenance and replacement cycles
 - Electricity demand
 - Fuel use
- Functionality & Effective Capacity
- Materials Performance
 - Changes from design expectation
- Pavement Performance
 - Hail, softening, cracking from freeze thaw and other causes

6. Emergency Response

- Procedures and systems to address
 - Severe storm events
 - Flooding
 - Ice dams
 - Ice accretion
 - Water damage

7. Insurance Considerations

- Insurance rates
- The ability to acquire insurance
- Insurance policy limitations and exclusions

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Performance Response Consideration IV

8. Policy Considerations

 - Codes
 - Guidelines
 - Standards
 - Internal operations and maintenance policies and procedures
 - Public sector policy
 - Land use planning
9. Environmental Effects

 - Release of toxic or controlled substances
 - Degradation of air quality
 - Damage to sensitive ecosystems
 - Physical harm to birds and animals
 - Contamination of potable water supplies
 - Public perception and interaction
10. Socio-Economic Effects

 - Accessibility to critical facilities such as hospitals, fire and police services
 - Transportation of goods to a community
 - Energy supply to a community
 - Dislocation of affected populations
 - Provision of basic services such as potable water distribution and wastewater collection
 - Closure of public services
 - Community business viability
 - Tourism
 - Destruction or damage to heritage buildings, monuments, archaeological resources, historically important resources, etc.
11. Sovereignty

 - Army Base

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Probability Scoring

Infrastructure Components		Infrastructure Response Considerations										Climate Parameter 1				
		Structural Design	Functionality	Serviceability	Watershed, Surface Water & Groundwater Operations, Maintenance & Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Environmental Effects	Enter Infrastructure Threshold Value Here	Enter rationale for Infrastructure Threshold here. Identify reference to code or standard if relevant.				
		Mark Relevant Responses with ✓										Y/N	P	S	R	Rationale For Severity Score
1	Component 1															
2	Component 2															
3	Component 3															
4																
5																
6																

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Mike Zubko Airport

Background

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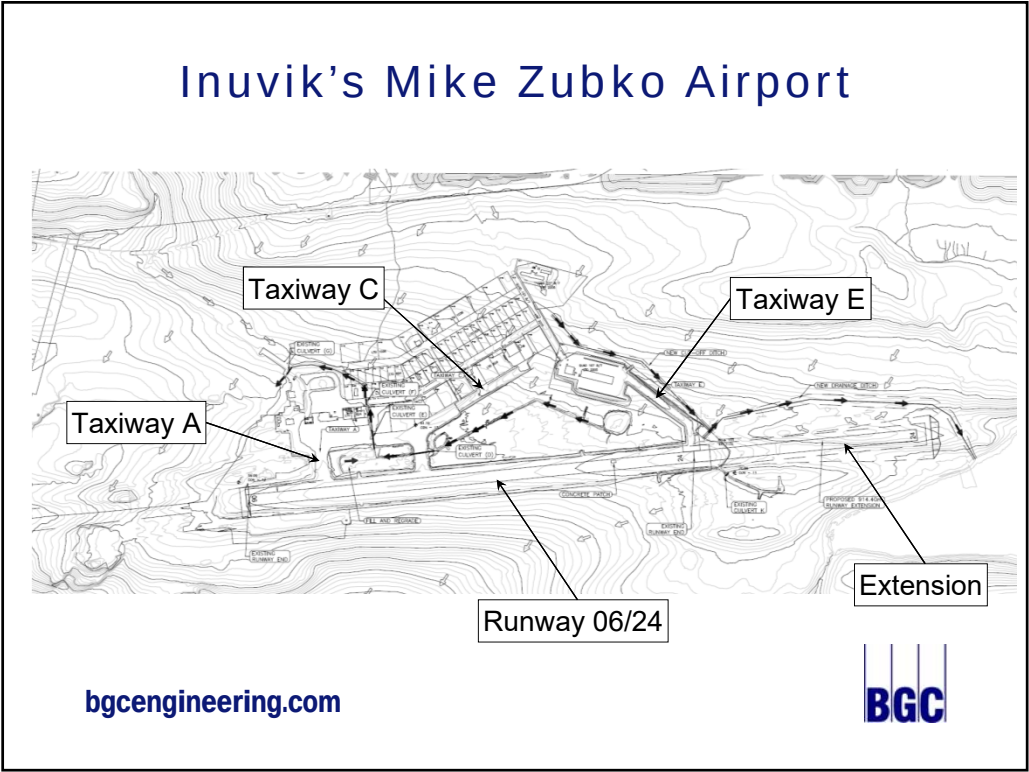


GNWT – DOT Presentation



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Structural Challenges

- Sinkhole / Differential settlements
- Ponding / Drainage
- Sloughing

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Sinkhole



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Sinkhole



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Sinkhole

- Settlements located about 12 metres north of the runway centreline and 325 metres west of the east end of the runway
- Sinkhole which initially became apparent in 2013, and reappeared earlier in 2015
- May be related to the warming and degradation of the permafrost subgrade

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Taxiway E



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Taxiway E



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Sloughing



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Settlements



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Ponding



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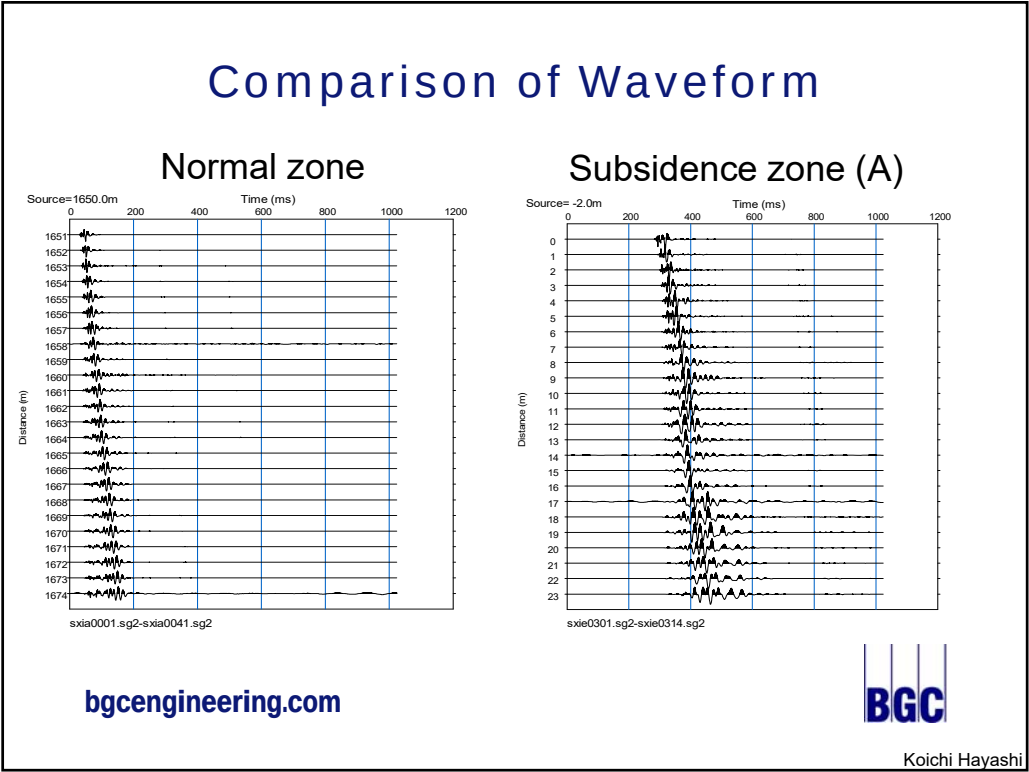
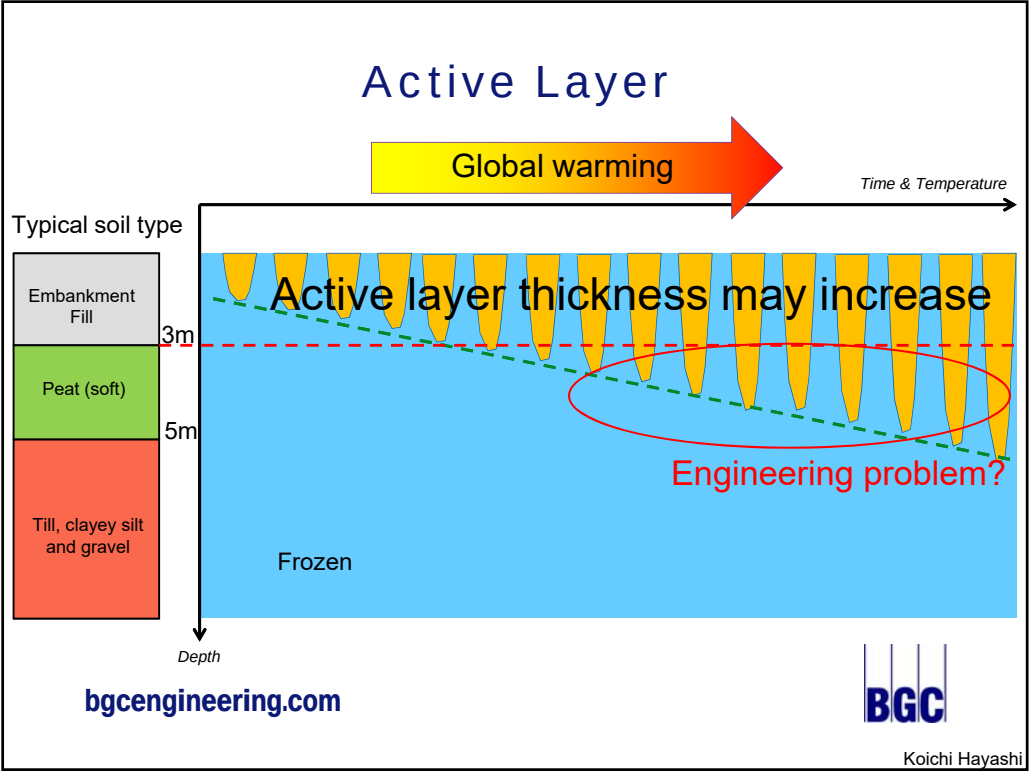
BGC

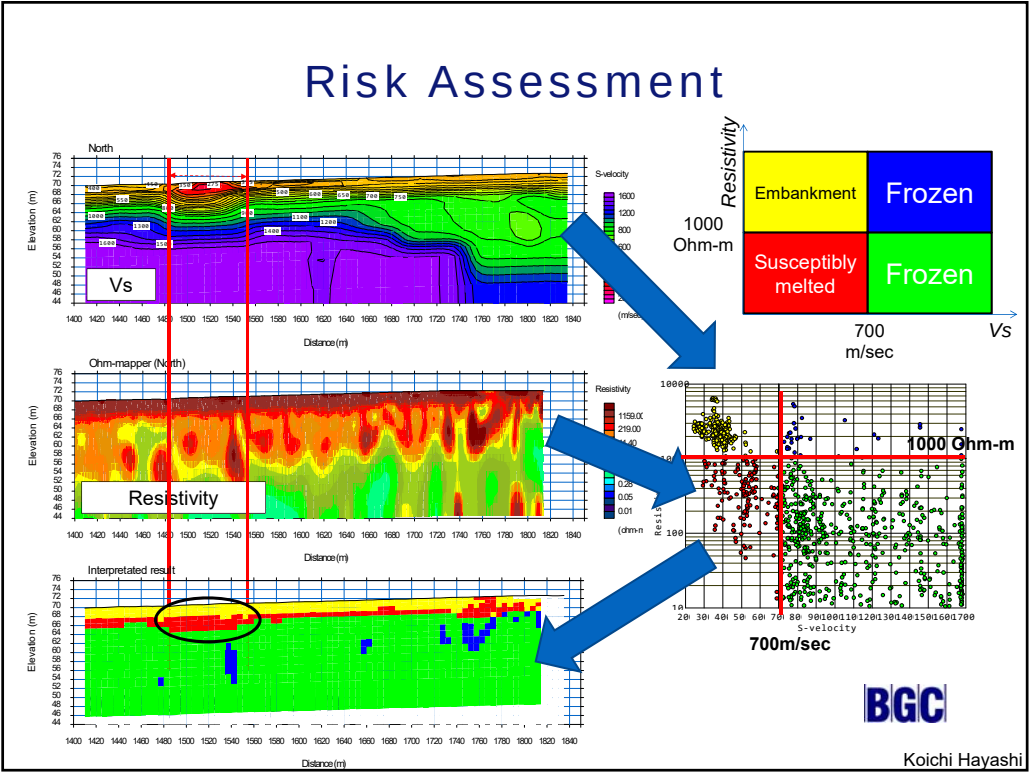
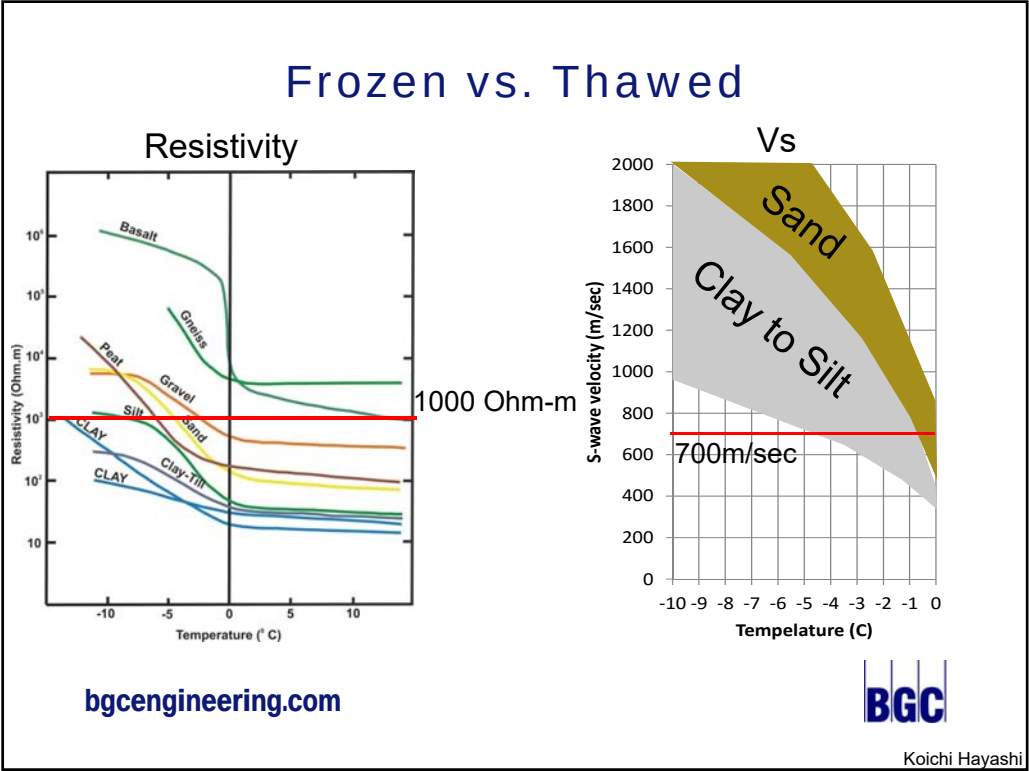
Geophysics



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Koichi Hayashi





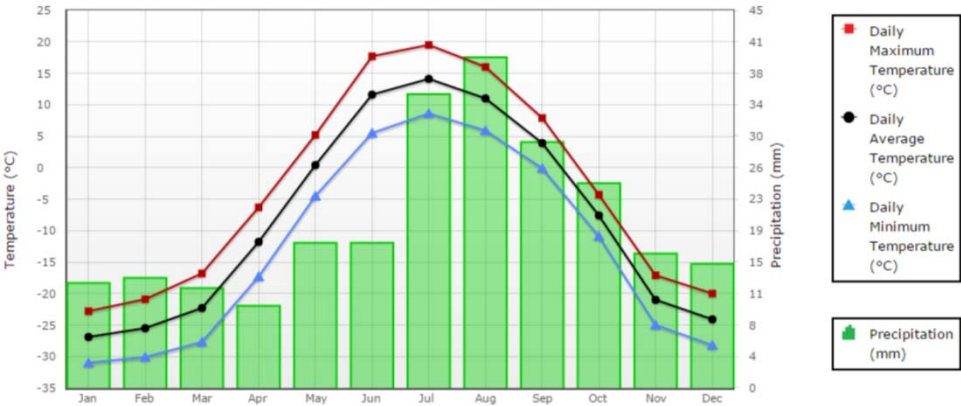
Climate Change

Mike Zubko Airport, Inuvik, Northwest Territories

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Climate Normals



Environment Canada

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Climate Baseline

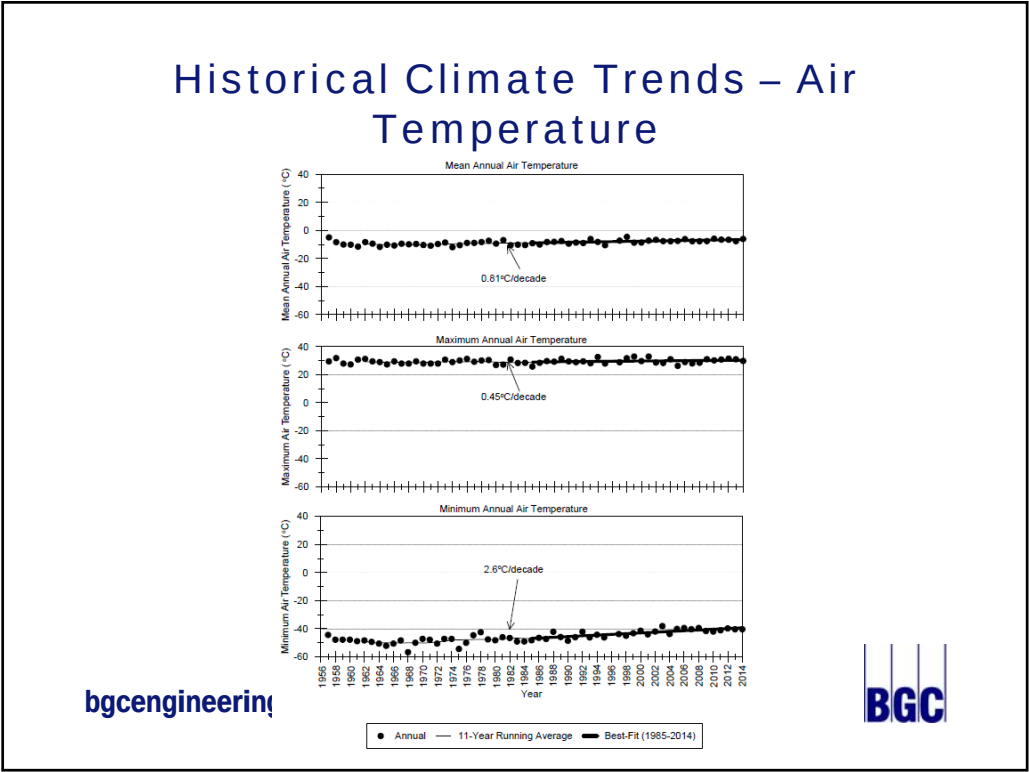
Climate Normals (1981-2010)

Month	Air Temperature (°C)	Wind Speed (km/hr)	Precipitation (mm)	Daily Solar Radiation (MJ/m²)
January	-26.9	7.1	12.5	1
February	-25.5	7.8	13.1	5
March	-22.3	9.0	11.9	14
April	-11.8	10.0	9.8	23
May	0.4	11.6	17.3	30
June	11.6	12.4	17.3	31
July	14.1	11.1	35.0	30
August	11.0	10.4	39.4	24
September	3.9	10.1	29.3	15
October	-7.6	9.0	24.4	7
November	-21.1	7.2	16.0	2
December	-24.1	7.1	14.8	0
Annual	-8.2	9.4	240.6	-

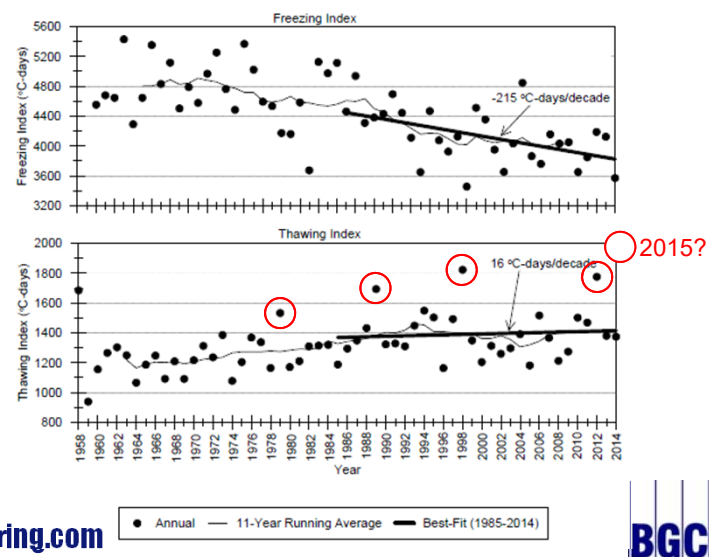
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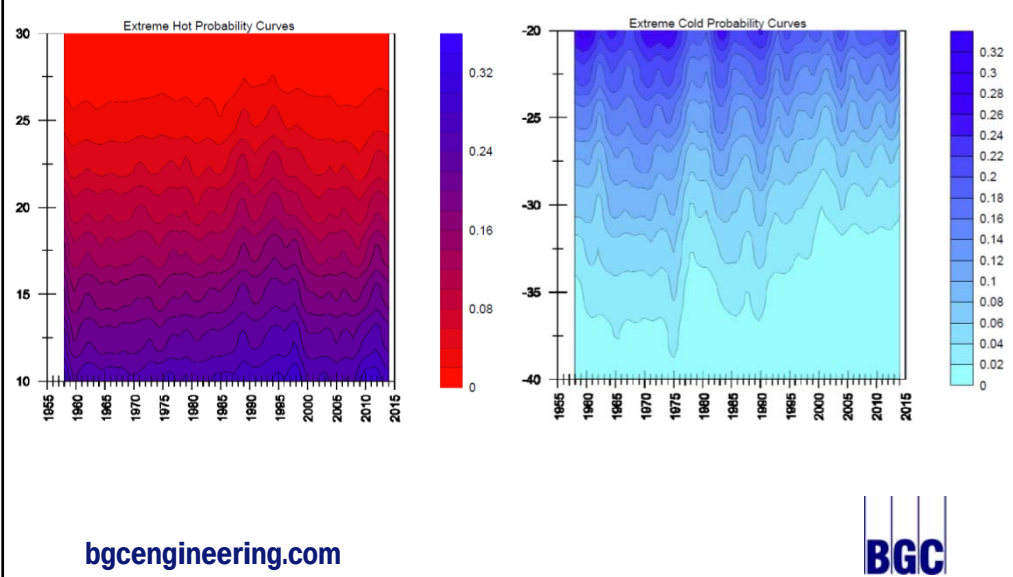
Environment Canada



Historical Climate Trends – Air Temperature



Temperature Extrema



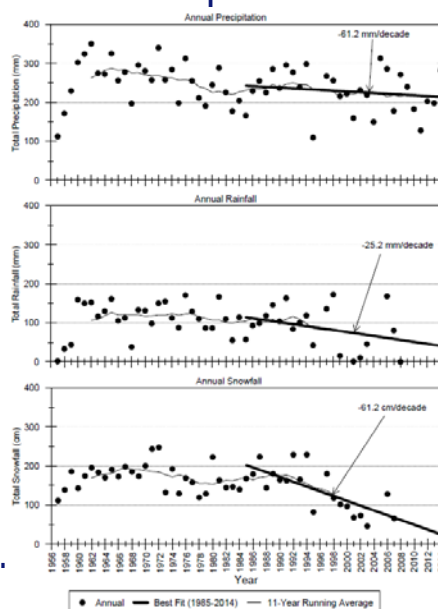
Historical Climate Trends – Air Temperature

- Annual air temperatures have been steadily increasing over the past 30 years
- The increase in winter temperatures is significantly higher than the increase in summer air temperatures
- 4 of the 5 warmest years on record occurred in the past 25 years:
 - 1998 (-4.8°C), 2010 (-5.9°C), 2014 (-6.1°C), 1993 (-6.1°C)
- The number of freeze/thaw cycles in both spring and fall months have been steadily declining over the past 30 years

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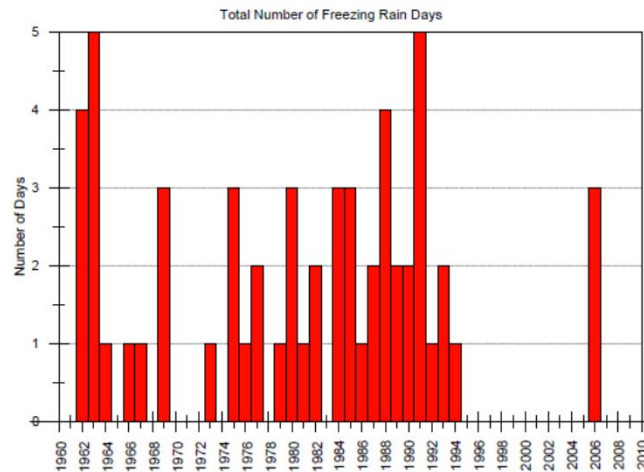
Historical Climate Trends - Precipitation



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Freezing Rain



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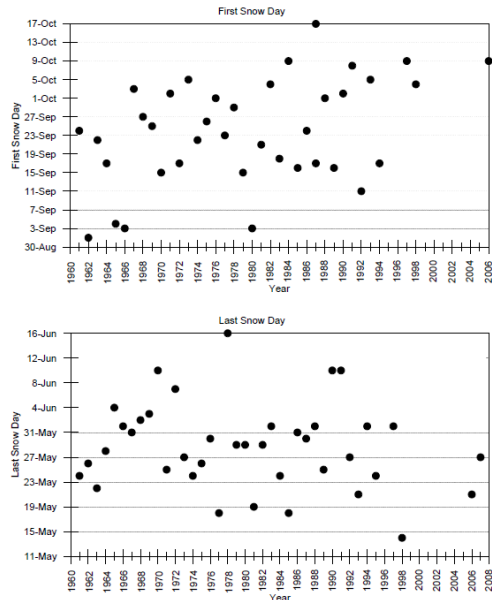
Historical Climate Trends - Precipitation

- Annual mean precipitation has shown a steady decrease over the past 30 years
- Each season shows decreased precipitation except summer months
- Summer months have shown an increase in precipitation
- No trend in freezing rain days

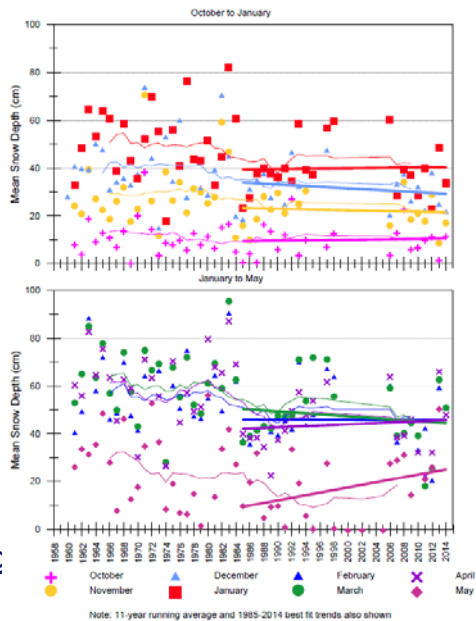
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Historical Climate Trends – Snow Cover



Historical Climate Trends – Snow Cover



Historical Climate Trends – Snow Cover

- First snow days have occurred later in the season in recent years
- Last snow days have occurred earlier in the spring
- Snow depths in April and May have increased over the last 30 years
- Snow depths in November and December have increased over the last 30 years

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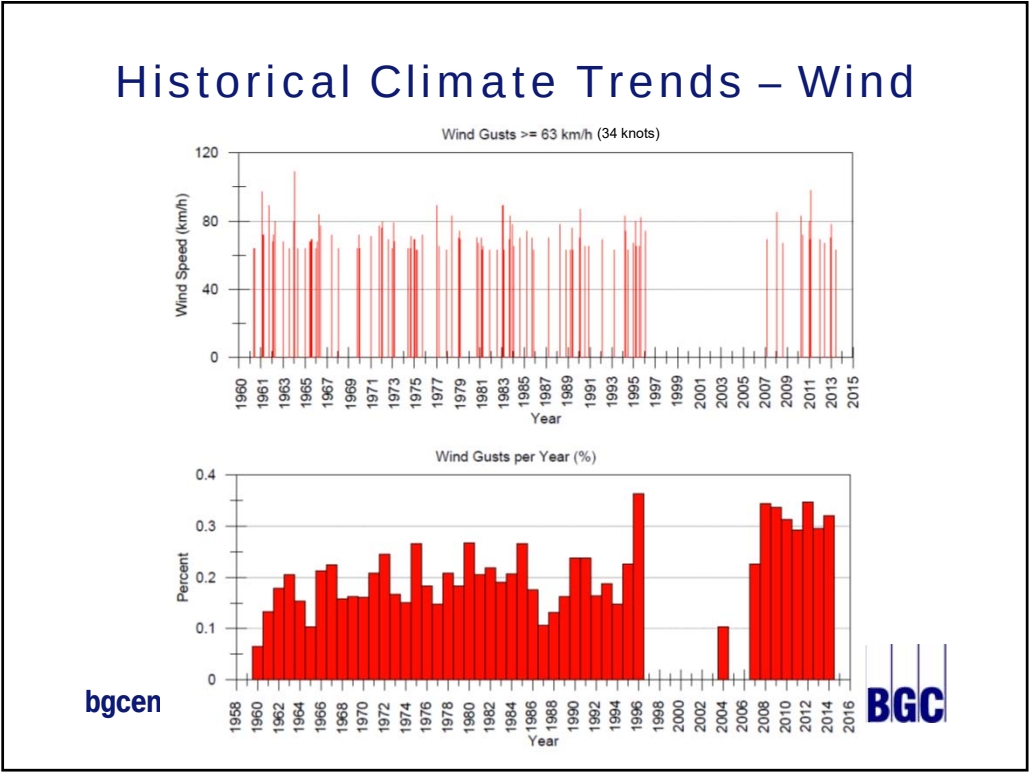
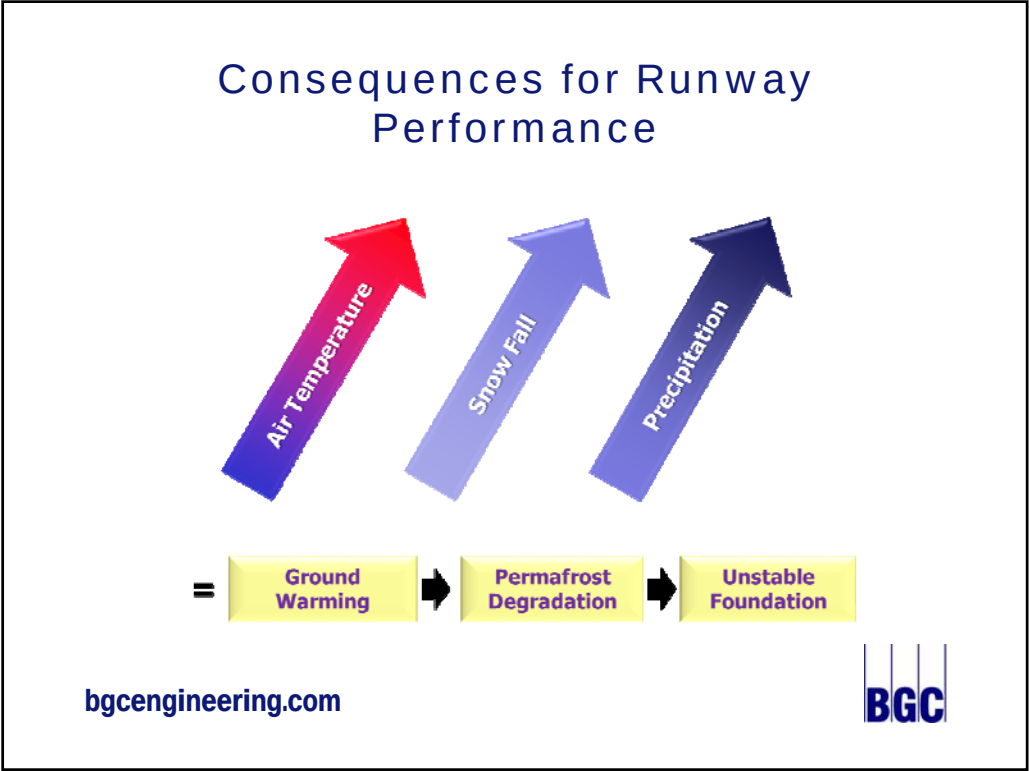


Consequences for Runway Performance

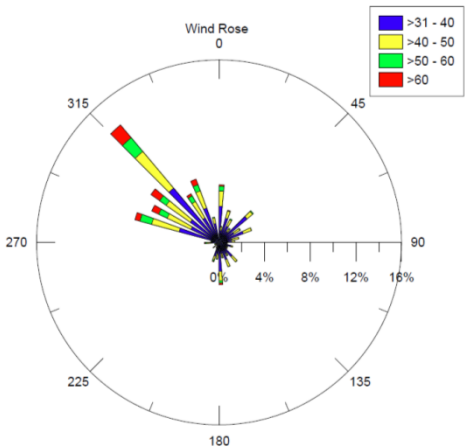
- Warmer air temperatures mean warmer permafrost temperatures; warmer summer air temperatures results in increased depths of seasonal thaw.
- Increased snowfall results in increased snow depth which would insulates the embankment slopes from the cold winter air temperatures thereby having a similar thermal impact as warmer air temperatures.
- Increased precipitation could result in more surface and groundwater flow which could contribute to convective warming if it flows through the embankment.

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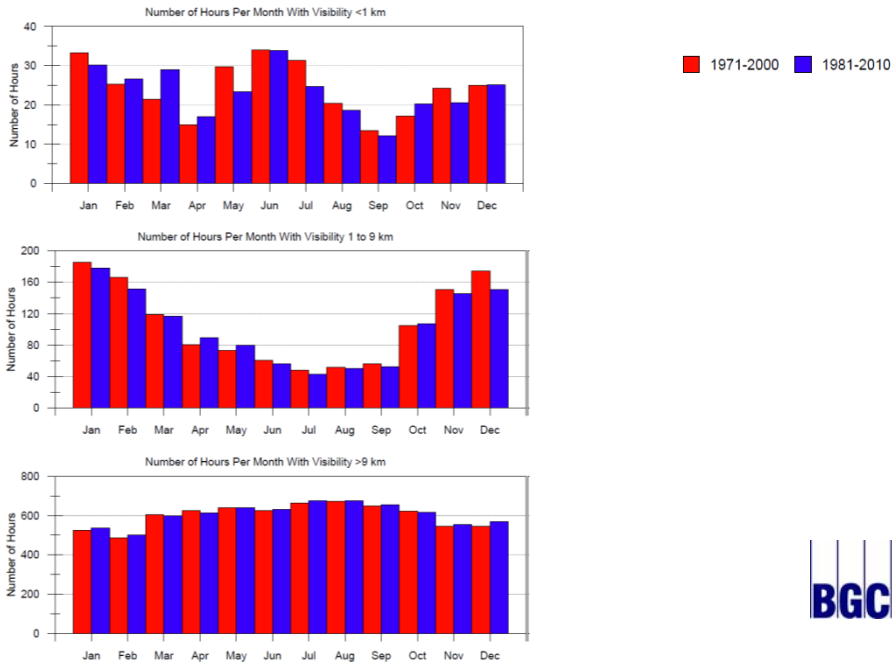
Wind Direction

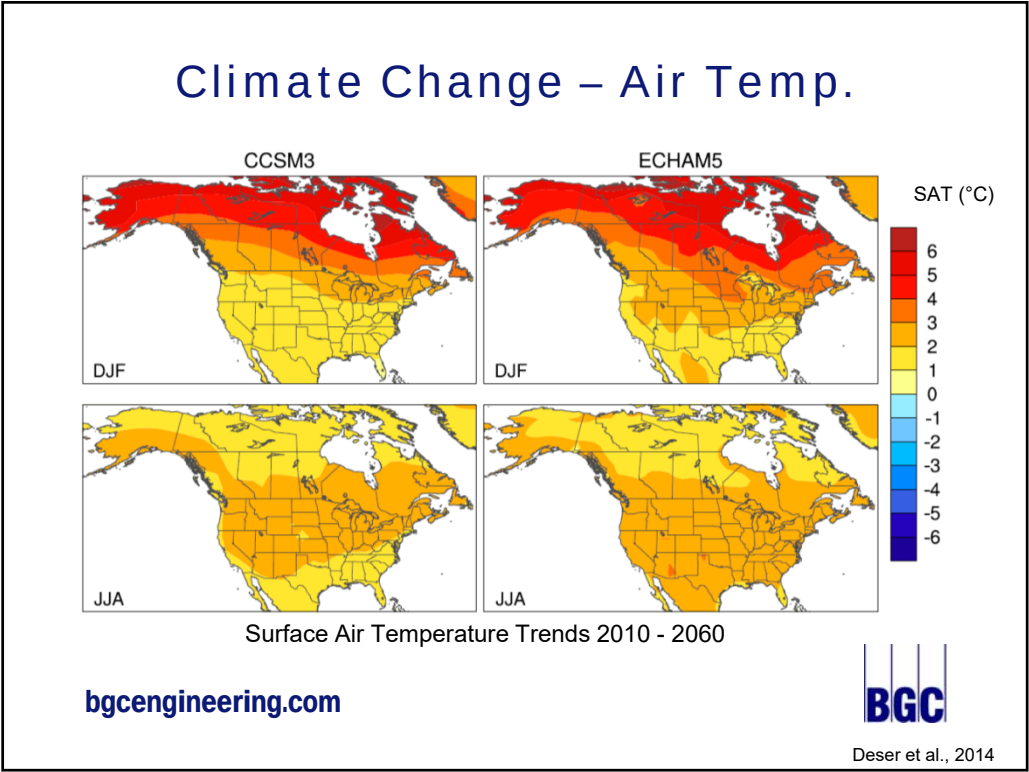
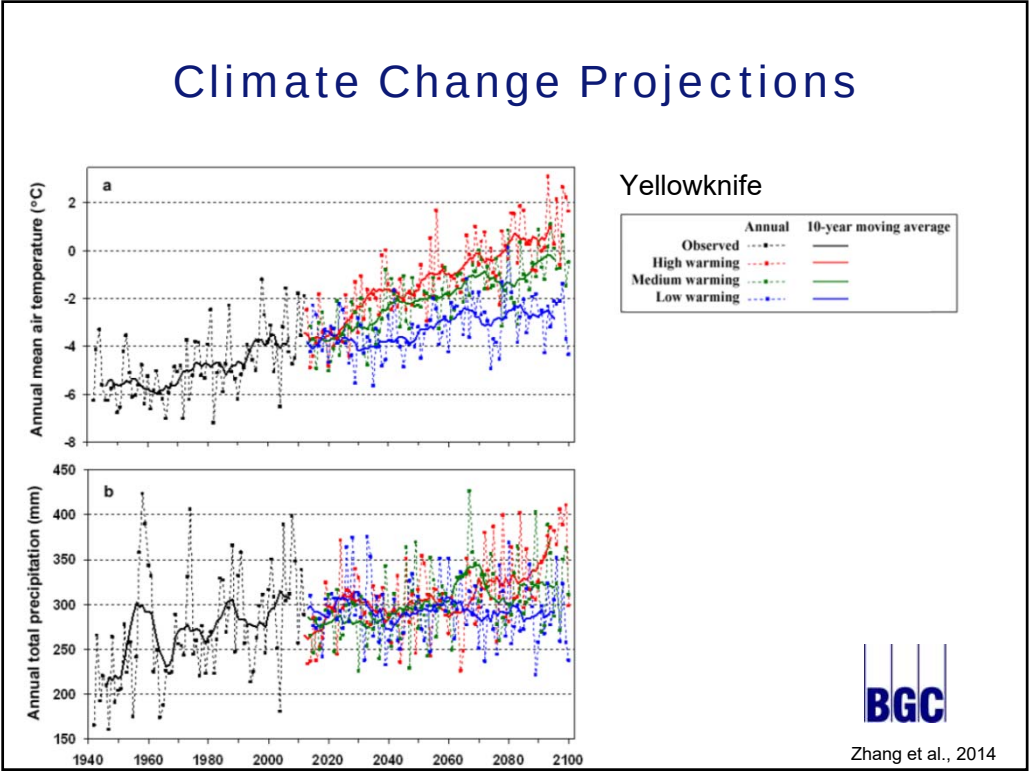


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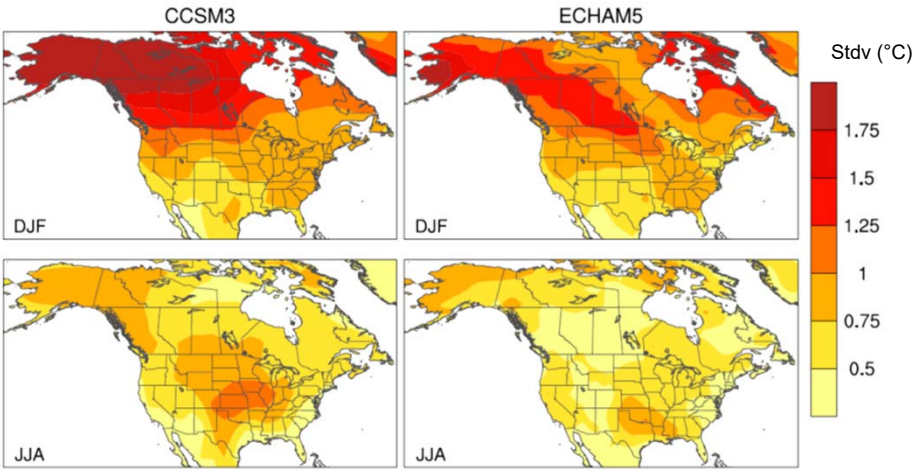


Historical Climate Trends – Visibility





Climate Change – Air Temp.



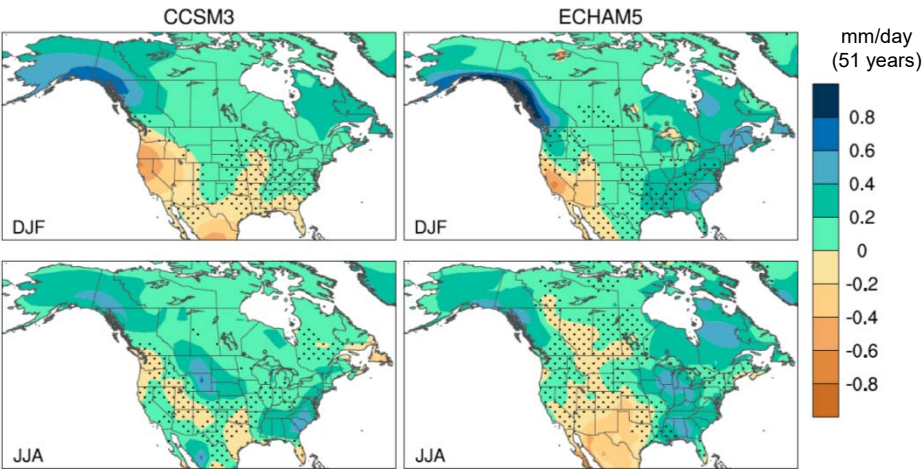
Surface Air Temperature Trends 2010 - 2060

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Deser et al., 2014

Climate Change – Precipitation

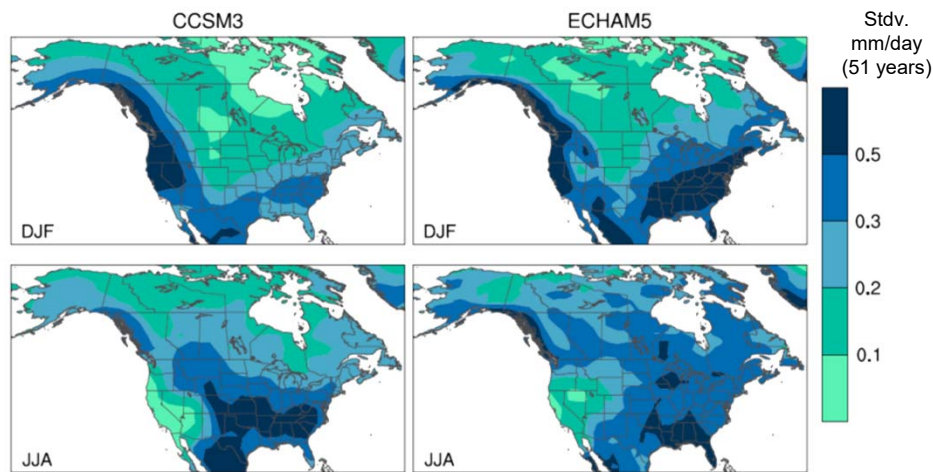


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Deser et al., 2014

Climate Change – Precipitation

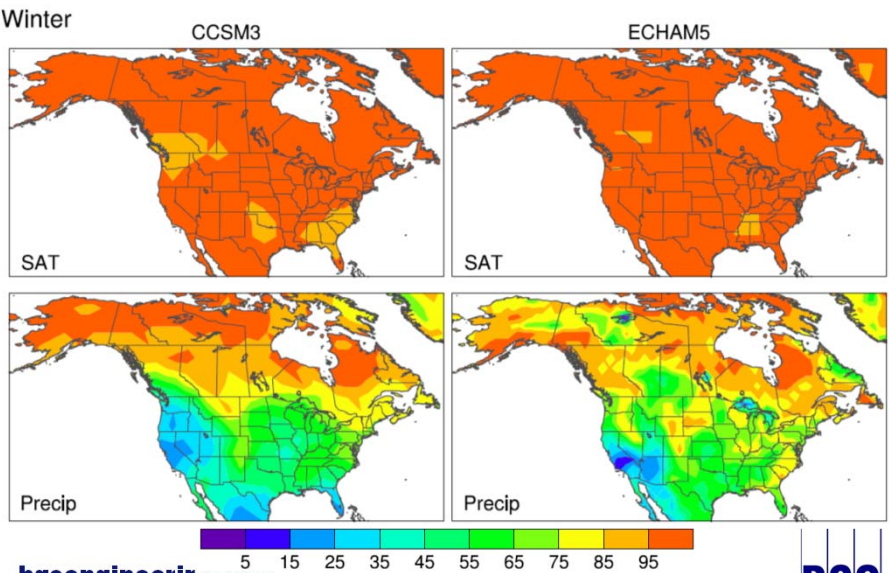


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Deser et al., 2014

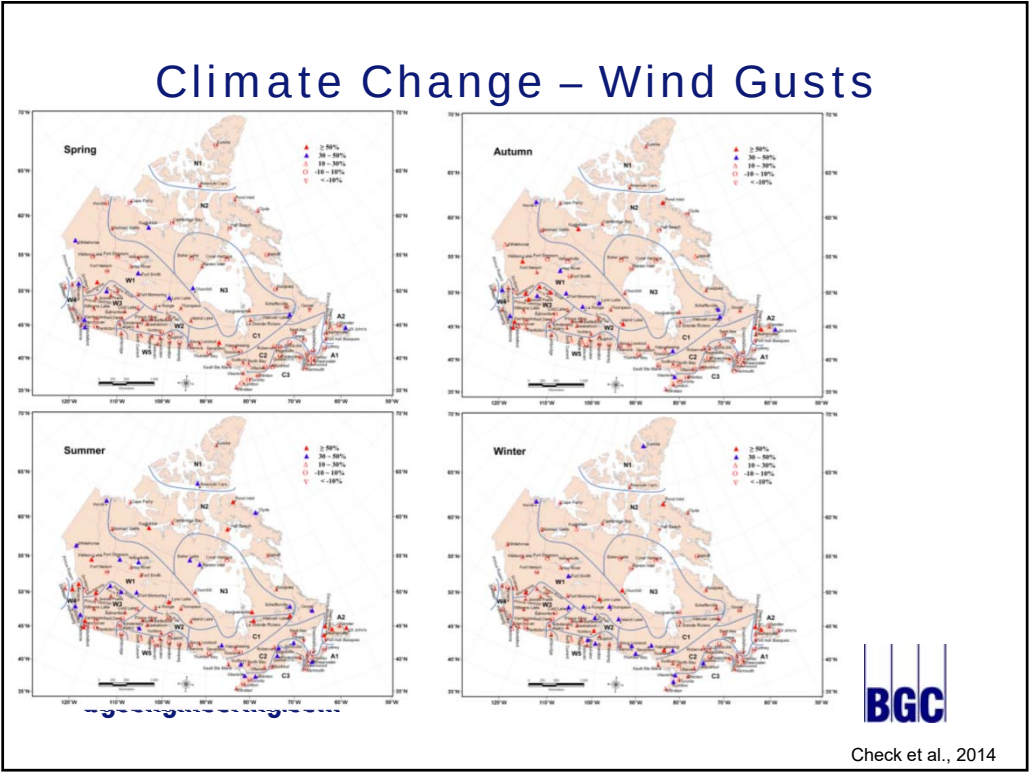
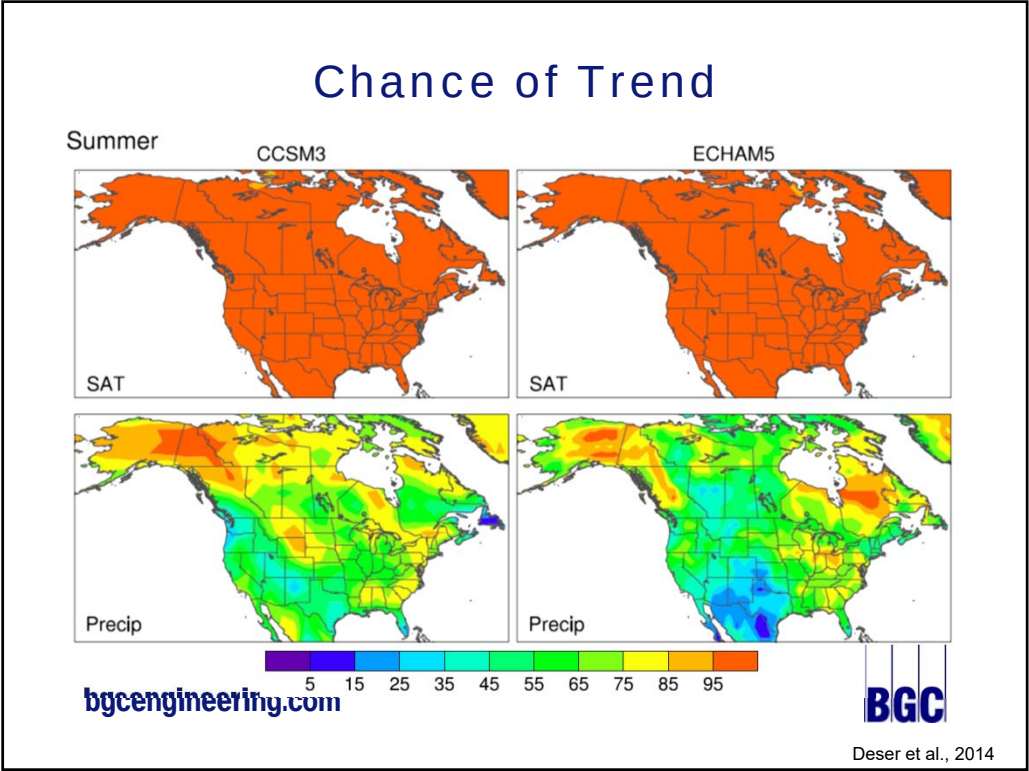
Chance of Trend



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Deser et al., 2014



Climate Change Projections

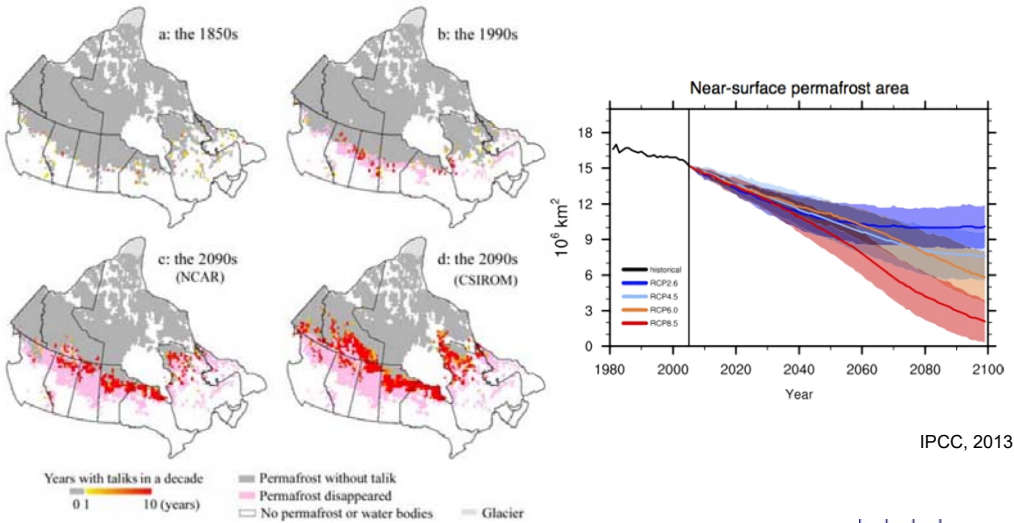
By 2045 (~30 years):

- Increase in mean annual air temperature: ~3°C
 - More winter than summer warming
- Increase in precipitation: 5 – 20%
 - However, data show something else for now
- Increase in wind gust frequency (2081-2100)
 - Spring: -10 – 10%; Summer, Autumn, Winter: 30 – 50%;

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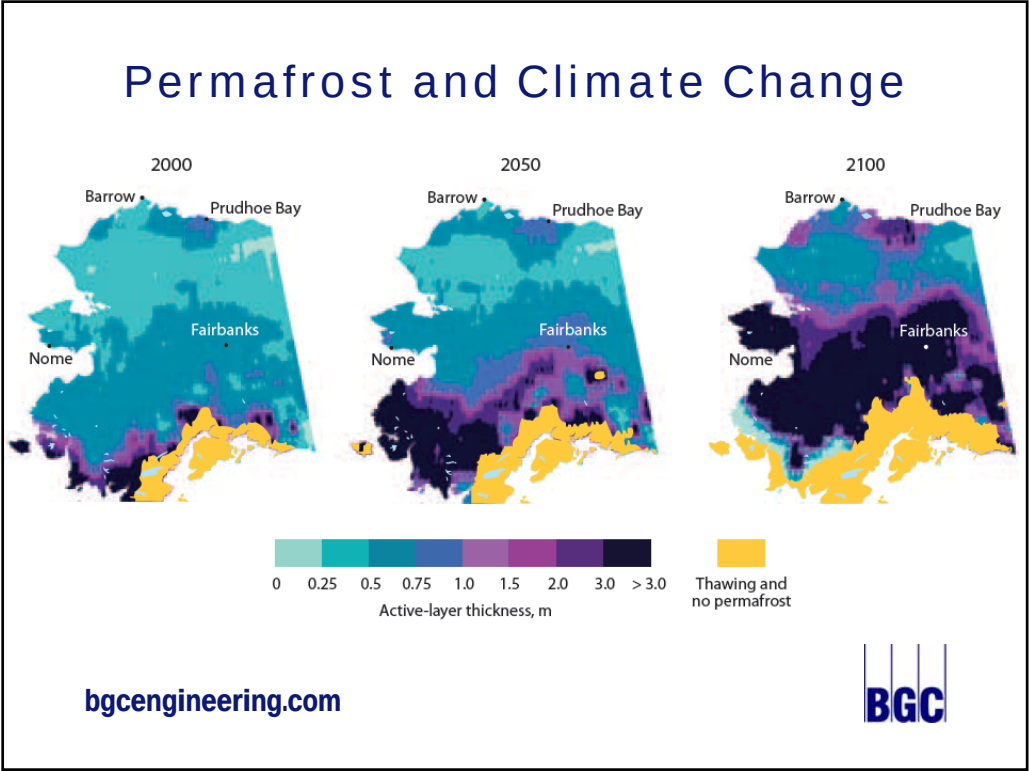


Permafrost and Climate Change



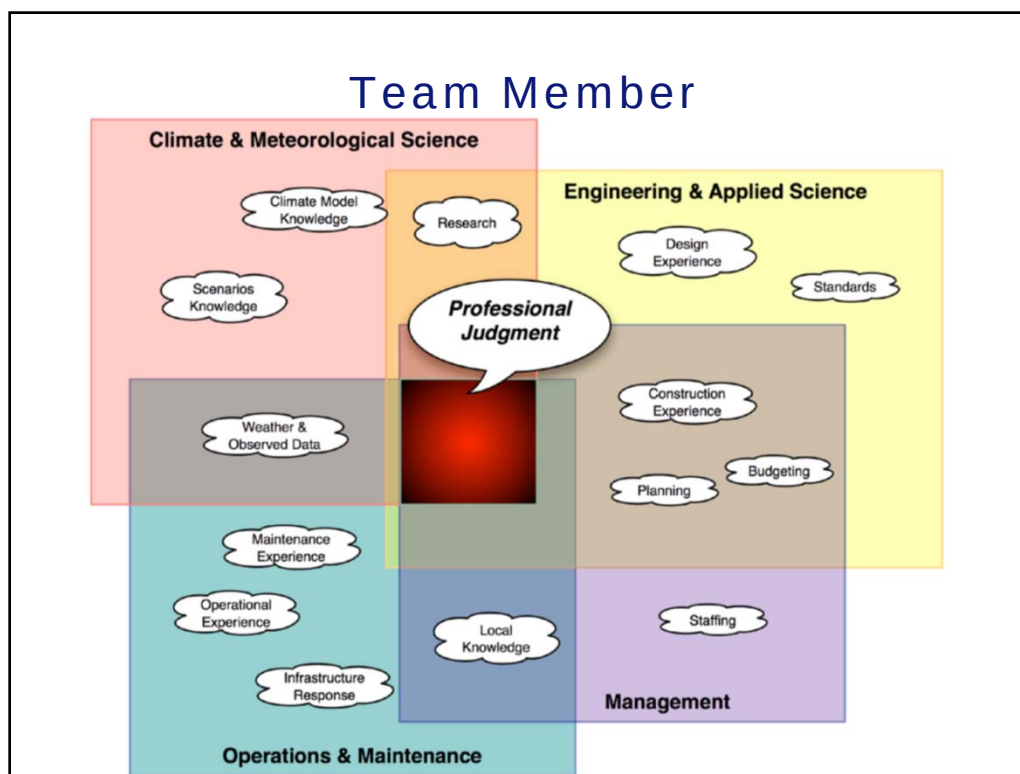
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Workshop

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Goal

- Input for the risk matrix, concentrating on severity values
- Finding good justifications and reasons for the assigned values
- Work in groups, i.e. break-out sessions
- Change groups
- Develop dynamics

Each individual's opinion is valued

- And try to have fun!

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Break-out Sessions

- Three Workshop / Break-out Sessions allocated
- 1. After Site Visit
- 2. Early Afternoon No. 2
- 3. Late Afternoon No. 3

Session 1:	Session 2:	Session 3:
Discussion on Infrastructure Components & Climate Events	Severity Discussion of Combinations	Severity and Probability Discussion of Combinations

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Break-out Session I Groups

Group 1	Group 2	Group 3
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...

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Break-out Session II Groups

Group 1	Group 2	Group 3
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...

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Break-out Session III Groups

Group 1	Group 2	Group 3
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...
• ...	• ...	• ...

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Climate Events

- Average Daily Air Temperature
- Freezing Index
- Thawing Index
- Freeze / Thaw Cycles
- Minimum Air Temperatures
- Maximum Air Temperatures
- Diurnal Temperature Variability
- Heat Wave
- Cold Wave
- Rainfall – Frequency
- Rainfall – Duration
- Rainfall Intensity / Storms
- Fall Rainfall
- Hail
- Snow Accumulation
- Snow Storms- Duration
- Snow Storms- Frequency
- Snow Timing
- Blowing Snow
- Rain on Snow
- Gusts / Extreme Wind / Storm Events
- Ice Storms
- Change in Groundwater Table
- Flooding
- Forest Fire
- Fog / Visibility

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List by no means conclusive



Infrastructure Components

Physical Infrastructure:

- Runway Surface
- Taxiway Surface (A, C & E)
- Apron Surface
- Runway Fill
- Taxiway Fill (A, C & E)
- Roads
- Culverts
- Ditches and Channels
- Security Fence

List by no means conclusive

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Supporting Systems/Infrastructure

- Marking
- Lightning
- Vegetation

Maintenance & Operation

- Normal Winter Operation
- Normal Summer Operation
- Snow Clearing
- De-icing
- Crack Filling – Cold Patch
- Summer Maintenance
- Weather Station

Other

- Emergency Procedures
- Medevac



Site Visit

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Goal

- Visiting Infrastructure Components
- Appreciation for Environmental Conditions
- Understanding Problems
- Discover new Components and Potential Interactions

- Interactive Trip -> PLEASE
 - Interrupt
 - Ask Questions
 - Discuss
 - Make Notes

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APPENDIX E

NON-TECHNICAL EXECUTIVE SUMMARY

Executive Summary

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) has developed a standardized protocol to assess the vulnerability of Canada's public infrastructure to climate change. Case studies have been carried out to date across Canada, testing and calibrating this protocol on various infrastructures. BGC Engineering Inc. was commissioned by Transport Canada in partnership with the Government of the Northwest Territories and with Engineers Canada to apply the vulnerability assessment protocol to Inuvik's Mike Zubko Airport. The airport is located in an area of continuous, partially ice-rich permafrost. The airport, located 12 km east of the community of Inuvik, was originally constructed between 1956 and 1958. Today, it consists of a single, 6001 ft (1830 m) long asphalt runway (06/24), five taxiways, and aprons in the civil section as well as the military base. In 2014, about 50,000 passengers and 12,000 aircraft movements were recorded.

Following the PIEVC protocol, more than 850 infrastructure element – climate event combinations were formed of which 465 were assessed. The assessment indicated that based on current understanding no immediate engineering action is required to address impacts from climate change. The components do have sufficient resilience considering available historic data and future projections. There are, however, significant uncertainties and data gaps that should be reduced by increasing monitoring efforts aimed at critical elements. The following actions are recommended based on the vulnerability assessment:

- Collection of data related to frost formation;
- Evaluation of the drainage systems and its maintenance efforts;
- Collection of information on the visibility;
- Monitor local snow accumulation, protocol current snow management plans and plan future requirements;
- Carry out review of maintenance and operational procedures;
- Keep records of various maintenance activities in a systematic way; and
- Reassess the climate change vulnerability every five years with several stakeholders, as more baseline data, infrastructure performance information, and improved climate models become available.

The changing climate will likely result in increased maintenance and repair efforts for which resources must be provided and standard procedures adapted. Collection of additional baseline data will help making informed decisions in the near future on where resources are best allocated.