Mackenzie Valley Highway Project

Climate Lens Part II: Climate Change Resilience Assessment

April 26, 2021

Prepared for:

Government of the Northwest Territories
Infrastructure Department

Prepared by:

K’alo-Stantec Ltd.
Yellowknife, NWT

Project Number: 144903017

Attestation of Completeness

I/we, the undersigned attest that this Resilience Assessment was undertaken using recognized assessment tools and approaches (i.e., ISO 31000:2009 Risk Management—Principles and Guidelines) and complies with the General Guidance and any relevant sector-specific technical guidance issued by Infrastructure Canada for use under the Climate Lens.

Prepared by: ______________________________

Shane O'Hanlon, B.Eng., M.Sc.

Prepared by: ______________________________

Bernadette Middleton, M.Sci,, ENV SP

Prepared by: ______________________________

Riley Morris M.Sc., P.Eng

Validated by* ______________________________

Wayne Penno, P.Eng., MBA

*Resilience Assessments must be prepared, or at a minimum validated by, a licensed professional engineer, certified planner, or appropriately specialized biologist or hydrologist.

Respectfully Submitted,

K'ALO-STANTEC LTD.

____

Warren McLeod, P.Eng., Principal

Table of Contents

LIST OF TABLES

LIST OF APPENDICES

Executive Summary

The Mackenzie Valley Highway Project is a proposed 321 km stretch of all-season gravel roadway between the communities of Wrigley and Norman Wells. The project is located in the Mackenzie Valley of the Northwest Territories (NWT).

As the Project proponent is seeking federal funding under the Investing in Canada Infrastructure Program (ICIP), a Climate Resilience Assessment (CRA) has been prepared in accordance with Infrastructure Canada requirements and in accordance with Infrastructure Canada's Climate Lens General Guidance V.1.2 (Infrastructure Canada 2019). This CRA covers the infrastructure and systems of the Project. This assessment applies approaches consistent with ISO 31000:2018 standard Risk Management—Principles and Guidelines, which are appropriate for Climate Resilience assessments for new assets under the Climate Lens.

The typical design life of a gravel roadway in the north is expected to be between 20 and 25 years, after which time it is expected that the proponent will rehabilitate the roadway. The timescale selected for assessment of future climate change impacts on the Project will therefore follow two iterations of this design life and consider climate projections to the 2080s, i.e. the climate period from 2071-2100. A longer time horizon will allow for more forward planning related to longer-term impacts, such as permafrost degradation. The assessment summarizes projected climate data for the greenhouse gas emissions scenario, Representative Concentration Pathways (RCP) 8.5, as defined by the Intergovernmental Panel on Climate Change (IPCC).

This assessment has identified the following climate parameters that may pose hazards to The Project:

- Mean Seasonal Temperatures
- High Temperature Extremes
- Low Temperature Extremes
- Precipitation Extremes
- Sustained Rainfall
- Dry Spells
- Daily Frost
- Freeze-Thaw Days

Infrastructure interactions to each climate parameter were examined and an associated risk rating was assigned to each. The climate parameters that presented the greatest number of risks to the Project are mean seasonal temperatures, extreme high and low temperatures, and extreme precipitation.

Based on professional judgement, the following recommendations have been made regarding climate risk management measures that seek to address the highest-rated risks:

- Consider incorporating the following mitigative measures into road design parameters:
    - where applicable, apply active and passive heat mitigation techniques such as thermosyphons, air convection embankments (ACE), air ducts and heat drains (HD), reflective surfaces, insulation and embankment thickening to reduce permafrost degradation.
    - using a fill only, embankment concept rather than a cut and fill approach to reduce permafrost degradation.
    - use woven geotextile to reinforce embankments and reduce differential settlement due to permafrost degradation.
    - incorporate approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components to reduce permafrost degradation.
    - use geofabrics, geosynthetic materials, wattles or other erosion control products in ditches covered by organics to minimize erosion of the existing fine-grained soils.
    - take advantage of the natural topography and grades along the alignment that are gentle so sidehill cuts are eliminated to reduce permafrost degradation.
    - stage the construction such that the placement of granular surfacing is delayed until any significant differential settlement has occurred.
    - confine the project footprint to the extent possible, to existing cut lines and areas that have already been disturbed to reduce permafrost degradation.
- Plan for more frequent inspections and monitoring of the performance of the infrastructure (e.g., culverts are clear in the spring and the fall) and ensure that there are sufficient additional resources for maintenance and rehabilitation for repairs when settlement occurs. Regularly monitor road maintenance efforts and climate data to better correlate the change in road surface with climate related parameters and their potential changes. Use this information as part of an adaptative management approach to future maintenance and rehabilitation efforts.
- Focus on collecting baseline information for the components that are thought to be most vulnerable to climate change. Avoid constructing in these areas if possible, and where not, deploy methods to minimize thermal disturbance (e.g., incorporating approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components).
- Review and refresh operator training program on best practices as it relates to the management of gravel roads (e.g. straight salt and liquids should not be used).
- Rapid pothole repair/regrading may be needed to reduce potential infiltration of water into the sub-base with more frequent rain events. Develop a policy to complete road inspections after extreme weather events.
- Maintain natural drainage patterns by using adequately sized and positioned culverts. Consider additional snow clearing in the ditches during winter to allow for a controlled spring runoff.

- Where possible, snow should be bladed down the side slopes, away from the shoulders. Late-winter maintenance should blade snow and hard pack down to the embankment's side slope area prior to spring melt. Ensure that late winter maintenance clears ice pack and snow from the road surface to prevent damming of melt water. Frequent snow removal can minimize the insulating effect of the snow.
- Where possible, implement a more aggressive road monitoring and maintenance program. Conduct periodic surrounding surface surveys. Remote sensing techniques such as LiDAR, SAR, or Optical methods, can be repeated every 5 to 20 years to identify those areas where surface features such as topography, vegetation, surface water flow, pond developments, or thermograms activities have changed. Conduct inspections after severe events to ensure the integrity of roadway and drainage systems.

The analysis and recommendations in this assessment are based on information available within the timeline and scope of this project, and on the authors' experience with climate risks assessments. As the Project is still in the design phase, a full application of the Engineers Canada's Public Infrastructure Engineering Vulnerability Committee's vulnerability assessment protocol (PIEVC Protocol) process was not possible. Rather, a methodology consistent with the PIEVC Protocol and that conforms to the ISO 31000:2018 standard Risk Management—Principles and Guidelines has been used. This approach is aligned and compatible with PIEVC Protocol methodology and conforms with the requirements of ISO 31000:2018.

Abbreviations

CCHIP	Climate Change Hazards Information Portal
CRA	Climate Risk Assessment
HVAC	Heating, Ventilation and Air Conditioning
GHG	Greenhouse gas
GCM	Global Climate Models
ICIP	Investing in Canada Infrastructure Program
IDF	Intensity, Duration, Frequency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
O&M	Operations and Maintenance
NRCAN	Natural Resources Canada
PIEVC	Public Infrastructure Engineering Vulnerability Committee (Engineers Canada Vulnerability Assessment Protocol)
Project	Mackenzie Valley Highway Project
RCP	Representative Concentration Pathways
RSI	Risk Sciences International
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization

1.0 INTRODUCTION

This report summarizes the Climate Resilience Assessment performed as part of the Climate Lens Analysis as required by the Investing in Canada Infrastructure Program (ICIP). The ICIP is a bilateral agreement between Infrastructure Canada and the provinces and territories. As the Project proponent is seeking federal funding under the Community, Culture and Recreation Fund, a Climate Resilience Assessment has been prepared in accordance with Infrastructure Canada requirements (Infrastructure Canada 2018). This report has been prepared in accordance with Infrastructure Canada's Climate Lens General Guidance V.1.2 (Infrastructure Canada 2019).

1.1 PURPOSE

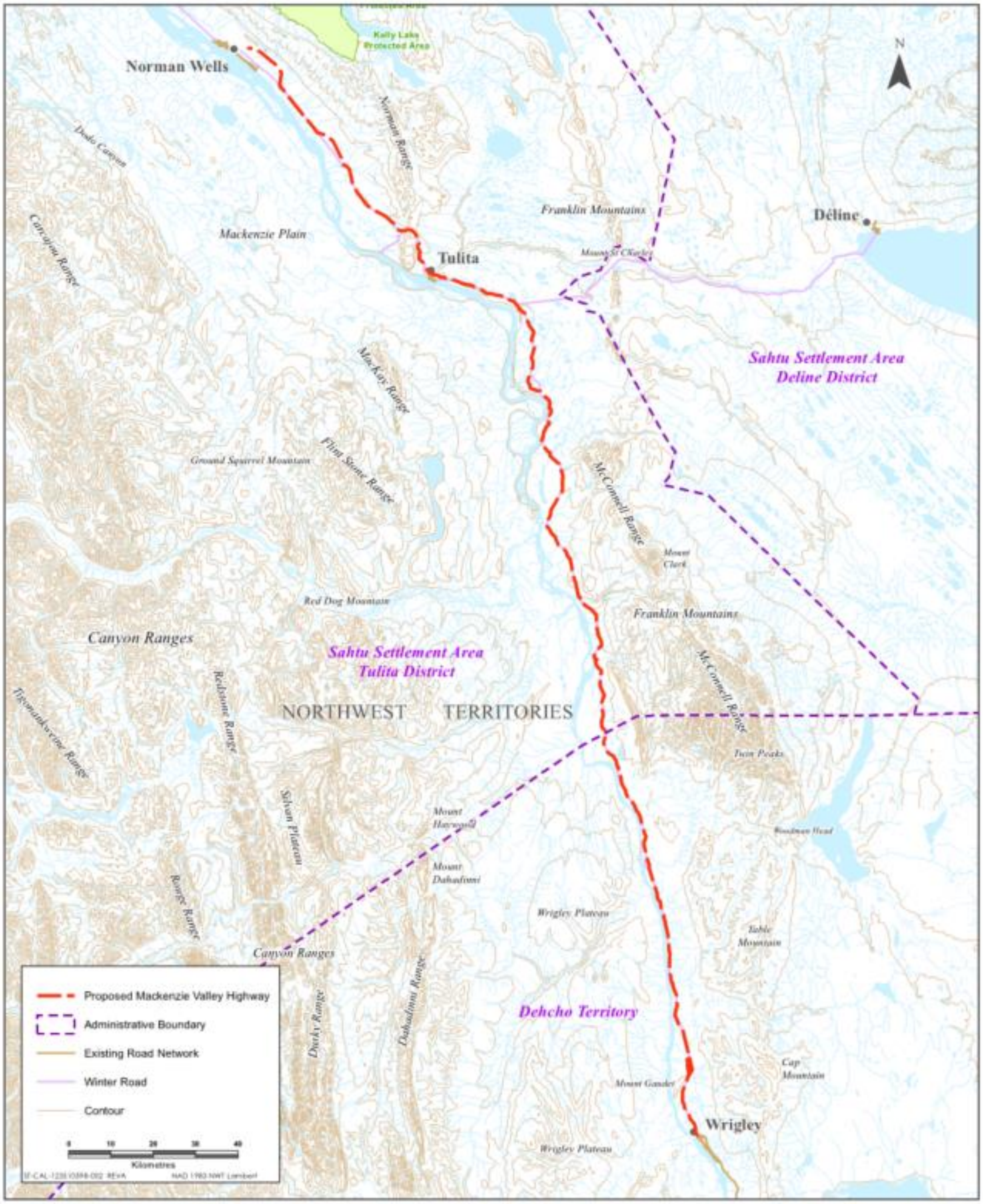
The intent of Infrastructure Canada's Climate Lens is to "incent behavioral change and consideration of climate impacts into the planning of infrastructure projects with a view to implementing Canada's mid-century goals of a clean growth low-carbon economy" (Infrastructure Canada, 2018). This assessment identifies the climate risks to the Project at a broad systems-level based on a future climate scenario and provides an understanding of the climate impacts on the Project over its construction and operational life. This assessment is intended to inform the design team of projected changes in climate and associated risks to consider at the project's detailed design stage.

1.2 PROJECT OVERVIEW

The Mackenzie Valley Highway Project is a proposed 321 km stretch of all-season gravel roadway between the communities of Wrigley and Norman Wells. The development includes the following components:

- Construction of a 321 km all-season gravel highway from Wrigley to Norman Wells;
- Construction of select watercourse crossing structures;
- Construction and operation of temporary and permanent borrow sources;
- Construction and operation of temporary support infrastructure and workspaces including camps, laydowns and staging areas;
- Ongoing highway operations and maintenance; and
- Reclamation of areas not required for ongoing operations.

Figure 1. Site Location Map



The focus of this assessment is on the physical assets proposed for the Project and does not consider other elements (such as third-party goods or services suppliers and administration, etc.) that are usually included in a PIEVC Protocol climate risk assessment. A review of this assessment, possibly leading to a more in-depth analysis, is recommended during future design stages of the Project, specifically design development.

1.3 GENERAL CLIMATE PROFILE

Climate data and trends—current and future projections—used in this assessment were obtained from published literature, the Risk Sciences International (RSI) Climate Data Portal (CCHIP) and the Norman Wells A (ID: 2202800) weather monitoring station. The scope of the assessment did not include additional, site specific future climate modelling. Future climate projections were based on downscaled, climate data published Intergovernmental Panel on Climate Change (IPCC).

Cross-verification for the gathered climate data was completed to identify possible discrepancies between the data sources used. The typical design life of a gravel roadway in the north is expected to be between 20 - 25 years, after which time it is expected the Proponent will rehabilitate the roadway. The timescale selected for assessment of future climate change impacts on the Project will therefore follow two iterations of this design life and consider climate projections to the 2080s (i.e. the climate period from 2071-2100). A longer time horizon will allow for more forward planning related to longer-term impacts, such as permafrost degradation. The assessment summarizes projected climate data for GHG emissions scenario, representative concentration pathways (RCP) 8.5, as defined by the IPCC. Additional details on the climate profile used in this assessment are presented in Appendix A.

The general topography of the region is represented by a rolling surface with a variable topography including ridges reaching 1040m above sea level. Permafrost conditions are highly variable, with continuous to extensive and discontinuous conditions with low to medium ice content.

Stantec’s additional research into the climate trends and projections confirmed the following findings:

- The area has experienced (and is projected to continue experiencing) increases for annual mean daily temperature, average maximum daily temperature and average minimum daily temperature. This trend applies to all seasons. By the 2080s, the annual mean daily temperature is projected to increase by 5.5 degrees under RCP 8.5 for Norman Wells and 6.2 degrees for Fort Simpson. This represents an increase in the risk of permafrost thaw.
- The number of extreme heat temperature events—i.e., days with temperatures greater than 30°C—has averaged around 2.1 days/year from 1981 to 2010 at Norman Wells - Tulita and 4.2 days/year from 1981 to 2010 at Wrigley-Fort Simpson. By the 2080’s, the number of days over 30°C is projected to increase to 14.4 days/year (under RCP 8.5), at Norman Wells - Tulita and 24.8 days/year, at Wrigley-Fort Simpson.
- The number of extreme cold temperature days—i.e., days below minus 30°C—is expected to decline from 51 days per year (1981-2010) to 10.7 days/year by 2080 under RCP 8.5 for Norman Wells – Tulita and from 37.5 days per year (1981-2010) to 6.5 days/year at Wrigley – Fort Simpson.

- Total annual precipitation in the area has increased between 1981 - 2010. Future climate projections indicate continued increases in precipitation both annually and seasonally (more so during the summer) in the coming decades. By the 2080s, under RCP 8.5 total annual precipitation is projected to increase 21.3% for Norman Wells and 25.2% for Fort Simpson.
- Projections for snowfall in the area are less confident than for other precipitation and temperature-based climate variables and are not included in this Climate Lens assessment.
- Precipitation events are projected to become 17.0% to 56.2% more intense for Norman Wells, and 14.4% to 49.4% more intense for Fort Simpson under RCP 8.5, for all design storms ranging from 5 minute to 24-hour duration, and 2 to 100-year return frequency, based on historic and projected Intensity Duration Frequency (IDF) curves. This translates to increased over-land flooding due to the overwhelming of storm and drainage systems. Flooding is also likely to occur due to more rapid snow melt periods, and an increase in the number and intensity of rainfall events.
- The length of dry spells in the area are expected to remain relatively consistent in the future.
- The number of days without frost is expected to increase by approximately 30% for both Norman Wells and Fort Simpson under the 2080's RCP 8.5. With warmer temperatures projected for the coming decades, the number of freeze-thaw events for the area is projected to have a slight decrease under future climate. The decrease is only slight because most freeze-thaw events typically happen in months with temperatures fluctuating around 0°C. The number of freeze-thaw events in May, August, September, October and November are projected to decrease significantly, while there is a slight increase projected in November, December, January, February and March. By the 2080's, fluctuations around 0°C are projected to be more common all through the winter months.

2.0 METHODOLOGY

The Climate Lens General Guidance V1.2 recognizes Engineers Canada's PIEVC Protocol as a methodology for climate change resilience. As the Project is still in the design phase, a full application of the PIEVC process was not possible. Rather, a methodology consistent with the PIEVC Protocol and that conforms to the ISO 31000:2009 standard Risk Management—Principles and Guidelines has been used. It is recommended the proponent complete a more detailed climate resilience analysis once the funding is in place.

2.1 RISK ASSESSMENT PROCESS

This climate resilience assessment evaluates the future climate impacts on the Project's proposed components and associated infrastructure and identifies the potential risks associated with future changes in climate and extreme weather events. It is a high-level assessment of risks to the infrastructure, buildings or facilities due to extreme weather and climate uncertainty based on current climate and future climate projections in the area. Extreme weather events may include, but are not limited to, extreme heat, high intensity / short duration precipitation, and high wind.

The resilience assessment team solicited input on the climate risks to the Project through interviews with the design consultants, potential operators, and Government of Northern Territories (the client, see professionals listed in Table 10). Data gaps were filled through desktop analysis of relevant Project documents or related publicly available data. The climate resilience assessment (based on the requirements of the Guidance) uses similar principles as those of the PIEVC Protocol and other risk assessment methodologies that conform to ISO 31000:2009 to identify relevant climate parameters and relevant infrastructure responses, establishing a risk evaluation matrix, and assigning risk ratings to each infrastructure response to climate considerations. This assessment will inform design teams of potential risks that should be considered during the design stage of Project implementation. Figure 2 below shows the general risk assessment process.

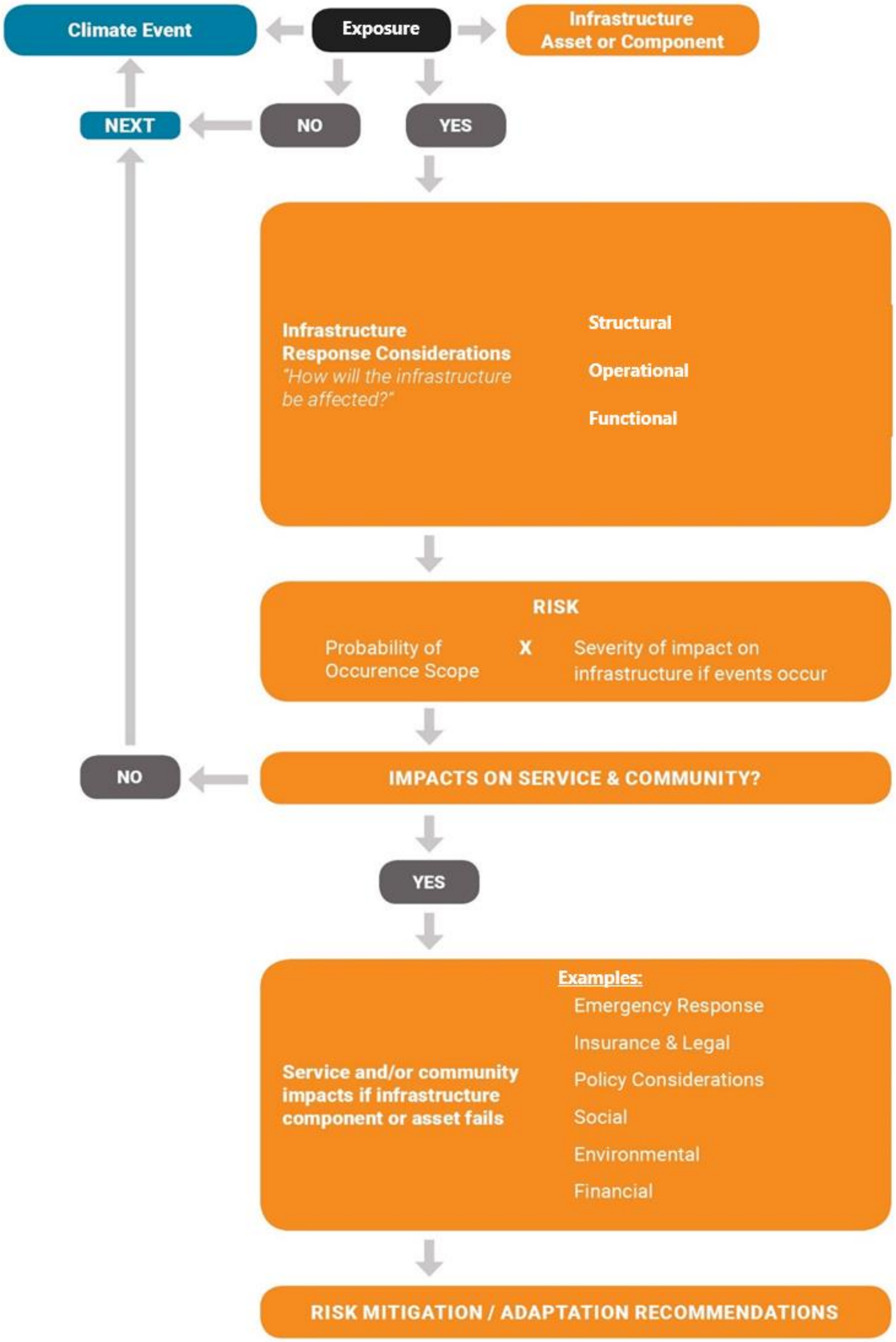


Figure 2. Illustration of the Risk Assessment Process

2.2 TIMESCALE OF ASSESSMENT

The typical design life of a gravel roadway in the north is expected to be between 20 - 25 years, after which time it is expected the proponent will rehabilitate the roadway. The timescale selected for assessment of future climate change impacts on the Project will therefore follow two iterations of this design life and consider climate projections to the 2080s (i.e. the climate period from 2071-2100). A longer time horizon will allow for more forward planning related to longer-term impacts, such as permafrost degradation. Short-term (up to 2020s) and mid-term (up to 2050s) climate change implications trend in the same direction for the climate parameters identified for this assessment and thus have not been separately discussed.

2.3 PLAUSIBLE CLIMATE SCENARIOS

Climate modeling uses various GHG emissions scenarios, known as Representative Concentration Pathways (RCPs), to project future climate variables under different concentrations and rates of release of GHGs to the atmosphere, as well as different global energy balances.

Various future trajectories of GHG emissions are possible depending on the global mitigation efforts in the coming years. RCPs are established by the IPCC, the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC, 2014).

The IPCC has set four GHG emissions scenarios through RCPs. RCP 8.5 is the internationally recognized most pessimistic - “business as usual” GHG emissions scenario. Other GHG emissions scenarios represent more substantial and sustained reductions in GHG emissions: RCP 6, 4.5 and 2.6 (Figure 3). For example, the RCP 2.6 emissions scenario may be achievable with extensive adoption of biofuels/renewable energy and large-scale changes in global consumption habits, along with carbon capture and storage. RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures. RCP 4.5 is considered the ‘medium stabilization’ scenario where global mitigation efforts result in intermediate levels of GHG emissions (IPCC, 2014).

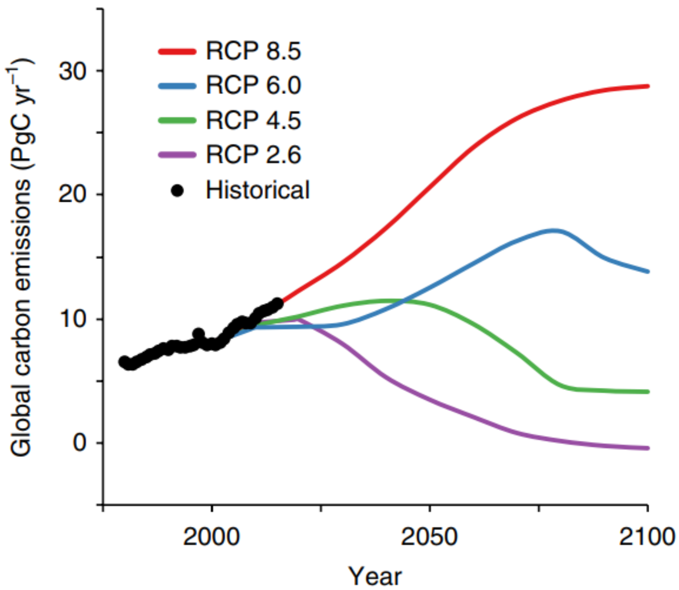


Figure 3. Historical CO_2 emissions for 1980-2017 and projected emissions trajectories to 2100 for the four Representative Concentration Pathway (RCP) scenarios. Figure from Smith and Myers, 2018.

Although some progress has been made, current estimates of GHG emissions are still close to following the RCP 8.5 path and thus this assessment is based on climate parameters estimated under the RCP 8.5 scenario. The recent IPCC Special Report on Global Warming of 1.5ºC (Allen et al., 2018) supports the selection of the RCP 8.5 for this assessment.

2.4 IDENTIFICATION AND ASSESSMENT OF CLIMATE HAZARDS

For this assessment, a rating system compatible with the PIEVC Protocol was adopted for the likelihood (probability) of a climate event occurring and for the consequence (severity of the impact) on the components of the infrastructure system, should the climate event occur.

Based on the information and documents reviewed for this assessment, the climate events presented in Table 1 were identified as having potential impacts on Project components. These climate events were evaluated for their projected change in probability of occurrence (likelihood) at the selected assessment time-horizon. The table also presents the confidence level associated with the projections for each climate parameter. For example, projections based on Global Climate Models (GCMs) and downscaling of such models are considered:

- Adequate (higher confidence) for general temperature and precipitation projections
- Less adequate (lower confidence) for extreme parameters
- Inadequate for combined events (low confidence) such as hail, freezing rain, etc.

Combined events are inferred based on other parameters, resulting in lower confidence for projections of combined event parameters. For example, freshet events are a complex process and the study area experiences freshet snow-melt events. These events are difficult to project and are dependent on various other climate variables. Flooding projections studies have suggested that, under future climate, snowmelt-driven floods will increase and occur earlier in the season due to the projected increases in winter and spring temperatures (Poitras et al., 2011; Gaur et al., 2018; Bonsal et al., 2019; Gaur et al., 2019). With increasing winter temperatures, an increase in winter streamflow and an earlier peak in snowpack melt is projected (Poitras et al., 2011; Gaur et al., 2018). Earlier snowmelt has already been observed within Canada (Zhang et al., 2001; Burn et al., 2016). Results from Gaur et al. (2018) suggest spring snowmelt-driven floods will occur up to two months earlier by the end of the century. Confidence may also refer to whether other studies have been done for the climate events projections in the geographical area.

Table 1. Climate Parameters Selected for Resilience Assessment (2080s-Time Horizon)

Climate Parameter	Trend	Confidence Level	Parameter Remark
Temperature			
Mean Seasonal Temperatures	Increase	High	**Norman Wells -** Average temperature is expected to increase by 5.5°C with winter increasing the most (7.7°C), spring and autumn temperatures following average (5.5°C), and summer to increase on average by about 3.2°C by the 2080s. **Fort Simpson -** Average temperature is expected to increase on average by 6.2°C with winter increasing the most (8.6°C), spring and autumn temperatures following the average (5.9°C), and summer to increase on average by about 4.4°C by the 2080s.
High Temperature Extremes	Increase	High	**Norman Wells -** There is a significant increase in number of days with temperature >= 30°C with the number of maximum temperature events increasing from 2 days to 14 days by the 2080s. **Fort Simpson -** There is a significant increase in number of days with temperature >= 30°C with the number of maximum temperature events increasing from 4 days to 25 days by the 2080s. This is likely to result in an increased risk of wildfires and the warming of permafrost layers.
Low Temperature Extremes	Decrease	High	**Norman Wells -** There is a significant decline in number of days with temperatures <= -30°C with the number of maximum temperature events declining from 51 days to 11 days by the 2080s. This is likely to result in more rain events occurring in the shoulder seasons (Autumn and Spring) and may be in the form of rain on snow events. **Fort Simpson -** There is a significant decline in number of days with temperatures <= -30°C with the number of maximum temperature events declining from 38 days to 7 days by the 2080s. This is likely to result in more rain events occurring in the shoulder seasons (Autumn and Spring) and may be in the form of rain on snow events. This could affect the performance of the gravel road since, on a frozen base, the wet surface would degrade and cause problems.
Precipitation			
Precipitation Extremes	Increase	Medium-High	Projected IDF information suggests increased storm intensity for all short duration rainfalls (5 min events to 24-hour events). The projected percentage increase from the historical data to the period of 2039- 2100 for precipitation event intensities range from 17% – 56.2 % for Norman Wells and 14.4% - 49.4% for Fort Simpson.

Climate Parameter	Trend	Confidence Level	Parameter Remark
Sustained Rainfall	No Change	Medium-Low	Similar to short duration events, 3, 5, and 7-day rainfall accumulations are expected to remain relatively stable.
Dry Spells	No Change	Medium-Low	**Norman Wells -** The number of dry days appear to be slightly increasing. **Fort Simpson -** The number of dry days appear to be slightly decreasing. The maximum dry spell length between the two areas are generally stable over the previous 35-year span. The difference between the two sites could be largely driven by four specific years where Norman Wells' dry periods were much longer than those in Fort Simpson.
Daily Frost	Decrease	Medium-High	**Norman Wells -** Average frost-free days are expected to increase by approximately 30% and both Norman Wells and Fort Simpson by the 2080s. This will have an impact on the warming of permafrost layers and lead to an increased risk of ground shifting.
Freeze-Thaw Days	Decrease	Medium-High	**Norman Wells -** The number of freeze-thaw events is projected to decrease from 44 to 30 per year by the mid-2080s. **Fort Simpson -** The number of freeze-thaw events is projected to decrease from 58 to 39 per year by the mid-2080s. Most freeze-thaw events typically happen in months with temperatures fluctuating around 0°C.

2.5 ASSETS UNDER ASSESSMENT

The Project assets and systems were grouped into the categories as presented in Table 2.

Table 2. List of Project Components Being Assessed

Project Infrastructure Component	Project Infrastructure Sub-Components
Structural Elements / Physical Infrastructure	• Road Base and Subgrade • Road Embankments / Cuts • Surface Drainage • Culverts & Ditches
Miscellaneous	• Maintenance • Emergency Response • Administration / Personnel & Engineering

This climate resilience assessment does not include the deconstruction or rehabilitation of the gravel road and associated structures at the end of their useful life. In addition, this assessment has been limited to the roadway structure and does not include associated infrastructure (e.g., bridges, camps, laydowns, pits). Any subsequent climate assessments completed at a later stage of the project could include ancillary infrastructure.

2.5.1 Consequence of Impact

Table 3 shows the three consequence of impacts that were considered as part of this assessment. The list of consequence of impacts provides a framework for considering the potential impacts of climate on the Project's components.

Table 3. Consequence of Impact

Consequence of Impact
Structural Integrity *For example, climate change may lead to premature failure of structural elements due to external stresses.*
• Component Failure • Component Deterioration • Increased Loading / Stress • Change in Materials Performance
Operations & Maintenance (O&M) *For example, climate change may increase the need for maintenance to the roadway and drainage systems.*
• Occupational Safety, Health & Safety • Reduced Serviceability • Increased Maintenance / Rehabilitation Cycles and Frequencies • Increased Public Vehicle Maintenance Requirements • Change in Operational Performance
Functionality *For example, climate change may impact the ability of the infrastructure system to deliver at normal levels of service (i.e. lane or roadway closures, reduced surface quality).*
• Violation of Policies and Procedures • Public/Occupant Health and Safety Hazard • Loss of Service (Temporary) • Loss of Service (Permanent)

The consequence of community and environmental impacts were not assessed in detail as part of this assessment.

2.5.2 Impact on Project Assets

The potential impacts from both extreme events and incremental or slow onset climate parameters on Project assets are presented in Table 4.

Table 4. Potential Climate Impact on the Project Assets

Climate Parameter	Infrastructure Component Impacted	Description of Interaction
Temperature		
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Ground temperatures are highly influenced by air temperatures. Increasing air and ground temperatures will initiate thawing and will result in changes to the permafrost active layer. These changes to the active layer can result in settlement and damage to the road surface resulting in structural failure and potential safety issues. This could result in higher maintenance requirements to ensure the road surface and user safety.
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Road Embankments / Cuts	Long-term warming has the potential to melt or weaken the permafrost. The melting of the permafrost has the potential to affect surface and groundwater flows and the groundwater table. Changes to the groundwater regime could result in differential settlement, erosion, cracking and flooding of the road surface. These all present a safety issue to road users and increased maintenance requirements for the O&M team.
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Surface Drainage	Significant thawing of the permafrost could result in ponding on road surface and impacts to roadside drainage (culvert erosion, culvert blockage) and roadside erosion. Where the road is constructed on-ice rich permafrost, settlement could be extreme resulting in significant surface water ponding and pothole formation.
Mean Seasonal Temperatures	Miscellaneous: Maintenance	In the permafrost zone, accelerated melting and differential settlement would result in damage to the road surface which would require increased maintenance needs to ensure user safety.
High Temperature Extremes	Miscellaneous: Emergency Response	Increasing air and ground temperatures could result in increases in the occurrence of forest fires resulting in localised road closures to minimise hazardous driving conditions and site safety risks.
High Temperature Extremes	Miscellaneous: Administration / Personnel & Engineering	Heat waves could result in worker heat stroke, fatigue, and exhaustion.
Low Temperature Extremes	Miscellaneous: Maintenance	Freezing rain and snow may cause unsafe driving conditions and resultant road closures. These weather conditions would increase the level of roadside maintenance and the volume of salt and sand needed on the road surface.
Precipitation		
Precipitation Extremes	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Saturated roads may reduce the structural integrity of the road, resulting in potholes and increased erosion of the road surface.
Precipitation Extremes	Structural Elements / Physical Infrastructure: Road Embankments / Cuts	Heavy periods of rainfall could result in both internal and surface saturation of roadside embankments. This saturation could result in reduced structural integrity and increased levels of erosion, washout, and loss of sediment. These could impact wildlife in local watercourses.

Climate Parameter	Infrastructure Component Impacted	Description of Interaction
Precipitation Extremes	Miscellaneous: Maintenance	Increased frequency of rainfall will mainly affect road surface maintenance work. More frequent flooding events may require increased maintenance of the ditches, culverts and road surface.
Sustained Rainfall	Structural Elements / Physical Infrastructure: Culverts & Ditches	Heavy rainfall events could result in exceeding the design flow capacities of the roads proximal culverts and bridges. These events could result in water overtopping, ponding, fast flowing water and erosion.
Sustained Rainfall	Miscellaneous: Administration / Personnel & Engineering	Extreme storms may hinder maintenance activities. In addition, it affects road safety and the ability of personnel to get to their workplace.
Daily Frost	Structural Elements / Physical Infrastructure: Culverts & Ditches	Low temperatures combined with periods of precipitation and snow can result in blockages of roadside culverts from ice and snow. These blockages prevent roadside water drainage and can result in localised flooding.

2.6 RISK ANALYSIS AND EVALUATION

In this assessment, the risk rating is defined as follows.

Risk Rating = Probability Rating x Consequence of Impact Rating

- Likelihood Rating: a rating that represents the probability or likelihood of occurrence of a climate event above a selected threshold, ranging from 1 (highly unlikely) to 5 (frequent)
- Consequence of Impacts Rating: a rating of the impacts on the infrastructure asset or component should the climate event occur, ranging from 1 (insignificant) to 5 (catastrophic)

Risks are evaluated under current climate conditions to establish a baseline. Future risks are assessed considering future (projected) climate changes. The condition of the infrastructure in the future climate is assumed to be well maintained and thus will maintain a similar level of resilience to climate events. Deterioration of the Project components is not considered in the selected lifespan of this assessment.

The trends indicated for each climate parameter are based on the change in probability from the current climate to the future climate. For this assessment, a rating scale of 1 to 5 for the probability (likelihood) of a climate event occurring was adopted (Table 5). The probability score is assigned based on the evaluation of historical occurrences and future climate projections for each climate variable.

Table 5. Probability Rating Based on Climate Event Occurrence

Occurrence	Qualitative Descriptor	Descriptor	Rating
>1:50 year	Highly Unlikely	Not likely to occur in assessment period; or not likely to increase in intensity and/or duration during the assessment period	1
1:10-50 year	Remotely Possible	Likely to occur once between 10-50 years; or likely to increase in intensity and/or duration over a 10 to 50-year period	2
1:1-10 year	Occasional	Likely to occur at least once a decade; or likely to increase in intensity and/or duration over a decade	3

Occurrence	Qualitative Descriptor	Descriptor	Rating
10/year to 1:1	Normal	Likely to occur between once-ten times annually; or likely to increase in intensity and/or duration on an annual basis	4
>10/year	Frequent	Likely to occur more than ten times annually	5

Using Table 5, the following future likelihood ratings for the climate parameters selected were assessed and are presented in Table 6. For the risk assessment, the climate parameters and probability ratings used are based on the period 2071 to 2100. The events considered are those at an intensity that causes disruptions in service (functionality), damages (structural integrity) or O&M disruptions.

Table 6. Future Probability Rating for Selected Climate Parameters (2080s)

Climate Parameter	Probability Rating
Mean Seasonal Temperatures	5
High Temperature Extremes	5
Low Temperature Extremes	4
Frost Days	3
Freeze-Thaw Days	3
Precipitation Extremes	2
Sustained Rainfall	5
Dry Spells	4

With the selected climate event probabilities determined for future climate conditions, a "severity of impact" rating must also be determined. This constitutes the "Infrastructure Response Considerations" step of the Assessment Process presented in Figure 2. The specific severity of impact rating criteria is presented in Table 7. These ratings are partially based on the degree to which a climate event causes a loss of service. For example, taking a component such as the road base and subgrade - a minor rating would mean that a grader or other maintenance equipment may need to be sent out, outside of the regular maintenance cycle, to maintain the roadway surface, but would not result in a closure of the roadway. A severe rating may require the closure of the building for a period of time. Service in the context of the Project is defined as the roadway's ability to provide reliable and safe passage, free of disruption. It is assumed the Project design will be appropriately suited to the current climate.

Table 7. Severity of Impact Rating

Severity		
1	**Insignificant** - No serious impact from a weather event	• Can be corrected through routine maintenance with no impact to O&M budgets • No structure damage to the road
2	**Minor** - Some extra costs for repairs and maintenance.	• No loss of service. • Infrastructure is still operable and accessible • Some extra costs associated with O&M budgets but no requirement for regional response funds

3	**Moderate** - Some damage to infrastructure	• Extra costs and labour required to complete repairs. • Some specialized labour or equipment required to complete repairs • Some loss of service.
4	**Major** - Significant damage to infrastructure.	• Significant extra costs and labour required to complete repairs • Specialized labour or equipment required to complete repairs • Replacement of component required • Significant loss of service – closure of one lane.
5	**Catastrophic** - Complete loss of the asset after a weather event.	• Repair not possible • Extended period of loss of service – road closure.

Using the equation “Risk Rating = Probability Rating x Consequence Rating” provides numerical risk ratings from 0-25 as shown in Figure 4.

Severity Rating (S) (Consequence)							
	Catastrophic (Very High)	**5**	**5**	**10**	**15**	**20**	**25**
	Major (High)	**4**	**4**	**8**	**12**	**16**	**20**
	Moderate	**3**	**3**	**6**	**9**	**12**	**15**
	Minor (Low)	**2**	**2**	**4**	**6**	**8**	**10**
	Insignificant (Very Low)	**1**	**1**	**2**	**3**	**4**	**5**
			1	**2**	**3**	**4**	**5**
			Highly unlikely (Very Low)	Remotely possible (Low)	Occasional (Moderate)	Normal (High)	Frequent (Very High)
			Probability Rating (P) (Likelihood)				

Figure 4. Risk Ratings - Evaluation Matrix. Adapted from Climate Lens General Guidance

In Table 8, risk ratings are explained with suggested risk treatments as per the Climate Lens General Guidance.

Table 8. Risk Classification. Adapted from Climate Lens General Guidance

Risk Classification	Risk Rating	Description of Risk	Risk Treatment
Negligible	1	No permanent damage. No service disruption occurs.	Risks do not require further consideration
Low	2-3	Minor asset/equipment damage. Minor service disruption may be possible. No permanent damage. Minor repairs or restoration expected.	Controls likely, but not required.
Moderate	4-6	Expected limited damage to asset or to equipment components. Minor repairs and some equipment replacement may be required.	Some controls required to reduce risks to lower levels. Risk to be monitored

Risk Classification	Risk Rating	Description of Risk	Risk Treatment
		Brief service disruption may be possible.	for changes over time.
High	8-12	May result in significant permanent damage; or loss of asset or component that may require complete replacement. More lengthy service disruption may be possible.	High priority control measures required.
Extreme	>15	May result in significant permanent damage; or loss of asset or component that may require complete replacement. Significant service disruptions may be possible.	Immediate controls required.

3.1 RISK PROFILE

The purpose of this assessment is to identify the climate risks to the Project at a broad systems-level for a future climate scenario. As such, a risk profile for project assets and components under future climate conditions was prepared (Table 9). The confidence in future climate projections was considered in assessing the risks shown in the risk profile.

It is important to note the climate change impacts risk profile is a prioritization of impacts relative to each other, not against an external benchmark. Designations of 'moderate' or high' risk items should be considered in the context that many risks can be mitigated or monitored through future operations and maintenance policies and procedures.

In general, many climate risks can be mitigated through O&M policies and procedures. It is outside the scope of this assessment to complete a detailed review of O&M policies for their effectiveness in reducing climate risks. However, this assessment may motivate an internal review of O&M policies with a focus on adapting to climate risks.

The most significant risk to the project is related to the potential degradation of permafrost soils. Permafrost conditions in the project area are highly variable, where some locations present more stable soil, while more ice-rich, thaw-sensitive permafrost are very unstable and sensitive to change (conversation with senior, northern civil engineer 2019, Couture 2003). Construction over these highly sensitive soils (which are suspected to exist within the project site area) can lead to significant settlement and increased maintenance or regular rehabilitation (conversation with senior, northern civil engineer 2019). It is recommended that a geotechnical assessment be completed prior to roadway construction.

Table 9. Project Risk Profile Under Projected Future Climate

Climate Parameter	Infrastructure Component Impacted	Description of Climate Interaction	Probability	Severity	Risk Rating	Adaptation Considerations
Temperature						
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Ground temperatures are highly influenced by air temperatures. Increasing air and ground temperatures will initiate frost thawing and will result in changes to the depth of the active layer of the permafrost. These changes to the active layer of permafrost can result in settlement and damage to the road surface resulting in potholes and potential safety issues. This could result in higher maintenance requirements to ensure the road surface and user safety.	5	3	15	Consider incorporating the following mitigative measures into road design parameters: - where applicable, apply active and passive heat mitigation techniques such as thermosyphons, air convection embankments (ACE), air ducts and heat drains (HD), reflective surfaces, insulation and embankment thickening. - using a fill only, embankment concept rather than a cut and fill approach. - use woven geotextile to reinforce embankments and reduce differential settlement. - incorporate approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components. - use geofabrics, geosynthetic materials, wattles or other erosion control products in ditches covered by organics to minimize erosion of the existing fine grained soils. - take advantage of the natural topography and grades along the alignment that are gentle so sidehill cuts are eliminated. - stage the construction such that the placement of granular surfacing is delayed until any significant differential settlement has occurred. - confine the project footprint to the extent where possible, to cut lines and other areas that have already been disturbed.
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Road Embankments / Cuts	This warning can result in permafrost soils melting or weaken and unfrozen soils heaving. This can reduce the service life of the road embankment. Subgrade temperatures may also be affected by changes in ground and surface water flows. Where the subgrade is unfrozen, changes in the ground water table can result in settlement and shifting of the road / embankments (sloughing) and the sinking and cracking of road shoulders resulting in road instability, and structural failure that presents safety issues.	5	4	20	Plan for more frequent inspections, and monitoring, of the performance of the infrastructure (e.g., culverts are clear in the spring and the fall) and that there are sufficient additional resources for maintenance and rehabilitation when settlement occurs. Regularly monitor road maintenance efforts and climate data to better correlate the change in road surface with climate related parameters and their potential changes. Use this information as part of an adaptative management approach to future maintenance and rehabilitation efforts.

Climate Parameter	Infrastructure Component Impacted	Description of Climate Interaction	Probability	Severity	Risk Rating	Adaptation Considerations
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Surface Drainage	Thawing of permafrost also results in ponding of surface water and potential erosion and drainage issues. Abrupt differential thaw settlements on road surfaces are commonly observed where the road is constructed over a foundation that transitions between bedrock and ice-rich permafrost soils. Where massive ice has been initially present in the soil, these settlements can become extreme. With ground temperatures being strongly influenced by air temperatures, this interaction could become more prevalent.	5	3	15	Focus on collecting baseline information for the components that are thought to be most vulnerable to climate change, including the identification and documentation of locations of ice-rich permafrost. Avoid constructing in these areas if possible, and where not, deploy methods to minimize thermal disturbance (e.g., incorporating approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components). Review seasonal load limits to be enforced during spring thaw periods. Also consider posting reduced speed signs in problematic areas when road conditions seasonally deteriorate.
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Culverts & Ditches	Increasing temperature would initiate snowmelt through either freshet or precipitation events. These events create fast flowing surface water and increase the potential erosion of ditches and culverts through the generation of fast flowing surface water.	5	4	20	No recommendation.
Mean Seasonal Temperatures	Miscellaneous: Maintenance	In the continuous permafrost zone, occurrence of icings on road surfaces may increase with climate warming, as active permafrost layers become thicker and subsurface water flows increase.	5	4	20	Complete road inspection activities during spring thaw to evaluate drainage and thaw-related problems. Address problems like rutting, etc. in a timely manner.
Mean Seasonal Temperatures	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Extreme temperatures and dry periods can result in cracking of the edges of the road. Cracking of the edges of the road can present safety issues for road users and would result in increased maintenance.	5	2	10	No recommendation.
High Temperature Extremes (>30degC)	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Wildfires destroy insulating ground cover (grasses / vegetation) and can increase ground temperatures. This may impact permafrost resulting in accelerated thawing and structural problems.	5	3	15	No recommendation.

Climate Parameter	Infrastructure Component Impacted	Description of Climate Interaction	Probability	Severity	Risk Rating	Adaptation Considerations
High Temperature Extremes (>30degC)	Miscellaneous: Emergency Response	Wildfires are also a public and maintenance staff safety risk and can result in road closures.	5	3	15	No recommendation.
High Temperature Extremes (>30degC)	Miscellaneous: Administration / Personnel & Engineering	Heat waves can result in worker fatigue and exhaustion.	5	2	10	No recommendations, as a public notification system is already in place to help mitigate bottlenecks and other effects of closure as a result of fire.
Low Temperature Extremes (<-30degC)	Structural Elements / Physical Infrastructure: Culverts & Ditches	During low temperature events water flowing through non-heated roadside culverts can become frozen blocking the culvert. This blockage will prevent surface water flow and can result in localized and roadside flooding.	4	4	16	Plan for more frequent inspections, and monitoring, of the performance of the infrastructure (e.g., culverts are clear in the spring and the fall) and that there are sufficient additional resources for maintenance and rehabilitation when settlement occurs. Summer maintenance activities include grading, blading, replacement of surface gravel, dust control, and clearing of culverts. Winter maintenance activities will include snow removal and ice control as part of the road maintenance.
Low Temperature Extremes (<-30degC)	Miscellaneous: Maintenance	Freezing rain is a significant traffic hazard. Untrained operators may over-sand which can physically change the road’s crown, shoulders and compromise the load bearing capacity, or over-salt the road which can turn the road into mud.	4	3	12	Implement an operator training program on best practices as it relates to the management of gravel roads (e.g., straight salt and liquids should not be used).
Precipitation						
Precipitation Extremes	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Intense rain events may exceed the design flow capacities for culverts, resulting in water ponding against, overtopping, or flowing uncontrollably through the road embankment. Saturated road embankments may lose structural strength, causing potholes when heavily loaded.	2	3	6	Fast pothole repair may be needed to reduce potential infiltration of water into the subbase with more frequent rain events. Develop a policy to complete road inspections after extreme weather events.
Precipitation Extremes	Structural Elements / Physical Infrastructure: Road Embankments / Cuts	Embankments can be susceptible to changes in spring melt, rainfall frequency, intensity and duration, as well as groundwater levels resulting in internal erosion. Internal and external erosion can impact the structural integrity, raising the possibility of washouts, more repair work and loss of sediment to watercourses, affecting the	2	4	8	Maintain natural drainage patterns by using adequately sized and positioned culverts. Consider additional snow clearing in the ditches during winter to allow for a controlled spring runoff.

Climate Parameter	Infrastructure Component Impacted	Description of Climate Interaction	Probability	Severity	Risk Rating	Adaptation Considerations
		surrounding environment (e.g. sensitive or fish-bearing watercourses).				
Precipitation Extremes	Structural Elements / Physical Infrastructure: Culverts & Ditches	More snow accumulation requires increased effort in snow clearing, which is likely to result in additional load to the road surface. Insufficient late winter snowpack removal can result in soft areas. High-volume snowmelt may also result in flooding and increase pore water pressure and erosion, damaging permafrost.	2	4	8	Late-winter maintenance should blade snow and hard pack down the embankment's side slope area prior to spring melt. Ensure that late winter maintenance clears ice pack and snow from road surfaces to prevent damming of melt water. Frequent snow removal can minimize the insulating effect of the snow.
Precipitation Extremes	Miscellaneous: Maintenance	Increased amounts and frequency of rainfall will mainly affect road surface maintenance work. More frequent flooding events may require increased maintenance of the ditches and culverts.	2	4	8	Where possible, conduct inspections after severe events to ensure integrity of systems. Implement a more aggressive road monitoring and maintenance program. Conduct periodic surrounding surface surveys. Remote sensing techniques such as LiDAR, SAR, or Optical methods, can be repeated every 5 to 20 years to identify those areas where surface features such as topography, vegetation, surface water flow, pond developments, or thermograms activities have changed.
Sustained Rainfall	Structural Elements / Physical Infrastructure: Culverts & Ditches	Extreme weather events may overwhelm the capacity of some existing drainage-structures which can result in localized flooding and washouts, and negative effects to the surrounding environment. Drainage structures that cross the embankment, such as culverts and rock drains, are considered at higher risk to climate change than diversion structures that do not (e.g., flow channels and ditches) because of the potential severity.	5	2	10	Develop emergency planning procedures for flooding and erosion control at susceptible locations. Additional studies may be required to identify critical locations susceptible to flooding and to better understand flooding hazards / potential water volumes.
Sustained Rainfall	Miscellaneous: Administration / Personnel & Engineering	Extreme storms may hinder maintenance activities. In addition, it affects road safety and the ability of personnel to get to their workplace	5	2	10	Consider preparing O&M, construction policies, and worker safety policies on working and traveling in extreme weather events.
Dry Spells	Miscellaneous: Maintenance	Dust may form after long droughts and limit visibility on the road. Dust particles that settle directly onto plants can smother leaf surfaces and increase leaf surface temperature, all of which can reduce the overall photosynthetic efficiency in the plant	4	2	8	Consider employing water-based dust control methods during construction and restrict construction traffic to the planned footprint. In terms of maintenance, it is recommended that: - road inspections occur more frequently that the current norm. - there are sufficient resources for the maintenance and rehabilitation of the road, particularly during summer months when traffic is likely to generate more dust from the road surface.

Climate Parameter	Infrastructure Component Impacted	Description of Climate Interaction	Probability	Severity	Risk Rating	Adaptation Considerations
						- lower speed limits are posted as slower travel will generate less dust in summer, dryer months.
Frost Days	Structural Elements / Physical Infrastructure: Culverts & Ditches	Road surface or culverts can be structurally affected by changing numbers of frost cycles due to deformations associated with the volumetric changes when water freezes to ice and vice-versa. The increase in the number of frost-free days is likely to reduce this impact.	3	3	9	No recommendation.
Freeze-Thaw Days	Structural Elements / Physical Infrastructure: Road Base and Subgrade	Snowmelt-driven flooding creates fast flowing surface water and increases groundwater which can result in roadside flooding. Flooding on the road can cause potholes and damage to the road surface. Freezing of floodwater on the road can cause safety implications to road users.	3	3	9	Regular maintenance and clearing of culverts will reduce the potential for blockages and any associated roadside flooding.
Freeze-Thaw Days	Structural Elements / Physical Infrastructure: Road Embankments / Cuts	Snowmelt-driven flooding create fast flowing surface water and groundwater and surface water flow which can lead to erosion and material movement down from steep embankments	3	3	9	No recommendation.
Freeze-Thaw Days	Structural Elements / Physical Infrastructure: Culverts & Ditches	Snowmelt-driven flooding creates fast flowing surface water and increases the potential of erosion of ditches and culverts.	3	4	12	To avoid the premature erosion at the base of roadside culverts could be layered with a geotextile membrane with overlying rocks and gravel. Steam heaters will reduce the amount of freeze related blockages at culverts.

3.0 ANALYSIS OF RESILIENCE OPTIONS

3.1 IDENTIFICATION OF RESILIENCE MEASURES

As shown in Table 9, there are many risks to infrastructure that can be efficiently and effectively addressed through operations and maintenance procedures. It is recommended O&M policies and procedures be reviewed and revised as necessary to ensure they have an emphasis on improving system resilience, and health and safety requirements of users and Project staff, under a changing climate.

3.2 COST/BENEFIT ANALYSIS

Cost/benefit analysis of resilience design options are not available as final design details were not available at the time of the assessment. It is outside the scope of this assessment to complete a cost/benefit analysis of resilience design options. Furthermore, many resilience measures can be addressed through operations and maintenance procedures, and as such have no costs associated with design measures.

3.3 CONSIDERATION OF RESILIENCE PRINCIPLES

As recommended by the Climate Lens—General Guidance V1.2, the following is a discussion of how the climate change resilience principles have been incorporated into this assessment.

3.3.1 Proportionate Assessment

The Mackenzie Valley Highway Project is a proposed 321 km stretch of all-season gravel roadway between the communities of Wrigley and Norman Wells.

The analysis and recommendations in this Resilience Assessment are based on information available within the timeline and scope of this project, and on the authors' experience with climate risks assessments, for example, the application of Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) vulnerability and risk assessment tool - the PIEVC Protocol. This assessment represents a level of effort and detail consistent with the criticality of the Project's service and the level of detail of information available.

The Project will be a critical asset to the Government of the Northwest Territories and as such, an extensive climate risk assessment, using, for example, the PIEVC Protocol vulnerability assessment in the Project's detailed design stage to ensure that owners, designers, construction team and operators of the Project understand the full range of climate risks to the Project over its operational life. A full PIEVC Protocol assessment can take 3-6 months and involve numerous multiday and multiple stakeholder workshops but would result in higher capacity for the Project team to understand the broad spectrum of climate risks to the Project.

3.3.2 Systemic Analysis of Risk

By using an approach which aligns with Engineers Canada's PIEVC Protocol and conforms to ISO 31000 Risk Management framework, this high-level risk identification and assessment was carried out with the intention to meet the requirements set by Infrastructure Canada's Climate Lens—General Guidance V1.2.

3.3.3 Pursuit of Multiple Benefits

This assessment has identified that many climate risks to the Project can be addressed through O&M policies and procedures. As the Project is an extension to an existing gravel roadway, existing O&M policies and procedures will be adopted based on the recommendations in this report. It is outside the scope of this climate resilience assessment to complete detailed review of existing O&M policies for effectiveness in reducing climate risks. However, this climate assessment may motivate internal reviews of O&M policies with a focus to adapting to climate risks for the Project as these have been identified in this assessment.

3.3.4 Avoidance of Unintended Consequences

At the current stage of the Project, it is too early to fully consider the unintended consequences of risk transference or mitigation strategies. Stantec recommends this principle to be considered in detail during the design-build of the Project. For example, regular maintenance including grading must be completed to avoid excessive corrugation, pitting, uneven settlement, etc. Due to the projected increase in severe weather events and permafrost degradation, maintenance needs may increase. Maintenance activities such as these will help to maintain the asset to its intended level of service, however, may lead to increased GHG emissions as an unintended consequence. In general, O&M measures for climate adaptation are not GHG intensive. For potentially energy and GHG-intensive risk mitigation strategies, Stantec recommends incorporating design targets for the reduction of operational GHGs to avoid long-term unintended environmental consequences.

3.4 RESILIENCE MEASURES SELECTION

As the Project is in the preliminary design stage, resilience measures for individual system components have not been designed in detail.

Stantec recommends that resilience measures be further developed and evaluated as the Project progress into procurement, detailed design, construction and operation. This may be done through referencing the climate vulnerabilities identified through this assessment as a starting point, and by conducting a full PIEVC Protocol climate vulnerability assessment involving multiple internal and external stakeholders to develop a comprehensive profile of climate risks throughout the Project's lifecycle.

4.0 DESCRIPTION OF EVIDENCE BASE

To anticipate the climate vulnerabilities for the Project infrastructure, Stantec relied on the review of documents from other projects completed by other agencies with similar infrastructure or with similar climate hazards, and discussions with expert staff advisors. The infrastructure responses and comments regarding the impact to each selected climate parameter are evaluated based on the professional judgement of the assessors and a review of the following documents.

- Canada's Climate Change Report - Environment and Climate Change Canada, 2019;
- Other published literature

A series of interviews were carried out with members of the Owner's Design Team to discuss climate risks that can be addressed through design or may impact the construction.

Table 10 Interview Participants

Name	Role, Organization
Dustin Dewer	Norther Territories GOVT
Michael Hempler	Northern Territories GOVT
Todd McCauley	GNWT – Regional superintendent Sahtu Region
Rob Thom	GNWT – Transportation Planner

4.1 CLIMATE DATA

Stantec evaluated climate data from nearby weather stations, which was obtained through the CCHIP created by RSI. For this assessment, climate data from the Norman Wells A weather monitoring station (ID: 2202800) was used to represent the climate at the project site location.

Future climate projections are based on downscaled, published Intergovernmental Panel on IPCC data; the scope of this assessment did not include additional, site-specific future climate modelling. Cross-verification between climate information sources was conducted to identify possible discrepancies between the data sources used and are described in the detailed climate analysis report (Appendix A).

4.2 INDIGENOUS HISTORICAL KNOWLEDGE OF CLIMATE

Indigenous historical knowledge of climate for the Project area was not referenced for this assessment. This type of climate knowledge is typically relied upon in project locations where relevant climate data from weather stations is unreliable, unusable, or otherwise unavailable. For the Project, historical climate data from nearby Environment Canada weather stations was readily available and reliable and thus have been used.

4.3 PROJECT TEAM

This resilience assessment was prepared by K’alo-Stantec Ltd. Table 11 identifies Stantec team members that were involved with the assessment.

Table 11. Resilience Assessment Team

Name	Qualifications	Project Role
Bernadette Middleton	M.Sci, ENV SP	Resilience Assessor
Riley Morris	M.Sc., P.Eng.	Climate Advisor
Shane O’Hanlon	M.Sc., B.Eng.	Reviewer - Resilience Assessor
Wayne Penno	P.Eng., MBA	Qualified Validator – Resilience
Warren McLeod	P.Eng.	Independent Peer Reviewer

5.0 CONCLUSION

This climate resilience assessment conducted for the Project was generally based on the principles of Engineers Canada's PIEVC Protocol assessment and is consistent with ISO 31000 Risk Management Framework. This assessment serves to inform the proponent on the future climate related risks that should be considered at the design and construction stages of the Project.

This assessment has identified eight climate parameters that can pose hazards to Project infrastructure. Infrastructure interactions to each climate parameter were examined and an associated risk rating was assigned to each. The climate parameters that presented the greatest number of risks to the Project are mean seasonal temperatures, extreme high and low temperatures, and extreme precipitation.

Table 9 lists all the estimated risks to the Project. It is important to note that the climate change impacts are a prioritization of impacts relative to each other, not against an external benchmark. Designations of 'moderate' or high' risk items should be considered in the context that many risks can be mitigated or monitored through O&M policies and procedures. This assessment does not include an evaluation of the effectiveness of O&M policies to reduce or mitigate climate risks, as these have not been confirmed. Some of the risks may be addressed at the detailed design stage of Project.

Although moderate and high risks have been identified at this stage of the project, many risks can be monitored or mitigated as part of O&M policies and procedures during the lifecycle of the assets. Furthermore, since the design life of the roadway is less than the time horizon for this assessment, some mitigation measures can be applied or managed sequentially with regular roadway rehabilitation cycles.

Recommended climate risk management measures for the highest rated risks ('Extreme') include:

- Consider incorporating the following mitigative measures into road design parameters:
    - where applicable apply active and passive heat mitigation techniques such as thermosyphons, ACE, air ducts and HD, reflective surfaces, insulation and embankment thickening to reduce permafrost degradation.
    - using a fill only, embankment concept rather than a cut and fill approach.
    - use woven geotextile to reinforce embankments and reduce differential settlement.
    - incorporate approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components.
    - use geofabrics, geosynthetic materials, wattles or other erosion control products in ditches covered by organics to minimize erosion of the existing fine-grained soils.
    - take advantage of the natural topography and grades along the alignment that are gentle so sidehill cuts are eliminated.
    - stage the construction such that the placement of granular surfacing is delayed until any significant differential settlement has occurred.

  - confine the project footprint to the extent where possible, to cut lines and other areas that have already been disturbed.

- Plan for more frequent inspections, and monitoring, of the performance of the infrastructure (e.g., culverts are clear in the spring and the fall) and that there are sufficient additional resources for maintenance and rehabilitation when settlement occurs. Regularly monitor road maintenance efforts and climate data to better correlate the change in road surface with climate related parameters and their potential changes. Use this information as part of an adaptative management approach to future maintenance and rehabilitation efforts.
- Focus on collecting baseline information for the components that are thought to be most vulnerable to climate change, including the identification and documentation of locations of ice-rich permafrost. Avoid constructing in these areas if possible, and where not, deploy methods to minimize thermal disturbance (e.g., incorporating approaches to lowering the water table in the immediate vicinity of the roadbed by using ditches or similar components).
- Review and refresh the operator training program on best practices as it relates to the management of gravel roads (e.g. straight salt and liquids should not be used).
- Rapid pothole repair may be needed to reduce potential infiltration of water into the subbase with more frequent rain events. Develop a policy to complete road inspections after extreme weather events.
- Maintain natural drainage patterns by using adequately sized and positioned culverts. Consider additional snow clearing in the ditches during winter to allow for a controlled spring runoff.
- Where possible, snow should be bladed down the side slopes, away from the shoulders. Late-winter maintenance should blade snow and hard pack down to the embankment's side slope area prior to spring melt. Ensure that late winter maintenance clears ice pack and snow from road surfaces to prevent damming of melt water. Frequent snow removal can minimize the insulating effect of the snow.
- Where possible, implement a more aggressive road monitoring and maintenance program. Conduct periodic surrounding surface surveys. Remote sensing techniques such as LiDAR, SAR, or Optical methods can be repeated every 5 to 20 years to identify those areas where surface features such as topography, vegetation, surface water flow, pond developments, or thermograms activities have changed. Conduct inspections after severe events to ensure the integrity of roadway and drainage systems.

6.0 REFERENCES

Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M.Wairiu, and K. Zickfeld, 2018: Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Bonsal, B.R., D.L. Peters, F. Seglenieks, A. Rivera, and A. Berg. 2019. Changes in freshwater availability across Canada; Chapter 6 in Bush, E. and D.S. Lemmen (Eds.) Canada's Changing Climate Report. Government of Canada, Ottawa, Ontario, pp. 261-342

Burn, D.H., P.H. Whitfield, and M. Sharif. 2016. Identification of changes in floods and flood regimes in Canada using a peaks over threshold approach. Hydrological Processes, 30: 3303-3314. doi:10.1002/hyp.10861

Couture, R., S. Smith, S.D. Robinson, M.M. Burgess, and S. Solomon. 2003. On the Hazards to Infrastructure in the Canadian North Associated with Thawing of Permafrost. Geological Survey of Canada, Edmonton, Alberta.

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull. Report and national map at 1:7500 000 scale.

Engineers Canada. 2012. PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate Principles & Guidelines, Revision PG-10, May 2012

Gaur, A., A. Gaur, and S.P. Simonovic. 2018. Future Changes in Flood Hazards across Canada under a Changing Climate. Water, 10: 1441. doi:10.3390/w10101441

Gaur, A., A. Gaur, D. Yamazaki, and S.P. Simonovic. 2019. Flooding Related Consequences of Climate Change on Canadian ities and Flow Regulation Infrastructure. Water, 11: 63. doi:10.3390/w11010063

Infrastructure Canada. 2019. Climate Lens General Guidance V1.2 , 2019. Retrieved online from https://www.infrastructure.gc.ca/pub/other-autre/cl-occ-eng.html

IPCC 2014 Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved online from https://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf

McHattie, R.L. 2015. Low Volume Gravel Roads in Alaska: A Practical Guide for Owners and Others.

NRCAN. 2008. From Impacts to Adaptation: Canada in a Changing Climate. Retrieved online from https://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2008/10253

Poitras, V., L. Sushama, F. Seglenieks, M.N. Khaliq, and E. Soulis. 2011. Projected Changes to Streamflow Characteristics over Western Canada as Simulated by the Canadian RCM. Journal of Hydrometeorology, 12: 1395-1413. doi:10.1175/JHM-D-10-5002.1

Smith, M.R. and S.S. Myers. 2018. Impact of anthropogenic CO_2 emissions on global human nutrition. *Nature Climate Change*, 8: 834-839.

APPENDICES

Appendix A CLIMATE PROFILE

1.0 INTRODUCTION

1.1 DESCRIPTION OF CLIMATE PROFILES

Climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of meteorological variables such as temperature, precipitation and wind over a period of time. Climate profiles are important tools that describe what climate trends have been occurring in recent history (i.e., over the last 30 years or longer), and also describe future climate conditions to help inform design and/or adaptation actions. Climate profiles rely on the historical climate record (usually in the form of meteorological data measured at weather stations) to describe climate from recent history, and on climate projections (developed by global climate models or GCMs). The historical climate profile puts future climate projections into context: e.g. design performance from the past can be compared to both historical and future climate to better understand what (if any) design changes should be implemented to ensure better performance in the future.

When developing a profile of the historic climate of an area, the most valuable data is typically temperature, precipitation, and wind. Meteorological data from the last 30 years is preferred to help give a representative estimate of the climate of recent history at a given location – though longer periods are of even greater benefit in that they add even more to the story of an area's historical climate. Environment and Climate Change Canada (ECCC) provides the largest database of observational historical climate data in Canada.

Climate projections are descriptions of the future climate and are most often collected from Global Climate Models (GCMs) developed by many organizations across the world. It is not recommended to rely only on one or two of these GCMs to estimate future climate. Instead, an average of several GCMs tends to give a more reliable estimate of future climate. There are nearly 40 GCMs that have contributed to the Fifth Coupled Model Intercomparison Project (CMIP5; Taylor et al., 2012), which forms the basis of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013). The Pacific Climate Impacts Consortium (PCIC) has taken a subset of 24 of these models to produce reliable, high-resolution downscaled climate projections localized to specific areas of interest in Canada (Cannon, 2015; Cannon et al., 2015).

In addition to the physics of the GCMs, global progress towards meeting GHG emissions targets is also a large source of uncertainty in future climate projections. There are four Representative Concentration Pathways (RCP)[1] scenarios adopted by the IPCC that are based on various future greenhouse gas concentration scenarios. This climate profile will focus on the "business as usual" greenhouse gas concentrations scenario, RCP 8.5. Current global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions (Smith and Myers, 2018).

The IPCC is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC). The assessments are policy-relevant but not policy-prescriptive: they may present projections of future climate change based on different scenarios and the risks that climate change poses and discuss the implications of response options, but they do not tell policymakers what actions to take.

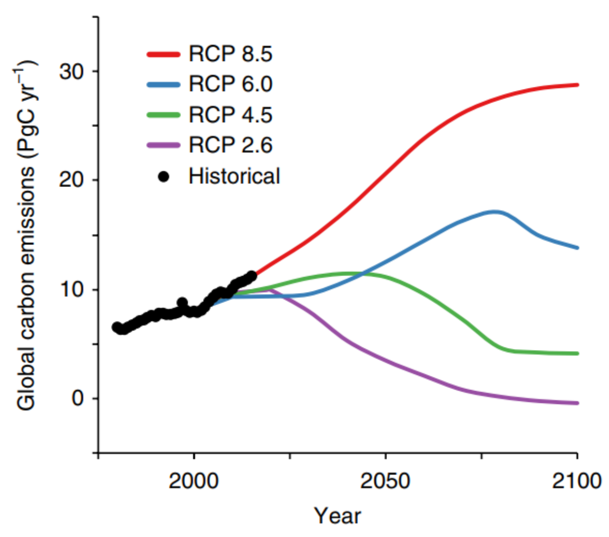


Figure 5 Historical CO_2 emissions for 1980-2017 and projected emissions trajectories until 2100 for the four RCP scenarios. Figure from Smith and Myers, 2018

[1] RCP: Representative Concentration Pathways – a greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its Fifth Assessment Report (AR5) in 2013.

1.2 CLIMATE PROFILES FOR THE MACKENZIE VALLEY HIGHWAY PROJECT

Two climate zones were defined, corresponding with ecological regions in the area, which generally align with differentiation in climate and weather patterns of the breadth of the Mackenzie Valley Highway. Regardless, comparison of the datasets between available data in the area suggests that Fort Simpson A is adequately representative of the climate in the region.

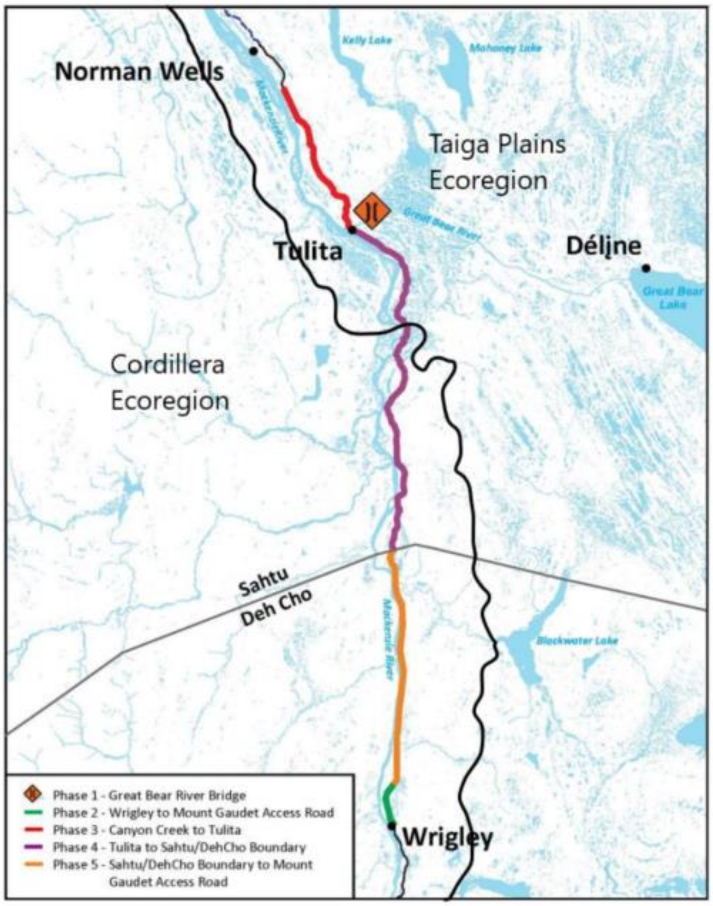


Figure 6 Map of Proposed Highway Construction Plan, Overlain by Climate Zones Selected for this Assessment: Cordillera and Taiga Plains Eco Regions.

A review of available historical observation data identified various weather stations throughout the region with data archived by ECCC. Many of these stations, however, either are no longer in operation or have short records and do not provide sufficient data for climate analysis (including the calculation of 1981-2010 Climate Normals values). Of the stations with sufficiently long records covering the recent decades, an individual station was selected to represent each climate zone and used for detailed analysis (Table 12); selected stations shaded in grey). Station proximity to the proposed highway was also considered when selecting the representative stations. A summary of the coordinates of the ECCC weather stations used for each climate zone is shown in Table 11. In this case, the Norman Wells A station was selected because of its long record, the completeness of the dataset, and its location with respect to the proposed highway. The Fort Simpson A station was chosen for similar reasons; however, it is located at a distance (~180km SE) from the proposed terminus of the highway. This distance in location was prioritised in this case over the poor dataset at the Wrigley A weather station, which has a significant number of missing days of data. Regardless, comparison of the datasets between available data in the area suggests that Fort Simpson A is adequately representative of the climate in the region. In order to characterize the general differences between the two climate zones, general comparisons of 1981-2010 Climate Normals values between weather stations is presented in Table 12.

Table 12 Location of Observation Stations used for Historical Climate Profile

Climate Zone	Observation Station Name (Station ID)	Latitude	Longitude	Record Range (Length in yrs)
Norman Wells – Tulita	Norman Wells A (ID: 2202800)	65.2813 N	-126.7986 W	1943-2020 (78)
	Tulita A (ID: 2201700)	64.9097 N	-125.5694 W	1903-2020 (118)
Wrigley – Fort Simpson	Wrigley A (ID: 2204000)	63.2094 N	-123.4366 W	1943-2020 (78)
	Fort Simpson A (ID: 2202104)	61.7602 N	-121.2366 W	1895-2020 (126)

Table 13 Climate Normals Differences between the Two Climate Zones

Climate Parameter	Norman Wells A (ID: 2202800/1) 1981-2010	Fort Simpson A (ID: 2202104) 1981-2010
Annual Mean Temperature (°C)	-5.1	-2.9
Annual Maximum Temperature (°C)	-0.4	2.7
Annual Minimum Temperature (°C)	-9.9	-8.2
Annual Total Precipitation (mm)	294.4	387.6
# of Days/Year with Tmax > 30°C	2.1	4.2
# of Days/Year with Tmin < -30°C	51.0	37.5

The time horizons for the study were selected as current conditions (based on 1981-2010 Climate Normals) establishing the baseline. This climate profile presents projected climate information for three time horizons: the 2020s (2010 to 2039), the 2050s (2040 to 2069), and the 2080s (2070 to 2099). Typically, the 2020s are used to evaluate how recent trends correlate with projections in the near future. The 2050s and 2080s climate time horizons are presented as longer-term climate projections to help inform infrastructure design and adaptation planning.

2.0 TEMPERATURE

2.1 MEAN TEMPERATURE

Table 14 Change in Annual Mean Temperature from the 1981-2010 Baseline under RCP 8.5

Time Period	Climate Zone (Station Name; ID)	1981-2010 Baseline (°C)	Projected Change in Annual Mean Temperature from 1981-2010 Baseline (°C)		
			2020s	2050s	2080s
Annual	Norman Wells A (ID: 2202800)	-5.1	1.0	3.1	5.5
	Fort Simpson A (ID: 2202104)	-2.8	1.7	3.7	6.2
Winter	Norman Wells A (ID: 2202800)	-24.5	1.5	4.3	7.7
	Fort Simpson A (ID: 2202104)	-22.2	2.4	5.2	8.6
Spring	Norman Wells A (ID: 2202800)	-5.7	0.8	2.7	5.1
	Fort Simpson A (ID: 2202104)	-1.6	1.5	3.4	5.9
Summer	Norman Wells A (ID: 2202800)	15.3	-0.2	1.3	3.2
	Fort Simpson A (ID: 2202104)	15.8	1.0	2.5	4.4
Fall	Norman Wells A (ID: 2202800)	-5.6	1.7	3.8	5.9
	Fort Simpson A (ID: 2202104)	-3.1	1.7	3.8	5.9

2.2 MAXIMUM TEMPERATURE

2.2.1 Annual and Seasonal Average

Table 15 Change in Annual Maximum Temperature from the 1981-2010 Baseline under RCP 8.5

Time Period	Climate Zone (Station Name; ID)	1981-2010 Baseline (°C)	Projected Change in Annual Maximum Temperature from 1981-2010 Baseline (°C)		
			2020s	2050s	2080s
Annual	Norman Wells A (ID: 2202800)	-0.4	0.8	2.7	5.0
	Fort Simpson A (ID: 2202104)	2.7	1.6	3.5	5.8
Winter	Norman Wells A (ID: 2202800)	-20.4	1.1	3.7	6.8
	Fort Simpson A (ID: 2202104)	-17.5	2.2	4.8	7.9
Spring	Norman Wells A (ID: 2202800)	0.2	0.3	2.0	4.3
	Fort Simpson A (ID: 2202104)	4.8	1.4	3.1	5.4
Summer	Norman Wells A (ID: 2202800)	20.7	-0.2	1.2	3.1
	Fort Simpson A (ID: 2202104)	22.1	1.0	2.4	4.3
Fall	Norman Wells A (ID: 2202800)	-1.9	1.3	3.3	5.3
	Fort Simpson A (ID: 2202104)	1.3	1.5	3.5	5.5

2.2.2 Extreme Maximum Temperature Frequency

It is useful to view projected increases in temperatures as the change in the occurrence of days with a temperature higher than a certain extreme heat threshold. The climate projections for the occurrence of days with temperatures greater than 30°C are presented below.

Table 16 Occurrence of Maximum Daily Temperatures > 30°C: Historic (1981-2010) and Projected under RCP 8.5

Climate Zone (Station Name)	Annual Occurrence of Days with Max. Temp > 30°C (days/year)			
	1981-2010	2020s	2050s	2080s
Norman Wells-Tulita (Norman Wells A)	2.1	2.6	7.0	14.4
Wrigley-Fort Simpson (Fort Simpson A)	4.2	5.8	12.9	24.8

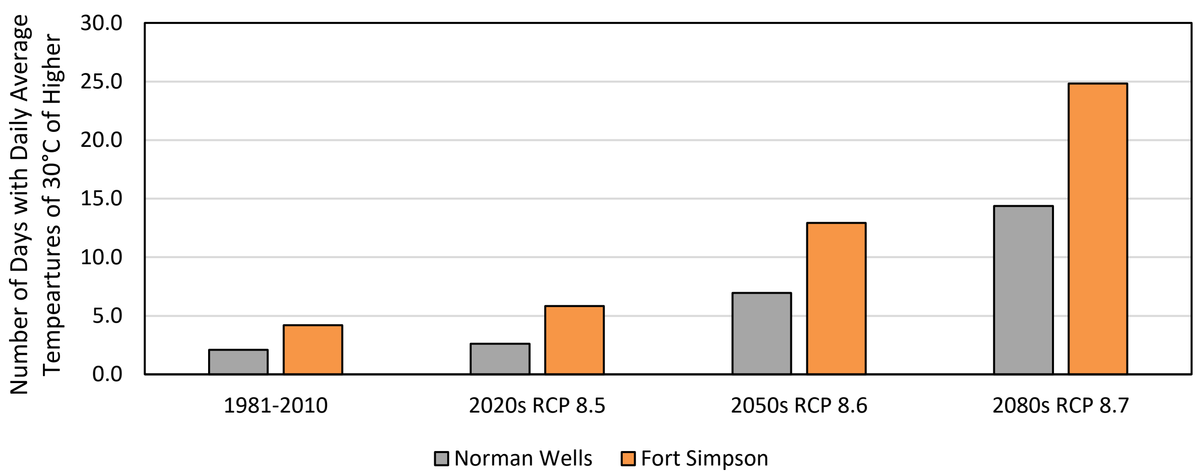


Figure 7 Occurrence of Maximum Daily Temperature > 30°C by Time Period and Location

2.3 MINIMUM TEMPERATURE

2.3.1 Annual and Seasonal Average

Table 17 Change in Annual Minimum Temperature from the 1981-2010 Baseline under RCP 8.5

Time Period	Climate Zone (Station Name; ID)	1981-2010 Baseline (°C)	Projected Change in Annual Minimum Temperature from 1981-2010 Baseline (°C)		
			2020s	2050s	2080s
Annual	Norman Wells A (ID: 2202800)	-9.9	1.3	3.5	6.1
	Fort Simpson A (ID: 2202104)	-8.2	1.7	3.9	6.5
Winter	Norman Wells A (ID: 2202800)	-28.5	1.7	4.7	8.5
	Fort Simpson A (ID: 2202104)	-26.8	2.5	5.5	9.3
Spring	Norman Wells A (ID: 2202800)	-11.6	1.2	3.3	5.9
	Fort Simpson A (ID: 2202104)	-8.1	1.6	3.7	6.3
Summer	Norman Wells A (ID: 2202800)	9.7	0.0	1.6	3.5
	Fort Simpson A (ID: 2202104)	9.5	1.0	2.6	4.5
Fall	Norman Wells A (ID: 2202800)	-9.3	2.0	4.3	6.5
	Fort Simpson A (ID: 2202104)	-7.6	1.8	4.1	6.3

1. Extreme Minimum Temperature Frequency

It is useful to view projected increases in temperatures as the change in the occurrence of days with a temperature lower than a certain extreme cold threshold. The climate projections for the occurrence of days with temperatures less than -30°C are presented below.

Table 18 Occurrence of Minimum Daily Temperatures < -30°C: Historic (1981-2010) and Projected under RCP 8.5

Climate Zone (Station Name)	Annual Occurrence of Days with Min. Temp < -30°C (days/year)			
	1981-2010	2020s	2050s	2080s
Norman Wells-Tulita (Norman Wells A)	51.0	40.8	24.0	10.7
Wrigley-Fort Simpson (Fort Simpson A)	37.5	29.4	16.7	6.5

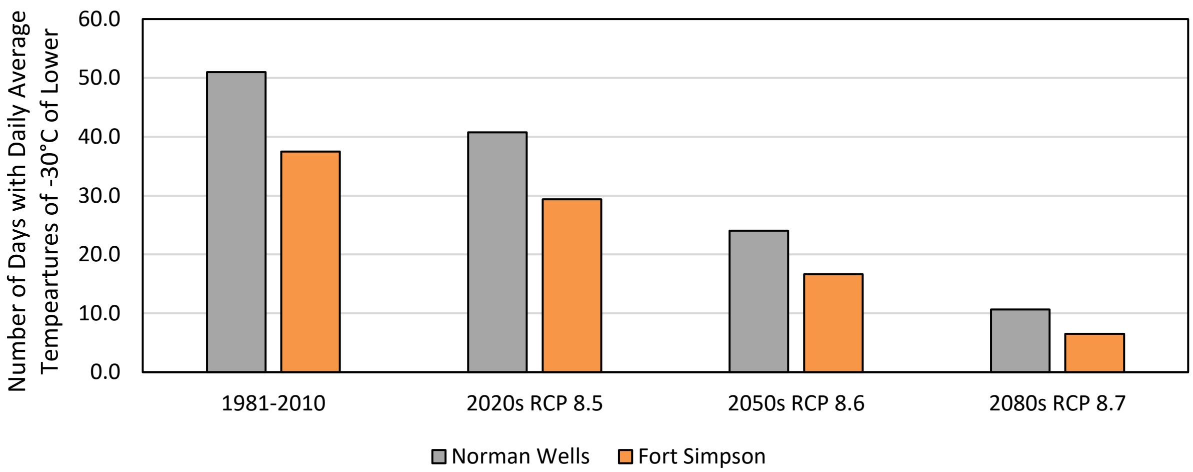


Figure 8 Occurrence of Minimum Daily Temperature < -30°C by Time Period and Location

3.0 PRECIPITATION

3.1 TOTAL ANNUAL & SEASONAL ACCUMULATION

Table 19 Projected Percent Change in Average Total Annual Precipitation from the 1981-2010 Baseline under RCP 8.5

Time Period	Climate Zone (Station Name; ID)	1981-2010 Baseline (°C)	Projected Change in Total Annual Precipitation from 1981-2010 Baseline (%)		
			2020s	2050s	2080s
Annual	Norman Wells A (ID: 2202800)	294.4	1.10	1.00	0.92
	Fort Simpson A (ID: 2202104)	387.6	0.92	1.00	1.10
Winter	Norman Wells A (ID: 2202800)	48.7	0.83	0.73	0.67
	Fort Simpson A (ID: 2202104)	55.6	0.67	0.73	0.83
Spring	Norman Wells A (ID: 2202800)	40.8	0.54	0.60	0.68
	Fort Simpson A (ID: 2202104)	61.8	0.54	0.60	0.68
Summer	Norman Wells A (ID: 2202800)	126.3	1.45	1.56	1.65
	Fort Simpson A (ID: 2202104)	173.8	1.45	1.56	1.65
Fall	Norman Wells A (ID: 2202800)	78.5	1.02	1.11	1.25
	Fort Simpson A (ID: 2202104)	96.4	1.02	1.11	1.25

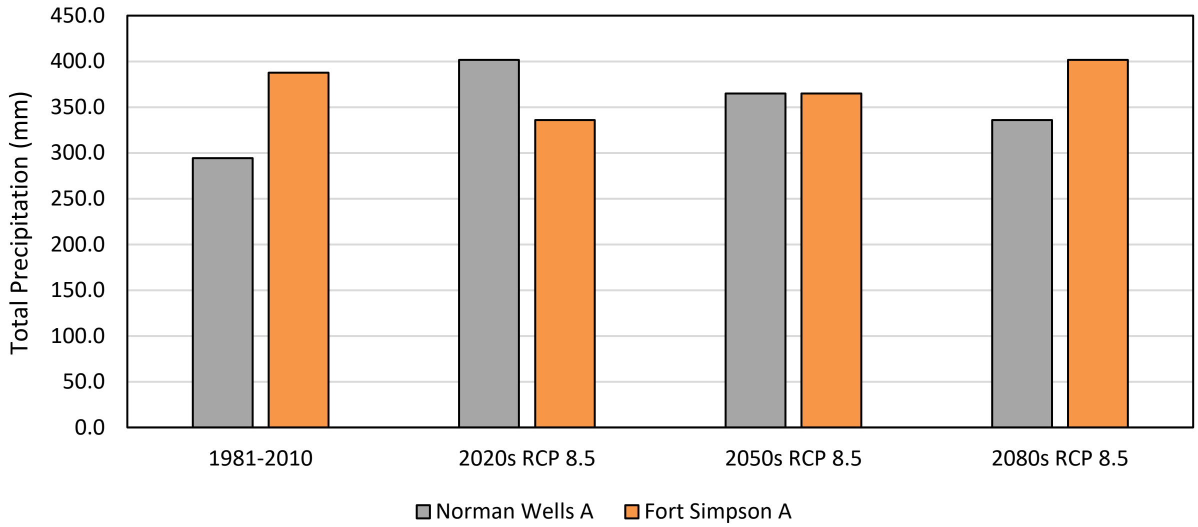


Figure 9 Average Annual Total Precipitation by Time Period and Location

3.2 INTENSITY-DURATION-FREQUENCY (IDF)

In the following subsections, total precipitation amount (mm) for specific time intervals (5 minutes to 24 hours) for various return periods (2 years to 100 years) are provided. These precipitation amounts are part of IDF data, which relates short-duration, high rainfall intensity with its frequency of occurrence. Evaluating historic and projected IDF data provides insight into how the short-duration, high intensity rainfall events will change under future climate conditions. Ideally, IDF data generated by Environment and Climate Change Canada from a weather station within the climate zones would be used. Both the Norman Wells A and Fort Simpson A weather stations present IDF projection data, which were used in this climate profile, as described under sections 3.2.1 and 3.2.2, respectively. Projections for future climate IDF data are available based on results from 24 Global Circulation Models that simulate future climate conditions. The projected IDF data presented here is based on bias-corrected results from 9 downscaled climate models under the RCP 8.5 emission scenario from the Pacific Climate Impacts Consortium. The “ungauged” interpolations and projections are published by the Institute for Catastrophic Loss Reduction (ICLR) at Western University, London, Ontario.

3.2.1 Norman Wells – Tulita Climate Zone

For the Norman Wells-Tulita climate zone, a gauged station at the Norman Wells A weather monitoring station (latitude, longitude: 65.28, -126.80) with data spanning from 1974 to 2016 used. Historical and projected total precipitation amount (mm) in specific time intervals (5 minutes to 24 hours) for various return periods (2 years to 100 years) are provided below.

Table 20 Historical Precipitation Event Accumulation IDF data (mm) – Norman Wells A

T (years)	2	5	10	25	50	100
5 min	2.92	4.62	5.74	7.17	8.22	9.27
10 min	4.25	6.7	8.32	10.37	11.89	13.4
15 min	5.06	7.81	9.63	11.93	13.63	15.32
30 min	6.58	10.32	12.8	15.93	18.25	20.56
1 h	8.82	13.58	16.74	20.72	23.68	26.61
2 h	11.17	15.97	19.15	23.16	26.14	29.1
6 h	16.37	22.01	25.74	30.45	33.95	37.42
12 h	39.43	54.38	66.74	86.01	101.83	113.15
24 h	48.51	65.25	76.43	90.82	101.83	113.15

Table 21 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Norman Wells A, RCP 8.5, 2020s (2010-2039)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	3.12	6.8%	4.85	5.0%	6.36	10.8%	8.25	15.1%	9.69	17.9%	11.19	20.7%
10 min	4.6	8.2%	7.21	7.6%	9.43	13.3%	12.03	16.0%	13.88	16.7%	16	19.4%
15 min	5.48	8.3%	8.46	8.3%	10.96	13.8%	13.92	16.7%	16	17.4%	18.37	19.9%
30 min	7.15	8.7%	10.94	6.0%	14.16	10.6%	18.04	13.2%	20.82	14.1%	23.86	16.1%
1 h	9.45	7.1%	14.27	5.1%	18.38	9.8%	23.86	15.2%	28.02	18.3%	32.14	20.8%
2 h	12.37	10.7%	17.63	10.4%	21.87	14.2%	26.64	15.0%	29.6	13.2%	33.07	13.6%
6 h	18.82	15.0%	25.39	15.4%	30.02	16.6%	33.62	10.4%	35.38	4.2%	37.18	-0.6%
12 h	22.43	12.9%	30.5	13.1%	36.69	15.9%	42.62	13.3%	45.63	8.6%	50.07	7.9%
24 h	25.86	7.2%	37.16	5.2%	46.43	8.7%	60.34	15.9%	70.66	19.7%	80.32	21.9%

Table 22 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Norman Wells, RCP 8.5, 2050s (2040-2069)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	3.19	9.2%	5	8.2%	6.32	10.1%	8.27	15.3%	9.91	20.6%	12.18	31.4%
10 min	4.71	10.8%	7.41	10.6%	9.35	12.4%	12.16	17.3%	14.37	20.9%	17.34	29.4%
15 min	5.61	10.9%	8.68	11.1%	10.89	13.1%	14.05	17.8%	16.57	21.6%	20.06	30.9%
30 min	7.32	11.2%	11.26	9.1%	14.1	10.2%	18.18	14.1%	21.48	17.7%	26.16	27.2%
1 h	9.66	9.5%	14.67	8.0%	18.39	9.9%	23.8	14.9%	28.53	20.5%	35.1	31.9%
2 h	12.69	13.6%	18.14	13.6%	21.92	14.5%	27.06	16.8%	31.35	19.9%	37.11	27.5%
6 h	19.49	19.1%	26.07	18.4%	30.03	16.7%	34.99	14.9%	38.97	14.8%	42.11	12.5%
12 h	23.12	16.4%	31.42	16.5%	36.83	16.3%	43.86	16.6%	49.79	18.5%	56.62	22.0%
24 h	26.44	9.6%	38.14	8.0%	47	10.0%	60.11	15.4%	71.33	20.9%	88.27	33.9%

Table 23 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Norman Wells A, RCP 8.5, 2080s (2070-2099)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	3.45	18.2%	5.4	16.9%	7.02	22.3%	9.17	27.9%	11.39	38.6%	13.95	50.5%
10 min	5.09	19.8%	8.02	19.7%	10.4	25.0%	13.32	28.4%	16.35	37.5%	19.32	44.2%
15 min	6.07	20.0%	9.4	20.4%	12.08	25.4%	15.39	29.0%	18.86	38.4%	22.15	44.6%
30 min	7.92	20.4%	12.17	17.9%	15.62	22.0%	19.96	25.3%	24.52	34.4%	29	41.1%
1 h	10.44	18.4%	15.75	16.0%	20.3	21.3%	26.48	27.8%	32.9	38.9%	38.75	45.6%
2 h	13.75	23.1%	19.47	21.9%	24.07	25.7%	29.18	26.0%	34.92	33.6%	38.76	33.2%
6 h	21.12	29.0%	28.18	28.0%	32.82	27.5%	36.27	19.1%	40.38	18.9%	42.01	12.3%
12 h	25.06	26.1%	33.72	25.0%	40.26	27.1%	46.3	23.1%	53.04	26.2%	56.88	22.6%
24 h	28.53	18.2%	41.07	16.3%	51.37	20.2%	66.7	28.1%	82.87	40.4%	102.95	56.2%

The above results indicate an increase in precipitation accumulation can be expected for all rainfall events at Norman Wells, identified as being representative of the Norman Wells-Tulita climate zone. Under RCP 8.5, the projected percentage increase from the interpolated historical data for precipitation events range from -0.6% to 21.9% for the 2020s (2010-2039), 8.0% to 33.9% for the 2050s (2040-2069), and 12.3% to 56.2% for the 2080s (2070-2099).

Historical and projected intensity rates (mm/hr) in specific time intervals (5 minutes to 24 hours) for various return periods (2 years to 100 years) are provided below.

Table 24 Historical Precipitation Event Intensity IDF data (mm/hr) – Norman Wells A

T (years)	2	5	10	25	50	100
5 min	35.02	55.42	68.93	86	98.66	111.22
10 min	25.52	40.21	49.93	62.21	71.33	80.37
15 min	20.24	31.23	38.51	47.7	54.53	61.3
30 min	13.16	20.65	25.6	31.86	36.5	41.11
1 h	8.82	13.58	16.74	20.72	23.68	26.61
2 h	5.59	7.99	9.57	11.58	13.07	14.55
6 h	2.73	3.67	4.29	5.08	5.66	6.24
12 h	1.66	2.25	2.64	3.13	3.5	3.87
24 h	1.01	1.47	1.78	2.17	2.46	2.75

Table 25 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Norman Wells A, RCP 8.5, 2020s (2010-2039)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	37.49	7.1%	58.24	5.1%	76.28	10.7%	99.01	15.1%	116.3	17.9%	134.29	20.7%
10 min	27.58	8.1%	43.28	7.6%	56.58	13.3%	72.18	16.0%	83.29	16.8%	96.02	19.5%
15 min	21.9	8.2%	33.82	8.3%	43.82	13.8%	55.67	16.7%	64.02	17.4%	73.47	19.9%
30 min	14.3	8.7%	21.88	6.0%	28.32	10.6%	36.09	13.3%	41.64	14.1%	47.73	16.1%
1 h	9.45	7.1%	14.27	5.1%	18.38	9.8%	23.86	15.2%	28.02	18.3%	32.14	20.8%
2 h	6.18	10.6%	8.81	10.3%	10.94	14.3%	13.32	15.0%	14.8	13.2%	16.53	13.6%
6 h	3.14	15.0%	4.23	15.3%	5.00	16.6%	5.6	10.2%	5.9	4.2%	6.2	-0.6%
12 h	1.87	12.7%	2.54	12.9%	3.06	15.9%	3.55	13.4%	3.8	8.6%	4.17	7.8%
24 h	1.08	6.9%	1.55	5.4%	1.93	8.4%	2.51	15.7%	2.94	19.5%	3.35	21.8%

Table 26 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Norman Wells, RCP 8.5, 2050s (2040-2069)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	38.33	9.5%	59.98	8.2%	75.87	10.1%	99.28	15.4%	118.89	20.5%	146.15	31.4%
10 min	28.24	10.7%	44.45	10.5%	56.10	12.4%	72.98	17.3%	86.19	20.8%	104.05	29.5%
15 min	22.43	10.8%	34.73	11.2%	43.55	13.1%	56.22	17.9%	66.30	21.6%	80.24	30.9%
30 min	14.64	11.2%	22.51	9.0%	28.19	10.1%	36.35	14.1%	42.96	17.7%	52.32	27.3%
1 h	9.66	9.5%	14.67	8.0%	18.39	9.9%	23.80	14.9%	28.53	20.5%	35.10	31.9%
2 h	6.35	13.6%	9.07	13.5%	10.96	14.5%	13.53	16.8%	15.67	19.9%	18.56	27.6%
6 h	3.25	19.0%	4.35	18.5%	5.01	16.8%	5.83	14.8%	6.49	14.7%	7.02	12.5%
12 h	1.93	16.3%	2.62	16.4%	3.07	16.3%	3.66	16.9%	4.15	18.6%	4.72	22.0%
24 h	1.10	8.9%	1.59	8.2%	1.96	10.1%	2.50	15.2%	2.97	20.7%	3.68	33.8%

Table 27 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Norman Wells A, RCP 8.5, 2080s (2070-2099)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	41.42	18.3%	64.8	16.9%	84.24	22.2%	110.06	28.0%	136.66	38.5%	167.43	50.5%
10 min	30.56	19.7%	48.15	19.7%	62.42	25.0%	79.91	28.5%	98.1	37.5%	115.9	44.2%
15 min	24.27	19.9%	37.58	20.3%	48.33	25.5%	61.56	29.1%	75.43	38.3%	88.59	44.5%
30 min	15.83	20.3%	24.33	17.8%	31.24	22.0%	39.93	25.3%	49.04	34.4%	58.01	41.1%
1 h	10.44	18.4%	15.75	16.0%	20.3	21.3%	26.48	27.8%	32.9	38.9%	38.75	45.6%
2 h	6.88	23.1%	9.74	21.9%	12.04	25.8%	14.59	26.0%	17.46	33.6%	19.38	33.2%
6 h	3.52	28.9%	4.7	28.1%	5.47	27.5%	6.05	19.1%	6.73	18.9%	7	12.2%
12 h	2.09	25.9%	2.81	24.9%	3.35	26.9%	3.86	23.3%	4.42	26.3%	4.74	22.5%
24 h	1.19	17.8%	1.71	16.3%	2.14	20.2%	2.78	28.1%	3.45	40.2%	4.29	56.0%

3.2.2 Wrigley – Fort Simpson Climate Zone

For the Wrigley-Fort Simpson climate zone, a gauged station at the Fort Simpson A weather monitoring station (latitude, longitude: 61.76, -121.24) with data spanning from 1969 to 2017 is used. Historical and projected total precipitation amount (mm) in specific time intervals (5 minutes to 24 hours) for various return periods (2 years to 100 years) are provided below.

Table 28 Historical Precipitation Event Accumulation IDF data (mm) – Fort Simpson A

T (years)	2	5	10	25	50	100
5 min	4.23	6.46	7.94	9.81	11.2	12.58
10 min	6.22	9.8	12.17	15.16	17.39	19.59
15 min	7.62	12.14	15.13	18.9	21.71	24.49
30 min	9.61	14.98	18.54	23.03	26.37	29.68
1 h	11.51	17.29	21.12	25.96	29.55	33.12
2 h	14.37	20.34	24.29	29.29	33	36.68
6 h	21.22	28.34	33.05	39.01	43.43	47.82
12 h	26.89	35.71	41.55	48.92	54.4	59.83
24 h	34.09	47.09	55.7	66.58	74.65	82.66

Table 29 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2020s (2010-2039)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	4.37	3.3%	6.63	2.6%	8.13	2.4%	10.34	5.4%	12.70	13.4%	15.09	20.0%
10 min	6.38	2.6%	10.08	2.9%	12.52	2.9%	16.14	6.5%	19.95	14.7%	23.72	21.1%
15 min	7.92	3.9%	12.76	5.1%	15.79	4.4%	20.36	7.7%	24.88	14.6%	29.01	18.5%
30 min	10.24	6.6%	16.14	7.7%	19.58	5.6%	24.95	8.3%	29.56	12.1%	34.25	15.4%
1 h	12.55	9.0%	19.03	10.1%	22.46	6.3%	28.10	8.2%	32.18	8.9%	36.95	11.6%
2 h	16.09	12.0%	22.83	12.2%	25.91	6.7%	31.47	7.4%	34.33	4.0%	38.63	5.3%
6 h	24.44	15.2%	32.33	14.1%	35.48	7.4%	41.05	5.2%	43.59	0.4%	46.53	-2.7%
12 h	31.19	16.0%	40.90	14.5%	44.70	7.6%	51.27	4.8%	54.17	-0.4%	57.36	-4.1%
24 h	38.78	13.8%	53.12	12.8%	59.27	6.4%	70.31	5.6%	75.50	1.1%	83.11	0.5%

Table 30 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2050s (2040-2069)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	4.62	9.2%	6.87	6.3%	8.85	11.5%	11.53	17.5%	13.80	23.2%	16.01	27.3%
10 min	6.73	8.2%	10.42	6.3%	13.67	12.3%	18.00	18.7%	21.68	24.7%	25.31	29.2%
15 min	8.33	9.3%	13.18	8.6%	17.32	14.5%	22.67	19.9%	27.08	24.7%	31.71	29.5%
30 min	10.71	11.4%	16.67	11.3%	21.59	16.5%	27.67	20.1%	32.50	23.2%	37.73	27.1%
1 h	13.08	13.6%	19.65	13.6%	24.89	17.9%	31.04	19.6%	35.72	20.9%	40.49	22.3%
2 h	16.73	16.4%	23.58	15.9%	28.87	18.9%	34.51	17.8%	38.53	16.8%	42.41	15.6%
6 h	25.32	19.3%	33.58	18.5%	39.53	19.6%	45.01	15.4%	48.42	11.5%	51.23	7.1%
12 h	32.30	20.1%	42.58	19.2%	49.80	19.9%	56.22	14.9%	59.98	10.3%	63.07	5.4%
24 h	40.21	18.0%	54.99	16.8%	66.05	18.6%	77.08	15.8%	84.62	13.4%	91.38	10.5%

Table 31 Projected Precipitation Event Accumulation IDF data (mm) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2080s (2070-2099)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	4.87	15.1%	7.39	14.4%	9.4	18.4%	12.37	26.1%	15.31	36.7%	18.60	47.9%
10 min	7.12	14.5%	11.19	14.2%	14.5	19.1%	19.35	27.6%	24.03	38.2%	29.27	49.4%
15 min	8.81	15.6%	14.15	16.6%	18.39	21.5%	24.46	29.4%	29.80	37.3%	35.90	46.6%
30 min	11.31	17.7%	17.91	19.6%	22.94	23.7%	29.91	29.9%	35.95	36.3%	42.70	43.9%
1 h	13.81	20.0%	21.15	22.3%	26.45	25.2%	33.59	29.4%	39.05	32.1%	44.51	34.4%
2 h	17.65	22.8%	25.51	25.4%	30.69	26.3%	37.37	27.6%	42.09	27.5%	46.51	26.8%
6 h	26.75	26.1%	36.46	28.7%	42.03	27.2%	48.75	25.0%	52.88	21.8%	56.44	18.0%
12 h	34.12	26.9%	46.22	29.4%	52.92	27.4%	60.88	24.4%	65.60	20.6%	69.57	16.3%
24 h	42.48	24.6%	59.58	26.5%	70.23	26.1%	83.49	25.4%	92.32	23.7%	100.29	21.3%

The above results indicate an increase in precipitation accumulation that can be expected for all rainfall events at the Fort Simpson A weather station, determined to be representative of the Wrigley-Fort Simpson climate zone. Under RCP 8.5, the projected percentage increase from the interpolated historical data for precipitation events range from -4.1% to 21.1% for the 2020s (2010-2039), 5.4% to 29.5% for the 2050s (2040-2069), and 14.2% to 49.4% for the 2080s (2070-2099).

Historical and projected intensity rates (mm/hr) in specific time intervals (5 minutes to 24 hours) for various return periods (2 years to 100 years) are provided below.

Table 32 Historical Precipitation Event Intensity IDF data (mm/hr) – Fort Simpson A

T (years)	2	5	10	25	50	100
5 min	50.76	77.57	95.33	117.76	134.4	150.92
10 min	37.29	58.78	73	90.98	104.31	117.55
15 min	30.48	48.54	60.5	75.62	86.83	97.95
30 min	19.23	29.97	37.08	46.07	52.74	59.35
1 h	11.51	17.29	21.12	25.96	29.55	33.12
2 h	7.18	10.17	12.15	14.65	16.5	18.34
6 h	3.54	4.72	5.51	6.5	7.24	7.97
12 h	2.24	2.98	3.46	4.08	4.53	4.99
24 h	1.42	1.96	2.32	2.77	3.11	3.44

Table 33 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2020s (2010-2039)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	52.41	3.3%	79.53	2.5%	97.54	2.3%	124.02	5.3%	152.35	13.4%	181.13	20.0%
10 min	38.26	2.6%	60.46	2.9%	75.11	2.9%	96.83	6.4%	119.70	14.8%	142.29	21.0%
15 min	31.70	4.0%	51.02	5.1%	63.15	4.4%	81.42	7.7%	99.51	14.6%	116.05	18.5%
30 min	20.47	6.4%	32.28	7.7%	39.16	5.6%	49.89	8.3%	59.11	12.1%	68.50	15.4%
1 h	12.55	9.0%	19.03	10.1%	22.46	6.3%	28.10	8.2%	32.18	8.9%	36.95	11.6%
2 h	8.05	12.1%	11.42	12.3%	12.95	6.6%	15.74	7.4%	17.16	4.0%	19.31	5.3%
6 h	4.07	15.0%	5.39	14.2%	5.91	7.3%	6.84	5.2%	7.26	0.3%	7.75	-2.8%
12 h	2.60	16.1%	3.41	14.4%	3.72	7.5%	4.27	4.7%	4.51	-0.4%	4.78	-4.2%
24 h	1.62	14.1%	2.21	12.8%	2.47	6.5%	2.93	5.8%	3.15	1.3%	3.46	0.6%

Table 34 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2050s (2040-2069)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	55.38	9.1%	82.39	6.2%	106.24	11.4%	138.38	17.5%	165.59	23.2%	192.15	27.3%
10 min	40.40	8.3%	62.52	6.4%	82.02	12.4%	108.01	18.7%	130.06	24.7%	151.85	29.2%
15 min	33.31	9.3%	52.71	8.6%	69.28	14.5%	90.69	19.9%	108.33	24.8%	126.83	29.5%
30 min	21.42	11.4%	33.34	11.2%	43.18	16.5%	55.35	20.1%	65.01	23.3%	75.45	27.1%
1 h	13.08	13.6%	19.65	13.6%	24.89	17.9%	31.04	19.6%	35.72	20.9%	40.49	22.3%
2 h	8.36	16.4%	11.79	15.9%	14.44	18.8%	17.25	17.7%	19.27	16.8%	21.20	15.6%
6 h	4.22	19.2%	5.60	18.6%	6.59	19.6%	7.50	15.4%	8.07	11.5%	8.54	7.2%
12 h	2.69	20.1%	3.55	19.1%	4.15	19.9%	4.69	15.0%	5.00	10.4%	5.26	5.4%
24 h	1.68	18.3%	2.29	16.8%	2.75	18.5%	3.21	15.9%	3.53	13.5%	3.81	10.8%

Table 35 Projected Precipitation Event Intensity IDF data (mm/hr) and Percent Change from Historical (%), Fort Simpson A, RCP 8.5, 2080s (2070-2099)

T (years)	2		5		10		25		50		100	
	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change	Total (mm)	% Change
5 min	58.50	15.2%	88.71	14.4%	112.74	18.3%	148.45	26.1%	183.74	36.7%	223.23	47.9%
10 min	42.70	14.5%	67.16	14.3%	86.98	19.2%	116.13	27.6%	144.20	38.2%	175.63	49.4%
15 min	35.22	15.6%	56.59	16.6%	73.55	21.6%	97.83	29.4%	119.21	37.3%	143.60	46.6%
30 min	22.63	17.7%	35.82	19.5%	45.88	23.7%	59.83	29.9%	71.90	36.3%	85.40	43.9%
1 h	13.81	20.0%	21.15	22.3%	26.45	25.2%	33.59	29.4%	39.05	32.1%	44.51	34.4%
2 h	8.83	23.0%	12.75	25.4%	15.35	26.3%	18.68	27.5%	21.04	27.5%	23.25	26.8%
6 h	4.46	26.0%	6.08	28.8%	7.00	27.0%	8.12	24.9%	8.81	21.7%	9.41	18.1%
12 h	2.84	26.8%	3.85	29.2%	4.41	27.5%	5.07	24.3%	5.47	20.8%	5.80	16.2%
24 h	1.77	24.6%	2.48	26.5%	2.93	26.3%	3.48	25.6%	3.85	23.8%	4.18	21.5%

3.3 1,3,5 DAY ACCUMULATION

Table 36: Record Maximum 1/3/5 Day Precipitation Accumulation

Climate Zone (Station Name)	Duration	Precipitation Accumulation (mm)	Event End Date
Norman Wells-Tulita (Norman Wells A)	1-day	50.8	September 6, 1988
	3-day	77.8	June 24, 1981
	5-day	82.0	June 27, 1981
Wrigley-Fort Simpson (Fort Simpson A)	1-day	86.4	July 24, 1935
	3-day	127.9	July 2, 1988
	5-day	132.4	July 2, 1988

1-day (24 hour) accumulation projections are provided in the IDF section above. While projections for multi-day (3 and 5 day) accumulations are available, these projections do not necessarily capture extremes and have higher uncertainty and, therefore, are not provided in this climate profile. Nevertheless, based on the projected increases in precipitation accumulations for shorter duration events (i.e. up to 24-hour duration events), it is highly probable this increasing trend would also extend to longer duration accumulations as well.

3.4 SNOW FALL

Total annual snowfall is presented in Figure 10 for historical periods at Norman Wells A from 1943 to 2019 and at Fort Simpson A from 1895 to 2019. Projections for snowfall are less confident than for other precipitation and temperature-based climate variables and are thus not presented in the climate risk assessment. Historical trends in precipitation falling as snow are generally observed to increase in this area. Significant departures from the mean are intermittently observed. These inconsistencies may be due to sporadic short periods of extreme precipitation resulting from subtropical air currents that flow northeastwards from the Hawaiian Islands towards the Mackenzie Basin (termed the "Pineapple Express") (Woo et al 2007), resulting in a high level of variability in precipitation records for the area.

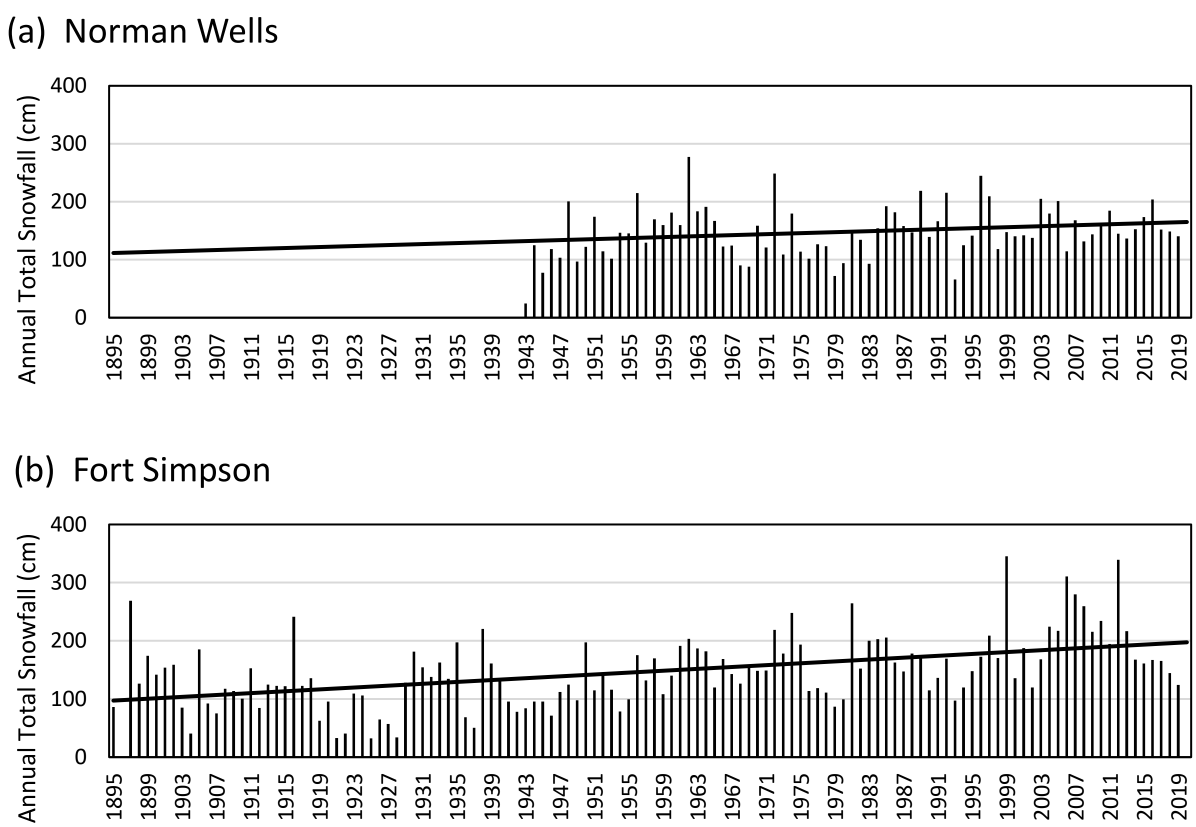


Figure 10: Annual Total Snowfall for (a) Norman Wells A and (b) Fort Simpson A for available data between 1943 and 2019 and 1895 and 2019 respectively.

3.5 DRY SPELLS

Dry spells are a measure of the number of consecutive days where daily precipitation is less than 1 mm. The historic data for longest annual dry spell duration for Norman Wells and Fort Simpson is summarized in Figure 11. It should be noted there may be more than one dry spell of significant length in a given year but Figure 11 only shows the longest dry spell.

The figure shows that between the two locations, slightly diverging trends appear in the maximum annual dry spell length between 1984 to 2019. Norman Wells' dry days appear to be slightly increasing while Fort Simpson is slightly decreasing. This difference could be largely driven by four specific years where Norman Wells' dry periods were much longer than those in Fort Simpson – for the highest of which, there was no available data for Fort Simpson. Nonetheless, maximum dry spell length between the two areas are generally stable over the 35-year span presented below. Projected dry spell durations under the future effects of climate change were unavailable for this assessment, however the trend shown in Figure 11 could be extrapolated to the future to suggest the length of dry spells may continue to present a generally stable trend, possibly increasing very slightly. The projections for dry spell duration are not made with the same level of confidence as other climate variables in this report.

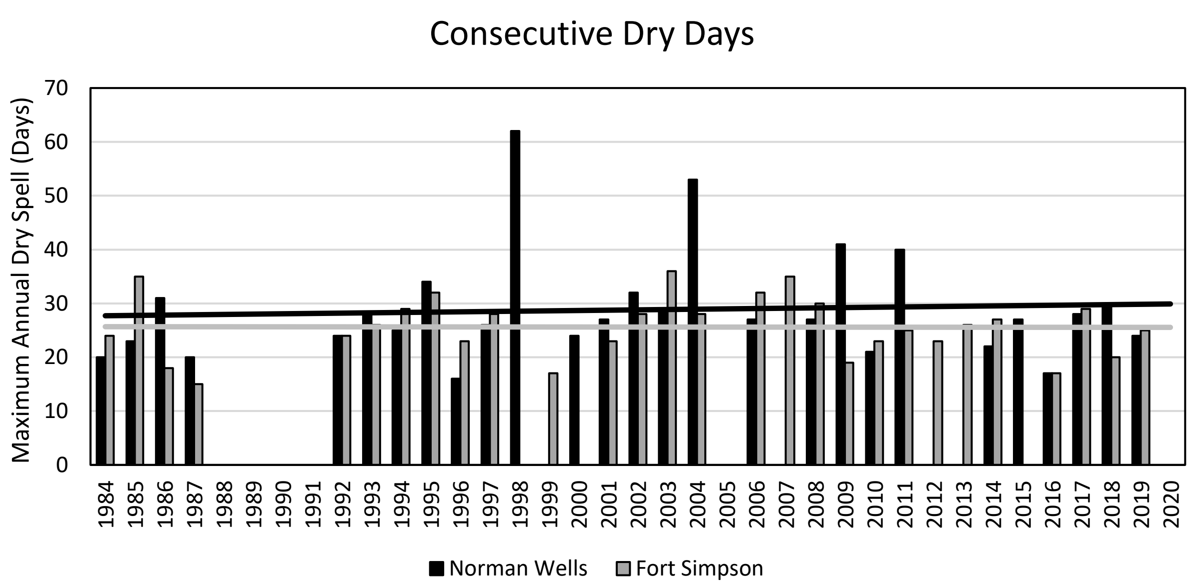


Figure 11: Maximum Annual Dry Spells, Norman Wells A and Form Simpson A, 1984-2019

4.0 FROST DAYS

The number of frost days per year for the historical baseline period as well as future projections periods is summarized in the table below for Norman Wells and Fort Simpson. Frost days are defined as the number of days per year where the minimum daily temperature is less than 0°C. The data presented here demonstrates a projected decreasing trend in the number of frost days per year, which aligns with temperature trends identified in Section 2.

Table 37: Average Frost Days, Norman Wells

Frost Days		
Period	**Norman Wells-Tulita (Norman Wells)**	**Wrigley-Fort Simpson (Fort Simpson)**
Baseline (Historical 1981-2010)	240.0	224.7
2020s (2011-2040)	228.4	212.5
2050s (2041-2070)	214.5	197.2
2080s (2071-2100)	201.1	182.8

5.0 FREEZE-THAWS

Freeze-thaw cycles are days (24-hr periods) when the air temperature fluctuates between freezing and non-freezing temperatures. A freeze-thaw cycles is therefore a day with the maximum temperature greater than 0°C and the minimum temperature equal to or less than -1°C. A minimum temperature threshold of -1°C (instead of 0°C) is used to increase the likelihood that water present at the surface actually freezes. The historic and projected annual number of freeze-thaw cycles for each climate zone is presented below.

Table 38 Annual Freeze-Thaw Cycles (Day with Maximum Temperature > 0°C & Minimum Temperature ≤ -1°C): Historical (1981-2010) and Projected under RCP 8.5

Climate Zone (Station Name)	Average Annual Freeze-Thaw Cycles			
	1981-2010	2020s	2050s	2080s
Norman Wells-Tulita (Norman Wells A)	43.8	36.4	32.3	30.3
Wrigley-Fort Simpson (Fort Simpson A)	57.1	49.7	44.0	39.1

For both climate zones, the annual number of freeze-thaw cycles is projected to decrease under future climate conditions. The number of freeze-thaw cycles per month will likely continue to be greatest during the fall and spring “transition” or “shoulder” seasons (e.g., November and March) through mid-century before notably declining by the end of the century. Despite the projected overall decrease in the annual number of freeze-thaw cycles, the number of freeze-thaw cycles during the winter months is projected to increase slightly. With warmer winter conditions projected under climate change, a shift is projected in the typical times of year that have temperatures fluctuating around the freezing mark – i.e., temperature fluctuations around 0°C are projected to become more common during the winter months. Freeze-thaw cycles during winter months, such as January and February, have the potential to be particularly damaging to infrastructure.

6.0 WIND

Wind data is available at the Norman Wells A and Fort Simpson A weather stations sporadically from 1960 through to 2020, with increasing data frequency in recent years. Climate Normal data from 1981-2010 and daily maximum gust data are available at both stations. Climate Normals data is presented in Table 39 and Table 40 below and windroses based on daily maximum and hourly mean gust data are provided in Figures 12 through 15.

Table 39 1981 to 2010 Canadian Climate Normals, Wind, Norman Wells A Station (source: Environment and Climate Change Canada, Climate Normals)

Month	Speed (km/h)	Most Frequent Direction	Maximum Hourly Speed (km/h)	Date (yyyy/dd)	Direction of Maximum Hourly Speed	Maximum Gust Speed (km/h)	Date (yyyy/dd)	Direction of Maximum Gust	Days with Winds >= 52 km/h	Days with Winds >= 63 km/h
Jan	8.3	SE	80	1962/22	W	113	1962/22	W	0.6	0.1
Feb	8.9	SE	74	1986/19	NW	106	1986/19	NW	0.5	0.2
Mar	10.3	W	66	1971/07	SE	114	1965/10	NW	0.3	0.1
Apr	11	SE	68	1965/12	W	97	1965/12	W	0.2	0.1
May	11.9	SE	59	1980/03	NW	85	1979/02	SE	0.1	0
Jun	11.7	SE	65	1979/11	NW	83	1979/11	NW	0.2	0
Jul	11	SE	61	1959/25	NW	100	1967/24	W	0.2	0
Aug	10.5	SE	80	1962/31	W	117	1962/31	W	0.2	0.1
Sep	10.7	SE	70	1988/06	NW	94	1988/07	NW	0.1	0.1
Oct	10.4	NW	63	1978/31	NW	93	1990/27	E	0.2	0
Nov	8.4	NW	67	1977/21	NW	101	1962/03	E	0.3	0.1
Dec	8.3	SE	72	1963/12	E	105	1963/12	E	0.5	0.1
Year	10.1	SE	80	1962/22	W	117	1962/31	W	3.3	0.9

Table 40 1981 to 2010 Canadian Climate Normals, Wind, Fort Simpson A Station (source: Environment and Climate Change Canada, Climate Normals)

Month	Speed (km/h)	Most Frequent Direction	Maximum Hourly Speed (km/h)	Date (yyyy/dd)	Direction of Maximum Hourly Speed	Maximum Gust Speed (km/h)	Date (yyyy/dd)	Direction of Maximum Gust	Days with Winds >= 52 km/h	Days with Winds >= 63 km/h
Jan	7.2	NW	46	2003/07	NW	80	1985/03	SW	0	0
Feb	8.4	NW	59	1988/21	NW	89	1988/21	NW	0.1	0
Mar	9.8	NW	50	1995/22	N	79	1967/13	N	0	0
Apr	10.1	SE	56	1986/20	SW	83	1984/16	SW	0.2	0
May	10.1	SE	59	1983/21	N	91	1983/21	N	0.2	0.1
Jun	9.1	SE	46	2002/22	NW	72	1964/26	N	0.2	0
Jul	8.2	NW	48	1964/10	S	89	1970/19	S	0.1	0
Aug	8.5	NW	66	1974/04	SW	146	2004/17	N	0.1	0
Sep	8.5	SE	65	1985/12	NW	87	1964/04	N	0.1	0
Oct	8.7	NW	50	1971/25	N	77	1971/25	N	0	0
Nov	7.9	NW	46	1985/20	N	78	1985/20	N	0	0
Dec	6.8	NW	48	1999/24	NW	80	1999/23	SW	0	0
Year	8.6	SE	66	1974/04	SW	146	2004/17	N	1.2	0.2

Wind data from the three Norman Wells Airport stations were merged to generate windroses2 for this climate profile. In addition, the Fort Simpson Airport station was used to produce daily and hourly windroses. Figure 12 displays hourly mean wind speed and direction observed from 1953-2019 at the Norman Wells Airport while Figure 13 displays the speed and direction of the maximum hourly wind observed each day from 1958 to 2019. The following windroses contain some missing information as direction information was not recorded when wind gusts were less than 31 km/h. These points were excluded from the plots.

---

[2] Windroses show the distribution of wind direction (direction from which the wind is blowing) observed at a particular location over a time period. The length of each line represents the frequency of the wind from that direction and, therefore, windroses provide information on the prevailing wind direction(s) at a given location. Windroses also provide information on the wind speeds observed from each direction.

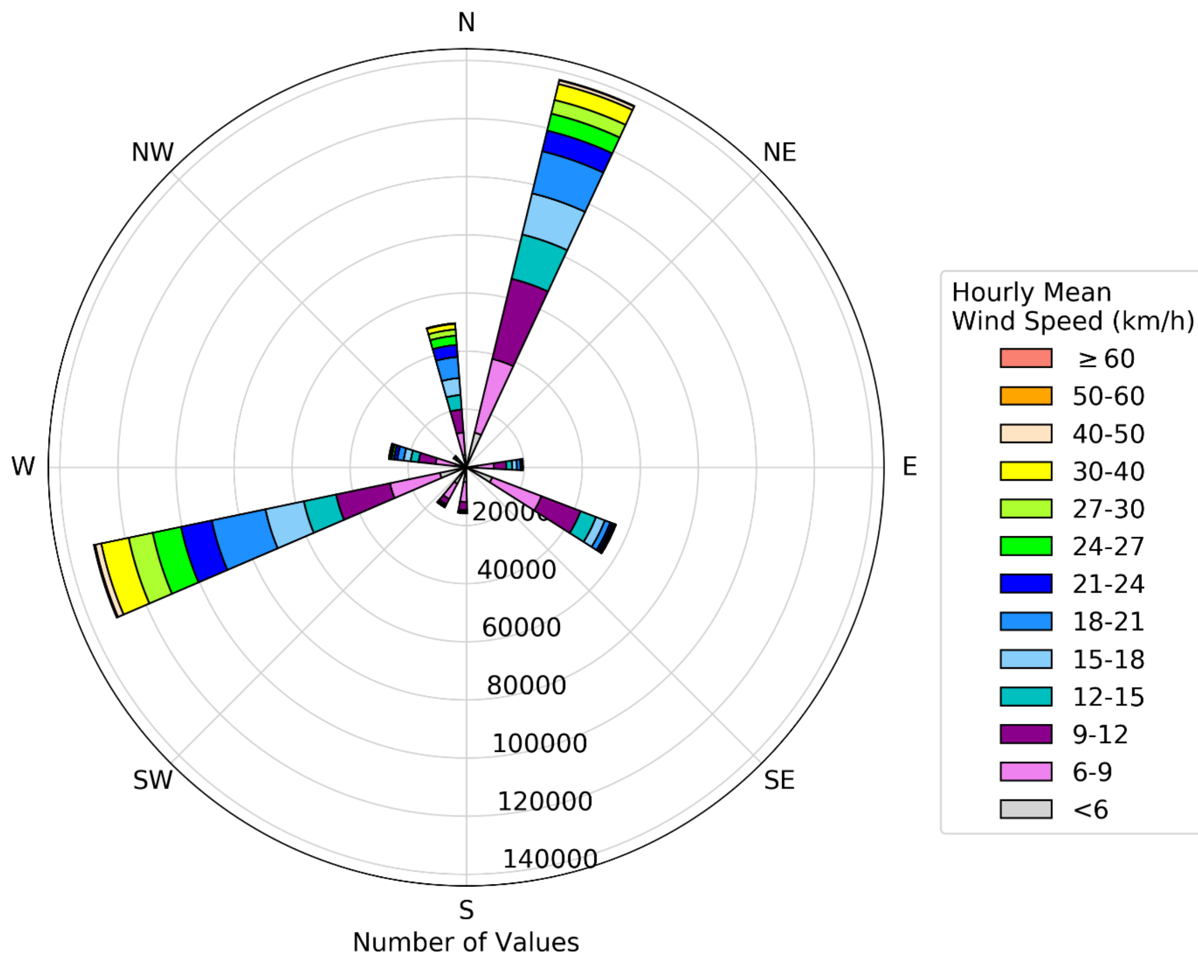


Figure 12 Hourly mean wind speed and direction from 1953-2019 observed at the Norman Wells A.

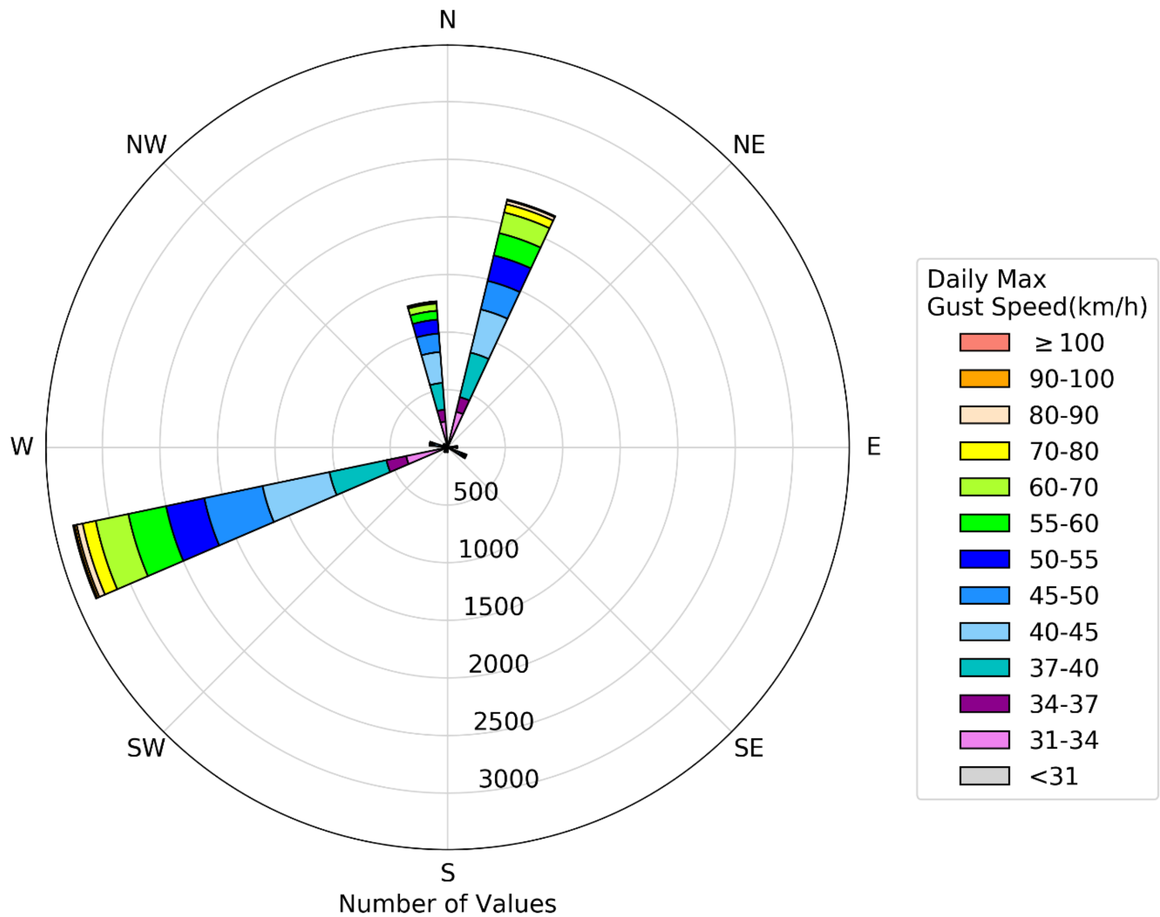


Figure 13 **Daily maximum wind gust speed and direction from 1958-2019 observed at the Norman Wells A.**

Figure 14 displays hourly mean wind speed and direction observed from 1953-2019 at the Fort Simpson A station while Figure 15 displays daily maximum wind gust speed and direction observed from 1960-2019.

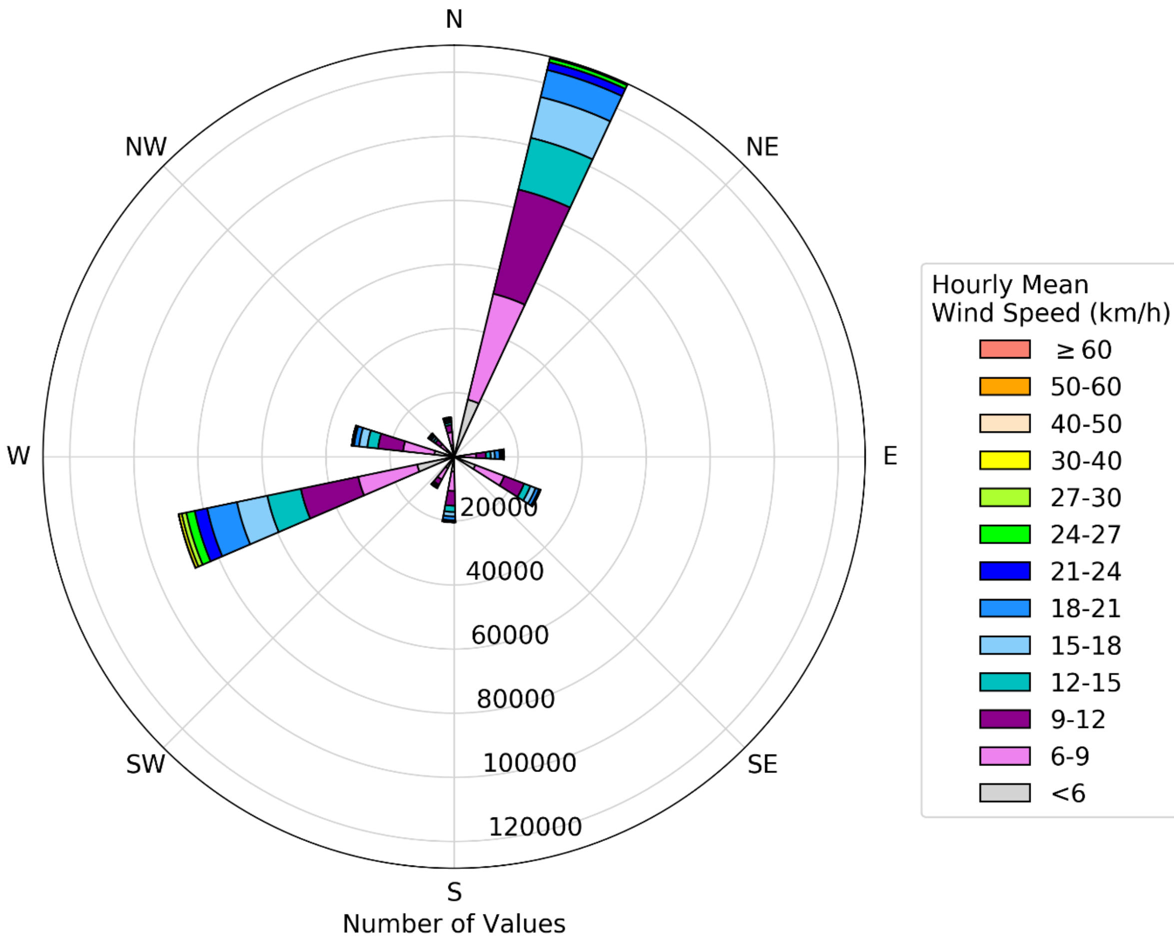


Figure 14 Hourly mean wind speed and direction from 1953-2019 observed at the Fort Simpson A.

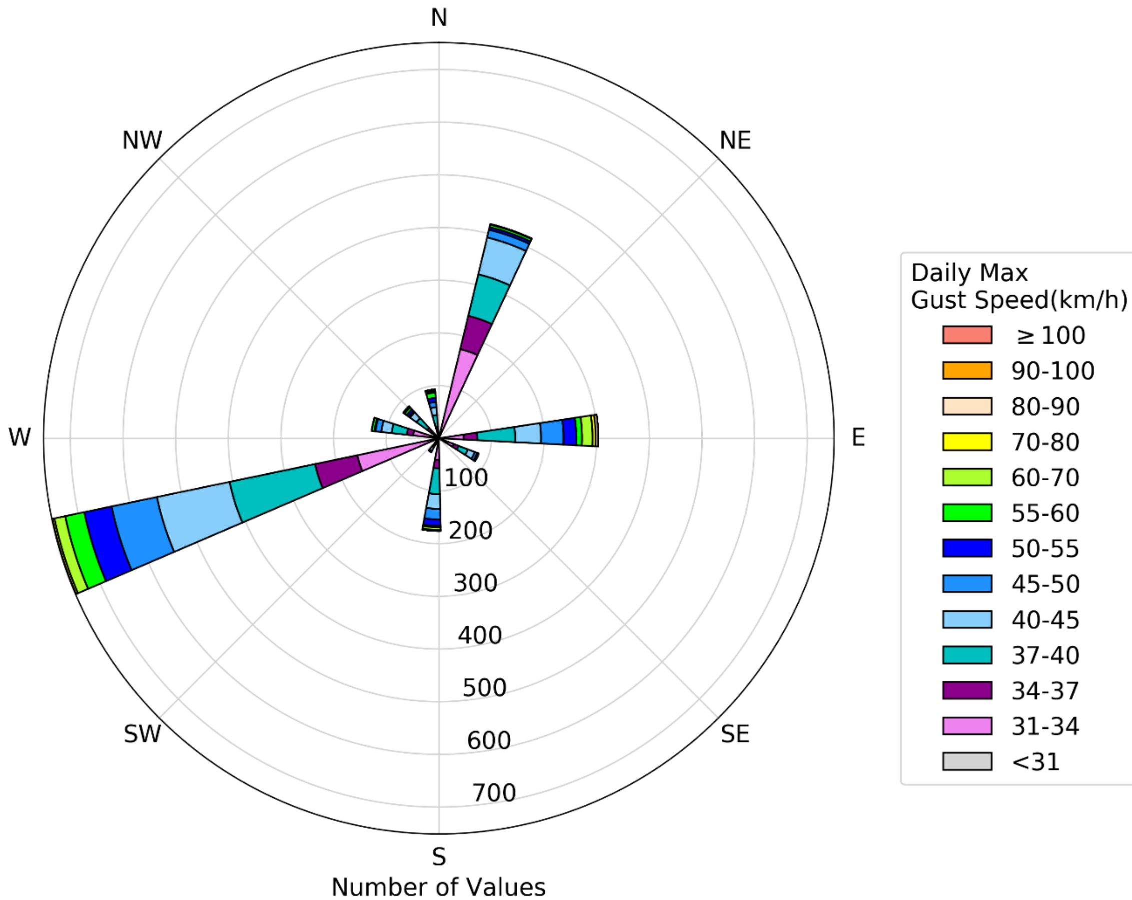


Figure 15 Daily maximum wind gust speed and direction from 1960-2019 observed at the Fort Simpson A.

7.0 REFERENCES

Cannon, A. J. 2015. Selecting GCM Scenarios that Span the Range of Changes in a Multimodel Ensemble: Application to CMIP5 Climate Extreme Indices. *Journal of Climate*, 28: 1260-1267. doi:10.1175/JCLI-D-14-00636.1

Cannon, A.J., S.R. Sobie, and T.Q. Murdock. 2015. Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes? *Journal of Climate*, 28: 6938-6959. https://doi.org/10.1175/JCLI-D-14-00754.1

Donat, M.G., L.V. Alexander, H. Yang, I. Durre, R. Vose, J. Caesar. 2013b. Global Land-Based Datasets for Monitoring Climatic Extremes, Bull. Amer. Meteor. Soc., 94, 997–1006. https://doi.org/10.1175/BAMS-D-12-00109.1. Download: Donat, et al. (2013b) GHCNDEX (PDF).

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Schardong, A., A. Gaur, S.P. Simonovic, and D. Sandink. 2018. *Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate: Technical Manual v.3*; Water Resources Research Report No. 103. Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering: London, Ontario, Canada; p, 67. ISBN 978-0-7714-3107-4.

Smith, M.R. and S.S. Myers. 2018. Impact of anthropogenic CO_2 emissions on global human nutrition. *Natural Climate Change*, 8: 834-839. https://doi.org/10.1038/s41558-018-0253-3

Taylor, K.E., R.J. Stouffer, and G.A. Meehl. 2012. An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society*, 93: 485-498. https://doi.org/10.1175/BAMS-D-11-00094.1

Woo, M-K, P. Modeste, L. Martz, J. Blondin, B. Kochtubajda, D. Tutcho, J. Gyakum, A. Takazo, C. Spence, J. Tutcho, M. Modeste, B. Kenny, and W. Modeste. 2007, Science Meets Traditional Knowledge: Water and Climate in the Sahtu (Great Bear Lake) Region, Northwest Territories, Canada. Arctic 60(1): 37-46.