GOVERNMENT OF NORTHWEST TERRITORIES

ASSESSMENT OF CLIMATE CHANGE IMPACTS ON INFRASTRUCTURE IN ALL NWT COMMUNITIES

WSP REF.: 191-14133-00

DATE: 28 JULY 2021

wsp PIEVC CVIIP Government of Northwest Territories

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FINAL REPORT

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LIST OF ACRONYMS

CAN-EWLAT	Canadian Extreme Water Level Adaptation Tool
CMIP	Coupled Model Intercomparison Project
ECCC	Environment and Climate Change Canada
GNWT	Government of the Northwest Territories
GHG	Greenhouse Gas
IDF	Intensity-Duration-Frequency
IPCC	Intergovernmental Panel on Climate Change
MACA	Department of Municipal and Community Affairs
NBC	National Building Code
NRCan	Natural Resources Canada
NWT	Northwest Territories
PIEVC	Public Infrastructure Engineering Vulnerability Committee

GLOSSARY OF CLIMATE TERMS

Adaptation — The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Adaptive capacity — The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Cascading Effects — Cumulative impacts between the primary impact of a climate hazard and its secondary consequences.

Coastal erosion — Long-term removal of sediment and rocks along the coastline due to the action of waves, currents, and tides.

Cold snap — A rapid fall in temperature requiring substantially increased protection to several essential services. The threshold of temperature considered to signal a cold snap is dependent on the geographical region and time of year. In this report, cold snaps are only considered during the winter season.

Cooling degree-day — Measure of the quantity of cooling required in a year. In Canada, 18°C is considered the temperature above which cooling is required to maintain comfort inside buildings. Daily cooling degree-days are the number of °C a given day's mean temperature is above 18°C. For example, if the mean daily temperature is 22°C, the cooling degree-day value is 4°C. Annual cooling degree-days are the sum of daily cooling degree-days.

Climate — Patterns of variability in atmospheric conditions in a given region over a long period of time, often decades or longer. This is in contrast to weather which describes current atmospheric conditions (i.e. it is currently raining or windy).

Climate change	Refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.
Exposure	Presence of people, livelihoods, assets, services, resources or infrastructure in place in a specific region that could be adversely affected by climate change.
Extremely hot day	A day during which the temperature rises to at least 34°C.
Freeze-thaw cycle	Count of days where maximum temperature is above 0°C and the minimum temperature is below 0°C. Under these conditions, it is likely that some water at the surface was both liquid and solid at some point during the day.
Freezing rain	Rain falling at negative temperatures causing freezing on contact with surfaces.
Frost day	A day during which the lowest temperature of the day is less than 0°C.
Frost-free season	Interval between the first frost of the fall and the final frost of the spring.
Global climate model	Mathematical representation of the major climate system components and their interactions.
Hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts
Heating degree-day	Measure of the quantity of heating required in a year. In Canada, 18°C is considered the temperature below which heating is required to maintain comfort inside buildings. Daily heating degree-days are the number of °C a given day's mean temperature is below 18°C. For example, if the mean daily temperature is 10°C, the heating degree-day value is 8°C. Annual heating degree-days are the sum of daily heating degree-days.
Heat wave	Extended period of extreme heat. A heat wave is usually defined as a period of three or more consecutive days with maximum temperatures above 30°C.
Heavy precipitation day	A day when the total precipitation (rainfall, hail, or snow) is above a designated mark (10mm or 20mm) in liquid form.
Impact	The effect of extreme weather and climate events and of climate change on natural and human systems. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts

Intensity-duration-frequency (IDF) curve	IDF curve is a representation of the probability that a given rainfall intensity or quantity occurs over a sub-daily time period.
Interacting Risks	Risk resulting from multiple climate impacts on a single system.
Lowest minimum temperature	The lowest recorded temperature of the year.
Maximum 1-day precipitation	The maximum amount of rain or snow that can be accumulated in a 24h-period once a year. This is an indicator of extreme precipitation.
Maximum 3-day precipitation	The maximum amount of rain or snow that can be accumulated in a 3-day period once a year. This is an indicator of extreme precipitation.
Maximum 5-day precipitation	The maximum amount of rain or snow that can be accumulated in a 5-day period once a year. This is an indicator of extreme precipitation.
Mean annual temperature	The average temperature over the course of one year.
Mean maximum July temperature	The average temperature reached during the warmest part of the day in July.
Mean minimum January temperature	The average temperature reached during the coldest part of the day in January.
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Resilience	The ability of a system to absorb disturbances while maintaining the same basic structure and ways of functioning.
Return period	Statistical measurement representing the average time between the occurrence of two events. For example, a 100-year return period flood zone is the area that is likely to be flooded every 100 year in average. The reciprocal of return period is the annual frequency of occurrence. A 100-year return flood has 1/100 chance (1% chance) of occurring each year.
Risk	A measure of the expected outcome of an uncertain event, which is estimated by combining an event's likelihood and expected consequences or severity.
Risk rating	The assessment of the level of risk through a pre-defined scale.
Scenario	A plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of climate change.
Sensitivity	The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).
Storm surge	Coastal flood due to rising water associated with low pressure weather systems.
Very cold day	A day during which the temperature drops to -30°C or below.
Vulnerability	The degree to which a service or an asset can cope with a given climate change impact. It is a function of its exposure, its sensitivity and its adaptive capacity. When infrastructure has insufficient capacity to withstand the projected or anticipated loads that may be placed on it.
Wind gust	A brief increase in the speed of the wind, usually less than 20 seconds.
Wind regime	Characteristics of wind in a specific region, such as mean wind speed, wind direction and maximum gust speed.

EXECUTIVE SUMMARY

CONTEXT AND OBJECTIVES

Communities in Canada's North in general, and the Northwest Territories (NWT) more specifically, are facing unique challenges regarding climate change adaptation. Not only are they experiencing climate change impacts at an accelerated rate compared to what is observed globally, but they are also exposed to a vast quantity of climate-induced hazards affecting weather (e.g. droughts, high winds), ground stability (e.g. permafrost degradation, coastal erosion) or coastal and riverine environments (e.g. sea level rise or fluvial flooding) due to its geography. Consequently, the climate change impacts present significant environment, social and economic risks to NWT communities. To address the situation, the Government of the Northwest Territories (GNWT) released its *2030 NWT Climate Change Strategic Framework* (GNWT, 2018), which includes the following goals:

- Improve knowledge of the climate change impacts occurring in the NWT; and
- Build resilience and adapt to a changing climate.

The objective of this project is to conduct a high-level climate change vulnerability assessment of all GNWT- and community-owned infrastructure located within or associated with NWT communities using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol.

The specific objectives of the assessment are to:

- Review the available documentation regarding the infrastructure, historical climate and projected climate trends across NWT;
- Identify changes in climate that can affect the various types of infrastructure;
- Identify infrastructure that is vulnerable to extreme weather events or to significant changes in climatic conditions;
- Assess risk associated with potential climate change/infrastructure interactions;
- Develop adaptation and mitigation measures for existing infrastructure, including maintenance and inspection procedures as well as construction and siting practices;
- Provide recommendations for future work.

APPROACH

The PIEVC Protocol is a five-step method developed by Engineers Canada and adapted to evaluate the climate change vulnerability of a wide range of infrastructure (e.g. buildings, municipal infrastructure, airports, etc.), although it is aimed towards the assessment of the individual components of a single infrastructure.

Climate risk on the GNWT- and community-owned assets located within or associated with the 33 NWT communities were assessed at the regional scale, given that the five administrative regions of the NWT (North Slave, South Slave, Dehcho, Sahtu and Beaufort Delta) are more homogeneous in terms of climate and geographical context. Excluded in this assessment were airports and road infrastructure connecting communities.

CLIMATE HAZARDS

Interactions between climate and the infrastructure were assessed for 27 climate parameters to capture hazards associated with temperature increase (e.g. heat waves), precipitation increase (e.g. snow load), shifts in wind regime (e.g. stronger wind gusts), permafrost thaw, wildfire activity or coastal hazards (e.g. storm surges) and riverine flooding. Out of all the hazards, five have been identified by WSP and confirmed by MACA to be of primary concern for GNWT infrastructure assets:

1. Permafrost degradation;
2. Flood;
3. Wildfire;
4. Coastal erosion and/or submersion;
5. Snow load.

RISK PROFILE

Risk levels were calculated as the product of the probability of occurrence of an interaction between an infrastructure element and climate parameter (P) with the potential severity of consequences of such an interaction (S). Both P and S were evaluated on a scale of 1 to 7. Risk levels were then categorized as described in the following table:

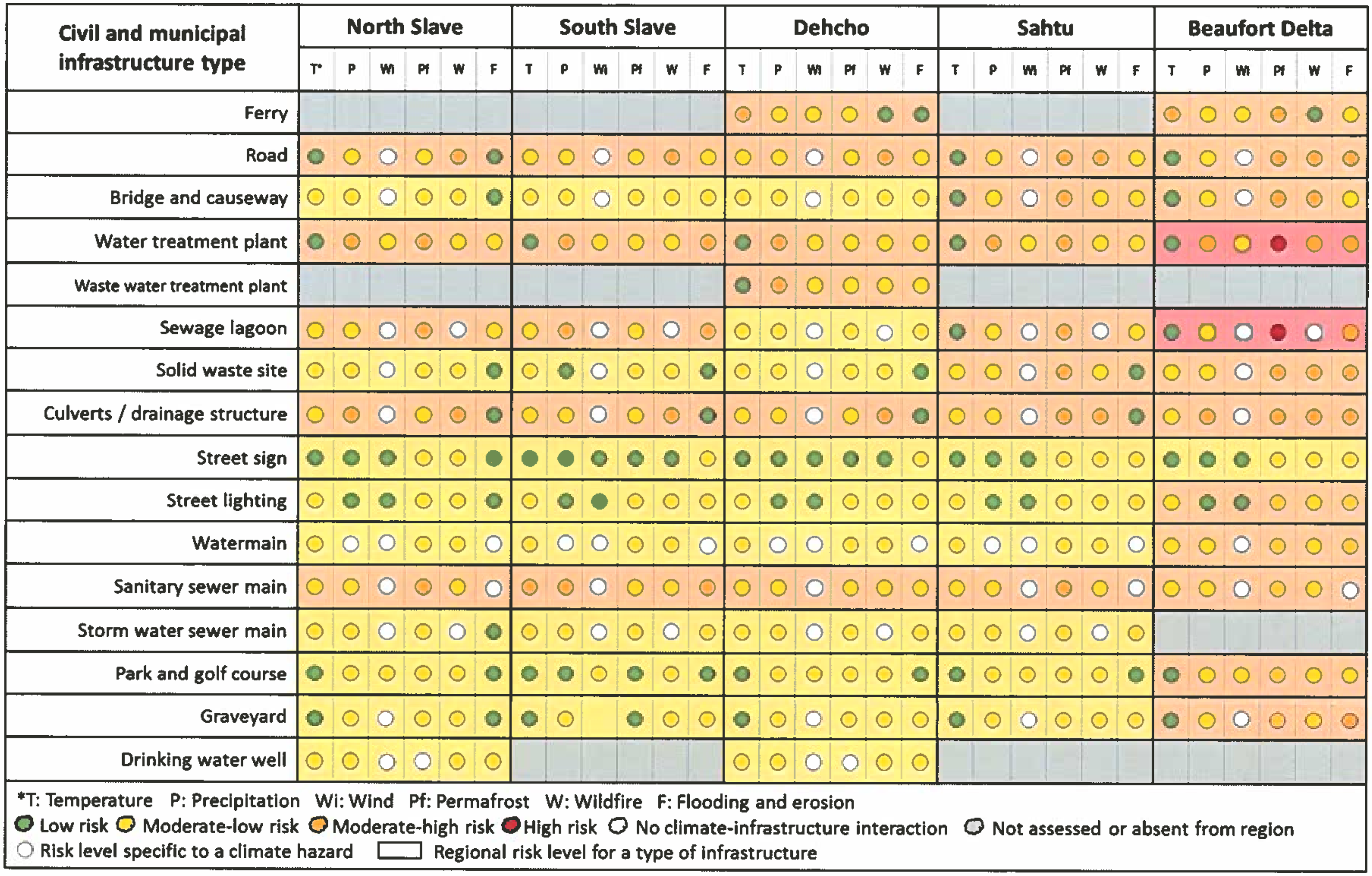
Risk (R) range	Threshold	Response
< 12	Low risk	No action necessary
12 – 27	Moderate-low risk	Monitor climate and infrastructure parameters Action may be required
28 – 41	Moderate-high risk	Monitor climate and infrastructure parameters Action may be required Targeted analysis (Step 4) may be required to reassess risk
> 41	High risk	Targeted analysis (Step 4) may be required to reassess risk Immediate action required
7	Special case	Investigation required into reasoning or impact fora risk with very low probability and very high severity, and also for very high probability and very low severity. Documentation of discussion and acceptance of risk by Owner is required by the Protocol.

Of the 1,902 interactions between climate and infrastructure that were assessed at the regional level and confirmed by group consensus in the workshop, there were:

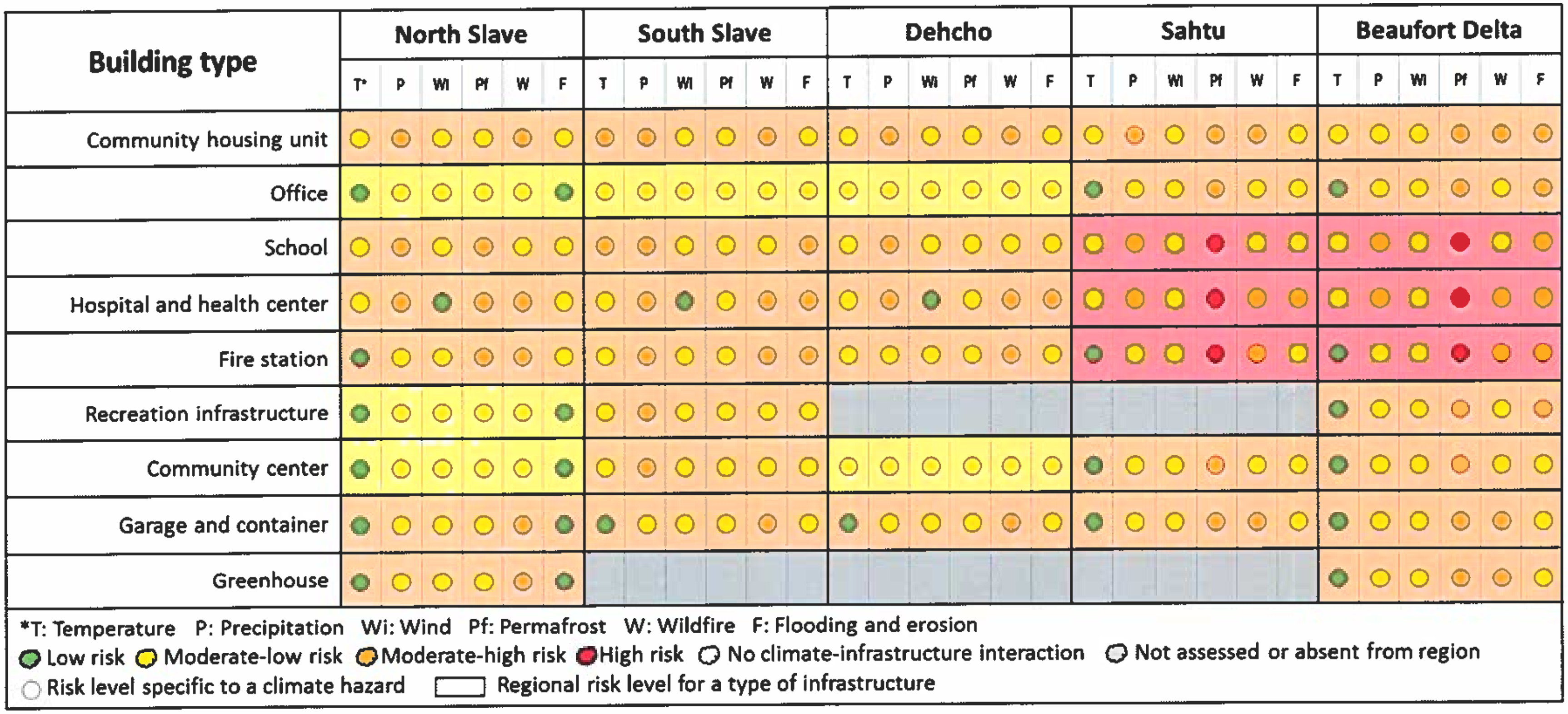
- 12 high risk interactions (6 on buildings, 4 on energy infrastructure, and 2 on civil and municipal infrastructure, R > 41);
- 179 moderate-high risk interactions (R = 28 – 41);
- 989 moderate-low risk interactions (R = 12 – 27); and
- 722 low risk interactions (R < 12);

The summarized risk profile for the infrastructure and municipal, buildings and energy sectors are presented in the following tables. Details of the determination of each risk interaction is presented in Section 4.2 of the report. The highest risk levels at the territorial scale for civil and municipal infrastructure categories, included roads, water and waste water treatment plants, sewage lagoons, culverts and drainage structure, as well as sanitary sewer mains. Water treatment plant and sewage lagoons were considered at a high risk level for Beaufort Delta region due to permafrost activity in the Mackenzie Delta. Buildings are most sensitive to snow load, permafrost, flooding and wildfire, when surrounded by forest. Permafrost thaw and wildfires represent the most significant risks to the energy infrastructure.

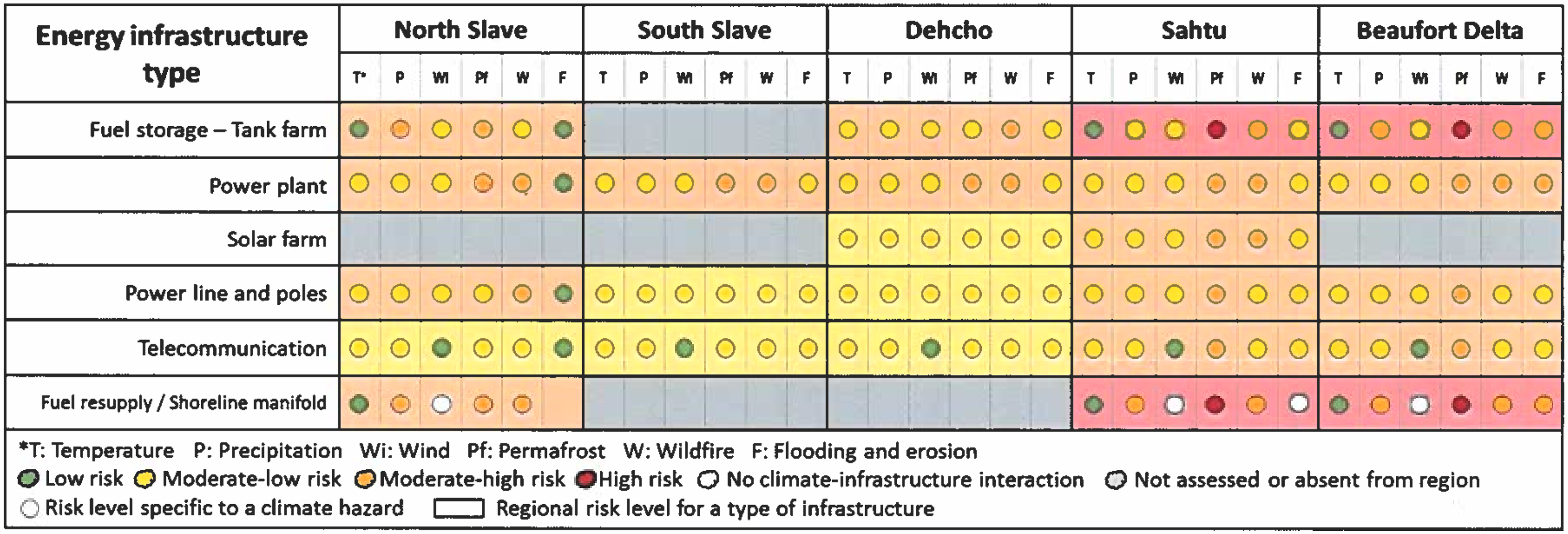
Risk profile for the civil and municipal infrastructure type.



Risk profile for the buildings.



Risk profile for energy infrastructure.



RECOMMENDATIONS

WSP proposes general adaptation measures for the high and moderate-high risks that were identified and their impacts on every type of infrastructure as selected for each infrastructure category. The most appropriate measures are also selected for each of the NWT's 33 communities. The recommendations for the different climate hazards mostly fall within one category of this subset of general recommendations:

- Address identified data gaps as new information becomes available;
- Adopt policy requiring design practitioners to investigate pending changes to design standards and codes related to infrastructure design in a changing climate
- Adopt policy where all infrastructure and retrofit projects have a detailed climate risk assessment completed at the design phase and owner signs off on accepted level of risk;
- Proceed to update this climate change risk assessment in five years;
- Prioritize infrastructure sensitive to cascading climate hazards (e.g. wildfire accelerating permafrost degradation);
- Reassessment of permafrost, flood and wildfire hazards in some area would be required as more data is available;
- Implement maintenance programs to improve the life of infrastructure (e.g. snow maintenance program to insulate permafrost around buildings in spring);
- Increase monitoring of permafrost and hydrological conditions near critical infrastructure;
- Seize opportunities regarding climate change impact on infrastructure (e.g. increasing winter temperature will decrease energy expenses due to buildings heating load, extended operations for coastal operations due to extended ice-free season);
- Increase emergency preparedness in high-risk areas;
- Adapt zoning and land-use to limit development in high-risk areas.

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1 INTRODUCTION

1.1 CONTEXT

Communities in Canada's North in general, and the Northwest Territories (NWT) more specifically, are facing unique challenges regarding climate change adaptation. Not only are they experiencing climate change impacts at an accelerated rate compared to what is observed globally, but they are also exposed to a vast quantity of climate-induced hazards affecting weather (e.g. droughts, high winds), ground stability (e.g. permafrost degradation, coastal erosion) or coastal and riverine environments (e.g. sea level rise or fluvial flooding) due to its geography. Consequently, the climate change impacts present significant environment, social and economic risks to NWT communities. For this reason, the Government of the Northwest Territories (GNWT) released its *2030 NWT Climate Change Strategic Framework* (GNWT, 2018), which includes the following goals:

- Improve knowledge of the climate change impacts occurring in the NWT; and
- Build resilience and adapt to a changing climate.

This Framework has guided the development of the GNWT's *2030 NWT Climate Change Strategic Framework 2019-2023 Action Plan*, which aims at reflecting "The GNWT's commitment and investment to addressing climate change" (GNWT, 2019) by "strengthening [NWT's] understanding of the effects of climate change, while implementing solutions that increase [its] resiliency and ability to adapt to climate change now and for future generations" (GNWT, 2018). Both the Framework and the Action Plan align with and support the implementation of the *Pan-Canadian Framework on Clean Growth and Climate Change* and contribute to the international commitment that the Government of Canada took by ratifying the Paris Agreement that aims to strengthen the ability of countries to deal with the impacts of climate change.

In this context, GNWT requires support in the form of recommendations for the implementation of adaptation and mitigation measures to ensure that municipal infrastructure located in the NWT's 33 communities reduce their exposure to climatic risks and effectively adapt to climate change impacts.

1.2 OBJECTIVES

The objective of this project is to apply the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol (hereafter named the Protocol) to conduct a high-level climate change vulnerability assessment of all GNWT- and community-owned infrastructure located within or associated with NWT communities with the exception of airports and roads between communities. The Protocol is a five-step method developed by Engineers Canada and adapted to evaluate the climate change vulnerability of a wide range of infrastructure (e.g. buildings, municipal infrastructure, etc.).

The specific objectives of the assessment are to:

- Review the available documentation regarding the infrastructure, historical climate and projected climate trends across the NWT;
- Identify changes in climate that can affect the different infrastructure;
- Identify the infrastructure that are vulnerable to extreme weather events or to significant changes in climatic conditions;
- Assess risk associated with potential climate change/infrastructure interactions;

- Develop adaptation and mitigation measures for existing infrastructure, including maintenance and inspection procedures as well as construction and siting practices;
- Give recommendations for future work.

1.3 APPROACH

GNWT requested the approach generally follow the PIEVC Protocol as it is a nationally recognized tool for assessing infrastructure risk due to climate change. Engineers Canada created the Protocol with the objective of providing clear guidance to engineers and geoscientists to support the design, construction, maintenance and regulation of climate change resilient public infrastructure and understand where current policies, codes and standards may require updating. The Protocol aligns with the ISO 31000 Risk Management Standard, to allow consistent and accurate assessments of infrastructure vulnerability to be performed (Engineers Canada, 2019).

The ISO31000 standard was created to help organizations to manage risks, make decisions, set and achieve objectives, and improve performance. While the standard is not specific to climate change, it can be tailored to any type of risk (e.g. natural, industrial, geopolitical) at different scales. According to ISO 31000, risk management is achieved as an iterative process between these different phases:

1. Context definition
2. Risk identification
3. Risk analysis
4. Risk evaluation
5. Risk treatment
6. Recording and reporting

Additionally, the Protocol allows for flexibility to adapt to the scope of the assessment and provides a process for documenting decisions such that the basis of the risk assessment is well understood by those reviewing the results. Where deviations from the Protocol were required for a high-level risk assessment, our approach remained consistent with the principles of the ISO 31000 standard. The process flowchart for the Protocol is presented in Figure 1 (Engineers Canada, 2016). Steps 1-3 involve scoping the assessment, gathering and assessing quality of data, and conducting a risk assessment. If it is determined during those three steps that critical information is lacking, or there is significant uncertainty in an area of the assessment, then the assessment proceeds to Step 4. Step 4 involves a more in-depth engineering analysis of the infrastructure. If there is no significant uncertainty, then the assessment can proceed directly to Step 5, conclusions and recommendations.

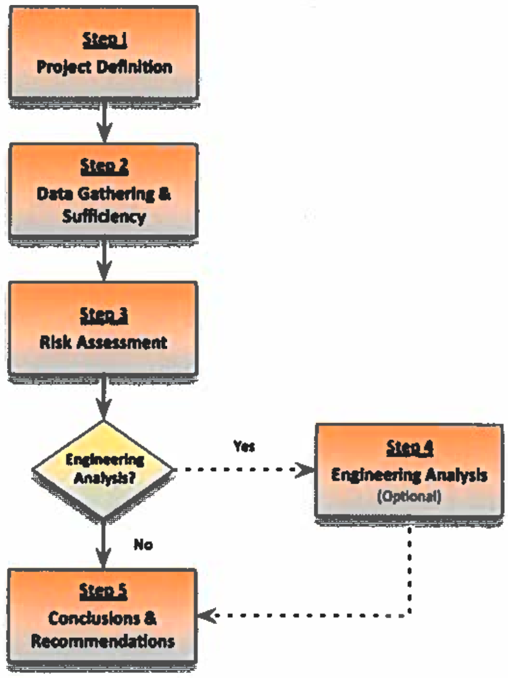

Figure 1 PIEVC Protocol process

Source: https://pievc.ca/documents

The Protocol was initially developed as a framework to conduct detailed climate change vulnerability assessments on specific infrastructure assets or community wide systems. The present project differs from a classic PIEVC assessment by the fact that the it encompasses a variety of infrastructure assets (civil and municipal infrastructure, buildings and energy infrastructure) spread across diverse geographic contexts. WSP adapted its approach to the Protocol to the high-level nature of the project. These adjustments are presented in Table 1.

Table 1 WSP's adapted approach to the PIEVC Protocol

Step	Protocol recommendations and key activities[1]	Adjustments by WSP	Rationale
1	– Identification and general description of the infrastructure – Identification of relevant climate parameters – Definition of boundary conditions for the assessment – **Site visit**	No site visit GNWT staff who are very familiar with all the infrastructure collaborated with WSP to provide sufficient information.	The objective of the project is to provide a high-level assessment on vulnerabilities by infrastructure asset type. Conducting site visits in every community would provide a level of detail that exceeds this objective.

Step	Protocol recommendations and key activities[1]	Adjustments by WSP	Rationale
2	– Assess data sufficiency including availability, quality or level of uncertainty; – In-depth definition of necessary data as identified in Step 1 – **Breakdown of infrastructure components** – Description of relevant climate information (baseline, expected changes, probability of changes occurring) – Time Horizon – **Identification of climate/infrastructure component interactions** – **Identification of climate threshold values that will trigger the climate/infrastructure component interaction** –	Breakdown is kept at the asset-type level. Identification of climate/infrastructure interactions.	For a given asset, there can be a variety of designs and that level of detail would go beyond the scope of the present study. To ensure consistency, thresholds were defined using the same method for all regions, but the threshold value varies according to the specific climate of each region.
3	– Risk assessment: - Confirmation of steps 1 and 2 - Analysis of likelihood of climate/infrastructure interaction - Assessment of interaction severity - Calculation of risk scores and establishment of risk profile – Validation of risk assessment through a workshop with client	No changes	N/A
4[2]	– **Detailed engineering analysis for high risk and high uncertainty of climate/infrastructure component interactions**	Gap analysis and prioritization of future investigation (e.g. site investigation, specific climate impacts, etc.) have been included as recommendations in Step 5.	Given the variety of design and geographic context, and the high-level nature of the assessment, load calculation for a specific infrastructure would go beyond the scope of the present study. However, a number data gaps are to be expected at this level hence the relevance of a gap analysis.
5	– Recommendations with regards to: - Remedial actions - Monitoring activities and re-evaluation - Management actions – Identification of study limitations and recommendations for further study	No changes	N/A

1. **The activities for which WSP adapted our approach to the Protocol are in bold.**
2. Optional.

For the purposes of streamlining communication of the findings, only key findings and recommendations are presented. Complete information is available in the appendices.

2 PROJECT DESCRIPTION

In this study, risk is investigated under the lens of how the infrastructure elements interact with its physical environment, and how severe the consequences would be from an environmental, social and economical standpoint. In that regard, risk is specific to the context, and defining the context of the assessment and which types of infrastructure are included is integral to Step 1 of the Protocol. Therefore, the complete list of assets included in the assessment is presented, as well as the regional delineation and general description of the regions used for the climate change assessment. The time horizon selected for the assessment is specified, as are the jurisdictional considerations related to the organizations and level of governments impacted by the assessment. The relevant climate parameters and climate-related hazards selected are also presented. The remaining requirements from Step 2 of the PIEVC Protocol are covered in further chapters.

2.1 IDENTIFIED INFRASTRUCTURE

The following list (Table 2) of GNWT- and community-owned assets located within or associated with the 33 NWT communities to be included in the assessment was provided by MACA. These assets were combined under three categories: civil and municipal, buildings, and energy. This grouping of infrastructure facilitated the identification of climate thresholds that will trigger a climate-infrastructure interaction. For example, the buildings should comply to the National Building Code (NBC). Therefore, the design criteria defined in the latter will provide rationale to identify thresholds for different climate-buildings interactions (e.g. snowload). As per the definition of the project, airports, territorial roads and highways have been excluded from the study. As mentioned in section 1.2, airports and roads between the communities are excluded from the assessment.

Table 2 Infrastructure included in the assessment

Infrastructure Category	Infrastructure Type	
Civil and municipal	Ferry / marine transportation centres	Sanitary sewer mains (above and below ground)
	Municipal roads	Storm sewer mains (above and below ground)
	Street signs	Sewage lagoons
	Street lighting (traffic lights and street lights)	Culverts and other drainage structures
	Bridges and causeways	Solid waste sites
	Water treatment plants	Parks (territorial parks and playgrounds)
	Wastewater treatment plants	Golf courses
	Watermains (above and below ground)	Graveyards
Buildings	GNWT / Community housing units	Fire stations
	Offices	Cultural buildings
	Schools	Garages and generator containers
	Hospitals and health care centres	Greenhouses
	Recreational infrastructure (sport centres, arenas, etc.)	
Energy	Fuel storage facilities or tank farms (NTPC-, GNWT- or community owned)	
	Fuel resupply / supply lines	Solar farms
	Fuel shorelines manifolds	Power lines and poles
	Power plants	Telecommunication (above and below ground)

The GNWT has divided its territory into five administrative regions: South Slave, North Slave, Dehcho, Sahtu and Beaufort Delta, which have very different geographical, topographical and climate realities. Thus, WSP's analysis is aligned with these five regions, as it is assumed that with most communities within a region being located in relative proximity, the climate trends will be similar at the regional level. Map 1 illustrates the five regions and the location of all 33 NWT communities within these regions. A brief description of every region follows.

Map 1 NWT's administrative regions and communities

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

2.2 SITE DESCRIPTION

2.2.1 NORTH SLAVE REGION

The North Slave region consists of the following communities: Behchokǫ̀, Gametì, Łutselk'e, Wekweètì, Whatì, Yellowknife and Dettah. Yellowknife is the largest city of NWT, with close to 20,000 inhabitants, of which 23% identifies as Indigenous. The other communities of the North Slave Region are almost exclusively composed of Indigenous population, with a vast majority from the Dene Nation. Behchokǫ̀ is the largest Dene community with a population of more than 1,600 people.

Figure 2 Active fire in the Taiga Shield near the Snare River hydroelectric facility

The North Slave Region is in the Canadian Shield physiographic region characterized by gently rolling terrain, where exposed bedrock outcrops dominate. The depressions between the bedrock outcrops are often occupied by wetlands. A complex and dense drainage network composed of rivers and lakes is organized in rectangular and multi-basin patterns. Communities in the North Slave Regions are located on the shores of lakes whose levels are not fluctuating sufficiently to cause flooding concerns. Behchokǫ̀, Łutselk'e, Yellowknife and Dettah are located on the shore of Great Slave Lake, which is the deepest lake in Canada. Great Slave Lake likely has an impact on surrounding climate, because of its high-water volume and associated capacity to store heat. Water remains cold during the four months that it is ice-free. Cold water inhibits cloud formation and controls the surrounding air temperature by limiting the amount of daytime heating. This in turn will affect permafrost and vegetation dynamics. For example, it has been found that non-forested lowlands are located on the downwind side of Great Slave Lake (Szeto and Crawford, 2005).

Most communities of the North Slave Region are located in the Taiga Shield High Boreal Ecoregion. This region is characterized by two major vegetation types associated with the geomorphic context. Lichen woodland occurs on bedrock outcrops with thin or no soils. This vegetation type is dominated by jack pine, black spruce, white spruce and paper birch. On deeper soil with more limited drainage, moss forest characterized by dense black spruce canopy will be the dominant vegetation type. Fire disturbance has a major influence on this ecoregion, with jack pine dominating the areas with shorter fire return intervals (Figure 2). Gameti is located in the Low Subarctic Ecoregion of the Taiga Shield, characterized by gently rolling terrain with open canopied black spruce – dwarf birch woodlands or white spruce – dwarf birch woodlands on coarser glacial deposits. Fire patterns are characterized by lower intensity surface burns with return periods often exceeding 140 years. Wekweètì is located in the

Figure 3 White spruce stand on sandy alluvial deposits near Wekweètì

Taiga Shield High Subarctic Ecoregion. Fire activity is less intense and usually limited to surface inferior to 200 hectares (Department of Environment and Natural Resources, 2008). Consequently, white spruce, which has a longer longevity and whose seeds withstand colder temperatures, is getting more dominant towards the tree line (Figure 3). Whati is located in the Taiga Plains Low Subarctic Ecoregion. Much of the Taiga Plains drains into the Arctic Ocean through the Mackenzie Valley. This lowland region was mostly covered by postglacial Lake McConnell which deposited extensive lacustrine fine-grained deposits. This substrate favors the presence of peatlands which are extensive in the Mackenzie Valley. The typical landscape of the Taiga Plains Low Subarctic Ecoregion is a mosaic of semi-close to open treed uplands and wetlands. Primary upland vegetation is open mixed black and white spruce stands with an understory composed of shrub species such as dwarf birch and Labrador tea (Department of Environment and Natural Resources, 2009).

The North Slave region is located in the discontinuous permafrost zone. Communities are often located over igneous bedrock, which is not sensitive to ground displacement due to permafrost thaw. However, the ice-rich areas are very sensitive to thawing since the permafrost is warm (-1 to 0°C).

2.2.2 SOUTH SLAVE REGION

South Slave region consists of the following communities: Enterprise, Fort Providence, Fort Resolution, Fort Smith, Hay River, Kakisa, and K'átł'odeeche. Several highways connect these communities with each other and several others in the region. They stretch over large expanses of relatively undisturbed terrain and forest, which increases their vulnerability.

Communities in the South Slave Region are located in the Taiga Plains Mid Boreal Ecoregion, which has the mildest climate of the Taiga Plains in NWT due to its southern location. Vegetation in the uplands is composed of productive mixed-wood large continuous forests on well drained sites. On level terrains where the water table is higher, fens with black spruce and larch along with peat plateaus are common (Department of Environment and Natural Resources, 2009).

Figure 4 The South Slave region is characterized by a network of lakes and a flat topography.

(https://cabinradio.ca/13997/news/environment/environmental-audit-dives-into-health-of-nwts-water/)

Fort Resolution and Hay River are located on the southern shore of the Great Slave Lake. The major fluvial systems of the region are the Slave, Hay and Mackenzie Rivers. The Slave River flows through Fort Smith and Fort Resolution. Hay River flows through Hay River and K'átł'odeeche. The Mackenzie River flows Fort Providence. Communities in the South Slave Region are not prone to flooding, except for Hay River and K'átł'odeeche First Nation Reserve which are located in a flood-prone delta. Hay River usually floods due to ice-jam events, such as in 2009 when a large ice jam event between Enterprise and Louis Falls caused evacuation, road flooding, and filled the West and East channels to capacity.

The South Slave region is located in the sporadic permafrost zone and is the least sensitive to permafrost thawing. Permafrost is sporadic and found on sandy soil with limited ice content. In ice rich areas, given that the southernmost permafrost is warm (i.e. between -0.5 and 0 °C), permafrost is sensitive to thawing.

2.2.3 DEHCHO REGION

The Dehcho region consists of the following communities: Fort Liard, Fort Simpson, Jean Marie River, Nahanni Butte, Sambaa K'e, and Wrigley. Fort Simpson is the biggest community with more than 1,200 inhabitants. Most of the population of the region is Dene or Metis.

Dehcho Region is located in the Interior Plains physiographic region (Figure 5). This region is characterized by a series of low-lying plateaus, flat topography and extensive wetlands (mostly peat bogs). All the communities of the Dehcho Region are located in the Taiga Plain Mid-Boreal Ecoregion, as described in the South Slave Region section above.

Fort Liard is located on the bank of the Liard River, which takes its source in the Mackenzie Mountains close by. Therefore, spring runoff peaks quickly during freshet and puts pressure on the ice cover of the Mackenzie River at their confluence, where Fort Simpson is located. This pressure will cause the ice cover to break up and can cause ice jams. Nahanni Butte is located on a sediment bar of the Nahanni River which peaks quickly during spring freshet. In 2018 the water levels rose in the Mackenzie River which resulted in flooding of Jean Marie River, though there was no reported damage. More severely, in 2012 residents of Nahanni Butte were evacuated due to rising flood waters, and the town's power plant was temporarily shut down as a precaution.

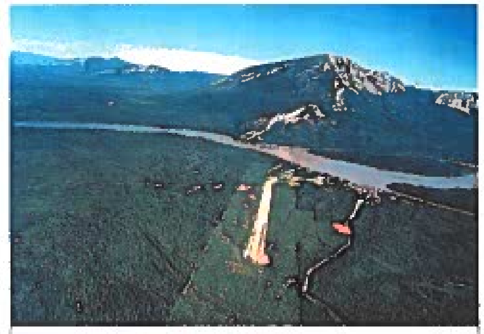

Figure 5 Nahanni Butte is located in the flatlands on the foothill of Nahanni National Park.

(https://www.statsnwt.ca/community-data/infrastructure/NahanniButte.html)

Sambaa K'e and Jean Marie River are located in the sporadic permafrost zone and the other communities are located in the discontinuous permafrost zone. In ice rich zones, the permafrost is sensitive to thawing given its thermal condition near melting point (- 0.5 to 0 °C).

2.2.4 SAHTU REGION

The Sahtu region consists of the following communities: Colville Lake, Deline, Fort Good Hope, Norman Wells and Tulita. Norman Wells is the regional center of the Sahtu region. Apart of Norman Wells, the other communities are almost exclusively composed of Sahtu Dene population, with a slight proportion who identify themselves as Metis.

Sahtu region is located at the junction of the Interior Plains (described above) and the Cordillera physiographic regions. The later region encompasses different mountain ranges such as the Mackenzie and the Richardson Mountains. No communities are located within high relief environment; however, topography affects the climate through orogenic barrier effect (Figure 6). Except Colville Lake, all communities are located in the Taiga Plains Low Subarctic Ecoregion as defined in the North Slave Region section. Colville Lake is located in the Taiga Plains High Subarctic Ecoregion. Much of the region is covered by gently sloping till deposits. Most of the forested area of this region was burned by recent forest fires, which means that that primary succession shrublands are widespread. The dominant tree species is white spruce, which will form denser populations at the southern limit of this region and very open

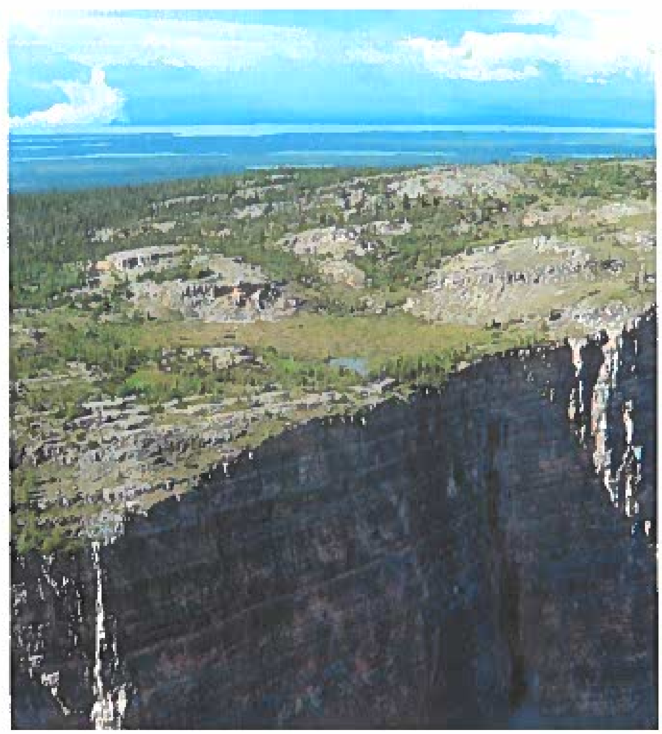

Figure 6 The Taiga Plains behind the Discovery Ridge, east of Norman Wells

woodlands in the north (Department of Environment and Natural Resources, 2009).

Fort Good Hope, Norman Wells and Tulita are built on the banks of the Mackenzie River. Colville Lake and Deline are built on the shores of Colville and Great Bear Lake. The latter is the largest lake entirely within Canada's borders. Its drainage basin is characterized by a regular and gentle topography with extensive storage capacity. This storage capacity, along with the massive volume of Great Bear Lake, provide moderating effort in lake and associated tributaries levels (Kokelj, 2001).

Fort Good Hope and Colville Lake are located in the continuous permafrost zone, and the three southernmost communities are located in the discontinuous permafrost zone. Ice-rich permafrost is frequent enough to cause concern regarding ground stability, especially given the thermal condition of the permafrost (between -2 and 0 °C) (Department of Environment and Natural Resources, 2015).

2.2.5 BEAUFORT DELTA REGION

The Beaufort Delta region consists of the following communities: Aklavik, Fort McPherson, Inuvik, Paulatuk, Sachs Harbour, Tsiigehtchic, Tuktoyaktuk and Ulukhaktok. Beaufort Delta region is populated mostly by Indigenous people. The Mackenzie Delta has a higher proportion of Gwich'in population, whereas communities to the North and to the East are mostly composed of Innuvialiut population. Inuvik is the regional center with a population of 3,243 inhabitants.

The communities within the Mackenzie Delta are located within the Taiga Plain High Subarctic Ecoregion, as described in the Sahthu Region section above (Figure 7). Tuktoyaktuk and Paulatuk are located in the Southern Arctic Tundra Plains Ecoregion. Tuktoyaktuk region is characterized by lowlands and broad coastal plains covered by pre-Laurentian weathered till or bedrock. Paulatuk is localized on a narrow coastal plain of dolomites and shales blanketed by till and fluvial deposits. The vegetation cover is continuous tundra composed of dwarf and low-shrubs on uplands and sedge, moss and shrubs in wetter areas (Figure 8). The landscape of the Southern Arctic Tundra Plains is characterized by periglacial features attributed to the presence of continuous permafrost: ice-wedge polygons, frost-shattered bedrock, low- and high-centre polygons, non-sorted circles, palsas and pingos (Department of Environment and Natural Resources, 2012). Sachs Harbour and Ulukhatktok are located in the Low Arctic North Ecoregion, which is characterized by similar vegetation assemblages than in the Southern Arctic Tundra: shrub tundra will dominate on well drained sites, whereas wetter sites will be covered by sedge – grass – moss tundra. Periglacial features are common in the landscape and is comprised of ice-wedge polygons, non-sorted circles, sorted circles and turf hummocks (Department of Environment and Natural Resources, 2013).

Figure 7 Aklavik community in the Mackenzie delta

Figure 8 Dry tundra south of Tuktoyaktuk

Tuktoyaktuk, Paulatuk, Sachs Harbour and Ulukhatktok are coastal communities on the shores of the Beaufort Sea, characterized by a microtidal semi-diurnal regime. Wave action and oceanic storms affect the coastal hazard dynamics.

Other communities are located on the bank of the Mackenzie River or one of the channels of the delta. They are sensitive to riverine flooding and ice jam flooding. Aklavik is often mentioned as the most sensitive community to flooding, as it is built on a meander bar at low elevation. Fort McPherson is also sensitive to ice jam and spring flooding during freshet.

Beaufort Delta region is located in the continuous permafrost zone. The communities of the Mackenzie Delta are the most vulnerable to permafrost thawing. The permafrost is warm (-3 to -1 °C) and ice rich. Therefore, the five communities of the Mackenzie Delta (Fort McPherson, Tsiigehtchic, Aklavik, Inuvik, Tuktoyaktuk) shows high sensitivity to permafrost thawing (Figure 9). Other Innuvialiut communities are located in a zone of cold permafrost (-8 to -5 °C) which is less sensitive to thawing.

Figure 9 Thaw slump on the Peel Plateau near Fort McPherson

Table 3 lists the types of infrastructure found in each region.

Table 3 Infrastructure present in NWT regions

Infrastructure Category	Infrastructure Type	Region				
		North Slave	South Slave	Dehcho	Sahtu	Beaufort Delta
Civil and municipal	Ferry / marine transportation centres	N	N	Y	N	Y
	Municipal roads	Y	Y	Y	Y	Y
	Street signs	Y	Y	Y	Y	Y
	Street lighting	Y	Y	Y	Y	Y
	Bridges and causeways	Y	Y	Y	Y	Y
	Water treatment plants	Y	Y	Y	Y	Y
	Wastewater treatment plants	N	N	Y	N	N
	Watermains (above ground)	N	N	N	N	Y
	Watermains (below ground)	Y	Y	Y	Y	Y
	Sanitary sewer mains (above ground)	N	N	N	N	Y
	Sanitary sewer mains (below ground)	Y	Y	Y	Y	Y
	Storm sewer mains (above ground)	Y	N	N	N	N
	Storm sewer mains (below ground)	Y	Y	Y	Y	Y
	Sewage lagoons	Y	Y	Y	Y	Y
	Drinking water well	Y	N	Y	N	N
	Culverts and other drainage structures	Y	Y	Y	Y	Y
	Solid waste sites	Y	Y	Y	Y	Y

Infrastructure Category	Infrastructure Type	Region				
		North Slave	South Slave	Dehcho	Sahtu	Beaufort Delta
	Parks (Municipal)	Y	Y	Y	Y	Y
	Golf courses	Y	Y	Y	Y	Y
	Graveyards	Y	Y	Y	Y	Y
Buildings	GNWT / Community housing units	Y	Y	Y	Y	Y
	Offices	Y	Y	Y	Y	Y
	Schools	Y	Y	Y	Y	Y
	Hospitals and health care centres	Y	Y	Y	Y	Y
	Fire stations	Y	Y	Y	Y	Y
	Recreational infrastructure	Y	Y	Y	Y	Y
	Cultural buildings	Y	Y	Y	Y	Y
	Garages and generator containers	Y	Y	Y	Y	Y
	Greenhouses	Y	N	N	N	Y
Energy	Fuel storage facilities or tank farms	Y	N	Y	Y	Y
	Fuel resupply / supply lines	Y	N	N	Y	Y
	Fuel shorelines manifolds	Y	N	N	Y	Y
	Power plants	Y	Y	Y	Y	Y
	Solar farms	N	N	Y	Y	Y
	Power lines and poles	Y	Y	Y	Y	Y
	Telecommunications (above ground)	Y	Y	Y	Y	Y
	Telecommunications (below ground)	Y	Y	Y	Y	Y

2.3 TIME HORIZON AND JURISDICTIONAL CONSIDERATIONS

The assessment includes assets designed during different periods with variations in expected operational lifespan. Mechanical, electrical and communication components, windows and surfacing materials typically have a design life of 15-30 years. Building components, water and sewer infrastructure and drainage systems usually have a design life of 50-75 years, whereas structural components of buildings typically have a design life of 40-70 years. Hence, the climate trends will be assessed according to two time-horizons: the near future (2021-2050) and the extended future (2051-2080).

Jurisdictions, laws, regulations, guidelines, and administration processes can affect an organization's risk tolerance. However, jurisdictions that have a direct control or influence over the planning, permitting, construction and operation of the proposed infrastructure are hard to identify, due to the governmental structure of the NWT: while the GNWT itself is based on the model of a consensus system of government, all communities of the NWT are incorporated under a variety of legislations and thus have different powers. The complete jurisdictional portrait can be found in Appendix A. The main jurisdictional considerations are as follows:

- Waters Act (S.N.W.T. 2014, c. 18);

- Mackenzie Valley Resource Management Act (S.C. 1998, c. 25);
- Community-specific bylaws;
- Public-Health Act, including the Public Sewerage Systems Regulations (R.R.N.W.T. 1990, c.P-22), the General Sanitation Regulations (R.R.N.W.T. 1990, c.P-16) and the Water Supply Systems Regulations (R.-108-2009);
- National design standards and codes adopted by the GNWT, such as the National Building Code of Canada and the National Fire Code of Canada;
- Guidelines from the GNWT and other Canada-wide associations and organizations;
- Land use plans and zoning provisions.

2.4 SELECTED CLIMATE PARAMETERS AND CLIMATE-RELATED HAZARDS

Climate parameters and climate-related hazards that arise from their interaction must be identified to assess infrastructure vulnerability associated with design, development and management. Table 4 summarizes the climate parameters selected by WSP's technical team, based on the available historical and projected climate change, as well as design codes and standards in effect.

Table 4 Relevant climate variables and parameters for NWT regions.

Climate variable	Climate parameter	
Temperature	Mean annual temperature	Number of frost days
	Mean minimum January temperature	Number of very cold days (<-30°C)
	Mean maximum July temperature	Number of freeze-thaw cycles
	Summer cooling degree-days	Length of frost-free season
	Intensity of winter cold snaps	Number of heat waves
	Heating degree-days	Number of extremely hot days (>34°C)
Precipitation	Total annual precipitation	Freezing rain
	Total annual rain	Winter precipitation
	Heavy precipitation days	Summer precipitation
	Changes in precipitation as snow	Hail episodes and lightning
	Extreme short-duration precipitation events (24 hr maximum 1:5, 1:50, 1:100)	
Wind	Summer wind regime	
	Average hourly speed	
	Gust speed	
Fluvial	Regional historical floods	
Maritime	Sea level rise, stronger storm surges, higher tides and coastal erosion[1]	
	Sea ice extent and duration of ice-free season[1]	

1. Relevant to Beaufort Delta region only, since it is the only region on the shore of the Beaufort Sea.
Definition of climate parameters can be found at the beginning of the report.

Climate-related hazards can be generated from the interaction of these parameters. Table 5 shows the regional risk level associated with the different climate-related hazards, as identified by MACA in the *2014 Northwest Territories Hazard Identification Risk Assessment*. These hazards have been included in the vulnerability assessment.

Table 5 Climate-related hazard risk level[1] for NWT regions

Climate-related hazard	Region				
	North Slave	South Slave	Dehcho	Sahtu	Beaufort Delta
Flood (open-water, ice jam and coastal submersion)	L	H	H	H	H
Snow load	M	M	M	M	M
Winter storm	M	M	M	M	H
Wind storm	M	L	L	L	M
Extreme weather	M	L	L	L	L
Ice hazard	L	L	L	M	L
Permafrost degradation	M	L	L	L	M
Wildfire	H	H	H	H	H
Earth movement – Other[2]	L	M	L	M	H

1. H: High risk level | M: Moderate risk level | L: Low risk level.
2. Includes coastal erosion (Beaufort Delta), landslides (South Slave, Sahtu) and riverbank erosion (N. Slave, S. Slave, Dehcho).
Adapted from MACA (2014).

The Protocol also requires identifying, when possible, the combination or sequencing of meteorological events that could affect the infrastructure. Based on our professional judgement, infrastructure vulnerability could be caused by the following:

- Sea level rise combined with extreme precipitation and storm surges, increasing the risk of flooding and coastal erosion;
- Strong winds combined with snow load on buildings can weaken the structure even more;
- Freezing rain followed by extremely cold temperatures, resulting in impacts to power infrastructure potentially leaving communities without power for extended periods;
- Changes in seasonal precipitation combined with increases in temperature, which can contribute to permafrost degradation in select areas;
- Wind, evapotranspiration and increased temperature, contributing to wildfire.

Out of these climate-related hazards, five have been identified by WSP to be of primary concern for GNWT infrastructure assets. Major direct and indirect impacts as compiled by Boyle, Cunningham and Dekens (2013) are described below. Impacts and cost of recovery caused by these hazards have been discussed in detail during a workshop with relevant stakeholders held in Yellowknife on March 3rd and 4th, 2020. The consensus from workshop participants concluded that the vulnerability due to the first four hazards identified is the main concern for GNWT and all stakeholders consulted.

2.4.1 PERMAFROST DEGRADATION

For all types of civil and municipal, building and energy infrastructure, permafrost degradation or thaw or an increase in the frequency of freeze-thaw cycles may lead to soil and slope instability, soil subsidence, and ground movement. Thawing permafrost may also alter the regional hydrogeology.

This could impact the stability of civil and municipal as well as energy infrastructure (detailed in Table 3) via reduction or loss of function (i.e. road slumping, pavement cracking, or pipe failure). Loss of containment due to reduced strength and reliability of containment structures could result in sewage or fuel spills.

FEATURE EVENT

Changes in ambient air temperature are translated into changes in ground temperature, resulting in a thawing of permafrost. When permafrost impacts shorten the remaining life of the assets over time, there are costs incurred relative to the pre-climate impact scenario.

https://climatechange.toolkitnwtac.com/wp-content/uploads/sites/21/2018/02/reports-section.pdf

Building infrastructure integrity could be lost due to damage to building foundations, potentially leading to buildings being condemned.

Impacts of permafrost degradation on all the assets may also lead to reduced aesthetics and an increased need for repair and maintenance. There is a potential for a decrease in safety to workers and the public, which could reduce general perception of safety of public infrastructure.

2.4.2 FLOOD

An increase in intensity of rain precipitation could potentially lead to an exceeded capacity of storm sewer mains, culverts and other drainage structures, provoking subsequent flooding events and overflows.

Building assets are at risk of being impacted by increased precipitation and intensity of rainfall events. Such events could potentially lead to increased corrosion, mould growth, reduced structural integrity, accelerated deterioration, premature weathering, increased fractures and spalling in building foundations, decreased durability of materials, and increased maintenance and repair.

FEATURE EVENT

Aklavik is especially prone to floods due to its location on the banks of a horseshoe bend in the Peel Channel of the Mackenzie Delta.

The May 2006 flood, which required the evacuation of 300 people as the community was under several feet of water, is to this day the costliest flood event in NWT history.

Flooding events caused by an exceeded capacity of storm sewer mains, culverts and other drainage structures due to increased frequency and intensity of rainfall, could potentially lead to sewer service backups and flooded basements and subsequent increases in maintenance and repair as well as insurance costs.

While ice jams present a significant flood hazard in several communities located adjacent to rivers, the focus of the climate change related flooding is due to changes in precipitation patterns. Projecting the complex interconnectivity of climatic conditions that influence ice jamming processes is challenging and have been identified as a data gap for further study.

2.4.3 WILDFIRES

Hotter and drier summers and the appearance of heat waves show an increased potential for drought and wildfires, which put all asset types at risk for damage to the infrastructure and possible loss of function. In the case of energy infrastructure, there is also a risk of explosion for damage caused by wildfires.

Changing summer conditions may also lead to an increase in energy consumption, and thus costs, due to a more frequent use of air conditioning devices for all assets with building structures.

The first appearance of heat waves may require new procedures and policies not only with regards to the operation and maintenance of the infrastructure, but also in terms of policies to ensure the health and safety of workers and the public.

FEATURE EVENT

The record-breaking wildfire season of 2014 will be hard to forget: 385 fires (57 % more than average) burned 3.4 M hectares of forest land, costing $56.1 M in firefighting costs only.

Thankfully, no serious injuries or deaths were recorded.

https://www.enr.gov.nt.ca/sites/enr/files/web_pdf_fmd_2014_fire_season_review_report_4_may_2015.pdf

2.4.4 COASTAL EROSION AND/OR SUBMERSION

Coastal erosion and submersion are the result of sea level rise, coupled with stronger storm surges, higher tides, as well as reduced sea ice extent and/or the duration of the ice-free season.

Roads, bridges, causeways, sewage lagoons, solid waste sites, culverts and other drainage structures could be impacted via exceeded capacity and a loss or reduction of function, or even the loss of the infrastructure itself due to washouts. Increased costs are to be expected for repair and maintenance as well as for a potential relocation or raise of the infrastructure. This also applies to all energy infrastructure located near the sea shore.

FEATURE EVENT

Coastal erosion has been severe in Tuktoyaktuk throughout its entire history. Between 1950 and 2018, the town's coastline has retreated at a rate of 0.8 m/yr on the peninsula, which caused significant impacts on infrastructure. For example, in 1982, erosion caused by severe sea storms caused the relocation of the RCMP detachment, the abandonment of the elementary school and the loss of the curling rink to the sea.

Baird, 2019; Wolfe et al., 1998

Potential impacts on water treatment plants operations could derive from the contamination of water sources (i.e. saltwater, bacteria, sediments, turbidity, colour, etc.).

Reduced sea ice extent and/or duration of the ice-free season could increase the vulnerability of ferry and marine transportation infrastructure to damage from increased erosion and wave action. An improved access could increase ship traffic, which would require altered operation schedules and increased maintenance and repair of existing assets, as well as opportunities for new construction and operational activities.

Building assets near the sea shore could potentially be impacted via basement flooding, leading to increased repair bills and insurance costs.

2.4.5 SNOW LOAD

Increased precipitation as snow and /or changes to precipitation (i.e. wetter snow) have the potential to affect all assets with building structures. Indeed, an increase in snow load beyond design codes implies a greater risk for roof collapse. Also, condensation within the building envelope could form, leading to a loss of or reduced function of the components, and increased maintenance and repair operations and costs. Condensation within the building envelope could also facilitate the formation of mould, thus leading to potential health hazards such as respiratory problems.

FEATURE EVENT

On May 5, 2004, the roof of the Samuel Hearne Secondary School in Inuvik collapsed due to a record-breaking build-up of snow.

Consequences could have been catastrophic, as the collapse happened only 40 minutes before the 380 grade 7 to 12 students were scheduled to begin classes that day.

https://www.maca.gov.nt.ca/sites/maca/files/resources/hira-inuvik_final.pdf

3 CURRENT AND FUTURE CLIMATE OF NWT

3.1 GLOBAL AND NATIONAL CONTEXT

The International Panel on Climate Change Fifth Assessment Report concludes that the Earth has warmed during the Industrial Era and that it is extremely likely that anthropogenic greenhouse gas emission is the main cause of this warming. This includes increases in air temperature, sea surface temperature, and ocean heat content. Along with this global warming, we observe an increase in atmospheric water vapour and decline in snow and ice cover. The global relative sea level is increasing at an accelerated rate due to the thermal expansion of warming ocean and addition of water from glacial melting.

At the national level, the Canada's Changing Climate Report (NRCan, 2019) states the following conclusions regarding climate change:

- The annual average temperature increased by 1.7 °C since 1948. This increase was greatest during winter and for northern Canada (+2.3 °C). Northern Canada will continue to warm at twice the global rate.
- Precipitation has increased in many parts of Canada, with a decreased proportion of the precipitation falling as snow. Annual and winter precipitation will continue to increase.
- Extreme warm temperatures have become hotter. This trend will continue and will increase the severity of droughts and heat waves. More intense rainfall will increase pluvial flooding risk.
- The proportion of sea ice has decreased and will continue decreasing. Permafrost temperatures are increasing.
- The three oceans surrounding Canada have warmed, become more acidic and less oxygenated.
- Coastal flooding and erosion is expected to increase due to local sea-level rise.

Figure 10 presents the observed and projected changes across Canada in average annual temperature and precipitation. Since 1948, warming was especially significant in the western part of Canada's North (Northern Yukon, Beaufort Delta region) and precipitation increased substantially in above the 70th parallel. Changes in the distribution of these two climate variables drive most changes in extreme events associated with warm temperature or extreme precipitation, as well as changes in permafrost or sea level.

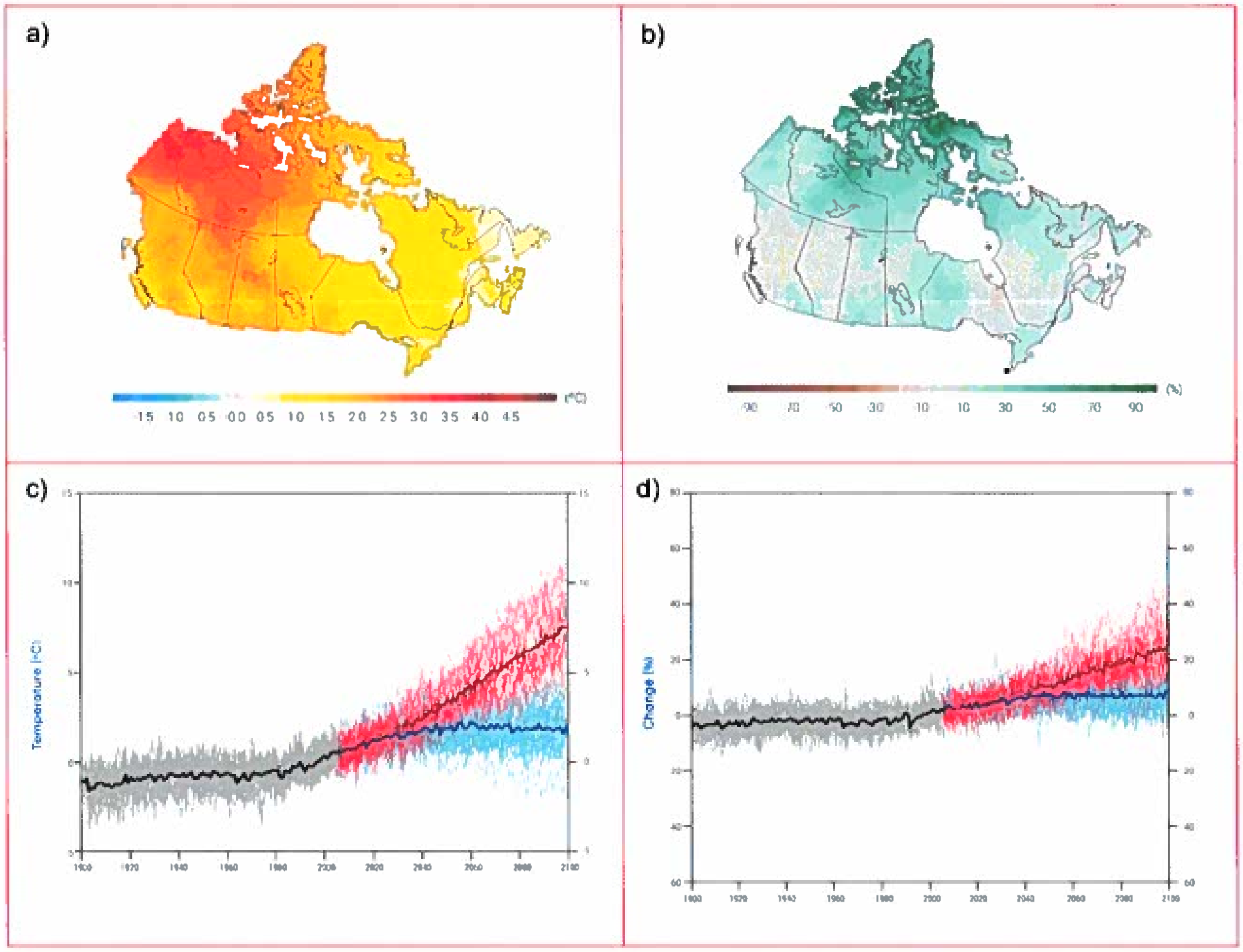

Figure 10 Observed (a,b) and projected (c,d) changes in average annual temperature (a,c) and annual precipitation (b,d) in Canada.

3.2 CLIMATE BASELINE, OBSERVED TRENDS AND PROJECTED CLIMATE CHANGE

Globally, climate change will result in a long-term rise in the Earth's average temperature. On a local scale, impacts will vary and include shifts in temperature, precipitation, wind, and other weather patterns, including extreme weather events. Broadly speaking, the local climate projections are divided into two different commonly used 'scenarios', or 'Representative Concentration Pathways (RCP)': the **active scenario (RCP 4.5)** and the **passive scenario (RCP 8.5)**. The active scenario is modelled assuming that there is a significant decrease in global greenhouse gas (GHG) emissions from the 2040s, while the passive scenario has been designed by assuming the worst case 'business-as-usual' approach without any mitigation

WEATHER OR CLIMATE?

Weather refers to the short-term changes in the atmosphere while *climate* describes long-term trends in weather. For example, when someone says, "It is warm today", they are referring to weather, but if they say, "Yellowknife has cold winters", they are referring to climate.

measures implemented at global scale and a constant increase in GHG emission until the depletion of fossil fuel stocks. The passive scenario is the trajectory in which most changes are more significant, especially in the North where the effects of climate change are exacerbated. Given the current state of global climate negotiations, the passive scenario remains the most likely at this stage, and thus is the scenario chosen for this assessment. This is a reasonable approach to take considering the level of uncertainty and that the impacts under the more moderate active scenarios have similar outcomes at mid-century (2050s).

The current state of climate conditions in terms of historical extreme weather events, observed trends and projected future conditions are presented below in Table 6. The evolution of major climate parameters is described in more detail below for each climate category identified: temperature, precipitation, flooding and coastal hazards, wildfires and permafrost thawing. Data was obtained from historical datasets and climate normals from Environment and Climate Change Canada (ECCC, 2019), the Climate Atlas of Canada (Prairie Climate Center, 2019), the IDF_CC tool (Western University, 2018; Simonovic *et al.*, 2018) and Canadian Disaster Database (Public Safety Canada, 2013). For each region, the climate baseline, historical trend and future projections were calculated as the average value for the weather stations or the grid points (for climate models) representing the communities for which the data were accessible.

Table 6 **Climate baseline and projected climate change for the five NWT regions from climate model simulations**

	Climate parameter	Trend	North Slave 1976-2005[1]	North Slave 2021-2050	North Slave 2051-2080	South Slave 1976-2005	South Slave 2021-2050	South Slave 2051-2080	Dehcho 1976-2005	Dehcho 2021-2050	Dehcho 2051-2080	Sahtu 1976-2005	Sahtu 2021-2050	Sahtu 2051-2080	Beaufort Delta 1976-2005	Beaufort Delta 2021-2050	Beaufort Delta 2051-2080
Temperature	Mean annual temperature (°C)	↑	-6.14	-3.56	-0.96	-4.82	-0.84	1.64	-3.64	-1.32	1	-6.98	-4.38	-1.78	-10.16	-7.03	-3.97
Temperature	Number of very cold days (< -30 °C)	↓	61.2	38.8	19.2	43.4	26.2	12.2	41.8	26.2	14	59.6	36.4	18.4	73.9	39.3	15.3
Temperature	Number of days < 0 °C	↓	237	220.9	205.5	223.2	206.5	189.9	229	213.4	197.2	243.6	228.82	213.5	269.6	251.9	234.3
Temperature	Number of extremely hot days (>34 °C)	↑	0	0.10	0.56	0.04	0.46	2.14	0.02	0.46	2.20	0.02	0.18	1.08	0	0.09	0.46
Temperature	Number of heating degree-days	↓	8,816	7,910	7,036	7,799	6,962	6,158	7,927	7,124	6,378	9,129	8,206	7,338	10,272	9,099	8,066
Temperature	Number of heat waves	↑	0.02	0.2	0.7	0.18	0.6	1.7	0.18	0.68	1.76	0.14	0.34	0.98	0.03	0.14	0.39
Temperature	Number of freeze-thaw cycles	↓	42.3	38.3	35.9	53.3	48.2	45.3	57.8	51.7	46.3	41.3	37.1	33.7	34.6	31.6	30.9
Precipitation	Annual total precipitation (mm)	↑	263.4	294	315.4	319	362.2	370.4	366.4	402	429	272.8	304.4	334	212.3	239.1	268.4
Precipitation	Winter precipitation (mm)	↑	48.5	54.0	59.8	58.4	64.8	70.2	70.2	77.8	83.8	48.8	55.2	61	36.1	41	46.4
Precipitation	1:50 24-hr precipitation (mm)	↑	60.2	67.4	78.2	76.2	82	83.3	74.7	83.7	92.9	59	72.79	71.5	40.6	49.54	53.7

Likelihood to observe the trend:

Very high	High	Moderate	Low	Very low

1: 1976-2005 is the 30-year baseline period used by the Climate Atlas of Canada. The Climate Atlas of Canada allows the comparison of the outputs of the models during this period with the near (2021-2050) and far (2051-2080) futures.

3.2.1 TEMPERATURE

The climate in the Northwest Territories varies from south to north. While the southern part (South Slave, North Slave, Dehcho) has a subarctic climate, the northern part (the Beaufort Delta region, Beaufort Sea islands and Sahtu) mostly have a polar climate. The average annual temperature goes from -12.8°C (in coastal areas of the Beaufort Delta region) to -2.5°C in the South Slave region (as recorded by weather stations between 1981-2010[1]). Summer seasons tend to be short and cool. The winter season spans from October to April with uninterrupted daily average minimum temperatures in Yellowknife, according to the Canadian Climate Normals. In July, daily maximum temperatures come close to 19°C to 23°C on average, depending on the region. On the other hand, daily minimum temperatures in January range from -32°C to -26°C on average. Higher temperatures are commonly recorded in the southern regions. Across the NWT, 247 days have a negative mean temperature (Figure 11). Days exceeding 30°C are absent in the northern regions, whereas 4 days per year are usually exceeding 30°C in the Dehcho region. Historically, at the scale of the Territory, there has been an increase in all recorded temperature metrics. Annual mean temperature increased by 0.4°C and 0.5°C per decade between 1950 and 2013 for the South and the North, respectively (blue trend lines on Figure 12) More recently, this trend has accelerated since 1980 to reach an increase of 0.55 °C and 0.75°C per decade for the South and the North, respectively (red trend lines on Figure 12). Years that were considered as extremely warm before 1980 are now considered the new norm.

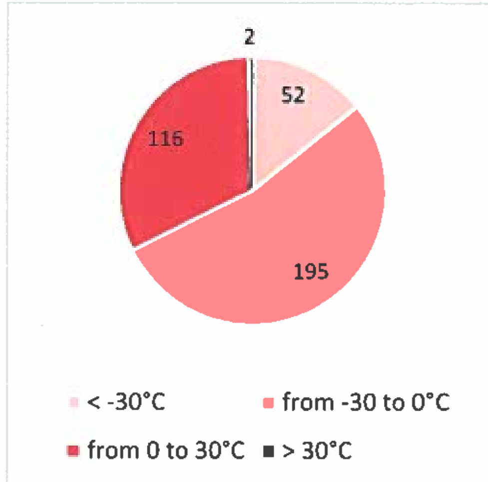

Figure 11 Historical average daily temperature for the NWT (1981-2010)

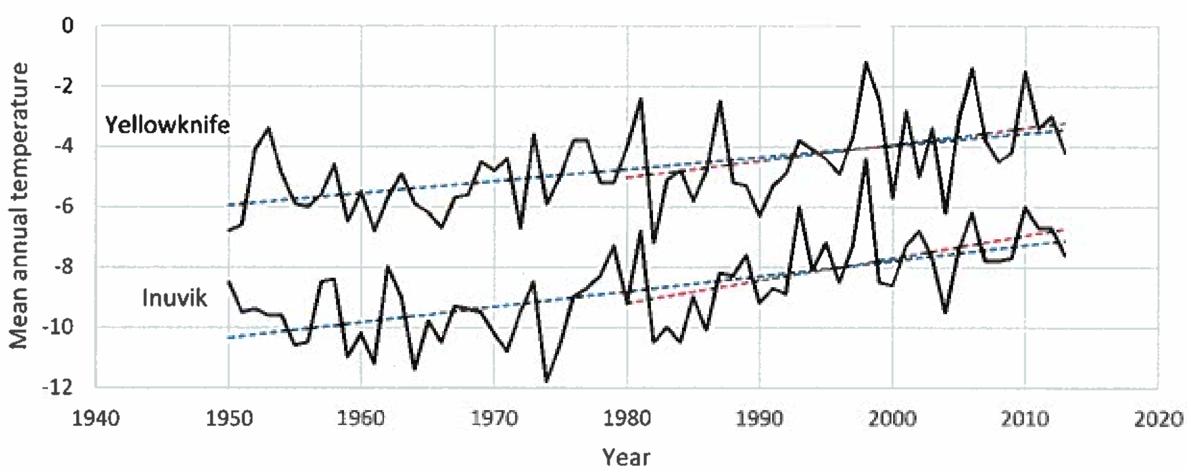

Figure 12 **Annual mean temperature in the Northwest Territories (1950-2013[2]) for the southern regions (illustrated with Yellowknife) and the northern regions (illustrated with Inuvik).**

[1] The 1981-2010 baseline corresponds to observed historical data, whereas the 1976-2005 baseline corresponds to modeled historical simulations. Temperature data at the scale of NWT were unavailable beyond 2013.

[2] Temperature data at the scale of NWT were unavailable beyond 2013.

There are however regional disparities in the rate of warming, with the northernmost regions experiencing the changes in climate at an accelerated rate. Figure 13 shows the average per decade increases in temperature metrics from the mid-20th century. While there has been an increase across all indicators, the rate of change of cold temperature metrics tend to be much larger than for warm temperature metrics. This indicates that winter conditions are likely to be modified sooner than summer conditions.

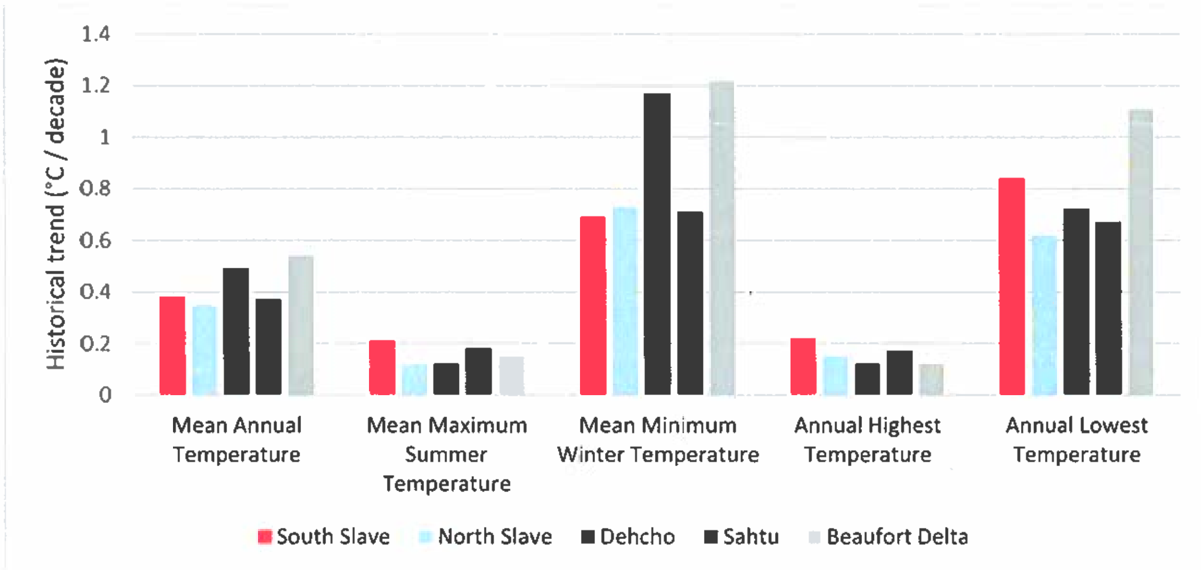

Figure 13 **Regional historical trends of temperature metrics between 1950 and 2013.** *Each color represents the rate of warming for a given region. For example, in the South Slave region, since 1950, the mean annual temperature increases by 0.4 °C per decade in average.*

Record historical temperature events corroborate these trends, as the maximum temperature recorded in every region dates from after 1980, while no new minimum temperature record has been set since 1975. This warm shift is causing the occurrence of the first heatwaves experienced in all Northern Canadian Territories. A heat wave is defined as having the maximum temperature above 30°C for at least three consecutive days. A heatwave warning was issued for the South Slave region over a course of five days in July 2019.

In the coming decades, these trends are likely to proceed and even accelerate if no GHG mitigation measures are implemented at global scale. By the 2051-2080 period, the number of very cold days (below -30°C) will be divided by a factor of 3 or 4, depending on the region, and the number of freeze-thaw cycles are also likely to decrease. Heat waves will happen twice a year on average in Dehcho and South Slave, whereas they will significantly impact the Beaufort Delta region. During these events, two days exceeding 34°C may occur every year, but temperature will be back below 20°C every night in all scenarios.

Record Historical Temperature Events

Maximum temperature:

- 36.7 °C on 1981/08/09 (South Slave)
- 36.6 °C on 1994/07/23 (Dehcho)
- 35.0 °C on 1989/07/14 (Sahtu)
- 32.8 °C on 2001/07/20 (MacKenzie Delta)
- 32.5 °C on 1989/07/19 (North Slave)
- 24.2 °C on 1982/07/07 (Beaufort Coast)

Minimum temperature:

- -56.7 °C on 1968/02/04 (MacKenzie Delta)
- -54.4 °C on 1947/02/04 (Sahtu)
- -53.3 °C on 1968/02/03 (Dehcho)
- -52.2 °C on 1975/01/10 (Beaufort Coast)
- -51.2 °C on 1947/02/01 (North Slave)
- -48.3 °C on 1947/02/01 (South Slave)

3.2.2 PRECIPITATION

The Northwest Territories are characteristically dry compared to the rest of Canada. On average, annual precipitation is about 280mm over all regions (as recorded between 1981-2010). Southern regions are more influenced by mid-latitude cyclones and are thus likely to get more precipitation: 336mm and 387mm for South Slave and Dehcho, respectively. Half of this accumulation falls as snow, with a greater proportion in northern regions due to lower mean temperatures. Heavy precipitation days are relatively rare and occur more often in South Slave and Dehcho, in accordance with larger annual precipitation. Days with an accumulation of snow greater than 25cm happened only on rare occasions (Figure 14). The largest snow storm ever recorded in the NWT happened in Sahtu with 165cm accumulated in 24 hours in March 1962.

Since the 1950s, the trending of precipitation regimes has been unclear due to high discrepancies in total precipitation from one year to another. The historical trends in total annual precipitation are significant only for the North Slave region, for Dehcho and the oceanic part of the Beaufort Delta region with an increase of 11, 14 and 10mm per decade, respectively. In other regions, the trend is negative and is not statistically significant. Snow accumulation has also increased for all regions except in South Slave and the inland part of Beaufort Delta. On average, the snowfall trend across the NWT is increasing at a rate of seven centimetres per decade since the 1950s.

Record Historical Precipitation Events

Daily rainfall:

- 85.8 mm on 1988/06/30 (Dehcho)
- 82.8 mm on 1973/08/15 (North Slave)
- 59.9 mm on 1991/09/13 (South Slave)
- 49.3 mm on 1967/07/19 (Sahtu)
- 41.0 mm on 1998/07/08 (Beaufort Coast)
- 21.8 mm on 1959/07/13 (MacKenzie Delta)

Daily snowfall:

- 165 cm on 1962/03/23 (Sahtu)
- 122 cm on 1962/01/31 (South Slave)
- 102 cm on 1976/03/19 (Dehcho)
- 99 cm on 1983/04/15 (MacKenzie Delta)
- 81 cm on 1958/03/05 (North Slave)
- 56 cm on 1960/05/30 (Beaufort Coast)

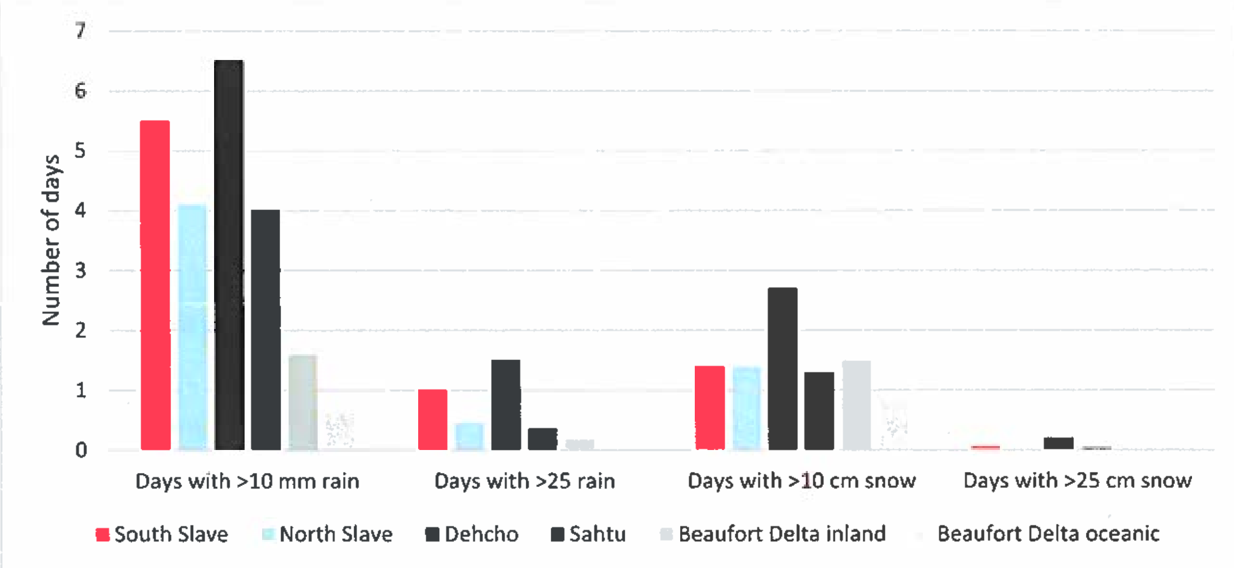

Figure 14 Number of annual heavy precipitation days for the five NWT regions between 1950 and 2013

In the coming decades, these trends are likely to increase even more. By the 2051-2080 period, total annual precipitation will increase by 16 to 26% depending on the region, if GHG mitigation measures are not implemented at global scale. In the NWT, these increases in annual precipitation and short-duration extreme precipitation events are likely to result in increasing pluvial flooding and snow load, especially in a warming context with wetter, heavier snowfall.

3.2.3 FLOODING AND COASTAL HAZARDS

Sea level is projected to rise along the coasts of Beaufort Delta. The CAN-EWLAT tool projects an increase between 19cm and 47cm, depending on the time horizon and the emission scenario selected, whereas a federal report suggests a 70 cm sea level rise by the end on the 21st century under a passive scenario (NRCan, 2016). Beaufort Delta coastlines will be the most exposed to sea level rise compared to other coastlines in Northern Canada. These regional discrepancies are largely due to differences in vertical land motion. There is an absence of local data on sea ice cover in the Beaufort Sea: Historic trends are expected to continue or accelerate, with some models projecting almost complete loss of summer ice cover before mid-century. Overall, Canadian Arctic sea ice is thinning; average spring ice thickness was 2.4 m in 2008 but is projected to be only 1.4 m by 2050. (NRCan, 2016).

1993 Storm Surge

On September 22, 1993, a severe storm with northwesterly winds of up to 96 km/h generated a 1.68 m surge and raised water levels to 2.2 m above chart datum. Powerful waves, together with the high-water levels, resulted in damage to or destruction of about half the shore protection at Tuktoyaktuk, and flooding in the community and parts of the Mackenzie Delta.

The combination of increased sea level rise and loss of ice cover will result in more destructive wave action on the coastal communities (Tuktoyaktuk, Paultakuk, Sachs Harbour and Ulukhaktok). This will translate to more powerful storm surges and accelerated coastal erosion. In the Beaufort Sea, under existing conditions, the estimated 100-year return period for storm surge is 2.6 m (Baird, 2019), although the return period for extreme-water-level events is expected to increase from once every 25 years to about once every 4 years by 2100 (NRCan, 2016). These projections do not factor the expected increase in storm intensity and reduction of sea ice cover. Coastal erosion is already a significant process on the Tuktoyaktuk Peninsula, as the historical erosion rates are 0.8 m/yr on unprotected shorelines. Based on historical erosion rates, much of the peninsula will be eroded by 2050 if left unprotected. These rates are considered conservative as they do not factor in the increase in sea level (Baird, 2019). Indeed, erosion rates are already accelerating in the Beaufort Sea. In the recent past, coastal erosion has been accelerated at Paulatuk. Rates of erosion and proportion of eroded coasts are given in Table 7.

Table 7 **Evolution of coastal erosion at Paulatuk between 1995 and 2016 (Sankar et al., 2019)**

	Rate of erosion in m/year		Eroded coasts in %	
	1995-2005	2006-2016	1995-2005	2006-2016
Western sector of Paulatuk	0.19	0.24	68	80
Eastern sector of Paulatuk	0.29	0.34	78	93

Fluvial flooding (open water or ice jam) is already a major hazard for many communities in the NWT. The combination of sea level rise, which will prevent water outflow from the Mackenzie River, accelerated freshet, change in baseflow induced by the impact of permafrost thawing on hydrogeology and the expected increase in precipitation will likely all lead to more frequent and more intense floods in NWT communities. However, the absence of any hydrological modeling prevents the corroboration of these hypothesis. Therefore, the regional flood probability for this assessment will be based on historical events, except for Aklavik where the whole community is below the 10-year return period water level for ice-jam floods (NHC, 2019). Hay River, K'atl'odeeche, Fort Liard, Fort Simpson, Jean Marie River, Nahanni Butte, Fort Good Hope, Tulita, Aklavik and Fort McPherson are at risk of fluvial flooding. Projecting the complex interconnectivity of climatic conditions that influence the frequency and severity of ice jamming processes is challenging and have been identified as a data gap for further study.

Riverbank erosion impacts several communities, although at the time of publishing the report, minimal information was available regarding the magnitude of erosion specific to each community. Communities with infrastructure threatened by riverbank erosion are: Fort McPherson, Tsiigehtchic, Fort Good Hope, Norman Wells, Tulita, Fort Simpson, Hay River and Fort Smith.

3.2.4 WILDFIRES

Wildfire is an important natural process of the boreal forest, whose biodiversity is dependent on fire disturbance. Given the dry summers of NWT, the landscape is typically affected by wildfires every summer. From a given latitude, trees are not able to grow due to cold climate conditions. The delimitation is called the treeline. In NWT, the treeline concerns Canada's boreal forest (which consists in closed-crown conifer forests with a conspicuous deciduous trees) and the Arctic tundra (mainly composed of composed of dwarf shrubs, sedges and grasses, mosses, and lichens). The treeline progresses northward from east to west towards the Mackenzie Delta. Therefore, communities surrounded by forested areas are located in every region of the NWT (the entire area of Dehcho and Sahtu, 80% of South Slave, 70% of North Slave and 30% of Beaufort Delta).

In the context of climate warming, it is expected to see a structural shift in northern forest in terms of growth form and stand dynamics, towards denser tree cover and taller trees (Payette *et al.*, 1989; Payette and Lavoie, 1994). However, given that the treeline was spatially stable despite the changes in climate during the last 3500 years, the northward expansion of the treeline is expected to significantly lag climate warming (MacDonald *et al.*, 1998). In terms of fire activity, the increased biomass and reorganization of the vegetation in the boreal forest and subarctic ecoregion could favor fires of higher intensity (Sulphur *et al.*, 2016), but it is not believed that the communities located above the present-day treeline will be at risk of fire activity during the next century.

There is no statistically significant trend in increasing wildfire activity at the territorial scale, based on the fire history map available from NWT Geospatial Atlas (Figure 15). Despite the lack of statistical trend, visual inspection of Figure 15 suggests that years of extreme fire activity increased in intensity from 1965 onwards. Wildfires need fuel to burn, so the frequency of extreme forest fires should not accelerate substantially to leave time for biomass accumulation between their occurrence. It is expected that this upward trend will continue during the 21st century. Indeed, at a larger spatiotemporal scale, rapid climate warming at the geological timescale is associated with increased wildfire activity (Marlon et al. 2009). Despite the projected increase in precipitation, studies show that the occurrence of large wildfire could increase by 34% by the end of the century in the boreal forest of Ontario and Manitoba (Girardin et al. 2008).

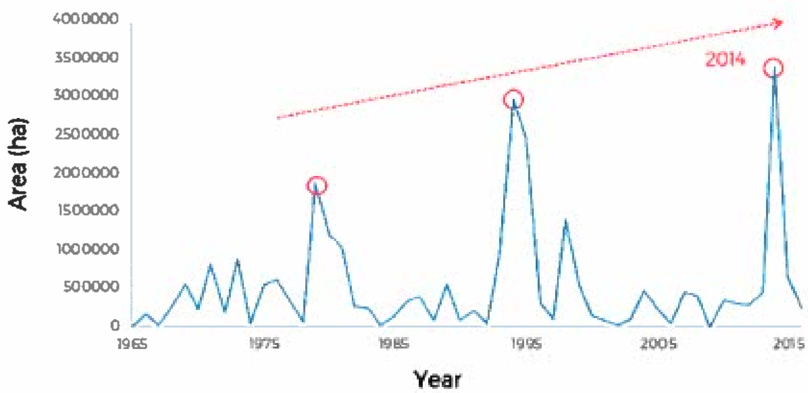

Figure 15 **Forest area burned per year in the NWT between 1965 and 2016 (source: NWT Fire Management Division, 2016)**

3.2.5 PERMAFROST

Permafrost is defined as ground having a temperature that remains negative for a period of at least two consecutive years. The surface cover plays a major role in the fluctuations of permafrost temperatures (vegetation, organic matter, snow thickness), and permafrost thickness depends on several factors, such as the geological conditions, air temperature and soil characteristics of the region under study.

In the specific context of the Northwest Territories, permafrost has a major effect on the hydrology, hydrogeology, landscape and ecology. From north to south, NWT communities are located in continuous, discontinuous and sporadic areas of permafrost (Figure 16). Resiliency of most infrastructure components depend on the stability of permafrost characteristics in each community. Permafrost is indeed the foundation of most northern communities, and information about the evolution of its condition is key to plan and manage almost all infrastructure in the most efficient way possible. Permafrost thawing may lead to soil and slope instability, soil subsidence, and ground movement, thereby potentially impacting building assets via damaged building foundation, increased repair/maintenance, decreased safety to workers and the public, increased risk for loss of infrastructure integrity leading to a condemned infrastructure, and reduced aesthetics and/or public perception of safety.

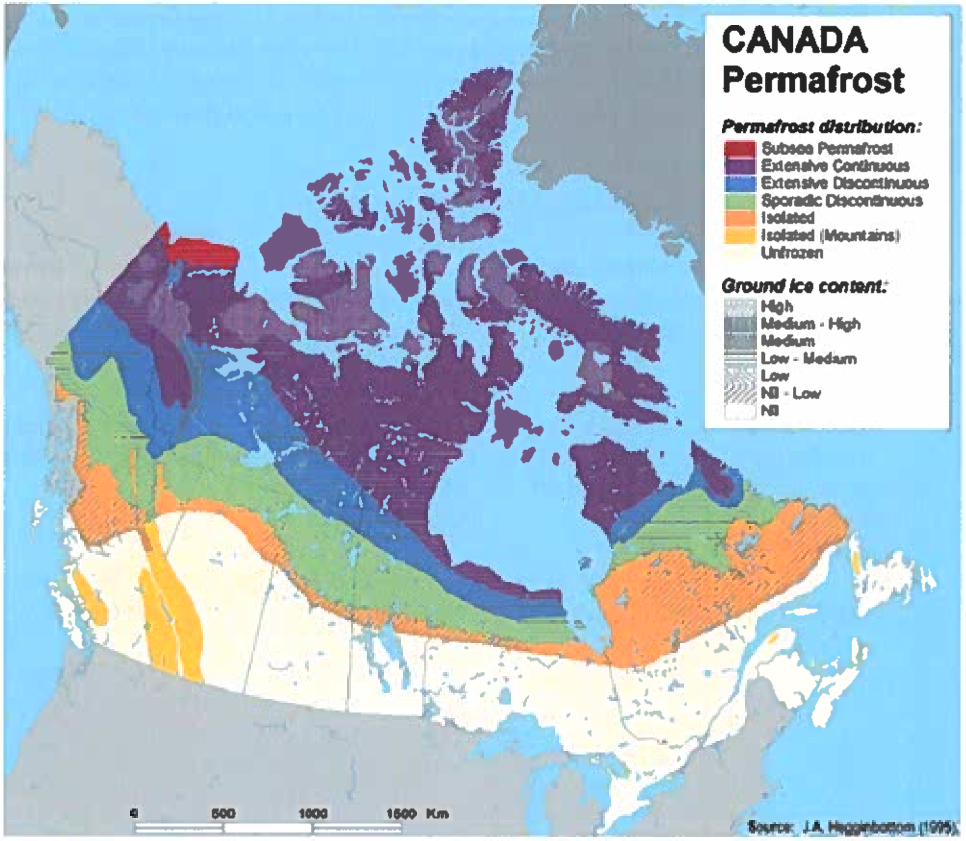

Figure 16 **Types of permafrost in Canada at the end of the 20th century (Environment and Natural Resources – NWT, 2014)**

Under the influence of climate change, permafrost thawing is becoming one of the main issues that NWT will have to face in the near future (NRCan, 2016). Some consequences are already visible in several communities where foundations of building and road infrastructure is rapidly deteriorating.

Table 8 summarizes the historical characteristics of permafrost in each of the five regions identified in the NWT. Permafrost thaw is thus mostly related to air temperature increase. The basic hypothesis is that the southern limit of discontinuous permafrost in North America tends to coincide with the isothermal line of the mean annual air temperature of -1°C. The assumption is that if the annual mean temperature is >-1°C, the probability of permafrost thaw is increased. However, the level of risk due to permafrost thawing also varies with other parameters:

- The ice content of permafrost is an important parameter to consider for permafrost thawing: the greater ice content is, the larger is thawing (MacKay, 1972). Identifying ice-rich permafrost allows sustainable planning and accurate delimitation of most sensitive areas.
- Permafrost thawing is also exacerbated when rainfall is increasing. Precipitation as rain transports heat down to the ice contained in the ground, making it melt, which is a process called thermo-erosion (i.e. it creates positive feedback loops). An increase in annual mean precipitation, in the number of heavy rain precipitation events, in the intensity of major precipitation events or a combination of these are indicators of higher risk of permafrost thawing. If several of these trends occur simultaneously, thawing could be accelerated.

The assessment of permafrost degradation in the NWT in the recent past has been challenging due to the lack of specific permafrost mapping of the communities. However, it has been shown that permafrost is warming by 1.5°C / decade in Nunavut according to historical data, which is the closest surrogate that was available (NRCan, 2016). The active layer of permafrost (i.e. the top layer of soil that thaws during the summer and freezes again during the fall) has been deepening at global scale. In NWT, the deepening is estimated at 9 to 21% per decade in Sahtu, Beaufort Delta and Dehcho (Tarnocai *et al.*, 2004). Active-layer monitoring can give early-warning information on the degradation of permafrost. In the coming decades, permafrost covered surface is expected to decrease by 1.6 ± 0.7 million km^2 per 1°C of warming at global scale (Koven *et al.*, 2013), but no regional projections are available for Canadian territories.

Table 8 Historical conditions of permafrost for each NWT region

	South Slave	North Slave	Dehcho	Sahtu	Beaufort Delta
Type of permafrost	Sporadic	Discontinuous	Sporadic to discontinuous	Continuous to discontinuous	Continuous
Ice content	Sandy soil with limited ice content, but ice-rich in Hay River and Fort Smith	Bedrock (not sensitive) + some ice-rich areas	Ice-rich zones in Fort Liard, Fort Simpson, and Nahanni Butte	Ice-rich in most communities	Ice-rich in all communities
Permafrost thermal condition	Warm (-0.5 to 0°C)	Warm (-1 to 0°C)	Warm (-0.5 to 0°C)	Warm (-2 to 0°C)	Warm (-3 to -1°C, for the MacKenzie Delta) Cold (-8 to -5°C, for the oceanic communities)
Current risk of thawing	Low (Moderate for Hay River and Fort Smith)	Moderate (Low for Dettah and Gameti)	Moderate (Low for Wrigley and Jean Marie River)	Moderate	High for the McKenzie delta, Moderate elsewhere
Major historical event	Sinkhole consumed a recreational cabin near Fort Resolution, but likely caused by a lightning strike combined with flowing water (CBC, 2012).	Northern Frontier Visitor Center in Yellowknife closed after sinking and shifting caused by permafrost led to structural problems (Fenn, 2018).			In Inuvik, structural damage on several buildings from shifting grounds: the Igloo Church and a warehouse slated for demolition due to a cracked structure (Ormiston and Seldon, 2019; The Canadian Press, 2019)

Reference: https://www.enr.gov.nt.ca/sites/enr/files/permafrost-homeowners-guide.pdf

3.2.6 WIND

Wind is one of the hardest climate change components to project, both in terms of direction and magnitude. Wind projection is the indirect result of assessing circulation patterns from daily temperature and precipitation outputs from global models.

With the effects of climate change, wind speed will evolve as a function of location and season. In Figure 17, the evolution of wind speed is shown for the end of the 21st century compared to the most recent period. Averaged changes from a 19-member ensemble of CMIP3 global climate models in the mean of the daily averaged 10-m wind speeds (top) and 99th percentile of the daily averaged 10-m wind speeds (bottom) is shown for the period 2081-2100 relative to 1981-2000 (% change), plotted only where more than 66% of the models agree on the sign of the change. Stippling indicate areas with high model agreement.

On the upper panels, we can see that the Northwest Territories will likely experience a non-robust increase in average wind speed during all seasons (blue shade). On the lower panels, winter extreme winds will likely increase (represented here as the 99th percentile of the daily wind speed distribution). Summer extreme winds will decrease in intensity by the end of the century (yellow shade). These changes to extreme winds are not considered robust and equal to plus or minus 5% approximately.

Record historical wind events

Maximum hourly windspeed:

- 97 km/h on 1965/02/25 (Beaufort Coast)
- 87 km/h on 1964/09/04 (South Slave)
- 80 km/h on 1962/08/31 (Sahtu)
- 72 km/h on 1957/09/07 (North Slave)
- 66 km/h on 1974/08/04 (Dehcho)
- 65 km/h on 2008/12/16 (Makenzie Delta)

Maximum gust speed:

- 146 km/h on 2004/08/17 (Dehcho)
- 129 km/h on 1972/10/02 (South Slave)
- 117 km/h on 1962/08/31 (Sahtu)
- 113 km/h on 1956/11/23 (North Slave)
- 113 km/h on 1973/01/28 (Beaufort Coast)
- 109 km/h on 1964/12/21 (Mackenzie Delta)

Wind can cause damages to infrastructure directly through extreme gusts, indirectly by spreading wildfire or coupled with heavy precipitation. Storms with extreme wind gust speeds occur almost annually in northernmost communities. During the workshop, stakeholders mentioned that gusts above 150 km/h occurred annually recently in Beaufort Delta and Sahtu regions.

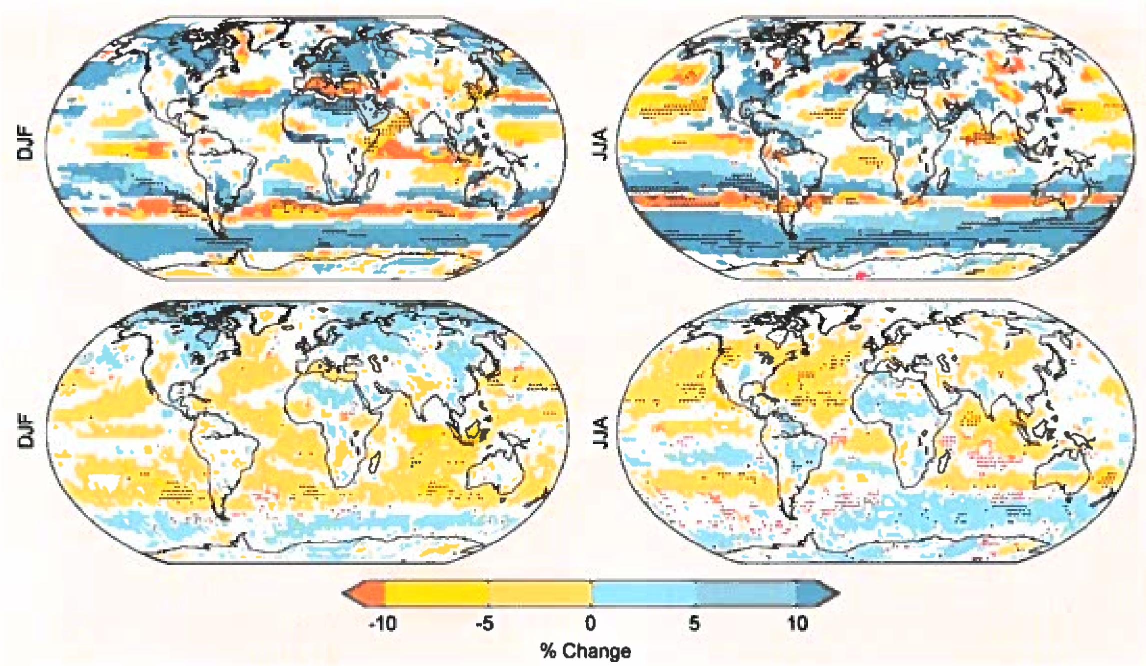

Figure 17 **Change in daily average windspeed (upper panels) and extreme windspeed (lower panels), for winter (left panels) and summer (right panels) months.**

Source: from Collins *et al.* (2013)

3.3 DATA SUFFICIENCY ASSESSMENT

WSP has used the best available resources to inform professional judgements on the assets studied.

With regards to infrastructure thresholds and location, confirmation and complementary information was provided through the GNWT stakeholder workshop held in Yellowknife. As previously mentioned, the high-level nature of the assessment makes it impossible to evaluate the vulnerability of each and every GNWT- and community-owned infrastructure located within or associated with the 33 NWT communities. Thus, infrastructure vulnerability was established through expert judgement and reliable scientific literature, as well as input from experienced MACA staff and other relevant stakeholders. Members of the Northwest Territories Association of Communities (NWTAC) were not able to attend the workshop with the various other stakeholders, and as such, their valuable anecdotal local knowledge has not been extensively included in the assessment. This has been addressed as a data gap and opportunity for further study in Section 5.2.

Climate information was for the most part of excellent quality. Historical data from ECCC is precise and accurate. Climate change data portals such as the Climate Atlas of Canada and climatedata.ca present the most up-to-date information regarding expected climate change projections. Projections of high-intensity precipitation events are however more uncertain, as projections are based on the daily outputs of global climate models, spatially downscaled to a regional level, that do not take into account local conditions that influence extreme precipitation events, such as topography. However, the projected increases fall within the best practice guidelines derived from a peer-reviewed research about trends in extreme precipitation at the scale of Canada (Mailhot *et al.* 2012). Also, even if there is a low confidence in the numbers, there is a high likelihood to observe an increase.

Local, reliable projections regarding certain climate parameters and climate-related hazards are not readily available. That is the case for permafrost thawing, sea-ice extent, sea-level rise, coastal storms and wildfire activity. Scientific literature, available near-by surrogate information and professional judgement was thus used. The absence of local data on permafrost condition was overcome by extrapolating from regional permafrost conditions. However, permafrost condition will be spatially variable within a region depending on geomorphological, micro-climatic, hydrological, hydrogeological and ecological factors, as well as the built environment.

Flood zones were delineated from the data available on the NWT Geospatial Atlas. However, most of this data is based on the highest known water level, in the absence of flood modeling.

Including traditional knowledge was beyond the scope of the assessment but would provide valuable inputs in historical local climate trends, especially in the context where instrumental data is scarce or lacking in some regions.

4 RISK ASSESSMENT

This chapter combines the remaining requirements of defining climate threshold values and establishing changing-climate probability scores (Step 2) to calculate the level of risk associated with each climate/infrastructure interaction, and thus providing a risk profile of all GNWT community assets (Step 3). Section 4.1 details every component of the risk assessment and the different scales and matrices used, while Section 4.2 presents the results of the assessment and describes the corresponding risk profiles.

4.1 RISK ASSESSMENT COMPONENTS

The objective of a climate-change risk assessment is to identify and describe risks to key infrastructure based on climate and weather effects and vulnerabilities.

Risk (R) is defined as the product of the likelihood of a climate/infrastructure interaction occurring and the severity of the impacts resulting from this interaction. To properly define infrastructure risk profiles, there are key components to establish and steps to follow. When a climate/infrastructure interaction is identified, infrastructure thresholds with regards to climate parameters must first be defined. Then, an evaluation of the likelihood or probability (P) of these thresholds being triggered by a specific climate parameter changing over the time horizon of the assessment must be done. Severity of the consequences (S) on the infrastructure as well as economy, society and the environment is also evaluated for each interaction. Risk is thus calculated using the following formula:

VULNERABILITY

Vulnerability is the degree to which an infrastructure component is likely to suffer from a specific impact.

$$R = P \times S$$

It is important to mention that both probability and severity are assessed independently from one another. Probability of climate change triggering a threshold is not to be influenced by the severity of possible consequences, and vice-versa.

4.1.1 INFRASTRUCTURE THRESHOLDS

In order to assess the vulnerability of an infrastructure to climate change, it is important to know the climate thresholds the infrastructure was designed to. If a climate parameter exceeds this design threshold, the infrastructure is vulnerable to changing climate conditions, and will have an increased risk of facing issues into the future (Figure 18).

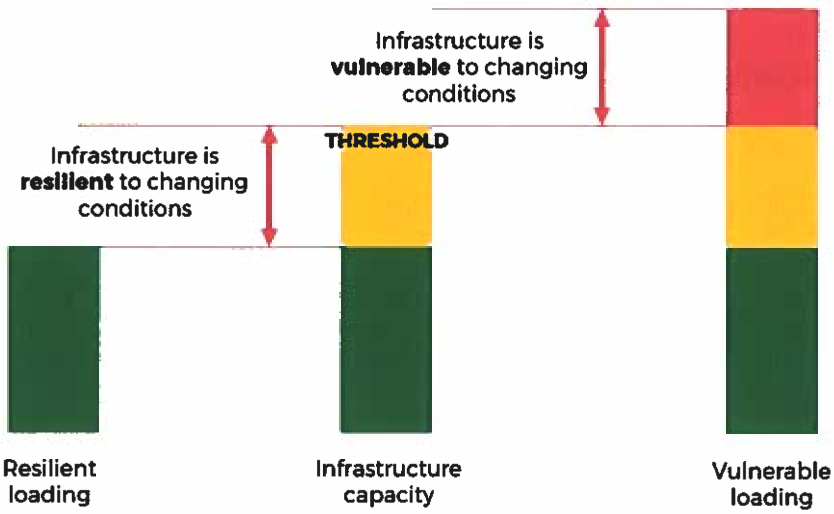

Figure 18 Design thresholds and vulnerability to climate change

For this assessment, the thresholds were defined using a variety of methods and tools. Design criteria from national design standards and codes adopted by the GNWT were selected when available, such as for snow load or drainage capacity. For wind, the thresholds follow the Enhanced Fujita scale damage indicators from Environment and Climate Change Canada (ECCC). When no design criteria existed, 1976-2005 historical means were selected. The assumption behind this choice is that the existing assets adequately function in present-day conditions but exceeding these values could have various impacts.

To ensure consistency within the assessment, WSP defined the thresholds with the same method in the different regions, but the threshold value varies according to the specific climate of each region. In Table 9, we present, document and justify the parameters that were used to elaborate the threshold. The specific regional values of the thresholds are presented in Appendix B. When the historical mean is used as a threshold, the assumption is that the infrastructure works adequately in present-day conditions.

Table 9 Definition of climate thresholds selected

Threshold	Infrastructure type	Clearly document the source of the threshold value.	Provide justification for the threshold value selected.
January temperature < X °C	Buildings	National Building Code (NBC), 2015, Table C2	The 2.5% January design temperature is the value used in design of heating system.
July temperature > X °C	Buildings	NBC, 2015, Table C2	The 2.5% July design temperature is the value used in design of cooling and dehumidifying system.
Annual cooling degree days > X	Buildings	Historical mean from the Climate Atlas of Canada	Cooling Degree Days are equal to the number of degrees Celsius a given day's mean temperature is above 18°C. and is used to estimate how much air-conditioning is required in a year.

Threshold	Infrastructure type	Clearly document the source of the threshold value.	Provide justification for the threshold value selected.
Lowest annual minimum temperature < X °C	Buildings Civil Energy	Historical mean from the Climate Atlas of Canada	Extreme minimum temperature will affect thermal performance of buildings and the freezing of water.
Heating degree days > X	Buildings	Historical mean from the Climate Atlas of Canada	The rate of consumption of energy needed to keep the interior of a small building at 21°C when the outside air is below 18°C is proportional to the difference between 18°C and the outside temperature.
Total annual precipitation > X mm	Buildings	NBC, 2015, Table C2	The average annual total precipitation interpolated from precipitation observations from 1379 stations from 1961-1990.
Total annual rain > X mm	Buildings	NBC, 2015, Table C2	The total amount of rain that normally falls is used as a general indication of wetness.
1:5 24-hour maximum precipitation > 40 mm	Buildings Civil Energy	Kokelj et al., 2015	A significant increase in magnitude and intensity of rainfall was linked in the Peel Plateau region with regional acceleration in thaw slump activity
1:50 24-hour maximum precipitation > X mm	Buildings	NBC, 2015, Table C2	Roof drainage design is typically done using 1:10 15-minutes maximum precipitation. NBC 2015 indicates that if roof drainage becomes ineffective due to increased load, that 1:50 24-hour maximum precipitation could be used.
1:5 24-hour maximum precipitation > X mm 1:100 24-hour maximum precipitation > X mm	Storm main Civil (culverts)	City of Yellowknife Municipal Stormwater Management Plan (March 2011) ECCC, IDF Curve	Design of minor and major system components are typically based on historical IDF curves

Threshold	Infrastructure type	Clearly document the source of the threshold value.	Provide justification for the threshold value selected.
Snow load > X kPa	Buildings	NBC, 2015, Table C2	Vertical load transformation into snow depth was done using the following formula: $$s = h\rho g$$ where: h= height (m) s = pressure (Pa) ρ = snow density (kg / m3) g = gravity (9,8 m/s2) Snow density values are defined by Paterson (1994).
Daily snow accumulation > 10cm	Buildings Civil Energy	Expert judgment	Strong wind conditions in winter combined with major snow episodes can cause snow drift and prevent access to roads and strategic buildings.
Winter precipitation > X mm	Civil Energy	Historical mean from the Climate Atlas of Canada	Increased winter precipitation will pose a risk to most civil infrastructure (e.g. increased structural load, increased maintenance), but could also have a positive impact due to insulating effect of snow. All mains are located under plowed roads. This threshold is thus not considered for sewer and water mains.
Annual number of freeze-thaw cycle > X	Buildings Civil Energy	Historical mean from the Climate Atlas of Canada.	Freeze-thaw cycles deteriorate many infrastructure components.

Threshold	Infrastructure type	Clearly document the source of the threshold value.	Provide justification for the threshold value selected.
Maximum gust > X km/h	Buildings Civil Energy	ECCC Enhanced Fujita Scale damage indicators	Threshold varies by type of infrastructure and level of damages. Heritage churches: 70 km/h Elementary school: 75 km/h Manufactured homes: double wide / trees (falling on electric transmission lines): 80 km/h Metal building systems / Small barns or farm outbuildings / Small professional buildings less than 500 m^2: 85 km/h Institutional buildings: 95 km/h Free standing light poles / Electric transmission lines: 110 km/h Free-standing towers: 120 km/h
Maximum hourly wind pressure > X kPA	Energy (fuel storage facility)	NBC, 2015 Table C2	No similar type of infrastructure in the ECCC enhanced Fujita scale of damage. Hourly wind pressure is converted in hourly wind speed using the following formula: $Q = 1.6V^2$ Where: Q: wind pressure (Pa) V: wind velocity (m/s)
Daily maximum gust > 60km/h	Buildings Civil Energy	Experts judgement	Strong wind conditions in winter combined with major snow episodes can cause snow deflation and prevent access to roads and strategic buildings.
Change in hail episodes and lightning: qualitative threshold	Buildings Civil Energy	Experts judgement	Probability and severity of consequences will be based on historical events.
Length of frost-free season > X days	Buildings Civil Energy	Historical mean from the Climate Atlas of Canada.	The assumption is that the infrastructure adequately functions in present-day conditions.

Threshold	Infrastructure type	Clearly document the source of the threshold value.	Provide justification for the threshold value selected.
Number of annual heat waves > X	Buildings Civil Energy	Historical mean from the Climate Atlas of Canada.	Heat waves will increase evaporation rates and the likelihood of wildfires.
Number of days above > X °C	Buildings	Historical mean from the Climate Atlas of Canada.	During really hot days, evaporation will increase, which will increase the likelihood of wildfires.
Total summer precipitation > X mm.	Buildings Civil Energy	Kokelj et al., 2015	Permafrost degradation is linked to summer moisture conditions.
Number of heavy precipitation (> 10mm) days > X days	Buildings Civil Energy	Kokelj et al., 2015 Historical mean from the Climate Atlas of Canada.	Permafrost degradation is enhanced by the thermal conductivity of water.
Summer wind conditions	Buildings Civil Energy	Expert judgements based on CIMP5 climate projections.	Increased wind in summer will be favourable to the spreading of wildfires.
Sea ice cover < X%	Buildings Civil Energy	Experts judgement based on CIMP5 climate projections.	Reduced sea ice cover will increase the coastal vulnerability to erosion. Increased erosion rates will put coastal infrastructure at risk.
Sea level rise > X mm	Buildings Civil Energy	Experts judgement based on CIMP5 climate projections.	Increased sea level will affect the risk of submersion and coastal erosion to coastal infrastructure.
Annual mean temperature > -1°C	Buildings Civil Energy	Brown, 1960, Brown, 1966	The southern limit of discontinuous permafrost in North America tends to coincide with the isothermal line of the mean annual air temperature of -1°C. The assumption is that if the annual mean temperature is >-1°C, the probability of permafrost thaw is increased.

4.1.2 CHANGING-CLIMATE PROBABILITY SCORES

Climate change probability scores help to create the risk profiles. As mentioned above, the probability score is defined as the synoptic likelihood that a specific climate parameter will change over the time horizon of the assessment such that one or more of the infrastructure thresholds defined in the previous section is triggered.

The scale used to evaluate the probability score for each climate parameter/infrastructure threshold interaction follows Method A of the Protocol (Table 10).

Table 10 PIEVC Protocol probability score definitions (Method A)

Score	Probability
0	Negligible / Not applicable
1	Highly unlikely /Improbable
2	Remotely possible
3	Possible / Occasional
4	Somewhat likely / Normal
5	Likely / Frequent
6	Probable / Very frequent
7	Highly probable / Approaching certainty

Given the quantity of thresholds and justifications for the different infrastructure types, an Excel spreadsheet was compiled for each infrastructure type. These are presented in Appendix C, along with the complete risk profile.

4.1.3 SEVERITY OF IMPACTS

The last component needed to complete the risk profiles is the severity score of consequences on the infrastructure from each climate/infrastructure interaction. All relevant infrastructure responses are considered, which include effects such as:

- Structural design – safety; load carrying capacity;
- Loss of functionality – level of service; level of effective capacity; component selection;
- Serviceability – ability to conduct routine maintenance activities;
- Watershed and environmental effects – discharge quality in sensitive fisheries environments;
- Material performance – rate of degradation, capacity to achieve expected level of performance;
- Operations and maintenance – occupational safety; equipment performance; functional and effective capacity; changes from design expectation; pavement performance;
- Emergency response – procedures and systems to address severe storm events, flooding, water damage, road closures;
- Insurance considerations – rates; ability to insure; policy limitation or exclusions;
- Policy and legal considerations – codes; guidelines; internal policies and procedures; land use planning;

- Social effects – public safety, transportation of goods to a community; accessibility to critical facilities such as hospitals, fire and police services; community business viability; public perception, reputation and interaction, archaeological resources, heritage values, impacts on vulnerable populations (e.g. children, elderly) and First Nations territorial impacts.

The severity of these infrastructure responses is scored according to the severity scale shown in Table 11, which follows Method E of the Protocol.

Table 11 PIEVC Protocol severity score definitions (Method E)

Score	Severity of consequences and effects
0	Negligible / Not applicable
1	Very low / Some measurable change
2	Low / Slight loss of serviceability
3	Moderate loss of serviceability
4	Major loss of serviceability / Some loss of capacity
5	Loss of capacity / Some loss of function
6	Major / Loss of function
7	Extreme / Loss of asset

The severity scores differ for each climate/infrastructure interaction, but are consistent between regions, the only exception being threshold values related to permafrost, as permafrost composition and distribution differ from one region to another. Thus, severity ranking is higher in Beaufort Delta, moderate in the North Slave and Sahtu regions (-1 on the severity score) and -2 in the southernmost regions of South Slave and Dehcho.

As was done for the changing-climate probability scores, an Excel spreadsheet for the severity scores was compiled for each infrastructure type (Appendix C).

4.2 RISK PROFILE

The Protocol suggests three levels of risk (R) tolerance thresholds (high, moderate, low). For better-oriented recommendations and following expert judgement, the moderate risk tolerance level for this assessment has been divided into two thresholds (moderate-low and moderate-high). Table 12 presents the risk score ranges and the appropriate response associated with each threshold.

Table 12 Risk categories and associated response

Risk (R) range	Threshold	Response
< 12	Low risk	No action necessary
12 – 27	Moderate-low risk	Monitor climate and infrastructure parameters Action may be required
28 – 41	Moderate-high risk	Monitor climate and infrastructure parameters Action may be required Targeted analysis (Step 4) may be required to reassess risk
> 41	High risk	Targeted analysis (Step 4) may be required to reassess risk Immediate action required

7	Special case	Investigation required into reasoning or impact for a probability score of 7 or a severity score of 7. Overall risk should be revised based on secondary assessment.

Low risk interactions represent no immediate vulnerability. There tends to be a low potential for the climate variable to change and therefore the infrastructure is not at a higher risk than before. Medium risk interactions represent a potential vulnerability to infrastructure. Moderate-low risk may require additional monitoring of frequency of events or other action. Within the moderate-high risk threshold, there may be the requirement for additional monitoring or engineering analysis to further define the risk involved. If the risk is clear, then action may be required based on the infrastructure owner's risk tolerance. High risk interactions represent a definite vulnerability. It is recommended that the infrastructure owner takes immediate action to remediate the issue and prevent infrastructure failure (Engineers Canada 2016). Special cases refer to risks with either a high probability of occurrence (7) and a low severity of consequences (1), or a low probability of occurrence (1) and a high severity of consequences (7). These scenarios should be scrutinized by the practitioner to ensure the risk is fully understood.

Preliminary risk profiles for every infrastructure type and region were developed by WSP and then reviewed and validated with relevant stakeholders during a workshop held in Yellowknife on March 3rd and 4th, 2020. The probability (P) and severity (S) scales and their rationale were discussed, and adjustments were made to better reflect the stakeholders' perception and appreciation of the risk tolerance thresholds. Final risk profiles were then issued. Of the 1,902 interactions assessed, there were:

- 12 high risk interactions (6 on buildings, 4 on energy infrastructure, and 2 on civil and municipal infrastructure, R > 41);
- 179 moderate-high risk interactions (R = 28 – 41);
- 989 moderate-low risk interactions (R = 12 – 27);
- 673 low risk interactions (R < 12); and
- there were also 49 special cases (R = 7).

The distribution of these scores across sectors is detailed in Figure 19. An overall risk rating was determined as appropriate using expert judgement by considering the relative severity of the event if it were to occur independently of the probability ratings identified in Table 12.

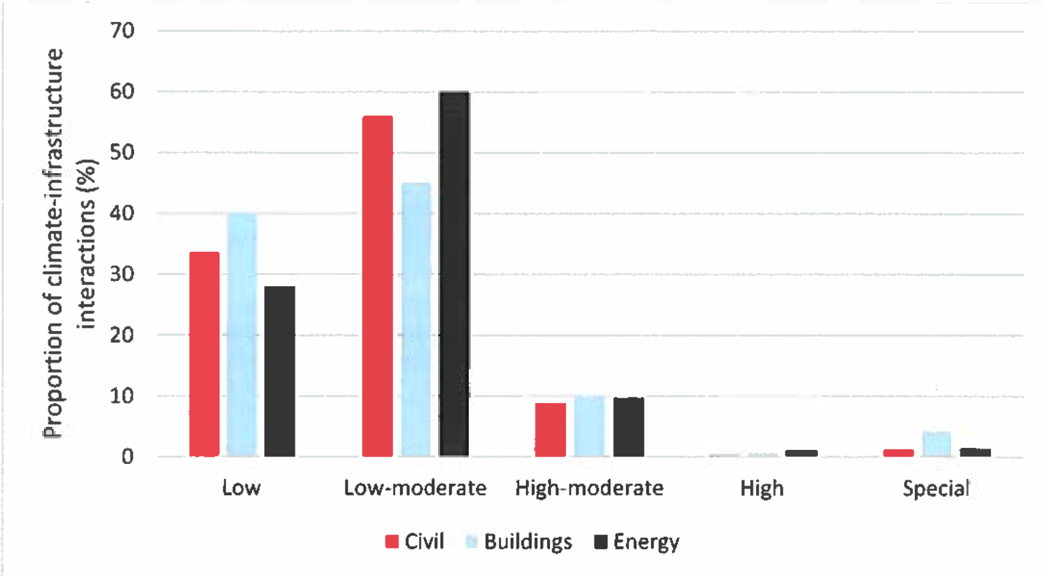

Figure 19 Distribution of risk scores across sectors (civil, buildings and energy)

The profiles for overall high risks and moderate-high risks for every infrastructure type are presented below. The complete risk profiles are included in Appendix C. In the regional summaries below, the climate hazards are split in six categories:

1. Temperature hazards (e.g. heat waves, freeze-thaw cycles);
2. Precipitation hazards (e.g. short-duration extreme precipitation, heavy snow fall);
3. Wind hazards (e.g. wind gust);
4. Permafrost degradation (induced by temperature or precipitation);
5. Wildfire activity;
6. Fluvial flooding and coastal hazards (including coastal flooding and erosion).

The 49 special cases were related to the risk associated with an increase in temperature, with small consequences such as a slight increase in coolingrequirements. Given the severity of consequences were really low, they were transferred to the low-risk category through consensus in the workshop.

4.2.1 CIVIL AND MUNICIPAL INFRASTRUCTURE

Table 13 presents a summary of the risk profile for the civil and municipal infrastructure. A complete profile is available in Appendix C. Roads, water and waste water treatment plants, sewage lagoons, culverts and drainage structure, as well as sanitary sewer mains are the infrastructure categories with the highest risk level at the territorial scale. In Beaufort Delta, water treatment plants and sewage lagoons risk level to permafrost thaw is high. For the former, permafrost thaw could shut down the operations of a critical service. For the latter, the failure of containment of the lagoons could result in sewage spills.

Extreme precipitation represents a moderate-high risk for water / wastewater treatment plants and drainage structures. For the former, the risk is mostly associated with snow load on the building structure. Damage to the roof structure could shut down plant operations. For the drainage structures, the risk is associated with short-duration extreme rain events. As these events increase in intensity, the design capacity of the culverts or other drainage structures could be exceeded, resulting in flooding events. Permafrost degradation represents the highest hazard to civil and municipal infrastructure, as it can affect the integrity of surface or below ground components as well as the structural integrity of buildings. Wildfires are expected to mostly affect roads, bridges, solid waste sites and drainage structure. During the workshop, the stakeholders considered that wildfires did not pose a threat to sewage lagoons, although it is likely that the berms and the surroundings of the lagoons are vegetated. A wildfire in proximity with a sewage lagoon can affect the integrity of the berms and cause a failure of containment. In Beaufort Delta region, fluvial and coastal hazards will affect most infrastructure types, as Aklavik is completely located in the 10-year return period ice jam flood zone and Tuktoyaktuk is almost completely located in a zone sensitive to coastal erosion or in the 100-year storm-surge zone.

Temperature is expected to have a moderate-high impact on ferries and marine transportation centers. The increase in temperature represents an opportunity as the lengthening of the frost-free season could result in an extended period of operations.

4.2.2 BUILDING INFRASTRUCTURE

Table 14 presents a summary of the risk profile for the buildings. A complete profile is available in Appendix C. At the scale of the territory, community housing units, schools, hospitals and health centers, fire stations, as well as garages and fuel containers are the categories with the highest risk level.

Snow load is a major concern for buildings, as the roof of a school collapsed in Inuvik in 2004. While a lot of roofs have been retrofitted since, in 2010, 12% of the roofs were on high alert for snow-load related collapse (Auld et al. 2010). As permafrost continues to thaw, the loss of structural integrity due to ground settlement will result in greater impacts from snow load (Murray et al., 2012), especially in the context of the ongoing trend towards wetter, heavier snow fall, as noted by some of the workshop attendees. Snow accumulation is also a concern for the community housing units, as the envelope of these buildings is not always weatherproof as it ages. The melting of snow accumulated on the exterior walls of the building promotes leakage and water accumulation within the interior components of the envelope. This will cause accelerated degradation and the development of mold, which will in turn result in health hazards to the occupants. Permafrost thawing is also a major concern for buildings, especially in regions where the ice content is higher (Sahtu and Beaufort Delta). In these regions, the risk level concerning permafrost for schools, hospitals, health centers and fire stations is considered high, since they provide critical services and can be occupied by vulnerable populations. During the workshop participants mentioned that the hospital in Inuvik is exposed to building settlement.

Given the fact that most buildings are located in a community and are not directly surrounded by forest, the stakeholders that attended the workshop mentioned that the severity of consequences for wildfires should be moderate, as people could be evacuated before being in danger. However, the severity of consequences remained high for community housing as some of the units are located in remote locations, for hospitals and health centers as the occupants will be harder to evacuate, and for fuel storage containers given the explosion hazard.

Fluvial flooding is a considered a moderate-high risk in South Slave and Beaufort Delta given the flooding history that affected some of the communities in these regions, mostly Hay River and Aklavik. Houses in Nahanni Butte and Fort Good Hope are also located near the river banks and could be prone to flooding. In Tuktoyaktuk, all building assets are located within the zone sensitive to coastal submersion and erosion. Coastal submersion and erosion are also expected to pose a threat to housing in Paulatuk and Ulukhaktok.

4.2.3 ENERGY INFRASTRUCTURE

Table 15 presents a summary of the risk profile for the energy infrastructure. A complete profile is available in Appendix C. Fuel storage facilities and tank farms and fuel resupply and shoreline manifolds were identified as high risk at the territorial scale in Sahtu, and Beaufort Delta. All energy infrastructure was identified as moderate-high risk at the territorial scale, especially in Dehcho, Sahtu, and Beaufort Delta, which are regions where communities are mostly dependent on fuel-based energy sources.

Temperature-induced permafrost thaw was identified as high risk for fuel storage facilities and tank farms, and fuel resupply and shoreline manifolds in Sahtu and Beaufort Delta. Temperature-induced permafrost thaw was also identified as moderate-high risk for all energy infrastructure in at least one region, and cumulative rain-induced permafrost thaw was also identified as moderate-high risk for fuel storage facilities and tank farms, power plants, and fuel resupply and shoreline manifolds in at least one region. Permafrost thaw could seriously damage energy infrastructure and the risk threshold of high risk and moderate-high risk was mostly due to the potential for loss of infrastructure function and fuel spills, and with consideration given to the relative ice content of permafrost in each region.

Wildfires were identified as moderate-high risk for fuel storage facilities and tank farms, power plants, solar farms, power poles, and fuel resupply and shoreline manifolds. Wildfires could seriously damage energy infrastructure and the risk threshold of moderate-high risk was mostly due to the potential for loss of infrastructure and explosion.

Sea level rise, stronger storm surges, higher tides and coastal erosion were identified as moderate-high risk for fuel storage facilities and tank farms, power plants, and fuel resupply and shoreline manifolds in Beaufort Delta, and fluvial flooding was identified as moderate-high risk for fuel storage facilities and tank farms in Beaufort Delta. The risk threshold of moderate-high risk for sea level rise, stronger storm surges, higher tides, coastal erosion, and fluvial flooding was mostly due to the potential for loss of infrastructure function. Communities such as Tuktoyaktuk are located within the zone sensitive to coastal submersion and communities such as Aklavik, are historically sensitive to flooding.

Fuel resupply and shoreline manifolds could be sensitive to snowstorms. Snowstorms could delay distribution of fuel to communities in the Northwest Territories, which is vital especially in northern communities, and accidents could lead to fuel spills, and thus snowstorms exhibit a moderate-high risk. Extreme precipitation was also identified as moderate-high risk for fuel storage facilities and tank farms. Extreme precipitation events could impact the containment capacity of the infrastructure, which would subsequently reduce a level of safety in the event of a fuel spill.

Table 13 **Risk profile for infrastructure from the civil and municipal sectors**

Civil and municipal infrastructure type	North Slave						South Slave						Dehcho						Sahtu						Beaufort Delta					
	T*	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F
Ferry	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Mod-high	Mod-low	Mod-low	Mod-low	Low	Low	N/A	N/A	N/A	N/A	N/A	N/A	Mod-high	Mod-low	Mod-low	Mod-high	Low	Mod-low
Road	Low	Mod-low	None	Mod-low	Mod-high	Low	Mod-low	Mod-low	None	Mod-low	Mod-high	Mod-low	Mod-low	Mod-low	None	Mod-low	Mod-high	Mod-low	Low	Mod-low	None	Mod-high	Mod-high	Mod-low	Low	Mod-low	None	Mod-high	Mod-high	Mod-high
Bridge and causeway	Mod-low	Mod-low	None	Mod-low	Mod-low	Low	Mod-low	Mod-low	None	Mod-low	Mod-low	Mod-low	Mod-low	Mod-low	None	Mod-low	Mod-low	Mod-low	Low	Mod-low	None	Mod-high	Mod-low	Mod-low	Low	Mod-low	None	Mod-high	Mod-high	Mod-low
Water treatment plant	Low	Mod-high	Mod-low	Mod-high	Mod-low	Mod-low	Low	Mod-high	Mod-low	Mod-low	Mod-low	Mod-high	Low	Mod-high	Mod-low	Mod-low	Mod-low	Mod-low	Low	Mod-high	Mod-low	Mod-high	Mod-low	Mod-low	Low	Mod-high	Mod-low	High	Mod-high	Mod-high
Waste water treatment plant	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Low	Mod-high	Mod-low	Mod-low	Mod-low	Mod-low	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sewage lagoon	Mod-low	Mod-low	None	Mod-high	None	Mod-low	Mod-low	Mod-high	None	Mod-low	None	Mod-high	Mod-low	Mod-low	None	Mod-low	None	Mod-low	Low	Mod-low	None	Mod-high	None	Mod-low	Low	Mod-low	None	High	None	Mod-high
Solid waste site	Mod-low	Mod-low	None	Mod-low	Mod-low	Low	Mod-low	Low	None	Mod-low	Mod-low	Low	Mod-low	Mod-low	None	Mod-low	Mod-low	Low	Mod-low	Mod-low	None	Mod-high	Mod-low	Low	Mod-low	Mod-low	None	Mod-high	Mod-high	Mod-high
Culverts / drainage structure	Mod-low	Mod-high	None	Mod-low	Mod-high	Low	Mod-low	Mod-low	None	Mod-low	Mod-high	Low	Mod-low	Mod-low	None	Mod-low	Mod-high	Low	Mod-low	Mod-low	None	Mod-high	Mod-high	Low	Mod-low	Mod-high	None	Mod-high	Mod-high	Mod-high
Street sign	Low	Low	Low	Mod-low	Mod-low	Low	Low	Low	Low	Low	Low	Mod-low	Low	Low	Low	Low	Low	Mod-low	Low	Low	Low	Mod-low	Mod-low	Mod-low	Low	Low	Low	Mod-low	Mod-low	Mod-low
Street lighting	Mod-low	Low	Low	Mod-low	Mod-low	Low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low
Watermain	Mod-low	None	None	Mod-low	Mod-low	None	Mod-low	None	None	Mod-low	Mod-low	None	Mod-low	None	None	Mod-low	Mod-low	None	Mod-low	None	None	Mod-low	Mod-low	None	Mod-low	Mod-low	None	Mod-low	Mod-low	Mod-low
Sanitary sewer main	Mod-low	Mod-low	None	Mod-high	Mod-low	None	Mod-high	Mod-high	None	Mod-low	Mod-low	Mod-high	Mod-low	Mod-low	None	Mod-low	Mod-low	Mod-low	Mod-low	Mod-low	None	Mod-high	Mod-low	None	Mod-low	Mod-low	None	Mod-low	Mod-low	None
Storm water sewer main	Mod-low	Mod-low	None	Mod-low	None	Low	Mod-low	Mod-low	None	Mod-low	None	Mod-low	Mod-low	Mod-low	None	Mod-low	None	Mod-low	Mod-low	Mod-low	None	Mod-low	None	Mod-low	N/A	N/A	N/A	N/A	N/A	N/A
Park and golf course	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Low	Mod-low	Low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Low	Low	Mod-low	Mod-low	Mod-low	Mod-low	Mod-low
Graveyard	Low	Mod-low	None	Mod-low	Mod-low	Low	Low	Mod-low		Low	Mod-low	Mod-low	Low	Mod-low	None	Mod-low	Mod-low	Mod-low	Low	Mod-low	None	Mod-low	Mod-low	Mod-low	Low	Mod-low	None	Mod-low	Mod-low	Mod-high
Drinking water well	Mod-low	Mod-low	None	None	Mod-low	Mod-low	N/A	N/A	N/A	N/A	N/A	N/A	Mod-low	Mod-low	None	None	Mod-low	Mod-low	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*T: Temperature P: Precipitation Wi: Wind Pf: Permafrost W: Wildfire F: Flooding and erosion
Low risk · Moderate-low risk · Moderate-high risk · High risk · No climate-infrastructure interaction · Not assessed or absent from region
Risk level specific to a climate hazard · Regional risk level for a type of infrastructure

Table 14 Risk profile for buildings

Building type	North Slave						South Slave						Dehcho						Sahtu						Beaufort Delta					
	T*	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F
Community housing unit	ML	MH	ML	ML	MH	ML	MH	MH	ML	ML	MH	ML	ML	MH	ML	ML	MH	ML	ML	MH	ML	MH	MH	ML	ML	ML	ML	MH	MH	MH
Office	L	ML	ML	ML	ML	L	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	L	ML	ML	MH	ML	ML	L	ML	ML	MH	ML	MH
School	ML	MH	ML	MH	ML	ML	MH	MH	ML	ML	ML	MH	ML	MH	ML	ML	ML	ML	ML	MH	ML	H	ML	ML	ML	MH	ML	H	ML	MH
Hospital and health center	ML	MH	L	MH	MH	ML	ML	MH	L	ML	MH	MH	ML	MH	L	ML	MH	MH	ML	MH	ML	H	MH	MH	ML	MH	ML	H	MH	MH
Fire station	L	ML	ML	MH	MH	ML	ML	MH	ML	ML	MH	MH	ML	ML	ML	ML	MH	ML	L	ML	ML	H	MH	ML	L	ML	ML	H	MH	MH
Recreation infrastructure	L	ML	ML	ML	ML	L	ML	MH	ML	ML	ML	ML													L	ML	ML	MH	ML	MH
Community center	L	ML	ML	ML	ML	L	ML	MH	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	L	ML	ML	MH	ML	ML	L	ML	ML	MH	ML	ML
Garage and container	L	ML	ML	ML	MH	L	L	ML	ML	ML	MH	ML	L	ML	ML	ML	MH	ML	L	ML	ML	MH	MH	ML	L	ML	ML	MH	MH	ML
Greenhouse	L	ML	ML	ML	MH	L																			L	ML	ML	MH	MH	ML

*T: Temperature P: Precipitation Wi: Wind Pf: Permafrost W: Wildfire F: Flooding and erosion
Low risk · Moderate-low risk · Moderate-high risk · High risk · No climate-infrastructure interaction · Not assessed or absent from region
Risk level specific to a climate hazard · Regional risk level for a type of infrastructure

Table 15 **Risk profile for infrastructure from the energy sector**

Energy infrastructure type	North Slave						South Slave						Dehcho						Sahtu						Beaufort Delta					
	T*	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F	T	P	Wi	Pf	W	F
Fuel storage – Tank farm	Low	Moderate-high	Moderate-low	Moderate-high	Moderate-low	Low	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-low	Low	Moderate-low	Moderate-low	High	Moderate-high	Moderate-low	Low	Moderate-high	Moderate-low	High	Moderate-high	Moderate-high
Power plant	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Moderate-high
Solar farm	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-high	Moderate-low	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Power line and poles	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-high	Moderate-low	Moderate-low
Telecommunication	Moderate-low	Moderate-low	Low	Moderate-low	Moderate-low	Low	Moderate-low	Moderate-low	Low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Low	Moderate-high	Moderate-low	Moderate-low	Moderate-low	Moderate-low	Low	Moderate-high	Moderate-low	Moderate-low
Fuel resupply / Shoreline manifold	Low	Moderate-high	No climate-infrastructure interaction	Moderate-high	Moderate-high		Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Low	Moderate-high	No climate-infrastructure interaction	High	Moderate-high	No climate-infrastructure interaction	Low	Moderate-high	No climate-infrastructure interaction	High	Moderate-high	Moderate-high

*T: Temperature P: Precipitation Wi: Wind Pf: Permafrost W: Wildfire F: Flooding and erosion

Low risk Moderate-low risk Moderate-high risk High risk No climate-infrastructure interaction Not assessed or absent from region

Risk level specific to a climate hazard Regional risk level for a type of infrastructure

5 CONCLUSION AND RECOMMENDATIONS

This final chapter meets the requirements of Step 5 of the Protocol. Assumptions, limitations and data gaps are discussed in Section 5.1. WSP's recommendations for general adaptation measures for the major risks that were identified and their impacts on the infrastructure of the NWT's 33 communities are listed in Section 5.2.

5.1 ASSUMPTIONS, LIMITATIONS AND DATA GAPS

For the effective application of the Protocol to a high-level assessment, the following assumptions were made:

- **Climate trends will be similar at the regional level:** Although the raw data is available for the most common climate variables, climate modelling at the scale of the communities requires extensive data processing, requiring additional effort.. Since most communities within a region are located close enough, the trends should be similar enough for this level of assessment. However, the climate projections presented should not be used for design and it is the professional responsibility of the designer to review climate data for each specific site;
- **Permafrost sensitivity will be homogeneous within the boundaries of each community:** Permafrost distribution maps were not available at the scale of each community, except for Jean Marie River and Dettah. Thus, permafrost distribution from the 5th edition of the National Atlas of Canada has been used, to which has been applied isothermal line of the mean annual air temperature of −1°C for future conditions as per Brown (1960, 1966);
- **Risk to infrastructure located close to the historical floodplain has been assessed according to how critical their services are to the public.** No data on expected trends in flood levels in the context of climate change is available. For example, a recreation park located next to a flood zone would not be considered as critical as a hospital.

There is an inevitable level of uncertainty to consider in using climate modeling as it relies in part on our understanding of future greenhouse gas emissions. Downscaling regional or global climate models to generate local climate projections can be helpful, though users must bear in mind that the projections resulting from the downscaling process will generally have additional uncertainty introduced by this process. Recommendations are therefore provided based on the best information available at this stage of the study. Despite this uncertainty, taking action to implement adaptation measures addressing the higher risks will increase the resilience of the concerned infrastructure.

WSP recognizes that, often, much more detailed information is needed to adequately review risk. As a result, much of this assessment is qualitative, confirmed through the stakeholder workshop, and recommendations are made as to where additional study will be useful for each region and/or community. As one of the objectives of this assessment was to determine where to focus future efforts, remaining data gaps are addressed through recommendations in section 5.2.

Cost estimates were impossible to provide given the high-level nature of the assessment and the lack of data to ensure proper accuracy of the estimates.

5.2 RECOMMENDATIONS AND ENGINEERING CONSIDERATIONS

In accordance with the requirements from Step 5 of the Protocol and the high-level nature of the assessment, WSP proposes general adaptation measures for the high and moderate-high risks that were identified and their impacts on every type of infrastructure as selected for each infrastructure category (civil, buildings, energy). These adaptation measures are also presented for each of the NWT's 33 communities in a summary sheet format (see Appendix D), along with maps of climate change potential impacts on infrastructure (see Appendix E).

Climate change information is constantly evolving. As new model outputs are produced, it is likely that:

- the uncertainty regarding some climate parameters (e.g. IDF curves) will substantially decrease;
- new climate indicators that better capture risk to infrastructure will become available (e.g. wind speed, rate of permafrost thawing, magnitude and frequency of ice jams, region-specific heat wave indicators including humidity);
- climate data and projections will become available at a better spatial resolution;
- projected climate trends will be modified.

Along with changes in socioeconomic conditions, in demography and in community development, this ongoing improvement in climate science will contribute to the need of updating this assessment. The best practices prescribe an update of any climate change risk assessment every five years.

- It is therefore the recommendation of WSP that GNWT reconduct this assessment in five years.

Cascading effects refer to a chain of events between the primary impact of a climate hazard and its secondary consequences. Interacting risks refer to multiple impacts on a single system. While they have the potential to be cumulative, cascading effects and interacting risks were beyond the scope of this assessment but can exacerbate the risk level. Therefore, priority should be made for infrastructure that is sensitive to cascade events regardless of specific infrastructure risk since its failure could critically affect other infrastructure. For example, the following scenarios or combinations thereof could lead to flooding induced cascading events:

- Extreme precipitation plus inadequate/undersized drainage infrastructure;
- Ice jams;
- Sea-level rise; and
- Storm surges.

Potential flooding induced cascade events include but is not limited to:

- Permafrost thaw settlement and subsequent damage to infrastructure;
- Flooded basements;
- Bridge and road washouts; and
- Erosion of underlying soils that may damage infrastructure in a similar manner as described for permafrost thaw settlement.

We therefore recommend that GNWT engage local stakeholders to capture the potential cascading effects and interacting risks. Including traditional knowledge was beyond the scope of the assessment but would provide valuable inputs in historical local climate trends, especially in the context where instrumental data is scarce or lacking in some regions. Additionally, a lot of the information necessary to conduct the assessment was gathered during the workshop which could not be attended by knowledgeable stakeholders. These stakeholders identified gaps in the project at a stage where conducting new analyses was not possible. As a result, we recommend that the following topics be covered as a follow-up to this assessment or in a second iteration of a climate change impact assessments:

- Consider ice jam flooding and open water flooding as two separate hazards as they do not necessarily affect the same communities. Moreover, projected trends in the frequency and magnitude of both hazards might differ as they are caused by a different set of hydroclimatic events;
- Assess the impacts to the hydrogeological regime in more detail as it relates to permafrost degradation;
- Include riverbank erosion and slumping as a separate hazard, as many communities are experience high rates of land loss due to this hazard;
- Analyze the trends in changing wind direction and its impact on infrastructure;
- Include the recollections of extreme historical events by the different stakeholders;
- Verify if fluvial erosion and flooding are relevant hazards in Paulatuk and Ulukhaktok;
- Consider that fluvial erosion and slumping are amongst the major threats to graveyards in many communities;
- Verify if future results regarding net sea level rise and isostatic readjustment of the continental crust modifies the risks associated with coastal hazard. These are ongoing research topics by ECCC and the Geological Survey of Canada.

5.2.1 EFFECTS OF PERMAFROST DEGRADATION

The interaction of temperature-induced permafrost thaw on water treatment plants and sewage lagoons were identified as high risk in Beaufort Delta. The interaction of temperature-induced permafrost thaw on schools, hospitals, fire stations, fuel storage facilities and tank farms, and fuel resupply and shoreline manifolds, were also identified as high risk in Sahtu and Beaufort Delta. Temperature-induced permafrost thaw was identified as moderate-high risk for all infrastructure except street signs, stormwater sewer mains, and drinking water wells in at least one region, and cumulative rain-induced permafrost thaw was also identified as moderate-high risk for schools, hospitals, fire stations, fuel storage facilities and tank farms, power plants, and fuel resupply and shoreline manifolds in at least one region.

Factors that contribute to higher risk includes the following:

- Relative ice content of permafrost in each region;
- Failure/loss of function of infrastructure that provide essential service;
- Sewage spills;
- Fuel spills; and
- Potential for contamination of potable water.

The absence of permafrost mapping at the community scale is one of the major data gaps of this assessment. However, the NWT Geological Survey is in the process of completing permafrost mapping at the community scale[3], which would be helpful in refining the risk profile related to permafrost.

- Coordinate with NWT Geological Survey that is in the process of gathering, processing and analysing permafrost data from geotechnical reports on public infrastructure in a centralized database.
- Refine the permafrost risk based on the release of permafrost hazard maps at the community scale by NWT Geological Survey, expected for 2021.
- Review all newly released permafrost data to continuously identify infrastructure that may be susceptible to permafrost thaw so that mitigation efforts can be implemented.

The following recommendations are general recommendations for most infrastructure potentially impacted by permafrost thaw, and additional recommendations for specific infrastructure are given in subsequent sections. It should be noted that the recommendations given are adaptations related to permafrost thaw only. For example, some effects of seasonal frost heave can resemble those produced by thaw settlement, and some of the actions to mitigate seasonal frost are opposite for permafrost thaw (Northern Infrastructure Standardization Initiative (NISI) Training Course 2020). Thus, confirmation of the presence of permafrost is recommended.

- Maintain proper site grading and drainage to facilitate rapid drainage of surface water away from infrastructure; provide splash pads for all downspouts.
- Avoid installation of new construction around existing infrastructure that could negatively affect the permafrost thermal regime.
- Maintain adequate ventilation by ensuring air spaces and ducts are not obstructed and screens are not clogged.
- Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote cooling of permafrost in winter and allowed to remain in place to insulate the ground in the spring.
- Manage snow so that melt water in the spring does not pond around infrastructure.
- Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
- Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components.
- Monitor and document the effectiveness of existing mitigation measures that have been implemented such as thermosyphons (refer to CSA-S500-14 - Thermosyphon foundations for buildings in permafrost regions) or mechanical cooling.
- Consider shading the ground on the south facing side of infrastructure with vegetation or solar shades.
- Re-level buildings regularly to mitigate structural damage and ensure that drainage elements are working as intended to direct drainage away from the building.
- Refer to CSA-S501-14 - Moderating the effects of permafrost degradation on existing building foundations for more detail on the above recommendations.

[3] https://www.nwtgeoscience.ca/services/northwest-territories-thermokarst-mapping-collective

5.2.1.1 PERMAFROST THAW - DRAINAGE INFRASTRUCTURE

- Engage a professional engineer when planning to excavate drainage ditches or swales in ice-rich permafrost.
- Inspect, maintain, and monitor drainage infrastructure.
- Increase snow clearing efforts for municipal and building drainage infrastructure.

5.2.1.2 PERMAFROST THAW - WATERMAINS AND SANITARY SEWER MAINS (BELOW GROUND)

- Consider use of pipe with restrained joints, especially for critical areas when replacing below ground sanitary sewer mains.
- Limit the length of time that sections of excavations and installation of infrastructure are done.
- Engage geotechnical engineer with knowledge of permafrost to provide design and construction recommendations for pipe installations.

5.2.1.3 PERMAFROST THAW - PARKS AND GOLF COURSES

Consider reframing the perception of permafrost thaw as a potential opportunity. Specific examples of potential opportunities are as follows:

- Collaborate with elders, climate change and permafrost experts, and local teachers to create and install educational interpretive panels in parks about climate change and permafrost thaw.
- Incorporate climate change and its impacts in local school programs.
- Allow a golf course to deform while keeping the par score and advertise the golf course as the only course to become more challenging over time.
- Advertise sites for tourists to visit where permafrost thawing can be safely viewed.
- Apply for additional funding/grants for research, pilot studies, etc., and then advertise to universities to conduct research in Beaufort Delta on adaptation and mitigation studies.
- Encourage engineering schools to have design competitions to solve specific permafrost related problems and then encourage the students to present their potential solutions in the communities.

5.2.2 WILDFIRES

Wildfires were identified as moderate-high risk for most infrastructure in at least one region and factors that contribute to higher risk includes the following:

- Risk to people and difficulty with evacuations;
- Fire damage or loss of infrastructure that provide essential service; and
- Explosion –Hydrocarbon fuels can explode under some conditions when exposed to an ignition source (ie vapour cloud explosion or explosion of pressurized tanks due to heat of wildfire)..

The following recommendations are general recommendations for most infrastructure potentially impacted by wildfires, and additional recommendations for specific infrastructure are given in subsequent sections.

- Increase emergency preparedness efforts (Refer to CSA S504:19: Fire resilient planning for northern communities)
  - Conduct wildfire exposure assessments for critical infrastructure so that mitigation efforts can be prioritized.
  - Prepare/update emergency infrastructure-based wildfire preparedness plans with input from the Fire Marshal of each community and with input from staff where possible; update the plan after wildfire events and share findings with other communities.
  - Ensure that infrastructure-based wildfire preparedness plans are reviewed and updated annually by communities prior to fire season.
  - Ensure that each plan has an assigned designated responsible staff member.
- Increase FireSmart efforts for vegetation removal and maintenance within a 10 m radius of infrastructure; and vegetation reduction (especially dead trees and debris piles) within 30 m radius; and on slopes.
- Assess fire suppression resources and capacities i.e. fire pumps, nearby water bodies, hydrants on water distribution system, water reservoirs, and wells.
- If fire suppression capacity is insufficient, engage professional engineer to identify suitable upgrades.
- Explore additional water delivery options such as helicopter, airtanker, etc.
- Do not permit development in areas at high-risk for wildfires.

5.2.2.1 CIVIL, BUILDINGS, AND ENERGY INFRASTRUCTURE WITH BUILDING STRUCTURES

- Inspect infrastructure and replace flammable materials with fire resistant materials in high risk areas.
- Remove accumulated debris from roofs and gutters regularly.
- Renovated or new construction should be built with fire resistant materials.

5.2.2.2 FUEL-STORAGE FACILITIES, TANK FARMS, AND OTHER FUELS

- Clean up all spilled flammable fuels, especially around fuel storage tanks.
- Furnish fuel tank tops with water or foam sprinklers.
- Consider increasing redundancy by splitting and distributing fuel to low-risk areas.
- Close propane tank valves when not in use.
- Locate propane tanks at least 10 m from buildings/structures.

5.2.2.3 POWER POLES, ROADS, AND FUEL RESUPPLY

- Reduce and maintain vegetation along powerline, road, and pipeline rights-of-way.
- Remove vegetation down to bare mineral soil or gravel surface at the base of power transformers, switches or at distribution sites.

- Identify and remove hazard trees to reduce powerline ignitions and interruptions.

5.2.2.4 OTHER CONSIDERATIONS

During the risk workshop, sewage lagoons and buildings located in the centre of communities were not considered by MACA to be at risk to wildfires.

Wildfires can damage infrastructure via radiant heat and can ignite infrastructure when flammable materials are within 30 m (Beverly *et al.*, 2010). Short-range ember transport (up to 100 m) is a common feature of most wildfires, long-range ember transport (100-500 m) is less common, but possible, and very long-range ember transport (500-2000 m) is observed under extreme fire behavior conditions (Beverly *et al.*, 2010). Thus, a wildfire exposure assessment for all infrastructure that was not considered is recommended.

5.2.3 ANNUAL PRECIPITATION

Annual precipitation was identified as moderate-high risk for sewage lagoons and sanitary sewer mains in South Slave region and as moderate-low risk in all other regions, as infiltration allowances factored into design and actual design capacities are unknown. To reduce the impact of increased annual precipitation on sewage lagoons and sanitary sewer mains, the following are recommended:

- Monitor, evaluate, and adjust operational procedures for sewage lagoons to maintain capacity as required.
- Install rain guards in sanitary sewer manholes.
- Consider prioritizing sanitary sewer main sections that are most vulnerable to loss of capacity (i.e. downstream sections) when undertaking upgrade or replacement projects.

5.2.4 EXTREME PRECIPITATION

Extreme precipitation was identified as moderate-high risk for drainage infrastructure and fuel storage facilities in North Slave and Beaufort Delta regions. To reduce the potential impact of extreme precipitation on drainage infrastructure, the following is recommended:

- Consult with engineering professionals to assess and identify site specific drainage vulnerabilities.
- Consider the recommendations listed for drainage infrastructure under the permafrost section (see above).
- Refer to CSA S503:15 Community Drainage System Planning, Design, and Maintenance in Northern Communities, for guidance on inspection and maintenance of community drainage systems.

Since extreme precipitation could impact the secondary containment capacity of fuel storage facilities reducing the safety factor in the event of a fuel spill, the following is recommended:

- Ensure that an adequate means for water removal from containment structures (i.e. pump, hose, etc.) is readily available and staff are familiar with their use.

5.2.5 FROST-FREE SEASON

Frost-free season was identified as moderate-high risk for ferry infrastructure in Dehcho and Beaufort Delta. However, projected increases in the length of the frost-free season may be an opportunity for these communities. An increase in the length of the frost-free season could extend the seasonal length of ferry operations. The following are recommended:

- Increase budgets to allow for operational expenses such as additional staffing hours and increased seasonal fuel consumption.
- Investigate slow steaming versus extra staffing costs (resulting from longer travel times) to optimize operational expenses.
- Develop (or revise) a seasonal tourism plan, to optimize increased potential tourism-related revenue.

5.2.6 HEAVY SNOWFALL AND SNOWSTORMS

To reduce the potential impact of heavy snowfall and snowstorms on affected infrastructure, the following is recommended:

- Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
- Ensure portable back-up generators for critical infrastructure are available in the event of power outages and that they are regularly tested and maintained.
- Consult with CSAS505:20 *Techniques for considering high winds and snow drifting and their impact on northern infrastructure* when assessing options for reducing the risk of damage.

5.2.7 FREEZING RAIN AND FREEZE-THAW

The following recommendations are general recommendations for most infrastructure potentially impacted by freezing rain and freeze-thaw, and additional recommendations for specific infrastructure are given in subsequent sections.

- Perform regular inspections of infrastructure after freezing rain and freeze-thaw events and document any noticeable changes; repair or replace damaged components as required.
- Increase budgets to account for increased power costs, increased staffing levels, purchase of additional equipment to deal with freezing rain and freeze-thaw events, shorter life expectancy of affected components; and increased component redundancy.
- Ensure portable back-up generators for critical infrastructure are available in the event of power outages and that they are regularly tested and maintained.
- Apply sand/salt on walkways.
- Train and retrain staff in safe operating practices.

5.2.7.1 WATER TREATMENT PLANTS AND WASTEWATER TREATMENT PLANTS

Freezing rain and freeze thaw events can potentially increase weathering of outdoor infrastructure components (i.e. freeze-thaw can exacerbate corrosion) which may reduce service life of infrastructure components. It can also potentially cause damage to electrical components that could lead to power loss or loading damage that could lead to roof collapse. To ensure that critical infrastructure such as water treatment plants and wastewater treatment plants remain operational the following is recommended.

- Improve process control to deal with freezing rain and freeze-thaw events.
- Add redundancy for critical equipment that could be affected by freezing rain and freeze-thaw events.

5.2.7.2 SANITARY SEWER MAINS (UNDER GROUND)

- Ensure that non-frost susceptible fill is used when installing underground infrastructure in regions that are susceptible to freeze-thaw.

5.2.8 COASTAL HAZARDS AND FLUVIAL FLOODING

Along with permafrost, flooding hydrological or hydrogeomorphological modeling is a major data gap to identify the return period, the spatial extent and the water levels of floods at the community scale. For Aklavik, high resolution flooding (open water and ice-jam) maps based on recent studies were available. However, for most communities, the flood zone is defined by historical events, with no associated return periods. According to discussions with stakeholders, the Water Resources Division of the Department of Environment and Natural Resources (ENR) is currently updating flooding information for the communities.

- Coordinate with ENR to include new flooding information and adapt the risk profile in terms of flood hazard at the community scale.
- Make sure that flood modelling includes ice-jam induced floods as the water levels associated with this process are usually higher.
- Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities.
- Develop site specific flood mitigation and adaptation options for the projected sea level rise. These might include building and/or increase elevation of sea walls, dikes, etc., in coastal regions.
- Do not permit development in floodplains or in areas where existing and future coastal erosion hazards are high.
- Identify and relocate at-risk critical infrastructure.
- Consult with CSA W205:19 *Erosion and sedimentation management for northern community infrastructure*
- Invest in further research for site specific mitigation and adaptation strategies for ice jam induced flooding. Strategies may include the following types of mitigation measures: structural (i.e. dikes, levees, ice booms, or ice storage zones); non-structural (i.e. monitoring and detection, ice cutting, mechanical removal, or ice breaking); or emergency (i.e. sandbagging and/or evacuation).

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APPENDIX

A JURISDICTION AND GUIDELINES

Category	Items
Jurisdictions that have direct control/influence on the infrastructure;	– The Northwest Territories has a consensus system of government instead of one based on party politics; – All members (19) are elected as independents; – Election of Speaker and Cabinet (6) by secret ballot; – Remaining members have the balance of power; – The communities of the Northwest Territories are incorporated in several ways, under a variety of legislation; – First Nations Designated Authorities are incorporated in communities where the Band government is the primary authority for delivering municipal services; – Jurisdictions that have direct control/influence on the infrastructures are hard to identify.

Sections of laws and bylaws that are relevant to the infrastructure;	– Waters Act S.N.W.T. 2014, c.18
	– Mackenzie Valley Resource Management Act S.C. 1998, c. 25
	– Yellowknife By-laws (only applicable in Yellowknife):
	    – No.4469: Building By-Law
	    – No. 4996: Emergency Management By-Law
	    – No. 3965: Cemetery By-Law
	    – No. 4502: Emergency Responses and Fire Service By-Law
	    – No. 4656: General Plan By-Law 2011
	    – No. 4564: Public Parks and Recreation Facilities By-Law
	    – No. 4376: Solid Waste Management By-Law
	    – No. 4663: Water and Sewer Service By-Law
	    – No. 4404: Zoning By-Law
	– Smaller communities have their own bylaws or follow higher level regulations.

Sections of regulations that are relevant to the infrastructure;	– Public Health Act – Public Sewerage Systems Regulations R.R.N.W.T. 1990, c.P-22 – General Sanitation Regulations R.R.N.W.T. 1990, c.P-16 – Water Supply Systems Regulations R.-108-2009 – Guidelines for Canadian Drinking Water Quality
Standards that are relevant to the design, operation and maintenance of the infrastructure;	– The National Building Code of Canada and the National Fire Code of Canada have been adopted in the NWT – Table C2 presents the climate design criteria for buildings. – The 2017 National Energy Code has been adopted by GNWT – The 2015 National Plumbing Code is in force in the GNWT – The 2018 Canadian Electric Code is in force in the GNWT – CSA-B149 is the gas code in force in the GNWT – Specifications for fuel facilities are provided in the references
Guidelines that are relevant to the design, operation and maintenance of the infrastructure;	– Canadian Standards Association documents developed under the Northern Infrastructure Standardization Initiative (NISI) – NISI 101 illustrated guides and videos – Good Building Practices for Northern Facilities (2019, Draft), DPW&S- GNWT, Fourth Edition – Northern Land Use Guidelines, GNWT 2015 – Northwest Territories Seismic Operations – Access (roads and trails) – Pits and quarries – Guideline for Industrial Waste Discharges in the NWT – Good Engineering Practice for Northern Water and Sewer Systems (2017), MACA-GNWT, Second Edition

APPENDIX

B

REGIONAL THRESHOLDS

Climate Parameter	North Slave	South Slave	Dehcho	Sahtu	Beaufort D.
Mean minimum winter temperature (°C)	-41	-38	-42	-43	-39
Mean maximum summer temperature (°C)	25	27	26	28	18
Summer cooling degree-days (#)	19	36	31	22	9
Lowest minimum temperature	-44	-43	-44	-45	-44
Heating degree-days (#)	8,170	7,300	7,660	8,510	9,150
Total annual precipitation (mm)	275	150	350	250	250
Total annual rain (mm)	175	175	220	140	80
1:50 24-hr rain (mm)	60	60	44	60	33
1:5 24-hr rain (mm)	36.1	47.0	47.1	33.5	N/A
1:100 24-hr rain (mm)	67.2	84.7	82.7	77.8	51.2
Snow load 1:50 (kPa)	2.2	2.3	2.3	2.9	1.5
Total winter precipitation (mm)	48	58	70	49	36
Freeze-thaw cycles (#)	42	53	58	41	35
Wind gust (km/h)	75 / 80 / 85 / 95 / 110 / 120				
Hourly wind pressure 1:10 (kPa)	0.36	N/A	0.30	0.34	0.31
Hail and lightning impact	Qualitative				
Frost-free season (# days)	102	108	105	95	65
Sea-ice extent, sea-level rise, storm surges	N/A				Qualitative
Days with temperature > 34 °C (#days)	0	0	0	0	0
Number of annual heat waves (#/year)	0	0.2	0	0	0
Permafrost: annual temperature (°C)	-1	-1	-1	-1	-1
Permafrost: summer precipitation (mm)	92	118	165	108	77
Permafrost: 1:5 24-hr precipitation (mm)	40	40	40	40	40
Permafrost: days with >10 mm rain (# days)	1.7	3.3	4.3	2.1	1
Wildfire: increased summer wind	Qualitative				
Daily snow accumulation with wind	Snow > 10 cm / Wind > 60 km/h				
Fluvial flooding	Historical floodplain				

APPENDIX

C

INFRASTRUCTURE-SPECIFIC RISK PROFILES

APPENDIX

C-1 CIVIL AND MUNICIPAL

FERRIES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean minimum winter temperature	Mean minimum January temperature < -X	N				N				Y	0	4	0	N				Y	1	4	4	Consequences include damages to piping due to freezing.
Mean maximum summer temperature	Mean maximum July temperature > X °C	N				N				Y	1	1	1	N				Y	4	1	4	Consequences include minor discomfort to office occupants. Severity is low because of the absence of warm night.
Summer cooling degree-days	Summer cooling degree-days > X	N				N				Y	7	1	7	N				Y	7	1	7	Potential for increased energy expenses related to cooling load and staff discomfort, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	N				N				Y	1	4	4	N				Y	1	4	4	Increased heating load. Condensation inside building could cause mold. Localized free-thaw cycles due to the thermal contrast between indoor heating and outdoor temperature could damage building envelope. Increased potential of frozen water/sewer services.
Annual precipitation	Total annual precipitation > X mm	N				N				Y	6	1	6	N				Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Annual rainfall	Total annual rain > X mm	N				N				Y	4	1	4	N				Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm (buildings)	N				N				Y	6	1	6	N				Y	6	1	6	Consequences are leakage and increased humidity in the envelope. Severity is low because 40 mm in 24 hours is moderate.
Snow	Snow load 1/50 > X Kpa (buildings)	N				N				Y	4	4	16	N				Y	3	4	12	Potential damage to roof. Damage could be major, although not occupied during winter conditions, so no health and safety concerns.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	N				N				Y	4	4	16	N				Y	4	4	16	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. Weathering or reduced service life of infrastructure components (i.e. cracking of pavement, corrosion on steel structure). Damage could be major, although not occupied during winter, so no HSE concerns.
Wind	Wind > 85 km/h	N				N				Y	4	3	12	N				Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 120 km/h	N				N				Y	1	6	6	N				Y	2	6	12	Metal panels pulled from the infrastructure.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

FERRIES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Hail and lightning impacts	Qualitative	N				N				Y	3	4	12	N				Y	3	4	12	Potential for reduced function and/or damage of infrastructure components (i.e. damaged building roof or windows, fire from lightning strike)
Frost-free season	Frost-free season > X days	N				N				Y	7	4	28	N				Y	7	4	28	Positive: Extended period of operation and increased marine traffic
Sea ice extent Length of ice-free season	Qualitative	N				N				N				N				Y	4	4	16	Positive: Extended period of operation and increased marine traffic
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Increased erosion and sedimentation may require relocation or increased dredging efforts, and potential flooding events may damage or could lead to loss of infrastructure components
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	N				N				Y	6	2	12	N				Y	4	2	8	Potential increase in cooling load, and increased training in first aid related to heat stroke/heat exhaustion.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	N				N				Y	6	3	18	N				Y	7	5	35	Potential reduced function or failure of infrastructure due to thaw settlement (i.e. loss of structural strength and foundation damage). For Dehcho, severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. Note for Beaufort Delta, increased severity due to potential loss of essential service.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precipitation > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	N				N				Y	6	3	18	N				Y	4	5	20	Potential reduced function or failure of infrastructure due to thaw settlement (i.e. loss of structural strength and foundation damage). For Dehcho, severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. Note for Beaufort Delta, increased severity due to potential loss of essential service.
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	N				N				Y	5	2	10	N				Y	5	2	10	Potential fire damage or failure of infrastructure due to thaw settlement of permafrost (i.e. loss of structural strength and building foundation damage) or fire. Note, reduced severity as marine infrastructure not in forested area.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

ROADS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	3	3	Y	1	3	3	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increased weathering could increase maintenance and repair requirements. In Dehcho, Beaufort Delta and Sahtu, most of roads are gravel roads. The severity is then lower for these regions.
Annual rainfall	Total annual rain > X mm	Y	2	3	6	Y	4	3	12	Y	4	3	12	Y	4	3	12	Y	5	3	15	Increased cracking, pooling, erosion of subbase leading to increased maintenance.
Extreme precipitation	1:100 24hr rain > X mm	Y	6	3	18	Y	5	3	15	Y	5	3	15	Y	5	3	15	Y	6	3	18	Risk of accelerated erosion.
Snow	Mean winter precip > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	Y	6	3	18	Potential for increased snow plowing requirements.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Potential increased cracking of pavement and pavement deformation from frost heaving. Severity is higher in North Slave due to higher population. Increased potential for accidents due to freezing rain
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Potential increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation of infrastructure.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Potential for pavement softening and asphalt bleeding. Low severity because the frequency of heat waves will remain low, although northern pavement design probably does not account for high temperatures.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	5	35	Potential increased maintenance, reduced function, or failure of infrastructure due to thaw settlement of permafrost. Severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. For Beaufort Delta, settling of roads greatly affects the performance and function.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	6	4	24	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	5	20	Potential increased maintenance, reduced function, or failure of infrastructure due to thaw settlement of permafrost. Severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. For Beaufort Delta, settling of roads greatly affects the performance and function.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

ROADS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wildfires	**CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C**	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Potential increased maintenance, reduced function, or failure of infrastructure due to thaw settlement of permafrost and/or fire/extreme heat could damage roads (i.e. cracking of asphalt, melting of asphalt, and igniting asphalt). North Slave, Highway was closed during 2014 fire season which limited the transportation of food and other supplies.
Snow/wind gust	**"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"**	Y	4	5	20	Y	4	5	20	Y	4	5	20	Y	5	5	25	Y	5	5	25	Potential for increased snow plowing requirements, and increased potential of reduced visibility may cause accidents.
Fluvial flooding	**Regional historical floods.**	Y	2	5	10	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	5	5	25	Roads can be damaged or washed away.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

BRIDGES AND CAUSEWAYS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				Rationale
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Potential increased weathering (i.e. cracking of pavement) could increase maintenance and repair requirements.
Extreme precipitation	1:5 24hr rain > X mm	Y	6	4	24	Y	6	4	24	Y	5	4	20	Y	5	4	20	Y	6	4	24	Drainage structures on bridge may not be designed for new extreme events, and could lead to vehicles hydroplaning.
Snow	Mean winter precip > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	Y	6	3	18	Potential for increased snow plowing requirements and subsequent increased traffic disruptions (i.e. one way traffic).
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	Potential increased weathering/reduced service life of infrastructure components (i.e. cracking of pavement, and freeze-thaw can exacerbate corrosion). Increased potential for accidents due to freezing rain.
Hail and lightning impacts	Qualitative	Y	3	3	9	Y	3	3	9	Y	3	3	9	Y	3	3	9	Y	3	3	9	Potential for increased fire events from lightning strike; fire/extreme heat could damage steel and road components of bridges (i.e. deflection and loss of structural integrity of steel, cracking of asphalt, melting of asphalt, and igniting asphalt).
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	N				N				N				N				N				Data gap: what is the design temperature range in terms of expansion / contraction of materials.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	5	35	Potential reduced function or failure of infrastructure due to thaw settlement of permafrost. Severity is a function of the regional ice content and does not necessarily reflect local characteristics.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	5	20	

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

BRIDGES AND CAUSEWAYS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	Y	5	5	25	Y	5	4	20	Y	5	4	20	Y	5	5	25	Y	5	6	30	Potential fire/extreme heat could damage steel and road components of bridges (i.e. deflection and loss of structural integrity of steel, cracking of asphalt, melting of asphalt, and igniting asphalt)
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	4	16	Y	4	4	16	Y	4	4	16	Y	5	4	20	Y	5	4	20	Potential for increased snow plowing requirements, and increased potential of reduced visibility may cause accidents
Fluvial flooding	Regional historical floods.	Y	2	5	10	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	5	5	25	Potential for bridges to be inaccessible or even washed out during heavy flood.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

WATER TREATMENT PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damages to piping due to freezing. Increased energy use and uninsulated in South slave and Dehcho regions.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Potential for increased energy expenses related to cooling load and staff discomfort, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Increased heating load, condensation inside building could cause mold, and localized free-thaw cycles could damage building envelope. Potential of frozen water/sewer services. Increased heating requirements.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Potential for increased energy expenses related to heating load and staff discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	1	6	Y	7	1	7	Y	6	1	6	Y	6	1	6	Y	1	2	2	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Annual rainfall	Total annual rain > X mm	Y	2	1	2	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	1	2	2	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Leakage and humidity in the envelope. Severity is low because 40 mm in 24 hours is moderate. Potential for increased turbidity, microbial loading, colour, metals, and other contaminants via resuspension of bottom sediments and subsequently increases disinfection by-products.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	7	21	Y	4	7	28	Y	4	7	28	Y	4	7	28	Y	3	7	21	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot. Severity is high given it is a critical infrastructure.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	7	28	Y	5	7	35	Y	4	7	28	Y	4	7	28	Y	4	7	28	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Potential increased weathering/reduced service life of infrastructure components (i.e. freeze-thaw can exacerbate corrosion) .
Wind	Wind > 85 km/h	Y	3	3	9	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	4	12	Y	3	4	12	Y	3	3	9	Y	4	4	16	Y	4	4	16	Loss of roof covering.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

WATER TREATMENT PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wind	Wind > 120 km/h	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	2	5	10	Y	2	5	10	Failure of exterior door. Some impacts on the furnace.
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Reduced function or damage of infrastructure components (e.g. damaged building roof or windows). PLC impacted.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Erosion and flooding could lead to source water contamination (saltwater, bacteria, sediments). Flooding could damage or lead to loss of infrastructure. Note, increased severity due to potential loss of essential service.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Increase in cooling load, water production demand, and training in first aid related to heat stroke/heat exhaustion. Cold water WTP will help to keep the building cool.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	3	15	Y	6	3	18	Y	7	5	35	Y	7	6	42	Reduced function or failure of infrastructure. Increased severity due to potential loss of essential service, and consideration given to ice content of permafrost. For South Slave and Dehcho: lower severity due to the presence of sporadic discontinuous permafrost.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	3	18	Y	6	3	18	Y	5	5	25	Y	4	6	24	
Wildfires	CUMULATIVE: Increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	Y	5	4	20	Y	5	4	20	Y	5	6	30	Y	5	7	35	Fire damage or failure of infrastructure. Increased severity due to potential loss of essential service.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	3	12	Y	4	3	12	Y	4	3	12	Y	5	3	15	Y	5	3	15	Potential for increased snow removal requirements for access and parking.
Fluvial flooding	Regional historical floods.	Y	2	6	12	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	5	6	30	Source water contamination (i.e. bacteria, sediments, turbidity). Flooding could damage or lead to loss of infrastructure. Note, increased severity due to potential loss of essential service.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

WASTE WATER TREATMENT PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	N				N				Y	0	4	0	N				N				Consequences include damages to piping due to freezing. Increased energy use.
Summer cooling degree-days	Summer cooling degree-days > X	N				N				Y	7	1	7	N				N				Potential for increased energy expenses related to cooling load and staff discomfort, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	N				N				Y	1	4	4	N				N				Potential increased heating load, potential increased condensation inside building could cause mold, and potential increased localized free-thaw cycles could damage building envelope components. Increased potential of frozen water/sewer services.
Heating degree-days	Heating degree-days > X	N				N				Y	1	2	2	N				N				Potential for increased energy expenses related to heating load and staff discomfort.
Annual precipitation	Total annual precipitation > X mm	N				N				Y	6	1	6	N				N				Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the low-humidity conditions. Increased potential of exceeding design capacity
Annual rainfall	Total annual rain > X mm	N				N				Y	4	1	4	N				N				Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the low-humidity conditions. Increased potential of exceeding design capacity
Extreme precipitation	1:50 24hr rain > X mm	N				N				Y	6	3	18	N				N				Consequences are leakage and increased humidity in the envelope. Severity is low because 44 mm in 24 hours is a moderate amount of precipitation. Increased potential of temporarily exceeding design capacity
Snow	Snow load 1/50 > X Kpa (buildings)	N				N				Y	4	7	28	N				N				Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot. Severity is high given it is a critical infrastructure.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	N				N				Y	4	7	28	N				N				An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Potential increased weathering/reduced service life of infrastructure components (i.e. freeze-thaw can exacerbate corrosion) .
Wind	Wind > 85 km/h	N				N				Y	4	3	12	N				N				Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

WASTE WATER TREATMENT PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wind	Wind > 110 km/h	N				N				Y	3	3	9	N				N				Loss of roof covering.
Wind	Wind > 120 km/h	N				N				Y	1	5	5	N				N				Failure of exterior door. Some impacts on the furnace.
Hail and lightning	Qualitative	N				N				Y	3	5	15	N				N				Reduced function or damage of infrastructure components (e.g. damaged building roof or windows). Communications systems impacted.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	N				N				Y	6	3	18	N				N				Potential reduced function or failure of infrastructure due to thaw settlement of permafrost (i.e. loss of structural strength and building foundation damage). Note, increased severity due to potential loss of essential service, and consideration given to relative ice content of permafrost.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	N				N				Y	6	3	18	N				N				
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	N				N				Y	5	4	20	N				N				Potential fire damage or failure of infrastructure. Note, increased severity due to potential loss of essential service, and consideration given to relative ice content of permafrost.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	N				N				Y	4	3	12	N				N				Potential for increased snow removal requirements for access and parking.
Fluvial flooding	Regional historical floods.	N				N				Y	4	6	24	N				N				Increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation of infrastructure. Note, increased severity due to potential loss of essential service. Need to confirm presence of WWTP in flood prone area

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SEWAGE LAGOONS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				Rationale
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Potential increased blockage in flow channel and outlet structure due to freezing, and potential reduced service life of liner.
Annual precipitation	Total annual precipitation > X mm	Y	6	4	24	Y	7	4	28	Y	6	4	24	Y	6	4	24	Y	5	4	20	Potential of exceeding design capacity. Potential for sewage overflow; severity lower as monitoring is anticipated.
Snow	Mean winter precipitation > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	Y	6	3	18	Negative: Increased snow plowing requirements for access roads and parking lot. Positive: Less heat loss due to snow cover, which may extend period for BOD removal. Increased insulation of flow channel and outlet structures may prevent frozen blockages or ice formation and a faster recovery in spring operation.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	N				N				N				N				Potential of reduced function or failure of infrastructure (i.e. containment/liner damage) due to freeze-thaw contraction/expansion stressing and cracking. Freeze thaw would impact clay liners (only in North Slave).
Frost-free season	Frost-free season > X days	Y	7	2	14	Y	7	2	14	Y	7	2	14	Y	7	2	14	Y	7	2	14	Potential for extended period for BOD removal and subsequent change in operation schedule.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Potential increased erosion and flooding could lead to loss of containment and sewage spill. Potential impact on infrastructure may require relocation of infrastructure.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Increase in cooling load, water production demand, and training in first aid related to heat stroke/heat exhaustion. Cold water WTP will help to keep the building cool.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	3	15	Y	6	3	18	Y	7	5	35	Y	7	6	42	Reduced function or failure of infrastructure (containment/liner) due to thaw settlement, and failure of containment could result in a sewage spill.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	3	18	Y	6	3	18	Y	5	5	25	Y	4	6	24	

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SEWAGE LAGOONS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Snow/wind gust	**"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"**	Y	4	3	12	Y	4	3	12	Y	4	3	12	Y	5	3	15	Y	5	3	15	Potential for increased snow removal requirements for access and parking.
Fluvial flooding	**Regional historical floods.**	Y	2	6	12	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	5	7	35	Major health and environmental issues if the lagoon were to be breached. Aklavik Lagoon flows backward toward the community during floods. The others would not have large health risks, but environmental risk is still a concern.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SOLID WASTE SITES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				Rationale
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Potential increased weathering/reduced service life of liner
Snow	Mean winter precip > X mm	Y	6	2	12	Y	5	2	10	Y	6	2	12	Y	6	2	12	Y	6	2	12	Potential for increased snow plowing requirements for access roads and parking lot
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	Potential of reduced function or failure of infrastructure (containment/liner damage) due to freeze-thaw contraction/expansion stressing and cracking of liner and/or frost heaving; failure of containment could cause leachate issues.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Increased erosion and flooding could damage infrastructure leading to containment/leachate issues. Potential impact on infrastructure may require relocation of infrastructure
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Potential increased odour problems
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	5	35	Thaw settlement could reduce function of infrastructure or loss of containment. For South Slave, Dehcho: Severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. For Beaufort Delta: Severity is higher due to the presence of continuous permafrost with high ice content
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	Y	5	5	25	Y	5	4	20	Y	5	4	20	Y	5	5	25	Y	5	6	30	Potential fire damage or thaw settlement could reduce function of infrastructure or loss of containment.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SOLID WASTE SITES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	3	12	Y	4	3	12	Y	4	3	12	Y	5	3	15	Y	5	3	15	Potential for increased snow removal requirements for access and parking
Fluvial flooding	Regional historical floods.	Y	2	2	4	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	5	5	25	Landfills far from the flood zone, hence the low severity. For Beaufort Delta: Landfill located in the flood zone in Aklavik, health and environmental issues.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

CULVERTS / DRAINAGE STRUCTURES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Potential increased weathering/reduced service life.
Extreme precipitation	1:100 24hr rain > X mm	Y	6	5	30	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	6	5	30	Potential loss of function and flooding events.
Snow	Mean winter precip > X mm	Y	6	4	24	Y	5	4	20	Y	6	4	24	Y	6	4	24	Y	6	4	24	Increased potential for drainage/ponding issues during snow melt in spring.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	Potential increased weathering/reduced service life (i.e. freeze-thaw can exacerbate corrosion) and culvert could undergo deformation from frost heaving.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Impacts may require relocation of infrastructure.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	4	28	Thaw settlement could reduce function of infrastructure. For South Slave, Dehcho: Severity is lower due to the presence of sporadic discontinuous permafrost with low ice content. For Beaufort Delta: Severity is higher due to the presence of continuous permafrost with high ice content
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Fire could damage culverts (i.e. deflection and loss of structural integrity) and thaw settlement could reduce function of infrastructure.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	5	20	Y	5	5	25	Flooding could result in backups and flooding outside of the flood plain. Increased maintenance due to sedimentation and increase potential for damage or loss of infrastructure.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

STREET SIGNS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				Rationale
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	1	1	1	Potential increased weathering/reduced service life
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	1	4	Y	5	1	5	Y	4	1	4	Y	4	1	4	Y	4	1	4	Potential increased weathering/reduced service life (i.e. freeze-thaw can exacerbate corrosion and heaving of the concrete foundation)
Wind	Wind > 110 km/h	Y	3	1	3	Y	3	1	3	Y	3	1	3	Y	4	1	4	Y	4	1	4	Visible damage to the infrastructure.
Wind	Wind > 120 km/h	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	2	3	6	Y	2	3	6	Bent or broken poles.
Hail and lightning	Qualitative	Y	3	1	3	Y	3	1	3	Y	3	1	3	Y	3	1	3	Y	3	1	3	Potential for increased fire events from lightning strike; fire/extreme heat could damage infrastructure (i.e. deflection and loss of structural integrity of steel)
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	1	5	Potential increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation of infrastructure
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	2	12	Y	5	1	5	Y	6	1	6	Y	7	2	14	Y	7	2	14	Potential reduced function or failure of infrastructure due to thaw settlement of permafrost. Severity adjusted to regional ice content.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	2	10	Y	6	1	6	Y	6	1	6	Y	5	2	10	Y	4	2	8	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	3	15	Y	5	2	10	Y	5	2	10	Y	5	3	15	Y	5	3	15	Potential fire/extreme heat could damage infrastructure (i.e. deflection and loss of structural integrity of steel) or reduced function or failure of infrastructure.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	2	8	Y	4	2	8	Y	4	2	8	Y	5	2	10	Y	5	2	10	Potential increased snow removal efforts and/or reduced visibility, and potential temporary loss of function (i.e. obstruction of infrastructure)
Fluvial flooding	Regional historical floods.	Y	2	3	6	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	5	3	15	Street signs can be damaged or washed away

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

STREET LIGHTING

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Increased potential for traffic signal malfunctions, which is a safety concern
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	Increased weathering/reduced service life (i.e. freeze-thaw can exacerbate corrosion and heaving of the concrete support). Traffic signal malfunctions, which is a safety concern
Wind	Wind > 110 km/h	Y	3	1	3	Y	3	1	3	Y	3	1	3	Y	4	1	4	Y	4	1	4	Visible damage to the infrastructure.
Wind	Wind > 120 km/h	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	2	3	6	Y	2	3	6	Bent or broken poles.
Hail and lightning	Qualitative	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Potential for fire events from lightning strike; fire/extreme heat could damage infrastructure (deflection and loss of structural integrity of steel)
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Potential increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation of infrastructure
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	Y	5	2	10	Y	6	2	12	Y	7	3	21	Y	7	4	28	Potential reduced function or failure of infrastructure due to thaw settlement of permafrost. Severity adjusted to regional ice content.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	Y	6	2	12	Y	6	2	12	Y	5	3	15	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	4	20	Y	5	3	15	Y	5	3	15	Y	5	4	20	Y	5	5	25	Potential fire/extreme heat could damage infrastructure (i.e. deflection and loss of structural integrity of steel) or reduced function or failure of infrastructure due to thaw settlement of permafrost
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	4	16	Y	4	4	16	Y	4	4	16	Y	5	4	20	Y	5	4	20	Potential increased snow removal efforts and/or reduced visibility, and potential temporary loss of function (i.e. obstruction of infrastructure) could cause accidents.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Street lighting can be damaged or washed away if not properly anchored.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

WATERMAINS*

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Increased potential for freezing could cause loss of service and potential contamination of potable water
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	5	20	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	4	5	20	Increased potential for freeze-thaw contraction/expansion stressing and cracking of watermains/fittings could lead to loss of service and potential contamination of potable water
Hail and lightning impact	Qualitative																	Y	3	4	12	Potential for increased fire events from lightning strike; fire damage could lead to loss of service and potential contamination of potable water or failure of infrastructure
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Potential increased erosion and flooding could damage infrastructure leading to loss of service and potential contamination of potable water. Potential impact on infrastructure may require relocation of infrastructure
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	4	28	Thaw settlement could result in potential loss of service and potential contamination of potable water. Severity adjusted to the regional ice content.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	Y	5	4	20	Y	5	3	15	Y	5	3	15	Y	5	4	20	Y	5	4	20	Potential Loss of service if fire damages fire hydrants.
Fluvial flooding	Regional historical floods.	N				N				N				N				Y	5	6	30	Mains can be damaged or washed away. Water contamination possible.

**Watermains are below ground in every region except in Beaufort Delta where they are above ground in some communities. Watermains are not in every community.*

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SANITARY SEWER MAINS*

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and cold days	Lowest minimum temperature < -X °C	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	1	6	6	Increased potential for freezing could cause minor to severe backups and/or fractures/cracks resulting in sewage spills.
Annual precipitation	Total annual precip > X mm	Y	6	4	24	Y	7	4	28	Y	6	4	24	Y	6	4	24	Y	5	4	20	Potential of exceeding design capacity, dependant on infiltration design criteria.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	Potential for freeze-thaw contraction/expansion stressing and cracking of sewer mains/fittings could lead to loss of service and sewage spills. Severity based on stringent sewage spill regulation to be confirmed.
Hail and lightning impact	Qualitative																	Y	3	5	15	Potential for increased fire events from lightning strike; fire damage could lead to loss of service and severe backups and/or fractures/cracks resulting in sewage spills
Heat waves and extremely warm temperature	Days with temperature > 34 °C > 0/yr Number of heat waves > 0.2/year	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Potential increased load on system could lead to minor backups.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	4	20	Y	6	4	24	Y	7	5	35	Y	7	5	35	Thaw settlement could lead to a reduction in pipe slopes causing minor to severe backups and/or fractures/cracks resulting in sewage spills. Note, increased severity due to likely extended time required to detect sewage leak location. Beaufort Delta: Thaw settlement could lead to a reduction in pipe slopes causing minor to severe backups and/or fractures/cracks resulting in sewage spills
Cumulative rain events (impact on permafrost)	Summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	4	24	Y	6	4	24	Y	5	5	25	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); number of heat waves days > 34 °C	Y	5	5	25	Y	5	4	20	Y	5	4	20	Y	5	5	25	Y	5	5	25	Reduction in pipe slopes causing minor to severe backups and/or fractures/cracks resulting in sewage spills. Note, increased severity due to likely extended time required to detect sewage leak location. Beaufort Delta: Thaw settlement could lead to a reduction in pipe slopes causing minor to severe backups and/or fractures/cracks resulting in sewage spills.
Fluvial flooding	Regional historical floods.	N				Y	5	6	30	Y	4	6	24	N				N				Hay River and Fort Simpson: mains can be damaged, resulting in sewage spill. Capacity issue for sewer systems via manholes.

Sanitary sewer mains are below ground in every region except in Beaufort Delta where they are above ground in some communities.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

STORM WATER SEWER MAINS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and cold days	Lowest minimum temperature < -X °C	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	N				Potential increased weathering/reduced service life
Extreme precipitation	1:5 24hr rain > X mm	Y	6	4	24	Y	6	4	24	Y	5	4	20	Y	5	4	20	N				Potential loss of function (i.e. capacity exceedance) that could lead to overflow events
Snow	Mean winter precip > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	N				Increased potential for drainage/ponding issues during snow melt in spring and increased maintenance
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	N				Potential increased weathering/reduced service life (i.e. freeze-thaw can exacerbate corrosion) and corrugated metal pipe could undergo deformation from frost heaving.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	Y	5	2	10	Y	6	2	12	Y	7	3	21	N				Potential reduced function or failure of infrastructure due to thaw settlement of permafrost
Cumulative rain events (impact on permafrost)	Summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	Y	6	2	12	Y	6	2	12	Y	5	3	15	N				
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	N				Flooding could result in backups and flooding outside of the flood plain. Increased maintenance due to sedimentation.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

PARKS AND GOLF COURSES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and cold days	Lowest minimum temperature < -X °C	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Potential increased weathering/reduced service life infrastructure components (i.e. cracking of pavement of access roads and parking lot)
Snow	Mean winter precip > X mm	Y	6	2	12	Y	5	2	10	Y	6	2	12	Y	6	2	12	Y	6	2	12	Increased potential for drainage/ponding issues during snow melt in spring
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	2	8	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	4	2	8	Potential increased cracking of pavement and pavement deformation from frost heaving
Wind	Wind > 75 km/h	Y	5	1	5	Y	5	1	5	Y	5	1	5	Y	5	1	5	Y	4	1	4	Small branches broken.
Wind	Wind > 85 km/h	Y	3	4	12	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	Large branches broken could harm people.
Wind	Wind > 110 km/h	Y	3	6	18	Y	3	6	18	Y	3	6	18	Y	4	6	24	Y	4	6	24	Mature trees can get uprooted.
Hail and lightning	Qualitative	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Potential for increased fire events from lightning strike; potential reduced function or loss of infrastructure components (e.g. access roads)
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	3	15	Increased erosion and flooding could damage or lead to loss of infrastructure components (i.e. sloughing of underlying soils, washout, inundation of access roads, parking lot, etc.).
Heat waves and warm temperature	Days with extremely warm temperature > 0/yr Number of heat waves >	Y	4	1	4	Y	6	1	6	Y	6	1	6	Y	5	1	5	Y	4	1	4	Potential increased training in first aid related to heat stroke/heat exhaustion
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	Y	5	2	10	Y	6	2	12	Y	7	3	21	Y	7	4	28	Permafrost thaw could affect the structural strength of the park infrastructure (playground, benches). Severity is moderate in North Slave given historical damage to Fritz Theil Park. Severity is a function of the regional ice content and does not necessarily reflect local characteristics
Cumulative rain events (impact on permafrost)	Summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	Y	6	2	12	Y	6	2	12	Y	5	3	15	Y	4	4	16	
Wildfires	Increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	4	20	Y	5	3	15	Y	5	3	15	Y	5	4	20	Y	5	4	20	Closure of the park / golf course when wildfires are too close to town.
Fluvial flooding	Regional historical floods.	Y	2	2	4	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	5	2	10	Loss of access to the parks during flooding events. Minor damages to infrastructure and trail due to slumping.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

GRAVEYARDS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and cold days	Lowest minimum temperature < -X °C	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Potential increased weathering/reduced service life infrastructure components (i.e. cracking of pavement of access roads and parking lot)
Snow	Mean winter precip > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	Y	6	3	18	Potential for increased snow plowing requirements for access roads and parking lot
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	2	8	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	4	2	8	Potential increased cracking of pavement and pavement deformation from frost heaving
Hail and lightning	Qualitative	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Y	3	2	6	Potential for increased fire events from lightning strike; thaw settlement could result in potential reduced function or loss of infrastructure components (i.e. access roads, parking lot, etc.)
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Increased erosion and flooding could damage or lead to loss of infrastructure components (i.e. sloughing of underlying soils, washout, inundation of access roads, parking lot, etc.). Potential impact on infrastructure may require relocation of infrastructure components
Heat waves and warm temperature	Days with extremely warm temperature > 0/yr Number of heat waves >	Y	4	1	4	Y	6	1	6	Y	6	1	6	Y	5	1	5	Y	4	1	4	Potential increased training in first aid related to heat stroke/heat exhaustion
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	Y	5	2	10	Y	6	2	12	Y	7	3	21	Y	7	4	28	Potential increased maintenance, reduced function, or failure of infrastructure components (i.e. access roads, parking lot, etc.) due to thaw settlement of permafrost. Potential loss of cultural heritage and emotional value. Severity is a function of the regional ice content and does not necessarily reflect local characteristics
Cumulative rain events (impact on permafrost)	Summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	Y	6	2	12	Y	6	2	12	Y	5	3	15	Y	4	4	16	
Wildfires	Increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	4	20	Y	5	3	15	Y	5	3	15	Y	5	4	20	Y	5	4	20	Potential for increased maintenance, reduced function, or failure of infrastructure components (i.e. access roads, parking lot, etc.) due to thaw settlement of permafrost and/or fire damage. Potential loss of cultural heritage and emotional value.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Loss of access during flood and damage to spiritual landscape.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

DRINKING WATER WELLS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and cold days	Lowest minimum temperature < -X °C	Y	1	5	5	N				Y	1	5	5	N				N				Increased potential for freezing could cause loss of service.
Snow	Mean winter precip > X mm	Y	6	2	12	N				Y	6	2	12	N				N				Opportunity: high winter year will maintain the water table higher
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	5	20	N				Y	4	5	20	N				N				Increased potential for freeze-thaw contraction/expansion stressing and cracking of infrastructure components could lead to loss of service
Wildfires	Increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	N				Y	5	5	25	N				N				Potential fire/extreme heat could damage surface components and prevent access to the well.
Fluvial flooding	Regional historical floods.	Y	2	6	12	N				Y	4	6	24	N				N				Water contamination: need to confirm the presence of wells in the flood zones.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

APPENDIX

C-2 BUILDINGS

COMMUNITY HOUSING UNITS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	6	6	Y	2	6	12	Y	0	6	0	Y	1	6	6	Y	1	6	6	Damage to piping due to freezing water and loss of comfort. Material not adapted to extreme temperature will favor leakage. Lack of ventilation may increase mold development.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	3	4	12	Y	4	4	16	Mold development and proliferation. Material of housing is not adapted to extreme temperatures, which will favor leakage.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	1	6	6	Damage to piping due to freezing water and loss of comfort. Material not adapted to extreme temperature will favor leakage. Lack of ventilation increase mold development.
Heating degree-days	Heating degree-days > X	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Increase energy expenses and occupant discomfort. Increased need for cooling.
Annual precipitation	Total annual precipitation > X mm	Y	6	5	30	Y	7	5	35	Y	6	5	30	Y	6	5	30	Y	5	5	25	Increased precipitation will affect the moisture content of material and will accelerate the degradation of material. Increased development of mold. High-humidity condition is favorable to exposition to heavy metal found in the wall paint.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	6	18	Y	4	6	24	Y	4	6	24	Y	4	6	24	Y	3	6	18	12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Severity is high due to high potential to harm people.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Severity is high due to high potential to harm people.
Wind	Wind > 80 km/h	Y	4	3	12	Y	5	3	15	Y	4	3	12	Y	5	3	15	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	6	18	Y	3	6	18	Y	3	6	18	Y	4	6	24	Y	4	6	24	Loss of shingles or other roof covering (up to 20%), broken windows. Health and safety hazard.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Uplift of roof deck and loss of significant roof covering material (more than 20%).
Hail and lightning	Qualitative	Y	3	6	18	Y	3	6	18	Y	3	6	18	Y	3	6	18	Y	3	6	18	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning strike. Damage to the envelope from lightning impacts. Flooding potential caused by large amounts of hail blocking drainage systems.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

COMMUNITY HOUSING UNITS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	4	16	Y	6	4	24	Y	6	4	24	Y	5	4	20	Y	4	4	16	Housing becomes too warm during warm spells. Warm indoor temperatures favour mold development and proliferation. Material of housing may not be adapted to extreme temperatures that will favor leakage. Houses will need to be adapted for more cooling capacity.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	4	28	Y	7	5	35	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes. Severity is modulated by regional ice content of permafrost.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	6	4	24	Y	6	3	18	Y	6	3	18	Y	5	4	20	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	7	35	Y	5	7	35	Y	5	7	35	Y	5	7	35	Y	5	7	35	Partial or complete destruction of building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	5	20	Y	4	5	20	Y	4	5	20	Y	5	5	25	Y	5	5	25	Snow compaction adjacent to the building envelope, which is often compromised by existing damage to older buildings and lack of vapor barrier, leads to the envelope attracting water when the snow melts. This leads to leakage, material durability, isolation and mold problems. Access issues to building.
Fluvial flooding	Regional historical floods.	Y	2	6	12	Y	5	5	25	Y	4	6	24	Y	4	6	24	Y	5	6	30	Extensive property damage due to flooding and fluvial erosion.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

OFFICES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damages to piping due to freezing water and need to close the office due to cold temperature.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Consequences include minor discomfort to occupants and the need to close the office due to warm temperatures. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	More energy expenses, albeit minor and possibility of free cooling options.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the office due to cold temperature.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increased energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	2	12	Y	7	2	14	Y	6	2	12	Y	6	2	12	Y	5	2	10	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope. Many buildings do not have proper drainage systems and water could damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	6	18	Y	4	6	24	Y	4	6	24	Y	4	6	24	Y	3	6	18	12% of the buildings at risk of collapse due to snow load (Auld et al. 2010).
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	3	9	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	4	5	20	Y	4	5	20	Loss of roof covering.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Inward or outward collapse of overhead doors. Severity is high because of health and safety hazard.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

OFFICES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning strike. Damage to the envelope from lightning impacts. Flooding caused by large amounts of hail blocking drainage systems.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Consequences include minor discomfort to occupants and the need to close the office due to warm temperatures. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	5	35	Y	7	5	35	Damage to building structure and/or foundation, which can lead to water infiltration and associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the office for sanitary reasons. For Sahtu and Beaufort Delta: Severity is high because of high ice content permafrost in the Mackenzie Valley.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	5	25	Y	4	5	20	
Wildfires	CUMULATIVE: Increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Offices are mainly located in the center of communities, they will be evacuated before fire reaches the community. Damage or destruction of the building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow drift formation. Severity is low because offices typically do not provide essential services.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Disruption of the service and damage to the building. Presence of offices in the floodplain to be confirmed.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SCHOOLS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the school due to cold temperature. Historically, no school closure above -50°C and no reported event of freezing pipes.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Consequences include minor discomfort to occupants and the need to close the school due to warm temperatures. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	More energy expenses, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the school due to cold temperature. Historically, no school closure above -50°C and no event of freezing pipes.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increase energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	2	12	Y	7	2	14	Y	6	2	12	Y	6	2	12	Y	5	2	10	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope. Most buildings don't have proper drainage systems and water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	7	21	Y	4	7	28	Y	4	7	28	Y	4	7	28	Y	3	7	21	School roof collapsed following a blizzard in 2004. If occurring during attendance hours, this could result in fatalities.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	7	28	Y	5	7	35	Y	4	7	28	Y	4	7	28	Y	4	7	28	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. School roof collapsed following a blizzard in 2004. If occurring during attendance hours, this could result in fatalities.
Wind	Wind > 75 km/h	Y	5	2	10	Y	5	2	10	Y	5	2	10	Y	5	2	10	Y	4	2	8	Visible damage to the envelope
Wind	Wind > 110 km/h	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	4	4	16	Y	4	4	16	Loss of roof covering (less than 20%) and light poles.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SCHOOLS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning strike. Damage to the envelope from lightning impacts. Flooding caused by large amounts of hail blocking drainage systems.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	7	35	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation. Severity of consequences is higher with regards to mold because of the presence of children whose immune systems are weaker.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	1	4	Y	6	1	6	Y	6	1	6	Y	5	1	5	Y	4	1	4	Consequences are minor because high temperatures likely during the summer break.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	4	20	Y	6	4	24	Y	7	6	42	Y	7	6	42	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the school for sanitary reasons. For Sahtu and Beaufort Delta: Severity is high because of high ice content permafrost in the Mackenzie Valley.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	4	24	Y	6	4	24	Y	5	6	30	Y	4	6	24	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Assumption is that students will not attend school if wildfires are nearby. Schools are mainly located in the center of communities, they will be evacuated before the fire reaches the community. Damage to or destruction of the building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	6	12	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	5	6	30	Disruption of the service and damage to the building. Potential for mold development and associated health hazard.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

HOSPITALS AND HEALTH CENTERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and loss of serviceability due to cold temperature.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Consequences include discomfort to occupants.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	More energy expenses, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and loss of serviceability due to cold temperature.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increase energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	2	12	Y	7	2	14	Y	6	2	12	Y	6	2	12	Y	5	2	10	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope. Most buildings don't have proper drainage systems and water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	7	21	Y	4	7	28	Y	4	7	28	Y	4	7	28	Y	3	7	21	12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Increased severity of consequences due to the higher vulnerability of patients (decreased mobility, continuous presence), which could result in fatalities.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	7	28	Y	5	7	35	Y	4	7	28	Y	4	7	28	Y	4	7	28	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Increased severity of consequences due to the higher vulnerability of patients (decreased mobility, continuous presence), which could result in fatalities.
Wind	Wind > 75 km/h	Y	5	2	10	Y	5	2	10	Y	5	2	10	Y	5	2	10	Y	4	2	8	Visible damage to the envelope of health centres.
Wind	Wind > 95km/h	Y	3	2	6	Y	3	2	6	N				Y	4	2	8	Y	4	2	8	Visible damage to hospitals (e.g. slight loss of cladding to the envelope).

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

HOSPITALS AND HEALTH CENTERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wind	Wind > 120km/h	Y	1	7	7	Y	1	7	7	Y	1	4	4	Y	2	7	14	Y	2	7	14	Damage to penthouse roof and walls. Loss of rooftop HVAC equipment. Severity in Dehcho is lower because there are only health centres.
Hail and lightning	Qualitative	Y	3	7	21	Y	3	7	21	Y	3	7	21	Y	3	7	21	Y	3	7	21	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning strike. Damage to the envelope from lightning impacts. Flooding caused by large amounts of hail blocking drainage systems.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	7	35	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	3	12	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	4	3	12	Consequences include discomfort to occupants. Severity is higher because of the presence of vulnerable people.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	4	20	Y	6	4	24	Y	7	6	42	Y	7	6	42	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	4	24	Y	6	4	24	Y	5	6	30	Y	4	6	24	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Hospitals are mainly located in the center of communities, they will be evacuated before fire reaches the community. However, evacuation will be difficult. Failure or destruction of the building.
Snow/wind gust	daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	2	8	Y	4	2	8	Y	4	2	8	Y	5	2	10	Y	5	2	10	Issue with the access to the building due to snow deflation. Snow removal will be prioritized for key infrastructures.
Fluvial flooding	Regional historical floods.	Y	2	7	14	Y	5	7	35	Y	4	7	28	Y	4	7	28	Y	5	7	35	Disruption of the service and damage to the building. Severity is higher because it is a critical infrastructure. To be confirmed if in flood zones.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

FIRE STATIONS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and loss of serviceability due to cold temperature.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Consequences include minor discomfort to occupants and the need to close the station due to warm temperatures. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	More energy expenses, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and loss of serviceability due to cold temperature. Severity is high given that the infrastructure provide essential services.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increase energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	2	12	Y	7	2	14	Y	6	2	12	Y	6	2	12	Y	5	2	10	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope. Most buildings don't have proper drainage systems and water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	6	18	Y	4	6	24	Y	4	6	24	Y	4	6	24	Y	3	6	18	12% of the buildings at risk of collapse due to snow load (Auld et al. 2010).
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	3	9	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	4	4	16	Y	4	4	16	Loss of roof covering (up to 20%)
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Inward or outward collapse of overhead doors.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

FIRE STATIONS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning strike. Damage to the envelope from lightning impacts. Flooding caused by large amounts of hail blocking drainage systems.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation, all of which could impact the availability of fire response in case of need, with potential severe social consequences.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Consequences include minor discomfort to occupants.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	4	20	Y	6	4	24	Y	7	6	42	Y	7	6	42	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the fire station for sanitary reasons. For Sahtu and Beaufort D.: Severity is high because of high ice content in the Mackenzie Valley.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	4	24	Y	6	4	24	Y	5	6	30	Y	4	6	24	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	7	35	Y	5	7	35	Y	5	7	35	Y	5	7	35	Y	5	7	35	Partial or complete destruction of building. Severity is high given that the infrastructure provides essential services, especially for wildfires.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	6	12	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	5	6	30	Severity is critical given that the loss of access to the fire department during flood decreases the capacity of intervention from the first responders.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

RECREATION INFRASTRUCTURE

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the infrastructure due to cold temperature.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Potential for increased energy expenses related to cooling load.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Potential for increased energy expenses related to cooling load, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Increased heating load, increased condensation inside building, and increased localized free-thaw cycles could damage building envelope. Increased potential of frozen water/sewer services.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Decreased energy expenses related to heating load for ice arena; increased energy expenses related to heating load and staff discomfort for other type of recreation infrastructure.
Annual precipitation	Total annual precipitation > X mm	Y	6	1	6	Y	7	1	7	Y	6	1	6	Y	6	1	6	Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Leakage and increased humidity in the envelope. Absence of proper drainage systems means that water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	6	18	Y	4	6	24	Y	4	6	24	Y	4	6	24	Y	3	6	18	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	3	9	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	4	5	20	Y	4	5	20	Loss of roof covering.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, failure of exterior door.
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Damage to roofs and building envelope. Water intrusion upon melting. Power outages and power surges of electrical circuits from lightning. Flooding caused by large amounts of hail blocking drainage systems.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

RECREATION INFRASTRUCTURE

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	For Beaufort Delta only: Potential increased erosion and flooding could damage or lead to loss of infrastructure components (i.e. sloughing of underlying soils, washout, inundation of access roads, parking lot, etc.). Potential impact on infrastructure may require relocation of infrastructure
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Consequences include minor discomfort to occupants and the need to close the infrastructure due to warm temperatures. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	5	35	Y	7	5	35	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the facility for sanitary reasons. For Sahtu and Beaufort Delta: Severity is high because of high ice content in the Mackenzie Valley.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	5	25	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Recreation centres are mainly located in the center of communities, they will be evacuated before fire reaches the community. Failure or destruction of the building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	N				N				Y	5	5	25	Disruption of service and damage to the building.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

COMMUNITY CENTERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the infrastructure due to cold temperature.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	3	1	3	Y	4	1	4	Consequences are minor discomfort to occupants.
Summer cooling degree-days	Summer cooling degree-days > X	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	Y	7	1	7	More energy expenses, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Y	1	4	4	Consequences include damage to piping due to freezing water and need to close the centres due to cold temperature.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increase energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	1	6	Y	7	1	7	Y	6	1	6	Y	6	1	6	Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	3	18	Y	6	3	18	Y	6	3	18	Y	5	3	15	Y	6	3	18	Consequences are leakage and increased humidity in the envelope. Most buildings don't have proper drainage systems and water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	6	18	Y	4	6	24	Y	4	6	24	Y	4	6	24	Y	3	6	18	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	6	24	Y	5	6	30	Y	4	6	24	Y	4	6	24	Y	4	6	24	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	2	6	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	4	2	8	Visible damage to the infrastructure.
Wind	Wind > 110 km/h	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	4	4	16	Y	4	4	16	Loss of roof covering.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Collapse of overhead doors.
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Damage to roofs and building envelope. Hail penetration of the outer shell can cause water intrusion upon melting, leading to mold and durability problems. Power outages and power surges from lightning strike. Flooding caused by large amounts of hail blocking drainage systems.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

COMMUNITY CENTERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation, leading to mold formation and proliferation.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Consequences include minor discomfort to occupants.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	3	15	Y	6	3	18	Y	7	5	35	Y	7	5	35	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the facility for sanitary reasons. For Sahtu and Beaufort Delta: Severity is high because of high ice content in the Mackenzie Valley.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	3	18	Y	6	3	18	Y	5	5	25	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Cultural centres are mainly located in the center of communities, they will be evacuated before fire reaches the community. Failure or destruction of the building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Disruption of service and damage to the building. To be confirmed if in flood zones.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

GARAGES AND CONTAINERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	2	2	Y	2	2	4	Y	0	2	0	Y	1	2	2	Y	1	2	2	Consequences include some loss of comfort.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	Y	1	1	1	Y	1	2	2	Y	3	2	6	Y	4	2	8	Consequences are minor discomfort to occupants.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Consequences include some loss of comfort.
Heating degree-days	Heating degree-days > X	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	1	2	2	Increase energy expenses and occupant discomfort.
Annual precipitation	Total annual precipitation > X mm	Y	6	1	6	Y	7	1	7	Y	6	1	6	Y	6	1	6	Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	2	12	Y	6	2	12	Y	6	2	12	Y	4	2	8	Y	6	2	12	Consequences are leakage and increased humidity in the envelope. Most buildings don't have proper drainage systems and water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	4	12	Y	4	4	16	Y	4	4	16	Y	4	4	16	Y	3	4	12	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	2	6	Y	5	2	10	Y	4	2	8	Y	4	2	8	Y	4	2	8	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	4	4	16	Y	4	4	16	Loss of roof covering.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Inward or outward collapse of overhead doors.
Hail and lightning	Qualitative	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Potential for reduced function and/or damage of infrastructure components (i.e. damaged building roof or windows, fire from lightning strike).
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Possible loss of buildings, or need for relocation. Increased vulnerability to inundation.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

GARAGES AND CONTAINERS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	1	4	Y	6	1	6	Y	6	1	6	Y	5	1	5	Y	4	1	4	Consequences include minor discomfort to occupants.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	Y	5	2	10	Y	6	2	12	Y	7	4	28	Y	7	4	28	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage and the need to close the facility for sanitary reasons.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	Y	6	2	12	Y	6	2	12	Y	5	4	20	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Failure or destruction of the building. Severity is high especially for generator containers.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	Y	4	1	4	Y	4	1	4	Y	5	1	5	Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Disruption of service and damage to the building. To be confirmed if in flood zones.

P = Probability of occurrence   S = Severity of consequences   R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

GREENHOUSES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Heating degree-days	Heating degree-days > X	Y	1	3	3	N				N				N				Y	1	2	2	Increase in energy expenses.
Annual precipitation	Total annual precip > X mm	Y	6	1	6	N				N				N				Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	1	6	N				N				N				Y	6	2	12	Leakage and increased humidity in the envelope. Absence of proper drainage systems means that water would damage the foundations. Associated maintenance costs exceed their financial capacity.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	4	12	N				N				N				Y	3	4	12	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010).
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	N				N				N				Y	4	4	16	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010).
Wind	Wind > 85 km/h	Y	3	2	6	N				N				N				Y	4	2	8	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	4	12	N				N				N				Y	4	4	16	Loss of roof covering.
Wind	Wind > 120 km/h	Y	1	6	6	N				N				N				Y	2	6	12	Broken windows, including clear story windows or skylights. Collapse of overhead doors.
Hail and lightning	Qualitative	Y	3	4	12	N				N				N				Y	3	4	12	Potential for reduced function and/or damage of infrastructure components.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Loss of buildings, or need for relocation. Increased vulnerability to inundation. Need to confirm presence of infrastructure in the exposed zone.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	N				N				N				Y	4	2	8	Increased need in water. Increased moisture if improper ventilation, which could lead to mold development.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	3	18	N				N				N				Y	7	4	28	Damage to building structure and/or foundation, which can lead to water infiltration and its associated consequences. Damage or rupture of pipes, which can lead to water shortage.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	3	15	N				N				N				Y	4	4	16	

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

GREENHOUSES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	N				N				N				Y	5	6	30	Partial or complete destruction of building.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	1	4	N				N				N				Y	5	1	5	Issue with the access to the building due to snow deflation. Severity is low.
Fluvial flooding	Regional historical floods.	Y	2	4	8	N				N				N				Y	5	4	20	Loss of access and damage to the infrastructure. To be confirmed if in flood zones.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

APPENDIX

C-3 ENERGY SECTOR

FUEL STORAGE – TANK FARMS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	N				Y	0	4	0	Y	1	4	4	Y	1	4	4	Damages to piping due to freezing, however, no historical event ever recorded of pipe freezing. Tank farms are not insulated, but this has not been an issue in the past.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	1	1	N				Y	1	2	2	Y	3	2	6	Y	4	2	8	Minor discomfort to office occupants. Severity is low because of the absence of warm night temperature during summer.
Summer cooling degree-deays	Cooling degree-days > X	Y	7	1	7	N				Y	7	1	7	Y	7	1	7	Y	7	1	7	Potential for increased energy expenses related to cooling load and staff discomfort, albeit minor.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	4	4	N				Y	1	4	4	Y	1	4	4	Y	1	4	4	Increased potential for fuel blending/additive requirements and/or storing fuel oil indoors to prevent clouding and gelling of fuel.
Heating degree-days	Heating degree-days > X	Y	1	2	2	N				Y	1	2	2	Y	1	2	2	Y	1	2	2	Increased energy expenses related to heating load and staff discomfort. However, most of tank farms do not have heating capacity.
Annual precipitation	Total annual precipitation > X mm	Y	6	2	12	N				Y	6	3	18	Y	6	3	18	Y	5	3	15	Higher moisture conditions will accelerate the degradation of granular pad.
Extreme precipitation	1:50 24hr rain > X mm	Y	6	1	6	N				Y	6	1	6	Y	5	1	5	Y	6	1	6	Leakage and increased humidity in the envelope. The envelope of tank farms is not an issue.
Extreme precipitation	1:5 24hr rain > X mm	Y	6	5	30	N				Y	5	5	25	Y	5	5	25	Y	6	5	30	Increased maintenance to remove water from berms (a cascade effect could happen in the event of a fuel spill due to rainwater).
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	5	15	N				Y	4	6	24	Y	4	6	24	Y	3	6	18	Potential damage to roof. Potential for increased snow plowing requirements for access roads and parking lot.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	3	12	N				Y	4	4	16	Y	4	4	16	Y	4	4	16	An increase in freezing rain events following snow precipitation will increase the load on roof structures, which could collapse. Increased weathering/reduced service life of components.
Wind	Wind > 85 km/h	Y	3	3	9	N				Y	4	4	16	Y	4	4	16	Y	4	4	16	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).
Wind	Wind > 110 km/h	Y	3	4	12	N				Y	3	5	15	Y	4	5	20	Y	4	5	20	Loss of wood or metal roof panels (up to 20%). Collapse of large doors.
Wind	Wind > 120 km/h	Y	1	5	5	N				Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Collapse of overhead doors.
Hail and lightning	Qualitative	Y	3	5	15	N				Y	3	6	18	Y	3	6	18	Y	3	6	18	Potential for reduced function and/or damage of infrastructure components (i.e. damaged building roof or windows, fire from lightning strike); fire may cause fuel to explode.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

FUEL STORAGE – TANK FARMS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation) and/or fuel spill. Potential impact on infrastructure may require relocation of infrastructure
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	N				Y	6	2	12	Y	5	2	10	Y	4	2	8	Potential increase in cooling load, and increased training in first aid related to heat stroke/heat exhaustion
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	N				Y	6	4	24	Y	7	6	42	Y	7	6	42	Potential reduced function or failure of infrastructure due to thaw settlement of permafrost (i.e. loss of structural strength and building foundation damage). Note, increased severity due to potential loss of essential service and fuel spill.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	N				Y	6	4	24	Y	5	6	30	Y	4	6	24	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	N				Y	5	7	35	Y	5	7	35	Y	5	7	35	Fire may cause fuel to explode – vapour explosions or tank failure. Note, increased severity due to potential loss of essential service.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	3	12	N				Y	4	3	12	Y	5	3	15	Y	5	3	15	Potential for increased snow removal requirements for access and parking
Fluvial flooding	Regional historical floods.	Y	2	5	10	N				Y	4	6	24	Y	4	6	24	Y	5	6	30	Loss of access and damage to the infrastructure.

Dehcho, Sahtu and Beaufort Delta are regions were most communities are 100% dependent on fuel distribution.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

POWER PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean min. winter temperature	Mean minimum January temperature < -X	Y	1	4	4	Y	2	4	8	Y	0	4	0	Y	1	4	4	Y	1	4	4	Consequences include damages to piping due to freezing, however, no historical event ever recorded of pipe freezing. Power plants are not insulated, but this has not been an issue in the past.
Mean max summer temperature	Mean max July temperature > X °C	Y	1	2	2	Y	1	2	2	Y	1	2	2	Y	3	2	6	Y	4	2	8	Consequences include minor discomfort to office occupants. Severity is low because of the possibility to implement free-cooling practices given the absence of warm night temperature during summer.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	7	2	14	Y	7	2	14	Y	7	2	14	Y	7	2	14	Y	7	2	14	Potential for increased energy expenses related to cooling load and staff discomfort, albeit minor. Potential for increased energy production demand
Heating degree-days	Heating degree-days > X	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Potential increased heating load, potential increased condensation inside building could cause mold, and potential increased localized free-thaw cycles could damage building envelope components. Increased potential of frozen water/sewer services. Increased potential for energy production demand and increased potential for power disruptions.
Annual precipitation	Total annual precipitation > X mm	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Y	1	3	3	Potential for increased energy expenses related to heating load and staff discomfort and potential for increased energy production demand
Extreme precipitation	1:50 24hr rain > X mm	Y	6	1	6	Y	7	1	7	Y	6	1	6	Y	6	1	6	Y	5	1	5	Higher moisture conditions will accelerate the degradation of the envelope. Severity is low given the semi-arid conditions.
Snow	Snow load 1/50 > X Kpa (buildings)	Y	3	5	15	Y	4	5	20	Y	4	5	20	Y	4	5	20	Y	3	5	15	Potential damage to roof; 12% of the buildings at risk of collapse due to snow load (Auld et al. 2010). Potential for increased snow plowing requirements for access roads and parking lot.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	4	16	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	4	4	16	An increase in freezing rain events following snowfall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Potential increased weathering/reduced service life of infrastructure components (i.e. freeze-thaw can exacerbate corrosion)
Wind	Wind > 85 km/h	Y	3	3	9	Y	5	3	15	Y	4	3	12	Y	4	3	12	Y	4	3	12	Visible damage to the infrastructure (e.g. slight loss of cladding to the envelope).

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

POWER PLANTS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Wind	Wind > 110 km/h	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	4	5	20	Y	4	5	20	Loss of wood or metal roof panels (up to 20%). Collapse of large doors.
Wind	Wind > 120 km/h	Y	1	6	6	Y	1	6	6	Y	1	6	6	Y	2	6	12	Y	2	6	12	Broken windows, including clear story windows or skylights. Collapse of overhead doors.
Hail and lightning	Qualitative	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Y	3	5	15	Reduced function and/or damage of infrastructure; fire may cause fuel to explode.
Frost-free season	Frost-free season > X days	Y	7	3	21	Y	7	3	21	Y	7	3	21	Y	7	3	21	Y	7	3	21	Potential for decreased energy production demand.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation of infrastructure. Note, increased severity due to potential loss of essential service.
Heat waves and extremely warm temperature	Days with extremely warm temperature (> 34 °C) > 0/yr Number of heat waves >	Y	4	2	8	Y	6	2	12	Y	6	2	12	Y	5	2	10	Y	4	2	8	Potential increase in cooling load, and increased training in first aid related to heat stroke/heat exhaustion. Potential for increased energy production demand
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	Y	5	5	25	Y	6	5	30	Y	7	5	35	Y	7	5	35	Potential reduced function or failure of infrastructure due to thaw settlement of permafrost (i.e. loss of structural strength and building foundation damage). Note, increased severity due to potential loss of essential service.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	Y	6	5	30	Y	6	5	30	Y	5	5	25	Y	4	5	20	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	7	35	Y	5	6	30	Y	5	6	30	Y	5	6	30	Y	5	6	30	Fire may cause fuel to explode. Failure of the infrastructure. Note, increased severity due to potential loss of essential service. Severity higher in North Slave to account for higher population.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	3	12	Y	4	3	12	Y	4	3	12	Y	5	3	15	Y	5	3	15	Potential for increased snow removal requirements for access and parking
Fluvial flooding	Regional historical floods.	Y	2	5	10	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	5	5	25	Disruption of the utility. Need to confirm presence of power plants in flood prone areas

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SOLAR FARMS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Mean max summer temperature	Mean max July temperature > X °C	N				N				Y	1	2	2	Y	3	2	6	N				Extremely warm temperatures mean a loss in production efficiency of the infrastructure. Accelerated deterioration of some components of the structure. There is a very little chance that temperature gets so high that inverters reach their upper-limit temperature and temporarily stop producing energy.
Summer cooling degree-deays	Cooling degree-days > X	N				N				Y	7	2	14	Y	7	2	14	N				In case of insufficient cooling capacity due to very high temperature, batteries and transformers may exceed their upper-limit temperature and temporarily stop storing energy.
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	N				N				Y	1	3	3	Y	1	3	3	N				Temperature might get so low that inverters and batteries reach their lower-limit temperature and temporarily stop producing energy.
Heating degree-days	Heating degree-days > X	N				N				Y	1	3	3	Y	1	3	3	N				In case of insufficient heating capacity due to very low temperature, transformers and switchgears may get below their lower-limit temperature and temporarily be damaged.
Extreme precipitation	1:50 24hr rain > X mm	N				N				Y	6	1	6	Y	5	1	5	N				In case of pluvial flooding, corrosion of racking can be emphasized, and infiltration at the concrete foundations is possible. Since the infrastructure will be recently built, the severity of the consequences remains low for the time horizon selected.
Snow	Mean winter precipitation > X mm	N				N				Y	6	4	24	Y	6	4	24	N				Excessive load on panels can add massive pressure on plant racking and foundations and accelerate their deterioration. Accessibility to the farm could be challenged.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	N				N				Y	4	4	16	Y	4	4	16	N				An increase in freezing rain events following snow fall events will increase the load on roof structures, which could collapse. 12% of the buildings at risk of collapse due to snow load alone (Auld et al. 2010). Potential increased weathering/reduced service life of infrastructure components (i.e. freeze-thaw can exacerbate corrosion)
Wind	Wind > 85 km/h	N				N				Y	4	4	16	Y	4	4	16	N				Strong winds alone can slightly damage solar panels due to additional lateral loads. Combined with high snow loads, strong winds can increase the risk of panels breaking.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

SOLAR FARMS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Hail and lightning	Qualitative	N				N				Y	3	5	15	Y	3	5	15	N				Hail and lightning impacts can seriously damage the solar panels and the electrical network of the farm.
Frost-free season	Frost-free season > X days	N				N				Y	7	3	21	Y	7	3	21	N				Potential for decreased energy production demand
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	N				N				Y	6	4	24	Y	7	5	35	N				Potential reduced function or failure of infrastructure due to thaw settlement of permafrost (i.e. loss of structural strength and building foundation damage). Severity is lower in Dehcho due to the presence of sporadic discontinuous permafrost with low ice content.
Cumulative rain events (impact on permafrost)	CUMULATIVE: summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	N				N				Y	6	4	24	Y	5	5	25	N				
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	N				N				Y	5	5	25	Y	5	6	30	N				Potential fire damage or loss of infrastructure due to wildfire. Most communities in Dehcho has been dependent on fuel availability until now. The loss of the infrastructure would mean loss of redundancy for isolated communities.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	N				N				Y	4	4	16	Y	5	4	20	N				Strong winds alone can slightly damage solar panels due to additional lateral loads. Combined with high snow loads, strong winds can increase the risk of panels breaking.
Fluvial flooding	Regional historical floods.	N				N				Y	4	5	20	Y	4	5	20	N				In case of fluvial flooding, corrosion of racking can be emphasized, and infiltration at the concrete foundations is possible. Serviceability of the infrastructure would be challenged. Need to confirm if the infrastructure is located in the flood zone.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

POWER LINES AND POLES

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Potential increased damage to power lines and subsequent loss of service
Extreme precipitation	1:100 24hr rain > X mm	Y	6	3	18	Y	5	3	15	Y	5	3	15	Y	5	3	15	Y	6	3	18	Manholes and pull boxes will need to be cleaned more often to ensure proper drainage
Snow	Mean winter precipitation > X mm	Y	6	4	24	Y	5	4	20	Y	6	4	24	Y	6	4	24	Y	6	4	24	Increased potential for loss of service/failure of infrastructure from increased loading by wet snow accumulation on lines and poles
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	5	20	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	4	5	20	Increased potential for loss of service/failure of infrastructure after ice buildup could snap power lines and/or poles after freezing rain events.
Wind	Wind > 110 km/h	Y	3	6	18	Y	3	6	18	Y	3	6	18	Y	4	6	24	Y	4	6	24	Broken wood cross members.
Hail and lightning	Qualitative	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Increased fire events from lightning strike.
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Potential increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation).
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	4	20	Y	6	4	24	Y	7	4	28	Y	7	4	28	Potential increased maintenance or failure of infrastructure due to thaw settlement of permafrost.
Cumulative rain events (impact on permafrost)	summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	4	24	Y	6	4	24	Y	5	4	20	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	Y	5	5	25	Y	5	5	25	Y	5	5	25	Y	5	5	25	Potential fire damage or loss of infrastructure due to wildfire. Severity higher in North Slave due to denser population.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	5	20	Y	4	5	20	Y	4	5	20	Y	5	5	25	Y	5	5	25	Increased potential for loss of service/failure of infrastructure after the combination of wet snow accretion and wind could snap power lines and/or poles.
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Service failure, damages to power lines.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

TELECOMMUNICATIONS

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Y	1	5	5	Potential diminished signal, or loss of function
Snow	Mean winter precipitation > X mm	Y	6	3	18	Y	5	3	15	Y	6	3	18	Y	6	3	18	Y	6	3	18	Loss of service/failure of infrastructure from increased loading by wet snow accumulation on communication lines and poles.
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	5	20	Y	5	5	25	Y	4	5	20	Y	4	5	20	Y	4	5	20	Increased potential for loss of service/failure of infrastructure. Ice buildup could damage infrastructure after freezing rain events
Wind	Wind > 120 km/h	Y	1	1	1	Y	1	1	1	Y	1	1	1	Y	2	1	2	Y	2	1	2	Minimal damage to the infrastructure
Hail and lightning	Qualitative	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Potential for increased fire events from lightning strike; increased potential for fire damage or loss of infrastructure due to fire
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	5	25	Increased erosion and flooding could reduce function or damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation). Potential impact on infrastructure may require relocation.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	4	24	Y	5	4	20	Y	6	4	24	Y	7	4	28	Y	7	4	28	Potential increased maintenance or failure of infrastructure due to thaw settlement of permafrost.
Cumulative rain events (impact on permafrost)	summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	4	20	Y	6	4	24	Y	6	4	24	Y	5	4	20	Y	4	4	16	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	5	25	Y	5	4	20	Y	5	4	20	Y	5	4	20	Y	5	4	20	Potential fire damage or loss of infrastructure due to wildfire. Severity higher in North Slave due to denser population.
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	4	16	Y	4	4	16	Y	4	4	16	Y	5	4	20	Y	5	4	20	Increased potential for loss of service/failure of infrastructure after the combination of wet snow accretion and wind could damage communication lines and poles
Fluvial flooding	Regional historical floods.	Y	2	4	8	Y	5	4	20	Y	4	4	16	Y	4	4	16	Y	5	4	20	Service failure, damages to communication lines.

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

FUEL RESUPPLY MANIFOLD

Climate parameter	Infrastructure threshold	N. SLAVE				S. SLAVE				DEHCHO				SAHTU				BEAUFORT D.				
		Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Rationale
Winter cold snaps and very cold days	Lowest minimum temperature < -X °C	Y	1	6	6	N				N				Y	1	6	6	Y	1	6	6	Resupply disruptions (i.e. breakdown of transportation infrastructure such as trucking vehicle failure or potential increased transportation related accidents).
Snow	Mean winter precipitation > X mm	Y	6	5	30	N				N				Y	6	5	30	Y	6	5	30	Resupply delay/disruptions due to snow driving conditions and/or transportation related accidents. Note increased potential for fuel spill
Freeze-thaw cycles and freezing rain	Freeze-thaw cycles and freezing rain > X cycles	Y	4	5	20	N				N				Y	4	5	20	Y	4	5	20	Resupply disruptions due to driving conditions and/or transportation related accidents. Deformation of pipelines from frost heaving.
Hail and lightning	Qualitative	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Y	3	4	12	Fire events from lightning strike; fire damage.
Frost-free season	Frost-free season > X days	Y	7	3	21	N				N				Y	7	3	21	Y	7	3	21	Potential for extended period of resupply of fuel due to extended period of operations.
Sea ice extent and duration of ice-free season	Qualitative	Y	4	4	16	N				N				Y	4	4	16	Y	4	4	16	Potential for extended period of resupply of fuel due to extended period of marine and trucking operations
Sea level rise Storm surges Coastal erosion	Qualitative	N				N				N				N				Y	5	6	30	Increased erosion and flooding could damage or lead to loss of infrastructure (i.e. sloughing of underlying soils, washout, inundation) and/or fuel spill.
Temperature (impact on permafrost)	Permafrost thaw > -1 °C/yr combined with historical events on infrastructure	Y	6	5	30	N				N				Y	7	6	42	Y	7	6	42	Increased potential for resupply delay/disruptions due to difficult driving conditions (related thaw settlement), and/or potential increased transportation related accidents, and deformation of pipelines from thaw settlement. Note increased potential for fuel spill
Cumulative rain events (impact on permafrost)	summer precip > Xmm; IDF 1:5 24hr > 40mm; heavy precipitation days (>10mm)	Y	5	5	25	N				N				Y	5	6	30	Y	4	6	24	
Wildfires	CUMULATIVE: increased wind April-November (qualitative); nb of heat waves days > 34 °C	Y	5	6	30	N				N				Y	5	7	35	Y	5	7	35	Potential for resupply delay/disruptions due to difficult driving conditions, and/or potential increased transportation related accidents. Note increased potential for fuel spill and explosion
Snow/wind gust	"CUMULATIVE: daily snow accumulation > 10cm; daily maximum gust > 60km/h"	Y	4	5	20	N				N				Y	5	5	25	Y	5	5	25	Increased potential for resupply delay/disruptions due to snow driving/reduced visibility and/or potential increased transportation related accidents. Note increased potential for fuel spill

P = Probability of occurrence S = Severity of consequences R = Risk level (Green: Low ; Yellow: Moderate-low ; Orange: Moderate-high ; Red: High)

APPENDIX

D

RECOMMENDATIONS FOR COMMUNITIES

APPENDIX

D-1 NORTH SLAVE

BEHCHOKỘ

NORTH SLAVE

Located at the meeting point of Great Slave Lake's North Arm and Marian Lake, Behchokǫ̀ is the largest Dene community in the NWT with a population of more than 1,600 people. Accessible year-round by road from Yellowknife or Fort Providence, it is where the Tłįchǫ Government has established its headquarters. Although many creeks and rivers surrounds Behchokǫ̀, the community is at a low-risk level for flooding as the levels of Great Slave Lake and Marian Lake do not fluctuate significantly. Impacts from permafrost thaw are a concern, as the city is located in the discontinuous permafrost zone, with isolated pockets with high ice content especially in marine clay rich zones. The eastern side of Rae, the west-side of Edzo and Sah Naji Kwe Lodge have high to extreme FireSmart Hazard rating regarding wildfires. Examples of critical infrastructure are the schools, health centers, elder centers and water treatment plant. In 1999, the community was evacuated due to wildfires. Examples of critical infrastructures are health centres, schools

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	Moderate-High (orange)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	Moderate-High (orange)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	Moderate-High (orange)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of flooding to the school	Moderate-Low (yellow)	Address flooding as it occurs with a culvert and pump. Monitor the situation to evaluate if it degrades over time. Address accordingly.
Risk of explosion or failure of the diesel generators due to wildfire	Moderate-High (orange)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	Moderate-High (orange)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Investigate the situation in the school affected by annual flooding to assess the need and possibility to take remedial actions.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Behchokǫ̀.

DETTAH

NORTH SLAVE

Located only 6 km opposite of Yellowknife on the east bank of Yellowknife Bay, Dettah is a Yellowknives Dene settlement of a little over 200 inhabitants. The community is at a low-risk level for flooding as the level of Great Slave Lake does not fluctuate significantly. Although built on gently rolling shield-rock terrain, impacts from permafrost thaw are still a concern. The Deton'Cho Training Center sector has a extreme FireSmart Hazard rating regarding wildfires. Examples of critical infrastructure are the school and the firehall.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	● (Moderate-High)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Dettah.
- Conduct an assessment of lakeside erosion, as some community members addressed it as a concern in MACA's Natural Hazard Identification

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GAMETÌ

NORTH SLAVE

Gametì is small Tłı̨chǫ Dene community established in the 1970s about halfway between Great Bear Lake and Great Slave Lake along the waterways connecting both lakes. Gametì is located on a point between Rae Lake and Lac Ste. Croix. It is accessible by air from Yellowknife or via ice roads during the winter. The community is at a low-risk level for flooding as the level of lake systems does not fluctuate significantly. Although built on gently rolling shield-rock terrain, impacts from permafrost thaw are still a concern. Being located on a point with a low proportion of forested area Gametì has a Low to Moderate FireSmart rating, although the road from the community to the airport crosses a High FireSmart rating zone. Examples of critical infrastructure are the school, health center and diesel plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	●	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	●	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	●	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	●	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Gametì.

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ŁUTSELK'E

NORTH SLAVE

Łutselk'e is the only community located on Great Slave Lake's East Arm. Only accessible by air, boat or snowmobile, this community of about 300 Chipewyan Dene residents is the site of the Thaidene Nene National Park. As the level of Great Slake Lake does not fluctuate significantly, it is at a low-risk level for flooding. Impacts from permafrost thaw are a concern, as the city is located in the discontinuous permafrost zone, with isolated pockets with high ice content especially in marine clay rich zones. The eastern sector of the community (including the health center) and the Frontier Fishing Lodge have High and Extreme FireSmart wildfire risk ratings, respectively. Examples of critical infrastructure are the school, the health center, the water treatment plant, the elders' facility, the solar farm and the diesel farm.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	●	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing and critical infrastructure (e.g. health center)	●	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	●	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	●	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Łutselk'e.

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WEKWEÈTÌ

NORTH SLAVE

Wekweètì is the smallest and most remote of the Tłįchǫ Dene communities of the NWT. It is located on rolling rock terrain above the Snare River, close to the Barrenlands and diamond mines that are a major player in NWT's economy, and thus moderately exposed to permafrost thaw. Given its northern position in the North Slave Region, permafrost is likely thicker and more widespread than the southernmost communities. While the Community Wildfire Protection Plan states that the community is at a low risk, there was a large wildfire near town in 2014.The community is at low-risk level for flooding as the lake system within the Snare River basin is not sensitive to water level fluctuations. It as accessible by air and by winter road from Behchokǫ̀ during some part of the winter. Previous climate impacts include a week of dense fog preventing planes to land and supplies to be delivered in 2011. Examples of critical infrastructure are the school, the health center, the water treatment plant, and the tank farm.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of structural damage to buildings due to snow load	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing and critical infrastructure	●	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	●	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	●	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Wekweètì.

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WHATÌ

NORTH SLAVE

Whatì is a Tłįchǫ Dene community of about 500 set on ancestral territory on the shore of Lac La Martre. It is accessible by flight through Yellowknife or by a 125 km drive by ice road from Behchokǫ̀ in the winter. The area is surrounded by marshes. The community is at a low-risk level for flooding as the level of Lac La Martre does not fluctuate significantly. Impacts from permafrost thaw are a concern, as the city is located in the discontinuous permafrost zone. The eastern sector of the community (including the tank farm and the arena) has High FireSmart wildfire risk rating. Examples of critical infrastructure are the school, the health center, the water treatment plant and the diesel farm.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	🟠	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing and critical infrastructure (e.g. health center)	🟠	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	🟠	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	🟠	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Whatì.

YELLOWKNIFE

NORTH SLAVE

Located on the north bank of Great Slave Lake, Yellowknife is the capital and largest city of the NWT, with close to 20,000 inhabitants, of which 23% identifies as Indigenous. As the level of Great Slave Lake does not fluctuate significantly, Yellowknife is at a low-risk level for flooding. Impacts from permafrost thaw are a concern, as the city is located in the discontinuous permafrost zone. Sectors of the city, which is surrounded by vegetation, have a high to extreme FireSmart Hazard rating regarding wildfires. Examples of essential infrastructures in and near the community are Yellowknife Airport, Yellowknife Highway (NWT 3), Stanton Territorial Hospital, the Bluefish hydro dam, water treatment plants as well as power plants and telecommunication infrastructures. Example of property damage from permafrost thaw include the Northern Frontier Visitor Center, which was closed after sinking and shifting caused by permafrost led to structural problems.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	Moderate-High Risk (orange)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of pluvial flooding due to extreme precipitation	Moderate-Low Risk (yellow)	Consult with engineering professionals to assess and identify site specific drainage vulnerabilities. Inspect, maintain, and monitor drainage infrastructure.
Risk of structural damage to buildings due to snow load	Moderate-High Risk (orange)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing and critical infrastructure (e.g. health center)	Moderate-High Risk (orange)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the diesel generators due to wildfire	Moderate-High Risk (orange)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the critical infrastructure due to permafrost	Moderate-High Risk (orange)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Yellowknife.
- Conduct hydraulic modeling to identify zones at risk of flooding during extreme precipitation events.

APPENDIX

D-2 SOUTH SLAVE

ENTERPRISE

SOUTH SLAVE

A small community with a population around 120, Enterprise is located about an hour north of the Alberta border, at the junction of Mackenzie Highway (NWT 1) and Hay River Highway (NWT 2) This community is not prone to flooding and is one of the least sensitive to permafrost thawing, as it is located in the sporadic permafrost zone. Wildfires are however a significant concern, since Enterprise is surrounded by forests and relatively undisturbed terrain, which increases its vulnerability. The center of Enterprise has an Extreme fire risk rating. As the community relies on Hay River for school and medical needs, the road system within the boundary of the community is a critical infrastructure. In 2013, the roof of the municipal garage collapsed under the load of snow.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road, culverts and power lines damage due to wildfires	● (orange)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads and power lines.
Risk of structural damage to buildings due to snow load	● (orange)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	● (orange)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of mould development in houses due to high precipitation.	● (orange)	Monitor air quality and the condition of the envelope of community housing.
Risk of failure of the critical infrastructure due to permafrost	● (yellow)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● (orange) Moderate-High Risk ● (yellow) Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Enterprise.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

FORT PROVIDENCE

SOUTH SLAVE

Fort Providence is a Dene community of 770 perched on the north bank of the Mackenzie River, about 70 km from its source at Great Slave Lake. It is accessible year-round by highway, from Hay River, Yellowknife or Fort Simpson. This community is not prone to flooding and is one of the least sensitive to permafrost thawing, as it is located in the sporadic permafrost zone. Fort Providence is surrounded by forests and relatively undisturbed terrain, which makes the wild fire risk Very High to Extreme around the village. Examples of essential infrastructures in and near the community are the school, the health center and the water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing (especially the northern boundary of the town)	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High)	Clean up all flammable fuels Replace flammable materials with fire resistant materials
Risk of failure of the water treatment plant due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map of the GNWT Atlas suggests that the community is not at risk of flooding. Given the proximity and low elevation above the Mackenzie River, confirm the low flood risk through hydrological modelling.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort Providence.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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FORT RESOLUTION

SOUTH SLAVE

Located at the confluence of Slave River and Great Slave Lake, Fort Resolution is a Chipewyan and Métis community of about 500 and the oldest community in the NWT. It is accessible by Highway 6, off Highway 5 from Hay River or Fort Smith. This community is not prone to flooding and is one of the least sensitive to permafrost thawing, as it is located in the sporadic permafrost zone. The South End and the Little Buffalo River areas have a High to Extreme wildfire risk rating. Examples of essential infrastructures in and near the community are the school, the health center and the water treatment plant. The sewage lagoon is built above the water supply. Seepage could result in water contamination. Power was cut off in 2014 when fires threatened the Taltson Hydroelectric Plant, which had to be shut down.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing (especially the northern boundary of the town)	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of wildfires to sewage lagoon	● (Moderate-High)	Conduct wildfire exposure assessment for sewage lagoon. Remove accumulated debris around the infrastructure.
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of the water treatment plant due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort Resolution.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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FORT SMITH

SOUTH SLAVE

Adjacent to the Alberta border and Wood Buffalo National Park, Fort Smith is a community of about 2,500 on the banks of Slave River accessible from Edmonton or by Highway 5 from Hay River. This community is not prone to flooding and exhibits moderate sensitivity to permafrost thaw. It is however significantly at risk for wildfires as it is surrounded by forests and relatively flat terrain, especially in East and West areas of town, as well as Towering Pines and Bell Rock residential developments, which all have High to Extreme Risk ratings. The health center has a High FireSmart Hazard rating. Examples of essential infrastructures in and near the community are the school, college, health center and water treatment plant. Power was cut off in 2014 when fires threatened the Taltson Hydroelectric Plant, which had to be shut down. In 2016, a small forest fire burned 5 km away from Fort Smith, which prepared its residents for evacuation.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing and health center	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High)	Clean up all flammable fuels Replace flammable materials with fire resistant materials

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map of the GNWT Atlas suggests that the community is not at risk of flooding. Given the proximity and low elevation above the Mackenzie River, confirm the low flood risk through hydrological modelling.
- Conduct a study to confirm that riverbank collapse is not a threat, as the event from 1908 damaged many infrastructure.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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HAY RIVER

SOUTH SLAVE

Hay River stretches along the west bank of the Hay River, near its source at Great Slave Lake. With a population of 3,600, it is the hub of First Nations culture in the NWT. It is one of the only two communities in the South Slave region particularly prone to flooding because ice jams events often happen along the Hay River. The community also exhibits moderate sensitivity to permafrost thaw, and is significantly at risk for wildfires as it is surrounded by forests and relatively flat terrain, especially for the southern residential areas and in West Point. As Hay River provides many services (e.g. health services), roads are critical infrastructure. Examples of other critical infrastructure are schools and water treatment plant. Cascading effects with the northern communities as the fuel is loaded on barges in Hay River and transported on the Mackenzie River. Historically, since 1960, 6 forest fires occurred in the 10 km buffer around Hay River. Moreover, flooding occurred frequently in Hay River, causing evacuations and extensive material damages.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires or floods	Moderate-High Risk	Increase emergency preparedness efforts, including plans for the continuity of services to the regional communities Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	Moderate-High Risk	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of flooding to the water and waste water treatment plants	Moderate-Low Risk	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of damage to sanitary sewer mains due to flooding or erosion	Moderate-Low Risk	Identify zones with the highest risk of erosion. Develop site-specific measures for these areas. Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of wildfires to community housing	Moderate-High Risk	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of flooding to essential services (e.g. schools and health center)	Moderate-High Risk	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of explosion or failure of the power plant due to wildfire	Moderate-High Risk	Clean up all flammable fuels Replace flammable materials with fire resistant materials

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Since ice jam flooding can produce extreme water levels, determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Hay River.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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KAKISA

SOUTH SLAVE

A Dene South Slavey community, Kakisa is the smallest of NWT's communities, with a population under 50. It is located on the shore of Kakisa Lake, just beside the source of the Kakisa River. This community is not prone to flooding and is one of the least sensitive to permafrost thawing, as it is located in the sporadic permafrost zone. Wildfires are however a significant concern, since Kakisa is surrounded by forests and relatively flat terrain, which increases its vulnerability. Indeed, during the 2014 fire season, the community had to evacuate its residents after a fire broke through established fire barriers. Examples of essential infrastructures in and near the community are the school, the health center, the diesel plant and the road as residents rely on services provided in other communities.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High)	Clean up all flammable fuels Replace flammable materials with fire resistant materials
Risk of failure of the water treatment plant due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map of the GNWT Atlas suggests that the community is not at risk of flooding. Given the proximity and low elevation above the Mackenzie River, confirm the low flood risk through hydrological modelling.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Kakisa.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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K'ATL'ODEECHE

SOUTH SLAVE

Kátł'odeeche First Nation community is located across the community of Hay River, on the east bank of the Hay River, near its source at Great Slave Lake. Most of its population of 300 is South Slavey Dene. It is particularly prone to flooding because ice jams events often happen along the Hay River. The community also exhibits moderate sensitivity to permafrost thaw. The wildfire hazard is High to Extreme, as it is surrounded by forests and relatively flat terrain. K'atl'odeeche relies on services located at Hay River (e.g. health center) and therefore the Indian River Road is critical to provide access to these services. Historically, since 1960, 6 forest fires occurred near K'atl'odeeche. Moreover, flooding occurred frequently in K'atl'odeeche, causing evacuations and extensive material damages.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires or floods	Moderate-High (orange)	Increase emergency preparedness efforts, including plans for the continuity of services to the regional communities Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	Moderate-High (orange)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of damage to sanitary sewer mains due to flooding or erosion	Moderate-Low (yellow)	Identify zones with the highest risk of erosion. Develop site-specific measures for these areas. Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of wildfires to community housing	Moderate-High (orange)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of flooding to essential services (e.g. schools and health center)	Moderate-High (orange)	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of explosion or failure of the power plant due to wildfire	Moderate-High (orange)	Clean up all flammable fuels Replace flammable materials with fire resistant materials

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Since ice jam flooding can produce extreme water levels, determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Conduct an assessment of streambank erosion risk.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Hay River or K'atl'odeeche.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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APPENDIX

D-3 DEHCHO

FORT LIARD

DEHCHO

Fort Liard is a river-front community of 600 Dene, Métis and non-Aboriginal residents at the foothills of the Mackenzie Mountains. It is located on the bank of Liard River just off Highway 7, almost 40 km north of the British Columbia border and only 30 km east of the Yukon border. Spring runoff peaking from the mountains during freshet put pressure on the surrounding rivers' ice cover, causing it to break up and cause ice jams. The community, built in the discontinuous permafrost zone, exhibits moderate sensitivity to permafrost thaw. Wildfires are also a concern. Examples of essential infrastructures in and near the community are Fort Liard Health Center as well as City Hall.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Wildfire impact to roads	●	Prepare/update emergency community and infrastructure-based wildfire preparedness plans; update the plan after wildfire events and share findings with other communities.
Wildfire impact to culverts	●	Increase FireSmart efforts for vegetation removal and maintenance within a 10 m radius of infrastructure.
Permafrost impact to water treatment plant	●	Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain as insulation in spring.
Wildfire impacts to buildings (community housing, health center, fire station)	●	Inspect infrastructure and replace flammable materials with fire resistant materials in high risk areas. Remove accumulated debris from roofs and gutters regularly.
Wild fire impacts to fuel storage	●	Increase FireSmart efforts for vegetation removal and maintenance within a 10 m radius of infrastructure.
Snow load impact to buildings (community housing, school, health center)	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Flood impact (every infrastructure close to the Liard river)	●	Limit development in floodplains, identify and relocate at-risk critical infrastructure. Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.

DATA GAPS AND PRIORITY STUDY

- The floodway fringe map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort Liard.

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FORT SIMPSON

DEHCHO

Located at the confluence of Liard River and Mackenzie River, Fort Simpson is Dehcho's regional centre and home to 1,200 residents from Dene, Métis and non-Aboriginal origin. Runoff peaking during freshet from the Mackenzie Mountains put pressure on the both rivers' ice cover, causing break up and ice jams flooding. The community exhibits moderate sensitivity and risk to permafrost thaw. Wildfires are also a concern, with a high FireSmart rating for Nogha Heights and Wildrose Acres developments. Examples of essential infrastructures in the community are the water and waste water treatment plants, Łíídlįį Kúę Elementary and Regional High School and the health center. Example of previous impact is the 1989 flood where 125 people were evacuated from Fort Liard and Fort Simpson.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of flooding to the water and waste water treatment plants	● (Moderate-Low)	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of damage to sanitary sewer mains due to flooding or erosion	● (Moderate-Low)	Identify zones with the highest risk of erosion. Develop site-specific measures for these areas. Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of wildfires to community housing (Norgha Heights and Wildrose Acres)	● (Moderate-High)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of flooding to essential services (e.g. schools and health center)	● (Moderate-High)	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High)	Clean up all flammable fuels Replace flammable materials with fire resistant materials
Risk of failure of the power plant due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort Simpson.

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JEAN MARIE RIVER

DEHCHO

Jean Marie River is a Dene community of less than 100 inhabitants situated on the low-lying flats where the Jean Marie River meets the Mackenzie River. It is accessible by river and airplane, and by a 27 km access road off of NTW's Highway 1. The water level rise of the the Mackenzie river, caused by spring runoff peaks from the Mackenzie Mountains and ice jams puts the community at-risk of flooding, as happened in 2018. Located in the sporadic permafrost zone, Jean Marie exhibits low sensitivity and risk to permafrost thaw. Wildfires are a particular concern, as shown in 2014 and 2015 when fires burned as near as 3 km from the community. Examples of essential infrastructures in the community are the Louie Norwegian school and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	🟠	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of flooding to the water treatment plant	🟡	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of damage to sanitary sewer mains due to flooding or erosion	🟡	Identify zones with the highest risk of erosion. Develop site-specific measures for these areas. Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of wildfires to community housing	🟠	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of flooding to essential services (e.g. schools and health center)	🟠	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of explosion or failure of the diesel generators due to wildfire	🟠	Furnish fuel tank tops with water or foam sprinklers Consider increasing redundancy by splitting and distributing fuel to low-risk areas
Risk of failure of the water treatment plant due to permafrost	🟠	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map is not available on the GNWT Atlas. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Jean Marie River.

NAHANNI BUTTE

DEHCHO

Located on the bank of the South Nahanni River, across the Nahanni Mountain, Nahanni Butte is home to just over 100 South Slavey Dene people. It is accessible by airplane and ice road in the winter or river taxi in the summer. Its location on a sediment bar makes the community at-risk of flooding during freshet, when the water levels of the South Nahanni and Liard Rivers quickly peak. In 2012, residents had to be evacuated and the power plant temporarily closed due to rising flood waters. Build in the discontinuous permafrost zone, Nahanni Butte shows moderate sensitivity and risk to permafrost thaw. Wildfires are also a concern, albeit the risk level is low to moderate, with higher risk to the houses located in the southeast region of the community. Examples of critical infrastructure are Charles Yohin School, the diesel generators and the health cabin.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	Moderate-High	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	Moderate-High	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of flooding to the diesel generators	Moderate-Low	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of wildfires to community housing	Moderate-High	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of flooding to housing and essential services (e.g. school)	Moderate-High	Consider developing site specific mitigation and adaptation strategies for ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations.
Risk of explosion or failure of the diesel generators due to wildfire	Moderate-High	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Replace flammable materials with fire resistant materials
Risk of failure of critical infrastructure due to permafrost hazard	Moderate-High	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- The floodzone map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Nahanni Butte.

SAMBAA K'E

DEHCHO

Accessible by air or by winter road, Sambaa K'e is a small Dene community of about 100 located on the sandy shores of Trout Lake, about 50 km north of the Alberta border and 125 km east of Fort Liard. Flooding is not a concern for this community, as the water level of Trout Lake does not fluctuate enough. Sambaa K'e is built in the sporadic permafrost zone, which makes it less sensitive and at-risk to permafrost thaw than other Dehcho communities. The surrounding forests increase the community's vulnerability to wildfires, especially in the western area. Examples of essential infrastructures in the community are the water treatment plant, Charles Tetcho School and the health center.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	● (Moderate-High)	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	● (Moderate-High)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing, water treatment plant and landfill	● (Moderate-High)	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the generators due to wildfire	● (Moderate-High)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Consider increasing redundancy by splitting and distributing fuel to low-risk areas.
Risk of failure of the water treatment plant due to permafrost	● (Moderate-High)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring..

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Sambaa K'e.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal

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WRIGLEY

DEHCHO

Wrigley is the northern-most Dene-Dehcho community of the NWT. Located at the end of Heritage Route (NWT Hwy 1), Wrigley is perched on a high bluff overlooking the Mackenzie River, with the Franklin Mountains just east of the community. Its 40 m elevation from the bank of the Mackenzie River makes it relatively out of danger regarding flooding. Although built in the discontinuous permafrost zone, Wrigley is at a low risk impacts from permafrost thaw. The surrounding forests increase the community's vulnerability to wildfires. In 2013, a fire burning 25 km near Wrigley threatened the Enbridge Pipeline and Pump Station, located 10km away from the community, and led to it being closed as a precaution. Examples of essential infrastructure in and near the community are the health center and the water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of road closure or road and culverts damage due to wildfires	●	Increase emergency preparedness efforts Reduce and maintain vegetation along roads
Risk of structural damage to buildings due to snow load	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North)
Risk of wildfires to community housing (southeast end) and water treatment plant	●	Limit development in areas at high risk for wildfires Maintain and remove debris from the fireguards Remove accumulated debris from roofs, gutters and yards Encourage residents to establish adequate defensible space around their structures, especially in the southeast end of the town
Risk of explosion or failure of the tank farm	●	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers Consider increasing redundancy by splitting and distributing fuel to low-risk areas.
Risk of failure of the water treatment plant due to permafrost	●	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring.

● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Wrigley.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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APPENDIX

D-4 SAHTU

COLVILLE LAKE

SAHTU

Colville Lake, home of about 160 Hareskin Dene people, sits on the south border of the lake of the same name, 80 km above the Arctic Circle. This remote community is only accessible by air via Norman Wells or by winter road from Fort Good Hope. Although the lake level does not fluctuate, spring runoff previously washed out the road between the community and the airport. The community is located in the continuous permafrost zone, which makes it at risk regarding impacts from permafrost thaw. Given the surrounding open-density forests near Colville Lake, the FireSmart risk level is Low. Examples of essential infrastructures in the community are the school, health center and water treatment plant. According to satellite imagery, the water treatment plant is located next to polygonal ground, which suggest important ice content and high sensitivity to thawing.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw, especially the water treatment plant	● (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components.
Risk of structural damage to buildings due to snow load	● (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of failure of roads and drainage infrastructure due to extreme precipitation and spring freshet.	● (Moderate-Low Risk)	Consult with engineering professionals to assess and identify site specific drainage vulnerabilities

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Colville Lake.
- Evaluate if the drainage systems and culverts are undersized to expected changes in magnitude of freshet and extreme precipitation.

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DÉLĮNE

SAHTU

The Dene community of Délįne, home of around 530 people, is the only community on the shores of Great Bear Lake, the largest lake located entirely within Canada's borders. It is situated on the western shore of the lake, approximately 550 km northwest of Yellowknife, and is only accessible by airplane or winter roads. Because the water level of Great Bear Lake does not vary much, Délįne is at a low risk for flooding, although previously ice was pushed on the shore during the breakup which caused minimal damage. The community is located in the discontinuous permafrost zone and is considered at a moderate risk level regarding impacts from permafrost thaw. Wildfires are also a great concern with the forests surrounding Délįne. Despite the fact that most of the community is in a zone with a Low FireSmart rating, Délįne was evacuated in 2011 due to wildfire. Examples of essential infrastructures in the community are the school, health center, tank farm and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	● (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components.
Risk of structural damage to buildings due to snow load	● (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	● (Moderate-High Risk)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of explosion or failure of the tank farm due to wildfire	● (Moderate-High Risk)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Délįne.

FORT GOOD HOPE

SAHTU

Fort Good Hope is located on the banks of the Mackenzie River, approximately 135 km north of Norman Wells, and is accessible by plane and ice road in the winter. Its population of 570 is mostly Sahtu Dene and Métis. Flooding is a hazard for Fort Good Hope, as the community is situated in a river bend downstream of where the Mackenzie River narrows from 4 km wide to only 500 m, rushing by 40 m limestone cliffs. The community is considered at moderate risk to permafrost thaw, as it is built on ice-rich permafrost in the continuous permafrost zone. Fort Good Hope is also at a High level of risk for wildfires: in 2018, a wildfire only 25 km from the community burned over 8,000 hectares. Examples of essential infrastructures in the community are the school, health center, tank farm and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	🔴 (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components.
Risk of structural damage to buildings due to snow load	🟠 (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	🟠 (Moderate-High Risk)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of explosion or failure of the tank farm due to wildfire	🟠 (Moderate-High Risk)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers
Risk of flooding and streambank erosion to critical infrastructure and essential services	🟠 (Moderate-High Risk)	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.
Risk of flooding to community housing	🟠 (Moderate-High Risk)	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.

🔴 High risk 🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort Good Hope.
- The floodzone map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.

NORMAN WELLS

SAHTU

Nestled between the Mackenzie River and the Franklin Mountains, Norman Wells is the regional centre and air transportation hub of the Sahtu Region. In Norman Wells, flood hazard is limited to the overtopping of the islands which are used as production bases for oil and gas. Located in the discontinuous permafrost zone, Norman Wells is considered at moderate risk to permafrost thaw, where buildings already started to shift due to ground settlement. As for the other communities of the region, wildfires are a great concern due to the forests surrounding Norman Wells, especially in the eastern residential areas. The community was evacuated in 1995 and 2003 due to wildfire activity. Examples of essential infrastructures in the community are the school, health center, tank farm and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	● (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	● (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	● (Moderate-High Risk)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of explosion or failure of the power plant due to wildfire	● (Moderate-High Risk)	Clean up all flammable fuels Furnish fuel tank tops with water or foam sprinklers

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Norman Wells.
- The floodzone map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.

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TULITA

SAHTU

The Dene community of Tulita, located where Great Bear River empties into the Mackenzie River, sits across the river from the Mackenzie Mountains, right underneath the sacred mountain of Bear Rock. A mere 70 km southeast of Norman Wells, Tulita is accessible by airplane as well as ice road during the winter. Flooding is a serious hazard for this community, as the water treatment plant, the power plant and the houses south of Bear Rock Drive are located in or close to the floodplain. Streambank erosion is a major concern in Tulita. Located in the discontinuous permafrost zone, Tulita is considered at moderate risk to permafrost thaw. Wildfires are a serious concern, with zones of extreme FireSmart hazard in the main townsite and the northern residential area. Tulita was evacuated in 1995 due to wildfire activity. Examples of essential infrastructures in the community are the school, health center, tank farm and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	High risk (red)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	Moderate-High Risk (orange)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to community housing	Moderate-High Risk (orange)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards
Risk of flooding and streambank erosion to critical infrastructure and essential services	Moderate-High Risk (orange)	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.
Risk of flooding to community housing	Moderate-High Risk (orange)	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Tulita.
- Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.

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APPENDIX

D-5 BEAUFORT DELTA

AKLAVIK

BEAUFORT DELTA

Aklavik is a Gwich'in community of 600 situated in a horseshoe meander bar of the Peel Channel, on the western flank of the Mackenzie Delta. Its location and low elevation make it extremely sensitive to riverine and ice jam flooding. Indeed, the whole community is below the 10-year return period water level for ice jam. Serious flood events include the May 2006 flood, which saw 300 people being evacuated, as well as the 2013 flood, where water levels reached 5 m above normal. Aklavik is 55 km west of Inuvik and is only accessible by airplane or winter road. Located in a zone of warm and ice-rich continuous permafrost, the community shows high sensitivity to permafrost thawing. The FireSmart risk rating is low for Aklavik. Examples of essential infrastructures in the community are the school, health center, tank farm and water treatment plant.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	🔴	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Consider use of pipe with restrained joints, especially for critical areas when replacing below ground sanitary sewer mains.
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of flooding and streambank erosion to critical infrastructure and essential services	🟠	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.
Risk of flooding to community housing	🟠	Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Identify and relocate at-risk critical infrastructure.

🔴 High risk 🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Aklavik.
- Identify zones of where streambank erosion is most critical.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.

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FORT MCPHERSON

BEAUFORT DELTA

A community of about 900 residents, of which more than 80% is of Gwich'in descent, Fort McPherson is located in the Mackenzie Delta on the east bank of the Peel River, just off Dempster Highway (NWT Hwy 8). The community is sensitive to ice jam flooding, especially in the spring during freshet. In 2013, cabins near Fort McPherson were dislodged due to severe ice jam flooding. Located in a zone of warm and ice-rich continuous permafrost, the community shows high sensitivity to permafrost thawing. The FireSmart Hazard rating for Fort McPherson is qualified as high, especially in the sector of East cabin and in the southwest corner of the town. The water intake at Deep Lake is far from the community and water supply was cut off in the past during a wildfire episode.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	🔴	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Consider use of pipe with restrained joints, especially for critical areas when replacing below ground sanitary sewer mains.
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to critical infrastructure and community housing	🟠	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards Respect the recommendations from the Community Wildfire Protection Plan
Risk of flooding to critical infrastructure and essential services	🟠	Consider developing site specific mitigation and adaptation strategies for fluvial and ice jam induced flooding; strategies may include structural, non-structural, or emergency mitigations. Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Identify and relocate at-risk critical infrastructure.
Risk of flooding to community housing	🟠	

🔴 High risk 🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Fort McPherson.
- The floodzone map suggests that the whole community is at risk of flooding. Determine through historical events and hydrological modelling the sectors where flood risk is highest, either in terms of flooding frequency or water level.

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INUVIK

BEAUFORT DELTA

With a mixed population of 3,250 Inuvialuit, Gwich'in and non-Indigenous residents, Inuvik is the administrative centre and the hub of the Inuvik region. It is located in the Mackenzie Delta, just off Dempster Highway (NWT Hwy 8), about 100 km north of Tsiigehtchic, and is considered the gateway to the Beaufort Delta. The community is sensitive to riverine and ice jam flooding. Located in a zone of warm and ice-rich continuous permafrost, the community shows high sensitivity to permafrost thawing. Several buildings have seen structural damage from shifting grounds, such as the Igloo Church (formerly Our Lady of Victory Church) which has seen 3-4 inches of ground sloping and support beams lifted off the ground. It is estimated that 40-75% of the buildings are likely to incur foundation damage due to permafrost thawing. The FireSmart Hazard rating for the community of Inuvik is qualified as extreme on the southern areas of the town (South industrial area, Shell Lake, Airport cabins). The 1968 fire burned to the eastern limit of the town.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	● (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Consider use of pipe with restrained joints, especially for critical areas when replacing below ground sanitary sewer mains.
Risk of structural damage to buildings due to snow load	● (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to critical infrastructure and community housing	● (Moderate-High Risk)	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards Respect the recommendations from the Community Wildfire Protection Plan

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Inuvik.
- Verify the roof structure to identify which building is to prioritize in terms of snow removal.
- Evaluate the cumulative potential impacts of thaw settlement on foundation and increased vertical load induced by snow on buildings.

PAULATUK

BEAUFORT DELTA

Paulatuk is an Inuvialuit community of about 250 people situated on the south shore of Darnley Bay in the Amundsen Golf, near the western end of the Northwest Passage, and is only accessible by airplane. This coastal community is sensitive to storm surges and coastal erosion, especially on the eastern side where most of the community is. Located in a zone of cold, continuous permafrost, it is less sensitive to permafrost thaw than are the communities in the Mackenzie Delta, though consequences could be severe in zones of permafrost with high ice content. In 2012, the community school sank 8 inches despite being recently built.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	🔴	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of coastal erosion to the infrastructure located on the peninsula	🟠	Develop site specific flood mitigation and adaptation options for the projected sea level rise and associated processes, especially on the eastern sector. These might include building and/or increase elevation of sea walls, dikes, etc. Consider relocating critical infrastructure.
Risk of coastal flooding to the critical infrastructure	🟠	Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Do not permit development in floodplains or in areas where existing and future coastal erosion hazards are high.

🔴 High risk 🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Paulatuk.
- Monitor closely the coastal erosion rate and changes in coastal erosion and deposition dynamics. Further study is needed on the interacting effects of wind, sea level rise and wave action on the erosion rates.
- Conduct a cost-benefit or multi-criteria analysis to evaluate what would be the best approach to coastal risk management in Paulatuk. Options include status quo, engineering solutions, infrastructure relocation, etc.

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SACHS HARBOUR

BEAUFORT DELTA

Sachs Harbour is the northernmost community in the NWT. Located on the southwestern coast of Banks Island, where the Amundsen Gulf meats the Beaufort Sea, this High Arctic Inuvialuit community of 130 is only accessible via air. This coastal community is sensitive to storm surges and coastal erosion. Located in a zone of cold, continuous permafrost, it is less sensitive to permafrost thaw than are the other communities of the Inuvik region, though consequences could be severe in zones of permafrost with high ice content. Slope failure is already frequently occurring in Sachs Harbour as a result of thermal erosion of permafrost by running water.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	🔴	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	🟠	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of coastal erosion to the infrastructure located on the peninsula	🟠	Develop site specific flood mitigation and adaptation options for the projected sea level rise and associated processes. These might include building and/or increase elevation of sea walls, dikes, etc. Consider relocating critical infrastructure.
Risk of coastal flooding to the critical infrastructure	🟠	Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Do not permit development in floodplains or in areas where existing and future coastal erosion hazards are high.

🔴 High risk 🟠 Moderate-High Risk 🟡 Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Sachs Harbour.
- Conduct multi-year aerial imagery analysis to estimate historical coastal erosion rates.
- Monitor closely the coastal erosion rate and changes in coastal erosion and deposition dynamics. Further study is needed on the interacting effects of wind, sea level rise and wave action on the erosion rates.

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TSIIGEHTCHIC

BEAUFORT DELTA

Accessible via ferry after a 60 km drive from Fort McPherson or a 125 km drive from Inuvik, Tsiigehtchic is a small Gwich'in community of just under 200 residents. This community is located on the south bank of the Mackenzie River. Despite being at an altitude that makes it safe to flood hazard, Tsiigehtchic is at risk of streambank erosion. The cemetery and two churches are considered exposed to erosion. Located in a zone of warm, ice-rich continuous permafrost of the Mackenzie Delta, Tsiigehtchic shows high sensitivity to permafrost thawing. The community is also at high-risk for wildfires; in 2018, a wildfire was reported burning within 10 km south of the community.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	High risk	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost. Consider use of pipe with restrained joints, especially for critical areas when replacing below ground sanitary sewer mains.
Risk of structural damage to buildings due to snow load	Moderate-High Risk	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of wildfires to critical infrastructure and community housing	Moderate-High Risk	Limit development in areas at high risk for wildfires Remove accumulated debris from roofs, gutters and yards Respect the recommendations from the Community Wildfire Protection Plan
Risk of streambank erosion to infrastructure and housing.	Moderate-High Risk	Identify and relocate at-risk critical infrastructure. Identify zones with the highest risk of erosion. Develop site-specific measures for these areas.

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Tsiigehtchic.
- Conduct a specific assessment of infrastructure risk to streambank erosion.

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TUKTOYAKTUK

BEAUFORT DELTA

Tuktoyaktuk is a traditional Inuvialuit community of about 900 people located at the end of the Inuvik-Tuktoyaktuk Highway (NWT Hwy 10), where the Mackenzie Delta rivers and channels meet the Beaufort Sea. The community is extremely at-risk of coastal erosion and flooding from storm surges. Indeed, significant coastal erosion is already underway in Tuktoyaktuk, which has put a row of homes and a graveyard at risk on the peninsula. Historical events include the 1982 storm surge that resulted in the relocation of the RCMP detachment, as well as the abandonment of a rink and a school. Located in a zone of ice-rich continuous permafrost, the community shows high sensitivity to permafrost thawing. Wildfires are not a concern, as Tuktoyaktuk is located above the tree line.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	● (High risk)	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	● (Moderate-High Risk)	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of coastal erosion to the infrastructure located on the peninsula	● (Moderate-High Risk)	Develop site specific flood mitigation and adaptation options for the projected sea level rise and associated processes, especially on the peninsula. These might include building and/or increase elevation of sea walls, dikes, etc. Consider relocating critical infrastructure.
Risk of coastal flooding to the critical infrastructure	● (Moderate-High Risk)	Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Do not permit development in floodplains or in areas where existing and future coastal erosion hazards are high.

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Tuktoyaktuk.
- Monitor closely the coastal erosion rate and changes in coastal erosion and deposition dynamics. Further study is needed on the interacting effects of wind, sea level rise and wave action on the erosion rates.
- Conduct a cost-benefit or multi-criteria analysis to evaluate what would be the best approach to coastal risk management in Tuktoyatuk. Options include status quo, engineering solutions, infrastructure relocation, etc.

ULUKHAKTOK

BEAUFORT DELTA

Located along the shores of Queens Bay in the Amundsen Gulf, on the west coast of Victoria Island, Ulukhaktok is a community of approximately 500 Inuvialuit residents. Accessible by air, it is home to the world's northernmost golf course. This coastal community is sensitive to storm surges and coastal erosion, although there are no local data available on the historical dynamics of these hazards. Located in a zone of cold, continuous permafrost, it is less sensitive to permafrost thaw than are the other communities of the Inuvik region, though consequences could be severe in zones of permafrost with high ice content.

RISK IDENTIFIED		PROPOSED ADAPTATION MEASURE
Risk of failure of the critical infrastructure due to permafrost thaw	●	Verify the presence of permafrost and its geotechnical characteristics on the site Implement a snow maintenance program that ensures snow is regularly removed near critical infrastructure to promote ground cooling in winter, and allowed to remain to insulate in the spring. Perform regular inspections to monitor and document ground surface deformations, progression of cracks and deformations in foundations, doors and windows sticking or not sealing, and damage to structural components. Consider monitoring ground temperature using in-ground temperature sensors near or under critical infrastructure to provide an early indication of changes in the thermal regime of the permafrost.
Risk of structural damage to buildings due to snow load	●	Develop a safe snow removal plan for roofs of infrastructure buildings (refer to CSA S502:14 Managing Changing Snow Load Risks for Buildings in Canada's North).
Risk of coastal erosion to the infrastructure located on the peninsula	●	Develop site specific flood mitigation and adaptation options for the projected sea level rise and associated processes. These might include building and/or increase elevation of sea walls, dikes, etc. Consider relocating critical infrastructure.
Risk of coastal flooding to the critical infrastructure	●	Prepare a flood response plan; evaluate flood response and update plan after flooding events and share findings with other communities. Do not permit development in floodplains or in areas where existing and future coastal erosion hazards are high.

● High risk ● Moderate-High Risk ● Moderate-Low Risk

DATA GAPS AND PRIORITY STUDY

- Confirm the presence and the characteristic (e.g. thermal characteristics, depth, ice content) of permafrost under or near the critical infrastructure. Verify the availability of geotechnical surveys in Ulukhaktok.
- Conduct multi-year aerial imagery analysis to estimate historical coastal erosion rates.
- Monitor closely the coastal erosion rate and changes in coastal erosion and deposition dynamics. Further study is needed on the interacting effects of wind, sea level rise and wave action on the erosion rates.

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APPENDIX

E

MAPS OF THE CLIMATE CHANGE IMPACTS AT THE COMMUNITY SCALE

Government of
Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 1
Communities Location

Sources :
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Northwest Territories Centre for Geomatics, http://www.geomatics.gov.nt.ca

0 100 200 km

NAD83, Northwest Territories Lambert

2020-06-02

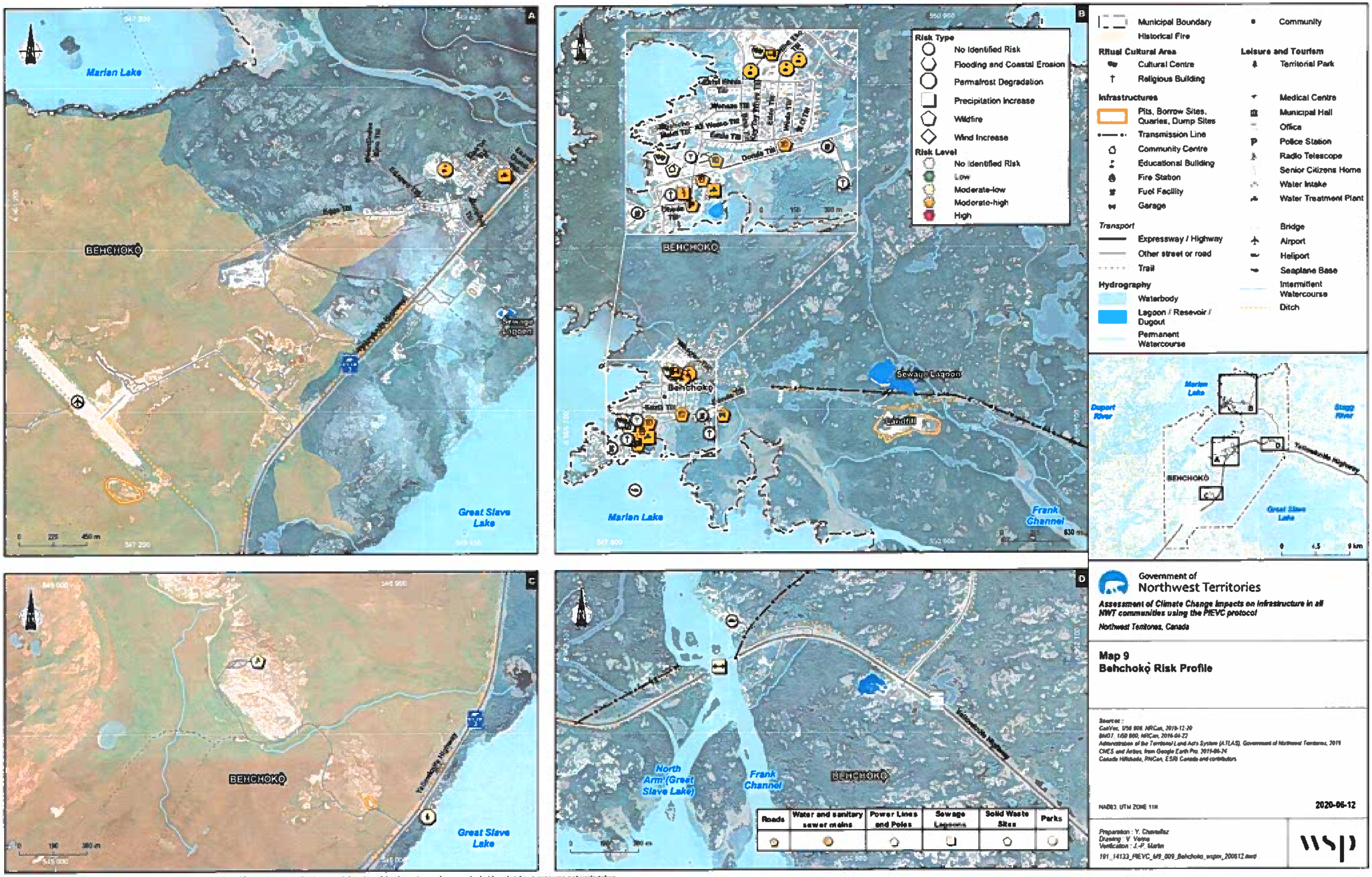
Preparation : Y. Chevalier
Drawing : V. Venne
Verification : J.-P. Martin
191_14133_PIEVC_M1_001_global_wspm_200612.mxd

wsp

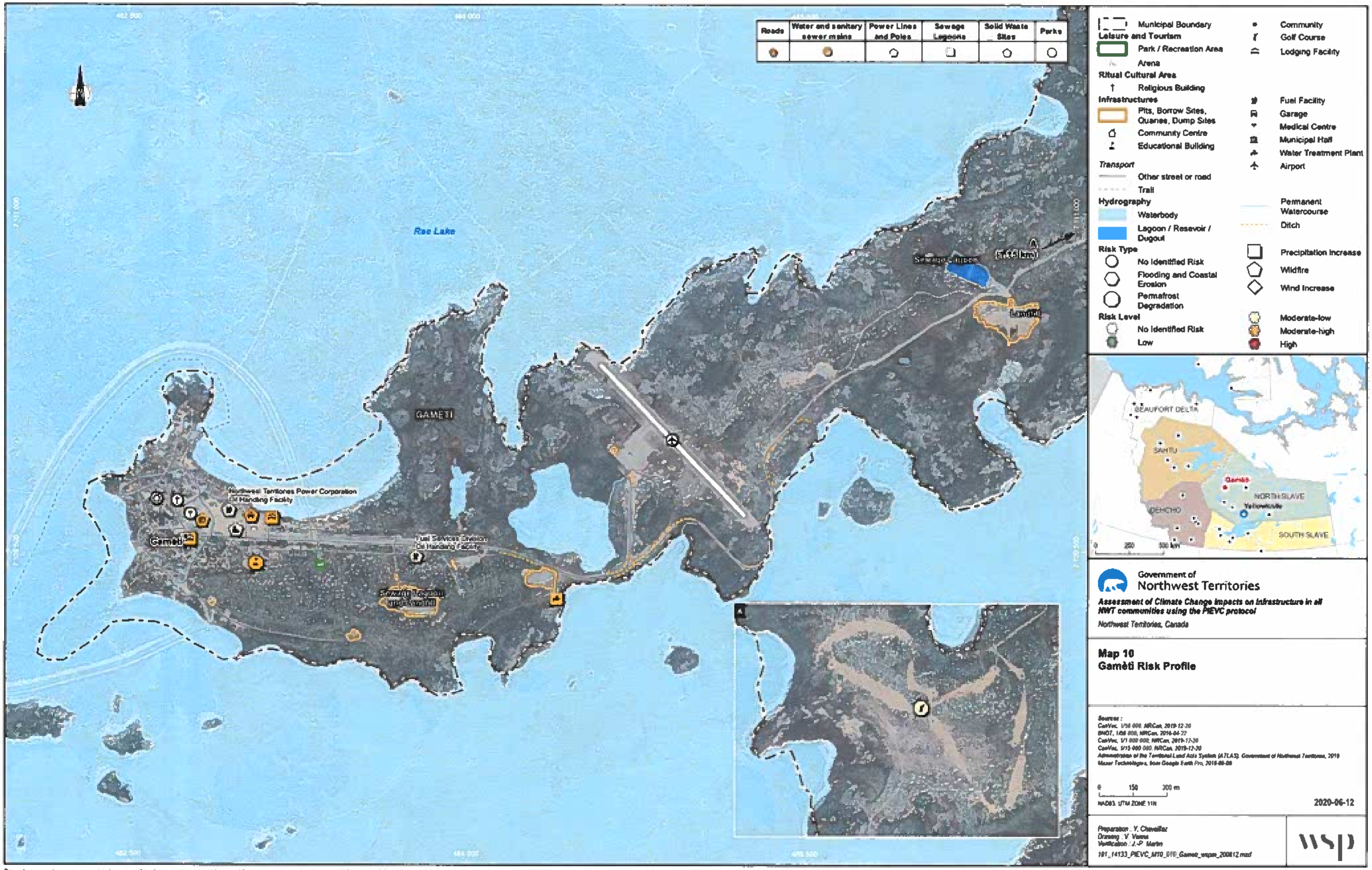
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

APPENDIX

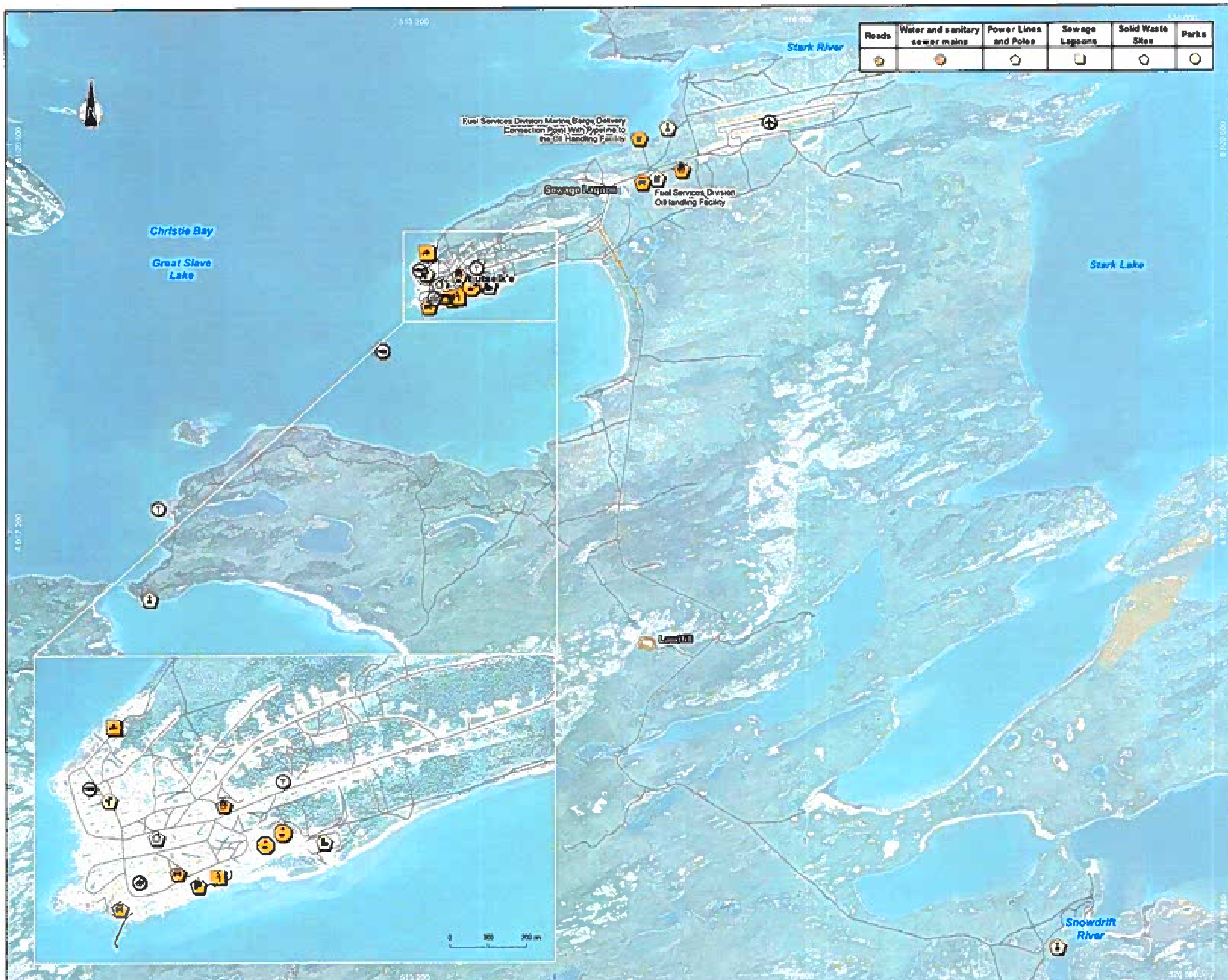
E-1 NORTH SLAVE



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Roads	Water and sanitary sewer mains	Power Lines and Poles	Sewage Lagoons	Solid Waste Sites	Parks
◉	◉	⬠	☐	⬠	○

Historical Fire
Ritual Cultural Area
Cemetery
Religious Building
Infrastructures
Pits, Borrow Sites, Quarries, Dump Sites
Communication Tower
Community Centre
Educational Building
Fire Station
Fuel Facility
Transport
Other street or road
Hydrography
Waterbody
Lagoon / Reservoir / Dugout
Risk Type
No Identified Risk
Flooding and Coastal Erosion
Permafrost Degradation
Risk Level
No Identified Risk
Low
Community
Leisure and Tourism
Arena
Garage
Medical Centre
Police Station
Power Corp Solar Array
Senior Citizens Home
Trading Post
Water Treatment Plant
Airport
Seaplane Base
Permanent Watercourse
Intermittent Watercourse
Ditch
Precipitation Increase
Wildfire
Wind Increase
Moderate-low
Moderate-high
High

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 11
Łutselk'e Risk Profile

Sources:
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-72
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-06-18

NAD83 UTM ZONE 12N

2020-06-12

Preparation: Y. Chevalley
Drawing: V. Verna
Verification: J.-P. Martin
191_14133_PIEVC_M11_011_Lutselke_wspo_200612.mxd

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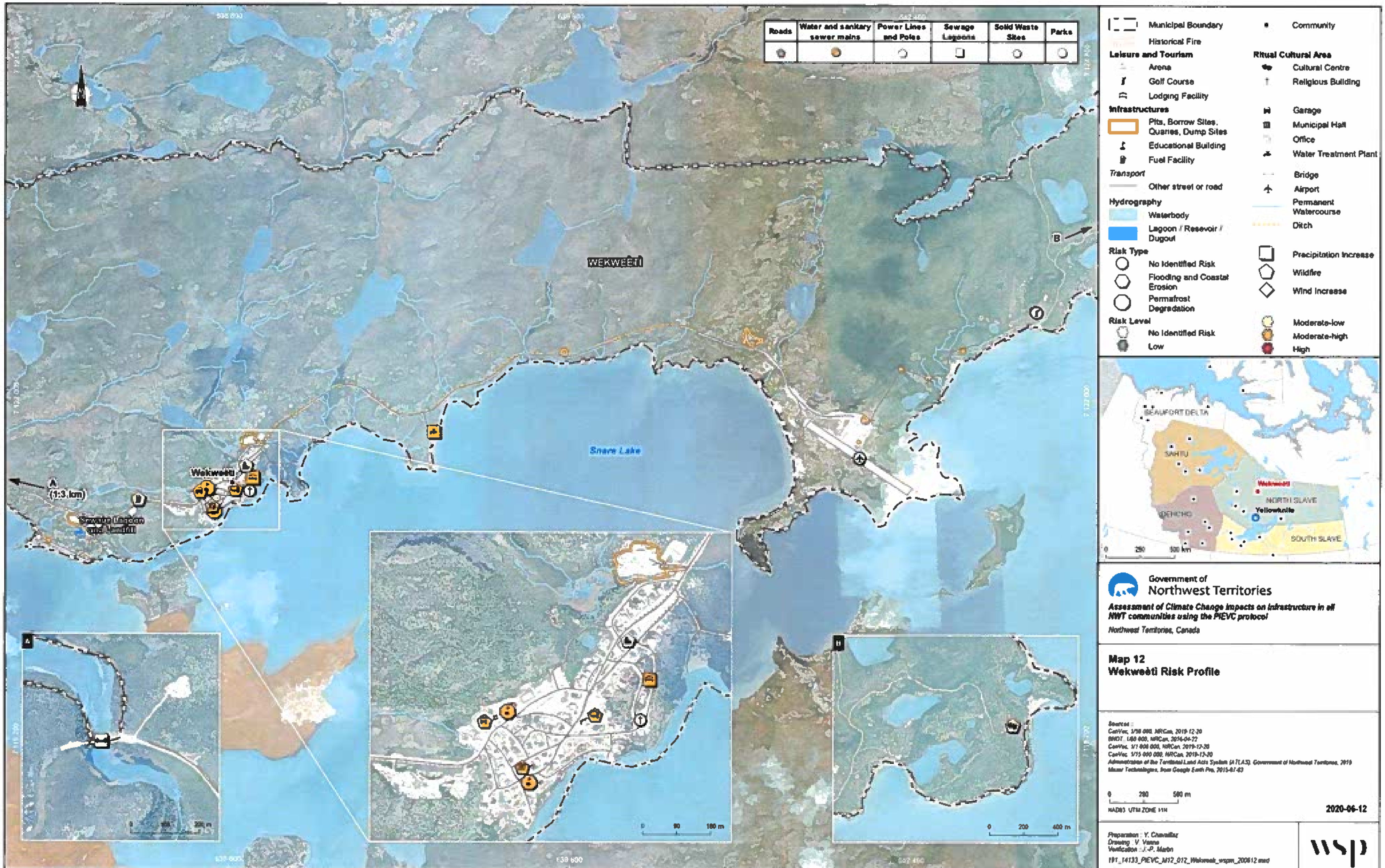

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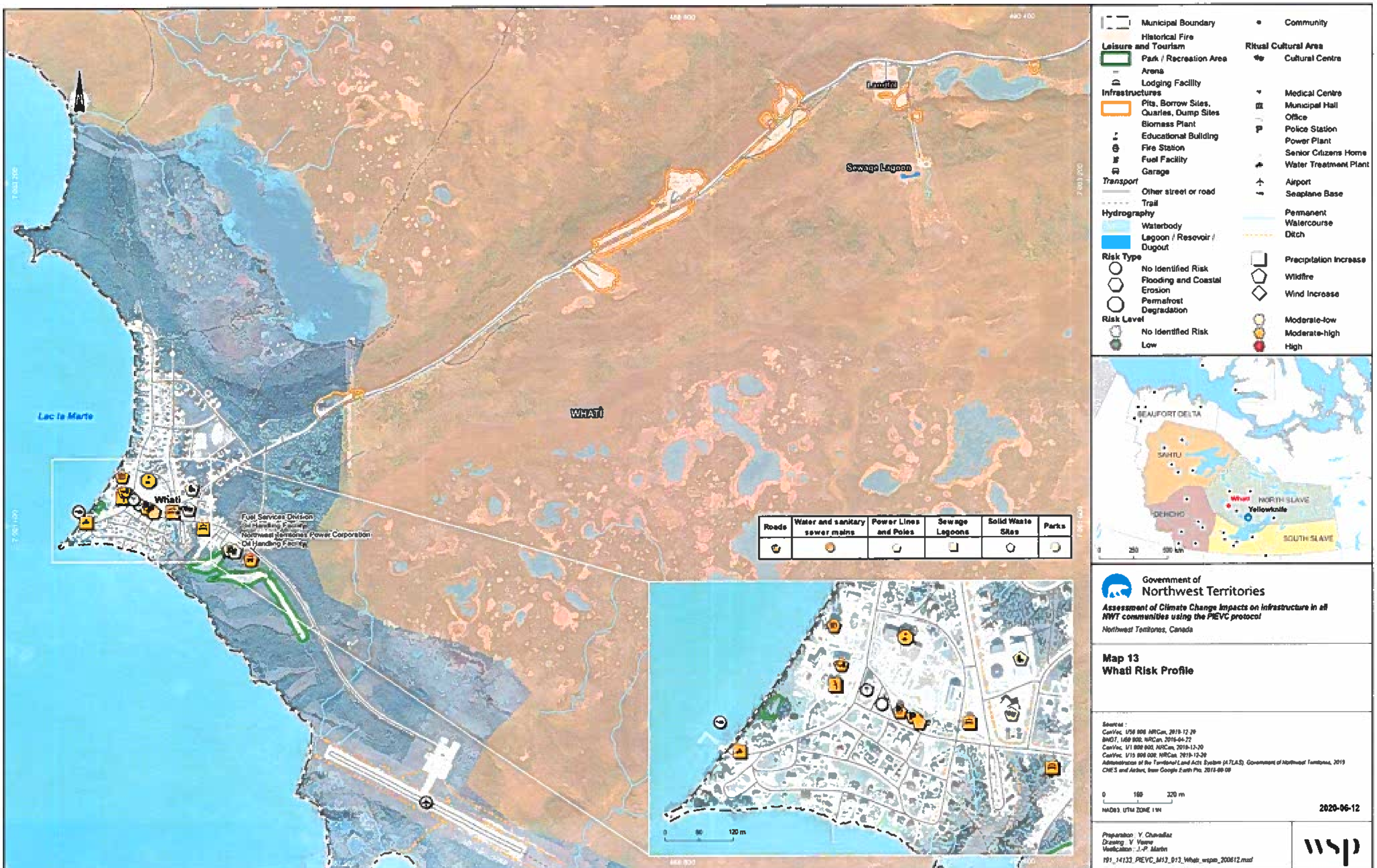
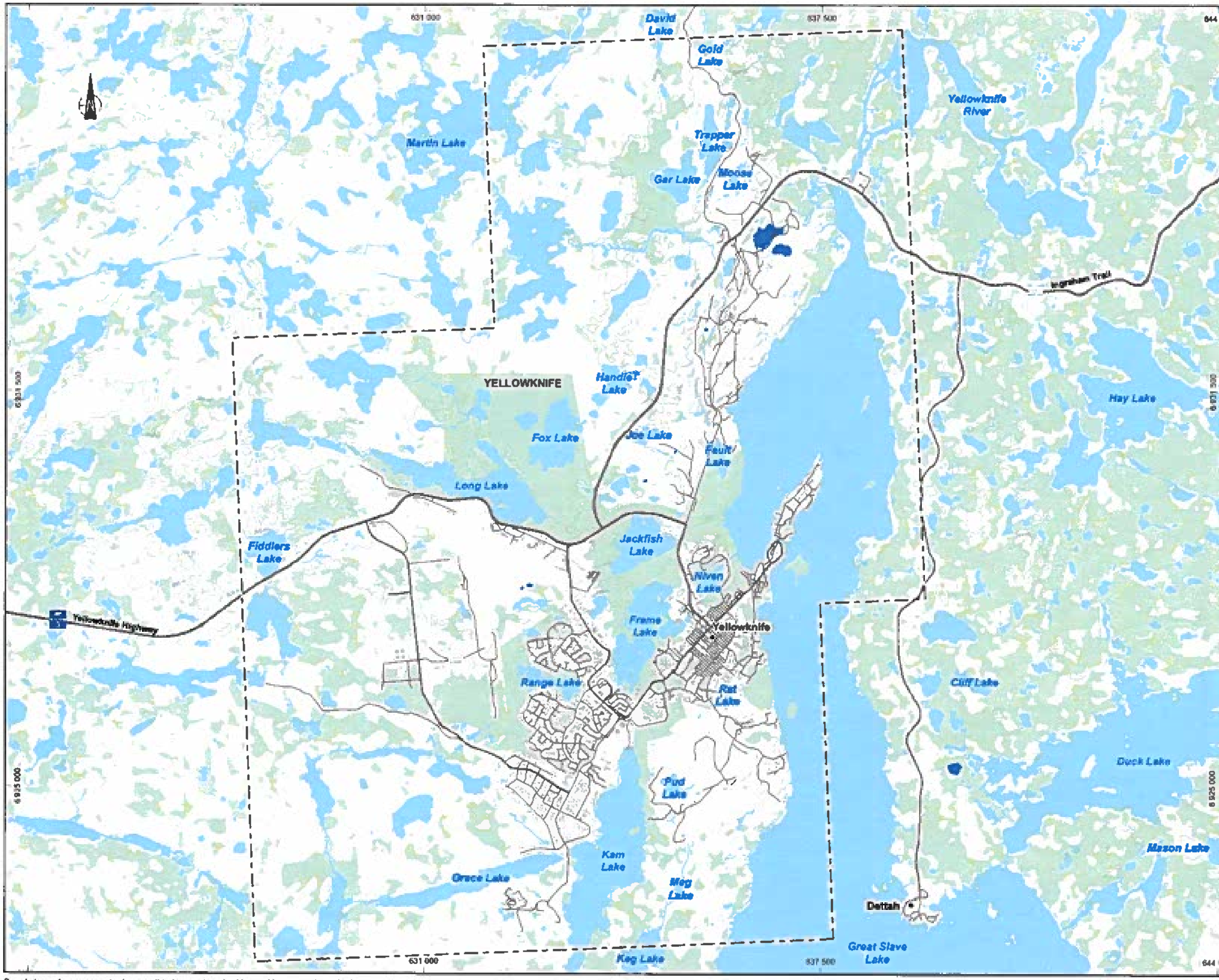


Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Municipal Boundary
Historical Fire
Community

Infrastructures

Expressway / Highway
Collector
Other street or road

Hydrography

Waterbody
Lagoon / Reservoir / Dugout
Permanent Watercourse
Intermittent Watercourse

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 14
Yellowknife Large-scale Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
Northwest Territories Centre for Geomatics, http://www.geomatics.gov.nt.ca
Canada Hillshade, RNCan, ESRI Canada and contributors

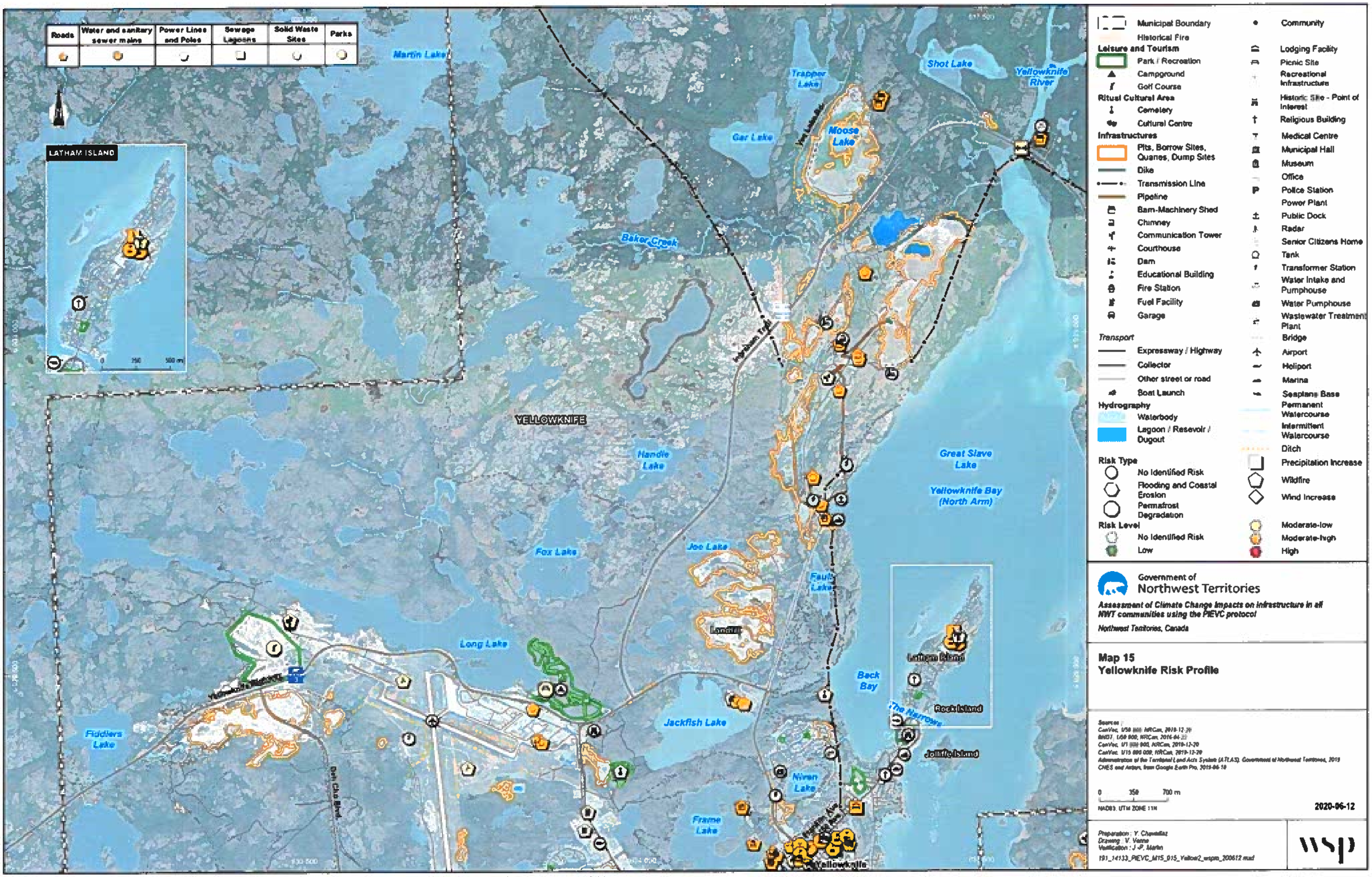
0 625 1 250 m
NAD83, UTM ZONE 11N

2020-06-12

Preparation : Y. Chavellez
Drawing : V. Veene
Verification : J.-P. Martin
191_14133_PIEVC_M14_014_Yellow1_wsp_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 15
Yellowknife Risk Profile

0 350 700 m

NAD83, UTM ZONE 11N

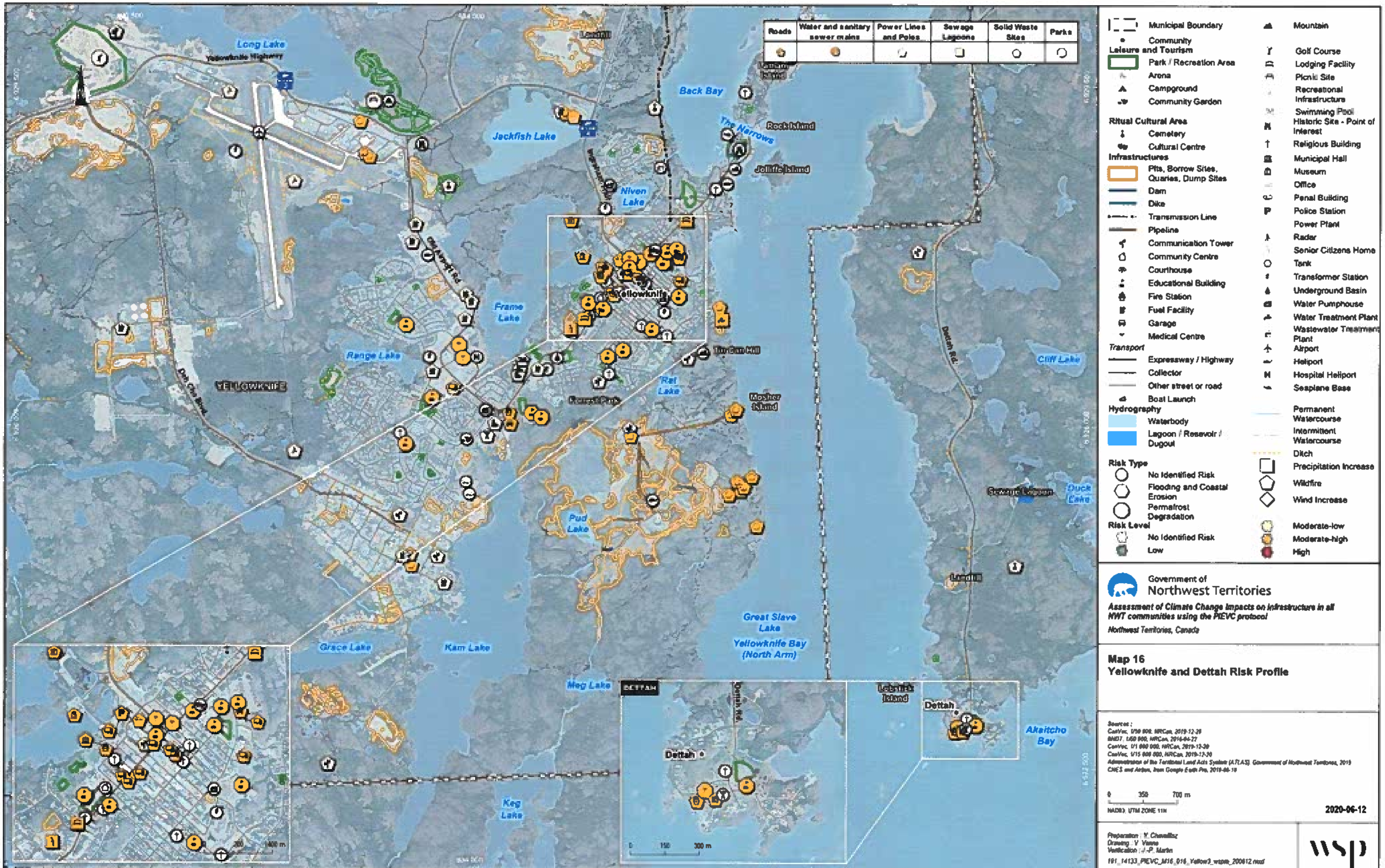
2020-06-12

Preparation : Y. Chevallaz
Drawing : V. Vanne
Verification : J.-P. Martin

191_14133_PIEVC_M15_015_Yellow2_wspm_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

APPENDIX

E-2 SOUTH SLAVE

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 2
Enterprise Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
SNDT, 1/50 000, NRCan, 2016-04-27
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-07-19

0 370 740 m

NAD83, UTM ZONE 11N

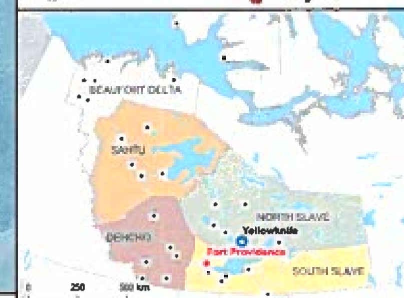
2020-06-12

Preparation : Y. Chevallaz
Drawing : V. Venne
Verification : J.-P. Martin

191_14133_PIEVC_M2_004_Enterprise_wspm_200612.mxd

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

Municipal Boundary
Leisure and Tourism
Arena
Campground
Infrastructures
Pits, Borrow Sites, Quarries, Dump Sites
Barn-Machinery Shed
Communication Tower
Educational Building
Fuel Facility
Water Treatment Plant
Hydrography
Waterbody
Lagoon / Reservoir / Dugout
Risk Type
No Identified Risk
Flooding and Coastal Erosion
Permafrost Degradation
Risk Level
No Identified Risk
Low
Community
Ritual Cultural Area
Cemetery
Religious Building
Transport
Expressway / Highway
Other street or road
Trail
Airport
Seaplane Base
Permanent Watercourse
Ditch
Precipitation Increase
Wildfire
Wind Increase
Moderate-low
Moderate-high
High



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 3
Fort Providence Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-07-16

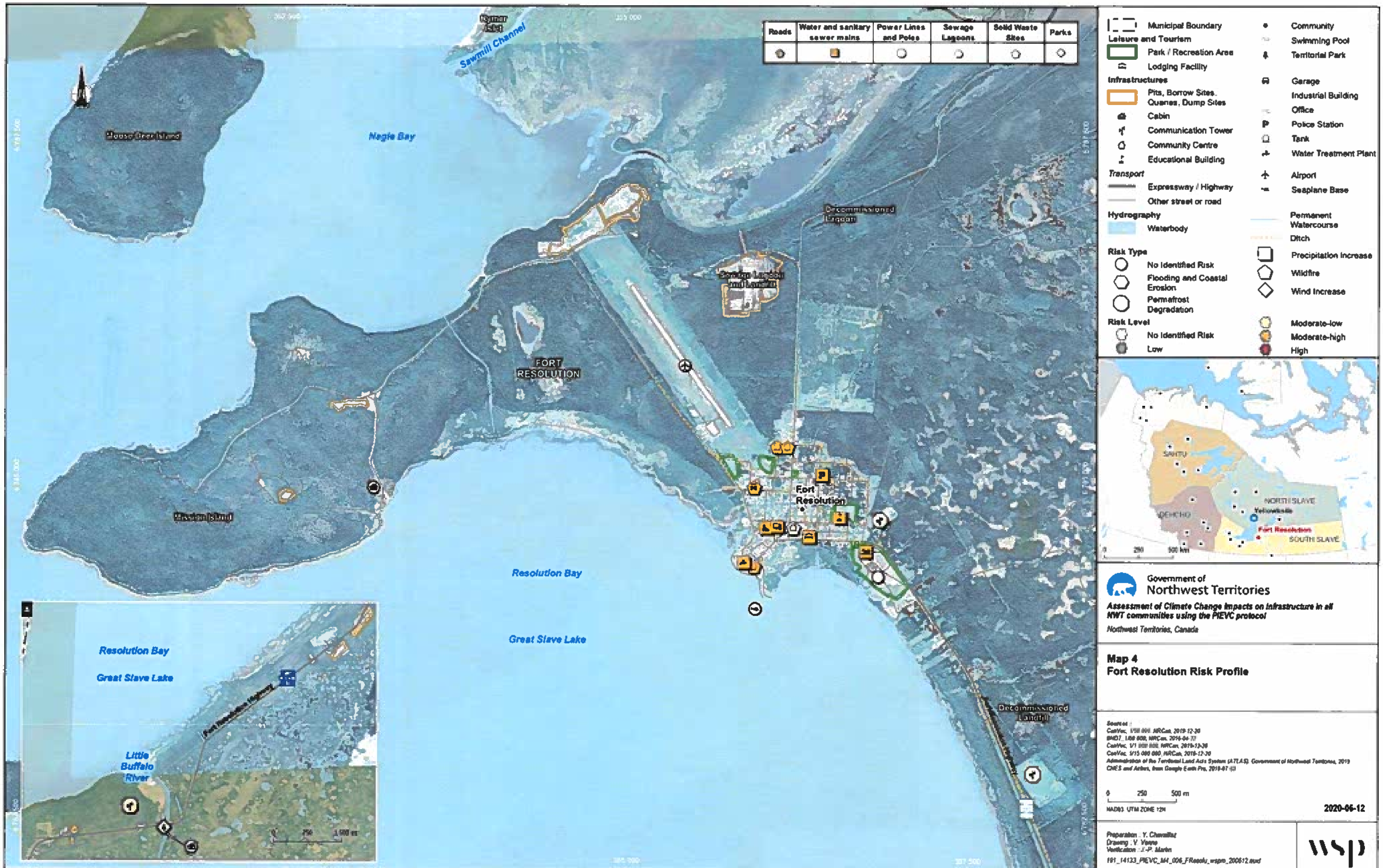
NAD83 UTM ZONE 11N

2020-06-12

Preparation : Y. Chevalier
Drawing : V. Vezina
Verification : J.-P. Martin
191_14133_PIEVC_MJ_005_FProv_wsp_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 4
Fort Resolution Risk Profile

0 250 500 m

NAD83 UTM ZONE 12N

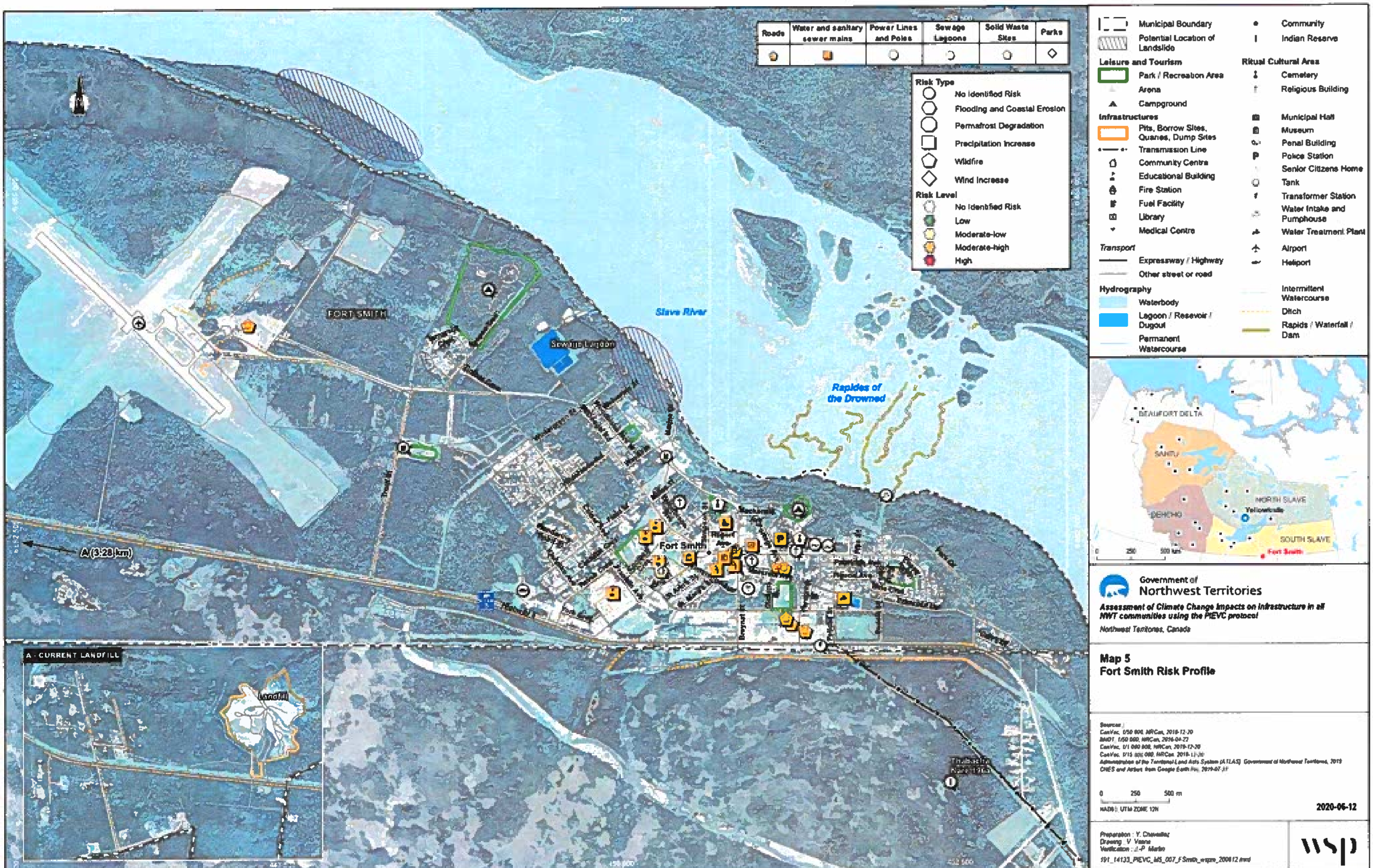
2020-06-12

Preparation : Y. Chevalier
Drawing : V. Veene
Verification : J.-P. Martin

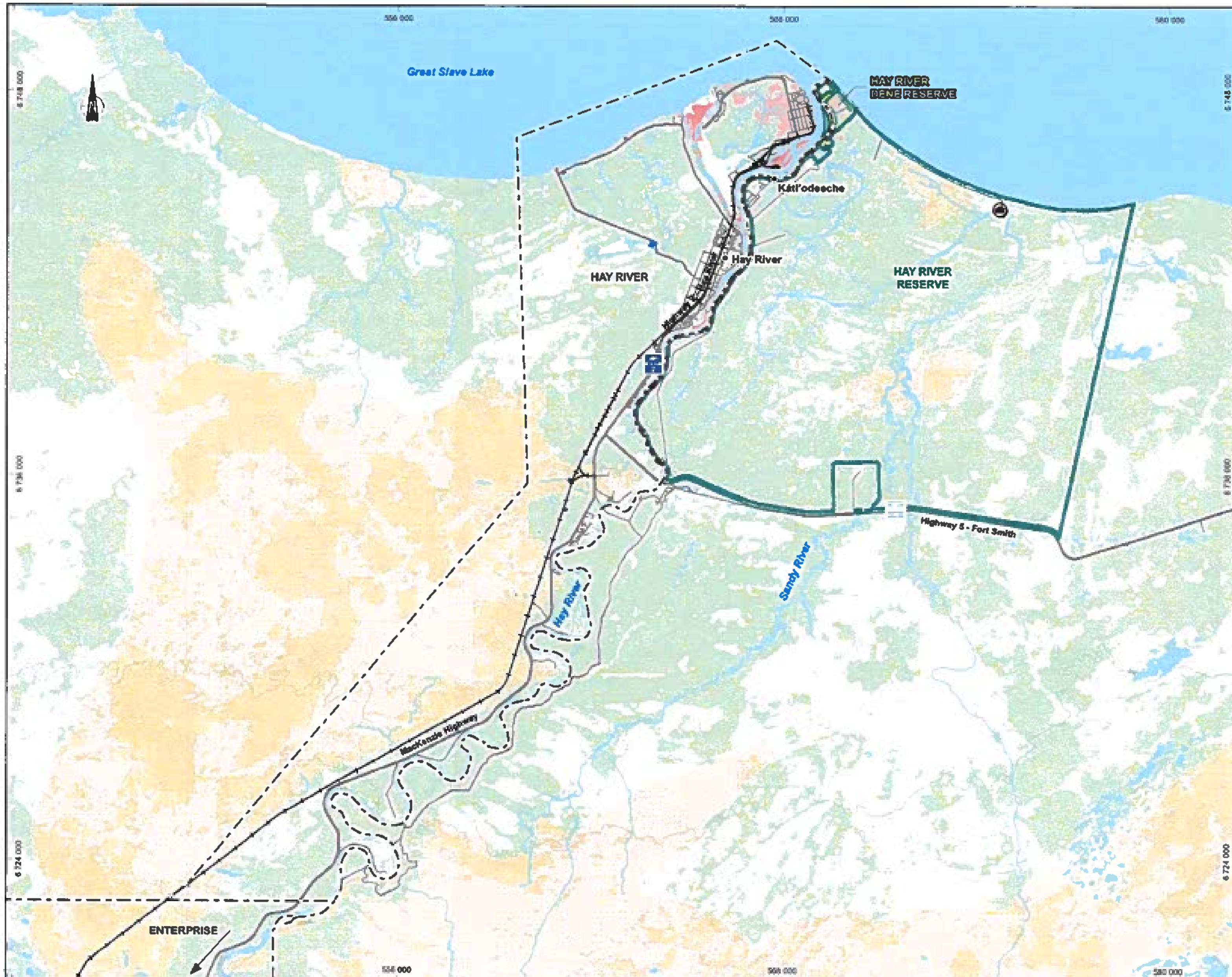
191_14133_PIEVC_M4_006_FResolu_wspm_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Municipal Boundary
Historical Fire

Infrastructures
Expressway / Highway
Collector
Other street or road
Railway

Hydrography
Waterbody
Lagoon / Reservoir / Dugout
Permanent Watercourse
Intermittent Watercourse

Risk Type
No Identified Risk
Flooding and Coastal Erosion
Permafrost Degradation
Precipitation Increase
Wildfire
Wind Increase

Risk Level
No Identified Risk
Low
Moderate-low
Moderate-high
High

Community
Camp

Land Authority
Hay River Reserve
Hay River Dene Reserve

Historical Floodplain
Floodway
Floodway Fringe

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 6
Hay River Large-scale Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
Northwest Territories Centre for Geomatics, http://www.geomatics.gov.nt.ca
Canada Hillshade, RNCan, ESRI Canada and contributors

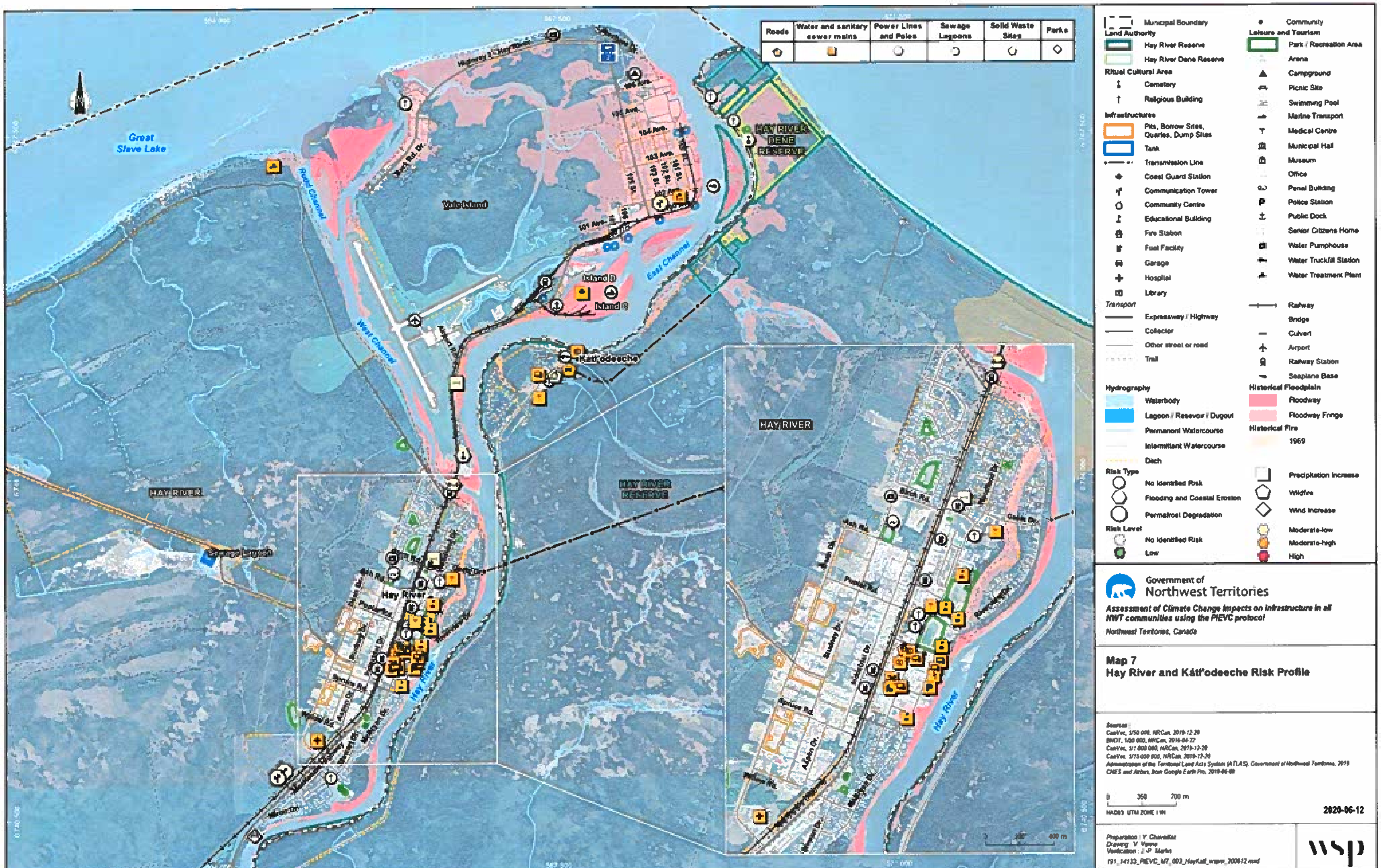
0 1 200 2 400 m
NAD83, UTM ZONE 11N

2020-06-12

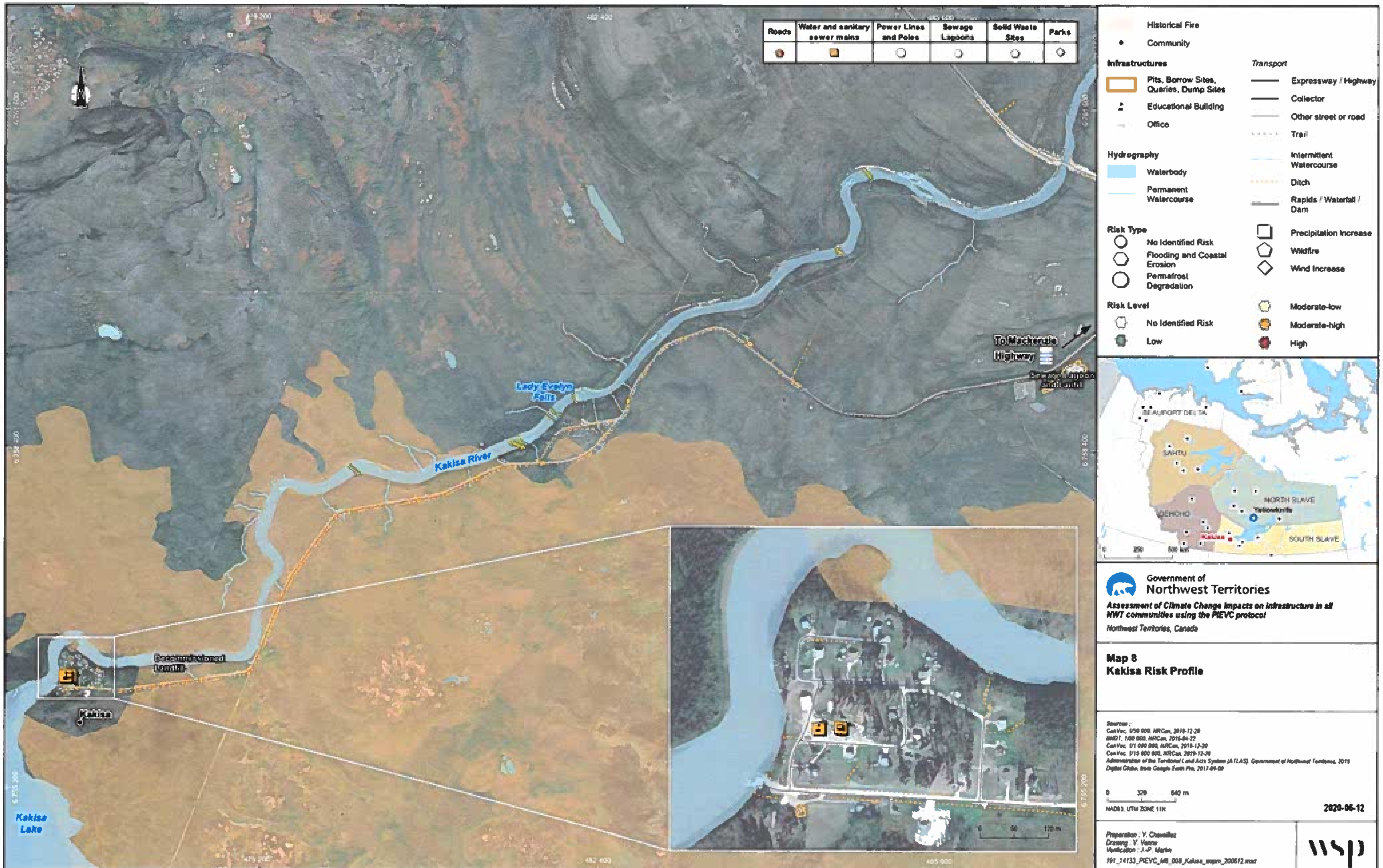
Preparation : Y. Chavellaz
Drawing : V. Veine
Verification : J.-P. Martin
191_14133_PIEVC_MI_002_HayRiver_wspm_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



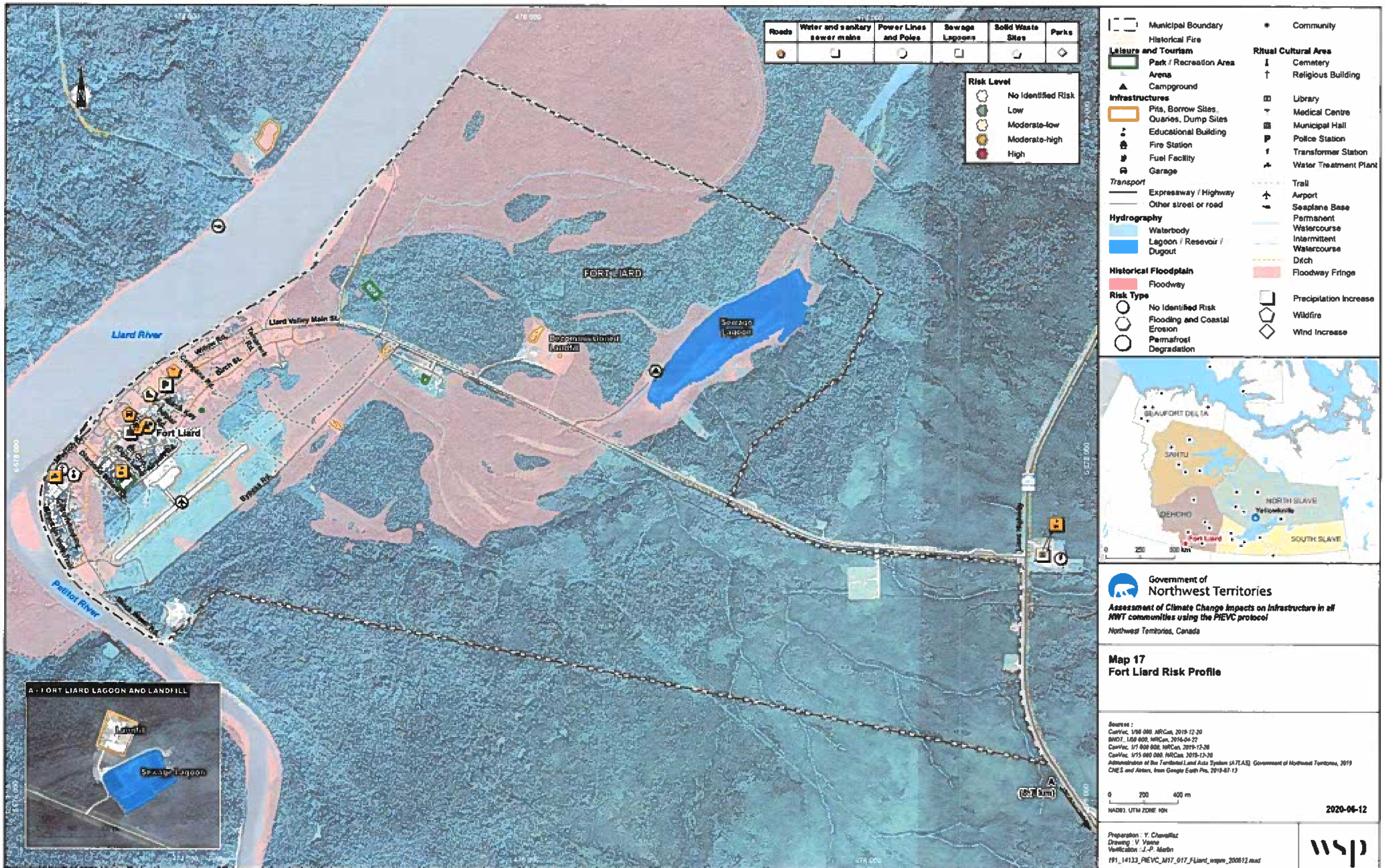
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken

APPENDIX

E-3 DEHCHO



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 17
Fort Liard Risk Profile

Sources:
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-07-13

0 200 400 m

NAD83, UTM ZONE 10N

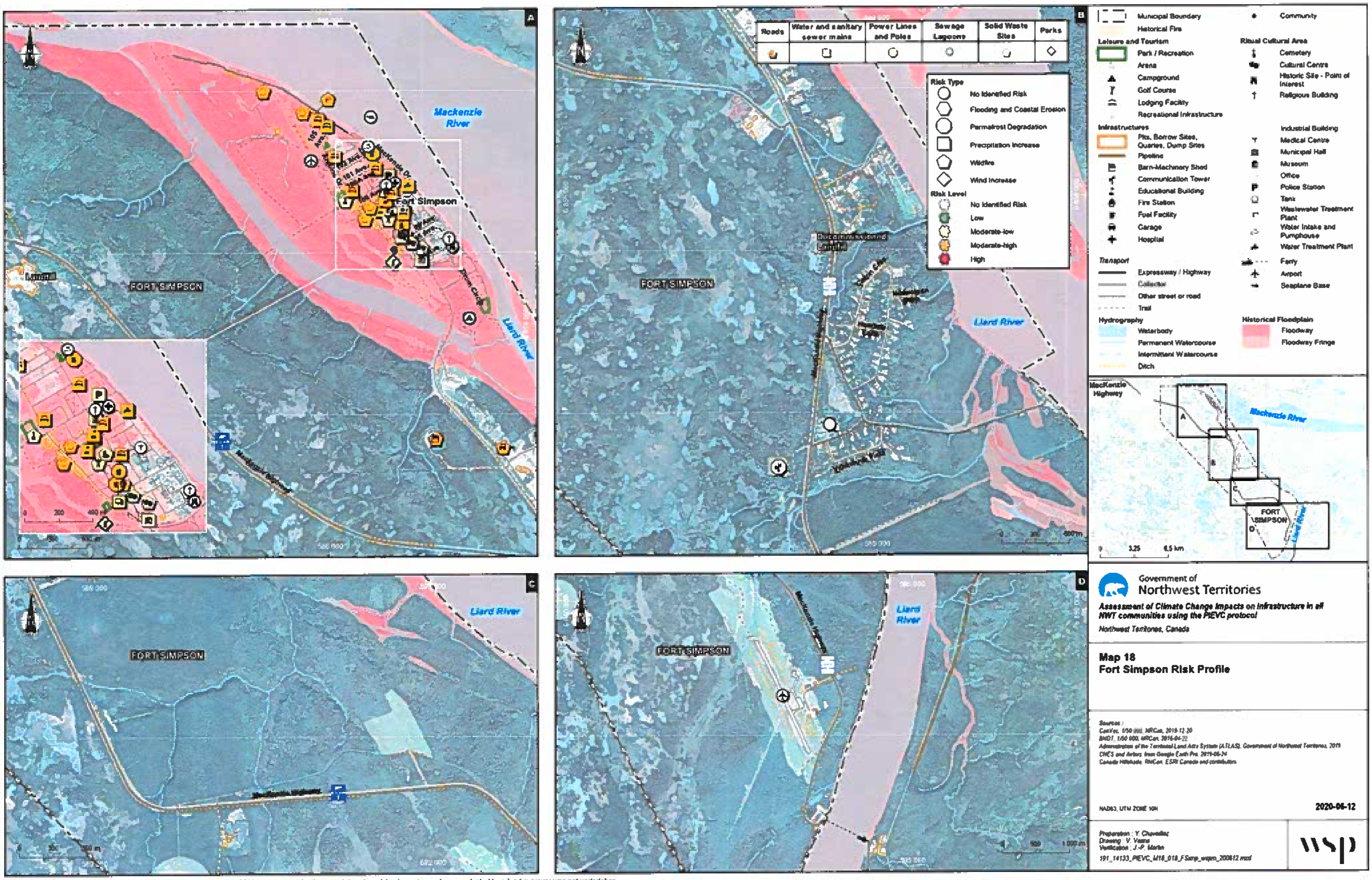
2020-06-12

Preparation: Y. Chevalier
Drawing: V. Veone
Verification: J.-P. Martin

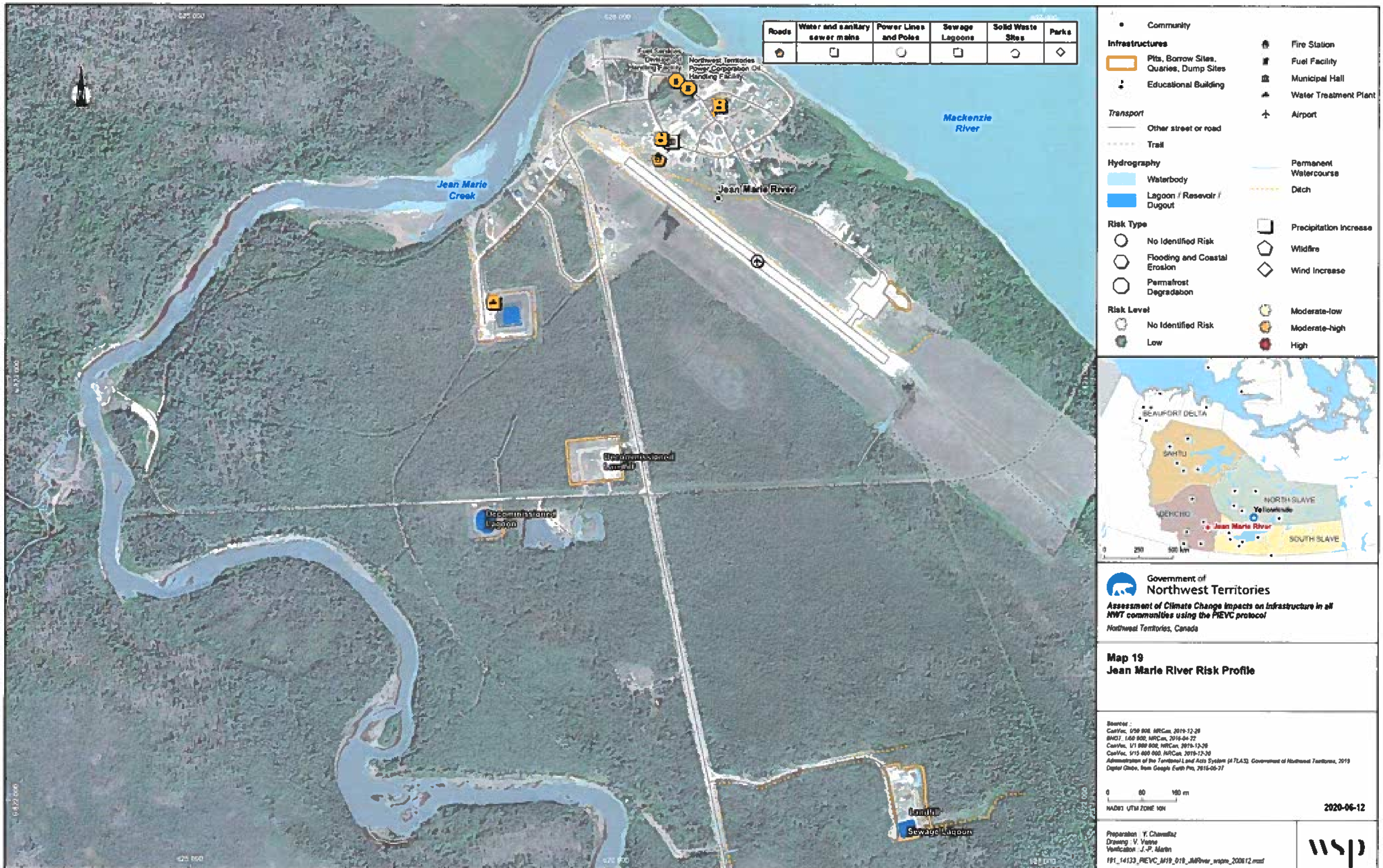
191_14133_PIEVC_M17_017_FLiard_wsp_200612.mxd

wsp

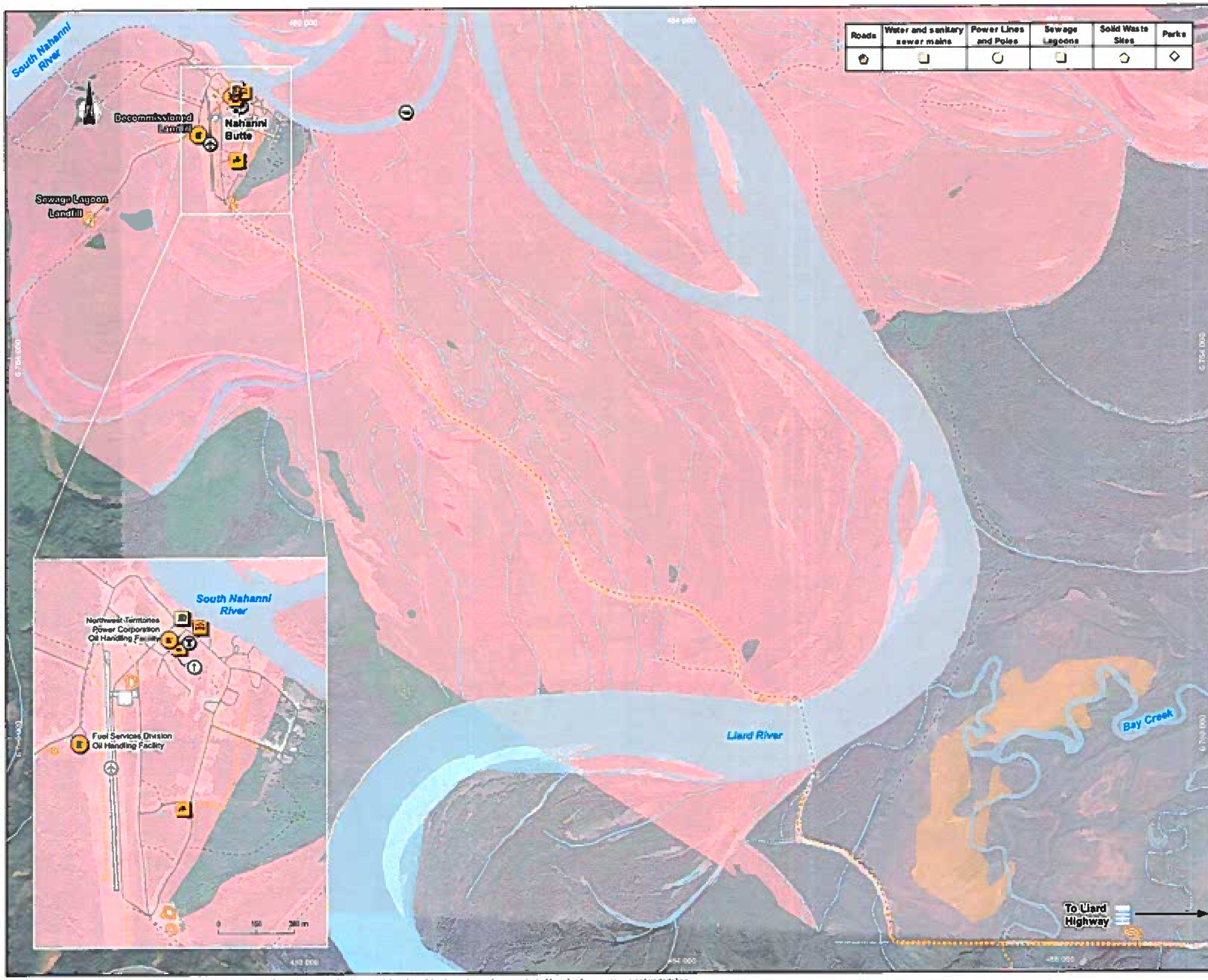
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Roads	Water and sanitary sewer mains	Power Lines and Poles	Sewage Lagoons	Solid Waste Sites	Parks

Historical Fire

Leisure and Tourism
- Lodging Facility
- Recreational Infrastructure

Infrastructures
- Pits, Borrow Sites, Quarries, Dump Sites
- Educational Building

Transport
- Other street or road
- Trail

Hydrography
- Waterbody
- Lagoon / Reservoir / Dugout

Historical Floodplain
- Floodway

Risk Type
- No Identified Risk
- Flooding and Coastal Erosion
- Permafrost Degradation

Risk Level
- No Identified Risk
- Low

- Community

Ritual Cultural Area
- Religious Building
- Fuel Facility
- Municipal Hall
- Water Treatment Plant
- Airport
- Seaplane Base
- Permanent Watercourse
- Intermittent Watercourse
- Ditch
- Floodway Fringe
- Precipitation Increase
- Wildfire
- Wind Increase
- Moderate-low
- Moderate-high
- High

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 20
Nahanni Butte Risk Profile

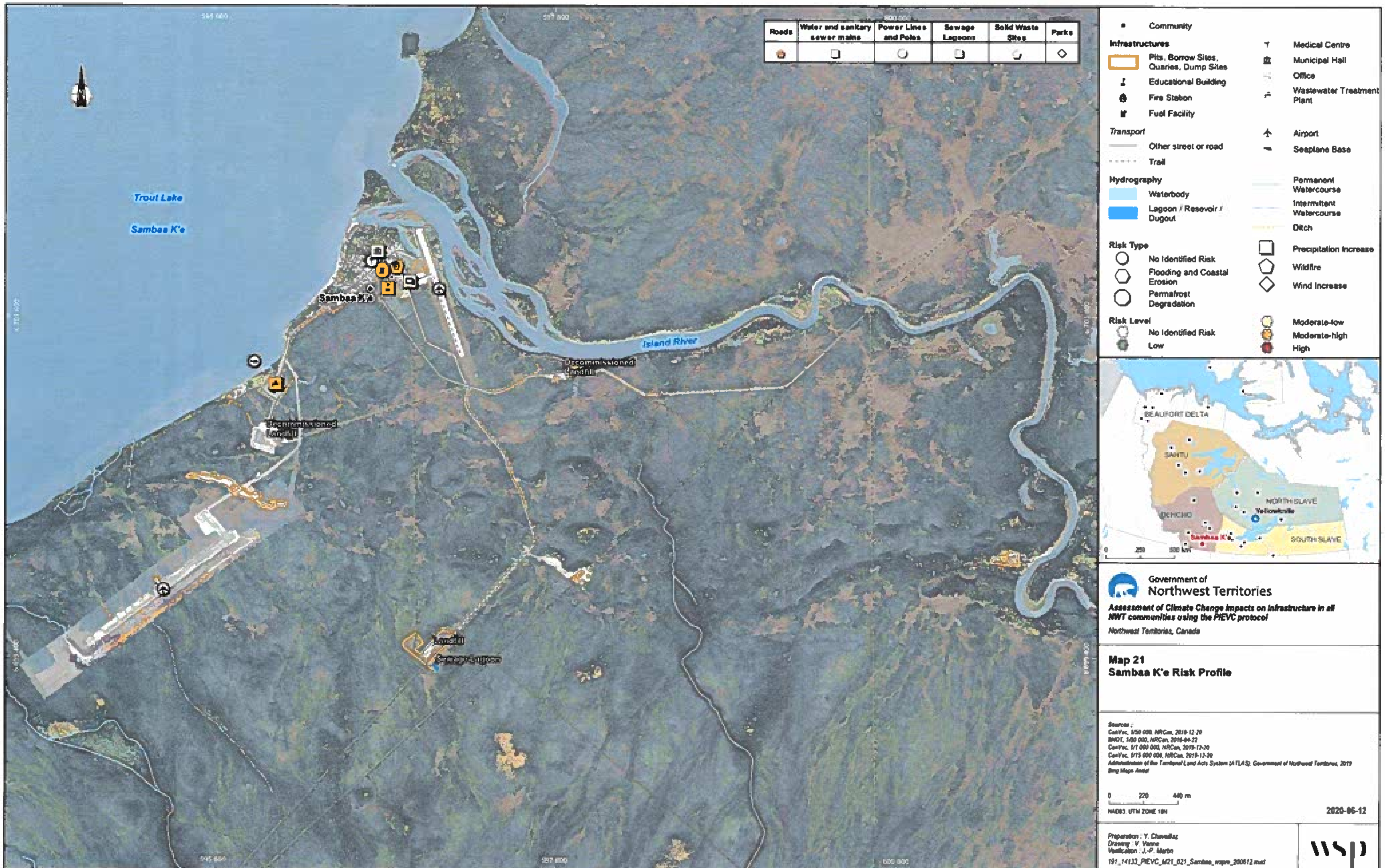
Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
Maxar Technologies, from Google Earth Pro, 2015-05-13

0 400 800 m
NAD83 UTM ZONE 10N

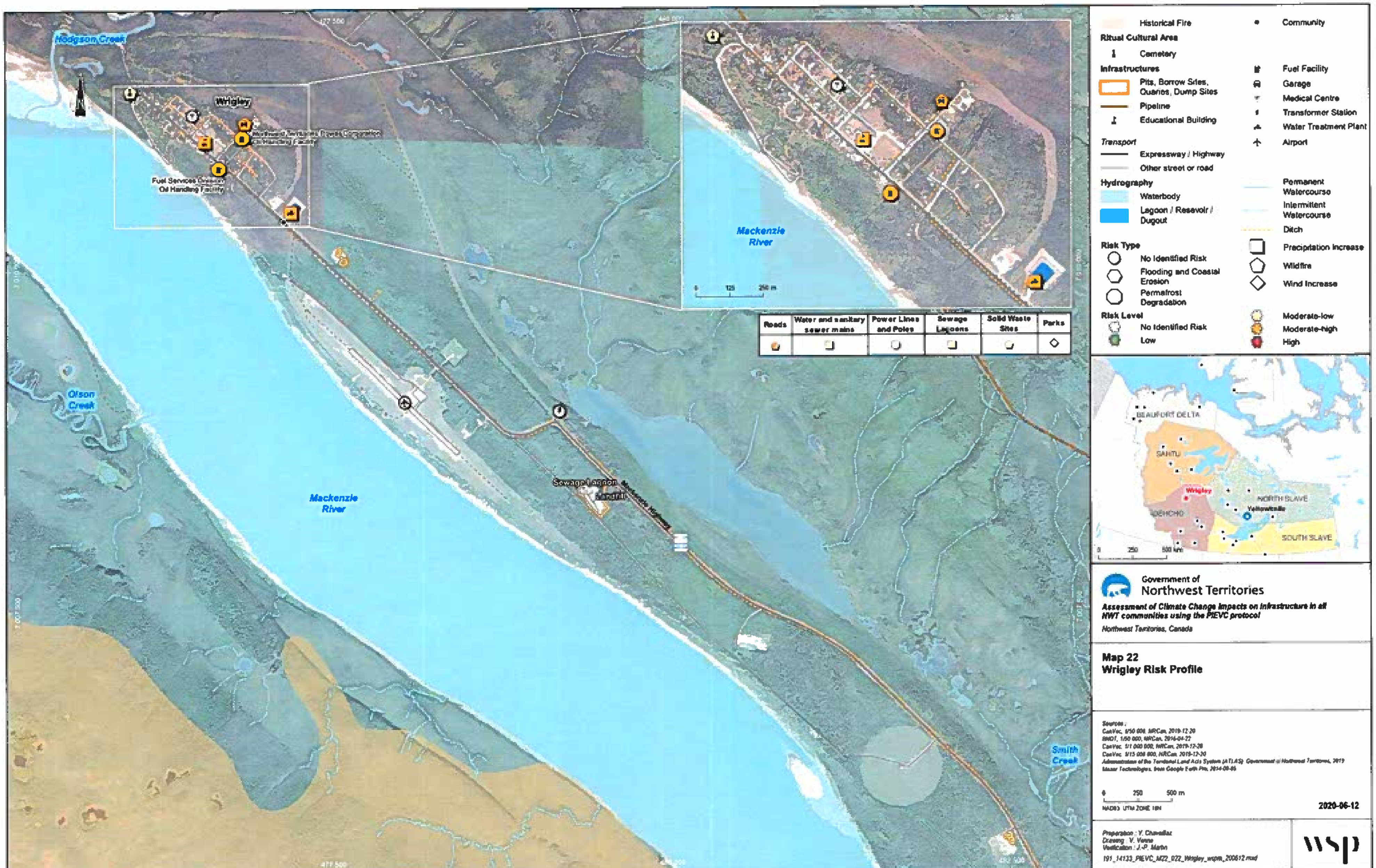
2020-06-12

Preparation : Y. Chevalier
Drawing : V. Vanne
Verification : J.-P. Marbe
191_14133_PIEVC_M20_020_Nahanni_wspto_200612.mxd

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



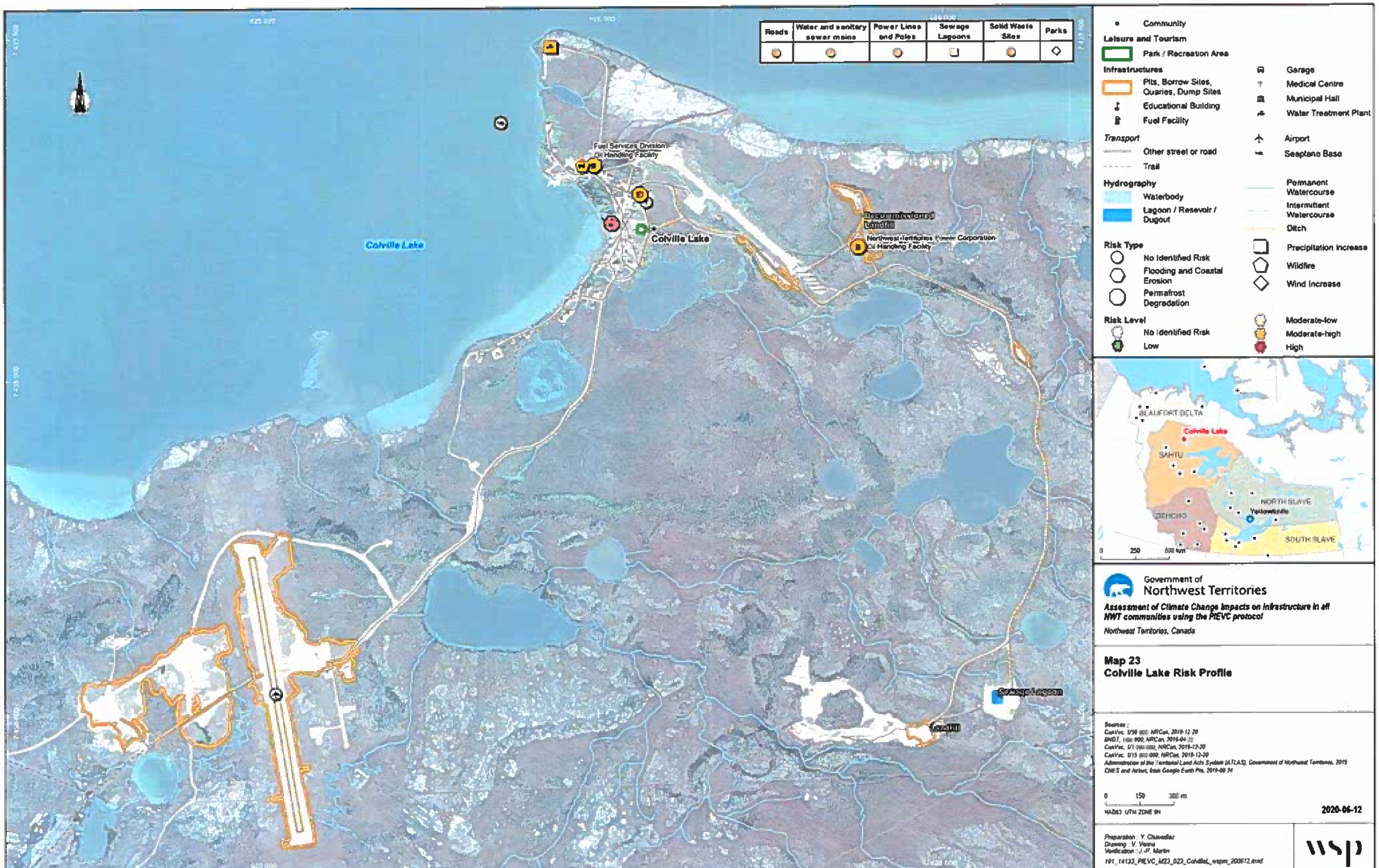
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



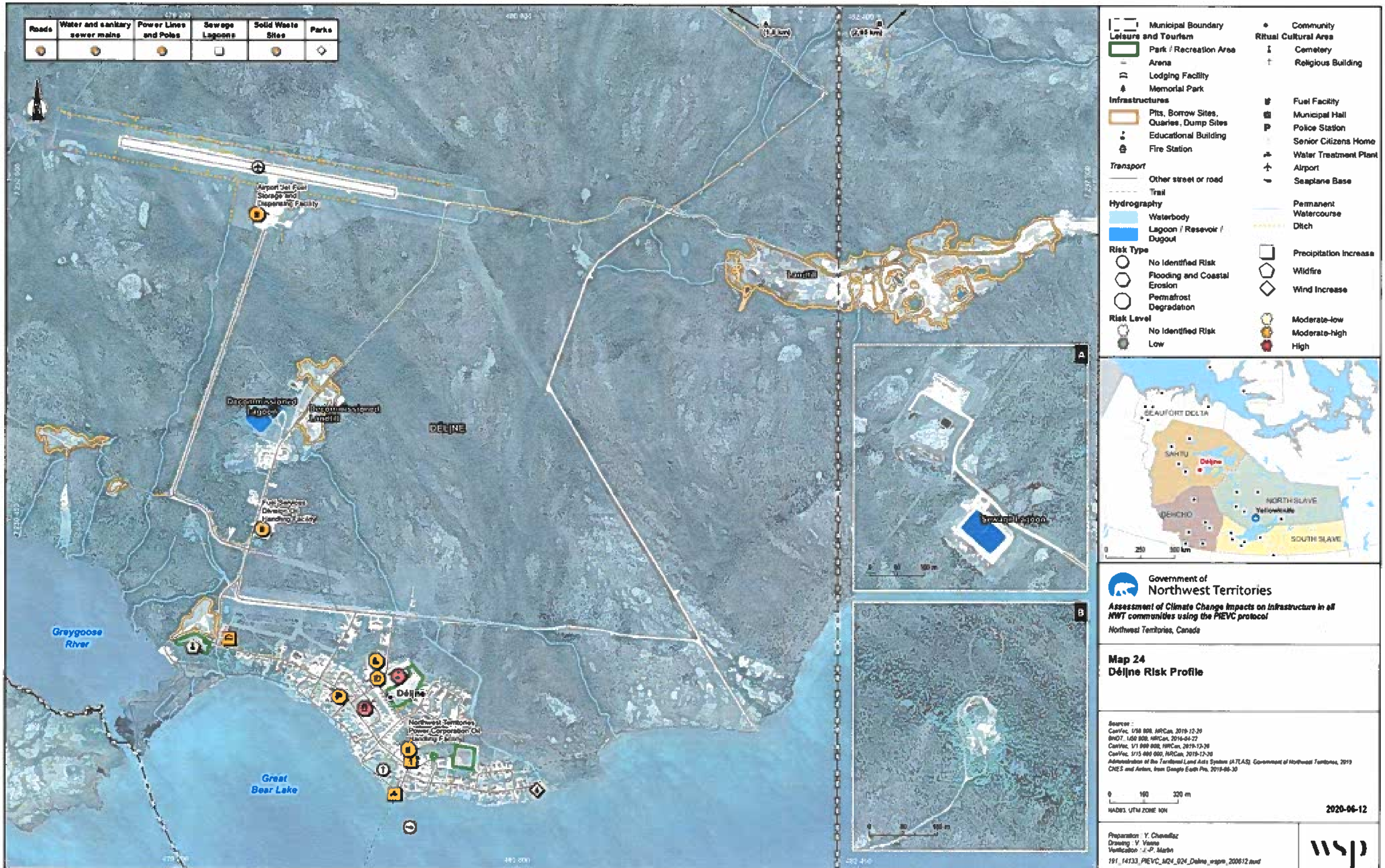
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

APPENDIX

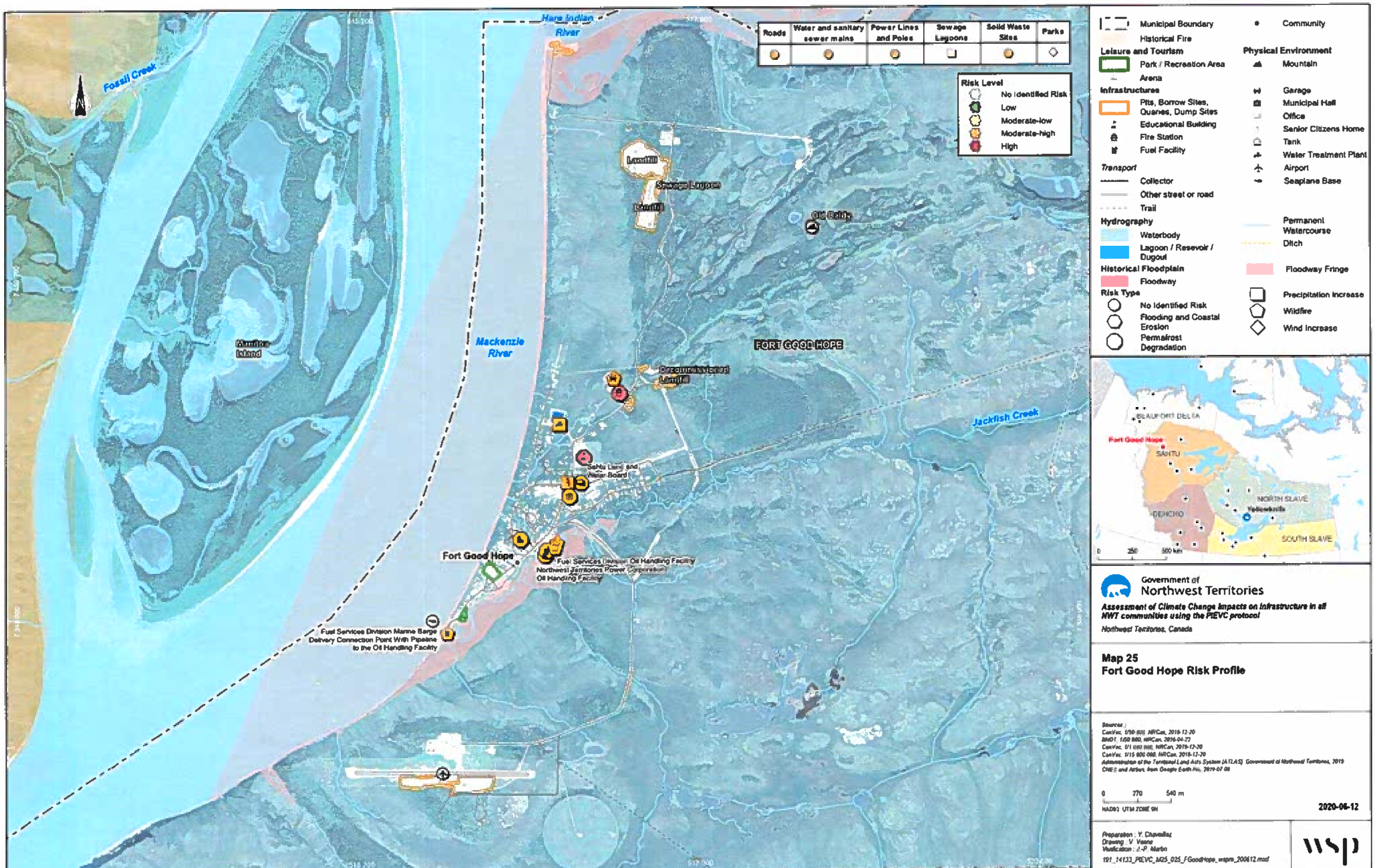
E-4 SAHTU



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 25
Fort Good Hope Risk Profile

Sources:
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-27
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-07-08

0 270 540 m
NAD83 UTM ZONE 9N

2020-06-12

Preparation: Y. Chavellaz
Drawing: V. Veane
Verification: J.-P. Marbo
191_14133_PIEVC_M25_025_FGoodHope_wsps_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 26
Norman Wells Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
CNES and Airbus, from Google Earth Pro, 2019-06-06

0 430 860 m
NAD83 UTM ZONE 9N

2020-06-12

Preparation : Y. Chavellaz
Drawing : V. Veyne
Verification : J.-P. Marion
191_14133_PIEVC_M26_026_NormanW_wsp_200612.mxd

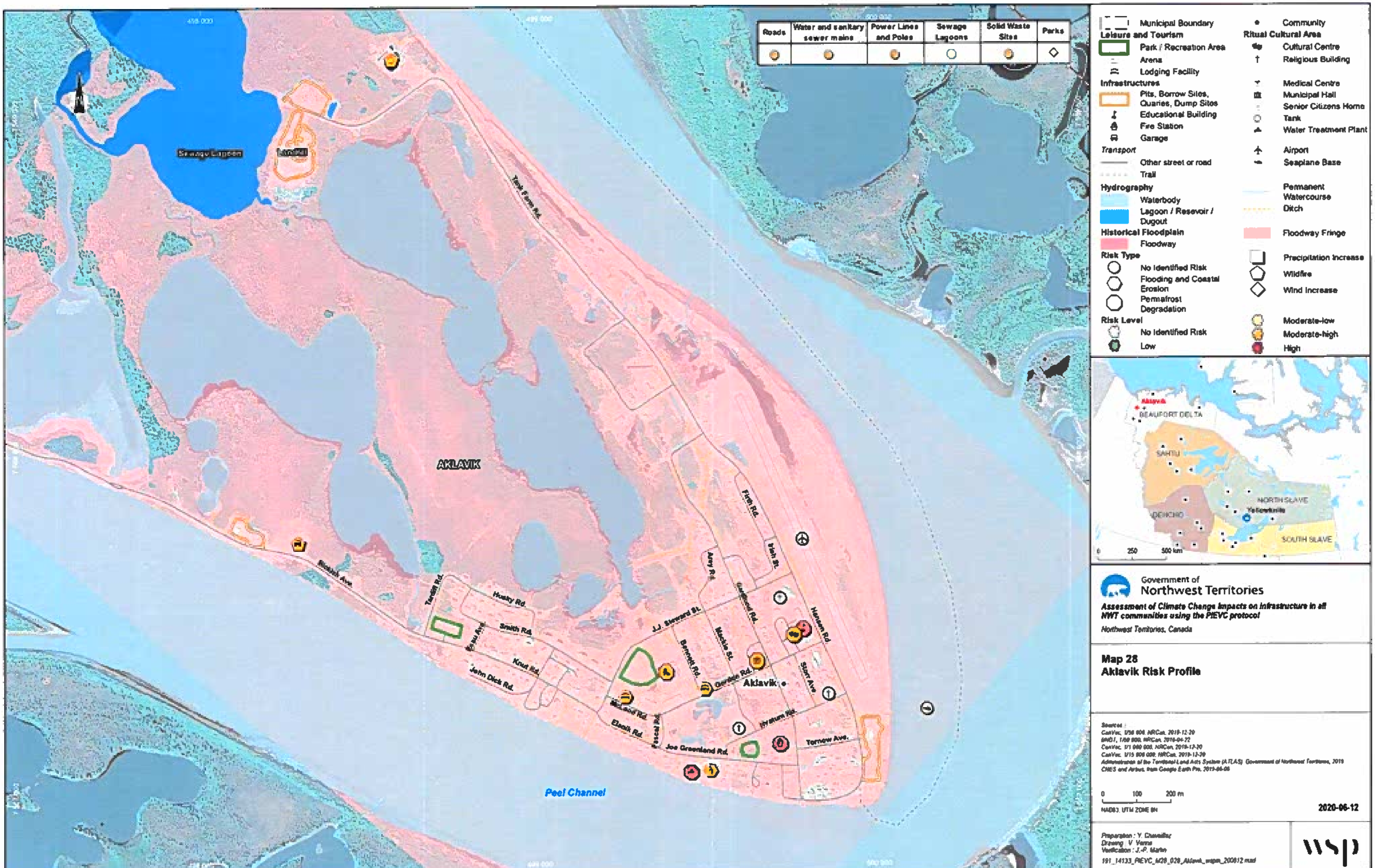
wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

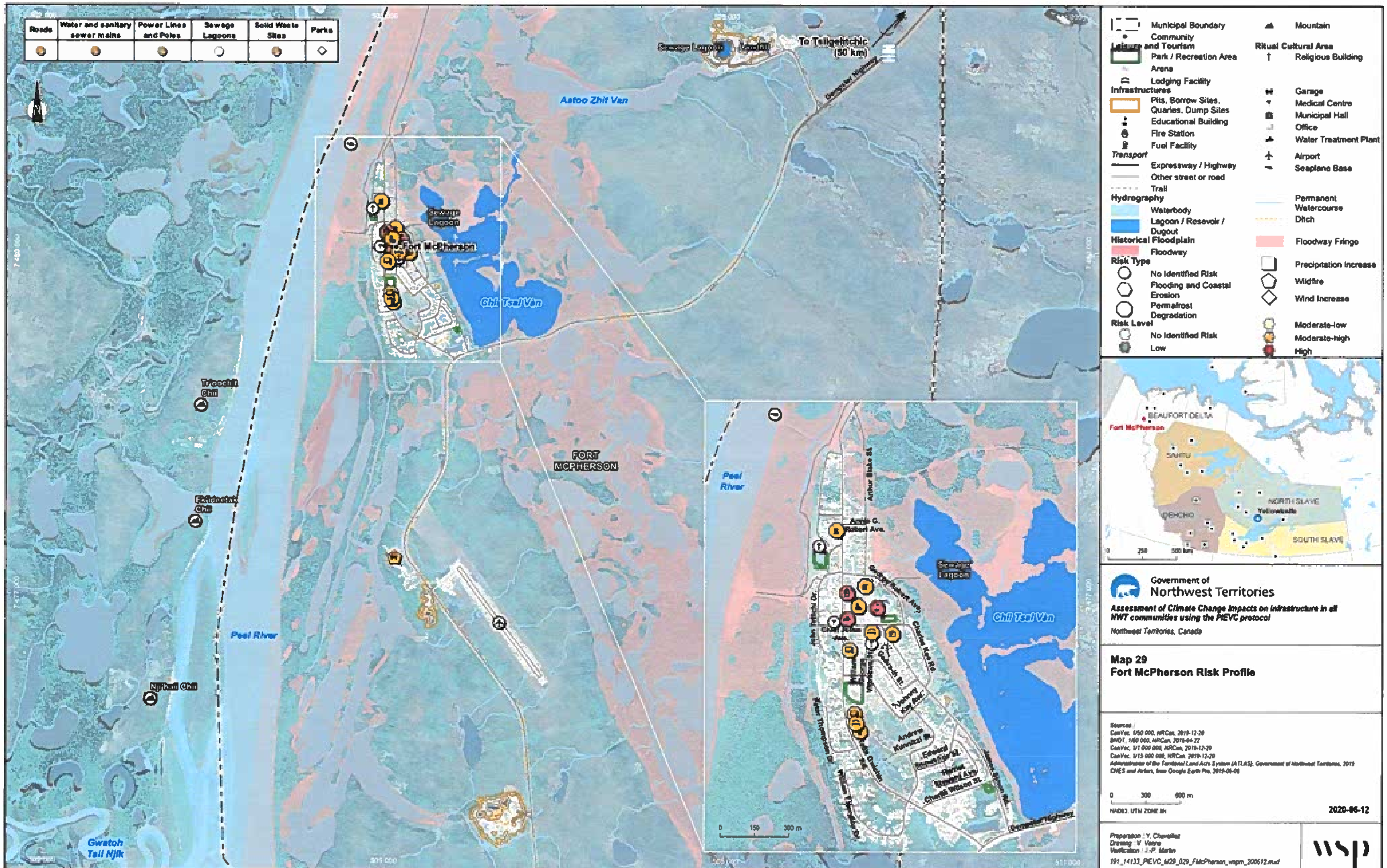
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.

APPENDIX

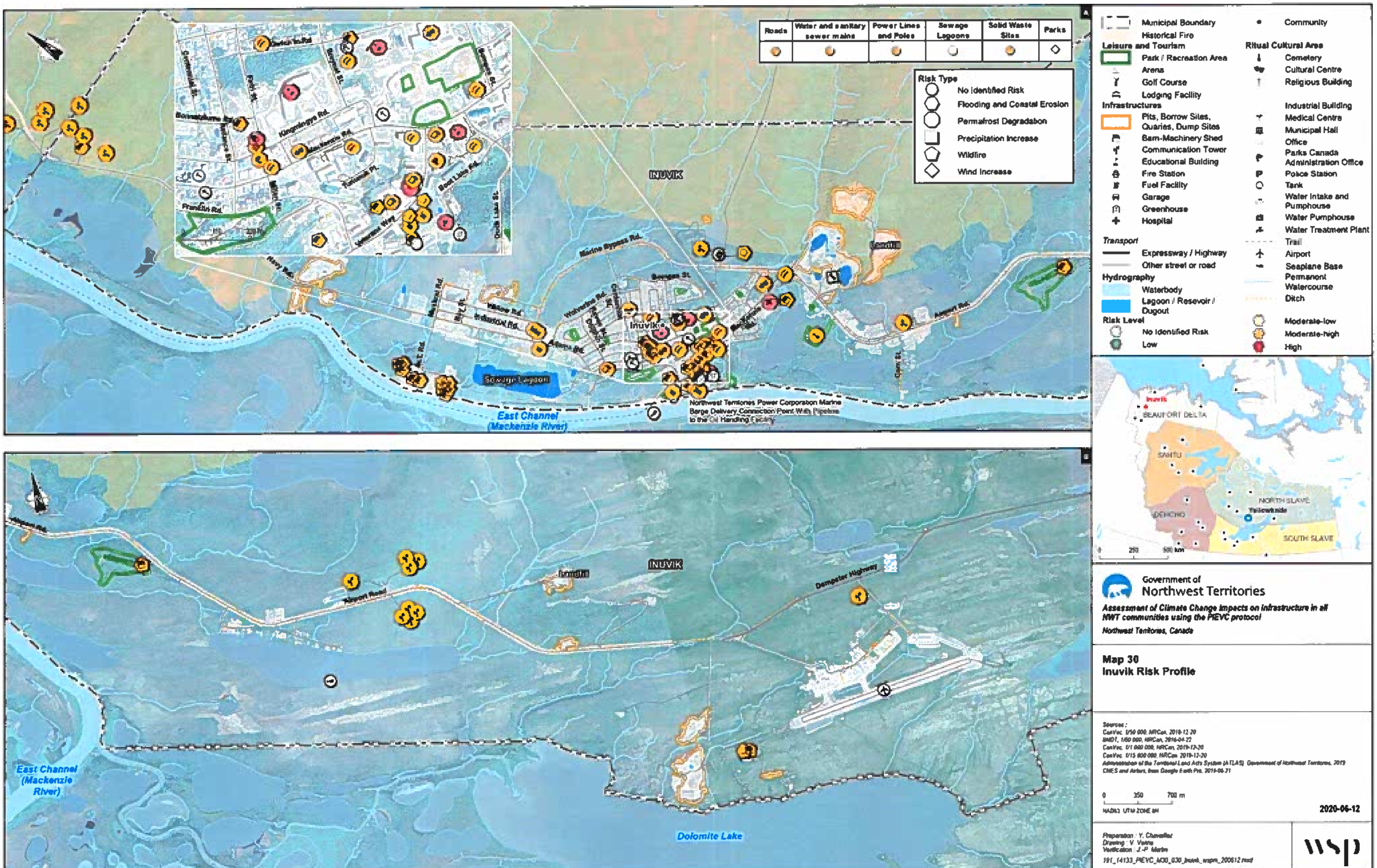
E-5 BEAUFORT DELTA



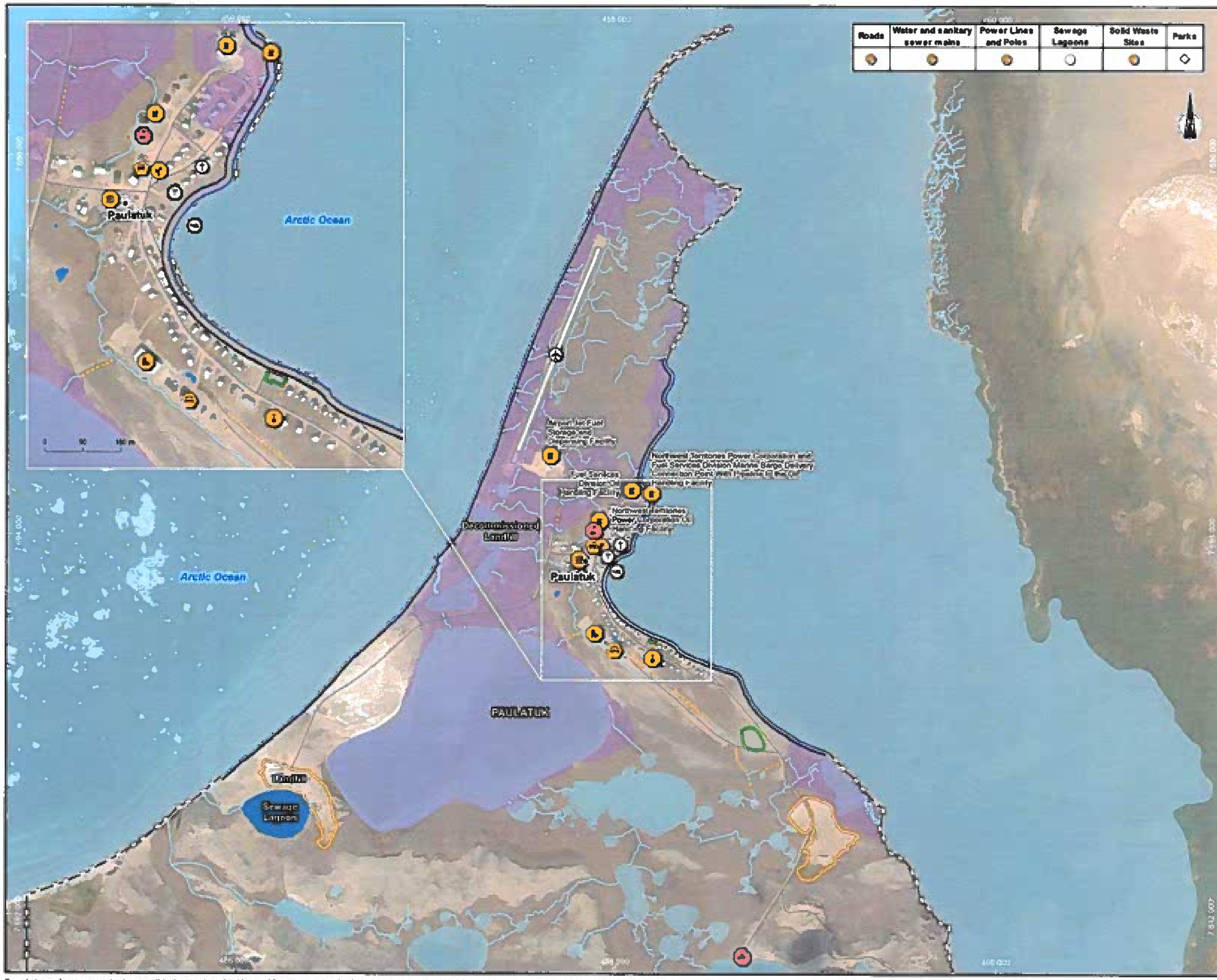
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Roads	Water and sanitary sewer mains	Power Lines and Poles	Sewage Lagoons	Solid Waste Sites	Parks
●	●	●	○	●	◇

Municipal Boundary
Leisure and Tourism
Park / Recreation Area
Arena
Lodging Facility
Infrastructures
Pits, Borrow Sites, Quarries, Dump Sites
Communication Tower
Educational Building
Transport
Other street or road
Hydrography
Waterbody
Lagoon / Reservoir / Dugout
Permanent Watercourse
Ditch
Risk Type
No Identified Risk
Flooding and Coastal Erosion
Permafrost Degradation
Risk Level
No Identified Risk
Low

Community
Ritual Cultural Area
Cemetery
Religious Building
Fuel Facility
Garage
Medical Centre
Municipal Hall
Water Treatment Plant
Airport
Seaplane Base
Coastal Risks
Projected Shoreline Position in 2050
Projected Shoreline Position in 2100
Expected Storm Surge
Precipitation Increase
Wildfire
Wind Increase
Moderate-low
Moderate-high
High

Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 31
Paulatuk Risk Profile

Sources :
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
Maxar Technologies, from Google Earth Pro, 2002-06-26

0 200 400 m

NAD83, UTM ZONE 10N

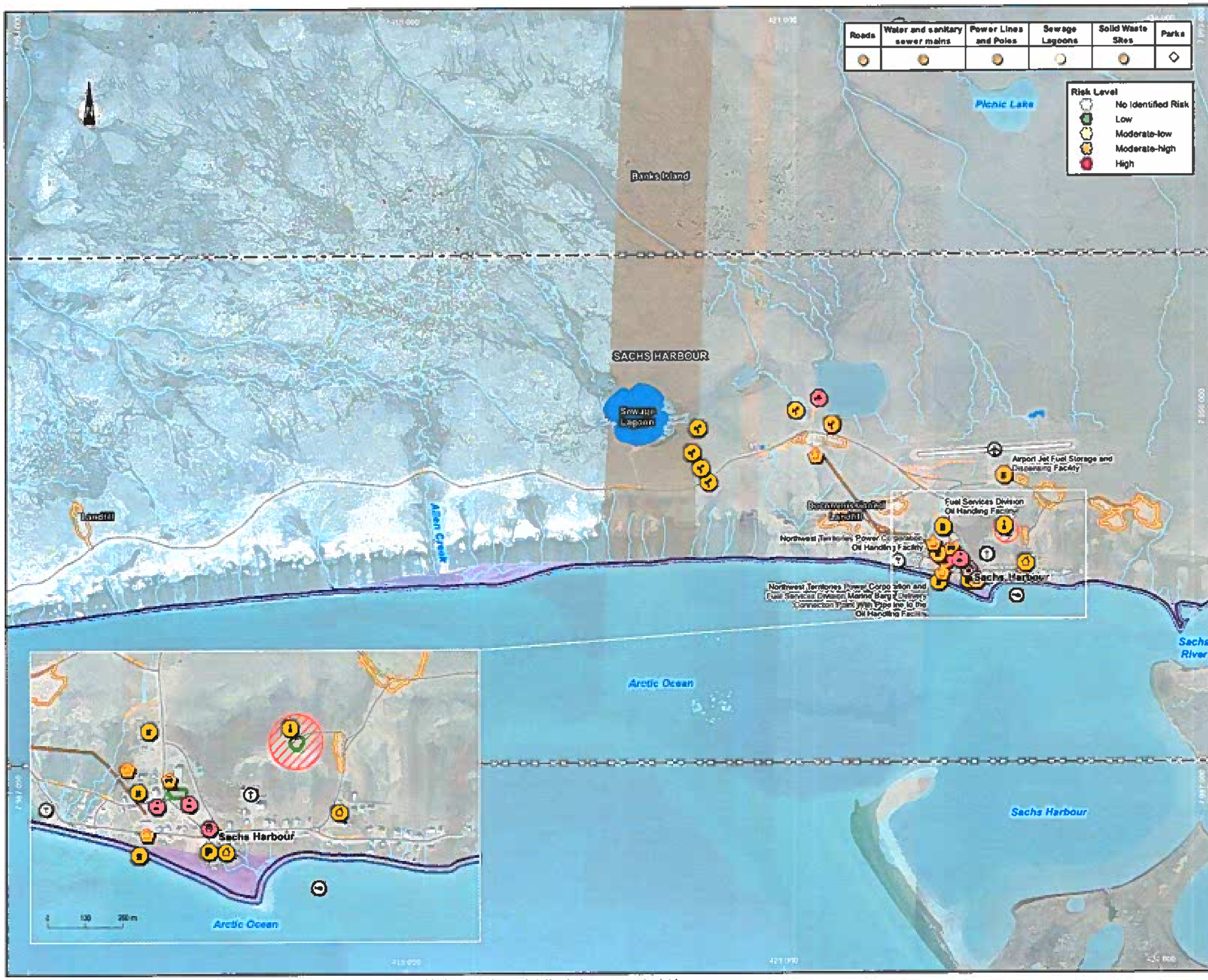
2020-06-12

Preparation : Y. Chevallaz
Drawing : V. Venne
Verification : J.-P. Marion

191_14133_PIEVC_M31_031_Paulatuk_wspm_200612.mxd

wsp

Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Government of Northwest Territories

Assessment of Climate Change Impacts on Infrastructure in all NWT communities using the PIEVC protocol

Northwest Territories, Canada

Map 32
Sachs Harbour Risk Profile

Sources:
CanVec, 1/50 000, NRCan, 2019-12-20
BNDT, 1/50 000, NRCan, 2016-04-22
CanVec, 1/1 000 000, NRCan, 2019-12-20
CanVec, 1/15 000 000, NRCan, 2019-12-20
Administration of the Territorial Land Acts System (ATLAS), Government of Northwest Territories, 2019
Maxar Technologies, from Google Earth Pro, 2017-08-27

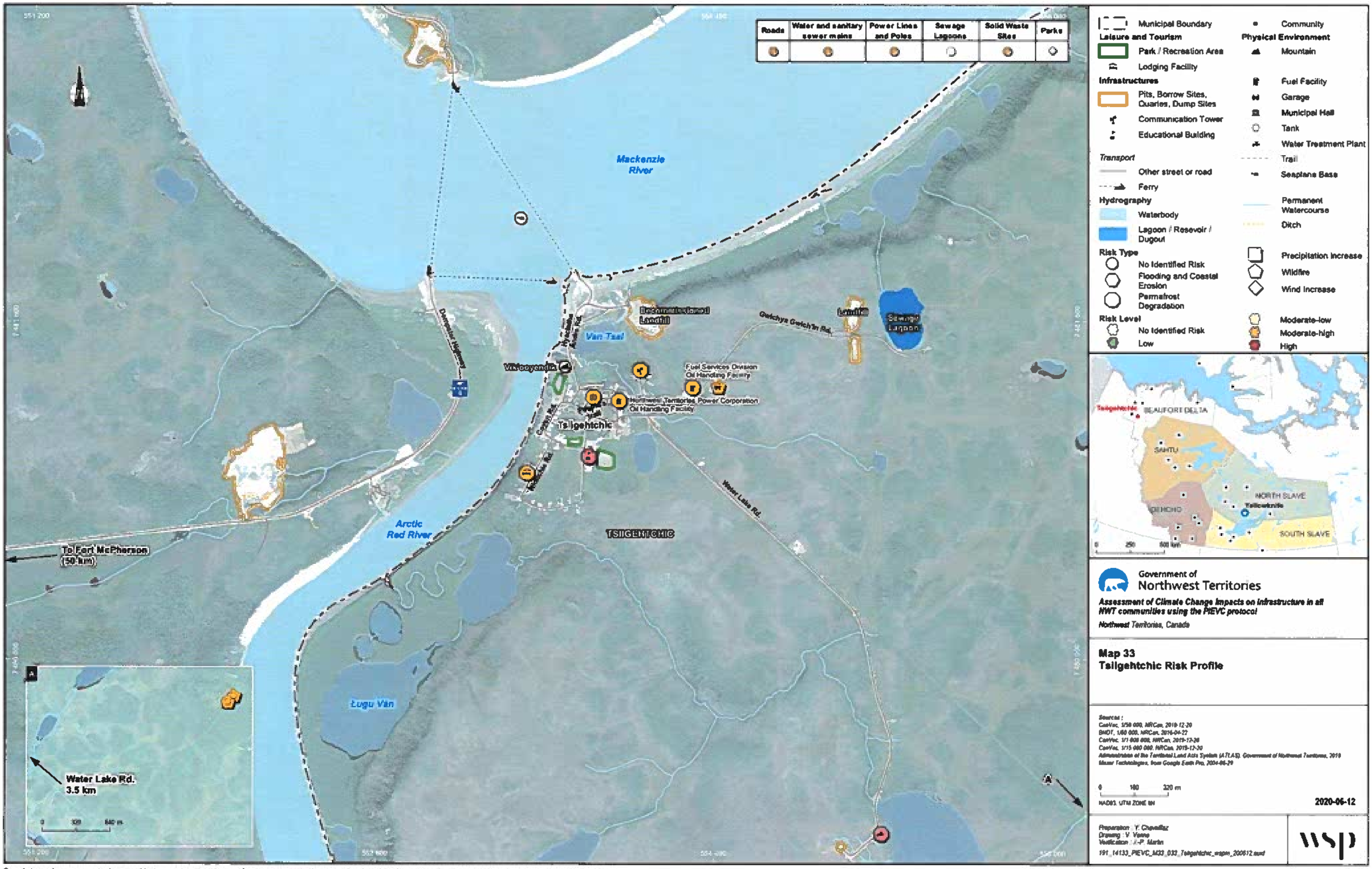
0 300 600 m
NAD83 UTM ZONE 10N

2020-06-12

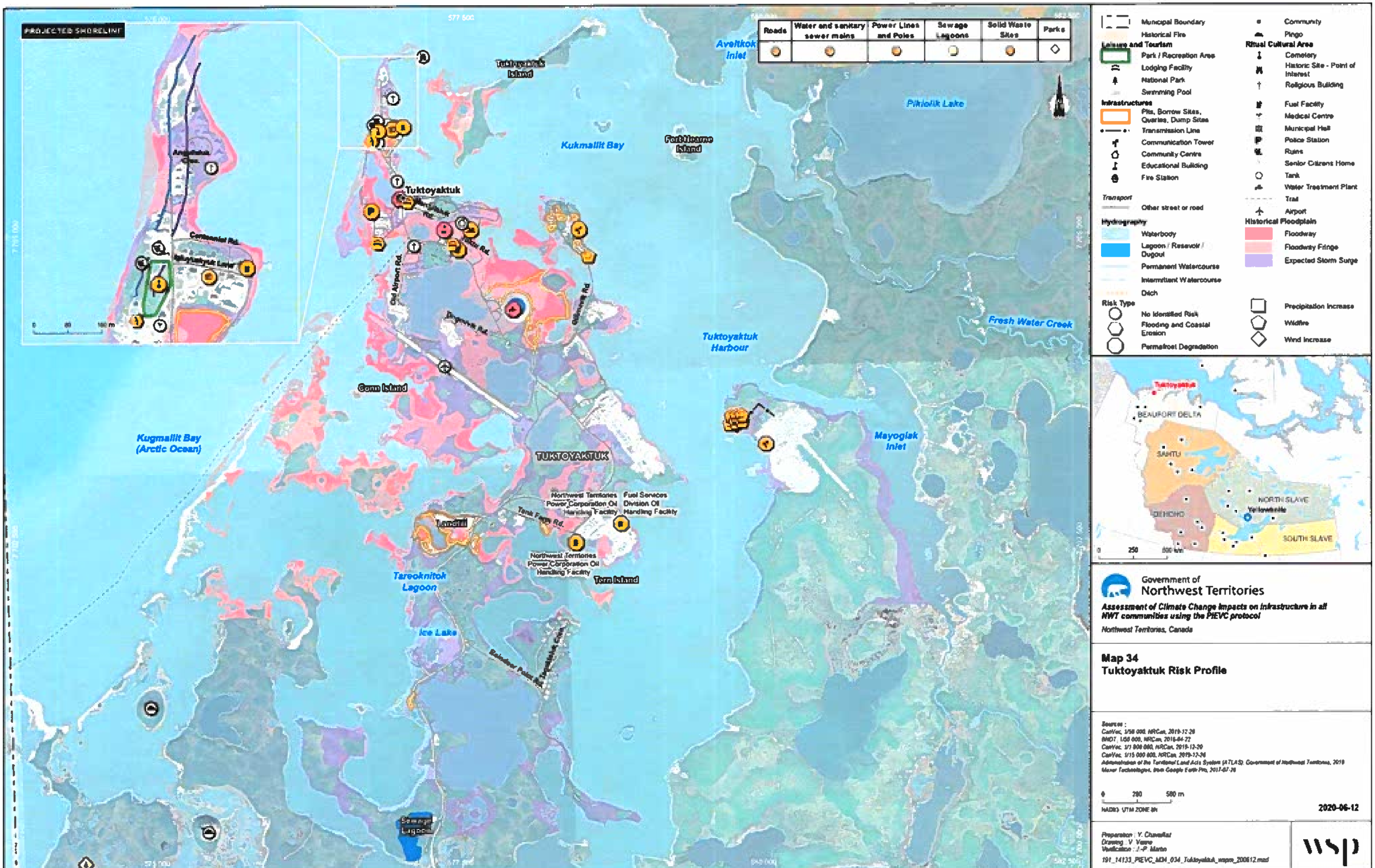
Preparation: Y. Chavellaz
Drawing: V. Vanne
Verification: J.-P. Martin
191_14133_PIEVC_M32_032_SachsH_wsam_200612.mxd

wsp

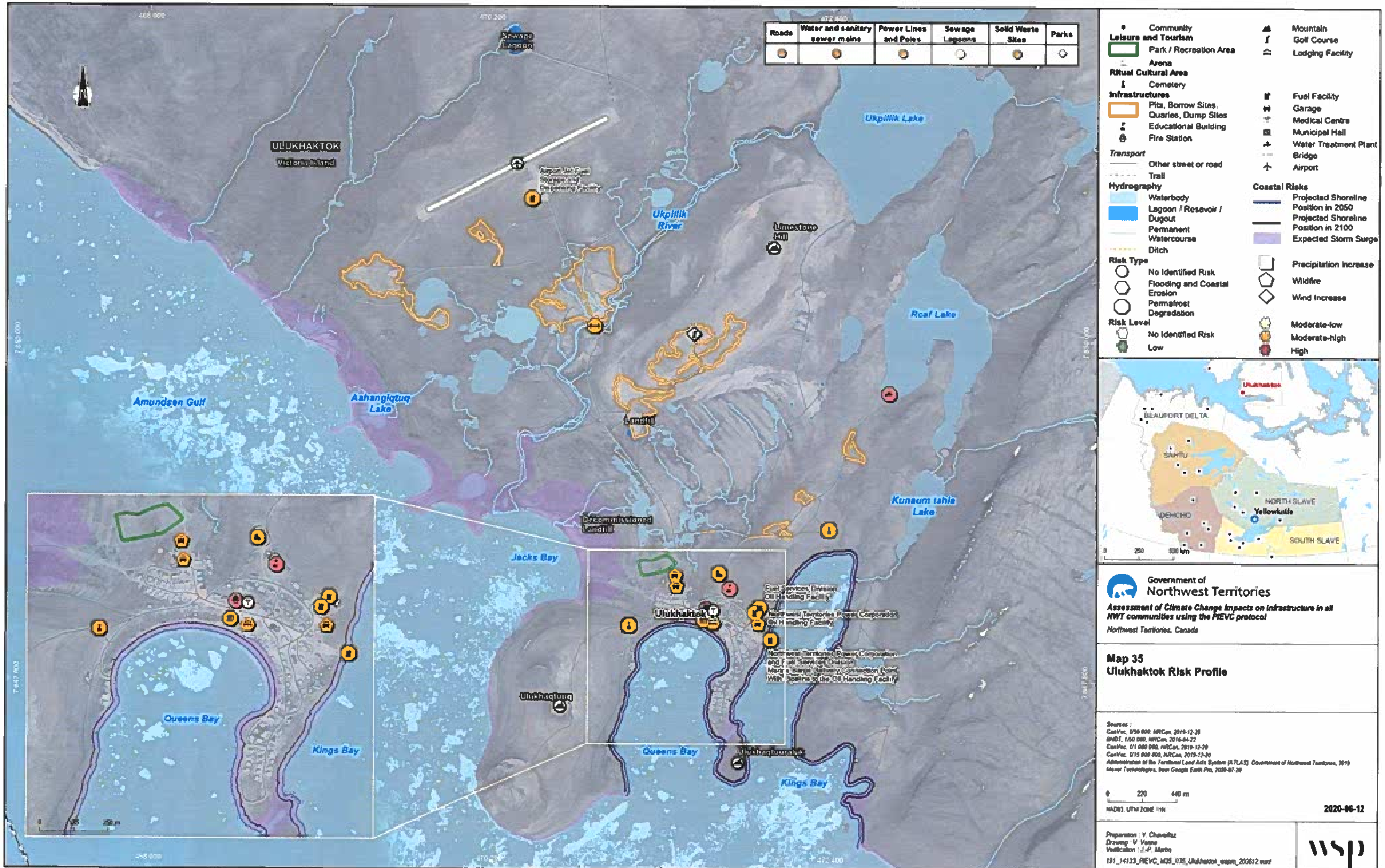
Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.



Boundaries and measurements shown on this document must not be used for engineering or land survey delineation. A land register analysis conducted by a land surveyor was not undertaken.