Appendix H

Investing in Canada Infrastructure Program Reports

DILLON CONSULTING

CITY OF IQALUIT

Climate Change Resilience Assessment Investing in Canada Infrastructure Program (Draft)

Landfill and Waste Transfer System

May 2019

Table of Contents

Tables

Appendices

DILLON CONSULTING

Attestation of Completeness

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

Prepared by: ____ _________________

[Name and credentials] [Date]

Validated by*: ____ _________________

[Name and credentials] [Date]

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

1.0 Introduction

The City of Iqaluit recently underwent a procurement process for the design of a new landfill and transfer station (the Project), as the existing landfill is nearing full capacity. The Project will include the construction of a new landfill, including new access to the location, a new recycling and eco-centre, an area for the future construction of a composting facility, new methods of waste collection and a leachate collection and treatment system. The Project is being designed with a 75 year service life.

The landfill site is located approximately 8 km northwest of the City of Iqaluit and occupies an approximate area of 19 hectares. Access to the landfill will be via a new road to the location.

The waste transfer station is located at the end of Kakivak Court cul-de-sac. The site will comprise of an office building (i.e., portable trailer), a scale kiosk, a large waste packaging and transfer station, and shipping container to hold hazardous waste.

A constructed lagoon made up of a two holding ponds in series will receive pumped leachate from the landfill collection system. The lagoon will serve to store leachate that is pumped out from the landfill to provide biological treatment before discharging to an engineered wetland area downstream. In the wetland, native plants will provide a surface for biofilm to grow, which filters the water naturally as semi-treated leachate passes through it. An area of approximately 2.5 ha for the lagoon holding ponds and wetland is anticipated to be used.

A screening-level climate change resilience assessment was conducted on the development area to determine climate change related impacts on the project infrastructure and develop potential resilience options. The following sections outline, in detail, the risks identified, the climate change hazards that exacerbate these risks, and possible mitigation measures.

2.0 Methodology

The methodology employed follows the approach described in Section 3 and Annex G of the Climate Lens General Guidance Document issued by Infrastructure Canada. The methodology and associated details are provided in the following sub-sections.

2.1 Scope and Timescale of Assessment

The assessment focused mainly on the infrastructure and assets related to the construction of the new landfill. The Project was assessed for the 75 year service life, although climate change impacts were assessed at two timeframes, specifically for the years 2050 and 2100.

2.2 Data Gathering

Infrastructure data was initially gathered based on the preliminary design during project conceptualization, and then further refined as the detailed design progressed. Assets and specific components were then divided into categories, which helped to guide the resilience assessment. The following categories and associated asset components are listed in **Table 1**, below.

Table 1: Infrastructure and Asset Component by Category

General Category	Specific Category	Asset Component
Landfill	Liner and Cover	• HDPE membrane liner • Geotextile liner • Granular fill • LDPE membrane cap • Geotextile cap
	Conveyance	• Leachate collection manholes • Leachate collection piping • Storm water culverts • Leachate pumping equipment
	Asphalt Surfaces	• Roadways • Parking lots
	Treatment Elements	• Lagoon (holding ponds) • Engineered wetland • Leachate pumping equipment

General Category	Specific Category	Asset Component
Equipment	Scale	• Concrete ramp with foundation/slab • Scale deck • Load cells
	Equipment	• Baler • Wrapper • Car crusher • Shredder • Pelletizer • Pellet furnace
Building Foundation	Concrete slab	• Scale deck and scale kiosk • Transfer station building
	Gravel pad	• Hazardous waste shipping container • Office building (trailer) • Attendant's kiosk
Building siding	Metal liner panel and pre-finished metal siding	• Transfer station building
	Metal siding	• Office building (trailer) • Scale kiosk • Attendant's kiosk
	Shipping container	• Hazardous waste shipping container
Metal roof	Metal panel roof	• Transfer station • Scale kiosk • Office building (trailer) • Attendant's kiosk
Electrical components	Wiring and outlets Communication equipment	• Transfer station building • Office building (trailer) • Scale kiosk • Hazardous waste storage shipping container
Mechanical components	HVAC Plumbing	• Transfer station building • Office building (trailer) • Scale kiosk • Hazardous waste storage shipping container

2.3 Climate Risk Assessment

The following sections outline the methodology used in identifying climate change risks as related to The Project infrastructure. The vulnerability assessment encompasses the following steps:

1. Identification and Assessment of Climate Hazards;
2. Identification of Impacts on the Asset; and
3. Definition of Consequences of the Impacts.

This section also includes the methodology used to analyze the risk by incorporating likelihood and severity ratings into the assessment. Likelihood ratings were applied during the identification of the impacts on the asset, and severity ratings were identified during the definition of consequences of the impacts.

2.3.1 Identification and Assessment of Climate Hazards

Through the use of Environment Canada's Climate Data Viewer and the Climate Atlas of Canada, climate data was collected for the City of Iqaluit. Observed historical climate data was assembled from the Climate Atlas of Canada for the years between 1950 and 2005 and from Environment Canada's Climate Data Viewer for the years between 1971 and 2000. Climate change projections for the City of Iqaluit were created for the time period between 2021-2100 using an ensemble of Global Climate Models (GCM). Climate change projections were collected for two emission scenarios, the RCP 4.5 and RCP 8.5, however only the projections from the RCP 8.5 scenario was used for this analysis, as it can be considered to be a more conservative scenario.

From the data available for the area, select climate parameters were identified to represent the Climate Hazards. The climate parameters identified are:

- changing temperatures (high and low);
- changing precipitation;
- snow depth;
- freeze-thaw cycles;
- high winds; and
- permafrost melt.

The following sub sections present the specific climate change data used for the resilience analysis.

2.3.1.1 Changing Temperatures (high and low)

High and low temperatures in Iqaluit are predicted to change throughout the lifespan of The Project. An increase in high annual temperatures and a decrease in low annual temperatures, on average, are expected in the future.

Low Temperatures

Very Cold Days are defined as the average number of days in a year when the temperature is below -30°C. The Minimum Temperature variable is the minimum temperature of the day, averaged over the year for the historic timescale, while the Coldest Minimum Temperature variable is the coldest temperature of the year, averaged over the timescale (i.e., historic); these variables are recoded in degrees Celsius (°C). Frost Days are the number of days in a year where the temperature is measured to be below 0 °C, while Icing Days are the number of days in a year where the temperature does not go above 0 °C; these variables are recorded as occurrences per year. As shown in **Table 2**, by 2100 it is expected that zero days on average will have temperatures below -30 °C, and the temperature is expected to increase overall. Frost Days and Icing Days are predicted to decrease, indicating a shorter winter season.

Table 2: Low Temperatures

Climate Parameter	Very Cold Days	Minimum Temperature	Coldest Minimum Temperature	Frost Days	Icing Days
Unit/Frequency	Annual - # Days	Annual - Mean (°C)	Annual - Mean (°C)	Annual - # Days	Annual - # Days
Historic[1]	32	-11.7	-37.26	250	208
Predicted 2050[2]	7	-8.39	-34.27	244	186
Predicted 2100[2]	0	-3.4	-29.16	195	143

1 Historic average from 1976-2005 from Climate Atlas of Canada (2018)
2 Climate Atlas of Canada (2018) predictions

Cold temperatures have an impact on the growing season, energy use, and animal life in the area. Frost Days and Icing Days are indicators of the severity and length of the winter season.

High Temperatures

The Warmest Maximum Temperature variable is defined as the highest temperature of the year, averaged over the timescale, while the Mean Temperature is the average temperature of the day, averaged over the year; these variables are recorded in degrees Celsius (°C). The Frost Free Season is defined as days in a year where the temperature does not go below 0 °C and is the approximate length of the growing season; this variable is recorded as occurrences per year. As shown in **Table 3**, Warmest Maximum Temperatures and the annual Mean Temperature are expected to increase by 2100. Additionally, the Frost Free Season is expected to increase, leading to a longer growing season.

Table 3: High Temperatures

Climate Parameter	Warmest Maximum Temperature	Mean Temperature	Frost Free Season
Unit/Frequency	Annual - Mean (°C)	Annual - Mean (°C)	Annual - # Days
Historic[1]	20.27	-8.24	93
Predicted 2050[2]	20.91	-5.07	68
Predicted 2100[2]	20.71	-0.28	141

1 Historic average from 1976-2005 from Climate Atlas of Canada (2018)
2 Climate Atlas of Canada (2018) predictions

2.3.1.2 Changing Precipitation

Heavy Precipitation occurrences are predicted to increase throughout the lifespan of this project. An increase in heavy rainfall events may impact storm drains and cause storm water systems to become overloaded. An increase in heavy snowfall events may disrupt transportation and may cause an increased load on roofs, causing damage to buildings.

Precipitation includes rain, drizzle, snow, and sleet. The Annual Precipitation variables were recorded in mm, while Heavy Precipitation days were recorded in occurrences per year. As shown in **Table 4**, the Annual Precipitation and Heavy Precipitation days are expected to increase by 2100. The Precipitation in Winter Months is expected to provide an indication on snowfall for the region.

Table 4: Total Precipitation

Climate Parameter	Annual Precipitation	Heavy Precipitation Days (10mm)	Heavy Precipitation Days (20mm)	Precipitation in Winter Months (December to February)[4]
Unit/Frequency	Annual (mm)	Annual - # Days	Annual - # Days	Seasonal (mm)
Historic	446.63[1]	6.5[1]	1.33[1]	54.3[2]
Future 2050	509.88[3]	10[3]	2[3]	65.54[2]
Future 2100	637.29[3]	12.4[3]	2.58[3]	79.28[2]

[1] Historic average from 1976-2005 from Climate Atlas of Canada (2018)
[2] Historic average from 1971-2000 from Environment Canada's Climate Data Viewer
[3] Climate Atlas of Canada (2018) predictions
[4] Winter months used as an indication of snowfall

2.3.1.3 Snow Depth

Snow Depth is predicted to decrease by 2100. Annual mean snow depths are expected to decrease by approximately 3 cm, while seasonally the changes appear more significant, as shown in **Table 5**. A decrease in snow depth is expected to impact the infrastructure, as well as flora and fauna in the area, in a positive manner (i.e., a reduced snow load on buildings may result in decreased stress on roofs and structures).

Table 5: Snow Depth

Climate Parameter	Snow Depth	Snow Depth	Snow Depth	Snow Depth	Snow Depth
Unit/Frequency	Annual - mean (cm)	Winter - mean (cm)	Spring - mean (cm)	Summer - mean (cm)	Autumn - mean (cm)
Historic[1]	13	21.7	24	0.67	7.33
Future 2041-2060[2]	11.54	20.18	22.68	0.19	4.31
Future 2100[2]	10.05	17.29	21.02	0.042	2.28

[1] Historic average from 1971-2000 from Environment Canada's Climate Data Viewer
[2] Environment Canada Climate Data Viewer predictions

2.3.1.4 Freeze-thaw Cycles

Freeze-thaw Cycles occur when the air temperature fluctuates between freezing and non-freezing temperatures. During these cycles, infrastructure may be substantially impacted and significant damage to roadways, underground piping, and other structures due to water freezing, melting, and re-freezing. As shown in **Table 6**, freeze-thaw cycles are expected to increase by 2100.

Table 6: Freeze-thaw Cycles

Climate Parameter	Freeze-thaw Cycles
Unit/Frequency	Annual - # Days
Historic[1]	34
Future 2050[1]	36
Future 2100[1]	47

[1] Historic average from 1976-2005 from the Climate Atlas of Canada (2018)
[2] Climate Atlas of Canada (2018) predictions

2.3.1.5 Wind Speed

High wind speeds are common in Iqaluit, specifically from the northwest and southeast, and can have an effect on other climate parameters, such as precipitation. High wind speeds can cause extensive damage to existing infrastructure. As shown in **Table 7**, wind speeds are predicted to slightly decrease in the years 2050 and 2100.

Table 7: Changes in Wind Speed

Climate Parameter	52 km/hr	63km/hr	90km/hr
Unit/Frequency	Average - # days	Average - # days	Average - # days
Historic	29.1[1]	9.5[1]	1[2]
Future 2050[3]	wind speed change = -0.3%		
Future 2100[3]	wind speed change = -0.9%		

[1] Historic average from 1971-2000 from Environment Canada's Climate Data Viewer
[2] Nawari and Stewart (2006 and 2008)
[3] Environment Canada Climate Data Viewer and Climate Norms

Unfortunately, there were no projections available to determine the occurrences of wind gusts (i.e., number of days with wind speed greater than 52 km/hr). For this analysis, the project team considered the impacts associated with high wind gusts as a constant Climate Change Hazard. Although the wind speed is expected to decrease overall, this does not provide any details on wind gusts, which can be the most damaging to Project infrastructure.

2.3.1.6 Permafrost

Infrastructure in Canada's north heavily relies on permafrost, snow, and ice for stability and utility. Permafrost is a major influence on natural processes and human activities, and has significant impacts on infrastructure design, construction, and maintenance. Due to climate change (i.e., warmer temperatures) and land development, permafrost is melting, damaging building foundations and threatening roads, pipelines, and communication infrastructure. Additionally, communities in Northern Canada are showing rapid rates of permafrost melt, affecting nearly all built structures in Iqaluit (Canada, 2009).

2.3.2 Identification of Impacts on the Asset

The specific categories, as developed during the Data Gathering phase, were used to help guide the initial risk identification exercise. The infrastructure components were assessed against the climate hazards to determine if there was a justifiable interaction. If an interaction was deemed possible, the impact on the asset was identified until all potential impacts were listed. This exercise continued for the remainder the categories listed and evolved into list of preliminary risks. These risks are presented in **Table 8** below.

Table 8: Risks Associated With Landfill Components

Category	Risk
Liner and Cover	• Damage and/or deterioration to HDPE/Geotextile liner. • Displacement of HDPE/Geotextile liner. • Damage and/or deterioration to LDPE cover/cap.
Conveyance	• Concrete deterioration within manhole. • Leachate overflowing landfill liner system. • Break in leachate piping. • Damage and/or deterioration to storm water culverts and structures. • Impact to functionality (i.e., blockage) of storm water culverts and structures. • Granular layer at the base of the landfill becomes plugged. • Pump failure from liner system to holding ponds.
Roadway and Parking Area	• Damage and/or deterioration to gravel area. • Damage and/or deterioration to roadway access to site.
Treatment Elements	• Treatment inefficiencies in engineered wetland. • Leachate overflowing from holding ponds. • Pump failure from lagoon to wetland. • Damage and/or deterioration to structural integrity of holding ponds.
Scale	• Damage and/or deterioration to concrete ramp. • Steel scale cracked or damaged. • Load cell digital and/or mechanism failure. • Scale and ramp foundation failure.
Equipment	• Vehicle/mobile equipment failure. • Unable to operate mobile equipment. • Leak in generator fuel tank.

Buildings associated with the landfill development were assessed as a separate general category. Building components were subdivided into five categories: foundation, building exterior, roof, electrical components, and mechanical components. Risks for each category are outlined in **Table 9**.

Table 9: Risks Associated With Building Components

Category	Risk
Slab/Foundation	• Significant structural damage to slab/foundation. • Crack in slab/foundation.
Building Exterior	• Damage or failure to metal cladding.
Roof	• Roof collapse or failure. • Damage and/or failure of metal roof panels.
Electrical components	• Electrical component failure/shortage/spikes. • Communication system failure (SCADA for treatment elements).
Mechanical components	• Heating and Cooling system overload. • Rupture of septic/sewage tank. • Breach of potable water storage tank.

The risks were populated based on infrastructure and known asset components at the 30% design phase. The Project design may change throughout the detailed design phase.

2.3.2.1 Likelihood of Risk

Upon the initial identification of the risks, the likelihood of the event occurring was established based on how likely the event will occur in the lifespan of the project (i.e., 75 years). **Table 10** displays the scale used to rank the likelihood of interaction occurring, as modeled after the Climate Lens guiding document.

Table 10: Likelihood of Risk Occurring

Score	Descriptor	Likelihood
1	Remote or Positive Impact	Not likely to occur in period
2	Unlikely	Likely to occur once between 50 and 75 years
3	Possible	Likely to occur once between 30 and 50 years
4	Likely	Likely to occur once between 10 and 30 years
5	Almost Certain to Occur	Likely to occur at least once a decade (1/10 years)

A likelihood rating was assigned to each interaction identified, therefore for each risk, multiple likelihood ratings were identified based on the likelihood for individual Climate Hazards to cause the risk. **Table 11** shows the likelihood ratings for the landfill infrastructure components, and **Table 12** shows the likelihood ratings for the building components, based on the initial risk list identified above.

Table 11: Likelihood Rating of Risks Associated with Landfill Infrastructure

Risks	Low Temperatures	Changing Precipitation	Snow Depth	Freeze-thaw Cycles	High Winds	High Temperatures	Permafrost
Liner and Cover							
Damage and/or Deterioration to HDPE/Geotextile liner	1		1	3			3
Displacement of HDPE/Geotextile liner		2		3			3
Damage and/or Deterioration to LDPE cover/cap	1		1		2		
Conveyance							
Concrete deterioration within manhole		1		2			3
Pump capacity compromised leading to leachate overflow within landfill liner system		2				1	
Break in leachate piping				3			3
Physical Damage to Storm water culverts and structures		1	1	3			
Impact on functionality of storm water culverts and structures		3	3	3			
Granular layer at the base of the landfill becoming overloaded or plugged	2	2		1			
Pump capacity compromised leading to longer pumping times and strain on pumps	1	2				1	
Roadway and Parking Area							
Damage and/or deterioration to gravel area		2	1	3			3
Roadway access to site		2	1	3			3

Risks	Low Temperatures	Changing Precipitation	Snow Depth	Freeze-thaw Cycles	High Winds	High Temperatures	Permafrost
Treatment Elements							
Treatment inefficiencies in engineered wetland	2	3	1			1	3
System becoming overloaded causing overflows	2	1	1			1	
Pumping from lagoon to wetland compromised		1	1		2		
Structural integrity of lagoon				1			1
Scale							
Damage and/or deterioration to concrete ramp		1	1				
Steel scale cracked or damaged	1		1	2			1
Mechanism of load cell failure	1		1	2			1
Scale and ramp foundation failure				3			3
Equipment							
Vehicle/mobile equipment failure	1						
Unable to operate mobile equipment	1		1		2		
Generator fuel tank	1				1		

Table 12: Likelihood Rating of Risks Associated with Building Components

Risks	Low Temperatures	Changing Precipitation	Snow Depth	Freeze-thaw Cycles	High Winds	High Temperatures	Permafrost
Slab/Foundation							
Significant structural damage to slab/foundation				2			3
Crack in slab/foundation				3			3
Building Siding							
Damage or failure of Metal Cladding					2		
Building Roof (metal)							
Roof collapse or failure			1				
Damage or failure of Metal roof panels			1		2		
Electrical Components (wiring, lighting, communications)							
Electrical component failure/shortage/spikes				1	2		1
Communication system failure					2		
Mechanical Components (HVAC, plumbing, heating)							
Stresses on heating and cooling causing system overloads	1					1	
Sewage tank ruptured	2			2			3
Storage Tank breached				2			3

2.3.3 Definition of Consequences of Impacts

The consequences of the impacts were discussed in conjunction with assigning a severity rating to the event. A workshop was conducted with the project design team to assign a severity score to each risk, as well as discuss the potential consequences of the event. The severity was assessed using three guiding categories: public and employee (social) safety as well as operational risk, environmental risk, and financial (economic) risk. **Table 13** displays the scale used to rank the severity of the interaction:

Table 13: Consequence of Risk Occurring

Score	Descriptor	Public and Employee	Environmental	Economic/Financial
1	N/A or Negligible impact	No injuries – near miss	Short term – no impact offsite	Negligible impact
2	Minor impact	Reputation impacted, loss of confidence	May impact offsite and ecosystem – small scale < 1 month	Minor maintenance and repair required
3	Moderate impact	Displacement to public inconvenience, and reputation impacted	Repairable impact offsite and ecosystem – duration up to 1 year	Significant maintenance and repair required
4	Major impact	Loss of livelihood, significant displacement, and reputation impacted	Extended range – long-term impact – may regenerate in ten years	Financial impact on proponent and stakeholders, significant capital costs to bring infrastructure to working order
5	Loss of asset or service	All of the above, an health and safety risk for staff and public	Long-term severe irreparable environmental impact – over extended range beyond site	Complete loss of the asset repairing full replacement

Professional assessment and judgement were critical elements used in assigning severity scores, and developing expected consequences. The workshop was made up of a multidisciplinary team of individuals who were knowledgeable about solid waste management, landfill infrastructure, and climate change vulnerability assessments. **Table 14** and

Table 15 below shows the results of the workshop, identifying a severity rating and consequence for each risk.

Table 14: Severity Rating and Consequence of Risks Associated with Landfill

Category	Risk	Severity Rating	Consequence
Liner and Cover	Damage and/or deterioration to HDPE/Geotextile liner	2	• Environmental impact – leachate discharge.
	Displacement of HDPE/Geotextile liner	2	• Potential environmental impact – leachate discharge.
	Damage and/or deterioration to LDPE cover/cap	1	• Potential operational and economic impact to complete maintenance and upkeep.
Conveyance	Concrete deterioration within manhole	2	• Minor economic impact to complete maintenance and upkeep.
	Leachate overflowing landfill liner system	4	• Environmental impact – leachate overflows out of the liner system within landfill, impacting the soil in the surrounding environment. • Economic impact to remedy the operational and environmental impacts.
	Break in leachate piping	3	• Environmental impact – leachate discharge.
	Damage and/or deterioration to storm water culverts and structures	3	• Impact to employee access (employee safety). • Operational and economic impact to remedy issue.
	Impact to functionality (i.e., blockage) of storm water culverts and structures	2	• Impact to employee access (employee safety). • Operational and economic impact to remedy issue.
	Granular layer at the base of the landfill becomes plugged	2	• Leachate not able to drain to intended manhole causing leachate to build up in some areas.
	Pump failure from liner system to holding ponds	2	• Economic and operational impact due to replacement of the pump and potential need for trucked services in the meantime.
Roadway and Parking Area	Damage and/or deterioration to gravel area	1	• Economic impact. • Employee safety impact – gravel area becomes deformed, causing pooled water, ice spots, etc.
	Damage and/or deterioration to roadway access to site	1	• Economic impact. • Employee safety impact – gravel area becomes deformed, causing pooled water, ice spots, etc..

Category	Risk	Severity Rating	Consequence
Treatment Elements	Treatment inefficiencies in engineered wetland	4	• Environmental impact – Effluent not meeting intended targets and could result in contaminants release.
	Leachate overflowing from holding ponds	3	• Environmental impact, operational impact – Untreated effluent can overflow beyond the lagoon berm walls into the surrounding environment, or could backlog into the landfill liner system and overflow in the surrounding environment.
	Pump failure from lagoon to wetland	1	• Minor economic impact. Portable pump from lagoon to wetland fails.
	Damage and/or deterioration to structural integrity of holding ponds	4	• Major economic impact to drain the holding pond and reconfigure lagoon. • Environmental impact. • Changes in the shape and liner system in the lagoon may impact hydraulic capacity, which would impact treatment efficiency.
Scale	Damage and/or deterioration to concrete ramp	1	• Economic impact to repair the concrete ramp.
	Steel scale cracked or damaged	1	• Economic impact to repair the steel scale.
	Load cell digital and/or mechanism failure	1	• Economic impact to repair the digital load cells.
	Scale and ramp foundation failure	3	• Significant economic impact and personnel strain to repair damage to the foundation of the steel ramp. • Repairs may involve a crane.
Equipment	Vehicle/mobile equipment failure	1	• Economic impact to repair equipment and rent similar equipment in the meantime.
	Unable to operate mobile equipment	1	• Operational impact, may lose 1-2 days of work due to inability to operate.
	Leak in generator fuel tank	2	• Economic impact, employee safety impact, environmental impact, but minimal because it will become apparent very quickly.

Table 15: Severity Rating and Consequences of Risks Associated with Building Components

Category	Risk	Severity Rating	Consequence
Slab/ Foundation	Significant structural damage to slab/foundation	4	• Employee safety risk. Major economic impact, not only to repair the foundation, but potential repairs to the structure, roof, equipment inside, etc.
	Crack in slab/foundation	2	• Minor economic impact to repair.

Category	Risk	Severity Rating	Consequence
Building exterior	Damage and/or failure of metal cladding	2	• Minor economic impact to repair.
Roof	Roof collapse	5	• Major economic impact, employee safety impact, operational impact in the event that the roof collapse results in interior equipment damage.
	Damage and/or failure of metal roof panels	2	• Minor economic impact to repair.
Electrical components	Electrical component failure/shortage/spikes	3	• Operational impact, minor economic impact to repair or replace damaged infrastructure due to electrical spikes.
	Communication system failure	2	• Economic impact when the communication system cannot notify attendants of a fire hazard or other hazards. • Could be catastrophic in the event of a fire (equipment, personnel, etc.).
Mechanical components	Heating and cooling system overload	2	• Operational impact, economic impact to repair or remedy.
	Rupture of septic/sewage tank	1	• Minimal environmental impact.
	Breach of potable water storage tank	1	• Minimal operational and economic impact.

2.4 Climate Risk Results

From the proceedings of the workshop, the final risk score was calculated based on standard risk assessment principles. Risk is defined as the possibility of injury, damage, loss, loss of function, or negative impact created by a climate hazard. Risk is a function of likelihood and severity, where Risk = Likelihood x Severity. Error! Reference source not found. shows the risk tolerance threshold used in evaluating the risk score.

Figure 1: Risk Evaluation Matrix

Severity					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5

Likelihood

A low score (i.e., yellow square) signifies a low or negligible risk where controls are likely not required, and where the project design will not require alterations. A medium score (i.e., orange square) signifies a moderate risk where some controls may be required to control or lower risks. These are typically the areas of "known" risks, where the risk is simply identified for consideration during the design of the project. A high score (i.e. red square) signifies a high or extreme risk where high priority or immediate controls are required. **Table 16** and **Table 17** below briefly display the risk scores for the landfill infrastructure and building components respectively.

Table 16: Risk Scores Calculated for Landfill Components

Category	Climate Hazard Interactions (Total)	Moderate Risks	High Risks
Liner and Cover	10	4	0
Conveyance	19	8	0
Roadway and Parking Area	8	0	0
Treatment Elements	14	2	2
Scale	12	2	0
Equipment	6	0	0
Total	69	16	2

Table 17: Risk Scores Calculated for Building Components

Category	Climate Hazard Interactions (Total)	Moderate Risks	High Risks
Slab/Foundation	4	3	1
Building Exterior	1	0	0
Roof	3	0	0
Electrical Components	4	1	0
Mechanical Components	7	0	0
Total	19	4	1

In total, the calculated risks amounted to 20 moderate risks and 3 high risk interactions. From the climate hazards used for the assessment, Freeze Thaw Cycles and Permafrost Melt were found to produce the most moderate and high risk interactions.

3.0 Analysis of Resilience Options

3.1 Identification of Resilience Measures Identified for Each Impact

Resilience measure were identified for moderate and high risk scores, as informed by the risk tolerance threshold scale. Risks and their contributing climate change hazards are shown in **Table 18** and **Table 19** for the high or extreme risks and moderate risks, respectively.

Table 18: High Risk Resilience Measures

Risk Event	Contributing Climate Change Parameter(s)	Resilience Measure
Treatment inefficiencies in engineered wetland	Changing precipitation Permafrost melt	• Monitor the effluent from the wetland and create a buffer zone/ensure buffer zone of the design lagoon does not encroach on waterways.
Significant structural damage to slab/foundation	Permafrost melt	• Include thermosiphon technology to control temperature below slab/foundation. • Complete regular checks for cracks. • Complete regular maintenance.

The high risk event related to treatment inefficiencies in the engineered wetland is a known risk, and one that is expected to improve as warmer temperatures in the north will contribute to effective biological treatment. Although this risk may be amplified by climate change, it is not expected to be different or changed as a result of an alternate design.

The high risk event related to structural damage in the slab or foundation structure is a known risk for foundation construction in the north. The design team has already considered permafrost melt into their foundation/slab design.

Table 19: Moderate Risks Resilience Measures

Risk Event	Contributing Climate Change Parameter(s)	Resilience Measure
Damage and/or deterioration to HDPE/geotextile liner	Freeze-thaw cycles Permafrost melt	• Liner manufacturer is expected to provide products suitable for intended application based on expected lifespan and future climate conditions. • Monitor leachate production over time to help identify gaps.
Displacement of HDPE/geotextile liner	Freeze-thaw cycles Permafrost melt	• Liner manufacturer is expected to provide products suitable for intended application based on expected lifespan and future climate conditions. • Monitor leachate production over time to help identify gaps.

Risk Event	Contributing Climate Change Parameter(s)	Resilience Measure
Concrete deterioration within manhole	Permafrost melt	• Concrete manholes are expected to be designed for the intended application based on expected lifespan and future climate conditions.
Pump capacity compromised	Changing precipitation	• Pump leachate back into system (if possible). • Truck leachate away for treatment and disposal. • Pump leachate into on-side holding tank for treatment at a later date.
Break in leachate piping	Freeze-thaw cycles Permafrost melt	• Underground piping is expected to be properly insulated to reduce impacts from freeze-thaw cycles and permafrost melt. • Piping manufacturer to provide products suitable for intended application based on expected lifespan and future climate conditions.
Physical damage to storm water culverts	Freeze-thaw cycles	• Have spare materials on hand, or use what is available. • Build alternative access road.
Impact on functionality of stormwater culverts and structures	Changing precipitation Snow depth Freeze-thaw cycles	• Schedule operators and attendants to frequently check culverts and clear physical debris.
Treatment inefficiencies in engineered wetland	Low temperature	• Monitor the effluent from the wetland and create a buffer zone/ensure buffer zone of the design lagoon does not encroach on waterways
System becoming overloaded causing overflows	Low temperature	• Pump leachate back into system (if possible). • Truck leachate away for treatment and disposal. • Pump leachate into on-side holding tank for treatment at a later date.
Scale and ramp foundation failure	Freeze-thaw cycles Permafrost melt	• Complete regular maintenance and upkeep scale and concrete ramp.
Significant structural damage to slab/foundation	Freeze-thaw cycles	• Include thermosiphon technology to control temperature below slab/foundation. • Complete regular checks for cracks. • Complete regular maintenance.
Crack in slab/foundation	Freeze-thaw cycles Permafrost melt	• Include thermosiphon technology to control temperature below slab/foundation. • Complete regular checks for cracks. • Complete regular maintenance.
Electrical component failure/storage/spikes	High wind gusts	• Adequately secure antennas and electrical equipment.

From the moderate risks, the resilience measures are mainly related to operational protocols and policy measures that are expected to be undertaken in order to lower the risk. There are no physical changes to the design that are expected to eliminate or further reduce these risks. The moderate risks are known risks to this Project.

3.2 Cost/Benefit Analysis

Based upon the results discussed above, the high risks resilience measures are being considered into the detailed design of the engineered wetland and landfill infrastructure. Currently, it is anticipated that the final design will address the risk identified with respect to the foundation as a standard expectation of designing infrastructure components to adapt to conditions in Canada's North. As such, no additional or unique adaptive measures have been identified for further analysis and consideration.

4.0 Conclusion

The City of Iqaluit underwent a procurement process for the design of a new landfill and transfer station, as the existing landfill is nearing full capacity. The Project included a Climate Lens Assessment to understand the production of greenhouse gases, as well as to complete a preliminary review of climate change vulnerabilities to the project infrastructure. The Project included the construction of a new landfill, including new access to the location, a new recycling and eco-centre (i.e., Transfer Station), an area for the future construction of a composting facility, new methods of waste collection and a leachate collection and treatment system.

A climate change resilience assessment was conducted on the development area to determine climate change related impacts on the Project infrastructure and develop potential resilience options. The assessment concluded with 20 moderate risks and 3 high risks identified. From the high risk items, two were related to the functionality of the engineered wetland and quality of the wetland effluent. Climate change data for the region suggests that an increase in average annual temperatures will increase the functionality of the engineered wetland by providing favourable conditions for biological treatment. This is a positive climate impact. The third high risk item was identified as the risk of crack or completed failure of slab/foundation construction. This risk is exacerbated by permafrost melt and more frequent events of freeze-thaw cycles. This is a known risk to the project team, and as per the report entitled “Geothermal Modelling and Geotechnical Recommendations” produced by Wood May 14, 2019, the design team chose to incorporate thermosiphon technology into the slab/foundation design of the Transfer Station. The Wood report investigated the impact of the thermosiphon on the expected temperature below the slab/foundation over 70 years. The assessment found that temperatures below the slab/foundation are expected to decrease over time, which suggests that the permafrost is not expected to melt in this area over the lifespan of the building.

Moderate risks resilience measures were mainly related to procedural and policy measures to implement with operational staff. Some examples included leachate monitoring to help identify leaks or issues in the leachate collection system, while others included having extra storm water infrastructure on hand (i.e., inventory) to be prepared in the event of a failure. These risks are being incorporated into the final design of the project through additional considerations.

5.0 References

Canada. National Round Table on the Environment and the Economy. (2009). *True North: Adapting Infrastructure to Climate Change in Northern Canada*. Ottawa: NTREE.

Government of Canada. Climate Data Viewer. https://climate-viewer.canada.ca/climate-maps.html#/?t=annual&v=sfcwind&d=cmip5&r=rcp85&cp=-87.19404176295366,60.83932726006354&z=4&ts=3 (accessed April 11, 2019).

Nawari, N., and Stewart, R.E. 2006. Climatological features of orographic low-level jets over Frobisher Bay. *Atmos.-Ocean*, **44**, 397-413.

Nawari, N., and Stewart, R.E. 2008. Channelling of high-latitude boundary-layer flow. *Non-linear Processes Geophys.*, **15**, 33-52.

Prairie Climate Centre. Climate Atlas of Canada. https://climateatlas.ca/data/city/246/minus30_2060_85 (accessed April 11, 2019).

Infrastructure Canada. 2018. *Climate Lens General Guidance*. Version 1.1.

Appendix A

Geothermal Modelling and Geotechnical Recommendations Report