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CITY OF IQALUIT

Climate Change Resilience Assessment

Solid Waste Landfill and Transfer Station - City of Iqaluit

Investing in Canada Infrastructure Program (ICIP)

October 2019 – 19-9543

Table of Contents

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Figures

Tables

Appendices

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: Julie DiCicco, P.Eng October 3, 2019

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[Name and credentials] [Date]

Validated by*: Mark Scaplen, P.Eng. October 3, 2019

______________________________________ ________________________

[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
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

General Category	Specific Category	Asset Component
		• 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

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

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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

Notes:
[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]

Notes:
[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

Notes:
[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

Notes:
[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%		

Notes:
[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; and • 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; and • Pump failure from liner system to holding ponds.
Roadway and Parking Area	• Damage and/or deterioration to gravel area; and • 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; and • 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; and • Scale and ramp foundation failure.

Category	Risk
Equipment	• Vehicle/mobile equipment failure; • Unable to operate mobile equipment; and • 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; and • Crack in slab/foundation.
Building Exterior	• Damage or failure to metal cladding.
Roof	• Roof collapse or failure; and • Damage and/or failure of metal roof panels.
Electrical components	• Electrical component failure/shortage/spikes; and • Communication system failure (SCADA for treatment elements).
Mechanical components	• Heating and Cooling system overload; • Rupture of septic/sewage tank; and • 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
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				

Risks	Low Temperatures	Changing Precipitation	Snow Depth	Freeze-thaw Cycles	High Winds	High Temperatures	Permafrost
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		

Risks	Low Temperatures	Changing Precipitation	Snow Depth	Freeze-thaw Cycles	High Winds	High Temperatures	Permafrost
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.

Category	Risk	Severity Rating	Consequence
	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.
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
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

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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. **Figure 1** shows the risk tolerance threshold used in evaluating the risk score.

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

Figure 1: Risk Evaluation Matrix

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**

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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
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

Risk Event	Contributing Climate Change Parameter(s)	Resilience Measure
		• 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 (see **Appendix A**), 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.

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Appendix A

Wood Report – Geothermal Modelling and Geotechnical Recommendations

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Geothermal Modelling and Geotechnical Recommendations

Transfer Station and Landfill in Iqaluit, Nunavut
Project # CG14359

Prepared for:

Dillon Consulting limited
Calgary, Alberta

14-May-19

Geothermal Modelling and Geotechnical Recommendations

Transfer Station and Landfill in Iqaluit, Nunavut

Project # CG14359

Prepared for:

Dillon Consulting limited
Calgary, Alberta

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Table of contents

List of tables

List of appendices

1.0 Introduction

At the request of Mr. Keith Barnes, Associate Engineer with Dillon Consulting Limited (Dillon), Wood Environment and Infrastructure Solutions a division of Wood Canada Limited (Wood), has conducted geothermal modeling and developed geotechnical recommendations for the proposed transfer station foundation and for the proposed landfill in Iqaluit, NU.

The geotechnical discussion provided in the present report is based on a review of the following reports and geotechnical drilling for the project:

- "Geotechnical investigation, Proposed Waste Transfer Station, Iqaluit, Nunavut, EXP Project No. OTT-00248813-AO", dated 19 October 2018. The geotechnical field investigation consisted of drilling six boreholes to depths of between 10 m and 15 m at the proposed waste transfer station site.
- "City of Iqaluit Waste Transfer Station and New Landfill Project, Desktop Study – Proposed New Landfill Site (Site 2), EXP Project No. OTT00248813-AO", dated 19 October 2018.

The reviewed geotechnical report and drilling results were prepared by EXP Services Inc.

2.0 Scope of Work

It was understood that the transfer station should be supported by a mat (slab-on-grade) foundation with no crawl space between underside of the station and the ground surface. Such a foundation option for heated structures within permafrost regions with ice-rich surficial materials can be used if some device or method be applied to eliminate or considerably reduce the amount of heat released by the heated structure into the permafrost. For the current project, two foundation options were considered: 1) thermosiphons to freeze surficial soils under the heated structure; 2) a thick layer of insulation immediately under the slab to reduce heat flux from the heated structure. The scope of work includes the following sections required for designing suitable foundations for the transfer station:

- Compilation of climate data;
- Regional geological and permafrost conditions;
- Results of geotechnical drilling;
- Results of geothermal modeling
- Geotechnical recommendations on suitable foundation options (slab-on-grade and slab-on-grade with thermosiphons, including soil design parameters); and
- Geotechnical recommendations on site grading and drainage.

The scope of work for the proposed landfill included geothermal modeling for the baled waste. The purpose of the modeling was determination of the period of time for freezing the baled waste and underlying soil of the active layer, if placement of the bales occurs at the end of summer.

3.0 Iqaluit Transfer Station and Landfill Location

The Town of Iqaluit is situated at the edge of the Hall Upland of the Davis Physiographic Region. The town overlooks the waters of Frobisher Bay, sitting on rocky terrain with numerous rock outcrops. Geographically, the town lies at about 63°45′ N latitude and 68°31′ W longitude. The proposed waste transfer station will be located on town lots 3586 228/17/18/20 and 3480 220/1 (Qaqqamuit Road), approximately 2 km north from the Iqaluit airport.

The proposed landfill site is an approximately 66.12 parcel of land, with the site to occupy approximately 22 hectares, and located approximately 8 km northwest of the City of Iqaluit.

4.0 Climate

Climate Normals data for periods 1971-2000 and 1981-2010 (Table 1) of the Iqaluit weather station were used to analyze climate conditions of the site. Comparison of the two sets of climate data (1971-2000 and 1981-2010) shows that the mean annual air temperature increased from -9.8 °C to -9.3 °C (0.5 °C increase), respectively, and the mean summer air temperature increased from 5.1 °C to 5.4 °C (0.3 °C increase), respectively. The increase of the mean winter air temperature is twice greater than the mean summer air temperature, being -17.2 °C to -16.6 °C (0.6 °C increase), respectively.

Based on the undertaken analysis of the climate data, it can be expected that the mean annual air temperature within the Iqaluit region may gradually increase within the following 20-30 years (operational life of the structure) by 1.5 °C to 2.0 °C.

Table 1: MEAN MONTHLY AIR TEMPERATURES (°C)

Time Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1971-2000	-26.6	-28.0	-23.7	-14.8	-4.4	3.6	7.7	6.8	2.2	-4.9	-12.8	-22.7
1981-2010	-26.9	-27.5	-23.2	-14.2	-4.4	3.6	8.2	7.1	2.6	-3.7	-12.0	-21.3

In addition to the air temperature, wind velocity in the winter months is required for the geothermal analyses. This meteorological data for period 1981-2010 is provided in Table 2 below.

Table 2: MEAN MONTHLY WIND VELOCITY

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind velocity, m/sec	4.4	4.2	4.1	4.5	4.7	---	---	---	---	4.9	5.2	4.5

5.0 Regional Geology and Permafrost

The surficial geology map of Iqaluit was reviewed to determine the surficial geology at locations of the transfer station and landfill site. It was understood that the glacial marine delta (plain) is expected to be encountered at the transfer station site where thickness of glacial deposits reworked by marine actions may well exceed 10 m. Contrary to the transfer station site, the surficial terrain at the landfill site is shown as till veneer with fragments of till blanket. The thickness of glacial deposits at the landfill site likely does not exceed 5 m. The glacial marine and glacial deposits typically represent mix of sand, silt and clay with numerous inclusions of cobbles and boulders. The glacial marine deposits at shallow depths typically are denser and have less fine content.

The glacial marine and glacial deposits are underlain with monzogranite bedrock which mainly consists of biotite and quartz.

Iqaluit lies within the continuous permafrost zone. The thickness of the active layer has been reported to vary from 1 m to 2 m, depending on ground vegetative cover and moisture content of surficial soils.

Permafrost temperature data obtained from a few previously investigated sites in the community suggest that the mean annual permafrost temperature within the community is in the range of -4 to -5 °C at a depth of 8-10 m.

6.0 Encountered Soil Profile

6.1 Transfer Station

A geotechnical field investigation at the transfer station site was undertaken on September 14, 2018. The drilling program of the field investigation consisted of advancing 6 boreholes drilled to depths of 10-15 m using an air-track drill.

The surficial material was generally represented by fill which consisted of gravelly sand with some cobbles. Moisture conditions varied and were noted to be dry to wet. Fill thickness varied from 1.0 m to 2.0 m. No laboratory moisture testing was done on the surficial fill.

Beneath the fill, gravelly sand to sandy gravel was encountered in four boreholes with a thickness ranging from 1.1 m to 8.0 m. BH-2 had no gravelly sand layer but was noted to have a 0.2 m thick layer of cobbles and boulders beneath the fill. BH-6 also did not have gravelly sand to sandy gravel beneath the fill, poorly graded sand was beneath the fill in this location. The moisture contents were highly variable, ranging from approximately 1% to 18%.

Well to poorly graded sand was noted below the gravelly sand to sandy gravel, in all boreholes with the exception of BH-3, where the sand layer was gravelly. The well graded gravel (found in BH-1 and BH-2) had a moisture content ranging from approximately 7% to 15%. The gravelly sand in BH-3 had a moisture content ranging from approximately 6% to 18%. The poorly graded sand (found in BH-4, BH-5 and BH-6) had a high variability in moisture content, ranging from approximately 5% to 23%.

Perched water was encountered at various depths in BH-2 (1.5 m depth), BH-3 (3.0 m depth), BH-4 (1.5 m depth), and BH-5 (1.2 m depth).

Mean annual permafrost temperature was measured to be in the range of -4.0 °C to -4.5 °C in BH2 and BH4, respectively.

Bedrock was not encountered at any of the borehole locations.

6.2 Landfill Site

Due to limited access to the landfill site, it was not possible to complete the proposed borehole program.

The regional geology map showed the majority of the landfill site covered with a till veneer, which was expected to be 0.5 m to 2 m in thickness. A till blanket, which can be up to 10 m thick, was shown close to the northeast corner of the site.

Review of the topographical map showed the landfill site area as undulating, with an elevation range from 155 m to 180 m. The location chosen from the preliminary desktop study has a ground surface elevation change of approximately 7 m within the area.

7.0 Geothermal Modelling

For the current study, a 2-dimensional version of SIMTEMP software (developed in-house by Wood) was used for temperature prediction of soil temperature under the slab of the transfer station. The program uses the finite element method to compute a numerical solution for the heat transfer problem. Physical/mathematical algorithms used in the SIMTEMP model have been published and the simulation process has been verified against well-known analytical solutions and with numerical solutions produced by other commercial/non-commercial geothermal modelling software. Wood has successfully used the SIMPTEMP program for a variety of geothermal applications over the last twenty years. Two geothermal analyses were carried out for the current transfer station project: the first geothermal run was for a slab-on-grade foundation with thermosiphons, while the second run was for the slab-on-grade foundation with no thermosiphons, but with thicker insulation placed immediately under the slab, and a thicker layer of granular fill material placed below the insulation. The finite element grid for both analyses consisted of 1539 nodes and 2912 triangle finite elements.

A sketch showing the cross-section used for the finite element grid for the 2-dimensional geothermal analysis with thermosiphons is shown on Figure 1, Appendix A. It can be seen that the grid profile consists of a 0.2 m thick slab, 0.1 m thickness of insulation, 0.5 m thickness of granular fill, and a 20 m thickness of in-situ sand/gravel underlain with bedrock. The thermosiphons are placed at a depth of 0.3 m below the base of the insulation, n the granular fill, with approximately a 3.0 m spacing across the station. A similar cross-section was used for the 2-dimensional geothermal modeling with no thermosiphons. It was assumed in this analysis that the insulation thickness is 0.3 m thick, and the layer of granular fill was 2 m thick (Figure 2, Appendix A).

The geothermal analyses started from September 1 and was run over a period of 70 years. Table 3 below provides the physical and thermal properties of identified materials.

Table 3: PHYSICAL AND THERMAL PROPERTIES OF IDENTIFIED MATERIALS

Material	Dry Density, Kg/m³	Moisture Content,%	Thermal Cond., W/m/°K		Heat Capacity, MJ/m³/°K		Latent Heat, MJ/m³
			frozen	unfrozen	frozen	unfrozen	
Granular Fill	2000	5	2.14	2.10	2.100	2.260	33.496
In-situ Sand and Gravel	1800	10	2.20	1.97	2.040	2.420	60.293
Bedrock	2500	2	2.91	2.91	2.512	2.512	16.748

7.1 Boundary and Initial Conditions

The initial temperature of the materials was assumed to be 2 °C from surface to 1.5 m depth, and -4 °C from 1.5 m to 100 m depth. The room temperature within the transfer station was assumed to be 10 °C. The concrete slab and insulation were modeled in the model as heat transfer coefficients. The total heat transfer coefficient (a) of the slab and insulation was calculated by the following equation:

$$a = \frac{1}{\frac{1}{a_{conc}} + \frac{1}{a_{ins}}} \quad (1)$$

Where:

a_{conc} – heat transfer coefficient for concrete, W/m²/°C;

a_{ins} – heat transfer coefficient for insulation, W/m²/°C.

It was assumed in the calculations that the thermal conductivity of concrete and insulation is equal to 1.5 W/m/°C and 0.034 W/m/°C, respectively.

The heat transfer coefficient for the thermosiphons (a) was calculated by Equation 2 below published in the report TR-14-1 "Review of Thermosiphon Applications" prepared by US Army Engineer Research and Development Centre (ERDC) and Cold Regions Research and Engineering Laboratory (CRREL).

$$a = 15.83 + 9.8W \tag{2}$$

Where:

W – wind velocity, m/sec, Table 2.

The temperatures of the granular fill surface or evaporator surface (T_{sur}) were calculated by the following equation:

$$a(T\_air - T\_sur) = (T\_sur - T\_node)k/D; \tag{3}$$

Where:

a– heat transfer coefficient, W/m²/°C;

T_{air} – ambient air temperature for 1981-2019 for thermosiphons (Table 1) or room temperature (10 °C);

T_{node} – soil temperature at depth D from granular fill surface, or from thermosiphon, °C;

D – distance between T_{sur} and T_{node} , m;

k– frozen or unfrozen soil thermal conductivity, W/m/°C.

7.2 Results

Figure 3, Appendix A, shows temperature profile at the end of August for the granular fill and in-situ sand and gravel for various years of the station operation at midpoint between thermosiphons. It can be seen on Figure 3 that the thickness of the thawed zone under the slab is about 0.5 m. Below this depth, the soil temperature quickly drops down to a temperature of approximately -4.8 °C after the first winter of thermosiphon operation. The soil temperature will gradually decrease at the 7 m depth, and after 30 and 70 years of station operation will be in the order of approximately -6.0 °C.

Figure 4, Appendix A, shows the temperature profile at the end of August for the granular fill and in-situ sand and gravel for various years of the station operation at the middle of the transfer station with no thermosiphons. As expected, the thaw depth gradually increases from approximately 2.0 m after 3 years of operation, to approximately 19.0 m at the end of the proposed 70-year service life of the transfer facility (70 years). Based on assessment of the moisture content for sand and gravel (approximately averaging 10 percent), it is considered that the total thaw settlement may approach 90-100 mm at the end of the station operational life.

8.0 Foundation Recommendations

8.1 Compacted Granular Pad Foundation

Based on results of field geotechnical investigations and geothermal modeling, it was concluded that the foundation system for the transfer station can be designed as a reinforced concrete slab supported on a compacted gravel pad – either with or without installation of thermosiphons. However, some limitations, will apply to the slab-on-grade foundation alternative that does not include thermosiphons to remove heat energy from the area below the structure. The following recommendations are provided for design and construction of slab on grade foundations, either with or without installation of thermosiphons.

8.1.1 Slab-On-Grade with Thermosiphons

Excavation for the granular pad should be at least 0.8 m deep and extend approximately 1 m beyond the footprint of the structure. The best time for excavation is late spring when the subgrade is still in a frozen state, but soil temperature to the 2 m depth likely is only marginally below 0 °C. Based on results of the geothermal modeling, it is considered that the thermosiphons can be installed 3 m apart at the 0.3 m depth below the underside of the insulation. It should be noted that final recommendations on installation of the thermosiphons will be prepared by a foundation designer.

Preparation of the subgrade for the granular pad should include removal of all localized surficial organic and compressible material. Proof rolling with locally available heavy equipment then should be carried out over the prepared subgrade for the granular pad area. Weak material identified by the proof rolling should be over excavated to a competent frozen/unfrozen surface and then be backfilled to excavation invert with compacted gravel.

Granular material for backfilling over-excavated soft zones and for pad construction should be free of organics and contain less than 10 percent fines. The gradation for gravel provided in Table 4 is intended to serve as a guideline in specifying granular material.

Table 4: RECOMMENDED GRADATION FOR 25 MM FILL

Sieve Size, mm	Percent passing by Weight
25	100
20	95-100
10	60-80
4.75	40-60
2.36	28-48
0.6	13-29
0.3	9-21
0.15	6-15
0.075	4-10

All fill up to 0.4 m depth should be placed in lifts not exceeding 0.2 m in loose thickness and should be compacted to not less than 95 percent of Standard Proctor Maximum Dry Density (SPMDD). A sand layer, compacted to at least 95 percent of SPMDD, then should be placed up to the elevation where the thermosiphons will be installed. Following installation of the thermosiphons, a leveling sand layer, approximately 0.1 m thick should be placed and compacted to 95 percent of SPMDD. Sand fill compacted to 98 percent of SPMDD then should be placed up to the elevation where the insulation will be placed. It is recommended that the extruded polystyrene insulation thickness should be not less than 100 mm. The insulation should extend over the entire excavation, and 1 m beyond the station footprint. The unfactored ULS bearing capacity of the compacted granular pad may be taken as 660 kPa, and the SLS bearing capacity may be taken 200 kPa. Short term settlement of the granular pad is expected to be in the order of 5 mm, and long-term settlement of the granular pad due to creep processes (after 70 years of operation) may expected to be in the order of 10-15 mm.

8.1.2 Slab-On-Grade with Thick Insulation

Based on results of the field geotechnical investigations and geothermal modeling, it can be concluded that a slab-on-grade foundation with thickened insulation is possible, if the following limitations are acceptable:

- The structure will tolerate a gradually increasing thaw settlement, up to approximately 50 mm after 30 years of operation;
- Installation of thermosiphons to operate for a limited period of time, may potentially be required after the 30th year of the operation to eliminate additional thaw settlement, over the period while the thermosiphons are operational; and
- The time over which the (temporary) thermosiphons are will be determined based on the tolerance of the structure to frost heave. Without temporary thermosiphons, the likely additional thaw settlement between operational years 30 and 70 is in the order of 30-40 mm.

Excavation for the granular pad should be at least 2 m deep and extend approximately 1 m beyond the footprint of the structure. The best time for excavation is late spring when the subgrade is still in a frozen state, but soil temperature to the 2 m depth are likely only marginally below 0 °C. Preparation of the subgrade for the granular pad should include removal of all localized surficial organic and compressible material. Proof rolling with locally available heavy equipment then should be carried out over the prepared subgrade for the granular pad area. Weak material identified by the proof rolling should be over excavated to a competent permafrost surface and then be backfilled to the excavation invert with compacted gravel.

Granular material for backfilling over-excavated soft zones and for pad construction should be free of organics and contain less than 10 percent fines. The gradation for gravel provided in Table 4 is intended to serve as a guideline in specifying granular material. The gradation provided is recommended for use for granular backfill that will be placed in a frozen state. Also, the moisture content of the frozen fill should be low (3-5 percent) which does not allow formation of frozen chunks of fill, which would be particularly susceptible to settlement upon thawing.

All fill should be placed in lifts not exceeding 0.2 m in loose thickness and should be compacted to not less than 98 percent of Standard Proctor Maximum Dry Density (SPMDD). A final lift of the granular pad should consist of a 0.1 m thick sand layer, compacted to at least 98 percent of SPMDD. A 300 mm thick layer of extruded polystyrene insulation should be placed on the sand layer and should be extended over the entire excavation, plus 1 m beyond the station footprint. The unfactored ULS bearing capacity of the compacted granular pad may be taken as 660 kPa, and the SLS bearing capacity may be taken 200 kPa. Short term settlement of the granular pad is expected to be in the order of 15 mm, and long-term thaw settlement of the granular pad (after 30 years of operation) may expected to be in the order of 50 mm.

9.0 Site Grading and Drainage

A site grading plan will need to address surface water management in periods of heavy runoff and snow melt. The final grade of the site should ensure that the drainage is directed away from the building to reduce the potential for thermal and water erosion. The final grade should have a minimum slope of 3 percent down away from the building within 2 m of the structure, and a minimum 2 percent slope down for several meters beyond the 2 m distance to shed water away from the structure.

Downspouts for eaves troughs should be directed away from the building with the discharge point at least 1.5 m meters from the exterior of the building. This will reduce the potential for erosion of the subgrade adjacent to the structure.

10.0 Design Review and Foundation Monitoring

It is recommended that a geotechnical review be conducted prior to finalization of design details and contract specifications. This review is considered to be an important part of the design process, as it enables Wood to ensure that the recommendations contained herein have been understood and interpreted correctly.

It is recommended that a qualified geotechnical engineer or technologist monitor the gravel pad construction.

In general, monitoring of gravel pad construction will include the following:

- Determination of dimensions for soft zones which require over excavation;
- Assessment of granular material quality; and
- Confirmation that adequate degree of compaction is obtained

The concrete slab for the transfer station should be underlain by relatively clean gravel fill to reduce the risk of sulphate attack. If this is implemented, Type GU (formerly Type 10) Portland cement can be used for the manufacture of foundation concrete.

11.0 Baled Waste Freezing

A 1-dimensional version of SIMPTEMP was used for assessment of the period of time required to freeze baled waste at the proposed landfill site in Iqaluit. It was assumed that the soil profile consists of 2 m of glacial deposits (sand and gravel at moisture content 10 percent) over granite bedrock. Based on data provided in the paper titled "Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content" (Waste management, Volume 22, 2002) it was assumed that the moisture content of the baled waste, by wet weight is about 50 percent. It was also estimated, following discussion with Dillon's design engineer, that the bulk density of the baled waste is 700 kg/m^3. The physical and thermal parameters for in-situ sand and gravel are shown in Table 3 above and the parameters for the baled waste are provided in Table 5.

Table 5: PHYSICAL AND THERMAL PROPERTIES OF IDENTIFIED MATERIALS

Material	Dry Density, Kg/m^3	Moisture Content by Dry Weight ,%	Thermal Cond., W/m/°K		Heat Capacity, MJ/m^3/°K		Latent Heat, MJ/m^3
			frozen	unfrozen	frozen	unfrozen	
Baled Waste	250	140	0.70	0.41	2.100	3.320	117.496

The upper boundary conditions were taken as the mean monthly air temperatures (Table 1). An n-factor of 1.1 was applied to the mean monthly air temperatures to obtain the waste surface temperatures in summer months. In winter months, the waste surface temperatures (T_{sur}) were calculated by the following equation:

$$\frac{1}{R}(T_{air} - T_{sur}) = (T_{sur} - T_{node})k_w/D\,; \qquad (4)$$

Where:

R– snow thermal resistance, m^2 °C W^{-1};

T_{air} – ambient air temperature for 1981-2019 (Table 1) ;

T_{node} – soil temperature at some distance from the surface, °C;

D – distance between T_{sur} and T_{node} , m;

k_w– frozen or unfrozen waste thermal conductivity, W/m/°C.

A heat flux corresponding to the geothermal gradient of 0.02 °C/m was used as the bottom boundary conditions.

11.1 Results

Two geothermal analyses were carried out. For the first analysis, the baled waste at a temperature of 10 °C was placed on the unfrozen ground on October 1. It is considered as the worst-case scenario when the 3 m high bale at a temperature of 10 °C is placed on the unfrozen active layer, approximately 1.6 m thick with a temperature of approximately 2 °C.

For the second analysis, the baled waste at a temperature of 10 °C was placed on the frozen ground on December 1. It is considered as the better case scenario when the 3 m high bale at a temperature of 10 °C is placed on the partially frozen active layer (frozen from ground surface to 1.1 m depth), and only the 0.5 m thick bottom portion of the active layer is unfrozen at temperature 0.1 °C.

Figure 5, Appendix A shows the results for bales being placed on October 1 on the unfrozen ground surface. The results presented are for September30 for each year when maximum thaw of the ground is expected, to capture the bale and ground temperatures to 6 m depth. For the first year, the top 0.6 m of the bale was unfrozen (active layer in the bale). The bale was frozen from 0.7 m to 1.6 m depth. The bale and the ground were unfrozen from 1.7 m to 4.7 m depth. For year 2, the bale was frozen from 0.6 m to 2.1 m depth (thickness of frozen portion of the bale increased by 0.5 m). The bale and ground surface were unfrozen from 2.9 m to 3.8 m depth. At the end of year 3, the soil is in a frozen state beneath the bale but the soil temperature is just marginally below 0 °C . Only at the end of year 6, are the bale temperature (below bale active layer) and the soil temperature (below bale) equal, at approximately -1 °C .

Figure 6, Appendix A shows the results for bales being placed on December 31 on the frozen ground surface. The results presented are for September 30for each year when maximum thaw of the ground is expected, to capture the bale and ground temperatures to 6 m depth. For the first year, the top 0.6 m of the bale was unfrozen (active layer in the bale). The bale was frozen from 0.7 m to 1.6 m depth. The bale and the ground were unfrozen from 1.7 m to 3.4 m depth. For year 2 the ground is frozen completely beneath the bale, but the soil temperature is just marginally below 0 °C . For the following years, the ground temperature drops beneath the bales, as well as within the bottom portion of the bale, and at the end of year 5, the bale temperature (below bale active layer) and the soil temperature (below bale) are equal at approximately -1.8 °C .

It can be concluded based on results of the geothermal analyses that 5-6 years is required for complete freezing of the bale and soil below the bale, if the bale placement occurs at the end of summer or in early winter.

12.0 Limitations & Closure

12.1 Limitations

1. The work performed in the preparation of this report and the conclusions presented herein are subject to the following:

    a) The contract between Wood and the Client, including any subsequent written amendment or Change Order dully signed by the parties (hereinafter together referred as the "Contract");

    b) Any and all time, budgetary, access and/or site disturbance, risk management preferences, constraints or restrictions as described in the contract, in this report, or in any subsequent communication sent by Wood to the Client in connection to the Contract; and

    c) The limitations stated herein.

2. **Standard of care:** Wood has prepared this report in a manner consistent with the level of skill and are ordinarily exercised by reputable members of Wood's profession, practicing in the same or similar locality at the time of performance, and subject to the time limits and physical constraints applicable to the scope of work, and terms and conditions for this assignment. No other warranty, guarantee, or representation, expressed or implied, is made or intended in this report, or in any other communication (oral or written) related to this project. The same are specifically disclaimed, including the implied warranties of merchantability and fitness for a particular purpose.

3. **Limited locations:** The information contained in this report is restricted to the site and structures evaluated by Wood and to the topics specifically discussed in it, and is not applicable to any other aspects, areas or locations.

4. **Information utilized:** The information, conclusions and estimates contained in this report are based exclusively on: i) information available at the time of preparation, ii) the accuracy and completeness of data supplied by the Client or by third parties as instructed by the Client, and iii) the assumptions, conditions and qualifications/limitations set forth in this report.

5. **Accuracy of information:** No attempt has been made to verify the accuracy of any information provided by the Client or third parties, except as specifically stated in this report (hereinafter "Supplied Data"). Wood cannot be held responsible for any loss or damage, of either contractual or extra-contractual nature, resulting from conclusions that are based upon reliance on the Supplied Data.

6. **Report interpretation:** This report must be read and interpreted in its entirety, as some sections could be inaccurately interpreted when taken individually or out-of-context. The contents of this report are based upon the conditions known and information provided as of the date of preparation. The text of the final version of this report supersedes any other previous versions produced by Wood.

7. **No legal representations:** Wood makes no representations whatsoever concerning the legal significance of its findings, or as to other legal matters touched on in this report, including but not limited to, ownership of any property, or the application of any law to the facts set forth herein. With respect to regulatory compliance issues, regulatory statutes are subject to interpretation and change. Such interpretations and regulatory changes should be reviewed with legal counsel.

8. **Decrease in property value:** Wood shall not be responsible for any decrease, real or perceived, of the property or site's value or failure to complete a transaction, as a consequence of the information contained in this report.

9. **No third-party reliance:** This report is for the sole use of the party to whom it is addressed unless expressly stated otherwise in the report or Contract. Any use or reproduction which any third party makes of the report, in whole or in part, or any reliance thereon or decisions made based on any information or conclusions in the report is the sole responsibility of such third party. Wood does not represent or warrant the accuracy, completeness, merchantability, fitness for purpose or usefulness of this document, or any information contained in this document, for use or consideration by any third party. Wood accepts no

responsibility whatsoever for damages or loss of any nature or kind suffered by any such third party as a result of actions taken or not taken or decisions made in reliance on this report or anything set out therein. including without limitation, any indirect, special, incidental, punitive or consequential loss, liability or damage of any kind.

10. **Assumptions:** Where design recommendations are given in this report, they apply only if the project contemplated by the Client is constructed substantially in accordance with the details stated in this report. It is the sole responsibility of the Client to provide to Wood changes made in the project, including but not limited to, details in the design, conditions, engineering or construction that could in any manner whatsoever impact the validity of the recommendations made in the report. Wood shall be entitled to additional compensation from Client to review and assess the effect of such changes to the project.

11. **Time dependence:** If the project contemplated by the Client is not undertaken within a period of 18 months following the submission of this report, or within the time frame understood by Wood to be contemplated by the Client at the commencement of Wood's assignment, and/or, if any changes are made, for example, to the elevation, design or nature of any development on the site, its size and configuration, the location of any development on the site and its orientation, the use of the site, performance criteria and the location of any physical infrastructure, the conclusions and recommendations presented herein should not be considered valid unless the impact of the said changes is evaluated by Wood, and the conclusions of the report are amended or are validated in writing accordingly.

    Advancements in the practice of geotechnical engineering, engineering geology and hydrogeology and changes in applicable regulations, standards, codes or criteria could impact the contents of the report, in which case, a supplementary report may be required. The requirements for such a review remain the sole responsibility of the Client or their agents.

    Wood will not be liable to update or revise the report to take into account any events or emergent circumstances or facts occurring or becoming apparent after the date of the report.

12. **Limitations of visual inspections:** Where conclusions and recommendations are given based on a visual inspection conducted by Wood, they relate only to the natural or man-made structures, slopes, etc. inspected at the time the site visit was performed. These conclusions cannot and are not extended to include those portions of the site or structures, which were not reasonably available, in Wood's opinion, for direct observation.

13. **Limitations of site investigations:** Site exploration identifies specific subsurface conditions only at those points from which samples have been taken and only at the time of the site investigation. Site investigation programs are a professional estimate of the scope of investigation required to provide a general profile of subsurface conditions.

    The data derived from the site investigation program and subsequent laboratory testing are interpreted by trained personnel and extrapolated across the site to form an inferred geological representation and an engineering opinion is rendered about overall subsurface conditions and their likely behaviour with regard to the proposed development. Despite this investigation, conditions between and beyond the borehole/test hole locations may differ from those encountered at the borehole/test hole locations and the actual conditions at the site might differ from those inferred to exist, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface details and anomalies.

    Final sub-surface/bore/profile logs are developed by geotechnical engineers based upon their interpretation of field logs and laboratory evaluation of field samples. Customarily, only the final bore/profile logs are included in geotechnical engineering reports.

    Bedrock, soil properties and groundwater conditions can be significantly altered by environmental remediation and/or construction activities such as the use of heavy equipment or machinery, excavation, blasting, pile-driving or draining or other activities conducted either directly on site or on adjacent terrain. These properties can also be indirectly affected by exposure to unfavorable natural events or weather conditions, including freezing, drought, precipitation and snowmelt.

During construction, excavation is frequently undertaken which exposes the actual subsurface and groundwater conditions between and beyond the test locations, which may differ from those encountered at the test locations. It is recommended practice that Wood be retained during construction to confirm that the subsurface conditions throughout the site do not deviate materially from those encountered at the test locations, that construction work has no negative impact on the geotechnical aspects of the design, to adjust recommendations in accordance with conditions as additional site information is gained and to deal quickly with geotechnical considerations if they arise.

Interpretations and recommendations presented herein may not be valid if an adequate level of review or inspection by Wood is not provided during construction.

14. **Factors that may affect construction methods, costs and scheduling:** The performance of rock and soil materials during construction is greatly influenced by the means and methods of construction. Where comments are made relating to possible methods of construction, construction costs, construction techniques, sequencing, equipment or scheduling, they are intended only for the guidance of the project design professionals, and those responsible for construction monitoring. The number of test holes may not be sufficient to determine the local underground conditions between test locations that may affect construction costs, construction techniques, sequencing, equipment, scheduling, operational planning, etc.

    Any contractors bidding on or undertaking the works should draw their own conclusions as to how the subsurface and groundwater conditions may affect their work, based on their own investigations and interpretations of the factual soil data, groundwater observations, and other factual information.

15. **Groundwater and Dewatering:** Wood will accept no responsibility for the effects of drainage and/or dewatering measures if Wood has not been specifically consulted and involved in the design and monitoring of the drainage and/or dewatering system.

16. **Environmental and Hazardous Materials Aspects:** Unless otherwise stated, the information contained in this report in no way reflects on the environmental aspects of this project, since this aspect is beyond the Scope of Work and the Contract. Unless expressly included in the Scope of Work, this report specifically excludes the identification or interpretation of environmental conditions such as contamination, hazardous materials, wild life conditions, rare plants or archeology conditions that may affect use or design at the site. This report specifically excludes the investigation, detection, prevention or assessment of conditions that can contribute to moisture, mold or other microbial contaminant growth and/or other moisture related deterioration, such as corrosion, decay, rot in buildings or their surroundings. Any statements in this report or on the boring logs regarding odours, colours, and unusual or suspicious items or conditions are strictly for informational purposes

17. **Sample Disposal:** Wood will dispose of all uncontaminated soil and rock samples after 30 days following the release of the final geotechnical report. Should the Client request that the samples be retained for a longer time, the Client will be billed for such storage at an agreed upon rate. Contaminated samples of soil, rock or groundwater are the property of the Client, and the Client will be responsible for the proper disposal of these samples, unless previously arranged for with Wood or a third party.

12.2 Closure

The recommendations presented herein are based on the subsurface information provided in two geotechnical reports prepared by others for the currently proposed transfer station and landfill sites and estimates of subsurface soil properties based on the experience of Wood personnel with similar materials. Should the subsurface conditions encountered during subsequent phases of this project appear to be different than those described in this report, Wood should be advised immediately, and recommendations contained herein would be revised, if necessary.

Wood trusts that the information presented in this report satisfies the current needs of Dillon Consulting Limited. If there are questions or requests for additional information, please contact the undersigned at your convenience.

Yours truly,

Wood Environment & Infrastructure Solutions,
A Division of Wood Canada Limited

REGISTERED PROFESSIONAL ENGINEER
A. TCHEKHOVSKI
LICENSEE
NWT/NU

May 14, 2019

14-05-2019

Alexandre Tchekhovski, Ph. D., P. Eng.,
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Jamie Liston, B. Sc., G.I.T.
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Reviewed by:

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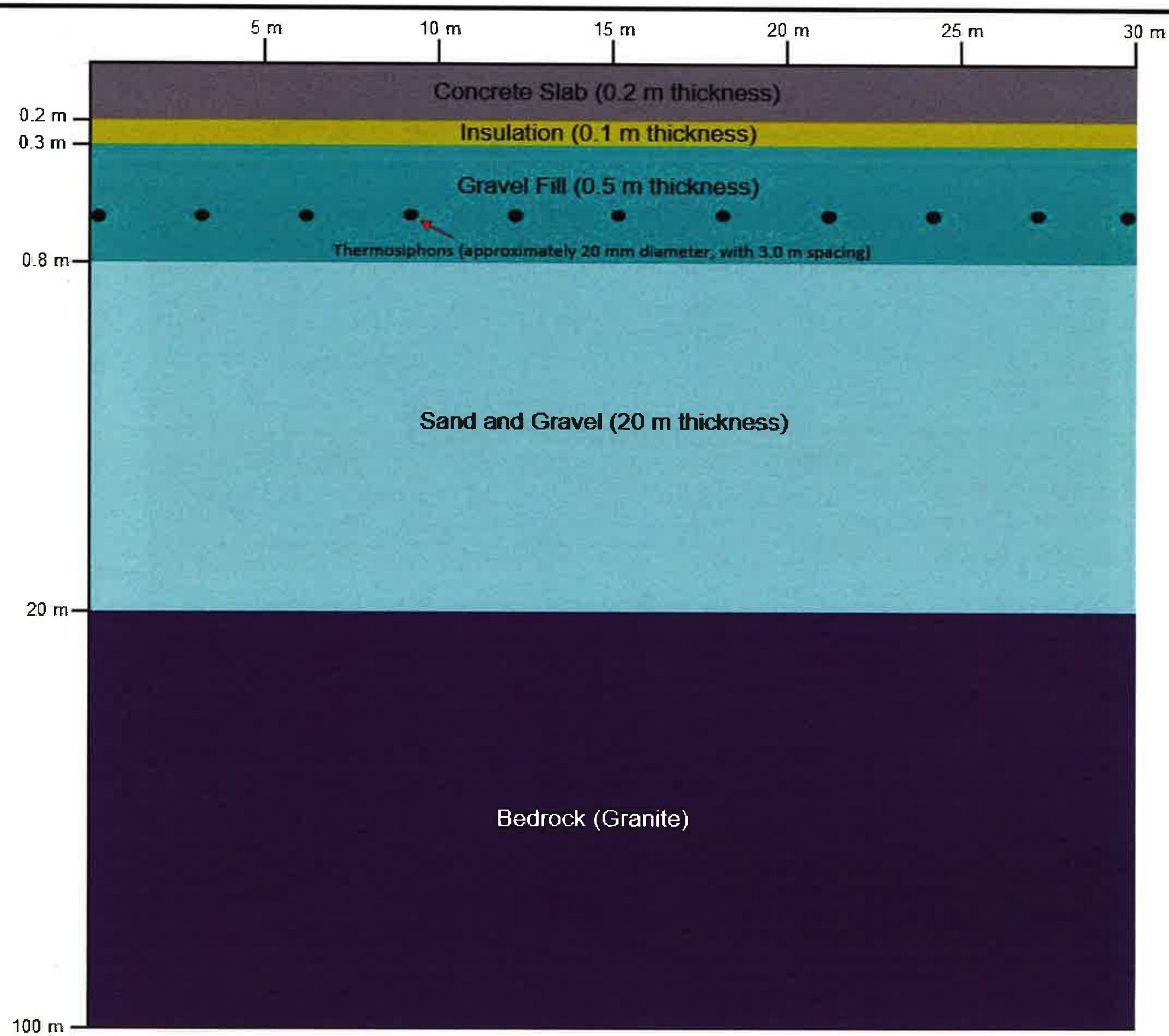
Senior Associate Geotechnical Engineer

PERMIT TO PRACTICE
Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited
Signature
Date May 14, 2019
PERMIT NUMBER: P 047
NT/NU Association of Professional Engineers and Geoscientists

AT/JL/KS
Attach.

Appendix A

Figures 1 - 6



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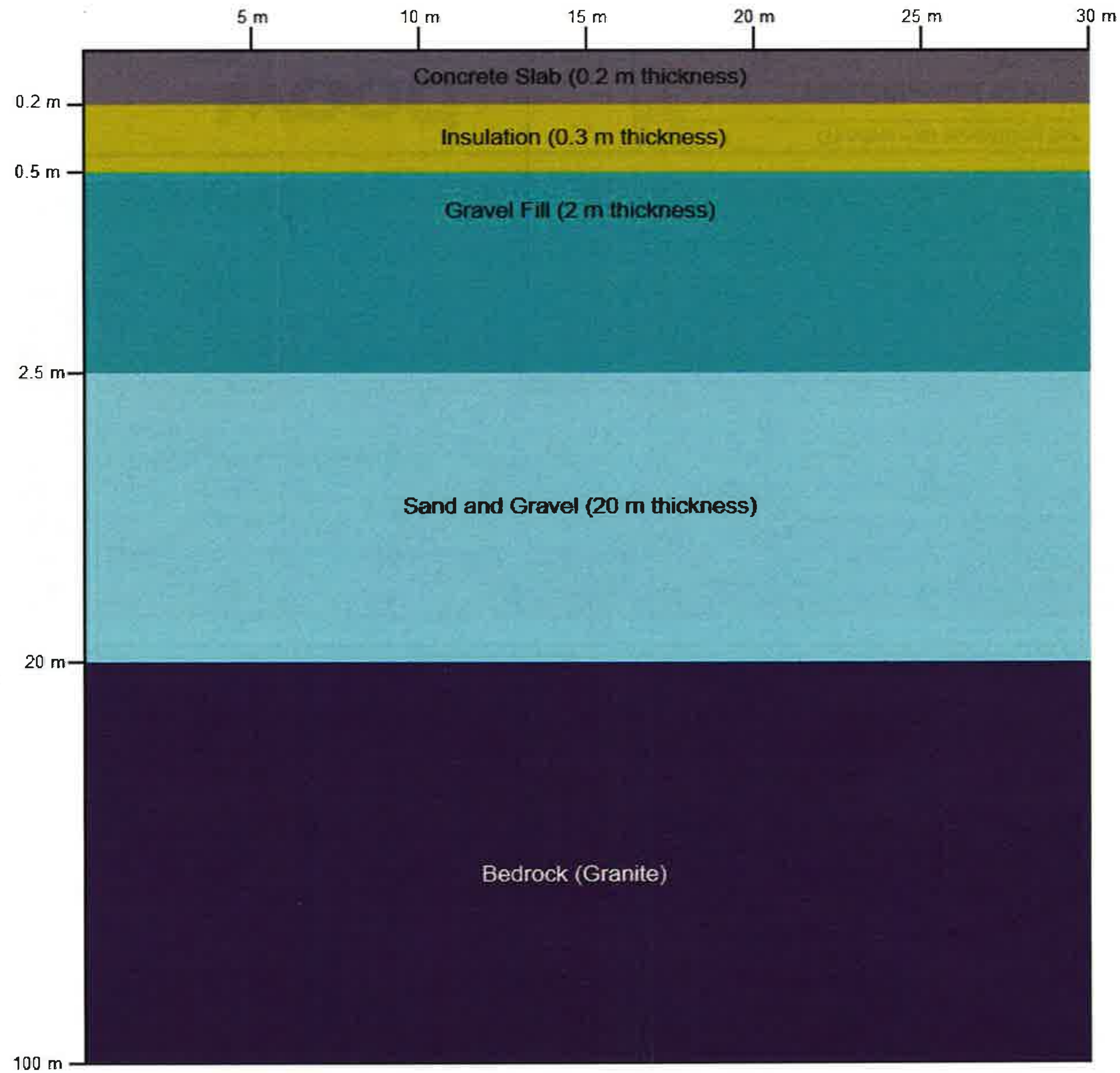

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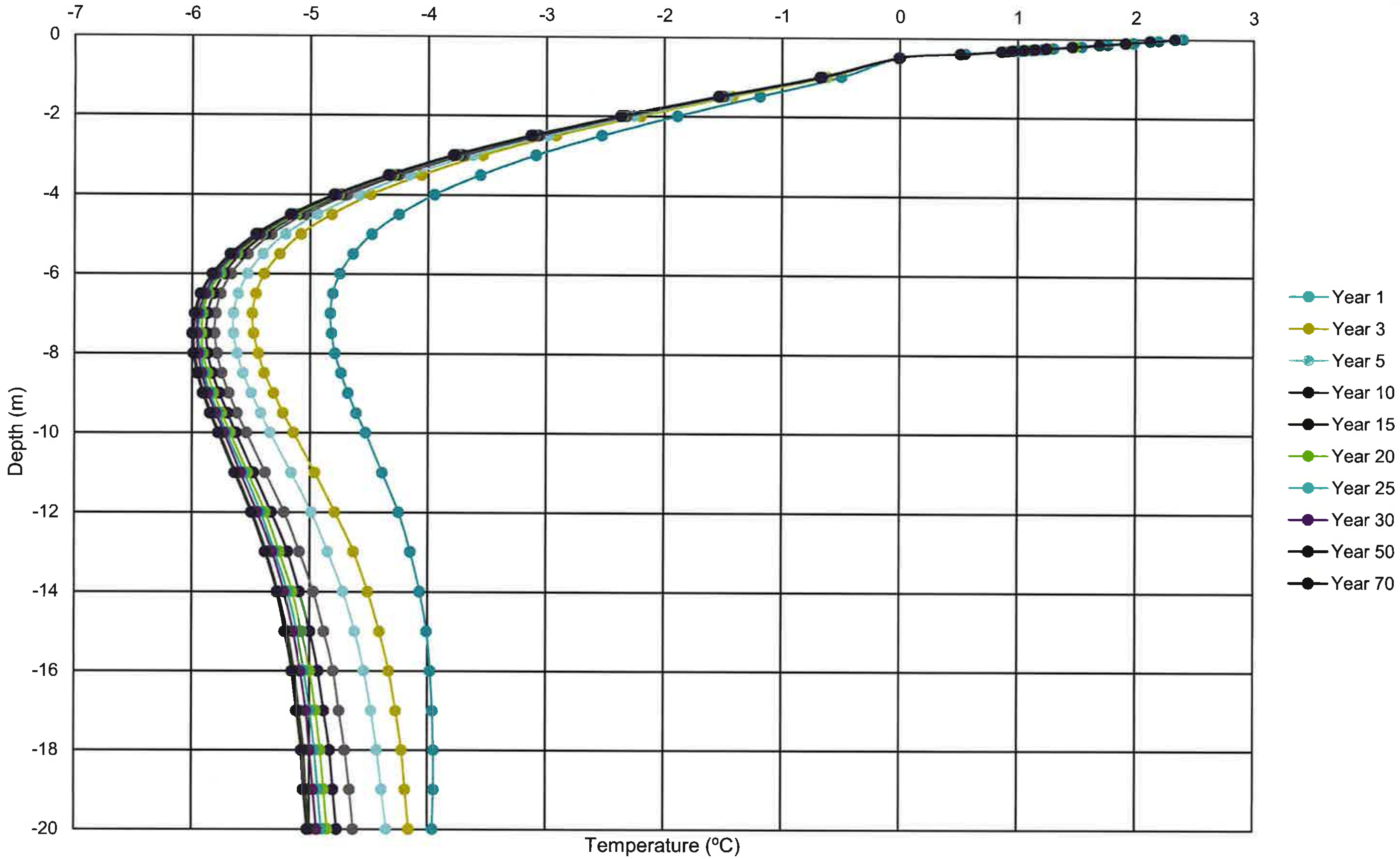

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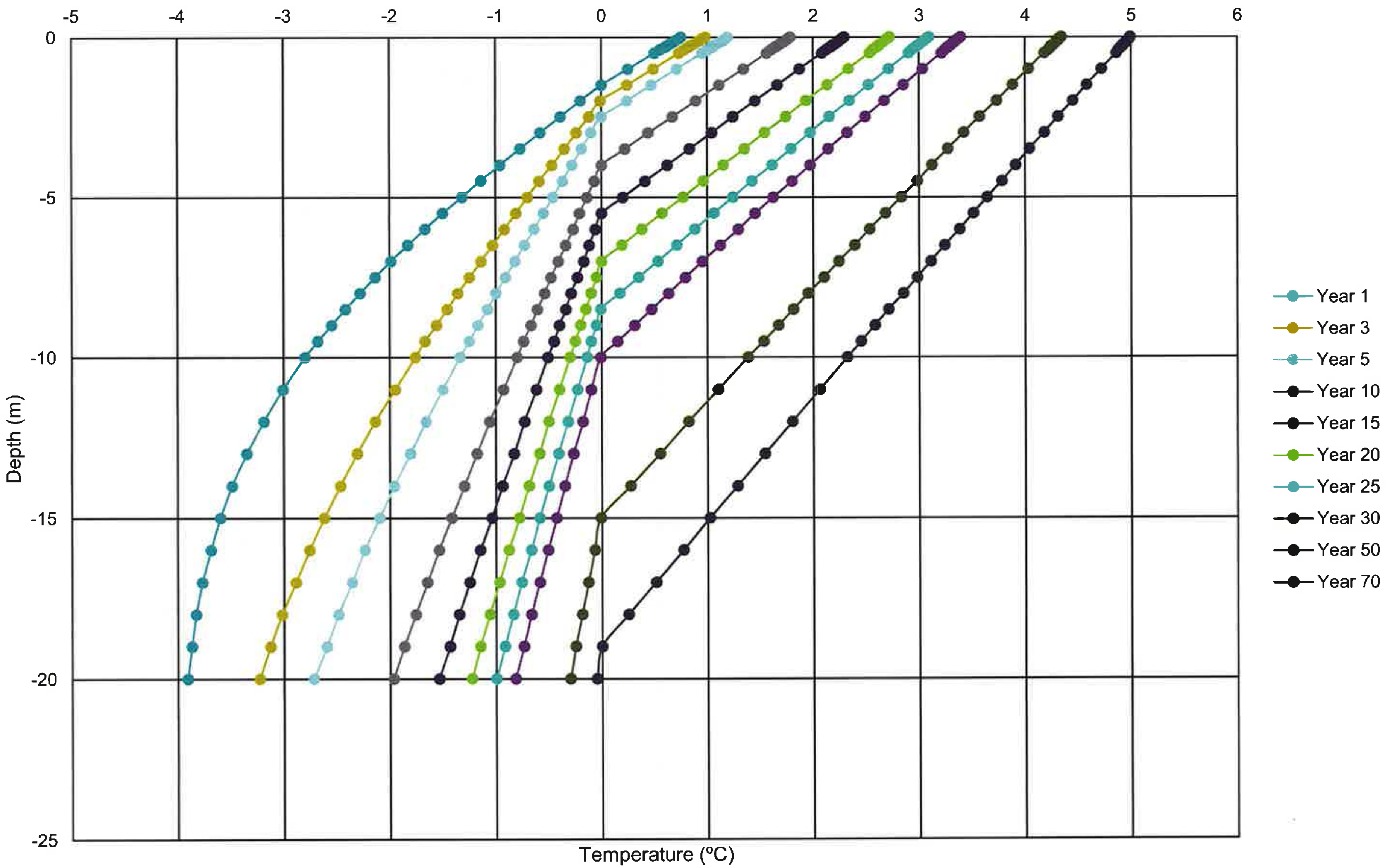

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CLIENT: Dillon Consulting Ltd.		

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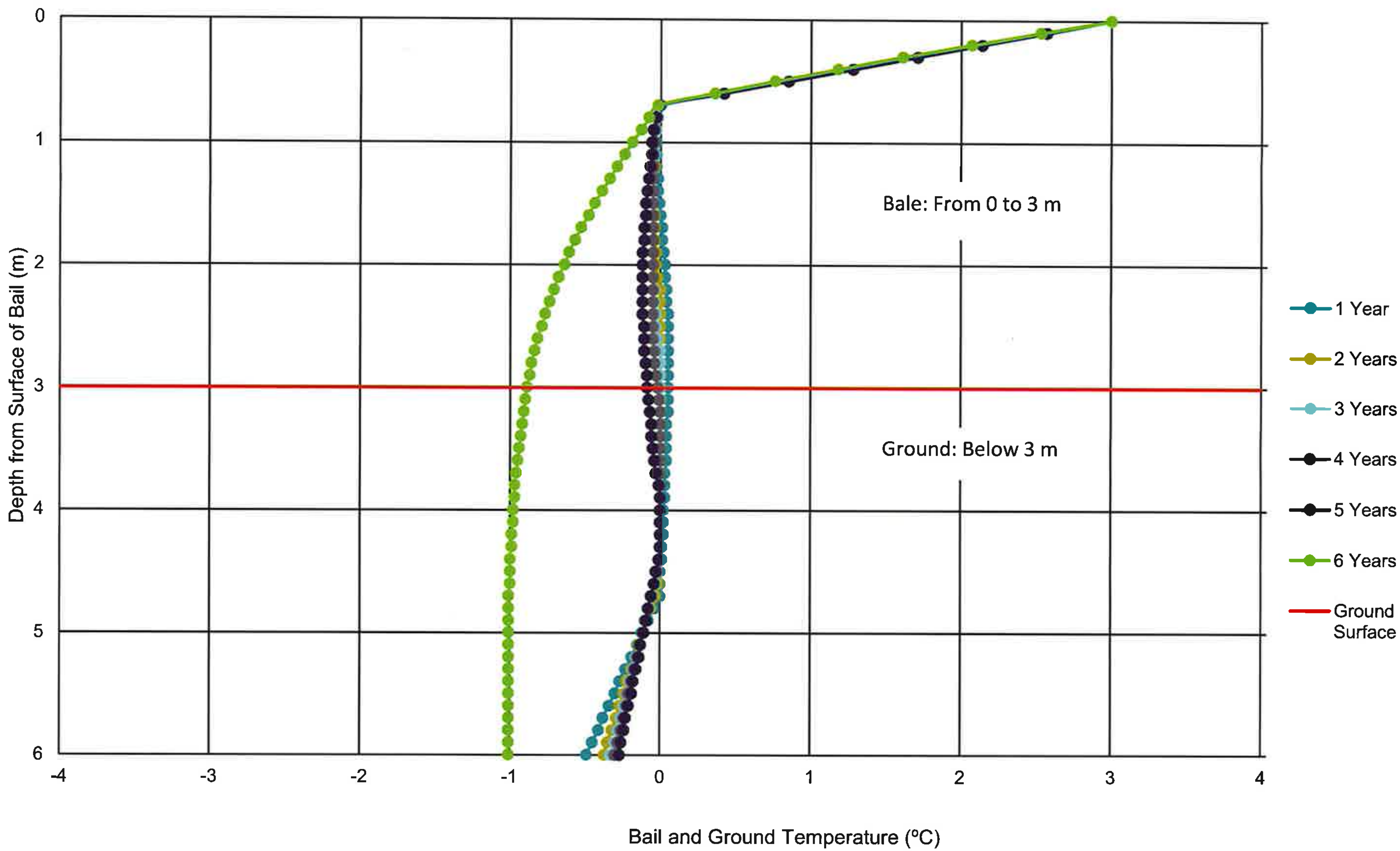

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PROJECT:	Geothermal Modelling for Transfer Station and Landfill
TITLE:	Temperature from Surface of Garbage Bail Extending to 4 m Below Ground Surface, Bales Placed Oct 1

CLIENT: Dillon Consulting Ltd.

DATE:	JOB No.:	FILE:	FIGURE No.:	REV.
May 2019	CG14359	Figure 1 to 6_May 13.xlsx	5	0

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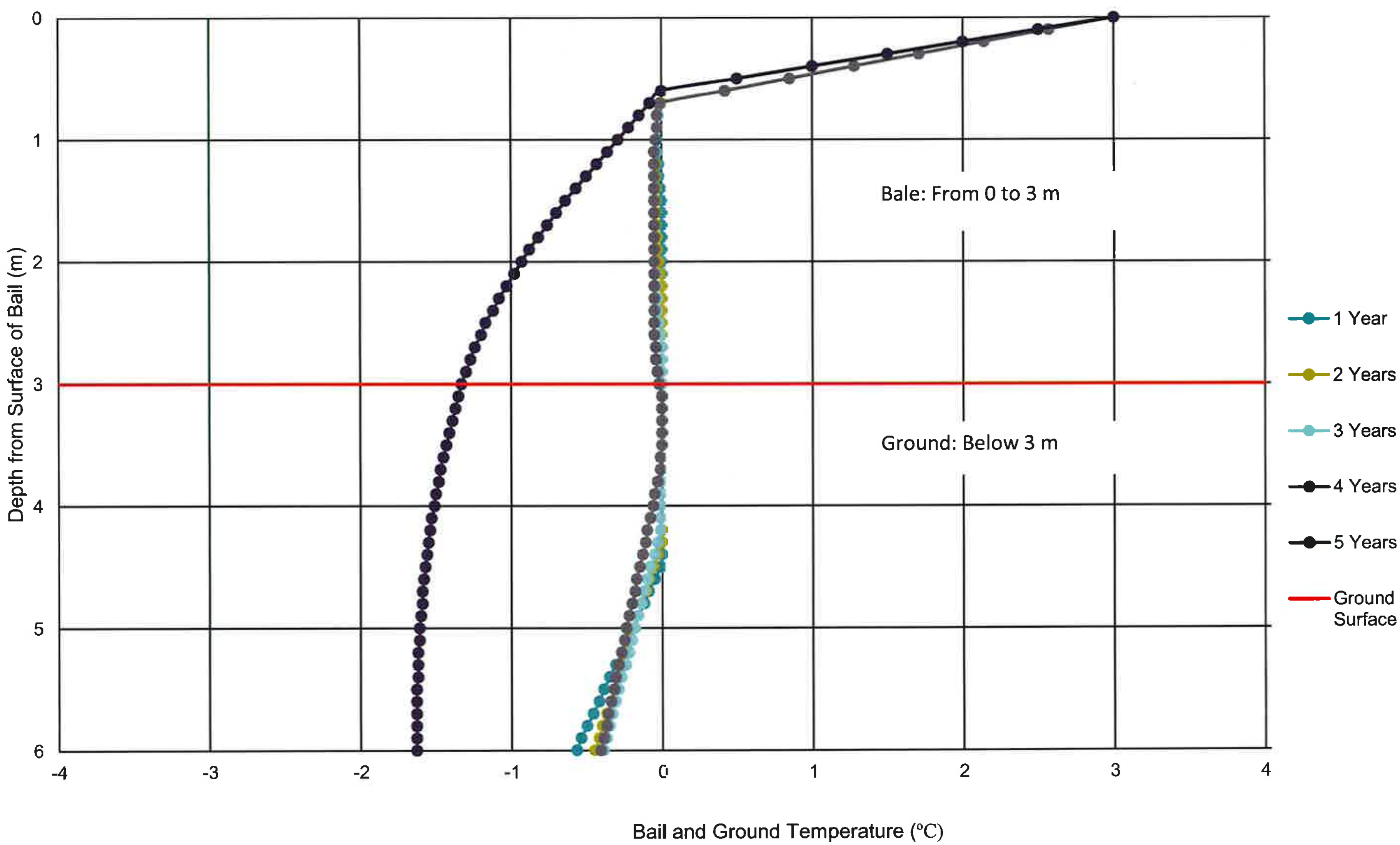

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	TITLE: Temperature from Surface of Garbage Bail Extending to 4 m Below Ground Surface, Bales Placed Dec 1			
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