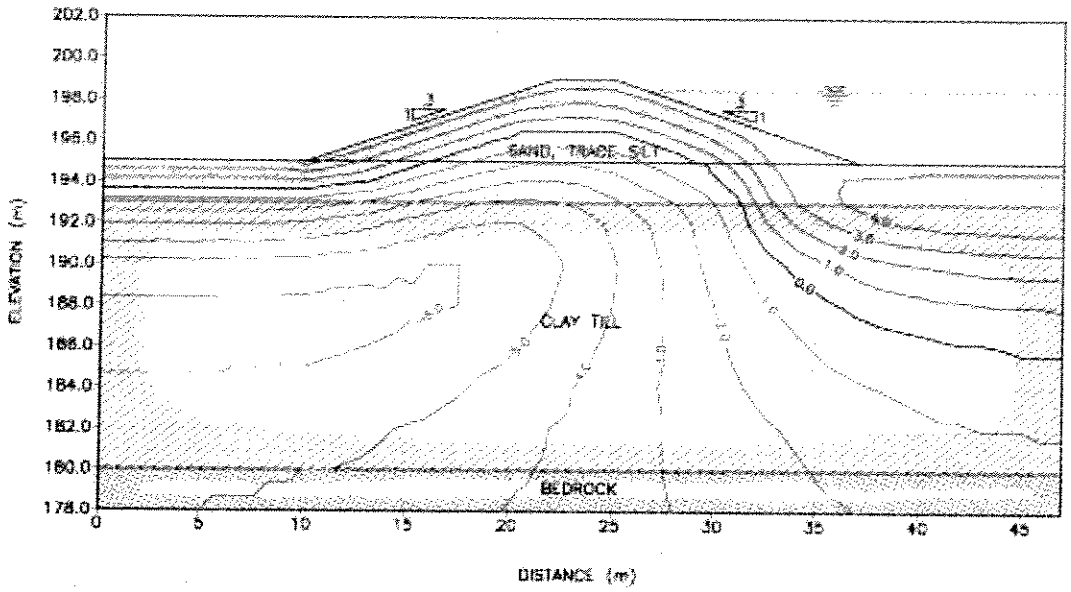

Figure 17 Temperatures in Lagoon Berm after 20 Years of Operation

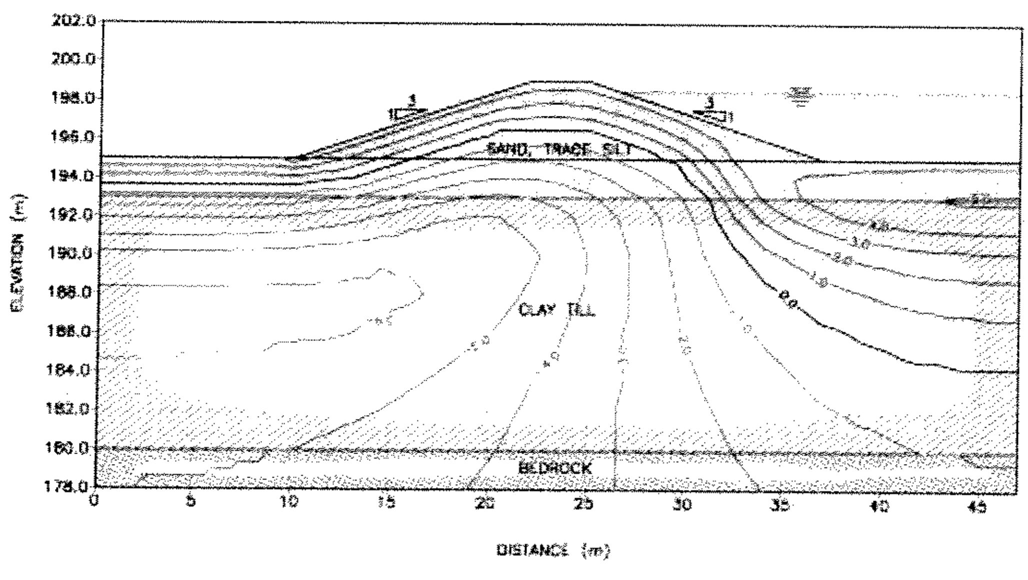

Figure 18 Temperatures in Lagoon Berm after 30 Years of Operation

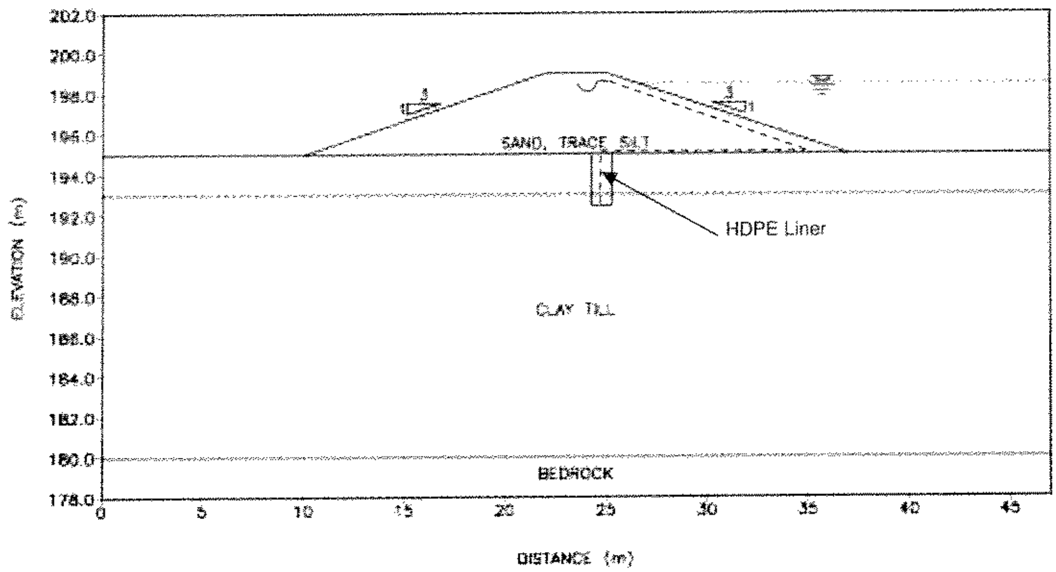

Figure 19 Proposed Layout of HDPE Liner (Option 1)

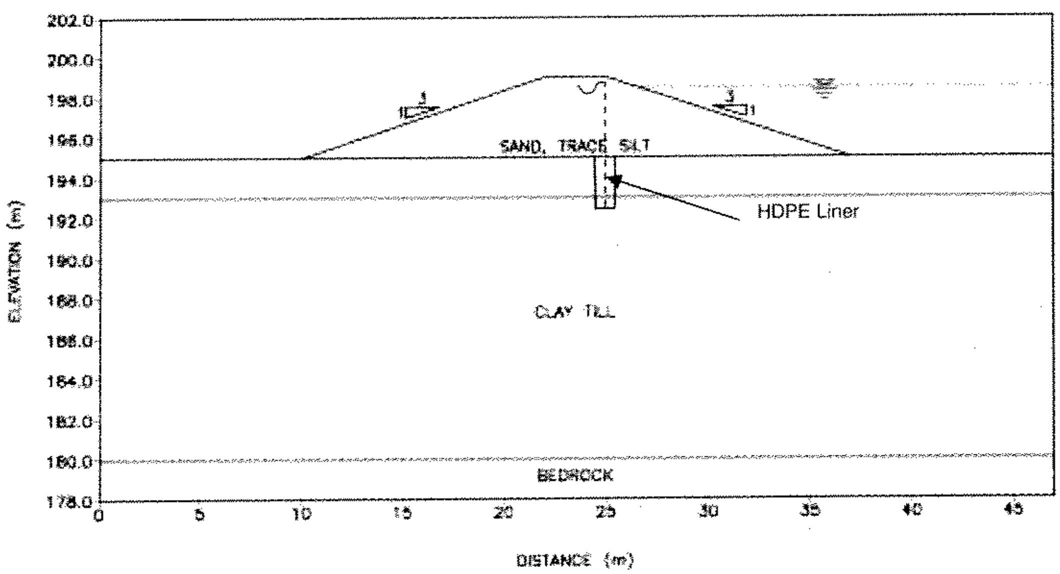

Figure 20 Proposed Layout of HDPE Liner (Option 2)

Promotion of permafrost aggradation into the berm is possible if an insulation layer is placed across the berm crest. The insulation layer will reduce the seasonal thawing that could penetrate into the berm crest. Figure 21 to 25 present predicted temperature contours within the berm, if the insulation layer (50 mm thick Styrofoam HI or equivalent) will be installed across the berm crest. The seasonal thaw at the berm crest will be reduced to 1.5 m after 1 year of operation and further to 1 m during the following years of operation. Insulation across the berm crest may be considered provided that the water level inside the lagoon could be maintained below the top of frozen zone. A sand layer, 100 mm thick, should be placed over the insulation and compacted to 95 % of SPMDD. A protective layer of gravel, about 200 mm thick, should be placed over the sand layer. For a greater effectiveness, the insulation layer could be extended about 3 m beyond the crest berm on the exterior slope and placed on compacted and smooth gravely/sandy surface. However, there is potential risk of seepage during the first year of lagoon operation when the berm materials have not frozen.

No geothermal analysis was carried out for the landfill section of the berm, which is only approximately 2 m high. Based on results of the geothermal analysis for the lagoon berm, it is our opinion that majority of the berm will be unfrozen at the end of summertime during the first five years of operation. Should the landfill contain a mixture of disposal soil and water, or dissolvable chemical substances, a geomembrane liner is recommended within the berm for a seepage control or environmental concern. Details of the liner layout may refer to Figure 19 and Figure 20. However, if the landfill, hazardous waste or land farm berm will have a height similar to the height of the sewage lagoon berm, then the results of the modeling are considered to be valid for these berm structures. It should also be clear that the soil temperature for the landfill, hazardous waste or land farm berm will be lower than the soil temperature of the sewage lagoon berm due to absence of water on inside slopes of these berms.

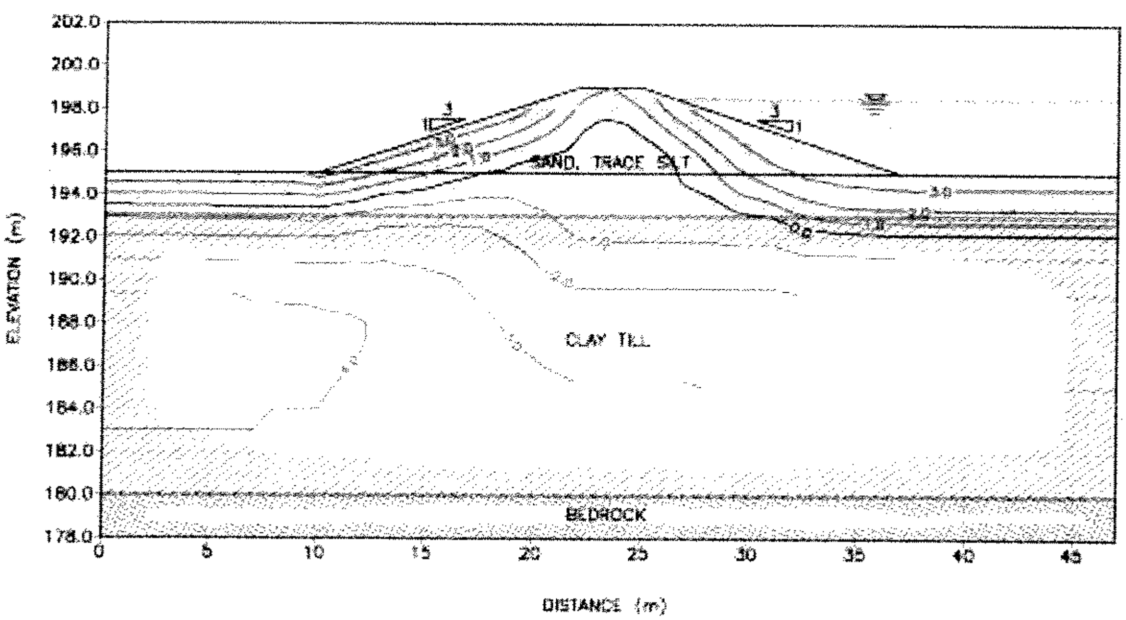

Figure 21 Temperatures in Lagoon Berm with Insulation after 1 Year of Operation

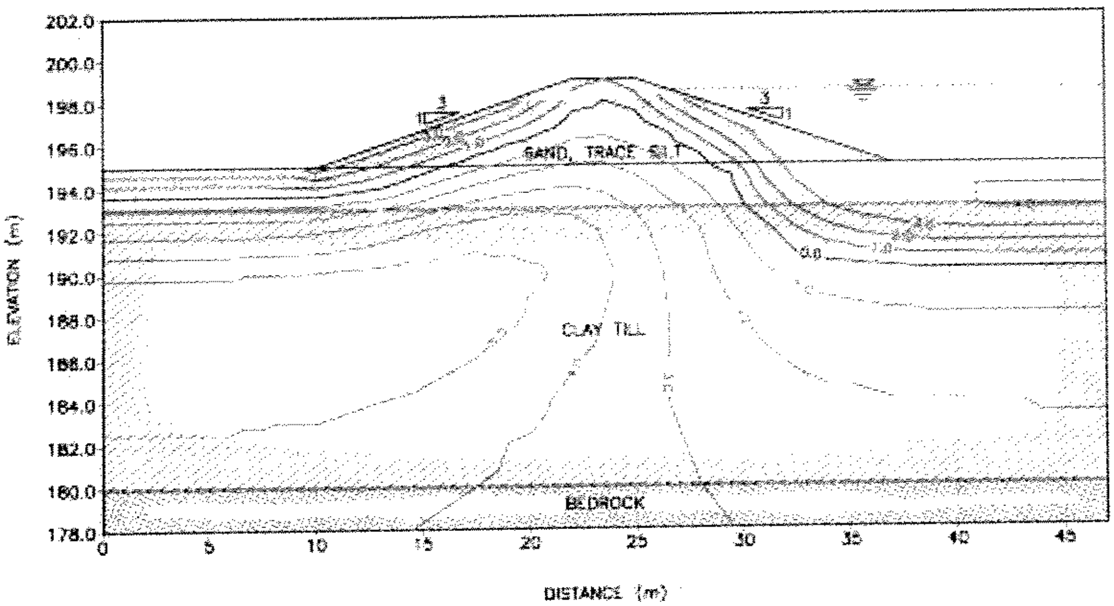

Figure 22 **Temperatures in Lagoon Berm with Insulation after 5 Years of Operation**

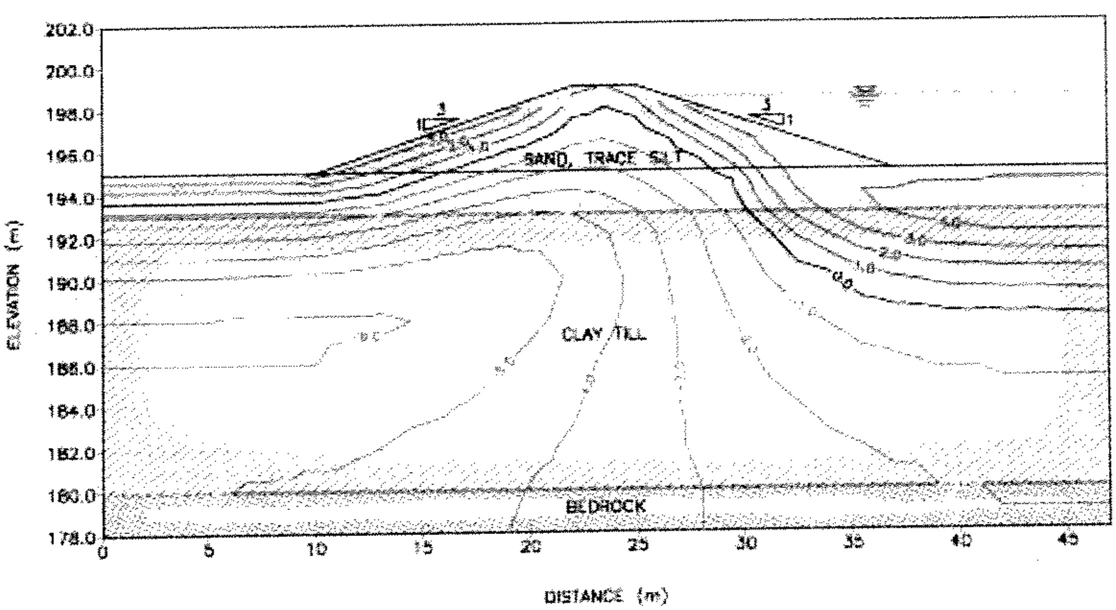

Figure 23 **Temperatures in Lagoon Berm with Insulation after 10 Years of Operation**

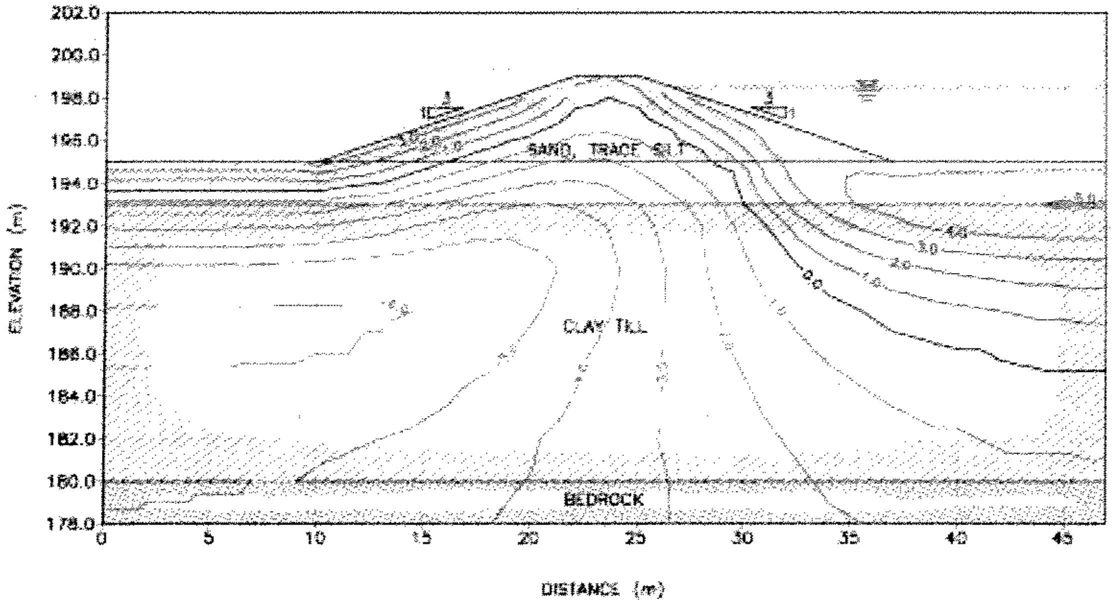

Figure 24 Temperatures in Lagoon Berm with Insulation after 20 Years of Operation

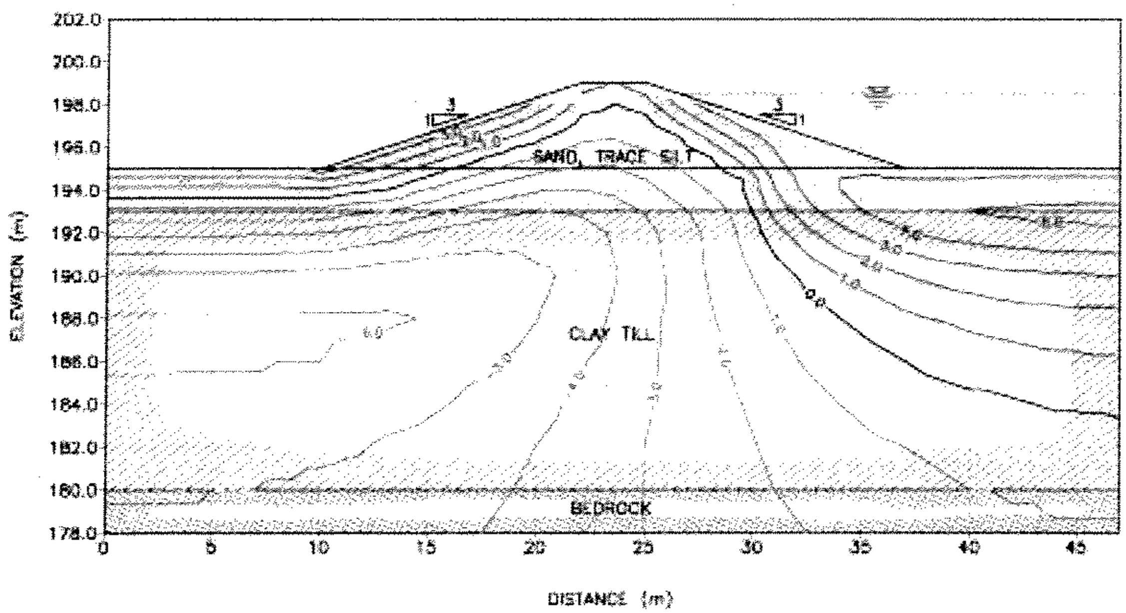

Figure 25 Temperatures in Lagoon Berm with Insulation after 30 Years of Operation

Since no measurement of ground temperature was performed during the site investigation, the permafrost temperature (initial soil temperature) in the foregoing geothermal model was predicted using a 1D geothermal analysis. The analysis includes parameters which determine the soil temperature: soil thermal conductivity, heat capacity and latent heat, snow cover, snow density and air/water temperature. The results suggest that the mean annual permafrost temperature at the site can be in a range from -3 °C to -6 °C (mainly depending on thickness of snow cover) and thickness of the active layer can be in a range from 0.5 m (mossy ground vegetation) to about 1.5 m (bared ground surface).

It is understood that the initial soil temperature is an important parameter to predict the berm and impoundment temperature during the first years of the berm/lagoon operation. However, after that time, the temperature conditions of the impoundment and berm are changed dramatically due to a warming effect of water in the impoundment and the berm configuration. The geothermal analysis has shown that it takes more than 30 years when soil temperatures within the impoundment and berm will be stabilized. At that time, the soil temperatures will differ considerably of the initial soil temperatures.

Moreover, AMEC experience in geothermal modeling shows that variations of soil thermal properties within a reasonable range of values, provide insignificant changes to long-term soil temperature. The boundary conditions have a greater impact on the berm temperature throughout the years of the berm/lagoon operation. Thus, AMEC considers that the estimated soil thermal properties and applied boundary conditions, used in the foregoing analysis, resulted in an adequate assessment of the berm temperature regime for long term consideration.

Potential of the global warming impact was not incorporated in the geothermal model. AMEC was involved in prediction of the global warming rate for several other projects, including Diavik Diamond Mine project. Our experience shows, that within range of the predicted global warming rate, no significant change of the berm temperature occurs during the following 5 to 10 years. There is a potential that after this period of time, implementation of the contingency plan will be required for the berm, based on results of thermal monitoring program as described in Section 6 below.

AMEC does not expect a noticeable change of the thawing depth under the lagoon impoundment due to global warming. It is explained by the fact that the global warming mainly occurs by increasing of winter air temperatures. However, the thawing depth under the impoundment depends mainly on the water temperature which is a function of the summer air temperature.

6.0 CONSTRUCTION MONITORING

It is recommended that a field geotechnical engineer or technologist be assigned to the site during entire time of the berm construction to provide the proper QC and QA. Responsibilities of the field inspection staff will include the following:

- Inspection of engineered fill quality, including such fill parameters as gradation, moisture content, frozen/unfrozen state, inclusions of cobbles or boulders;
- Coordination with the contractor requirements of the inspection during various stages of the berm construction.

- Estimation if the lift thickness corresponds to a capacity of available compaction equipment.
- Inspection of the compaction level for each lift, using sand cone density tests or other appropriate tests.
- Record of all geotechnical activities on the site and direct these activities if they contradict to the earth work specifications.
- Review of design drawings and specifications prior the construction is commenced;
- Provide recommendations if unforeseen site conditions will be encountered, including specific drainage and permafrost conditions.

The main requirements for the fill placement and compaction are provided below. Materials, used for the berm construction should be unfrozen at time of placement and spread in lift thicknesses, compatible with the available compaction equipment, to a maximum thickness of 300 mm and uniformly compacted to at least 95 percent of Standard Proctor Maximum Dry Density (SPMDD) at a moisture contents within ±3 percent of the optimum moisture content. Any cobbles and boulders within the lift should be removed. Minimum three sand cone tests should be carried out for each lift. The Proctor tests should be carried out on the stockpile material prior using of this material for construction. Additional tests (Proctor or sand cone tests) should be performed if it was determined by a field engineer or technologist.

After completion of the berm construction, an implementation of the following monitoring program is recommended:

- Thermal monitoring. Two thermistors strings are recommended to be installed in monitoring holes, advanced at the crest of the berm. The monitoring holes should be extended at least 5 m into the native soil. The temperature readings should be taken twice per year for the first 5 years of operation, after which the monitoring frequency would be reviewed.

- Movement monitoring. Survey monuments (at least three monuments per berm) should be installed along the interior and exterior crest of the berms. Depth of the monuments should provide that they are not subjected to frost heave forces. The monuments will be surveyed for vertical and horizontal movements twice during the first year of operation, after which the monitoring frequency would be reviewed.

- Seepage monitoring. If seepage is detected on the berm exterior slope, a remediation program should be developed. Water samples should also be taken weekly from the seepage and analysed for concentration of the critical constituents. If the water quality is not acceptable for a release, it should be temporarily captured in the seepage catchment sump.

All field observations, recommendations and monitoring data including field testing results will be documented and submitted to the NWB.

7.0 CLOSURE

The geotechnical analyses and recommendations presented herein are based on data provided to AMEC by Nuna Burnside Engineering and Environmental Ltd., review of the published reports and AMEC design experience for similar structures in permafrost areas. AMEC did not undertake any geotechnical investigations at the proposed lagoon and landfill sites. If additional geotechnical/permafrost investigations will be carried out and encountered soil conditions appear to be considerably different than those assumed in the present report, AMEC should be advised immediately and the recommendations contained herein should be revised, if necessary.

This report has been prepared for the exclusive use of Nuna Burnside Engineering and Environmental Ltd. and its agents for the specific application described in this report. Any use that a third party makes of this report, or any reliance or decisions based on this report are the sole responsibility of those parties. It has been prepared in accordance with generally accepted permafrost and foundation engineering practices. No other warranty, expressed or implied, is made.

Respectfully submitted,

**AMEC Earth & Environmental,
a division of AMEC Americas Limited**

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Geotechnical Engineer

PERMIT TO PRACTICE
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Date ________________
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amec

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KUGLUKTUK SEWAGE LAGOON

SOIL LOG
OF
TEST PITS
AT
LAGOON FOOTPRINT

TEST PIT #	DEPTH, (m)	SOIL DESCRIPTION
TP 601	0.00 – 0.10	PEAT / MUSKEG: Brown, moist
	0.10 – 1.00	SAND: Dark brown, moist, coarse to fine-grained, numerous sub-angular cobbles.
	1.00 –1.80	SAND: Dark brown, moist, compact to dense, some silt, gravel sizes to 75mm, numerous sub-angular cobbles.
	1.80 – 2.60	SAND: as above but wet, more silt, dense, with cobbles to 250mm size - permafrost at 1.8m
		Discontinued @ 1.80 m
TP 602	0.00 - 0.10	PEAT / MUSKEG: Brown, moist
-35m north of north edge of road	0.10 – 0.80	SAND: Dark brown, moist, coarse to fine-grained, some silt, compact with gravel & cobbles.
		Discontinued @ 1.8m on possible bedrock
TP 603	0.00 – 0.30	PEAT / MUSKEG: Brown, moist
	0.30 – 1.50	SAND: Dark brown, moist, compact, coarse to fine-grained, some silt, some gravel sizes, cobbles to 250 mm throughout. Boulders at 1.5 m
		Discontinued @ 1.5 m

KUGLUKTUK SEWAGE LAGOON

SOIL LOG OF TEST PITS AT LAGOON FOOTPRINT

TEST PIT #	DEPTH, (m)	SOIL DESCRIPTION
TP 604	0.00 – 0.25	PEAT / MUSKEG: Brown, moist
	0.25 – 1.80	GRAVEL: Dark brown, moist, sandy, numerous cobbles, some boulders, compact to dense, (pit stays open, suitable as embankment material) - water seepage at 1.80 m
		Discontinued @ 1.80 m
TP 605	0.00 – 0.15	PEAT / MUSKEG: Brown, moist
	@ 0.15	BEDROCK: Fractured layers, peeled with great effort by backhoe
		Discontinued @ 0.15 m
TP 606	same as TP 605	
TP 607	same as TP 605	
TP 608 to 612	0.00 - 0.15	PEAT / MUSKEG: Brown, moist
	0.15 - 1.00	SAND: Typical to sand encountered in previous test pits 601 – 603, wet (surface moisture)
		Discontinued @ 1.0 m
TP 613	0.00 – 0.15	PEAT / MUSKEG: Brown, moist
	0.15 – 0.75	SAND: Typical to sand encountered - permafrost @ 0.75 m.
		Discontinued @ 0.75 m.

KUGLUKTUK SEWAGE LAGOON
SOIL LOG
OF
TEST PITS
AT
LAGOON FOOTPRINT

BORE HOLE #	**DEPTH TO BEDROCK (m)**
BH 614 (at TP 602)	1.75 - (drilled to 2.0m)
BH 615 (east of TP 605)	1.65 – (drilled to 1.8m)
BH 616 (NE of TP 606, east of TP 607)	0.75 – (drilled to 1.2m)

SOURCE: Beach Ridge (running east/west) North of Lagoon Footprint

TEST PIT #	**DEPTH, (m)**	**SOIL DESCRIPTION**
TP 617 (east end)	0.00 – 0.10	PEAT / MUSKEG: Brown, moist
	0.10 – 0.90	SAND: Dark brown, moist, fine-grained, clean, loose to compact. - permafrost at 0.9m Discontinued @ 0.9 m
TP 618 (west of TP 617)	0.00 – 0.23	PEAT / MUSKEG: Brown, moist
	0.23 – 1.00	SAND: Dark brown, moist, medium to fine-grained, clean, loose to compact. - permafrost at 1.0 m Discontinued @ 1.0 m
TP 619 (west of TP 618)	same as TP 618	

KUGLUKTUK SEWAGE LAGOON
SOIL LOG
OF
TEST PITS
AT
LAGOON FOOTPRINT

SOURCE: Beach Ridge (running east/west) North of Lagoon Footprint

TEST PIT #	DEPTH, (m)	SOIL DESCRIPTION
TP 620 (NW of TP 619, along creek edge)	0.00 – 0.23	PEAT / MUSKEG: Brown, moist
	0.23 – 0.75	SAND: Dark brown moist, medium to fine-grained, clean, loose to compact - changes to grey/brown at 0.75 m - water seepage at 0.75 m
		Discontinued @ 0.75 m

SOIL LOG
OF
TEST PITS
AT
PROPOSED BORROW SOURCES

SOURCE: Northeast of Heart Lake at Face of Rock Ridge, North Side of Road

TEST PIT #	DEPTH, (m)	SOIL DESCRIPTION
TP 621	0.00 – 0.23	PEAT/ MUSKEG: Brown, moist
	0.23 – 0.75	CLAY: Dark brown, moist, firm, medium to high plastic. - permafrost at 0.75 m Discontinued at 0.75 m
TP 622	0.00 – 0.23	PEAT/ MUSKEG: Brown. Moist
	0.23 – 0.75	CLAY: Dark brown, moist, stiff, high plastic. - permafrost at 0.75 m Discontinued at 0.75 m

SOURCE: Plateau East of Hearth Lake, approx. 2.9 km east of Lagoon site

TEST PIT #	DEPTH, (m)	SOIL DESCRIPTION
TP 623	0.00 – 0.23	PEAT / MUSKEG: Brown, moist
	0.23 – 0.90	SAND: Dark brown, moist to wet, uniform, fine-grained, trace silt - permafrost at 0.90 m - sample #623R1 @ 0.23 – 0.90 m Discontinued @ 0.90 m
TP 624 (east of TP 623)	0.00 – 0.15	PEAT / MUSKEG: Brown. moist
	0.15 – 0.75	SAND: Dark brown, moist to wet, uniform, fine-grained, clean - permafrost at 0.75 m - sample #624R1 @ 0.15 – 0.75 m Discontinued @ 0.75 m

KUGLUKTUK SEWAGE LAGOON

SOIL LOG
OF
TEST PITS
AT
PROPOSED BORROW SOURCES

SOURCE: West of Road at End of Runway.

TEST PIT #	**DEPTH, (m)**	**SOIL DESCRIPTION**
TP 625 (exist. borrow off road's edge)	0.00 – 2.40	SAND: Dark brown, moist, fine-grained, uniform, clean - sample #625R1
	2.40 – 3.60	CLAY: Dark brown, wet, stiff, high plastic - sample #625R2 @ 2.4 – 3.6 m Discontinued @ 3.6 m

SOURCE: West of Road at End of Runway. (cont'd)

TEST PIT #	**DEPTH, (m)**	**SOIL DESCRIPTION**
TP 626 (west of TP 625)	0.00 – 0.15	PEAT / MUSKEG: Brown, moist
	0.15 – 0.75	SAND: Dark brown, moist, fine-grained, uniform, clean, - permafrost @ 0.75 m - sample #626R1 @ 0.15 – 0.75 m Discontinued @ 0.75 m

SOURCE: Existing borrow pit along SE side of runway

TEST PIT #	**DEPTH, (m)**	**SOIL DESCRIPTION**
TP 627 (exist. bank of pit)	0.00 – 2.00	SAND: Dark brown, damp, medium to fine-grained, clean.
(exist. pit floor)	2.00 – 3.00	SAND: Dark grey, moist to wet, coarse to fine-grained, clean - water seepage @ 3.0 m - TP sloughing at 1.0m below pit floor - sample $627R1 @ 2.0 – 3.0 m Discontinued @ 3.0 m