NEEGAN BURNSIDE

Attachment I – AMEC Earth and Environmental Geotechnical Responses

RESPONSES TO COMMENTS OF NUNAVUT WATER BOARD

The NWB comments in this section are typed in italics.

X Within Appendix D- Geotechnical Investigation of the Detailed Design Report, Standard Proctor compaction tests were completed on a small number of soil samples to obtain maximum dry density of construction materials. The angle of internal friction was estimated using "published correlation data for angle of internal friction and density" to be about 30°.

A. *What is the reference for the "published correlation"?*

   The correlation of the internal friction angle with dry density is published in Design Manual, NAVFAC DM 7.01.

B. *Is the correlation used appropriate for a uniform sand soil encountered at this site? If yes, why?*

   The provided correlation applies to various granular materials and the design values were selected for poorly graded sand (SP) based on the maximum dry density obtained from laboratory sieve analyses and compaction tests.

C. *Why wasn't direct shear testing completed to obtain a measure value of angle of internal friction?*

   The correlation between the internal friction angle and soil dry density have been investigated for many years and is well known. Therefore, the use of the published recommendation for the internal friction angle can be considered appropriate for the given project. Our experience with similar soils also allows to conclude that the use of the published values of the internal friction angle is appropriate for the given project, especially taking into account that the internal friction angle of 30 degrees is the low bound value for the given soil.

D. *How confident is the Hamlet in the selection of a 30° angle of internal friction?*

   The internal friction angle of 30 degrees is considered to be the lower bound value. For the compacted sand, a range of the internal friction angle may vary between 30° and 35°, depending on the sand moisture content and compaction energy.

XI. Within Appendix D – Geotechnical Investigation of the Detailed Design Report, it was stated that "the shear strength of the native soils will be characterized by a 28 to 30° friction angle."

A. *What is the basis for the selection of this value?*

   The test pits within the proposed lagoon revealed that surficial materials, encountered at the site, consist of loose to compact granular soils. Soils of the active layer are typically loose due to a disintegrating effect of freezing/thawing cycles. The typical friction angle for the loose granular material was selected based on a recommendation, provided in Bowles (1996).

B. *If this value was based on the standard Proctor test results and density correlation with angle of internal friction, what was the basis for selection of the in-situ density?*

A typical range of the unit weight (14 kN/m^3 to 18 kN/m^3) was considered in geotechnical analyses, representing loose granular material of various moisture content.

C. *Is the in-situ density of the native soils known? If so, what is the value and how was it determined?*

See XI B.

XII. *Within Appendix D – Geotechnical Investigation of the Detailed Design Report, the factor of safety of the berm with respect to global shear failure "is expected to be greater than 1.5 on the basis that the berm is unsaturated.*

A. *What method of analysis was completed to obtain the factor of safety?*

Three failure mechanisms were assumed in stability analyses:
Case 1: A circular failure within the berm material during first several months of the operation when the berm is still in an unfrozen state.
Case 2: A planar failure of the active layer on the exterior slope of the berm with a frozen core during summer periods of the berm operation.
Case 3: Berm stability against sliding along the interface of the berm and the native material.

In order to determine the stability of the berm slopes, the most critical section was considered for the analyses. The interior and exterior slope in this section are 3H:1V with the total slope height of approximately 4 m. The berm is supported by the unfrozen native granular material, underlain with frozen soil at 2 m below the original ground surface.

Case 1

This case considers that the berm slope is under construction or shortly after construction. The strength of the granular material after compaction governs the berm stability. The pore water pressure within soil particles will reduce the effective overburden stress of soil, and hence will decrease the shear strength of the soil at the failure slip. Assuming that granular material will be used for berm construction and short-term period of the unfrozen berm existence, the pore water pressure within the soil particles may be ignored. (Refer to XIII for stability of berm with consideration of pore water pressure.)

The limit equilibrium of the driving and resisting forces was predicted for assessment of the slope safety factor, using commercial computer software SLOPEW (Geostudio 2004). Due to various composition of the proposed berm fill, selection of the soil strength parameters is the major difficulty. For this reason, several sensitivity analyses were carried out with various soil strength parameters.

The potential failure slip with the low safety factor was initially determined, applying various radii of circle and various locations of the failure axis associated with the mean values of the soil strength parameters. The friction angle and the unit weight were fixed to their mean values, and the safety factors were computed by varying the cohesion. Similar calculations were performed by varying the friction angle or unit weight while other parameters were fixed to mean values. The estimated mean values, range of parameter values and results of slope stability analyses are summarized in Table 1.

Table 1 Input Parameters of Berm Fill and Results of Sensitivity Analyses

Input Parameters		Mean value	Range	Factor of Safety
Compacted Sand	Apparent Cohesion (kPa)	5	2 to 8	1.95 to 2.35
	Friction angle°	30°	28° to 33°	2.05 to 2.2
	Unit Weight (kN/m^3)	18	17 to 19	2.15 to 2.1
Native Loose Sand	Apparent Cohesion (kPa)	0	0	---
	Friction angle°	29°	28° to 30°	2.1 to 2.15
	Unit Weight (kN/m^3)	16	14 to 18	2.1 to 2.15

Figure 1 illustrates the factor of safety for the 3H:1V slope and the potential failure slip for the mean values of the soil parameters. Figure 2 presents the sensitivity plot. The strength parameters and unit weight are normalized in a range from 0 to 1. The point where three sensitivity lines are crossing, characterizes the deterministic factor of safety at the mean values for the strength parameters and the soil unit weight. The results indicate that the factor of safety against the slope failure is higher than 1.5 that is acceptable in the geotechnical practice.

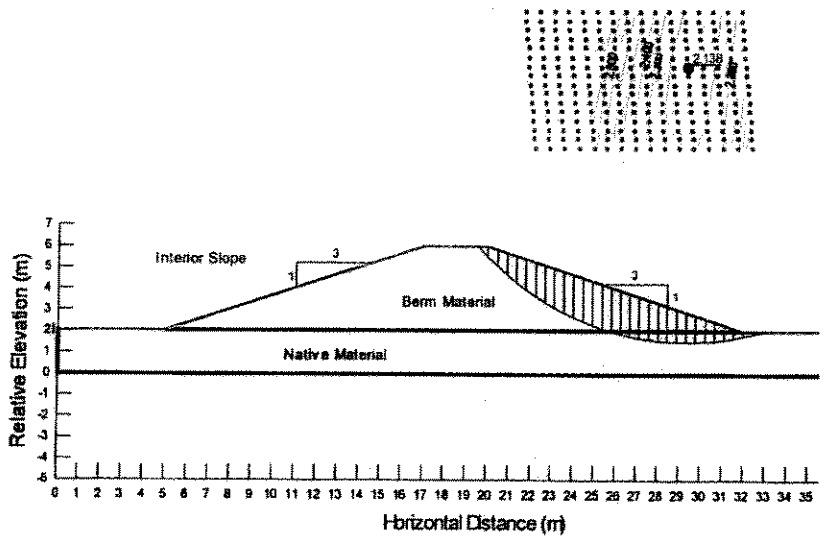

Figure 1 Factor of Safety for Lagoon Berm (Mean Value of Soil Parameters, No Pore Water Pressure)

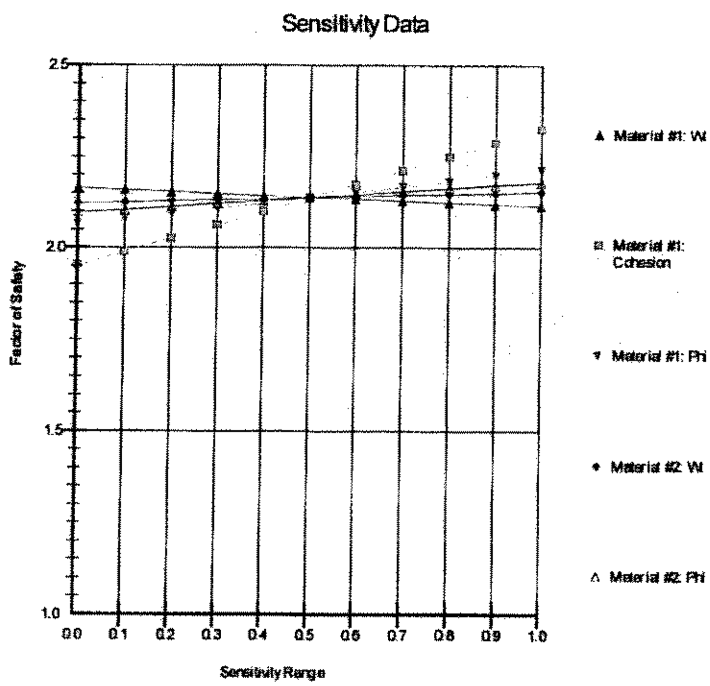

Figure 2 Sensitivity Plots for Slope Stability (No Pore Water Pressure)

Case 2

The active layer thickness on the berm slope was obtained based on results of the geothermal analysis. The maximum thickness of the active layer, as was predicted by geothermal analysis, can reach 2 m to 2.5 m at the end of summer.

The factor of safety was calculated using the limit equilibrium theory by comparing the total resistance force along the failure slip and the total driving force along the same failure slip. In addition to the resistance force along the slip, the side shear resistance of thaw material also was contributed to the total resistance, hence increasing stability of the slope.

The analyses were carried out for a 13 m long and 20 m wide berm slope. Similar to case 1, sensitivity analyses were carried out, using the same mean values and range of the soil parameters, outlined in Table 1. Results of the slope stability analyses for a thaw depth of 2 m and 2.5 m are presented in Figure 3. It can be seen at the figure that the safety factors against the slope failure within the active layer are well greater than the unity which suggests that the slopes will be in a stable condition.

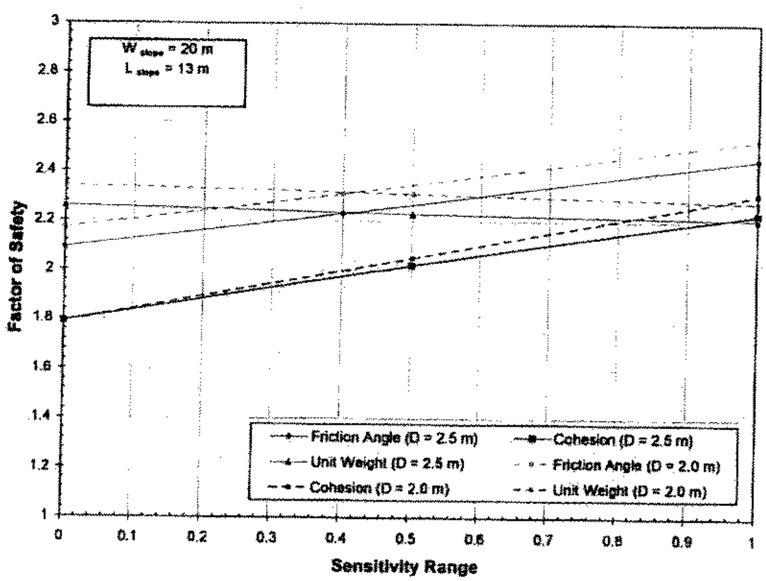

Figure 3 Sensitivity Plots for Stability of Active Zone

Figure 3 also indicates that the safety factor generally decreases by less than 5 percent with increasing of the active layer thickness from 2 m to 2.5 m. It was found also that the safety factor decreases by 3 percent to 5 percent with increasing of the slope width from 20 m to 50 m.

Case 3
Stability of the berm against sliding due to the hydrostatic pressure applied on the interior slope was assessed by assuming that the berm is a rigid retaining structure. The friction coefficient of 0.45 was used at the interface between the berm material and the native ground, as recommended in Canadian Foundation Engineering Manual (1992, 3rd). The lateral pressure on the interior slope was estimated based on fluid pressure with a unit weight of 10 kN/m^3. It was found that the factor of safety against sliding along the interface is greater than 4.

B. *What structure does this factor of safety of 1.5 correspond to?*

The results of the above analyses apply to the lagoon and landfill berm structures.

C. *In addition to the assumption of unsaturated berm conditions and angle of friction angle for the berm and native soils, what other assumptions are inherent in the stability analysis?*

See XII A (slope stability analysis) and XIII B (seepage analysis).

D. *The landfill and bulky materials disposal areas do not contain a geomembrane in the berm design. Unsaturated conditions have been assumed because of a liner covering the berm. What assumptions were used in the analysis of stability for these structures?*

The original design for the landfill and bulky material area berms does not propose using a liner since there will be no water in the containment. Unsaturated berm conditions were assumed for a stability consideration.

E. *The berms for each containment structure (i.e. landfill, lagoon, etc.) will have a unique loading condition applied to the inside slope of the berm and different berm geometry. What were the applied loadings applied to the berms for each containment structure assumed in the stability analysis?*

See XII A.

F. *The factor of safety was specified to be greater than 1.5. What was the actual value from the stability analysis for each structure?*

See XII A.

G. *How sensitive are the stability analysis to the assumed conditions of:*

- *Angle of internal friction*

- *Unsaturated conditions*

See XII A.

H. *Additional detail and description into the quality control and quality assurance (i.e., quality assurance program) of, but not limited to, soil type, material characteristics, moisture content, and density, used in constructing each structure is requested.*

A field geotechnical engineer or technologist should 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:

- <u>Thermal monitoring.</u> 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.

I. *A detailed monitoring plan, which includes, but not limited to, soil property testing methods (e.g. sieve, density, moisture content, etc.) and frequency of testing during construction is requested.*

See XII H.

J. *Detail and description into soil and material specifications acceptable for construction, as well as, specifications for as-placed conditions like moisture content, density, lift thickness, grain size distribution, and standard Proctor are also requested.*

See XII H.

K. *Will construction, quality assurance, and quality control monitoring be overseen by a qualified geotechnical engineer? If not, why not?*

See XII H.

XIII. *Within Appendix D – Geotechnical Investigation of the Detailed Design report, it was stated that if the geomembrane "extend(s) over the entire inner face of the berm from the crest to the toe and…laid horizontally within the sewage treatment lagoon for a sufficient horizontal width… piping and internal erosion will not occur in the foundation soil for the berm.*

A. *How has piping and internal erosion been accounted for in the design of the berm for the lagoon?*

See XIIIB response below.

B. *Has a seepage analysis been completed to assess piping potential of the soils? If so, what are the results? If not, why not?*

Seepage analyses for the proposed lagoon berm were carried out using the SEEP/W commercial finite element computer software. The purpose of the analyses was an assessment the exterior slope safety against the piping process shortly after completion of the berm construction, if no liner on the berm interior slope, a frozen core is not formed in the berm (one year after completion of berm construction) and the water level is raised instantaneously to the maximum design elevation. There is a concern that the water will infiltrate through the berm to exterior slope. The berm cross-section, used in the slope stability analysis, was also employed for the seepage analyses. The maximum water level at the berm interior slope was assumed to be 0.5 m below the berm crest. Two scenarios were analyzed:

- Berm supported by frozen native soil (impermeable layer).
- Berm supported by a 2 m active layer, overlying permafrost (impermeable layer).

The saturated hydraulic conductivity of the berm material (uniform sand) was assessed based on D. Swanson (1991) and the hydraulic conductivity functions for unsaturated conditions were estimated using the method, proposed by Green and Corey (1971). Figure 4 presents the total pressure head for Scenario 1 under steady flow conditions and Figure 5 shows the x-y hydraulic gradient within the proposed berm. It was found that the maximum hydraulic gradient near the toe of the exterior slope (i_{exit}) varies between 0.3 and 0.35.

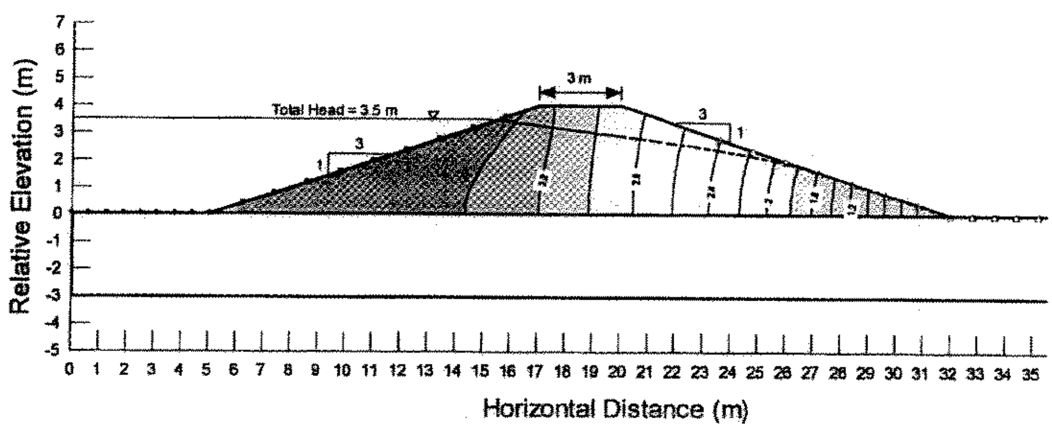

Figure 4 Total Pressure Head within Berm Fill due to Seepage (Scenario 1)

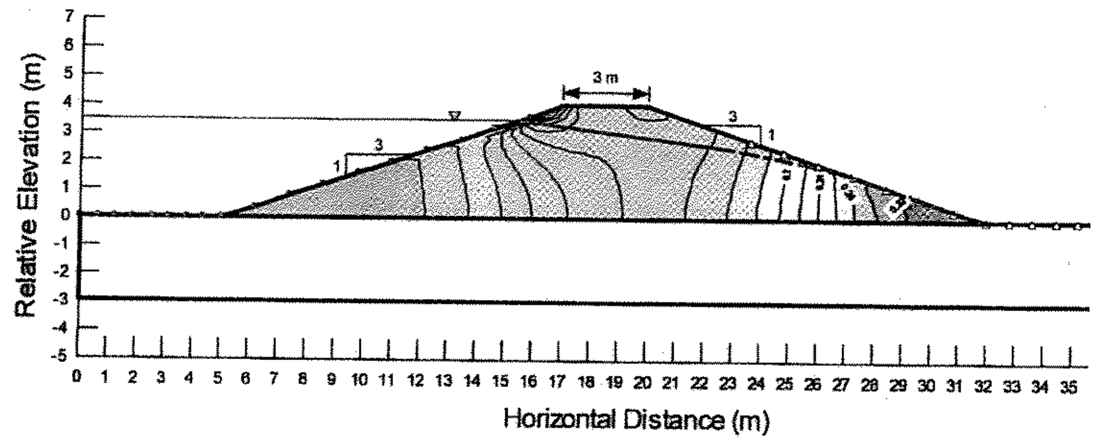

Figure 5 X-Y Gradient within Berm Fill due to Seepage (Scenario 1)

The safety factor against the piping can be defined as the ratio of i_{cr} to i_{exit} where i_{cr} is the critical hydraulic gradient of berm material. The i_{cr} may be evaluated using void ratio and specific gravity of soil and generally varies from about 0.85 to 1.1 (Das 1983). The safety factor against piping was calculated to be greater than 2 which is acceptable for a short term period prior to freezing of the berm material.

Figure 6 illustrates the estimated XY gradient for Scenario 2. It was found that a 2 m thick permeable layer has an insignificant impact to the XY gradient values.

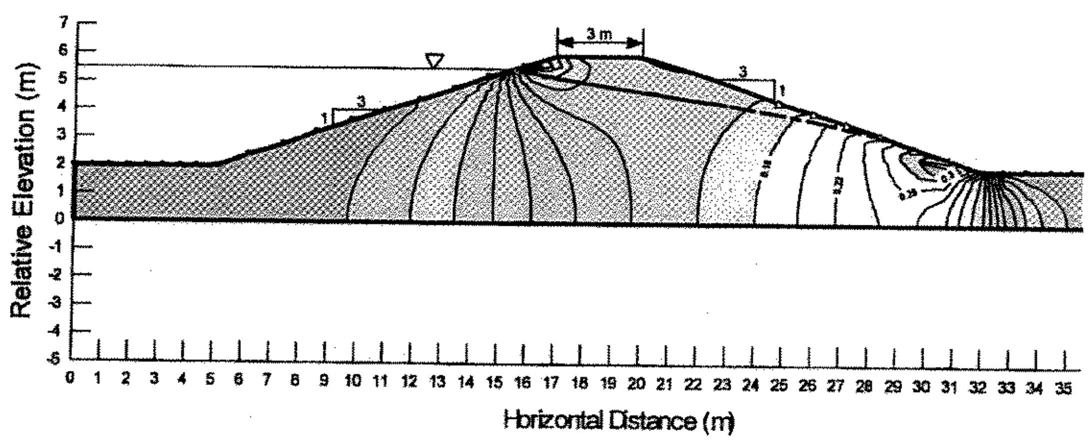

Figure 6 X-Y Gradient within Berm Fill due to Seepage (Scenario 2)

In order to assess a potential impact of soil hydraulic properties on the piping, the hydraulic conductivity function was changed by increasing the saturated hydraulic conductivity by 100 %. The estimated XY gradient is presented in Figure 7. Comparisons of Figure 7 and Figure 5 indicated that the stability against piping is not sensitive within a typical range of the soil hydraulic conductivity.

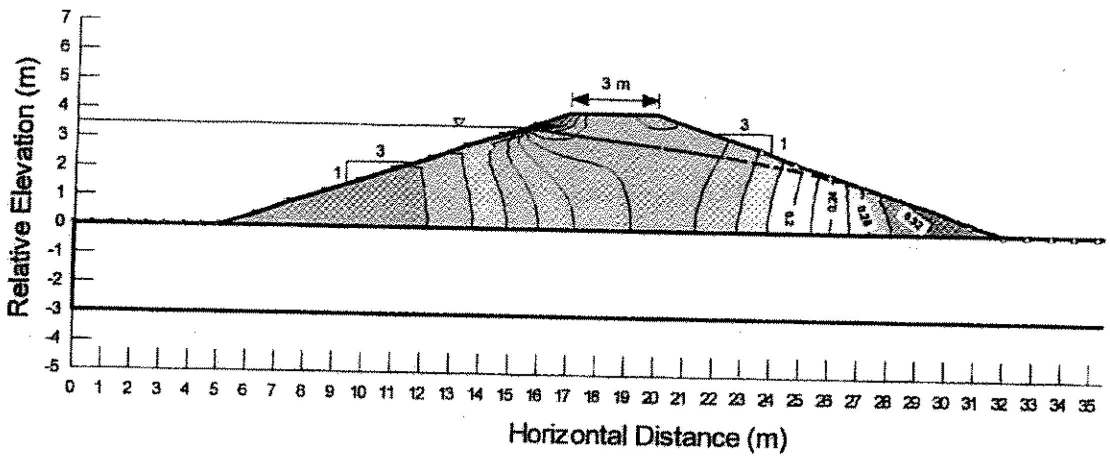

Figure 7 X-Y Gradient within Berm Fill due to Seepage (Case 1 & High Conductivity)

As mentioned earlier, the pore water pressure within soil particles will reduce the effective overburden stress of soil and decrease the shear strength of soil at the failure slip. The stability of the berm slope was re-assessed by incorporating the pore water pressure (see Figure 4) within the berm in the slope stability analysis. The results of the analyses, using the mean values of the soil parameters and the sensitivity plots for both scenarios are illustrated in Figure 8 through Figure 11. It was noted that Scenario 2 (2 m of the unfrozen sand below the berm) yields a lower factor of safety. The results also indicate that stability of the berm slope is more sensitive to the cohesion and unit weight of the soil than other parameters. If lower bounds of the soil parameters were assumed, the safety factor is 1.1 which is close to a marginal value. Based on this result, AMEC recommends installation of a liner over the interior slope of the lagoon berm.

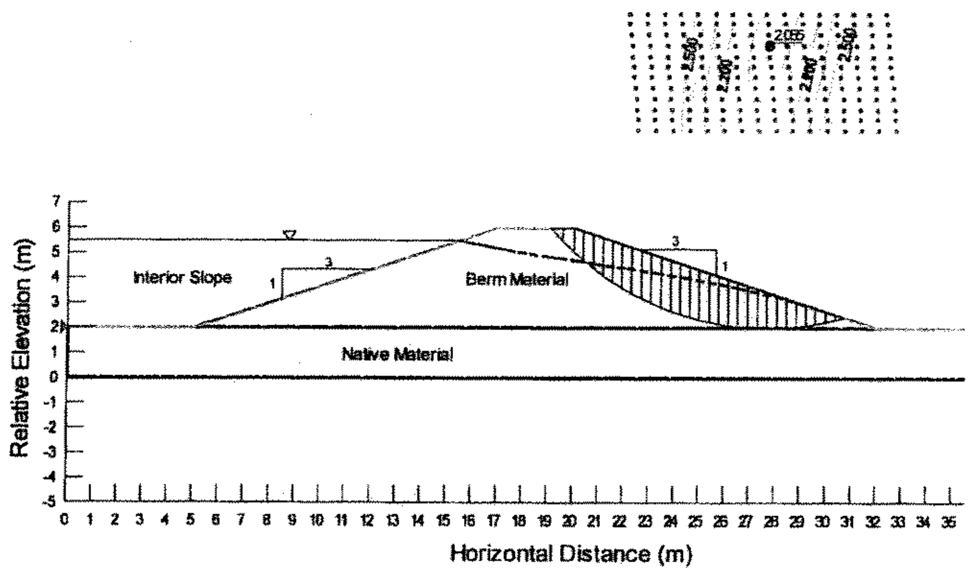

Figure 8 Factor of Safety for Lagoon Berm (Mean Value of Soil Parameters – Case 1)

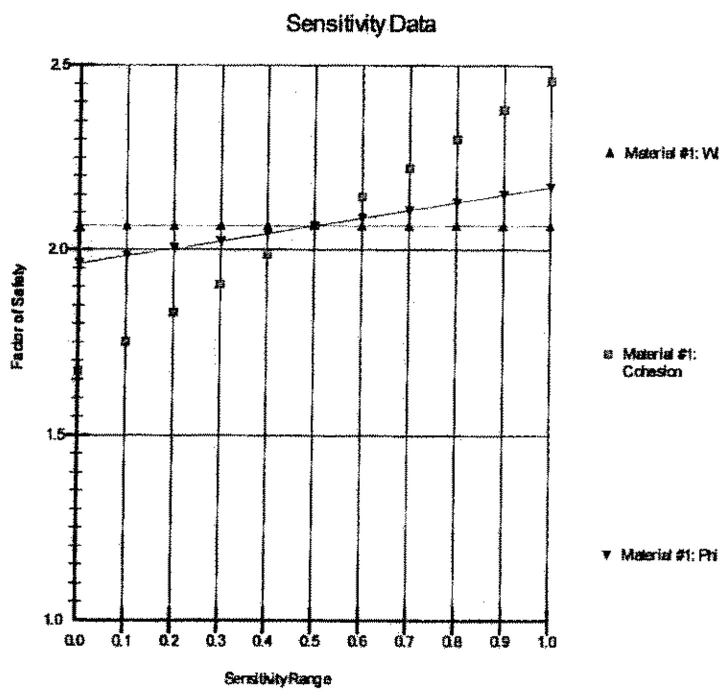

Figure 9 Sensitivity Plots for Case 1

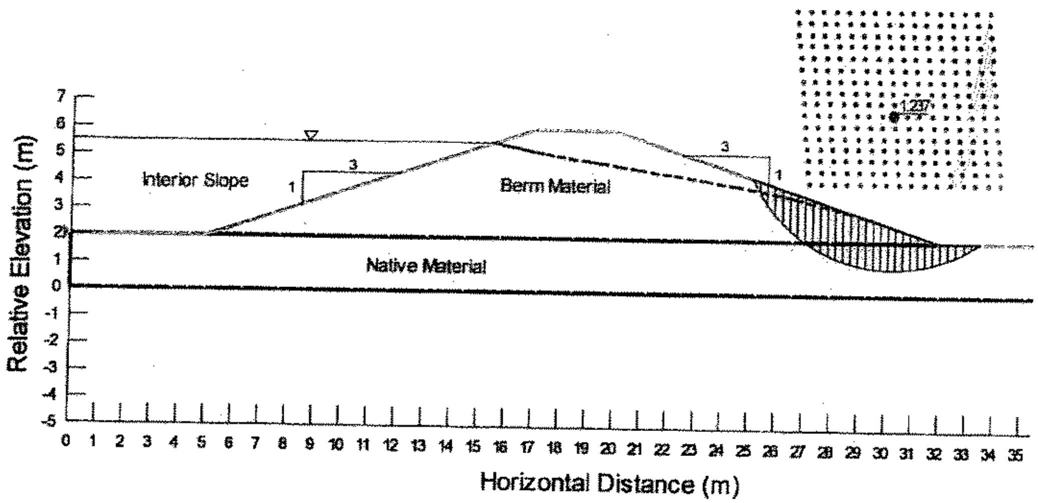

Figure 10 Factor of Safety for Lagoon Berm (Mean Value of Soil Parameters – Case 2)

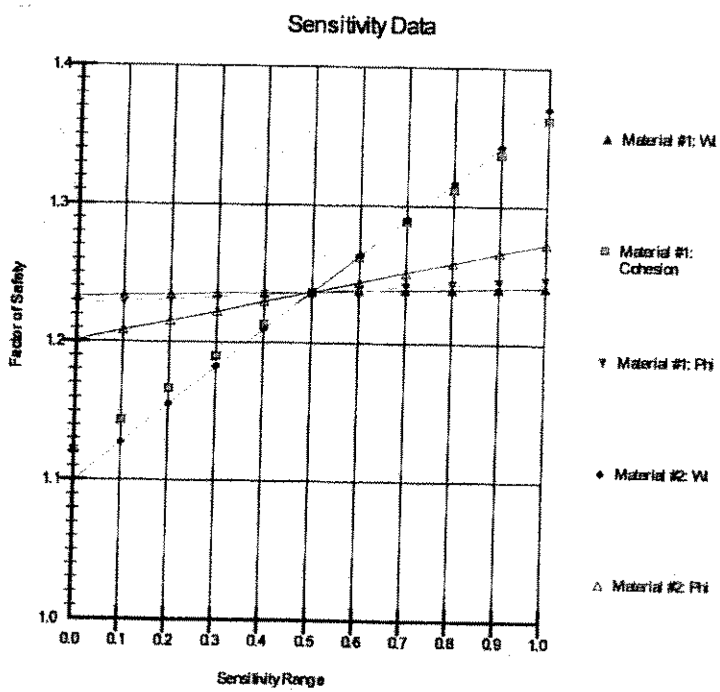

Figure 11 Sensitivity Plots for Case 2

The discharge schedule indicates that the water depth at the interior slope of the lagoon may not reach 3.5 m within the first few years of the lagoon operation. For comparison purpose, similar analyses were carried out assuming that the water level to be located 1.5 m below the berm crest. An estimated phreatic line within the berm and the safety factor for such scenario, applying mean values of the soil parameters are illustrated in Figure 12 and the results of sensitivity analyses are presented in Figure 13. It can be concluded that the berm will be stable if the water level in the lagoon will be maintained 1.5 m below the berm crest.

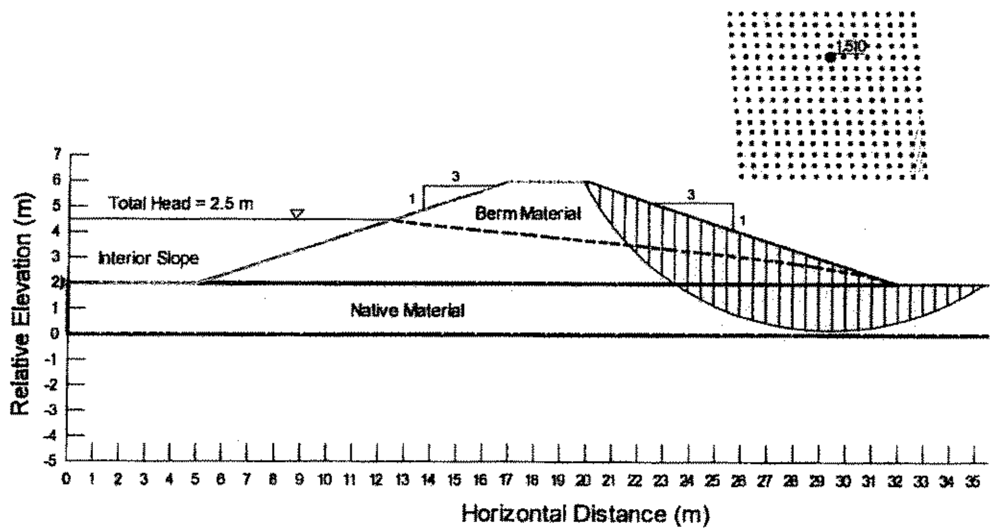

Figure 12 Factor of Safety for Lagoon Berm

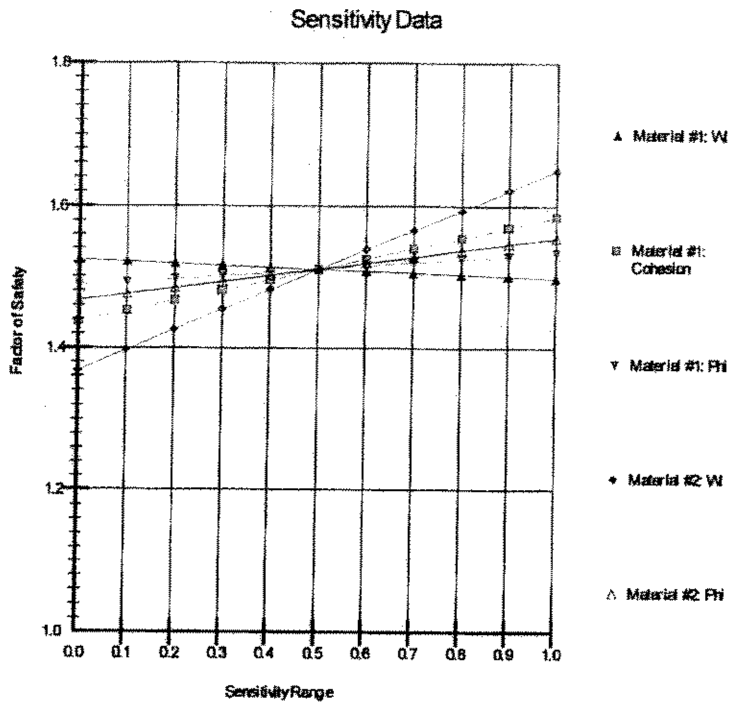

Figure 13 Sensitivity Plots for 2.5 m depth

C. *Figure 6- Proposed Sewage Lagoon Plan for the Detailed Design report provides a top view drawing of the lagoon. Cross-sections A-A' and B-B' which contain details of the berm configuration, are provided in Figure 7. The text and drawing in Figure #7 is too small to identify any details. A properly formatted drawing is requested.*

See Nuna Burnside response.

D. *What, if any site/foundation prep work is required before berm development occurs? Will the same practices be completed for the other containment structures?*

Prior to construction of the berms (including lagoon and landfill berm), the existing peat or organic mat, if any, should be removed from underneath of the proposed berm locations and the exposed native soil should be compacted with a minimum of 10 tons vibratory roller to the satisfaction of a field engineer. Any soft material, observed in the prepared subgarde, should be removed and replaced with engineered fill, compacted to 95 percent of SPMDD.

However, AMEC does not recommend removal of the organic material from the sewage impoundment area. Permafrost disturbance within the impoundment area would intensify thawing of frozen soils under lagoon.

E. *Figure #7 Section B-B' does provide a more clear depiction of the lagoon berm compared to section A-A'. The drawing provides no detail regarding geomembrane layout and positioning. The text in the Detailed Design Report provides minimal discussion on geomembrane configuration in the berm.*

1. *Why are the engineering drawings not reflective of that described in the Detailed Design Report?*

   See Nuna Burnside response.

2. *If a geomembrane is used in the berm design, the engineering drawings must reflect this and be corrected throughout the submission documents.*

   See Nuna Burnside response.

3. *Additional detail and discussion is requested into how geomembrane layout and extent will be of "sufficient horizontal width" so that "piping and internal erosion will not occur in the foundation soil for the berm".*

   Location of the geomembrane in the berm is discussed in XXIV.

4. *Will the geomembrane be keyed into the foundation? If so, what are the design details?*

   The geomembrane will be keyed into the foundation (see Figure 19 & 20). Also see Nuna Burnside response.

5. *Will the geomembrane be anchored within the berm? If so, what are the design details and engineering analysis?*

   Please see Figure 19 & 20. Also see Nuna Burnside response.

XIV *There are no details or discussion on the bearing capacity of the foundation soils under potentially thawing conditions or the expected amount of settlement for the berms. The geotechnical investigation did not establish the ground ice content in the foundation soils which could lead to differential settlements and foundation instability.*

A. *Does the Hamlet agree that bearing capacity and settlement are important geotechnical considerations in the design, stability, and containment of these structures? If not, why not?*

   AMEC agrees that the bearing capacity and settlement of frozen/thawed soils are important issues for the berm geotechnical design. Geothermal analyses show that during the operation period of time, the berm will be founded on frozen sand. In frozen conditions, such soils have compressive strength greater than 200 kPa. Minor thawing occurs only near the toe of the interior slope covered with water (see results of the geothermal analysis). The allowable bearing capacity of compacted unfrozen sand is generally higher than 125 kPa while the allowable bearing capacity of frozen sand, as was mentioned above, is not less than 200 KPa. Both values (125 kPa and 200 kPa) are greater than the vertical stress induced by the proposed berm. The creep settlement of the frozen sand under a minimal load will be negligible.

A review of geological information for the existing Coppermine sewage lagoon and solid waste disposal (Thurber Consultants Ltd. 1985) indicated that the geological profile at the site likely consists of sand, approximately 2 m thick, over clay till over bedrock. Boreholes, drilled within the community, revealed that the thickness of overburden would be in a range of 7 m to 15 m.

Moisture content of sand deposits ranged from 10 percent to 19 percent. Such amount of water in soil is not enough to fill up pores (porosity 0.3) with ice, resulting in a minimum settlement of thawing soil (sand). It is estimated, based on our experience that the settlement strain of the sand will be in an order of 0.01 and total settlement of the 2 m thick sand layer would be about 2 cm. The settlement strain in the clay till is slightly higher. It was assessed, based on published data, the moisture content of the clay till would be in a range from 20 percent to 25 percent, corresponding to the thaw settlement strain of about 0.02 to 0.04 (average 0.03). The geothermal analyses confirmed that the thaw depth under the interior slope of the berm in the clay till can reach about 4 m, corresponding to approximate thaw settlement 8 cm to 10 cm (usually thaw settlement is less than the thaw settlement strain, calculated or obtained in a laboratory). The settlement of the earth structure in a range 8 cm to 10 cm can be considered acceptable. However, a monitoring program should provide a regular topographic survey of the berm. If the thaw settlement is greater than 15 cm, than some remediation measures should be taken, such as backfilling of settled areas.

B. *Have any thermistors been installed to provide site specific temperature data for design purposes?*

The site-specific temperature data were not used for the design purposes. The initial temperature conditions are important to the berm integrity only during first years of the berm operation. 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 a snow cover over the berm. The geothermal analysis has shown that it takes more than 30 years when soil temperatures under the water and within the berm will be stabilized. At that time, the soil temperatures will differ considerably of the initial soil temperatures. However, we agree 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.

For assessment of the permafrost temperature (initial soil temperature) at the site prior construction, a 1D geothermal analysis was undertaken. The 1D geothermal model included all parameters which determine the soil temperature: soil thermal conductivity, heat capacity and latent heat, snow cover, snow density and air/water temperature. It was modeled 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). Moreover, AMEC experience in geothermal modeling shows that variations of soil thermal properties within a reasonable range of values, provide insignificant changes to 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 soil thermal properties and applied boundary conditions, used in the analysis, resulted in an adequate assessment of the berm temperature regime.

Question XV to XXII - Environmental issues

XXIII See Nuna Burnside response to this question.

XXIV *The landfill does not contain a geomembrane liner.*

A *Does the Hamlet agree that the landfill, which does not contain a liner, could have seepage through and under the berm?*

Please see XXIV (C).

B *If permafrost aggregation is relied upon in the design of the landfill berm to limit seepage, does the Hamlet have an understanding of the thermal regime with time and what are these details?*

Please see XXIV (C).

C *If the berms are not lined nor have permafrost aggregation, how will seepage be prevented through the active zone?*

The geothermal modeling program SIMPTEMP, 2D version (developed in-house by AMEC) was used to analyze a berm geothermal regime. The geothermal program uses the finite element method to compute a numerical solution of the heat transfer problem. Physical/mathematical algorithms used in the SIMTEMP model have been published, and the simulation process has been verified both against well-known analytical solutions of the heat transfer problem, and as compared with numerical solutions produced by other commercial/non-commercial geothermal software. AMEC has successfully used the SIMPTEMP program for a variety of geothermal applications over the ten years period.

The analysis considered the following geometry for lagoon:

- Height of berm is 4 m.
- Width of crest is 3 m.
- Depth of water is 3.5 m.
- Interior and exterior slopes of berm are 3H:1V.
- Local soil (sand, trace silt) is proposed for the dyke core construction.

Table 2 below provides surface temperatures that were applied at the berm, downstream terrain beyond the berm, ice surface and also reservoir water temperatures in summertime.

Table 2 Surface Temperatures and water temperatures Applied in Geothermal Model

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Berm	-25.0	-24.7	-22.8	-15.3	-4.8	6.8	13.9	11.4	3.6	-6.5	-17.6	-23.0
Downstream Terrain	-19.5	-19.2	-17.7	-11.9	-3.7	6.8	13.9	11.4	3.6	-6.5	-17.6	-23.0
Ice Surface	-19.5	-19.2	-17.7	-11.9	-3.7	—	—	—	—	-6.5	-17.6	-23.0
Water	—	—	—	—	—	5.2	10.7	8.8	2.8	—	—	—

The provided temperatures were derived by an application of various n-factors to the mean monthly air temperatures at Kugluktuk weather station for period from 1971 to 2000.

The initial temperature of the berm material and the active layer was taken to be 4 °C, while the frozen soil below the active layer was assigned at -4 °C. The soil profile consisted of 2 m thick sand layer (moisture content 10 percent) and a 13 m thick clay till layer (moisture content 20 percent to 25 percent) overlying bedrock (moisture content 2%). It was assumed in the analysis that the berm material properties are the same as properties of the native sand layer. The water level in the lagoon was instantaneously raised at the maximum elevation (0.5 m below the berm crest), beginning from October 1. The model ran for 30 years.

Figure 12 shows that after the first year of berm operation, the active layer at the berm crest is about 3 m. The majority of the berm core has a temperature in a range from 0.5°C to 3°C while the ground temperature near the berm core and under the dyke is about -0.5°C. Due to the warming effect of the lagoon water, the ground temperature beyond the interior slope of the berm (impoundment area) is about one degree warmer than the ground temperature beyond the exterior slope of the berm.

Figures 13 through 16 show that no significant temperature changes were observed within and underneath the berm from the fifth to thirtieth year of the berm operation. However, it can be seen that the thickness of the unfrozen zone under the lagoon impoundment increases up to 10 m. The thickness of the active layer in the berm was estimated to be 2 m to 2.5 m.

The numerical simulation showed that a frozen core within the lagoon berm will be formed only near the berm base. Thus, a potential for the percolation of water/effluent through the berm will depend on elevation of the water level in the lagoon. If the water level will be at the elevation, shown in Figures 14 through 18, then the percolation of the water would occur. AMEC recommends that a geomembrane be installed in the lagoon berm for seepage protection. A typical section for layout of the liner is provided in Figure 19. The cut–off trench, at least 2.5 m deep, should be excavated at a position of the interior slope crest. The liner should be placed vertically in the cut-off trench and then backfilled with compacted clayey material or grouted. The liner curtain should then follow the ground surface to the toe of the interior slope and then cover the interior slope to elevation higher than the expected maximum water level, as shown in Figure 19. The liner should be covered with a 0.5 m thick riprap layer. An alternative liner option is shown in Figure 20. It is understood that the constructability of the alternative option is more complex however the liner is nearly half as wide. The alternative option suggests covering the interior berm slope with a 0.5 m thick riprap layer to protect the slope against thermal and wave erosion.

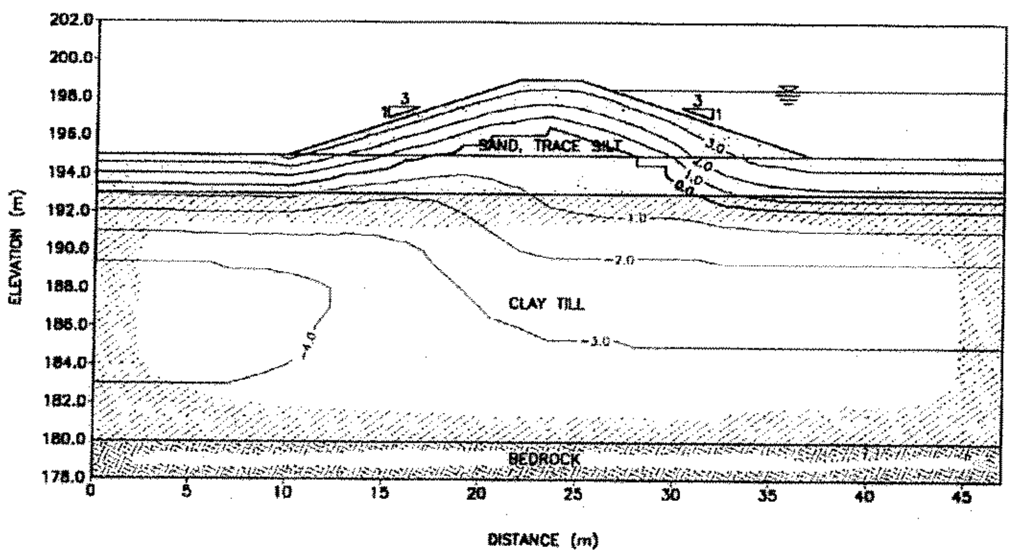

Figure 14 Temperatures in Lagoon Berm after 1 Year of Operation

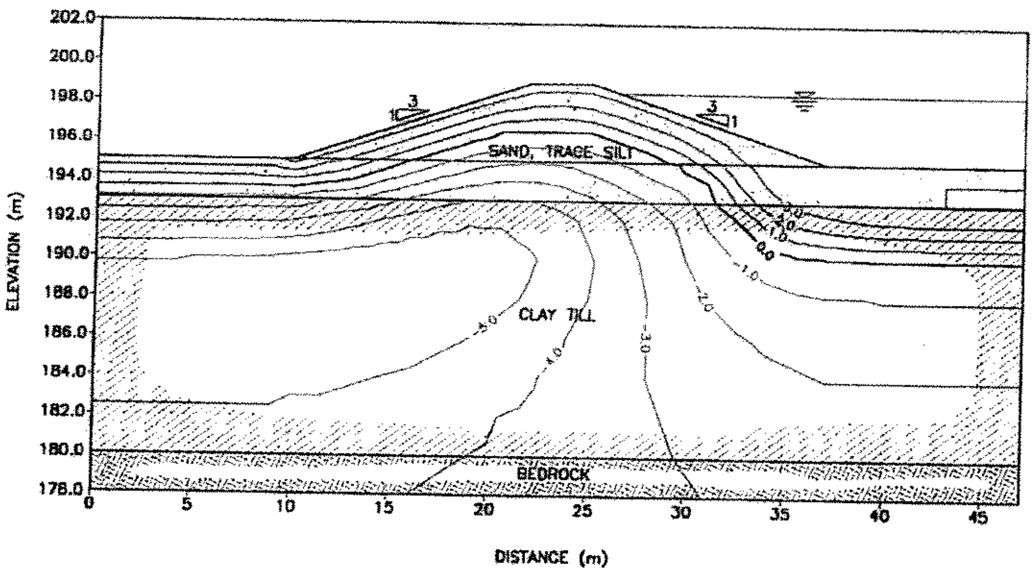

Figure 15 **Temperatures in Lagoon Berm after 5 Years of Operation**

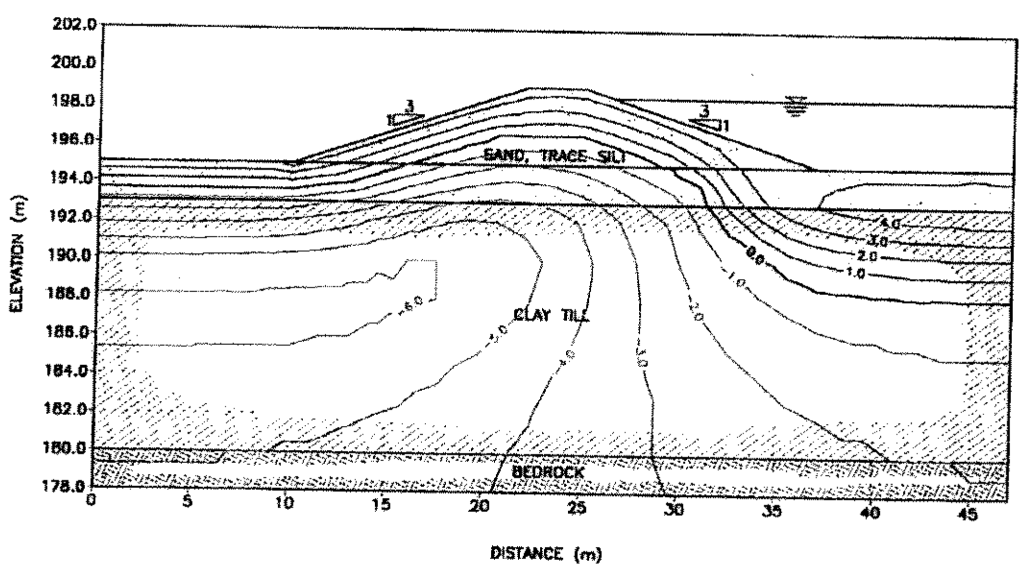

Figure 16 **Temperatures in Lagoon Berm after 10 Years of Operation**

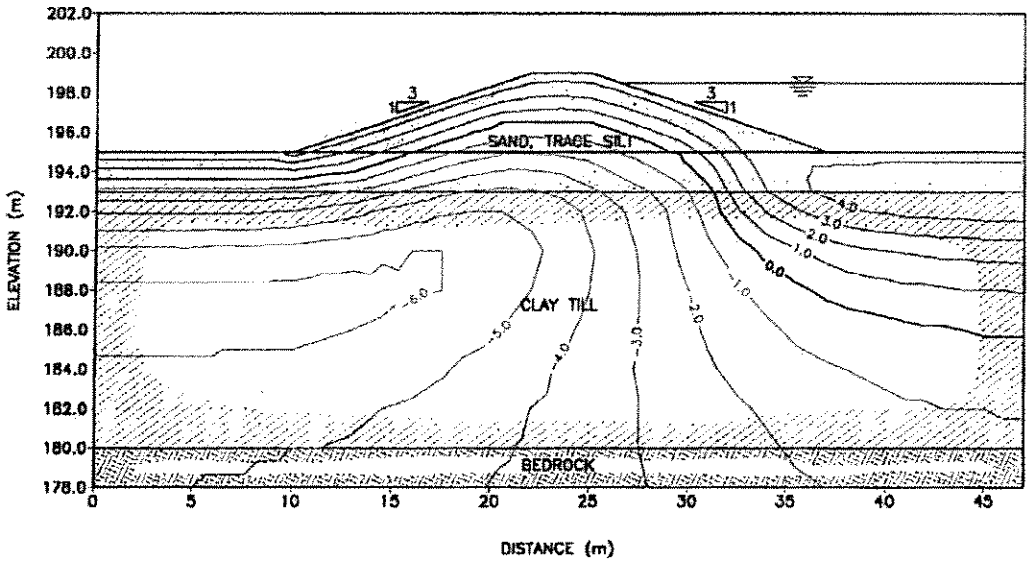

Figure 17 Temperatures in Lagoon Berm after 20 Years of Operation

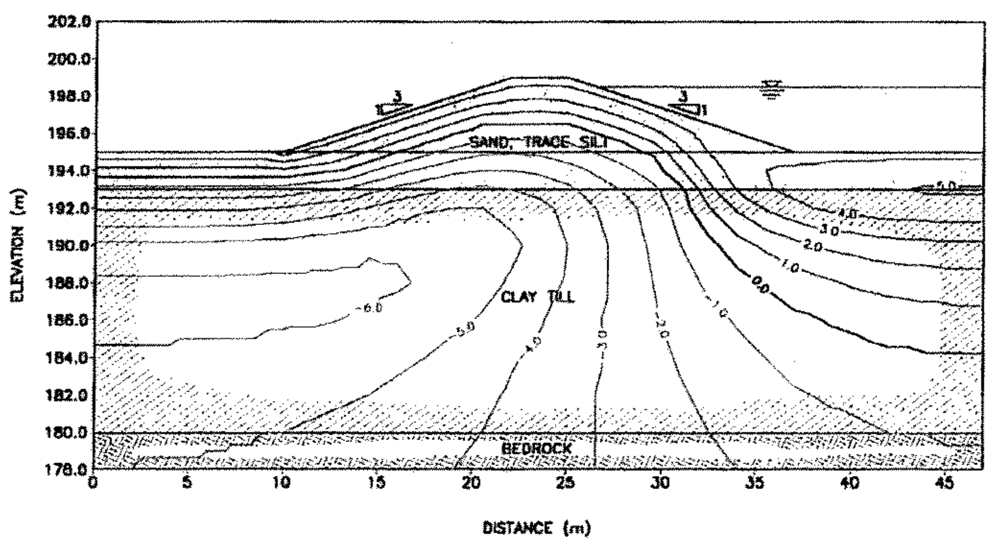

Figure 18 Temperatures in Lagoon Berm after 30 Years of Operation

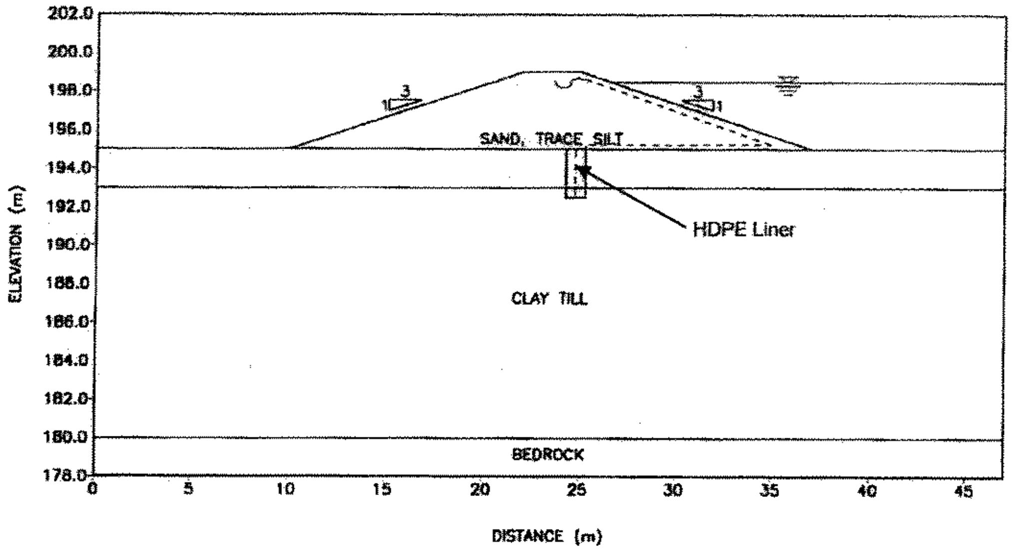

Figure 19 Proposed Layout of HDPE Liner (Option 1)

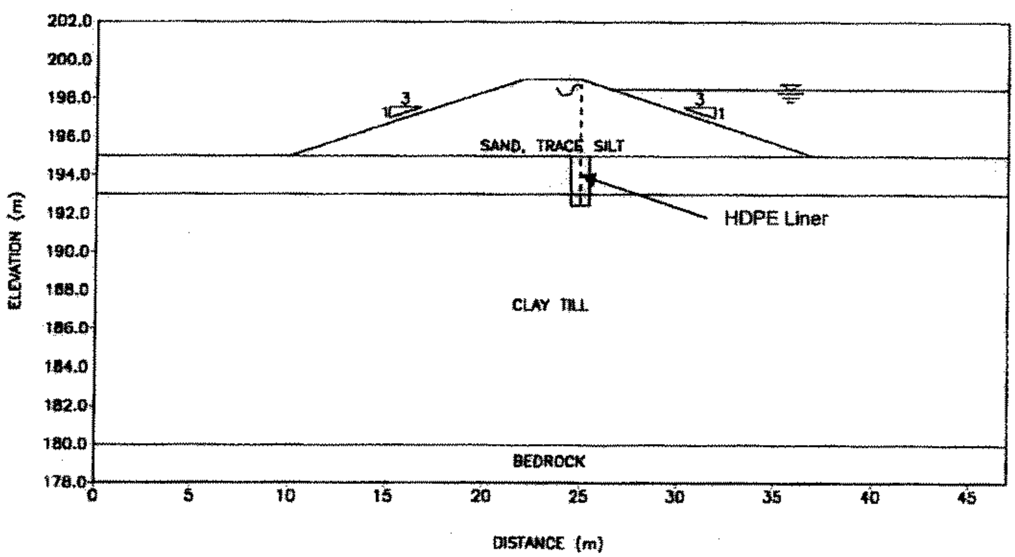

Figure 20 Proposed Layout of HDPE Liner (Option 2)

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. 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. 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.

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.

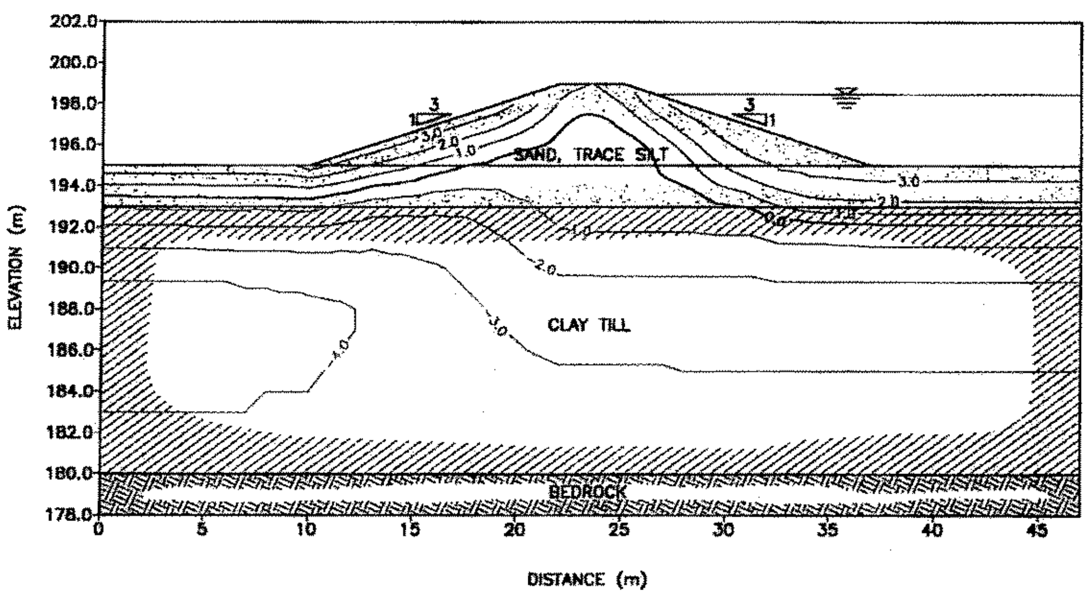

Figure 21 Temperatures in Lagoon Berm with Insulation after 1 Year of Operation

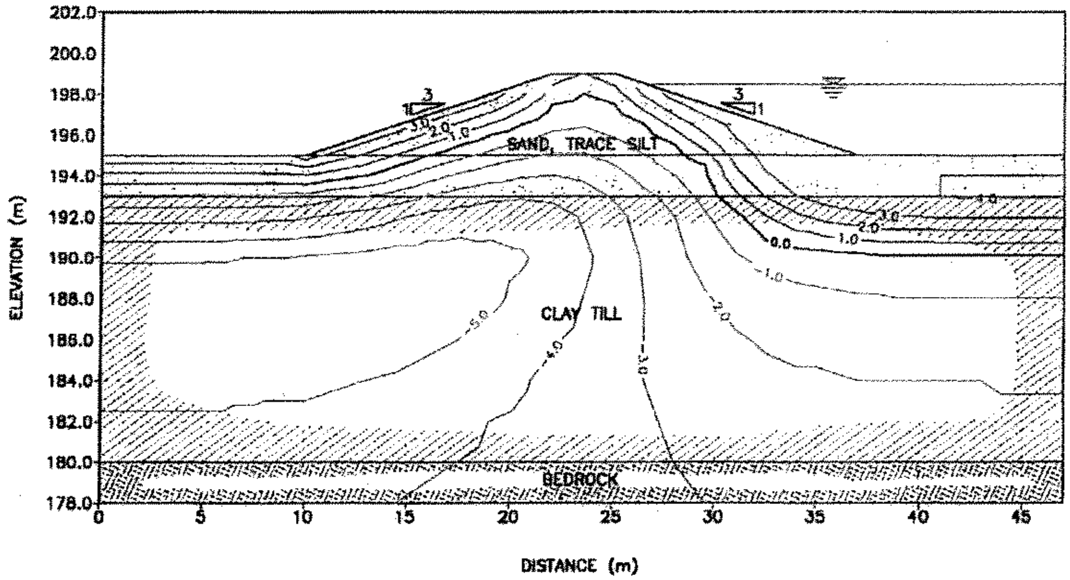

Figure 22 Temperatures in Lagoon Berm with Insulation after 5 Years of Operation

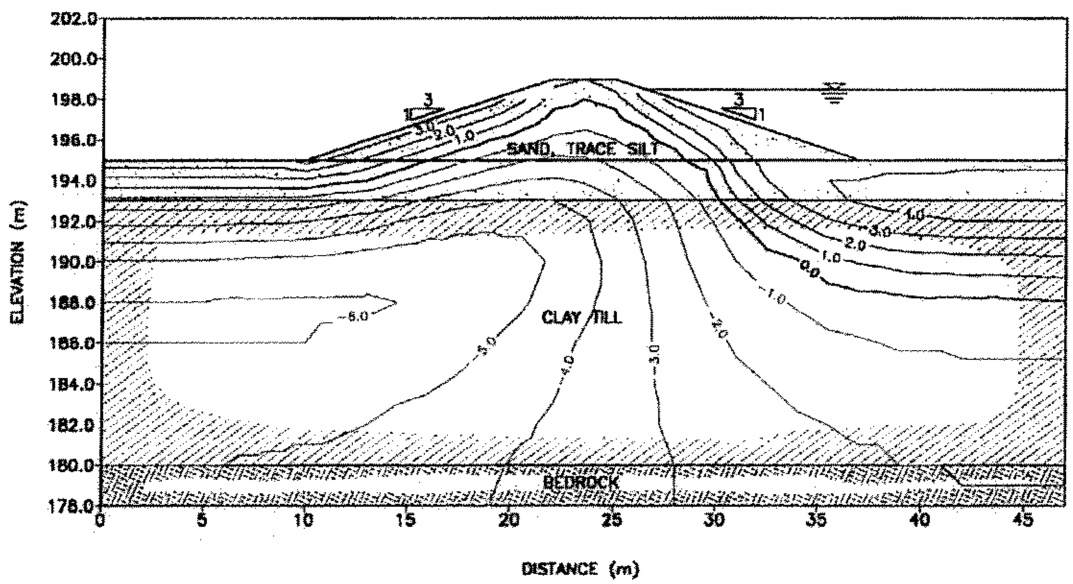

Figure 23 Temperatures in Lagoon Berm with Insulation after 10 Years of Operation

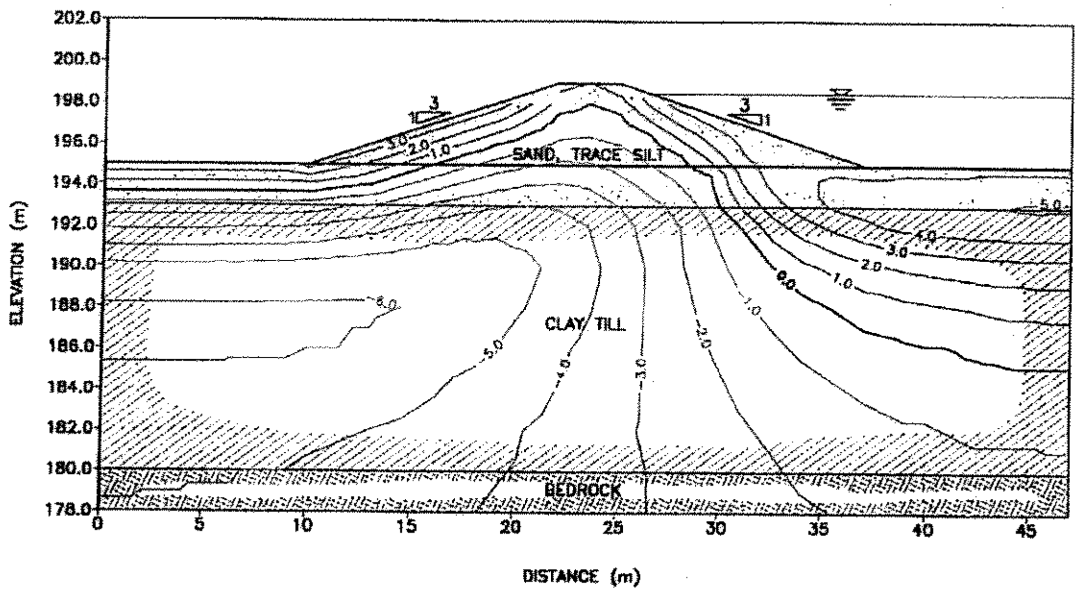

Figure 24 **Temperatures in Lagoon Berm with Insulation after 20 Years of Operation**

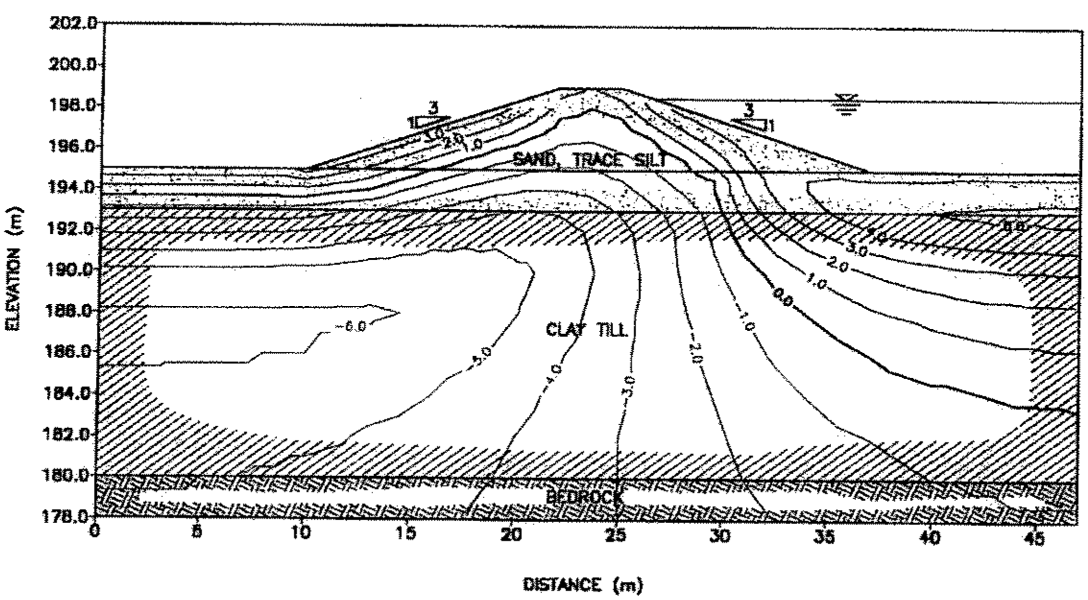

Figure 25 **Temperatures in Lagoon Berm with Insulation after 30 Years of Operation**

XXV *Is permafrost aggregation relied upon for long term containment of waste from the landfill? If so, what design details will promote this containment practice?*

See Nuna Burnside response.

XXVI *The lagoon, hazardous waste depot, and landfarm specify a geomembrane to be included in the design.*

A. *What provisions have been made in the design to protect the liner integrity from construction operation, and environmental damage?*

Please refer to HDPE Liner, Construction Specification, Kugluktuk .

B. *There was no description or detail regarding construction specification, installation, construction and long-term monitoring, quality control, or quality assurance for the installation of the liner. Additional detail and discussion is requested to address each of these issues to ensure that the liner will not be damaged during construction and will perform as designed for the service life of the facility.*

See Nuna Burnside response.

XXVII *The Hamlet is requested to provide additional detail and description to address each of the points provided below.*

A. *Which, if any, of these containment structures use a liner on the base of the facility?*

Please see Nuna Burnside response.

B. *If a liner is not included on the base of a facility, is permafrost aggregation relied upon for containment? If so, additional detail and description is requested to justify this practice and demonstrate containment.*

See Nuna Burnside response.

XXVIII *Section 4.4 Erosion of the Detailed Design Report, provides a brief on contingency measures for erosion prone areas. As part of the repair, blast rock is to cover the repaired area. What are the characteristics of the blast rock that will limit future erosion, and what thickness of blast rock will be required?*

See Nuna Burnside response.

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