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.

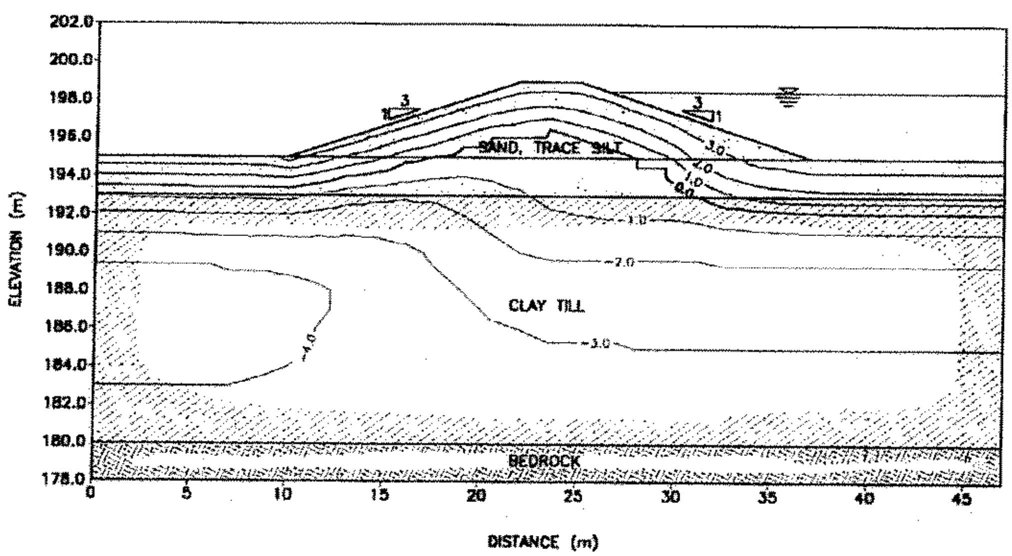

Figure 14 Temperatures in Lagoon Berm after 1 Year of Operation

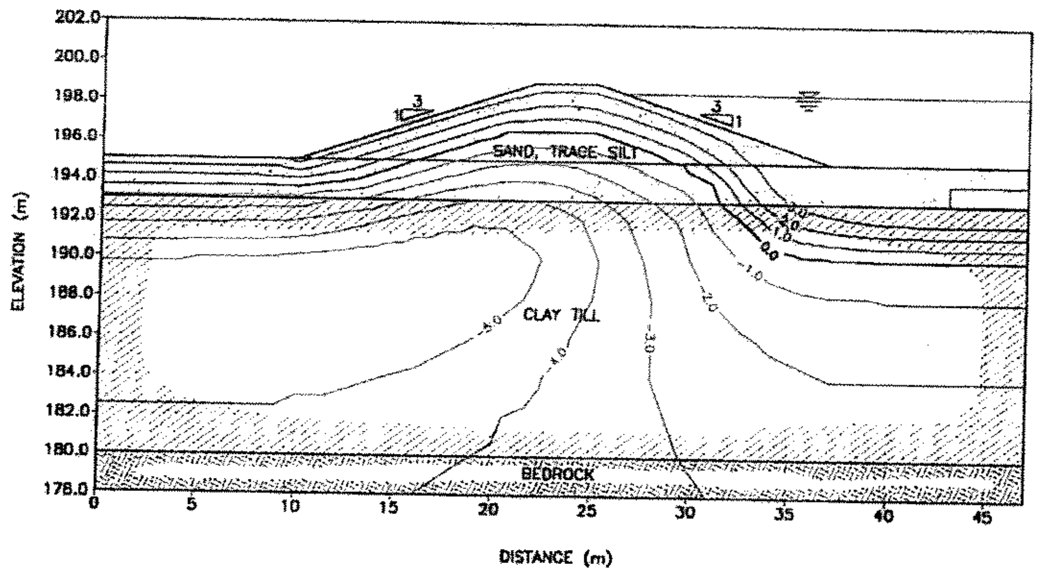

Figure 15 Temperatures in Lagoon Berm after 5 Years of Operation

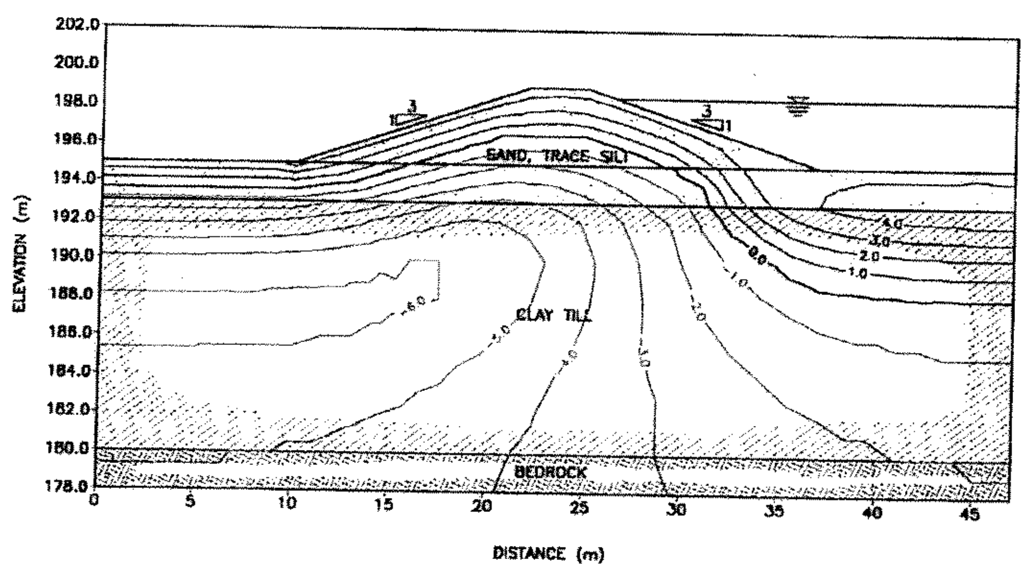

Figure 16 Temperatures in Lagoon Berm after 10 Years of Operation

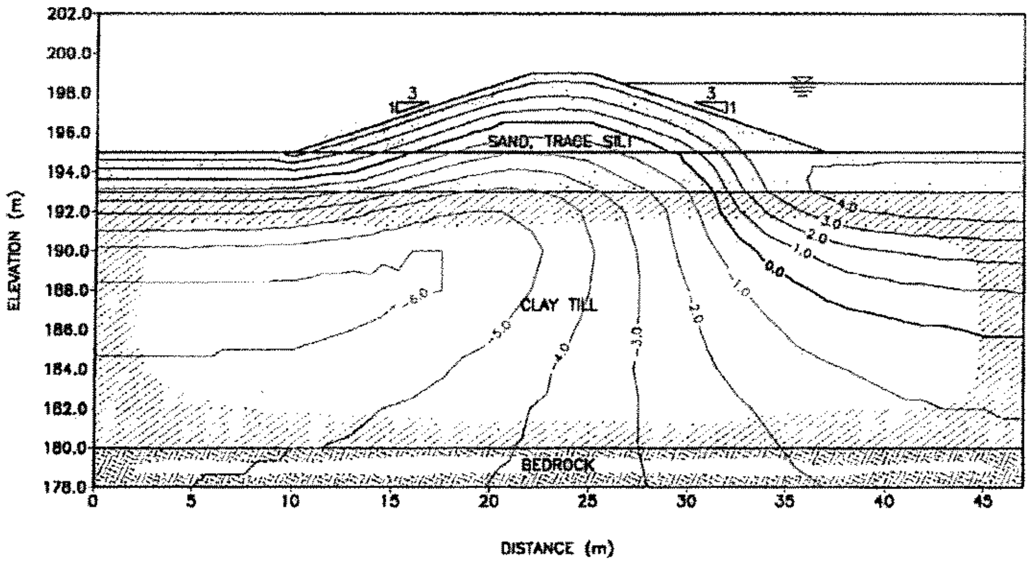

Figure 17 Temperatures in Lagoon Berm after 20 Years of Operation

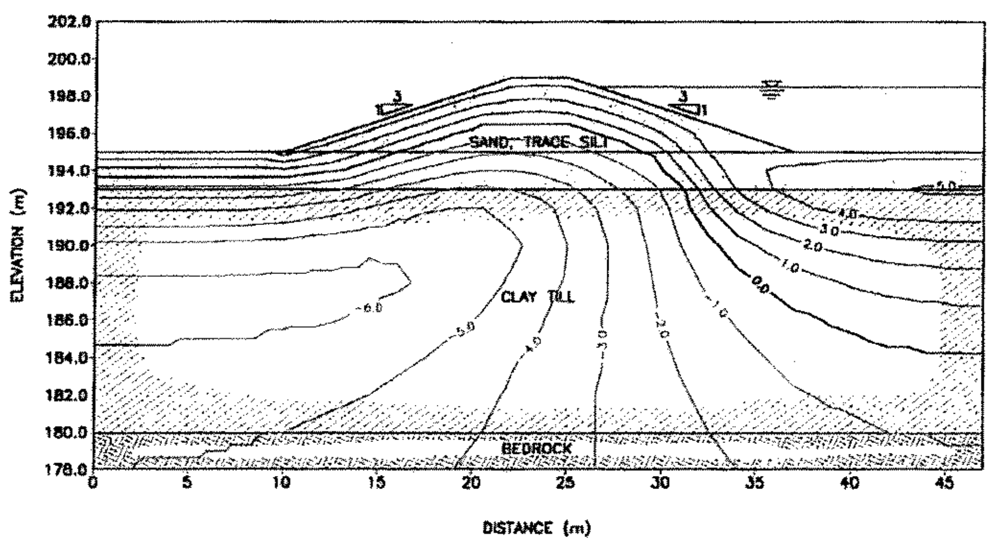

Figure 18 Temperatures in Lagoon Berm after 30 Years of Operation

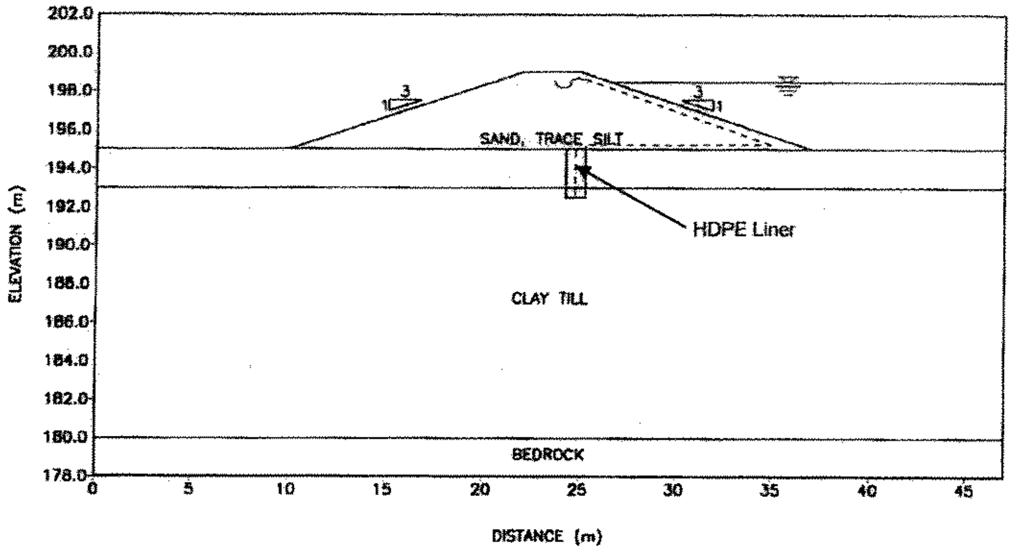

Figure 19 Proposed Layout of HDPE Liner (Option 1)

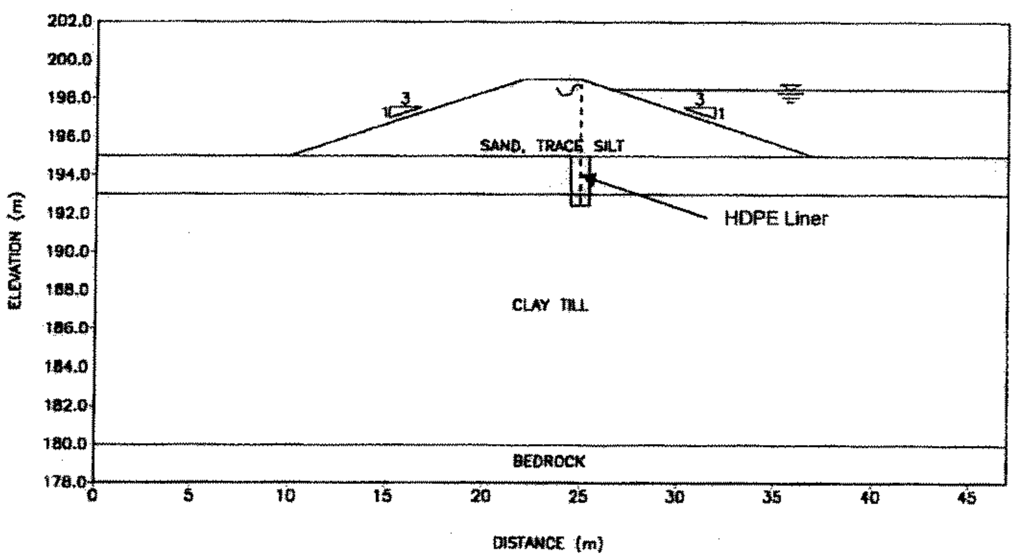

Figure 20 Proposed Layout of HDPE Liner (Option 2)

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.

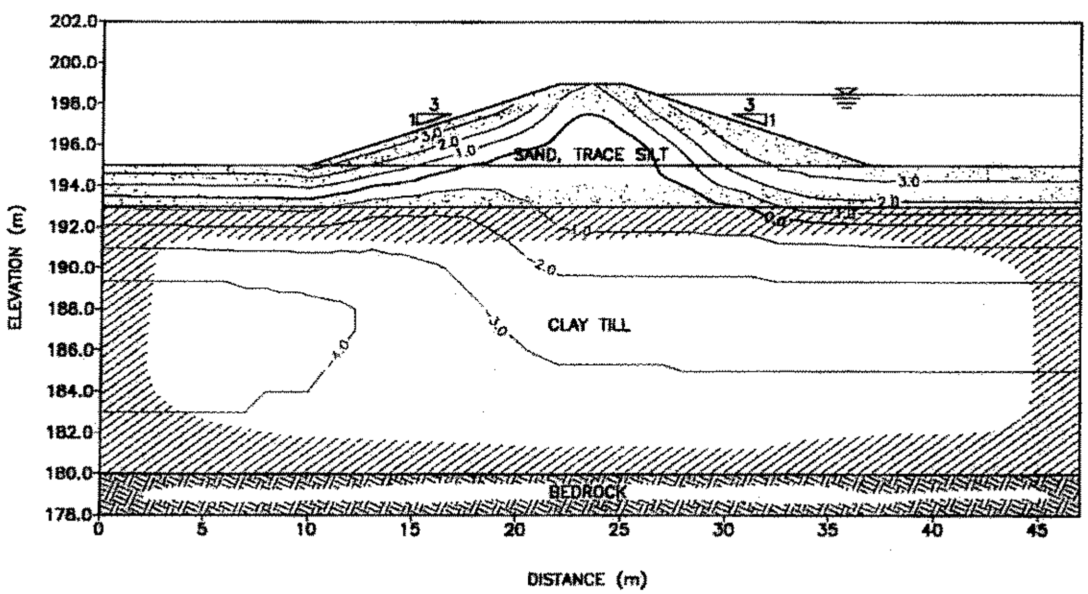

Figure 21 Temperatures in Lagoon Berm with Insulation after 1 Year of Operation

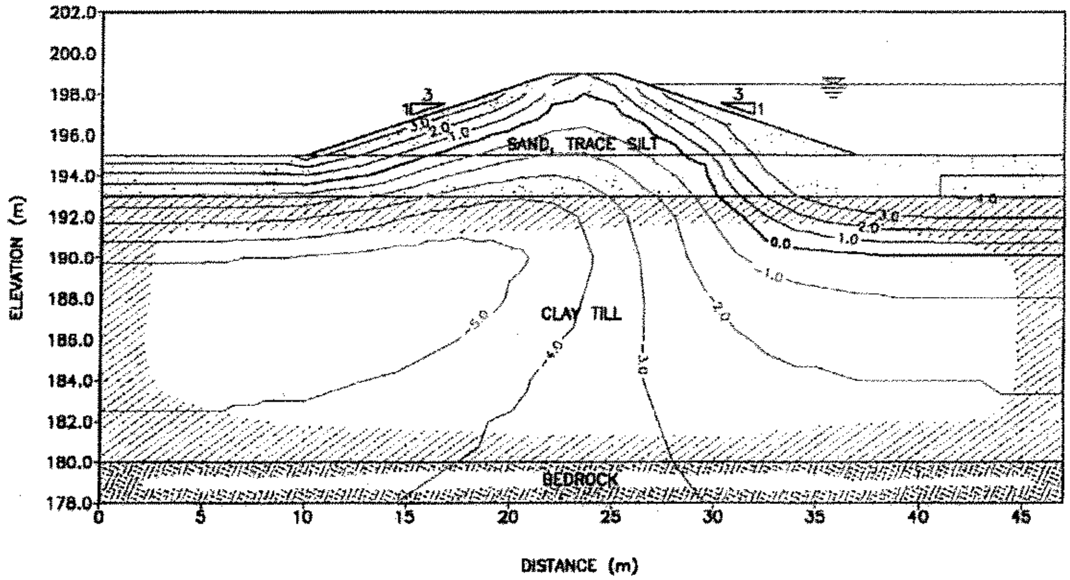

Figure 22 Temperatures in Lagoon Berm with Insulation after 5 Years of Operation

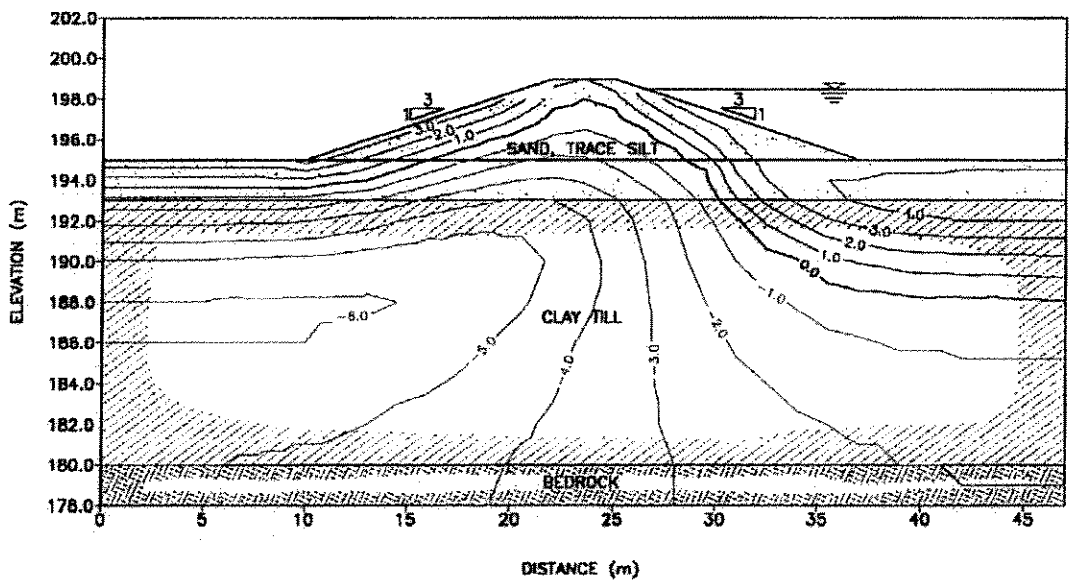

Figure 23 Temperatures in Lagoon Berm with Insulation after 10 Years of Operation

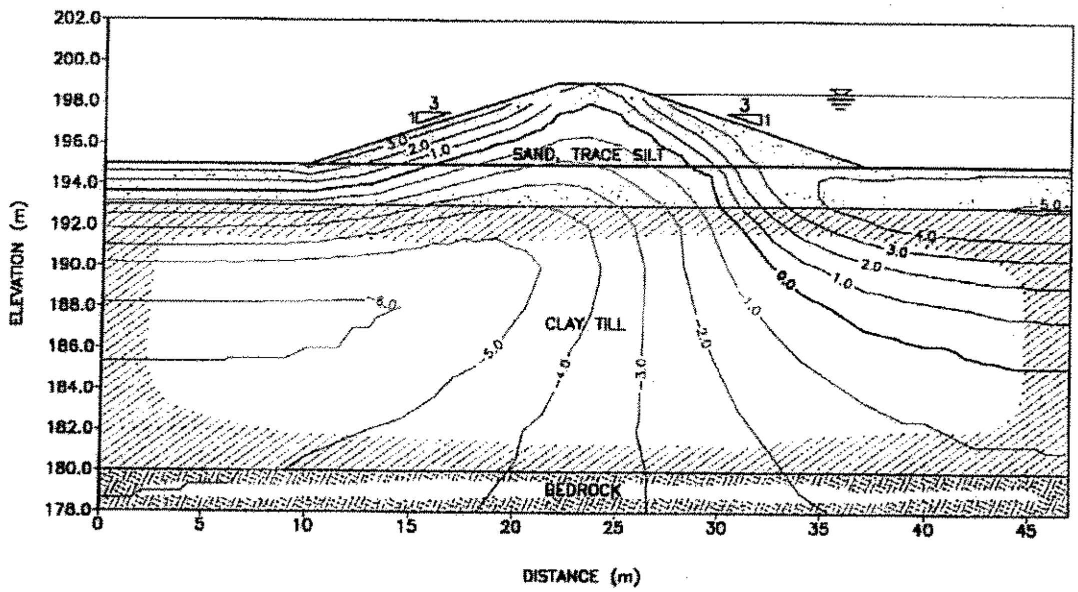

Figure 24 Temperatures in Lagoon Berm with Insulation after 20 Years of Operation

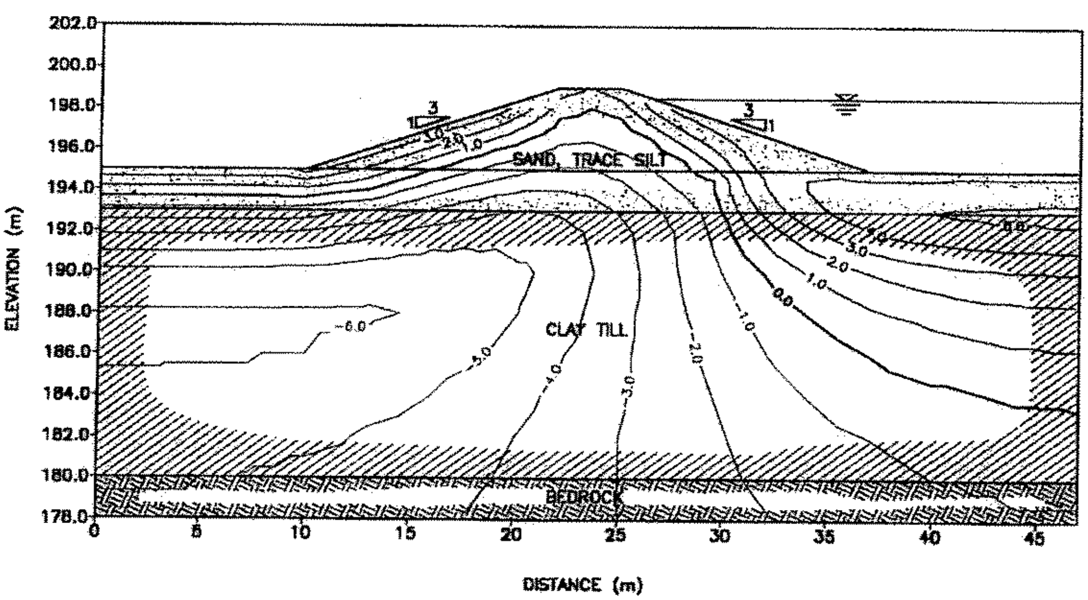

Figure 25 Temperatures in Lagoon Berm with Insulation after 30 Years of Operation

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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