NCI

GEOTHERMAL ANALYSIS OF PROPOSED SEWAGE LAGOON IGLOOLIK, NU

Prepared for:

Trow Associates Inc.
Ottawa, ON

Prepared by:

Naviq Consulting Inc.
Calgary AB

Naviq Project No. J011G
June 2010
Revision 0

Important Notice

This Report represents the professional engineering work of Naviq Consulting Inc. (Naviq) performed to normal engineering principles and practices and to a reasonable standard of care for the engineering work and the terms of reference provided by Naviq's contractual customer, Trow Associates Inc. (the "Customer"). The standard of care for the professional engineering and related services performed or furnished by Naviq to the Customer is the care and skill ordinarily used by members of Naviq's profession practicing under similar conditions at the same time and in the same locality.

This Report may not be relied on for detailed design, construction, or any other purpose not specifically identified in this Report. This Report is confidential and prepared solely for the use of the Customer. The contents of this Report may not be used or relied on by any party other than the Customer and their authorized agents and clients. Neither Naviq, its sub consultants nor their respective employees assume any liability for any reason, including, but not limited to, negligence, errors, or omissions to any third party for any information or representation herein. The extent of any warranty or guarantee of this Report or the information contained therein in favour of the Customer is limited to the warranty or guarantee, if any, contained in the Terms and Conditions, provided in Appendix A of this Report.

Important Terms and Conditions that apply to this Report are contained in Appendix A. These Terms and Conditions limit the liability of Naviq Consulting Inc.

GEOTHERMAL ANALYSIS OF PROPOSED SEWAGE LAGOON: IGLOOLIK, NU

REV	DESCRIPTION	ORIGINATOR	REVIEWER	NAVIQ APPROVAL	DATE (DD-MON-YYYY)	CLIENT APPROVAL	DATE (DD-MON-YYYY)
0	Issued for use	JMO		JMO	9 June 2010	N/A	N/A
		Jim Oswell	Ron Coutts	Jim Oswell			

EXECUTIVE SUMMARY

This report provides details of geothermal analyses conducted in support of the design of a sewage lagoon structure near Igloolik, NU. The analyses considered a variety of conditions including climate warming, pore water salinity effects, initial soil temperatures in the containment structures and others.

Soil conditions were taken from a geotechnical report prepared for the project by Trow Associates Inc. Climatic data were taken from Environment Canada climate normals.

The geothermal modeling indicates seasonal thawing of the lagoon structure (berm) to a depth of about 3 m below the crest on a season basis after 20 years, with climate warming applied at 0.16 °C/year.

For the site specific conditions assumed, it is recommended that a controlling design isotherm of -2 °C be used. This value includes an amount to account for freezing point depression of high saline soils, and for uncertainties in some input parameters.

The reliance on a frozen core dam concept as the primary containment method is not considered to be prudent based on the analyses conducted. Therefore, a liner or other barrier should be incorporated into the design. Details on the installation of the liner are discussed. Installation of the liner in cut-off trench to unweathered bedrock or permafrost is recommended.

No secondary cooling of the containment berm structure is presently recommended. However, monitoring of ground temperatures and seepage through the containment structure should be undertaken during operations. Secondary cooling, by way of thermosyphons, may be required if operational monitoring indicate warmer than anticipated temperatures or seepage within the berm structure.

It is recommended that drainage piping or access manholes in or through the containment structure be avoided because of a number of geothermal and geotechnical issues related to performance of the earthen berm structure.

REVISION LOG

The following table lists the changes made in this version of the report compared to previous revisions.

Section/Figure	Description of Revision
	This table is blank in the current version (Revision 0).

TABLE OF CONTENTS

TABLE OF FIGURES

.

1.0 INTRODUCTION

Naviq Consulting Inc. (Naviq) was retained by Trow Associates Inc. (Trow) of Ottawa, ON to provide permafrost engineering and geothermal analysis with respect to the design of a municipal waste-water (sewage) lagoon in Igloolik, NU.

The scope of work included conducting a geothermal assessment of the proposed lagoon containment dykes to assess the geothermal behavior of the structure over its projected lifespan.

This report addresses the geothermal modeling of the proposed containment structure.

2.0 GEOTECHNICAL INVESTIGATIONS AND RELATED INFORMATION

Trow undertook a geotechnical investigation at the site of the proposed lagoon adjacent land fill from September 29 and October 5, 2009 and on November 3 and 4, 2009. Eleven boreholes were drilling within the proposed footprint of the proposed lagoon containment berms, and also through segments of the existing lagoon berms. This section provides a summary of the geotechnical character of the subsurface conditions. For a full description of the site conditions, and other important details of the investigation and testing, the reader is referred to the geotechnical investigation report (Trow, 2010).

2.1 Subsurface Conditions

The boreholes at the proposed lagoon site were advanced to depths of 1.65 m to 5.5 m. At the time of the geotechnical investigation, the active layer was assessed to range in thickness from 0.6 m to 1.7 m.

The general stratigraphy at the borehole locations consisted of a surface layer of organics or top soil-like material between 0.05 m and 0.4 m thick, being predominately sand and gravel sized particles. This layer was underlain by coarse grained soils consisting of variable proportions of sand and gravel, with some fines (particles smaller than 0.08 mm) content. The natural moisture content of these soils was typically measured to be about 10 percent, by dry weight.

Table 2.1 presents the subsurface stratigraphy that was used for the purposes of the geothermal analysis.

Table 2.1. Subsurface stratigraphy used for the geothermal assessment

Soil unit	Top of stratum (m)	Bottom of stratum (m)	Water content (%)	Dry density (kN/m^3)
Silty sand	0	2	5	19
Sandy silt Till	2	3.25	15	20
Siltstone bedrock (weathered)	3.25	5.5	10	22
Siltstone bedrock (unweathered)	5.5	20	5	22

2.2 Ground Temperatures

Thermistor cables were installed in two boreholes at the lagoon site. The ground temperatures were measured for several days in early November 2009. In addition, ground temperatures were also measured at the site of the proposed Community Centre in late October, 2009 (Trow 2009). It is considered that these recorded temperatures are not sufficient to provide a full ground temperature profile.

The Geological Survey of Canada (GSC) maintains a multi-bead thermistor cables at a site within the Igloolik municipal limits. Figure 2.1 presents the minimum and maximum ground temperature profiles for the GSC data. Also included are the Trow temperature data from the Community Centre and lagoon sites Trow (2009, 2010).

The mean annual ground temperature in Igloolik is approximately -8.5 ˚C. The Trow ground temperature data from the lagoon site is seen to fit within the limits of the GSC data.

The active layer was considered to be 1.35 m deep.

2.3 Lagoon Structure Dimensions and Construction

The lagoon containment berms are understood to have the following dimensions:

Crest width	3 m
Typical dyke height	4.5 m
Downstream face slope	3.5H:1V
Upstream face slope	3H:1V

The containment structure is assumed to be constructed from locally available soils, to be placed in controlled lifts and compacted in non-freezing conditions to achieve an engineered level of compaction. This construction method will necessitate construction in the summer months. Furthermore, this construction method is intended to avoid damage to the organic layer outside of the footprint of the lagoon structure.

Subject to the geothermal analyses reported herein, the containment structure will be designed, constructed and operated as an impermeable berm using an internal impermeable liner to provide the primary containment. Permafrost that is present under the containment structure or may develop within the containment berm will provide secondary containment. It is understood that removal of treated effluent will be by pumping over the berms. No discharge conduits will be constructed through the structure.

Within the lagoon containment area, a layer of water saturated sludge, 0.5 m thick was assumed to be present overlying the native soils.

3.0 GEOTHERMAL ANALYSIS OF CONTAINMENT STUCTURE

The geothermal performance of the lagoon dykes is a function of the thermal energy balance between the atmosphere and the ground surface on and around the dykes. As such, ground surface temperatures vary continuously throughout the year. When climate warming is considered, the seasonal air surface temperature is assumed to increase at a specified constant rate. The mean annual ground temperatures will respond to long term changes in the mean annual air temperature.

The controlling design temperature for the analysis should incorporate adjustments to account for freezing point depression because of pore water salinity and for uncertainty in the model input parameters.

This subsection outlines the various boundary conditions that have been applied to the physical problem, lists the various analyses considered, and presents the results of the analyses. Numerical modeling results are presented in Section 4 of this report. The presence of an impermeable liner within the containment structure has been ignored in these analyses.

3.1 Numerical Model Input Parameters and Boundary Conditions

3.1.1 Climatic Data

The Hamlet of Igloolik is located at 69° 22.8' N and 81° 48.0' on Igloolik Island within the Foxe Basin, immediately east of Melville Peninsula. It is located in the zone of continuous permafrost. Environment Canada provides historical climatic data records from the early 1980s.

The long-term mean annual air temperature at the Igloolik airport is -13.1 °C. The freezing index is approximately 5100 °C-days and the thawing index is approximately 400 °C-days. Mean monthly temperatures in December and January are in the order of -30 °C and mean monthly temperatures in June and July are in the order of +5 °C.

Total annual snowfall is about 1.8 m. Snow and sub-freezing temperature are possible all year-round.

3.1.2 Ground Temperatures and Permafrost Depth

Ground temperatures were measured at the proposed lagoon site by Trow during their geotechnical investigations. A full ground temperature profile was also measured by the GSC. Figure 2.1 present these data.

Mean annual ground temperatures, based on the GSC data are expected to be in the order of -8.5 °C.

Permafrost is likely to extend over 500 m below ground surface.

3.1.3 Climate Warming

The design life of the containment structure is expected to be in the order of 20 years. For this period, climate warming is assumed to be active and should be accounted for in the design of the structure. One method of addressing the potential for regional atmospheric warming in a particular location is to extrapolate the historical warming rate forward for the design life of the project. Figure 3.1 presents the mean annual air temperature for the Igloolik airport for the period of 1983 through 2007. A linear regression best-fit line has been fitted to the data, and the slope of the regression line represents the annual historical warming trend. For the available data, the historical warming rate is 0.16 °C/year. This value is considered to be very high compared to historical climate warming trends for other communities in the Melville

Peninsula/Baffin Island. A more typical regional climate warming rate is about 0.08 °C/year.

Using the Igloolik specific climate warming data, if this is projected forward for a design life of 20 years, the mean annual air temperature may rise by approximately 3.2 °C.

Climate warming is incorporated into the geothermal modeling by adjusting the mean annual air temperatures for each year of the simulation. In the case of the lagoon contents (sewage), a temperature warming rate of one-half the air temperature rate was applied (0.08 °C/year). This is considered to be a conservative assumption.

3.1.4 Soil Pore Water Salinity

The soils in the Baffin Island region are known to contain salts within the soil. The effect of salinity is to depress the freezing and thawing temperature below 0 °C. This means that saline soils will freeze and thaw at temperatures colder than 0 °C and this depressed temperature must be used to assess the freeze-thaw behaviour of the soils.

Trow (2009) reported salinities in the range of 0.26 PPT to 1.32 PPT, which are considered to represent soils of low salinity. Hivon and Sego (1993) reported on the pore water salinity of soils across northern Canada. Although they did not report salinities for soils in Igloolik, they reported salinities for regional communities as follows:

Repulse Bay	0.5 to 10.4 PPT
Cape Dorset	0.4 to 25.2 PPT
Pelly Bay	12.0 to 33.7 PPT
Arctic Bay	1.0 to 32.0 PPT

From the above information it is considered prudent to assume a conservative soil pore water salinity of about 20 PPT.

Freezing point depression is a linear function of pore water salinity. For soil pore water with a salinity of 35 PPT, the freezing point will be depressed to about –2°C. For this analysis a soil salinity of 20 PPT was assumed, with a corresponding freezing/thawing temperature of about -1.1 °C.

3.1.5 Lagoon Content Elevation and Temperatures

The elevation and temperature of the lagoon contents will be seasonally variable and transient over the life of the structure. It is understood that the lagoon berm height and lagoon volume is based on projected community population growth over the next 20 years. Hence, full lagoon sewage elevations are not expected to be reached for many years.

The operation of the lagoon assumes that the effluent will be removed seasonally, typically between early August and mid-September each year. Refilling of the lagoon would take place from September through July of the following year.

For the geothermal analyses a constant lagoon elevation at one-half the height of the containment berm was assumed. The assumption of the fixed lagoon elevation is considered to very conservative in the initial life of the structure as the mean annual height of the sewage in the early period of the facility will be much less than that assumed. In later years of the structure, the fixed elevation of the lagoon will be essentially neutral from a modeling perspective because the sewage height will fluctuate throughout the year.

For the lagoon contents, a single temperature regime was considered. The lagoon temperature was assumed to be +1 °C all year around when no climate warming was considered. In a separate study for a sewage lagoon at Clyde River, NU Naviq compared two scenarios for lagoon temperatures where in the first case the lagoon temperature was held constant at +1 °C all year around, and in the second case the temperature of the surface of the lagoon varied according to seasonal conditions, with higher surface temperatures when the lagoon was empty in late summer, and cooler, but still “warmer than ambient” temperatures during the winter months. Comparison of the results of this modeling showed that the constant positive temperature approach was more conservative and was therefore adopted for this study (Naviq, 2008).

When long-term climate warming was considered in the analyses, a warming rate of 0.08 °C/year was applied to the lagoon temperature of +1 °C. Thus after 20 years, the lagoon content temperature was assumed to be +2.6 °C.

3.2 Geothermal Input Parameters

Table 3.1 lists the geothermal properties of the various soil layers assumed in the analysis. Table 3.2 list the climatic input data for the analysis. Table 3.3 presents the surface energy balance input parameters corresponding to the ground surface.

3.3 Analysis Scenarios

The first modeling step was to perform a one-dimensional model calibration whereby climate data representative of Igloolik was input to the model, and calibration was performed such that the model calculated long-term ground temperatures at depth that were also generally representative of Igloolik. The purpose of this analysis was to establish the surface boundary conditions (surface energy balance) that would result in ground temperatures typical of the local environment. The metrological inputs included: monthly air temperature, snow cover, surface albedo, and evapotranspiration rates. Snow thermal conductivity and factors for summer albedo and evapotranspiration were adjusted to achieve model-computed ground temperatures that were consistent with representative ground temperatures for Igloolik.

Two-dimensional geothermal analyses were then conducted using the commercial program TEMP/W, developed by Geo-Slope International. This program is capable of analyzing a variety of complex temperature problems, both steady state and transient in nature.

The analyses conducted for this study included the following:

- Initial model calibration of site conditions without the presence or influence of the lagoon structures
- Placement of the lagoon structure and modeling geothermal response for 20 years without applying climate warming.
- Placement of the lagoon structure and modeling geothermal response for 20 years including applying climate warming, as described in Section 3.1.3.

- Placement of the lagoon structure and modeling geothermal response for 20 years including applying climate warming and snow drifting on the downstream toe of the lagoon berm. To simulate snow drifting, the climate warming scenario was modified such that the normal snow thickness function (values listed in Table 3.2) were increased by a factor of two along the downstream slope of the lagoon berm.

The initial modeling scenario was set-up with an initial simulated period of five years with an undisturbed ground surface and non-climate warming boundary conditions. This initial period was intended to allow the model to reach a seasonal steady state geothermal condition. After the initial five year simulation, the containment structure was placed on the ground surface (instantaneously on about August first of Year 5). The berm was assumed to have constant temperature of +8 °C. The simulations were then run for an additional 20 years for various modeling scenarios.

Table 3.1. Thermal data of soils for input to geothermal model.

Material	Thermal Conductivity Thawed (W/m-°C)	Thermal Conductivity Frozen (W/m-°C)	Water Content (g/g)	Unfrozen Water Content Parameter A	Unfrozen Water Content Parameter B	Dry Density (kg/m^3)	Heat Capacity Thawed (kJ/d-m-°C)	Heat Capacity Frozen (kJ/d-m-°C)
Silty Sand	2.1	2.30	0.05	0.01	-0.80	1940	1796	1588
Sandy Silt	1.60	2.00	0.15	0.05	-0.50	2040	2759	2105
Siltstone bedrock (weathered)	2.50	2.80	0.10	0.01	-0.80	2240	2528	2061
Siltstone bedrock (unweathered)	3.00	3.10	0.05	0.005	-0.90	2240	2073	1834
Lagoon Sludge	1.30	1.80	0.56	0.300	-0.80	1000	3064	1888

Table 3.2. Climatic data for input to geothermal model.

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Air temperature (°C)	-30.6	-31.2	-28	-19.3	-8.3	1.6	7	4.9	-0.4	-8.9	-19.5	-26.1
Wind velocity (km/hr)	15.4	14.9	15.5	15.9	16	14.2	12.7	15.7	17.5	19.8	18	15.9
Monthly solar radiation (W/m^2)	4.8	17.9	82.3	184	266.3	273.6	215.5	135.6	72.6	29.1	7.3	0
Snow depth (cm)	31	33	37	41	42	20	0	0	1	10	22	28

Note:
Air temperature and wind velocity are taken from Igloolik airport data.
Snow depths were taken from Hall Beach airport data because no equivalent data was available for Igloolik.
Monthly solar radiation data was taken from published historical data for the Canadian arctic (Thompson, 1967).
Last and first snow cover days of year are ordinal days 172 (June 22) and 259 (September 17), respectively.

Table 3.3. Surface energy balance input parameters.

Property	Undisturbed Terrain	Containment Berm	Containment Berm with Snow Drift
Summer Albedo [1]	0.20	0.20	0.20
Winter Albedo [1]	0.85	0.85	0.85
Evapotranspiration Factor [1]	0.20	0.20	0.20
Snow Depth Factor [2]	1.0	1.0	2.0
Snow Thermal Conductivity (W/m-°C)	0.19		
[1] Values can range from 0 to 1. [2] Values can range from 0 and up.			

4.0 GEOTHERMAL MODELING RESULTS

This section addresses the results of the geothermal modeling described in Section 3. In interpreting geothermal modeling the results are a reflection of the assumptions made as input parameters and boundary conditions. If these values are representative of the actual conditions, then the results should be comparably representative of the future conditions.

As noted in Section 3, the pore water salinity that may be present in the soils in and around Igloolik can be high. For this study, a pore water salinity of 20 PPT has been assumed. This will result in a freezing and thawing temperature depression of about 1 °C.

For design purposes, it is prudent to incorporate conservatism to account for uncertainty in the input design parameters. Conservatism can be incorporated by using a colder design temperature than would be normally needed. In this case the controlling parameter is the thawing temperature of the soils, which is -1 °C when pore water salinity is accounted for. For design purposes therefore, it is proposed that the “adjusted” design temperature be assigned as -2 °C, one degree below the control temperature.

4.1 Initial Pre-Construction Conditions

A base case was implemented wherein the first five years of the geothermal analysis considered only the undisturbed soil prior to containment berm construction. Figure 4.1 shows the model domain for this analysis and the temperature distribution after 4.59 years, which corresponds to ground temperatures representative of early August. As shown in the Figure 4.1 the active layer depth in mid-summer is approximately 1.35 m, based on the depth of the -1 °C isotherm below the undisturbed terrain.

4.2 Long-Term Thermal Performance – No Climate Warming

Building on the base case, above, at 4.59 years, the containment berm was instantaneously placed at a temperature of +8 C to simulate placement of relatively warm soil during summer construction. At the same time the sludge layer, with a thickness of 2 m was also applied with the liquid effluent boundary condition set to a constant +1 °C for the entire simulation time period. The model was run for an additional 20 years.

Figure 4.2 shows results from 20 years after containment berm construction and is representative of the maximum thaw each year. As shown in the figure, the maximum active layer depth in the undisturbed terrain remains just over 1 m. The relatively warm effluent temperature in the lagoon however increases the maximum thaw depth (based on the -1°C isotherm) to approximately 8.0 m below the lagoon.

This figure shows that the -2 °C isotherm progresses to between 2 m and 2.5 m below the crest of the berm during thawing each year. This means that under the conditions analyzed approximately 66% of the berm cross section (by area) warms to -2 °C or higher annually.

An unfrozen zone (talik) develops under the lagoon, based on a melting temperature of -1 °C. If ice-rich soils are present these soils may melt, resulting in settlement of lagoon base and potentially the upstream toe of the containment structure.

The downstream terrain is thermally unaffected by the presence of the lagoon structure. A small amount of warming of the soil at the downstream toe of the dyke may result in some localized thaw settlement.

4.3 Long-Term Thermal Performance – Climate Warming

Figure 4.3 presents a cross-section of the lagoon structure showing the temperature contours in late summer after 20 years of operation for the case where the air temperature experiences a annual warming rate of 0.16°C/year and the lagoon contents increase at an annual rate of 0.08 °C/year.

In Figure 4.3 it is seen that the ground temperature at depth remote from the lagoon (lower left corner) is in the order of -5 °C. This is compared to the -8°C temperature seen in Figure 4.1, and reflects the significant warming as a result of the 20 years of atmospheric warming applied at the ground surface.

The progression of the -2 °C isotherm within the berm structure has deepened compared to the non-climate warming case. Approximately 80% of the dyke cross-section (by area) thaws out by late summer. The -2 °C isotherm is approximately 3 m below the crest of the containment berm. On the upstream side of the berm structure, the -2 °C isotherm has shifted towards the center of the berm, compared to the non-climate warming case. This transition arises because of the annual increase in the lagoon content temperatures according to the applied climate warming rate. The volume of the unfrozen zone under the lagoon area is greater than for the case of no climate warming. This could result in more thaw settlement of the subgrade compared to the no climate warming case.

4.4 Long-Term Thermal Performance – Climate Warming and Snow Drifting Effects

Figure 4.4 presents the predicted late-summer ground temperature contours for the case where climate warming and snow drifting on the downstream of the containment berm is applied. To simulate snow drifting, climate warming analysis was modified such that the normal snow thickness function was increased by a factor of two along the slope of the dyke opposite the lagoon. Therefore this case includes the combined effects of snow drifting and climate warming.

Snow drifting on the downstream slope of the berm provides an insulating effect during winter and thus increases ground temperatures. Thaw in this case is increased somewhat but the effect of snow drifting on overall ground temperatures is not as significant as ground temperature increases caused by climate warming.

For this case essentially 100% of the berm structure is warmer than the design temperature of -2 °C during the summer, 20 years after construction. The active layer on the downstream side of the structure progressed from an initial depth of about 1.5 m to about 2.5 m.

5.0 DISCUSSION OF MODELING RESULTS AND IMPLICATION TO LAGOON DESIGN

Section 3 described the various geothermal model inputs and the analyses that were to be undertaken for this study. Section 4 presented the results of the geothermal modeling. This section provides a discussion of the implications of the modeling results to the lagoon design.

The geothermal modeling showed that long-term thawing into the bedrock at depth will develop. It is considered likely that the unweathered bedrock may provide a suitably impermeable barrier to the lagoon contents. Hence, in terms of assessing potential seepage paths, the -2 °C isotherm was truncated to the weathered-unweathered bedrock interface in Figure 4.2 through Figure 4.4.

The geothermal modeling has confirmed that the installation of an impermeable liner within the lagoon containment structure (berm) is a prudent design approach, and that integrity of an ice-core containment structure may not be sufficient in all years, under the climate warming and snow drifting scenarios considered.

The position and depth of the toe of the liner warrants some consideration. The toe of the liner should be keyed into an impermeable stratum to limit potential seepage below the liner system. Based on this geothermal analysis two approaches may be considered for determining the position of the liner key. In one approach, Figure 4.3 (climate warming, no snow drifting) may be used as the design condition. For this scenario, the toe of the liner could be position at about the original ground elevation (Elevation 0 m). At this elevation, the ground temperatures (after 20 years) would be in the order of -3 °C near the center of the containment berm structure. The liner could then be carried up through the containment structure as it is constructed. Because Figure 4.3 does not represent a worse case scenario in terms of geothermal effects, monitoring of the ground temperatures would be an essential component to the design and operation of the facility. If ground temperatures were found to be warmer than expected, based on the geothermal modeling, then an intervention and mitigation strategy would need to be applied. This may consist of the installation of vertical thermosyphons to provide additional cooling to the structure.

The second approach is to use Figure 4.4 (climate warming with snow drifting) as the design condition. In this case, the toe of the liner may need to be installed near the downstream toe of the berm in undisturbed native ground at a depth in the order of 2 m to 2.5 m below grade, at the -2 °C isotherm. Such a design approach will be more difficult (and expensive) to construct but it represents a more conservative design approach than that represented by Figure 4.3 and hence the likelihood of a future intervention and mitigation is less. Monitoring of the ground temperature is still considered to be a prudent operational activity.

A liner is not considered warranted under the main lagoon containment area. The geothermal modeling shows that while there may be significant thawing under the containment area (particularly in the climate warming case), the overall lateral containment of the frozen mass surrounding the containment area should be adequate to confine or restrict any seepage. Seepage will also be likely impeded by the presence of unweathered bedrock at depth.

The design and construction installation details for an impermeable liner should be undertaken considering the environment in which the liner will operate and the construction equipment and skills available for installation. Issues to be considered include, but may not be limited to protection from ice and vehicle damage, slope stability, keying the liner into the subgrade and others.

The operation of impermeable liners and perforations or apertures within the berm structure is generally incompatible. That is, where drainage pipes or access manholes are installed in the lagoon containment structure and these features penetrate the liner, an opportunity of leakage and seepage will be present. Therefore, the design of the structure should avoid the installation of drainage pipes, access manholes and other potential seepage points.

Monitoring during construction and operations represents part of good design practice. Therefore, to assess the performance of the lagoon structure, it is recommended that thermistors and seepage monitoring facilities be incorporated into the design and construction plans. Monitoring of ground temperatures and review of data on a regular basis, including assessment and investigation of unexpected data or trends should be part of the operating procedures.

6.0 RECOMMENDATONS

This section provides recommendations for the design, construction and operation of the sewage lagoon structure, based on the geothermal modeling and discussion presented in this report.

1. The use of moderately high saline soils for the berm construction has been assumed in this analysis. If low saline soils can be located and used for the berm construction, then a controlling design isotherm of -1 °C instead of -2 °C may be used. This would be generally advantageous in terms of geothermal performance.

2. The seasonal thawing of the berm structure, even in the absence of climate warming effects, means that a frozen-core impermeable design approach may not be feasible, based on the geothermal modeling conducted for this study. For this reason, it is recommended that primary containment be provided by a liner or other impermeable barrier or system. (This analysis ignores the fact that the maximum thaw in the lagoon containment berms occurs after the annual draw-down of the lagoon, so that seepage through the unfrozen zone of the berm may not occur.)

3. A liner or barrier in the containment berm to provide primary containment should ideally be located along the upstream face of the earth structure. At the upstream toe of the berm, the liner should be keyed into the native soil. On the cross-sections shown in Figure 4.2 through Figure 4.4 the key-trench should be located in the order of Station 45. The liner should be installed to unweathered bedrock, which is assumed to be at a depth of 5.5 m below the native ground surface.

   Other liner placements may be considered. As discussed above, a liner placement near the middle or downstream section of the containment berm may provide some construction and economic advantages. Issues such as the depth and position of the liner toe key and seepage pressures against the liner should be considered in the assessment for the final liner position.

4. Selection of the liner material requires careful consideration. Current industry practice is moving away from the use of high density polyurethane (HDPE) liners and geosynthetic clay liners (GCL). Both these systems have reportedly experienced performance issues in cold temperature applications. An alternative liner material that is gaining favor in locations such as the North Slope of Alaska (Prudhoe Bay area) is polymeric geomembranes, which may include thermoplastic polyurethane. Polyether polyurethane materials are reported to provide good low temperature properties. These materials are reportedly satisfactory for liner materials, landfill covers, potable water and fuel containment liners and similar applications.

5. The geothermal analyses have assumed that the lagoon berms will be constructed without any perforations or apertures. Drainage culverts and access manholes are two examples of openings that may be installed in or through the dyke structure. These apertures represent sources of geothermal discontinuities that could negatively impact the temperature regime in the vicinity of the apertures. In addition, it is possible that a drainage pipe through the berm could experience freeze-up and ice blockage for much of the year. Therefore, from a geothermal perspective, it is recommended that no drainage pipes or vertical access man holes be installed through or in the berm structure.

6. Where drainage pipes are installed through the lagoon berm, it will be necessary to pass the drainage pipe through the impermeable liner. Such a perforation represents a potentially serious source for leakage as it is often difficult to ensure an impermeable seal around the liner-drain pipe connection. Therefore, from a geotechnical perspective, it is recommended that no drainage pipes be installed through the containment structure.

7. Given the limitations in installing a vertical cut-off barrier to impede seepage towards the center of the berm structure, as discussed in Recommendation 3, it is further recommended that the thermal and seepage performance of the containment structure be incorporated into its design and operation. Sealed PVC casings should be installed through the structure and into the subgrade soils into which thermistor cables may be installed to monitor ground temperatures. These casings should be installed at approximately 15 m to 20 m centers along the crest of the containment berm. Selected casings could be "battered" to the upstream side so to provide the opportunity to monitor dyke and subgrade temperatures on the upstream side.

   To monitor seepage, vertical slotted standpipes should be installed at approximately 15 m to 20 m centers along the crest of the dyke. These standpipes should be of a diameter to permit the recovery of liquid within the standpipe for environmental/biological testing.

   Care should be taken to ensure that the monitoring casings do not penetrate the impermeable liner. Additional specifications on monitoring installations and instrumentation may be provided on request.

8. It is considered that the need for a secondary cooling system, such as thermosyphons is not supported by the current analysis, subject to the implementation of the above recommendations. If, during operations, monitoring of the berm and subgrade temperatures indicates a warming of the structure higher than predicted by this study, then thermosyphons may be considered. Based on a preliminary assessment, vertical thermosyphons, installed along the crest at approximately 2 m centers to a depth of about 2 m below the base of the berm would provide additional cooling of the core of the berm to maintain a frozen core. Shallow rigid insulation could also be installed in conjunction with the thermosyphons to reduce the seasonal active layer thickness. Additional modeling and design work is needed to advance any proposal to install thermosyphons.

7.0 CLOSURE

This report has been prepared for the exclusive use of Trow Associates Inc. for the specific application and project described herein. The use of this report by third parties or for an application not described in this report is at the sole risk and responsibility of those parties.

If at any time, the soil or climatic conditions be found to be different from what has been assumed in this report, Naviq should be notified and given the opportunity to examine the different conditions and the impact they may have on the analyses and recommendations reported herein.

Prepared by:
Naviq Consulting Inc.

J.M. Oswell, Ph.D., P.Eng.
Senior Permafrost Engineer

Reviewed by: R. Coutts, M.Sc., P.Eng. (AB)
Senior Geothermal Engineer
Ardent Innovation Inc.

NAPEGG Permit to Practice: P611

8.0 REFERENCES

Hivon, E.G. and Sego, D.C. 1993. Distribution of saline permafrost in the Northwest Territories, Canada. Canadian Geotechnical Journal, 30(3): 506 – 514.

Naviq Consulting Inc. 2008. Geothermal analysis of proposed sewage lagoon, Clyde River, NU. Revision 0. Prepared for Trow Associates Inc. Naviq Project No. J008, February 2008.

Thompson, H. A., 1967. The climate of the Canadian Arctic. Dominion Bureau of Statistics, Government of Canada, Ottawa, Canada.

Trow Associates Ltd. 2009. Draft Geotechnical investigation: Proposed Community Centre, Igloolik, Nunavut. Prepared for Mr. Shane Soloman, (re)public Architecture, Winnipeg MB. Trow Project No. OTGE00020275A, December 24, 2009..

Trow Associates Ltd. 2010. Liquid and solid waste management: Hamlet of Igloolik, NU. Prepared for Mr. Matthew Hamp Government of Nunavut, C&GS. Trow Project No. OTGE00019838B. Report date: March 16, 2010

APPENDIX A

TERMS AND CONDITIONS

TERMS AND CONDITIONS

The following Terms and Conditions form part of this Report. Acceptance of the report by the Client shall be interpreted as acknowledgement and agreement by the Client with the Terms and Conditions provided herein. Acceptance of the Report means that the Client has not objected to the Report in writing within seven days of receipt.

1. STANDARD OF CARE: Naviq Consulting Inc. (Naviq) will strive to perform Services in a manner consistent with that level of care and skill ordinarily exercised by other members of Naviq's profession currently practicing in the same locality under similar conditions.

   No other representation, guarantee, or warranty, express or implied, is included or intended in these terms and conditions, or in any communication (oral or written), report, opinion, document, or instrument of service.

2. CHANGES: Client may order changes within the general scope of the Services by altering, adding to, or deleting from the Services to be performed. Further, if Naviq believes any subsurface or physical condition at or contiguous to the site is of an unusual nature and differs materially from conditions generally encountered or generally recognized as inherent in the character of Services provided in these Terms and Conditions, a change exists. If any such change causes an increase or decrease in Naviq's cost of, or the time required for, the performance of any part of the Services, a mutually acceptable equitable adjustment shall be made to the price and performance schedule.

3. FORCE MAJEURE: Should performance of Services by Naviq be affected by causes beyond its reasonable control, Force Majeure results. Force Majeure includes, but is not restricted to: acts of God; acts of a legislative, administrative or judicial entity; acts of contractors other than contractors engaged directly by Naviq; fires; floods; labor disturbances; and unusually severe weather. Naviq will be granted a time extension and the parties will negotiate an equitable adjustment to the price for the Services, where appropriate, based upon the effect of the Force Majeure on performance by Naviq.

4. INSTRUMENTS OF SERVICE: All reports, drawings, plans, or other documents (or copies) furnished to Naviq by the Client, shall at Client's written request, be returned on completion of the Services hereunder; provided, however, that Naviq may retain one copy of all such documents. All reports, drawings, plans, documents, software, source code, object code, field notes and work product (or copies thereof) in any form prepared or furnished by Naviq under these Terms and Conditions are instruments of service. Exclusive ownership, copyright and title to all instruments of service remain with Naviq. Client's right of use of instruments of service, if any, is limited to that use reasonably considered necessary for performance of the Client's duties and obligations. The instruments of service are not intended or represented to be suitable for reuse by Client or others on extensions of the work or on any other project.

5. CLIENT'S RESPONSIBILITIES: Client agrees to: (i) provide Naviq all available material, data, and information pertaining to the Services, including, without limitation as appropriate, the composition, quantity, toxicity, or potentially hazardous properties of any material known or believed to be present at any site, any hazards that may be present, the nature and location of underground or otherwise not readily apparent utilities, summaries and assessments of the site's past and present compliance status, and the status of any filed or pending judicial or administrative action concerning the site; (ii) convey and discuss such materials, data, and information with Naviq; and (iii) ensure cooperation of Client's employees.

   Client shall indemnify, defend, and save Naviq harmless from and against any liability, claim, judgment, demand, or cause of action arising out of or relating to: (i) Client's breach of these Terms and Conditions; (ii) the negligent acts or omissions of Client or its employees, contractors, or agents; (iii) any allegation that Naviq is the owner or operator of a site, or arranged for the treatment, transportation or disposal of hazardous materials, including all adverse health effects thereof and (iv) site access or damages to any subterranean structures or any damage required for site access.

In addition, where the Services include preparation of plans and specifications and/or construction oversight activities for Client, Client agrees to have its construction contractors agree in writing to indemnify and save harmless Naviq from and against loss, damage, injury, or liability attributable to personal injury or property damage arising out of or resulting from such contractors' performance or nonperformance of their work.

6. LIMITATION OF LIABILITY: As part of the consideration Naviq requires for provision of the Services, Client agrees that any claim for damages filed against Naviq by Client or any contractor or subcontractor hired directly or indirectly by Client will be filed solely against Naviq or its successors or assigns and that no individual person shall be made personally liable for damages, in whole or in part.

   Client's sole and exclusive remedy for any alleged breach of Naviq's standard of care hereunder shall be to require Naviq to re-perform any defective Services. Notwithstanding any other provision of these Terms and Conditions, the total liability of Naviq, its officers, directors and employees for liabilities, claims, judgments, demands and causes of action arising under or related to the Services or these Terms and Conditions, whether based in contract or tort, shall be limited to the total compensation actually paid to Naviq for the Services or $10,000, whichever is less. All claims by Client shall be deemed relinquished unless filed within one (1) year after substantial completion of the Services.

   Naviq and Client shall not be responsible to each other for any special, incidental, indirect, or consequential damages (including lost profits) incurred by either Naviq or Client or for which either party may be liable to any third party, which damages have been or are occasioned by Services performed or reports prepared or other work performed hereunder.

7. DISPUTE RESOLUTION: If a claim, dispute, or controversy arises out of or relates to the interpretation, application, enforcement, or performance of Services under these Terms and Conditions, Naviq and Client agree first to try in good faith to settle the dispute by negotiations between senior management. If such negotiations are unsuccessful, the parties agree to attempt to settle the dispute by good faith mediation. If the dispute can not be resolved through mediation and unless otherwise mutually agreed, the dispute shall be settled by litigation in an appropriate court in the Province of Alberta. Client hereby waives the right to trial by jury for any disputes arising out of these Terms and Conditions.

   The non-prevailing party in any litigation shall reimburse the prevailing party for the prevailing party's documented legal costs (including reasonable attorneys' fees), in addition to whatever other judgments or settlement sums may be due.

8. WAIVER OF TERMS AND CONDITIONS: The failure of either Naviq or Client in any one or more instances to enforce one or more of these Terms and Conditions or to exercise any right or privilege in these Terms and Conditions or the waiver by Naviq or Client of any breach of the these Terms and Conditions shall not be construed as thereafter waiving any such terms, conditions, rights, or privileges, and the same shall continue and remain in force and effect as if no such failure to enforce had occurred.

9. SEVERABILITY: Notwithstanding any possible future finding by a duly constituted authority that a particular term or provision is invalid, void, or unenforceable, these Terms and Conditions have been made with the clear intention that the validity and enforceability of the remaining parts, terms, and provisions shall not be affected thereby.

10. GOVERNING LAWS: This Agreement shall be governed and construed in accordance with the laws of the Province of Alberta.

FIGURES

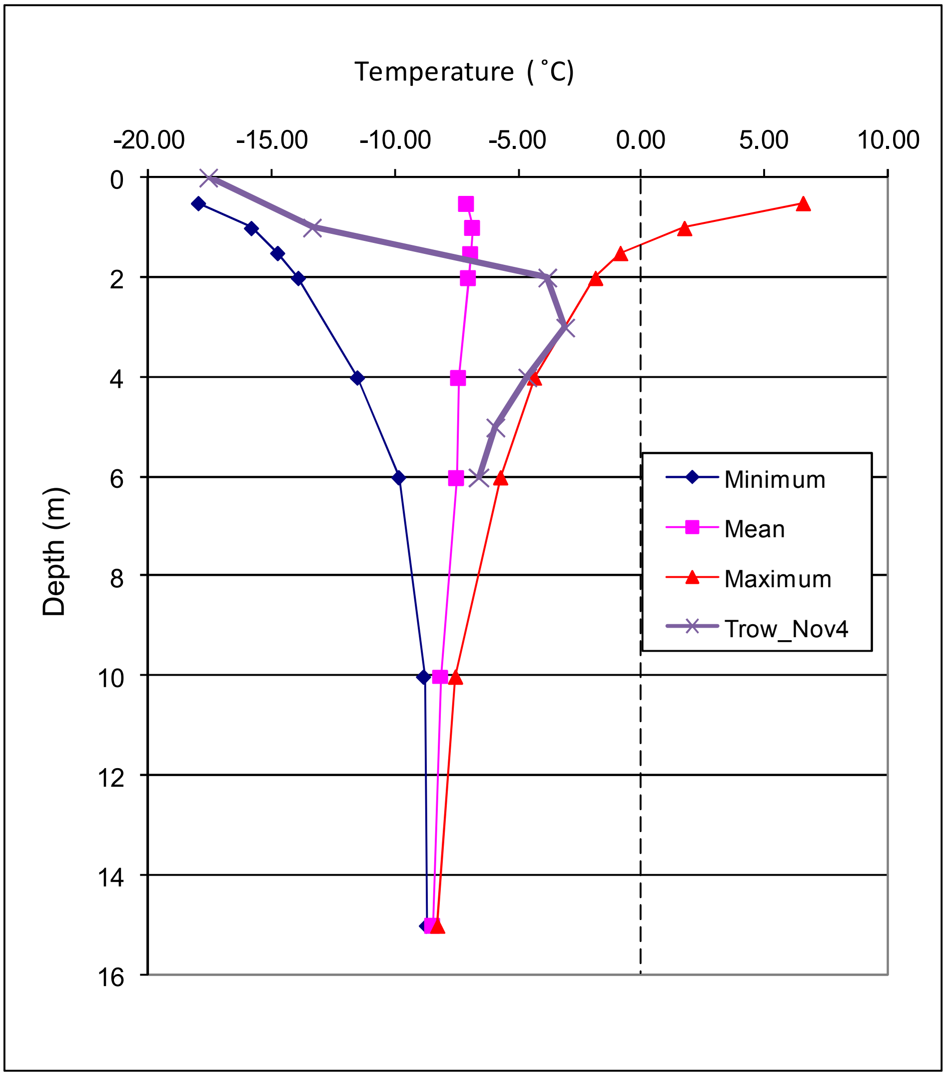

Figure 2.1. Ground temperature data for Igloolik, NU. (Data source: Geological Survey of Canada and Trow, 2009, 2010).

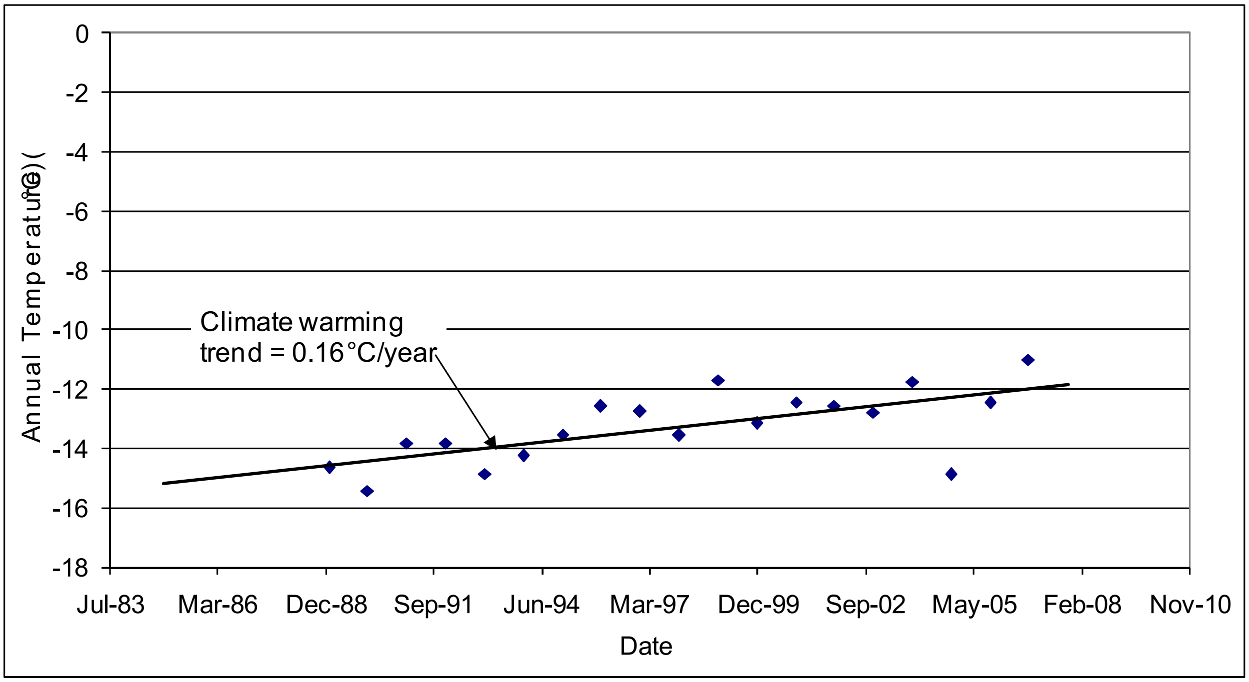

Figure 3-1. Historical variation in mean annual air temperature (1983 through 2007).
Data source: Environment Canada website.

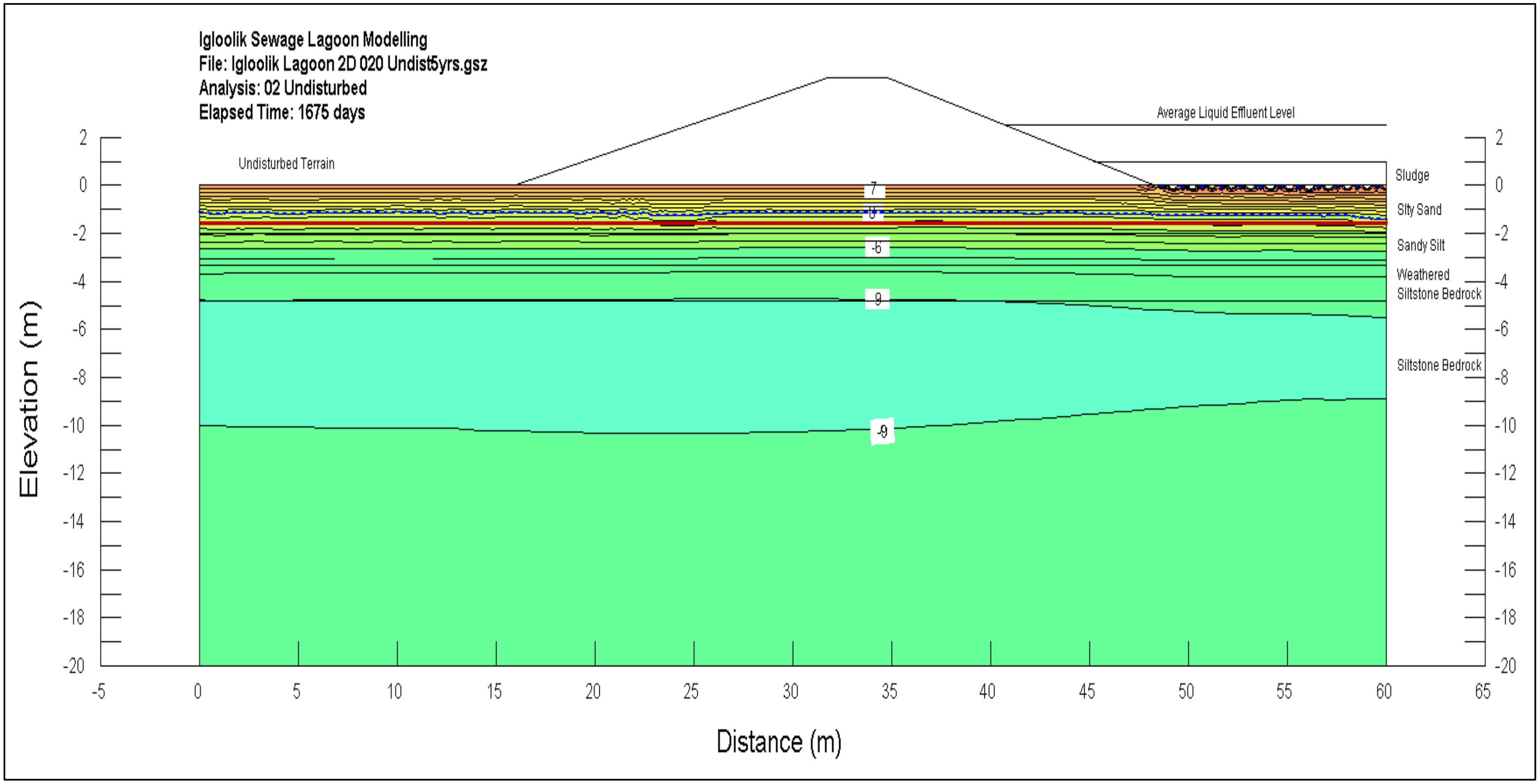

Figure 4-1. Cross-section of berm sub-grade showing ground temperature contours at maximum thaw at 4.59 years, prior to construction of the containment structure. The red contour line represents the -2 °C isotherm.

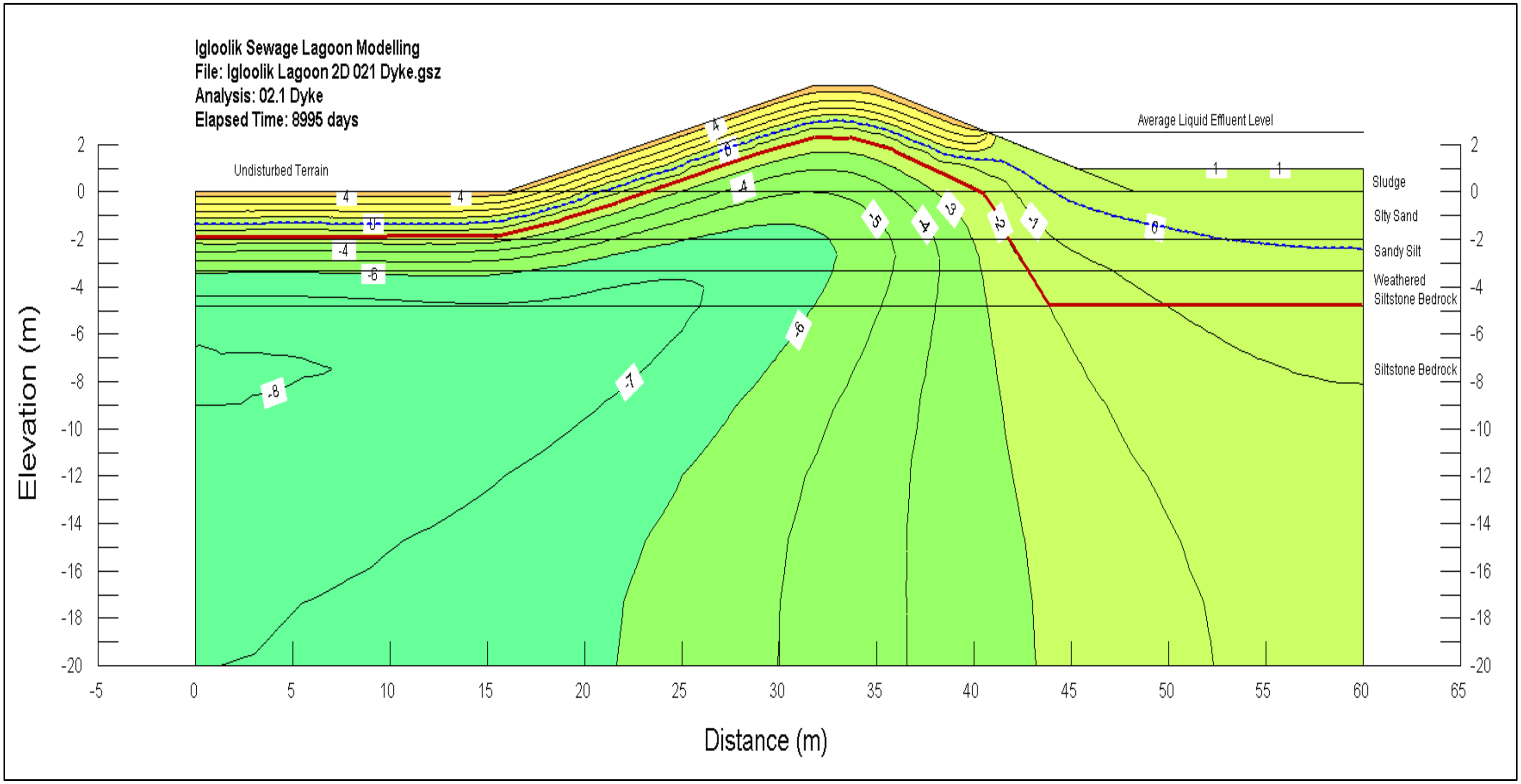

Figure 4-2. Cross-section of containment structure showing ground temperature contours after 20 years. No climate warming effects are included. The red contour line represents the -2 °C isotherm above the bedrock elevation and the weathered/unweathered bedrock interface.

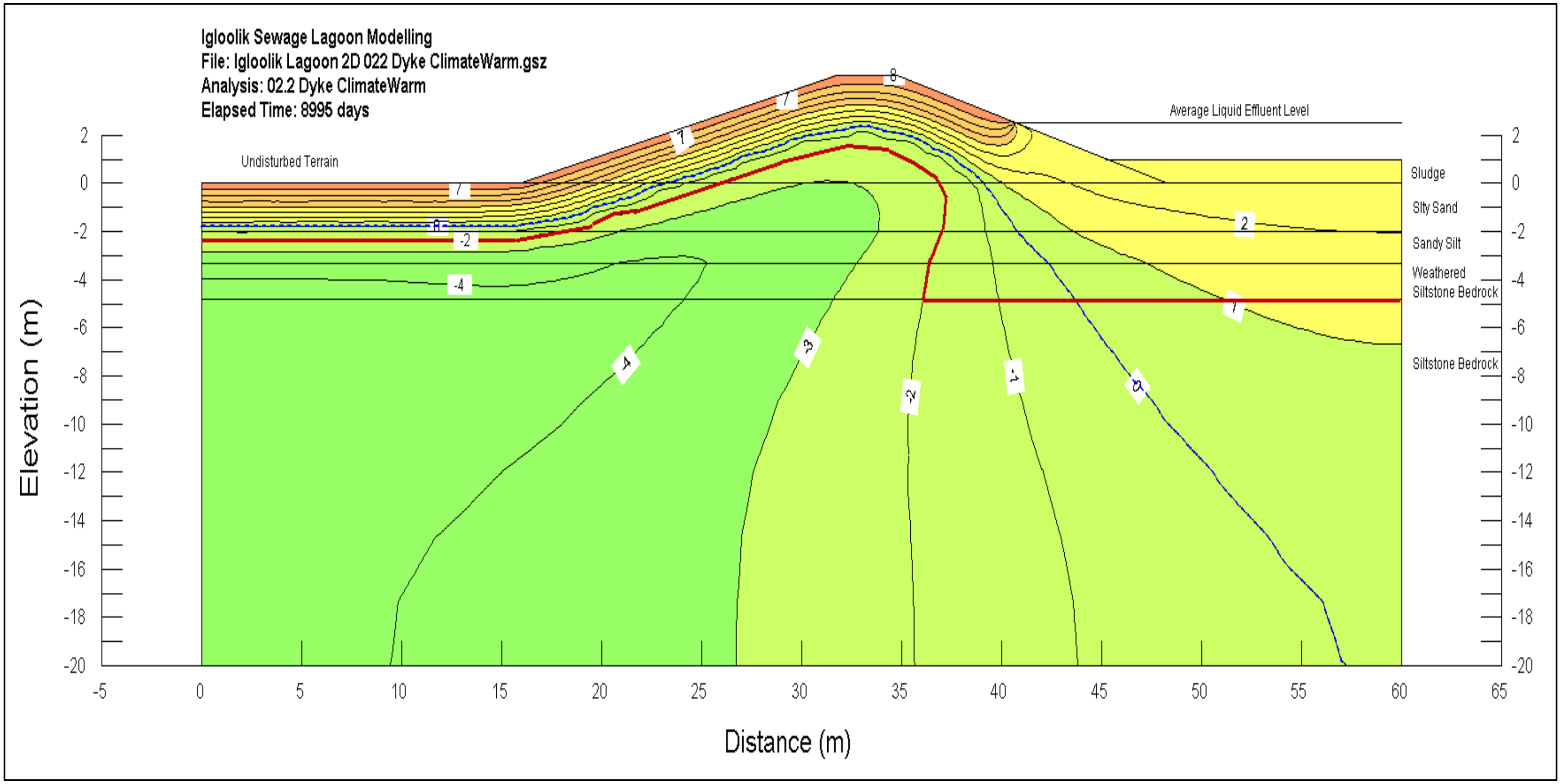

Figure 4-3. Cross-section of containment structure showing ground temperature contours after 20 years. Climate warming effects are included. The red contour line represents the -2 °C isotherm above the bedrock elevation and the weathered/unweathered bedrock interface.

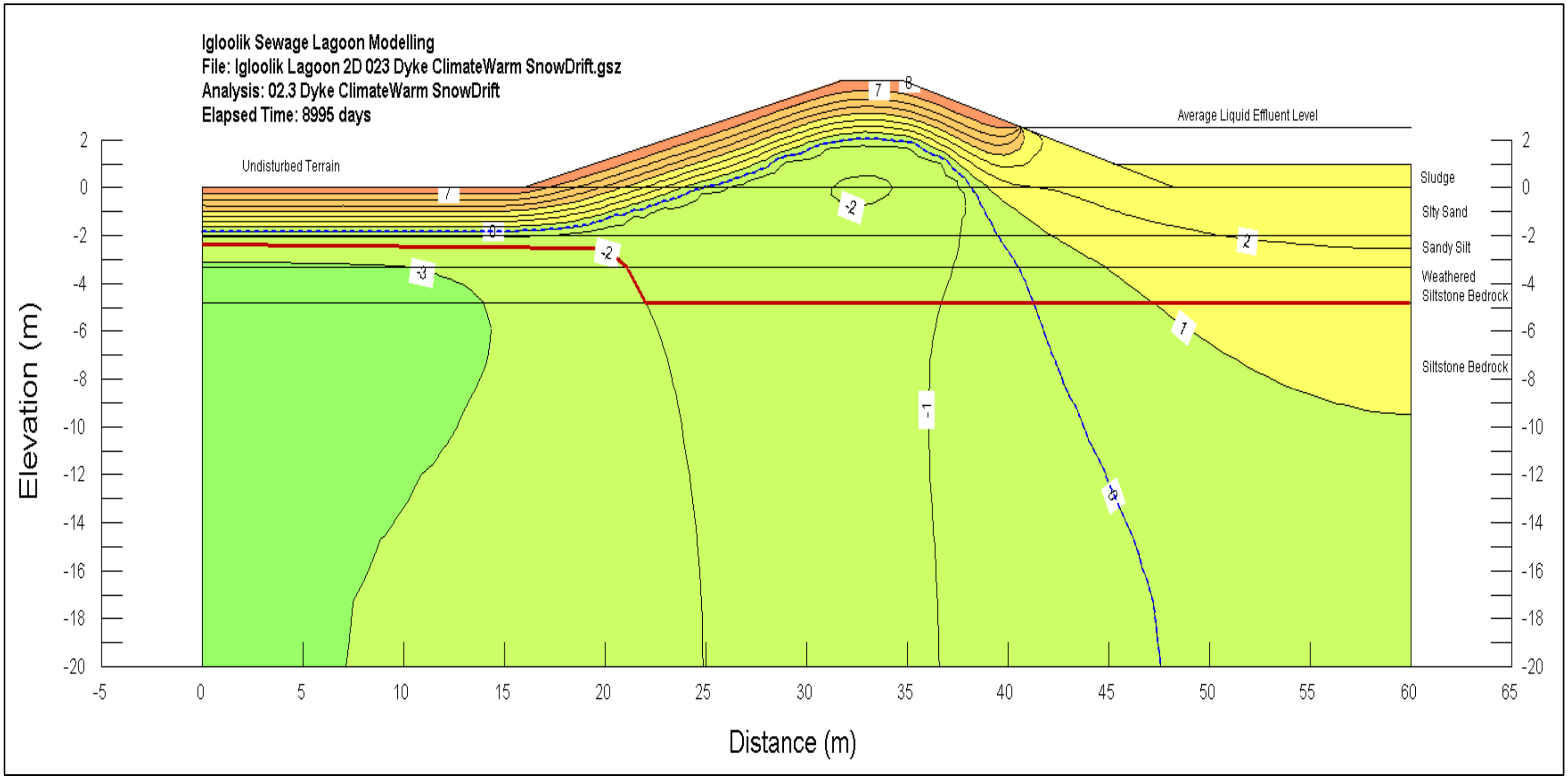

Figure 4-4. Cross-section of containment structure showing ground temperature contours after 20 years. Climate warming and snow drifting effects are included. The red contour line represents the -2 °C isotherm above the bedrock elevation and the weathered/unweathered bedrock interface.