NCI

Naviq Consulting Inc.
*Specialist Geotechnical and Permafrost Engineering*

# GEOTHERMAL ANALYSIS OF PROPOSED SEWAGE LAGOON

## ARCTIC BAY, NU

**Prepared for:**

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GEOTHERMAL ANALYSIS OF PROPOSED SEWAGE LAGOON: ARCTIC BAY, NU

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**EXECUTIVE SUMMARY**

This report provides details of geothermal analyses conducted in support of the design of a sewage lagoon structure near Arctic Bay, 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 (dyke) to a depth of about 2 m below the crest on a season basis. This depth of seasonal thawing is relatively insensitive to the applied climate warming rate.

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 at the upstream toe of the dyke are discussed.

Based on geotechnical information on the fractured condition of the native bedrock on the perimeter of the lagoon, it may be a prudent approach to install a liner in this area also.

No secondary cooling of the dyke structure is presently recommended. However, monitoring of ground temperatures and seepage through the dyke 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 dyke structure.

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

**TABLE OF CONTENTS**

## 1.0 INTRODUCTION

Naviq Consulting Inc. (NCI) 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 Arctic Bay, NU. The scope of work is described in a proposal from NCI to Trow, dated June 21, 2007 (Naviq Proposal: JP-07-03).

The scope of work included input to the geotechnical investigations for the lagoon structure to be conducted by Trow, assessment of design concepts for the lagoon structures and geothermal modeling to assess the functionality of the lagoon structures over the design life, recognizing issues such as potential permafrost degradation and climate warming.

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

## 2.0 GEOTECHNICAL INVESTIGATIONS AND RELATED INFORMATION

Trow undertook a geotechnical investigation at the site of the proposed lagoon on August 25 to 30, 2007. Nine boreholes were drilling along the alignment of the proposed retention dykes/berms and within the impoundment area of the containment structure. 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, 2007).

### 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.

A discrete ice layer was encountered in five of the nine boreholes drilled on the site. The depth of the top of the ice layer was typically about 1.5 m and the ice layer thickness ranged from 0.3 m to approximately 3.7 m, although in four of the boreholes, the ice layer thickness was between 0.3 m and 0.8 m.

Underlying the ice layer, sandy gravel soils or bedrock was encountered. The depth to bedrock ranged from about 1.5 m to about 3.8 m.

Around the perimeter of the lagoon area, geotechnical investigations characterized the near surface bedrock and soil materials as fractured (Rock Quality Designation = 0%) and or granular in nature.

## 2.2 Ground Temperatures

Thermistor cables were installed in two boreholes at the site. Table 2-1 presents the results of the ground temperature monitoring, as reported by Trow (2007).

**TABLE 2-1: Ground temperatures measured at proposed lagoon site on September 18, 2007 (Trow, 2007)**

| Borehole 7 | | Borehole 10 | |
|---|---|---|---|
| **Depth (m)** | **Temperature (°C)** | **Depth (m)** | **Temperature (°C)** |
| 0.3 | +2.0 | 0 | -1.0 |
| 0.8 | +1.0 | 0.5 | -2.0 |
| 1.3 | +1.0 | 1.0 | -3.0 |
| 1.8 | +0.5 | 1.5 | -4.0 |
| 2.3 | 0.0 | 2.0 | -5.0 |
| 2.8 | 0.0 | 2.5 | -5.6 |
| 3.3 | -0.5 | 3.0 | -6.5 |
| 3.8 | -1.0 | | |
| 4.3 | -2.0 | | |
| 4.8 | -3.0 | | |

## 2.3 Lagoon Structure Dimensions and Construction

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

| | |
|---|---|
| Crest width | 4 m |
| Typical dyke height | 4 m to 6 m |
| Downstream face slope | 3H:1V |
| Upstream face slope | 3H:1V |

The containment structure is assumed to be constructed from locally available sand and gravel soils, which are placed in controlled lifts and compacted 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 topsoil layer outside of the footprint of the dykes.

Subject to the geothermal analyses reported herein, the containment structure will be designed, constructed and operated as an impermeable dyke, using an internal liner, either HDPE or bentonite panels (geosynthetic clay liner) to provide the primary containment. Permafrost that 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 ground surface temperatures increases upward at a specified constant rate.

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 dyke structure has been ignored in these analyses.

### 3.1 Numerical Model Input Parameters and Boundary Conditions

#### 3.1.1 Climatic Data

Arctic Bay is located at 73° 0' N and 85° 01' W, in the northwest corner of Baffin Island, NU. It is located in the zone of continuous permafrost. Arctic Bay does not have a long-term historical climatic data record. However, Nanisivik Airport is located about 20 km southeast of the community and does have a metrological record for over 30 years.

The long-term mean annual air temperature for the area is -15 °C. The freezing index is approximately 4900 °C-days and the thawing index is approximately 300 °C-days.

Typical snow cover throughout the winter and spring months is about 350 mm. The last date of snow cover is in mid-June. Summer time mean monthly air temperatures during June, July and August are -0.4 °C, + 4.9 °C, and +1.5 °C, respectively. Winter time mean monthly air temperatures during December, January and February are -26.6 °C, -29.2 °C, and -30.3 °C, respectively.

#### 3.1.2 Ground Temperatures and Permafrost Depth

Ground temperatures were measured at the proposed lagoon site by Trow during their geotechnical investigations. Table 2-1 present this data. The measured temperatures in two separate boreholes are quite divergent and also appear to be warmer than would be typically expected.

Mean annual ground temperatures, based on a semi-empirical correlation to mean annual air temperature, are expected to be in the order of -10 °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 Navisivik airport for the period of 1977 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 0.08 °C/year.

If projected forward for a design life of 20 years, the mean annual air temperature may rise by approximately 1.6 °C.

Climate warming is incorporated into the geothermal modeling by adjusting the mean annual air temperature 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 (0.04 °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. 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 temperature colder than 0 °C and this depressed temperature must be used to assess the freeze-thaw behaviour of the soils.

Hivon and Sego (1993) reported on the soil salinity of soils across northern Canada. For Arctic Bay, they report that soil salinity ranges from 1.0 to 32.0 PPT (parts per thousand). For reference, normal seawater has a salinity of about 35 PPT. The Hivon and Sego (1993) data indicate that some soils in the local area may contain salt contents approaching seawater.

Freezing point depression is a linear function. For soil pore water with salinity of 35 PPT, the water will freeze at about –2°C.

For this analysis, a typical soil salinity of 20 PPT was assumed, with a corresponding freezing/thawing temperature of about -1 °C.

### 3.1.5 Initial Dyke Soil Temperatures

The long-term thermal performance of the dyke structure and subgrade is not impacted by the initial placement temperature of the dyke soils. However, in the initial period, during and immediately following construction, the dyke soils will be unfrozen and likely above normal soil temperatures. Therefore, in the initial time period following construction, cooling of the dyke structure and/or warming of the subgrade by the warm dyke soils could have some short-term thermal impact on performance.

For these analyses, it was assumed that the dyke soils will have an initial temperature of +8 °C, representative of the fact that the soil lifts placed during construction will be warmed by sunshine (solar radiation). The +8 °C value is based on the mean monthly summer air temperature of +5 °C in July, and multiplied by an N-factor of 1.6, a value generally typical of gravelly soils. For the numerical modeling, it assumed that the lagoon dyke is “instantaneously” constructed on about July 15.

### 3.1.6 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 dyke 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 dyke 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. In a recent separate study for a sewage lagoon at Clyde River, NU, NCI 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 (Naviq, 2008), and was therefore adopted for this study.

Further to the use of a constant lagoon temperature for the geothermal modeling, NCI considered the impact of seasonal temperature boundary conditions for the geothermal analyses of a lagoon structure. Figure 3-2 presents the modeling results. The temperature of the “disturbed” lagoon surface in late August is calculated to be about +1 °C from a surface energy balance model. This condition is considered to represent the surface of the lagoon after draw down. Immediately thereafter the surface temperature begins to decrease. Therefore, the application of the +1 °C lagoon surface temperature throughout the year was considered conservative, and represents the first scenario described above.

When long-term climate warming was considered in the analyses, a warming rate of 0.04 °C/year was applied to the lagoon temperature of +1 °C. Thus after 20 years, the lagoon content temperature was assumed to be +1.8 °C.

### 3.2 Analysis Scenarios

The first modeling step was to perform a one-dimensional model calibration whereby climate data representative of Arctic Bay 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 Arctic Bay. 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 Arctic Bay. Figure 3-3 presents the annual maximum, minimum and average temperature with depth and illustrates that the model computes a mean annual ground temperature of -6.5 °C using representative climate data for Arctic Bay, which is generally consistent with, or warmer than expected ground temperature values.

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:

- Time to freeze-in the dyke structure, following initial construction. This analysis was intended to assess the time required for the dyke structure to reach a thermal "dynamic steady-state" following construction and to determine if dyke core temperatures would be below freezing after the first winter.
- Assessment of the maximum thaw depth across the dyke structure and in the dyke foundation in the long-term, ignoring climate warming effects.
- Assessment of the maximum thaw depth across the dyke structure and in the dyke foundation in the long-term, including climate warming effects as discussed above.

## 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 Arctic Bay 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 Freeze Back of Lagoon Dyke Following Construction

The geothermal analysis assumed the entire dyke structure was instantaneously constructed and in-place on the native subgrade soil on about July 15 of the first year. The initial temperature of the dyke was assumed to be a uniform temperature of +8 °C, underlain by soils with temperatures ranging from near freezing or slightly warmer at the ground surface to about -6.5 °C at depth.

The analysis showed that the dyke would cool to ambient conditions by mid-winter the following year. That is, for construction in July, the dyke structure would be at ambient temperatures around mid-February the following year, just over six months after construction. This means that the structure will not retain a zone of unfrozen soil when the next thaw season begins. Hence, no artificial cooling of the structure by mechanical or other methods is necessary to provide more rapid freeze-back of the dyke soils.

### 4.2 Long-Term Thermal Performance – No Climate Warming

Figure 4-1 presents a cross-section of the lagoon structure showing the temperature contours in late summer. Because no climate warming is applied to this particular analysis, the results presented are representative of the temperatures in Years 1 through Year 20.

This figure shows that the -2 °C isotherm progresses to about 3 m below the crest of the dyke during thawing each year. This means that, under the conditions analyzed, approximately 75% of the dyke cross section warms to -2 °C or warmer 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 dyke 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 4-2 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 lagoon content surface is held at a constant temperature of +1 °C. This scenario was shown in Section 3 to be a conservative approach.

The progression of the -2 °C isotherm within the dyke structure is essentially the same as for the non-climate warming case. Approximately 75% of the dyke cross-section thaws out by late summer. On the upstream side of the dyke structure, the -2 °C isotherm has shifted towards the center of the dyke, compared to the non-climate warming case. This transition arises because of the annual increase in the lagoon content temperatures. The volume of the unfrozen zone under the lagoon area is significantly greater than for the case of no climate warming. This could result in much more thaw settlement of the subgrade compared to the non-climate warming case.

On the downstream side, the -2 °C isotherm is has deepened by about 0.9 m compared to the non-climate warming scenario. This could lead to additional thaw settlement compared to the non-climate warming case.

### 4.4 Seepage Containment along Lagoon Shoulders

It is understood that the perimeter of the lagoon containment area is underlain by shallow bedrock. Geotechnical investigations by Trow described the bedrock around the perimerter as being fractured with a Rock Quality Designation (RQD) equal to 0%, which represents a very poor quality rock. Where unconsolidated materials were encountered, they were described as granular. When these materials are saturated with water and allowed to freeze in a permafrost environment, they could be effectively impermeable to seepage. But if permafrost degradation develops into the fractured bedrock then seasonal frost cracking of the rock could occur that would open additional fractures and fissures.

With seasonal freezing and thawing of the near-surface soils and bedrock around the lagoon, the opportunity for some seepage of effluent through these materials can not be fully discounted.

## 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 presents 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 has confirmed that the installation of an impermeable liner within the dyke structure is a prudent design approach. While the modeling showed that the lagoon dykes do not thaw out completely during the seasonal thaw period, the results indicate that a sufficient volume of the dyke does thaw seasonally, and that an ice-core containment structure may not be sufficient in all years, and in during extreme warming seasons.

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.

The Trow geotechnical report has described the soils and bedrock surrounding the lagoon containment area as being granular and fractured rock. Seasonal thawing of these materials, could result in some lateral seepage of effluent providing a seepage path to an open discharge point is available (as opposed to a seepage path that encounters a frozen mass of soil or rock). While this seepage potential of the surrounding areas has not been characterized, it may be prudent to install liners in these areas to reduce the potential for any lateral migration of lagoon contents during the thaw seasons.

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 into the subgrade and others.

The installation of liners and perforations or apertures within the dyke structure is generally incompatible. That is, where drainage pipes or access manholes are installed in the dyke 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 highly saline soils for the dyke construction has been assumed in this analysis. If low saline soils can be located and used for the dyke construction, then a controlling design isotherm of -1 °C instead of -2 °C may be used. This would be advantageous in terms of geothermal performance.

2. The seasonal thawing of the dyke 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 dyke occurs after the annual draw-down of the lagoon, so that seepage through the unfrozen zone of the dyke may not occur.)

3. A liner or barrier in the dyke structure to provide primary containment should be located along the upstream face of the dyke. At the upstream toe of the dyke, the liner should be keyed into the native soil. On the cross-sections shown in Figure 4-1 and Figure 4-2 the key-trench should be located in the order of Station 45. The liner should be placed to a depth of 2 m below the native ground surface. This would place the base of the liner key beneath the 0 °C isotherm. It is not likely feasible from a construction perspective to install a key trench to intersect the -1 °C isotherm in the climate warming case, and virtually impractical to intersect the -2 °C isotherm.

4. These analyses have assumed that the lagoon dykes will be constructed without any perforations or apertures. Drainage culverts and access man holes 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 dyke 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 dyke structure.

5. Where drainage pipes are installed through the lagoon dyke, 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 dyke structure.

6. Given the limitations in installing a vertical cut-off barrier to impede seepage towards the center of the dyke structure, as discussed in Recommendation 3, it is further recommended that the thermal and seepage performance of the dyke structure be incorporated into its design and operation. Sealed PVC casings should be installed through the dyke 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 dyke. 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.

7. 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 dyke 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 dyke would provide additional cooling of the core of the dyke to maintain a frozen core. Shallow rigid insulation could also be installed in conjunction with the thermosyphons to reduce the seasonal active layer thickness.

8. Given the uncertainties of the soil and bedrock surrounding the lagoon containment area to remain impermeable for the life of the project, it may be prudent to install impermeable liners in these areas to reduce the potential for lateral migration of lagoon contents.

## 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, NCI 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.

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NAPEGG Permit to Practice: P611

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# FIGURES

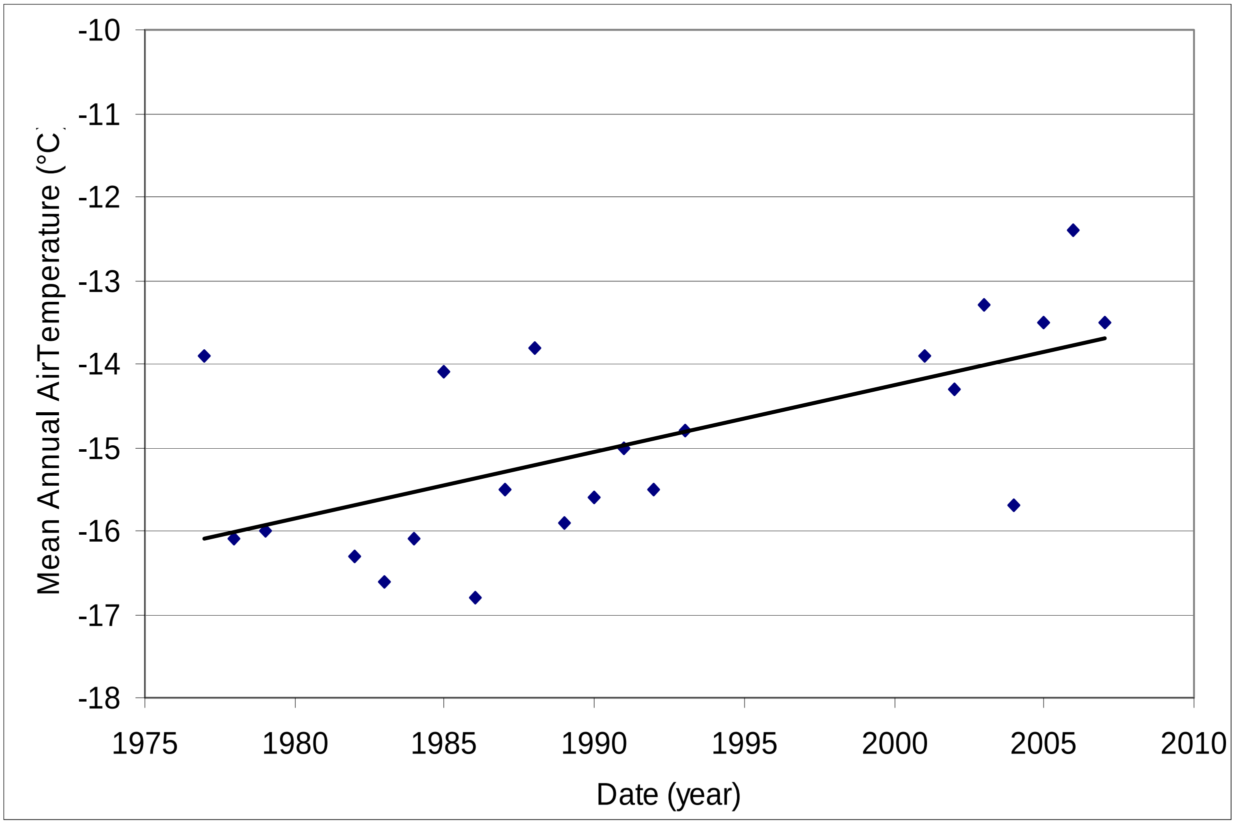


Figure 3-1. Historical variation in mean annual air temperature (1977 through 2007).
Data source: Environment Canada website.

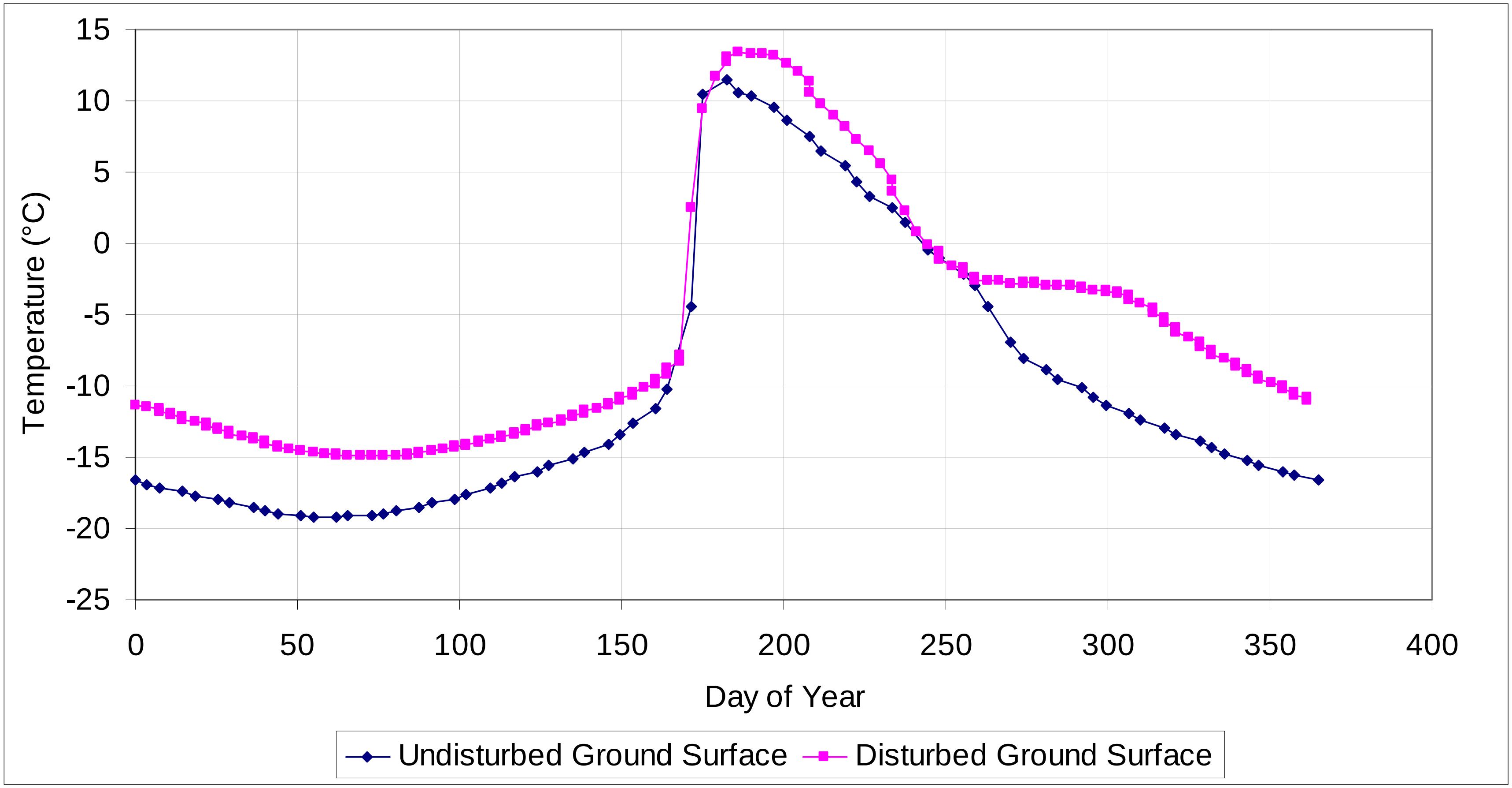


Figure 3-2. Temperature profile with time for undisturbed and disturbed ground surfaces.

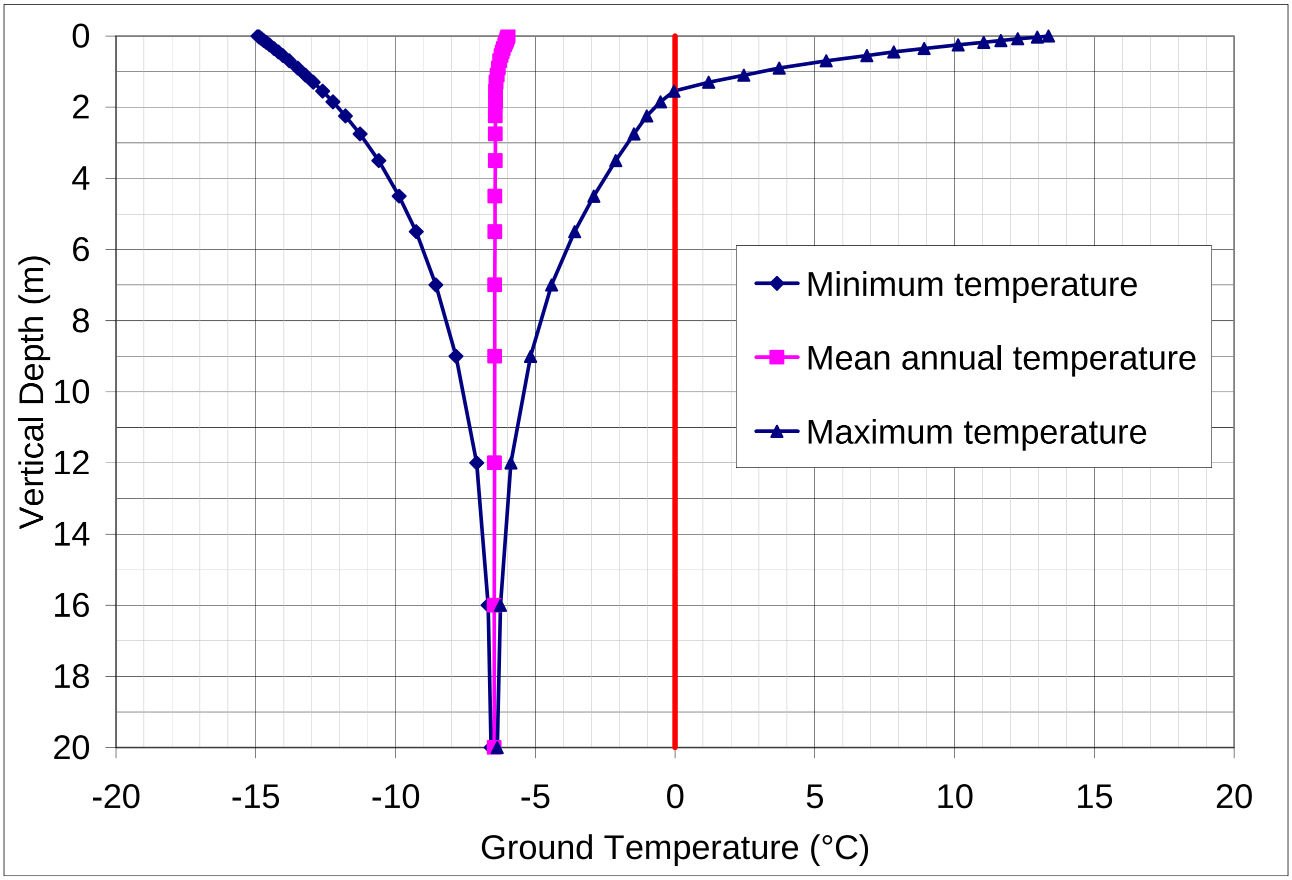


Figure 3-3 Ground temperature profile, based on one-dimensional geothermal modeling.

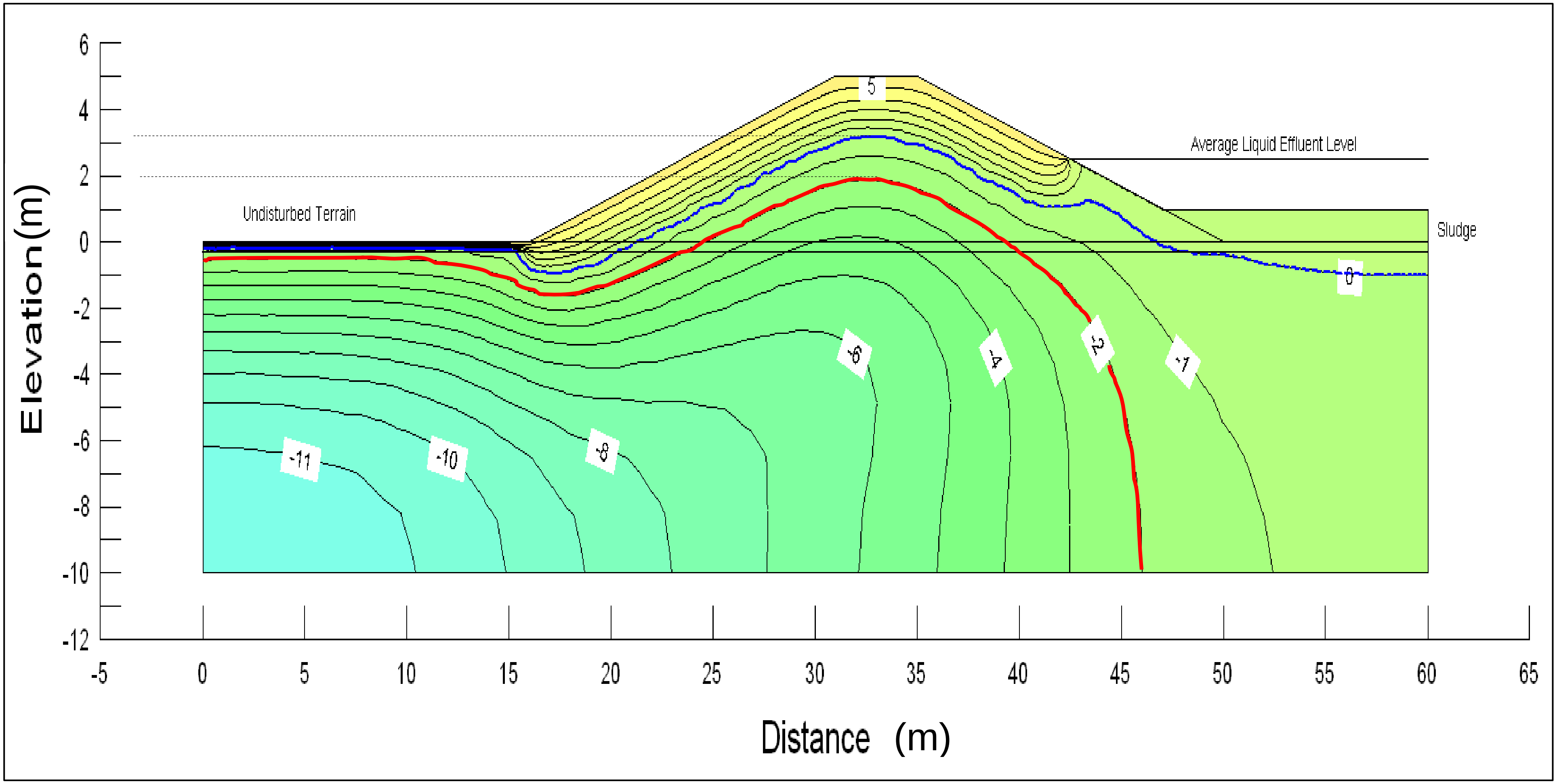


Figure 4-1. Cross-section of dyke structure showing ground temperature contours at maximum thaw during years 1 through 20. No climate warming effects are included.

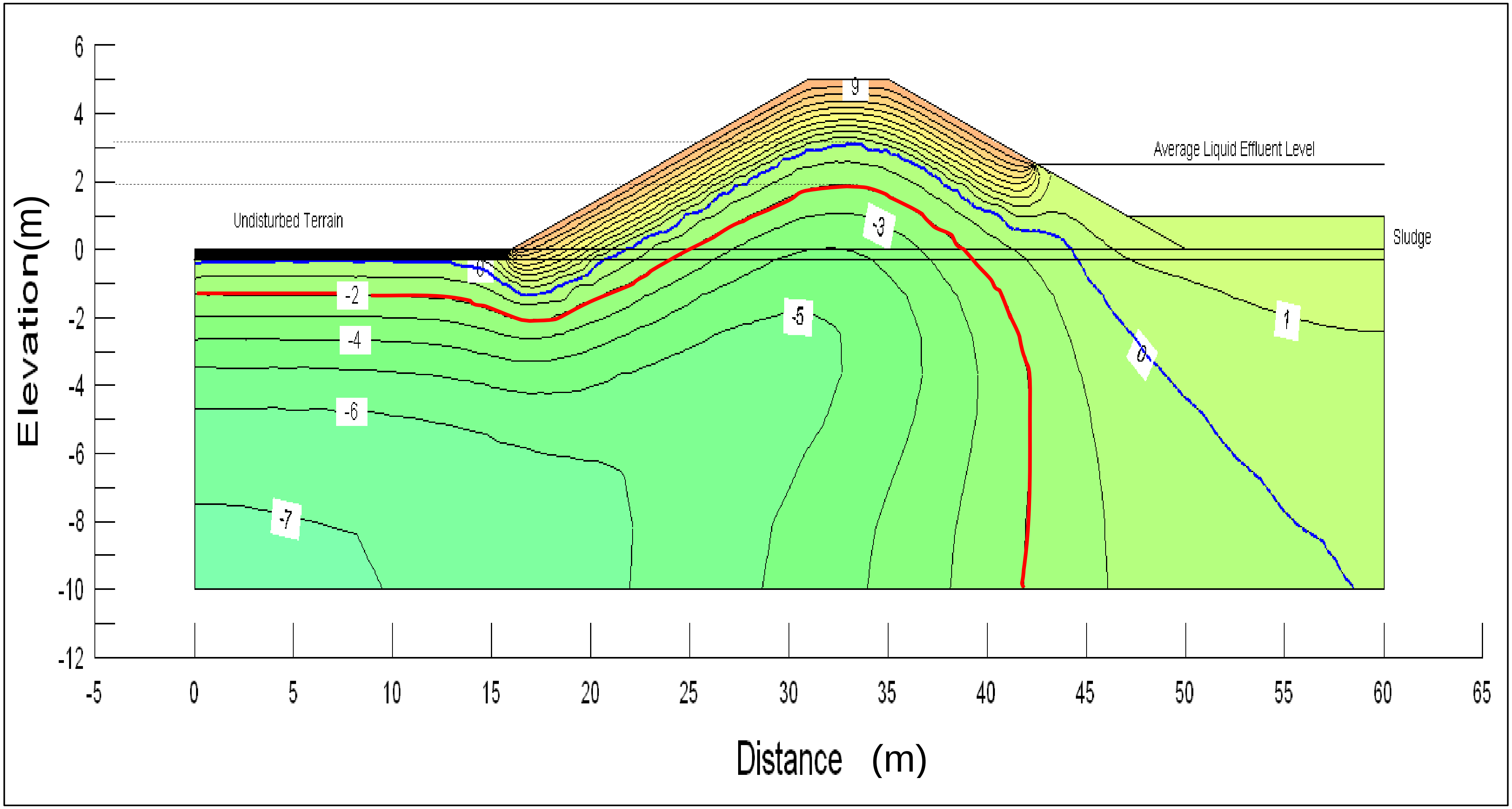


Figure 4-2. Cross-section of dyke structure showing ground temperature contours at maximum thaw after 20 years. Climate warming effects are included.