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Naviq Consulting Inc.
Specialist Geotechnical and Permafrost Engineering

GEOTHERMAL ANALYSIS OF ABANDONED SEWAGE LAGOON

ARCTIC BAY, NU

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REV	DESCRIPTION	ORIGINATOR	REVIEWER	NAVIQ APPROVAL	DATE (DD-MON-YYYY)	CLIENT APPROVAL	DATE (DD-MON-YYYY)
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EXECUTIVE SUMMARY

This report provides details of geothermal analyses conducted in support of the abandonment 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 subsoils and others.

Soil conditions were taken from a geotechnical report prepared for the project by Trow Associates Inc. and published technical literature. Climatic data were taken from Environment Canada climate normals. Based on information provided by **exp** Services Inc. the native soils are presently frozen under the lagoon area, except for the seasonal active layer.

It is understood that the abandonment plan for the lagoon entails the placement of 1.5 m of pit-run soils (capping soil) over the existing lagoon area to encapsulate any lagoon sludge or effluent that may be present.

The objective of the geothermal modeling was to assess the long-term (50 year) impact of climate warming on the potential deepening of the active layer within the capping soil and lagoon contents, which with time could cause any lagoon sludge to thaw and produce leachate.

The geothermal model inputs are described in the report. The mean annual air temperature was assumed to be -12 °C. This is warmer than the Environment Canada climate normal data (1971 – 2000). Mean monthly air temperatures provided by Environment Canada were adjusted to achieve a higher mean annual air temperature. Climate warming was applied to the model using a climate warming rate of 0.1 °C/year. The geothermal simulations were run for 50 years.

Two geothermal model lagoon abandonment scenarios were considered. Case 1 was the baseline case wherein the native soils below the lagoon were frozen to depth except for a shallow seasonal active layer of 1.2 m. It is understood that Case 1 represents the presently known site conditions. Case 2 considered a worst-case scenario wherein a 10 m talik (unfrozen zone) was assumed to be present under the lagoon at the time of abandonment and capping. A one-dimensional model was used for this study. The results are therefore conservative compared to a two-dimensional model, particularly in the case of Case 2 because the simulations ignore edge or lateral boundary effects that would tend to laterally freeze unfrozen soils faster.

The modeling results indicate that with long-term climate warming the surface active layer progresses from an initial depth of 1.0 m to about 1.3 m after 50 years. This is the result for both Case 1 and Case 2. In Case 2, with the initial 10 m talik, the talik naturally freezes back in about 10 years.

REVISION LOG

The following table lists the changes made in this version of the report compared to Revision 0.

Section	Description of Revision
Full report	Minor editorial edits
Section 3.1.4	Deleted subsection regarding salinity in capping soils
Section 5	Additional text discussing impact of soil salinity on thawing of lagoon contents.

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1.0 INTRODUCTION

Naviq Consulting Inc. (Naviq) was retained by **exp** Services Inc. (**exp**) of Ottawa, ON to provide permafrost engineering and geothermal analysis with respect to the abandonment of a municipal waste-water (sewage) lagoon in Arctic Bay, NU.

The scope of work included geothermal modeling to assess the potential impact of long-term (50 year) climate warming on the so-called capping strategy proposed for the abandonment plan for the lagoon. The abandonment strategy entails a plan to infill the lagoon area with approximately 1.5 m of pit-run materials. In the short term this new fill will freeze and encapsulate any lagoon sludge in permafrost, thus immobilizing the sludge. However, in the long-term, with potential climate warming, the capping material and lagoon sludge may thaw and leachate may be generated from the thawed lagoon sludge. The purpose of this study is to assess the potential thawing of the capping soils over the next 50 years.

2.0 GEOTECHNICAL INVESTIGATIONS AND RELATED INFORMATION

A geotechnical investigation in the vicinity of the lagoon site was conducted on August 25 to 30, 2007. Five boreholes were drilled within the general area of the lagoon structure, although no boreholes were drilled within the subject lagoon to be abandoned. 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 reports (Trow, 2007; Trow, 2008).

2.1 Regional Subsurface Conditions

The boreholes at the proposed lagoon site were advanced to depths of 1.6 m to 4.27 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 one of the boreholes (Borehole 5) drilled on the site. The depth to the top of the ice layer was typically about 1.5 m and the ice layer thickness was about 0.5 m.

Bedrock was encountered in one borehole (Borehole 4) at a depth of about 1.5 m.

For the purpose of the geothermal modeling, Table 2.1 presents the assume soil stratigraphy.

Table 2.1 Assumed soil stratigraphy used for geothermal modeling of abandoned lagoon.

Depth (m)	Stratigraphy	Engineering Properties
0 – 0.8	Unsaturated sand gravel, silty, fill	w= 8%; Dry density = 2000 kg/m^3
0.8 – 1.5	Saturated sand gravel, silty, fill	w= 15%; Dry density = 2000 kg/m^3
1.5 – 10	Saturated sand gravel, silty, native	w= 15%; Dry density = 2000 kg/m^3
10 – 25	Bedrock	w= 2%; Dry density = 2600 kg/m^3

2.2 Ground Temperatures

Thermistor cables were installed in two boreholes at the site during the 2007 geotechnical program. The results of the ground temperature monitoring are reported by Trow (2007). In addition, Ednie and Smith (2010) provide stable ground temperature data for the community in a borehole 15 m deep. The Trow (2007) and Ednie and Smith (2010) data are presented in Figure 2.1. The mean annual ground temperature is assumed to be -10 °C.

3.0 GEOTHERMAL ANALYSIS OF ABANDONED LAGOON

The geothermal performance of the abandoned lagoon is a function of the thermal energy balance between the atmosphere and the ground surface on and around the structure. As such, ground surface temperatures vary continuously throughout the year. When climate warming is considered, the seasonal air temperatures increases 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.

Given the assumed large area of the lagoon, a one-dimensional geothermal model was used. In this model the lagoon is assumed to continue for a large distance in both plan directions. Soil properties can be varied with depth, but are constant in the horizontal directions. The use of a one-dimensional model is generally conservative compared to the use of a two-dimensional model. This is because in a one-dimensional model there are no lateral or edge boundary effects that could influence the local geothermal conditions under the lagoon area.

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 (MAAT) for the area is -15 °C, measured for the period 1971 to 2000. 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 mean monthly air temperatures during June, July and

August are -0.4 °C, + 4.9 °C, and +1.5 °C, respectively. Winter mean monthly air temperatures during December, January and February are -26.6 °C, -29.2 °C, and -30.3 °C, respectively (1971 – 2000 climate normal data).

3.1.2 Ground Temperatures and Permafrost Depth

Ground temperatures were measured at the proposed lagoon site by Trow (2007) during their geotechnical investigations. In addition, recent research published by Ednie and Smith (2010) provide stable ground temperature data for Arctic Bay. Figure 2.1 present these data.

The mean annual ground temperature, based on the published data, has been taken as -10 °C.

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

3.1.3 Climate Warming

Climate warming is assumed to be active and should be accounted for in the design of the soil in-filled lagoon 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 2010. 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 0.1 °C/year, which is slightly warmer than the Baffin Island regional climate warming rate of 0.08 °C/year. The use of a higher climate warming rate is conservative.

Given recent climate warming, the 1971 – 2000 climate normal data are considered to be non-conservative. The MAAT data since about 2007 suggests that the MAAT may be closer to -12 °C. Based on this, the mean monthly air temperatures have been adjusted to achieve a MAAT of -12 °C rather than -15 °C. Figure 3.2 presents the long-term mean monthly air temperatures (1971 – 2000 climate normal data) and the adjusted air temperatures used for this modeling. The adjusted values are conservative relative to the historical data.

If projected forward for a period of 50 years, the mean annual air temperature may rise by approximately 5 °C.

Climate warming was incorporated into the geothermal modeling by adjusting the air temperature during the simulation.

3.1.4 Initial Lagoon Soil Temperatures

It is understood that there is no long-term talik present under the existing lagoon area. Normal seasonal active layer thawing occurs each year, estimated to be in the order of 1.0 m.

The mean annual ground temperature at depth has been assumed to be -10 °C, based on published data.

Capping soils placed over the lagoon area were assumed to be +1 °C (on average) at the time of installation.

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. In some cases metrological data was not available from data at the Nanisivik or Arctic Bay airports. In these cases data from Pond Inlet was used. 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 Arctic Bay was input to the model, and calibration was performed such that the model-calculated steady state ground (non-climate warming) temperature profile in undisturbed terrain at depth were 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 values for air temperature, snow cover, wind speed and solar radiation along with ground surface parameters of winter and summer ground surface albedo, and summer evapotranspiration factor. Snow thermal conductivity was the only parameter varied to achieve model-computed ground temperatures that were consistent with representative ground temperatures for undisturbed terrain in Arctic Bay.

For the purpose of this modeling two modeling scenarios for lagoon abandonment were considered:

Case 1. Frozen ground reflecting currently known conditions
Case 2. Talik to 10 m depth initially, reflecting conservative, worst case initial conditions

Case 1 reflects the geothermal conditions in the ground as they have been reported by **exp**, and thus represent realistic current conditions. Case 2, represents a potentially worst case scenario wherein an unidentified 10 m deep talik is present at the time of abandonment, such as might be formed if liquids were present within the lagoon all-year long. The purpose of Case 2 is to examine how long the talik will take to freeze back once abandonment and placement of the soil cap is complete.

For these analyses, it was assumed that the fill soils and active layer will have an initial average temperature of +1 °C. For the numerical modeling, it assumed that the lagoon capping soil is “instantaneously” constructed/placed in the first year.

For case 2, the talik was assumed to be 10 m deep and ground temperatures initially varied linearly from +1 °C at ground surface to 0.0 °C at 10 m depth.

3.4 Modeling Software

The numerical analyses were performed using the finite element software application TEMP/W 2007 (Geo-Slope 2007) combined with a surface energy balance (SEB) add-on module developed by Ardent Innovation Inc. The SEB calculation module is based on the SEB calculation methodology developed by Hwang (1976) and has been successfully been used on numerous geothermal analysis projects over the past several years.

The geothermal model is capable of analyzing complex problems and has been successfully calibrated to a wide range of close-form solutions to ensure that the numerical methods are correct and robust.

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 for input parameters and boundary conditions. If these values are representative of the actual conditions, then the results should be reasonably representative of the future conditions.

For design purposes, it is proposed that the “adjusted” design temperature be assigned as -1 °C. This value is chosen as a conservative measure and represents a “geothermal factor of safety”, in so far as conventional factors of safety cannot be applied to these analyses.

The initial ground temperature regime for the top 25 m of undisturbed terrain in Arctic Bay as predicted by the geothermal model is presented in Figure 4.1. Comparison of this ground temperature curve to that shown in Figure 2.1 for actual ground temperature data by Ednie and Smith (2010) shows a close relationship between the two temperature profiles. In the predicted ground temperature profile the active layer is estimated to be about 1 m, which is consistent with the data reported by Trow (2007) and stated in Section 2.1 above.

Table 4.1 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/ m^3-°C)	Heat Capacity Frozen (kJ/ m^3-°C)
Unsaturated Sand & Gravel	2.40	2.50	0.08	0.02	-0.40	2000	2090	1760
Saturated Sand & Gravel	2.70	3.80	0.15	0.02	-0.40	2000	2710	2060
Bedrock	4.00	4.00	0.02	0.005	-0.90	2600	2070	1960

Table 4.2 Climatic data for input to geothermal model.

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Adjusted Air temperature (°C)	-26.2	-27.3	-24.8	-17	-7.7	+2.6	7.9	4.5	-2.6	-11.9	-197	-23.6
Snow depth (cm)	19	18	20	22	23	6	0	0	2	10	16	17
Wind velocity (km/hr)	7.1	6.4	7.1	7.8	8.6	8.6	9.7	10.3	11.7	13.8	9.5	7.8
Monthly solar radiation (W/m^2)	1	10.7	67.8	169.5	266.3	280.9	217.9	128.3	16.9	19.4	3.4	0
Note: Air temperature and solar radiation are taken from Nanisivik airport data. Snow depth and wind velocity are taken from Pond Inlet airport data because no equivalent data was available for Arctic Bay/Nanisivik airports.												

Table 4.3 Surface energy balance input parameters.

Parameter	Value
Snow thermal conductivity (W/m-°C)	0.20
Summer albedo (ground surface)	0.20
Winter albedo (snow)	0.85
Evapotranspiration factor (summer only)	0.40
Greenhouse factor	0.83
Last snow cover day of year (Ordinal day)	171
First snow cover day of year (Ordinal day)	250

4.1 Case 1 – Climate Warming Effects on Active Layer Depth for Initially Frozen Conditions

The geothermal analysis assumed the entire soil cap was instantaneously constructed and in-place on the native lagoon subgrade soil in the first year. The initial temperature of the capping soils was assumed to have an average temperature of +1 °C through its 1.5 m thickness.

The analysis showed that the active layer (taken as the 0 °C isotherm) initially aggrades into the capping soil over the first five years after placement and then the active layer begins to deepen somewhat as a result of climate warming. After 50 years the active layer has advanced from an initial depth of 1.0 m to about 1.3 m. The -1 °C isotherm follows a similar trend, aggrading into the capping soil for the first five years and then slowly deepening with time.

Figure 4.2 presents the isotherm depths with time for the Case 1 scenario.

The slope of the stable portion of the curve, taken as the 20 year to 50 year period for the 0 °C isotherm is approximately 0.008 m/year of active layer deepening in response to a climate warming rate of 0.1 °C/year.

The slope of the stable portion of the curve, taken as the 25 year to 50 year period for the -1 °C isotherm is approximately 0.020 m/year of active layer deepening in response to a climate warming rate of 0.1 °C/year.

4.2 Case 2 - Climate Warming Effects on Active Layer Depth for Initial 10 m Deep Talik

In this scenario, the capping soils are placed instantaneously in the first year. With a talik present to 10 m depth, the unfrozen soil will begin to freeze back from the ground surface and from the permafrost below the talik. As a result of the cooling of the talik soils at depth, the permafrost below the talik actually warms gradually until the talik is fully frozen.

It is estimated that the 10 m deep talik will freeze-back within 5 to10 years after abandonment. These results are likely conservative in that the freeze-back ignores any contribution of lateral freezing from the edges of the talik. Figure 4.2 presents the freeze-back behaviour graphically.

During and after freeze-back, the surface active layer is generally behaving in a manner similar to Case 1. After 50 years, the surface active layer has progressed from an initial depth of 1.0 m to a depth of about 1.3 m.

The -1 °C isotherm follows a similar trend, aggrading upward towards the capping soil for the first ten years and then slowly deepening with time.

Figure 4.2 presents the isotherm depths with time for the Case 2 scenario.

The slope of the stable portion of the curve, taken as the 20 year to 50 year period for the 0 °C isotherm is approximately 0.008 m/year of active layer deepening in response to a climate warming rate of 0.1 °C/year. The slope is the same as for Case 1.

The slope of the stable portion of the curve, taken as the 25 year to 50 year period for the -1 °C isotherm is approximately 0.02 m/year of active layer deepening in response to a climate warming rate of 0.1 °C/year. The slope is the same as for Case 1.

5.0 DISCUSSION OF MODELING RESULTS AND IMPLICATION TO LAGOON ABANDONMENT

Section 3 described the various geothermal model inputs and the analyses that were 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 abandonment strategy.

Based on the geothermal modeling conducted for this study, it appears that after 50 years of climate warming at a constant rate of 0.1 °C/year the seasonal active layer will deepen only marginally by about 0.3 m.

Published literature has looked at predicted active layer deepening as a result of climate warming. Woo, Mollinga and Smith (2007) examined potential active layer deepening in the western Canadian Arctic for several sets of site conditions and climate change scenarios. For the scenario of tundra mineral soils with no surface organic layer, for an approximate period of 29 years (for the period 2021 through 2050), the estimated rate of active layer deepening was 0.006 m/year. This compares quite favourably to the currently estimated active layer deepening rate of 0.008 m/year.

The slope of the active layer thickness with time is, to a large extent, independent of the initial active layer thickness or possible talik. In this modeling an initial active layer thickness of 1.0 m has been used. But if the actual active layer is somewhat deeper or shallower, the annual change in thickness will be approximately the same.

The current modeling suggests that over the next 50 years the 0 °C isotherm will not penetrate to the base of the capping soils. The -1 °C isotherm will, after about 15 years, aggrade to a position at the interface of the capping soils and the in-situ lagoon soils, and then deepen to a depth of about 2 m, which is higher than it was at the time of abandonment.

Salinity effects should be considered in regard to the lagoon contents. The purpose of the completed analyses was to assess the long-term deepening of the active layer and the potential thawing of the lagoon contents. The effect of salinity is to depress the freezing and thawing temperature of soils. For soils with a salinity of about 17 PPT the freeze-thaw temperature is -1 °C; for soils with a salinity of about 32 PPT (normal seawater) the freeze-thaw temperature is -2 °C. To a large extent, the salinity of the capping soils is immaterial because it is the thawing temperature of the underlying lagoon contents that will govern leachate production. For example, if the lagoon contents thaw at -0.5 °C, then it is the depth of that particular isotherm that governs thawing of the lagoon contents, independent of the thawing temperature of the capping material.

6.0 CLOSURE

This report has been prepared for the exclusive use of **exp** Services 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.

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NAPEG Permit to Practice: P611

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APPENDIX A

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TERMS AND CONDITIONS

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   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 by Naviq.

   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 cannot 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

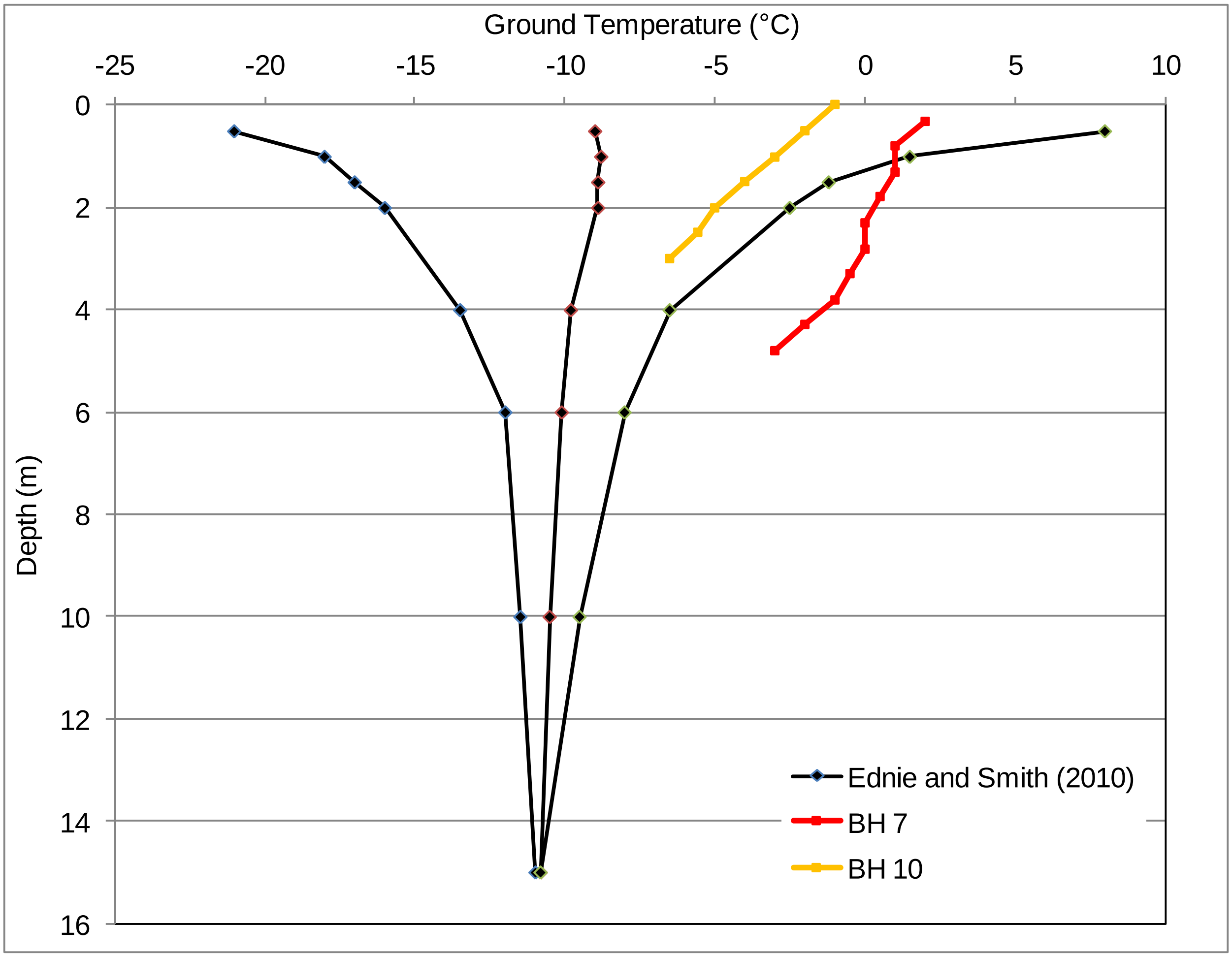

Figure 2.1 Ground temperature data for Arctic Bay from Ednie and Smith (2010) and data from Trow (2007).

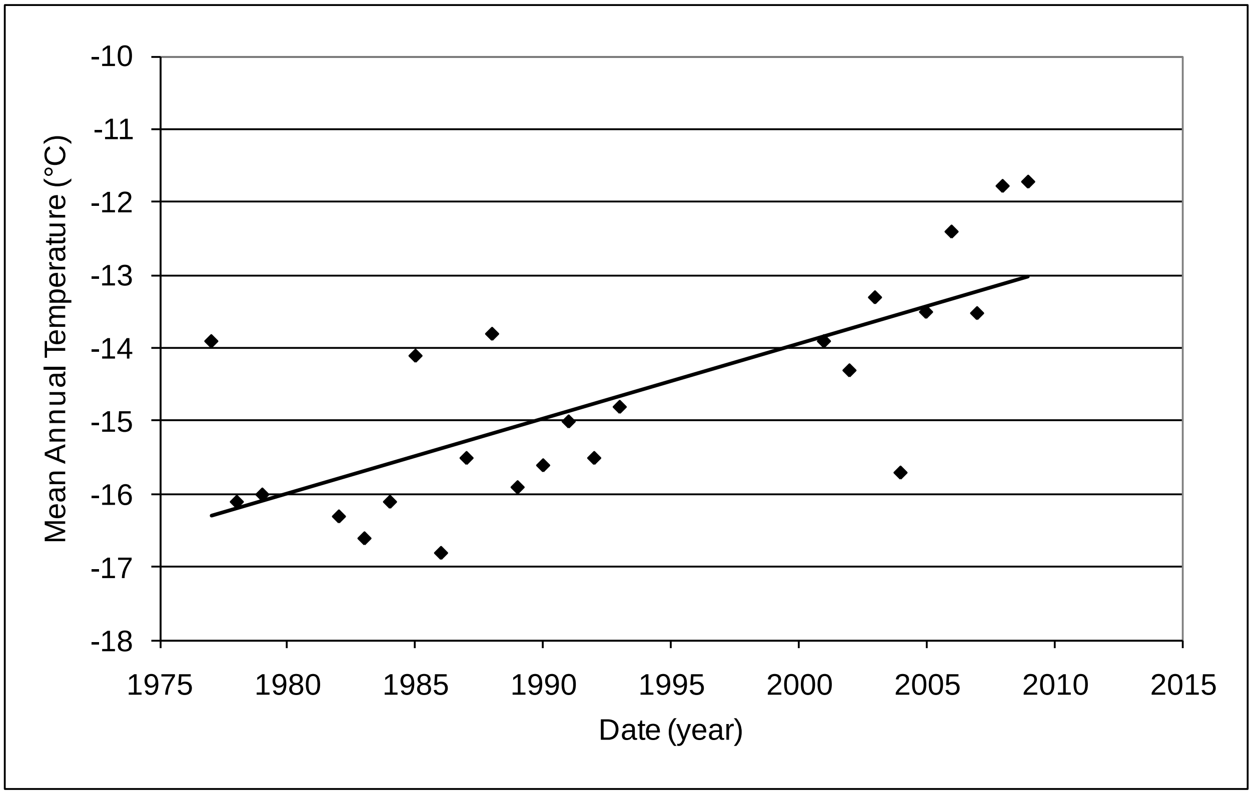

Figure 3.1 Historical variation in mean annual air temperature (1977 through 2007).
Data source: Environment Canada website.

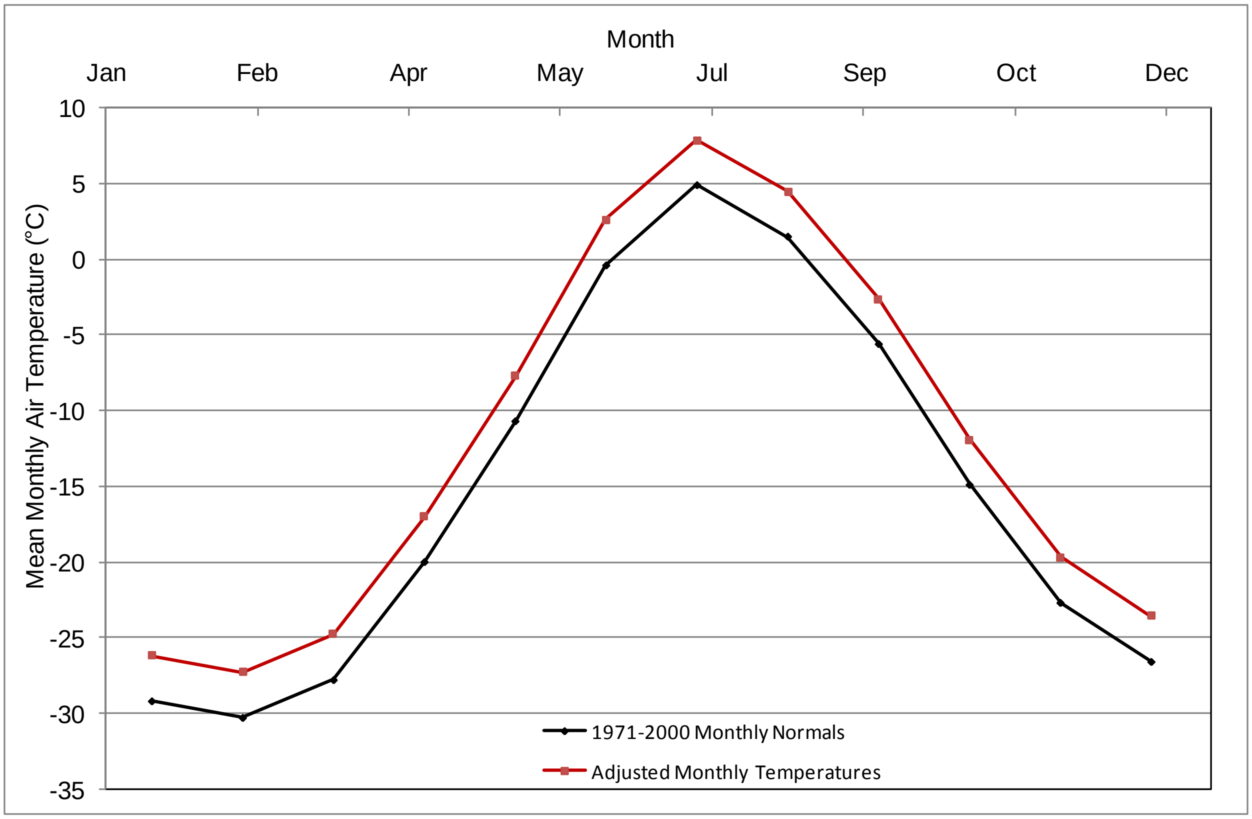

Figure 3.2 Mean monthly air temperatures for Nanisivik. Temperature curves represent 1991-2000 climate normals and adjusted monthly data to account for recent climate warming. (Data from Environment Canada website.)

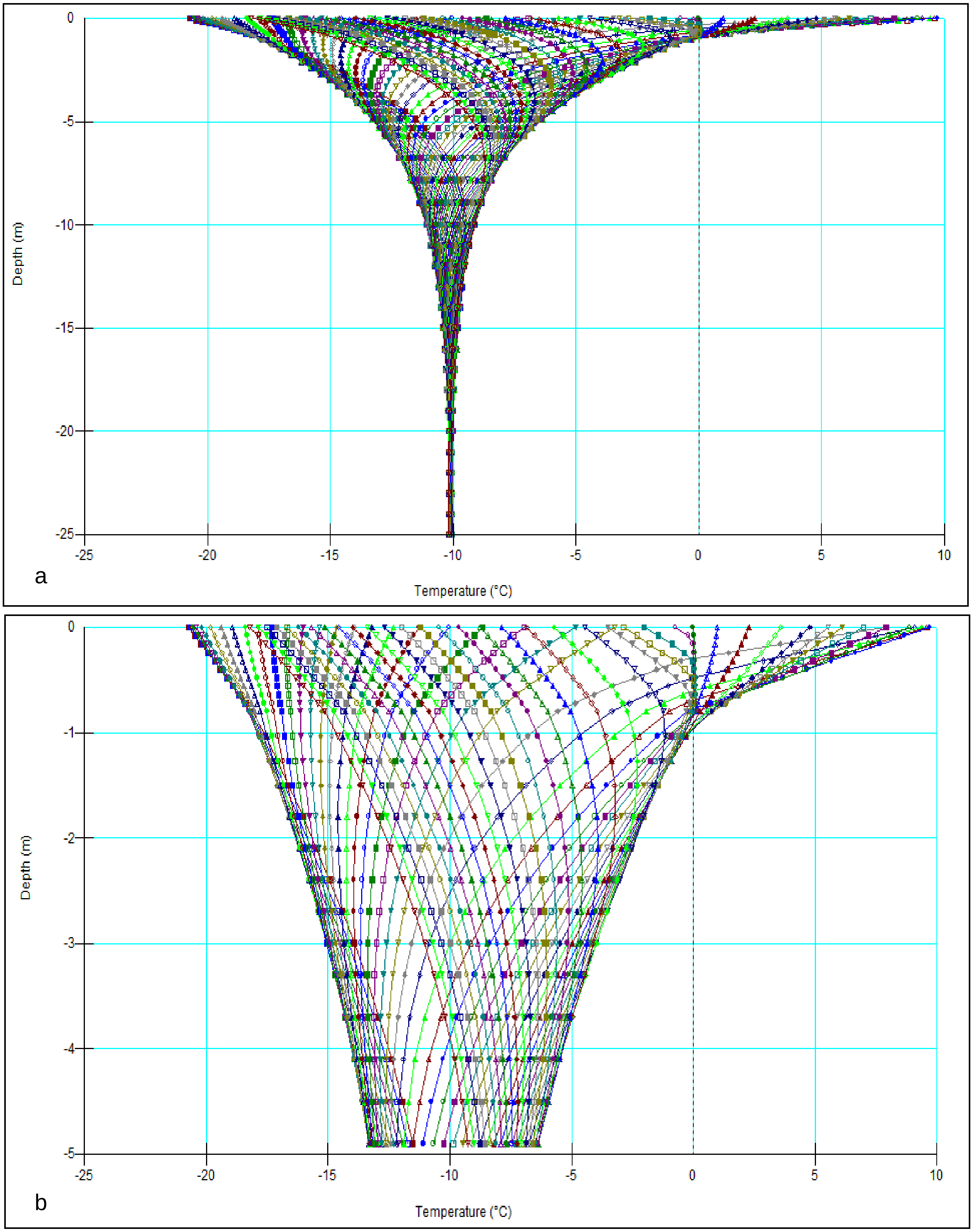

Figure 4.1. Ground temperature profile based on geothermal modeling: (a) profile to 25 m depth and (b) expanded profile for upper 5 m showing active layer depth of 1.0 m.

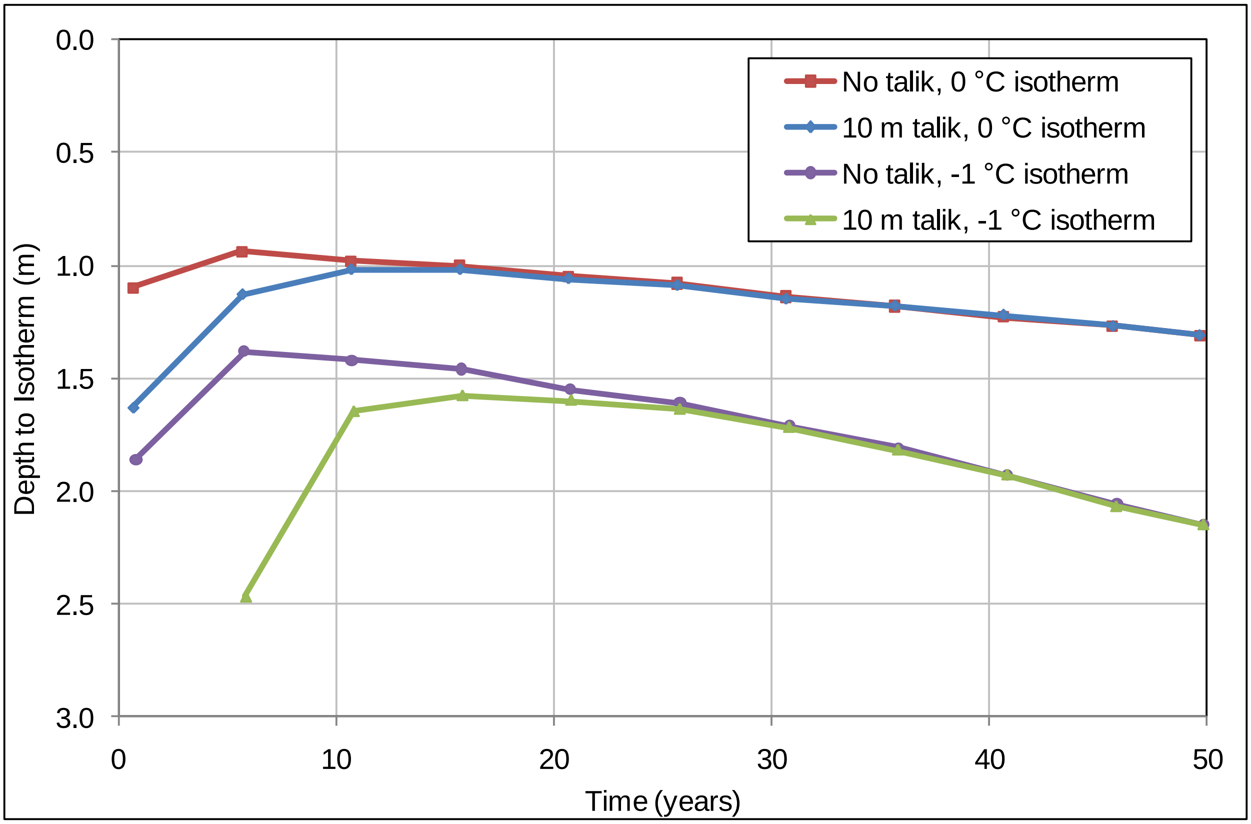

Figure 4.2. Depth of 0 °C and -1 °C isotherms for Case 1 and Case 2. The depth of 0 m represents the top of the capping soils placed at the time of abandonment. The top of the native soil/lagoon sludge is located at depth 1.5 m.