

# **BGC ENGINEERING INC.**

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## **AN APPLIED EARTH SCIENCES COMPANY**

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### **PROJECT MEMORANDUM**

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<b>To:</b>	<b>Wolfden Resources</b>	<b>Fax No.:</b>	<b>By email</b>
<b>Attention:</b>	<b>Andrew Mitchell</b>	<b>CC:</b>	
<b>From:</b>	<b>Ron Coutts / Jim Cassie</b>	<b>Date:</b>	<b>May 17, 2007</b>
<b>Subject:</b>	<b>Regulator Response – Permafrost Aggradation in Roadfill Embankment High Lake Project, Nunavut</b>		
<b>No. of Pages (including this page):</b>	<b>12</b>	<b>Project No:</b>	<b>0385-003-22.3</b>

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#### **REGULATORY QUESTION**

Wolfden has proposed to place roads, comprised of earth or rock fill embankments over native undisturbed terrain conditions, in order to cut-off shallow active layer seepage that may occur between various water bodies proximal to High Lake. Regulators requested additional thermal information to validate that the embankments would remain frozen for both operations and in the long term.

#### **RESPONSE**

In natural permafrost terrain, shallow groundwater flow can occur during the warm summer months when active layer thaw creates the potential for hydraulic connection, especially between nearby water bodies. When High Lake is converted into a tailings facility, it will be necessary to cut-off this potential seepage path to prevent any environmental impacts from TCF seepage into nearby natural lakes. The typical method of mitigating this potential issue is to place roadfill (various materials are possible) embankments, required for site access anyways, across areas of potential active layer seepage. The placement of an appropriate thickness of fill in winter then moves the active layer within in the roadfill section, causing the underlying permafrost to cool. This phenomena is sometimes referred to as “permafrost aggradation.” This has been successfully demonstrated in numerous northern projects including the tailings dams at Lupin Mine (NU) and the water management dams at the Snap Lake Project (NT).

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From the project's perspective, it is necessary to design an appropriate roadfill thickness that contains the active layer within the roadfill over some appropriate design period. As noted in the project description, Gartner Lee has estimated that TCF water discharge could occur in Year 16 (2 years into closure beyond 14 year mine life) when discharge compliant pond water will occur. If the pond water is compliant for discharge to the receiving environment, the Kennarctic River, then it is also assumed that compliant water seepage into nearby water bodies would be allowable. As such, it is necessary to estimate a roadfill thickness that will contain the active layer for approximately 16 to 20 years after road construction, or 2 to 6 years following an assumed 14 years of mine life.

Potential roadfill materials used for road construction at the mine site comprise the two following choices:

- Run-of-mine (ROM) rockfill derived from stripping and waste rock from open pits. This material is of variable size from cobbles and boulders down to gravel and sand.
- Esker sand and gravel, with some cobbles, derived from any nearby granular deposits.

Usually economic considerations will dictate which material is used for final construction. Both materials, except for occasional massive ground ice inclusions, contain relatively low moisture contents. The first material, the ROM rockfill, would have slightly lower moisture content versus the esker sand and gravel.

In order to validate this approach, BGC Engineering Inc. (BGC) undertook one dimensional (1D) geothermal modelling to validate the permafrost aggradation concept. This modelling was based on previous geothermal modelling undertaken for the High Lake dams, as reported in BGC (2007).

The modelling was performed using THERM2 by Nixon Geotech which includes a rigorous surface energy balance calculation and as such, does not require the use of n-factors to determine ground surface temperatures. Input to the model included soil material properties, climate data, and surface energy balance parameters presented in Tables 1 to 3, respectively. It should be noted that the roadfill material used in the model was the ROM rockfill which has lower moisture content than the esker sand and gravel. Use of the material with lower moisture content results in a deeper active layer, and thus, is considered to be a conservative modelling selection.

It should also be noted that the model does not account for convective heat transfer due to shallow groundwater flow. However, the low expected hydraulic gradients likely validate relatively low seepage quantities and associated heat flow considerations.

Three runs were performed using a 1D grid to a depth of 23 m. No geothermal gradient was applied at the base of the model due to the fact that the modelled depth was very shallow. The application of a geothermal gradient was an unnecessary complication that would have had no significant effect on the computed temperatures.

The three runs that were performed are summarized as follows:

- Run 1 – Calibration run to ensure that model calculated initial ground temperature of  $T_g = -4\text{C}$ . Calibration was performed by varying snow thermal conductivity. Model was run for 15 years.
- Run 2 – Used same model as in Run 1, but 2.5 m of road rockfill was added and a climate warming rate of  $0.05\text{C/yr}$ . The model was run for 14 years of operations with 20% of the normal snow cover to simulate roadway snow clearing during the winter months and with modified surface summer albedo and evapotranspiration surface energy balance parameters representative of the gravel road surface.
- Run 3 – Used same model as in Run 2, but reinstated the snow cover depth and surface summer albedo inputs to those used in Run 1 and ran the model for 120 years. Use of the normal snow cover depth reflects the fact that the roadway is not cleared of snow after operations cease. The reinstatement of the summer albedo values reflects the fact that likely within 5 to 10 years after the cease of operations, natural vegetation will cover the old roadway. The post-operations evapotranspiration value for the roadway was set to an intermediate value between the undisturbed terrain and the operational roadway to reflect the fact that not as much water may be available for evapotranspiration on the old roadway. It should be noted that at the end of Run 2, the mean annual ground temperature (MAGT) was nominally  $-8.2\text{C}$ . Therefore, Run 3 was started using an initial ground temperature of  $-8.2\text{C}$ .

Results from the geothermal modelling are shown in Figures 1 through 5. Figure 1 shows the temperature envelope profile from the calibration run (Run 1) showing that a MAGT of  $-4\text{C}$  was computed by the calibrated model. This is consistent with ground temperatures measured at dam sites, but is warmer than natural permafrost at the site.

Figure 2 shows the temperature envelope profile after 10 years of roadfill placement. A plot of the temperature profile after 14 years was not produced because of software limitations. However, it should be noted that the temperature profiles shown in Figure 2 are virtually identical to and therefore representative of the temperatures at the end of the 14 year operating period, as evidenced by the active layer depth with time shown in Figure 3. The maximum active layer depth does not change between years 10 and 14 as shown in Figure 3, therefore the temperature profiles shown in Figure 2 are representative of the thermal state after 14 years. It should also be noted that the MAGT drops to nominally  $-8.2\text{C}$ , due to the presence of the snow-cleared roadway, as shown on Figure 2.

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Figure 4 shows the subsurface thermal regime 10 and 20 years after closure. With the applied warming factor, the ground temperatures are  $-4.5^{\circ}\text{C}$  and  $-3^{\circ}\text{C}$  after 10 and 20 years respectively.

Figure 5 shows the long term thaw with time after operations. As shown on the figure, the thaw depth increases incrementally each year. After nominally 15 years, the thaw depth reaches the bottom of the road rock fill. It should also be noted that it takes an additional 20+ years for the thaw front to penetrate an additional 0.5 m to 3.0 m depth from the road surface, implying that additional road fill could be used to lengthen the time for the thaw front to reach the original ground surface.

In summary, the modelling results clearly show that construction of a roadway in winter will move the active layer up into the roadway. Hence, the original native active layer will remain frozen for at least 15 years after operations cease, or equivalently, for approximately 30 years after the start of mining operations at High Lake.

The information provided herein is based on simplified 1D modelling of assumed ground conditions. As such, the modelling information validates the proof-of-concept relative to permafrost aggradation over a 30 year time period, including an allowance for global warming. This information provided herein does not represent a final design for any actually constructed structure. Location specific geothermal analyses, using site specific ground conditions and material parameters, should be undertaken during the final design phase to provide site specific design recommendations. It is possible that other seepage control, including the use of geosynthetic materials, may be required in isolated area to control active layer seepage.

We trust the enclosed provides the required information. Please contact the undersigned should you have any questions or comments.

Respectfully submitted

**BGC Engineering Inc.**

per:



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Senior Geothermal Specialist



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Specialist Geotechnical Engineer

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**REFERENCES:**

BGC Engineering Inc., 2007. High Lake Project, NU, Geothermal Modelling of Tailings Dams.  
Memo produced for Wolfden Resources, April 26, 2007, 16 pages plus figures

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## TABLES

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**Table 1: Climate Data for THERM2 Geothermal Analysis**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg.
Mean monthly air temperature <sup>1</sup> (°C)	-30.1	-30.2	-27	-17.8	-6.2	4.4	10.1	8.3	2	-8.2	-20.6	-26.8	-11.8
Mean monthly snow depth <sup>1</sup> (cm) <sup>1</sup>	28	33.5	37.5	39.5	29	5	0	0	0.5	8	17	23	18.4
Mean monthly Wind Speed <sup>1</sup> (km/hr) <sup>1</sup>	20.7	20.1	18.4	16.9	17.3	16.8	17.1	18.5	19.6	20.2	18.9	19.8	18.7
Mean monthly solar radiation <sup>1</sup> (W/m <sup>2</sup> )	2.2	21.1	87.6	185.5	251.8	268	214.5	138.5	71.7	33	4.5	0	106.5
Mean monthly snow depth on cleared roadway (cm)	5.6	6.7	7.5	7.9	5.8	1.0	0.0	0.0	0.1	1.6	3.4	4.6	3.7

<sup>1</sup> Source: Environment Canada Website

**Table 2: Geologic Material Thermal Properties**

Material	Unfrozen Thermal Conductivity (W/m°C)	Frozen Thermal Conductivity (W/m°C)	Moisture Content (%)	A	B	Dry Density (Mg/m <sup>3</sup> )
Rock Fill	2.00	1.85	5.0	0.001	-1.00	2.00
Silty Sand Till	2.30	2.30	5.0	0.005	-0.80	2.00
Fractured Bedrock	3.00	3.00	2.0	0.002	-1.00	2.54
Intact Bedrock	3.30	3.30	1.0	0.001	-1.00	2.62

Notes:  
 Thermal conductivities from charts in Andersland and Ladanyi, 2004.  
 Moisture contents and dry densities estimated based on material type.  
 Parameters A and B define unfrozen moisture function  $W_u = A(-T)^B$ .

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**Table 3: Surface Energy Balance Parameters**

Parameter	Undisturbed Terrain	Roadway During Operations	Roadway Post-Operations
Snow Thermal Conductivity (W/m°C)	0.120		
Summer Albedo	0.25	0.20	0.25
Winter Albedo	0.85		
Evapotranspiration Factor	0.50	0.25	0.40
Greenhouse Factor	0.83		
Last Snow Day	152		
First Snow Day	277		

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## FIGURES

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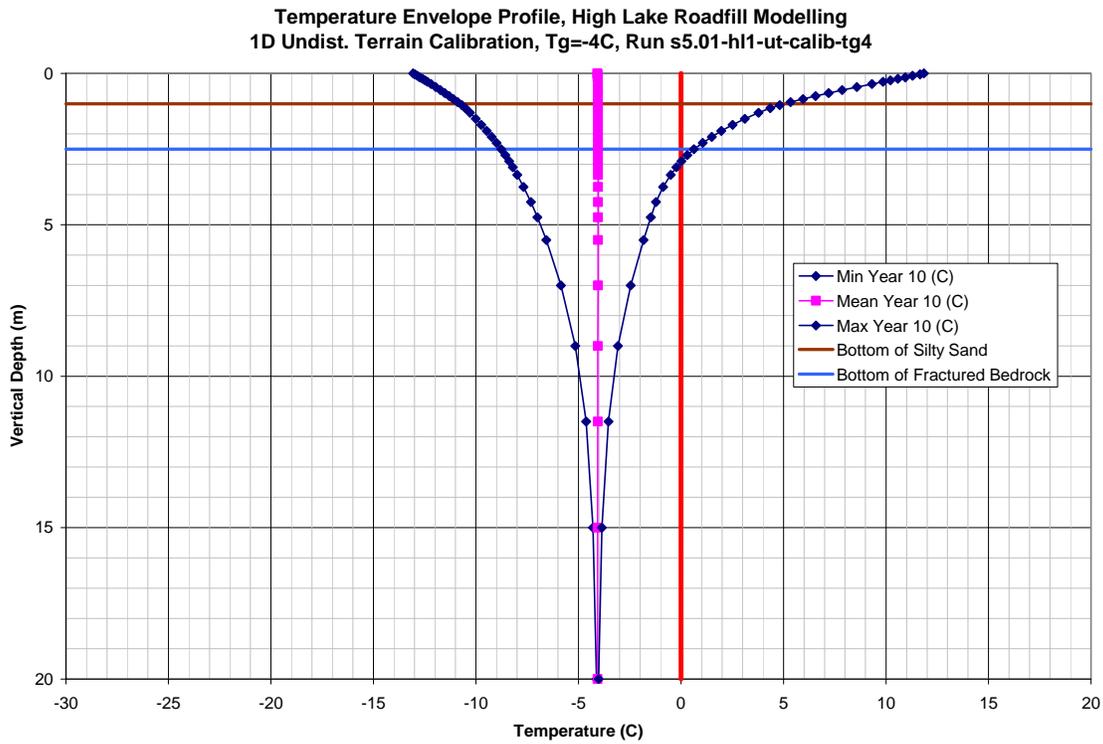


Figure 1 Temperature Envelope Profile, Run 1, Calibration

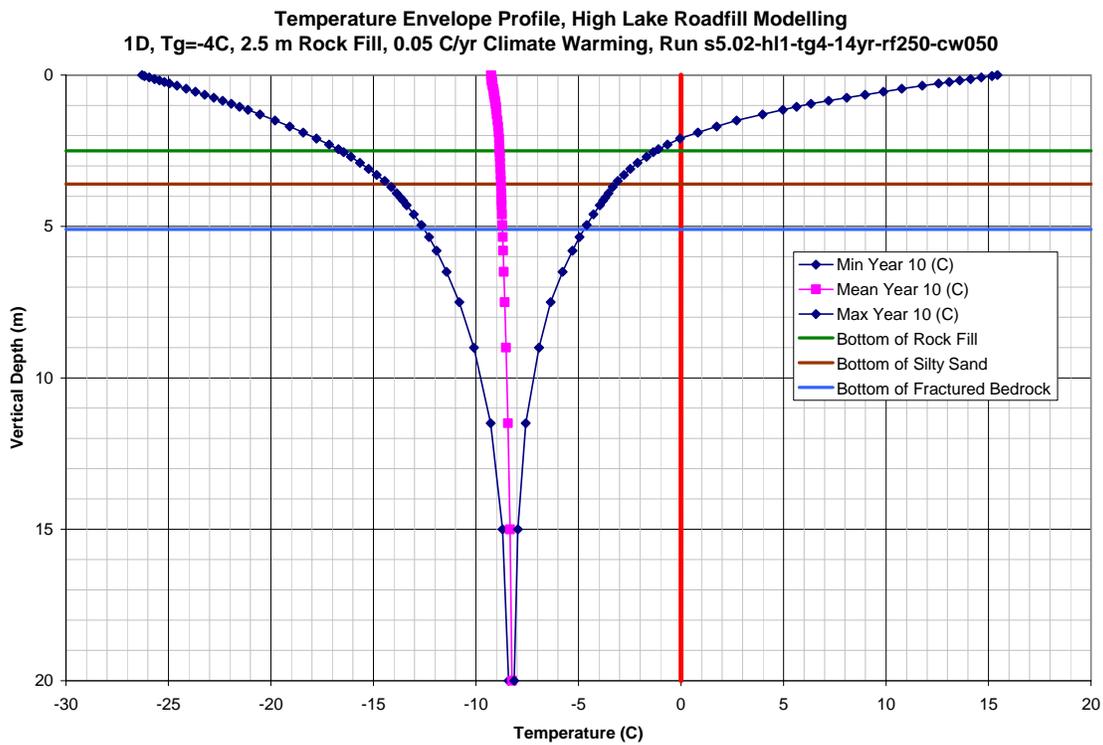


Figure 2 Temperature Envelope Profile, Run 2, after 10 Years

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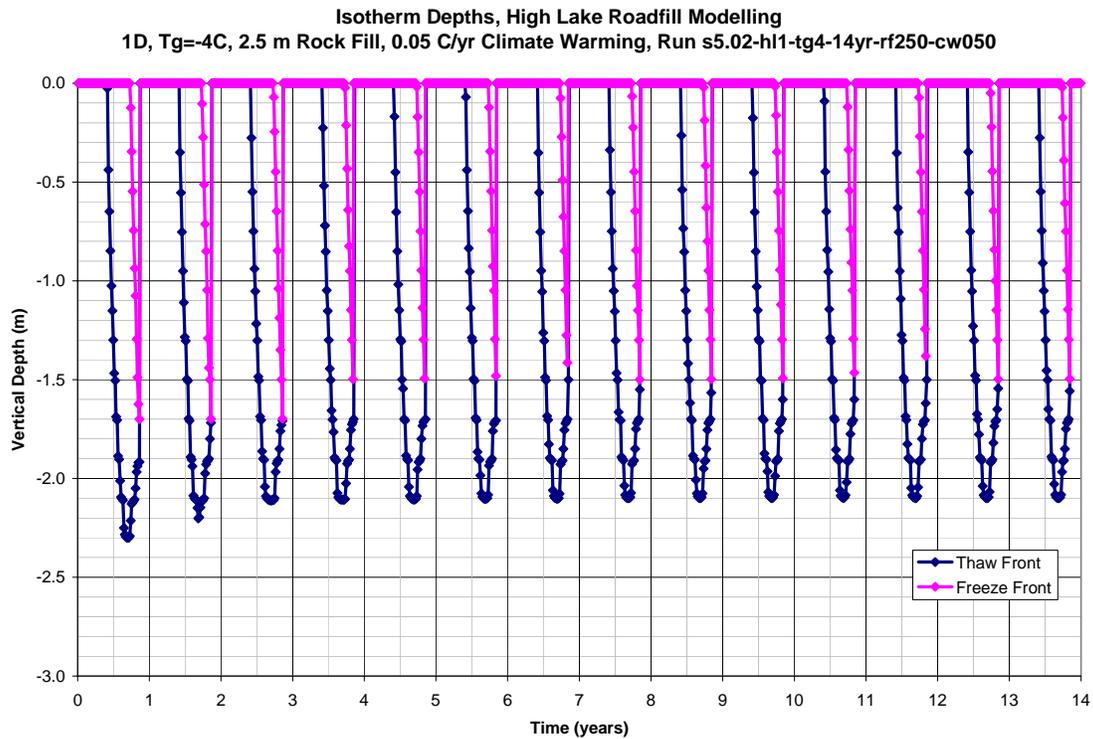


Figure 3 Active Layer Depth, Run 2, During Operations (14 Years)

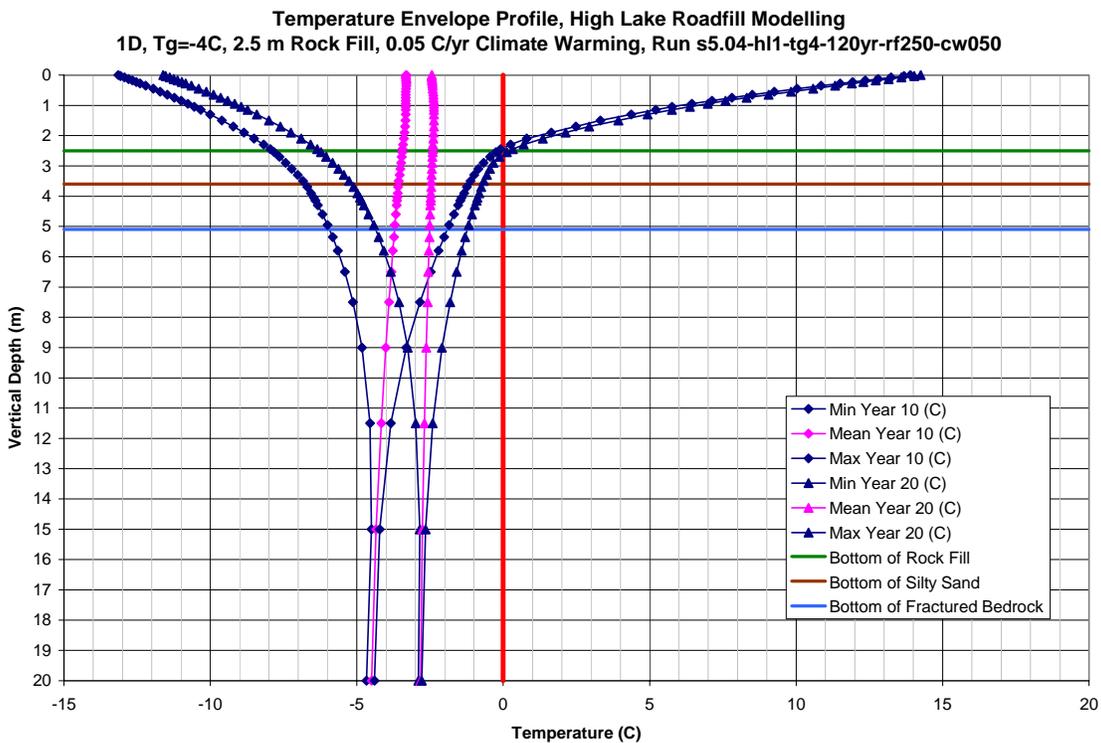
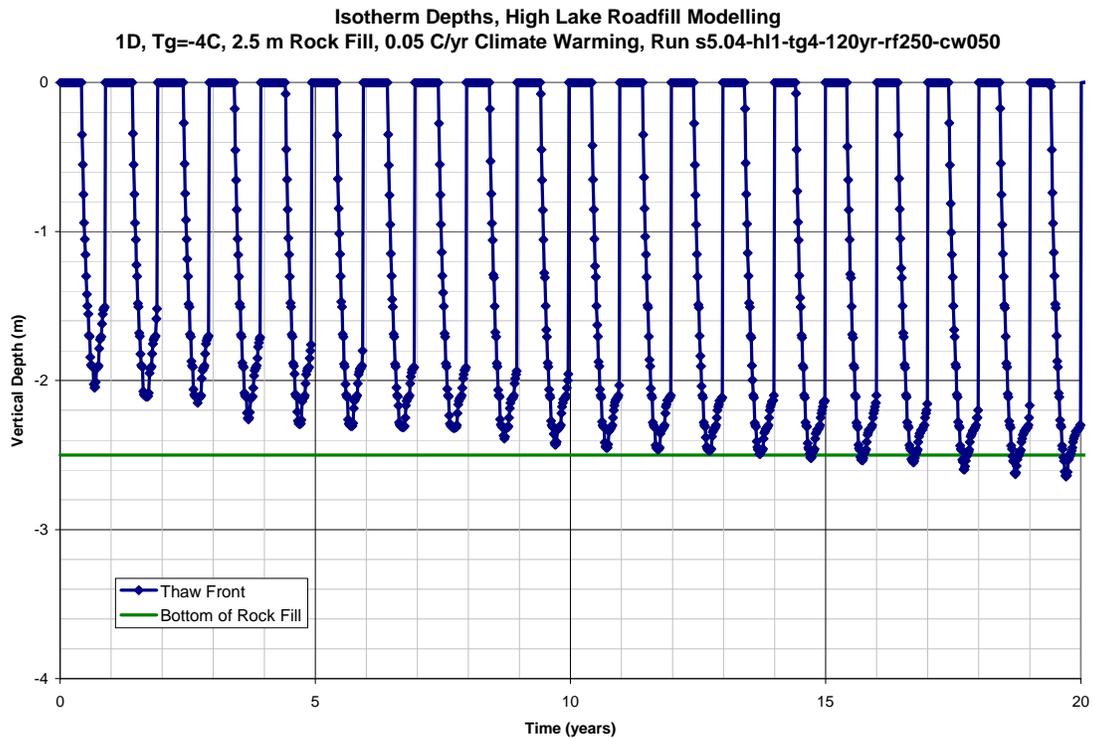


Figure 4 Long Term Thermal Regime, Run 3

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**Figure 5 Active Layer Depths, Run 3, 10 and 20 Years Into Closure**