GOLDER

**REPORT**

# Whale Tail Lake Thermal Assessment

Submitted to:

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Submitted by:

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# Table of Contents

## TABLES



## APPENDICES

# 1.0 INTRODUCTION

Agnico Eagle Mines Limited (Agnico Eagle) is planning mining of the Whale Tail Pit Project, a satellite deposit located on the Amaruq exploration property in Nunavut. The project site is located approximately 50 km northwest of Agnico Eagle's operating Meadowbank Mine.

Agnico Eagle plans to mine the Whale Tail deposit by open pit and underground mining. Agnico Eagle holds an advanced exploration Type B licence (2BB-MEA1318) for the underground development, which requires minimizing contact water discharge during the ramp advancement. The proposed ramp extends down to an elevation of about 225 m below sea level (or about 375 m below Whale Tail Lake surface level). To the extent possible according to the orebody depth, the ramp needs to be maintained within the permafrost regime to minimize the groundwater inflow into the ramp. Figure 1 shows the Amaruq Exploration site plan with Whale Tail Lake bathymetry, proposed mine facility locations, proposed open pit outlines, and thermistor locations. This figure also shows the locations of seven cross sections (A to G) used to prepare thermal models to evaluate current permafrost conditions in the project area.

Golder Associates Ltd. (Golder) was retained to carry out a thermal assessment for the Project to:

- Evaluate existing permafrost characteristics in the Whale Tail Lake and Project area.
- Evaluate existing talik conditions under the Whale Tail Lake adjacent to the Project site.

This report presents a review and summary of estimated permafrost conditions based on available thermistor data to date, as well as the results of a thermal modelling exercise prepared to assess permafrost conditions and the extent of talik formations beneath the Whale Tail Lake.

# 2.0 SITE CONDITIONS

## 2.1 Regional Permafrost Conditions

The Whale Tail Pit Project is in the zone of continuous permafrost. Permafrost refers to subsurface soil or rock where temperatures remain at or below 0ºC for at least two consecutive years. This is synonymous with perennially cryotic ground, which may be frozen, partially frozen, or non-frozen depending on the ice/water content of the ground, and the salinity of the groundwater. The base of the permafrost is expected to be an undulating surface and the actual depth to permafrost is variable.

The land surface of the Whale Tail Pit Project is underlain by permafrost except under the lake where water is too deep to freeze to the bottom during winter. Taliks (areas of unfrozen ground) are expected beneath a water body where the water depth is greater than the ice thickness. Closed talik formations show a depression in the permafrost table below relatively shallower and smaller lakes. Open talik formations that penetrate through the permafrost and connect the lake waterbody with the sub-permafrost regime are to be expected for relatively deeper and larger lakes in the Project area.

Published data regarding permafrost indicates that the ground ice content in the region is expected to be between 0% and 10% (dry permafrost) based on Natural Resources Canada (1995).

## 2.2 Subsurface Geology

The Whale Tail deposit is in the northern portion of the Whale Tail Lake. Based on previous site investigation data, soils in the project area are typically medium to coarse grained glacial till and colluvium with high coarse fragment content overlying bedrock at shallow depths (less than 1 m). Saturated soil layers overlying frozen layers have been observed on site. A review of the records of the six thermistor boreholes indicates soil thicknesses varying from 6.1 to 12.4 m. Underlying the soil, bedrock in the area generally consists of a stratigraphic sequence of greywacke, komatiite, and ultramafics, with varying thicknesses.

## 2.3 Site Climatic Conditions

Table 1 presents a summary of the site climate data for air temperature and precipitation. A mean annual air temperature of -11.3 °C was obtained for the site, based on climate data provided by Agnico Eagle (Golder 2016a).

**Table 1: Mean Climate Characteristics (Golder 2016a)**

| Month | Mean Air Temperature (°c) | Monthly Precipitation | |
|---|---|---|---|
| | | Rainfall (mm) | Snowfall Water Equivalent (mm) |
| January | -31.3 | 0 | 11 |
| February | -31.1 | 0 | 9 |
| March | -26.3 | 0 | 14 |
| April | -17.0 | 0.5 | 20 |
| May | -6.4 | 6 | 12 |
| June | 4.9 | 21 | 5 |
| July | 11.6 | 45 | 0 |
| August | 9.8 | 48 | 2 |
| September | 3.1 | 40 | 11 |
| October | -6.5 | 7 | 34 |
| November | -19.3 | 0 | 26 |
| December | -26.8 | 0 | 16 |
| Annual | -11.3 | 168 | 160 |

The thermal modelling exercise described in this document was prepared to allow for assessment of existing permafrost conditions in the project site, and therefore does not incorporate climate change in the long-term. Climate change is anticipated to be minimal and to have no impact on permafrost conditions during the operational stage of the Project.

## 2.4 Lake Elevation and Temperature

Lake elevation measurements for Whale Tail Lake were available from 25 July 2016 to 4 September 2016. The lake elevation varies from 151.2 m above sea level (masl) to 152.7 masl with an average elevation of 151.7 masl. The average depth of Whale Tail Lake is 4.4 m based on the bathymetry provided by Agnico Eagle. Based on bathymetry data, the maximum lake depth is 16.7 m, located in the area near borehole AMQ16-626 (Figure 1) and where the project's attenuation pond is planned.

Golder (2016b) reported that water temperature in the Whale Tail Lake ranged from 9 to 11.5°C during the summer months in 2015. In May 2017, thermistor AMQ17-1265A was installed in the Whale Tail Lake with its upper two beads being in water, which can be used as reference for lake water temperature at that location where the lake is about 11 m deep. Few scattered data for this thermistor was available between August and September 2017, and between July 2018 and the end of October 2018. During this period, the maximum lake temperature was 13.9 ºC on July 26, 2018, the minimum lake temperature was 0.08ºC measured on September 28, 2018, and the average water temperature was 3.2 ºC. Winter lake water temperature data was not available at the time of this study, but it is anticipated that the average annual lake temperature would be lower when considering lake winter temperatures. Typically, mean annual lake temperature is related to the depth of water in a permafrost region: the deeper the lake, the higher the lake bottom temperature. A typical lake bottom temperature range for northern lakes is +2 °C to +4 °C based on literature review and past project experience in the area (Burn 2002; Golder 2003).

# 3.0 SITE PERMAFROST CONDITIONS

The following sections present a summary of site permafrost conditions estimated based directly on available thermistor data and, indirectly on a Westbay well system.

## 3.1 Site Thermistor

### 3.1.1 Locations

The location of active thermistors within the vicinity of the area of interest is shown in Figure 1 and Table 2 presents a summary of installation information.

**Table 2: Borehole and Thermistor Summary**

| Borehole | Collar Coordinates | | | | Drilled Length (m) | Thermistor |
|---|---|---|---|---|---|---|
| | Northing (m) | Easting (m) | Inclination (°) | Azimuth (°) | | Depth Below Ground Surface (m) |
| AMQ15-294 | 607,073 | 7,255,676 | -45 | 221 | 323 | 144 |
| AMQ15-306 | 606,715 | 7,255,364 | -45 | 96 | 201 | 141 |
| AMQ15-324 | 606,497 | 7,254,995 | -45 | 300 | 501 | 317 |
| AMQ15-349A | 607,065 | 7,255,628 | -45 | 204 | 203 | 141 |
| AMQ15-421 | 607,098 | 7,255,491 | -51 | 274 | 501 | 388 |
| AMQ15-452 | 606,627 | 7,255,688 | -50 | 106 | 501 | 382 |
| AMQ17-1265A | 606,950 | 7,255,414 | -80 | 198 | 366 | 350 |
| AMQ17-1233 | 606,778 | 7,256,254 | -59 | 255 | 156 | 132 |
| AMQ17-1337 | 607,078 | 7,256,522 | -60 | 262 | 252 | 218 |
| AMQ17-1277A | 606,911 | 7,255,964 | -61 | 195 | 252 | 217 |

### 3.1.2 Thermistors Data Summary

Table 3 presents a summary of the permafrost conditions estimated from site thermistors and used as reference for calibration of thermal models as described in Section 4.

**Table 3: Summary of Permafrost Conditions in Site Thermistors**

| Hole ID | Approx. Collar Distance to Lake (m) | Zero Annual Amplitude | | Temperature at location of Thermistor Tip (°C) | Thermal Gradient (°C/m) [(b)] | Estimated Permafrost Depth (m) [(c)] |
|---|---|---|---|---|---|---|
| | | Approximate Depth (m) | Approximate Temperature (°C) | | | |
| AMQ15-294 | 31 | 19 | -3.1 | -1.5 | 0.004 | 507 |
| AMQ15-306 | 55 | 20 | -7.4 | -2.1 [(a)] | 0.052 | 164 |
| AMQ15-324 | 370 | 35 | -8.6 | -3.0 | 0.022 | 452 |
| AMQ15-349A | 40 | 18 | -5.2 | -1.4 | 0.011 | 262 |
| AMQ15-421 | 40 | 26 | -3.1 | -0.5 | 0.004 | 522 |
| AMQ15-452 | 50 | 23 | -3.3 | -1.1 | 0.012 | 472 |
| AMQ17-1265A | n/a | 20 | 2.7 | -0.35 | 0.006 | 410 |
| AMQ17-1233 | 32 | 10 | -4.6 | -5.2 | -0.013 | Insufficient data |
| AMQ17-1337 | 12 | 37 | -6.6 | -5.3 | 0.017 | 535 |
| AMQ17-1277A | 32 | 14 | -4.2 | -3.2 | 0.004 | >600 |

a) For AMQ15-306, temperature about 17 m above the thermistor tip due to erratic temperature readings below that point.
b) Gradients estimated based on temperature data along the lower 70 to 100 m of thermistor lines.
c) Estimated based on temperature at thermistors' tips and thermistor's thermal gradients

The parameters were estimated using average temperature values up to November 2018. It should be noted that these thermistors were installed adjacent to the Whale Tail Lake, and the thermal conditions are likely influenced by the warm (relative to the ground surface temperatures) lake water temperatures.

## 3.2 Westbay Well System

A Westbay well system that was installed on site with a drilled depth of 499 m, was completed from March to April in 2016 for monitoring of hydraulic heads, testing of hydraulic conductivity, and collection of groundwater samples from multiple intervals within this single borehole (Golder 2016c).

The 2018 groundwater monitoring program (Golder 2019) indicates that water samples were collected from fixed ports along the Westbay system between 276 m and 499 m below the ground surface, which suggests that the Westbay system is installed in open talik, or water sampling would not have been possible in depth. This information was also taken into consideration for calibration of the thermal models described in Section 4.

Groundwater salinity based on Total Dissolved Solids (TDS) data from the 2016 water sampling program varied between 3198 mg/L and 4100 mg/L, with an average of 3700 mg/L. Salinity estimated from the 2016 program is more accurate than 2018 data due to issues with water purge in 2018, as described in Golder 2019. Based on Andersland and Ladanyi (2004), this average salinity level would cause a depression in the freezing point of water from 0 °C to -0.21 °C, which was taken into consideration when estimating the limits of the cryopeg zone based on results of the thermal models.

# 4.0 THERMAL MODEL

To assess permafrost conditions in the project site and the extent of talik formations beneath the Whale Tail Lake, steady state two-dimensional (2D) thermal modelling was carried out using the finite element program TEMP/W of GeoStudio 2019 (Version 10.0), developed by GEO-SLOPE international Ltd. (GEO-SLOPE 2019).

The 2D thermal models were prepared for seven cross sections defined along the underground mine developments in areas influenced by the Whale Tail Lake and for areas away from the lake to evaluate the extent of talik formations in the project site. Following completion of the 2D models, a three-dimensional (3D) block model was completed using the software Datamine Studio RM (v1.4.175.0), developed by Datamine Corporate Ltd. The 3D block was prepared based on results obtained from the 2D sections as control reference temperatures.

This section presents the modelling limitations, assumptions, modelling approach, input parameters, and results.

## 4.1 Model Limitations

This study consisted of steady state 2D thermal models prepared for several cross sections defined within the Project site as shown in Figure 1. The models constitute a simplification of the field reality and carry limitations that shall be taken into consideration during interpretation of model results. The most important model limitations are as follows:

- The 2D nature of the thermal models can only capture heat transfer along the cross sections and does not incorporate 3D heat transfer coming from adjacent areas. This limitation has stronger impact on model results for cross sections that include large stretches of the Whale Tail Lake, or sections crossing shallow and narrow lakes, where the 3D nature of heat transfer from adjacent ground would greatly limit the impact of the lake on permafrost conditions. This limitation was partially overcome by using wide cross sections and adjusting the mean temperature of shallow lakes.
- Results of steady-state models show a condition where an equilibrium is attained among all the model input parameters and boundary conditions, including material thermal properties, ground and lake surface temperatures and upward heat flux coming from the earth. The permafrost has formed over many millennia and its conditions adjust continuously to changes in surface conditions such as ground and lake temperatures. This means that current permafrost conditions might not represent an equilibrium and therefore model results can differ from real field conditions. This limitation was partially overcome by calibrating the models against site thermistors data, but field information is limited compared to the size of area modelled.
- The 3D block was prepared using information from the 2D thermal models as reference. The model interpolates temperatures in-between cross sections along with additional control temperatures along the Whale Tail Lake. Therefore, the spatial distribution of the cross sections affects the model accuracy, with interpolation between cross sections that are separated by large distances being less accurate then interpolation between cross sections that are nearby.

## 4.2 Model Approach and Calibration Process

Steady-state thermal modelling was performed initially along six cross sections (A to F) as shown in Figure 1. The locations of the cross sections were defined in such a way that allowed for models to be partially calibrated based on data from existing site thermistors. Locations of the different cross sections were also defined to provide an estimate of current permafrost conditions along the alignment of the proposed underground mining and in areas where the existence of open or closed talik is uncertain.

The calibration process consisted of adjusting model input parameters until the predicted temperature profiles were in good agreement with measured temperatures along reference thermistors located near each of the cross sections. The following model input parameters were adjusted during the calibration process:

- Material thermal properties;
- Mean surface ground temperature;
- Mean Whale Tail Lake temperature;
- Mean temperature of shallow lakes other than the Whale Tail Lake; and
- Thermal gradients in areas under the Whale Tail Lake and away from the lake, based on site thermistors as presented in Table 3.

The models were considered calibrated when the same set of input parameters could be applied to the different cross sections and result in predicted temperature profiles that were in reasonable agreement with the thermistors data used as reference in each individual section. It should be noted that the thermistors were not aligned with the cross sections and their relative locations were defined using perpendicular projections onto the cross sections.

In addition to the cross sections A to F, a new cross section G was later included in the southern portion of the Whale Tail Lake parallel to Sections A and C (as shown in Figure 1), and closer to the planned location of the Whale Tail Dike where the nature of talik, whether open or closed, is uncertain. Section G was not used for calibration purpose, and ground temperatures were rather computed using the calibrated model input parameters obtained from Sections A to F. Nevertheless, a temperature profile computed for Section G was compared to measured temperatures along the thermistor AMQ15-306, which although is far away from the section, presents similarities in terms of the distance from the lake and dipping direction.

Table 4 summarizes the thermistors used as reference for calibration of each section. As Sections D and F had only one nearby thermistor, information from one additional thermistor was added to the calibration process for each of these sections. Although the added thermistors were far from the sections' alignments, their locations had similarities in terms of ground conditions and distance from the lake.

**Table 4: Thermistors used for calibration for each section.**

| Cross-section | Thermistor near section | Thermistor far from section |
|---|---|---|
| A | AMQ15_421 | |
| | AMQ15-324 | |
| | AMQ17-1265A | |
| B (not used for calibration) | AMQ15-421 | |
| | AMQ 17-1265A | |
| C | AMQ15-306 | |
| | AMQ15_349A | |
| D | AMQ15-324 | AMQ15-452 |
| E | AMQ15-294 | |
| | AMQ17-1277A | |
| | AMQ17-1233 | |
| F | AMQ17-1337 | AMQ15-324 |
| G (not used for calibration) | | AMQ15-306 |

Based on the calibration approach described above, calibration of Section B was not achieved. This section included thermistors AMQ15-421, which shows temperatures below the freezing point all along the thermistor string, and AMQ17-1265A, which shows the existence of a closed talik about 115 m deep underlain by frozen ground. However, the calibrated input parameters that produced good calibration results for Sections A, C, D, E, and F predicted temperatures in Section B along the alignments of AMQ15-421 and AMQ17-1265A that were always above the freezing point, suggesting the existence of an open talik in those locations, which isn't consistent with the reference calibration thermistors. It would not be possible to calibrate Section B unless a specific set of input parameter was defined only for this section and using temperature of the Whale Tail Lake that would be neither consistent with field measurements nor realistic. Therefore, Section B was deemed not possible to be calibrated and was further discarded.

For the other sections (i.e., A, C, D, E, and F), the calibration process resulted in two sets of model input parameters that produced predicted temperature profiles in general agreement with the reference calibration thermistors, but with variable depths of permafrost. Model results using the calibrated input parameter for Scenario 1 predicted a shallower permafrost location compared to model predictions using the calibrated input parameters defined in Scenario 2.

Model results for Sections A, C, D, E, F and G using the calibrated input parameters defined for Scenario 1 and Scenario 2, including temperature distribution, permafrost limits, and plots comparing predicted vs. measured temperatures from the reference calibration thermistors, are presented in Appendix A (Figures A1 to A6) and Appendix B (Figures B1 to B6), respectively. The modelled temperatures were in good agreement with the thermistor data in the end of the calibration process. The calibrated parameters were then applied to Section G to model the permafrost and talik conditions underneath a wider stretch of the Whale Tail Lake.

The calibrated model input parameters and boundary conditions are presented in the next sections.

## 4.3 Material Properties

The thermal properties adopted for the overburden and bedrock in the end of the calibration phase are summarized in Table 5. The thermal properties were based on typical values presented in Andersland and Ladanyi (2004) and were adjusted during the model calibration process.

It is expected that that the thermal properties of the bedrock will have a more significant effect on thermal conditions than the overburden soils because of the relatively shallow layer of overburden compared to the bedrock. Each section assumed a thickness of overburden till of about 12 m underlain by close to 600 m of bedrock to an elevation of -450 m below sea level at the base of the model geometry.

**Table 5: Material Thermal Properties Used in the Models**

| Material | Volumetric Water Content | Thermal Conductivity (W/m-°C) | | Volumetric Heat Capacity (MJ/m3-°C) | |
|---|---|---|---|---|---|
| | | Frozen | Unfrozen | Frozen | Unfrozen |
| Till | 30% | 1.8 | 1.5 | 2.0 | 2.5 |
| Bedrock | 1% | 3.0 | 3.0 | 2.0 | 2.0 |

The thermal models were simplified using constant thermal conductivities without considering phase change. This assumption is considered reasonable as the bedrock is expected to have low water content and the latent heat due to phase change is not significant.

The thermal models were solved considering groundwater with a phase change temperature of 0 °C. Salinity in the groundwater would result in a freezing point depression and would possibly lower the phase change temperature below 0 °C. However, considering the very low water content assumed for the bedrock, the effect of salinity would have no important impact on the model results in terms of predicted permafrost limits in the project site. Considerations to water salinity and water flow through zones with temperatures slightly below 0$^{o}$C are made in the hydrogeology modelling component of this study presented in a separate document.

## 4.4 Boundary Conditions

As discussed in Section 4.2, the calibration process resulted in two sets of model input parameters that produced model predicted temperature profiles generally in good agreement with temperature profiles measured at the locations of the reference thermistor strings in each cross section (as presented in Appendices A and B). Specifically, both sets of calibration parameters resulted in predicted temperature profiles that were consistent with temperature measured along thermistor AMQ17-1265A, which was a key reference thermistor for calibration purposes due to its strategic installation location in the lake, crossing talik and permafrost zones.

As the predicted depths of permafrost limits are affected by the model input parameters, thermal models were prepared using the two sets of calibration parameters for model sensitivity purposes, in an attempt to define the lower and upper bounds of predicted permafrost limits. The model input parameters defined for the two calibration scenarios are described below.

### 4.4.1 Calibrated Scenario 1

The calibrated boundary conditions for Scenario 1 models were as follows:

- A mean ground surface temperature of -10 °C was used as the model upper boundary condition outside of the Whale Tail Lake. This temperature is considered reasonable as compared with the -11.3 °C mean annual air temperature.
- Mean annual Whale Tail Lake bottom temperatures between 0°C and +3°C depending on lake depth as follows, assuming an average lake elevation of 151.7 m.
  - $0^{o}$C for lake depth less than 1 m;
  - $2^{o}$C for lake depths between 1 and 4 m; and
  - $3^{o}$C for portions of the Whale Tail Lake deeper than 4 m.
- For the shallow lakes or ponds that appear in Sections E and F, a mean annual lake bottom temperature of -7 °C was applied in the end of the calibration process. As described in Section 4.1, this approach was required to deal with limitations associated with the two-dimensional nature of the models.
- A heat flux of 0.048 J/sec was defined as the model lower boundary condition based on a bedrock thermal conductivity of 3 W/m-°C and a thermal gradient of 0.016 °C/m. The adopted geothermal gradient is in line with the thermal gradients estimated from thermistors data as summarized in Table 3.

### 4.4.2 Calibrated Scenario 2

The calibrated boundary conditions for Scenario 2 models were as follows:

- A ground surface temperature of -9.5 °C was applied to ground surface outside of the Whale Tail Lake.
- A mean annual lake bottom temperature of +3 °C was applied to the Whale Tail Lake irrespective of lake depth.
- For the shallow lakes or ponds that appear in Sections E and F, a mean annual lake bottom temperature of -7 °C was applied.
- A heat flux of 0.048 J/sec (geothermal gradient of 0.016 °C/m) was applied as the lower boundary condition of the model geometry in areas away from the Whale Tail Lake.
  - A heat flux of 0.018 J/sec (geothermal gradient of 0.006 °C/m) was applied at the base of the model geometry for areas beneath the Whale Tail Lake. This was based upon the lower thermal gradients estimated for thermistors located mostly under the Whale Tail Lake, specifically thermistor AMQ17-1265A, which is installed in the lake and shows thermal gradient of 0.0058 $^{o}$C/m for the lower 100 m of the thermistor string.

## 4.5 Three-Dimensional Block Model

A 3D block model was produced from the results of the 2D thermal modelling using Datamine Studio software, following the procedures summarized below.

- A block model volume was described to encompass the 2D thermal sections.
- Blocks of size of 20 m in Easting, 20 m in Northing and 10 m in Elevation were created below topography down to a depth of -450 m (i.e., base of the 2D thermal model cross sections).
- Temperature was estimated into each block using the temperature contours obtained from the 2D thermal sections, with the following controls applied:
  - Inverse power of distance cubed estimation methodology; 2D section temperature values closer to the block centroid carry more weight than those further away.
  - An elliptical search volume with a 5:1 horizontal to vertical anisotropy; horizontal continuity carries more weight than vertical continuity. The maximum search distance was 800 m horizontally.
  - Data points from at least two sections were needed to contribute to a block estimate.
  - The Whale Tail Lake boundary was used as a constraint, such that 2D section temperature values inside and outside the lake boundary had differing weights applied based on depth below surface. This results in the lake acting as a hard boundary close to the topographic surface and an increasingly soft boundary with increasing depth from the topographic surface. This constraint was necessary to prevent smoothing of temperature values across the lake boundary, which, when close to the topographic surface, results in positive temperature values outside the lake boundary.

Figure 2 shows the arrangement of the 2D cross sections used as input for the 3D block model.

# 5.0 MODEL RESULTS

## 5.1 Two-Dimensional Thermal Models

Permafrost limits computed for Sections A, C, D, E, F and G for both calibration Scenarios 1 and 2 are presented in Figures 3 to 8, which also show the estimated extent of the cryopeg zone where water could potentially flow through ground frozen at temperature of -0.21ºC due to the effect of salinity. Details of temperature distribution, as well as comparison of predicted temperature profiles with thermistor data are provided in Appendices A and B.

Section A was cut through the proposed underground ramp as shown in Figures 1 and 3, where the lake is approximately 300 m wide. Thermistors AMQ15-421 and AMQ17-1265A were projected onto the section to allow for comparison of predicted vs. measured temperature profiles under the Whale Tail Lake. In addition, thermistor AMQ15-324 was projected onto the section to represent ground temperature away from the lake. Plots of predicted temperatures compared to measured temperatures are presented in Appendices A and B for the calibration models Scenarios 1 and 2, respectively.

The thermal results indicate a closed talik formation underneath the lake for both calibration scenarios, which is consistent with temperature data obtained from thermistor AMQ17-1265A installed in the lake, and AMQ15-421 installed adjacent to the lake but that dips toward the Whale Tail Lake. In terms of permafrost depth, the predicted location of permafrost under the Whale Tail Lake was about 100 m shallower for Scenario 1 (lower permafrost limit approximately 350 m below lake level) compared to Scenario 2 (lower permafrost limit about 450 m below lake level). The location of permafrost in areas away from the lake was similar for both calibration scenarios with permafrost depth of about 480 m below ground.

The model results for Section A obtained for Scenario 1 suggest that the lower 25 m of the proposed underground ramp shown in Figure 3 may be in unfrozen ground. Based on the model results, the cryopeg zone extends to a maximum of 20 to 30 m above the base of permafrost.

Section C was also modelled through the proposed underground ramp as shown in Figures 1 and 4, where the lake is approximately 300 m wide. Thermistors AMQ15-306 and AMQ15-349A were projected onto the section to compare measured temperatures to the model results under the Whale Tail Lake; both thermistors' collars are located near the lake and dip toward ground portions beneath the lake. Plots of measured vs. predicted temperatures are presented in Appendices A and B.

Results of the thermal models indicate a closed talik formation underneath the lake for both scenarios, which is consistent with thermistor data. The location of the lower permafrost limit below the closed talik under the lake was about 100 m shallower for Scenario 1 (about 325 m below the lake) compared to Scenario 2 (about 425 m below the lake). The proposed ramp layout shown in Figure 4 indicates that the lower 50 m of the ramp may be in unfrozen ground for the calibration Scenario 1. The models also predict a permafrost depth of about 500 m below ground in areas away from the Whale Tail Lake.

Section D was modelled through the proposed underground ramp perpendicular to Sections A and C as shown in Figures 1 and 5, where the lake is approximately 200 m wide. The thermistor AMQ15-452 was projected onto the section to compare measured temperatures with the model results under the whale Tail Lake, while the projection of thermistor AMQ15-324 is in ground away from the lake. Details of computed vs. measured temperatures are presented in Appendices A and B.

The thermal results indicate a closed talik formation underneath the lake for both scenarios, in good agreement with the reference thermistor data. The lower permafrost limit computed for Scenario 1 was about 50 m shallower then computed for Scenario 2 (i.e., 450 m and 500 m below the lake, respectively). The model results suggest that the proposed ramp layout shown in Figure 5 will be in frozen ground for both scenarios. The models also predicted permafrost depth of about 510 m below ground in areas away from the Whale Tail Lake.

Section E was modelled to assess the talik beneath the lake south of the proposed ramp. The section crosses the Whale Tail Lake at different locations as shown in Figure 1 and 6. The lake width in the middle of the section is approximately 300 m and at the south end of the section it is about 350 m. The models predicted that, for both calibration scenarios, the area south of the proposed underground ramp will be in open talik. The model also results suggest that the proposed ramp layout shown in Figure 6 will be in frozen ground for both scenarios.

Section E was modelled to assess the nature of talik beneath the lake south of the proposed ramp. The section crosses the Whale Tail Lake at different locations as shown in Figure 1 and 6. The lake width in the middle of the section is approximately 300 m and at the south end of the section it is about 350 m. The models predicted that, for both calibration scenarios, the area south of the proposed underground ramp will be in open talik.

The predicted open talik in Section E is heavily influenced by the extent of lake in the two-dimensional configuration of the model. There were no thermistors available for model calibration in the south portion of Section E, and calibration based on thermistors installed north of the proposed ramp (i.e., AMQ15-294 and AMQ17-277A) showed model predicted temperature profiles generally warmer than measured temperatures (as presented in Appendices A and B). Therefore, the actual permafrost conditions beneath and in-between the two portions of the Whale Tail Lake that appear in Section E are possibly colder than predicted by the models.

Section E is perpendicular to the alignment of the proposed ramp, so the projected ramp location is shown in Figure 6 for reference. The upper 200 m of the ramp is relatively close to Section E, and the model results indicate that portion of the ramp will be in frozen ground. The lower portion of the ramp dips away from Section E and therefore model results cannot be used to evaluate whether that area would be in talik or not.

Section F was modelled to assess permafrost conditions away from the Whale Tail Lake as shown in Figures 1 and 7. Section F mainly passes through ground and crosses two small shallow lakes close to the north end of the section. The permafrost depth was estimated to be 500 m and 550 m below ground surface for Scenario 1 and Scenario 2, respectively.

The calibrated parameters were then applied to Section G, where the lake is approximately 500 m wide, to assess permafrost limits and the extent of the open talik predicted in Section E. Temperature profiles from thermistor (AMQ15-306) were extrapolated and projected onto Section G to evaluate consistency of the model predicted temperatures with the actual measurements. Although predicted temperatures were warmer than measured temperatures for both calibration scenarios, the thermal model indicates the existence of an open talik beneath the Whale Tail Lake as shown in Figure 8.

## 5.2 Three-Dimensional Block Model

The 3D block model was prepared using results obtained from the 2D models for the calibration Scenario 1, which predicted a shallower permafrost compared to the calibration Scenario 2. Although both Scenarios 1 and 2 had good agreement with temperature profiles obtained from the reference thermistors, the shallower permafrost predicted in Scenario 1 is considered to be a more critical scenario as it shows more of the underground may be located in unfrozen rock.

Results of the 3D block model were exported to CSV format with the following columns: X (Easting), Y (Northing), Z (Elevation) and Temperature, for use in the hydrogeology model. Figure 9 shows a 3D plot of the $0^{o}$C isoline computed based on the results of the 2D thermal modelling.

The model representation of temperature is good where the sections are close together and where sections of different orientations contribute to the temperature estimates. The model is less reliable as distance from sections increases. Also, although the lake constraint worked well, it was not completely successful within the entire block model.

The 3D block model is a basic construct and is intended for guidance rather than providing a definitive picture of temperature and permafrost limits in 3D. As the results obtained from the 2D thermal models are used as input for the 3D block, any limitation carried forward from the 2D models impacts the results of the 3D block model. Additional refinements would be necessary if the model was to be used for detailed understanding of permafrost limits in the Project site.

## 6.0 SUMMARY AND RECOMMENDATIONS

Golder has carried out thermistor data review and numerical modelling of the lake talik formations for the Whale Tail Lake area. Based on the latest thermistor data available, the permafrost characteristics in the project area are summarized below:

- The depth of permafrost in the Project site is estimated to be between 452 m and 522 m based on thermal gradients and ground temperatures at the lowest portions of the thermistor strings.
- The estimated depth of zero amplitude from the temperature profiles ranges from 18 m to 35 m.
- The temperatures at the depths of zero amplitude are in the range of -3.1 °C to -8.6 °C for on land thermistors and 2.7 °C for AMQ17-1265A.
- Temperatures in depth at the locations of the thermistors' tip vary between -0.35°C for AMQ17-1265A and -3 °C for AMQ15-324.
- The geothermal gradient estimated based on the lowest 70 to 100 m of the thermistor strings is in the range of 0.004 °C/m (AMQ15-294) to 0.052 °C/m (AMQ15-306).

The results of numerical modelling thermal assessment indicate that:

- Under the northern portion of the lake along the proposed ramp area, there is likely a closed talik formation.
- Open talik formations are probable in the southern portion of the lake where the Whale Tail Lake becomes wider.
- Permafrost depth between 480 m and 550 m for ground away from the Whale Tail Lake, and between 350 m and 450 m below surface in portions beneath the Whale Tail Lake.

The thermal model indicated that the lower 25 to 50 m of the proposed exploration ramp alignment in the northern portion of the lake may be in unfrozen ground. This range might be extended depending on salinity levels in the water that will result in depression of the water freezing point. A depression of the freezing point of about 0.2 °C (i.e. water freezing at temperature of -0.2°C instead of 0 °C) would result in about an additional 20 to 35 m of the ramp being subject to groundwater inflow based on predictions of the extent of the cryopeg zone in the models as shown in Figures 3 to 8.

The minimum ground temperature measured by thermistor AMQ17-1265A below the closed talik portion in the Whale Tail Lake is about -1°C, while ground temperature at the tip of the thermistor is -0.35°C. As mentioned above, increasing salinity levels will cause the freezing point of water to depress; the higher the salinity the greater the extent groundwater can flow through frozen ground. An estimation based on Andersland O.B. (2004) shows that groundwater salinity would need to be about 1.8% for the freezing point to depress to -1°C, in which condition water could potentially flow through frozen ground beneath the Whale Tail Lake and into the ramp. The average water salinity is currently estimated as 0.37% with a freezing point depression of -0.21°C, suggesting that water would not flow through the closed talik under the Whale Tail lake at current salinity conditions. Nevertheless, close monitoring of groundwater salinity levels during operation will be required to assess the extent of groundwater flow.

Sections E and F used information from thermistors AMQ17-1233 and AMQ17-1337, respectively, as reference for model calibration. These thermistors are installed within the proposed footprint of the IVR open pit, which will have an ultimate base elevation of 46 masl. Based on the results obtained for Sections E and F, the permafrost limits below thermistors AMQ17-1233 and AMQ17-1377 will be below the base of the IVR Pit.

Based on the thermal model results and thermistor data, it is interpreted that the ultimate base of the Whale Tail open pit (i.e. -127 masl) is expected to be within the permafrost regime, and the upper portion in the talik zone beneath the lake.

There currently are no deep thermistors installed in the south portion of the Whale Tail Lake, where the existence of open or closed talik is uncertain. Although results of water sampling obtained from the Westbay well system and results of the thermal models suggest there is open talik formation in that area, it is recommended that Agnico Eagle considers the installation of supplemental deep thermistors in the south portion of the lake to confirm this assumption.

# 7.0 CLOSURE

The reader is referred to the Study Limitations, which follows the text and forms an integral part of this technical memorandum.

We trust this document satisfies you current requirements. If you have any questions or require further assistance, please do not hesitate to contact the undersigned.

# Signature Page

**Golder Associates Ltd.**

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REGISTERED PROFESSIONAL ENGINEER
2019-04-08
S. OUELLET
LICENSEE
NT/NU

Serge Ouellet Ing. Ph.D., P.Eng. (NT/NU)
*Senior Mine Waste Management Engineer*

PERMIT TO PRACTICE
GOLDER ASSOCIATES LTD.
Signature
Date 8 APRIL 2019.
PERMIT NUMBER: P 049
NT/NU Association of Professional Engineers and Geoscientists

RM/FJ/SO/jr



https://golderassociates.sharepoint.com/sites/102627/technical work/01_thermal-modelling/reporting/rev0/18108905-276-rpt-thermalmodel_whaletaillake-rev0.docx

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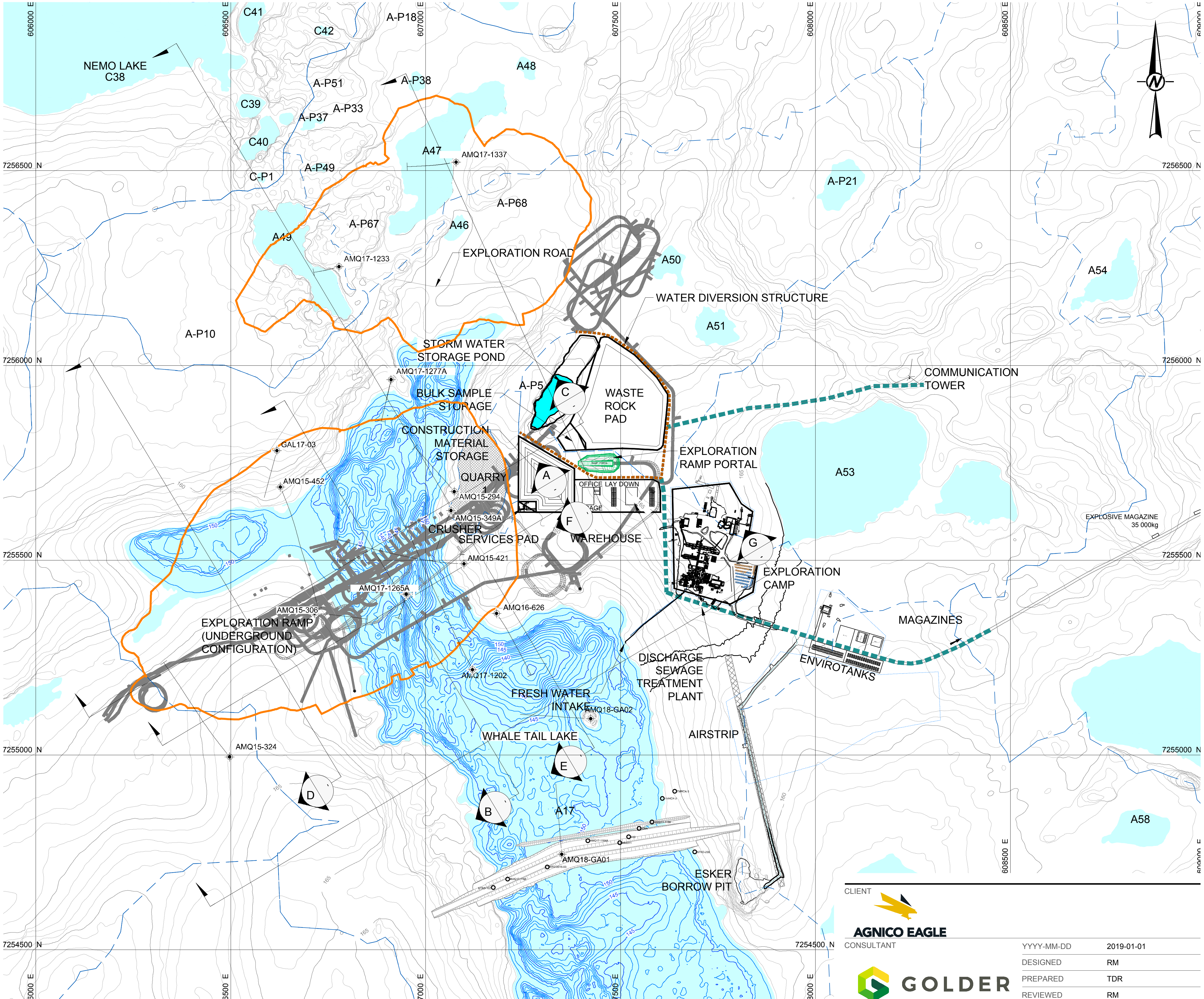
# FIGURES




**LEGEND**

- ROAD
- TEMPORARY ROAD
- NATURAL WATERSHED
- DITCH
- WATER DIVERSION STRUCTURE
- INTAKE (FRESHWATER PIPE)
- EXPLORATION ROAD
- THERMISTOR
- AMQ-POTENTIAL PIT

**REFERENCE**

BASE PLAN AND BATHYMETRY DATA RECEIVED FROM AGNICO EAGLE MINES LTD. DATE RECEIVED NOVEMBER 25, 2016.
CAD FILE: COURBESZM_AMARUQ_GLOBAL_UTM14_20150929.DWG
CAD FILE: 1665858-2100B-CM-0002.DWG
CAD FILE: 61-000-142-001_R0BLOC.DWG

UPDATED MAPPING PROVIDED BY CLIENT, FILENAME Thermistors planning Dec2018.dwg

0 125 250
1:7,500 METRES

CLIENT
AGNICO EAGLE

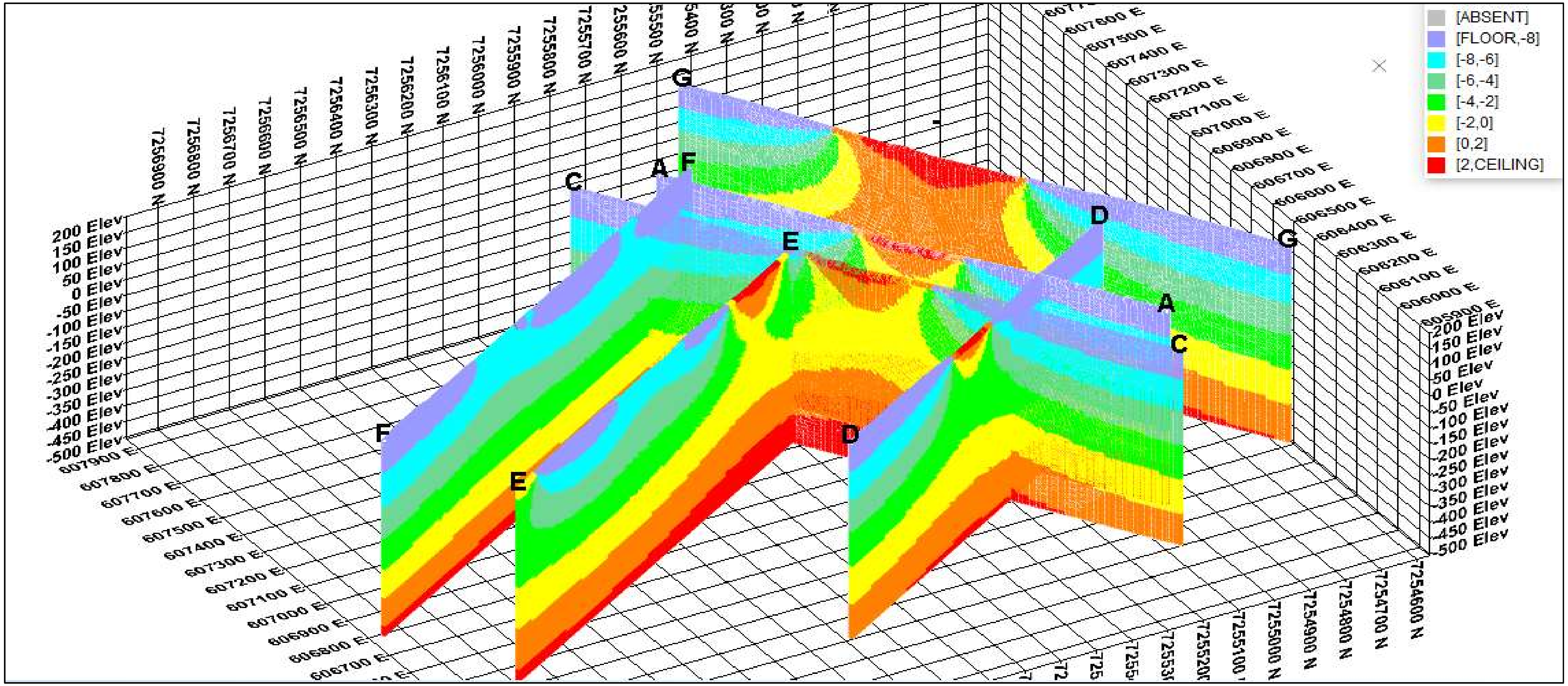
CONSULTANT
GOLDER

| | |
|---|---|
| YYYY-MM-DD | 2019-01-01 |
| DESIGNED | RM |
| PREPARED | TDR |
| REVIEWED | RM |
| APPROVED | FJ |

PROJECT
WHALE TAIL PIT PROJECT
WHALE TAIL LAKE THERMAL ASSESSMENT
NUNAVUT

TITLE
**SITE PLAN**

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 18108905 | 0001 | A | 1 |

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| Date: | Mar-19 |
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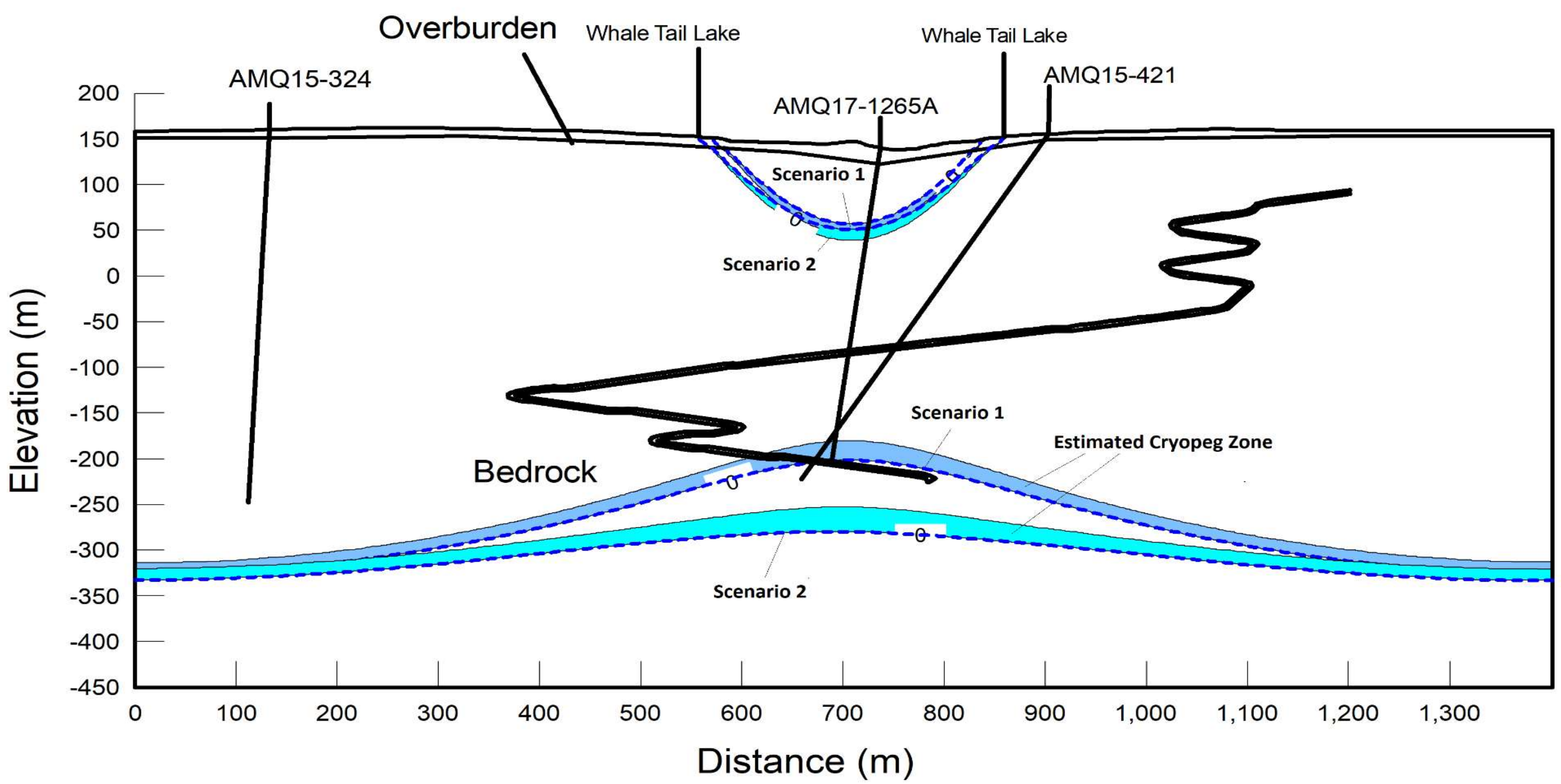
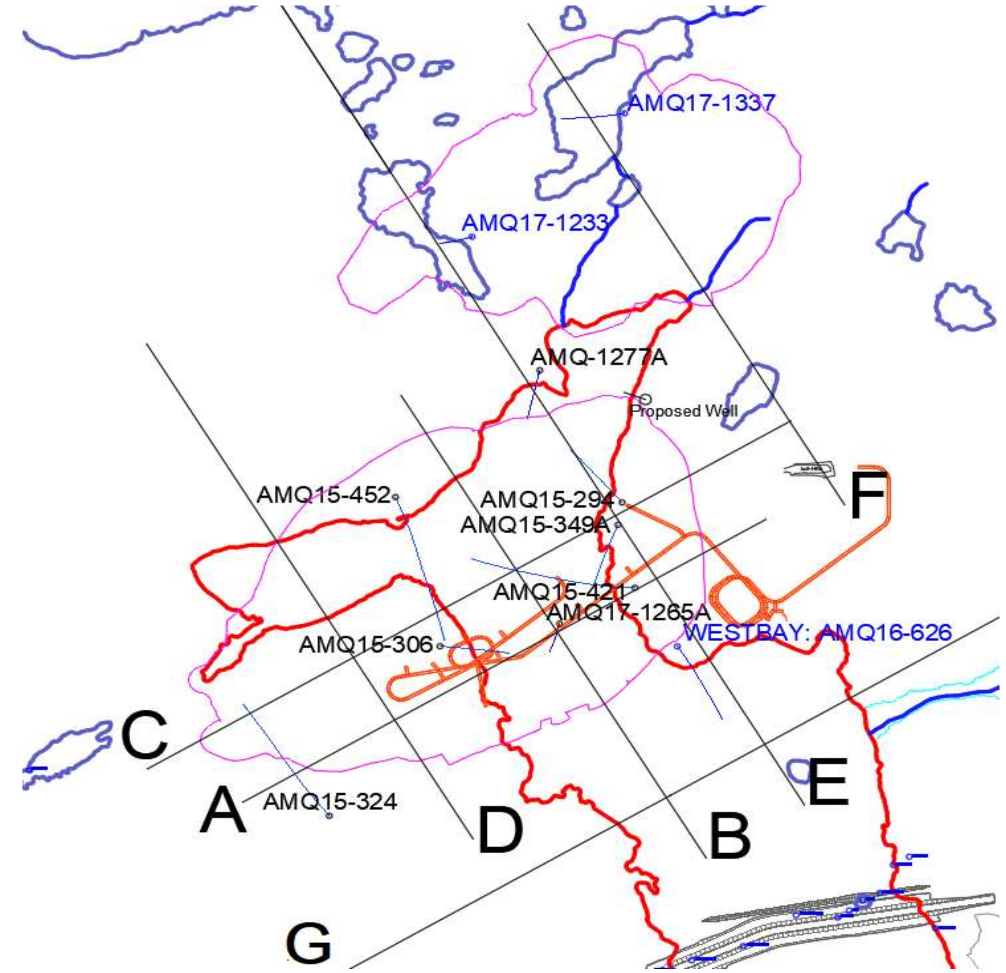
**Project: Whale Tail Pit Project**

**Title: 2D-thermal section used as input to create the 3D-thermal model**

| Project No. | Phase | Version | Figure No.: |
|---|---|---|---|
| 18108905 | | | **2** |




Zero Temperature Isoline

| | |
|---|---|
| Scenario | 1 |
| Ground Temperature (oC) | -10 |
| Whale Tail Lake Temperature (oC) | 0 to 3 |
| Shallow Lakes Temperature – other than Whale Tail Lake (oC) | n/a |
| Heat Flux (J/s) | 0.048 |
| Thermal Gradient (oC/m) | 0.016 |

| | |
|---|---|
| Scenario | 2 |
| Ground Temperature (oC) | -9.5 |
| Whale Tail Lake Temperature (oC) | 3 |
| Other shallow lake Temperature (oC) | n/a |
| Heat Flux (beneath ground) J/s<br>Thermal Gradient (oC/m) | 0.048<br>0.016 |
| Heat Flux (beneath WT Lake) J/s<br>Thermal Gradient (oC/m) | 0.018<br>0.006 |

**Client:**
**Agnico Eagle Mines Ltd.**

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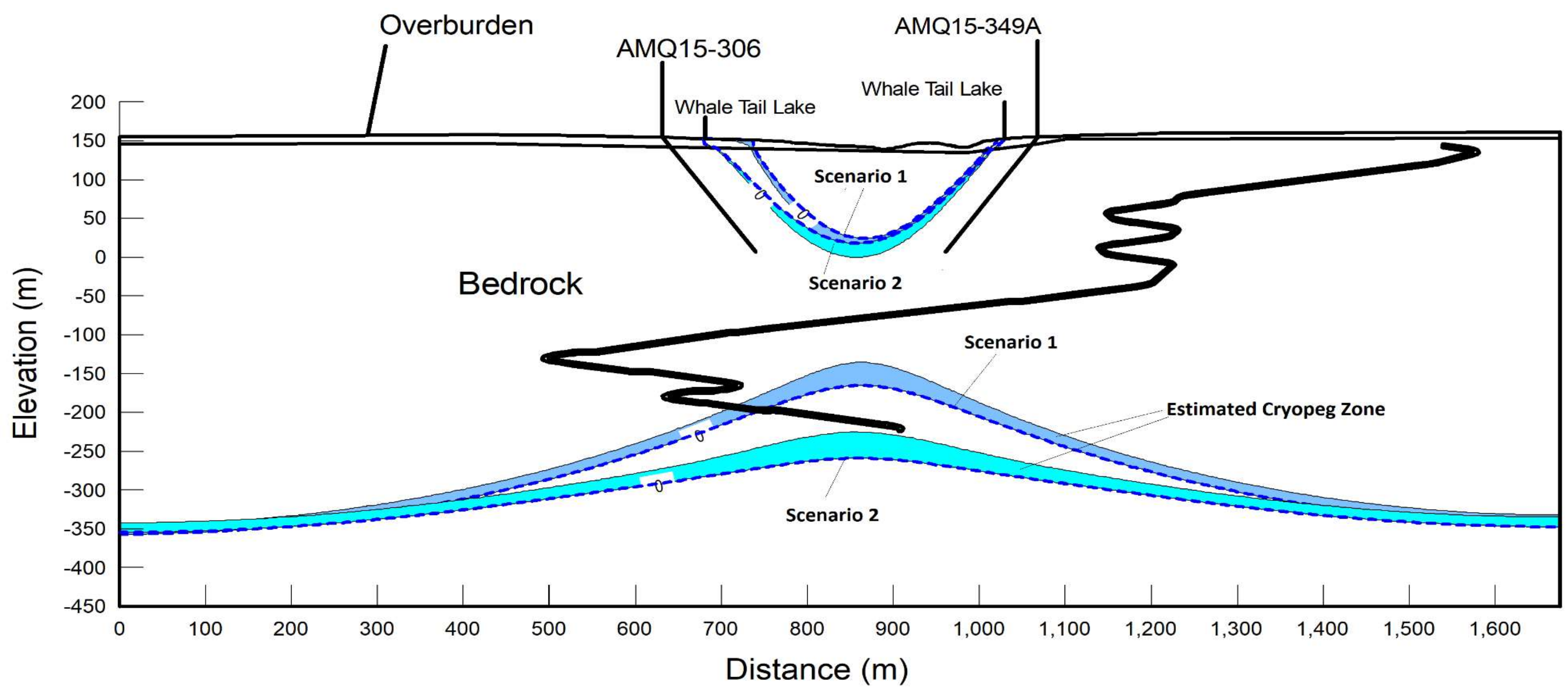
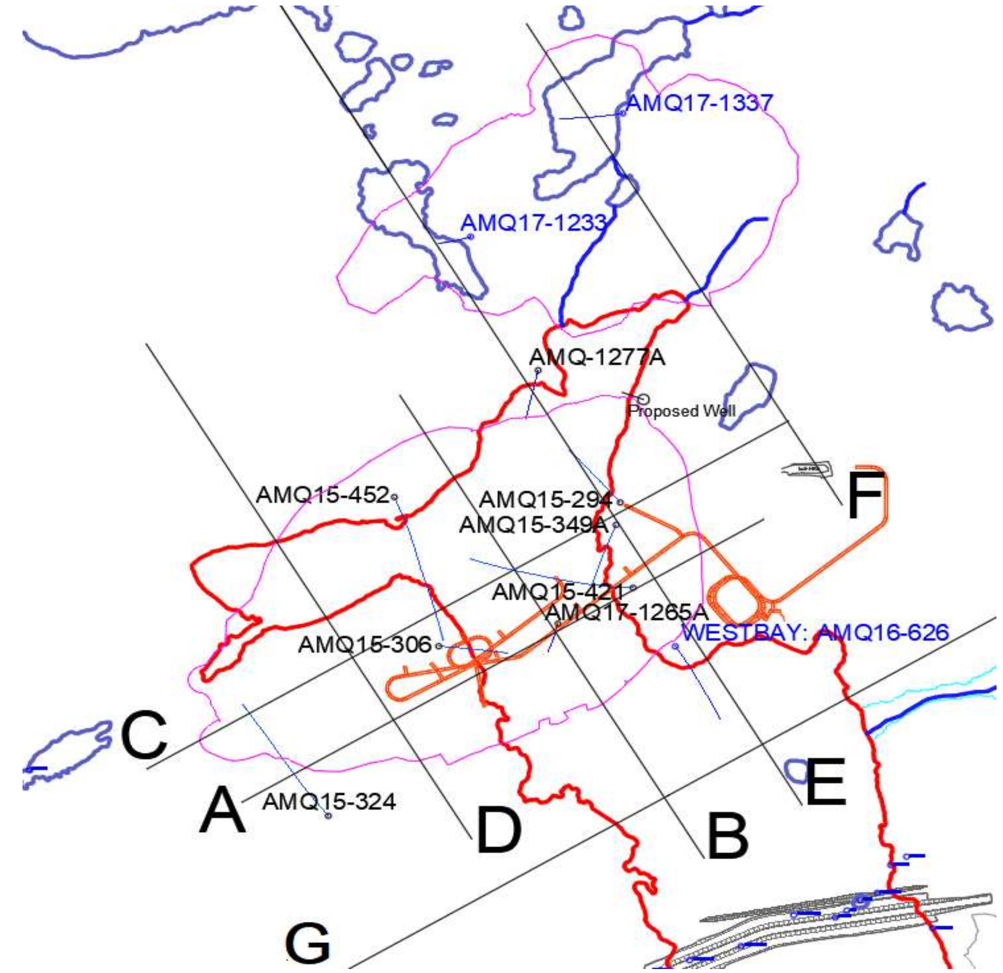
|---|---|
| Date: | Mar-19 |
| Design: | RM |
| Check: | FJ |
| Review: | |

**Project: Whale Tail Pit Project**

**Title: Thermal Model Calibration - Scenarios 1 & 2 - Section A**

| Project No. | Phase | Version | Figure No.: |
|---|---|---|---|
| 18108905 | | | **3** |




Zero Temperature Isoline

| Scenario | 1 |
|---|---|
| Ground Temperature (oC) | -10 |
| Whale Tail Lake Temperature (oC) | 0 to 3 |
| Shallow Lakes Temperature – other than Whale Tail Lake (oC) | n/a |
| Heat Flux (J/s) | 0.048 |
| Thermal Gradient (oC/m) | 0.016 |

| Scenario | 2 |
|---|---|
| Ground Temperature (oC) | -9.5 |
| Whale Tail Lake Temperature (oC) | 3 |
| Other shallow lake Temperature (oC) | n/a |
| Heat Flux (beneath ground) J/s<br>Thermal Gradient (oC/m) | 0.048<br>0.016 |
| Heat Flux (beneath WT Lake) J/s<br>Thermal Gradient (oC/m) | 0.018<br>0.006 |

**Client:**
**Agnico Eagle Mines Ltd.**

**Project: Whale Tail Pit Project**

GOLDER

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|---|---|
| Date: | Mar-19 |
| Design: | RM |
| Check: | FJ |
| Review: | |

**Title: Thermal Model Calibration - Scenarios 1 & 2- Section C**

| Project No. | Phase | Version | Figure No.: |
|---|---|---|---|
| 18108905 | | | **4** |