Appendix 20

Meadowbank In-pit disposal thermal and hydrogeological modelling update

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MEMORANDUM

Certifiée ISO 9001

TO :	Michel Groleau, Jenyfer Mosquera and Jamie Quesnel Agnico Eagle Mine (AEM)	**DATE :**	December 14th , 2018
C.C. :	Ruijie Chen, Emmanuelle Millet, Anh Long Nguyen and Dominic Tremblay		
FROM :	Marjan Oboudi, Nina Quan and Guillaume Comeau	**REF. :**	655183-000-4GCA-0001 Rev 01
SUBJECT :	Meadowbank In-Pit Tailings Disposal - Thermal and Hydrogeological Modeling Update to Address NRCan's Comments		

1.0 INTRODUCTION

Following the meeting in Ottawa with NRCan held on September 25th, 2018 regarding the Meadowbank In-Pit Tailings Disposal Modification – Hydrodrogeological and Permafrost, Agnico Eagle Mine (AEM) requested SNC-Lavalin to carry out the following tasks to address NRCan's outstanding comments:

1. Carry out the long term ground thermal modeling after in-pit tailings deposition and post closure for 20,000 years. The updated thermal modeling will be carried out for all the existing cross sections selected in previous work and an additional Section A1 at Portage Pit A selected together with NRCan during the meeting.
2. Update the hydrogeological modeling version 3's boundary conditions and permafrost limits.
3. Update the hydrogeological and contaminant transport models based on findings from the long term ground thermal modeling and the updated boundary conditions; and
4. Comments on the adequacy of the proposed groundwater monitoring wells network.

This memorandum presents a summary of the work on the thermal and hydrogeological modeling updates to address the above NRCan's comments. Table 1 summaries the NRCan's comments and the responses while Appendix A presents the details of the work carried out including the approaches, the results, interpretations and conclusions.

Table 1: Summary of NRCan's Comments and Responses

NRCan's Comments		Responses
Thermal Modeling	Long term ground thermal modeling after in-pit tailings deposition and post closure for 20, 000 years	Section 2.0
Hydrogeological and Contaminant Transport Modeling	Update hydrogeological modeling version 3's boundary conditions and permafrost limits	Section 3.2
	Update the hydrogeological and contaminant transport models	Sections 3.3 to 3.5
	Comment on the adequacy of the proposed groundwater monitoring well network	Section 3.6

2.0 LONG TERM EVOLUTION OF THERMAL REGIME

A thermal modeling was carried out in early 2018 for the in-pit tailings deposition detailed engineering study at the Goose Pit, Portage Pit A and Portage Pit E up to a 100-year period after closure. The modeling details and results were presented in the "In Pit Tailings Deposition Thermal Modeling Report", dated April 16th, 2018.

At the request of AEM to address NRCan's outstanding comments from the meeting on September 25th 2018, additional long term thermal modeling beyond 100 years and up to 20, 000 years after closure was carried out to evaluate the long term thermal regime/permafrost conditions for the three pits. Modeling summary of this work is presented in the following sub-sections.

2.1 Scope of Work

The scope of work for the long term thermal modeling involves two dimensional (2D) transient (up to 10,000 years) and steady state thermal analyses for the following five (5) cross-sections:

- Section A and Section A1 for Portage Pit A;
- Section E for Portage Pit E, and
- Section G1 and Section G2 for Goose Pit.

The sections are shown in Figure 2.1.

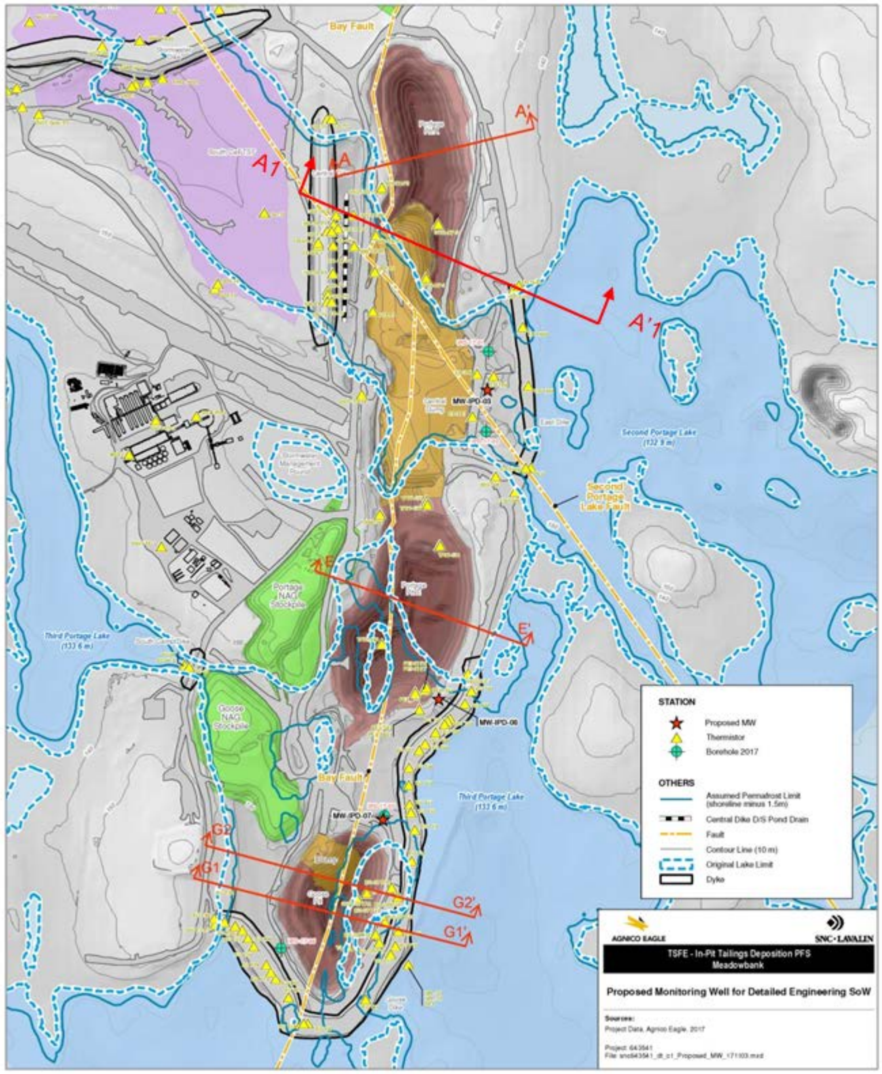

Figure 2-1: Thermal Modeling – Cross Section Locations

2.2 Methodology

The 2D thermal modeling was carried out using TEMP/W of GeoStudio 2016 developed by Geo-Slope International Inc. Calgary, Canada. Coupled seepage and thermal modeling was used to account for both conductive heat transfer under temperature gradient and convective heat transfer due to groundwater flow.

The modeling was staged in accordance with the main mine activities at the pit from lake dewatering, pit excavation and tailings deposition. Climate warming was projected for 100 year after pit closure and it is assumed remain constant beyond 100 years.

The thermal models are calibrated using available thermistor data including current (2018) and historical field data.

2.3 Assumptions and Boundary Conditions

The main assumptions for the thermal modeling include:

> The in-pit tailings deposition includes a water cover with a minimum thickness of 8 m during operation and after closure. A constant temperature of 4°C was assumed at the bottom of the water cover or the tailings surface as well as at the bottom of the lakes.
> A mean annual ground surface temperature of -6°C is assumed at the ground surface for steady state thermal modeling.
> The tailings deposition occurs instantaneously at the start of each stage for model simplification.

The air temperature boundary condition is presented in the presentation shown in the Appendix A. A projected climate warming with 4°C increase within 100 year after closure was assumed based on IPCC (IPCC, 2014), but no warming trend was projected further beyond.

2.4 Model Parameters

For the details on model parameters refer to the in-pit tailings deposition detailed design report (SNC-Lavalin, 2018). Table 2 summarizes the material properties used in the analysis.

Table 2: Key Material Properties

Material Property	Unit	Till	Bedrock	Weathered Bedrock	Fault Zone	Settled Tailings	Waste Dump
$K_{sat,unfrozen}$ (Saturated thermal conductivity)	$kJ/(day\,m\,°C)$	170	211	198	201	320	140
$K_{sat,frozen}$ (Saturated thermal conductivity)	$kJ/(day\,m\,°C)$	210	215	214	215	185	205
$C_{unfrozen}$ (Volumetric heat capacity)	$kJ/(m^3/°C)$	2366	2028	2125	2103	3085	2650
C_{frozen} (Volumetric heat capacity)	$kJ/(m^3/°C)$	2046	1998	2005	2003	2199	2085
K_{sat} (Hydraulic Conductivity)	m/sec	5×10−6	6×10−7	1×10−6	6×10−7	6×10−10	1×10−3

2.5 Analysis Results and Conclusions

The thermal modeling results are presented in the presentation shown in the Appendix A. The main conclusions from the long term thermal modeling are presented for each pit as follows.

❑ Goose pit

- The existing talik connection to Third Portage Lake is predicted to expand and the permafrost pockets on the pit walls will degrade and eventually disappear due to deposition of warm tailings and the pit lake effect at closure.

- Portage Pit E
  - The south portion of Pit E is predicted to have similar thermal conditions to Goose Pit with existing talik connection to Third Portage Lake and degrading permafrost pockets on pit walls;
  - At the north portion of the pit, a permafrost zone around the pit is predicted to remain until closure;
  - After pit closure a talik connection to the Third Portage Lake is predicted to develop on the east wall of the north portion and reaches ±60 m deep at about 100 year after closure;
  - A talik connection to the Third Portage Lake is predicted to develop at the bottom of northern portion of the pit at about 670 years after closure.
- Portage Pit A
  - The north portion of Pit A (at the location of Section A), a talik connection to Second Portage Lake is predicted to develop on the west wall at about 650 year after closure;
  - At Section A1, the south portion of Pit A, talik connections to the Second Portage Lake are predicted to develop on both east and west walls at closure which reaches about 25 m deep at 100 year after closure and about 50 m deep at 400 year after closure. The talik connection on the east wall closes due to the ground surface freeze back at about 200 year after closure and re-opens at about 620 years after closure.

3.0 HYDROGEOLOGICAL AND CONTAMINANT TRANSPORT MODELING UPDATES

A hydrogeological and contaminant transport modeling was carried out in late of 2017 for the in-pit tailings deposition detailed engineering phase at the Goose Pit, Portage Pit A and Pit E. The modeling details and results were presented in the "In-Pit Tailings Deposition Hydrogeological Modeling Report", dated June 2018.

At the request of AEM to address NRCan's outstanding comments from the meeting on September 25th 2018, an update on the hydrogeological and contaminant transport modeling (Version 3 to Version 4) was carried out. This section presents a summary of the work on the hydrogeological and contaminant transport updates.

3.1 Scope of Work

The scope of work includes the following:

- Update boundary conditions used in the hydrogeological modeling version 3;
- Update the permafrost conditions and limits used in the hydrogeological version 3;
- Carry out the hydrogeological and contaminant transport modeling update based on findings obtained from the long term ground thermal modeling. For modeling simplification, the work was conducted into the two times steps which the open talik was first observed (at Pit A, cross section A1). The steps are:
  - o Post Closure Step 1: 0 to 400 years.
  - o Post Closure Step 2: 400 years to 20,000 years.
- Estimate the mass fluxes and concentrations of the contaminants in Pit lake and Second Portage lake; and
- Comment on the adequacy of the proposed groundwater monitoring well network.

3.2 Permafrost Conditions and Limits Update

3.2.1 Permafrost Conditions

The consideration of the permafrost conditions in the hydrogeological model was carried out in two (2) time steps. Step 1 is based on the thermal modeling results at 400 years after closure and Step 2 is assuming the open talik below the pit. Figure 3-2 summaries the approached used in the two steps.

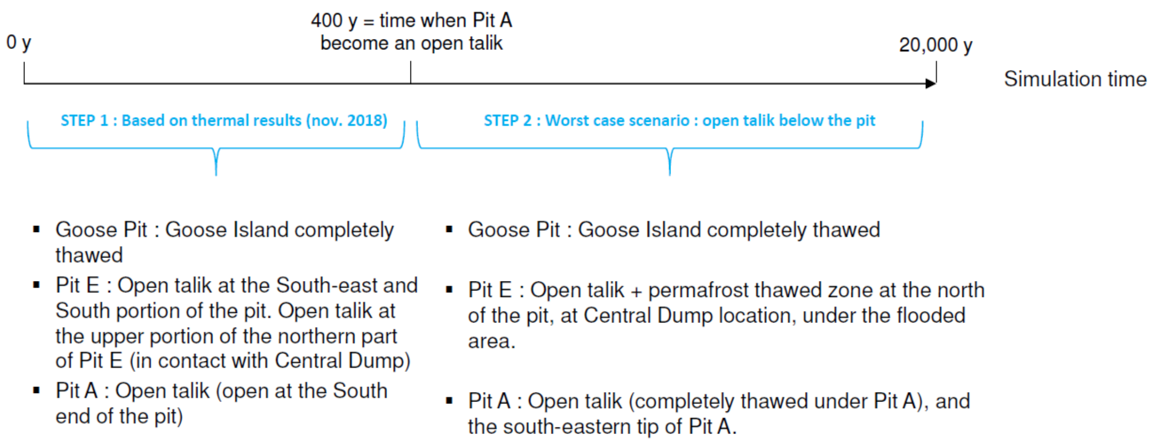

Figure 3-2: Permafrost Degradation Methodology

3.2.2 Key Findings

Thawing the permafrost under Pit A leads to the formation of an upward vertical gradient, which is higher at the northern end of Pit A. However, the southern end of Pit A is still showing a general downward flow path. Increasing the boundary hydraulic heads at the northern limit of the model is partially responsible.

3.3 Boundary Conditions Update

3.3.1 Boundary Conditions

The boundary conditions were developed based on Golder (2004 2005) simulated water level. Table 3 and Figure 3-3 present the boundary conditions used at the top of the model of the updated hydrogeological model.

Table 3: Flow Boundary Conditions (at the top of the model)

Figure color	Geographic position	Elevation (masl)	Layer	Boundary Condition
Grey zone	Permafrost area	variable	1	no flow
Blue area	3PL area and limit	variable	1	h = 133.6 m
Yellow Area	2PL area and limit	variable	1	h = 132.9 m

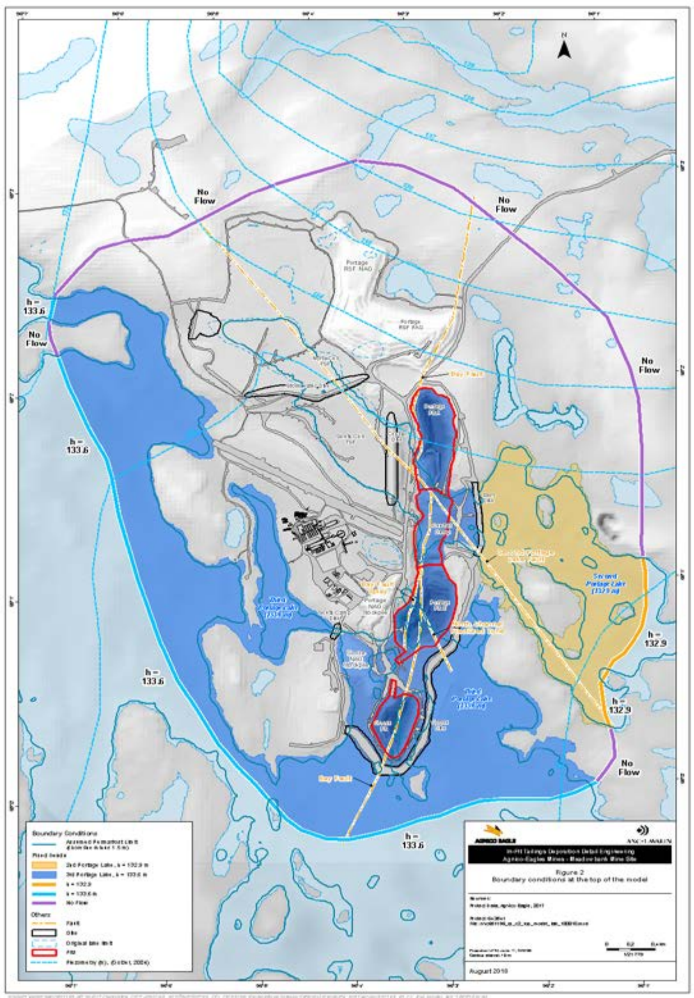

Figure 3- 3: Flow Boundary Conditions (at the top of the model)

The boundary conditions at the bottom of the hydrogeological model were developed based on Golder (2004, 2005) simulated water level and surveyed lake levels by AEM. Table 4 and Figure 3-4 show the permafrost and sub-permafrost boundary conditions as agreed with NRCan.

Table 4: Flow Boundary Conditions (at the bottom of the model, sub-permafrost conditions)

Section	Boundary Condition
A-B	No flow
B-C	No flow
C-D	No flow
D-E	No flow
E-F	132.9
F-G	132.9
G-H	No flow
H-I	135.6-136.6
I-J	136.6
J-K	136.6-135.6
K-A	No flow

Note: Changes in appear in red

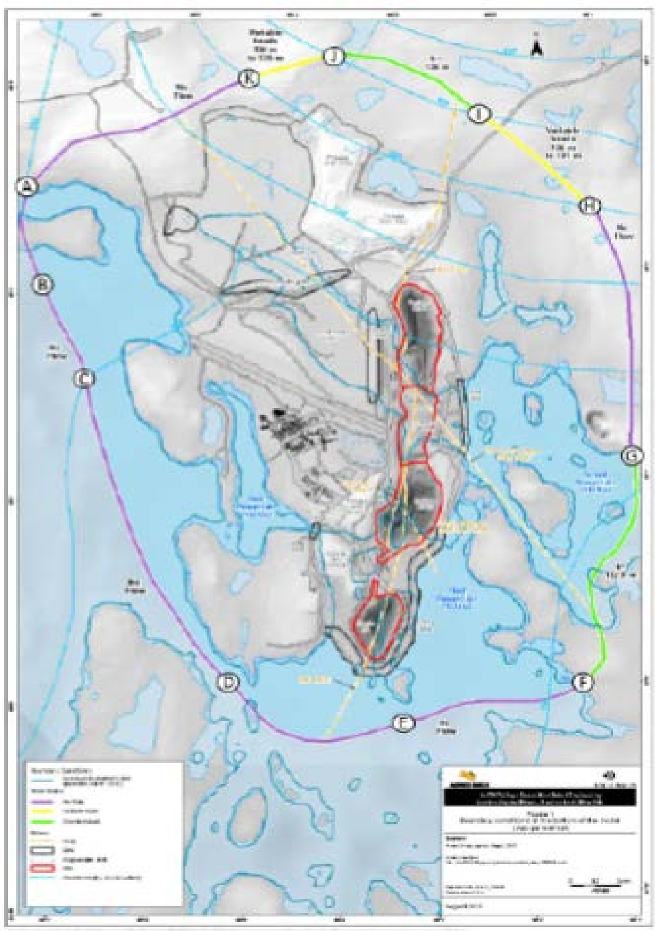

Figure 3-4: Flow Boundary Conditions (at the bottom of the model, sub permafrost conditions)

3.3.2 Key Findings

The following key findings were observed from the updated boundary conditions:

1. Changing E-G limits has slightly shifted the ground water flow paths to east direction.
2. Changing the northern boundary condition (H-K) leads to higher hydraulic head in the sub-permafrost layers and is partially responsible for upward flow below Pit A along with permafrost thawing and open talik formation as per thermal modelling results.

3.4 Hydrogeological and Contaminant Modeling Update

The hydrogeological and contaminant models were updated based on findings from the long term ground thermal modeling and boundary conditions previously discussed. The modeling update is carried out in two time steps: (1) post closure from 0 to 400 years and post closure from 400 years to 20,000 years. The assumptions and modeling results are presented in the presentation which is attached in the Appendix A.

The following are key findings from the contaminant transport simulations:

- General contaminant transport paths are quite similar compared to previous model (version 3).
- Thawing the permafrost around Pit E and Goose Pit seems to have insignificant impact on plumes migration paths. Pit E and Goose Pit still show downward flows, buried under Third Portage Lake and will discharge in Second Portage Lake with similar concentrations to reported in the previous model. Upward mass transfer to pit lakes will be limited to diffusion process for Pit E and Goose Pit.
- Modeling results suggest that contaminant plume from Pit E is not migrating towards the Central Dump, even though the talik exists between both entities.
- First arrival of chloride comes from Pit A and discharges to the Second Portage Lake but occurs sooner (after 400 years) than simulated with Model version 3 (2,000 years). This mainly due to the increase in boundary hydraulic heads of the sub-permafrost at the northern limit of the model.
- Higher hydraulic heads at the northern limit of the model along with the open talik below Pit A lead to an upward vertical gradient in the northern part of Pit A. If the maximum chloride upward flux at the northern part of Pit A is applied to Pit A lake area, Chloride and Arsenic mass fluxes into the overlying Pit A lake (and Third Portage Lake) will be 14 and 0.11 g/day, respectively.
- Chloride and Arsenic mass fluxes increase over time due to Pit A, Pit E and Goose Pit plume migration towards the Second Portage Lake. Mass fluxes in the 20,000 year period stays below 200 g/day of chloride and 1.5 g/day of arsenic.
- Arsenic fluxes are conservative since no attenuation or adsorption (fully mobile in groundwater) was considered. Arsenic treatment of the water cover is planned before pit lake reconnection to Third Pit Lake.

3.5 Water Budget and Concentrations at the Receivers

The water budget, developed for Meadowbank, was used to predict the chloride and arsenic concentrations to the receivers (Pit Lake and Second Portage Lake). Water inputs to receiver (Figure 3-5) include: groundwater seepage from Pit A upward flow, groundwater seepage to Second Portage Lake, surface water runoffs, evapotranspiration, sublimation, transfer from a lake to the other.

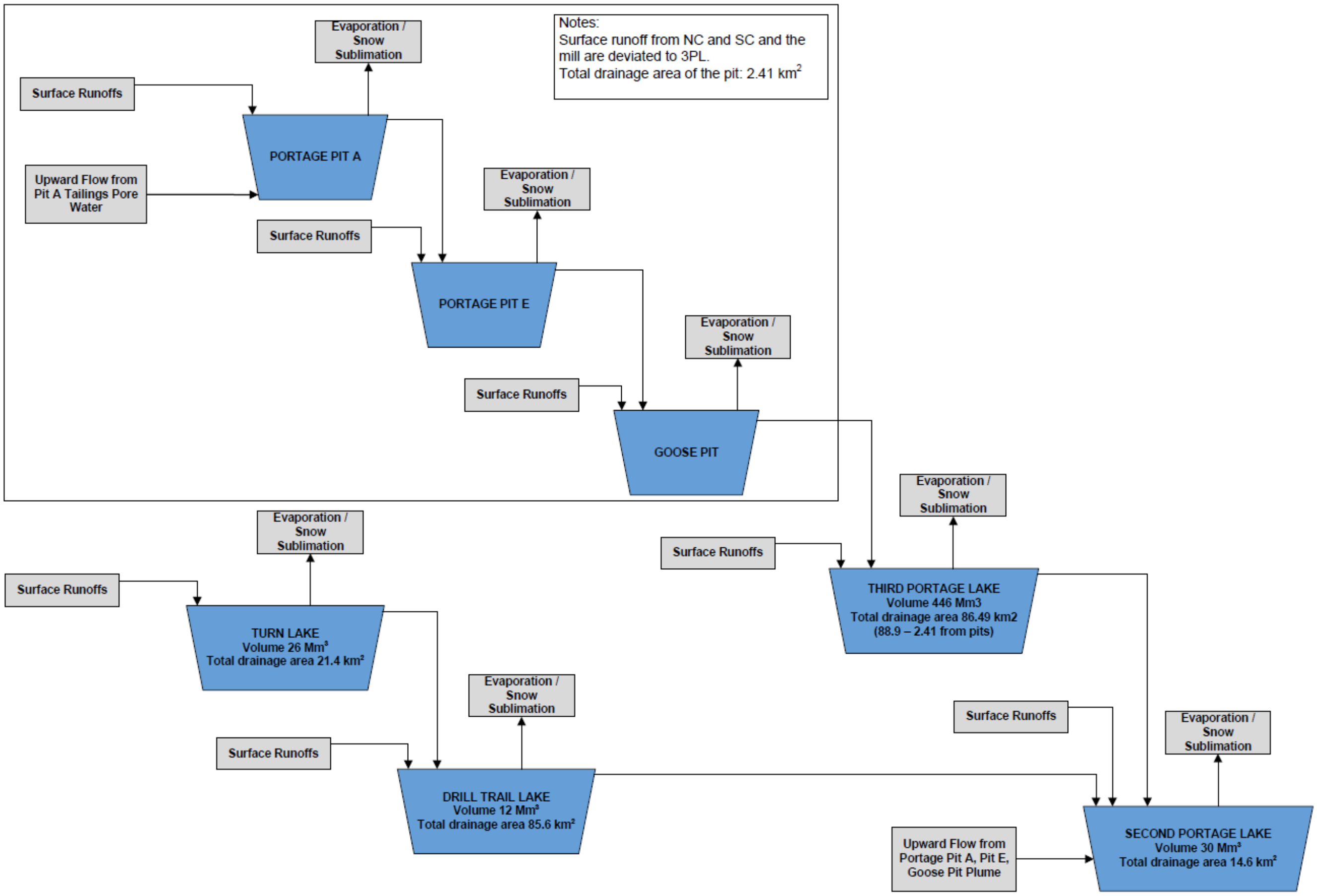

Figure 3-5: Water Budget and Transfers to lakes

3.5.1 Assumptions

The main assumptions for the water budget and concentration include:

- Water balance based on average net annual precipitation.
- Initial concentrations in the tailings pore water are based on water quality forecast evaluated in detail engineering (Version 2) with pit filled at full capacity and assume no water treatment of pore water.
- Model assumes that the water cover within Portage and Goose pits is treated prior to reconnection to Third Portage Lake.
- The concentration of Cl and As in the runoff water is assumed to be similar to the concentration measured in Third Portage Lake, and considered non-significant.
- Initial concentration of the water cover is considered equal to CCME guideline and was used for the long term forecasted concentrations
- Surface runoff from the mill and North and South Cell TSF are directed toward Third Portage Lake.
- 2PL, 3PL, Turn Lake and Drill Trail Lake hydrological characteristics are based on Cumberland report (2005) Baseline Physical Ecosystem report.

Table 5: Average annual runoffs and Groundwater seepage in Pit A Lake and Second Portage Lake

Parameters	Units	Pit A Lake	2PL watershed
Catchment Area	km²	0.88	213
Lake Volume	m³	9 309 579	556 394 737
Avg Annual runoff	m³/yr	89 855	21 822 970
Groundwater (GW) seepage to the lake, extracted from the hydrogeological model	m³/yr	43	21 718
Ratio GW / Runoff	%	0.05	0.1

Chloride and arsenic mass fluxes into Pit Lake and Second Portage Lake were extracted from the hydrogeological model and implemented in the water budget to calculate loads at different time steps. The chloride and arsenic forecast concentrations forecast are shown on Figures 3-6 and 3-7.

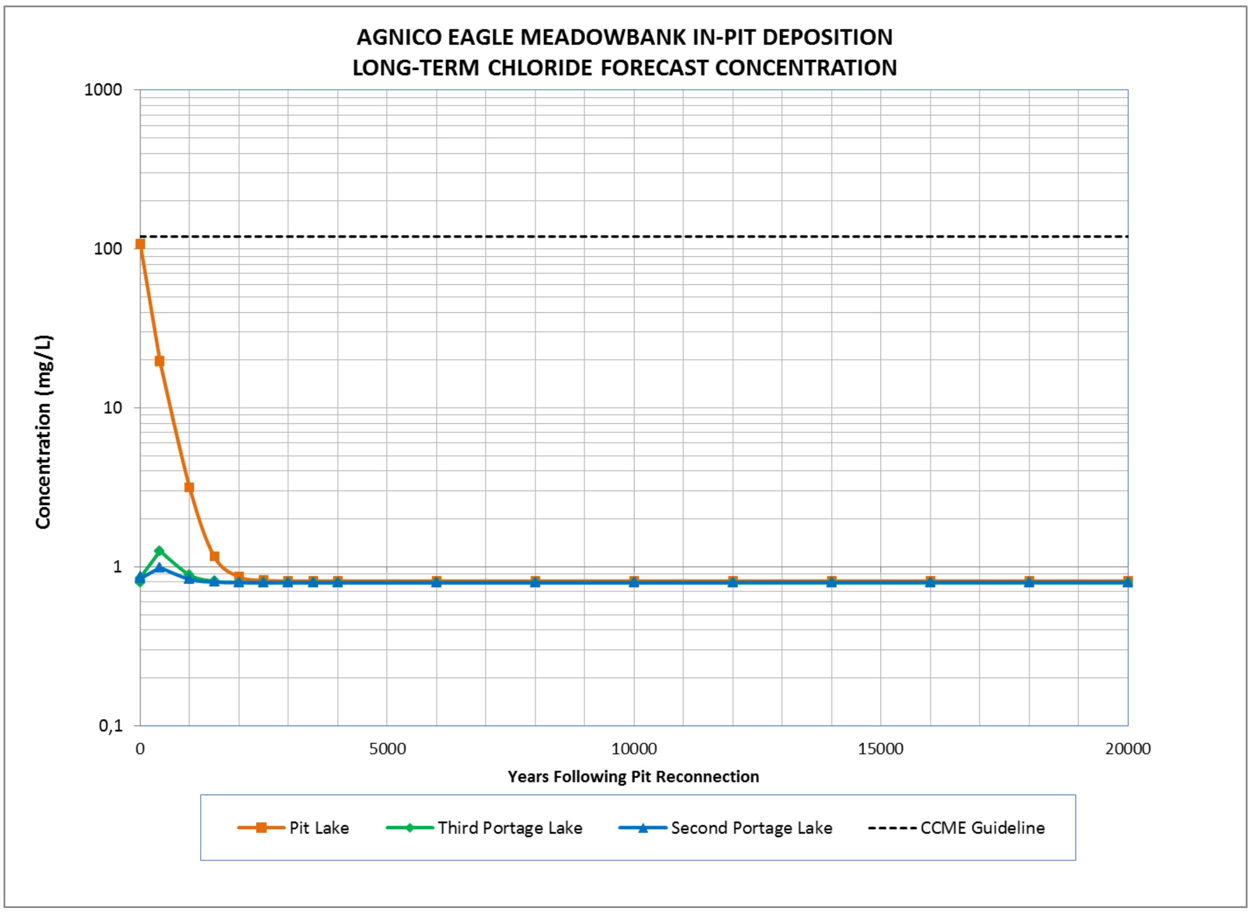

Figure 3-6: Long-term chloride forecast concentration in Pit Lake and Second Portage Lake

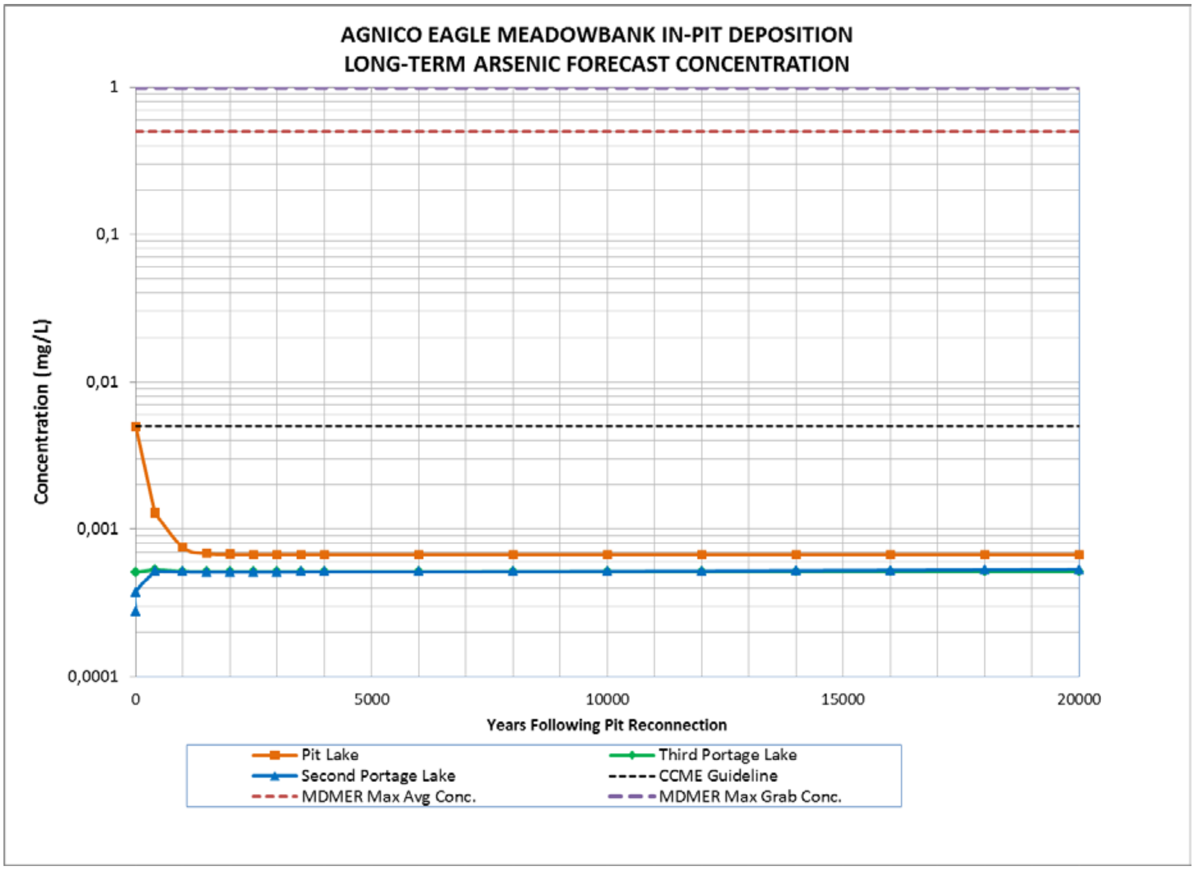

Figure 3-7: Long-term arsenic forecast concentration in Pit Lake and Second Portage Lake

3.5.2 Key Findings

The following key findings were observed from the water budget and forecast concentrations at the receiver:

1. Groundwater seepage volume in Pit A (43 m³/y) and in Second Portage Lake (21,718 m³/y) are low compared to fresh water runoff input in these lakes (0.9 Mm³/y for Pit A and 21.8 Mm³/y for Second Portage Lake watershed), (table 5);
2. In Pit lake, chloride and arsenic concentrations will decrease over time, even with a constant upward release of chloride from Pit A tailings pore water;
3. Even though chloride and arsenic fluxes increase over time at Second Portage Lake with arrival of the plume, their concentrations in the lake will remain below CCME guideline;
4. Insignificant concentration peaks observed at 400y is due to the transfer of chloride loads from the water cover to the surrounding Third and Second Portage Lakes, after lake reconnection.
5. Based on the Water Budget approach and the simulated mass fluxes from the hydrogeological model, forecasted chloride and arsenic concentrations in the Second and Third Portage Lakes do not show significant impacts on fresh water as they remains below CCME guidelines.

3.6 Groundwater Monitoring Well Network

Based the updated contaminant transport modeling, the proposed groundwater monitoring wells network was re-assessed and the following key findings were obtained:

- The current monitoring well network was designed for establishing baseline conditions and monitoring during operational phase but breakthrough curve analysis reveals that the current monitoring well network can also be used for long term monitoring (closure & post-closure).
- Current monitoring well network is capable of intercepting the plumes from Pit A, Pit E and Goose Pit.
- AEM already committed to implement tailings pore water quality, which are important to define contaminant source concentration and evolution with depths. Pit lake water quality will also be monitored, with emphasis to Pit A Lake, which will show upward flow once an talik will open. As per the water licence requirement, a final monitoring plan is required for closure and the contaminant transport model will be recalibrated based on data collected during operations. At that time, additional GW monitoring systems, if required, could be installed 1 or 2 years before closure.
- The monitoring wells network will be used to confirm contaminant transport model prediction in operation and closure. Calibration on transport parameters will be assessed at that time.

Appendix A : Meadowbank In-Pit Tailings Disposal – Update (Presentation)

Meadowbank In Pit Tailings Disposal - Update

Prepared by:

Marjan Oboudi
Ruijie Chen
Emmanuelle Millet
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December 12th, 2018

Table of content

Introduction

Introduction

Hydrogeological Model Version 4 is a result of the meeting held on September 25, 2018 with NRCan, Agnico Eagle, SNC-Lavalin, Golder and CIRNAC.

The purpose of this meeting was to discuss NRCan's outstanding concerns with permafrost and groundwater studies related to the assessment of potential impacts from the in-pit tailings modification at AEM's Meadowbank Mine in Nunavut, Canada. The NIRB had set out a shortened review process with one round of IRs and no public hearing and NRCan experts had outstanding concerns at the end of this process, and submitted a set of twelve comments to the Nunavut Water Board (NWB). This meeting was set to resolve these issues for the regulatory phase of the project.

Next Introduction slides are presenting an extract of the meeting record that summarize the commitments made by Agnico Eagle and presents a the objectives and design basis of the Hydrogeological Model Version 4.

Introduction

Extract from Meeting record
Agnico Eagle Mines (AEM) at Natural Resources Canada (NRCan)
Meadowbank In-Pit Tailings Disposal Modification (NIRB File No. 03MN107)
Hydrogeology and Permafrost Discussion

Date: September 25, 2018
Location: NRCan office (601 Booth Street, Ottawa, ON – Room 240)

(…)

Following review of the model, NRCan's comments were discussed in sequence, beginning with the thermal modelling. Discussion focused on how best to model permafrost degradation and how best to present the data. Specific locations for cross-sections within the model were discussed. NRCan and AEM reached agreement on the cross-sections to be presented in the next version and AEM committed to running the thermal modelling for 20,000 years and include this data, in steps, in the hydrogeological model.

Boundary conditions for the hydrogeological model were discussed next, with NRCan's proposed boundary conditions compared to those in Version 3 of the hydrogeological model. Key issues raised by NRCan were that the boundary conditions should represent the upwelling at the edge of the permafrost that could be a possibility and that the flow paths should represent the regional flow model prepared by Golder in 2004. Discussion included the elevation of the heads, which NRCan had adjusted to account for differences between lake levels in the Golder (2004) regional model and SNC Lavalin models, as well as changing the distribution of the boundary segments to better represent the flows shown in the Golder regional model.

Introduction

A discussion of the Groundwater Management Plan and the Groundwater Monitoring plan focused on the operational and closure phases of the monitoring plan, the locations of wells, including how they are chosen and the timing of their installation. AEM indicated that wells were set to collect baseline data as well as to monitor during operations. Some wells are limited by permafrost depth, and closure monitoring wells will be selected based on data collected during operations and a refined hydrogeological model informed by this data. AEM agreed to include the monitoring table requested by NRCan in their operational phase groundwater monitoring plan, and to update it for the closure phase. NRCan's suggestions regarding monitoring were primarily to ensure that each well's location is assessed based on the hydrogeological model. NRCan and CIRNAC suggested that closure monitoring wells be installed well in advance of closure in order to collect background data. AEM agreed that wells would be installed within a one to two year window before closure, based on weather and drill availability.

Seepage from the Central Dyke was addressed briefly. AEM explained that an area of high permeability under the Central Dyke resulted in a seepage pathway 50m wide, but that this had been reduced with the addition tailings with lower hydraulic conductivity. NRCan stated that this does not appear to be a serious issue and is of far less concern than the thermal modelling and boundary conditions. AEM asked if this issue was resolved and NRCan confirmed that it was.

AEM committed to running the thermal modelling based with the changes discussed and for 20,000 years, to run the hydrogeological model (Version 4) with the updated thermal data and boundary conditions (…)

End of the extract

PART I

Long Term Evolution of Thermal Regime

In Pit Tailings Deposition Long Term Thermal Modeling

I. Scope of Work

II. Methodology

III. Assumptions and Limitations

IV. Thermal Modeling Results

- Portage Pit A
- Portage Pit E
- Goose Pit

V. Conclusions

Scope of Work

Long term ground thermal modeling after in pit tailings deposition and post closure for:

- Goose Pit (Sections G1 and G2)
- Portage Pit E (Section E)
- Portage Pit A (Sections A and A1).

The model results are presented at the following major time steps:

- Prior to tailings deposition
- At Closure
- 100 Years after closure
- 1,000 years after closure
- 10,000 years after closure
- 20,000 years after closure

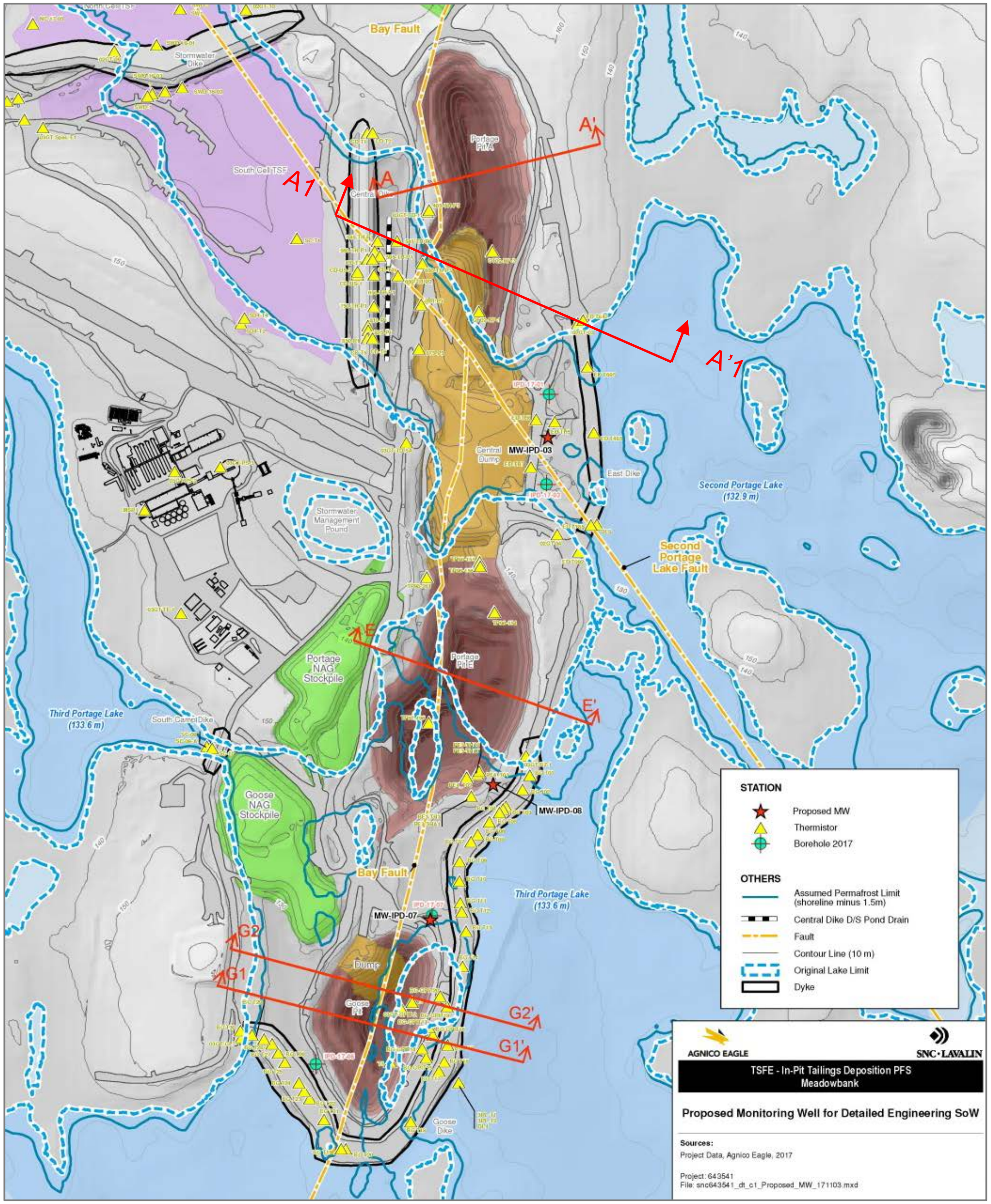
Additionally, time steps at which the permafrost is predicted to undergo significant changes (permafrost becomes disconnected) are presented.

The long term analysis results under Steady State Condition are also presented.

Section Locations

Section A1
Thermal modeling along NW-SE cross-section through SE corner of Portage Pit A

Section A1 is the new cross section selected during the NRCan review meeting (September 2018) and is located at the South East portion of Portage Pit A as presented on the next slide.



Major Differences between Current Analysis and the Thermal Modeling Presented in "In Pit Tailings Deposition Thermal Modeling Report, April 16, 2018"

Pit	Cross Section	Report April 16, 2018	Current Analysis
Portage Pit A	Section A	Thermal analysis up to 100 yrs after closure	• The model is updated to represent the potential permafrost degradation under the flooded Portage Pit A at post-closure • Long term thermal analysis up to 20,000 yrs after closure • Post closure steady state analysis
Portage Pit A	Section A1	Not selected	• A new thermal model section was created for Section A1 location which was selected during the NRCan review meeting (September 2018) • The model is updated to represent the potential permafrost degradation under the flooded Portage Pit A at post-closure • Long term thermal analysis up to 20,000 yrs after closure • Post closure steady state analysis
Portage Pit E	Section E	Thermal analysis up to 100 yrs after closure	• The model is updated to represent the potential permafrost degradation under the flooded Portage Pit E at post-closure • Long term thermal analysis up to 20,000 yrs after closure • Post closure steady state analysis
Goose Pit	Section G1	Thermal analysis up to 100 yrs after closure	• Long term thermal analysis up to 20,000 yrs after closure • Post closure steady state analysis
Goose Pit	Section G2	Thermal analysis up to 100 yrs after closure	• Long term thermal analysis up to 20,000 yrs after closure • Post closure steady state analysis

Methodology

- The thermal modeling was carried out using TEMP/W of GeoStudio 2016 developed by Geo-Slope International Inc. Calgary, Canada.
- Coupled seepage and thermal modeling was used to account for both conductive heat transfer under temperature gradient and convective heat transfer due to groundwater flow.
- Staged transient analysis for lake dewatering, pit excavation, tailings deposition and long term projected climate warming conditions.
- Model calibration using current temperature measurement data.
- A long term climate condition is considered by applying an average temperature increase of 4°C over a 100-year period after closure (IPCC, AR5, 2014) and then remaining the constant annual average temperature beyond.

Assumptions and Limitations

- Assumptions
  - Tailings temperature at discharge point is assumed at 10°C (Initial Temperature).
  - The bottom of the lake and of the pit water cover is assumed at a constant temperature of 4°C.
- Limitations
  - Heat conduction and convection are three-dimensional in reality which cannot be fully captured in 2D modeling
  - Tailings deposition is continuous for each stage in reality but was modeled as instantaneous at the start of each stage

Model Calibration

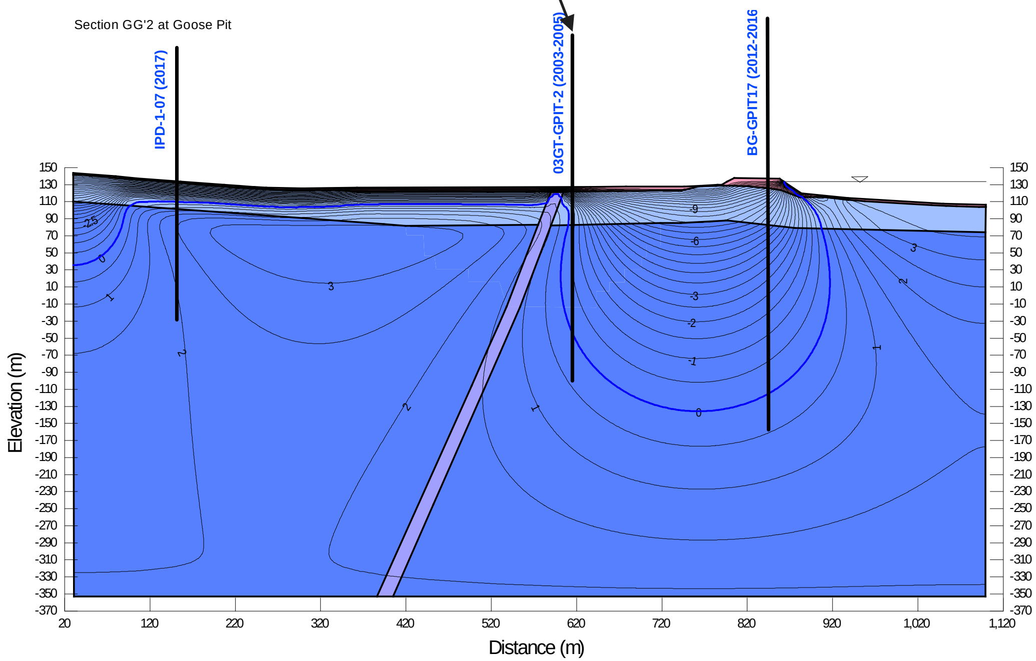
- **Thermal Conditions Before Pit Excavation**
  - **Portage Pit A (**GT02-NP-1, GT02-NP-3)
  - **Portage Pit E (**TP97-196**)**
  - **Goose Pit (**03GT-GPIT-2**)**

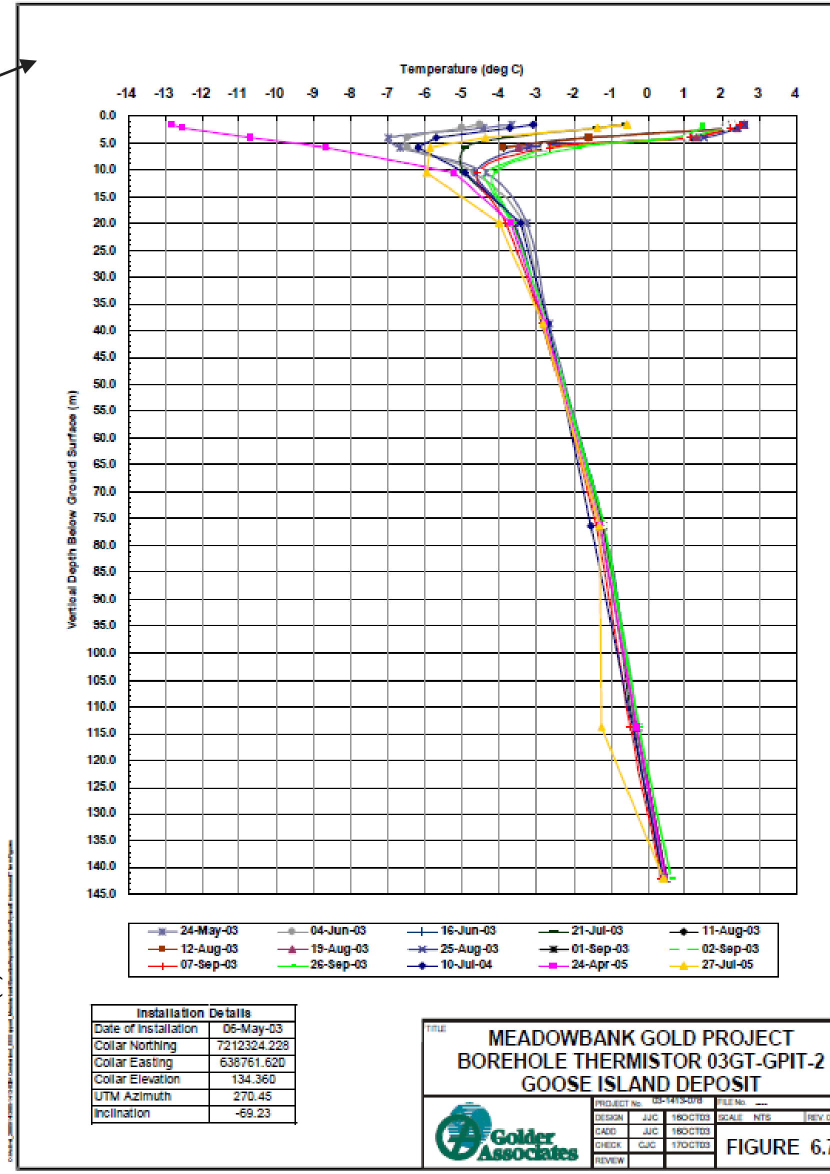
- **Current Thermal conditions**
  - **Goose Pit (**TH-IDP-17-01, TH-IDP-17-02, TH-IDP-17-06, TH-IDP-17-07**)**
  - **Central Dump** (IPD-17-08)

Thermistors information used in model calibration

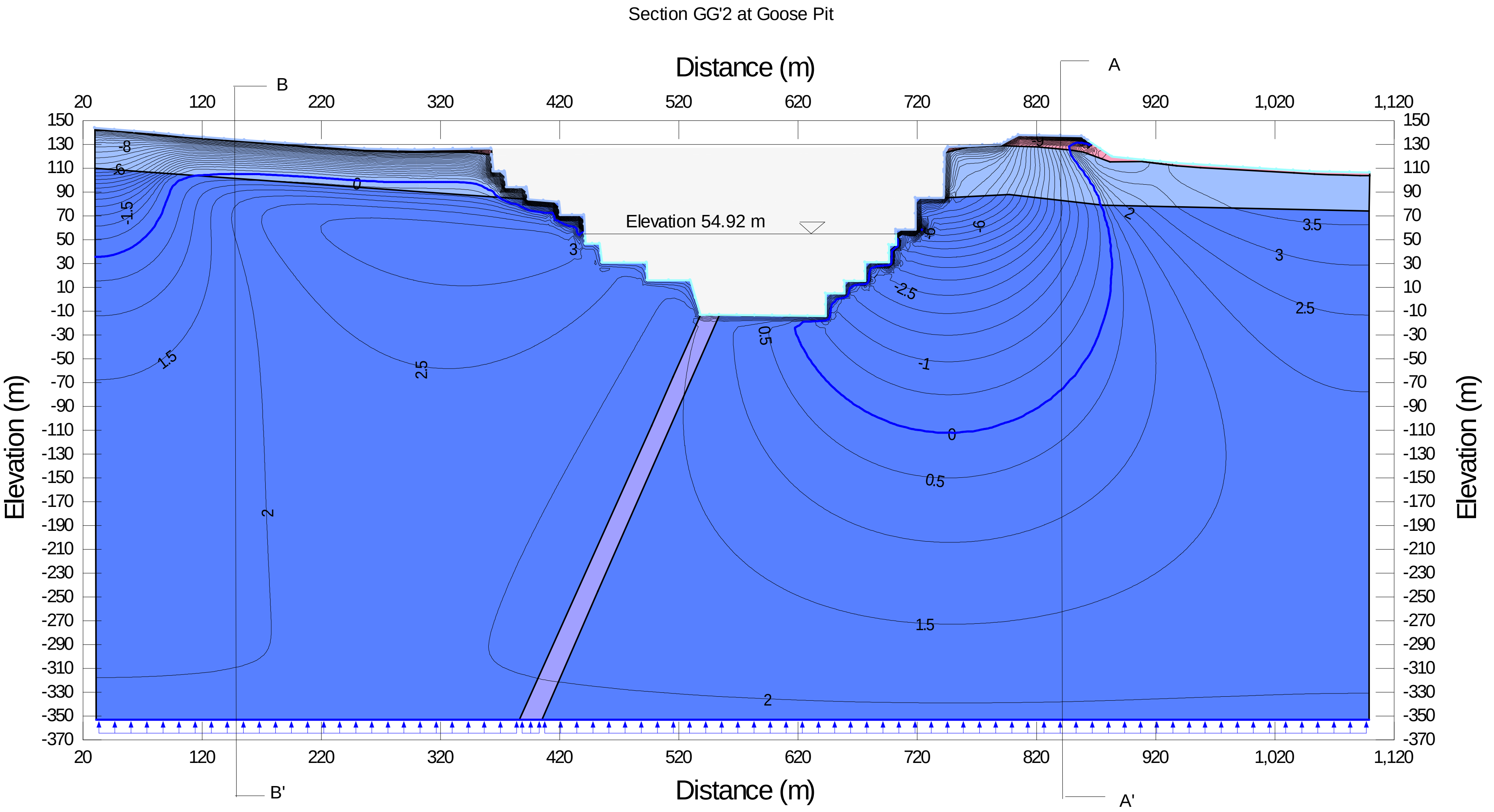
ID	Pit	Location wrt Pit	Ground Elevation	Date Start	Date End	Permafrost Bottom Depth (masl)	Permafrost Bottom Elevation (masl)
03GT-GPIT-2	Goose Pit	Center	134.6	2003-05-24	2005-07-27	158	-23
BG-GPIT13	Goose Pit	East road	133.1	2012-10-22	2016-11-24	17	116
BG-GPIT16	Goose Pit	East road	134.1	2012-10-22	2016-11-24	53	81
BG-GPIT17	Goose Pit	East road	134.9	2012-10-22	2016-11-24	172	-37
BG-GPIT20	Goose Pit	East road	136.6	2012-10-22	2016-11-24	161	-24
IPD-17-01	Goose Pit	East Road	129.9	2017-07-01	2017-10-05	30	100
IPD-17-02	Goose Pit	East Road	130.6	2017-07-01	2017-10-05	5	125
IPD-17-06	Goose Pit	Northeast	130.8	2017-07-01	2017-10-05	N/A	N/A
IPD-17-07	Goose Pit	Southwest	134.0	2017-07-01	2017-10-05	20	114
TP96-154	Portage Pit E	Northeast (inside pit)	145.3	1996-08-09	-	470	-325
TP97-196	Portage Pit E	Southwest (inside pit)	133.0	Jun 1999	July 2005	280	-147
TP98-261	Portage Pit E	Northwest	134.5	-	-	450	-316
WR-P3	Portage Pit A	Southwest	128.1	2016-01-18	2016-11-29	52	76
650-TH-P3	Portage Pit A	Southwest (inside pit)	109.5	2013-02-06	2016-11-29	236	-127
GT02-NP-1	Portage Pit A	South (inside pit)	134.0	2002-09-20	2005-07-27	326	-192
GT02-NP-3	Portage Pit A	South (inside pit)	135.0	2002-09-20	2005-09-03	370	-235
IPD-17-08	Portage Pit A	Within the Waste Dump	113.7	2017-12-04	2018-02-07	35	75

Thermal Conditions Before Pit Excavation Goose Pit (03GT-GPIT-2)

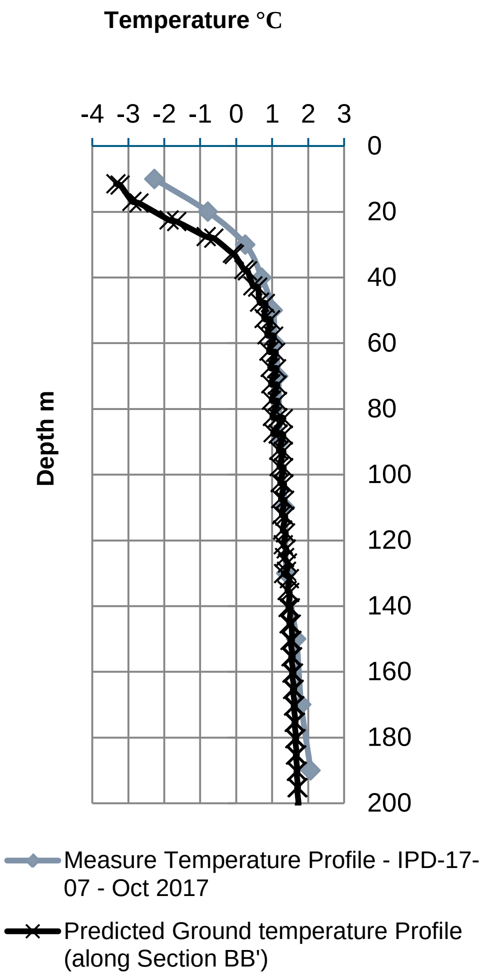


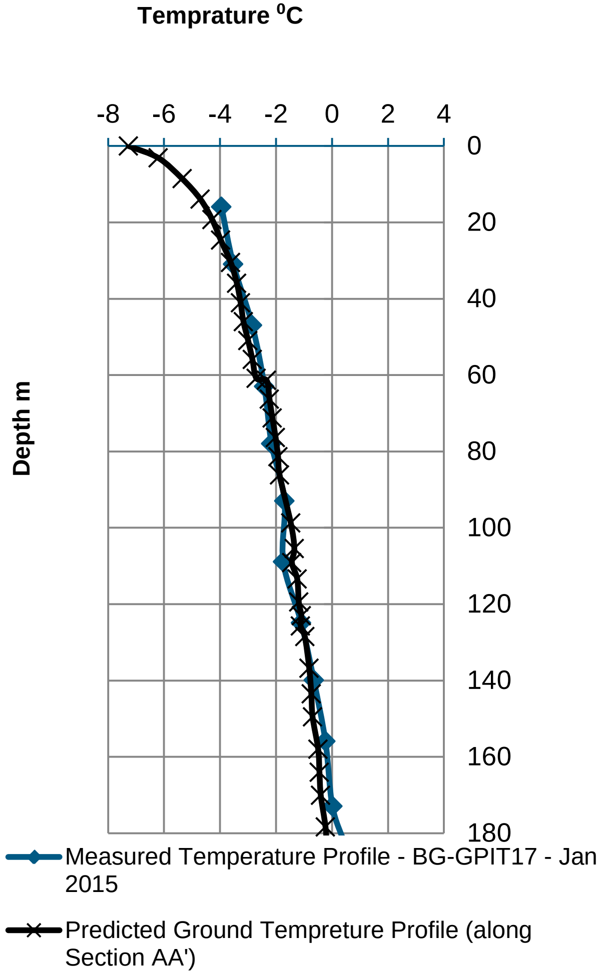


Model Calibration



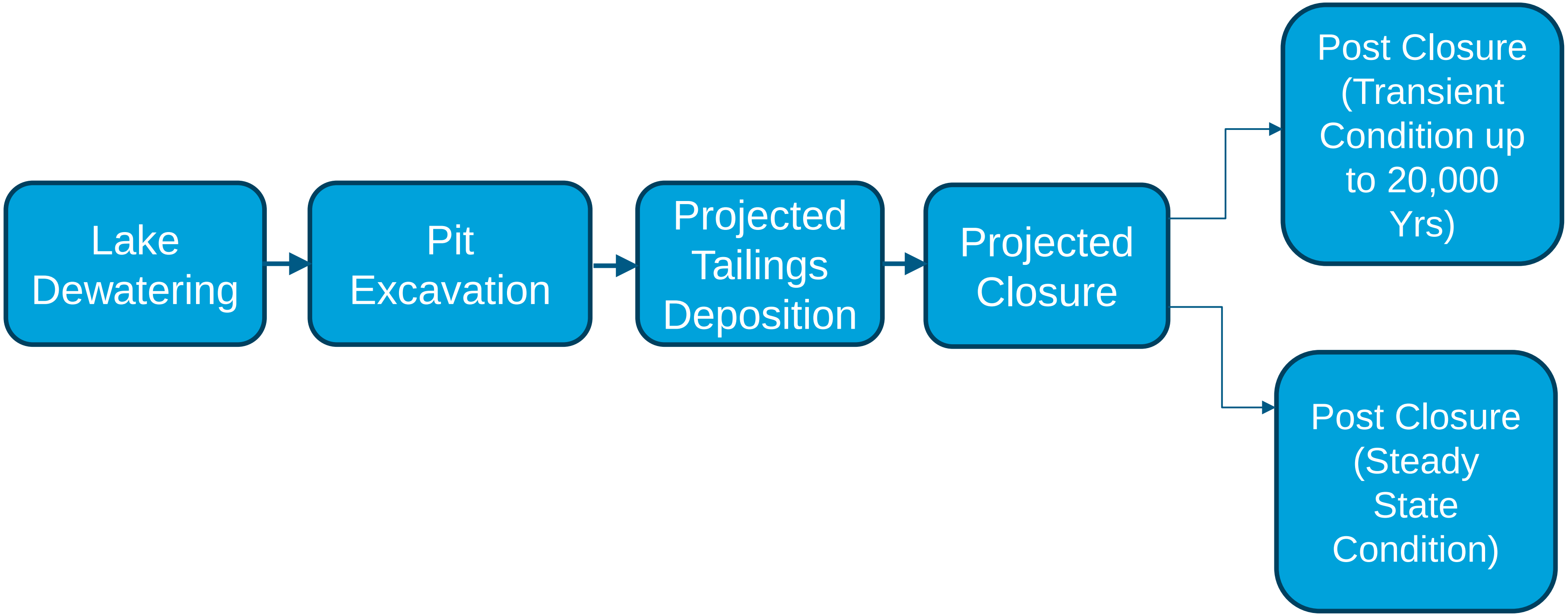
Model Section and Calibration





Thermal Modeling - Major Time Steps

Major Historical Constructions, Projected Tailings Deposition, Closure and Post Closure



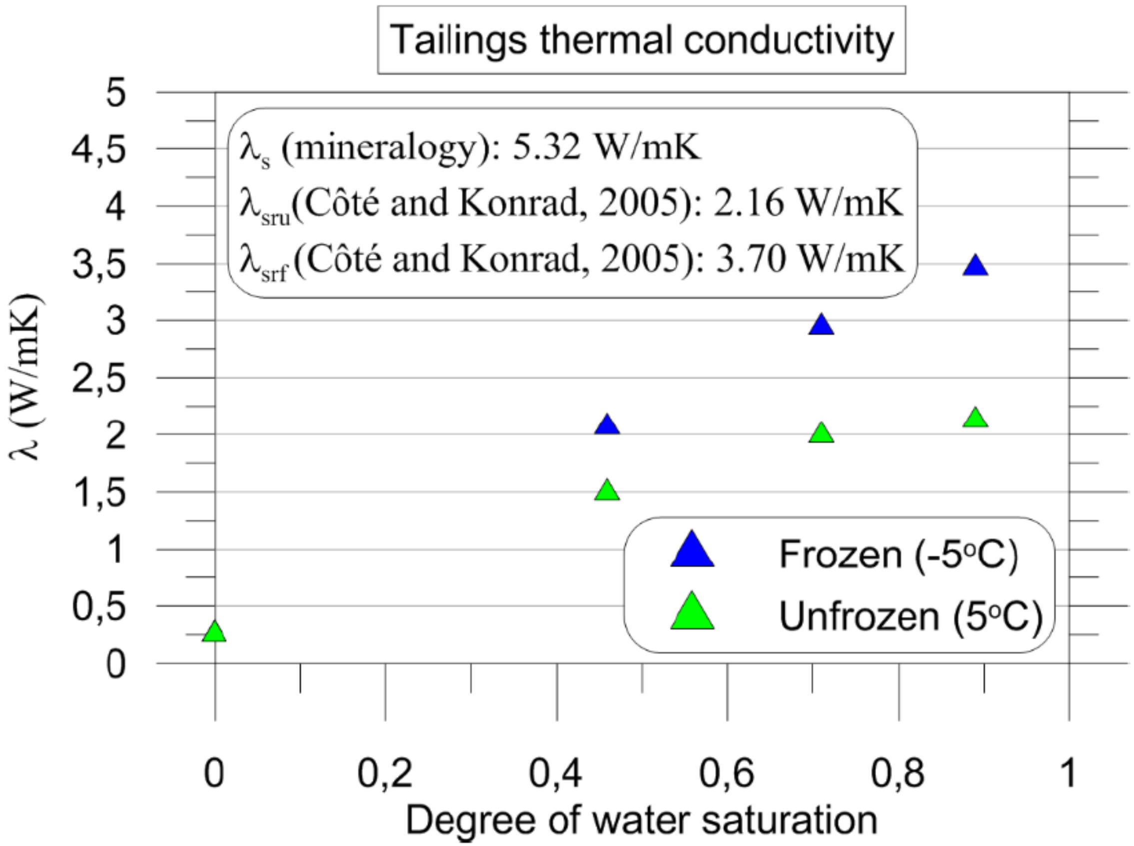
Pit Development and In Pit Tailings Deposition schedule

Name of Pit	Year of Excavation Start (i.e. start of mining)	Year of Excavation Complete (i.e. end of mining)
Goose Pit	2012	2015
Portage Pit A	2010	2018
Portage Pit E	2010	2017

					GOOSE PIT		PORTAGE PIT E		PORTAGE PIT A	
Number of Deposition	Proposed Starting Time of Deposition	Proposed Ending Time of Deposition	Nb. Days	Location	Tailings Surface Elevation at end of Deposition (m)	Pit Water Level at end of Deposition (m)	Tailings Surface Elevation at end of Deposition (m)	Pit Water Level at end of Deposition (m)	Tailings Surface Elevation at end of Deposition (m)	Pit Water Level at end of Deposition (m)
1	April/18	June/19	426	Goose Pit	108.92	127.52	-23.00	4.62	-3.00	66.87
2	July/19	June/20	336	Portage Pit E	108.92	125.13	49.11	63.16	-3.00	58.27
3	July/20	May/21	304	Portage Pit A	108.92	121.09	49.11	64.21	74.94	92.25
4	June/21	October/21	122	Goose Pit	120.40	127.78	49.11	87.38	74.94	90.02
5	November/21	May/23	546	Portage Pit E	120.40	128.70	82.90	99.57	74.94	96.84
6	June/23	April/24	305	Portage Pit A	120.40	128.57	82.90	102.44	99.21	105.11
7	May/24	May/25	365	Portage Pit E	120.40	128.70	99.08	112.69	99.21	110.55
8	June/25	September/25	92	Portage Pit A	120.40	127.63	99.08	113.40	105.99	115.78
9	October/25	May/26	212	Portage Pit E	120.40	128.70	107.78	116.86	105.99	114.84
10	June/26	September/26	92	Portage Pit A	120.40	127.63	107.78	117.51	111.65	119.72
11	October/26	May/27	212	Portage Pit E	120.40	128.70	115.39	120.78	111.65	118.89
12	June/27	September/27	92	Portage Pit A	120.40	127.63	115.39	122.74	116.44	124.68
13	October/27	May/28	213	Portage Pit E	120.40	128.70	122.24	126.09	116.44	124.59
14	June/28	November/28	153	Portage Pit A	120.40	127.91	122.24	127.59	122.74	128.85
15	December/28	March/29	90	Portage Pit E	120.40	128.44	125.30	129.51	122.74	128.35
16	April/29	June/29	61	Portage Pit A	120.40	127.63	125.30	129.71	125.43	130.52

Note: The above tailings deposition schedule was received on 2018-01-12.

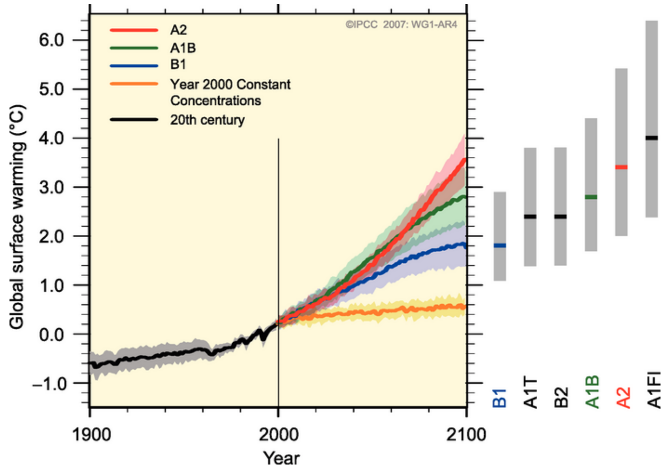
Material Properties



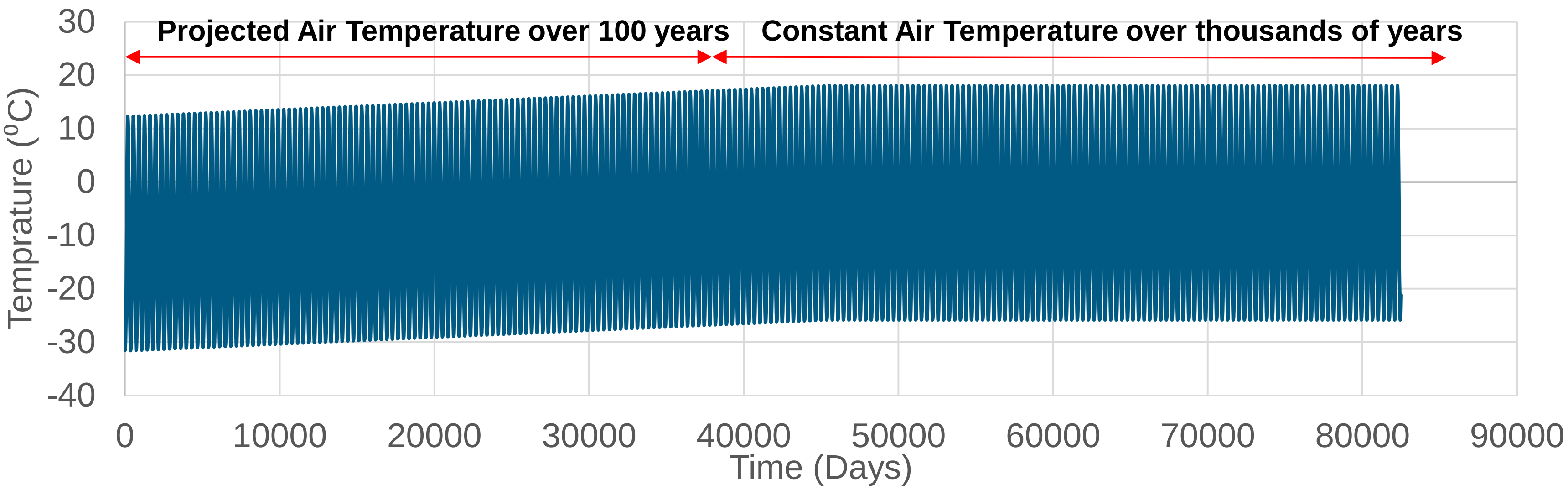
Material Properties

Item	Till	Bedrock	Weathered bedrock	Fault Zone	Settled Tailings	Waste Dump
$K_{sat,unfrozen}$ Saturated thermal conductivity $kJ/(day\ m\ °C)$	170	211	198	201	320	140
$K_{sat,frozen}$ Saturated thermal conductivity $kJ/(day\ m\ °C)$	210	215	214	215	185	205
$C_{unfrozen}$ Volumetric heat capacity of overburden soil $kJ/(m^3/°C)$	2366	2028	2125	2103	3085	2650
C_{frozen} Volumetric heat capacity of soil $kJ/(m^3/°C)$	2046	1998	2005	2003	2199	2085
Hydraulic Conductivity cm/s	5×10^{-4}	6×10^{-5}	1×10^{-4}	6×10^{-5}	6×10^{-8}	1×10^{-1}

Boundary Conditions

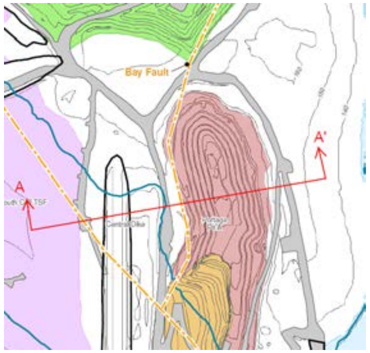


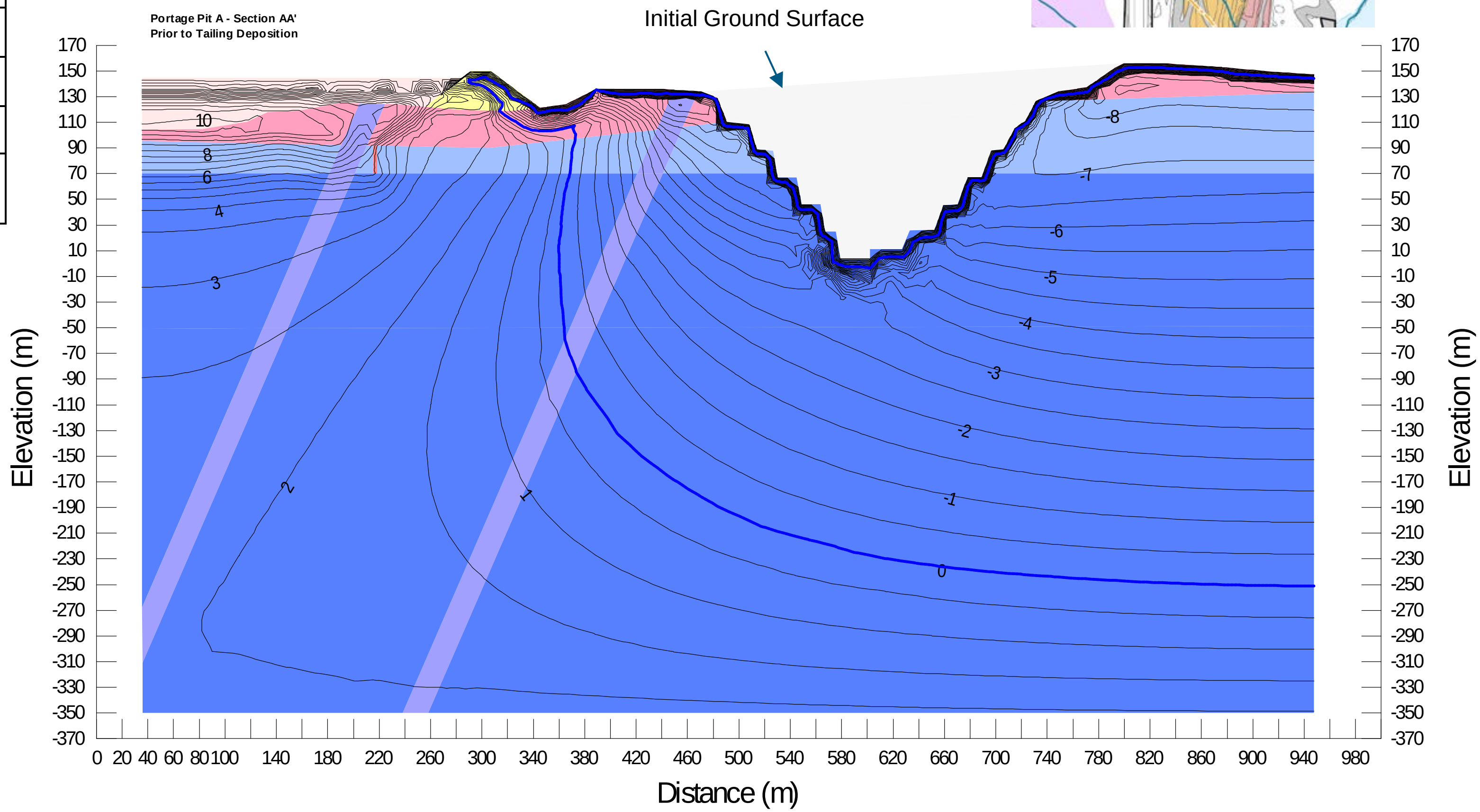
Best Estimate for High Scenario IPCC Projected Global Surface Warming (2007)



Pit A Thermal Modeling Results
Section A: Prior to Tailings Deposition

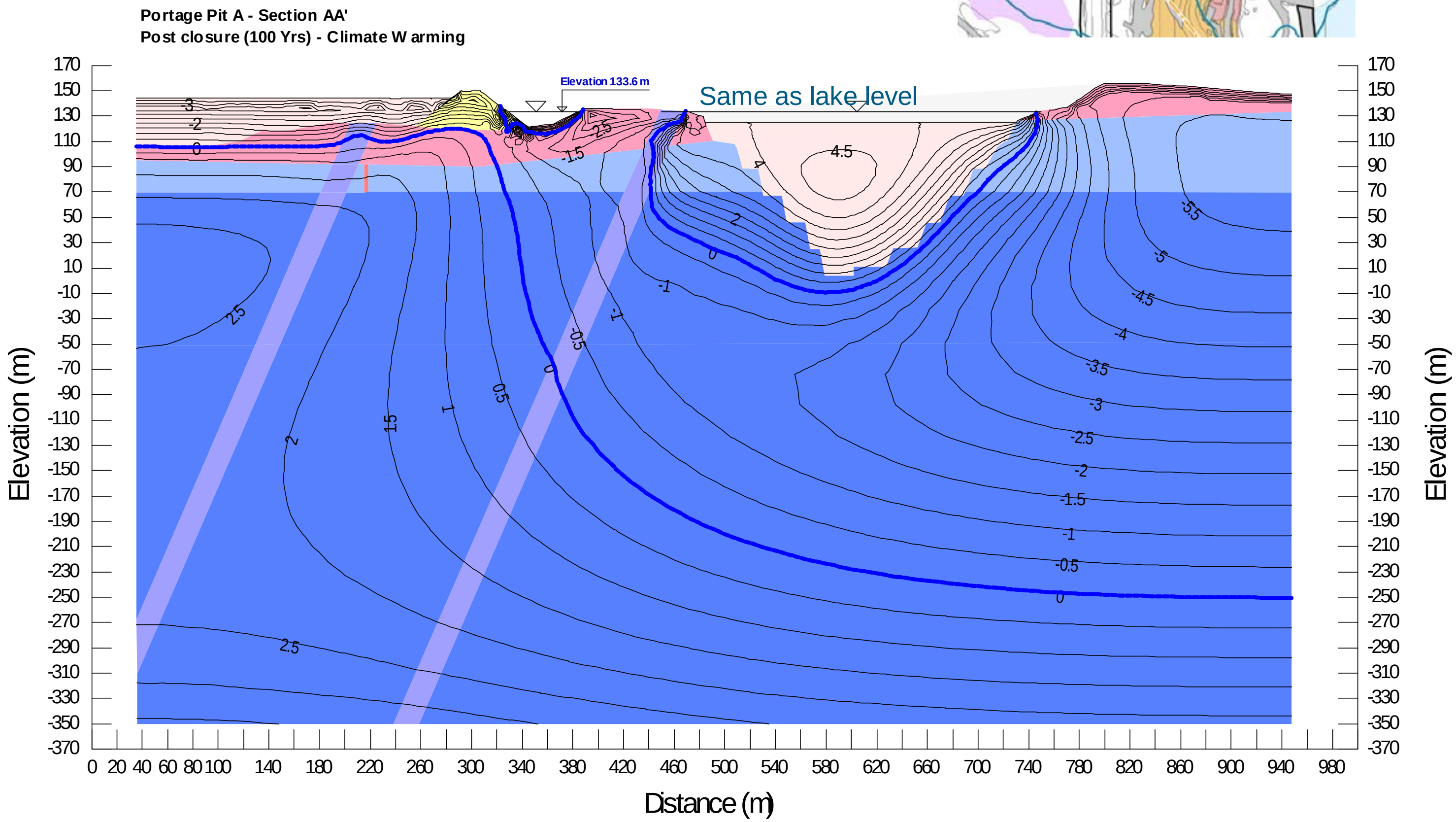
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Grouted Bedrock





Pit A Thermal Modeling Results
Section A: 100 Years After Closure

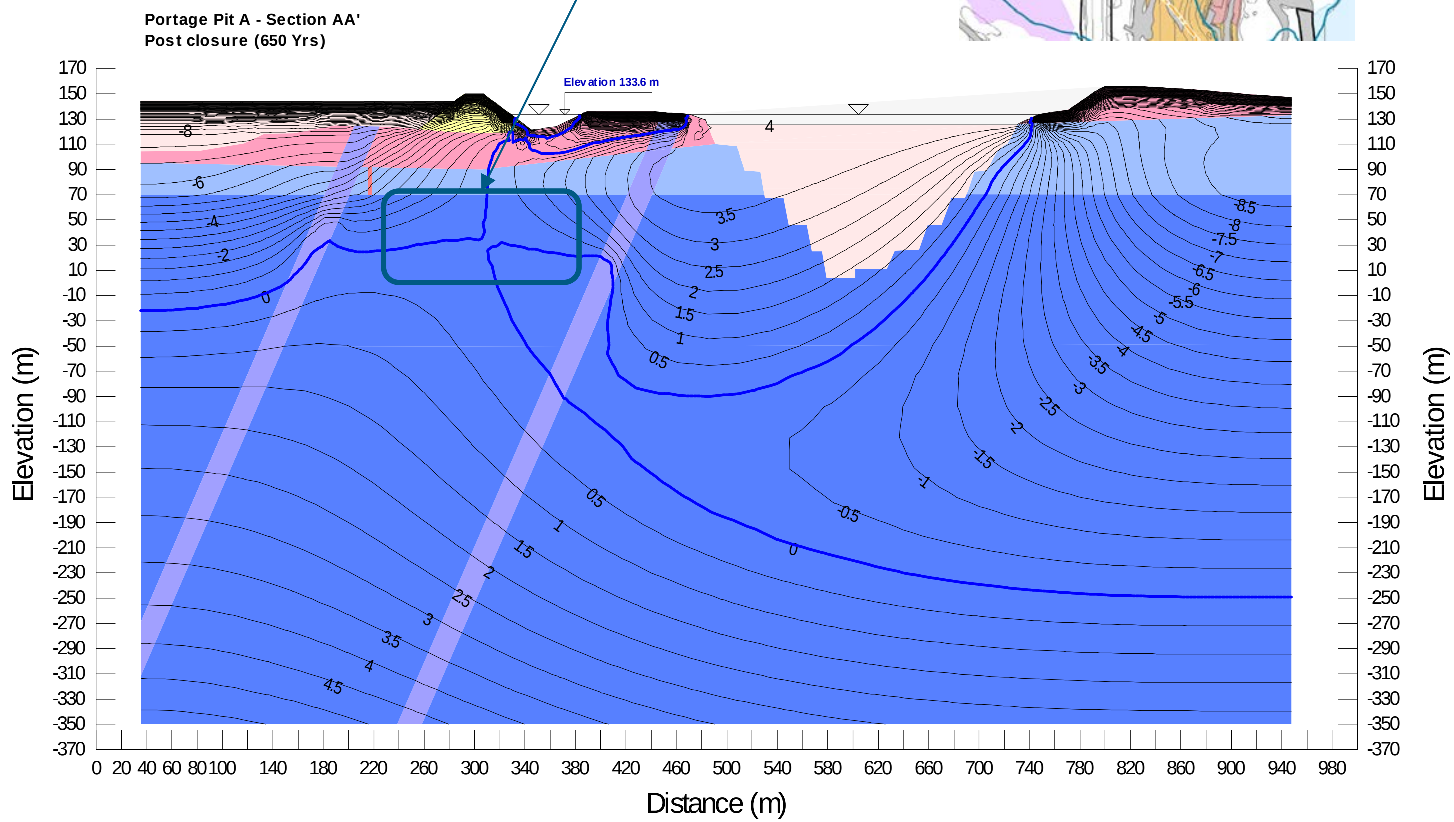
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Grouted Bedrock



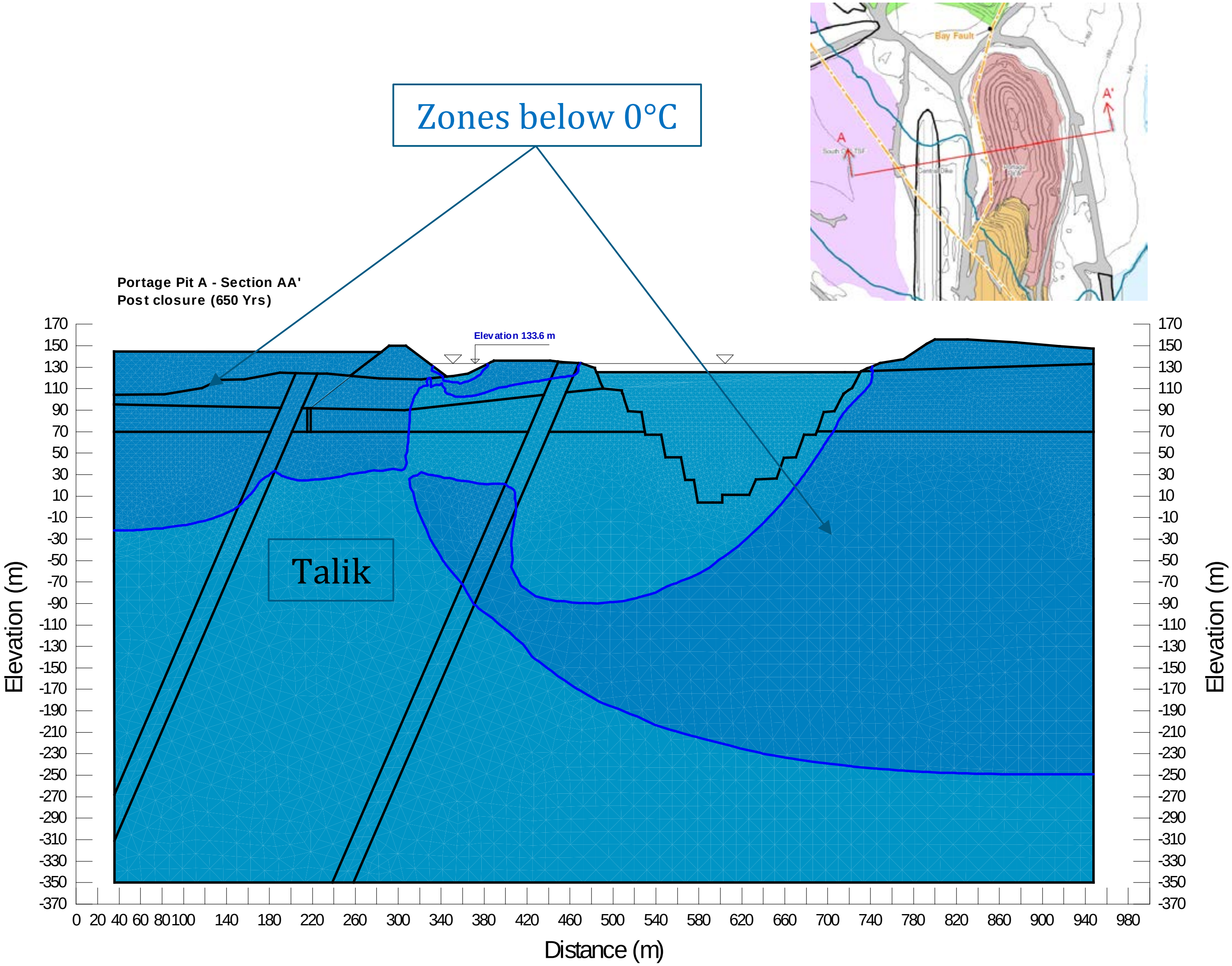
Pit A Thermal Modeling Results
Section A : 650 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Grouted Bedrock

Initiation of open talik

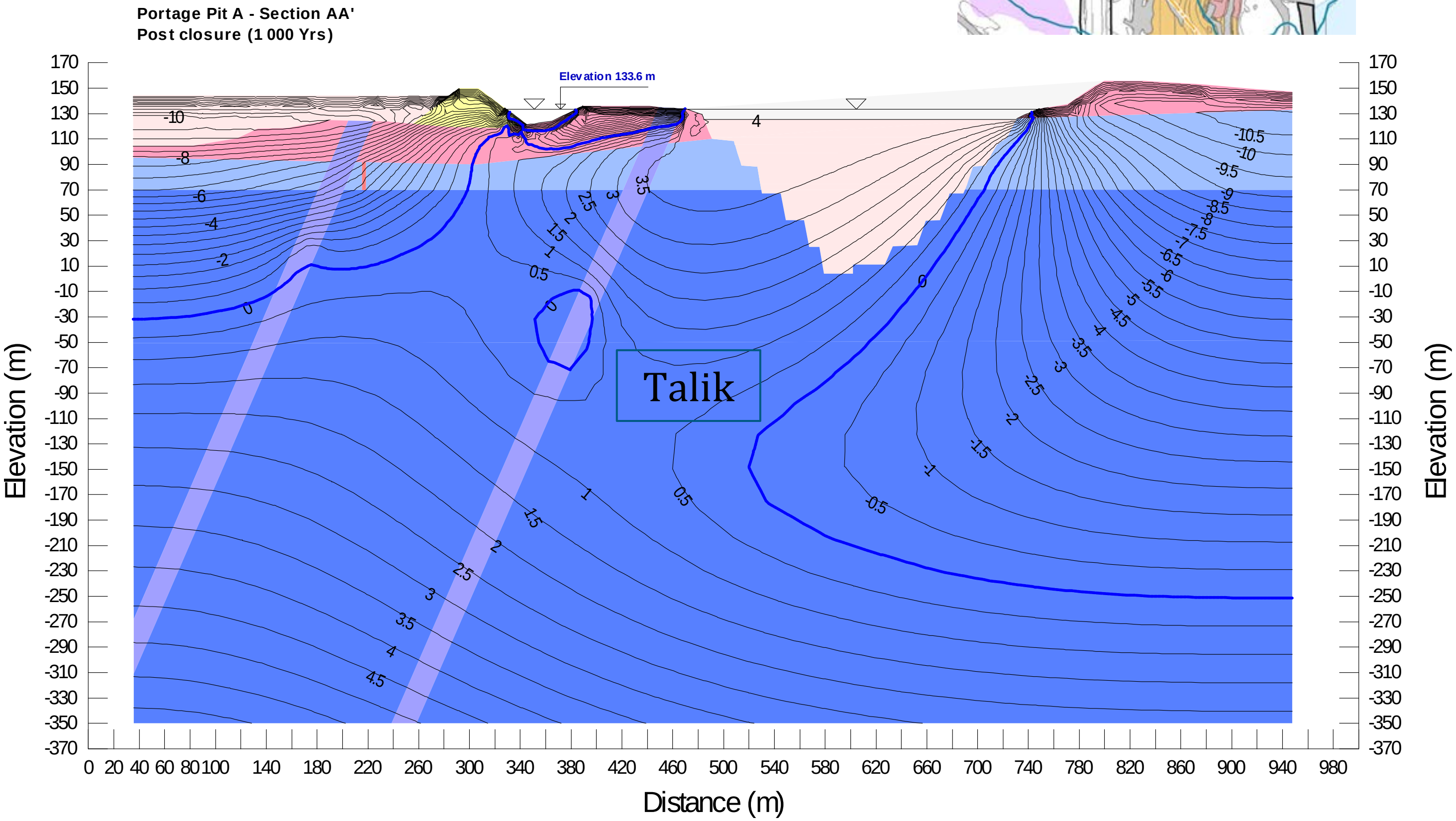


Pit A Thermal Modeling Results
Section A : 650 Years After Closure



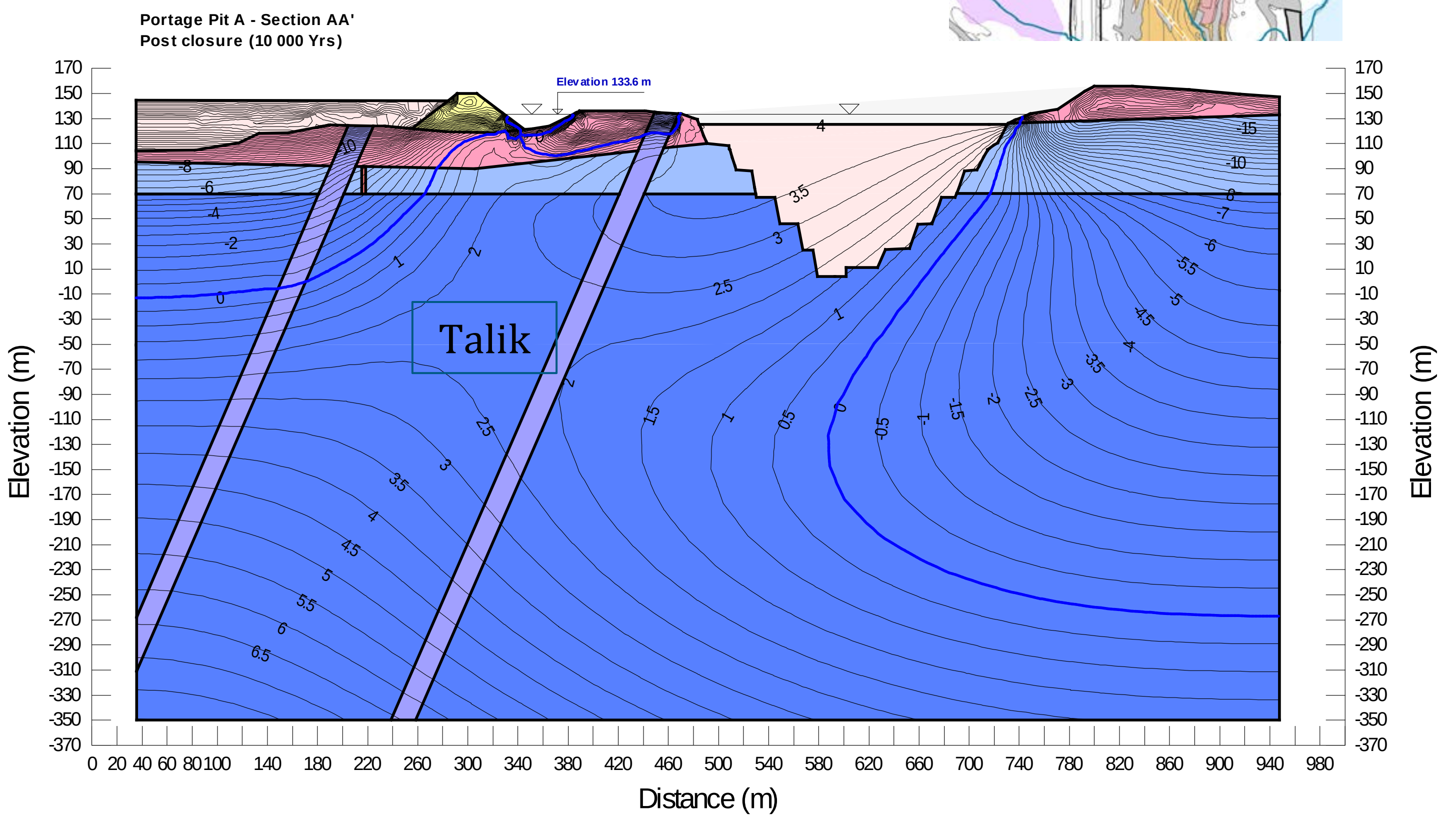
Pit A Thermal Modeling Results
Section A: 1,000 Years After Closure

Color	Name
(pale pink)	Settled Tailings
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(lavender)	Fault
(yellow)	Rockfill
(red)	Grouted Bedrock



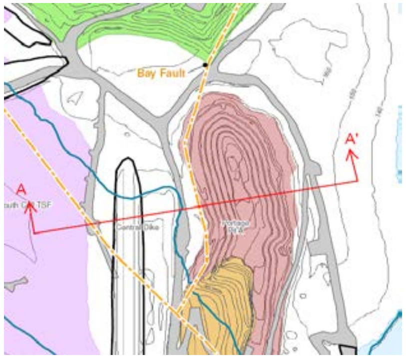
Pit A Thermal Modeling Results
Section A : 10,000 Years After Closure

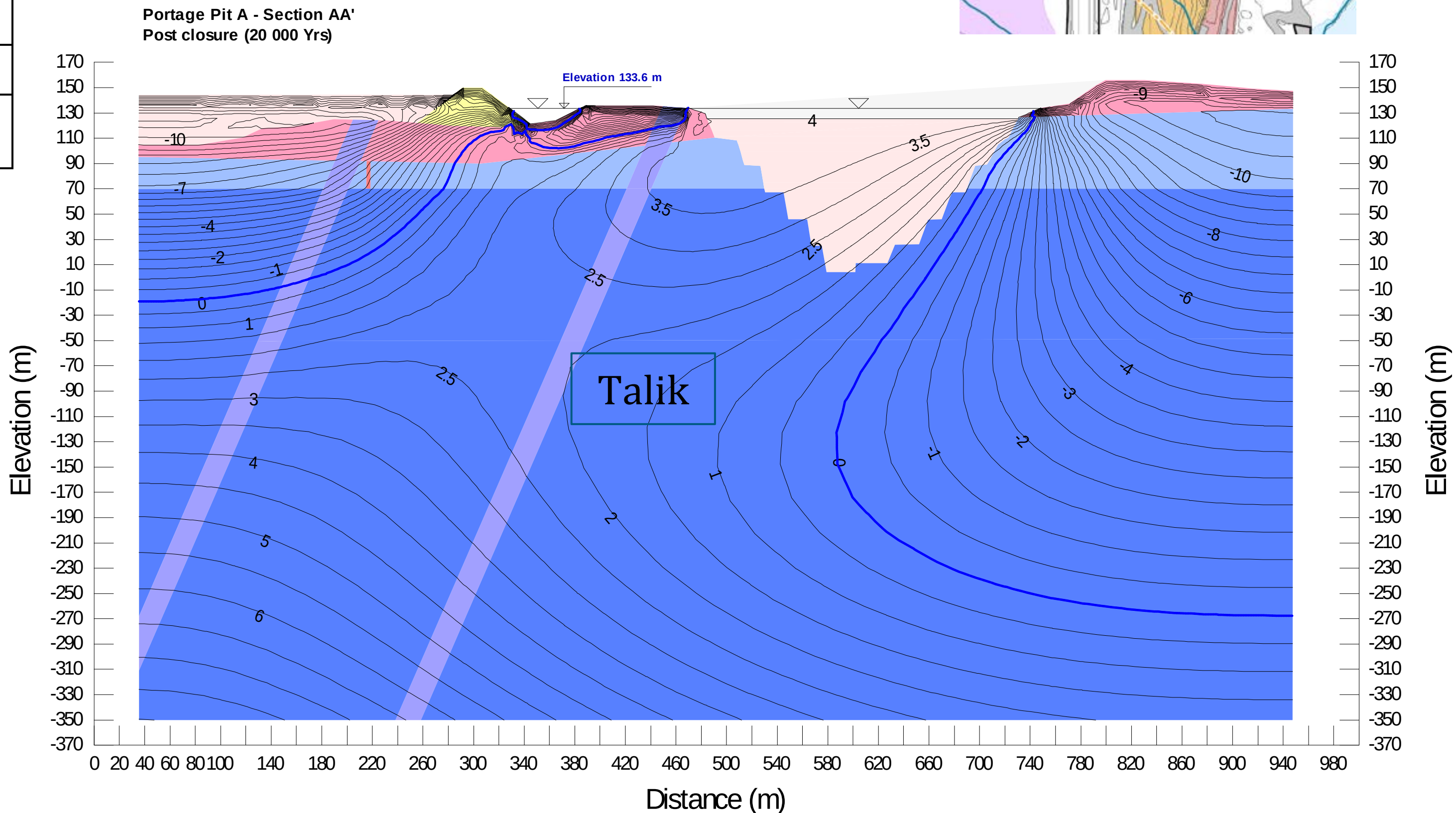
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Grouted Bedrock



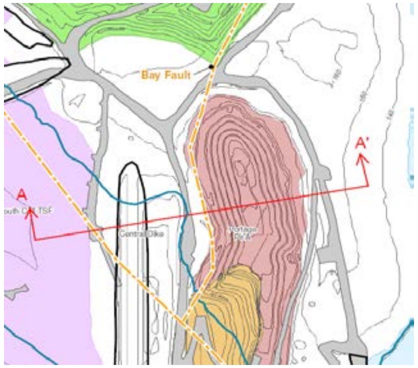
Pit A Thermal Modeling Results
Section A : 20,000 Years After Closure

Color	Name
(light pink)	Settled Tailings
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(purple)	Fault
(yellow)	Rockfill
(red)	Grouted Bedrock

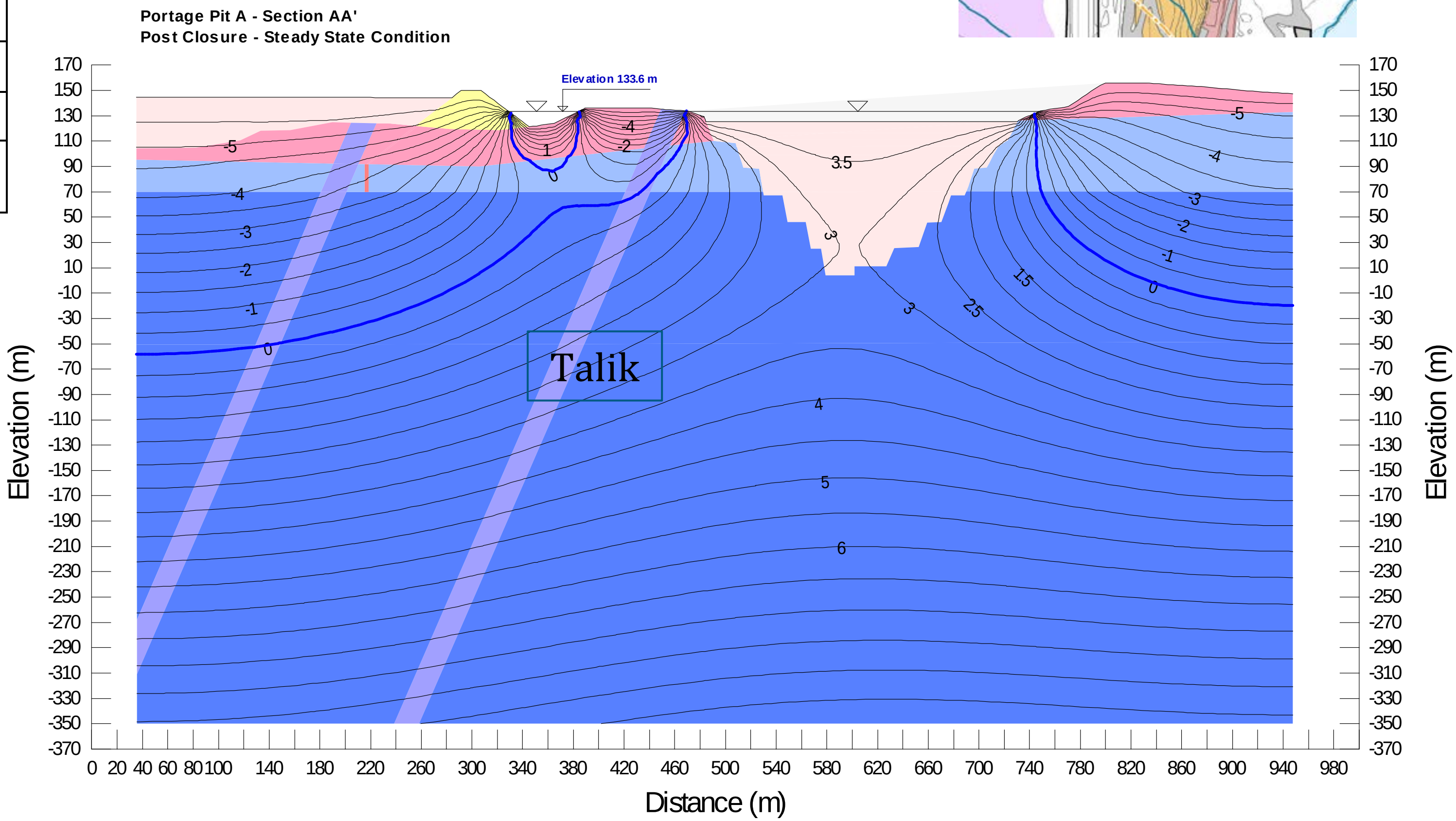




Pit A Thermal Modeling Results
Section A : Steady State Condition

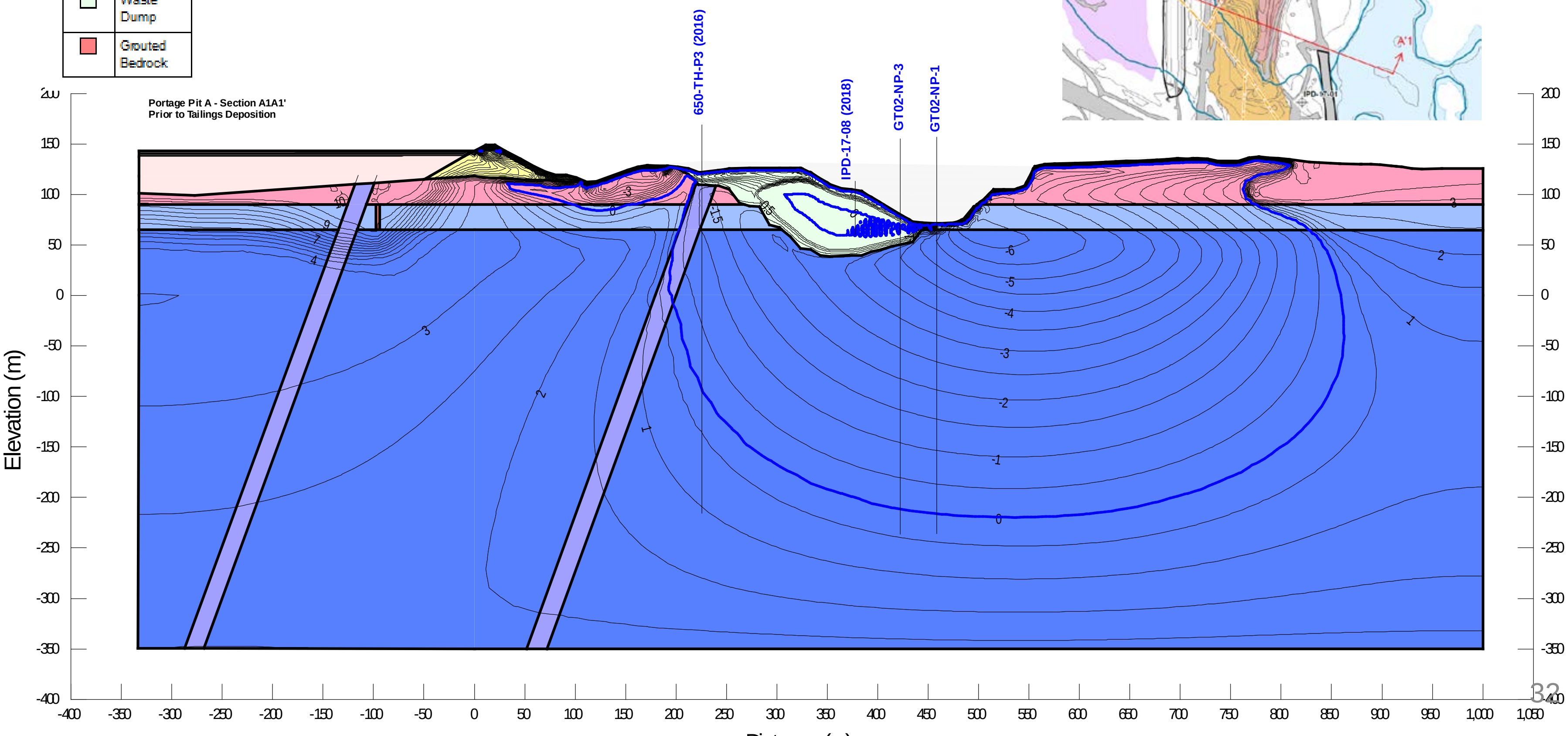


Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Grouted Bedrock



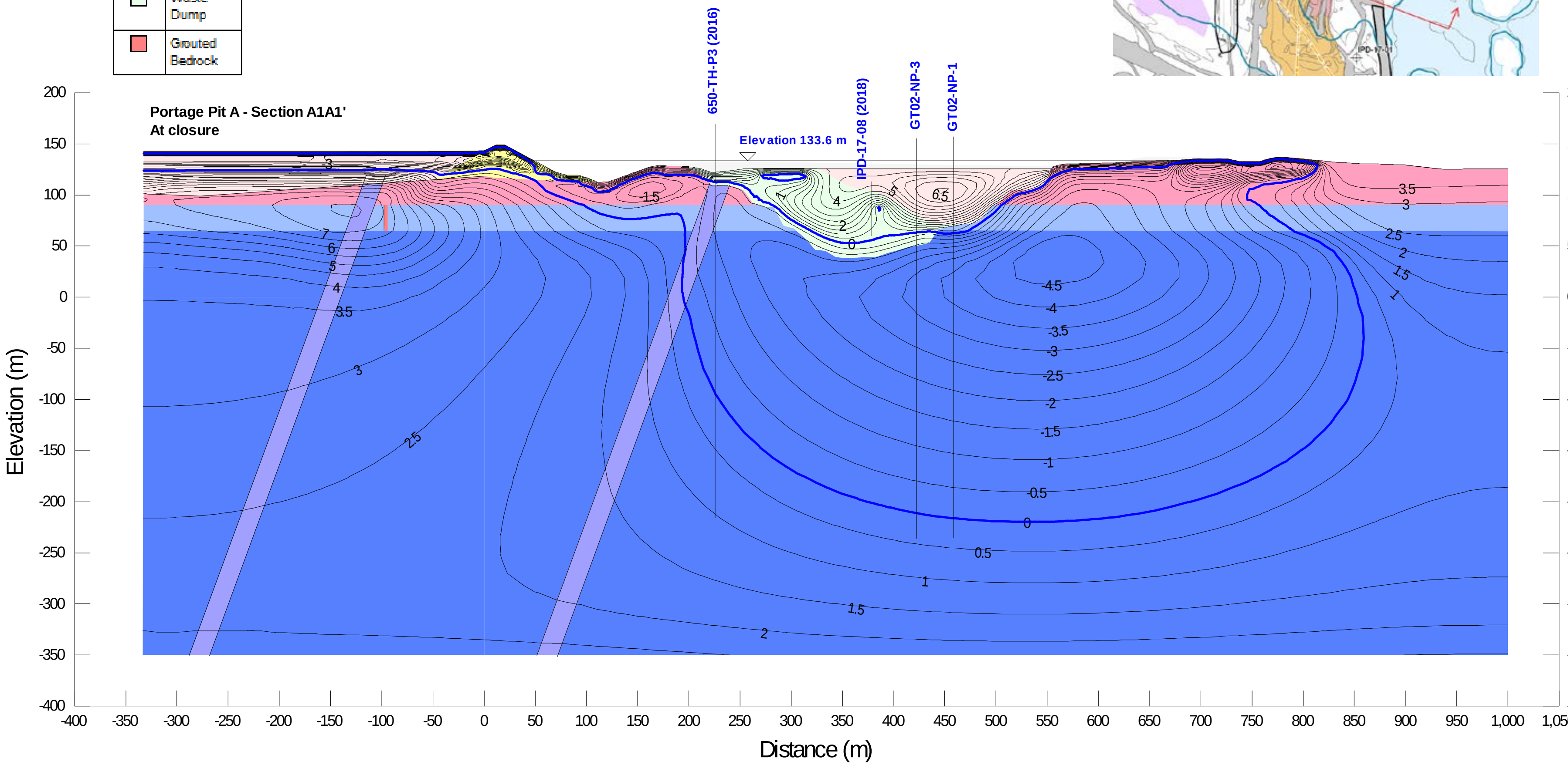
Pit A Thermal Modeling Results
Section A1: Prior to Tailings Deposition

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock

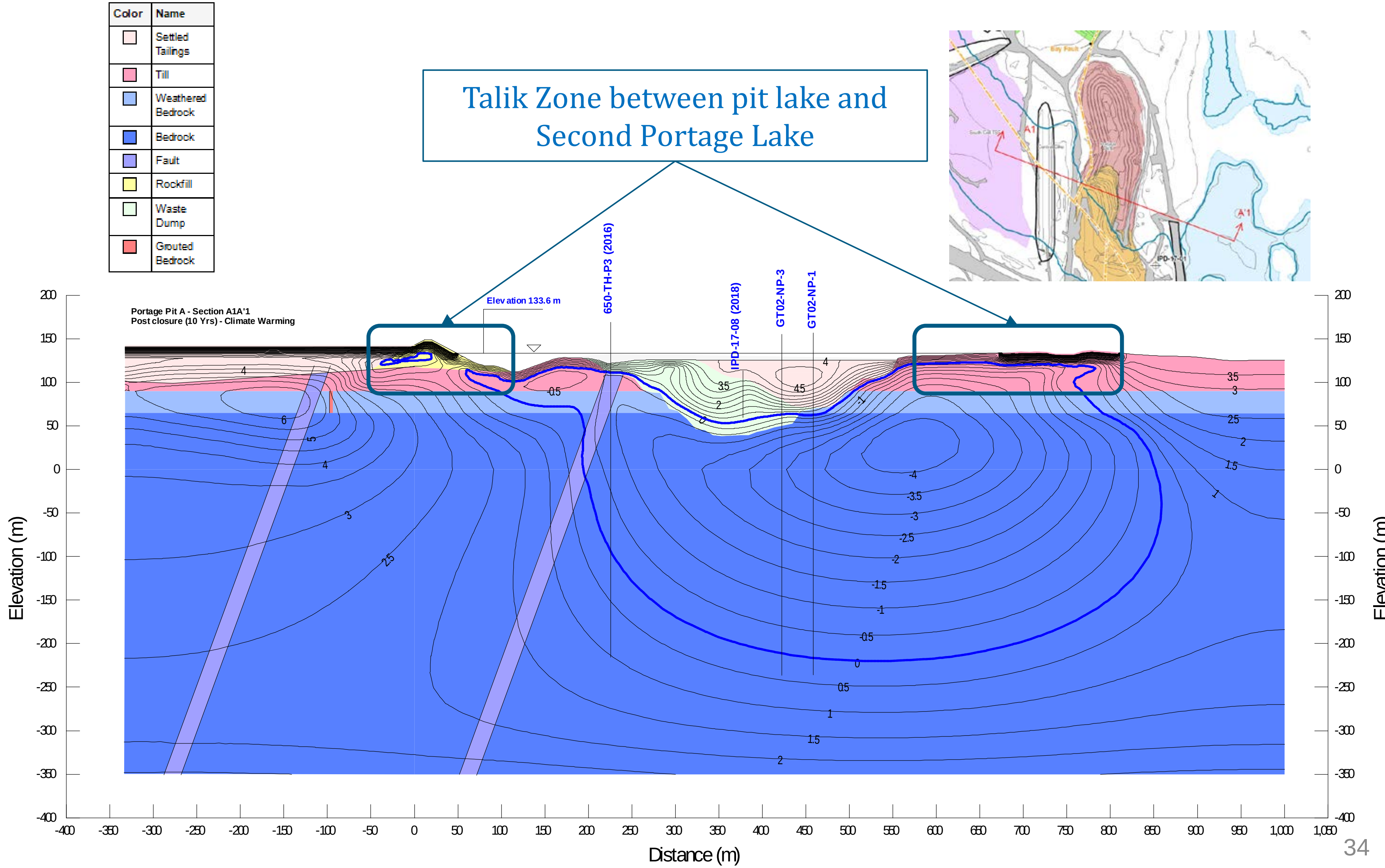


Pit A Thermal Modeling Results
Section A1: At Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock



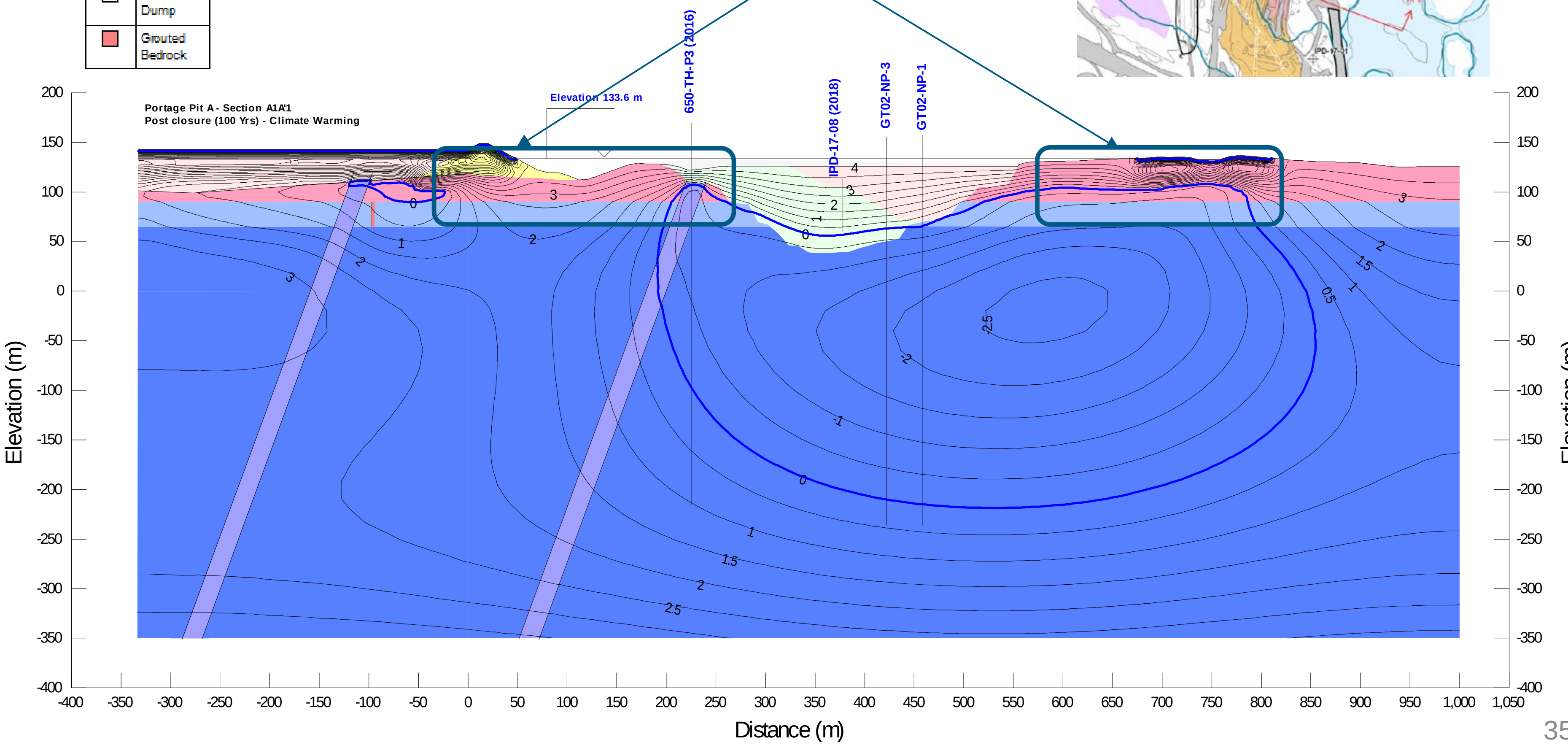
Pit A Thermal Modeling Results
Section A1: 10 Years After Closure



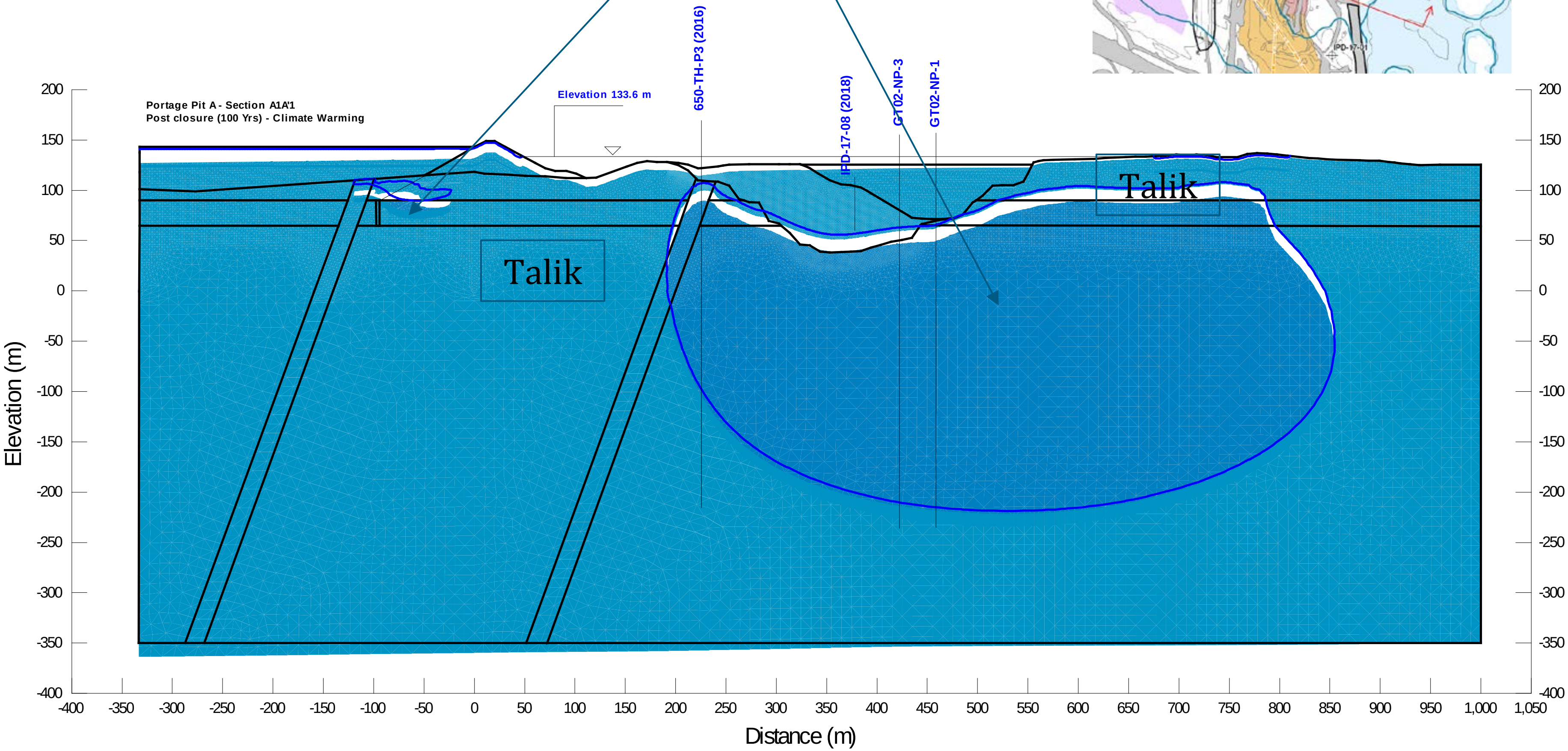
Pit A Thermal Modeling Results
Section A1: 100 Years After Closure

Color	Name
(light pink)	Settled Tailings
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(purple)	Fault
(yellow)	Rockfill
(light green)	Waste Dump
(red)	Grouted Bedrock

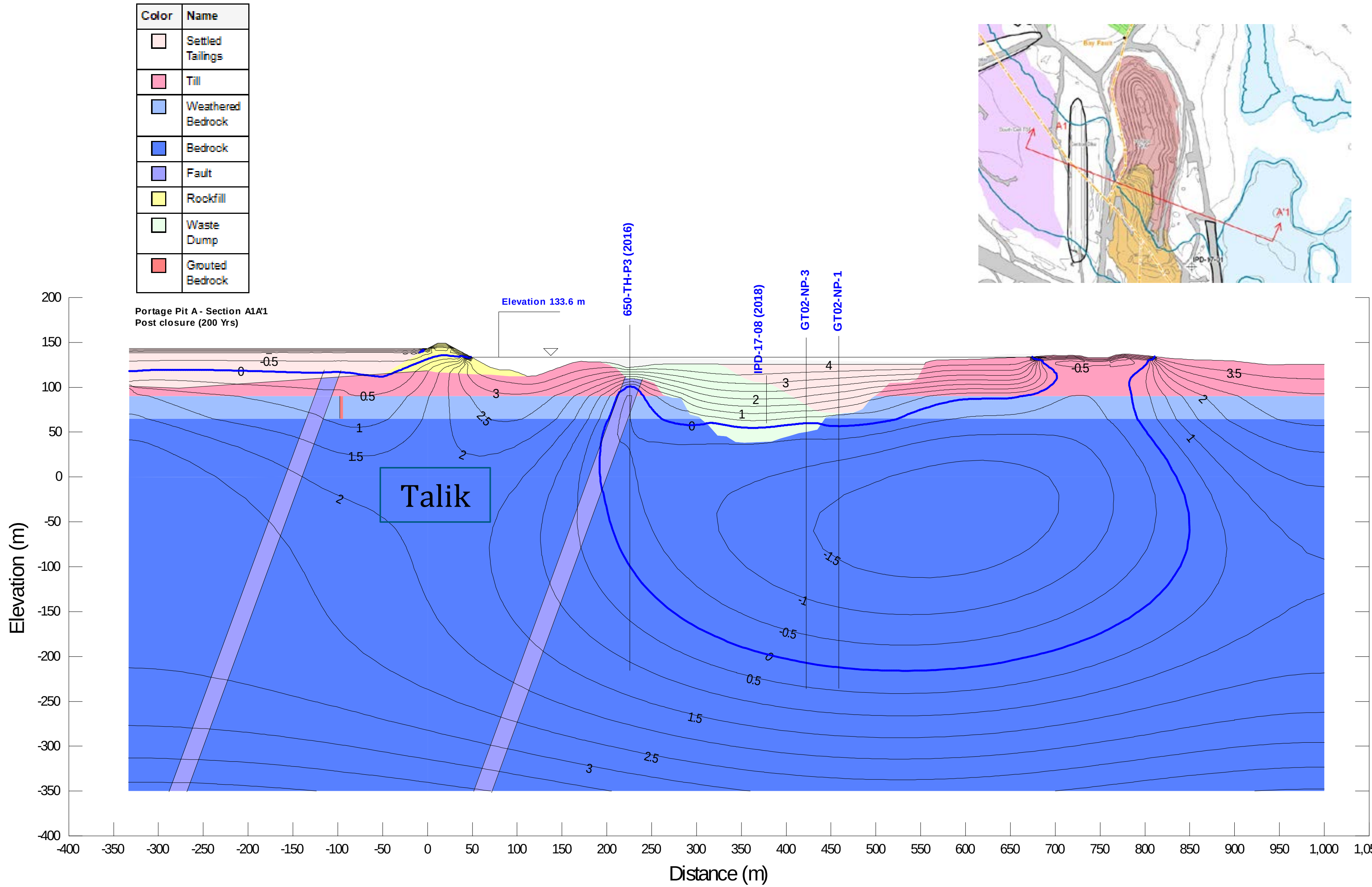
Talik Zone between pit lake and Second Portage Lake



Pit A Thermal Modeling Results
Section A1: 100 Years After Closure

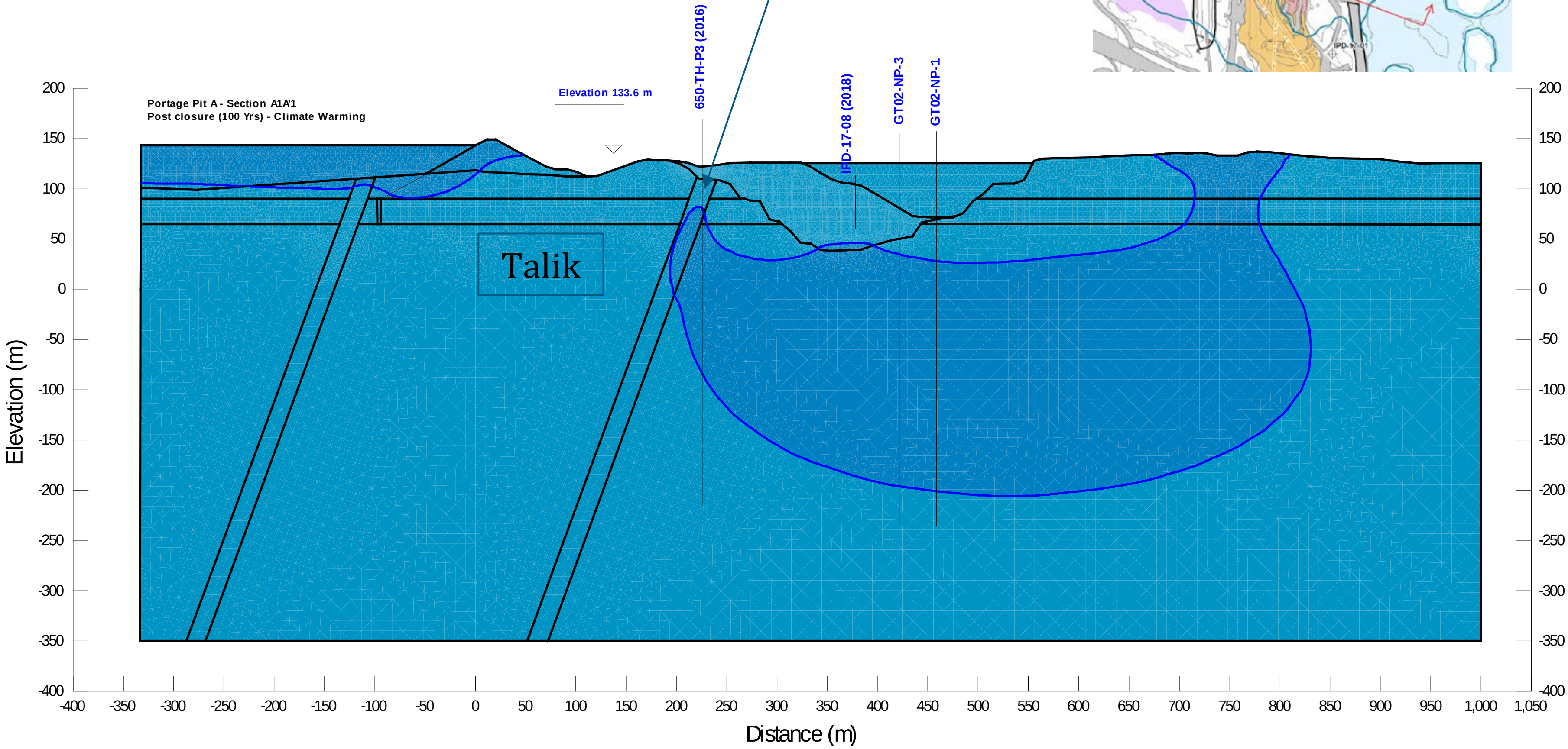


Pit A Thermal Modeling Results
Section A1: 200 Years After Closure



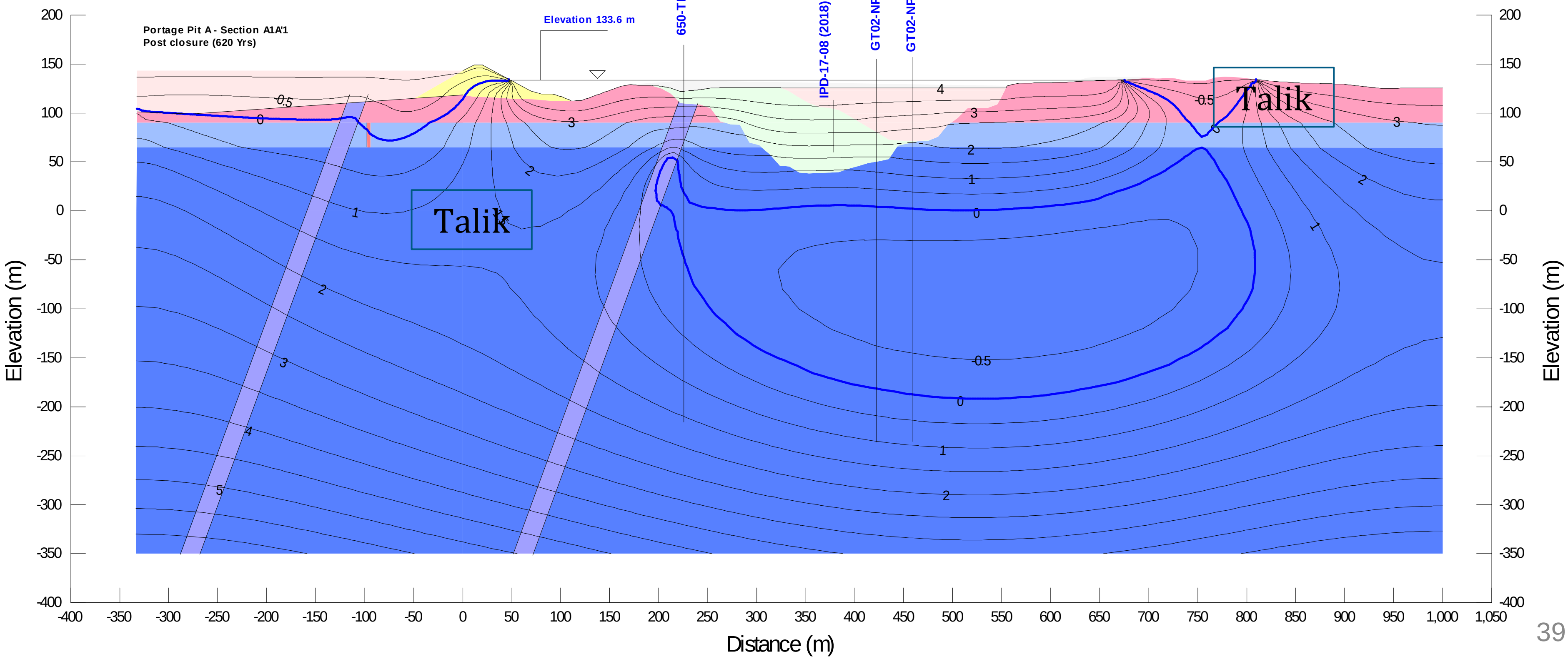
Pit A Thermal Modeling Results
Section A1: 400 Years After Closure

Talik Zone between pit lake and reconnected Third Portage Lake

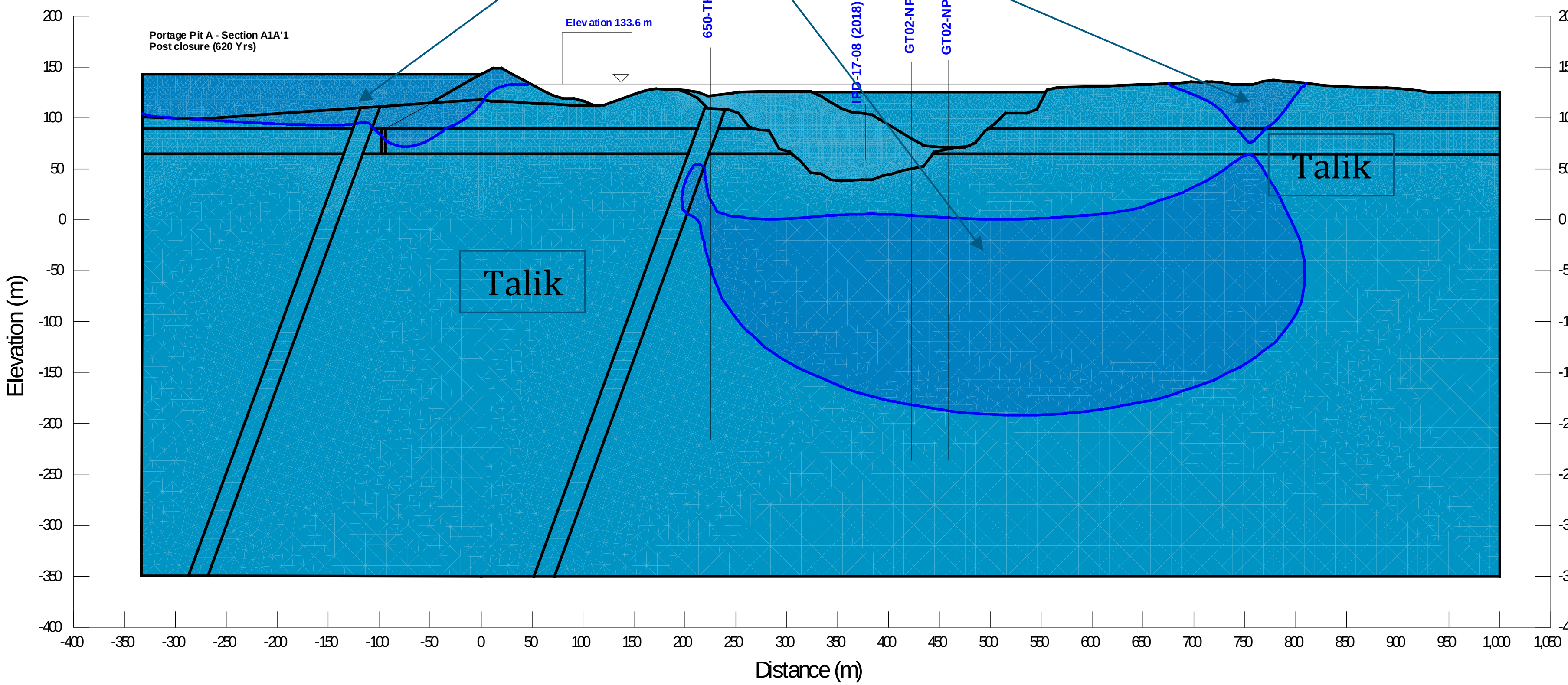


Pit A Thermal Modeling Results
Section A1: 620 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock

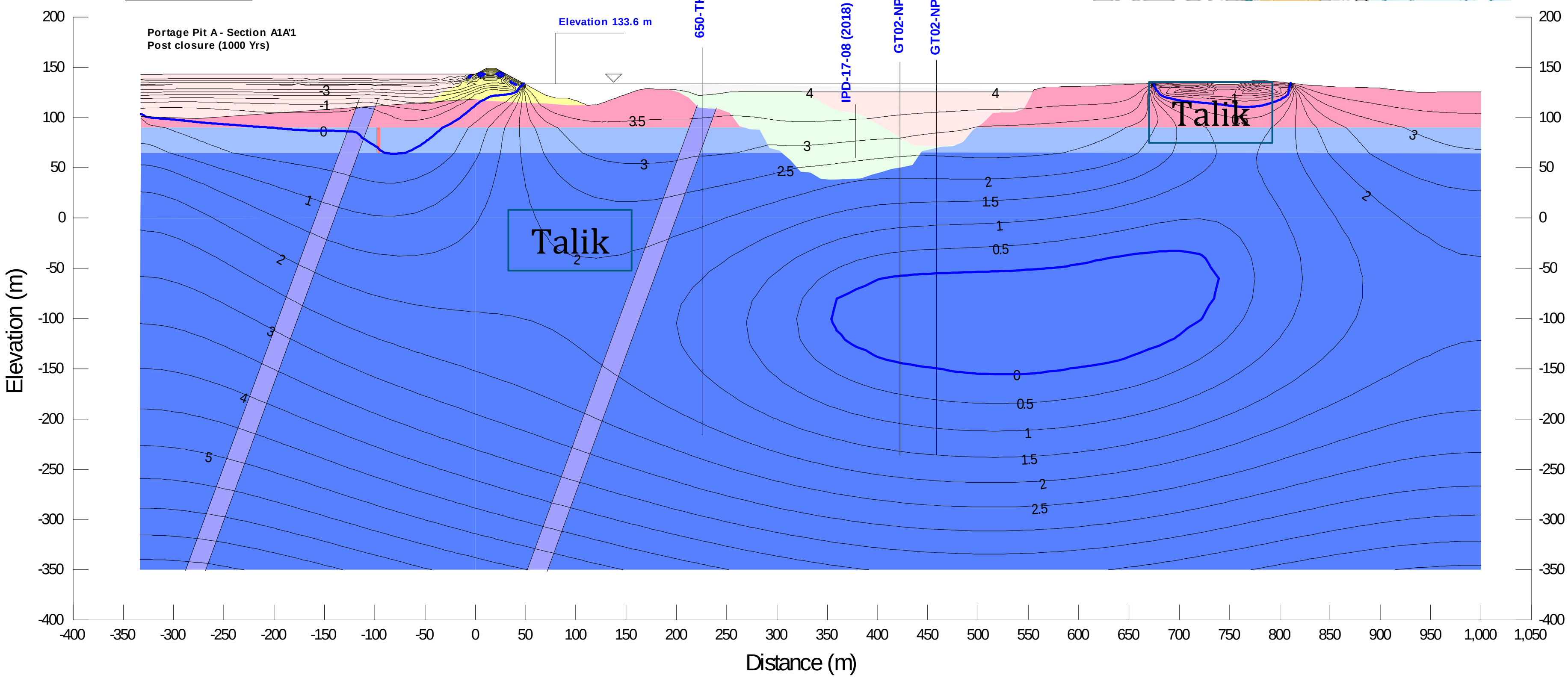


Pit A Thermal Modeling Results
Section A1: 620 Years After Closure



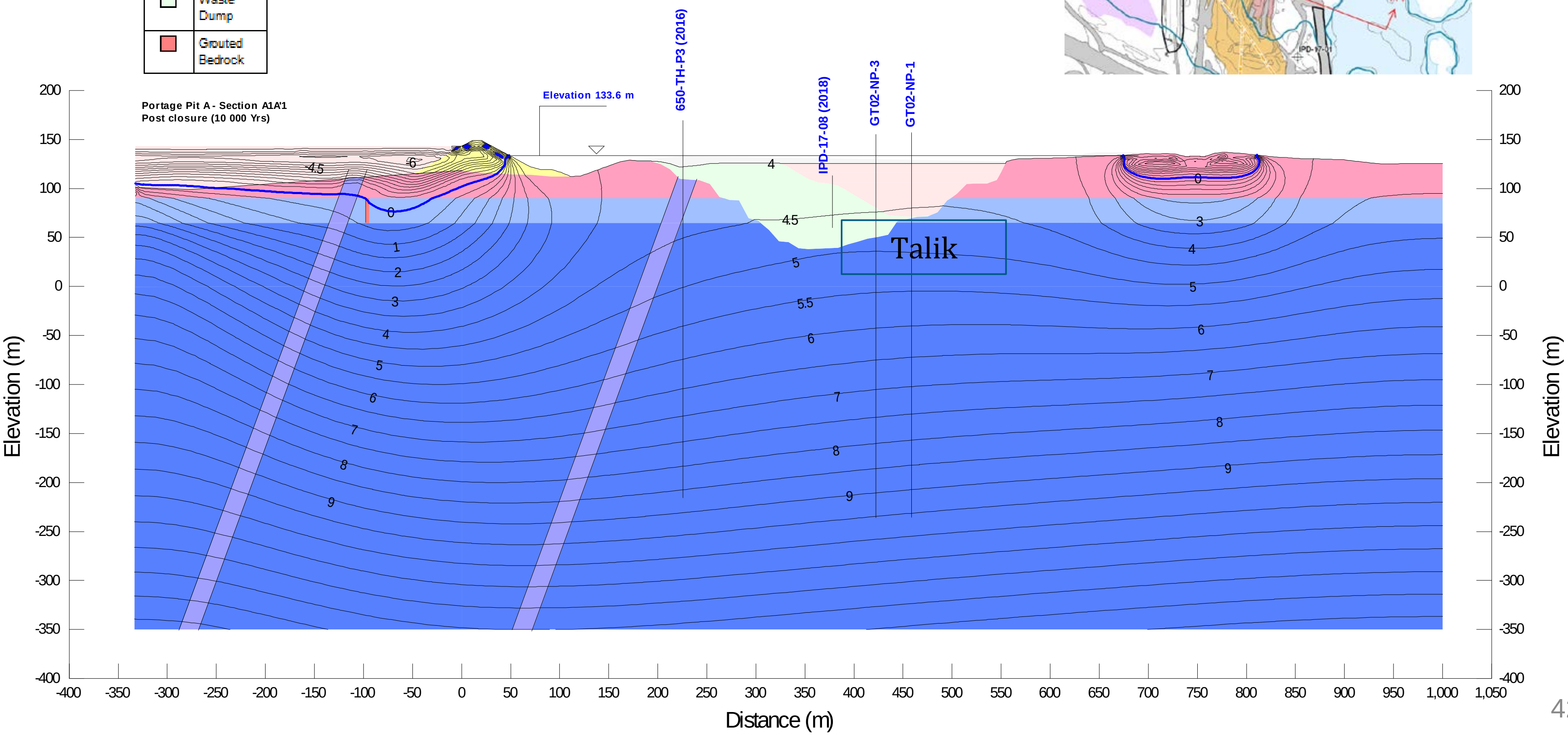
Pit A Thermal Modeling Results
Section A1: 1,000 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock

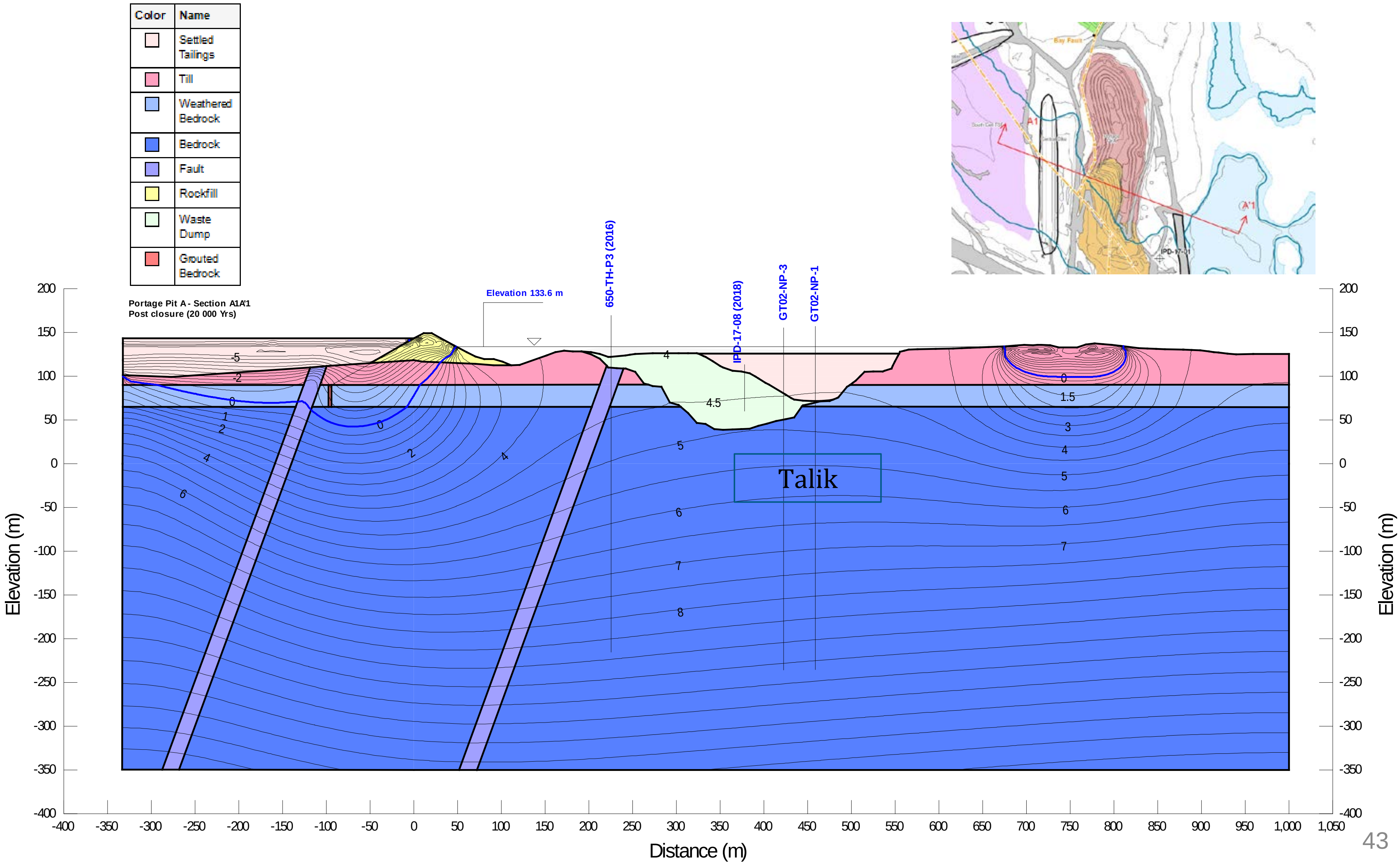


Pit A Thermal Modeling Results
Section A1: 10,000 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock

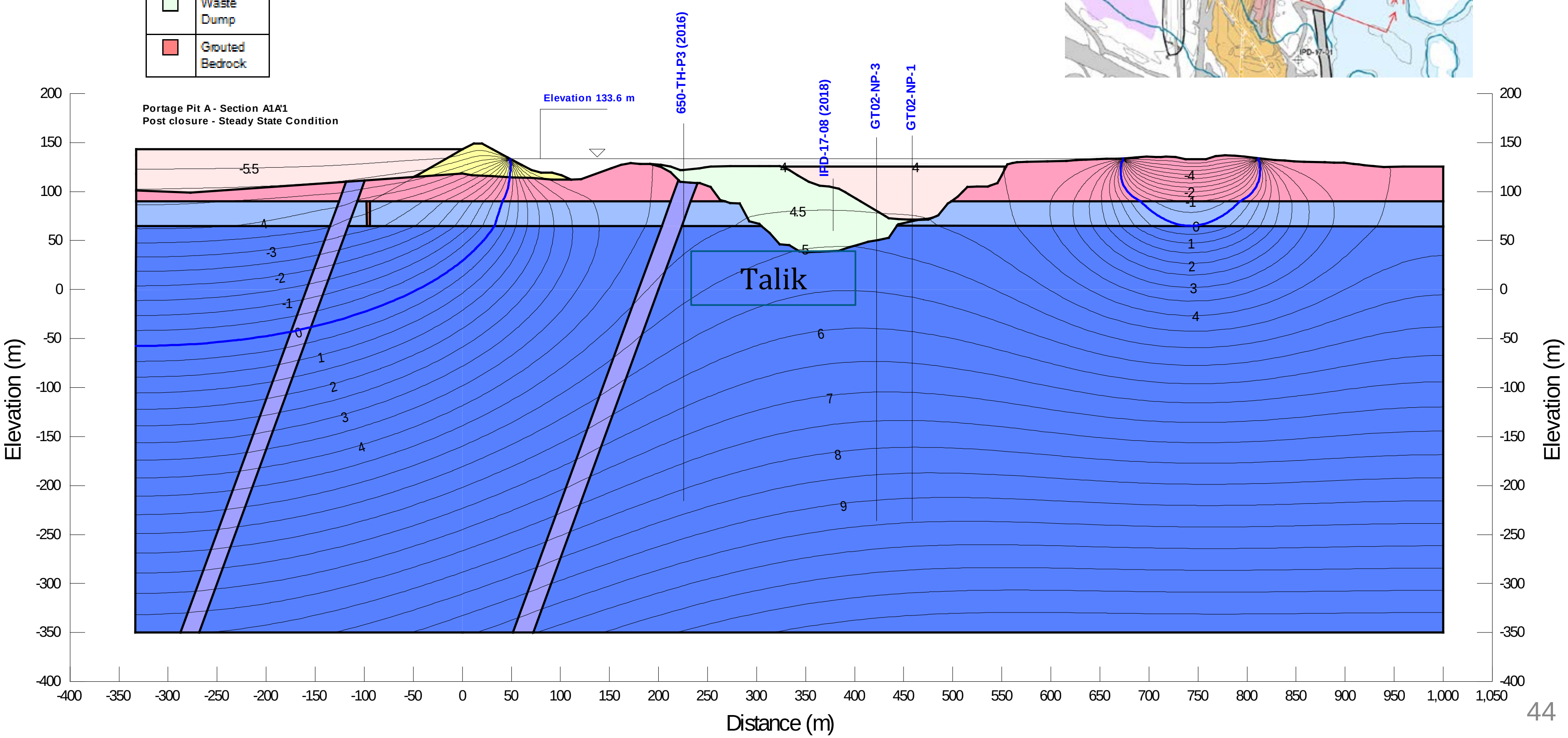


Pit A Thermal Modeling Results
Section A1: 20,000 Years After Closure



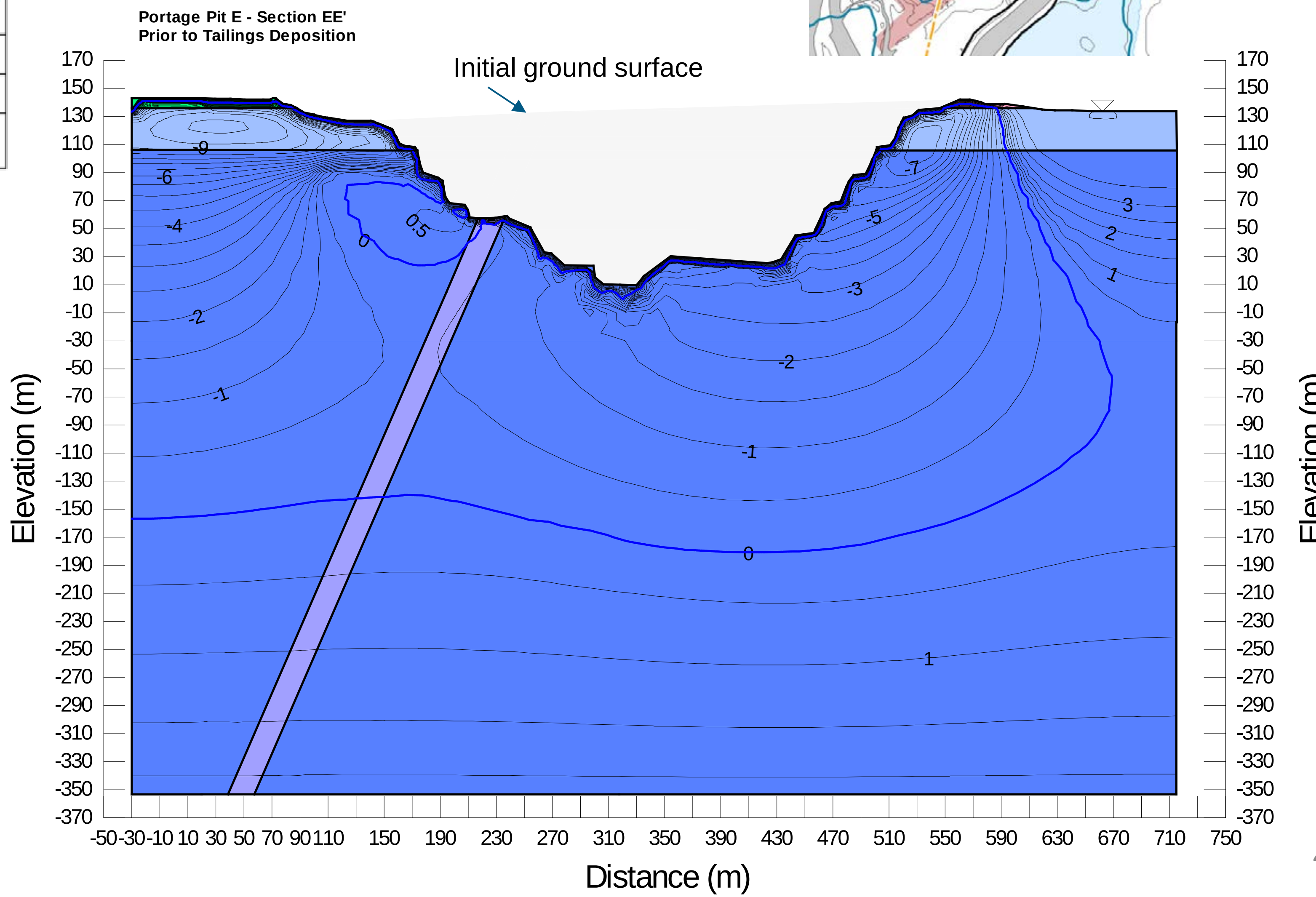
Pit A Thermal Modeling Results
Section A1: Steady State Condition

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	Rockfill
	Waste Dump
	Grouted Bedrock



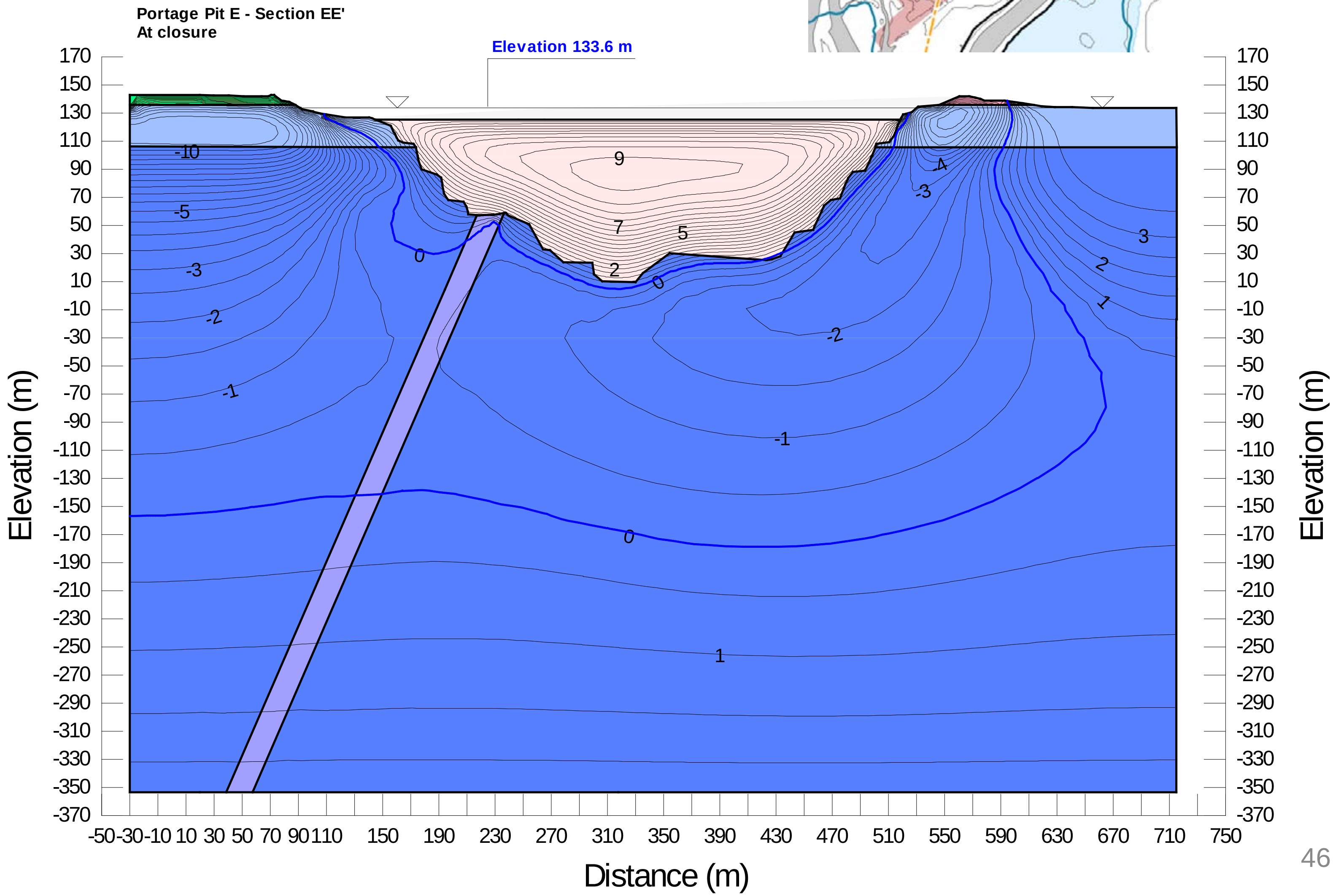
Pit E Thermal Modeling Results
Section E: Prior to Tailings Deposition

Color	Name
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(lavender)	Fault
(green)	NAG Stockpile



Pit E Thermal Modeling Results
Section E: At Closure

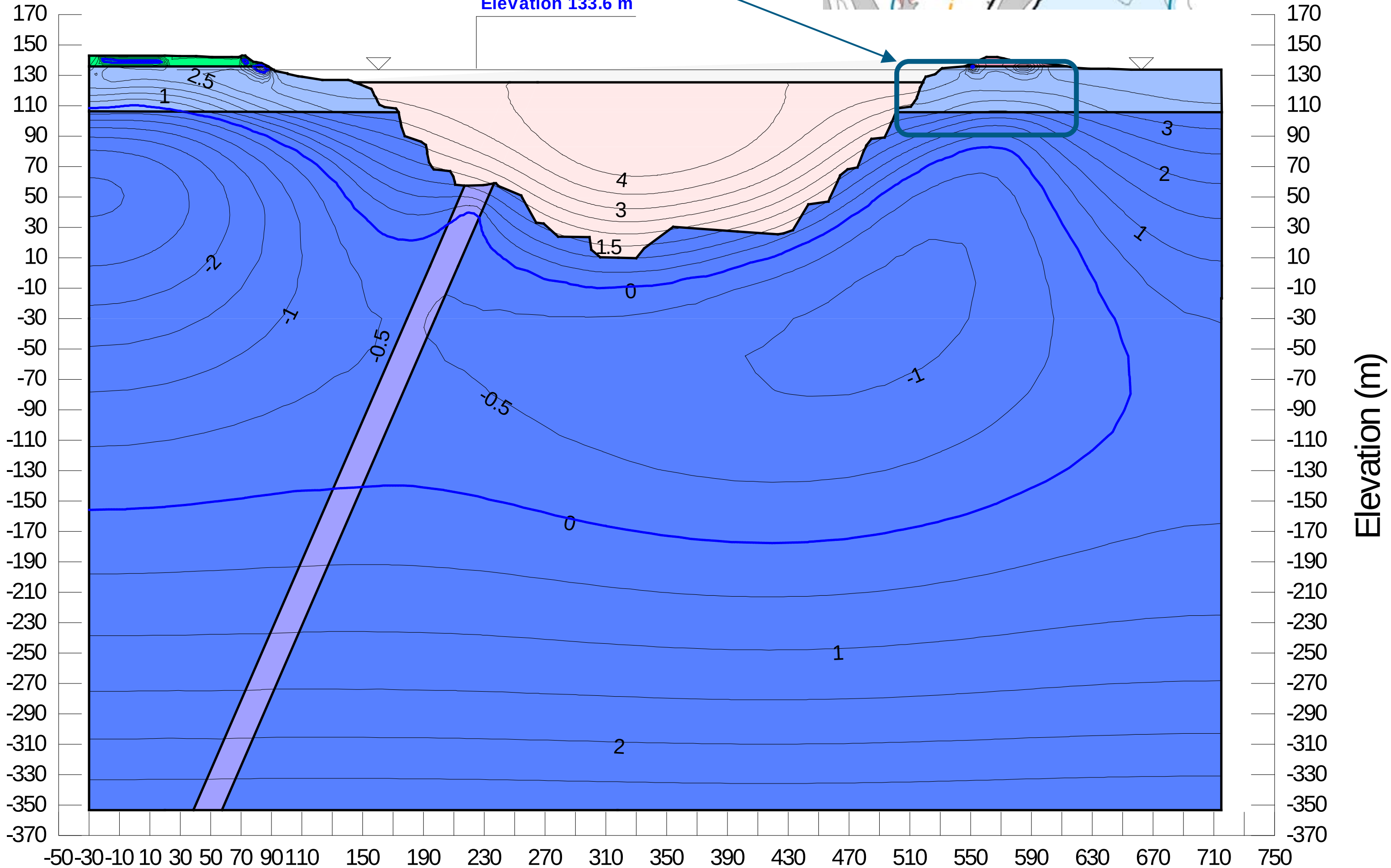
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile



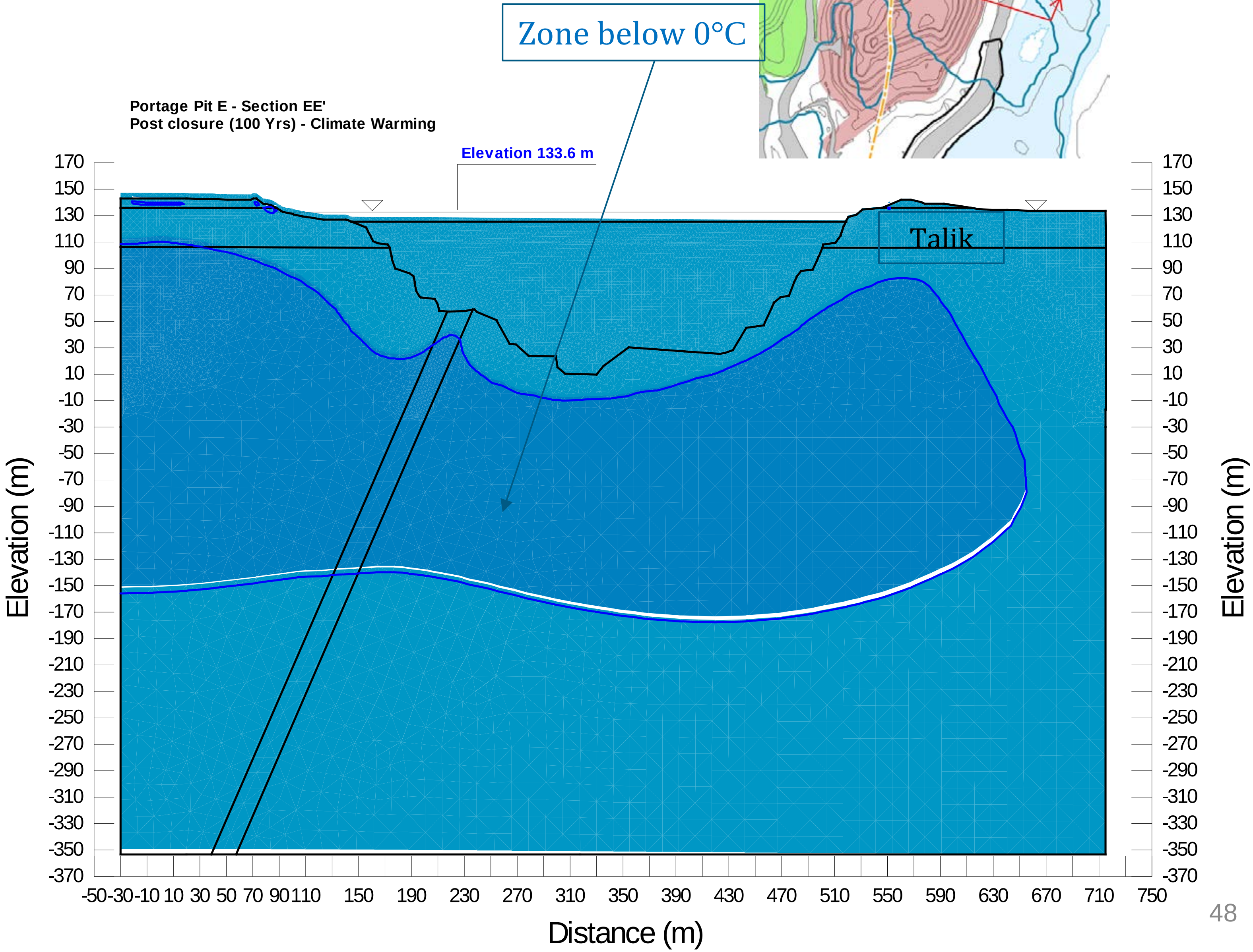
Pit E Thermal Modeling Results
Section E: 100 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile

Talik Zone between pit lake and Third Portage Lake

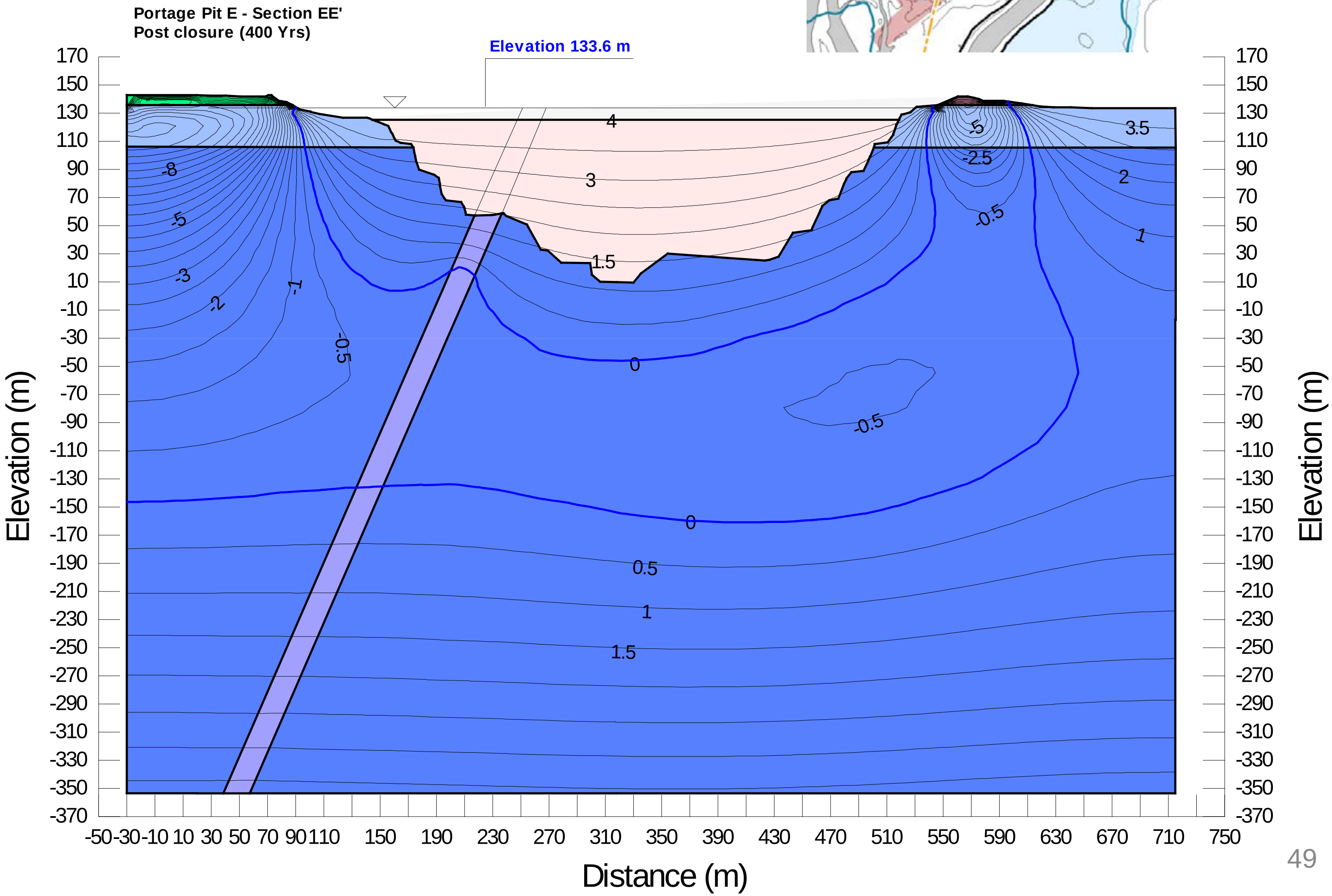


Pit E Thermal Modeling Results
Section E: 100 Years After Closure



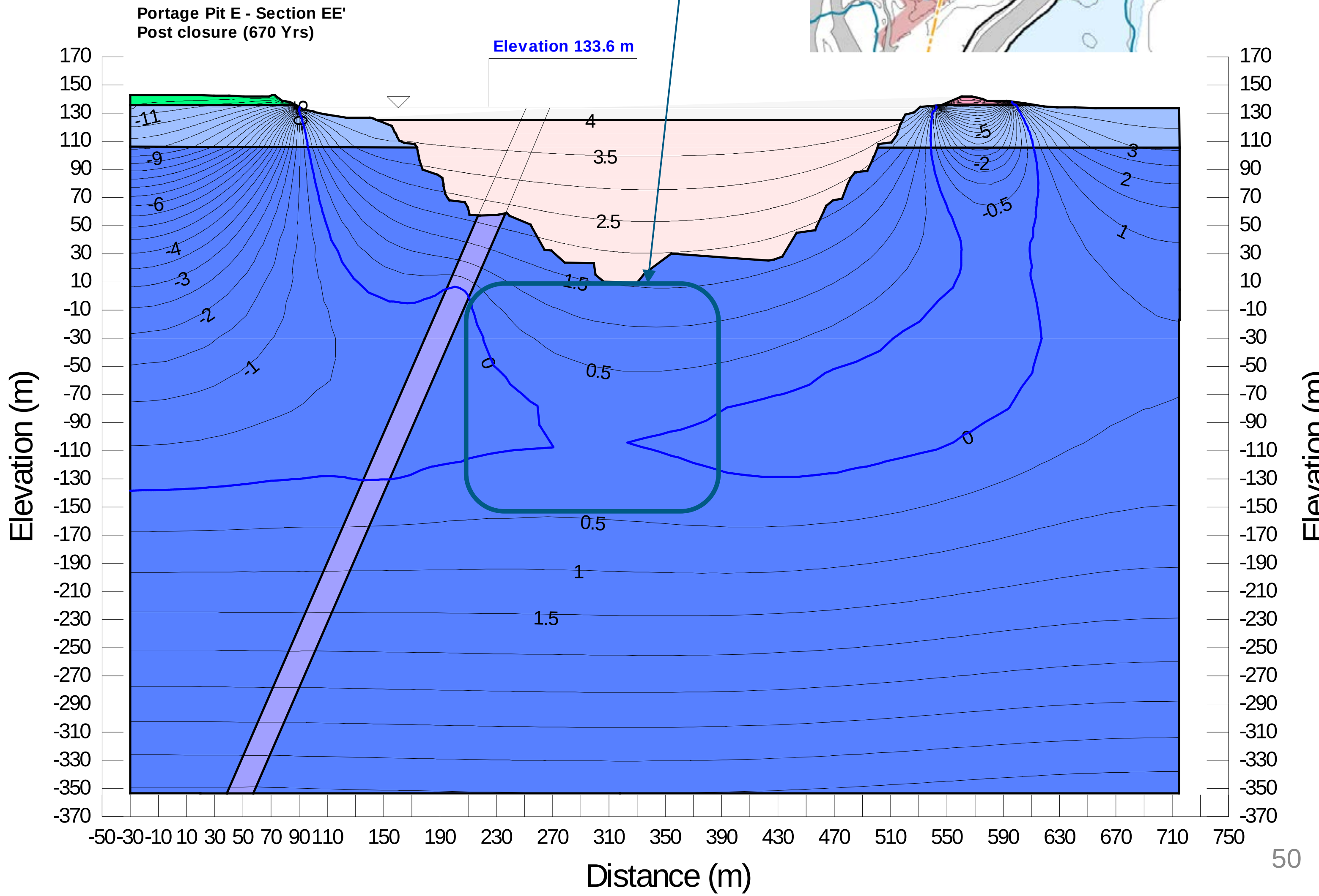
Pit E Thermal Modeling Results
Section E: 400 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile

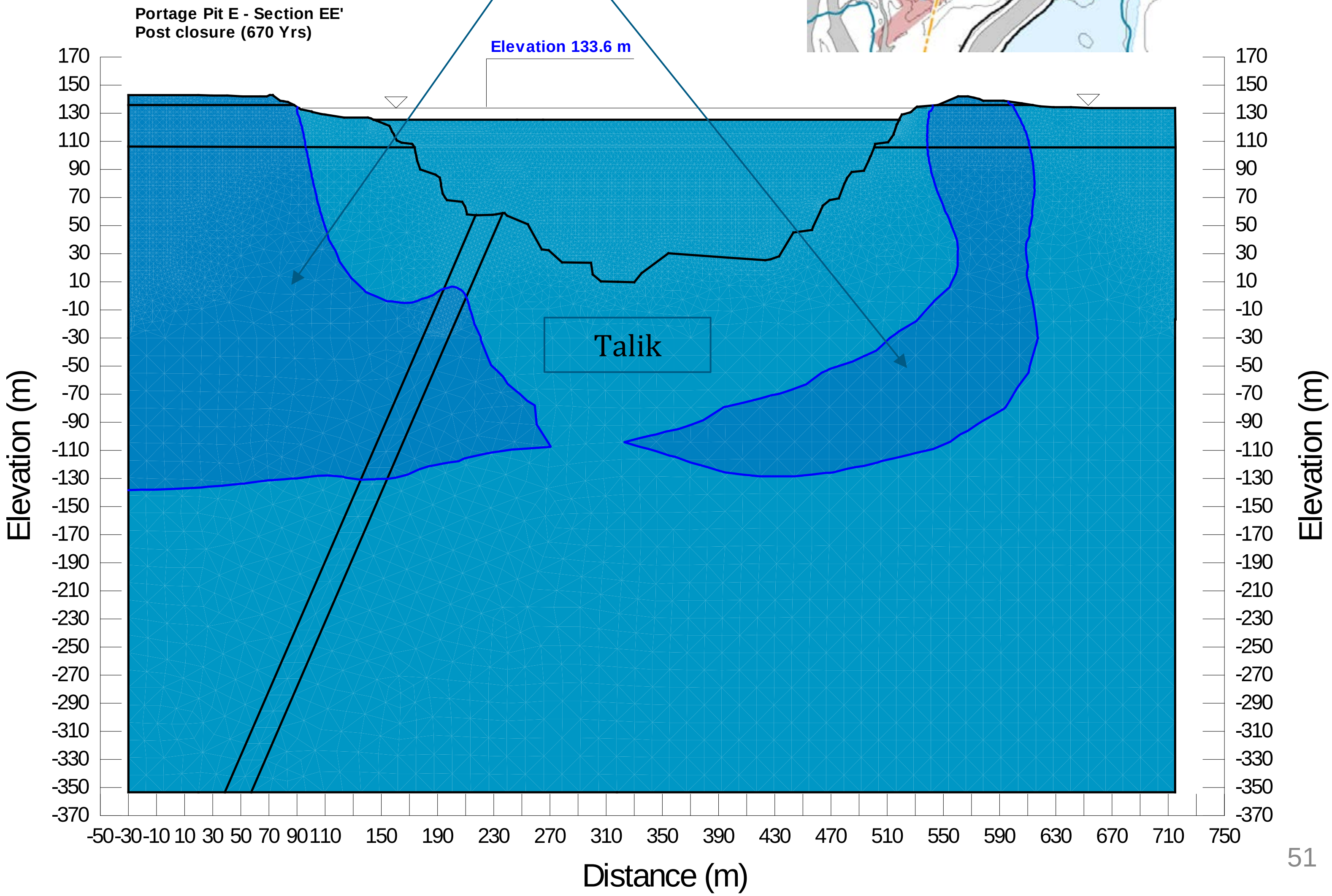


Pit E Thermal Modeling Results
Section E: 670 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile

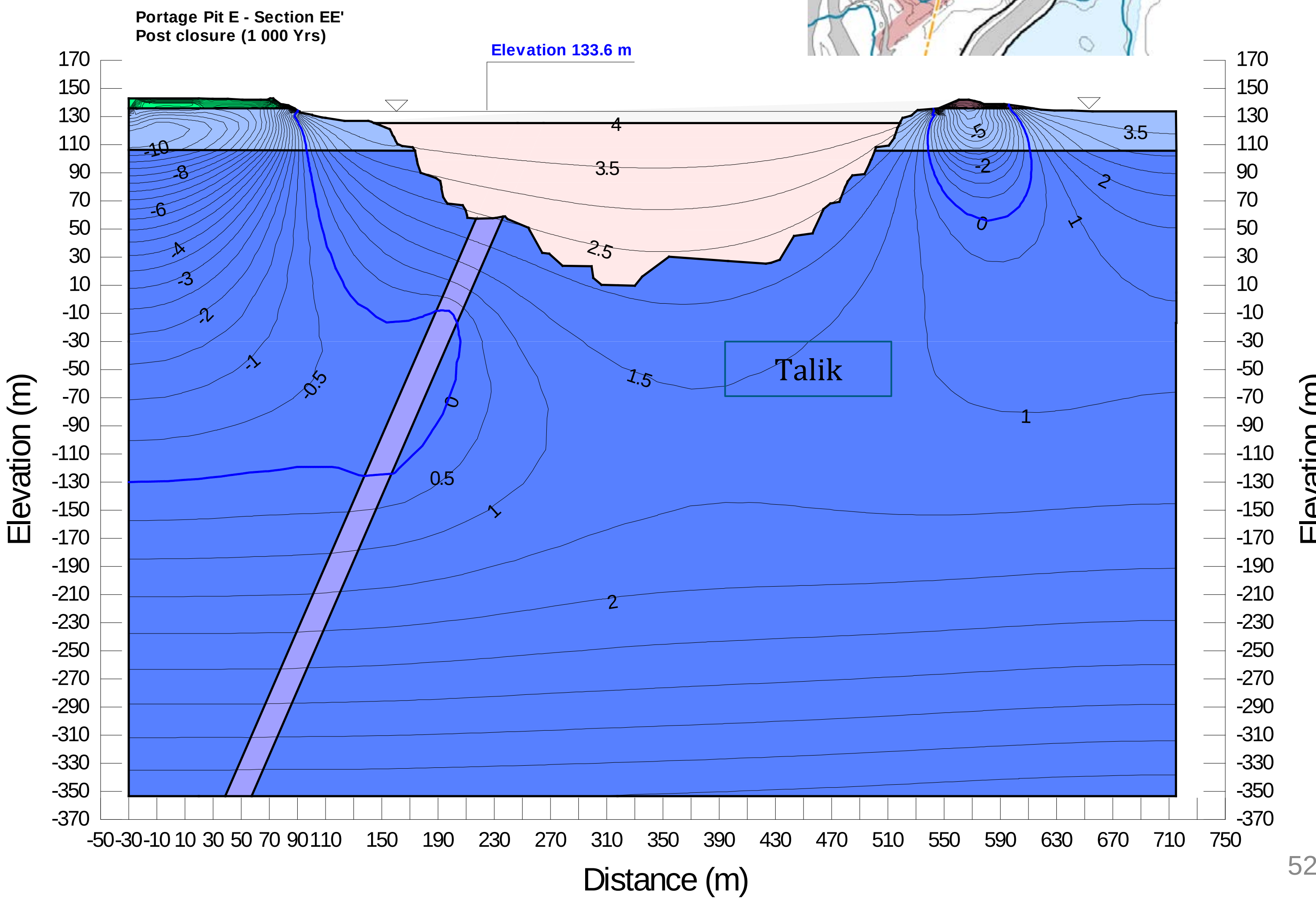


Pit E Thermal Modeling Results
Section E: 670 Years After Closure



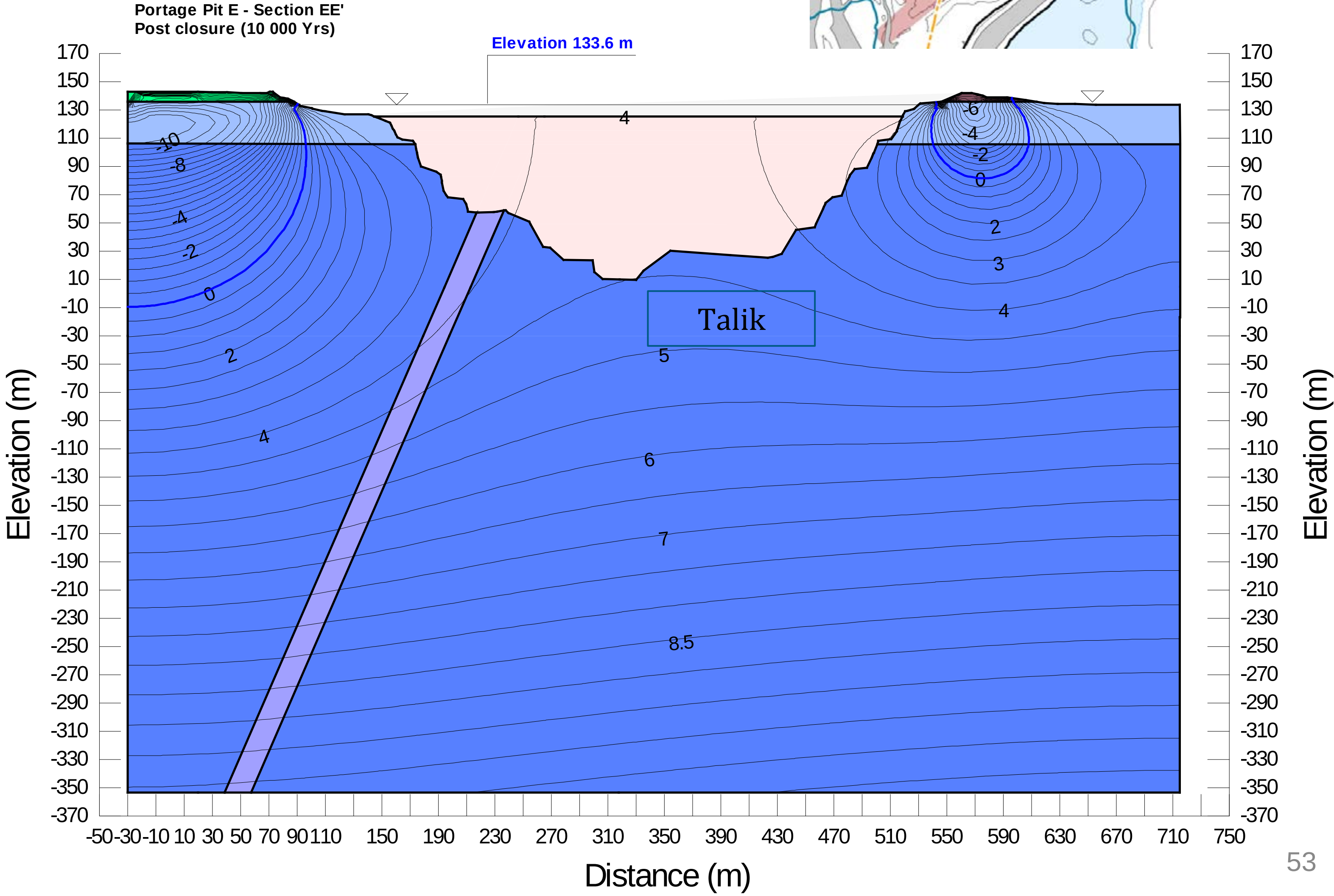
Pit E Thermal Modeling Results
Section E: 1,000 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile



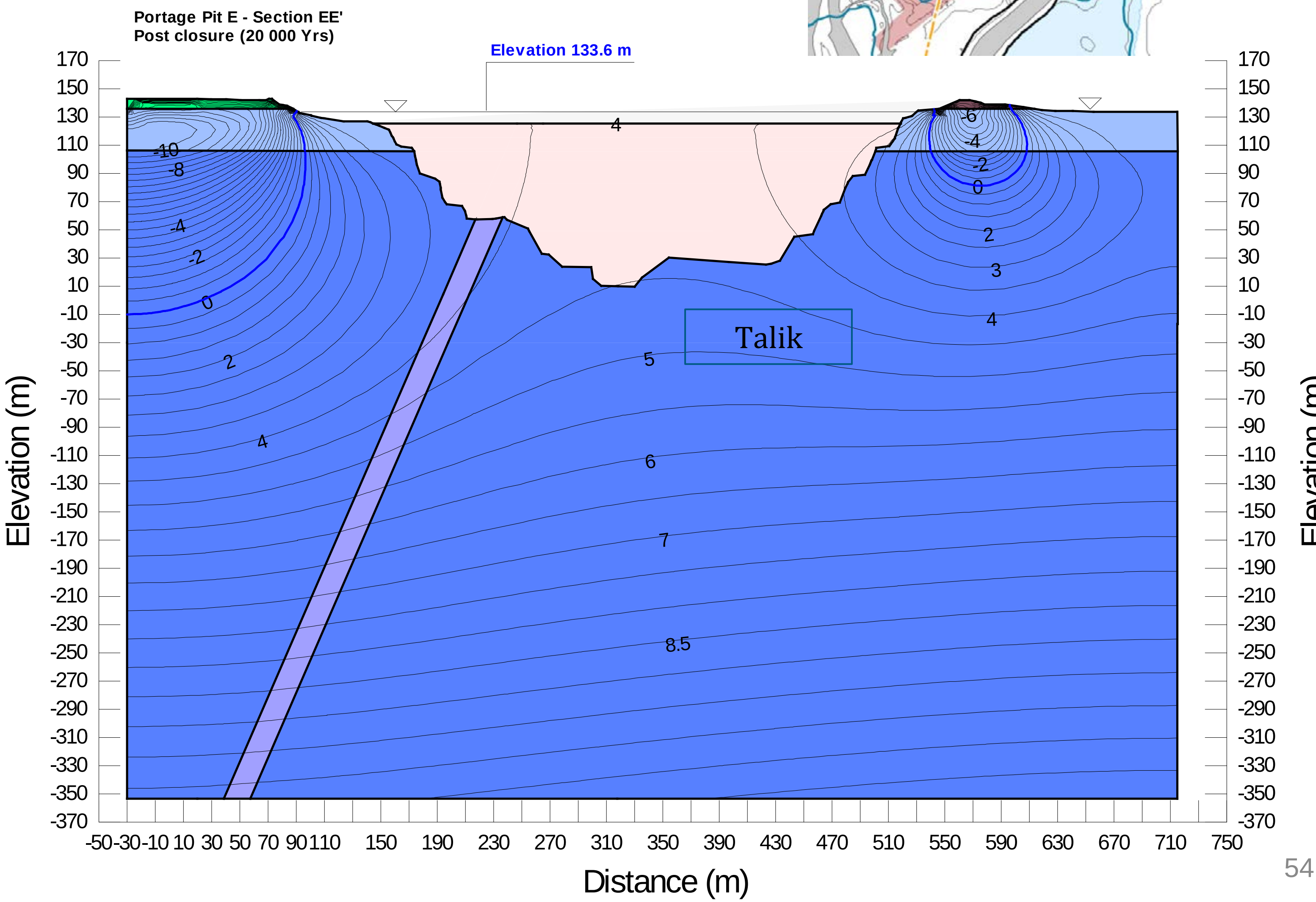
Pit E Thermal Modeling Results
Section E: 10,000 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile



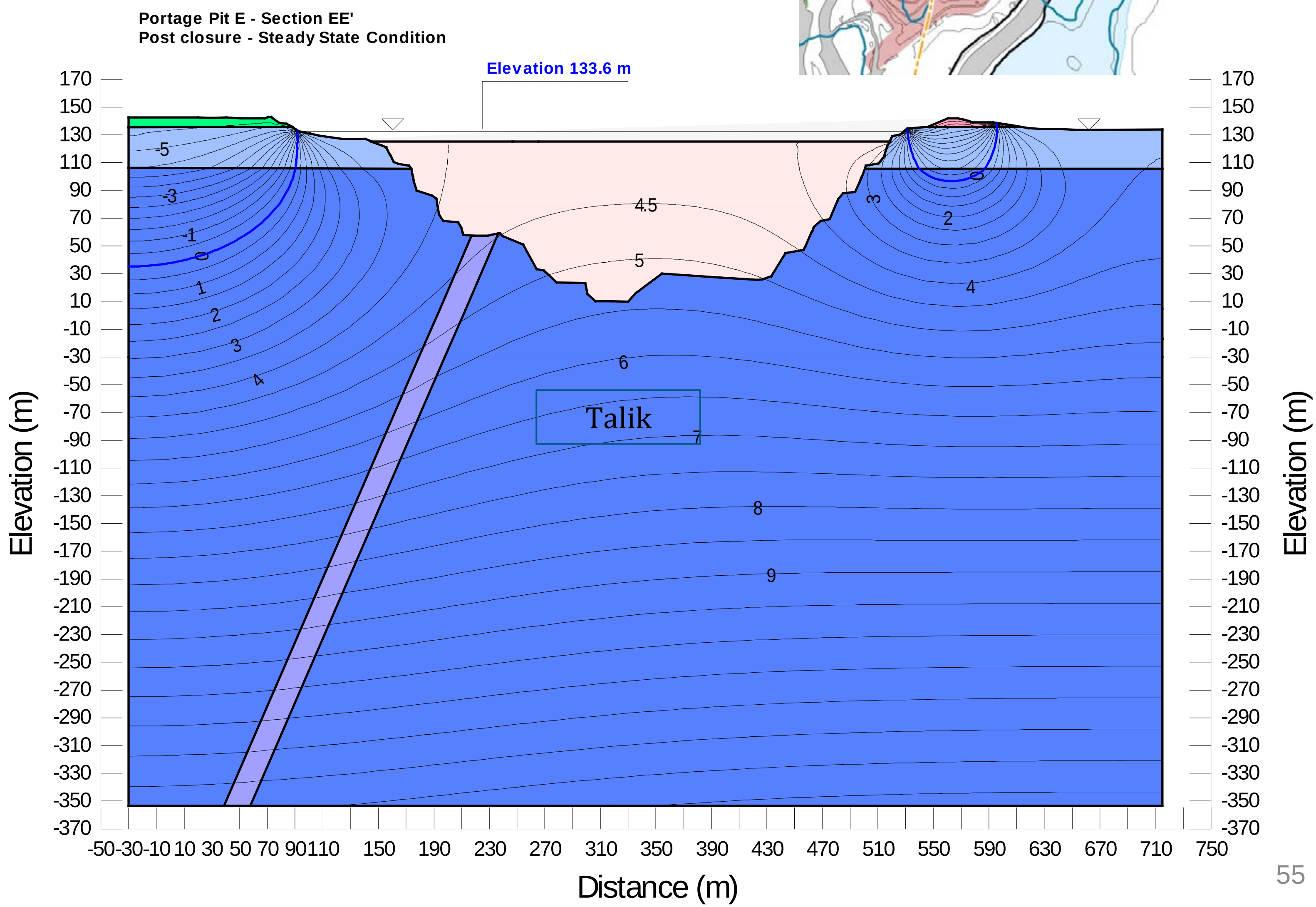
Pit E Thermal Modeling Results
Section E: 20,000 Years After Closure

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile



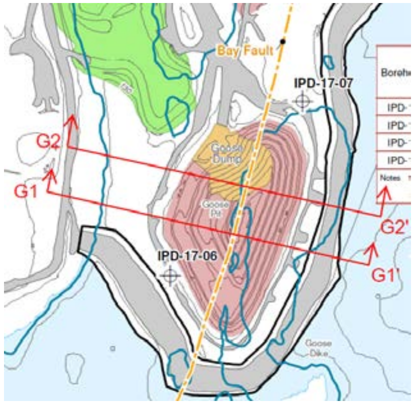
Pit E Thermal Modeling Results
Section E: Steady State Condition

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault
	NAG Stockpile

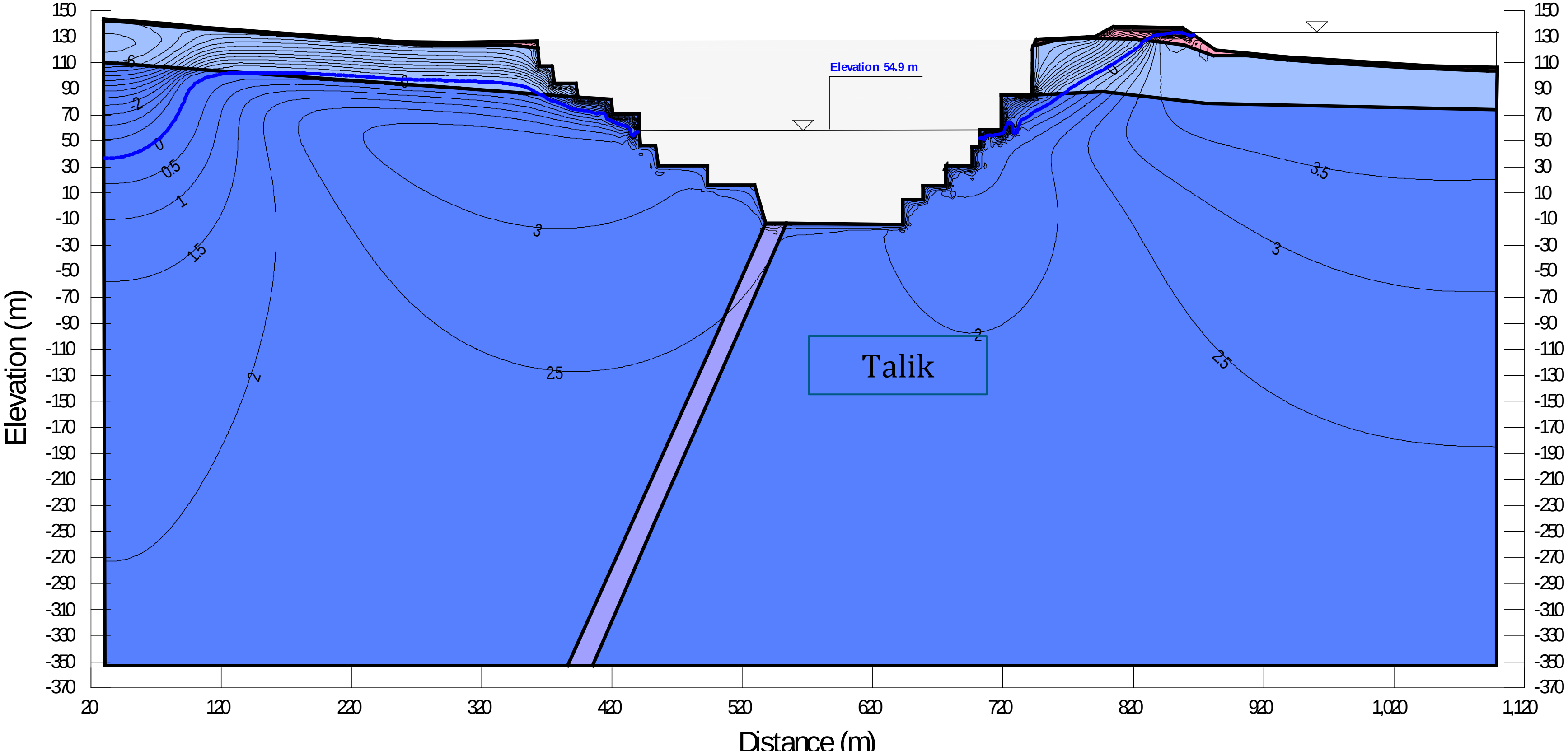


Goose Pit Thermal Modeling Results
Section G1: Prior to Tailings Deposition

Color	Name
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(purple)	Fault

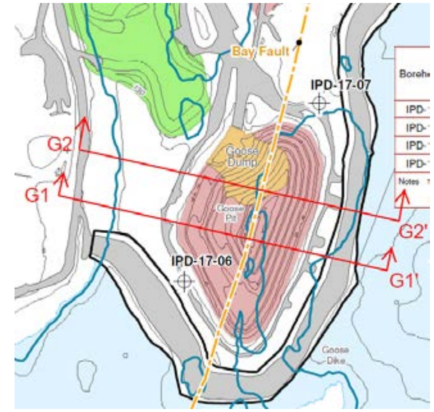


Goose Pit - Section G1G1'
Prior to Tailings Deposition

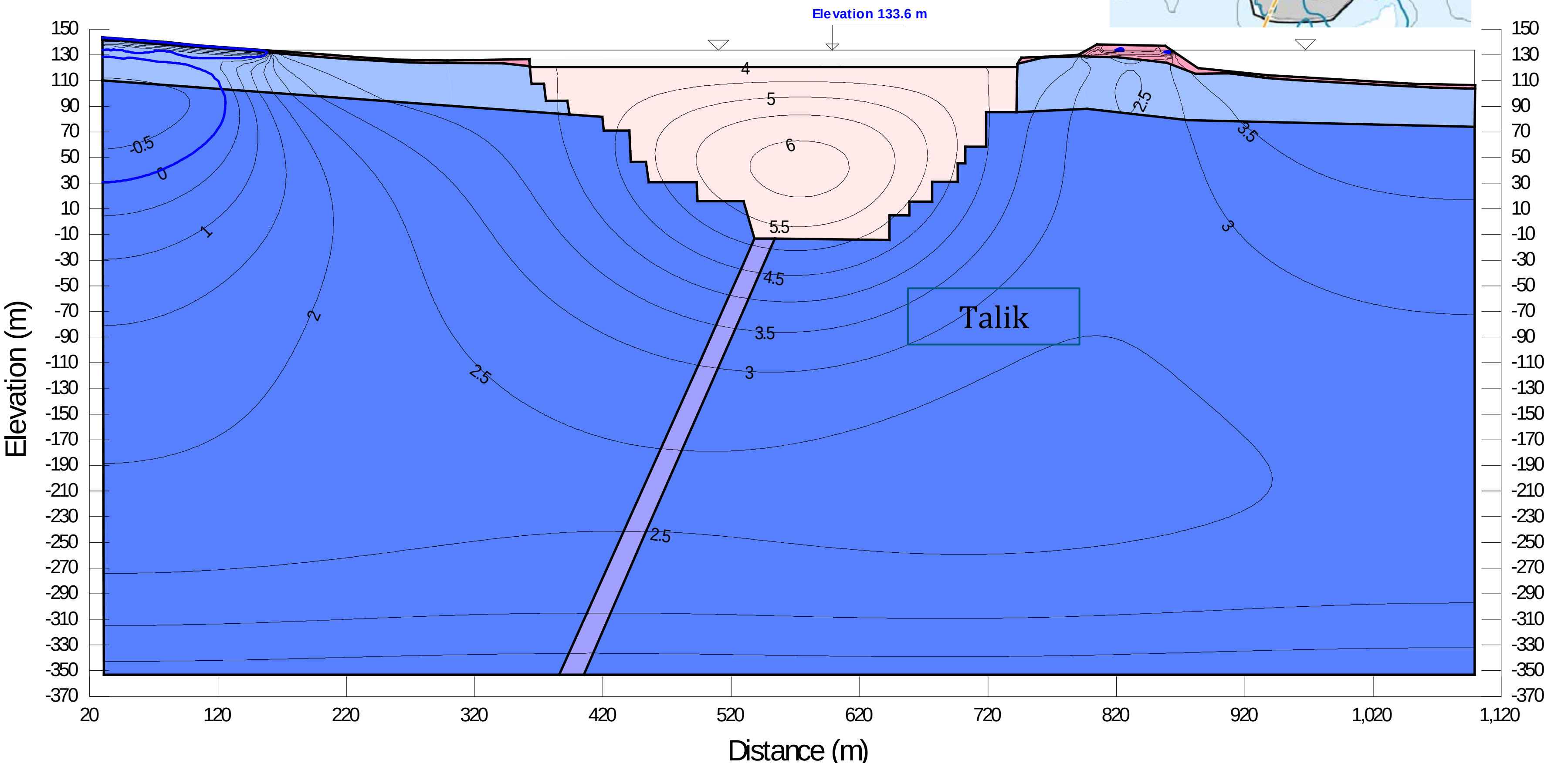


Goose Pit Thermal Modeling Results
Section G1: 100 Years After Closure

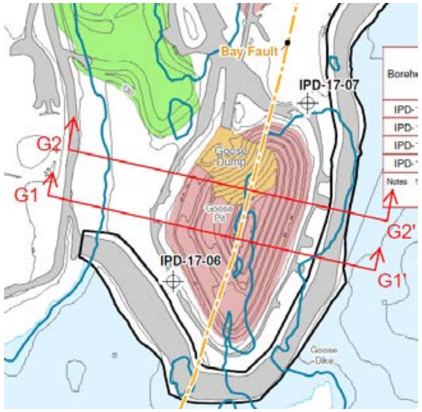
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault

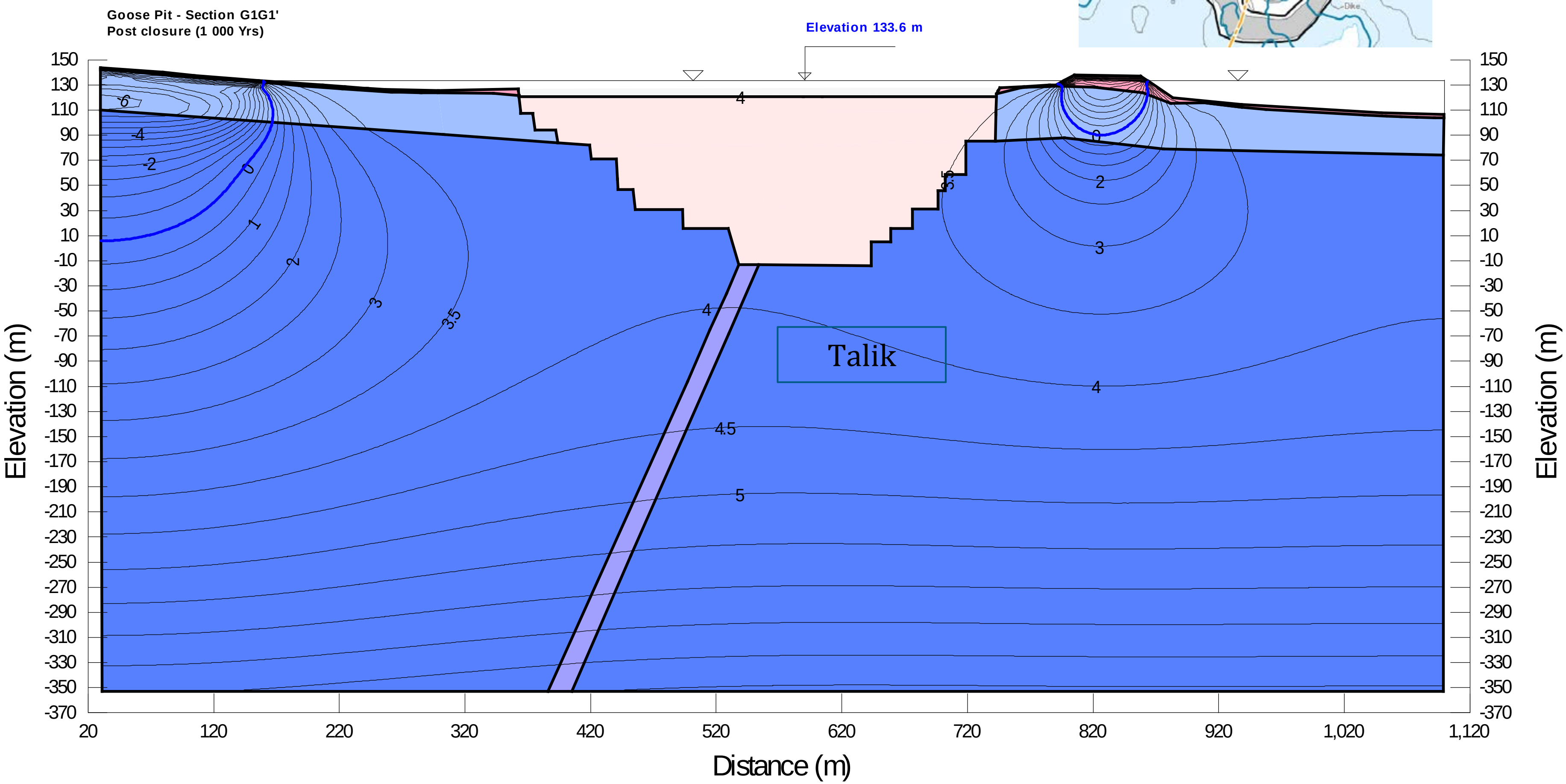


Goose Pit - Section G1G1'
Post closure (100 Yrs) - Climate Warming



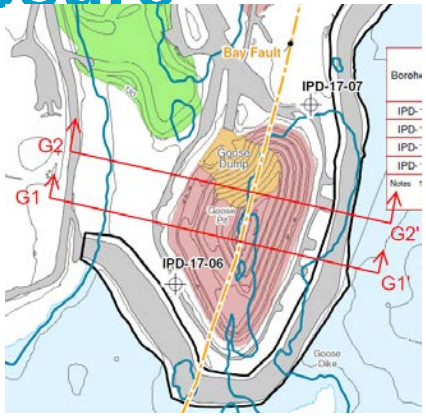
Goose Pit Thermal Modeling Results
Section G1: 1,000 Years After Closure

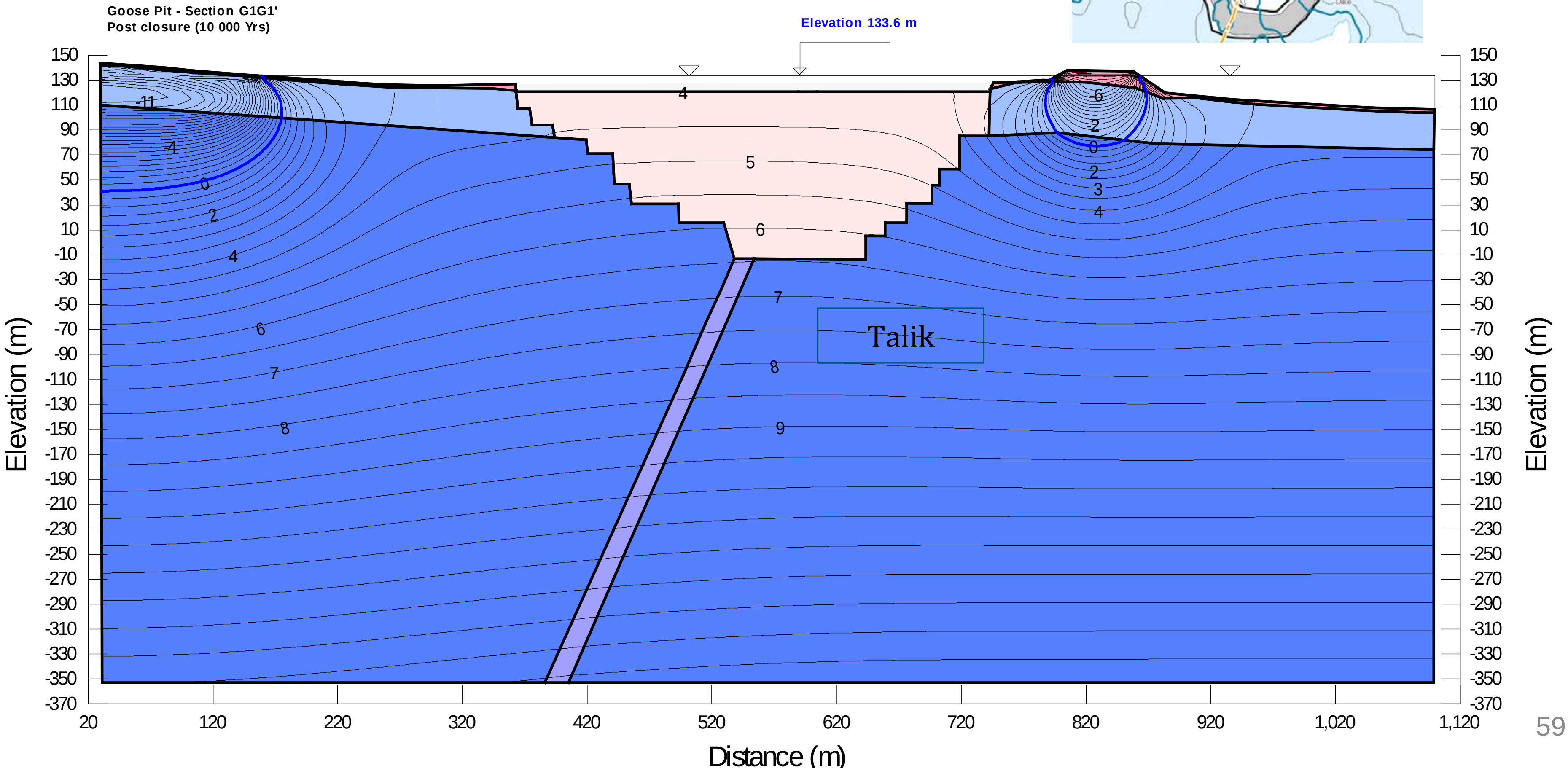




Goose Pit Thermal Modeling Results
Section G1: 10,000 Years After Closure

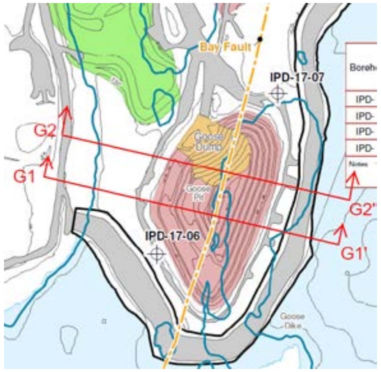
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault

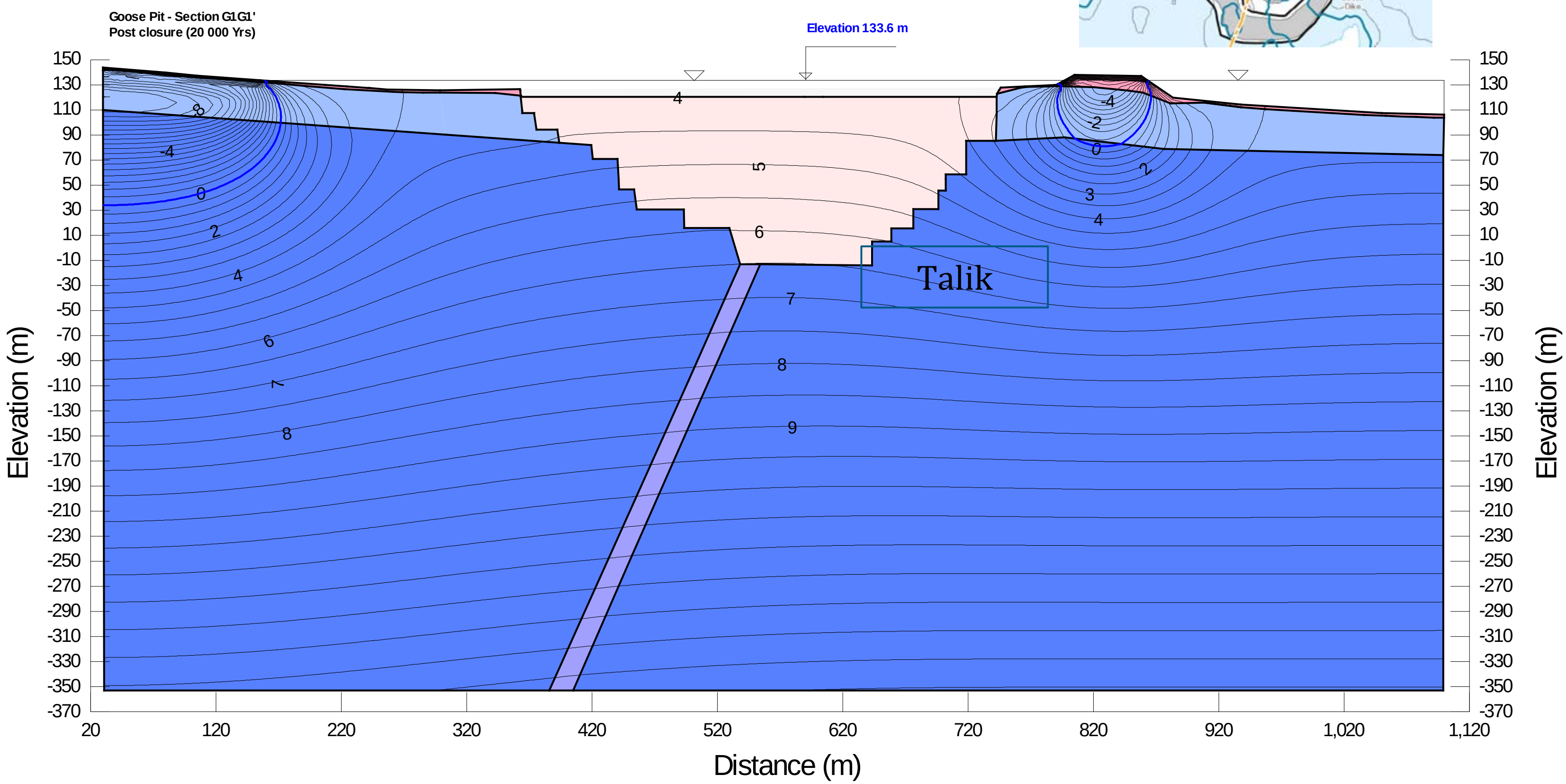




Goose Pit Thermal Modeling Results
Section G1: 20,000 Years After Closure

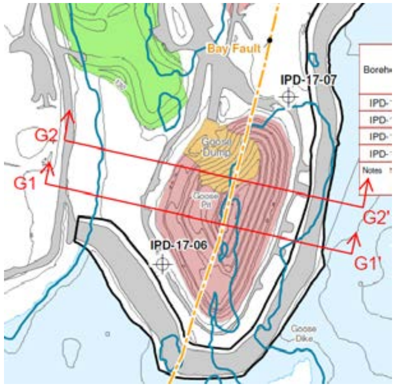
Color	Name
(light pink)	Settled Tailings
(pink)	Till
(light blue)	Weathered Bedrock
(blue)	Bedrock
(purple)	Fault

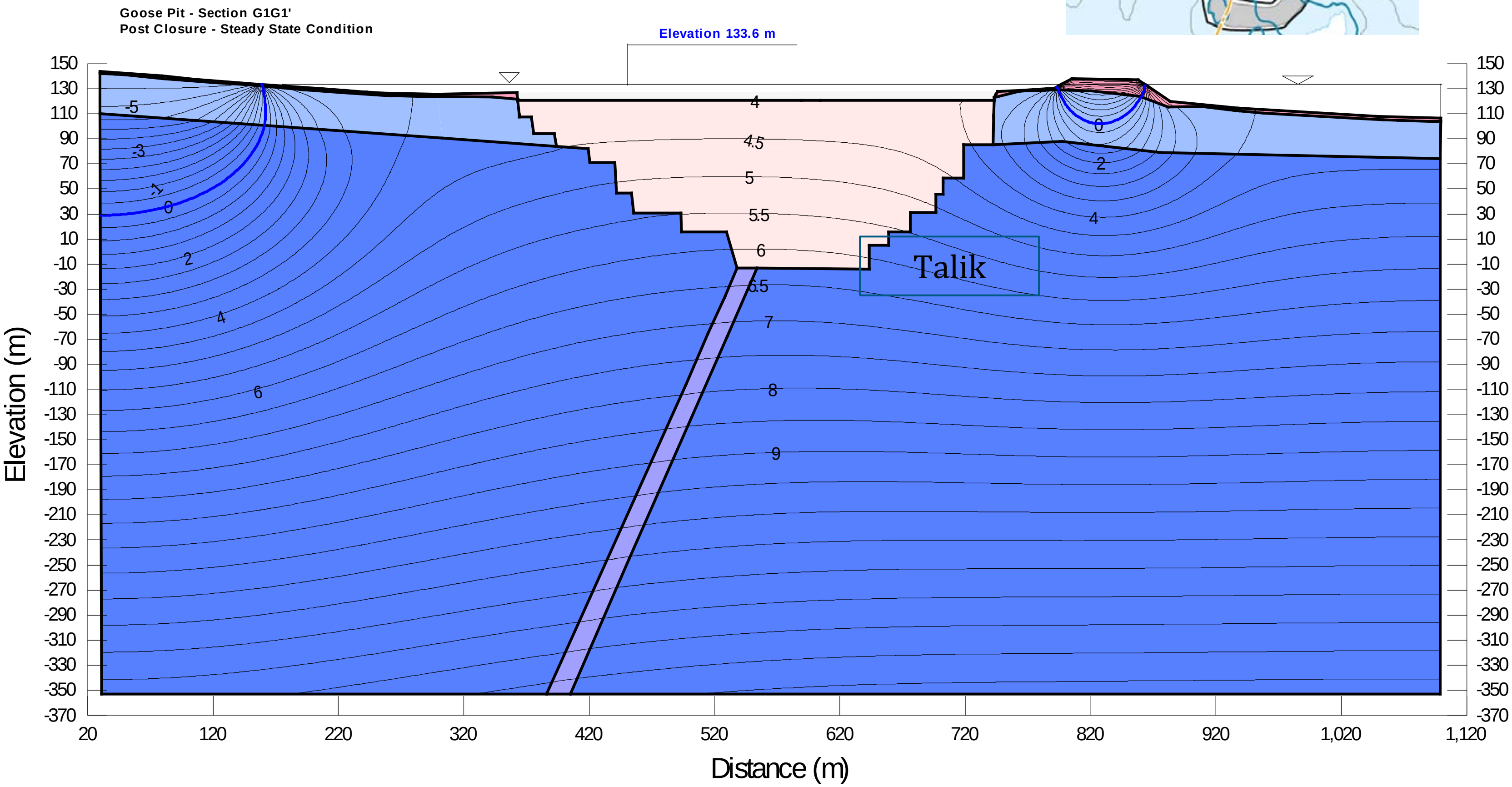




Goose Pit Thermal Modeling Results
Section G1: Steady State Condition

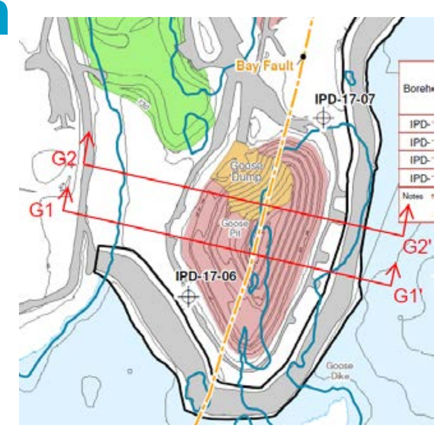
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault



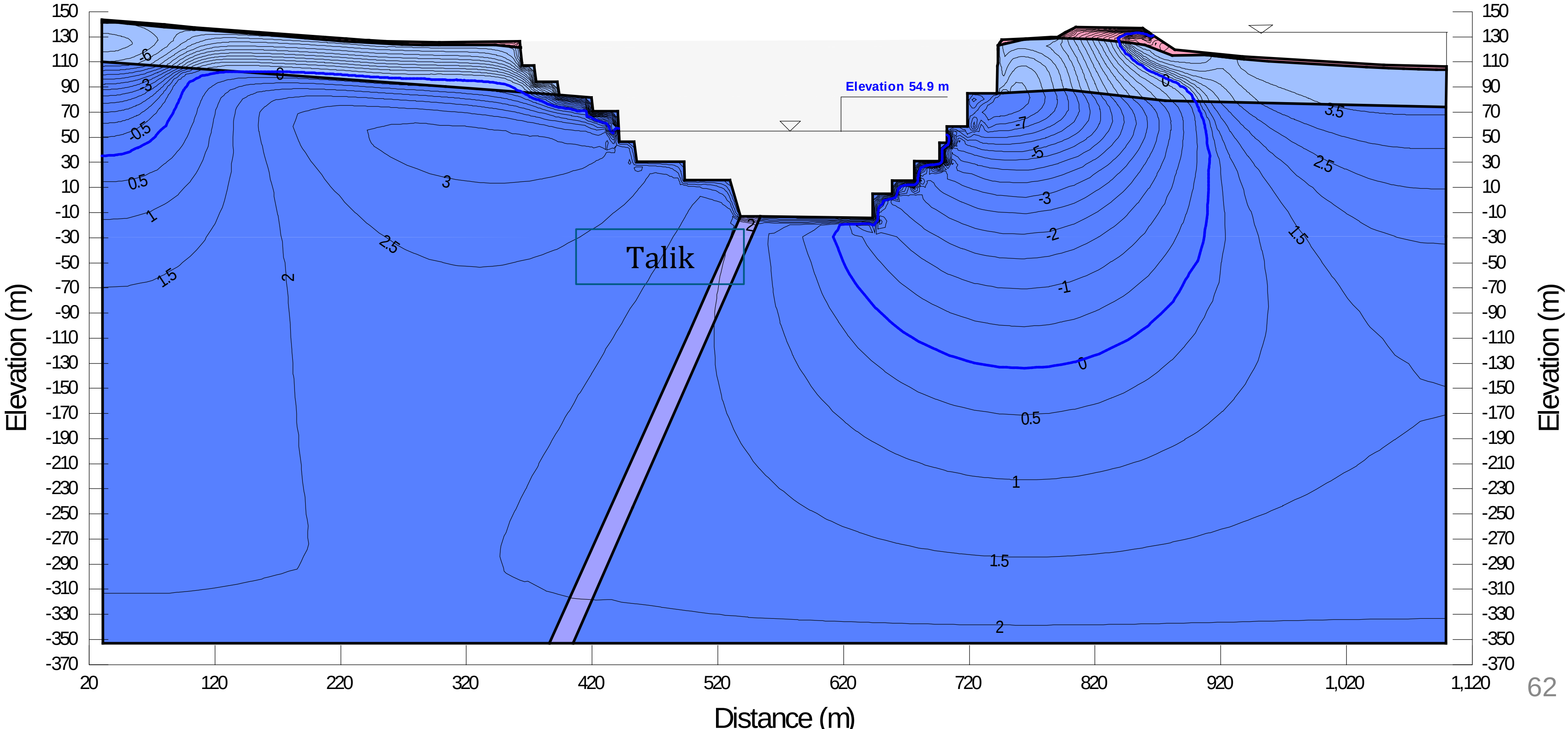


Goose Pit Thermal Modeling Results
Section G2: Prior to Tailings Deposition

Color	Name
	Till
	Weathered Bedrock
	Bedrock
	Fault

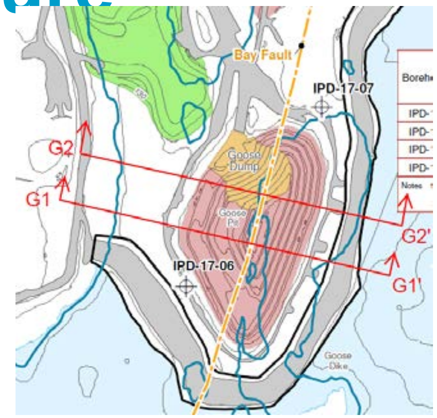


Goose Pit - Section G2G2'
Prior to Tailings Deposition

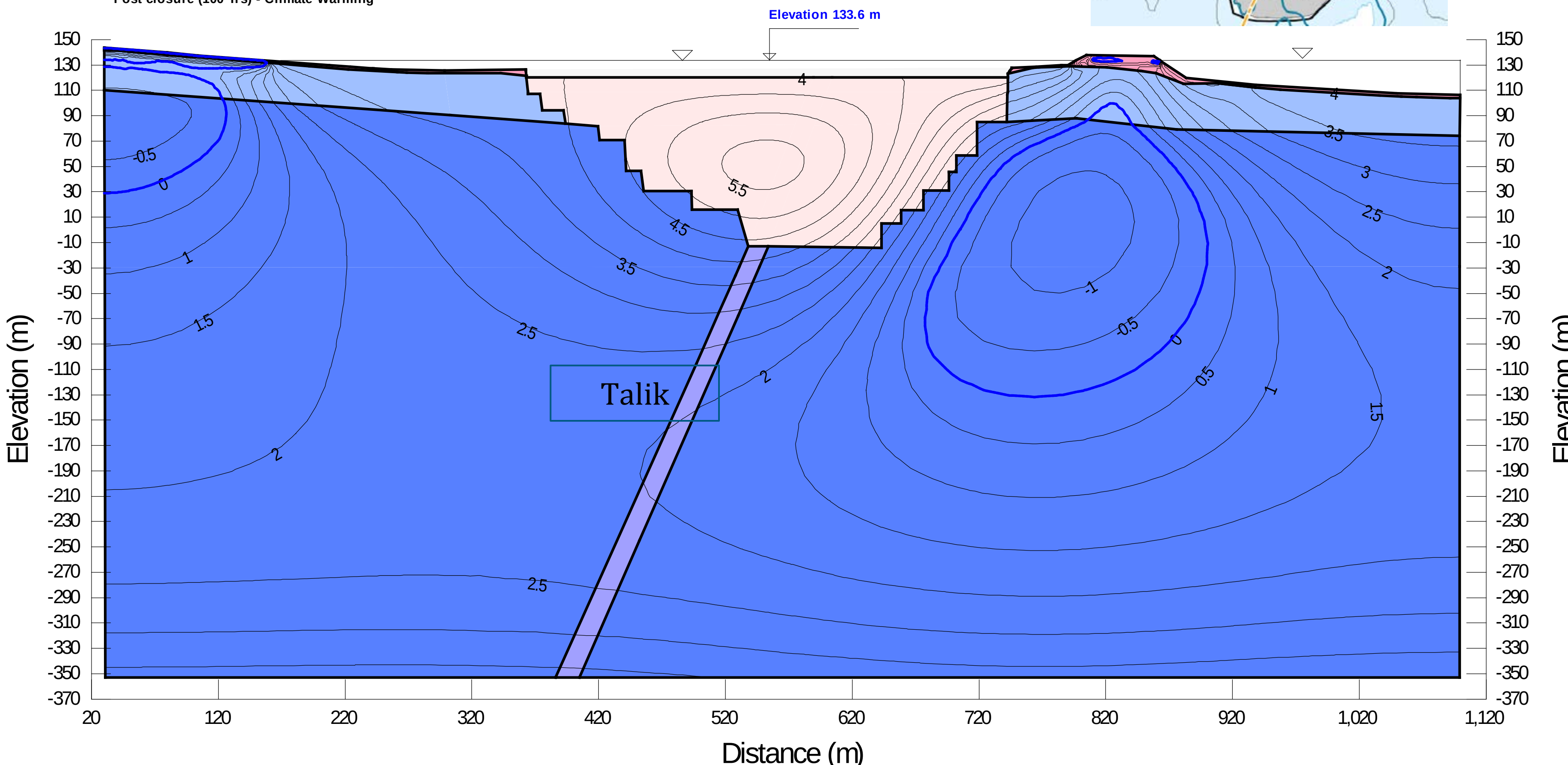


Goose Pit Thermal Modeling Results
Section G2: 100 Years After Closure

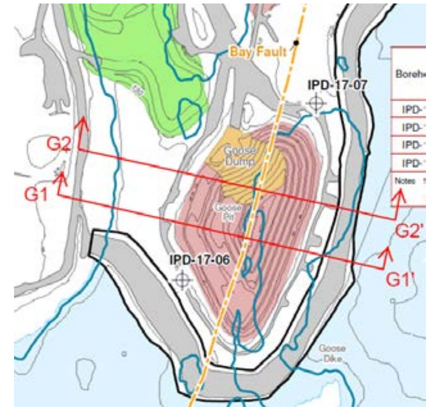
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault

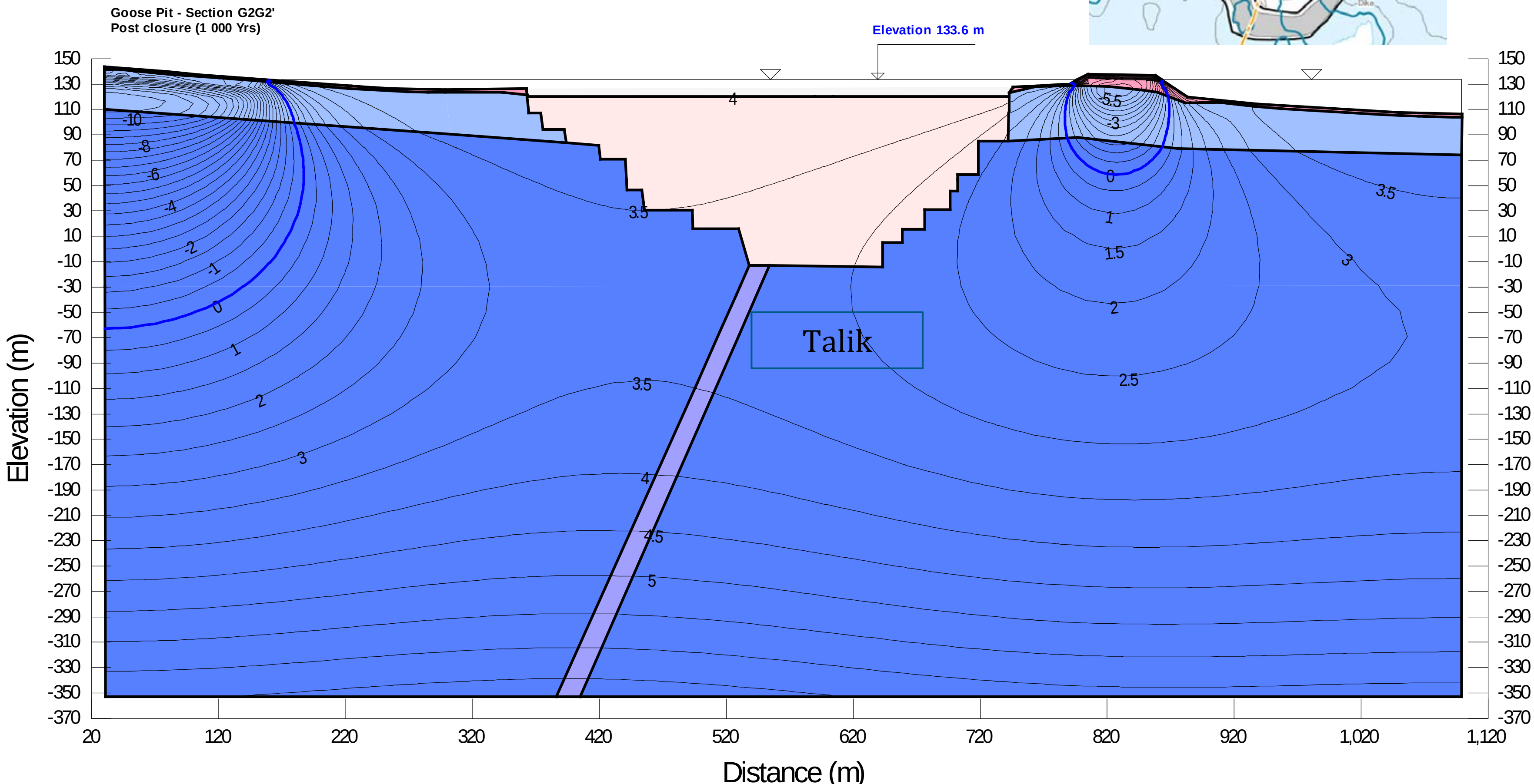


Goose Pit - Section G2G2'
Post closure (100 Yrs) - Climate Warming

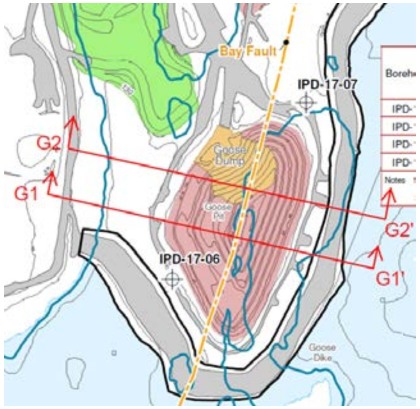


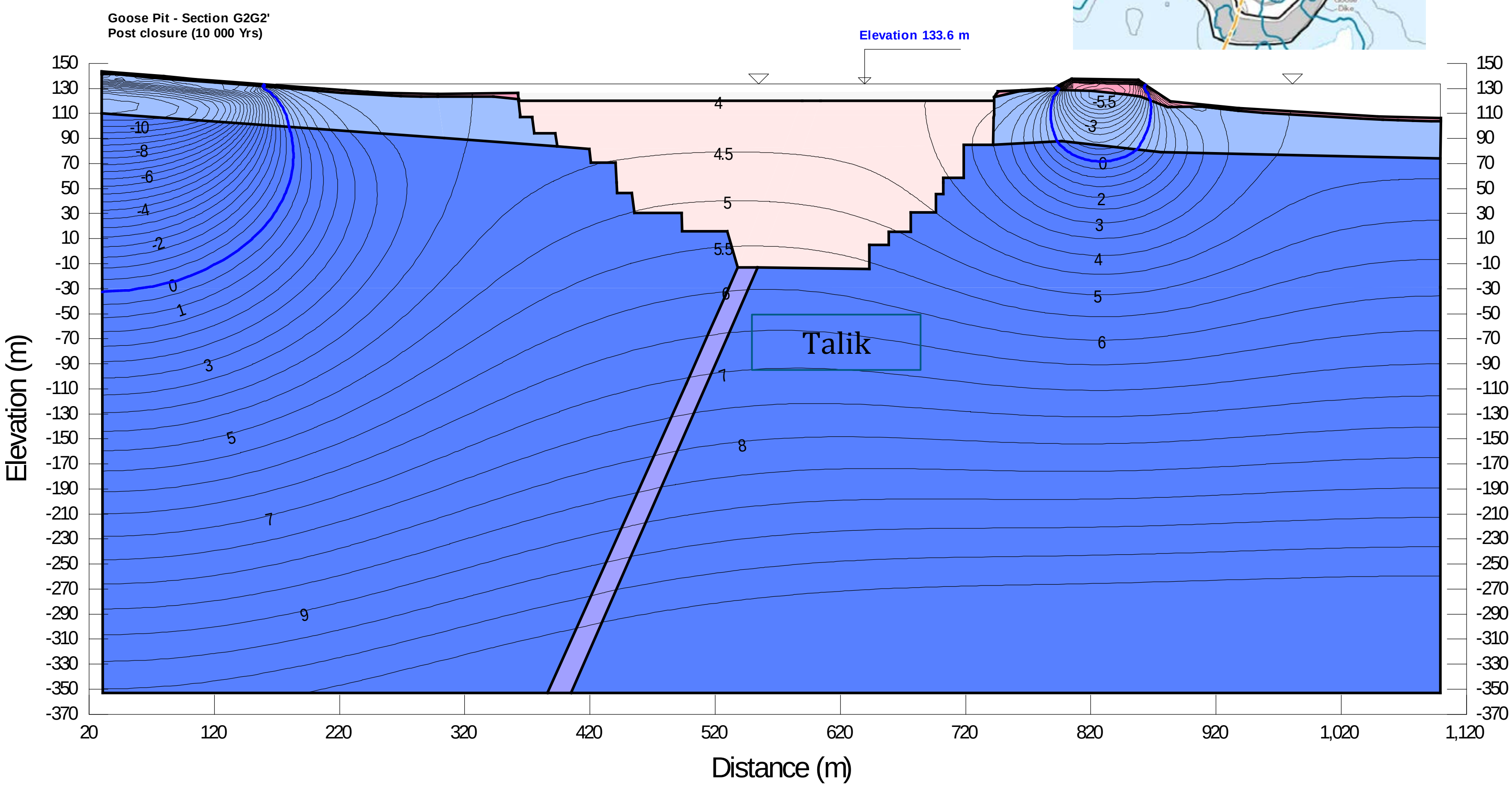
Goose Pit Thermal Modeling Results Section G2: 1,000 Years After Closure





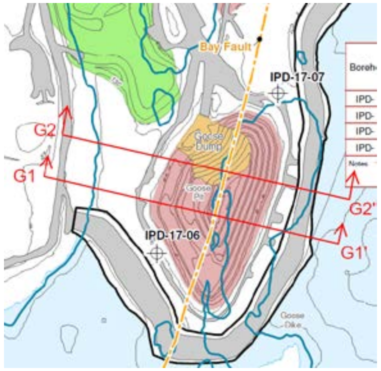
Goose Pit Thermal Modeling Results Section G2: 10,000 Years After Closure

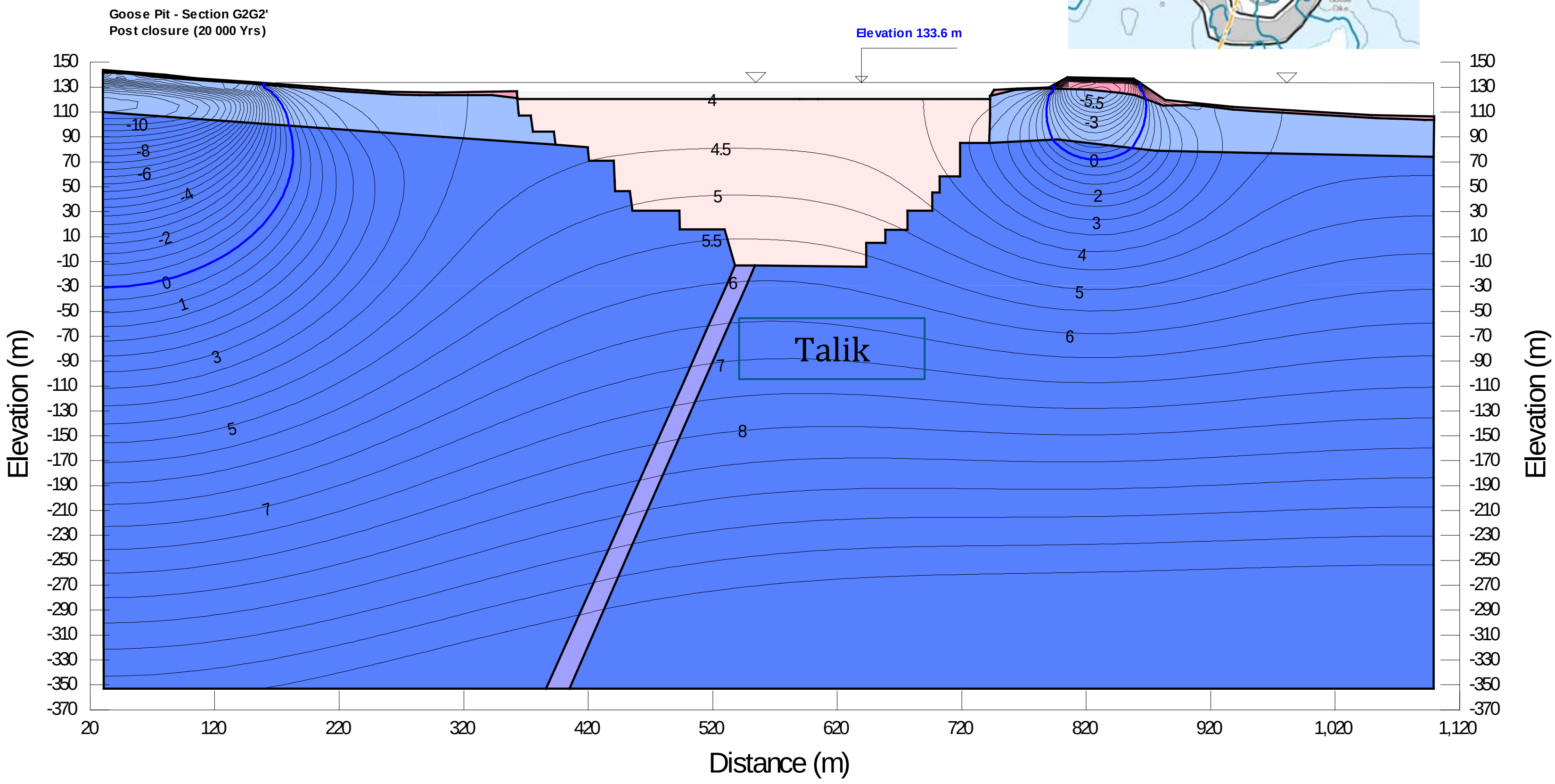




Goose Pit Thermal Modeling Results
Section G2: 20,000 Years After Closure

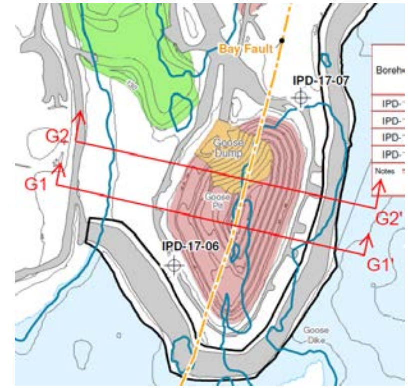
Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault

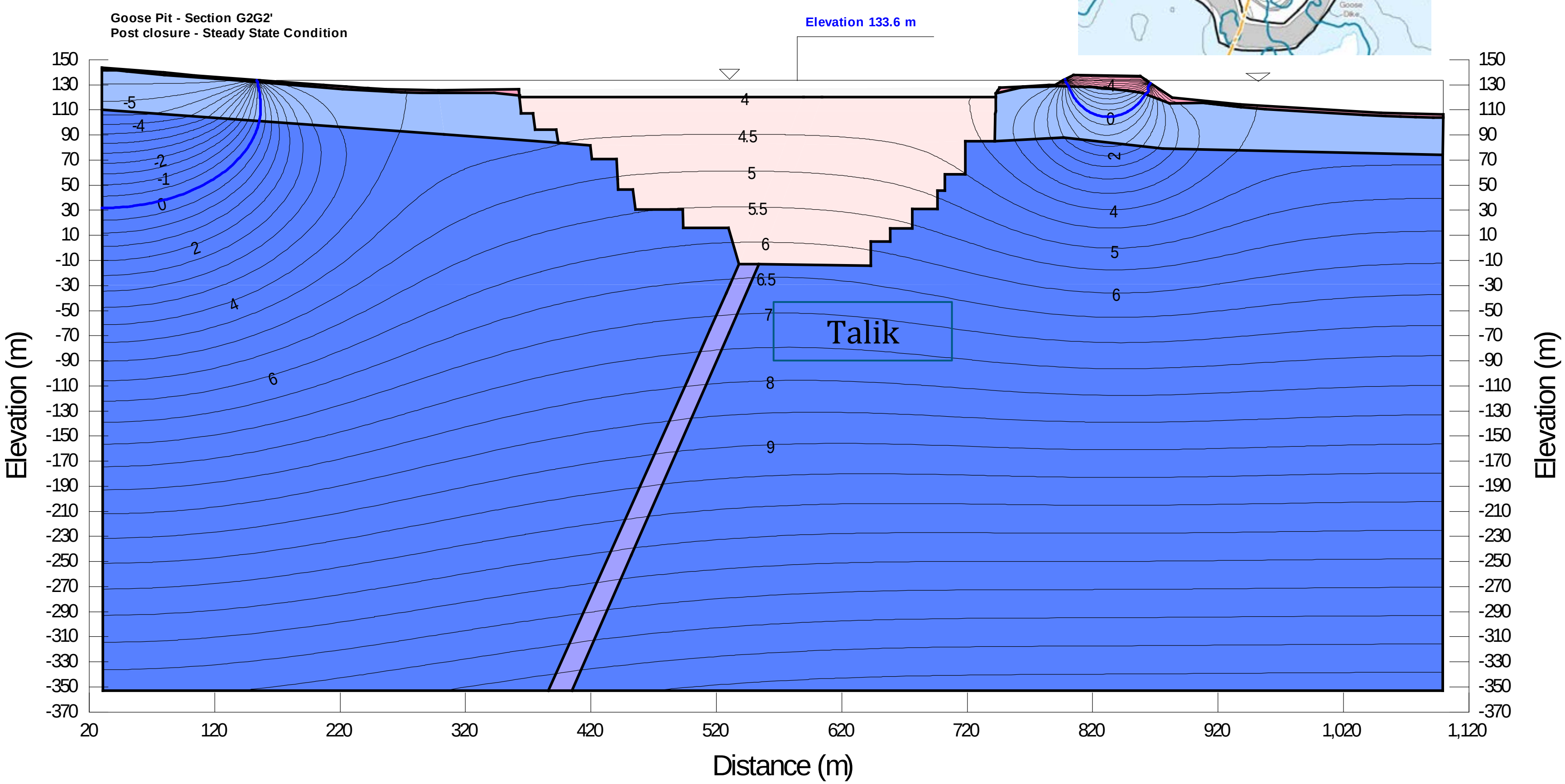




Goose Pit Thermal Modeling Results
Section G2: Steady State Condition

Color	Name
	Settled Tailings
	Till
	Weathered Bedrock
	Bedrock
	Fault





Conclusions for Thermal Modeling

The conclusions from the long term thermal modeling are presented below.

Portage Pit A

- The north portion of Pit A (at the location of Section A), a talik connection to Second Portage Lake is predicted to develop on the west wall at about 650 years after closure;
- At Section A1, the south portion of Pit A, talik connections to the Second and Third Portage Lake (pit lake) are predicted to develop on both east and west walls at closure which reaches about 25 m deep at 100 year after closure and about 50 m deep at 400 year after closure; the talik connection on the east wall closes due to ground surface freeze back at about 200 year after closure and re-opens at about 620 years after closure.

Portage Pit E

- The south portion of Pit E is predicted to have similar thermal condition to Goose Pit with existing talik connection to Third Portage Lake and degrading permafrost pockets on pit walls;
- At the north portion of the pit, a permafrost zone around the pit is predicted to remain until closure;
- After pit closure a talik connection to the Third Portage Lake is predicted to develop on the east wall of the north portion and reaches ±60 m deep at about 100 year after closure;
- A talik connection to the Third Portage Lake is predicted to develop at the bottom of north portion of the pit at about 670 years after closure.

Goose Pit

- The existing talik connection to Third Portage Lake is predicted to expand and the permafrost pockets on the pit wall will degrade and eventually will disappear due to deposition of warm tailings and the pit lake effect at closure.

PART II

Hydrogeological Model and Contaminant Transport Update
(Version 4)

Hydrogeological Model and Contaminant Transport Update (Version 4)

I. Permafrost Limit and Boundary Conditions Update
   - Permafrost degradation in 2 steps
   - Boundary conditions

II. Contaminant Transport Results - Post Closure Step 1 from 0 to 400 years
   - Simulated head maps
   - Simulated transport of chloride from Pit A, Pit E and Goose Pit

III. Contaminant Transport Results - Post Closure Step 2 from 400 to 20,000 years
   - Simulated head maps
   - Simulated transport of chloride from Pit A, Pit E and Goose Pit

IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

V. Monitoring network

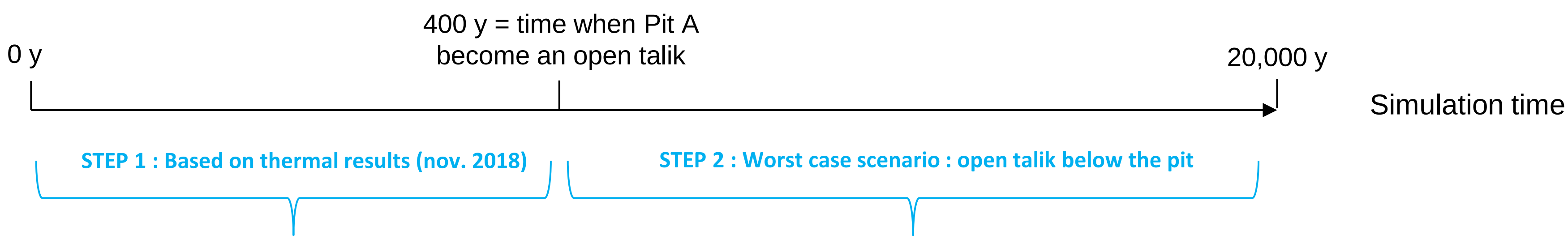
VI. Conclusions

I. Permafrost Limit and Boundary Conditions Update

Permafrost degradation in 2 steps

Boundary conditions

The thermal modeling results suggest that the open talik develops at different area within Pit A at various time from 400 years to 620 years after closure. At Pit E, the talik connection to the Third Portage Lake is predicted to develop at about 670 years. For model simplicity and to be conservative, 400 years after closure it was assumed and used in the hydrogeological modelling. From 400 to 20,000 years after closure, steady-state permafrost conditions were used, with open taliks below Pit A, Pit E and Goose Pit.



STEP 1 : Based on thermal results (nov. 2018)

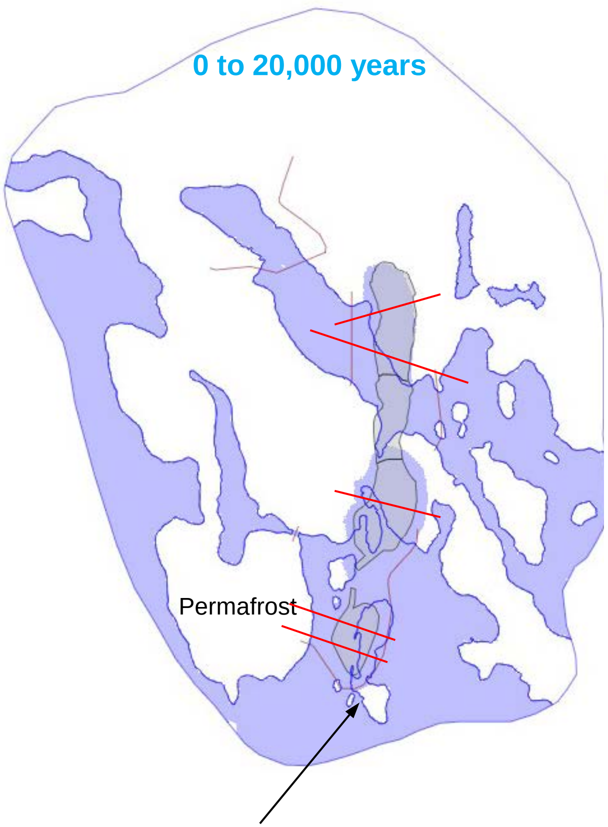
- Goose Pit : Goose Island completely thawed
- Pit E : Open talik at the South-east and South portion of the pit. Open talik at the upper portion of the northern part of Pit E (in contact with Central Dump)
- Pit A : Open talik (open at the South end of the pit)

STEP 2 : Worst case scenario : open talik below the pit

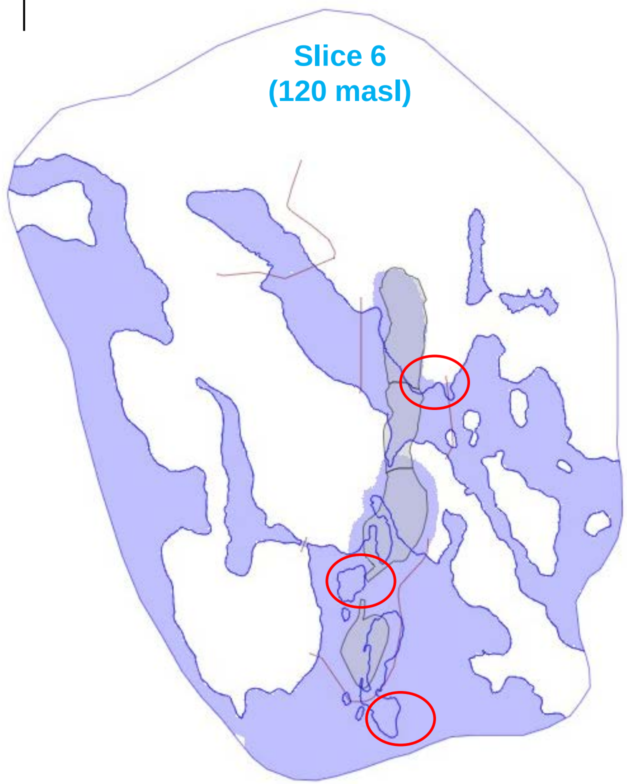
- Goose Pit : Goose Island completely thawed
- Pit E : Open talik + permafrost thawed zone at the north of the pit, at Central Dump location, under the flooded area.
- Pit A : Open talik (completely thawed under Pit A), and the south-eastern tip of Pit A.

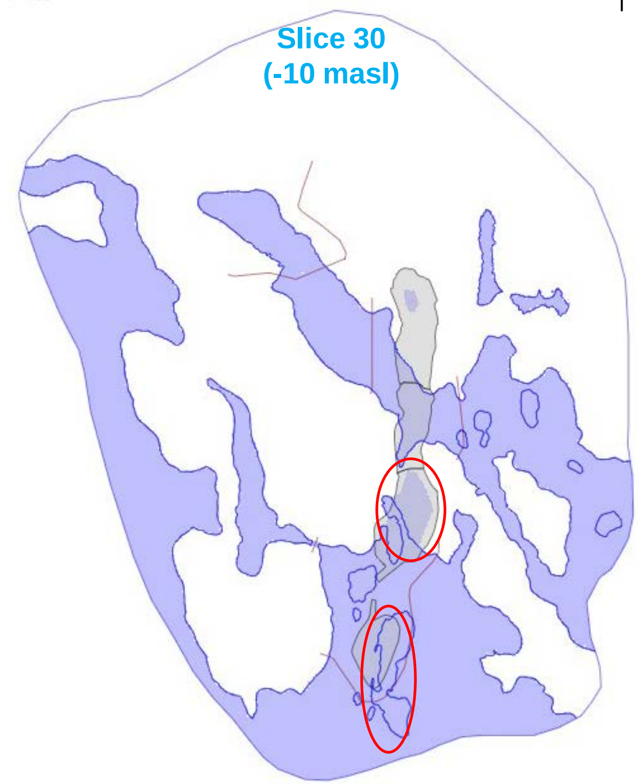
I. Permafrost Limit and Boundary Conditions Update: Permafrost Degradation (0 to 400 years)

Detailled Engineering



Model Version 4





Initial permafrost contour

Thermal sections

- North & South cells TSF (over Slice 6) are assumed frozen in all versions of the model.

Slice 6:

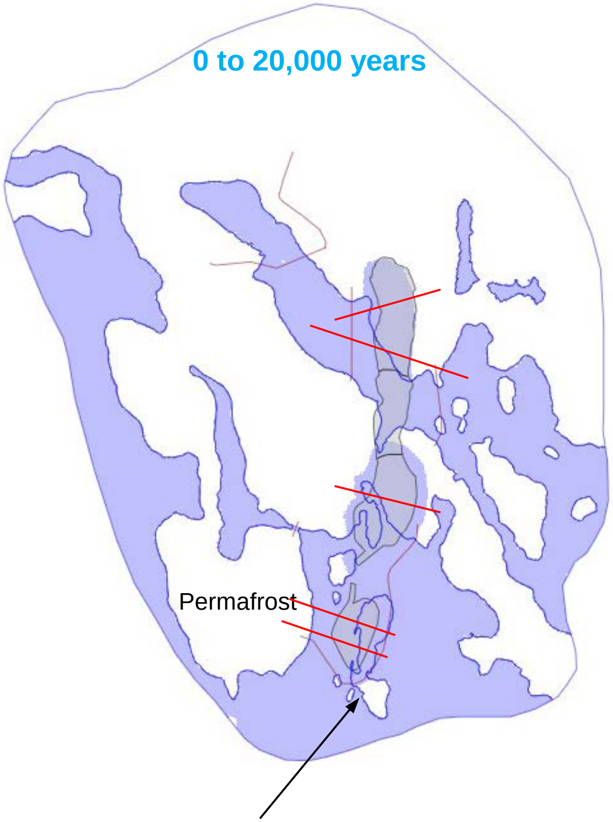
- Goose Pit : Goose Island completely thawed
- Pit E :
  - West : 70 m lateral thaw
  - East : 40 m lateral thaw
- Pit A :
  - West : 210 m lateral thaw
  - East : < to elements size
  - South-eastern tip of Pit A was thawed at the top of the model

Slice 30:

- Goose Pit : Goose Island completely thawed
- Pit E : 60 m width thawed under the pit, but permafrost remaining deeper
- Pit A : open talik, permafrost remaining under the pit

I. Permafrost Limit and Boundary Conditions Update: Permafrost Degradation (400 to 20,000 years)

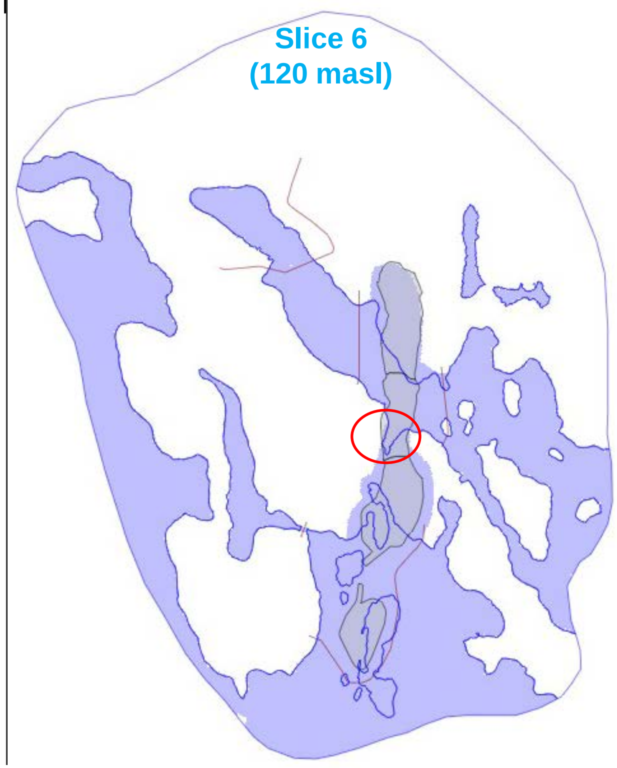
Detailled Engineering

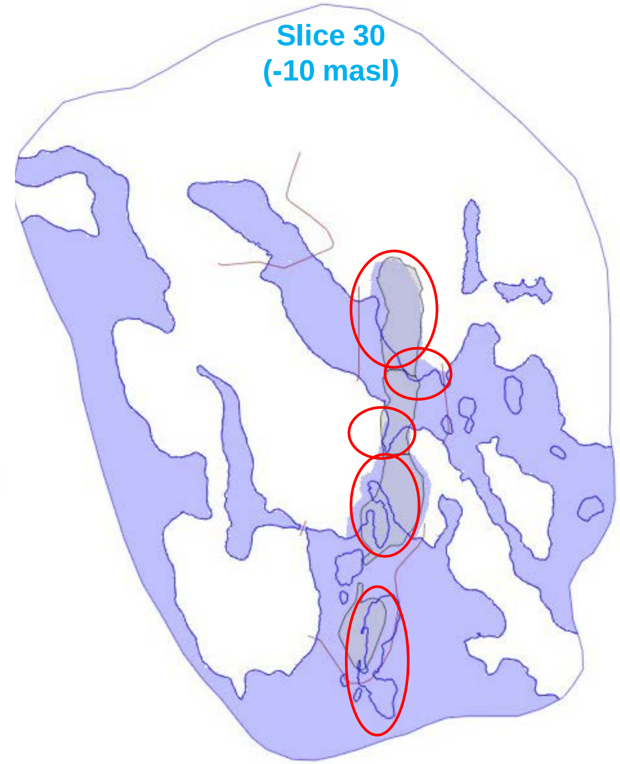


— Initial permafrost contour

— Thermal sections

Model Version 4





- Goose Pit : Goose Island completely thawed
- Pit E : Open talik + permafrost opening at the north of the pit, at Central Dump location, under the flooded area.
- Pit A : Open talik (completely thawed under Pit A), and the south-eastern tip of Pit A.

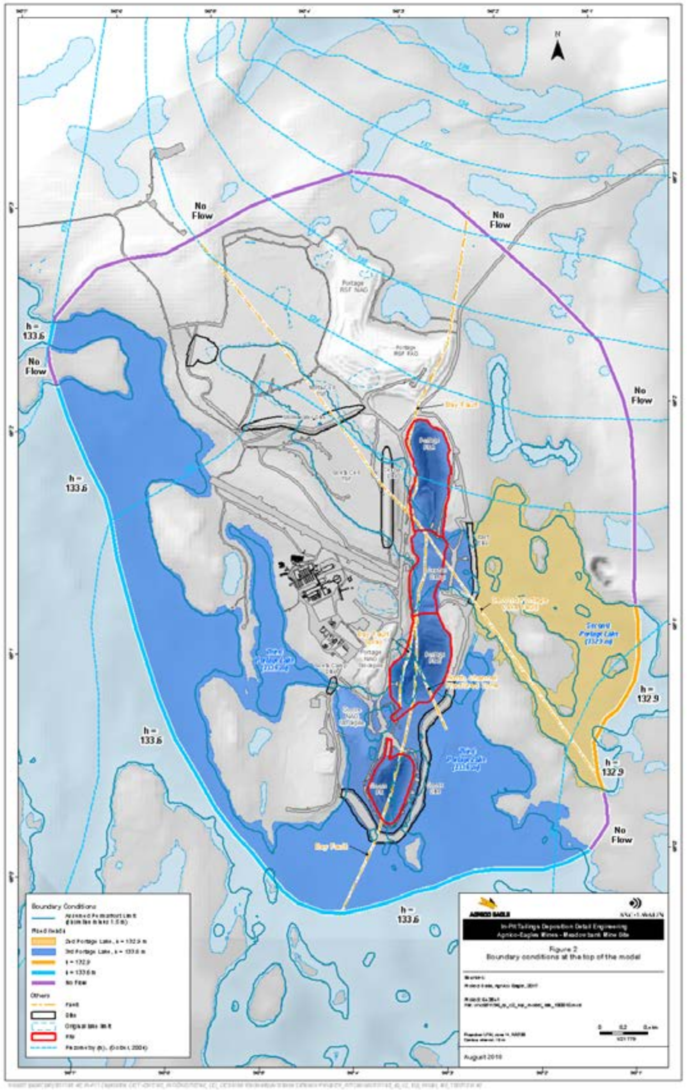
- North & South cells TSF (over Slice 6) are assumed frozen in all versions of the model.

I. Permafrost Limit and Boundary Conditions Update: Flow Boundary Conditions

Boundary conditions on the top of the model

- *No change made on the top boundary conditions.*
- *Boundary conditions at the top of the model, as agreed with NRCan (Sept.25 2018)*

Figure color	Geographic position	Elevation (masl)	Layer	Boundary condition
Grey zone	Permafrost area	variable	1	no flow
Blue area	3PL area and limit	variable	1	h = 133.6 m
Yellow Area	2PL area and limit	variable	1	h = 132.9 m



I. Permafrost Limit and Boundary Conditions Update: Flow Boundary Conditions

Boundary conditions at the bottom of the model

- ➢ *Based on Golder 2004 and 2005 simulated water level and surveyed lake levels by AEM*

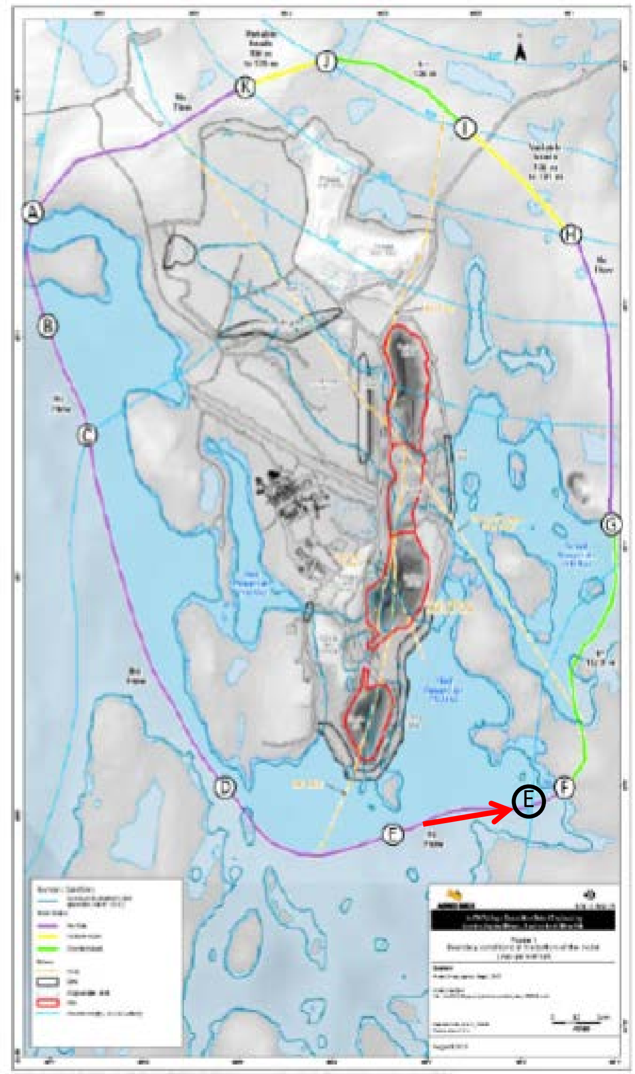
Permafrost and sub-permafrost boundary conditions ***as agreed with NRCan (Sept.25, 2018)***

**Changes from version 3 appear in red.*

Section	Boundary Condition
A-B	No flow
B-C	No flow
C-D	No flow
D-E	No flow
E-F	132.9
F-G	132.9
G-H	No flow
H-I	135.6-136.6
I-J	136.6
J-K	136.6-135.6
K-A	No flow

Changed from No flow to 132.9. E moved closer to F (E-F)

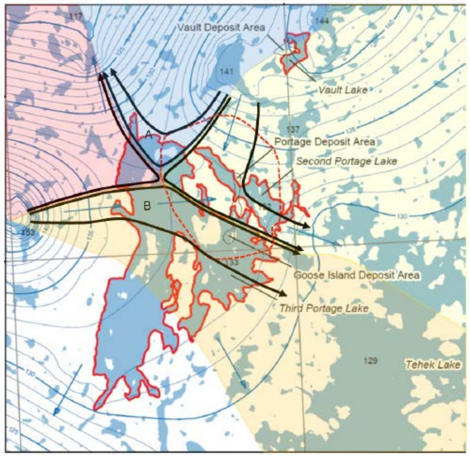
Increased by 0.6 m as recommended by NRCan. (H-I, I-J, J-K)

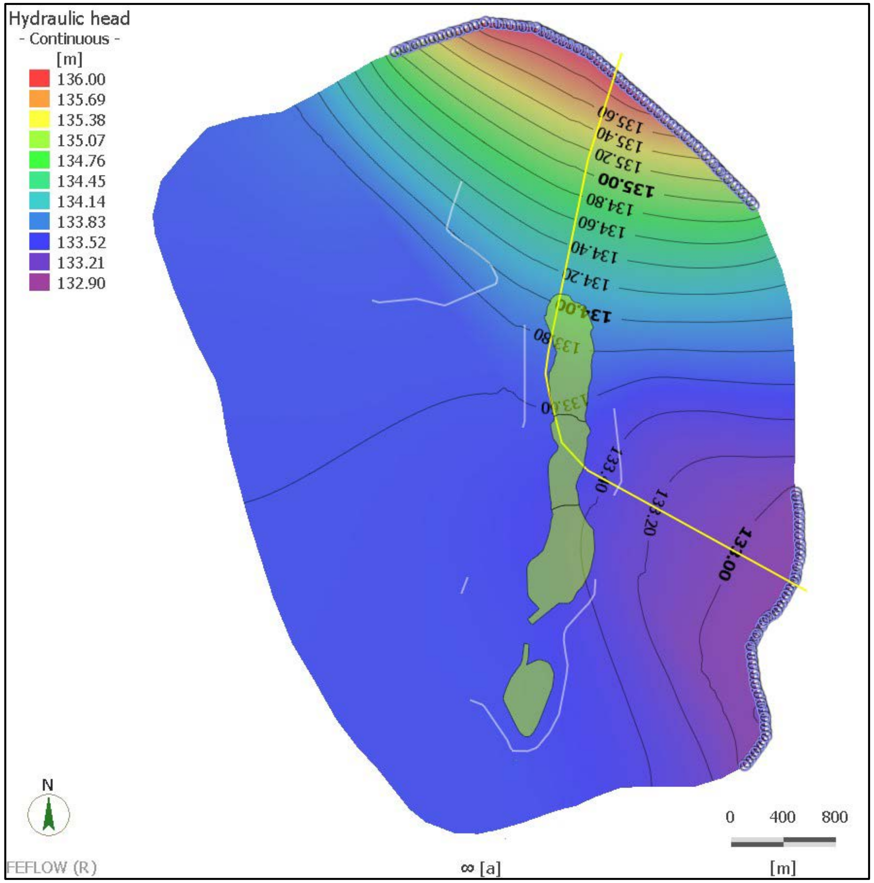


I. I. Permafrost Limit and Boundary Conditions Update: Flow Boundary Conditions

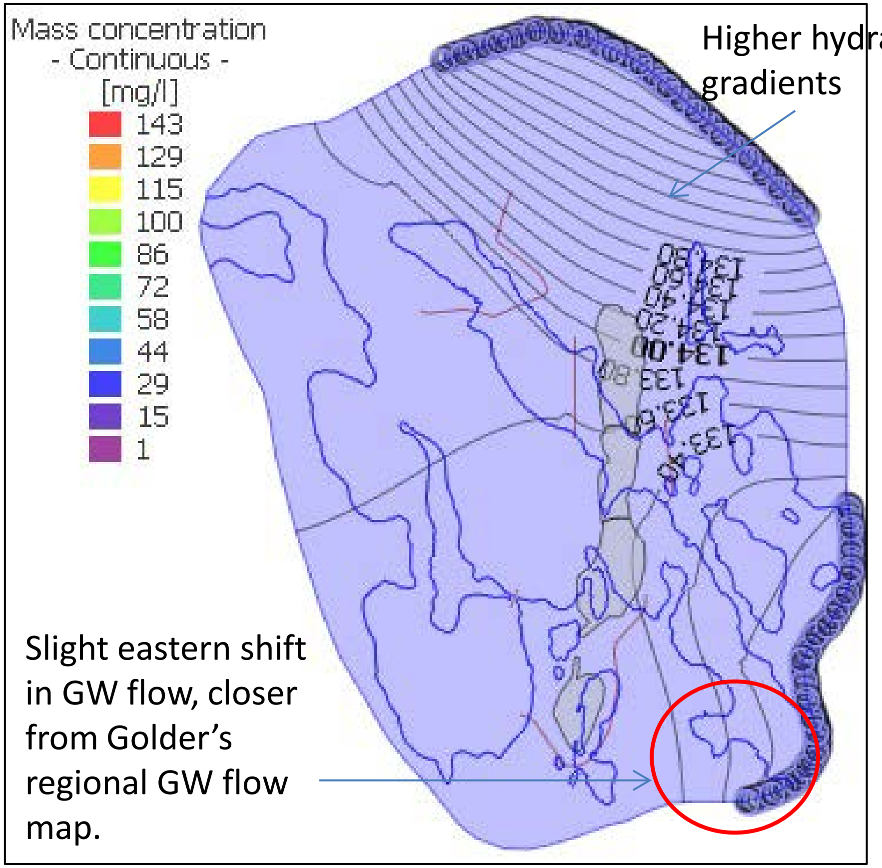
Comparison of hydraulic heads in a sub-permafrost Slice 44 (-500 masl)

Golder's map (modified by NRCan)





Model Version 3



Model Version 4

II. Contaminant Transport Results – Post Closure

Step 1 : 0 to 400 years

II. Contaminant Transport Results - Post closure Step 1 : 0 to 400 years

Assumptions : Post-closure, all pits filled with tailings and flooded

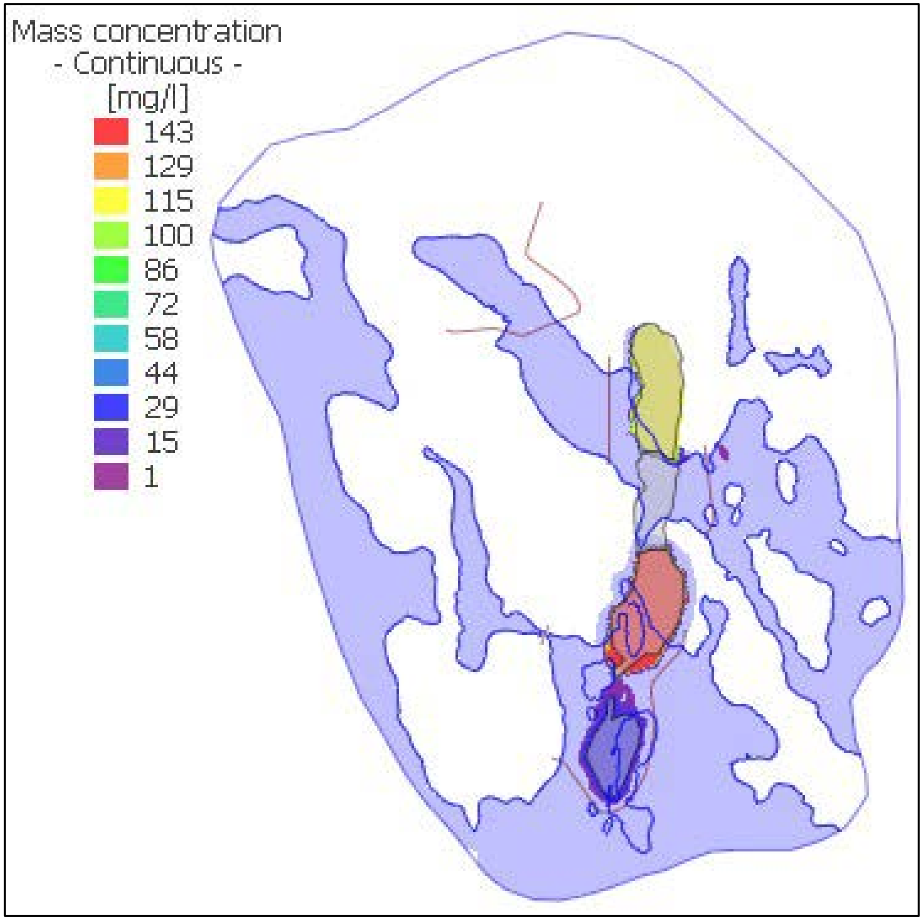
- Goose waste dump material is considered ($1x10^{-3}$ m/s)
- Tailings elevation = 125.6 masl (based on detail engineering, max capacity)
- Pits water elevation = 133.6 masl (3PL water level)
- North and South cells tailings are frozen
- No pumping activity at Central Dike
- Chloride and Arsenic initial concentration in pit tailings pore water are the same as presented in detailed engineering (Version 2) and are based on the water quality forecast (pit filled at full capacity and assume no water treatment) :

Pit	Chloride (mg/L)	Arsenic (mg/L)
Pit A	116	0.9
Pit E	141	1.1
Goose Pit	22	0.15

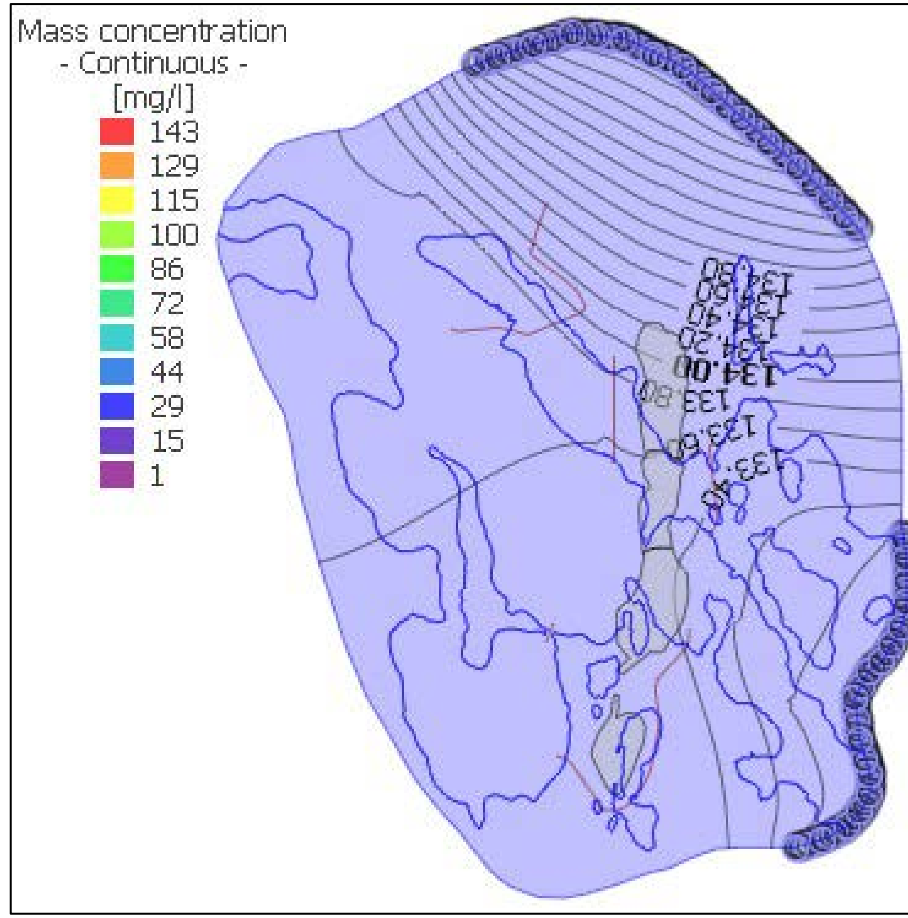
- The initial plume concentrations around Goose Pit are based on results from the Scenario 1 simulations (version 3 of the model), where Goose Pit is filled up with tailings and the plume migrates toward Pit E (under dewatering conditions)
- Step 1 simulation is run from 0 to 400 years after closure, with the permafrost degradation state corresponding to t = 400 years.

II. Contaminant Transport Results - Post closure Step 1 : 0 to 400 years

Chloride concentration & Simulated head maps, at t=400 y



Slice 6 (120 masl)



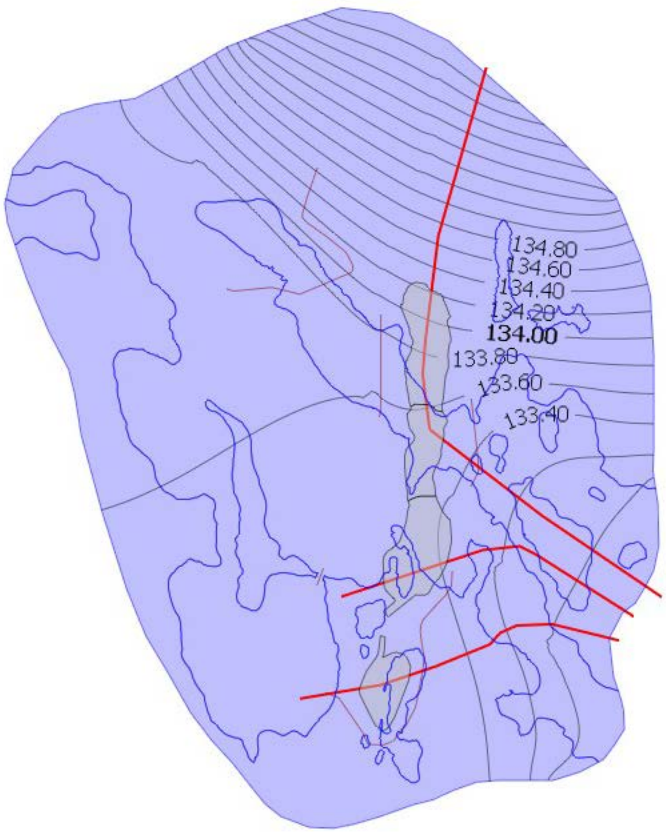
Slice 44 (-500 masl)

At t = 400y, chloride plumes have not reached the sub-permafrost layers of the model

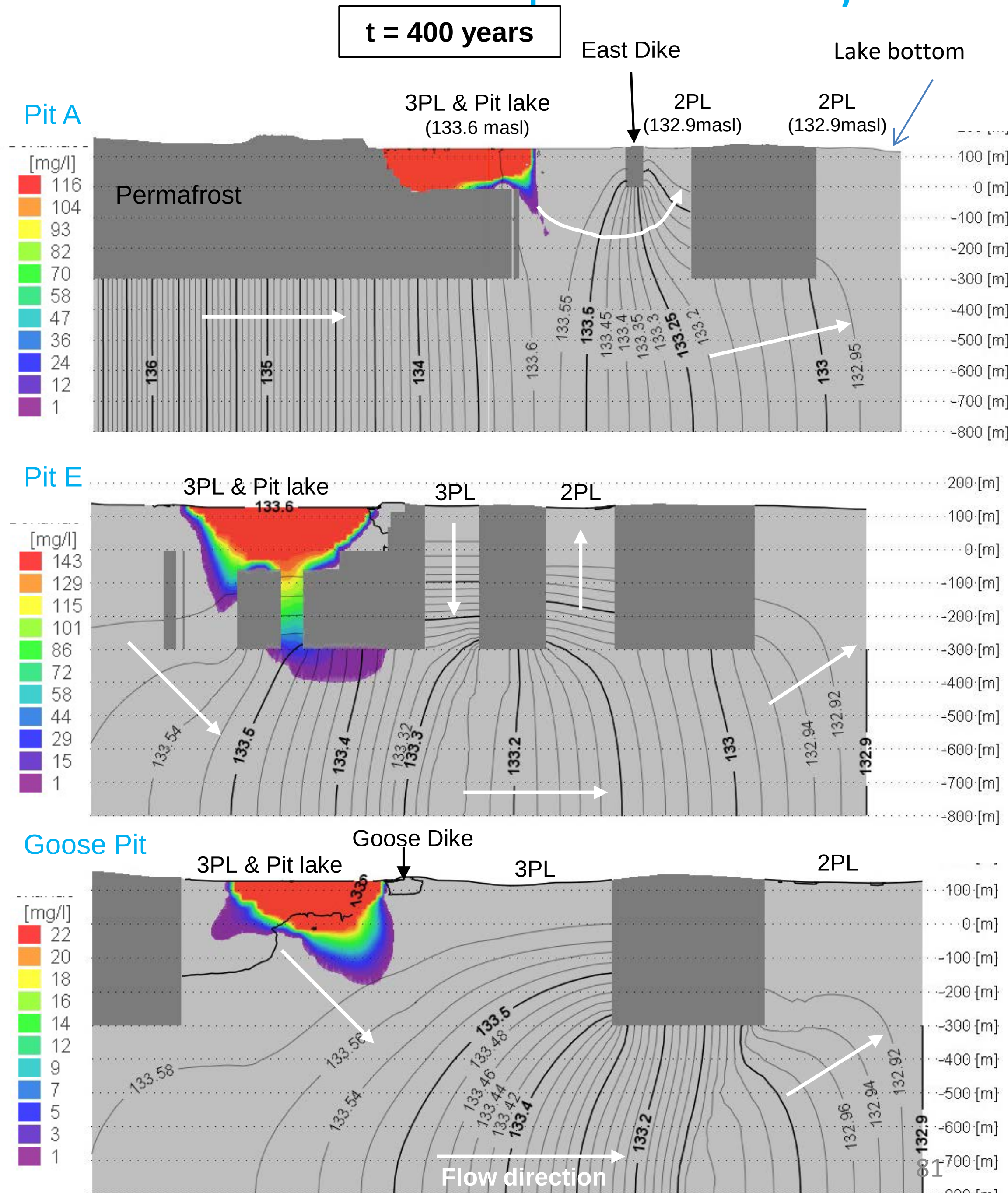
II. Contaminant Transport Results - Post closure Step 1 : 0 to 400 years

Chloride concentration

Slice 44 (-500 masl)

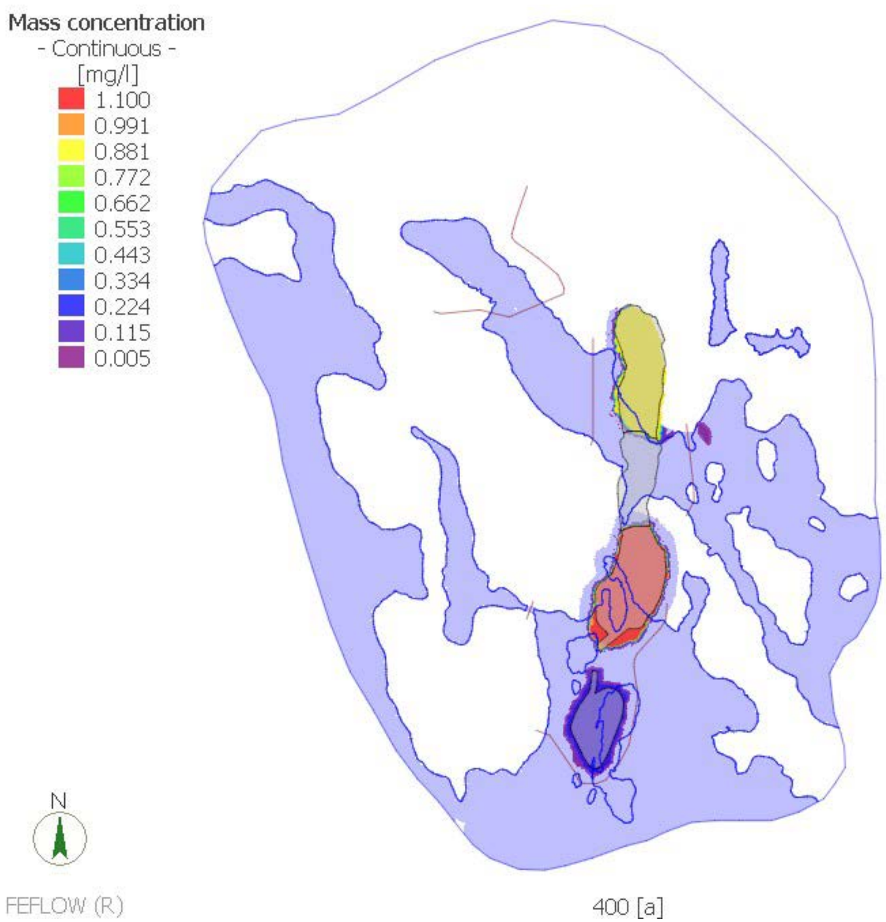


Cross-sections location, determined with sub-permafrost flow lines

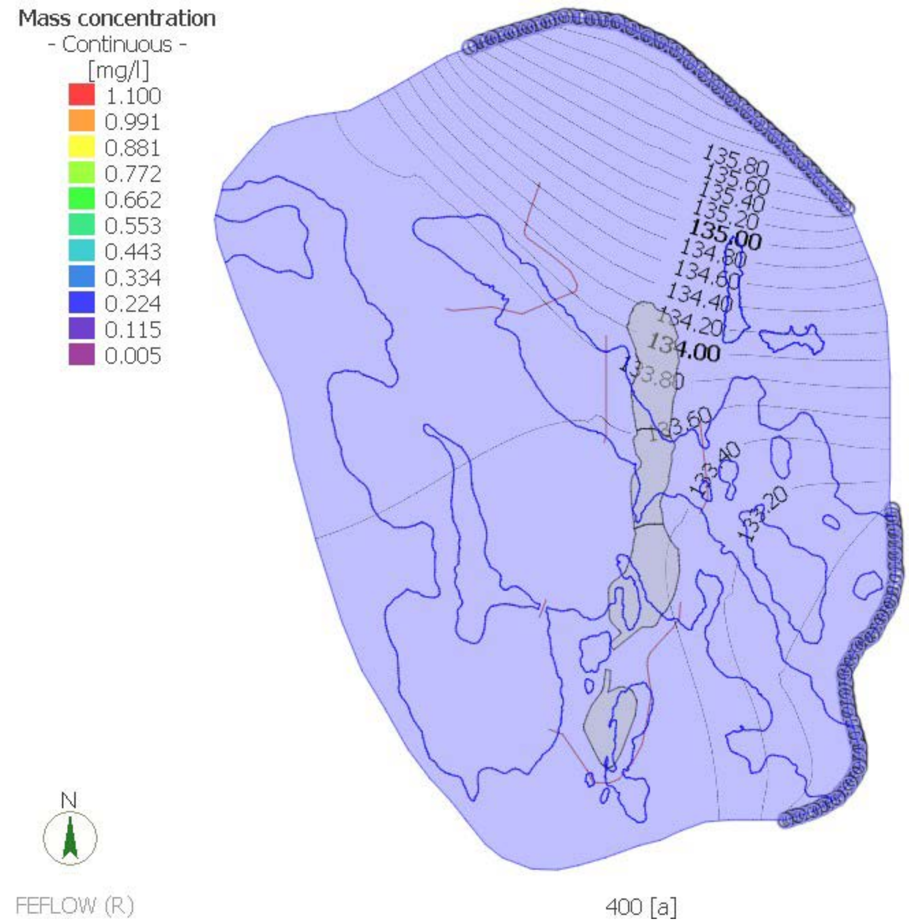


II. Contaminant Transport Results - Post closure Step 1 : 0 to 400 years

Arsenic concentration & Simulated head maps, at t = 400 y



Slice 6 (120 masl)

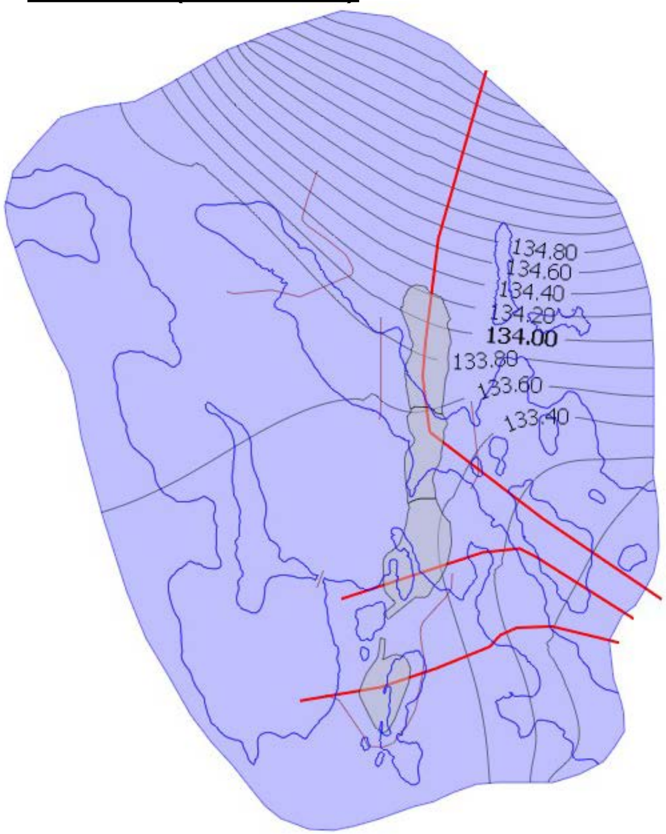


Slice 44 (-500 masl)

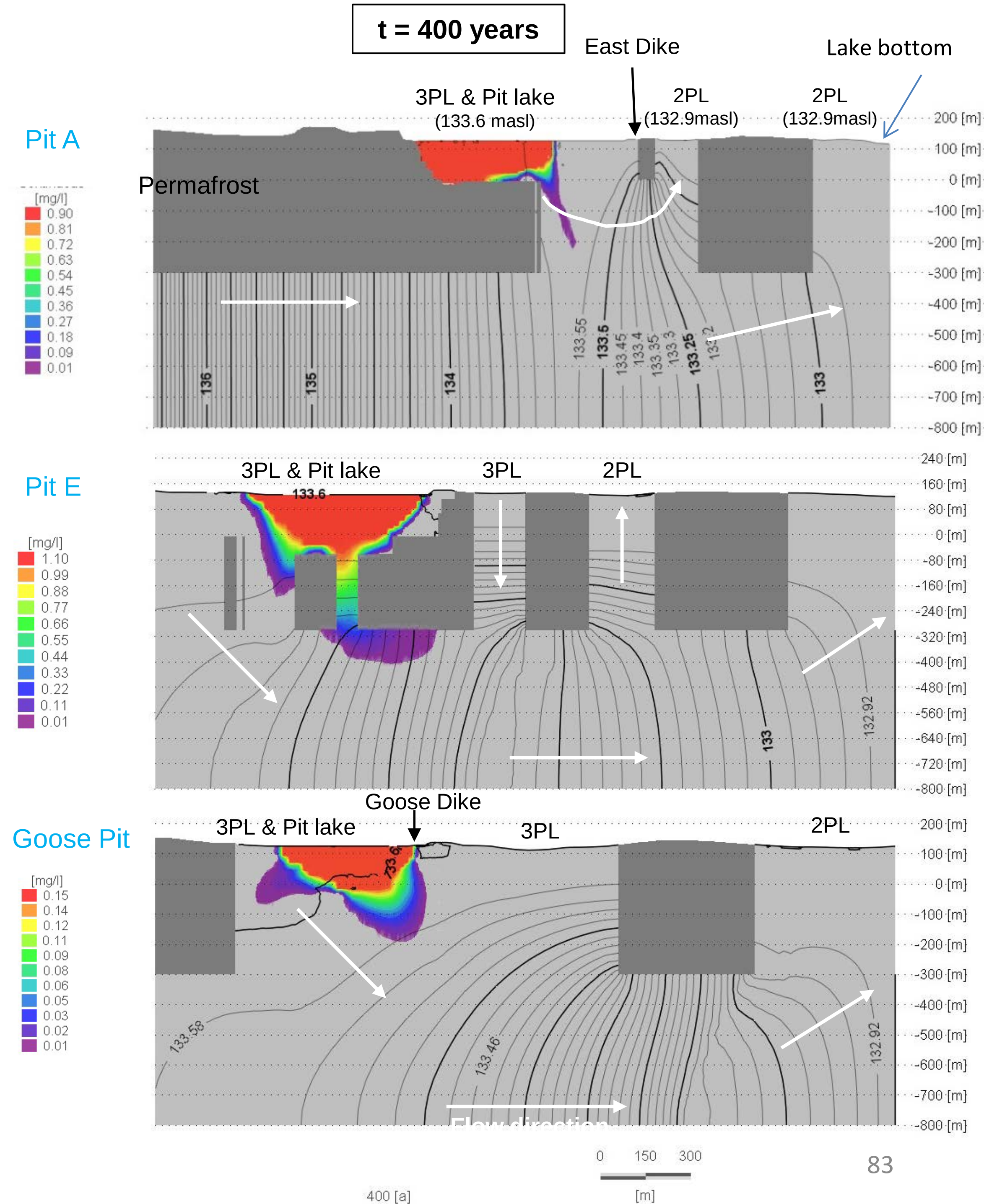
At t = 400y, arsenic plumes have not reached the sub-permafrost layers of the model

Arsenic concentration

Slice 44 (-500 masl)



Cross-sections location, determined with sub-permafrost flow lines



III. Contaminant Transport Results – Post Closure

Step 2 : 400 to 20,000 years

III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

Assumptions: Post-closure, all pits filled with tailings and flooded

Same assumptions as for Step 1, e.g.:

- Goose waste dump material is considered ($1x10^{-3}$ m/s)
- Tailings elevation = 125.6 masl (based on detail engineering, max capacity)
- Pits water elevation = 133.6 masl (3PL water level)
- North and South cells tailings are frozen
- No pumping activity at Central Dike
- Chloride concentration in pit tailings pore water remain the same as for period 1 (constant source) and are based on the water quality forecast (pit filled at full capacity and assume no water treatment) :

Pit	Chloride (mg/L)	Arsenic (mg/L)
Pit A	116	0.9
Pit E	141	1.1
Goose Pit	22	0.15

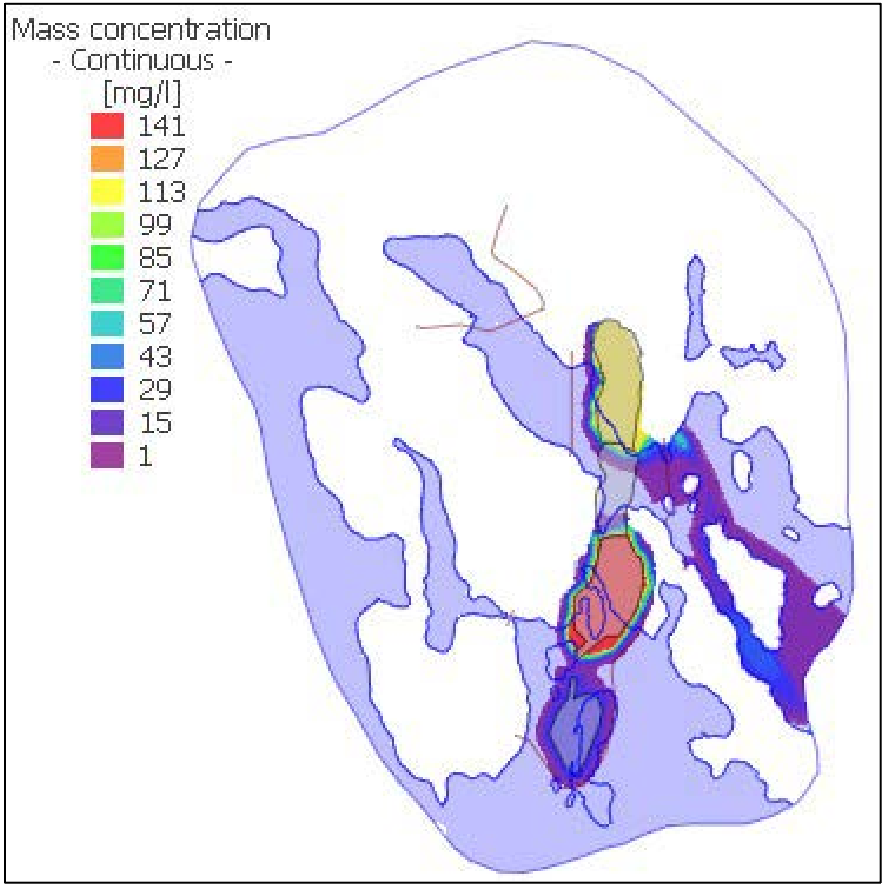
Different assumption from Step 1 is:

- Post closure Step 2 is run from 400 to 20,000 years with the steady-state (maximum) permafrost degradation conditions.

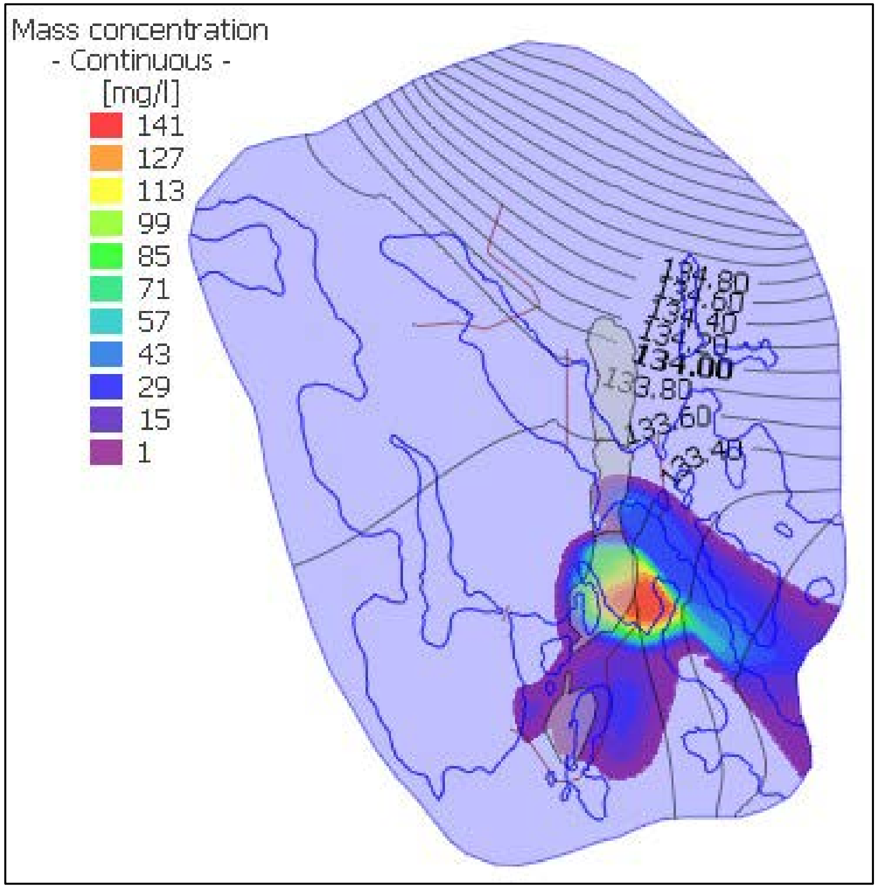
III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

Chloride concentration & Simulated head maps

t = 20,000 years



Slice 6 (120 masl)

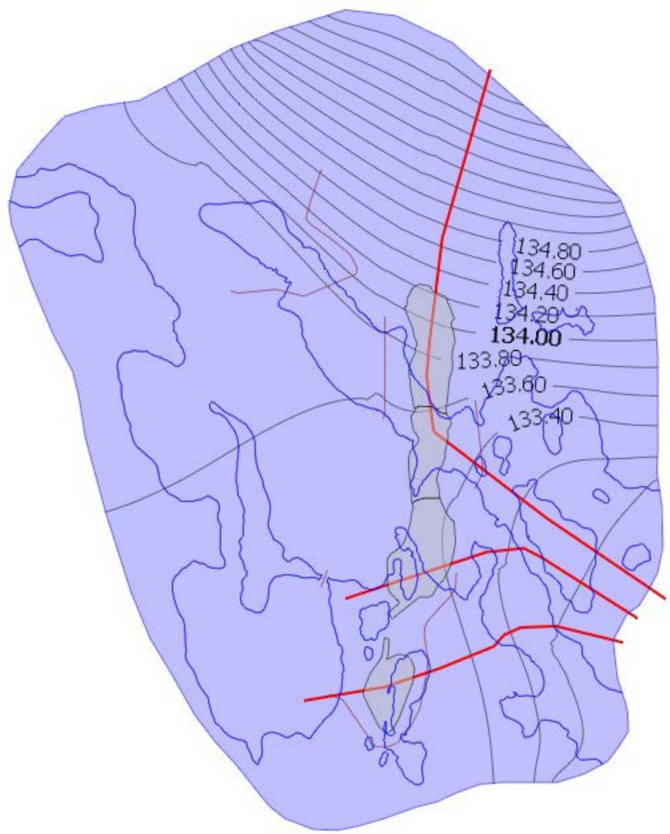


Slice 44 (-500 masl)

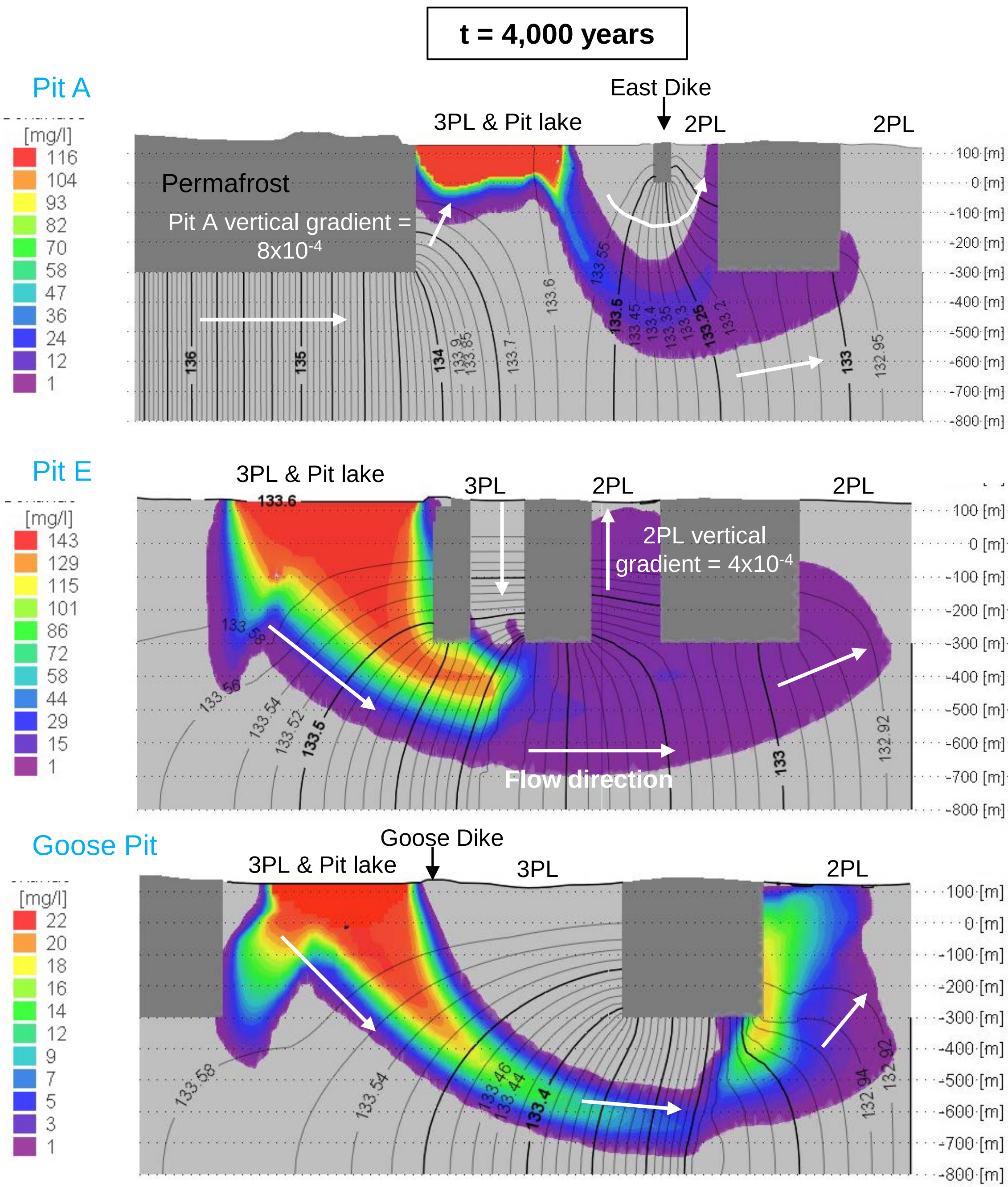
III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

Chloride concentration

Slice 44 (-500 masl)



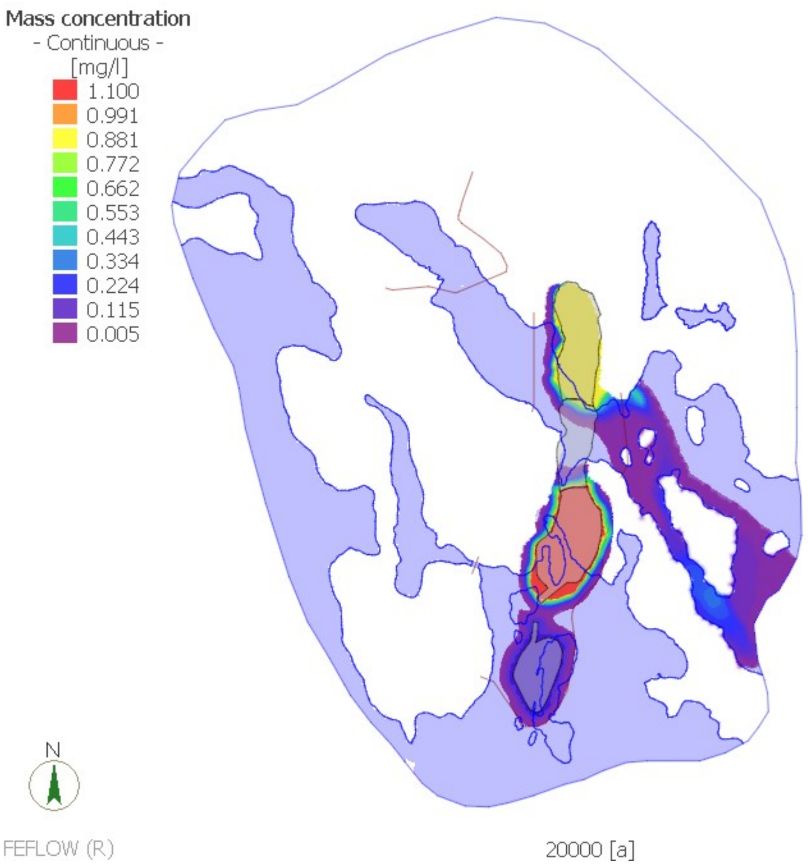
Cross-sections location, determined with sub-permafrost flow lines



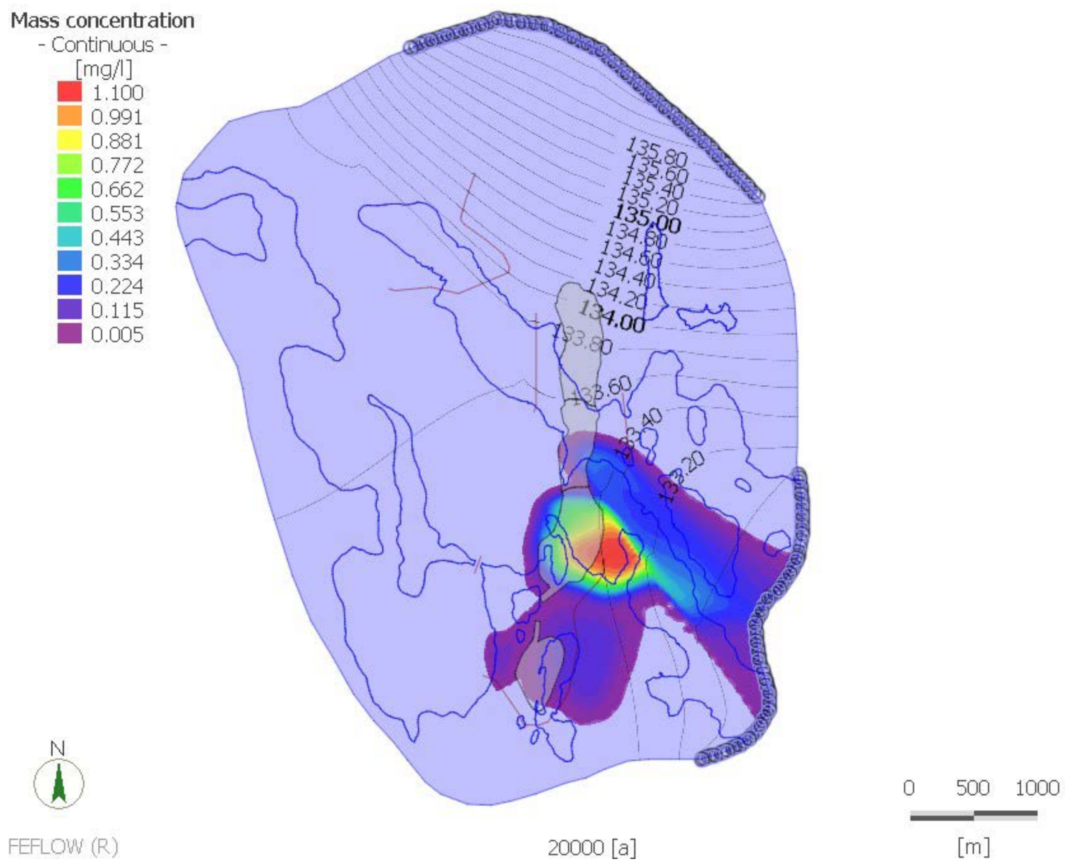
III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

Arsenic concentration & Simulated head maps

t = 20,000 years



Slice 6 (120 masl)

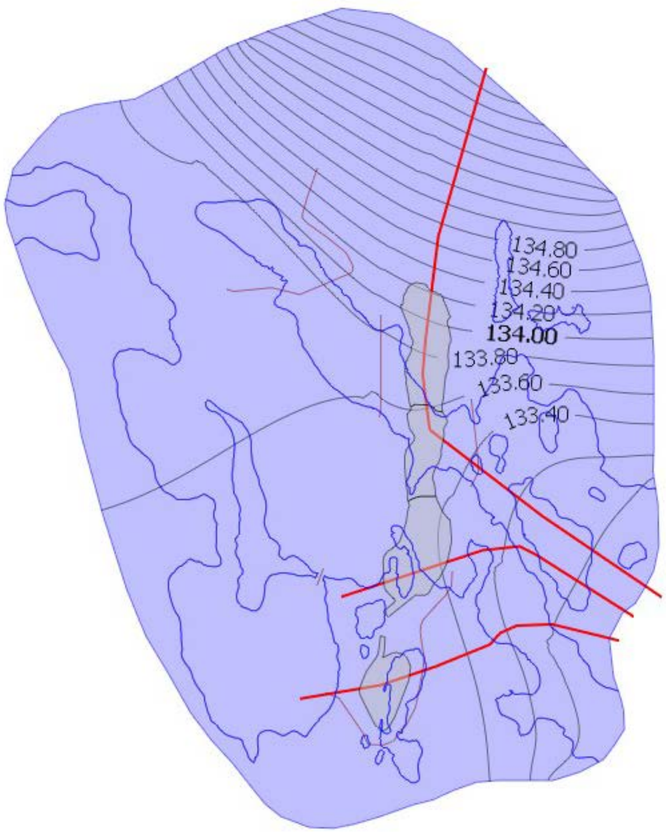


Slice 44 (-500 masl)

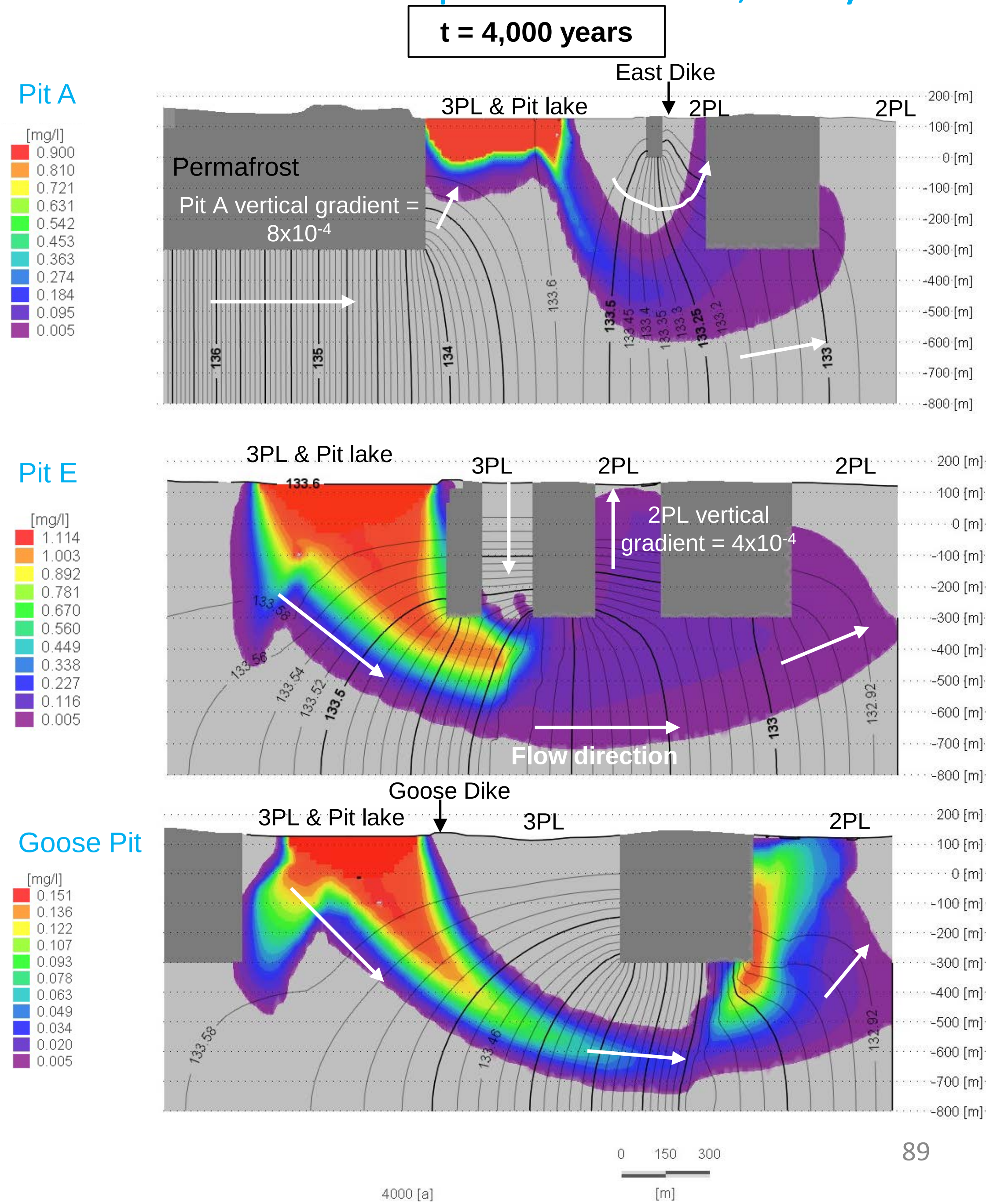
III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

Arsenic concentration

Slice 44 (-500 masl)



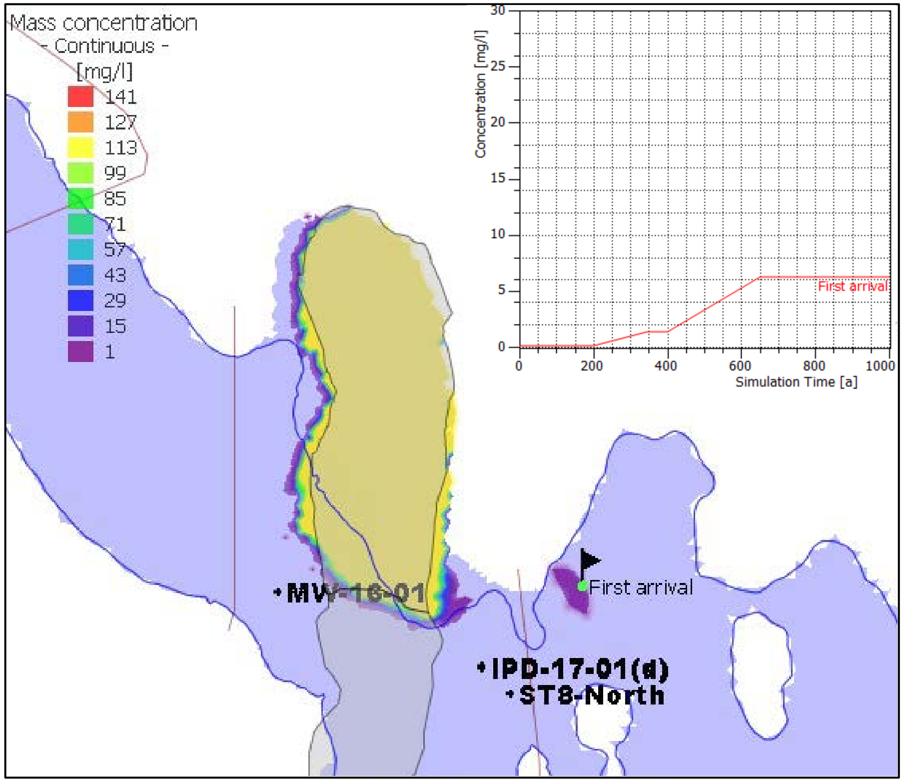
Cross-sections location, determined with sub-permafrost flow lines

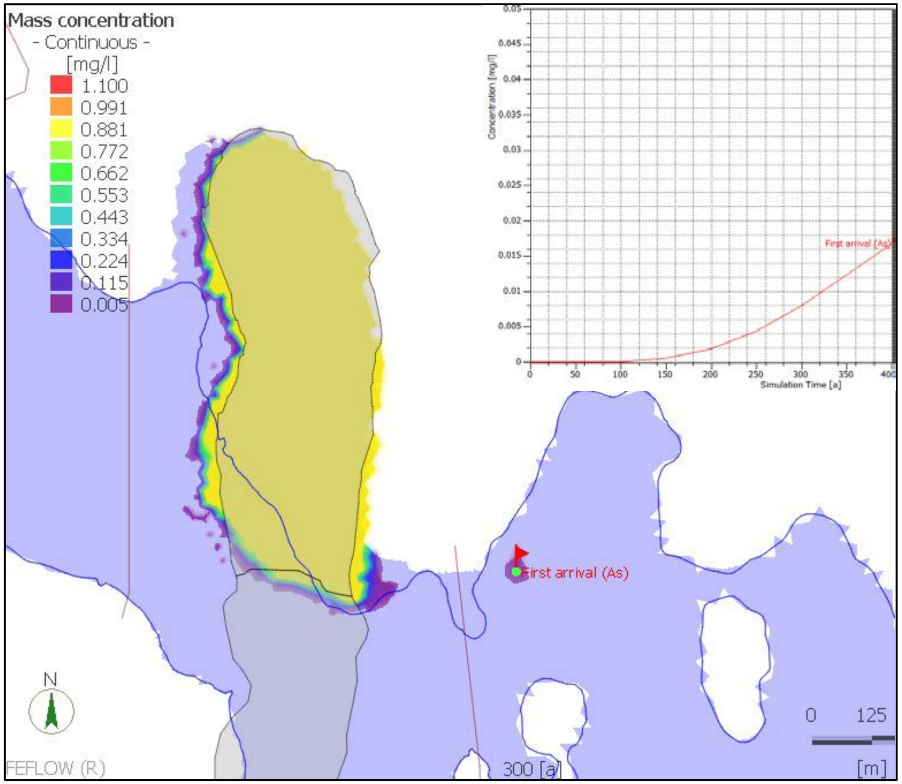


III. Contaminant Transport Results - Post closure Step 2 : 400 to 20,000 years

First arrival of Chloride and Arsenic at Second Portage Lake from Pit A

Parameter	Targeted concentration for the first arrival (mg/L)	Time following deposition (y)
Chloride	2	400
Arsenic	0,005	250





IV. Mass Flux and Concentrations in Pit Lake and Second Portage Lake

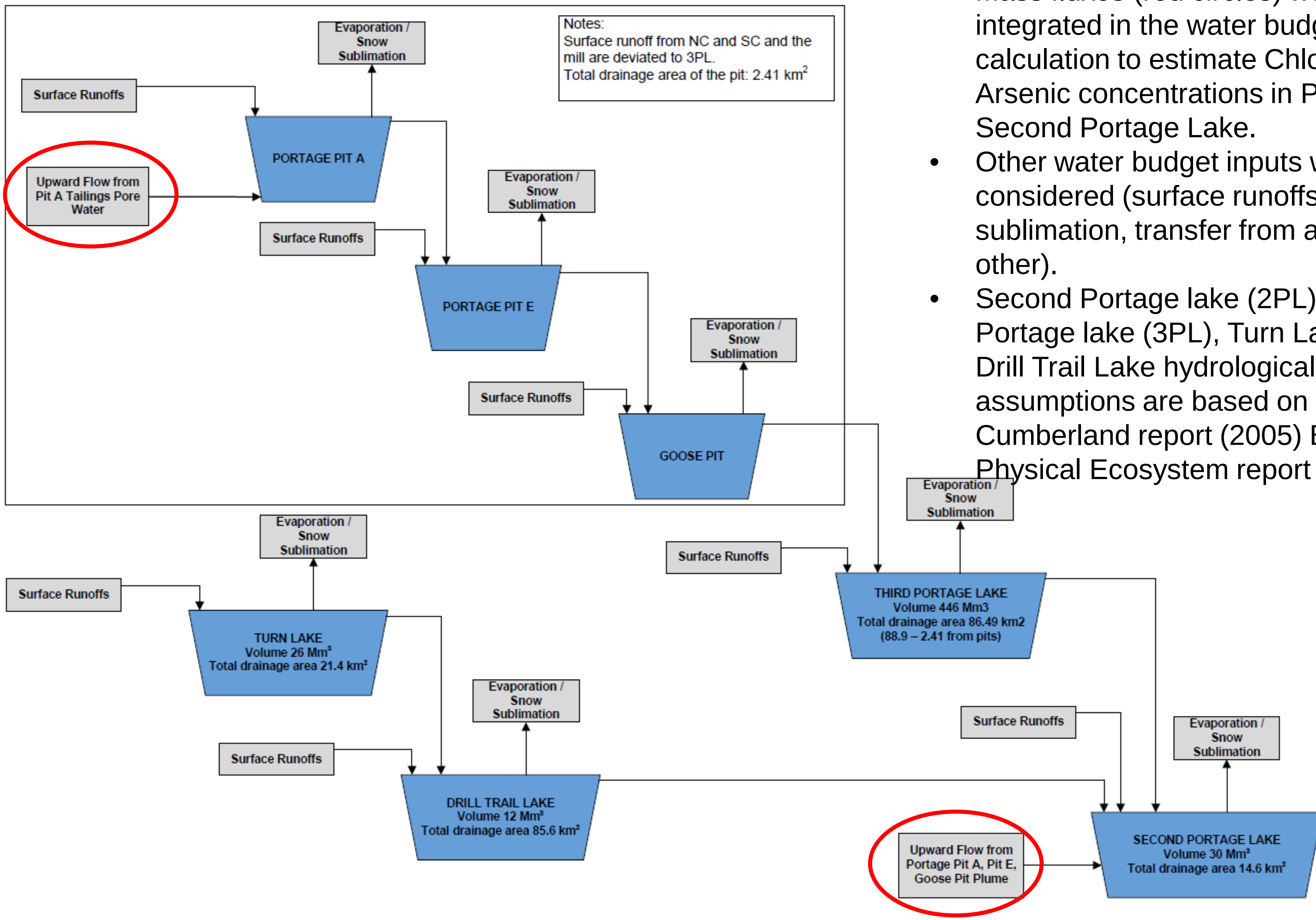
IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

The water budget approach - Assumptions

- Water balance based on average net annual precipitation.
- Initial concentrations in the tailings pore water are based on water quality forecast evaluated in detail engineering (Version 2) and are based on the water quality forecast (pit filled at full capacity and assume no water treatment)
- The concentration of Cl and As in the runoff water is assumed to be similar to the concentration measured in Third Portage Lake.
- Model assume that the water cover within Portage and Goose pits is treated prior to reconnection to Third Portage Lake.
- Initial concentration of the water cover is considered equal to CCME guideline and was used for the long term forecasted concentrations
- Surface runoff from the mill and North and South Cell TSF are directed toward Third Portage Lake.
- Catchment area, basin volumes and water management approach are per the following block diagram.

IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

The water budget approach – from modeled fluxes to concentration in lakes



- Mass fluxes (red circles) were integrated in the water budget calculation to estimate Chloride and Arsenic concentrations in Pit lakes and Second Portage Lake.
- Other water budget inputs were considered (surface runoffs, EVT, sublimation, transfer from a lake to the other).
- Second Portage lake (2PL), Third Portage lake (3PL), Turn Lake and Drill Trail Lake hydrological assumptions are based on Cumberland report (2005) Baseline Physical Ecosystem report

IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

Groundwater sources of contaminant in Pit lakes (Third Portage Lake)

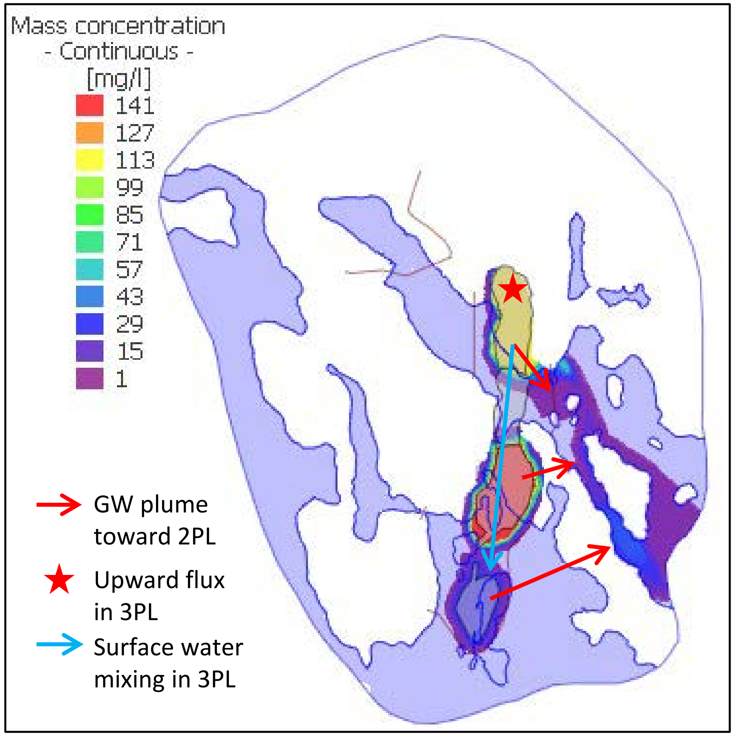
- Upward advective mass transport from Pit A tailings pore water
- Diffusion mass transport from Pit A, Pit E and Goose Pit tailings pore water to overlying pit lake (considered low)

Groundwater sources of contaminant in Second Portage Lake

- Groundwater plume from Pit A
- Groundwater plume from Pit E
- Groundwater plume from Goose Pit

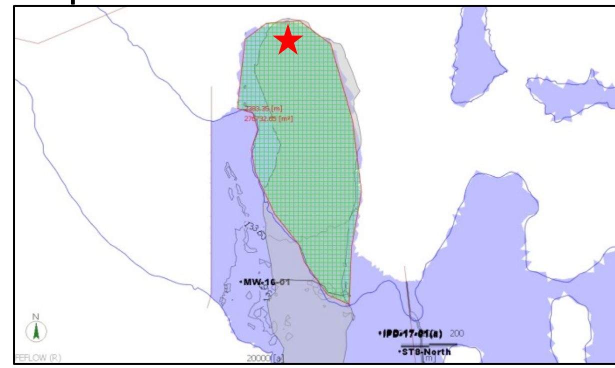
Surface water sources of contaminant

- Loads of chloride and arsenic from surface water runoffs are considered non significant.



IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

Extracted mass fluxes from the Version 4 contaminant transport simulations



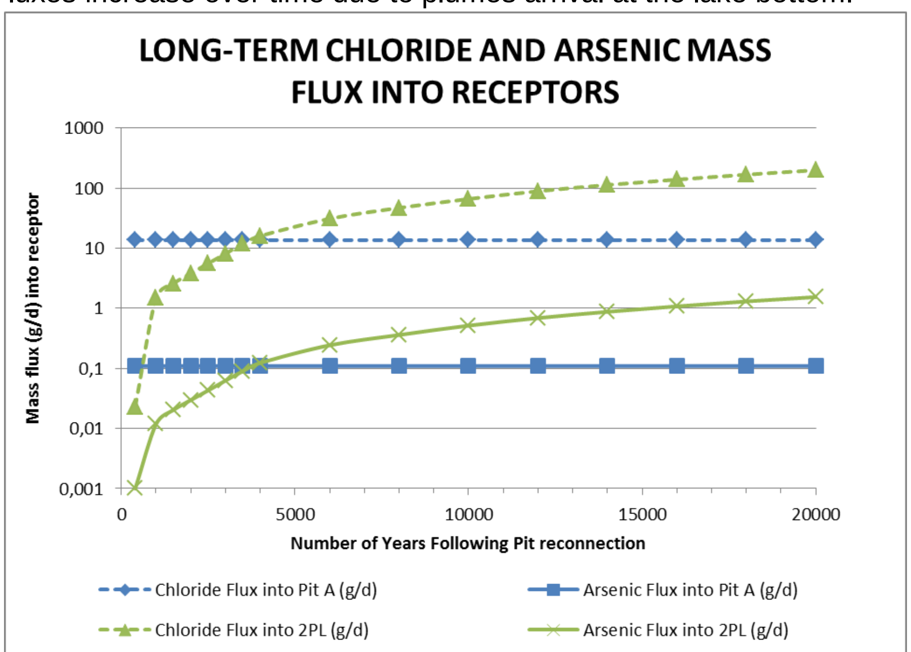
- Arsenic flux is very conservative since attenuation processes are not considered and that arsenic is considered fully mobile in groundwater. It will preferably adsorb on tailings material.
- Contaminant source is considered constant over time (worst case).

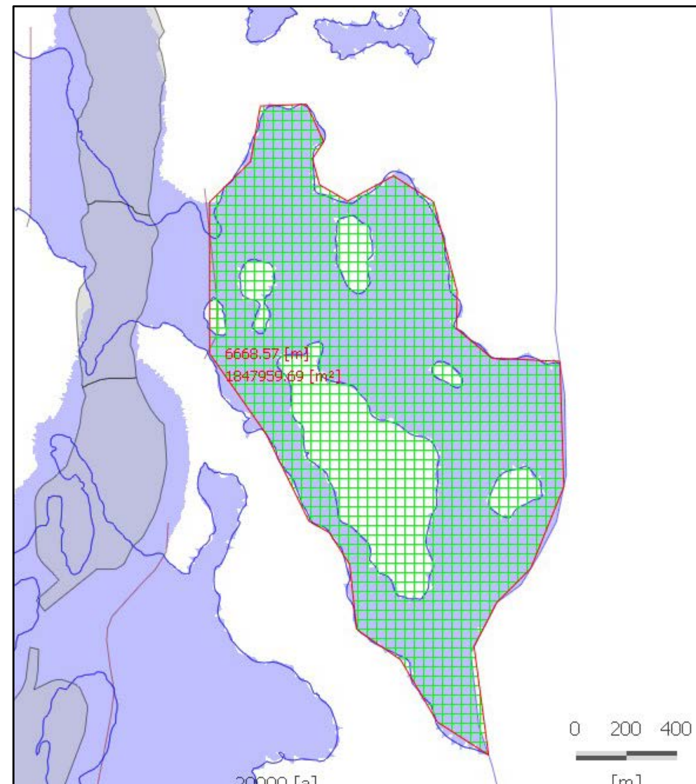
Pit A (blue curves):

- Cl and As mass fluxes (g/day/m²) were extracted in the northern portion of Pit A (red star), where upward vertical hydraulic gradient is at maximum.
- These fluxes were applied to the entire Pit A lake surface (worst case) since there is no longer upward flux in the southern part.
- Upward mass fluxes will occur only after open talik, corresponding to 400 y after deposition.

Second Portage Lake (green curves):

- Cl & As mass fluxes at the bottom of Second Portage Lake were extracted over the entire Second Portage Lake surface.
- Fluxes increase over time due to plumes arrival at the lake bottom.





IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

Comparison of surface water runoff vs groundwater fluxes to Pit A Lake and Second Portage Lake

- Groundwater input (43 m^3/y) to the Pit A lake is low compared to the surface water runoff contribution (89 855 m^3/y), e.g. 0.05%.
- Groundwater input (21,718 m^3/y) to Second Portage Lake is relatively low compared to the surface water runoff (21,8 Mm^3/y), e.g. 0.1%.

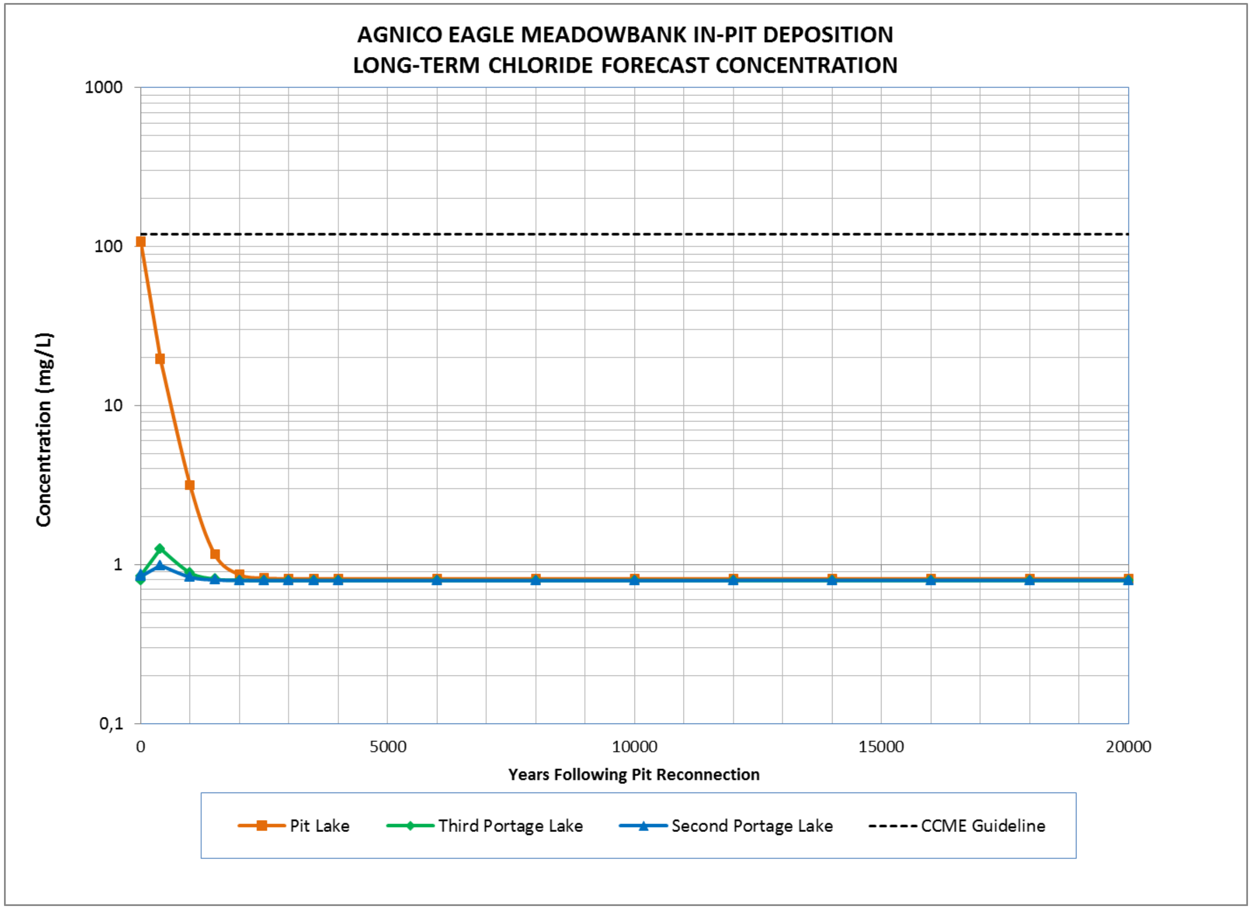
Parameters	Units	Pit A Lake	2PL watershed
Catchment Area	km^2	0,88	213
Lake Volume	m^3	9 309 579	556 394 737
Avg Annual runoff	m^3/yr	89 855	21 822 970
Groundwater seepage to the lake, extracted from the hydrogeological model	m^3/yr	43	21 718
Ratio GW / Runoff	%	0,05%	0,1%

- Surface water initial background concentrations slightly varies from a lake to the other:
  - Chloride (0.79 to 0.87 mg/L);
  - Arsenic (0.0003 to 0.001 mg/L).
- Water cover initial concentrations are:
  - Chloride (Pit A = 114 mg/L; Pit E = 120 mg/L; Goose Pit = 54 mg/L);
  - Arsenic (all pit lakes = 0.005 mg/L), as per water treatment objective before lake reconnection.

IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

*Long term **Chloride** forecast concentration in Pit Lake and Second Portage Lake*

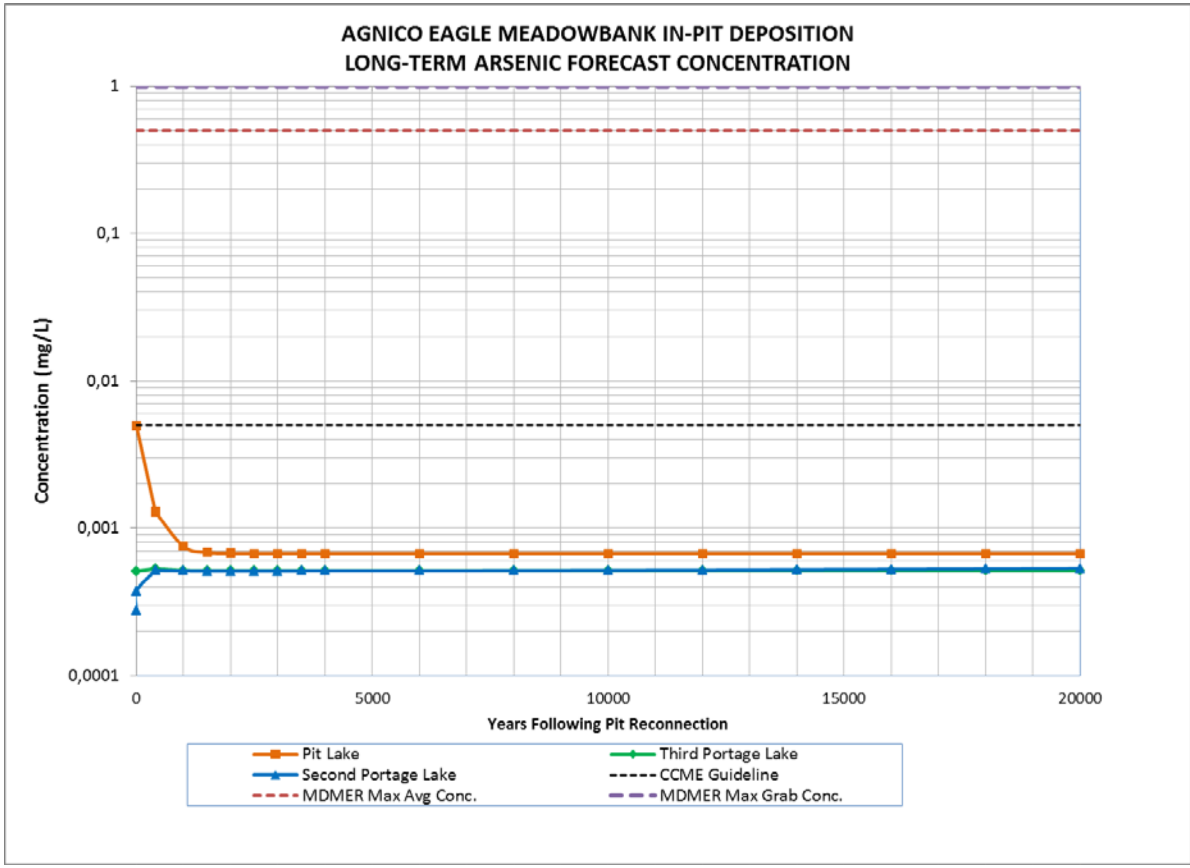
- In Pit A lake, chloride concentration will decrease over time, even with a release of chloride from Pit A tailings pore water
- In Second Portage Lake, chloride concentration stays under CCME guideline, even if the model suggest chloride seepages appearing at 400 years following in-pit deposition.
- Not significant impacts on fresh water are expected, based on the water quality forecast.
- Small concentration peaks observed at 400y is due to the transfer of Chloride loads from the water cover to the surrounding 3PL and 2PL after lake reconnection.



IV. Mass flux and Concentrations in Pit Lake and Second Portage Lake

Long term ***Arsenic*** *forecast concentration in Pit A Lake and Second Portage Lake*

- Arsenic treatment is considered in the forecast to reduce As concentration of Pit lakes at the CCME guideline level (treatment is already planned before lake reconnection to Third Portage Lake in order to meet quality objectives as per License conditions).
- Upward Arsenic flux from tailings pore water is considered as fully mobile (no adsorption, no chemical attenuation), which is a conservative assumption. Arsenic will preferably adsorb to tailings particles
- Small increase in concentration observed at 400yr is due to the transfer of Arsenic loads from the water cover to the surrounding 3PL and 2PL after lake reconnection.
- Long term Arsenic concentrations remains below CCME guideline even with the updward mass flux from Pit A and the groundwater plumes seeping into Second Portage Lake.

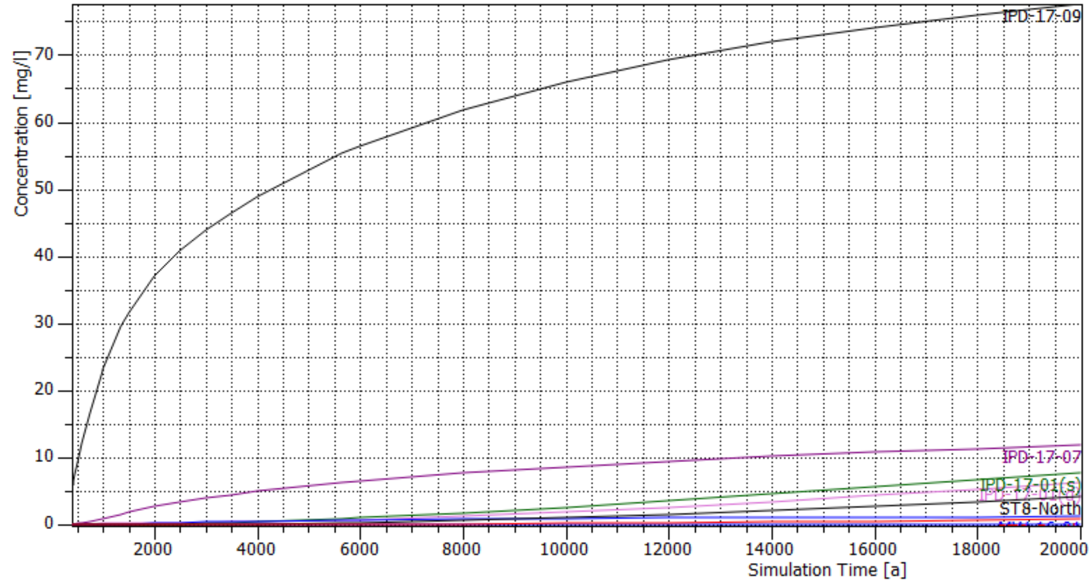


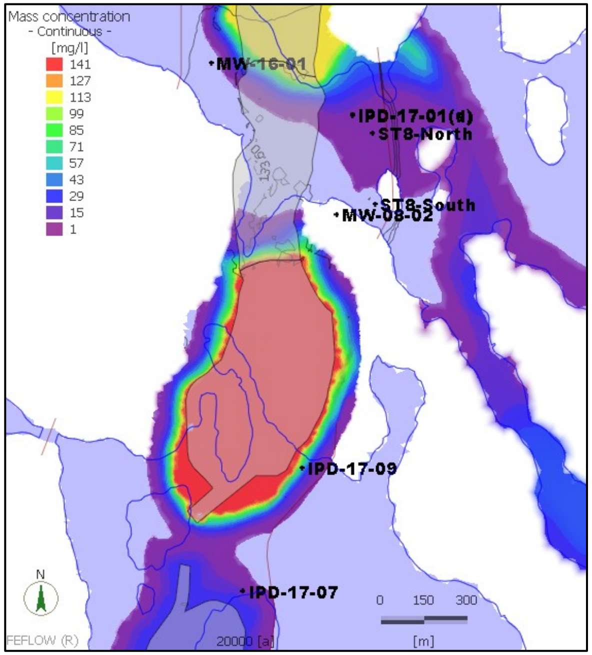
V. Groundwater Monitoring Network

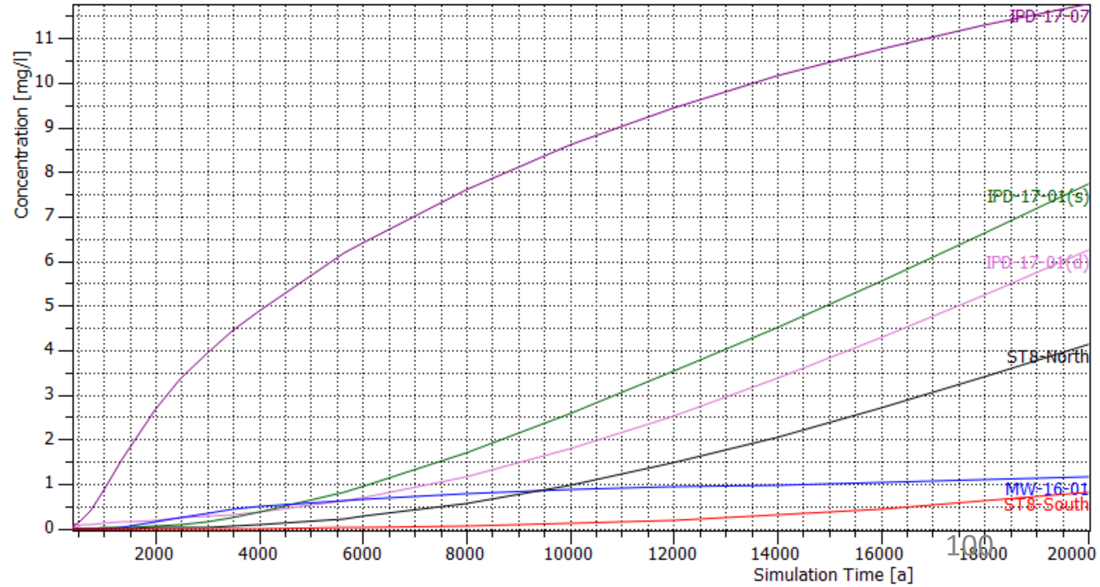
V. Groundwater Monitoring Network

Breakthrough Chloride concentrations at existing Monitoring wells

- All 4 new installed MW intercept contaminant plume from Pit A, Pit E and Goose Pit.
- Maximum concentration are observed at IPD-17-09, with [Cl] < 80 mg/L at 20,000y
- Concentrations at the other MW stay below 10 mg/L
- Existing MW network will be use for model calibration at closure.
- These new stations (IPD) are composed of a groundwater well and a thermistor.







V. Groundwater Monitoring Network

Existing Monitoring Wells and simulated Chloride concentrations

GW monitoring well	Location	X	Y	Ground Elevation (masl)	Screen depth interval (m BGS)	Screen Elevation interval (masl)	Mid-screen Elevation (masl)	Interception Date of 1mg/L (Model Version4)	Conc. of chloride at t = 6000 y (mg/L)
IPD-17-01(d)	East flat	639240.0	7214245.0	130.095	162,45 to 181,43	-32,36 to -51,34	-41.85	7,000	0.3
IPD-17-01(s)	East flat	639240.3	7214249.9	130.090	50,84 to 69,82	79,25 to 60,27	69.76	6,000	1.0
IPD-17-07	Goose Pit	638859.6	7212597.2	133.434	41,24 to 50,75	92,19 to 82,69	87.44	1,000	6.5
IPD-17-09	Pit E	639065.2	7213024.5	133.215	61,86 to 81,84	71,36 to 52,38	61.87	0	57
MW-08-02	East flat	639185.9	7213901.3	137.500	184 to 191	-46,5 to -53,5	-50	n/a	n/a
MW-16-01	Central Dike	638750.9	7214427.3	119.910	88,81 to 101,02	31,10 to 18,89	25	12,000	0.6
ST8-North	East flat	639309.4	7214183.4	131.000	6	125	125	9,500	0.3
ST8-South	East flat	639318.5	7213938.3	131.000	6	125	125	>20,000	0.1

V. Groundwater Monitoring Network

Proposed MW location prior closure, based on Model version 4

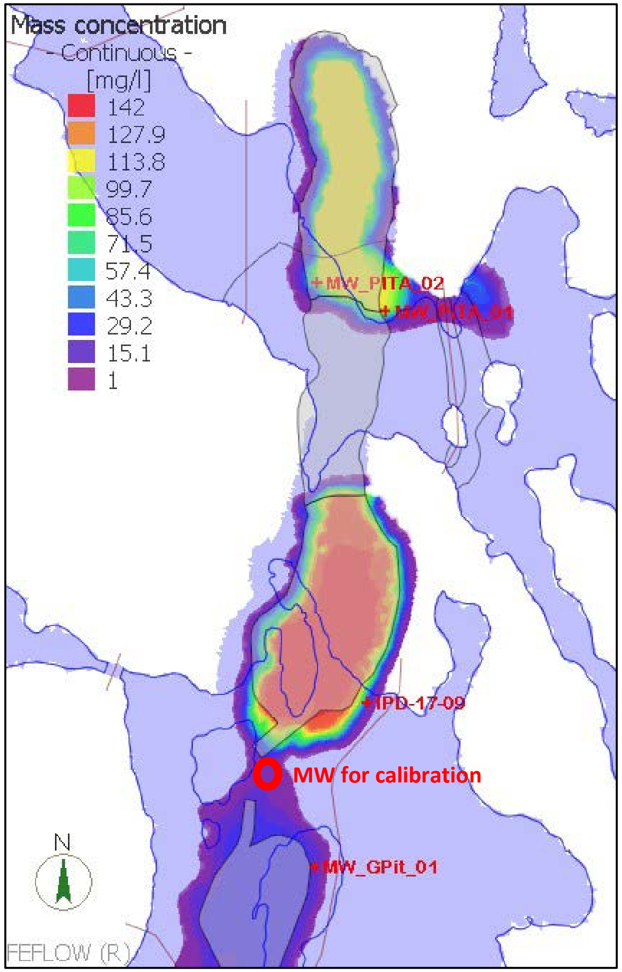
- The following monitoring stations are proposed to be installed to provide information on the thermal, hydraulic and geochemical conditions during in-pit tailings deposition, closure and post-closure periods. These stations are composed of a groundwater well and a thermistor.

GW monitoring well	Location	X	Y	Ground Elevation (masl)	Screen Elevation interval (masl)
IPD-17-09	Pit E	639065.2	7213024.5	133.215	71,36 to 52,38
MW_PitA_01	Pit A	639129	7214383	125.8	from 52 to top
MW_PitA_02	Pit A	638891	7214480	121.6	from 60 to top
MW_GPit_01	Goose Pit	638883	7212456	125.8	From -200 to top

For Goose Pit, the proposed well is in an actual permafrost area but it could be installed at closure after permafrost degradation.

Some existing frozen MW could be reactivated with thawing effects, but their integrity would have to be verified.

All monitoring requirement for closure and post-closure should be reassess with hydrogeological model recalibrated with operation data.

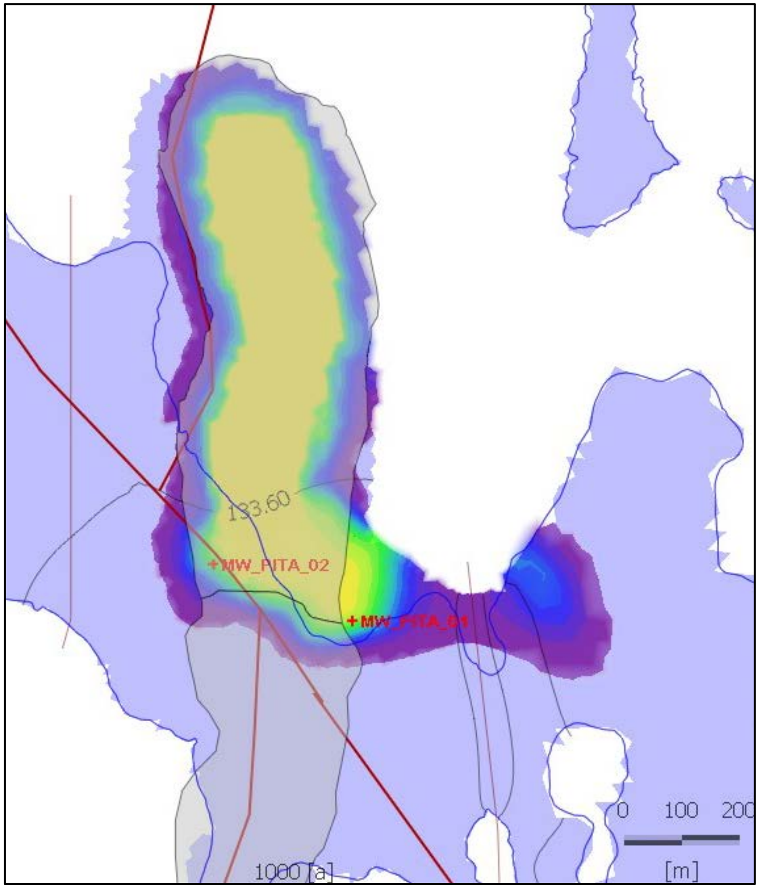


Slice 21 (40 masl)

V. Groundwater Monitoring Network

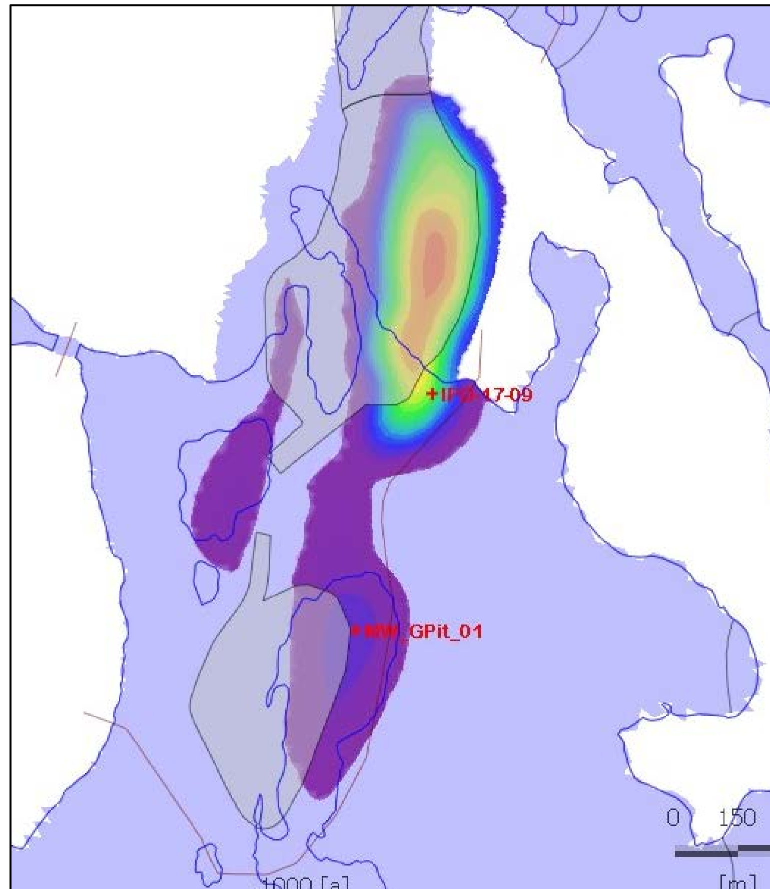
Close-up look on the proposed MW screen elevation to be installed after depostion

Pit A



Slice 21 (40 masl)

Pit E and Goose Pit



Slice 38 (-200 masl)

Conclusions

VI. Conclusions

NRCan's requests from Sept.25 meeting were addressed, as per agreement:

<u>Thermal modelling & Permafrost limit</u>

- Thawed areas were incorporated to the hydrogeological model in 2 time steps:
  - Step 1: 0 to 400 years at which an open talik occurs initially at Pit A (cross-section A1)
  - Step 2: 400 to 20,000 years (steady state permafrost thawing condition).
- Thawing the permafrost under Pit A leads to the formation of a upward vertical gradient, which is higher at the northern end of Pit A. However, the southern end of Pit A is still showing a general downward flow path. Increasing the boundary hydraulic heads at the northern limit of the model is partially responsible.

VI. Conclusions

Hydraulic boundary conditions (BC):

- No change of BCs of version 3 upper layers were required.
- Sub-permafrost BCs has been reassigned to the hydrogeological model, with agreement of NRCan, specifically:
  - A to E: No flow, with E moved closer to F at the piezometric line
  - E to G: fixed head of 132.2 masl
  - H to K: higher hydraulic heads, varying from 135,6 to 136,6 masl
  - All other limits were kept as No flow BC
- Sub-permafrost GW flow fits better with Golder's regional piezometric map
- Changing E-G limits has slightly shifted the GW flow paths to East direction.
- Changing the northern BC (H-K) lead to higher hydraulic head in the sub-permafrost layers and is partially responsible for upward flow below Pit A along with permafrost thawing and open talik formation as per thermal modelling results.

VI. Conclusions

<u>Contaminant transport simulations results:</u>

- General contaminant transport paths are quite similar compared to previous model (version 3).
- Thawing the permafrost around Pit E and Goose Pit seems to have insignificant impact on plumes migration paths. Pit E and Goose Pit still show downward flows, buried under Third Portage Lake and will discharge in Second Portage Lake with similar concentrations to reported in the previous model. Upward mass transfer to pit lakes will be limited to diffusion process for Pit E and Goose Pit.
- Modeling results suggest that contaminant plume from Pit E is not migrating towards the Central Dump, even though the talik exists between both entities.
- First arrival of chloride comes from Pit A and discharges to the Second Portage Lake but occurs sooner (after 400 years) than simulated with Model version 3 (2,000 years). This mainly due to the increase in boundary hydraulic heads of the sub-permafrost at the northern limit of the model.
- Higher hydraulic heads at the northern limit of the model along with the open talik below Pit A lead to an upward vertical gradient in the northern part of Pit A. If the maximum chloride upward flux at the northern part of Pit A is applied to Pit A lake area, Chloride and Arsenic mass fluxes into the overlying Pit A lake (and Third Portage Lake), will be 14 and 0.11 g/day, respectively.
- Chloride and Arsenic mass fluxes increase over time due to Pit A, Pit E and Goose Pit plume migration towards the Second Portage Lake. Mass fluxes in the 20,000 year period stays below 200 g/day of chloride and 1.5 g/day of arsenic.
- Arsenic fluxes are conservative since no attenuation or adsorption (fully mobile in groundwater) were considered. Arsenic treatment of the water cover is planned before pit lake reconnection to Third Portage Lake.
- Based on the Water Budget approach and the hydrogeological model, the groundwater seepage volume in Pit A (43 m^3/y) and in Second Portage Lake (21,718 m^3/y) are low compared to fresh water runoff input in these lakes (0.9 Mm^3/y for Pit A and 21.8 Mm^3/y for Second Portage Lake watershed).
- Based on the Water Budget approach and the simulated mass fluxes from the hydrogeological model, forecasted chloride and arsenic concentrations in both Second and Third Portage Lake do not show significant impacts on fresh water as they remains below CCME guidelines.

VI. Conclusions

<u>Groundwater Monitoring network</u>

- The current monitoring well network was designed for establishing baseline conditions and monitoring during operational phase but breakthrough curve analysis reveals that the current monitoring well network can also be used for long term monitoring (closure & post-closure).
- Current monitoring well network is capable of intercepting the plumes from Pit A, Pit E and Goose Pit.
- AEM already committed to implement tailings pore water quality, which are important to define contaminant source concentration and evolution with depths. Pit lake water quality will also be monitored, with emphasis to Pit A Lake, which will show upward flow once an talik will open. As per the water licence requirement, a final monitoring plan is required for closure and the contaminant transport model will be recalibrated based on data collected during operations. At that time, additional GW monitoring systems, if required, could be installed 1 or 2 years before closure.
- The monitoring wells network will be used to confirm contaminant transport model prediction in operation and closure. Calibration on transport parameters will be assessed at that time.

The End