AREVA

Kiggavik Project

Environmental Impact Statement

Tier 3 Technical Appendix 5E

Prediction of Water Inflows to Kiggavik Project Mines

December 2011

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this appendix is to predict the flux of groundwater and surface water entering the pits and the underground development as they are progressively developed. This document provides an assessment of:

- dewatering conditions during open pit mining at the Kiggavik, and Andrew Lake uranium deposits;
- dewatering conditions during underground mining at the End Grid uranium deposits; and
- water balance during open pit mining.

The water inflows issue is related to water management at the mine site.

1.2 SCOPE

The numerical model used to predict water inflows to the Kiggavik Project mines encompasses the local study area for hydrogeology. This model is approximately 30 km wide. Each proposed mining area (Kiggavik and Sissons) is approximately 8 km from the external model boundaries, and 10 km from the northern part of Judge Sissons Lake.

The following tasks were completed for this study:

- Review of available information necessary for development of a conceptual model of the dewatering conditions;
- Development of a numerical flow model;
- Predictive simulations for inflow to mine pit and underground workings; and
- Development of a water balance for the Kiggavik Project open pits considering both hydrological and hydrogeological components.

This model uses the current conditions of permafrost.

The regional model used to simulate water inflows is described in Appendix 5D (Groundwater Flow Model) and is based on baseline information presented in Appendix 5B (Geology and Hydrogeology Baseline).

2 TRANSIENT MODELLING OF MINING CONDITIONS

2.1 BACKGROUND

The objective of the transient model was to simulate progressive mining of the open pit and underground workings below the permafrost zone.

The proposed Kiggavik mine site will include three open pits; Main Zone, Centre Zone and East Zone. It is also proposed to develop a purpose built-pit (PBP) to provide aggregate material and for water management purposes. The Main Zone open pit will be 235 m deep, approximately. Centre Zone and East Zone are expected to reach a final depth of 100 m below ground surface (m-bgs), approximately, while the PBP will be about 30 m deep.

The proposed Sissons mine site will include one open pit at Andrew Lake and one underground mine at End Grid. The Andrew Lake open pit is expected to be 275 deep while the End Grid underground mine is planned to extend to approximately 420 m-bgs.

The permafrost in the Kiggavik and Sissons areas extends to 220 m-bgs and 240 m-bgs, respectively (see Technical Appendix 5B “Geology and Hydrogeology Baseline”). Therefore only Main Zone open pit, Andrew Lake open pit and the End Grid underground mine will extend in the unfrozen sub-permafrost formation. For these three mines the excavations will act as a sink for groundwater flow, with groundwater flowing through the bedrock to the mine opening once the mine has advanced below the bottom of the permafrost.

Groundwater interaction with Centre Zone, East Zone and the PBP is expected to be negligible as pit excavation will be entirely within permafrost. Some water inflows might be encountered from the interception of saline pockets. However these potential inflows are not considered to be significant with respect to volumes encountered. Therefore Centre Zone, East Zone and the PBP have not been included in the numerical model.

2.2 NUMERICAL MODEL

A numerical solution of the mining model was developed in three dimensional finite element using FEFLOW v6.0 (WASY 2010). Differences between the regional pre-mining model (see Technical Appendix 5D “Groundwater Flow Model”) and the mining model are as follows:

- Transient flow conditions applied in the model;

- At initial time, the initial conditions correspond to the pre-mining steady state solution;
- Discretization of the model was increased to account for the contour of the mines.

The domain of the mining model is identical to the pre-mining model. The model domain is approximately 30 km wide and covers an area of 740 km^2. Each proposed mining site is at a minimum distance of 8 km from external boundaries.

The model mesh consists of 465,276 mesh elements. The mesh geometry is illustrated in Figure 2.2-1. The model includes 12 layers in total which are detailed in Table 2.2-1. Cross-sections through the proposed Kiggavik and Sissons mines are included in Figure 2.2-2 and Figure 2.2-3. These figures illustrate the model layout and the mine envelopes used in the model.

Table 2.2-1 Layer Surfaces In Transient Mining Model

<table>
<tr><th>Units in Taliks</th><th>Units Outside of Taliks</th><th>Layer #</th><th>Slice #</th><th>Description</th></tr>
<tr><td rowspan="8">Fractured rock</td><td rowspan="5">Permafrost</td><td></td><td>--- 1 ---</td><td>Ground elevation</td></tr>
<tr><td>Layer 1/2</td><td></td><td></td></tr>
<tr><td>----------</td><td>--- 3 ---</td><td>Plane surface of constant elevation (End Grid only)
z=-100 mbgl (68 masl) = End Grid Level 1</td></tr>
<tr><td>Layer 3</td><td></td><td></td></tr>
<tr><td>----------</td><td>--- 4 ---</td><td>Base of permafrost (variable elevation)</td></tr>
<tr><td rowspan="3">Fractured rock</td><td>Layer 4</td><td></td><td></td></tr>
<tr><td>----------</td><td>--- 5 ---</td><td>0.5 m below permafrost (buffer layer for abrupt K change)</td></tr>
<tr><td>Layer 5 to 12</td><td>6 to 13</td><td>Plane surfaces of constant elevations
Slice 6, z= 325 mbgl (-157 masl) = End Grid Level 3
Slice 7, z=450 mbgl (-282 masl) = End Grid Level 4
Slice 8 = 568 mbgl (-400 masl)
100 m spacing from slice 9 to slice 13 (z= -900 masl)</td></tr>
</table>

2.3 MODEL BOUNDARIES

Initial Conditions

The hydraulic head distribution calculated under steady-state condition with the pre-mining model was used as initial condition for the transient mining model.

Boundary Conditions

With the exception of mine workings, the pre-mining and mining models have similar boundary conditions.

For modelling purposes the geometry of the mines was simplified and the mines were represented by mine envelopes. This simplification tends to provide conservative estimates of mine inflows because the envelopes are larger than the actual mine workings. For instance relative to the proposed mine developments the mine volumes considered in the model are 5%, 20% and 60% higher for Main Zone, Andrew Lake and End Grid, respectively.

<u>Time-dependent boundary conditions</u>:

Pit excavation and underground developments were simulated using time-varying boundary conditions. The external nodes of the mine envelopes were assigned a constant head boundary condition with the head value at each node varying with time as depth of excavation changes. These nodes were also assigned a seepage node constraint such that the node can only act as an exit point of groundwater as opposed to a source.

Seepage nodes were turned on sequentially, at times specified by the mining schedule used for modelling purposes. To keep a mine level inactive, both minimum and maximum flux constraints were set to zero flux. This boundary condition is illustrated in Figure 2.3-1.

<u>Simulated mining schedule</u>

The following procedure was used to simulate the mining schedule:

- Step 1 - Time T=0: Simulation starts; the access ramp is completed (not simulated) and mine Level 1 is excavated:
    - o Mine level 1; the seepage face nodes are activated at time T=0 and remain active until the end of the simulation; the head elevation is set equal to elevation of slice 3
    - o Mine level 2; the seepage face nodes are activated at time T=T0 with a starting head elevation equals to Level 1

Between time T0 and time Tn it is considered that the mine is excavated at a constant rate. The hydraulic head is decreased in the model at the same rate.

  - Mine level 3, the corresponding boundary condition (slice 5) is inactive.

- Step 2 - Time T=Tn; mine level 2 is excavated.

  - Mine level 1, the seepage nodes remain active

  - Mine level 2, the seepage nodes are assigned the elevation of model slice 2 and remain active until the end of simulation

  - Mine level 3, the seepage nodes are activated

    Between Tn and Tn+1, it is considered that the mine is excavated at a constant rate. The hydraulic head is decreased in the model at the same rate.

- Step 3 - Time T=Tn+1: mine level 3 is excavated and the previous procedure is repeated

Simulated Mining Schedule

The simulated mining schedules are presented in Figure 2.3-2. Transient simulations were conducted to simulate mine excavation over a 14-year period.

2.4 INPUT MODEL PARAMETERS

Hydraulic Conductivity Distribution

The hydraulic conductivity distribution used for the pre-mining model (see Table 2.4-1 and Technical Appendix 5D Groundwater Flow Model) was reused for the mining model.

Table 2.4-1 Hydraulic Conductivity Distribution

Unit ID	Depth (m)	HYDRAULIC CONDUCTIVITY (m/s)						
		Permafrost	Granite	Meta-sediment	Gneiss	Ortho-quartzite	Syenite	Barrensland Group
K1	0-5	$1x10^{-12}$	$5x10^{-05}$	$5x10^{-05}$	$5x10^{-05}$	$5x10^{-05}$	$5x10^{-05}$	$5x10^{-05}$
K2	5-100	$1x10^{-12}$	$5x10^{-07}$	$5x10^{-09}$	$5x10^{-08}$	$1x10^{-07}$	$8x10^{-08}$	$3x10^{-07}$
K3	100-215	$1x10^{-12}$	$5x10^{-08}$	$5x10^{-10}$	$5x10^{-09}$	$1x10^{-08}$	$8x10^{-09}$	$3x10^{-08}$
K4	215-450	-	$1x10^{-08}$	$1x10^{-10}$	$1x10^{-09}$	$5x10^{-09}$	$3x10^{-09}$	$8x10^{-09}$
K5	450-900	-	$1x10^{-09}$	$1x10^{-11}$	$1x10^{-10}$	$5x10^{-10}$	$3x10^{-10}$	$8x10^{-10}$

Major Structural Features

Although their hydraulic role has not been confirmed by site observation all potential major structural features were included in the model to ensure conservative prediction of fluxes into mine workings.

Major structural features were included in the model in the taliks and sub permafrost areas using quadrilateral 2D vertical discrete elements to simulate their geometry. A 10 m thickness and a specific storage of $1x10^{-4}$ m^{-1} were assigned to the discrete element.

Five models were developed to account for potential structural features such as faults and dykes that could be encountered during mining:

- Scenario 1 - No fault, no dyke. This scenario assumes that the potential major faults and dykes in the mining areas are not hydraulically active.
- Scenario 2 - This scenario assumes that the potential major faults and dykes in the mining areas are hydraulically active. The hydraulic conductivity value assigned to all structural features is set to $K=1x10^{-7}$ m/s.
- Scenario 3 - A lower hydraulic conductivity of $K=1x10^{-8}$ m/s is assigned to potential faults with a SE/NEW orientation.
- Scenario 4 - A lower hydraulic conductivity of $K=1x10^{-8}$ m/s is assigned to potential faults with a SW/NE orientation.
- Scenario 5 – This scenario assumes a higher hydraulic conductivity of $K=1x10^{-6}$ m/s for the dyke crossing Main Pit. Other potential structures are assigned a K value of $1x10^{-8}$ m/s.

Storage Properties

Permafrost

Specific storage was assumed to be zero.

Overburden

The overburden (active layer) was simulated as a 5m thick layer with specific storage of $1x10^{-5}$ m^{-1}.

Unfrozen Basement Rock

A specific storage of $1x10^{-5}$ m^{-1} was used for all layers and lithology units, with the exception of major structural features.

2.5 MODEL RESULTS

Predictions of groundwater inflows versus time for the five scenarios are presented in Figure 2.5-1 to Figure 2.5-5. Maximum predicted groundwater inflows at each mine are summarized in Table 2.5-1.

Predicted groundwater flow to the End Grid underground mine is approximately 160 m^3/day for the ultimate configuration of the mine. Most of this flow originates from the enhanced permeability zones assumed to be associated with the sub-vertical faults passing through the mine. If these faults are either not present or have a lower hydraulic conductivity than assumed then inflow to the mine would be lower than 100 m^3/day. This estimate is consistent with a preliminary estimate conducted by Golder in 2009 (see Attachment A).

Mining of the Andrew Lake and Main Zone pits is expected to take place over several years. During most of this time, the pits will be excavated in permafrost and groundwater inflows are expected to be negligible. In the final years of mining the pits are expected to extend below the bottom of permafrost; the results of the model simulations predict that groundwater inflow to the Andrew Lake and Main Zone pits will be lower than 100 m^3/year for the ultimate pit depth.

Figure 2.5-6 illustrates the distribution of hydraulic heads at the end of the simulation period. Figure 2.5-6 shows that because of the low hydraulic conductivity of the sub-permafrost bedrock the cone of depression resulting from the dewatering activities is limited to the immediate vicinity of the mines.

Table 2.5-1: Maximum predicted inflow during mining

Scenario	Major Faults	Main Zone cross-cutting dyke	Groundwater Inflow (m^3/d)		
			Andrew Lake Pit	End Grid UG Mine	Main Zone Pit
Scenario 1	None	None	6.1	27	19.5
Scenario 2	All faults K=1x10-7 m/s	K=1x10^{-7} m/s	15.4	158.2	20.4
Scenario 3	SE/NW faults K=1x10-8 m/s SW/NE faults K=1x10-7 m/s	K=1x10^{-8} m/s	15.5	158.2	19.8
Scenario 4	SE/NW faults K=1x10-7 m/s SW/NE faults K=1x10-8 m/s	K=1x10^{-7} m/s	8.4	62.2	20.4
Scenario 5	All faults K=1x10-7 m/s	K=1x10^{-6} m/s	15.5	158.2	21

3 OPEN PITS WATER BALANCE

3.1 INPUTS

The water balance for the Kiggavik and Andrew Lake open pits was estimated from the following components:

- Precipitation (rain, snow)
- Evaporation
- Sublimation
- Blowing snow
- Runoff from rain and snowmelt
- Groundwater inflow

Climate and hydrological parameters

Table 3.1-1 summarizes the hydrological parameters used for open pit water balance estimates. Additional information can be found in Technical Appendix 5A (Hydrology Baseline).

Table 3.1-1 Climate Parameters Used for Open Pit Water Balance Calculations

	Average daily air temp (deg C)	Rain (mm)	Snow (mm)	Drifting snow accumulation (mm)	Pit lake/pond evaporation (mm)	Sublimation (mm)
Jan	-32.4	0.1	13.2	4.3	0.0	5.0
Feb	-32.0	0.1	12.2	2.7	0.0	5.0
March	-27.1	0.0	17.0	0.9	0.0	5.0
April	-17.4	0.6	21.5	0.0	0.0	5.0
May	-6.3	6.7	13.3	0,2	0.0	5.0
June	4.3	21.9	4.4	2.1	19.5	0.0
July	11.2	43.6	0.0	7.0	81.5	0.0
Aug	9.7	46.2	1.0	5.5	59.5	0.0
Sep	2.7	37.3	10.6	3.5	19.5	0.0
Oct	-7.2	8.0	34.9	2.6	2.5	5.0
Nov	-20.0	0.3	27.5	2.4	0.0	5.0
Dec	-27.7	0.1	17.6	3.4	0.0	5.0
Total		164.9	173.2	34.4	182.5	40.0

Precipitation

Precipitation data at Baker Lake have been collected since 1949. An adjusted climate data set is also available for Baker Lake, which mainly corrects for snow gauge undercatch and accounts for the loss of snow on the instrument due to elevated wind speeds. Mean adjusted historical annual precipitation at Baker Lake is approximately 344 mm, of which approximately 170 mm falls as rain. Rainfall has been measured during a few seasons at Kiggavik however snowfall data have not been collected on site.

Evaporation

A number of methods were used to estimate evaporation and evapotranspiration for the Kiggavik Project (see Technical Appendix 5A).

Evaporation for Baker Lake was first estimated using the Priestley-Taylor method (Priestely and Taylor 1972), a method that is commonly used in Northern Canada (Gibson et al; Reid 2011; Reid 2004). This method requires inputs of net radiation, temperature, wind speed, atmospheric pressure, and water density. Climate data from Baker Lake were used for the calculation of evaporation due to its extended period of record; evaporation was determined to be 150mm.

Evaporation was also estimated using a revised Meyer formulation proposed by the Prairie Farm rehabilitation Administration (Martin, 2002) to estimate evaporation for various regions in Canada. The Meyer method requires inputs of temperature, relative humidity, wind speed, and lake surface temperature. The annual evaporation at Kiggavik in 2007 was calculated to be 179 mm using the modified Meyer method.

Site watershed balances were also conducted for each of the watersheds in which a continuous stream discharge existed for the years 2007 and 2008. Once the discharge is subtracted from the precipitation in particular drainage area, the remaining precipitation returns to the atmosphere via evaporation from open water surfaces, evapotranspiration from land surfaces or by sublimation losses from the snowpack. In 2007 and 2008, the mean values of these collective losses were 139 mm and 144 mm, respectively.

Similarly, watershed balances were also conducted with assumed values for evaporation (calculated using the Meyer method with site stream temperature data). Evapotranspiration was calculated as a residual from the water balance calculation, assuming other losses are negligible. The mean values for evaporation and evapotranspiration plus other losses were 190 mm and 133 m (in 2007) and 164 mm and 143 mm (in 2008).

The mean evaporation value used in the open pit water balance is 182.5 mm/year. Lake evaporation is expected to occur over a small area at the bottom of the pit, where a small pond can develop.

Sublimation, snow loss and blowing snow

The mean snow course data as snow water equivalent for the month of May at Baker Lake over the 1965-2006 period is 71.9 mm. The mean adjusted snowfall for the same period of record is 195.6 mm. Assuming a value of 25 mm to account for post snow survey, pre-melt precipitation, the difference between total adjusted snowfall and the snow course data for the period 1965-2006 is 195.6 mm – (71.9 mm + 25.0 mm), or approximately 98.7 mm. This estimate for snow loss if approximately 50% of the adjusted snowfall.

Pomeroy et al. (1997) have modeled blowing snow in the low Arctic, 50 km north of Inuvik, NWT. At this location, sublimation is estimated to be 28% of total annual snowfall, and an additional 18% of the total annual snowfall was transported to low areas (a total snow loss of 46% of the annual snow fall). If it assumed that a similar rate of sublimation and snow transport exists in the Baker Lake area, the estimations for annual sublimation and snow transport are 49.1 mm and 31.6 mm, respectively, using the adjusted historical snowfall data set.

Sublimation is expected to occur during cold months over the whole pit area from pit walls and over frozen pit bottom pond.

Groundwater inflow

Model results presented in section 2 were used as estimate of inflows from the sub-permafrost layer. The water balance assumes groundwater inflows during the winter months at Main Zone and Andrew Lake. However the predicted inflow rates are low and it is likely that groundwater seeps will freeze during winter.

The thin thawed active layer (~ 1.5 m) that may develop during operations was not considered as all flow at ground surface will be intercepted to prevent it from entering the open pit.

3.2 RESULTS

Predicted monthly inflows at each open pit mine are summarized in Table 3.2-1. The snowmelt in early summer months is the dominant source of water inflow to the pits.

The largest total inflows are predicted for the Andrew Lake and Main Zone open pits, with peak rates of 1050 m^3/day (32,000 m^3) and 745 m^3/day (22,716 m^3) in July, respectively. Inflow rates are much smaller for Centre Zone and East Zones pits. There is no groundwater inflow component for these open pits and the total inflows are predicted to be less than 500 m^3/day.

Table 3.2-1 Predicted Pit Water Inflows

Month	East Zone (m3)	Centre Zone (m3)	Main Zone (m3)	Andrew Lake (m3)
Jan	0	0	641	488
Feb	0	0	641	488
March	0	0	641	488
April	0	0	641	488
May	0	0	641	488
June	3,175	4,207	10,460	13,689
July	7,565	9,638	22,716	32,020
Aug	3,066	3,616	8,592	13,329
Sep	1,261	1,541	4,097	5,757
Oct	1,484	2,038	5,477	6,641
Nov	0	0	641	488
Dec	0	0	641	488
Total	16,551	21,040	55,829	74,852

4 SUMMARY

The groundwater flow model developed for the Kiggavik Project area (Technical Appendix 5D) was used to simulate the dewatering of the Kiggavik Project mines.

Transient simulations presented in this technical appendix suggest that the groundwater inflow to the proposed open pits would be low due to low hydraulic conductivity of the rock mass in which the pits would be excavated. Mining of the Andrew Lake and Main Zone pits is expected to take place over several years. During most of this time, the pits will be excavated in permafrost and groundwater inflows are expected to be negligible. In the final years of mining the pits are expected to extend below the bottom of permafrost; the results of the model simulations predict that groundwater inflow to the Andrew Lake and Main Zone pits will be lower than 100 m^3/year for the ultimate pit depth.

Predicted groundwater flow to the End Grid underground mine is approximately 160 m^3/day for the ultimate configuration of the mine. Most of this flow originates from the enhanced permeability zones assumed to be associated with the sub-vertical faults passing through the mine. If these faults are either not present or have a lower hydraulic conductivity than assumed then inflow to the mine would be lower than 100 m^3/day.

Water balance estimates for the open pits suggest that the snowmelt in early summer months would be the dominant source of water inflow to the pits. The largest total inflow is predicted for the Andrew Lake open pit, with a peak rate of 1050 m^3/day (32,000 m^3) in July. A peak rate of 745 m^3/day (in July) is predicted for Main Zone. Inflow rates are much smaller for Centre Zone and East Zones pits. There is no groundwater inflow component for these open pits and the total inflows are predicted to be less than 500 m^3/day.

5 REFERENCES

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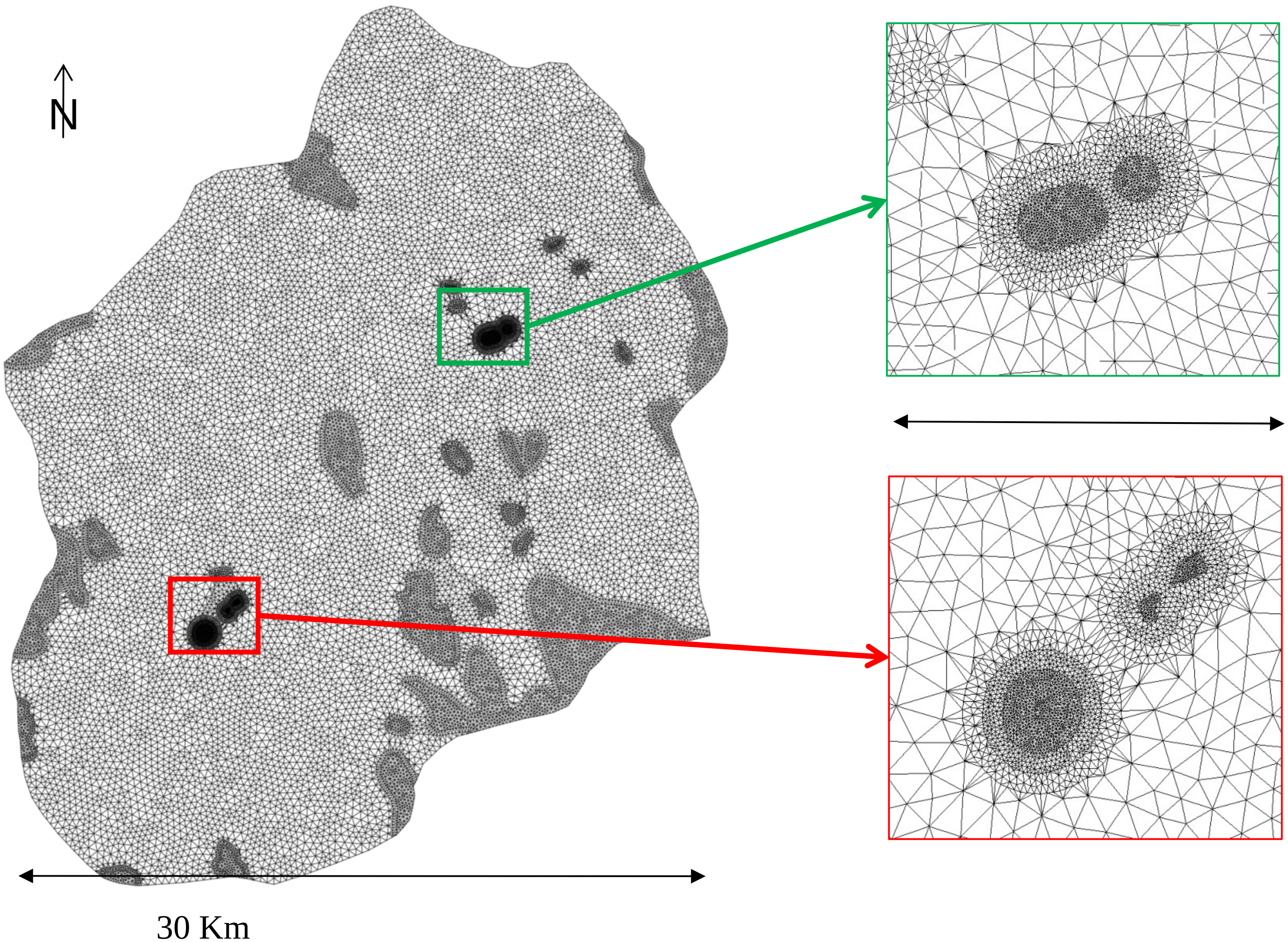

Figure 2.2-1
Model mesh geometry

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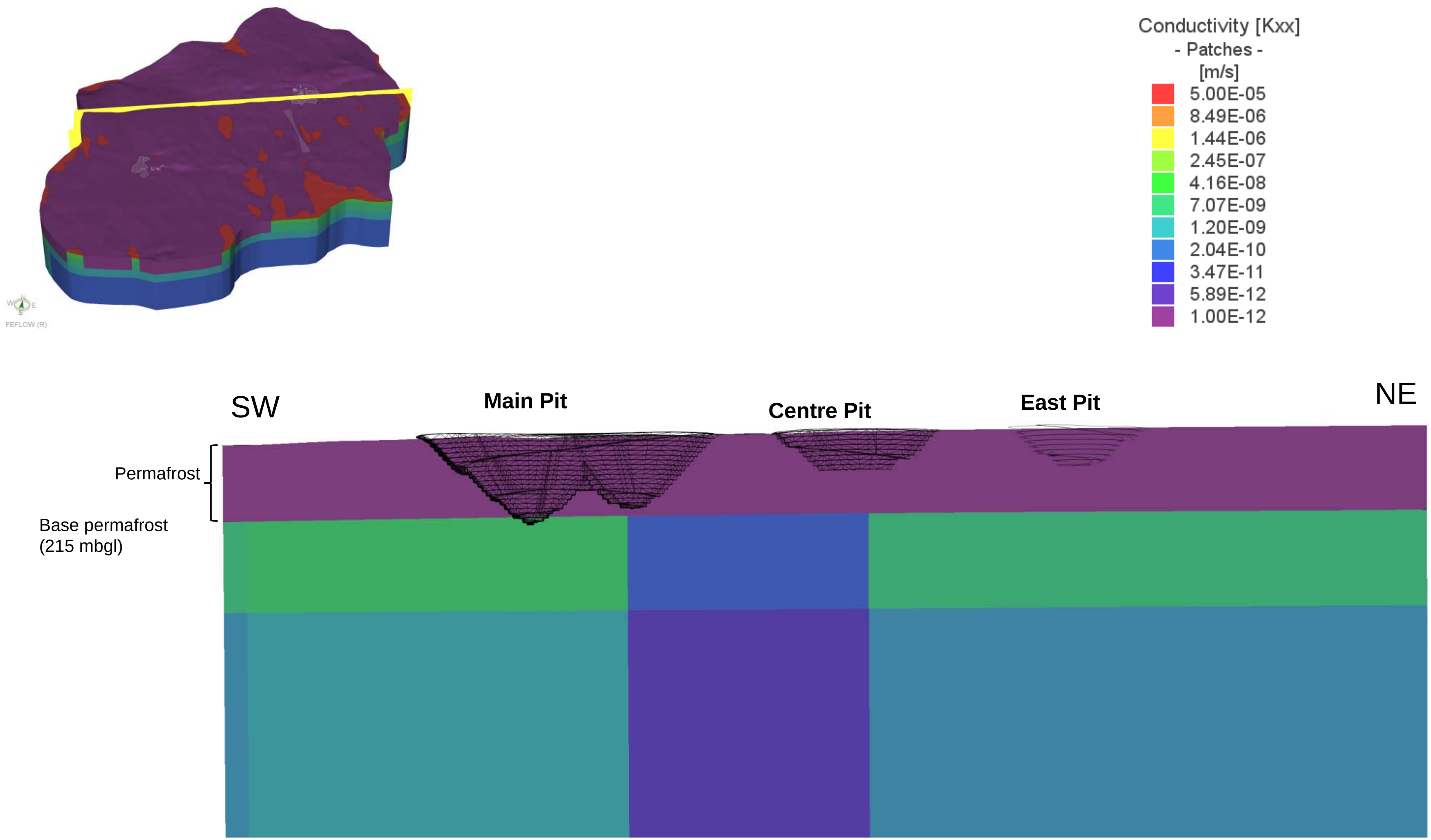

No vertical exaggeration

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Figure 2.2-2
Cross-section Kiggavik mine site

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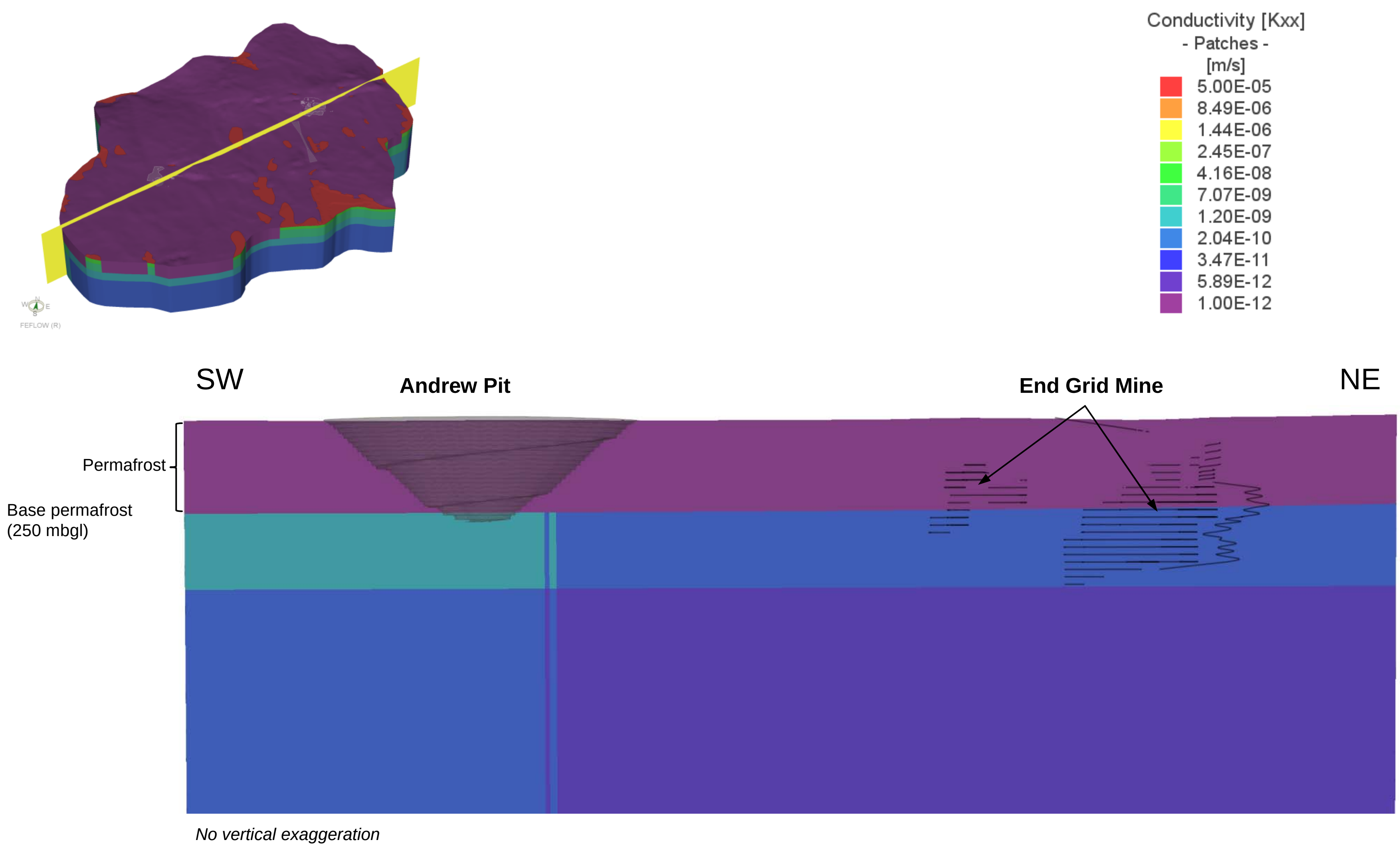

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Figure 2.2-3
Cross section Sissons mine site

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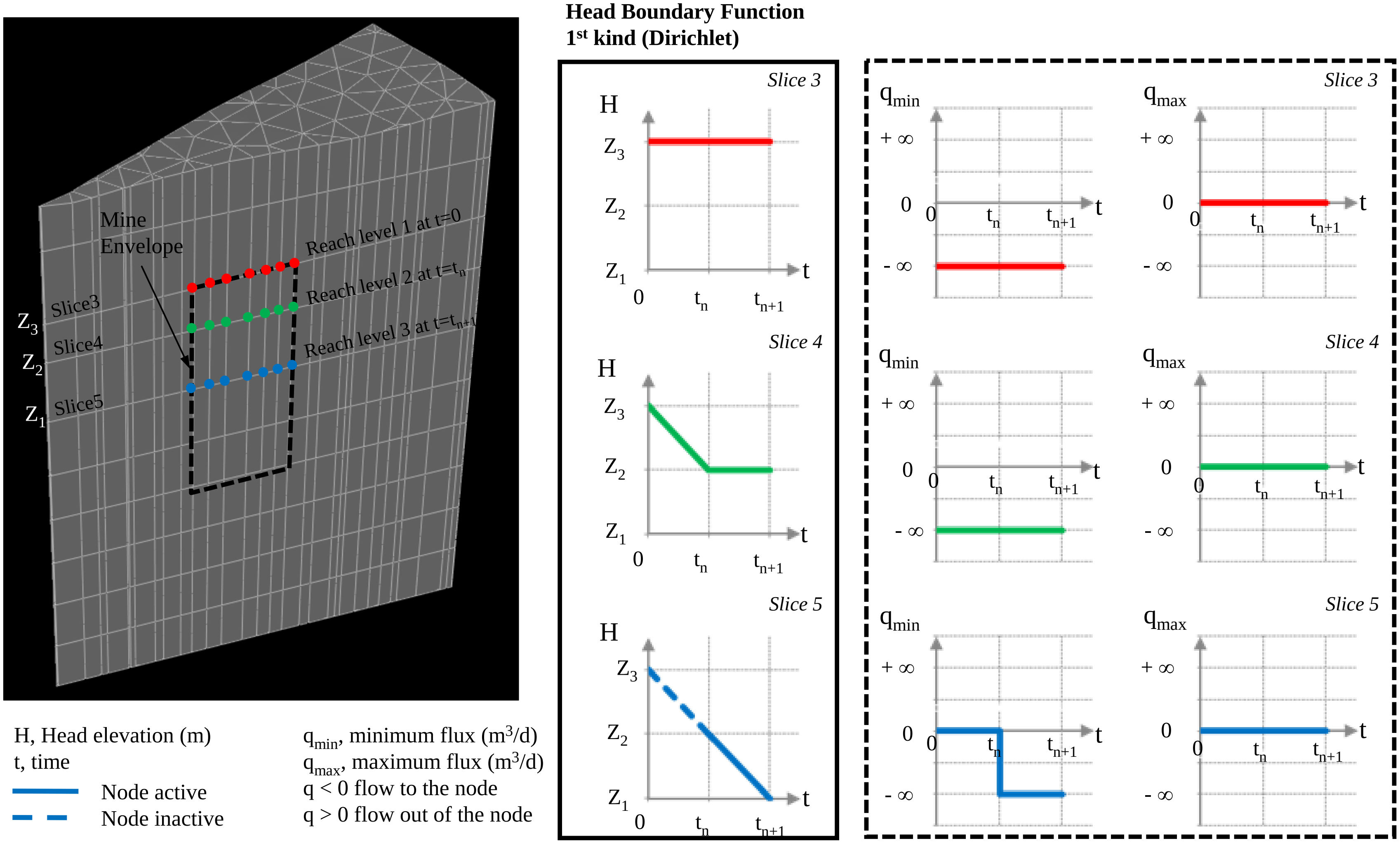

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Figure 2.3-1
Illustration of the node boundary conditions at mine levels

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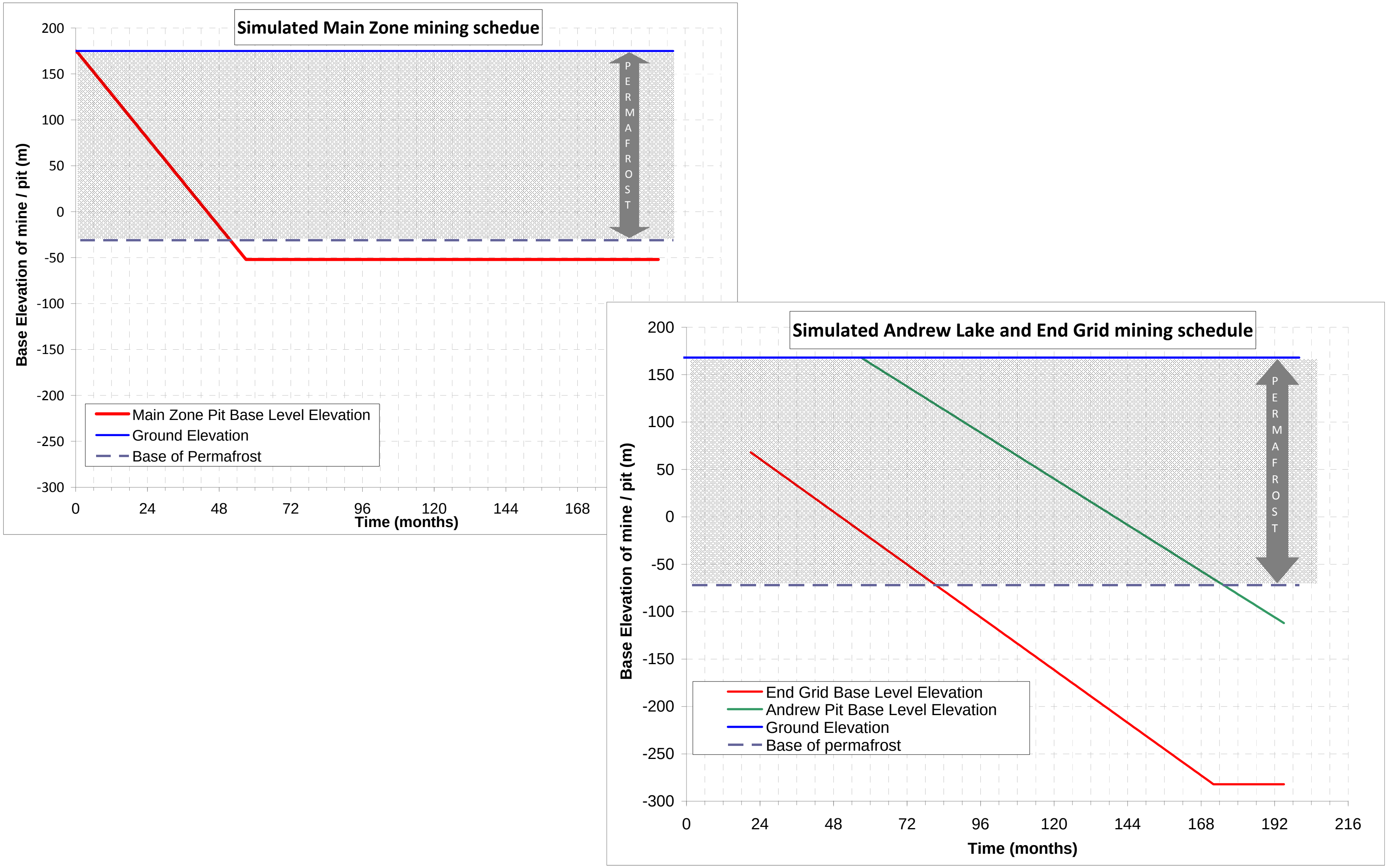

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Figure 2.3-2
Simulated mining schedule

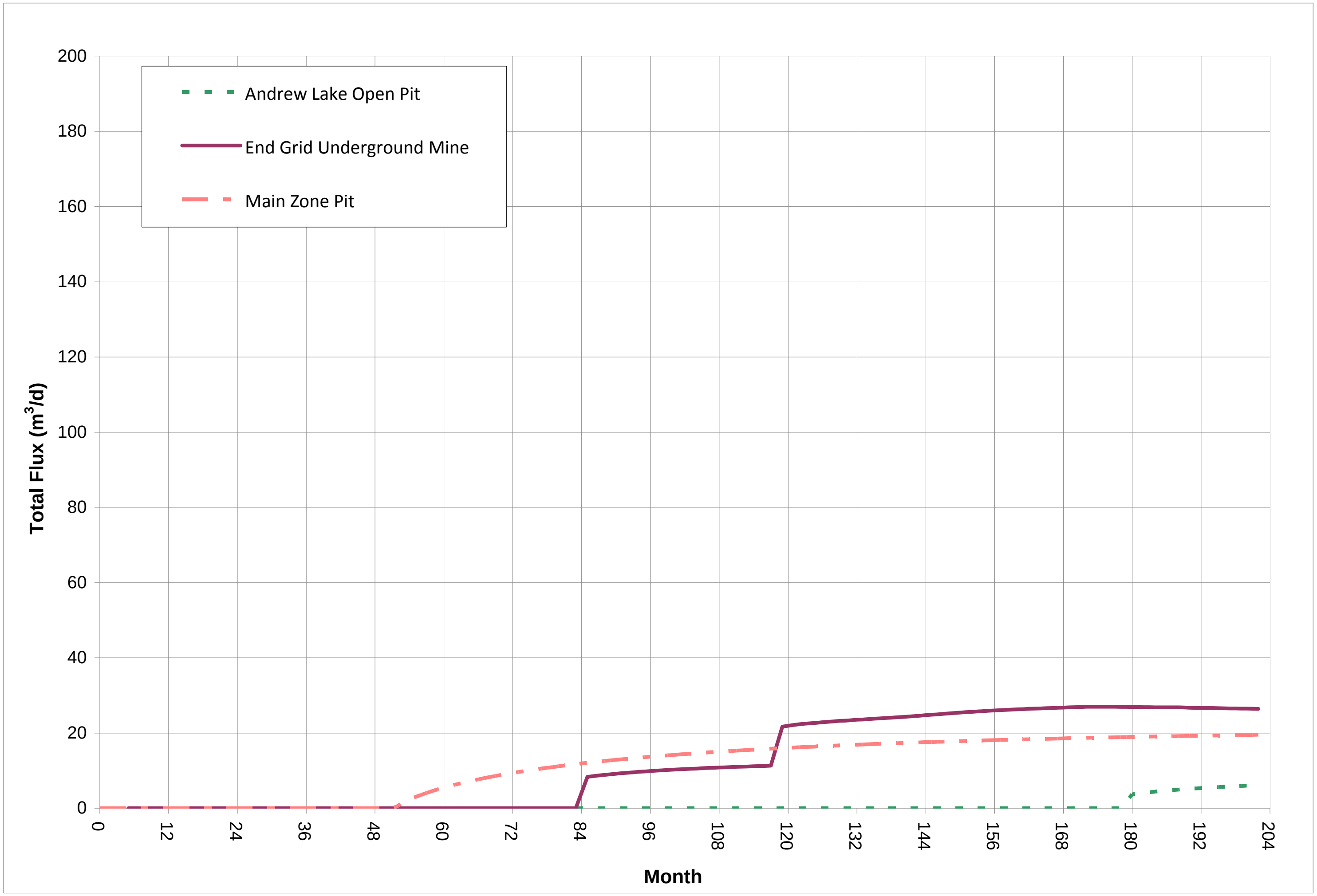

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Figure 2.5-1
Predicted mine inflows
Scenario 1 – No Fault no dyke

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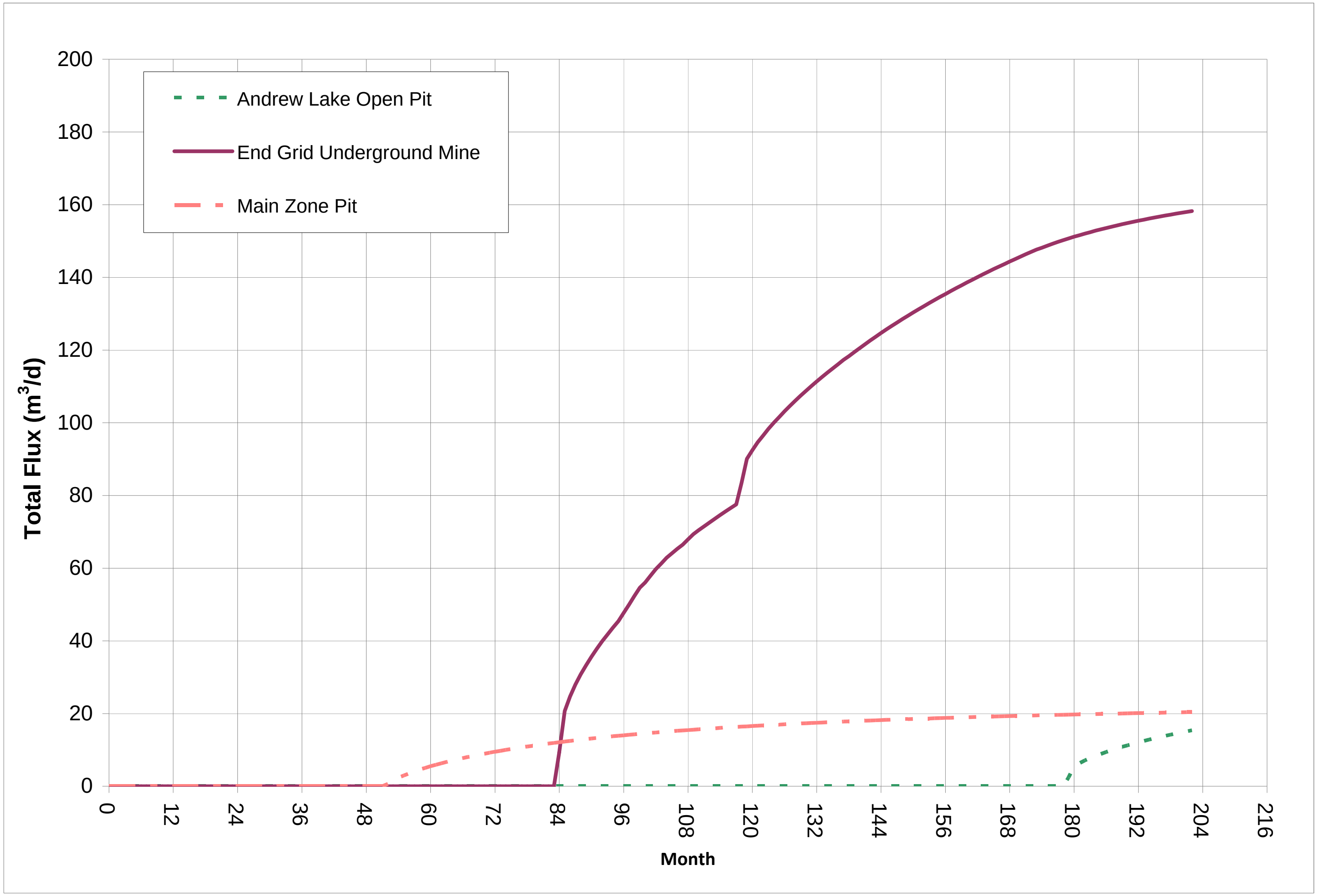

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Figure 2.5-2
Predicted mine inflows
Scenario 2 – All faults and dyke with $K=10^{-7}$ m/s

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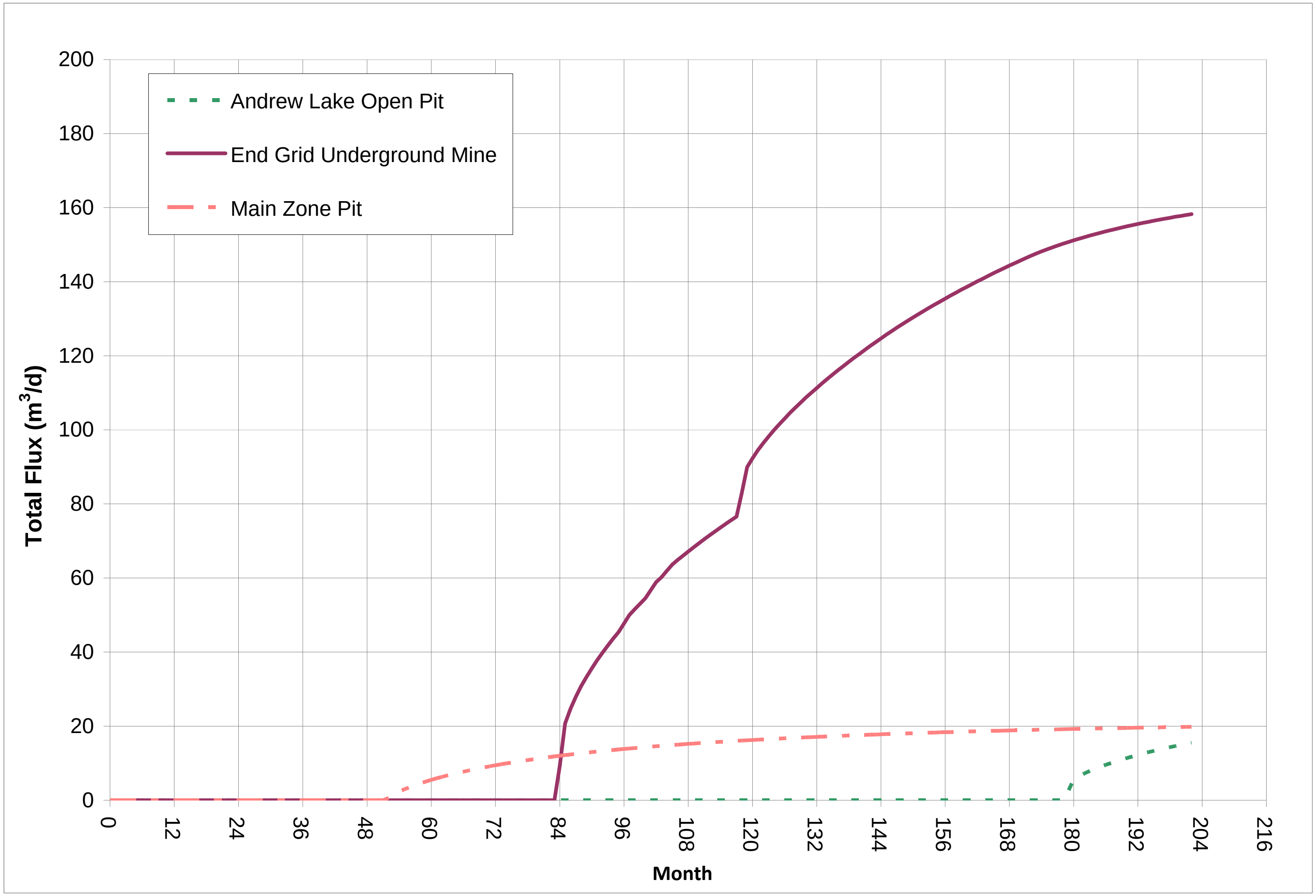

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Figure 2.5-3
Predicted mine inflows
Scenario 3 – SE/NW faults and dyke with K=10^{-8} m/s

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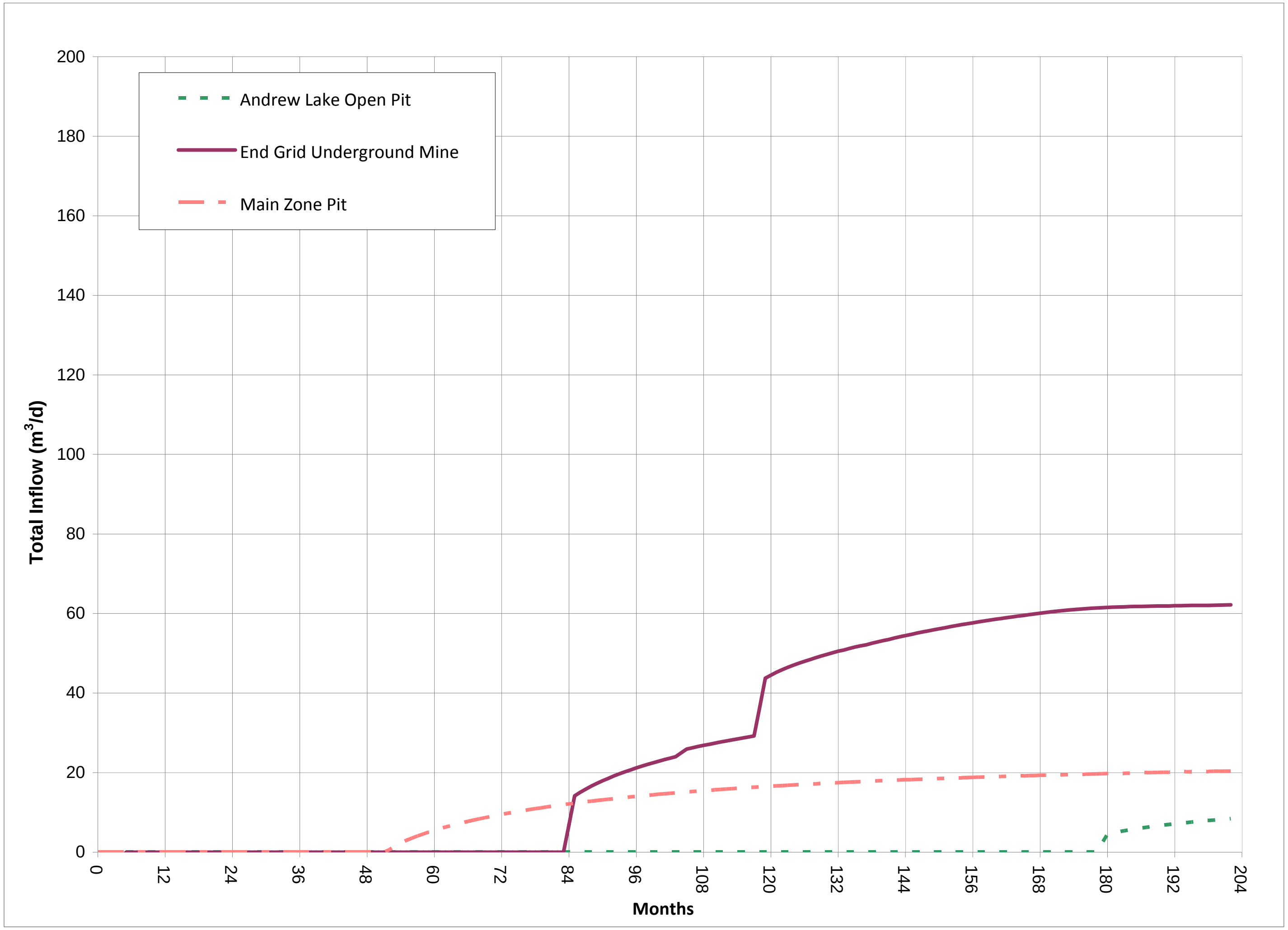

Technical Appendix 5E
Prediction of Water Inflows
Date 11/30/2011

Figure 2.5-4
Predicted mine inflows
Scenario 4 – SW/NE faults with K=10^{-8} m/s

SRK Consulting
Engineers and Scientists

Kiggavik Project

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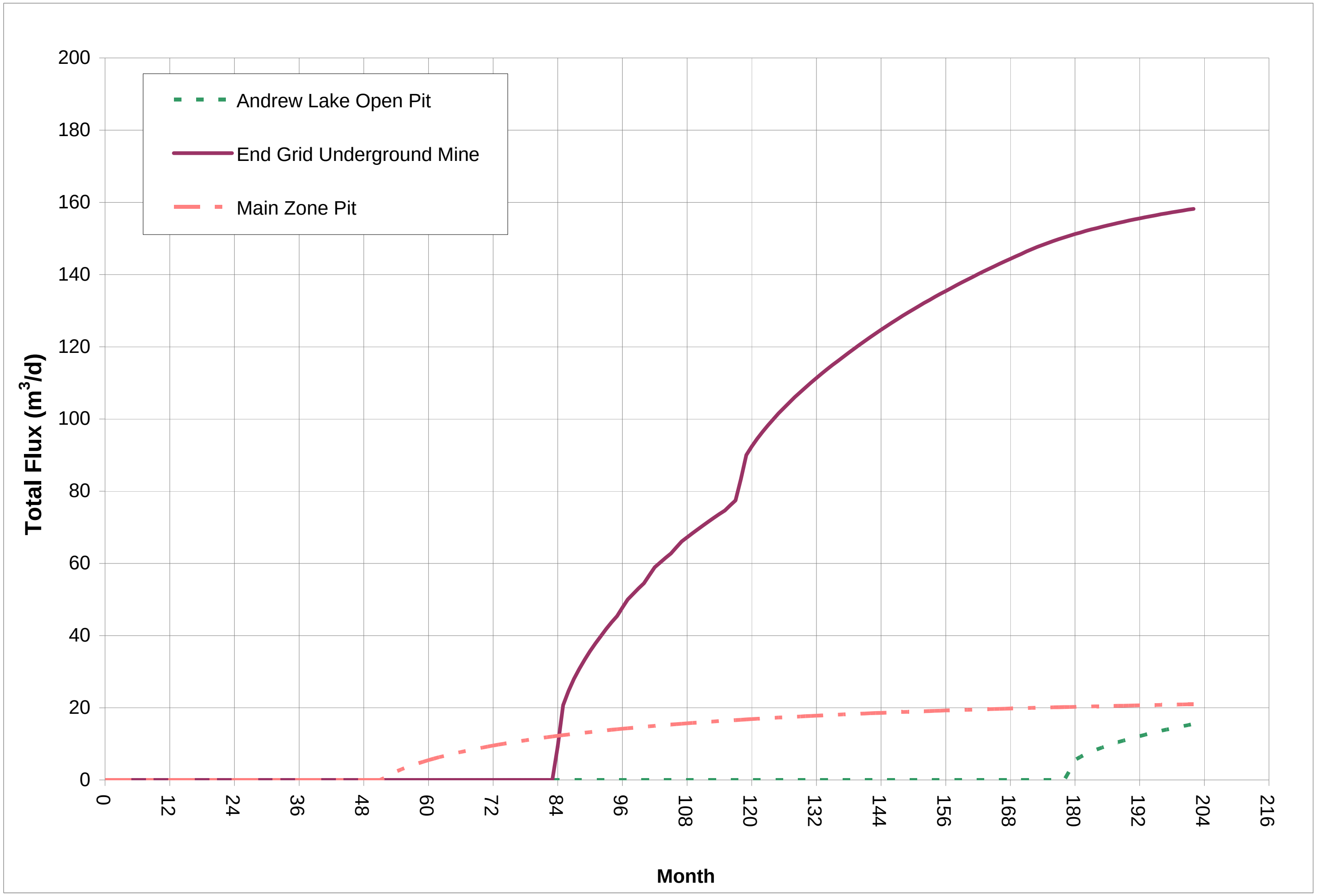

SRK Consulting
Engineers and Scientists

Technical Appendix 5E
Prediction of Water Inflows
Date 11/30/2011

Figure 2.5-5
Predicted mine inflows
Scenario 5 – Dyke with $K=10^{-6}$ m/s

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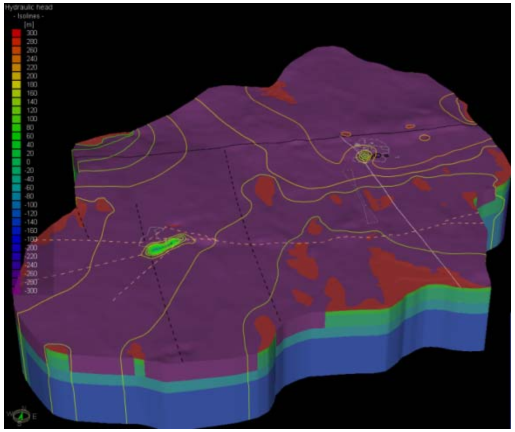
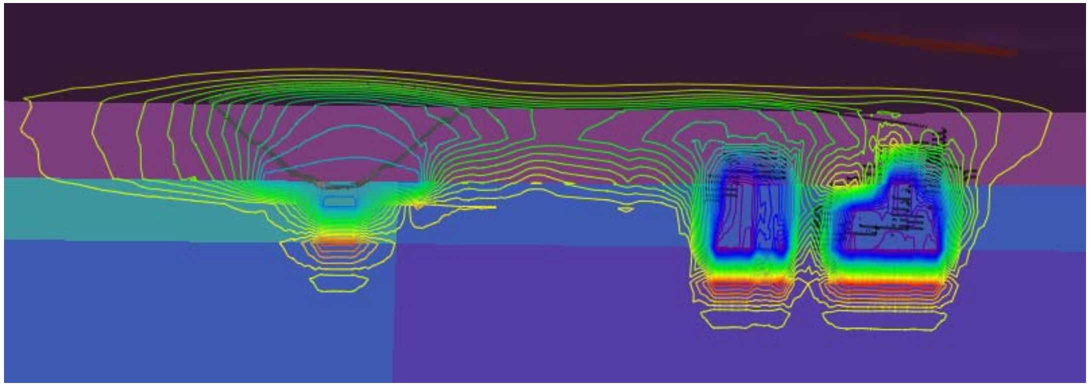
Simulated Hydraulic Head

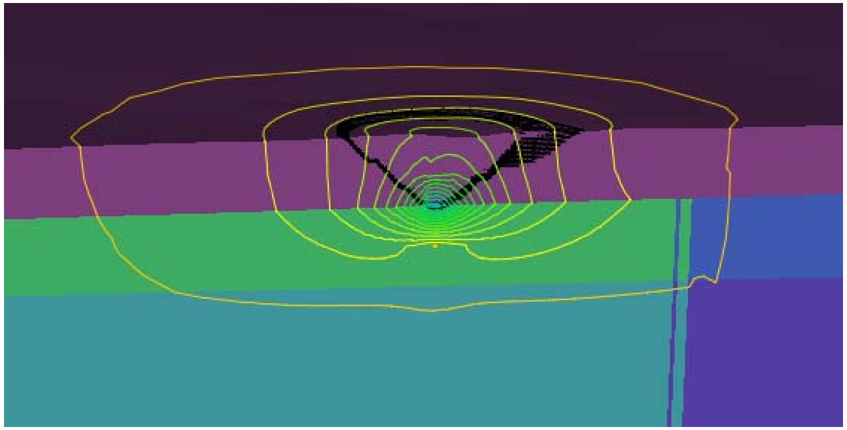


Vertical exaggeration x 5

Hydraulic head in Sissons Area at end of simulation



Hydraulic head in Kiggavik Area at end of simulation



Technical Appendix 5E
Prediction of Water Inflows
Date 11/30/2011

Figure 2.5-6
Simulated head distribution at time 14 years

SRK Consulting
Engineers and Scientists

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Attachment A

Predicted Groundwater Inflows - End Grid Underground Mine (Golder, Technical Memorandum, Project 09-1423-0001/3000, Nov. 12, 2009

TECHNICAL MEMORANDUM

DATE November 12, 2009 **PROJECT No.** 09-1423-0001/3000

TO Frederic Guerin
Areva

FROM Christine Bieber
Don Chorley

EMAIL cbieber@golder.com
dchorley@golder.com

PREDICTED GROUNDWATER INFLOWS – END GRID UNDERGROUND MINE

This memorandum presents the development of a revised conceptual model for the End Grid Mine based on field investigations conducted at Kiggavik by Golder and others. The revised conceptual model was then used to develop a numerical hydrogeological model of the area near to the End Grid deposit so that preliminary predictions of groundwater inflows to the End Grid Underground Mine could be made.

The initial Sections in this memorandum provide a review of hydrogeological and thermal data for the entire Kiggavik Project with later sections focusing on the End Grid Underground Mine.

1.0 BACKGROUND

The Kiggavik site is located approximately 75 km west of the community of Baker Lake, Nunavut, which is west of Chesterfield Inlet and Hudson Bay (Figure 1). Current plans include development of three open pits and one underground mine. The three open pits are designated as Andrew Lake Pit, Main Pit and Centre Pit, while the underground mine is designated as the End Grid Underground Mine (Figure 2).

The Main Pit and Centre Pit are in close proximity to one another, and the planned ultimate depths of the Main Pit and Centre Pit are approximately 200 m-bgs (metres below ground surface), and 110 m-bgs, respectively.

The Andrew Lake Pit and End Grid Underground Mine are located approximately 15 km southwest of the Main Pit and Centre Pit. The planned ultimate depth of the Andrew Lake Pit is approximately 270 m-bgs. The End Grid Underground Mine, located in close proximity to Andrew Lake, is scheduled to be developed over eight to ten years to a maximum depth of approximately 480 m-bgs.

2.0 KIGGAVIK HYDROGEOLOGICAL DATA

An initial review of available data for the Kiggavik Project was performed by Golder in 2007. These data did not include any hydraulic conductivity or sub-permafrost water chemistry measurements. Based on this review, recommendations were made for the collection of data required to provide appropriate estimates of mine inflow quantity and quality. These recommendations included the collection of thermistor data in the Kiggavik area to confirm the depth of permafrost, lake bathymetry to confirm/refute the existence of taliks, hydraulic testing to determine the hydraulic conductivity of deep bedrock, and groundwater sampling to determine groundwater quality in the deep bedrock.

The 2008 and 2009 field investigations were designed to address the data gaps identified for the Kiggavik Project. Additional data collected in 2008 and 2009 at the site included:

- Hydraulic testing data in 12 boreholes. Five of these tests were conducted in the area of the planned Main Pit and Centre Pit. The remainder were conducted in the area of the planned Andrew Lake Pit and End Grid Underground Mine.
- Thermistor data collected at the Sissons and Kiggavik sites.
- Hydraulic head data collected from four vibrating wire transducers.
  Two of these were located in the area of the Main Pit and Centre Pit, and two in the area of Andrew Lake Pit and End Grid Underground Mine.
- Bathymetry data were collected for three additional lakes in the project areas.

The interpretation of the structural geology in the Kiggavik Project area has been updated and provided to Golder by AREVA (October 14, 2009).

These data have been used to update the hydrogeologic conceptual model for the area of the End Grid Underground Mine.

3.0 SUMMARY HYDROGEOLOGICAL/THERMAL DATA – KIGGAVIK PROJECT

3.1 Permafrost

The Kiggavik project is located in an area of continuous permafrost. Recent data collected at the site (Golder, 2009), indicates that permafrost extends to a depth of approximately 210 m-bgs in the Main Pit and Centre Pit area, and approximately 240 m in the Andrew Lake Pit and End Grid Underground Mine area.

3.2 Deep Groundwater Flow Regime

In areas of continuous permafrost, the deep groundwater regime is connected by taliks (unfrozen ground) located beneath large lakes. Taliks are formed beneath lakes that do not freeze to the bottom in winter. If a lake is large enough, the talik extends down to the deep groundwater flow regime. The elevation of the water levels in lakes that have these deep taliks provides the driving force (hydraulic head) for the deep groundwater flow. The presence of the thick and low permeability permafrost beneath land located between large lakes results in negligible recharge to the deep groundwater flow from these areas. Smaller lakes have taliks that do not extend down to the deep groundwater regime and also do not influence the groundwater flow in the deep regime. Consequently, recharge to the deep groundwater flow regime is predominantly limited to areas of talik beneath large, surface water bodies. Generally, groundwater will flow from higher elevation lakes to lakes located at lower elevations. To a lesser degree, groundwater flow beneath the permafrost is influenced by density differences due to the upward diffusion of deep seated brines (density driven flow).

At the Kiggavik Project, a 2 m thick ice coverage is assumed to be developed in lakes during the winter months (Prowse and Ommaney, 1990); therefore lakes must be greater than 2 m deep to support a talik. In addition, previous analyses (Golder, 2007), have indicated that a circular unfrozen lake would need to have a minimum radius of approximately 145 m to support a talik extending to the groundwater flow system, while an elongate lake would need to have a half-width of approximately 80 m to support a talik.

Figure 3 identifies lakes near the Kiggavik site that satisfy both the minimum dimensional requirements and depth requirements to support a talik extending to the deep groundwater flow system. Figure 4 presents a conceptual cross-section of the deep groundwater flow system near the End Grid area.

3.3 Hydraulic Heads

Hydraulic heads in the deep groundwater flow system that are above ground surface elevation were previously anecdotally documented for the Kiggavik site (Golder, 1989). Hydraulic head data collected in three piezometers during the 2009 field season confirm that hydraulic heads in the sub-surface are near to or above ground surface. The hydraulic head measured in a piezometer located beneath the permafrost at the planned End Grid Underground Mine was approximately 9 m above ground surface (175.5 masl), while at Andrew Lake the hydraulic head measured in a piezometer was approximately 3 m above the ground surface (169.7 masl). The hydraulic head measured in one piezometer located at the planned Main Pit was approximately 25 m above ground. These hydraulic heads are generally consistent with the elevations of lakes confirmed to have taliks in the vicinity of the proposed mines. For example, the hydraulic head measured in one piezometer located near the planned Main Pit was approximately 215.5 masl. which is consistent with the elevations of nearby Ridge Lake (229 masl), and Cirque Lake (214 masl).

3.4 Hydrostratigraphy

Based on the results of packer tests conducted by SRK in 2008, and Golder in 2009, it appears that the hydraulic conductivity (K) of the rock is related to the rock type, with Syenitic gneiss (located at AND09-03 at Andrew Lake) and granitic rock (located at MZ09-03 and MZ09-04 at Main Zone, and CZ09-01 at Centre Zone) generally having a higher K than the metasediments. None of the packer tests undertaken to date were within intervals intersected by faults interpreted by AREVA to extend between boreholes, although at some locations (including at End Grid), faults logged in individual boreholes but not interpreted to extend laterally, intersected the test intervals. It should be noted that the 2009 field program targeted structures identified by AREVA prior to 2009. Boreholes were planned to intersect the locations of these faults based on this earlier structural mapping interpretation; however, none of these boreholes intersected any of the faults in the October 2009 structural map.

At the Main Zone and Centre Zone, near-surface rock consists of moderately weathered metasediments. From approximately 200 m-bgs (near the bottom of permafrost) to the depth of the investigations, the rock type is identified as granite (Golder, 2009). The results of hydraulic testing indicate that the hydraulic conductivity of this granite ranges from 1×10^{-8} m/s to 1×10^{-7} m/s.

The deposits in the Andrew Lake and End Grid area are located in pelitic and arenitic metasediments overlying granite gneisses, and granodiorites. Hydraulic testing conducted in the metasediments at Andrew Lake and End Grid Underground Mines indicates that the hydraulic conductivity of the metasediments from the base of the permafrost (approximately 240 m-bgs) to approximately 50 m beneath the permafrost, is approximately 1×10^{-9} m/s. Testing below this depth indicates that the hydraulic conductivity is less, with hydraulic conductivities ranging from 6×10^{-11} m/s to 6×10^{-10} m/s in packer intervals extending to up to 400 m-bgs. At the Andrew Lake deposit, testing in one packer interval located in syenitic gneiss indicated a much higher hydraulic conductivity of 1×10^{-6} m/s.

4.0 CONCEPTUAL HYDROGEOLOGICAL MODEL – END GRID AREA

Based on the results of hydraulic testing and structural mapping, a conceptual model of the End Underground Mine area has been developed (Figure 5). The hydraulic conductivity of the metasediments in the area of the End Grid Underground Mine is interpreted to be approximately 1×10^{-9} m/s from the base of the permafrost (approximately 240 m-bgs), to 50m beneath it (approximately 290 m below ground). Below this interval, the hydraulic conductivity is interpreted to be approximately one order of magnitude less (1×10^{-10} m/s). Areas of greater fracturing associated with sub-vertical fault zones passing through the mine (mapped locations provided by Areva) may have higher hydraulic conductivity and contribute substantially to mine inflows. No hydraulic testing data currently exists for zones interpreted to extend between boreholes; therefore, they were assumed to have a hydraulic conductivity of 1×10^{-6} m/s and a width of 1 m.

The End Grid Underground Mine is planned to extend to approximately 480 m-bgs. The permafrost in this area extends to 240 m-bgs; therefore approximately 240 m of the mine will be in the unfrozen sub-permafrost. The excavations End Grid Underground Mine will act as a sink for groundwater flow, with water induced to flow through the bedrock to the underground mine openings once the mine has advanced below the bottom of the permafrost (Figure 4).

5.0 PREDICTED INFLOWS – END GRID AREA

A hydrogeologic numerical model was previously developed for the End Grid Underground Mine and Andrew Lake Pit (Golder, 2007). This model was updated for the End Grid area based on the conceptual model described in Section 4.

In this update, the extent of the permafrost was revised from 260 m depth to 240 m-bgs. The hydraulic conductivity profile with depth in the model was also revised. The revised hydraulic conductivity profile is presented in Table 1 below.

Table 1: Model Parameter Values

Depth below Ground (m)	Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield(-)
Metasediments			
0-50	3.E-07	1.E-05	0.0006
50-200	2.E-08	1.E-05	0.0006
200-300	1.E-09	1.E-05	0.0006
300 and below	1.E-10	1.E-05	0.0006
Faults			
0 - 500	1.E-06	1.E-04	0.01
500 m and below	1.E-07	1.E-04	0.01

Areas of greater fracturing that are assumed to be associated with faults were assigned a hydraulic conductivity of 1 x 10^{-6} m/s and a width of 1 m to a depth of 500 m below ground. Below this depth, the hydraulic conductivity of the fault zones is assumed to be one order of magnitude less.

The mine schedule for the End Grid Underground Mine was assumed to last for 8 to 10 years. Mining below the bottom of the permafrost boundary was assumed is expected to occur over approximately 5 years.

Predicted groundwater flow to the End Grid Underground Mine is approximately 300 m^3/day for the ultimate configuration of the underground mine. Approximately 200 m^3/day of this flow originates from the enhanced permeability zones assumed to be associated with the sub-vertical faults passing through the mine. If these faults are either not present or have a lower hydraulic conductivity than assumed then inflow to the mine would likely be closer to 100 m^3/day.

6.0 DEPRESSURIZATION PROCEDURES

The planned End Grid Underground Mine extends down into the deep groundwater regime beneath the permafrost. During the development of the decline in permafrost, pressure heads beneath the permafrost will not be reduced; therefore, if prior depressurization is not undertaken, pressure heads will initially be 240 m or more when the mine first penetrates beneath the permafrost. If these pressures are determined to be high, based on potential stability concerns, or the inflow volumes are considered to be difficult to manage, then prior depressurization will need to be implemented.

An effective depressurization system would likely consist of vertical or sub-vertical boreholes drilled from a development excavation. The boreholes could either be allowed to flow under artesian conditions, or pumps could be installed (if larger diameter holes are drilled) to provide additional lowering of water levels.

Detailed designs for such depressurization systems and for handing the inflow water will need to be developed as part of the proposed Feasibility Studies. This will need to include analyses of the rates of depressurization that are achieved with vertical boreholes, and determinations of the number and locations of boreholes, the lead time required to drill the holes, and the inflows that will result.

7.0 CLOSURE

We trust that the information presented in this technical memorandum is sufficient for your present needs. If you have any questions, or require clarification, please contact the undersigned directly.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

Christine Bieber, M.Sc., P.Geo.
Hydrogeologist

ORIGINAL SIGNED

Don Chorley, M.Sc., P.Geo.
Principal, Senior Hydrogeologist

CB/DWC/nlb

Attachments

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8.0 REFERENCES

Golder Associates Ltd. 1989. Mining Geotechnical Aspects of the Proposed Kikkavik Uranium Operations, Volume I and II.

Golder Associates Ltd. 2007. Preliminary Assessment of Expected Groundwater Conditions Kiggavik-Sissons Project, Nunavut. submitted to AREVA Resources Canada Inc., 06-1321-065-5000

Golder Associates Ltd. 2009. 2009 Kiggavik Geotechnical and Hydrogeological Investigation Data Report. submitted to AREVA Resources Canada Inc., 09-1362-0613

Prouse, T.D. and Ommaney, C.S.L. 1990. Northern Hydrology Northern Perspectives.

SRK Consulting Inc., 2009. Kiggavik-Sissons: Hydrogeology and Thermal Data Report for 2008 Drilling Program, submitted t

LEGEND

- Project Site
- Provincial Boundary
- Waterbody

200,000 0 200,000

SCALE 1:10,000,000 METRES

PROJECT

AREVA RESOURCE CANADA INC.
PREDICTED GROUNDWATER INFLOWS
END GRID MINE

TITLE

PROJECT LOCATION

REFERENCE

Topographic features provided by the National Topographic Data Base.
Datum: NAD 83 Projection: UTM Zone 14

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1426-0001			Phase No: 3000
DESIGN	CB	05NOV09	**FIGURE 1**
GIS	MCM	05NOV09	
CHECK			
REVIEW			

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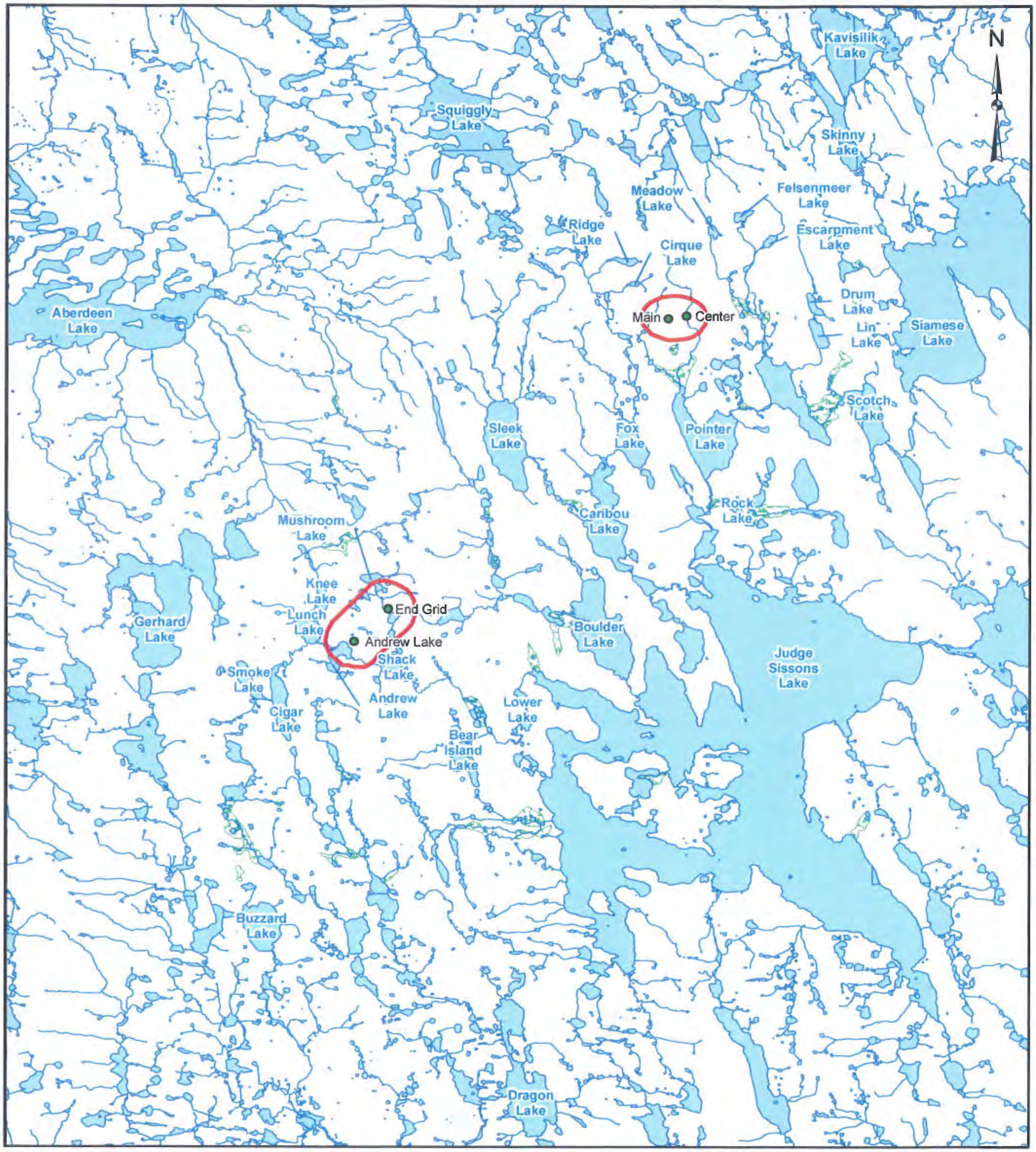

LEGEND

- Uranium Orebody
- Project Site
- Waterbody
- Wetland
- Watercourse

4,000 0 4,000

SCALE 1:200,000 METRES

PROJECT

AREVA RESOURCE CANADA INC.
PREDICTED GROUNDWATER INFLOWS
END GRID MINE

TITLE

PROJECT LOCATION

REFERENCE

Topographic features provided by the National Topographic Data Base.
Datum: NAD 83 Projection: UTM Zone 14

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1426-0001			Phase No: 3000
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GIS	MCM	05NOV09	**FIGURE 2**
CHECK			
REVIEW			

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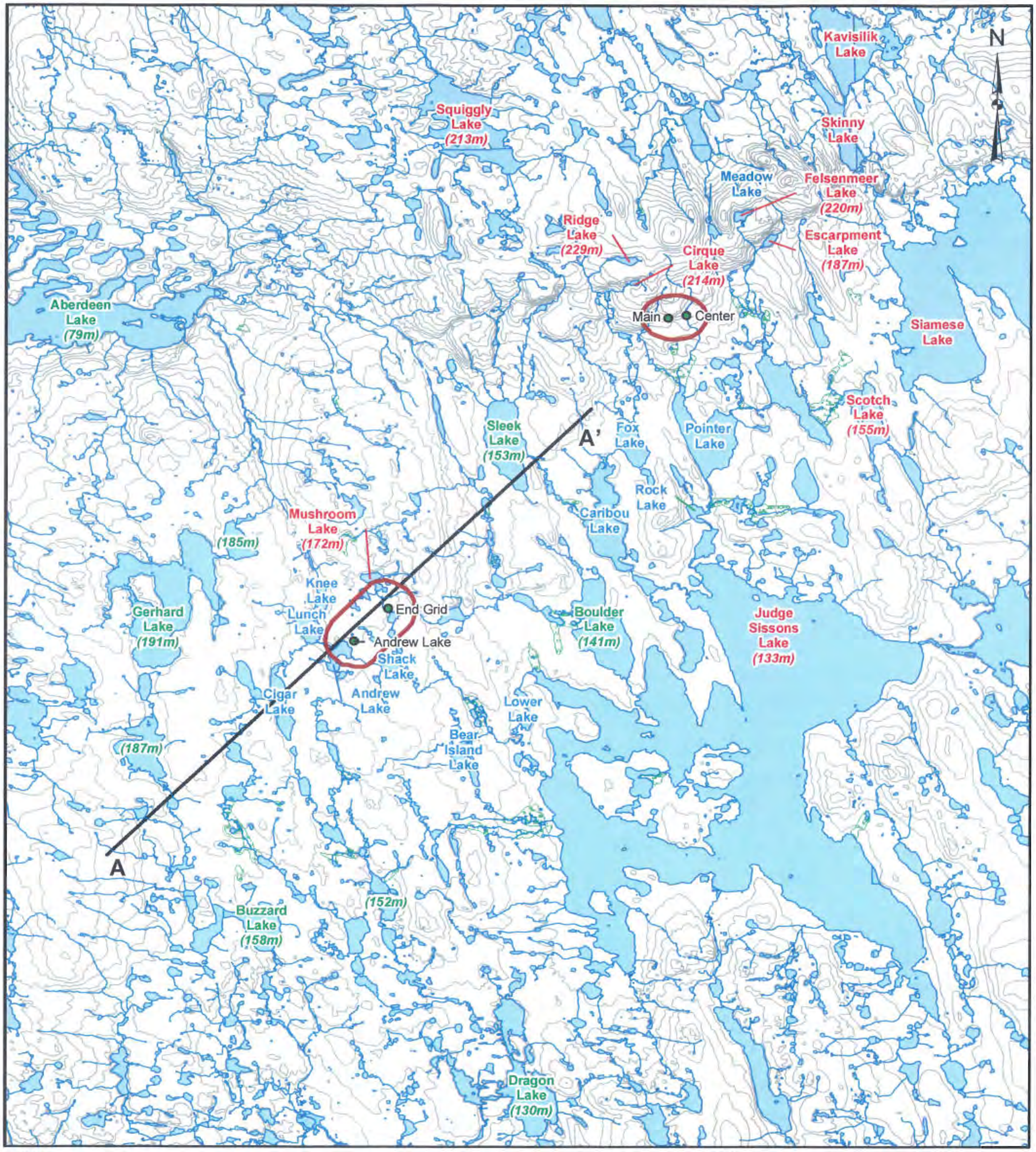

LEGEND

- Proposed Mine Location
- Waterbody
- Wetland
- Watercourse
- Contour (10m)
- Cross Section Location
- Lake Surface Area and Depth Confirmed to Support Talik
- Lake Surface Area will Support Talik but Bathymetry not Available
- Uranium Orebody

REFERENCE

Topographic features provided by the National Topographic Data Base.
Datum: NAD 83 Projection: UTM Zone 14

PROJECT

AREVA RESOURCE CANADA INC.
PREDICTED GROUNDWATER INFLOWS
END GRID MINE

TITLE

LAKES POTENTIALLY SUPPORTING OPEN TALIK FORMATION

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1426-0001			SCALE AS SHOWN	REV. 0
DESIGN	CB	05NOV09	**FIGURE 3**	
GIS	MCM	05NOV09		
CHECK				
REVIEW				

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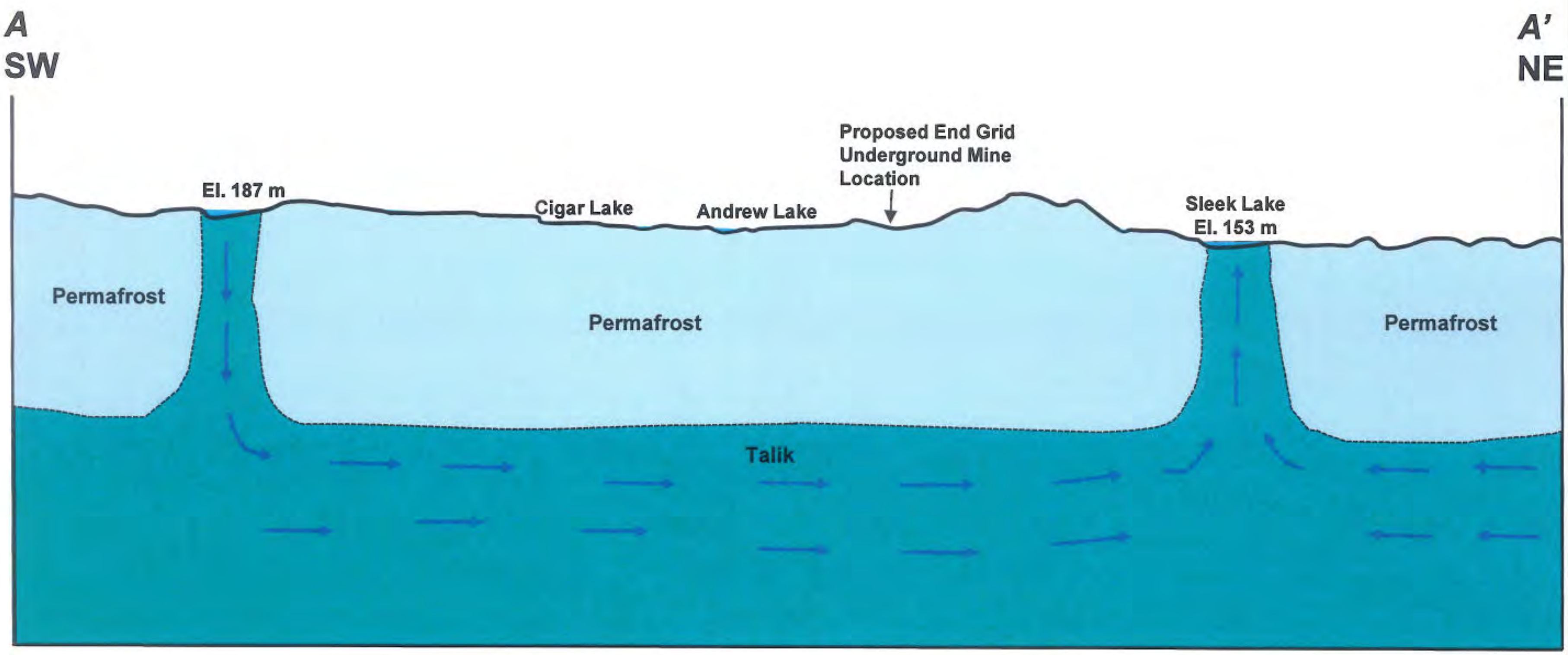

Schematic Only
Not to Scale

PROJECT	AREVA RESOURCE CANADA INC. PREDICTED GROUNDWATER INFLOWS END GRID MINE			
TITLE	CONCEPTUAL MODEL OF HYDROGEOLOGIC CONDITIONS FOR END GRID AREA - BEFORE MINING			
Golder Associates	PROJECT No.	09-1426-0001	PHASE No. 3000	
	DESIGN AP	06NOV09	SCALE NTS	REV.
	CADD AP	06NOV09	FIGURE 4	
	CHECK CB	06NOV09		
	REVIEW DC	06NOV09		

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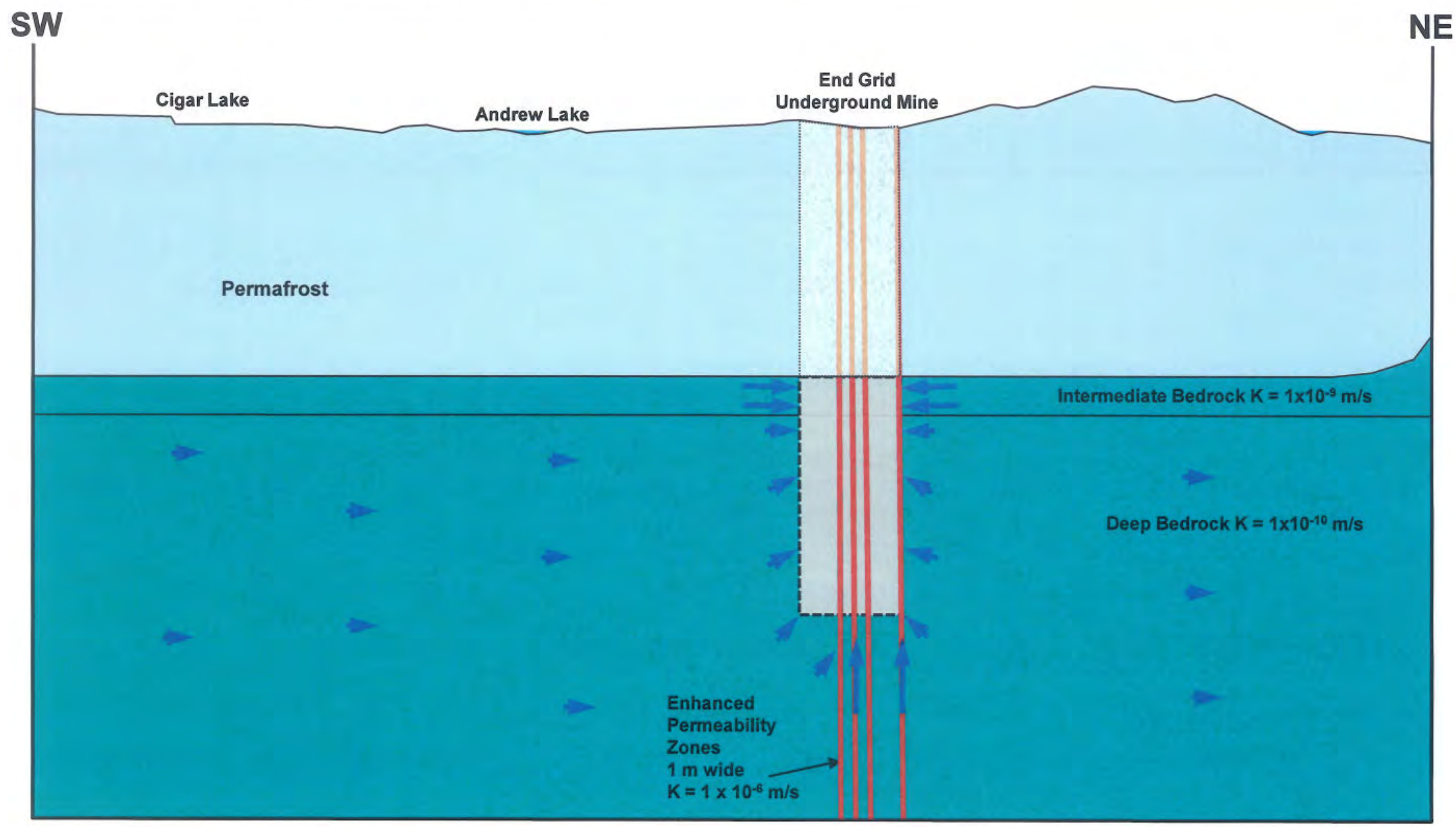

PROJECT	AREVA RESOURCE CANADA INC. PRELIMINARY ASSESSMENT OF EXPECTED GROUNDWATER CONDITIONS		
TITLE	CONCEPTUAL MODEL OF HYDROGEOLOGICAL CONDITIONS END GRID UG MINE DURING MINING		
PROJECT No.	09-1436-0001	PHASE No. 3000	
DESIGN	AP	06NOV09	SCALE NTS / REV.
CADD	AP	06NOV09	
CHECK	CB	06NOV09	FIGURE 5
REVIEW	WZ	12NOV09	

Golder Associates