DOMINION DIAMOND

APPENDIX 8A

HYDROGEOLOGICAL MODEL PRE-MINING, DURING MINING, AND CLOSURE

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Abbreviations

Abbreviation	Definition
Dominion Diamond	Dominion Diamond Ekati Corporation
C	concentration
CC	constant concentration
CH	constant head
DAR	Developer's Assessment Report
Dominion Diamond	Dominion Diamond Ekati Corporation
EA	Environmental Assessment
Ekati Mine	Ekati Diamond Mine
EPZ	enhanced permeability zone
ESA	effects study area
i.e.,	that is
K	hydraulic conductivity
n/a	not available
NWT	Northwest Territories
OP	open pit
Q	flow
TDS	total dissolved solids
Project	Jay Project

Units of Measure

Unit	Definition
%	percent
kg/m^3	kilograms per cubic metre
km	kilometre
km^2	square kilometre
m	metre
m^2	square metre
m^3/day	cubic metres per day
m/s	metres per second
m^2/s	square metres per second
masl	metres above sea level
mbgs	metres below ground surface
mg/L	milligrams per litre

8A1 INTRODUCTION

8A1.1 Background and Scope

The existing Dominion Diamond Ekati Corporation (Dominion Diamond) Ekati Diamond Mine (Ekati Mine) and its surrounding claim block is located approximately 300 kilometres (km) northeast of Yellowknife in the Northwest Territories (NWT), Canada. The Ekati Mine is centred at approximately 64.72°N latitude and 110.55°W longitude. Dominion Diamond proposes to develop the Jay kimberlite pipe (Jay pipe), along with associated mining and transportation infrastructure. The majority of the facilities required to support the proposed Jay Project (Project) and process the kimberlite currently exist at the Ekati Mine. There is an existing haul road between the Misery Pit operations and the Ekati processing plant.

The Project is located in the southeastern portion of the Ekati claim block approximately 25 km from the main facilities, and approximately 7 km east of the Misery Pit, in the Lac de Gras watershed. The Jay pipe, located beneath Lac du Sauvage, will be mined by open pit method. Lac du Sauvage is connected to Lac de Gras by a narrow channel at the northeast extent of Lac de Gras (Map 8A1-1).

8A1.2 Objectives

This appendix presents the results of a hydrogeological assessment of groundwater conditions that are expected to develop in the area of the planned Jay Project during mining and closure of the mine facilities. Specifically, the appendix addresses the approaches and assumptions adopted in the estimate of the potential groundwater inflows and groundwater quality (total dissolved solids [TDS] only) associated with the open pit mining of the Jay pipe. During this assessment, a three-dimensional numerical groundwater model representing the Jay pipe area and the surrounding areas was developed using FEFLOW (Diersch 2014). This model incorporates the mine plan described in the Project Description in Section 3 of the Developer’s Assessment Report (DAR).

During mining, the open pit will act as a sink for groundwater flow. Water originating from both Lac du Sauvage and from deep bedrock will be induced to flow through the bedrock to the mine workings. The average quality of mine inflow will be a result of the mixing of fresh groundwater flowing from Lac du Sauvage and brackish water (connate water) flowing up from deep bedrock.

The objective of the modelling study outlined in this appendix was to estimate inflow quantity and quality to the mine over the mine life (operation) and during refilling of the open pit (closure) for the purposes of the Environmental Assessment (EA). The results of this study are relevant to the hydrogeology pathways within the following key line of inquiry:

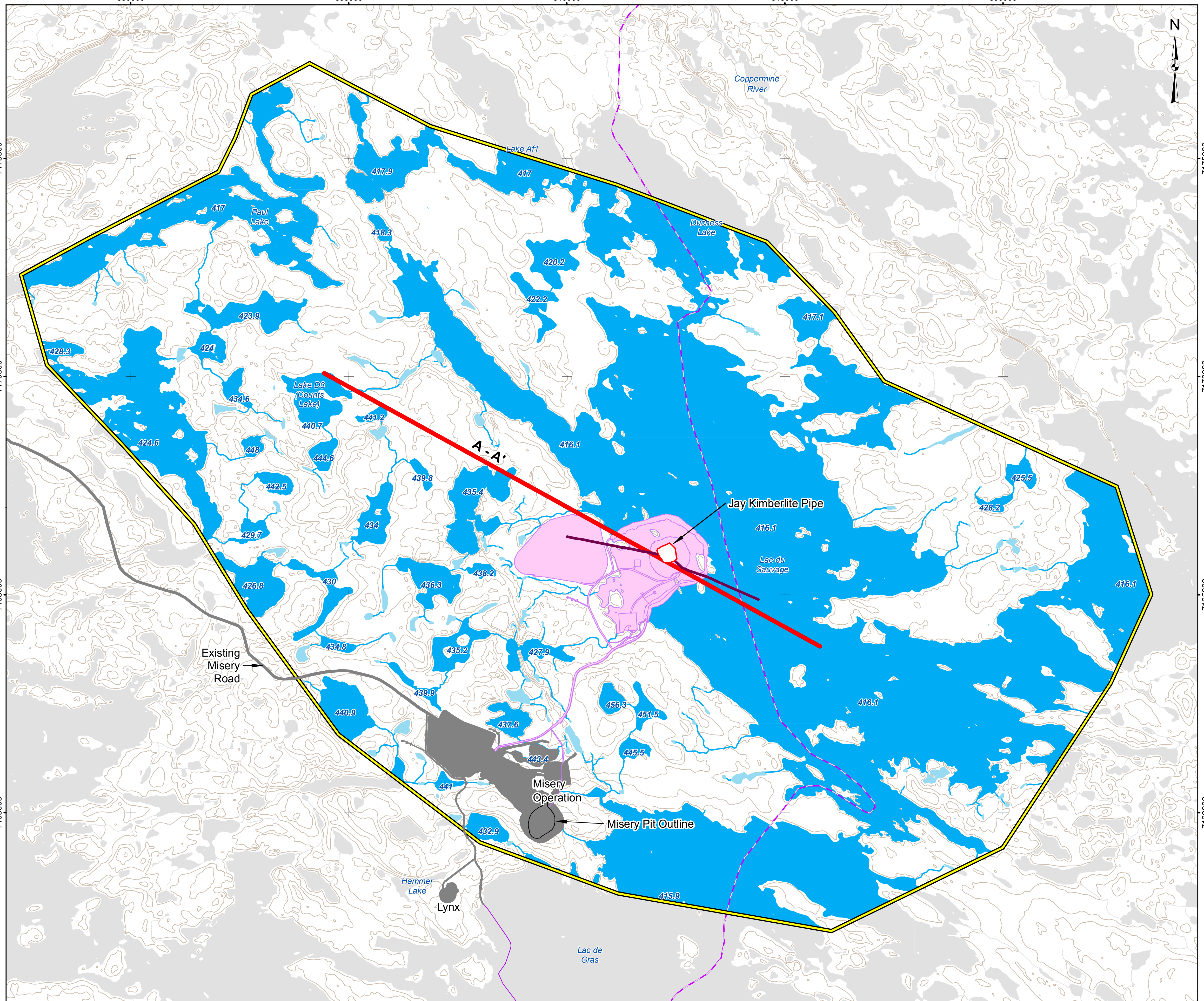
- Water Quality and Quantity (Section 8).

8A1.3 Effects Study Area

The proposed new mining operations would develop the Jay pipe. The Jay pipe is located in the southeastern portion of the Ekati Mine site, approximately 25 km southeast of the Ekati main camp and approximately 7 km east-northeast of the Misery Pit, below the waters of the Lac du Sauvage.

The hydrogeology effects study area (ESA) forms an irregular polygon approximately 15 by 25 km in size. Lac du Sauvage and the site of the proposed Project are located in the central part of the ESA, which covers an area of approximately 300 square kilometres (km^2) (Map 8A1-1). The area encompasses the majority of the Lac du Sauvage sub-basin, which ultimately drains to Lac de Gras. The elevations of large lakes (greater than 133,000 square metres [m^2]) within the ESA range from approximately 415.9 metres above sea level (masl) at Lac de Gras to 456 masl at a small lake approximately 3 km south of the Jay pipe. The two largest lakes within the ESA are Lac du Sauvage and Lac de Gras, which have the lowest lake elevations in the area at 416.1 masl and 415.9 masl, respectively.

The existing Misery Pit is located within the ESA, approximately 7 km to the southwest of the Project area, while the Lynx pipe is located outside the ESA, approximately 8.6 km southwest of the Project area. The existing Ekati Panda, Koala, Koala North, and Fox pits are located outside the ESA, approximately 25 km to the northwest of the Project area. The Diavik Mine A154 and A418 pits are also located outside the ESA approximately 12 km southwest of the Project area.



LEGEND

- EKATI MINE FOOTPRINT
- PROPOSED JAY FOOTPRINT
- KIMBERLITE PIPE
- WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- ELEVATION CONTOUR (10 m INTERVAL)
- WATERCOURSE OUTSIDE THE ESA
- WATERBODY OUTSIDE THE ESA
- CONCEPTUAL CROSS-SECTION
- ENHANCED PERMEABILITY ZONE (LATERAL EXTENT INFERRED)
- WATERCOURSE INSIDE THE ESA
- EFFECTS STUDY AREA (ESA)
- LAKE INSIDE THE ESA WITH INFERRED OPEN TALIK
- LAKE INSIDE THE ESA WITHOUT INFERRED OPEN TALIK
- 416.2 LAKE ELEVATION (masl)

NOTE

THE HYDROGEOLOGICAL MODEL EXTENT CORRESPONDS TO THE ESA

REFERENCE

CANVEC © NATURAL RESOURCES CANADA, 2012
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

DEVELOPER'S ASSESSMENT REPORT

2 0 2
SCALE 1:90,000 KILOMETRES

PROJECT
DOMINION DIAMOND
JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

HYDROGEOLOGICAL MODEL - EFFECTS STUDY AREA

Golder Associates

PROJECT	13-1328-0041		FILE No. DAR_Hydgeo_001_GIS
DESIGN	AP	16/07/14	SCALE AS SHOWN REV 0
GIS	LMR	16/10/14	
CHECK	CB	16/10/14	MAP 8A1-1
REVIEW	WZ	16/10/14	

G:\CLIENTS\DOMINION\DDEC Jay and Lynx Projects\Figures\13-1328-0041 Jay & Lynx EA\Hydrogeology\DAR\DAR_Hydgeo_001_GIS.mxd

8A2 CONCEPTUAL HYDROGEOLOGICAL MODEL

A conceptual hydrogeological model was developed to aid in the construction of the numerical groundwater model. A conceptual hydrogeological model is a pictorial and descriptive representation of the groundwater regime that organizes and simplifies the site conditions so they can be readily modelled. The conceptual model must retain sufficient complexity so that the analytical or numerical models developed from it adequately reproduce or simulate the actual components of the groundwater flow system to the degree necessary to satisfy the objectives of the modelling study.

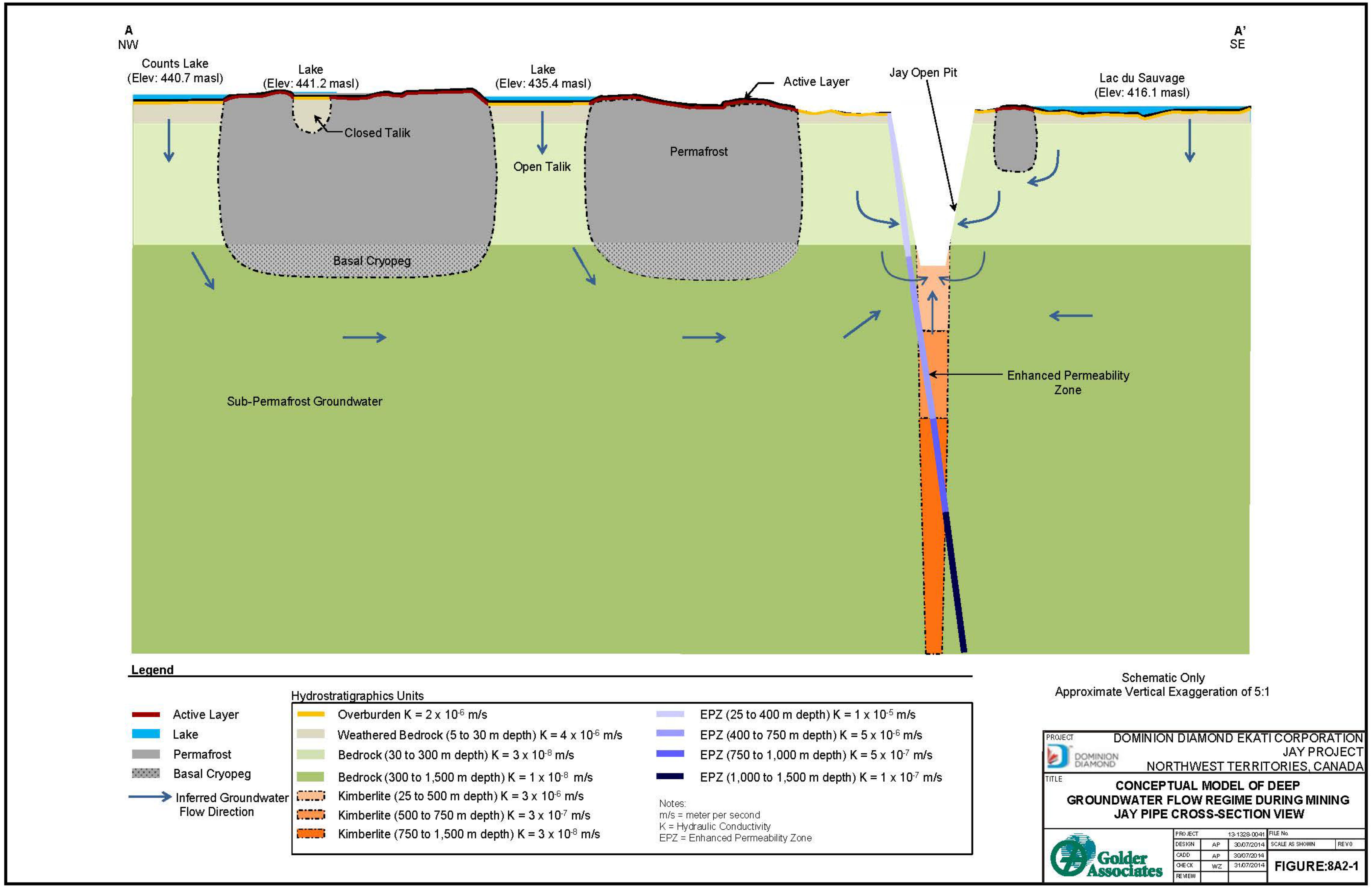
This conceptual model has been developed to describe key features of the pre-mining hydrogeological regime in the ESA as it is discussed in the Hydrogeology Baseline Report (Annex IX). The key features included in this model are the groundwater flow quantity and quality and the dominant groundwater flow direction. The following sections describe the conceptual understanding of groundwater conditions that are expected to develop during mining and closure. These conceptual models are then used as a basis for the construction of the numerical hydrogeological model at the site.

8A2.1 Groundwater Flow – Mining

The conceptual hydrogeological model for groundwater flow conditions near the proposed Project during mining (operations) is presented in Figure 8A2-1. The location of the conceptual cross-section AA' is shown in Map 8A1-1.

The proposed Jay open pit is planned to extend to approximately 370 metres below ground surface (mbgs) (approximately 45 masl) based on information provided by Dominion Diamond. During mining, the open pit will act as a sink for groundwater flow, with seepage faces developing along the pit walls. In response to mine dewatering, groundwater will be induced to flow through the bedrock and enhanced permeability zone (EPZ) to the open pit. Mine inflow will originate both from Lac du Sauvage recharge and from deep bedrock. The average quality of mine inflow will be a result of the mixing of fresh groundwater flowing from Lac du Sauvage and brackish water flowing from deep bedrock.

Figure 8A2-1 Conceptual Model of Deep Groundwater Flow Regime during Mining – Jay Pipe Cross-Section View



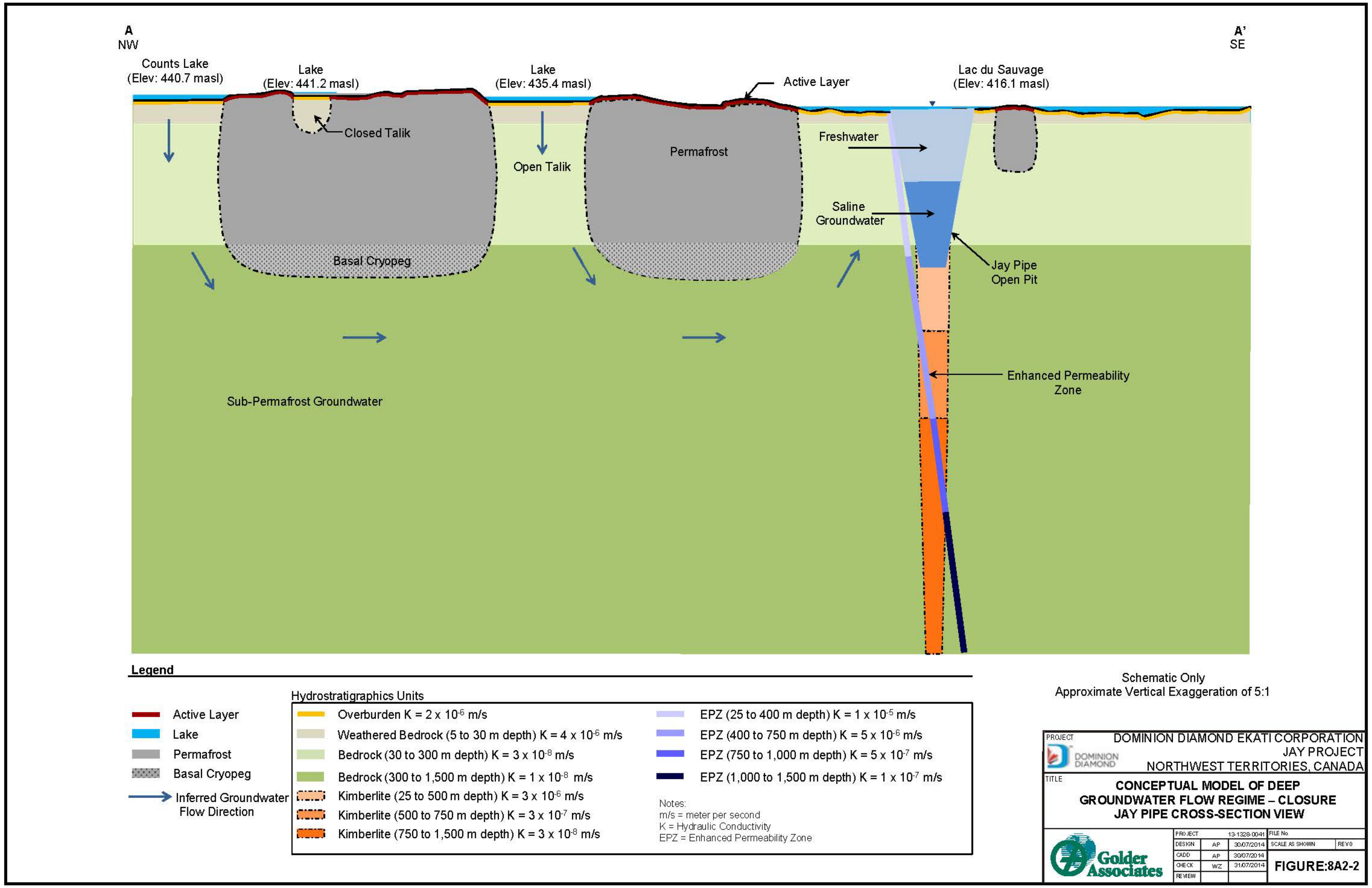
8A2.2 Groundwater Flow – Closure

The conceptual hydrogeological model for groundwater flow conditions near the proposed Project during closure is presented in Figure 8A2-2.

At closure, saline water from the Misery Pit water management pond will be pumped into the bottom of the Jay open pit. In addition, saline groundwater will continue to flow into the open pit through the bedrock. Water will also flow from the open pit into the bedrock, re-saturating the partially dewatered bedrock near the pit walls. This process will dissipate the large hydraulic head differences established during mine operation in the vicinity of the mine workings. The rate of natural saline groundwater inflow will become less as the water level in the former mine opening (i.e., Jay open pit) rises. Freshwater from Lac du Sauvage will also be pumped into the open pit to provide a freshwater cap to the saline water.

It is estimated that the open pit and the dewatered area of Lac du Sauvage surrounding the open pit will be back-flooded over a period of approximately four years.

Figure 8A2-2 Conceptual Model of Deep Groundwater Flow Regime – Closure – Jay Pipe Cross-Section View



8A3 NUMERICAL HYDROGEOLOGICAL MODEL

A numerical hydrogeological model was constructed based on the conceptual model outlined in the previous sections and in Annex IX. The purpose of the numerical model was to evaluate baseline hydrogeological conditions before mining and to estimate the quantity and quality of potential inflows to the open pit during the operation and closure phases of the Project.

8A3.1 Model Selection

The numerical code used for the development of a hydrogeological model should be capable of simulating key characteristics and features included in the site conceptual model. Consequently, FEFLOW, a finite-element code from DHI-WASY (Diersch 2014) was chosen for the development of the groundwater model. This code is capable of simulating transient, saturated-unsaturated groundwater flow and density-coupled solute transport in heterogeneous and anisotropic porous media under a variety of hydrogeologic boundaries and stresses. FEFLOW is particularly well suited for development of the site model because it allows for simultaneous predictions of groundwater flow and solute transport.

8A3.2 Model Extent and Mesh Configuration

The extent of the numerical model is based on the understanding of groundwater flow conditions near the Project site, with lateral model boundaries set sufficiently far from the location of the mine workings to allow adequate representation of pre-development conditions and potential seepage pathways during operation. The extent of the model and mesh are presented in Figures 8A3-1 and 8A3-2.

Figure 8A3-1   Three-Dimensional Extent of the Hydrogeological Model

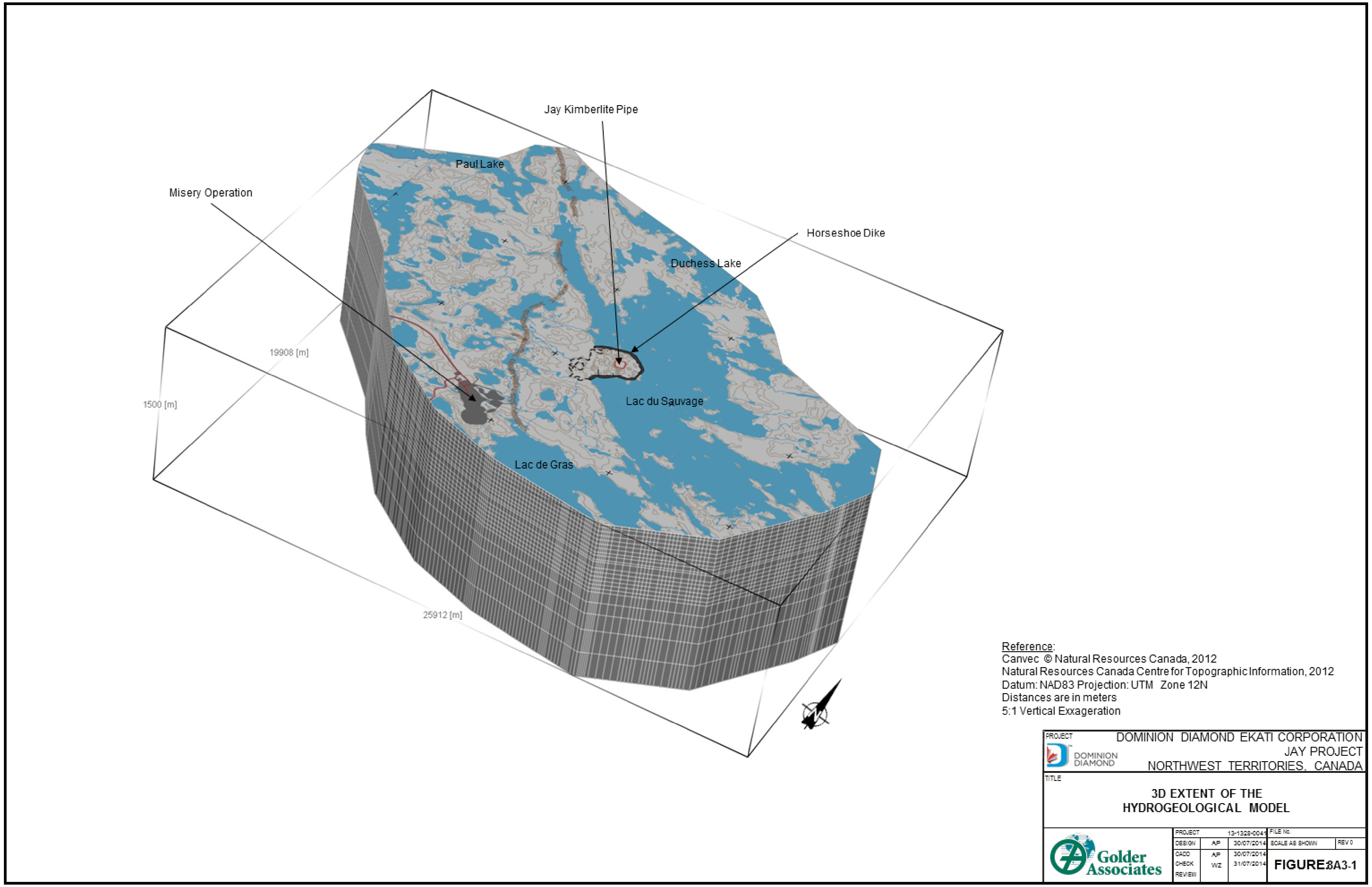
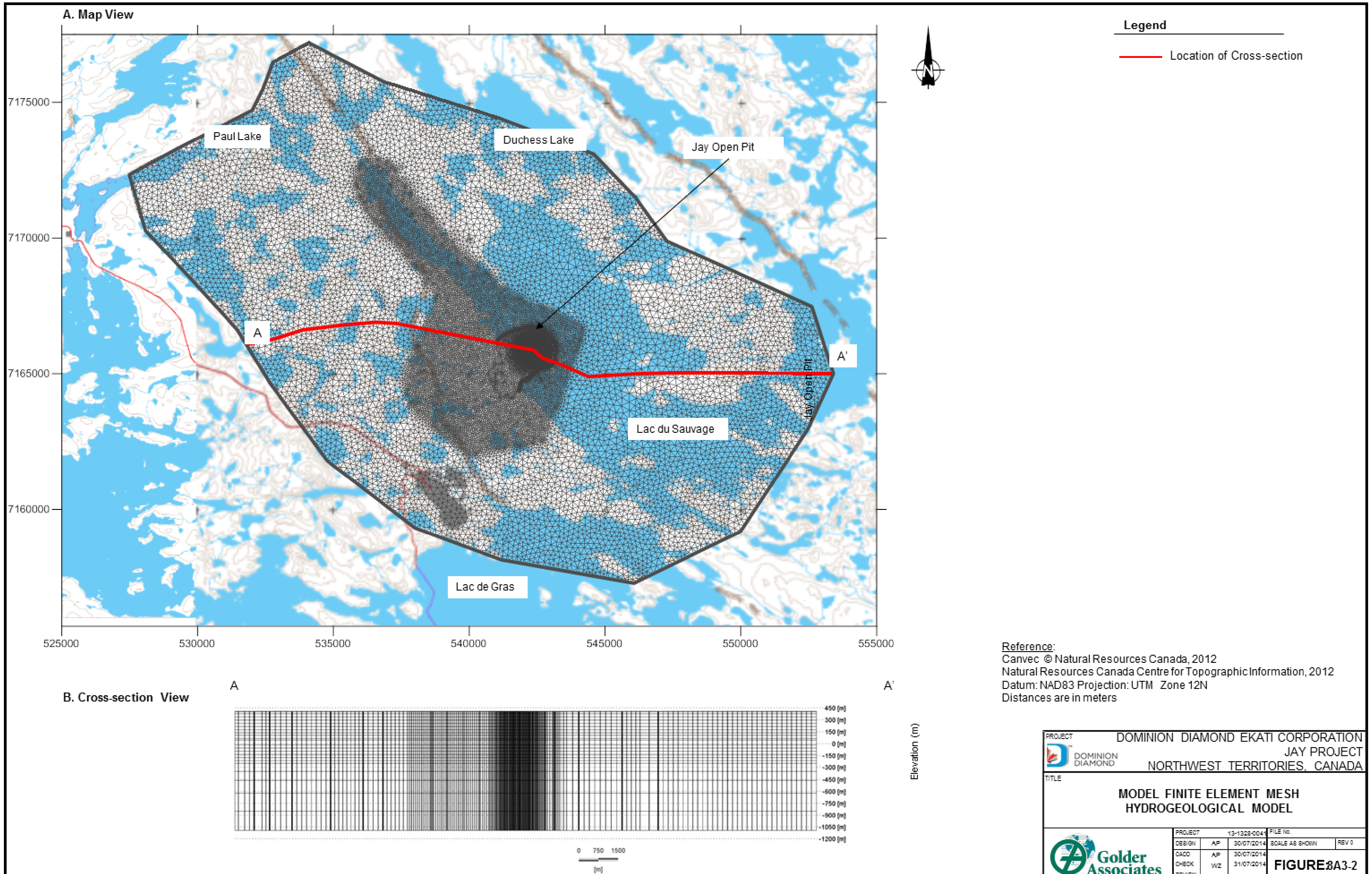


Figure 8A3-2 Hydrogeological Model Finite Element Mesh



Horizontally, the model extends approximately 25 km in an east-west direction and 16 km in a north-south direction, and is roughly centred on the Jay pipe. The planar area of the model domain is approximately 300 km^2. In the north and west, the model follows Paul Lake, 418 Lake, and Duchess Lake, and an inferred equipotential line between Duchess Lake and the west arm of Lac du Sauvage. In the south, the model follows Lac de Gras, and in the east, it follows an inferred equipotential line between Paul Lake and Lac de Gras.

The mesh consists of approximately one million triangular elements with a uniform spacing of 25 metres (m) in the areas of mine workings where strong hydraulic gradients are expected to develop during operation. Elements expand to a size of approximately 50 m in the area of Lac du Sauvage where lake dewatering will occur and where substantial groundwater drawdown is expected to occur. Elements progressively expand to a size of approximately 500 m along the model perimeter. Overall, the mesh spacing is considered to be of appropriate detail for simulation of hydrogeological conditions at the site.

Vertically, the model domain is discretized into 23 layers. The top of Layer 1 was set equal to the average planned elevation of dewatering for the area around the open pit during operation (406 masl). The bottom of Layer 23 was set to a constant elevation of -1,094 masl (approximately 1.5 km below ground surface), which is approximately 1,200 m below the ultimate depth of the deepest planned open pit mine level at the Jay pipe (45 masl).

8A3.3 Hydrostratigraphy and Model Parameters

Five hydrostratigraphic units, consisting of overburden, weathered bedrock, competent bedrock, kimberlite, and an EPZ associated with a sub-vertical faults, were represented in the model (Figure 8A3-3). A summary of the hydrogeological properties of each unit that were incorporated into the numerical groundwater model as a Reference Case scenario is provided in Table 8A3-1. The Reference Case scenario reflects the most likely estimate of hydrogeological conditions that are expected to be encountered during mining. Values of hydrogeological parameters were obtained from in situ hydrogeologic testing, where available, as discussed in the Hydrogeology Baseline Report (Annex IX). Where in situ values were not available, typical values published in the literature or derived from nearby sites were used.

Conservative assumptions have been made for model parameters (Table 8A3-2) such that they result in conservative (i.e., high) predictions of mine inflow quantity and quality, including travel times and saline upwelling.

Figure 8A3-3 Location and Extent of Hydrostratigraphic Units in the Hydrogeological Model

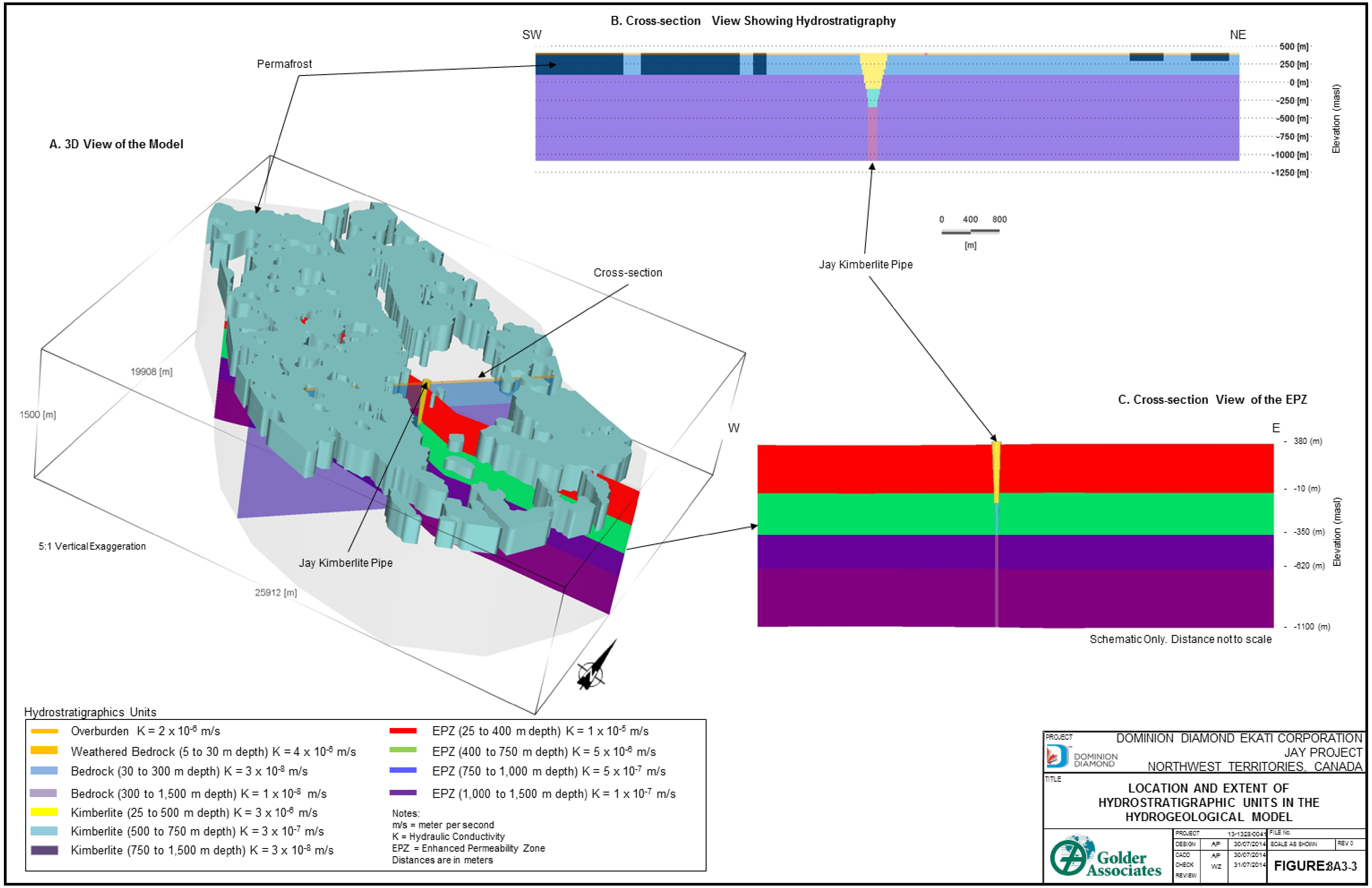


Table 8A3-1 Hydrogeological Parameters Used in the Model

Hydrostratigraphic Unit	Depth Interval (m)	Reference Case Horizontal Hydraulic Conductivity (m/s)[a]	Ratio of Vertical to Horizontal Hydraulic Conductivity[b]	Specific Storage (1/m)[c]	Specific Yield[c]	Effective Porosity[c]	Longitudinal Dispersivity (m)[d]	Transverse Dispersivity (m)[d]	Effective Diffusion Coefficient (m^2/s)
Overburden	0 – 5	2.E-06	1:1	1E-04	0.2	0.2	10	1	2E-10
Weathered bedrock	5 – 30	4.E-06	1:2	2E-04	0.03	0.03	10	1	2E-10
Competent bedrock	30 - 300	3.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Competent bedrock	300 - 500	1.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Competent bedrock	500 – 1,500	1.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Kimberlite (including contact zone)	25 - 500	3.E-06	1:2	1E-04	0.01	0.1	10	1	2E-10
Kimberlite (including contact zone)	500 - 750	3.E-07	1:2	1E-05	0.005	0.05	10	1	2E-10
Kimberlite (including contact zone)	750 – 1,500	3.E-08	1:2	1E-05	0.005	0.05	10	1	2E-10
EPZ[e]	25 - 400	1.E-05	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	400 - 750	5.E-06	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	750 – 1,000	5.E-07	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	1,000 – 1,500	1.E-07	1:1	1E-04	0.01	0.01	10	1	2E-10

a) Derived from hydraulic testing results at the Jay Project, supplemented by Golder (2004).

b) Vertical anisotropy assigned in both weathered rock and kimberlite based on the geological descriptions of these units.

c) Parameter values were conservatively derived from those used in the Diavik numerical model, which was calibrated to inflow quantity and quality observed during mine operations (Golder 2004). These values are within the ranges documented in the literature (Maidment 1992; Stober and Bucher 2007).

d) Parameter values were conservatively derived from those used in the Diavik numerical model, which was calibrated to inflow quantity and quality observed during mine operations (Golder 2004). These values are consistent with literature values (Schulze-Makuch 2005).

e) Enhance permeability zones assumed to be trending northwest-southeast, and to be 60 m wide in the Reference Case, based on the properties of EPZs observed at the Panda, Koala, and Diavik A154 mines, and on geological evidence.

EPZ = enhanced permeability zone; m = metre; m/s = metres per second; m^2/s = square metres per second.

Table 8A3-2 Conservative Hydrogeological Assumptions in Numerical Hydrogeological Model

Parameter	Lower Bound	Upper Bound	Value Assumed in Developer's Assessment Report	Comment
Porosity of competent bedrock[(a)]	0.001	0.023	0.001	Conservative: Shorter travel times and greater saline upwelling.
Specific storage of competent bedrock (1/m)[(a)]	1.E-07	1.E-05	1.E-05	Conservative: Greater release of water from storage in bedrock and greater calculated inflow quantity.
Hydraulic conductivity of weathered bedrock (m/s)	6.E-08	5.E-06	4.E-06	Conservative: The arithmetic mean was selected for shallow weathered bedrock above 30 mbgs. Higher hydraulic conductivities used in the model results in greater mine inflow quantity.
Hydraulic conductivity of competent bedrock (m/s)	2.E-10	5.E-07	3.E-08 (30 to 300 m depth); 1.E-08 (below 300 m depth)	Conservative: The selected values represent 3 times the geometric mean calculated from in situ testing.
Hydraulic conductivity of the EPZ (m/s)	9.E-07	5.E-05	1.E-05 (25 to 400 m depth); 5.E-06 (400 to 750 m depth); 5.E-07 (750 to 1,000 m depth); 1.E-07 (below 1,000 m depth)	Conservative: The shallow value of hydraulic conductivity represents the arithmetic mean of in situ testing. Extension of EPZ to the bottom of the model with high values of hydraulic conductivity will result in the promotion of higher saline water up into the mine workings.
Extent of the EPZ			extending laterally and vertically over the entire model domain	Conservative: Extension of the EPZ over the entire model domain will result in better connection between the open pit and Lac du Sauvage and deep groundwater system with higher saline water, and will promote greater inflow quantity and higher saline water up into the open pit.
Density effect			freshwater (1,000 kg/m^3)	Conservative: Shorter travel times and more upwelling than if density effects were considered.

a) Derived from the Diavik numerical model calibrated to inflow quantity and quality observed during mining operations (Golder 2004). This value is within the range documented in published literature (Maidment 1992; Stober and Bucher 2007).

EPZ = enhanced permeability zone; m = metre; m/s = metres per second; mbgs = metres below ground surface; kg/m^3 = kilograms per cubic metre.

An overall summary of the assumptions and limitations of the numerical modelling is provided in Table 8A3-3 including those associated with the underlying modelling codes.

Table 8A3-3 Assumption and Limitations of the Groundwater Model

Groundwater flow in the bedrock was simulated as “equivalent porous media.” Flow in bedrock is assumed to be laminar, steady, and governed by Darcy’s Law.
Horizontal mesh discretization of approximately 25 m and vertical mesh discretization of 40 m were used to provide sufficient spatial resolution for simulation of groundwater flow and transport near the open pit.
Values assigned to model input parameters were based on the 2014 winter program site investigations (Annex IX) and values published for nearby sites, or published in the literature where site-specific data were not available.
Surface waterbodies were simulated using specified head boundaries. It was assumed that the permeability of sediments beneath these waterbodies is similar to the underlying geologic strata. Thus, no restriction of flow between the surface water and individual hydrostratigraphic units was simulated.
Groundwater flow deeper than approximately 1.5 km below ground surface was assumed to be negligible and to have negligible influence on model predictions.

m = metre; km = kilometre.

8A3.4 Mine Schedule

The mine schedule discussed in the Project Description (Section 3) is summarized in Table 8A3-4. The dewatering of the area within the horseshoe dike will be conducted over a period of approximately six months (Period 1). After dewatering, pre-stripping of the open pit area will begin in Period 2 and will take approximately three months. Following pre-stripping, mining of the open pit will begin in Period 3 and will continue for 10 years (Period 12) when the pit bottom will reach an elevation of 45 masl. After mining is complete, the open pit will be filled with minewater from the Misery Pit and freshwater from Lac du Sauvage over a period of approximately 3 years (Period 13). During the last period of approximately one year (Period 14), the diked off area (sump) will be back-filled with freshwater to the original lake elevation of 416.1 masl.

Table 8A3-4 Jay Project Mine Schedule

Period	Phase	Pit Bench Elevation (masl)	Duration (Days)
1	Dewatering	406	180
2	Stripping	390	90
3	OP Mining	350	365
4	OP Mining	325	365
5	OP Mining	295	365
6	OP Mining	270	365
7	OP Mining	230	365
8	OP Mining	205	365
9	OP Mining	180	365

Table 8A3-4 Jay Project Mine Schedule

Period	Phase	Pit Bench Elevation (masl)	Duration (Days)
10	OP Mining	150	365
11	OP Mining	110	365
12	OP Mining	45	365
13	Closure (Pit Flooding)	45	1,018
14	Closure (Sump Flooding)	45	332

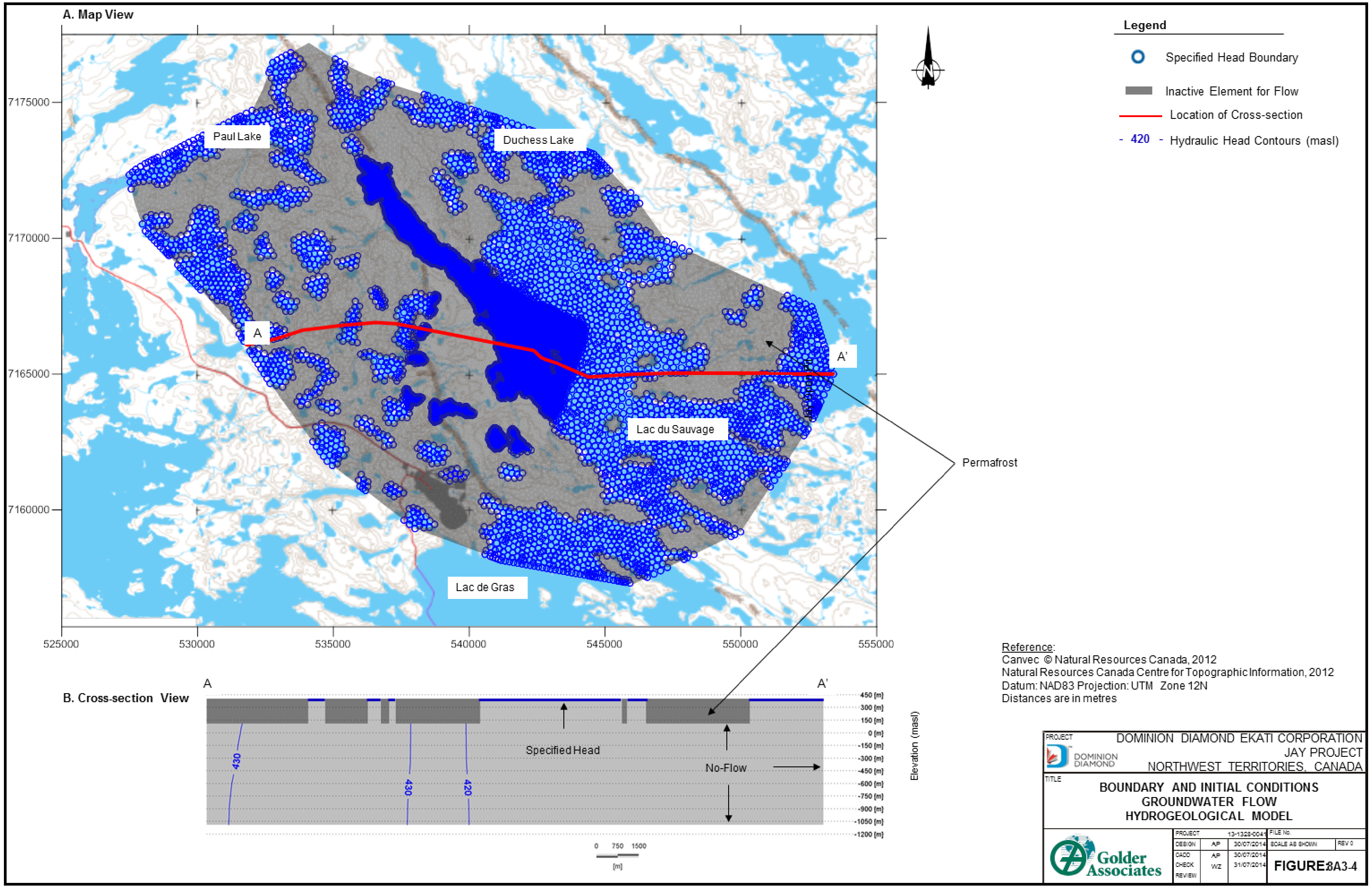
OP = open pit; masl = metres above sea level;

8A3.5 Model Boundary Conditions

8A3.5.1 Flow Boundary Conditions and Initial Conditions

Model boundary conditions provide a link between the model domain and the surrounding hydrologic and hydrogeologic systems. Two types of flow boundary conditions were used in the model: specified head, and no-flow (zero flux) boundaries. The locations of these boundaries are shown in Figure 8A3-4 and are summarized below.

Figure 8A3-4 Boundary and Initial Conditions – Groundwater Flow Hydrogeological Model



Specified head boundaries were assigned to Layer 1 of the model to represent all lakes assumed to have open taliks connected to the deep groundwater flow regime. Each of these boundaries was set to the surveyed average lake elevation. It was conservatively assumed that the surface water/groundwater interaction at all lakes is not impeded by lower-permeability lakebed sediments that may exist on the bottom of some of these lakes.

During operation, time-variable specified head boundaries were assigned to Layer 1 of the model to represent the lake dewatering and back-flooding in the area within the dike (sump area). For each of these boundaries, in the first year of lake dewatering, the water level was varied from the original water level elevation of Lac du Sauvage (416.1 masl) to the planned average operational water level elevation (406 masl), as specified in the water management plan. At the end of mining and after the back-flooding of the open pit during closure, these boundaries were modified such that they represented lake water level recovery to the original elevation of 416.1 masl.

Mine workings (open pit) were simulated in the model using time-variable specific head boundaries. At each mesh node within the perimeter of the open pit, a specified head boundary was assigned and the head value at this boundary was varied over time to represent progress of pit excavation according to the mine schedule described in Section 8A3.4. The pit bench elevations were derived from elevation contours representing the final pit design. In addition, all boundaries representing mine workings were constrained to allow only outflow from surrounding sediments/bedrock into the mine (i.e., these boundaries act as seepage faces). Furthermore, mesh elements inside the open pit in a given model layer were deactivated over time as the mining reached the bottom of the model layer.

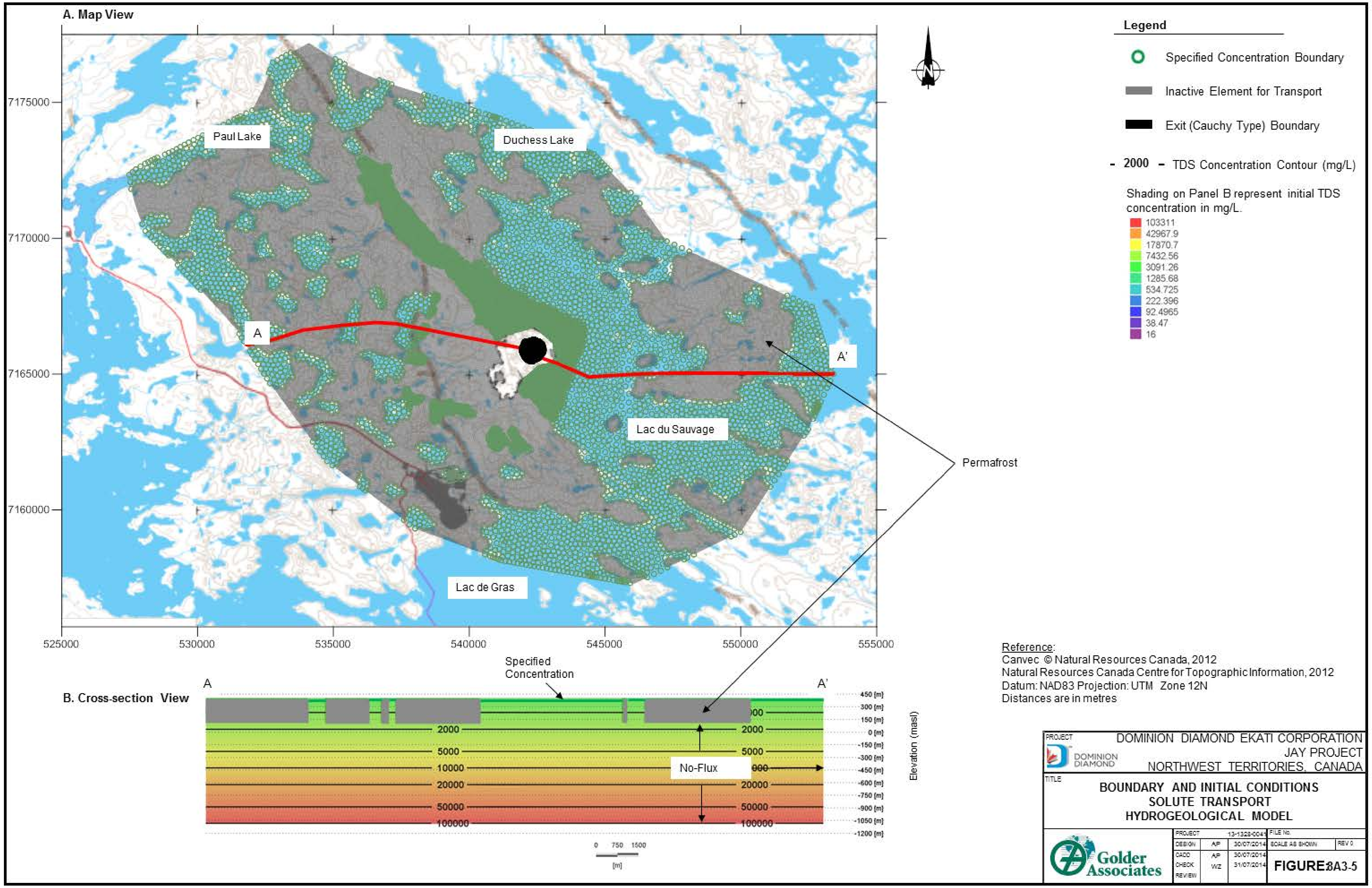
No-flow boundaries were used to represent inferred groundwater flow divides and flow lines along the perimeter of the model. These boundaries were located sufficiently far from the mine to have only a negligible impact on model predictions. However, the effect of these no-flow boundaries on model predictions was assessed as part of the sensitivity analysis discussed in Section 8A3.7. A no-flow boundary was also applied along the bottom of the model at a depth of 1.5 km below ground surface (-1,094 masl). Flow at greater depth is expected to be negligible, and therefore, to have negligible impact on model predictions. No-flow boundaries were also assigned along the edges of the permafrost as the permafrost is expected to be essentially impermeable. Mesh elements representing permafrost were deactivated in all model simulations.

Initial groundwater flow conditions represent the pre-mining groundwater flow regime described in Annex IX where the groundwater flow is controlled by the water elevation of the large lakes in the ESA. The groundwater flow pattern predicted by hydrogeological model simulating pre-mining conditions was evaluated qualitatively to assess if it was in agreement with the conceptual understanding of baseline site groundwater conditions. This groundwater flow pattern was then used as initial conditions in the hydrogeological model.

8A3.5.2 Transport Boundary Conditions and Initial Conditions

Three types of boundary conditions were used to simulate transport of TDS in groundwater: specified concentration boundaries, zero flux boundaries, and exit (Cauchy type) boundaries. The locations of these boundaries are shown in Figure 8A3-5.

Figure 8A3-5 Boundary and Initial Conditions – Solute Transport Hydrogeological Model



Specified concentration boundaries of zero milligrams per litre (mg/L) (freshwater) were assigned along the bottom of all lakes assumed to have with open taliks in connection with the deep groundwater flow regime.

Zero flux boundaries were applied along the bottom of Layer 23, 1.5 km below ground surface. Mass flux from beneath this depth was considered to have negligible impact on model predictions.

Exit (Cauchy type) boundaries were assigned to the nodes representing the pit walls. These boundaries simulated the movement of TDS mass out of the surrounding groundwater system and into the mine workings.

Initial TDS concentrations in each model layer were assigned based on the assumed Jay TDS depth profile discussed in the Hydrogeology Baseline Report (Annex IX) and shown in Figure 8A3-5, with the exception of Layer 1. Layer 1 represents the shallow till to 5 m depth. Groundwater in the till was assumed to be relatively fresh and to have TDS concentration equivalent to lake water.

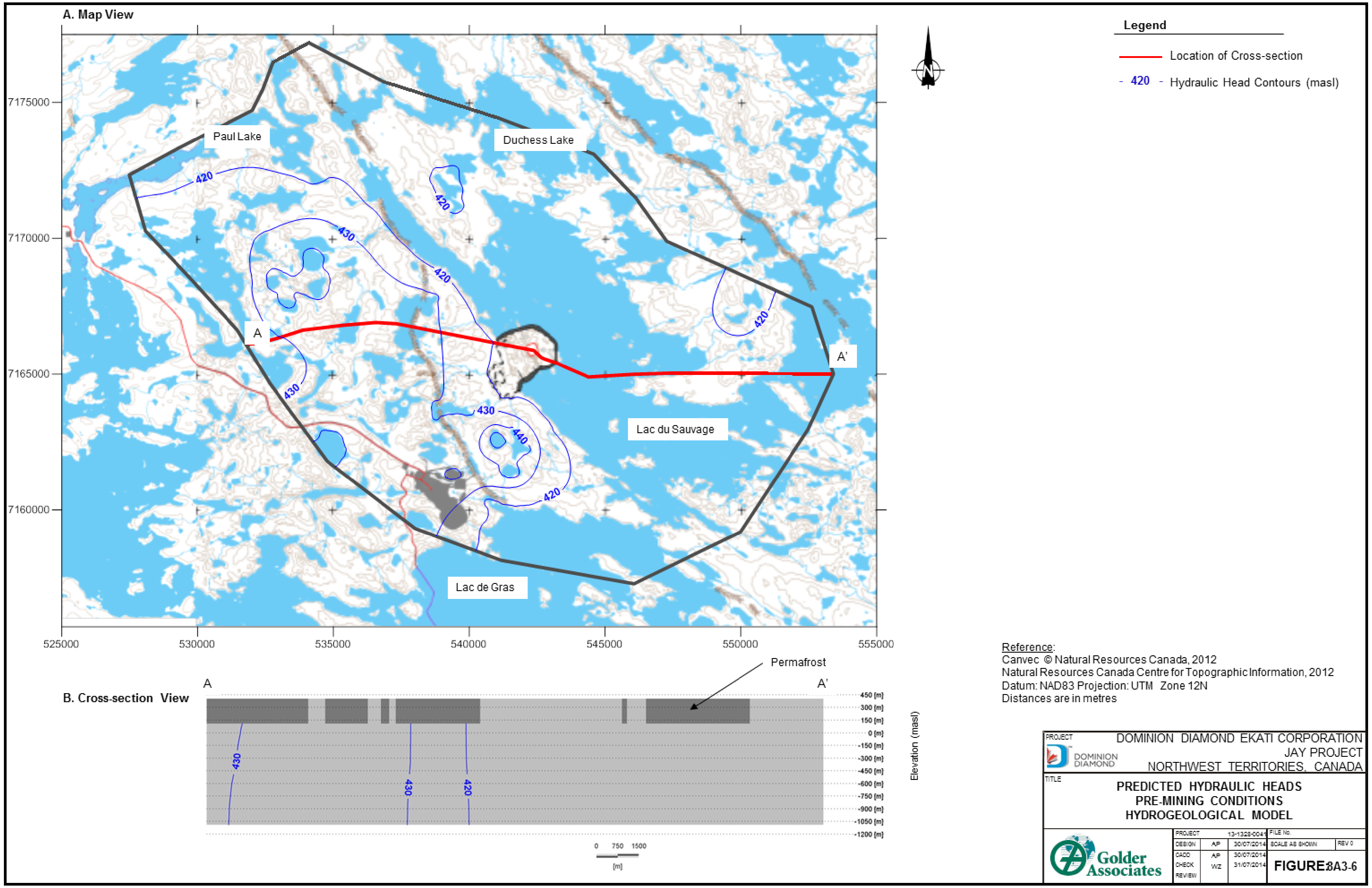
8A3.6 Model Predictions – Reference Case

The following section presents predicted hydrogeological conditions for the Project based on hydrogeological parameters discussed in Section 8A3.3 and presented in Table 8A3-2. These predictions are hereafter referred to as Reference Case predictions. Uncertainty in the predicted groundwater quantity and quality resulting from the uncertainty in these parameters is discussed in Section 8A3.7.

8A3.6.1 Current Conditions

Predicted hydrogeological conditions for the pre-mining flow field are presented in Figure 8A3-6. The predominant groundwater flow direction in the deep groundwater flow regime is to the northeast to Lac du Sauvage. Before mining, Lac du Sauvage represents a discharge zone with water discharging to the lake from several higher elevation lakes with open taliks located west and southwest from Lac du Sauvage. In addition, some of these higher elevation lakes are predicted to provide discharge to Lac de Gras south of Lac du Sauvage. Therefore, a groundwater flow divide is predicted to be present to the east of Lac du Sauvage.

Figure 8A3-6 Predicted Hydraulic Heads – Pre-mining Conditions Hydrogeological Model



8A3.6.2 Mining and Closure

Predicted hydrogeological conditions when the mine workings reach the ultimate depth (45 masl) are presented in Figures 8A3-7 and 8A3-8 for the Reference Case. Predicted groundwater inflow quantity and quality over the mine life including closure are presented in Table 8A3-5.

Figure 8A3-7 Predicted Hydraulic Heads – End of Mining – Reference Case Hydrogeological Model

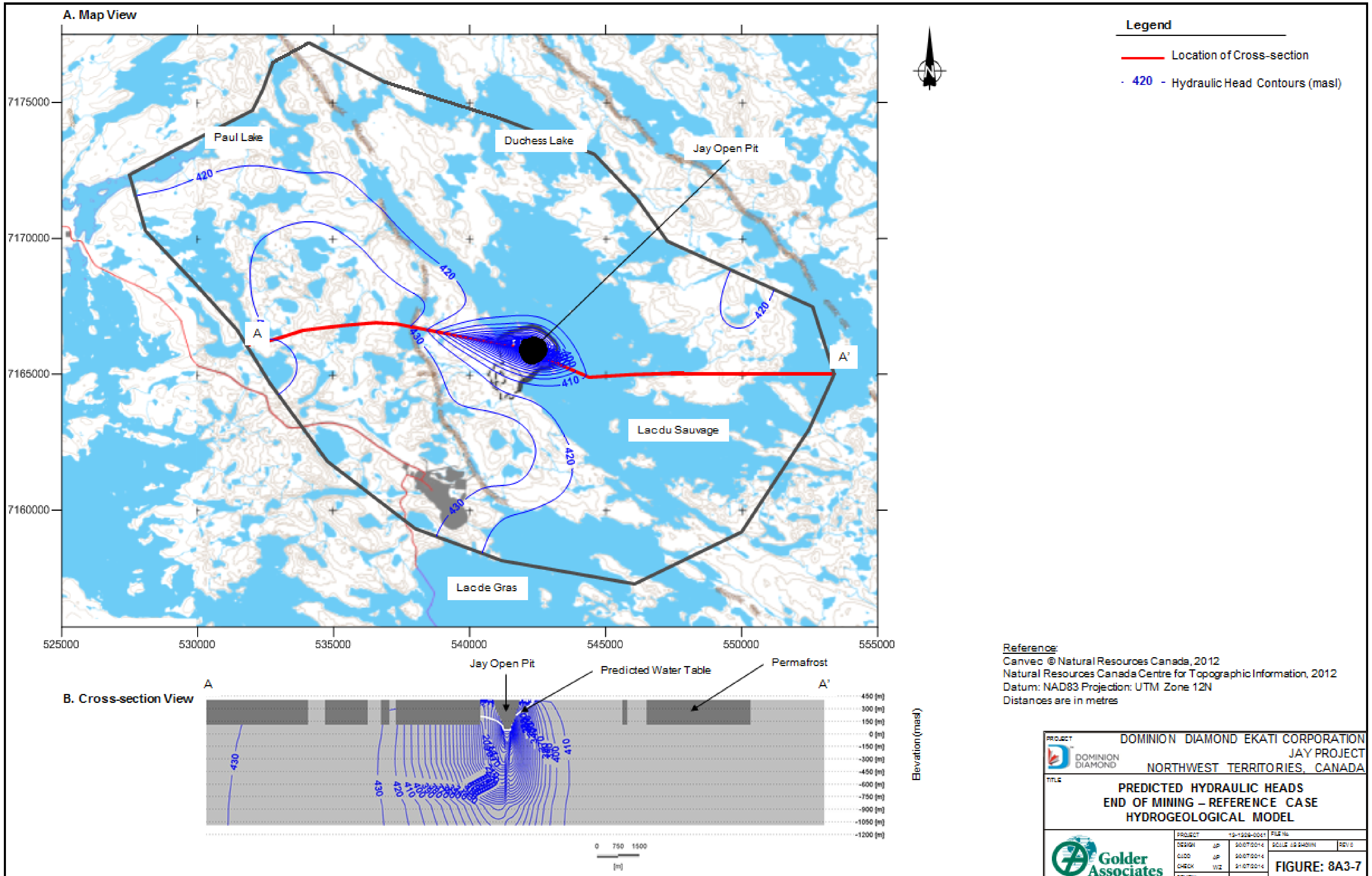


Figure 8A3-8 Predicted Drawdown and Total Dissolved Solids – End of Mining – Reference Case Hydrogeological Model

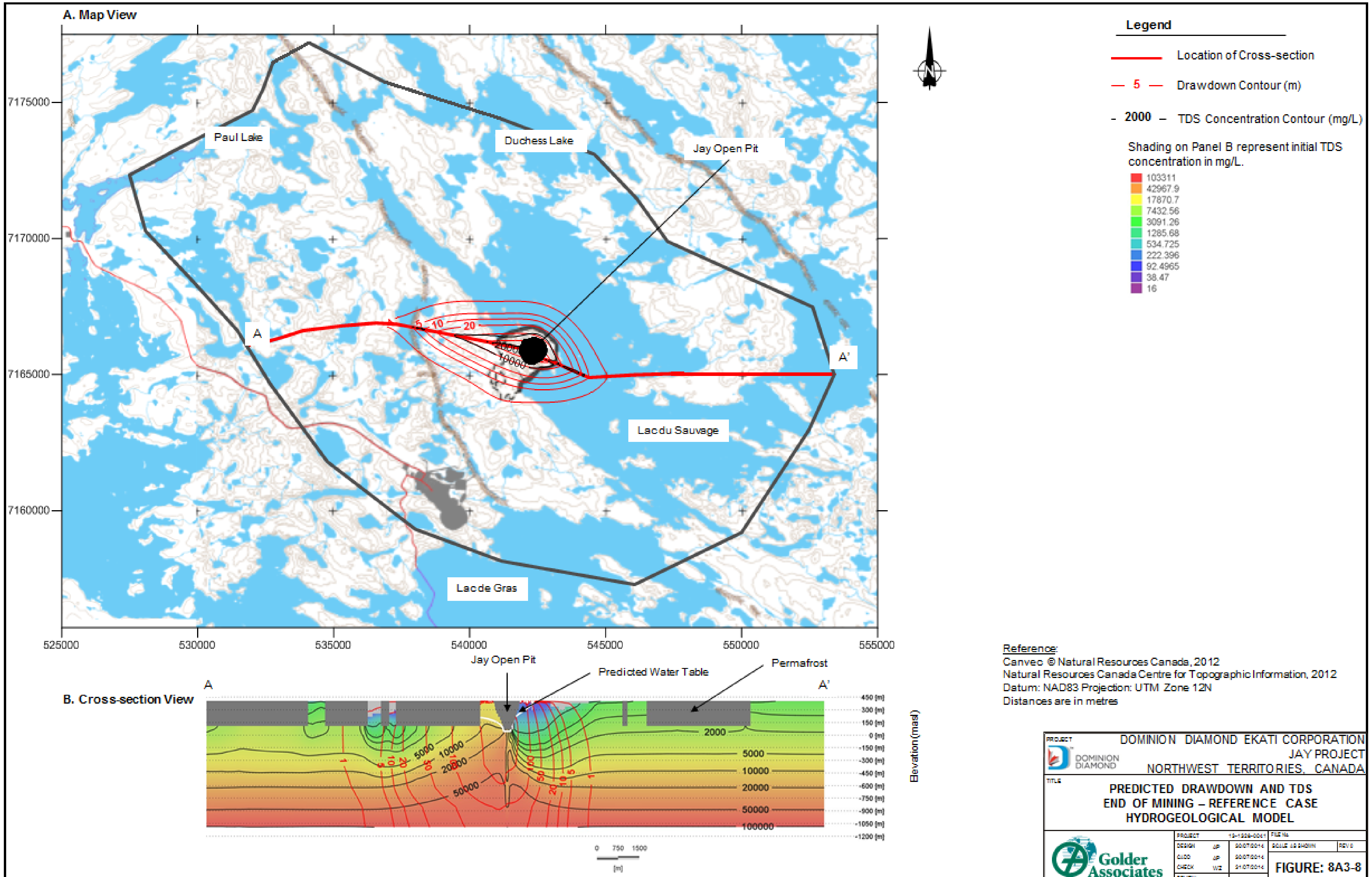


Table 8A3-5 Predicted Groundwater Inflow and Groundwater Quality Over the Mine Life (Reference Case)

Period	Phase	Duration (Days)	Reference Case			
			Groundwater Inflow (m^3/day)		Groundwater Quality (mg/L)	Lake Water in Total Inflow (%)
			Jay Pit	Diked Area Around Jay Pit	Jay Pit	
1	Dewatering	180	800	5,000	300	0
2	Stripping	90	10,000	200	400	0
3	OP Mining	365	5,900	0	1,100	2
4	OP Mining	365	6,500	0	1,700	14
5	OP Mining	365	7,100	0	2,100	28
6	OP Mining	365	8,000	0	2,600	35
7	OP Mining	365	9,400	0	3,100	39
8	OP Mining	365	10,200	0	3,600	47
9	OP Mining	365	10,300	0	4,100	50
10	OP Mining	365	10,800	0	4,700	51
11	OP Mining	365	11,400	0	5,500	53
12	OP Mining	365	13,700	0	7,100	48
13	Closure (OP Flooding)	1,018	6,300	0	2,300	72
14	Closure (Sump Flooding)	332	-900	-11,000	n/a	n/a

Note:

Positive values indicate predicted net groundwater inflow into the mine workings.

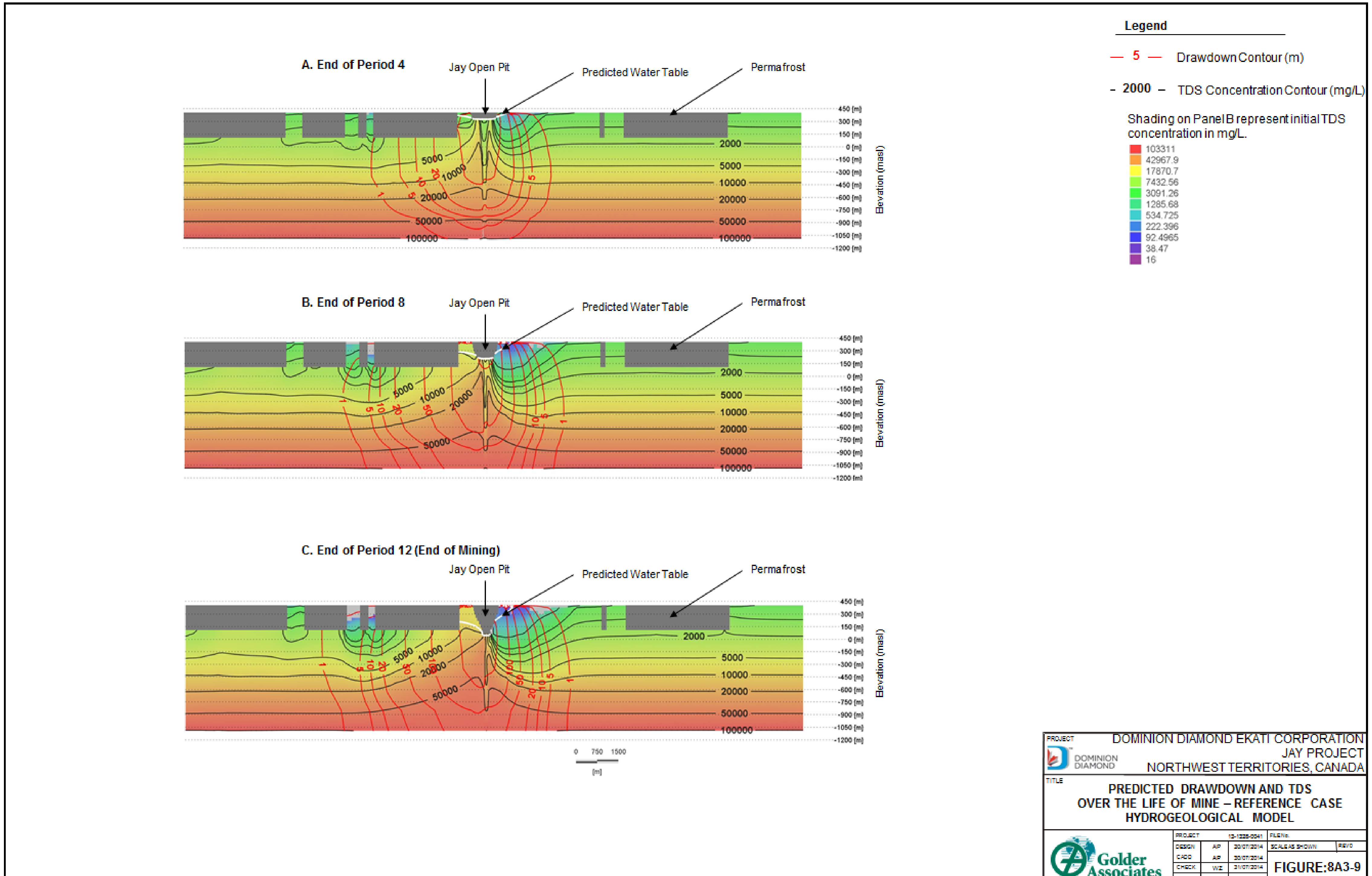
Negative values indicate new water outflow to the subsurface from the mine openings. During these stages, water level in the pit is higher than in surrounding rock, and flow is to fill the pores in the rock around the pit.

OP = open pit; n/a = not available; m^3/day = cubic metres per day; mg/L = milligrams per litre;% = percent.

In the early stages of mining when the pit depth is relatively shallow (pre-stripping), much of the groundwater inflow to the pit is attributed to water released from storage in the overburden and shallow bedrock beneath Lac du Sauvage and within the footprint of the dike. In the later stages of mining, these units have been dewatered, and groundwater inflow to the pit is through the EPZ and surrounding bedrock. As shown in Table 8A3-5, groundwater inflow to the Jay open pit is predicted to increase throughout its development, varying from approximately 5,900 cubic metres per day (m^3/day) in Period 2 to approximately 13,700 m^3/day in Period 12 when the pit reaches its ultimate extent (pit bottom at 45 masl).

Predictions of TDS concentration in mine inflow were based on the Jay TDS depth profile discussed in Annex IX. Based on this profile, the groundwater model predicts that the TDS concentration in inflow to the open pit would increase from approximately 300 mg/L in Year 2 to approximately 7,100 mg/L in Period 12 once the pit reaches its ultimate configuration (Table 8A3-5). This predicted increase in TDS concentration over the life of the pit is the result of the higher salinity of the groundwater in the deep bedrock that is encountered as the pit extends to greater depths, and the upwelling of higher TDS water from beneath the pit. Contribution to inflow from lake water from Lac du Sauvage is predicted to be negligible during the first two periods (dewatering and pre-stripping). As mining of the pit advances, the lake water contribution is predicted to increase from approximately 2 percent (%) in Period 3 when mining of the pit begins to a maximum of approximately 48% at the end of mining in Period 12. Predicted drawdown and TDS concentrations over the mine life for three selected periods (end of period 4, end of period 8, and end of mining) are presented in Figure 8A3-9.

Figure 8A3-9 Predicted Drawdown and TDS Over the Mine Life – Reference Case - Hydrogeological Model



Groundwater inflow to the open pit during the refilling of the mine workings in Period 13 is predicted to gradually decrease to a total average inflow of approximately 6,300 m^3/day. The TDS level in the groundwater inflow to the pit during refilling is predicted to decrease to an average of 2,300 mg/L. The variations in the contribution to the TDS of the pit inflow from surface water inputs are accounted for separately in the site water quality model described in Appendix 8E.

After Period 13, the hydraulic gradient between the flooded pit and surrounding surface water is expected to be negligible. Groundwater inflows to the flooded pit after this time were assessed using a post-closure model discussed in Appendix 8B.

These predictions consider only groundwater inflow to the proposed mine workings, and do not include potential inputs from direct precipitation within the footprint of the open pit and/or surface water runoff (if not diverted) from the surrounding areas. Therefore, dewatering rates may be higher than the groundwater inflow rates described in this section.

8A3.7 Sensitivity Analysis

Where uncertainty exists, several conservative assumptions were made in the numerical hydrogeological model as presented in Table 8A3-2. Therefore, the Reference Case predictions discussed in the preceding section reflect conservative hydrogeological conditions that could be encountered during operation and closure for the Project. However, due to inherent uncertainty in the subsurface conditions and parameters controlling groundwater flow, uncertainty exists in the model predictions such that the actual inflow could be somewhat higher or lower than the Reference Case values. This uncertainty was evaluated using sensitivity analysis. As part of this analysis, selected model parameters were systematically varied from the Reference Case values, and the results were used to identify the parameters to which predicted inflow was most sensitive.

Ten model input parameters were included in the sensitivity analysis. These included:

- Hydraulic conductivity of the competent bedrock was increased by a factor of 3 from Reference Case values.
- Hydraulic conductivity of the Jay pipe was increased by a factor of 3 from Reference Case values.
- Hydraulic conductivity of the EPZ was increased by a factor of 3 from Reference Case values.
- Dimensions of the EPZ were varied from the Reference Case scenario as follows:
  - A shorter EPZ (approximately 2 km long) centred in the area of the Jay pipe.
  - A shallower EPZ extending to 400 m depth only.
- Storage properties of competent bedrock: Values of specific storage were increased by a factor of 5 and values of specific yield were increased by a factor of 2.5 from the Reference Case values.
- Constant head boundary conditions were set along the perimeter of the model in all layers to assess the potential effect of lateral boundaries on predicted inflow.
- Depth to the permafrost bottom was decreased to 200 mbgs.

- The TDS depth profile was changed as follows:
  - The Jay TDS depth profile was replaced by the Diavik TDS depth profile (as in Figure 5.2-1 in Annex IX).
  - The Jay TDS depth profile was increased by a factor of 2 at all depths.
- Porosity was decreased in all units by a factor of 5 from the Reference Case values.
- Dispersivity was increased in all units by a factor of 5 from the Reference Case values.

The sensitivity factors summarized above were selected to adequately represent potential uncertainty in each model parameter. During the analysis, twelve simulations were completed (one adjustment for each parameter considered). At the end of each simulation, predicted maximum groundwater inflow and maximum TDS concentrations in the open pit (Period 12) were compared to the values predicted in the Reference Case, as presented in Table 8A3-6.

Table 8A3-6 Hydrogeological Model – Results of Sensitivity Analysis

	Period 12 (Jay Pit)		Period 12 (Jay Pit)	
	Pit Inflow		TDS Concentration	
Sensitivity Run	**Q (m^3/day)**	**Change (%)**	**C (mg/L)**	**Change (%)**
Reference Case	13,700	-	6,900	-
Hydraulic Conductivity – EPZ				
Increase hydraulic conductivity x 3	28,600	109	6,000	-13
Dimensions – EPZ				
"Short" EPZ (2,000m long)	10,400	-24	2,400	-65
"Shallow" EPZ (extending to 400 m depth only)	11,300	-18	800	-88
Hydraulic Conductivity – Country Rock				
increase hydraulic conductivity x 3	16,200	18	7,900	14
Hydraulic conductivity – kimberlite				
Increase hydraulic conductivity x 3	14,700	7	7,900	14
Storage Properties				
Increase specific storage x 5 and specific yield x 2.5 in country rock	15,400	12	7,700	12
Boundary Conditions				
CH and CC set along model perimeter in all layers	14,800	8	7,000	1
Permafrost				
Depth to permafrost bottom decreased to 200 m	14,400	5	7,000	1
TDS Depth Profile				
Jay TDS depth profile replaced with Diavik profile(a)	-	-	3,500	-49
TDS at all depths x 2	-	-	13,400	94

Table 8A3-6 Hydrogeological Model – Results of Sensitivity Analysis

Sensitivity Run	Period 12 (Jay Pit) Pit Inflow		Period 12 (Jay Pit) TDS Concentration	
	Q (m^3/day)	Change (%)	C (mg/L)	Change (%)
Porosity				
Decrease porosity in all units / 5	-	-	10,200	48
Dispersivity				
Increase dispersivity in all units x 5	-	-	6,800	-1

(a) The Diavik TDS Profile is shown in Figure 5.2-1 in Annex IX

C = concentration; CH = constant head; CC = constant concentration; EPZ = enhanced permeability zone; Q = flow; TDS = total dissolved solids; m^3/day = cubic metres per day;% = percent; mg/L = milligrams per litre; - = no change from Reference Case

The results of the sensitivity analysis indicate that the quantity of groundwater inflow predicted for the Jay Pit is most sensitive to the hydrogeological parameters assigned to the EPZ (hydraulic conductivity and dimensions). This result was expected as approximately 70% of the groundwater inflow to the open pit at the end of mining is predicted to originate from the EPZ. When the hydraulic conductivity of the EPZ was increased by a factor of 3 from the Reference Case value, the predicted groundwater inflow increased to approximately 28,600 m^3/day (109% higher than the Reference Case). When the EPZ dimensions were reduced, the predicted inflow decreased from the Reference Case predictions by 24% and 18% for the shorter and shallower EPZ, respectively. Model predictions of groundwater inflow into mine workings were also moderately sensitive to the hydraulic conductivity and storage properties assigned to the competent bedrock unit. Other parameters considered in the sensitivity analysis had a negligible influence on predicted inflow quantity.

Results of the sensitivity analysis also indicate that the predicted TDS concentration of mine inflows is directly related to the TDS depth profile. When the Diavik TDS depth profile was incorporated into the model, peak TDS concentration in groundwater inflow was predicted to decrease to 3,500 mg/L (approximately 49% less than in the Reference Case). When the TDS concentrations assigned based on the Jay TDS depth profile were increased by a factor of 2, peak concentration in groundwater inflow was predicted to increases to approximately 13,400 mg/L (94% higher than in the Reference Case). Predicted mine inflow quality was also sensitive to the dimensions of the EPZ. A significant reduction in mine inflow TDS was predicted when the depth of the EPZ was reduced to 400 m below the ground surface. The predicted peak TDS concentration in mine inflow in this sensitivity scenario was 800 mg/L (88% less than in the Reference Case). Shorter EPZ resulted in a decrease in predicted TDS in mine inflow to 2,400 mg/L (65% less than in the Reference Case).

8A4 MODEL PREDICTIONS – ENVIRONMENTAL ASSESSMENT CONSERVATIVE SCENARIO

The Reference Case predictions discussed in the preceding section provide conservative predictions of groundwater inflow quantity and quality for the Project and the associated sensitivity analyses quantify the uncertainty in these predictions. Based on these results, a model scenario was prepared that provides a reasonable upper bound of groundwater inflow to the mine. This scenario, hereafter referred to as the Environmental Assessment (EA) Conservative Scenario, results in a sufficient level of conservatism to provide a high level of confidence that the effects on the environment have not been underestimated.

In the EA Conservative Scenario, the following changes were made to the model parameters adopted in the Reference Case:

- The thickness of the EPZ at shallow depth (up to 750 m of depth) was increased from 60 m to 100 m such that the equivalent transmissivity was comparable to the transmissivity of the Duey's Fault at the Diavik mine. Duey's Fault provides significant contribution to mine inflow at Diavik, and it is considered the most transmissive EPZ at the Diavik and Ekati mines.
- The hydraulic conductivity of the competent bedrock at all depths was increased by a factor of 3 from the Reference Case values.

Predicted groundwater inflow quantity and quality over the mine life for the EA Conservative Scenario are presented in Table 8A4-1. Predicted hydrogeological conditions when the mine workings reach the ultimate depth are presented in Figures 8A4-1 and 8A4-2. Predicted drawdown and TDS concentrations over the mine life for three selected periods (end of period 4, end of period 8, and end of mining) are presented in Figure 8A4-3.

A comparison of results between Reference Case and EA Conservative Scenario is presented in Figure 8A4-4.

Table 8A4-1 Predicted Groundwater Inflow and Groundwater Quality Over the Mine Life (Environmental Assessment Conservative Scenario)

			Environmental Assessment Conservative Scenario			
			Groundwater Inflow (m^3/day)		Groundwater Quality (mg/L)	
Period	Phase	Duration (Days)	Jay Pit	Diked Area Around Jay Pit	Jay Pit	Lake Water in Total Inflow (%)
1	Dewatering	180	900	5,400	300	0
2	Stripping	90	10,400	300	400	0
3	OP Mining	365	7,700	0	1,200	1
4	OP Mining	365	9,500	0	2,000	16
5	OP Mining	365	10,700	0	2,500	29
6	OP Mining	365	12,100	0	3,000	37
7	OP Mining	365	14,300	0	3,600	42

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Table 8A4-1 Predicted Groundwater Inflow and Groundwater Quality Over the Mine Life (Environmental Assessment Conservative Scenario)

Period	Phase	Duration (Days)	Environmental Assessment Conservative Scenario			
			Groundwater Inflow (m^3/day)		Groundwater Quality (mg/L)	Lake Water in Total Inflow (%)
			Jay Pit	Diked Area Around Jay Pit	Jay Pit	
8	OP Mining	365	15,700	0	4,200	48
9	OP Mining	365	16,000	0	4,600	54
10	OP Mining	365	17,000	0	5,000	58
11	OP Mining	365	18,000	0	5,800	59
12	OP Mining	365	21,300	0	7,300	56
13	Closure (OP Flooding)	1,018	7,300	0	2,600	74
14	Closure (Sump Flooding)	332	-2,300	-11,000	n/a	n/a

Note:

Positive values indicate predicted net groundwater inflow into the mine workings.

Negative values indicate new water outflow to the subsurface from the mine openings. During these stages, water level in the pit is higher than in surrounding rock, and flow is to fill the pores in the rock around the pit.

n/a = not available; OP = open pit; m^3/day = cubic metres per day; mg/L = milligrams per litre;% = percent.

The quantity of groundwater inflow predicted in the EA Conservative Scenario over the mine life is overall higher than the Reference Case. At the end of mine life when the pit reaches its final depth (Period 12), the predicted inflow is approximately 21,300 m^3/day, or approximately 55% higher than the Reference Case inflow. The predicted TDS concentrations in inflow are similar to the ones predicted in the Reference Case; however, the TDS mass loading into the open pit is predicted to increase by approximately 55% compared to the Reference Case predictions due to higher inflow quantity predicted in the EA Conservative Scenario.

Figure 8A4-1 Predicted Hydraulic Heads End of Mining – Environmental Assessment Conservative Scenario

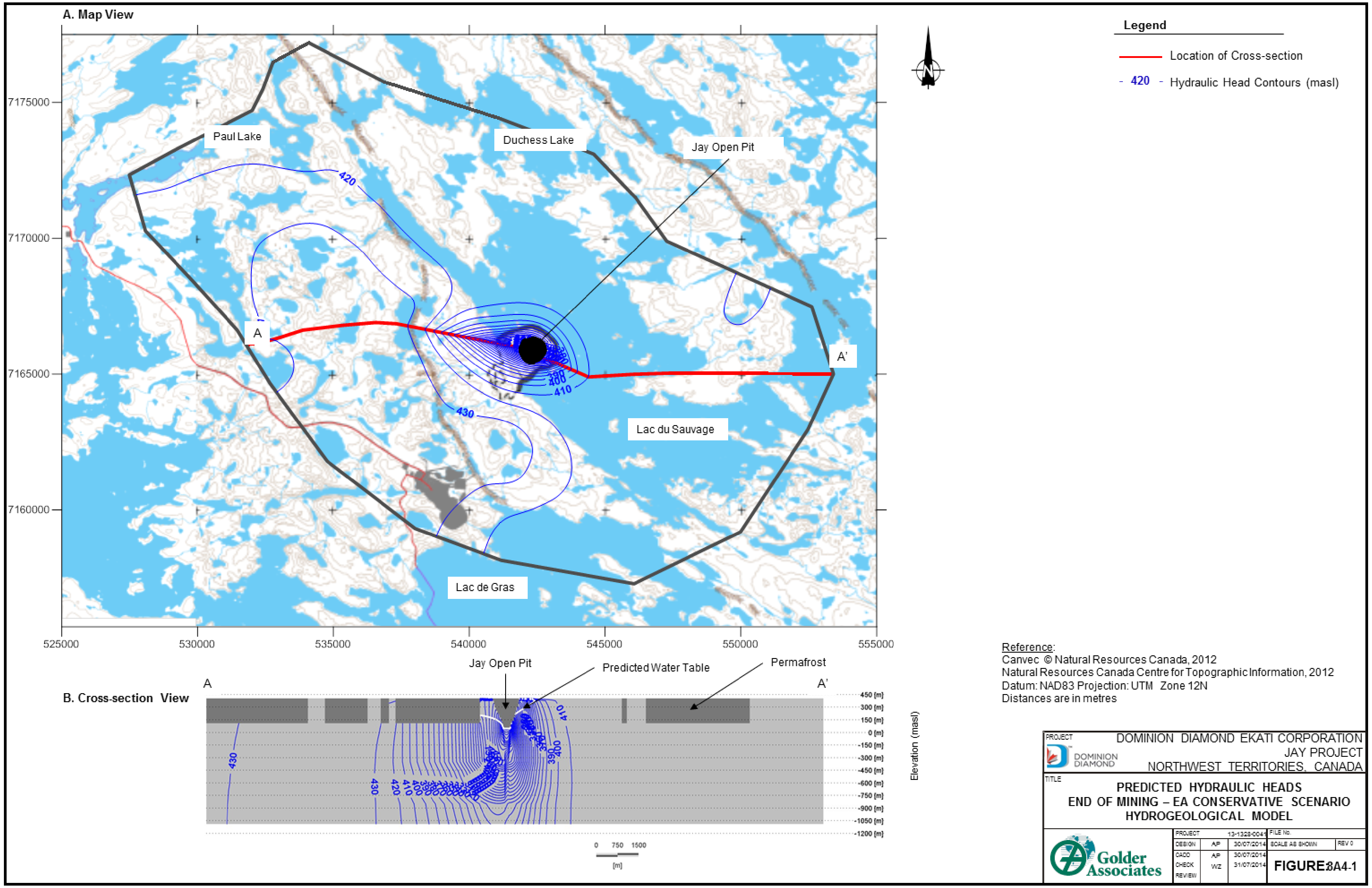


Figure 8A4-2 Predicted Drawdown and Total Dissolved Solids End of Mining – Environmental Assessment Conservative Scenario

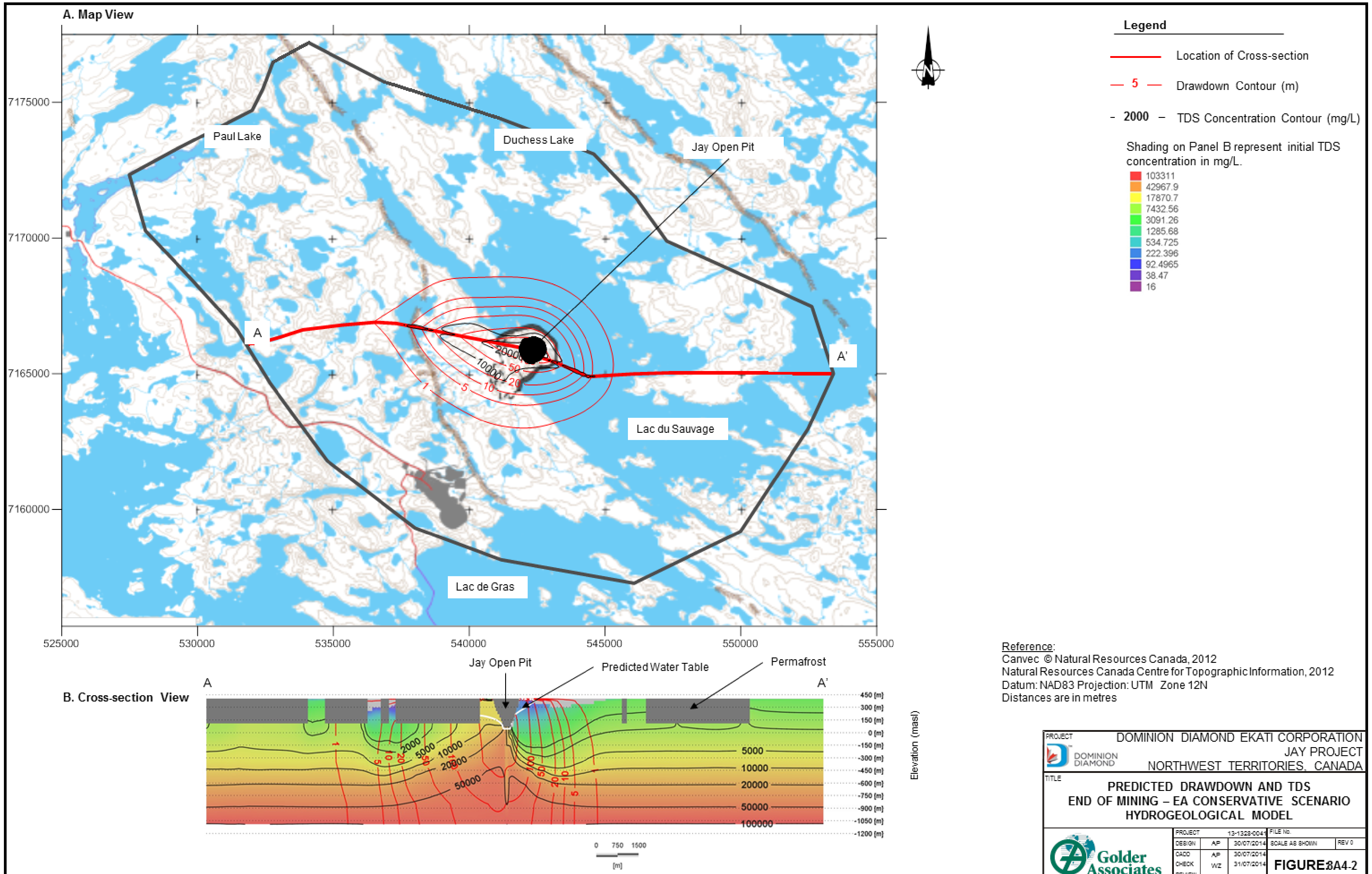


Figure 8A4-3 Predicted Drawdown and Total Dissolved Solids Over the Mine Life – Environmental Assessment Conservative Scenario - Hydrogeological Model

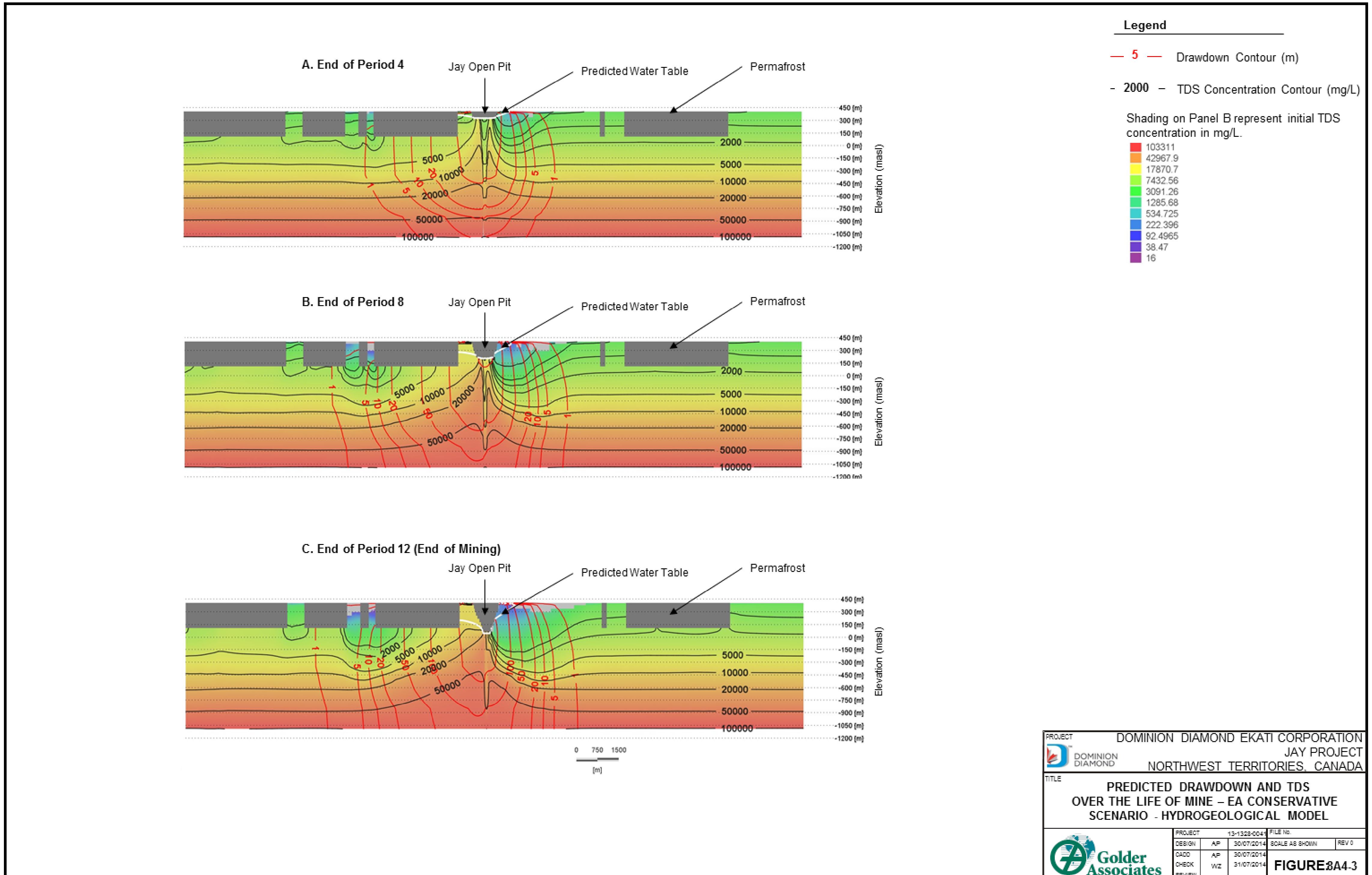
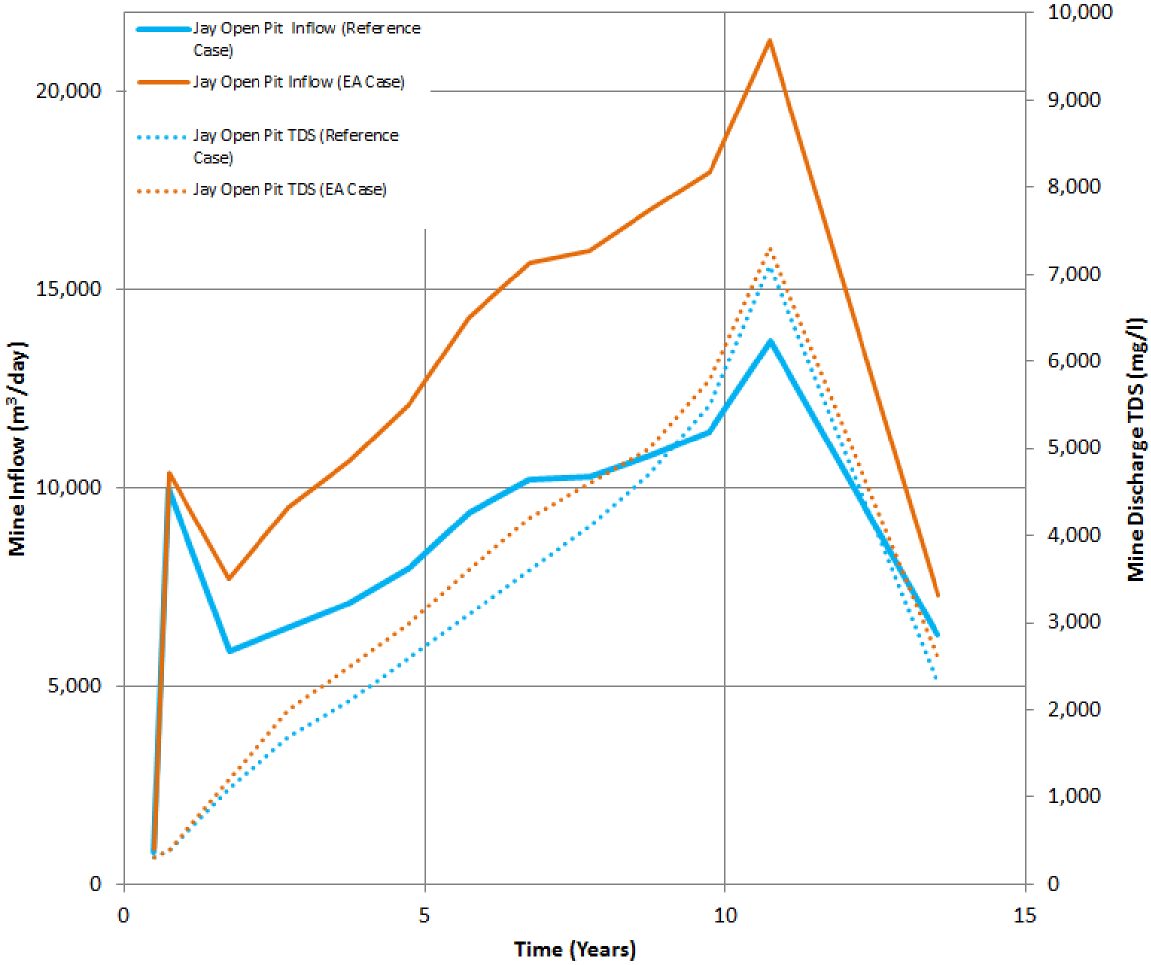


Figure 8A4-4 Predicted Groundwater Inflow and Groundwater Quality Over the Mine Life (Reference Case and Environmental Assessment Conservative Scenario)



8A5 CONCLUSION

The results of hydrogeological modelling presented in this appendix were used to estimate the quantity and quality (TDS) of groundwater inflow to the Jay open pit. In the Reference Case, which is based on conservative estimates of hydrogeological parameters controlling groundwater conditions near the pit, the inflow is predicted to gradually increase to approximately 13,700 m^3/day once the pit reaches its ultimate configuration. Similarly, TDS in groundwater inflow is predicted to gradually increase in response to mine dewatering, reaching approximately 7,300 mg/L at the end of mining. In the EA Conservative Scenario, which represents a reasonable upper bound of conditions that could be encountered during mining, the groundwater inflow to the proposed pit is predicted to increase to approximately 21,300 m^3/day over the mine life, or approximately 55% higher than in the Reference Case. As the TDS in mine inflow predicted in the EA Conservative Scenario is similar to the one predicted in the Reference Case, this corresponds to an approximate factor of 2 increase in TDS mass loading to the open pit. The EA Conservative Scenario results in a sufficient level of conservatism to provide a high level of confidence that the effects on the environment from changes to groundwater have not been underestimated.

8A6 REFERENCES

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