APPENDIX 8B

HYDROGEOLOGICAL MODEL FOR JAY PIT – POST-CLOSURE PERIOD

Table of Contents

Figures

Tables

Abbreviations

Abbreviation	Definition
EPZ	enhanced permeability zone
i.e.,	that is
NWT	Northwest Territories
TDS	total dissolved solids
the Project	Jay Project

Units of Measure

Unit	Definition
%	percent
m	metre
m/d	metres per day
m^3/d	cubic metres per day
m^3/d/m	cubic metres per day per unit width
masl	metres above sea level
mg/L	milligrams per litre
g/d	grams per day
g/d/m	grams per day unit width

8B1 INTRODUCTION

8B1.1 Background and Scope

The existing Dominion Diamond Ekati Corporation (Dominion Diamond) Ekati Mine and its surrounding claim block is located approximately 300 kilometres (km) northeast of Yellowknife in the Northwest Territories, 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.

8B1.2 Objectives

This appendix presents the results of a model study to assess the post-closure groundwater regime near the Jay Pit. The objectives of the model simulations were as follows:

- to evaluate the effects of higher total dissolved solids (TDS) water beneath the open pit on the groundwater flow system after closure of the mine workings; and,
- to evaluate the influence of solute transport by groundwater flow on the movement of solutes from the bedrock into the back-flooded Jay pit.

During mining operations, fresh water from Lac du Sauvage will be drawn down into the bedrock due to the hydraulic gradients that develop in response to mine dewatering (Hydrogeological Model Pre-Mining, During Mining, and Closure [Appendix 8A]). This fresh water will displace groundwater with higher TDS concentrations that existed under pre-mining conditions. Mining operations will also result in upward migration of higher TDS groundwater from depth in the region beneath the mine excavations. Consequently, the groundwater chemistry near the mine will be altered from pre-mining conditions. At closure, the Jay Pit will be filled initially with water from the Misery Pit water management pond and then back-flooded over a period of approximately three years. The dewatered area within the dike will be back-flooded to the original lake elevation of 416.1 metres above sea level (masl) over a period of approximately one year.

The intent of this study was to consider changes in the groundwater flow regime once the water levels in the pit and diked area reach their ultimate elevation of 416.1 m as pre-development conditions (post-closure period), and the influence, if any, that these changes may have on the water quality in the flooded pit over the long-term (100s of years). These results were used in the concurrent study that predicts overall water quality in the flooded pit. The results of this study are relevant to the following key line of inquiry:

- Water Quality and Quantity (Section 8).

8B2 CONCEPTUAL MODEL OF GROUNDWATER FLOW AND SOLUTE TRANSPORT AT POST-CLOSURE

Following re-filling of the Jay Pit and back-flooding the diked area of Lac du Sauvage at closure, several different groundwater flow and solute transport processes will take place:

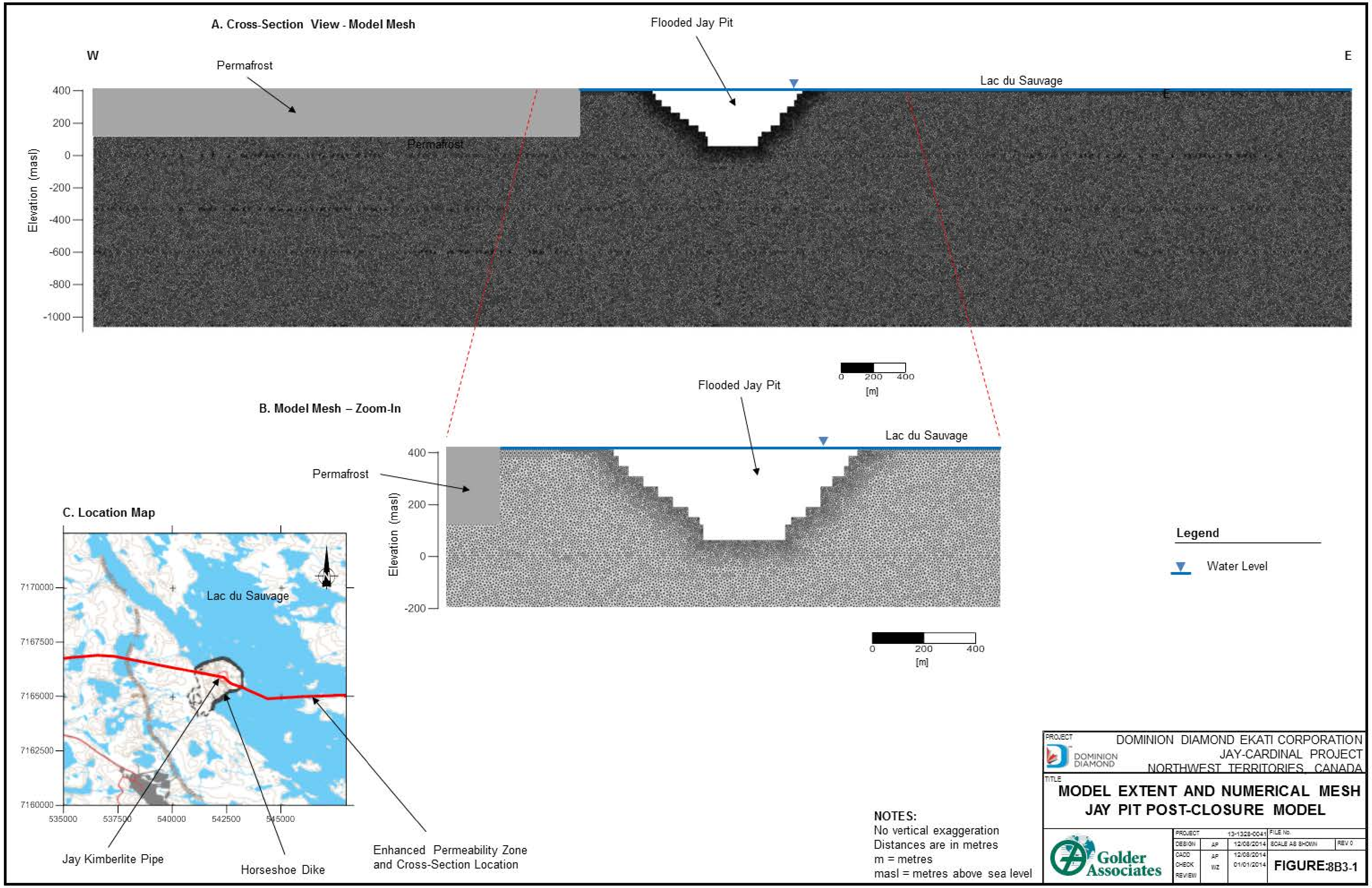
- Initially, lake water will flow from the flooded pit into the bedrock, re-saturating the partially dewatered bedrock near the pit walls and dissipating the large hydraulic head differences near of the mine workings.
- With the dissipation of these hydraulic head differences, there will be no significant regional gradients in hydraulic head that could displace the fresh lake water that will have infiltrated into the bedrock during mining operations. When the external hydraulic gradients are weak or absent, groundwater flow caused by lateral variations in fluid density (due to differences in TDS concentration) may dominate the groundwater flow system. The brackish groundwater with higher TDS concentrations that migrated upward during mining operations will begin to sink because of its higher density relative to the surrounding fresher groundwater. This effect can create a slow-moving, convective circulation system in the bedrock. Changes in the TDS concentration of the groundwater, and the TDS concentration of water discharging to the flooded pit, will reflect the combined influence of this density-driven flow and solute transfer by diffusion.
- The TDS profile in the bedrock beneath the site is expected to eventually return to near pre-mining conditions as freshwater that infiltrated the bedrock during mining operations is displaced by higher TDS groundwater, and as diffusion transfers dissolved mass into regions of lower solute concentrations.

8B3 SIMULATION OF GROUNDWATER CONDITIONS AT POST-CLOSURE

The simulation of groundwater flow and solute transport before mining, during mining, and at closure was carried out using the three-dimensional FEFLOW model (Diersch 2014) (Appendix 8A). Density-dependent transport of solutes was not included in these simulations because the buoyancy effects were considered negligible in relation to the hydraulic head gradients associated with mine dewatering. It was concluded that hydraulic heads in the bedrock will recover to a near-equilibrium state approximately three years after flooding of the Jay Pit is initiated. It was also concluded that at that time, the groundwater inflow to the flooded pit, predicted without density-driven effects, would be negligible.

To further analyze the hydrogeological conditions during post-closure, a two-dimensional model was developed that explicitly considered density-coupled groundwater flow and solute transport. This model was developed using FEFLOW and followed the enhanced permeability zone (EPZ) intersecting the Jay Pit that was included in the three-dimensional model. This was considered reasonable because the results of the three-dimensional modelling showed that the flow in this zone would be primarily oriented along its alignment, and that approximately 70 percent (%) of groundwater inflow to the Jay Pit could originate from this zone. The two-dimensional model extends approximately 4 km west and east from the centre of the Jay Pit (Figure 8B3-1); this extent of the model domain is considered appropriate to adequately represent post-closure conditions based on the results of solute transport modelling conducted using the three-dimensional model. The finite element mesh consists of approximately 200,000 elements, with the node spacing ranging from approximately 5 m near the pit walls to approximately 10 m near the base of the model, which is sufficient to maintain stability of the numerical solution.

Figure 8B3-1 Model Extent and Numerical Mesh – Jay Pit Post-closure Model



8B3.1 Model Boundaries and Initial Conditions

The model boundaries, extent of the hydrostratigraphic units, and the hydrogeological parameters are the same as used in the three-dimensional model (Appendix 8A), except for the following modifications necessary to simulate density effects at post-closure:

- The initial conditions for the post-closure simulation were set to the TDS concentration simulated for closure using the three-dimensional model based on the Jay TDS depth profile (Appendix 8A). The equivalent freshwater heads corresponding to these concentrations were assumed to be hydrostatic.
- Specified concentration and specified head boundaries were assigned along the pit walls to represent the flooded pit. The TDS depth profile for the flooded pit was based on the results of pit lake modelling discussed in Appendix 8G; the TDS depth profile is presented in Table 8B3-1. The equivalent freshwater heads assigned to these boundaries were calculated for individual mesh nodes based on their depth below the lake surface and the lake TDS profile. Boundary constraints were used to automatically turn off the specified concentration boundaries at locations where groundwater inflow to the flooded pit was predicted. Use of constraints allowed for proper representation of solute exchanges between the lake and groundwater, necessary for modelling density-driven convection flow (i.e., at locations where groundwater inflow to the lake was predicted, TDS mass was allowed to freely exit the model domain, whereas at outflow locations, recharge to groundwater was assigned lake water TDS).

Table 8B3-1 Total Dissolved Solids Depth Profile for the Flooded Jay Pit

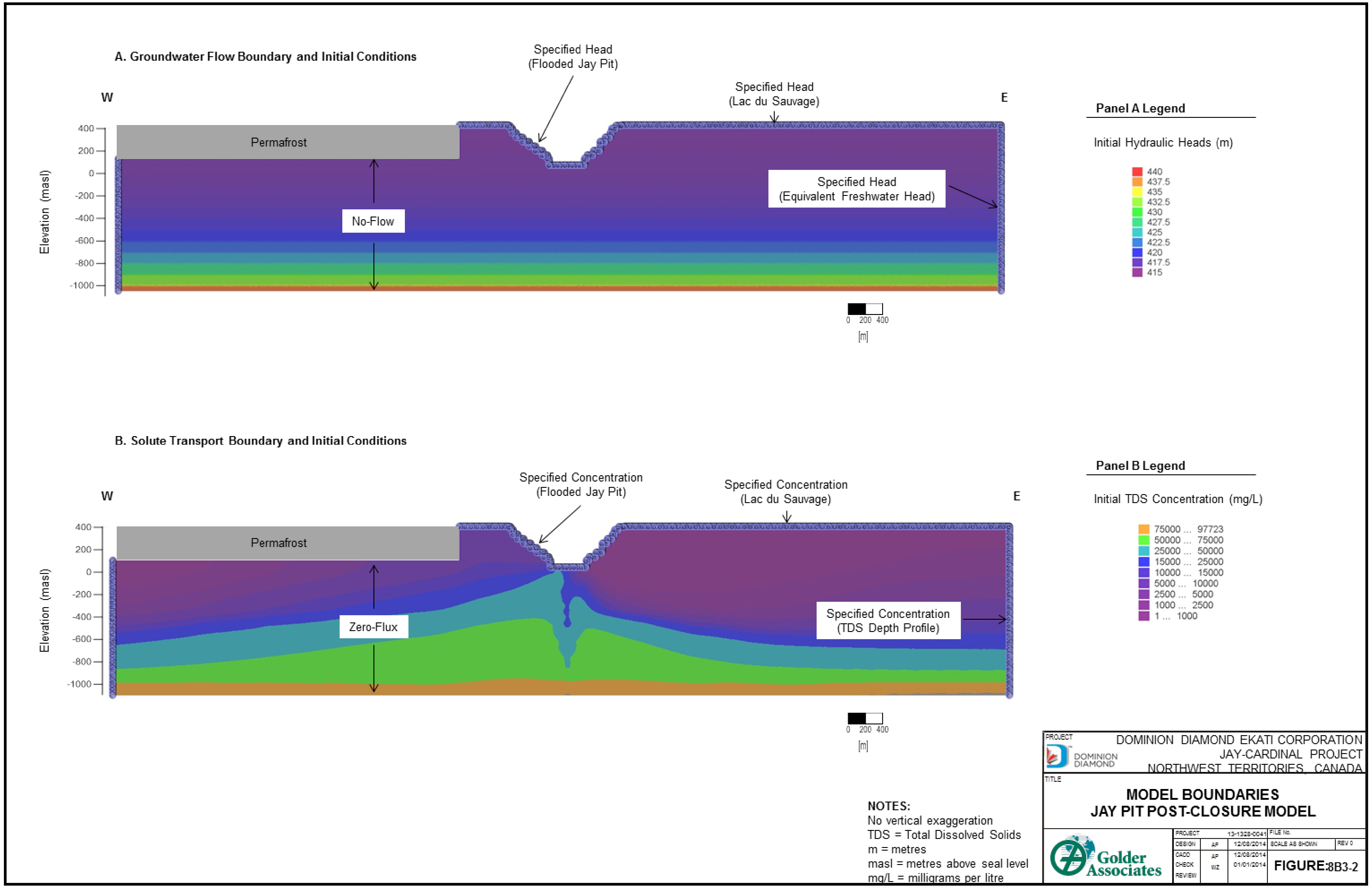
	Total Dissolved Solids (mg/L)	Elevation of Top of Layer (masl)
Top Layer	29.3	416
Middle Layer	232	291.5
Bottom Layer	2,736	258.2

masl = metre above sea level; mg/L = milligram per litre.

- Along the right and left boundaries of the model domain, specified head and specified concentration boundaries were assigned to represent an undisturbed TDS versus depth profile and hydrostatic conditions. The equivalent freshwater heads at these boundaries were calculated using the Jay TDS versus depth profile.

Boundary conditions for groundwater flow and solute transport are shown in Figure 8B3-2.

Figure 8B3-2 Model Boundaries – Jay Pit Post-Closure Model



8B3.2 Model Predictions

The two-dimensional hydrogeologic model described above was used to simulate post-closure conditions for a 1,000 year time period. Predicted flow rates and TDS mass fluxes for the 1 m-wide section that was represented in this model are summarized in Table 8B3-2.

Table 8B3-2 Predicted Fluxes and Mass Loading per 1-Metre Width of Enhanced Permeability Zone

Time (years)	Groundwater Inflow (m^3/d/m)	Water Losses from Pit Lake (m^3/d/m)	Mass Loading (g/d/m)
1	0.6	0.8	3,500
10	0.2	0.6	620
100	0.03	0.3	80
1,000	0.03	0.2	90

g/d/m = grams per day per unit width; m^3/d/m = cubic metres per day per unit width.

Flows and fluxes upscaled from the model predictions to the entire flooded pit are presented in Table 8B3-3. This up-scaling was based on the assumed thickness of the EPZ represented in the three-dimensional groundwater model, and under the assumption that this feature contributes approximately 70% of the pit lake inflow (i.e., flow rates and mass fluxes predicted per 1 m width were multiplied by 60 m and divided by 0.7). The latter assumption is considered conservative because in reality groundwater-pit lake water exchange outside the EPZ may be slower than within the EPZ due to lower permeability of the surrounding rock mass.

Table 8B3-3 Predicted Fluxes Upscaled to the Jay Pit

Time (years)	Groundwater Inflow (m^3/d)	Water Losses from Pit Lake (m^3/d)	Mass Loading (g/d)
1	50	70	300,000
10	20	50	50,000
100	3	30	7,300
1,000	3	20	7,800

g/d = grams per day; m^3/d = cubic metres per day.

Specific discharge vectors and TDS concentration contours are presented in Figure 8B3-3 and Figure 8B3-4 for 1, 10, 100, and 1,000 years after mine closure. These vectors are scaled to a different maximum value in each figure. For illustrative purposes only, relatively large vectors are used to plot these results, which may give the impression that the flow system is highly dynamic and fast flowing. However, these maximum predicted fluxes during post-closure are several orders of magnitude less than the fluxes predicted for groundwater flow during mining operations (a maximum of approximately 0.007 metres per day [m/d] compared to a maximum of approximately 1.5 m/d at the end of mining operations).

Figure 8B3-3 Predicted Groundwater Conditions near the Flooded Jay Pit at Post-Closure (Year 1 and Year 10)

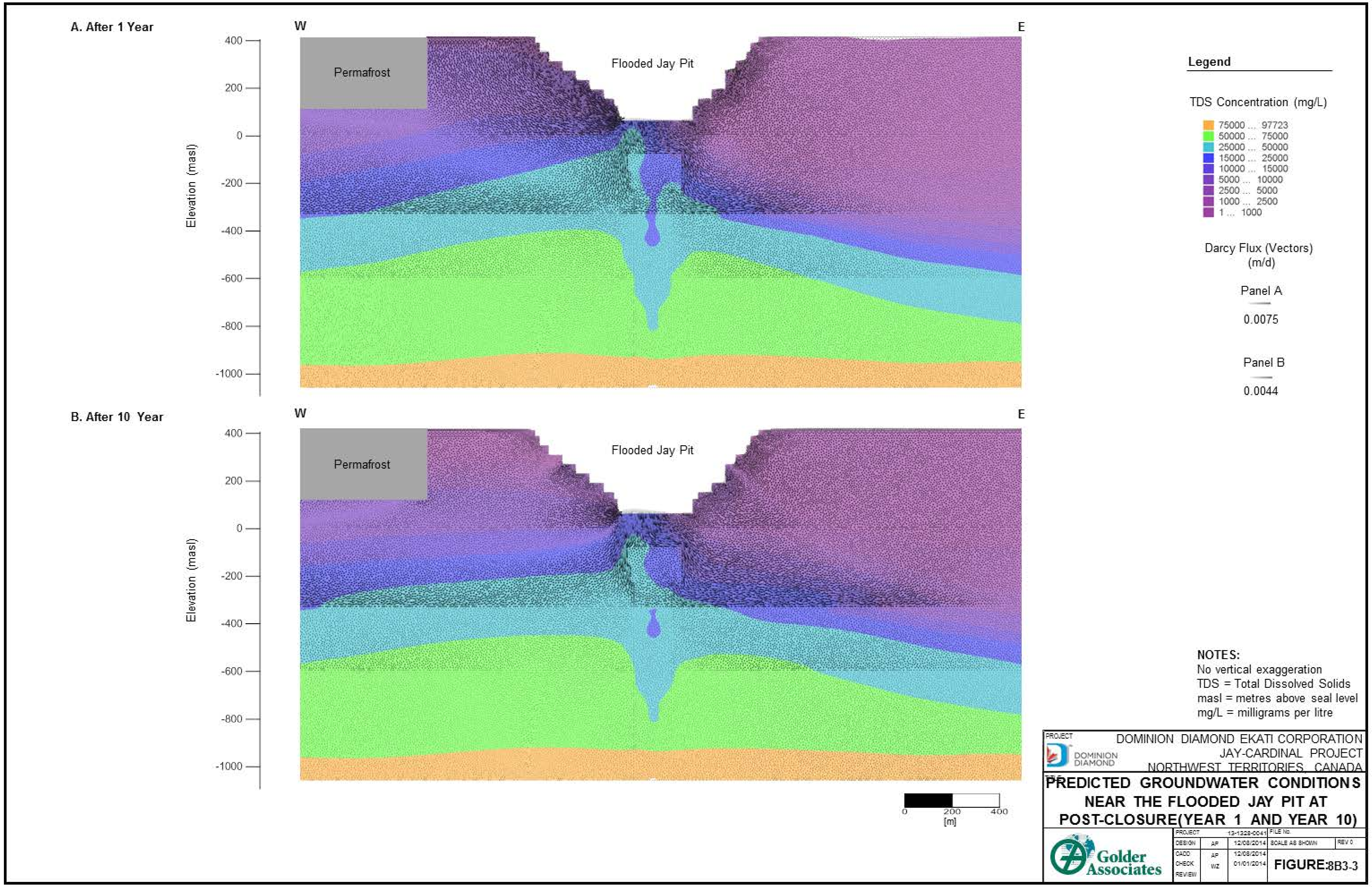
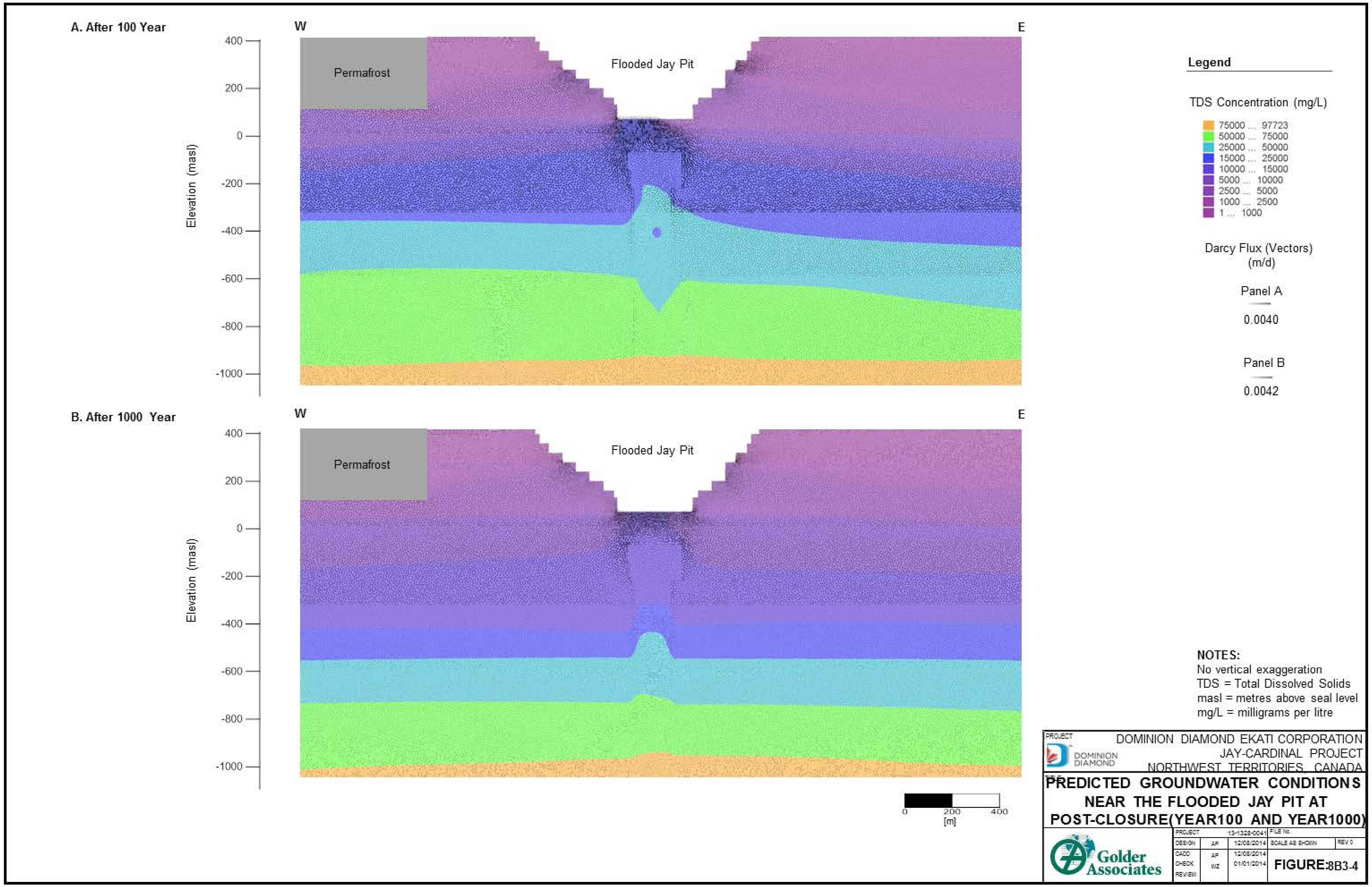


Figure 8B3-4 Predicted Groundwater Conditions near the Flooded Jay Pit at Post-closure (Year 100 and Year 1000)



The model results show that once the hydraulic heads return to near equilibrium shortly after mine back-flooding, high-TDS groundwater that has been upwelling towards the pit during mining operations starts sinking, creating convective flow beneath the mine workings. Over time, the high-TDS groundwater located near the pit sinks because its density is higher than the density of groundwater located at the same depth, but at greater distance from the pit. As this process develops, water from the back-flooded pit is drawn downwards from the bottom part of the pit into bedrock, while groundwater is flowing upward to the upper part of the pit. Groundwater fluxes are greater in the shallow portion of the EPZ and kimberlite (above 750 m below the ground surface), where the hydraulic conductivities are higher than at depth. At later times in the post-closure period (close to 1,000 years), as the pre-mining fluid density profile is restored, the effects of density-driven flow are reduced, groundwater fluxes decrease, and diffusion becomes a significant transport process.

Predicted groundwater inflow to the flooded pit gradually decreases from approximately 50 cubic metres per day (m^3/d) at 1 Year after mine closure to approximately 3 m^3/d at 100 years, and then it is constant until the end of the simulation at 1,000 years. Water loss from the back-flooded pit is predicted to gradually decrease from approximately 70 m^3/d at 1 year to 30 m^3/d at 100 years, and then to gradually decrease to approximately 20 m^3/d at 1,000 years.

The corresponding TDS mass flux into the flooded pit follows a similar pattern. It is predicted to gradually decrease from approximately 300,000 g/d at 1 Year after mine closure to approximately 7,300 g/d at 100 years, and then to increase to approximately 7,800 g/d at 1,000 years. These temporal changes in predicted TDS fluxes are considered reasonable because they reflect gradual changes in the convective circulation patterns and groundwater quality along the pit walls, as shown in Figure 8B3-3 and Figure 8B3-4.

8B4 DISCUSSION AND CONCLUSION

After flooding of the Jay Pit and dissipation of the large hydraulic head gradients created by the pit dewatering, near-hydrostatic fluid pressures that characterized the pre-mining groundwater regime will be re-established. These conditions will permit the development of a density-driven, groundwater flow system near the mine workings due to the high-TDS groundwater that upwelled during mining operations. This convective system will lead to groundwater discharge to the flooded pit and lake water recharge to the surrounding bedrock. Over the 1,000 years during the post-closure period, the groundwater inflow to the pit is predicted to gradually decrease from approximately 50 m^3/d to 3 m^3/d, whereas predicted water losses to the groundwater system will decrease from approximately 70 m^3/d to 20 m^3/d. The corresponding TDS mass flux into the flooded pit is predicted to decrease from approximately 300,000 g/d to 7,300 g/d.

8B5 REFERENCES

Diersch, HG. 2014. FEFLOW v. 6 Finite Element Subsurface Flow and Transport Simulation System. DHI-WASY Institute for Water Resources Planning and System Research Ltd., Berlin, Germany.