DOMINION DIAMOND

APPENDIX 8C

HYDROGEOLOGIC MODEL FOR MISERY PIT LAKE – POST-CLOSURE PERIOD

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Abbreviations

Abbreviation	Definition
EPZ	enhanced permeability zone
i.e.,	that is
TDS	total dissolved solids

Units of Measure

Unit	Definition
m	metre
m/s	metres per second
m^2/s	square metres per second.
m^3/d	cubic metres per day
masl	metres above sea level
mg/L	milligrams per litre

8C1 INTRODUCTION

8C1.1 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.

8C1.2 Objectives

This appendix presents the results of numerical hydrogeological model simulations that were completed to predict the long-term (100s of years) groundwater conditions near the Misery Pit after back-flooding of the pit to its ultimate elevation (post-closure period). The objectives of this study were to:

- evaluate pit lake water/deep groundwater exchange following filling of the Misery Pit with water originating from the Jay Pit; and,
- assess the potential pathway in deep groundwater system between the Misery Pit lake and Lac de Gras in the post-closure period.

During mining, groundwater flowing to the Jay open pit will be conveyed to the Misery Pit for storage and mine water management, with subsequent release to the environment. Because total dissolved solids (TDS) in groundwater inflow to the Jay Pit is predicted to increase throughout the life of the mine, the TDS in Misery Pit lake water will also gradually increase and reach its maximum at the end of mining. At closure, a portion of the mine water stored in the Misery Pit during operations will be pumped to the bottom of the Jay Pit; the higher-TDS water in Misery Pit (predicted TDS of 5,246 milligrams per litre [mg/L]) will be "capped" by approximately 60 metres (m) of freshwater (TDS of 52 mg/L) and the lake level will be maintained at 440 metres above sea level (masl), or approximately 24 m above the water level in Lac de Gras. Due to this difference between the water levels in the Misery pit lake and Lac de Gras, it is expected that a deep groundwater pathway may form between the Misery pit lake (i.e., flooded pit) and Lac de Gras. The intent of the modelling studies was to examine hydrogeological conditions that may develop along this potential pathway during post-closure. The results of this study are relevant to the following key line of inquiry:

- Water Quality and Quantity (Section 8).

8C2 CONCEPTUAL MODEL OF GROUNDWATER FLOW AND SOLUTE TRANSPORT DURING POST-CLOSURE

This section presents background information on groundwater conditions near the Misery Pit and the conceptual understanding of these conditions that was developed based on available background information.

8C2.1 Background

The Misery Pit was mined beneath Misery Lake from 2001 to 2005, when the pit bottom reached an elevation of approximately 265 masl. During mining, only minor groundwater inflows were reported (WMC 2009). During a 2010 site visit, pit inflow was observed to range between 170 cubic metres per day (m^3/d) and 260 m^3/d, and was thought to originate primarily from the active zone (SWS 2010). Overall, the permeability of bedrock surrounding the pit was considered to be relatively low. The current mine plan for the Ekati Mine envisions mining this pit to an ultimate elevation of 150 masl between year 2011 and 2018.

Data from near-pit thermistors indicate that a thick zone of permafrost, up to an elevation of approximately 50 masl, is present in bedrock surrounding the Misery Pit. In previous studies (WMC 2009; SWS 2010), it was postulated that an open talik was present beneath Misery Lake, and that the central portion of the existing pit was mined through this talik. Considering the original extent and water depth in Misery Lake, it is likely that an open talik is present beneath the bottom of the existing open pit.

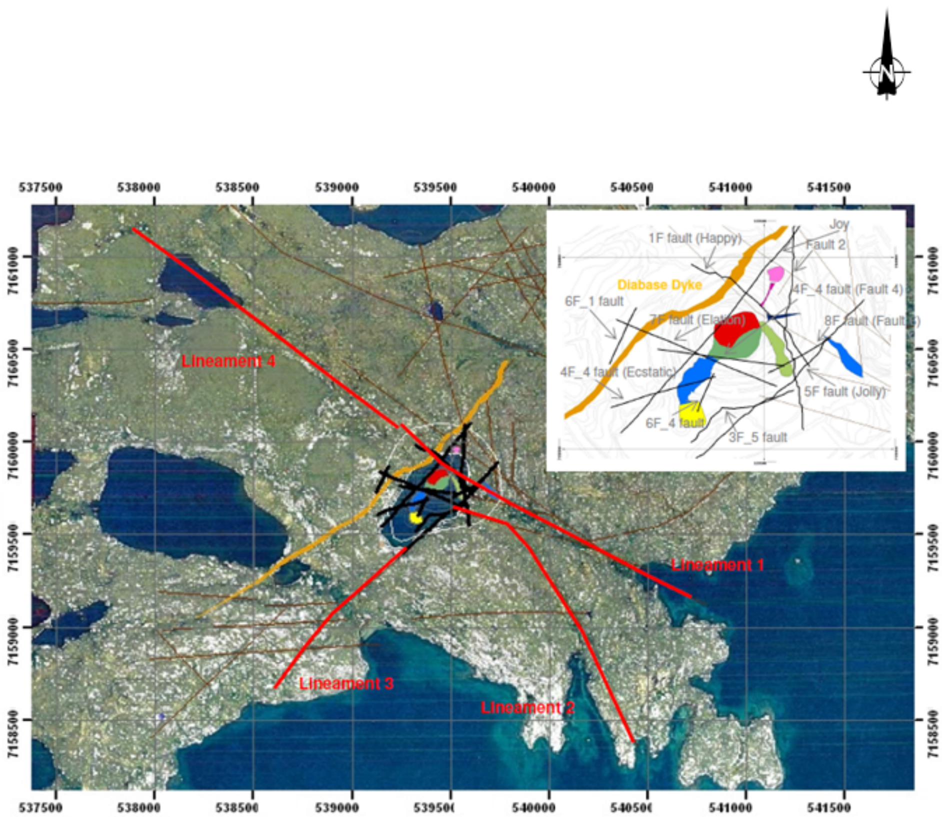
Past hydrogeological analyses and modelling (WMC 2009; SWS 2010) considered the potential presence of enhanced permeability zones (EPZs) that may exist in bedrock along structural discontinuities that were mapped during mining and/or that may follow surficial lineaments associated with these discontinuities away from the pit crest (Figure 8C2-1). The Water Management Consultants study (WMC 2009) focused on a potential EPZ that may extend southeast from the existing pit towards Lac de Gras. This zone, if present and extending past the Lac de Gras shoreline, was assumed to be the main contributor of groundwater inflow to the Misery Pit.

8C2.2 Conceptual Model

The conceptual model of current and post-closure groundwater conditions near the Misery Pit is presented in Figure 8C2-2. At present, the existing open pit is inferred to act as a sink for deep groundwater flow due to its connection to the higher hydraulic heads in the regional flow regime via the open talik existing beneath the pit bottom. From the perspective of assessing a potential groundwater pathway from the pit to Lac de Gras, the conceptual model conservatively assumes that most of the historical inflows originated from the EPZ extending southeast from the pit.

During operations, the Misery Pit will be filled with water originating from the Jay Pit, and at closure, it will be capped with freshwater to a level that is approximately 24 m above the Lac de Gras level. Following its formation, the pit lake will provide recharge to the deep groundwater system. Presence of the pit lake is also expected to increase the size of the open talik and reduce the depth of permafrost between the pit lake and Lac de Gras, thus enhancing the hydraulic connection between the pit lake and Lac de Gras possibly provided by the EPZ. Higher TDS water originating from the pit lake is expected to gradually displace groundwater surrounding the pit, and could migrate primarily via the EPZ towards the bottom of Lac de Gras, ultimately discharging to this lake.

Figure 8C2-1 Structural Bedrock Discontinuities and Surficial Lineaments near Misery Pit



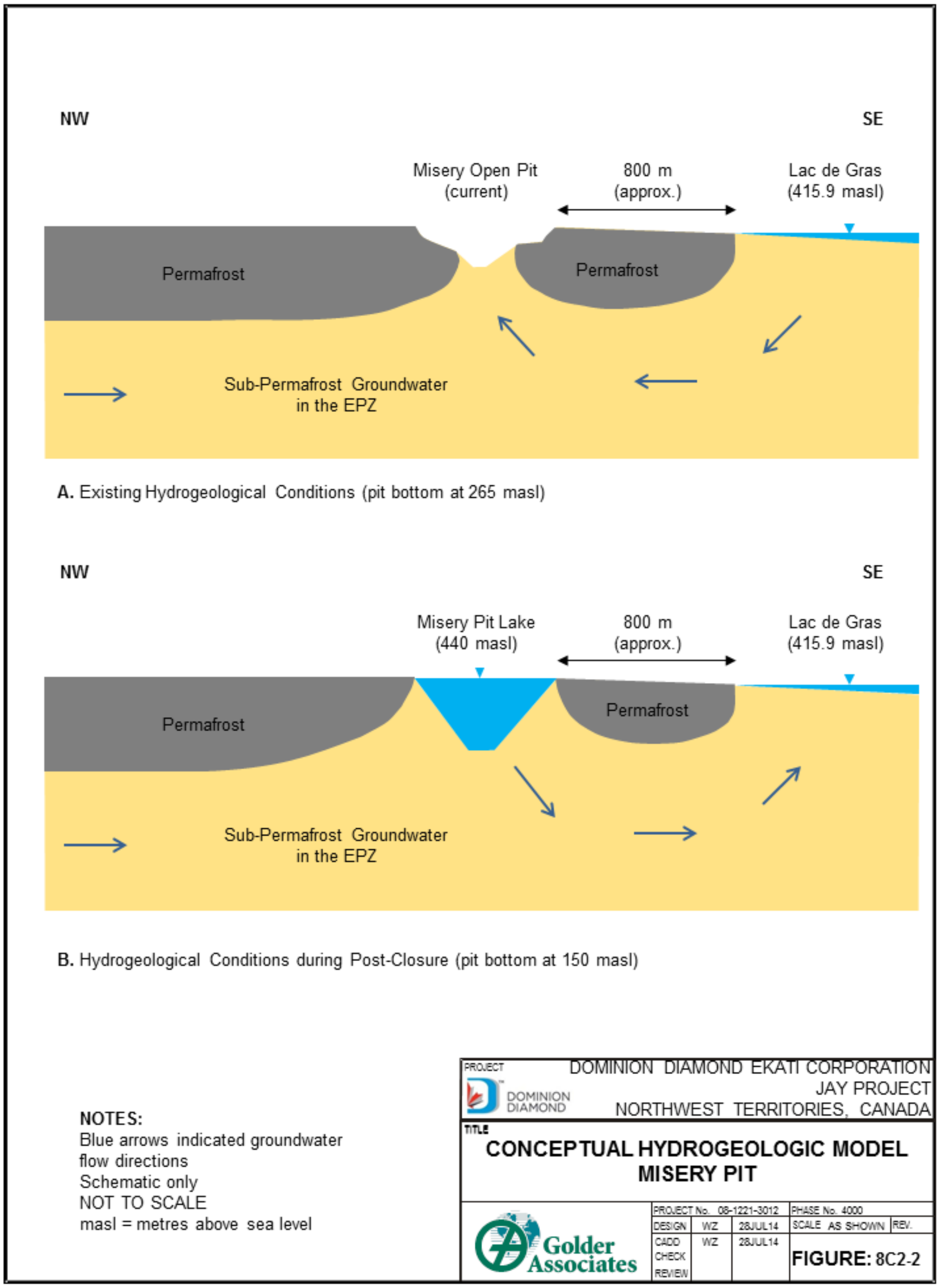
NOTES:
Reproduced based on Figure 2.9 in WMC (2009) report.
Lineament 1 corresponds to the orientation of the conceptual cross- section presented on Figure 2.
Distances are in metres.

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES, CANADA		
TITLE	**STRUCTURAL BEDROCK DISCONTINUITIES AND SURFICIAL LINEAMENTS NEAR MISERY PIT**		
Golder Associates	PROJECT No. 08-1221-3012		PHASE No. 4000
	DESIGN	WZ	28JUL14
	CADD	WZ	28JUL14
	CHECK		
	REVIEW		

SCALE AS SHOWN REV.

FIGURE: 8C2-1

Figure 8C2-2 Conceptual Hydrogeologic Model – Misery Pit



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8C3 SIMULATION OF GROUNDWATER CONDITIONS DURING POST-CLOSURE

The groundwater flow conditions during post-closure at the Misery Pit were simulated using FEFLOW, a finite-element modelling code from DHI-WASY (Diersch 2014). FEFLOW is capable of simulating density-coupled groundwater flow and solute transport in two- and three-dimensions under a variety of hydrogeological boundaries and stresses. The Misery Pit model is a two-dimensional cross-section that represents a potential deep pathway in groundwater along the EPZ that extends southeast from the Misery Pit towards Lac de Gras. The finite-element mesh was constructed, and the model was calibrated to inflows observed in the Misery pit during mining. The calibrated model was then used to simulate migration of higher-TDS water from the pit lake via the EPZ towards Lac de Gras in post-closure.

8C3.1 Model Construction

8C3.1.1 Model Mesh

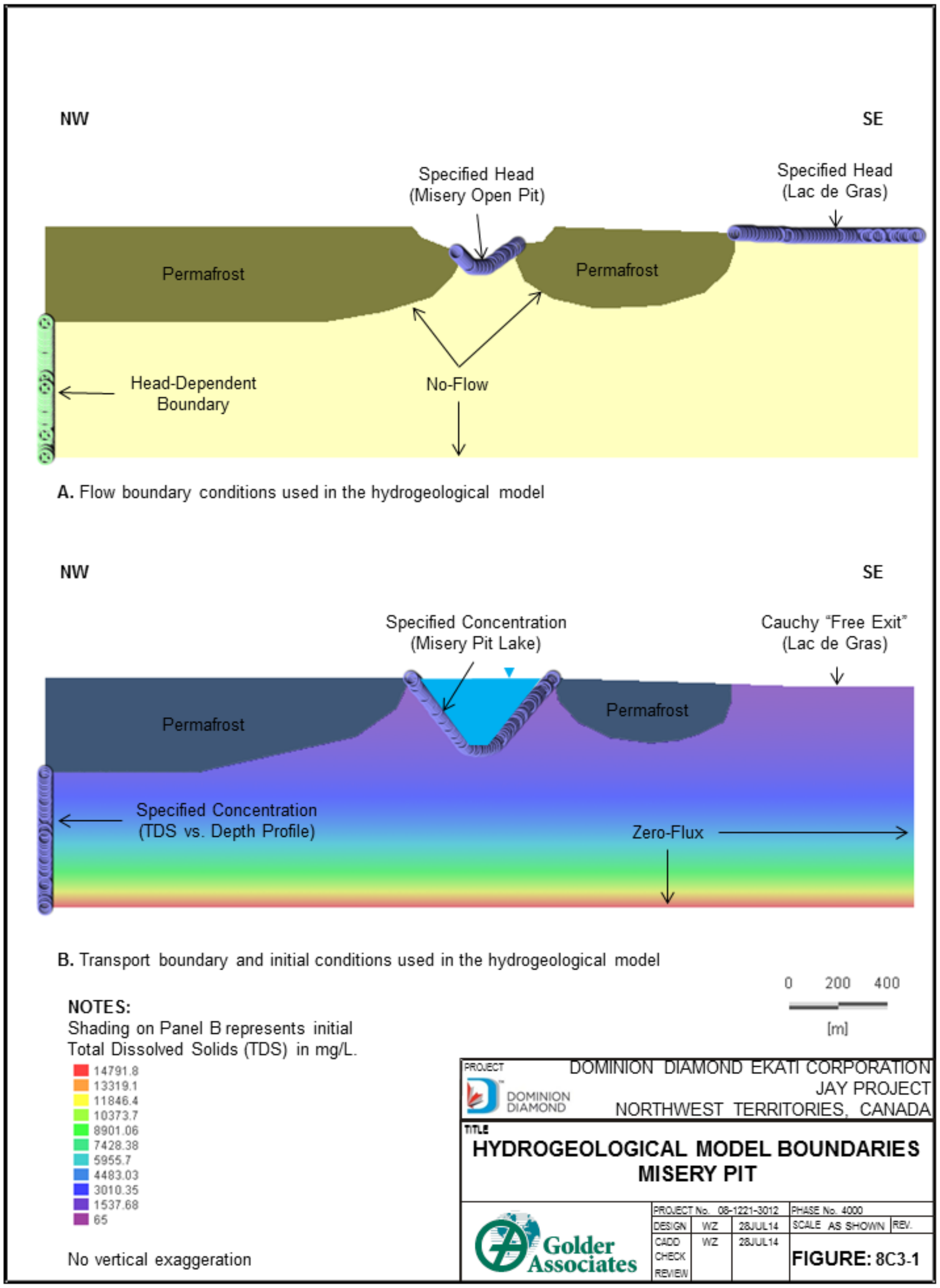
The model domain is presented in Figure 8C3-1. The model extends along the potential EPZ approximately 1,800 m northwest from the Misery Pit and approximately 1,700 m southeast towards and beneath Lac de Gras. The model top is set at an elevation of 440 masl, which corresponds to the pit lake level that will be maintained during post-closure. The bottom of the model is set at an elevation of -500 masl, or approximately 650 m below the ultimate bottom of the Misery Pit. The finite-element mesh consists of 94,000 triangular elements with a uniform nodal spacing of approximately 7 m to 10 m. This nodal spacing satisfies the mesh stability criteria for the transport of solutes everywhere within the model domain, thus reducing the effects of numerical dispersion on model predictions.

8C3.1.2 Boundary Conditions

Three types of flow boundary conditions were used in the model (Figure 8C3-1, Panel A). Specified head boundaries were used to represent Lac de Gras. These boundaries were applied along the 750-m long section of Lac de Gras within the model domain, and were assigned a head value of 415.9 masl, which corresponds to the average elevation of the water level in the lake. Specified head boundaries were also used to represent the Misery open pit during model calibration and the pit lake in model predictive simulations. In model calibration, specified head boundaries were assigned along the walls of the existing pit, with the pressure head equal to 0 m. These nodes were restricted to allow only groundwater outflow from the model domain (i.e., these boundaries represented seepage faces). In the predictive simulations, specified heads were assigned along the walls of the ultimate pit, with equivalent freshwater head calculated such that it was equivalent to a post-closure pit lake elevation of 440 masl.

No-flow boundaries were used to represent the permafrost under the assumption that its presence reduces hydraulic conductivity by several orders of magnitude. In predictive simulation, permafrost extent near the Misery Pit was reduced from the one used to represent the existing pit (current conditions used in model calibration) to account for the effects of the pit lake (Figure 8C3-1). No-flow boundaries were also applied along the model bottom because the groundwater flow at a greater depth was considered to have negligible influence on model predictions. A head-dependent boundary was assigned along the left side of the model domain to represent recharge from a lake likely underlain by an open talik and located approximately 3 km northwest of the Misery Pit. This boundary was assigned a hydraulic head of 440.9 m, which corresponds to the water elevation in this lake, and a conductance value that was based on a distance from the boundary to the lake of approximately 3 km.

Figure 8C3-1 Hydrogeological Model Boundaries – Misery Pit



Boundary conditions and initial conditions used in predictive simulations to define transport of high-TDS water from the Misery pit lake are shown in Figure 8C3-1 (Panel B). Specified concentration boundaries were assigned along the walls of the ultimate pit to represent the quality of the pit lake water during post-closure. These boundaries were set to 5,472 mg/L at nodes below 380 m elevation, and 52 mg/L above this elevation. Specified concentration boundaries were also assigned along the left side of the model to represent the TDS versus depth profile established in the in the Hydrogeology Baseline Report (Annex IX) and discussed in Section 8.2.1.2.3. This profile was also used to assign initial concentrations everywhere in the model domain. A Cauchy "free exit" boundary was applied along the bottom of Lac de Gras to allow outflow of solutes from the model domain to the lake. All other model boundaries (i.e., permafrost and model bottom) were assigned no-mass-flux boundaries.

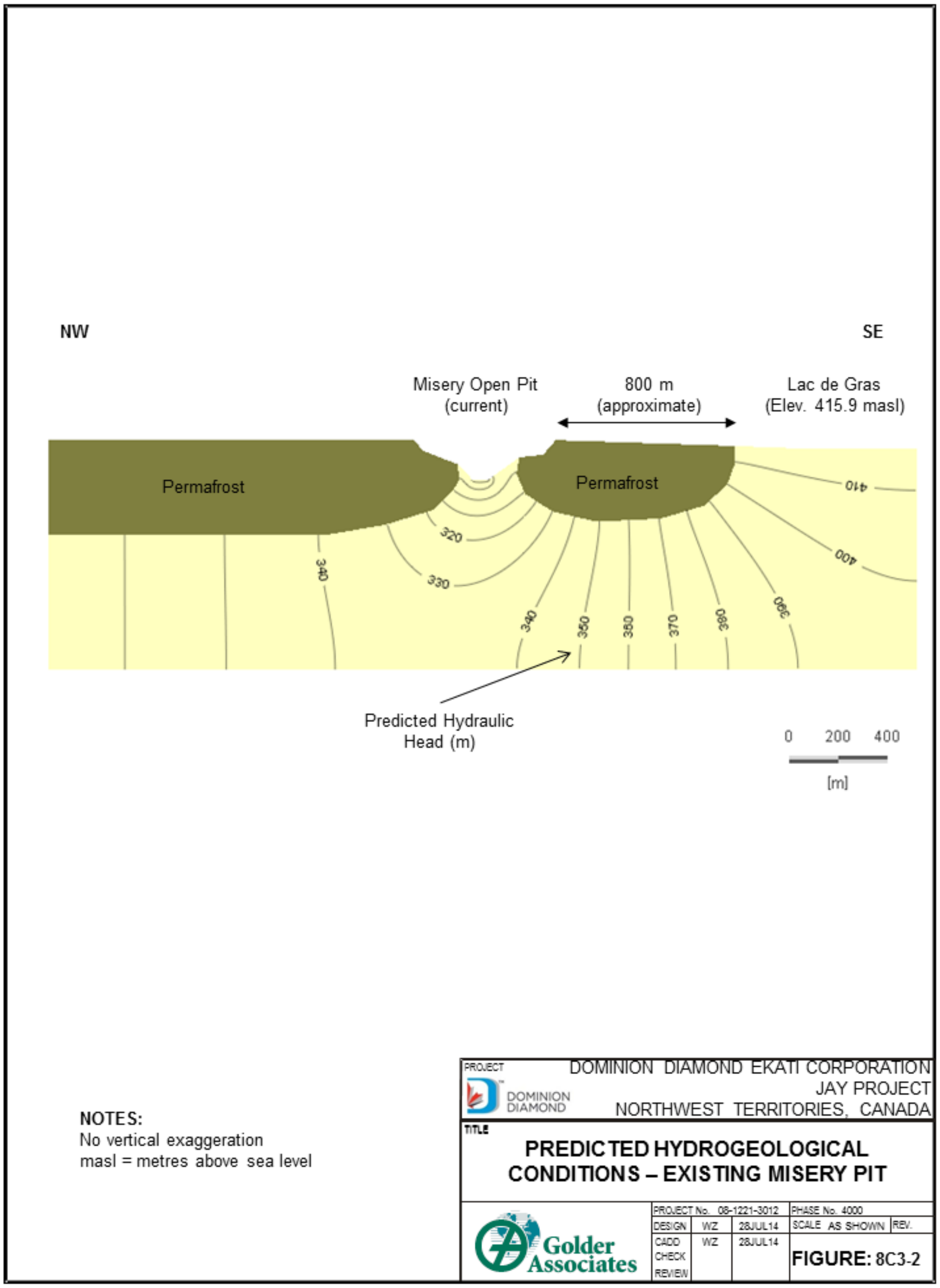
8C3.2 Model Calibration

The hydrogeological model representing the area near the Misery Pit was calibrated to inflows observed during mining of the existing pit. In this calibration, it was conservatively assumed that the inflows originated entirely from the EPZ extending southeast from the pit. In reality, some of this inflow was considered by Schlumberger Water Services (SWS 2010) to originate from the active layer; thus, the estimates of the hydrogeological properties derived from this calibration are conservatively high (i.e., the actual hydraulic connection between the Misery Pit and Lac de Gras via a deep groundwater pathway is likely weaker than connection represented in the calibrated model).

During model calibration, the model was run in steady state with the existing Misery Pit assumed to be fully dewatered, and the hydraulic conductivity and width of the potential EPZ were adjusted until the inflow predicted by the model was 260 m^3/d (i.e., the upper bound of inflow observed in 2010). Because the inflow through the EPZ is controlled by the product of EPZ hydraulic conductivity and its width (i.e., EPZ transmissivity), two plausible combinations of this parameter resulted in good calibration matches. In the first calibration scenario (Scenario 1), the EPZ hydraulic conductivity was found to be 1×10^{-5} metres per second (m/s), and the EPZ width was 6 m. In this scenario, the hydraulic conductivity is similar to the hydraulic conductivity of the EPZ inferred to exist near the Jay Pit and at Diavik Mine, but its width is smaller. In the second calibration scenario (Scenario 2), the EPZ hydraulic conductivity was found to be 1×10^{-6} m/s and the EPZ width was 60 m. In this scenario, the hydraulic conductivity is near to the bottom of the range in hydraulic conductivity of similar features at nearby kimberlite pipes; however, the EPZ width matches the inferred width of the EPZ near the Jay Pit and at Diavik Mine.
The groundwater flow pattern predicted by the calibrated model for the existing Misery Pit is presented in Figure 8C3-2. In agreement with the conceptual model described in the preceding section, the pit acts as a sink for deep groundwater flow, with recharge to the pit originating from Lac de Gras and from lakes northwest of the pit.

Because these calibration scenarios are considered to be equally plausible, both were used to provide predictions for the post-closure period. In both scenarios, the total seepage and mass loading predicted to originate from the Misery pit lake during post-closure are equivalent because they are controlled by EPZ transmissivity, which is equivalent in both cases. However, the predicted travel times between the pit lake and Lac de Gras will differ due to differences in assumed EPZ hydraulic conductivity in Scenario 1 and Scenario 2, thus providing a range for the travel time that reflects uncertainty in the hydraulic conductivity of potential EPZ.

Figure 8C3-2 Predicted Hydrogeological Conditions – Existing Misery Pit



A summary of hydrogeological parameters used in the model is presented in Table 8C3-1. Except for hydraulic conductivity and width of the EPZ zone, these parameters are identical to the ones used for the EPZ that is incorporated in the three-dimensional groundwater model for the Jay Pit, as discussed in Appendix 8A.

Table 8C3-1 Hydrogeological Model Parameters in the Misery Pit Lake Model

Model Parameter	Scenario 1	Scenario 2
Hydraulic Conductivity (m/s)	1E-5	1E-6
Ratio of Vertical to Horizontal Hydraulic Conductivity	1:1	1:1
EPZ Width (m)	6	60
Specific Storage (1/m)	1E-4	1E-4
Effective Porosity	0.01	0.01
Longitudinal Dispersivity (m)	10	10
Transverse Dispersivity (m)	1	1
Effective Diffusion Coefficient (m^2/s)	2E-10	2E-10

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

Note: Except for hydraulic conductivity and width, parameters assigned to the EPZ are the same as the ones adopted in the three-dimensional groundwater model discussed in Appendix 8A.

8C4 PREDICTED HYDROGEOLOGICAL CONDITIONS DURING POST-CLOSURE

The calibrated hydrogeological model was used to predict seepage of higher-TDS water from the Misery pit lake towards Lac de Gras. The model was run in transient mode for a period of 100 years in Scenario 1 and 1,000 years in Scenario 2, until near steady-state conditions were established. The model simulated density-dependent transport of higher-TDS water originating from the pit lake in the presence of higher-TDS groundwater naturally existing in bedrock surrounding the Misery Pit.

The predicted extent of the higher-TDS plume originating from the Misery Pit in Scenario 1 is shown in Figure 8C4-1. In this scenario, the plume core, defined as 50 percent of pit lake water with TDS below 401.9 m, or approximately 2,600 mg/L, is predicted to reach the bottom of Lac de Gras after approximately 1.5 years. For Scenario 2 (Figure 8C4-2), the plume core could reach the bottom of Lac de Gras after approximately 15 years. In both scenarios, seepage from the Misery pit lake to the subsurface and to Lac de Gras is predicted to be approximately 54 m^3/d.

The predicted discharge of groundwater originating from the pit lake to the bottom of Lac de Gras over time is presented in Figure 8C4-3. In Scenario 1, this discharge is predicted to occur after approximately 1 year following closure, and then to gradually increase to a steady-state value of 54 m^3/d after about 40 years. In Scenario 2, discharge of pit lake water to the bottom of Lac de Gras is predicted to start after about 10 years and would reach 54 m^3/d in approximately 400 years.

Figure 8C4-1 Predicted Hydrogeological Conditions during Post-closure Scenario 1 – Existing Misery Pit

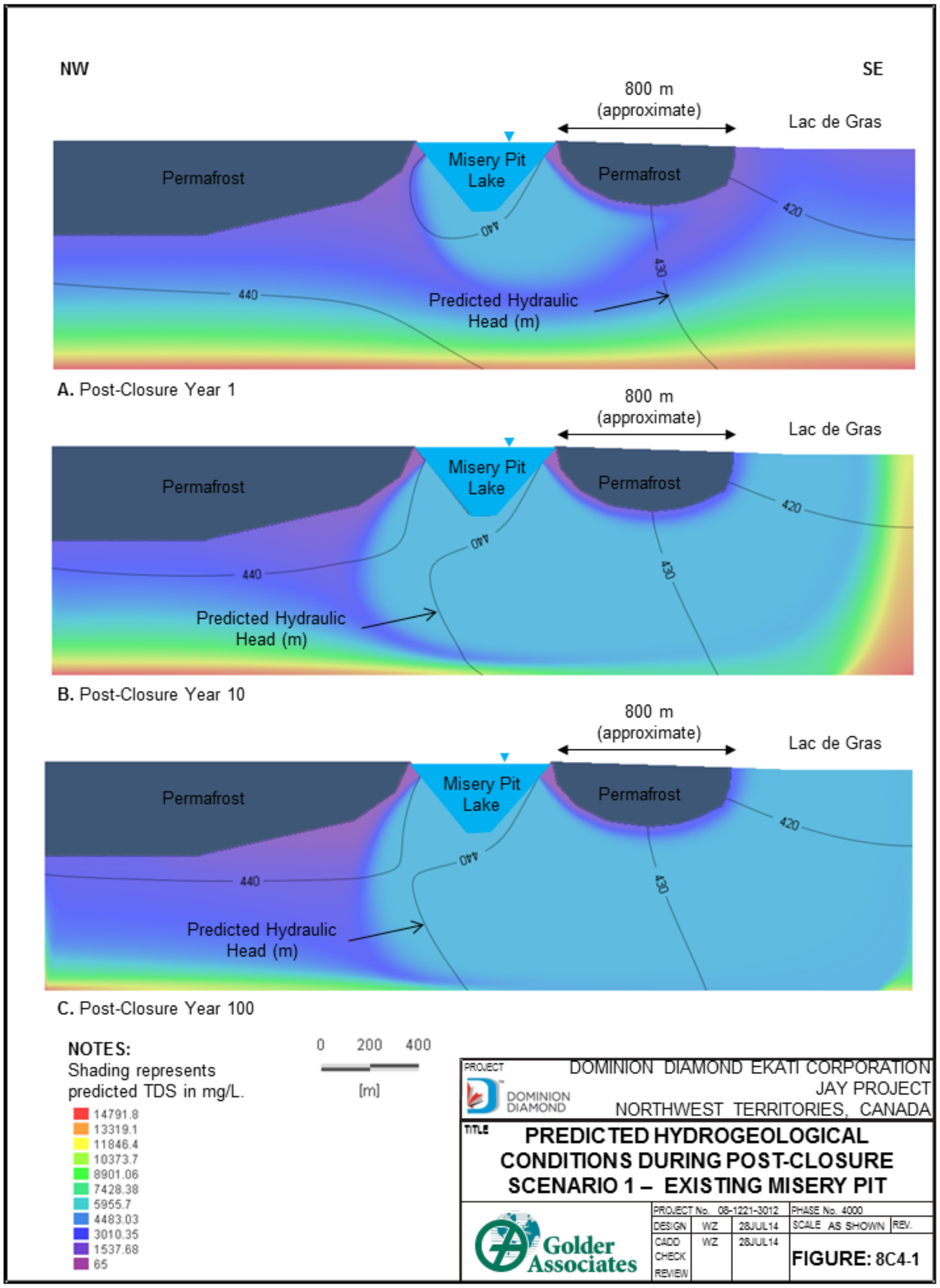


Figure 8C4-2 Predicted Hydrogeological Conditions during Post-closure Scenario 2 – Existing Misery Pit

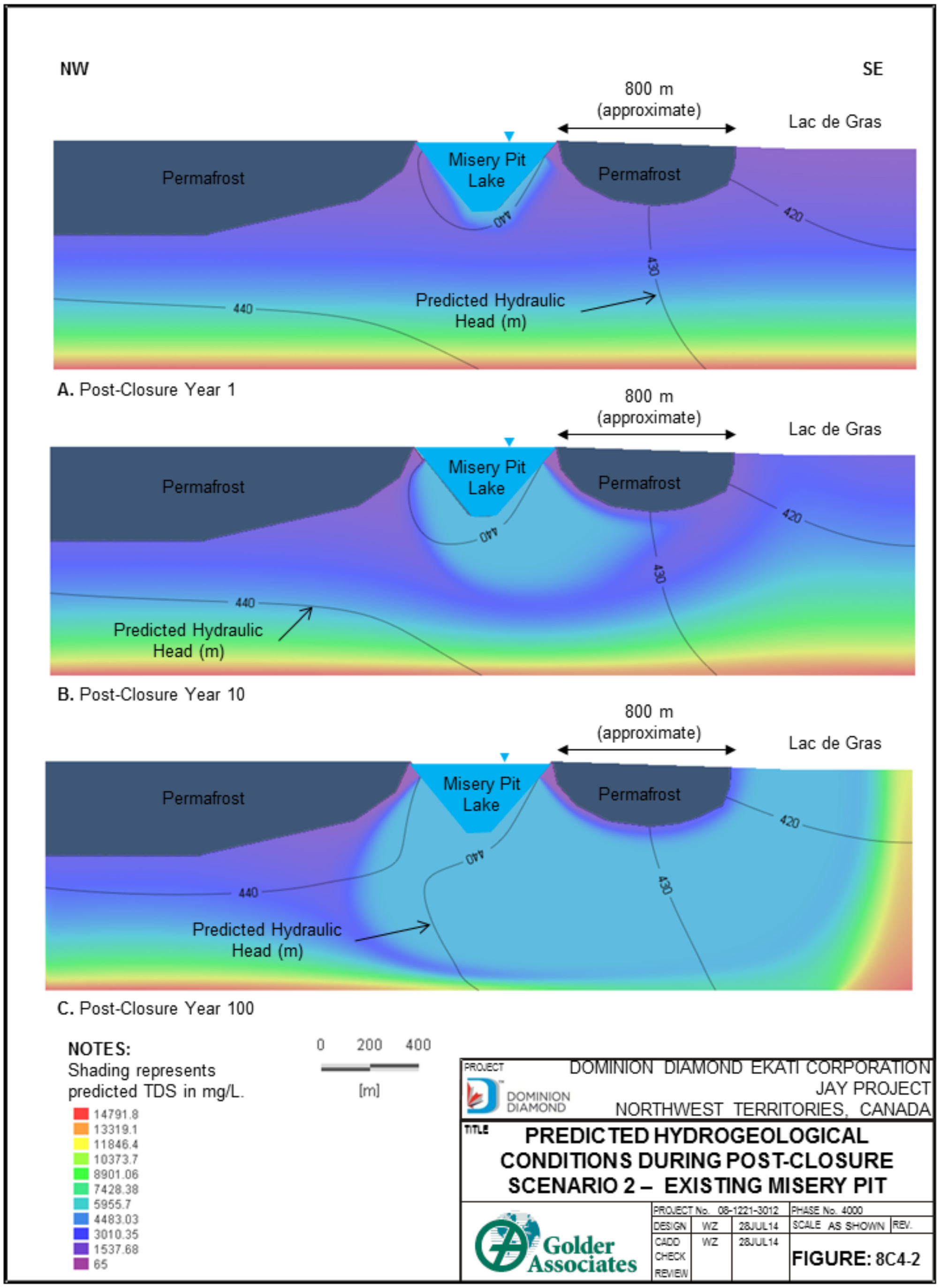
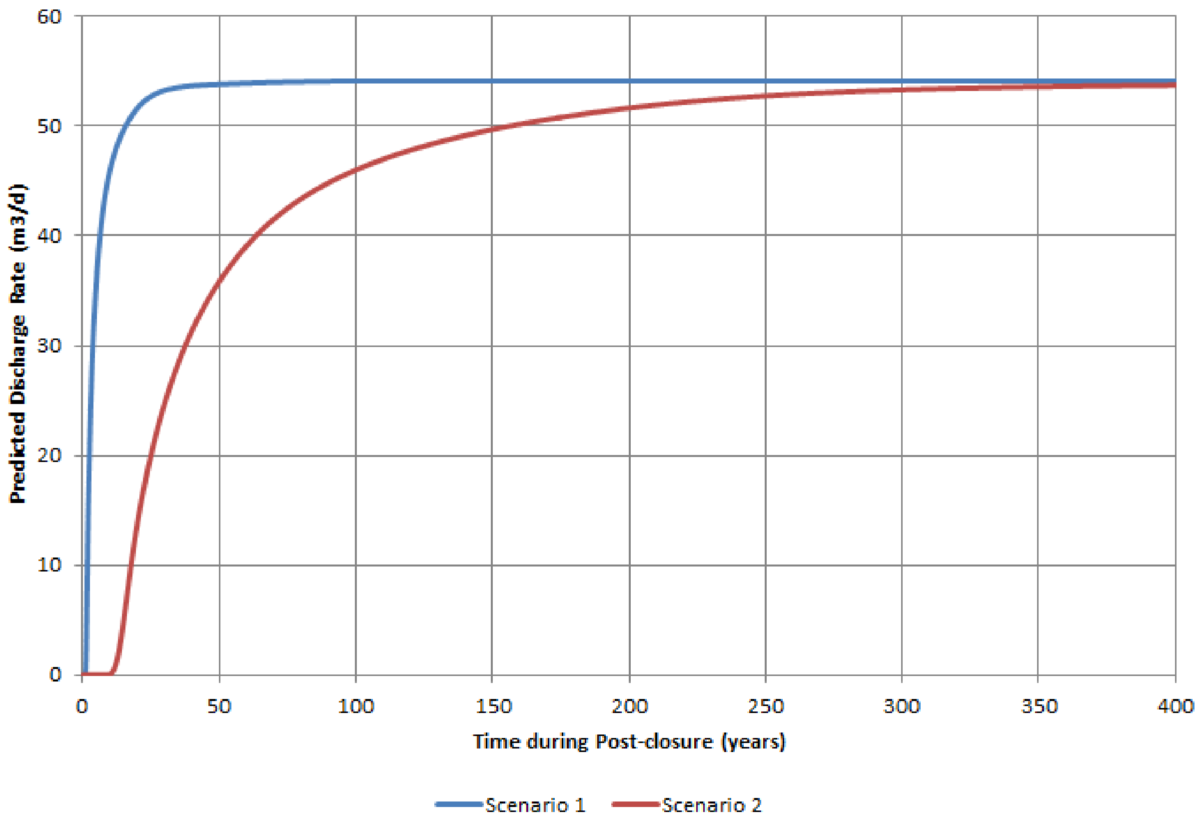


Figure 8C4-3 Predicted Discharge of Seepage from Misery Pit Lake to Bottom of Lac de Gras during Post-closure



8C5 DISCUSSION AND CONCLUSIONS

A two-dimensional hydrogeological model was used to assess post-closure conditions that could develop at the Misery pit lake. Model results indicate that the groundwater originating from the pit lake could reach the bottom of Lac de Gras between 1 year and 10 years after closure, depending on the hydrogeological properties of the EPZ that could act as a deep groundwater pathway. Discharge of seepage originating from the pit lake to Lac de Gras is predicted to reach approximately 54 m^3/d between 40 years and 400 years after closure, depending on the properties of the potential EPZ.

Several conservative assumptions were included in the hydrogeological model used to predict post-closure conditions:

- In model calibration, it was assumed that all inflow to the existing open pit that was observed in 2010 originated from the potential EPZ extending southeast from the pit wall. In reality, and as concluded by Schlumberger Water Services (SWS 2010), a portion of this inflow likely originates from the active layer, and some inflow could originate from the competent rock mass. Therefore, the EPZ transmissivity derived during model calibration, together with predicted seepage rates during post-closure, likely overestimate the actual values.
- The hydrogeological model assumes that the potential EPZ is associated with a structural discontinuity extending southeast from the Misery pit. In reality, other discontinuities identified in the Water Management Consultants study (WMC 2009) could act as a groundwater pathway, and the discontinuity extending southeast might not. Distance from the pit lake to Lac de Gras along these other discontinuities is larger than assumed in the model; thus, the predicted travel time for pit lake seepage to reach Lac de Gras could be less than the actual travel time.
- The hydrogeological properties of the potential EPZ were assumed to be the same everywhere within the model domain. It is possible that the effects of the disturbance zone associated with kimberlite emplacement extends a shorter distance from the pipe than assumed, and that the transmissivity of the potential EPZ away from the Misery Pit is less than immediately behind the pit walls. Thus, the predicted seepage rates during post-closure could overestimate the actual values.

8C6 REFERENCES

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