Golder Associates

TECHNICAL MEMORANDUM

DATE July 3, 2015 **PROJECT No.** 1419751

TO Mr. Richard Bargery
Dominion Diamond Ekati Corporation

CC Mr. Elliot Holland, Ms. Claudine Lee and Mr. Eric Denholm

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JAY PROJECT – UNCERTAINTY ANALYSES METHODS AND RESULTS FOR HYDROGEOLOGICAL MODELLING

1.0 INTRODUCTION

Dominion Diamond Ekati Corporation (Dominion Diamond) submitted a Developer's Assessment Report (DAR) to the Mackenzie Valley Environmental Impact Review Board (MVEIRB) in November 2014. Following the Jay Project (Project) Technical Sessions held in Yellowknife between April 21 and 24, 2015, Dominion Diamond agreed to provide analyses that would assess the degree of uncertainty or probability associated with the hydrogeological modelling in the DAR (i.e., the environmental assessment [EA] Conservative Scenario), as well as to develop a lower bound case. Furthermore, it was agreed that Dominion Diamond would provide a summary of the approach that was being proposed to the Government of Northwest Territories (GNWT) for their review and comments.

On May 5, 2015, Dominion Diamond presented the proposed approach in an e-mail from Richard Bargery of Dominion Diamond to Nathen Richea of the GNWT. On May 6, 2015, Mr. Richea, in an e-mail with attachments, asked for clarification on the first order approximation approach (FOA) and provided the probability distribution functions (PDFs) that the GNWT's consultants recommended for the Monte Carlo simulation (Zajdlik & Associates Inc. 2015). On May 11, 2015, Dominion Diamond provided additional clarification and detail on the FOA method and the revised PDFs that Dominion Diamond proposed to use in the Monte Carlo simulation. Additional clarification and information was provided to Nathen Richea of GNWT on May 21, 2015, in response to his e-mail of May 15, 2015. A summary of Dominion Diamond's engagement with the GNWT on the hydrogeological modelling and the memos provided by the GNWT consultants was submitted to the MVEIRB public registry on May 29, 2015.

This memo references three scenarios or (cases) for the hydrogeological modelling:

- the EA Conservative Scenario is described in Section 8A4 of Appendix 8A of the DAR; this scenario was carried through the water quality predictions in the DAR, with the water quality predictions being updated in Golder (2015a) as the updated assessment case.

- The Reasonable Estimate Case is described in in Section 8A3.6 of Appendix 8A of the DAR (previously referred to as the Reference Case); this was carried through in the water quality predictions for the Reasonable Estimate Case (Golder 2015a).
- The Lower Bound Scenario is being developed with the second round of Information Requests (IR Round 2), and will be provided to MVEIRB with the submission of IR Round 2.

2.0 UNCERTAINTY ASSESSMENT METHODS

In order to assess the degree of uncertainty or probability associated with the EA Conservative Scenario and Reasonable Estimate Case and a Lower Bound Scenario that will be developed prior to the end of the IR Round 2), Dominion Diamond have proposed two analyses:

- Monte Carlo Analyses: The term Monte Carlo refers to a method for assessing uncertainty involving the development of probability distribution functions which indicate the likelihood of occurrence for variables that are uncertain (such as the hydraulic conductivity of a hypothetical Enhanced Permeability Zone [EPZ]). These probability distribution functions are then randomly sampled for a large number of realizations. Each realization is subsequently run through the groundwater model yielding a probability distribution function for model predicted values such as groundwater inflow quantity and quality. Therefore, this method returns an estimate of the likelihood that a given groundwater quantity and quality will report to the open pit during mining. The computational time and resources required to undertake a Monte Carlo analysis of the full three-dimensional (3D model) are prohibitive. Following GNWT's consultants (ARKTIS Solutions Inc. 2015) recommendation, a Monte Carlo analysis has been undertaken on a two-dimensional (2D) model representing a hypothetical Enhanced Permeability Zone (EPZ) only. The 2D model is a surrogate for the 3D model. The values for inflow quantity and quality can, therefore, be used in a relative sense to assess the uncertainty of the EA Conservative (DAR Appendix 8A), and Reasonable Estimate (Golder 2015a) scenarios. For the Reasonable Estimate Case and the EA Conservative Scenario, the EPZ has been found to contribute from 50 to 70 percent of the inflow. However, if lower hydraulic conductivity values are assigned to the EPZ, then this contribution will decrease and the relative contribution of the flow through the competent rock will increase. The competent rock is not simulated in the 2D Monte Carlo simulations.
- First Order Approximation Method (FOA): The First Order Approximation is a method based on the linearization of the response function that involves performing a set number of simulations in which input parameters are independently adjusted to upper bound or lower bound values, and the impacts of variations in each individual parameter on model predictions are recorded. The approach is approximate, but it allows us to use the results from the full 3D numerical hydrogeological model developed for the Jay Project to assess uncertainties. Over a shorter computational time, the uncertainty can be assessed for a larger number of parameters than those proposed in Monte Carlo simulation, including parameters outside of the EPZ. The results of the FOA have informed the uncertainties associated with the lower end of the assumed hydraulic conductivity distribution of the EPZ.

Both of these analyses have been used to examine uncertainties in groundwater inflow quantity and quality during mining only as this period is the most critical to assessment of the feasibility of the overall water management strategy (i.e., the quantity and quality of groundwater inflows to be managed); this period can also be assessed independently within the groundwater model without feedback from the site wide water quality model. Modelling during the post-closure period involves integration of five interlinked models (as described in DAR Regulatory Engagement Request Response Follow up item 1, Dominion Diamond 2015); therefore, uncertainty in the post-closure period has been addressed by additional evaluation of a Lower Bound Scenario for both mining and post-closure in the groundwater models, site wide water quality, and hydrodynamic models (Golder 2015b). The following provides further detail on the methods used for assessment of uncertainty.

2.1 MONTE CARLO

Many of the GNWT recommendations contained in Zajdlik & Associates Inc. (2015) have been incorporated into our analyses with some refinement to take into account analogue sites near to the Jay Pit, recent research, and our experience in the north.

2.1.1 General Approach

The 2D model of the EPZ, as recommended by the GNWT, has been run as a surrogate for the full 3D model developed for the Jay Project. The 2D model grid and boundary conditions are presented in Appendix A. Employment of this surrogate model has reduced the computational time required for Monte Carlo analyses and allowed us to provide results within the time frame for the IR Round 2. These results cannot be directly compared with the results of the 3D model, but the uncertainty in predicted inflow quantity and quality due to uncertainty in the properties of a potential EPZ have been assessed and correlated with the predictions previously presented for the Reasonable Estimate (DAR Appendix 8A, Section 8A3.6) and EA Conservative Scenario (DAR Appendix 8A, Section 8A4), as well as the Lower Bound Scenario. Complete results of evaluation of the Lower Bound Scenario on the site wide water quality model and meromixis in the Misery Pit are provided in Golder (2015b).

As a result of concerns regarding individual model run stability, we have selected a manual implementation of the stochastic simulations consisting of three general steps:

- A random generator has been used to sample each of the probability distribution functions to determine the input parameters for each 2D model run;
- Each 2D model simulation was manually run and checked for stability, convergence, and mass balance; and,
- The results of the 2D model runs were used to develop a probability assessment of the groundwater inflow quantity and TDS loading.

2.1.2 Parameters

The following provides a discussion of parameter distribution functions (PDFs) which are also presented graphically in Figure 1. These parameters were developed considering data on nearby analogue sites, published material, and experience in the north (Hydrogeology Baseline, DAR Annex IX). The PDFs were developed for the same four parameters as those proposed by the GNWT (Zajdlik & Associates Inc. 2015), namely EPZ width, porosity, hydraulic conductivity, and total dissolved solids (TDS) depth profile. Each of these four parameters is discussed below together with our proposed distributions and parameterizations.

2.1.2.1 Width of the EPZ

The PDF for the EPZ considers the following:

- The width of Duey's Fault at the Diavik Mine has been measured accurately through observations in the open pit and through horizontal boreholes in the underground; therefore, the high end of this distribution should be 100 metres (m); and,
- A reasonable lower bound for the width is considered to be 10 m.

This distribution will define the width of the EPZ over its entire depth. This is a limitation of the use of the surrogate 2D model, as the width in the EA Conservative Scenario (DAR Appendix 8A) in the 3D model was stepped down with depth; from 0 to 400 m, it is 100 m wide, and from 400 to the bottom of the model, it is 60 m wide. In the Reasonable Estimate Case (DAR Appendix B), the width of the EPZ was assumed to be constant with depth as in the 2D representation.

The PDF for width is rectangular, bounded by 10 m and 100 m.

2.1.2.2 Porosity

The PDF for porosity is rectangular and bounded by 0.002 and 0.05. Porosity in fractured rock is weakly correlated with hydraulic conductivity; therefore, scenarios with unreasonable combinations of very low porosities and high hydraulic conductivities are unlikely. However, for the purpose of transparency, no parameter combinations generated were discarded.

2.1.2.3 Hydraulic Conductivity

The PDF for hydraulic conductivity in the upper 400 m of the EPZ is assumed to be a log-normal distribution that considers the data from other kimberlite pipes in the vicinity of the Jay pipe (DAR Annex IX, Table 4.4-1), as well as the EA Conservative Scenario (based on the hydraulic properties of Duey's Fault). All of these other EPZs (as well as two other pipes at the Diavik Mine) generally have hydraulic conductivities at least one order of magnitude less than Duey's or are much thinner. Our assumed distribution has a mean of 5×10^{-6} metres per second (m/s) with a lower estimate (5^{th} percentile value) of 1×10^{-6} m/s and a upper estimate (95^{th} percentile value) of 2.5×10^{-5} m/s, which is 2.5 times greater than the hydraulic conductivity in Duey's Fault (and that applied in the EA Conservative Scenario model).

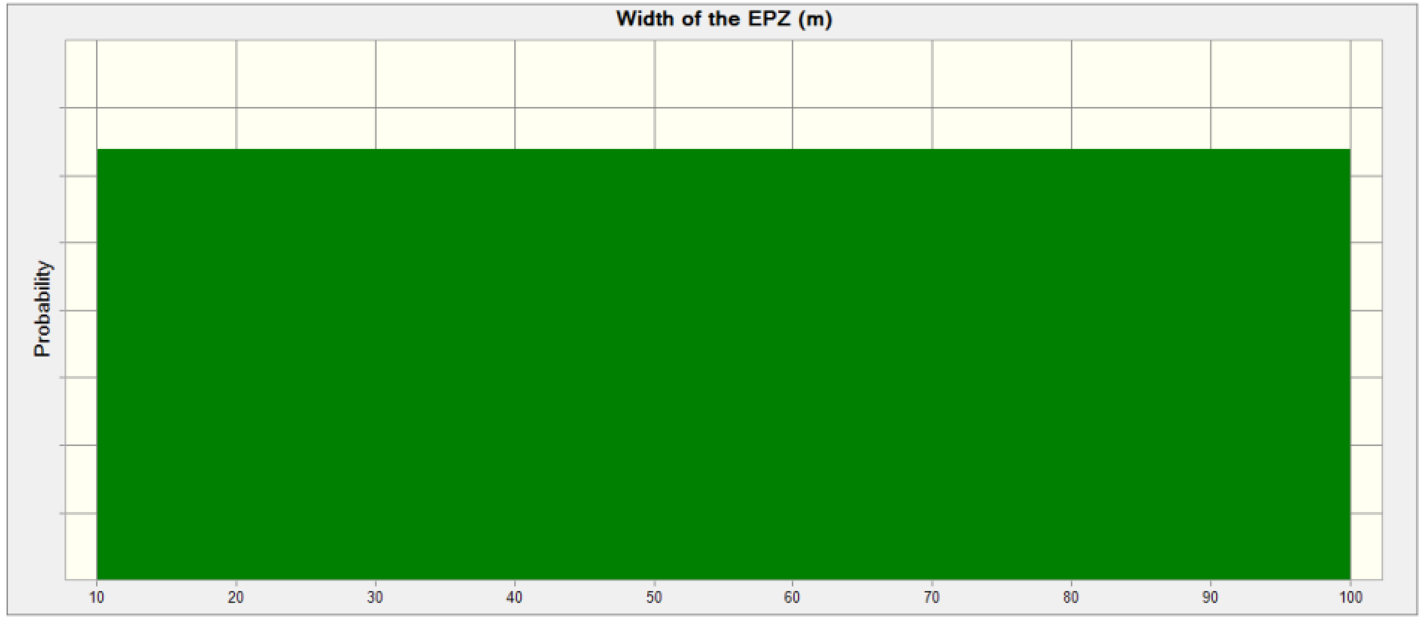
The above probability distribution has been used to define the hydraulic conductivity of the EPZ in the first 400 m depth, with the hydraulic conductivity at greater depths stepped down at the same rate that is in the Reasonable Estimate and EA Conservative Scenario (DAR Appendix B, and Appendix 8A).

2.1.2.4 TDS Profile

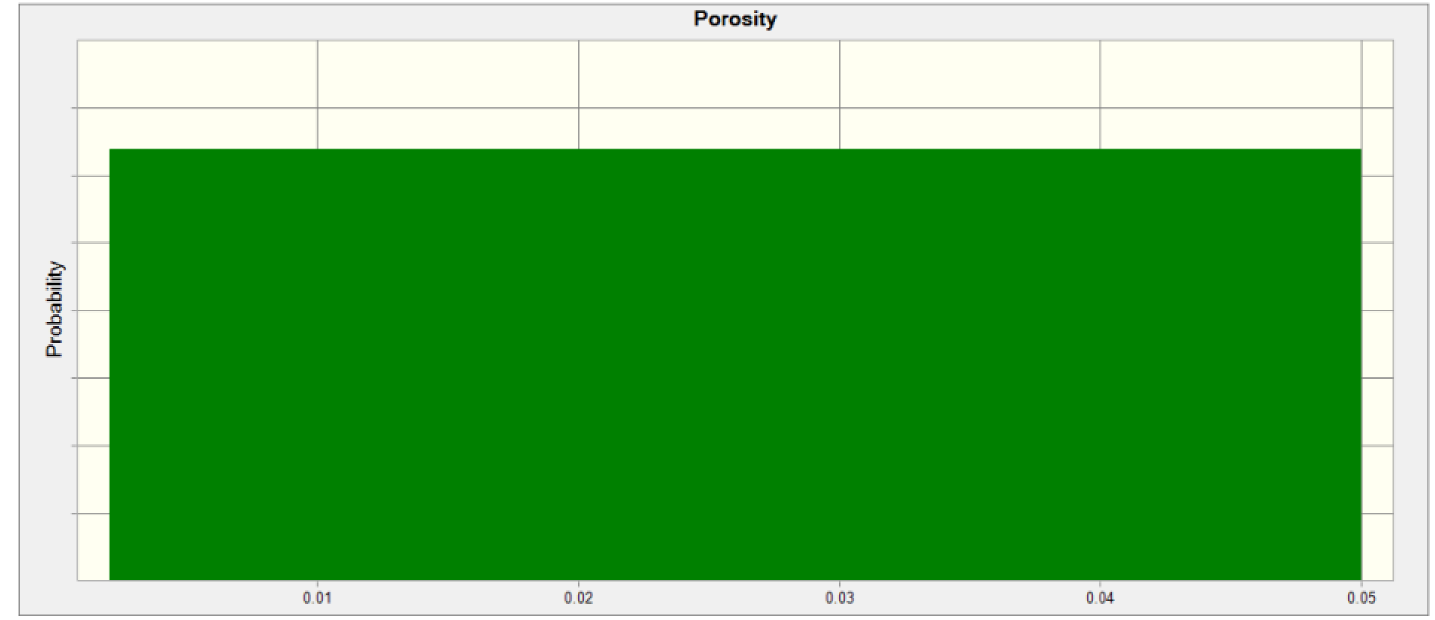
The PDF for the TDS has been assumed to be triangular with limits of 110 and 1,000 milligrams per litre (mg/L) TDS, and a mode equal to the intercept of the Jay Pit regression of 540 mg/L.

Figure 1 Probability Distributions

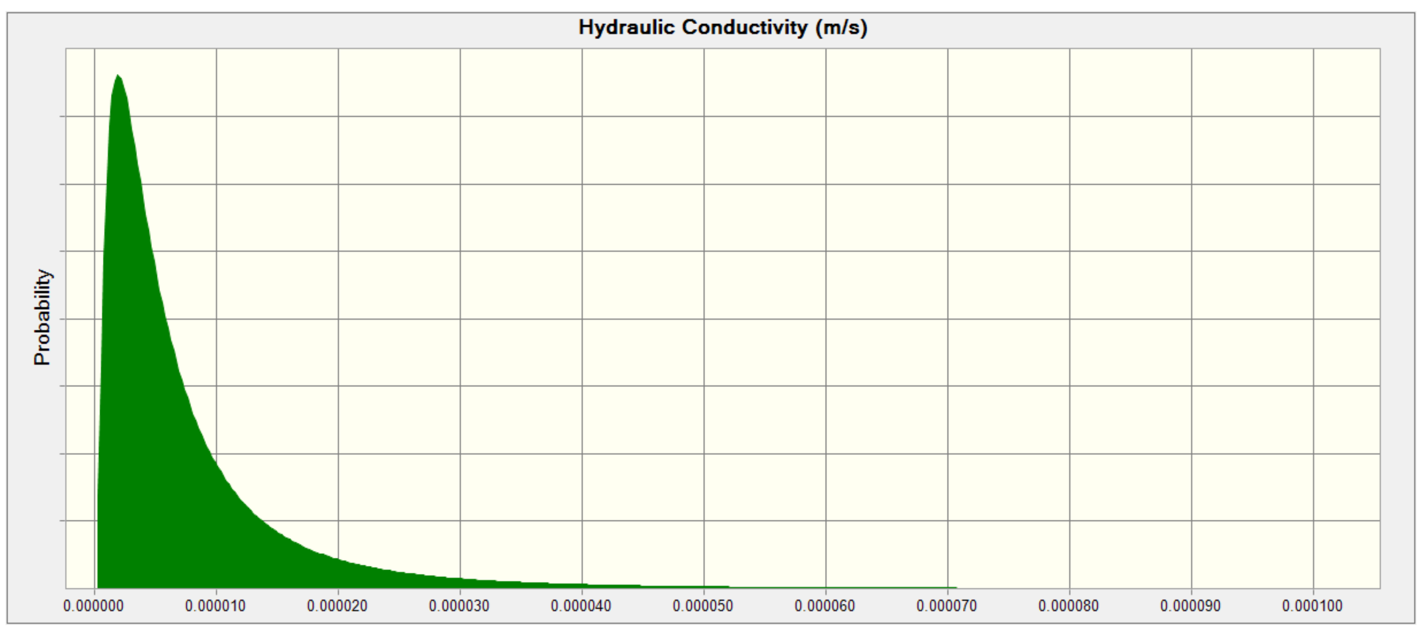
a) Probability Distribution Function for the Width of the Enhanced Permeability Zone



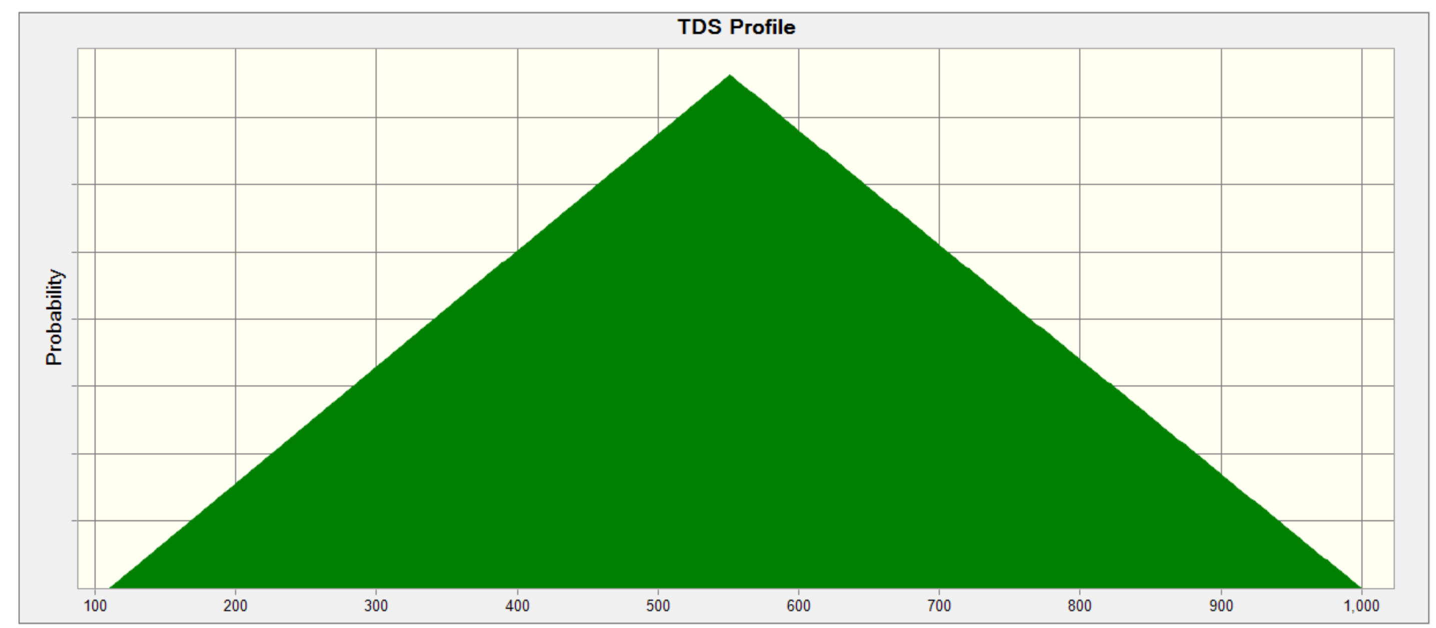
b) Probability Distribution Function for Porosity



c) Probability Distribution Function for Hydraulic Conductivity



d) Probability Distribution Function for the Total Dissolved Solids Profile



EPZ = enhanced permeability zone; TDS = total dissolved solids; m = metre; m/s = metres per second.

2.2 First Order Approximation

2.2.1 General Approach

The first order approximation approach is described in Benjamin and Cornell (1970) and UNESCO (2005). This approach relies on the assumption that input parameters are normally or log normally distributed, but it uses the results of simulations using the full 3D numerical hydrogeological model, developed for the Jay Project, to assess uncertainties. The uncertainty is assessed for a larger number of parameters than those proposed in Monte Carlo simulation presented below. In our approximation, it is assumed that the PDFs for the hydraulic conductivities in the kimberlite, the EPZ, competent rock and weathered bedrock, and the PDF for storage properties are all log-normal; whereas, the distributions of EPZ porosity, EPZ width, and TDS are normal. The standard deviation, variance, and coefficient of variation will be calculated for each model input parameter based on the assumption that for each parameter, two standard deviations are encompassed between the mean value and the upper or lower bound. For a normal distribution of parameter values, the standard deviation can be calculated by the following:

$$\sigma_X = \frac{1}{2}(X - m_X) \qquad (1)$$

where m_x is the mean value of the variable X, and the value of X substituted into this equation is a value of the variable, which is 2 standard deviations from the mean value. By definition, the coefficient of variation is $V = \frac{\sigma_x}{m_X}$, and the variance is $Var = \sigma_x^2$.

For a log-normal distribution of parameter values, the standard deviation of the natural log of a parameter Y is normally distributed; therefore, the standard deviation of ln Y is:

$$\sigma_{\ln Y} = \frac{1}{2}\ln\left(Y / m_Y \right) \qquad (2)$$

The coefficient of variation of the variable Y is related to the standard deviation of ln Y by the formula (pg. 266, Benjamin and Cornell 1970):

$$\sigma_{\ln Y}^2 = \ln(V_y^2 + 1) \qquad (3)$$

The standard deviation of the variable Y can then be calculated as $\sigma_Y = V_Y m_Y$ and the variance of Y follows as $Var = \sigma_Y^2$.

The uncertainty in the model predictions is a function of uncertainty in each of the input parameters. Assuming these hydraulic parameters are uncorrelated, a first order approximation of the variance can be calculated by the following (pg. 180-186, Benjamin and Cornell 1970):

$$Var[Q] \approx \sum_{i-1}^{I} \left(\frac{\Delta Q}{\Delta X_i} \right)^2 Var[X_i] \qquad (4)$$

where *Q* is the predicted inflow, X_i is a hydraulic parameter such as hydraulic conductivity, and *I* is the total number of hydraulic parameters that the predicted inflow depends on.

2.2.2 Probability Distributions

Initially, a base case simulation was performed using the base case values presented below in Table 1. This base case simulation employs mean parameter values that are consistent with the Reasonable Estimate Case

(DAR Appendix B) for all parameters except the EPZ width and hydraulic conductivity for which the values utilized in the Reasonable Estimate Case are considered to be conservatively high. Therefore, the base case values for hydraulic conductivity and width of the EPZ were selected to be consistent with the parameter distributions discussed in Section 2.1.2. The base case provides a reference point for all further FOA simulations that has been used to evaluate the impact of individual parameter variations.

For each parameter, two simulations were performed for which the parameter was adjusted to its upper bound value in the first simulation and its lower bound value in the second simulation. For all log normally distributed parameters (all hydraulic conductivities and specific storage), the upper bound values are assumed to be 5 times greater than the mean, and the lower bound values are assumed to be 5 times lower than the mean. For normally distributed parameters, the uncertainty factors shown in Table 1 were added or subtracted from the mean to calculate the upper and lower bound values.

Table 1: Parameters - First Order Approximation

Hydrostratigraphic Unit	Property	Units	Base Case Value	Uncertainty Factor	Upper Bound	Lower Bound
Log Normally Distributed Parameters						
EPZ	Hydraulic Conductivity	m/s	5.00E-06	5	2.5E-05	1.0E-06
Kimberlite	Hydraulic Conductivity	m/s	3.00E-06	5	1.5E-05	6.0E-07
Competent Bedrock	Hydraulic Conductivity	m/s	3.00E-08	5	1.5E-07	6.0E-09
Weathered Bedrock	Hydraulic Conductivity	m/s	4.00E-06	5	2.0E-05	8.0E-07
Overburden	Hydraulic Conductivity	m/s	2.00E-06	5	1.0E-05	4.0E-07
All	Specific Storage	1/m	1E-04 to 1E-05	5	5E-04 to 5E-05	2E-05 to 2E-06
Normally Distributed Parameters						
EPZ	Porosity	-	0.01	0.008	0.018	0.002
EPZ	EPZ Width	m	55	45	100	10
All	TDS profile intercept	mg/L	540	430	110	970

3.0 RESULTS OF ANALYSES

3.1 Monte Carlo

The results of the Monte Carlo analyses are presented in Figures 2 and 3 as cumulative probability plots for the following:

- Total groundwater inflow quantity and quality (TDS) over the first half of the period of mining from 0 days to 1,730 days; and,
- Total groundwater inflow quantity and quality (TDS) over the entire period of mining from 0 days to 3,920 days (end of mining).

The “0” in the above bullets corresponding to the start of dewatering the diked area which corresponds to the beginning of Period 1 presented in the DAR Appendix 8A (Table 8A3-4).The cumulative probability plots in

Figures 2 and 3 present cumulative distribution functions for total groundwater flow and mass loading. The value of the cumulative distribution function for a given groundwater inflow or mass loading value represents the likelihood that the predicted groundwater inflow or mass loading will be less than or equal to that value with a value of 1 corresponding to 100% likelihood, and 0 corresponding to 0% likelihood. The predicted inflow and mass loading for the Lower Bound, Reasonable Estimate, and EA Conservative Scenarios are also shown on Figures 2 and 3 for reference.

It should be noted, for example, that the 95 percentile of the water quantity will not necessarily correspond to the 95 percentile for the water quality; these may be different scenarios using entirely different parameters for hydraulic conductivity, width, porosity, and TDS profile. It has also been found that, for example, two times greater inflow quantity has a greater effect on management of the groundwater discharge in the Misery Pit than twice the groundwater quality (TDS). Because of this, groundwater quantity is the primary parameter to assess uncertainty of a given scenarios, with quality secondary.

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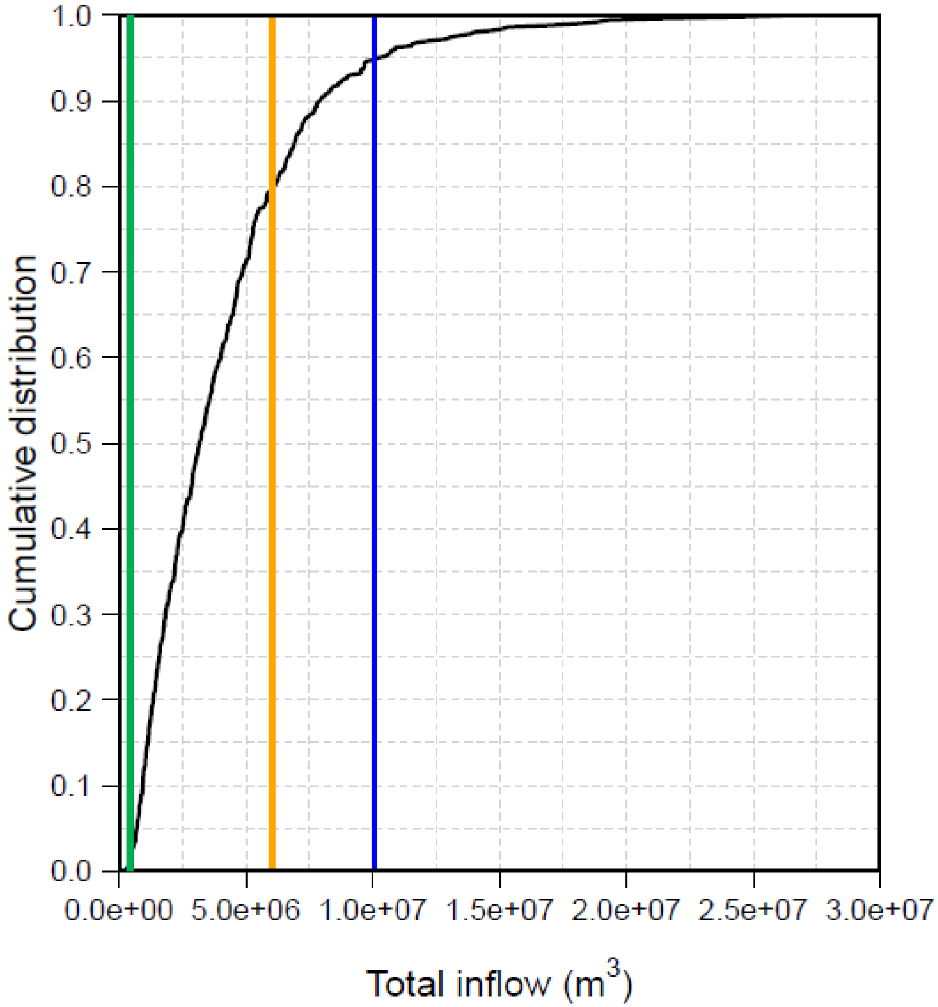

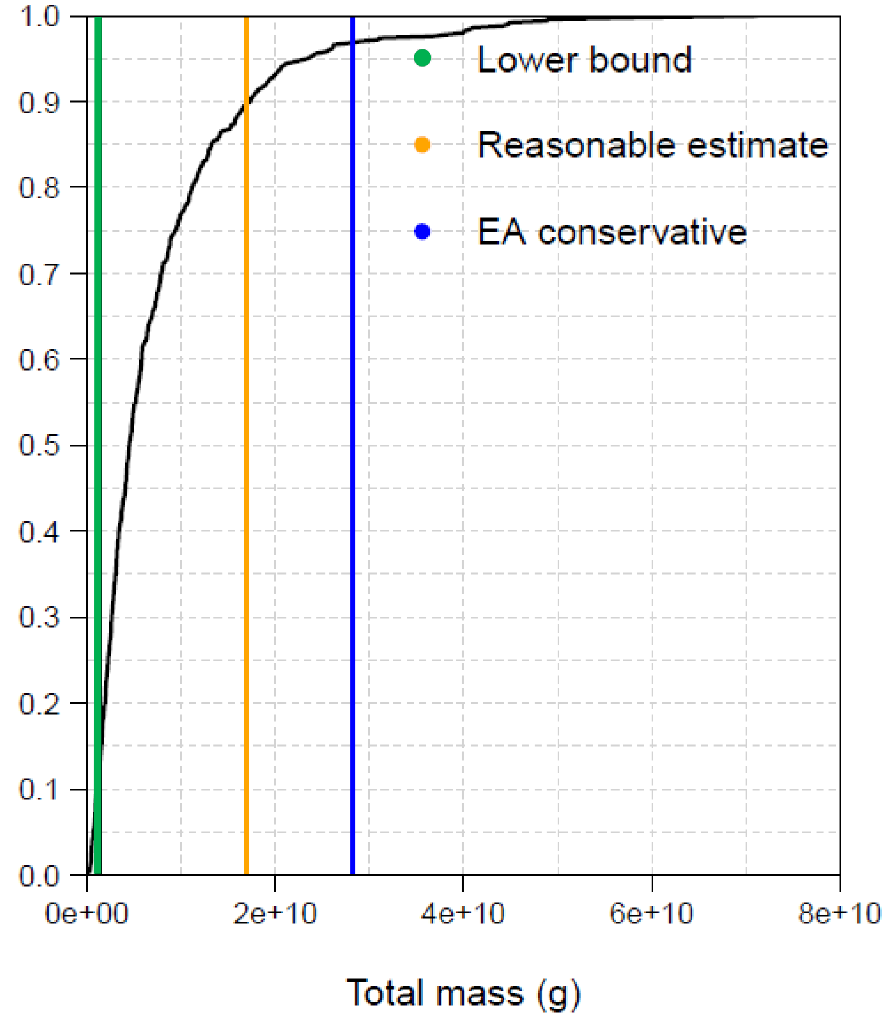

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES				
TITLE	CUMULATIVE PROBABILITY PLOT FOR THE PERIOD FROM 0 TO 1730 DAYS, MONTE CARLO SIMULATIONS				
Golder Associates	PROJECT No. 1419751-3400			FILE No. ----	
	DESIGN	SU	25JUN15	SCALE NTS	REV.
	CADD	SU	25JUN15	FIGURE 2	
	CHECK	NF	26JUN15		
	REVIEW	DC	29JUN15		

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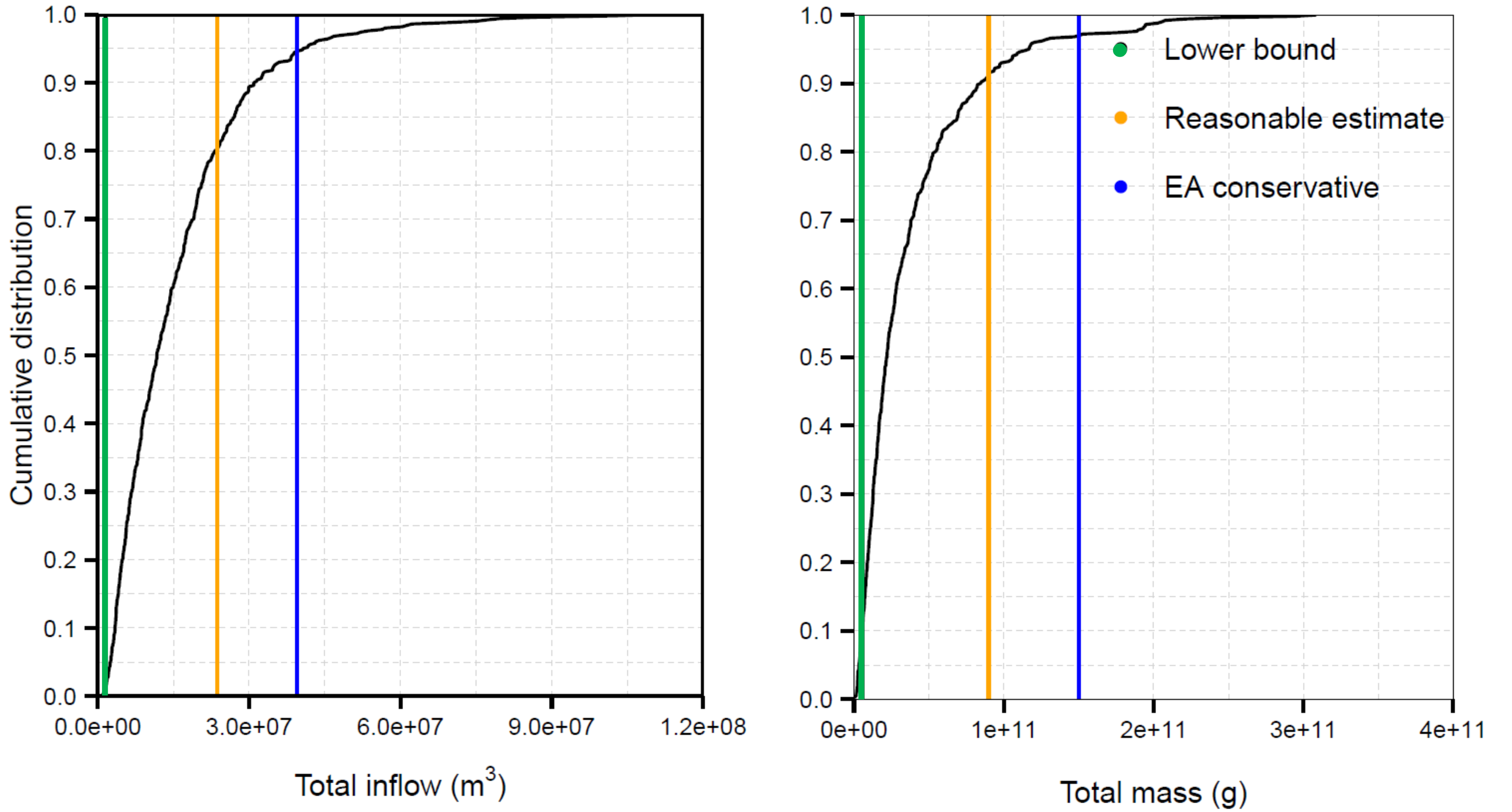

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES
TITLE	CUMULATIVE PROBABILITY PLOT FOR THE PERIOD FROM 0 TO 3920 DAYS, MONTE CARLO SIMULATIONS

Golder Associates

PROJECT No. 1419751-3400			FILE No. ----	
DESIGN	SU	25JUN15	SCALE NTS	REV.
CADD	SU	25JUN15	FIGURE 3	
CHECK	NF	26JUN15		
REVIEW	DC	29JUN15		

Table 2 presents the confidence intervals for total inflow and total mass for the EA Conservative, Reasonable Estimate, and Lower Bound scenarios based on the results of the Monte Carlo analysis. These results indicate that the EA Conservative Scenario corresponds to the 94th percentile for total groundwater inflow, and the 97th percentile for groundwater mass loading over the duration of mining. Therefore, these results confirm that the EA Conservative Scenario results in a sufficient level of conservatism to provide a high level of confidence that effects to the environment have not been underestimated as stated in the DAR (Appendix 8A, Section 8A4).

Table 2: Confidence Intervals – Monte Carlo Simulation

Scenario	0 days to 1,730 days		0 days to end of mining	
	Total Inflow (percentile)	Total Mass (percentile)	Total Inflow (percentile)	Total Mass (percentile)
EA Conservative	95	97	94	97
Reasonable Estimate	80	90	80	91
Lower Bound	1	12	1	11

3.2 First Order Approximation

The results of the FOA analyses are presented in Table 3. Consistent with previous sensitivity analysis (DAR Appendix 8A), these results indicate that the most sensitive parameters for prediction of total groundwater quantity to the end of mine life are the hydraulic conductivity of the EPZ, the width of the EPZ, and the hydraulic conductivity of the weathered bedrock with increases in these parameters resulting in the greatest increases in groundwater inflow quantity over the mine life. The most sensitive parameters for total mass loading to the end of mine life are EPZ hydraulic conductivity and width.

Table 3: First Order Approximation Results

Model Simulation	Parameter Values							Variance $[X_i]$	Total Flow to End of Mining (m^3)			Total TDS Loading to End of Mining (g)		
	Expected	Varied	Uncertainty Factor	Distribution	Standard Deviation of ln X	Standard Deviation of X	Coefficient of Variation		Q	n	$n*Var[X_i]$	Q	n	$n*Var[X_i]$
'Expected'									2.15E+07			5.10E+10		
K EPZ (m/s)	5.E-06	3.E-05	5	lognormal	0.8	-	0.95	2.E-11	4.36E+07	1.2E+24	2.8E+13	1.65E+11	3.3E+31	7.5E+20
	5.E-06	1.E-06	5	lognormal	0.8	-	0.95	2.E-11	1.41E+07	3.5E+24	7.9E+13	1.80E+10	6.8E+31	1.6E+21
K Kimberlite (m/s)	3.E-06	2.E-05	5	lognormal	0.8	-	0.95	8.E-12	2.39E+07	3.9E+22	3.2E+11	7.22E+10	3.1E+30	2.6E+19
	3.E-06	6.E-07	5	lognormal	0.8	-	0.95	8.E-12	1.89E+07	1.2E+24	9.6E+12	3.88E+10	2.6E+31	2.1E+20
K Competent Bedrock (m/s)	3.E-08	2.E-07	5	lognormal	0.8	-	0.95	8.E-16	3.01E+07	5.1E+27	4.2E+12	1.04E+11	2.0E+35	1.6E+20
	3.E-08	6.E-09	5	lognormal	0.8	-	0.95	8.E-16	1.81E+07	2.0E+28	1.6E+13	3.85E+10	2.7E+35	2.2E+20
K Weathered Bedrock (m/s)	4.E-06	2.E-05	5	lognormal	0.8	-	0.95	1.E-11	3.87E+07	1.2E+24	1.7E+13	4.29E+10	2.5E+29	3.7E+18
	4.E-06	8.E-07	5	lognormal	0.8	-	0.95	1.E-11	1.63E+07	2.7E+24	3.9E+13	5.49E+10	1.4E+30	2.1E+19
Ss All Units (1/m)	1.E-04	5.E-04	5	lognormal	0.8	-	0.95	9.E-09	2.92E+07	3.7E+20	3.3E+12	1.02E+11	1.6E+28	1.5E+20
	1.E-04	2.E-05	5	lognormal	0.8	-	0.95	9.E-09	1.96E+07	5.8E+20	5.3E+12	3.49E+10	4.1E+28	3.7E+20
Porosity EPZ (-)	0.01	0.018	0.008	Normal	-	0.004	0.40	2.E-05	-	-	-	4.39E+10	7.9E+23	1.3E+19
	0.01	0.002	0.008	Normal	-	0.004	0.40	2.E-05	-	-	-	6.52E+10	3.1E+24	5.0E+19
Width EPZ (m)	55	10	45	Normal	-	23	0.41	5.E+02	3.47E+07	8.6E+10	4.4E+13	1.15E+11	2.0E+18	1.0E+21
	55	100	45	Normal	-	23	0.41	5.E+02	1.34E+07	3.2E+10	1.6E+13	1.62E+10	6.0E+17	3.0E+20
TDS profile intercept at ground surface (mg/L)	540	970	430	Normal	-	215	0.40	5.E+04	-	-	-	9.16E+10	8.9E+15	4.1E+20
	540	110	430	Normal	-	215	0.40	5.E+04	-	-	-	9.44E+09	9.3E+15	4.3E+20
										Σ =	2.6E+14		**Σ =**	5.7E+21
										σ =	1.6E+7		**σ =**	7.6E+10
										σ÷expected	75%		**σ÷expected**	148%

Note: $n = (\Delta Q/\Delta X_i)^2$

A comparison of the results of FOA analyses with the predicted total inflow quantity and total TDS loading that have been predicted for the EA Conservative Scenario (DAR Appendix 8A) and the Reasonable Estimate Case (DAR Appendix B) is presented in Table 4 below. These results indicate that the EA Conservative Case predicts total groundwater inflow to the mine that is 1.9 standard deviations greater than the mean (base case), and total TDS loading from groundwater that is 2.4 standard deviations greater than the mean (base case). The Reasonable Estimate Case predicts total groundwater inflow to the mine that is 0.9 standard deviations greater than the mean (base case), and total TDS loading from groundwater that is 1.2 standard deviations greater than the mean (base case). The Lower Bound predicts total groundwater inflow to the mine that is 0.6 standard deviations less than the mean (base case), and total TDS loading from groundwater that is 0.5 standard deviations less than the mean (base case).

These results confirm that the predictions of groundwater inflow and quality presented in the DAR provide conservatively high estimates of the actual groundwater inflow quantity and quality that are likely to be encountered during mining while the Lower Bound estimate provides a reasonable lower estimate.

Table 3: Comparison of the Results of FOA Analysis with Scenarios in the DAR

Scenario	Total Flow		Total TDS Loading	
	m^3	Number of Standard Deviations from the mean	g	Number of Standard Deviations from the mean
Mean	2.15×10^7	0	5.10×10^{10}	0
EA Conservative	5.27×10^7	1.9	2.29×10^{11}	2.4
Reasonable Estimate	3.61×10^7	0.9	1.39×10^{11}	1.2
Lower Bound	1.15×10^7	-0.6	1.64×10^{10}	-0.5

Note: Volumes and loadings shown above are from the beginning from Period 1 to the end of Period 12 as presented in Appendix 8A Table 8A3-4.

If the distribution for total flow and total mass are assumed to be normal as described in UNESCO (2005) then the percentiles would be as follows:

Table 4: Confidence Intervals – Normal Distribution

Scenario	Total Flow (percentile)	Total Mass (percentile)
EA Conservative	97	99
Reasonable Estimate	82	88
Lower Bound	27	31

4.0 DISCUSSION OF RESULTS

The quantitative uncertainty analysis presented herein provides additional information about the probabilities associated with the groundwater inflow predictions presented in the DAR.

A combination of the FOA and Monte Carlo methods was employed in this quantitative assessment of uncertainty to take advantage of the strengths of each methodology. The FOA solution considers the full 3D model and varied eight parameters, whereas, the Monte Carlo simulation uses a 2D representation of the EPZ as a surrogate for the 3D model and varied only four parameters. However, the 2D model provides a complete Monte Carlo analysis, whereas, the FOA is an approximation. As discussed previously, when high values of hydraulic conductivity are assigned to the EPZ, the flow through the EPZ represents greater than 50% of the total inflow to the entire Jay Pit. Therefore, the 2D Monte Carlo is expected to provide reasonably accurate estimates of the confidence levels for the EA Conservative Scenario and the Reasonable Estimate, as these scenarios assume conservatively high values of hydraulic conductivity in the EPZ. At the relatively low hydraulic conductivity values assumed for the EPZ in the Lower Bound Scenario, the flow through the EPZ has been found to represent less than 10 percent of the total flow. Therefore, at low values for the EPZ hydraulic conductivity, the FOA method, because it uses the entire 3D model, is expected to provide a more accurate estimate of the confidence level (percentile). When reviewing the results of the two methods, each of their inherent limitations must be kept in mind.

Both the FOA and Monte Carlo methods confirm that the predictions of groundwater inflow and quality presented in the DAR for the EA Conservative Scenario and the Reasonable Estimate provide conservatively high estimates of the actual groundwater inflow quantity and quality that are likely to be encountered during mining. The results of both methods indicate that the EA Conservative Scenario corresponds to the 94th percentile or greater for total groundwater inflow, and the 97th percentile or greater for groundwater mass loading over the duration of mining. Therefore, these results confirm that the EA Conservative Scenario results in a sufficient level of conservatism to provide a high level of confidence that effects to the environment have not been underestimated as stated in the DAR (Appendix 8A Section 8A4).

As expected, the Lower Bound confidence estimate from the 2D Monte Carlo method is much lower than that estimated from the FOA method. Results of the Monte Carlo method estimate that the Lower Bound Scenario confidence level is about the 1 percentile for flow and 11 or 12 percentile for mass. The FOA method estimates that the confidence level is about 27 percentile for inflow and 31 percentile for mass. The actual confidence level, if the full 3D model were run as a Monte Carlo simulation, is somewhere between these two values. These results show that the Lower Bound provides a reasonable lower estimate of the actual groundwater inflow quantity and quality that could occur during mining of the Jay Pit.

5.0 CLOSURE

We trust that the above discussion satisfies your current requirements.

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APPENDIX A

TWO DIMENSIONAL SURROGATE MODEL FOR MONTE CARLO ANALYSES

Abbreviations

Abbreviation	Definition
2D	two-dimensional
3D	three-dimensional
bgs	below ground surface
DAR	Developer's Assessment Report
EPZ	enhanced permeability zone
TDS	total dissolved solids

Units of Measure

Unit	Definition
km	kilometre
m	metre
m/s	metres per second
m^2/s	square metres per second
masl	metres above sea level
mg/L	milligrams per litre

A1 NUMERICAL HYDROGEOLOGICAL MODEL

A1.1 Model Selection

The finite-element code FEFLOW from DHI-WASY (Diersch 2014) was selected for the development of the two-dimensional (2D) hydrogeological model for the following reasons:

- FEFLOW is capable of simulating transient, groundwater flow and solute transport in heterogeneous and anisotropic porous media under a variety of hydrogeologic boundaries and stresses;
- FEFLOW allows for simultaneous predictions of groundwater flow and solute transport; and,
- The full three-dimensional (3D) numerical model developed for the Jay Project (Developer's Assessment Report [DAR] Appendix 8A) was also developed in FEFLOW, allowing for more straightforward comparison of model outputs, and model construction.

Groundwater flow in the enhanced permeability zone was simulated as an "equivalent porous media". Flow in bedrock is assumed to be laminar, steady, and governed by Darcy's Law.

A1.2 Model Extent and Mesh Configuration

The orientation of the 2D model is aligned along the assumed enhanced permeability zone (EPZ) presented in Appendix 8A of the DAR.

The extent of the model and mesh are presented in Figure A1. The model extends approximately 22 kilometres (km) horizontally along the orientation of the assumed EPZ and is roughly centered on the Jay pipe. Vertically, the model extends approximately 1.5 km below ground surface (bgs), with the top of the model set to the approximate elevation of the ground surface in the area of the Jay Pit (406 metres above sea level [masl]), and the base of the model set to a constant elevation of -1094 masl (approximately 1.5 km bgs), which is approximately 1,200 metres (m) below the ultimate depth of the deepest planned open pit mine level at the Jay kimberlite pipe (elevation 45 masl). Groundwater flow deeper than about 1.5 km below ground surface (km bgs) is assumed to be negligible and to have negligible influence on model predictions

The mesh consists of approximately 30,000 nodes and 57,000 triangular elements. Triangular elements have a mesh spacing of approximately 25 m in the vicinity of the open pit, progressively expanding to a size of approximately 60 m away from the proposed open pit. Finer mesh spacing surrounding the open pit was incorporated to allow for adequate characterization of the strong hydraulic gradients that are expected to develop in the vicinity of the open pit during mining. Overall, the mesh spacing is considered to be of appropriate detail for simulation of hydrogeological conditions at the site.

A1.3 Hydrostratigraphy and Model Parameters

The 2D model consists of four hydrostratigraphic units: overburden, weathered bedrock, kimberlite, and the EPZ (Figure A2). Table A1 summarizes the hydrogeological parameter values assigned for the initial realization, which corresponds to the Reasonable Estimate case (Golder 2015). For further realizations, a random generator was used to sample probability distribution functions of hydraulic conductivity, porosity, total dissolved solids (TDS) profile, and width of the EPZ to determine the combination of model parameters for each individual model run. Parameter values of hydraulic conductivity and porosity were assigned in FEFLOW for each model run, while the width of the EPZ and the TDS profile were accounted for during post-processing of the FEFLOW output data.

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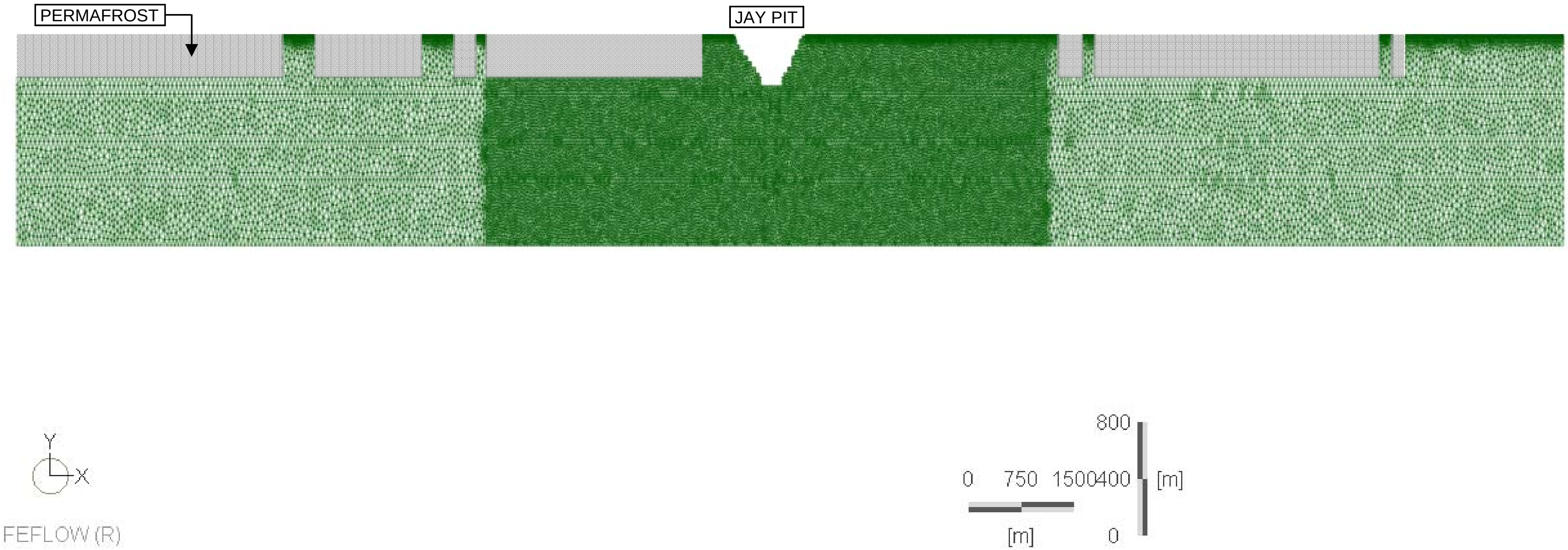


LEGEND

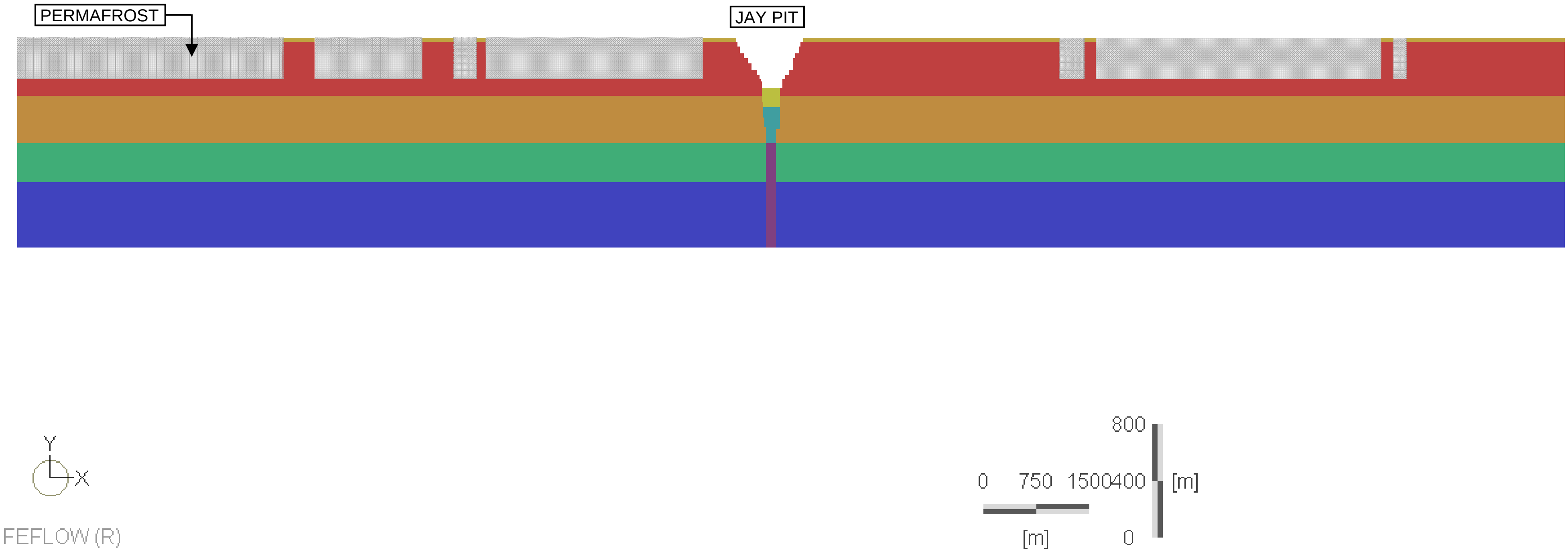
—MODEL GRID
PERMAFROST (INACTIVE)

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES
TITLE	MODEL GRID

PROJECT No. 1419751-3400			FILE No. ----
DESIGN	AM	23JUN15	SCALE NTS REV.
CADD	AM	23JUN15	FIGURE A1
CHECK	CB	25JUN15	
REVIEW	DC	26JUN15	

Golder Associates

REVISION DATE: BY: FILE:



LEGEND

- OVERBURDEN: 2E-6 m/s
- DIKE OVERBURDEN: 4E-7 m/s
- WEATHERED BEDROCK: 4E-6 m/s
- EPZ 30-400: 1E-5 m/s
- EPZ 400-750: 5E-6 m/s
- EPZ 750-1000: 5E-7 m/s
- EPZ 1000-1500: 1E-7 m/s
- KIMBERLITE 25-500: 3E-6 m/s
- KIMBERLITE 500-750: 3E-7 m/s
- KIMBERLITE 750-1500: 3E-8 m/s
- PERMAFROST (INACTIVE)

Note: Hydraulic conductivity values shown correspond to those assigned in the EA Conservative Scenario described in Appendix 8A of the DAR. The EPZ hydraulic conductivity values were varied in individual model realizations during uncertainty analysis.

PROJECT **DOMINION DIAMOND EKATI CORPORATION**
JAY PROJECT
NORTHWEST TERRITORIES

TITLE

HYDROSTRATIGRAPHY

Golder Associates

PROJECT No. 1419751-3400			FILE No. ----
DESIGN	AM	23JUN15	SCALE NTS REV.
CADD	AM	23JUN15	**FIGURE A2**
CHECK	CB	25JUN15	
REVIEW	DC	26JUN15	

Table A1: Hydrogeological Parameters Used in the Reasonable Estimate and EA Conservative Scenario 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]	Effective Porosity (-)[c]	Longitudinal Dispersivity (m)[d]	Transverse Dispersivity (m)[d]	Effective Diffusion Coefficient (m^2/s)
Overburden	0 to 5	2.E-06	1:1	1E-04	0.2	10	1	2E-10
Weathered Bedrock	5 to 30	4.E-06	1:2	2E-04	0.03	10	1	2E-10
Kimberlite (including contact zone)	25 to 500	3.E-06	1:2	1E-04	0.1	10	1	2E-10
Kimberlite (including contact zone)	500 to 750	3.E-07	1:2	1E-05	0.05	10	1	2E-10
Kimberlite (including contact zone)	750 to 1,500	3.E-08	1:2	1E-05	0.05	10	1	2E-10
EPZ[e]	25 to 400	1.E-05	1:1	1E-04	0.01	10	1	2E-10
EPZ[e]	400 to 750	5.E-06	1:1	1E-04	0.01	10	1	2E-10
EPZ[e]	750 to 1,000	5.E-07	1:1	1E-04	0.01	10	1	2E-10
EPZ[e]	1,000 to 1,500	1.E-07	1:1	1E-04	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) Enhanced permeability zones assumed to be trending northwest-southeast, and to be 60 m wide in the Reasonable Estimate Case, based on the properties of EPZs observed at the Panda, Koala, and Diavik A154 mines, and geological evidence.

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

A1.4 Model Boundary Conditions

A1.4.1 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 on Figure A3 and summarized below.

Specified head boundaries were assigned to the top layer of the model to represent all lakes assumed to have open taliks connected to the deep groundwater flow regime. These boundaries were set to the surveyed average lake elevations. 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. Transient specified head boundaries, constrained to outflow only, were assigned to mesh nodes representing the walls of the open pit; the head values at each node were set to vary over time to represent pit excavation according to the mine schedule described in the DAR. The pit bench elevations were derived from elevation contours representing the ultimate pit design.

No-flow boundaries were used to represent inferred groundwater flow divides along the edges of the model. These boundaries are located sufficiently far from the Jay Pit to have a negligible impact on model predictions (DAR Appendix 8A). A no-flow boundary was also applied along the bottom of the model at a depth of 1.5 km bgs (-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 (Hydrogeology Baseline, DAR Annex IX). Mesh elements representing permafrost were deactivated in all model simulations.

Initial groundwater flow conditions represent the pre-mining groundwater flow regime described in DAR Annex IX where the groundwater flow is controlled by the elevation of the large lakes in the study area. 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.

A1.4.2 Transport Boundary Conditions and Initial Conditions

Three types of transport boundary conditions were used to simulate transport of TDS in groundwater: specified concentration boundaries, zero flux boundaries, and exit (Cauchy type) boundaries (Figure A4).

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

Zero flux boundaries were applied along the base of the model, approximately 1.5 km bgs. 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 simulate the movement of TDS mass out of the surrounding groundwater system and into the open pit.

Initial TDS concentrations were assigned based on the assumed Jay TDS depth profile presented in the Hydrogeology Baseline (DAR Annex IX).

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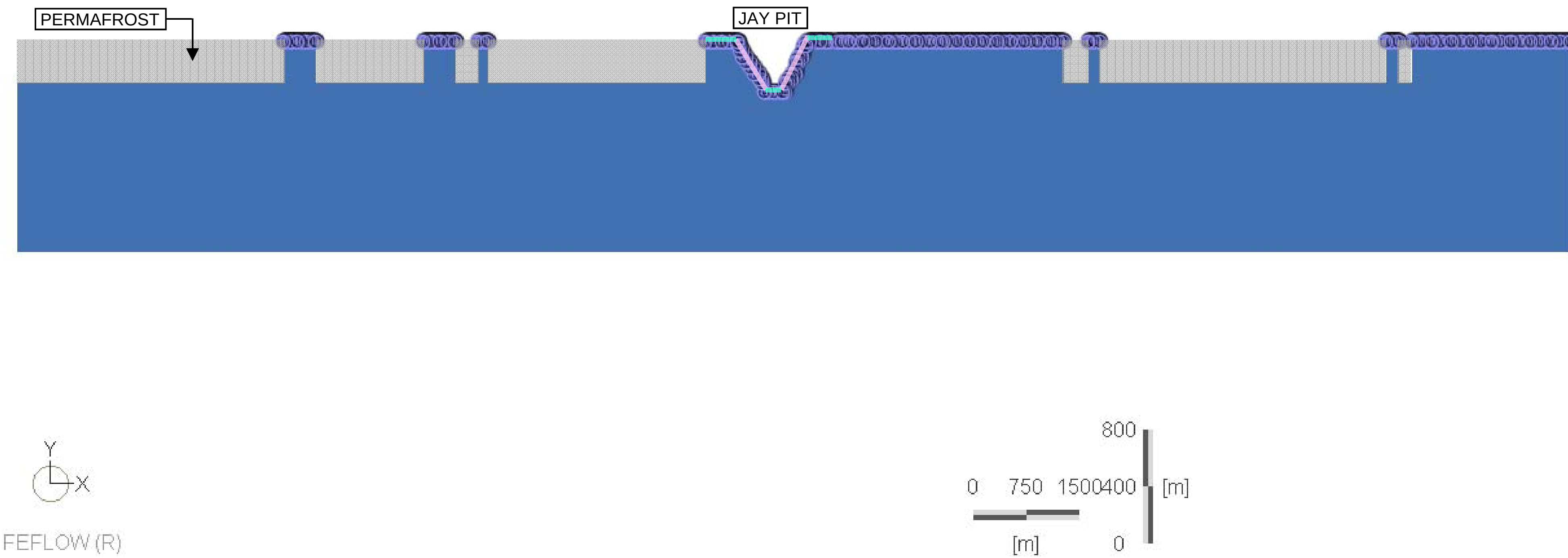


LEGEND

- TIME CONSTANT SPECIFIED HEAD
- TIME VARYING SPECIFIED HEAD
- TIME VARYING SPECIFIED HEAD WITH TIME VARYING MAX FLOW CONSTRAINT
- INITIAL HYDRAULIC HEAD = 416.1 MASL
- PERMAFROST (INACTIVE)

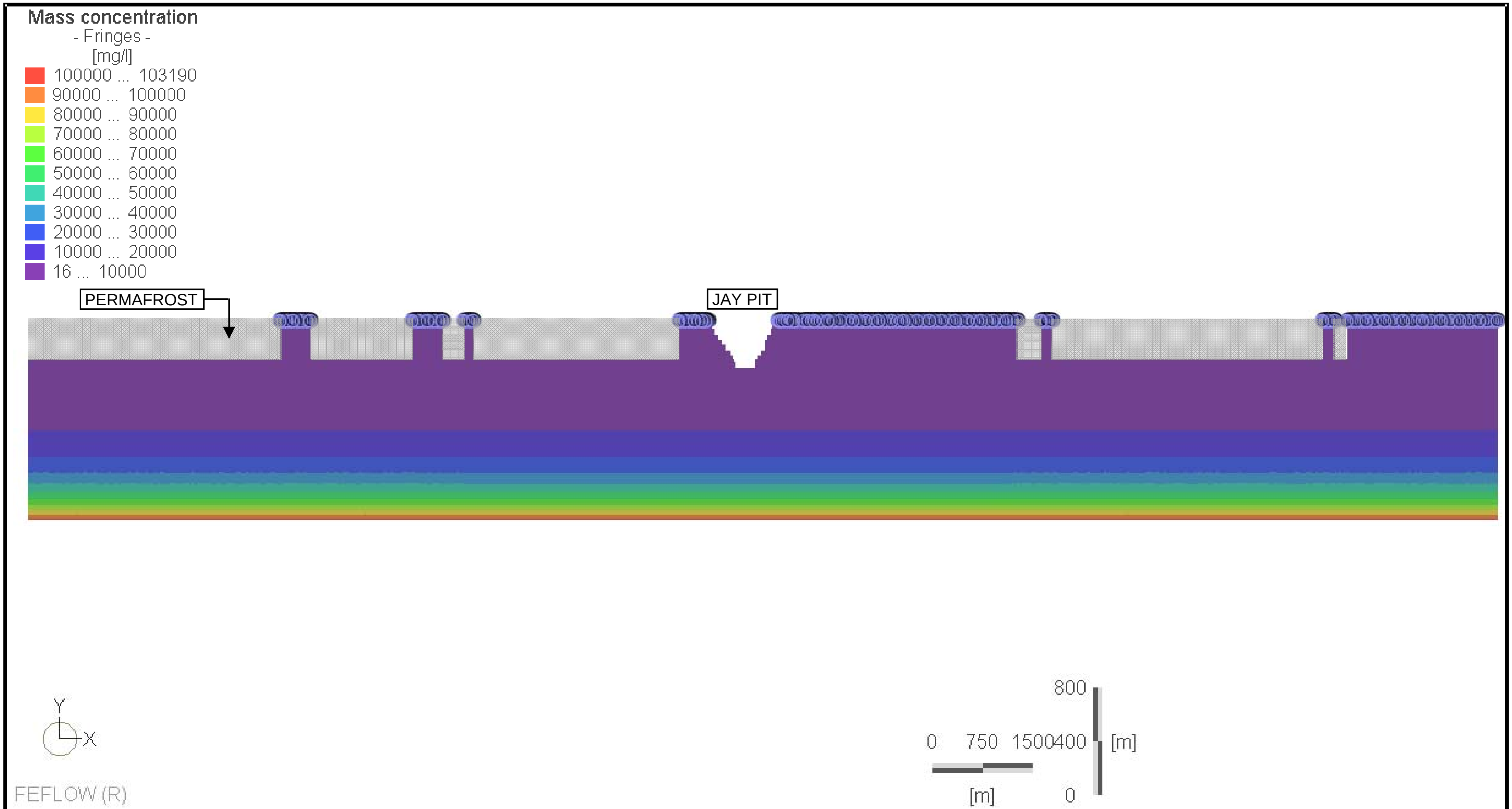
PROJECT
DOMINION DIAMOND EKATI CORPORATION
JAY PROJECT
NORTHWEST TERRITORIES

TITLE
FLOW INITIAL CONDITIONS AND BOUNDARY CONDITIONS

Golder Associates

PROJECT No. 1419751-3400			FILE No. ----	
DESIGN	AM	23JUN15	SCALE NTS	REV.
CADD	AM	23JUN15	**FIGURE A3**	
CHECK	CB	25JUN15		
REVIEW	DC	26JUN15		

REVISION DATE: BY: FILE:



LEGEND

- TIME CONSTANT SPECIFIED MASS CONCENTRATION AT 0 MG/L
- PERMAFROST (INACTIVE)

Note: TDS values shown correspond to those assigned in the EA Conservative Scenario described in Appendix 8A of the DAR. TDS values vary in individual model realizations.

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES			
TITLE	TRANSPORT INITIAL CONDITIONS AND BOUNDARY CONDITIONS			
Golder Associates	PROJECT No. 1419751-3400			FILE No. ----
	DESIGN	AM	23JUN15	SCALE NTS REV.
	CADD	AM	23JUN15	FIGURE A4
	CHECK	CB	25JUN15	
	REVIEW	DC	26JUN15	

A2 MODEL PREDICTIONS

Predicted hydraulic heads and TDS concentrations for the end of mining conditions are presented in Figures A5 and A6. These predictions are generally consistent with those presented for the 3D hydrogeologic model (DAR Appendix 8A). Therefore, the 2D model is considered to be appropriate for evaluation of uncertainty in the model predictions presented in the DAR.

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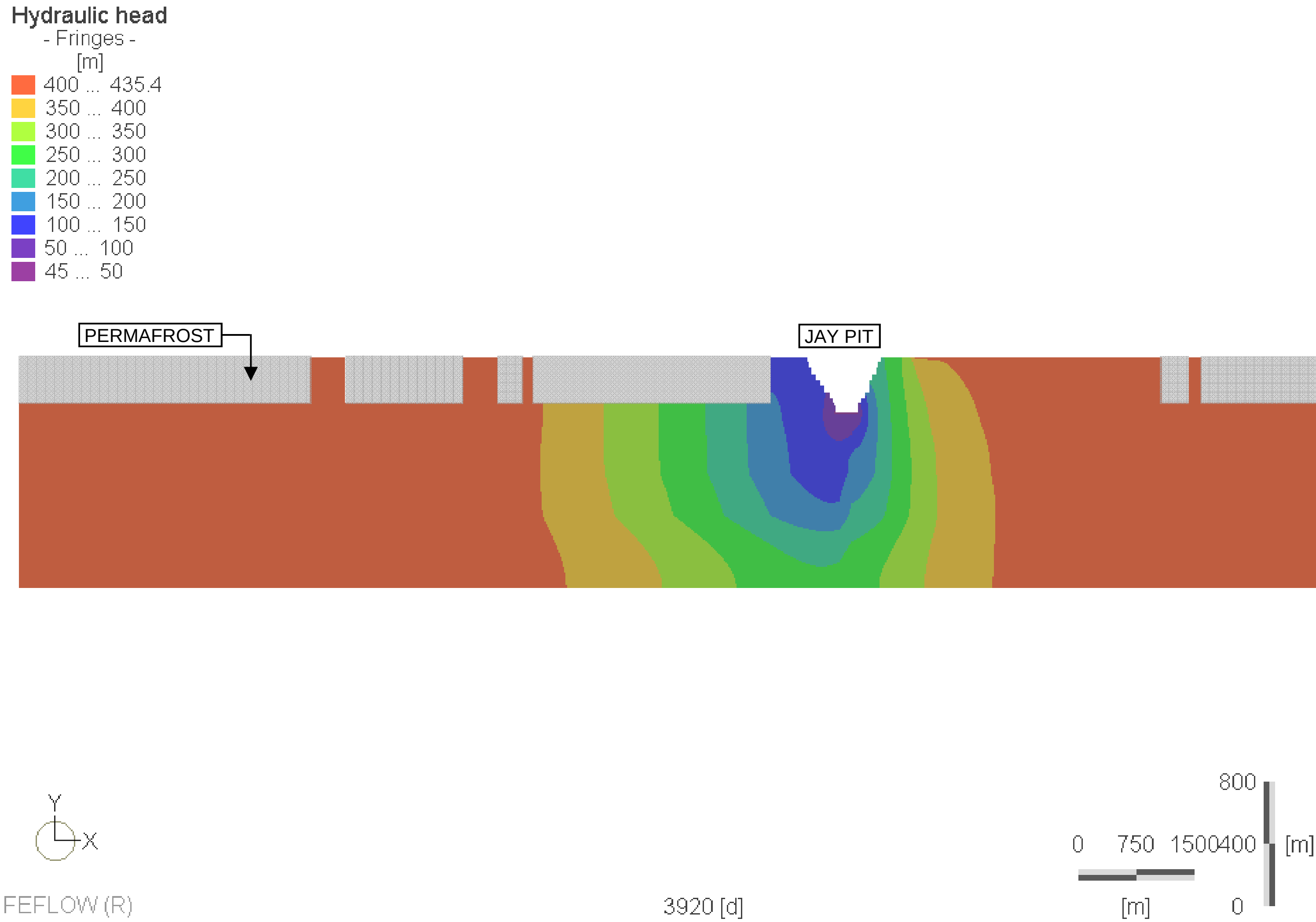

LEGEND

PERMAFROST (INACTIVE)

Note: Predictions shown for a scenario corresponding to the EA Conservative Scenario described in Appendix 8A of the DAR. Predictions for individual realizations vary.

PROJECT **DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES**

TITLE **MODEL PREDICTED HYDRAULIC HEAD END OF MINING**

Golder Associates

PROJECT No. 1419751-3400			FILE No. ----	
DESIGN	AM	23JUN15	SCALE NTS	REV.
CADD	AM	23JUN15	**FIGURE A5**	
CHECK	CB	25JUN15		
REVIEW	DC	26JUN15		

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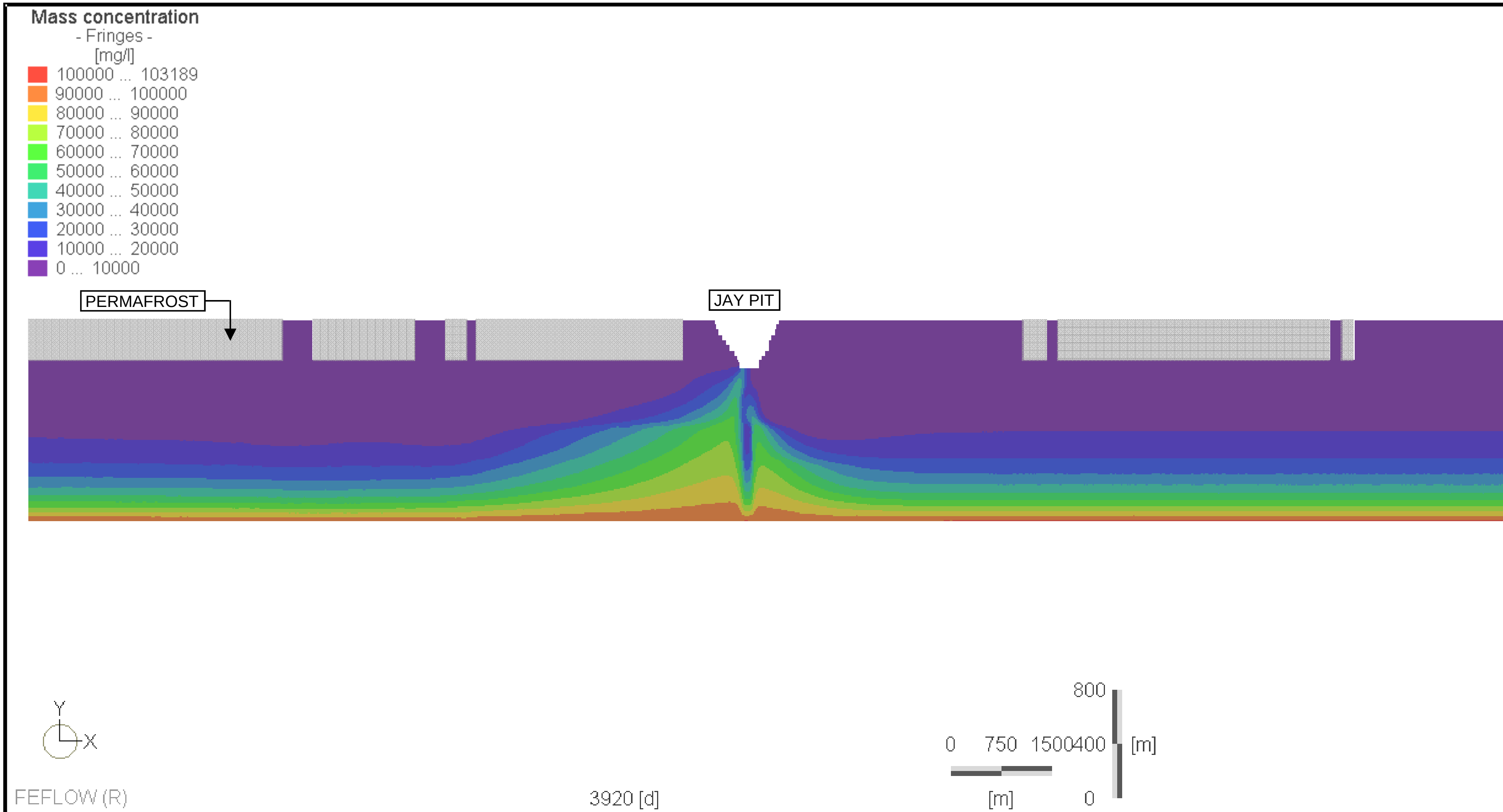

LEGEND

PERMAFROST (INACTIVE)

Note: Predictions shown for a scenario corresponding to the EA Conservative Scenario described in Appendix 8A of the DAR. Predictions for individual realizations vary.

PROJECT	DOMINION DIAMOND EKATI CORPORATION JAY PROJECT NORTHWEST TERRITORIES			
TITLE	MODEL PREDICTED TDS CONCENTRATION END OF MINING			
Golder Associates	PROJECT No. 1419751-3400			FILE No. ----
	DESIGN	AM	23JUN15	SCALE NTS REV.
	CADD	AM	23JUN15	FIGURE A6
	CHECK	CB	25JUN15	
	REVIEW	DC	26JUN15	

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