Appendix 6.5-A

Plume Migration Analyses to RES-2

AJAX PROJECT

Environmental Assessment Certificate Application / Environmental Impact Statement for a Comprehensive Study

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Project Memorandum

To:	**KGHM Ajax Mining Inc.**	**Doc. No.:**	**1125-007-M02-2015**
Attention:	**Nettie Ore**		**Rev 2.0**
From:	**Jessica Worley, Brent Mooder**	**Date:**	**July 15, 2015**
Subject:	**Ajax Project EA - Plume Migration Analyses to RES-2**		
Project No.:	**P15-033**		

1.0 INTRODUCTION

KGHM Ajax Mining Inc. (KAM) proposes to develop the Ajax Project, an open pit copper-gold mine at the historic Afton Mining Camp, south of the City of Kamloops, British Columbia (BC). BGC Engineering Inc. (BGC) was retained by KAM to provide a preliminary assessment of potential plume migration pathways and resulting contaminant concentrations in residential well 2 (RES-2) in support of the Human Health and Ecological Risk Assessment (HHERA) being completed by Stantec for the Ajax Project (Project) Environmental Assessment (EA).

1.1. Background

RES-2 (688,782 m easting, 5,609,430 m northing) is the nearest residential well downgradient from Ajax mining infrastructure and interpreted to be completed within the Peterson Creek Aquifer. The Peterson Creek Aquifer is a 2 km^2 sand and gravel aquifer located south of the Project site along Peterson Creek. The sand and gravel units are glaciofluvial and interbedded with silt and clay lenses (BGC 2015a). A depositional model associated with the Peterson Creek Aquifer is provided in the Ajax Project Baseline Groundwater Hydrology Assessment (BGC 2015b). The Peterson Creek Aquifer is conceptualized as either an unconfined heterogeneous aquifer overlying a bedrock aquifer, or a discontinuously confined (by overlying till and fine grained sediments) heterogeneous aquifer overlying bedrock (BGC 2015a).

To evaluate which seepage sources from mine infrastructure may reach well RES-2, forward and reverse particle tracking simulations were performed using a finite difference groundwater flow model. Three areas were selected as potential seepage points: the proposed East Mine Rock Storage Facility (EMRSF), the EMRSF pond and the Peterson Creek Downstream Pond (PCDP). The EMRSF, EMRSF pond and PCDP are located approximately 1762 m, 1403 m and 1501 m, respectively, from the centre of each source to RES-2.

2.0 METHODOLOGY AND ASSUMPTIONS

To assess the potential source areas that may contribute seepage water to well RES-2, forward and reverse particle tracking simulations were performed using a finite difference groundwater flow model. Section 2.1 describes the model and documents the method and assumptions for the particle tracking.

Information gained from the particle tracking exercise was then used in conjunction with analytical plume migration models to determine estimates of relative contaminant concentrations in RES-2. This process was based on several subsurface leaching scenarios (Section 2.3). Contaminant seepage concentrations at RES-2 were calculated from source terms for the EMRSF developed by Lorax Environmental Services Inc. (Lorax); water quality predictions in the PCDP and in the EMRSF were provided from the water quality model developed by Knight Piésold Ltd. (Knight Piésold) for the HHERA (Appendix A).

2.1. Groundwater Model and Particle Tracking

The groundwater flow model for the site was developed using MODFLOW-SURFACT (Version 3.0) and the graphical user interface Groundwater Vistas (Version 5.33, Build 28; ESI 2007). MODFLOW is an industry standard, three-dimensional finite difference groundwater flow model developed by the U.S. Geological Survey (Harbaugh et al. 2000). MODFLOW-SURFACT is a proprietary code developed by HydroGeoLogic Inc. (1996), which provides additional simulation modules for MODFLOW. The existing numerical model reflects the current mine plan and additional data collected since 2011 (BGC 2015c).

To evaluate which seepage sources from mine infrastructure may reach well RES-2, forward and reverse particle tracking simulations were performed using MODPATH, a commonly-used particle tracking program developed for MODFLOW (Version 3; Pollock 1994). Reverse particle tracking, or the simulation of particle movement in the upstream direction from receiver to source zone, was performed by placing particles along the well screen of RES-2 and pushing them in the reverse direction toward the potential sources. In this simulation, particles migrated towards PCDP. However, as the particle tracking simulation only takes into account advective transport (transport with the mean velocity of groundwater flow), dispersion, or the spreading of a plume that occurs due to mixing, could still bring affected water to RES-2 from the EMRSF and EMRSF pond, which are located directly north of the PCDP. To determine potential flow path lengths and groundwater travel times for the EMRSF and EMRSF pond, forward particle tracking, the simulation of particle movement from source zone to receiver, was then performed. Forward tracking found that particles migrating from the EMRSF and EMRSF pond passed approximately 50 m to 150 m north of RES-2. The 50 m to 150 m range is a result of simulating the migration of multiple particles at different locations within the EMRSF and the EMRSF pond, resulting in several possible path lines to RES-2.

The following main assumptions were made to carry out particle tracking:

1. The well screen for RES-2 fully penetrates the Peterson Creek Aquifer (i.e., the well screen is installed across the full vertical thickness of the aquifer).

2. The water discharge rate from RES-2 is an average of 3,200 L/day[1].
3. The average horizontal hydraulic conductivity (K_h) of the Peterson Creek Aquifer was 1.4×10^{-5} m/s, with an anisotropy, or differing vertical and horizontal hydraulic conductivity ratio (K_v/K_h) of 0.1. Based on this ratio, the vertical hydraulic conductivity was calculated as 1.4×10^{-6} m/s. The horizontal hydraulic conductivity value is based on data from single well response tests (BGC 2015b), while the anisotropy ratio used is consistent with guidance from Section 6.4.4 of the Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities (BC MoE 2012).
4. The average Peterson Creek Aquifer material effective porosity (i.e., the interconnected pore space) was estimated to be 0.25. The effective porosity of sand and gravel aquifers such as the Peterson Creek Aquifer generally ranges between 0.10 and 0.40 (Freeze and Cherry 1979), hence a median value of 0.25 was selected as the base case. Sensitivity of the model to the range of effective porosity is discussed in Section 2.4.2.

Reverse particle tracking simulated the groundwater arrival time from PCDP to RES-2 to be 55 years (Drawing 01). When hydraulic conductivity in the model was increased by an order of magnitude to 1.4×10^{-4} m/s to simulate the high range of possible values (BGC 2015a), arrival time decreased to 17 years. The simulation was run for approximately 110 years, with particles passing through PCDP, and terminating at a small, natural pond of water located northwest of PCDP. Forward particle tracking predicted a groundwater travel time of approximately 11 years for water migrating from the EMRSF and EMRSF pond towards RES-2. This is a conservative estimate for the EMRSF, as the model does not take into account the time for water to infiltrate through the pile and then migrate vertically through native materials to the water table. The groundwater flow model represents the mine rock as being dry, such that seepage would only occur via water infiltration from precipitation sources through the pile to the subsurface. Infiltration in the groundwater flow model is simulated by applying recharge to the footprint of the waste rock as it expands during the mine life; the base case assumption was an applied recharge of 2.7 mm per year (BGC 2015c).

2.2. Potential Contaminant Sources

Three potential sources of seepage and contamination to RES-2 were identified: the proposed East Mine Rock Storage Facility (EMRSF), the EMRSF pond, and the Peterson Creek Downstream Pond (PCDP) as shown on Drawing 01. The three potential solute sources are conceptualized as follows:

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[1] RES-2 flow rate was calculated from Kamloops' annual average per capita water use of approximately 800 litres/day (City of Kamloops nd). Assuming there are 4 users of RES-2, this equates to a volume of water of 3200 litres pumped from RES-2 per day.

- The proposed EMRSF will have a capacity of 420 Mt and will not be lined but will be covered post-closure. Therefore, long term seepage (200 years) from the EMRSF to the subsurface is simulated.
- The EMRSF pond is assumed to be lined with a geomembrane (Knight Piésold 2014). Thus, an instantaneous pulse of pond contents to the subsurface such as a liner breach, or other accident for example, was the incident scenario simulated.
- The proposed PCDP has been sited and designed at a conceptual level (Norwest 2015). If the pond is lined with a synthetic geomembrane (e.g., HDPE), seepage rates will be very low. If the pond is unlined, or is lined with compacted clay till from local sources, ongoing seepage may occur. Given the uncertainty in the PCDP final design, the pond was conservatively assumed to be a continuous source of seepage over the full footprint of the facility (i.e., in the groundwater flow model, the PCDP is assumed to be lined with compacted till).

2.3. Analytical Models

Mass transport equations that consider advective and dispersive transport of solutes dissolved in groundwater can be used to predict the migration and fate of contaminants in the subsurface. A plume migration analysis from the EMRSF and PCDP to RES-2 was completed using the Domenico and Robbins (1985) continuous-source solution. The plume migration analysis from the EMRSF pond to RES-2 was completed using the Baetsle (1969) pulse-source solution. Contaminant velocities were calculated by dividing the length of the plume migration path by the travel time. The plume path length and travel times were obtained from the groundwater model particle tracking simulations.

2.3.1. Continuous Source Model

Seepage from the EMRSF and from the PCDP was simulated as a continuous source loading (further described in Section 3.2 and 3.3, respectively). To simulate the migration and concentration of a plume from a continuous source at a particular location with time, the Domenico and Robbins (1985) solution was used. The analytical solution considers a source with a finite width and thickness, where the source extends from the water table down to a specified depth. The multi-dimensional method included consideration for longitudinal, transverse, and vertical dispersion together with advection in one dimension (1D). Domenico and Robbins (1985) solved the problem assuming that the three dimensional (3D) solution was made up of the product of three 1D solutions. Source dimensions and dispersivity values largely control the plume concentrations that are predicted using this model. The Domenico and Robbins (1985) solution is as follows:

$$\frac{C(x,y,z,t)}{C_o} = \frac{1}{8} erfc\left[\frac{(x-vt)}{2(\alpha_x vt)^{1/2}}\right]\left\{erf\left[\frac{(y+\frac{Y}{2})}{2(\alpha_y x)^{1/2}}\right] - erf\left[\frac{(y-\frac{Y}{2})}{2(\alpha_y x)^{1/2}}\right]\right\}\left\{erf\left[\frac{(z+Z)}{2(\alpha_z x)^{1/2}}\right] - erf\left[\frac{(z-Z)}{2(\alpha_z x)^{1/2}}\right]\right\}$$

Where:

$x =$ Longitudinal distance from the centre of the source

$y =$ Lateral transverse distance from the centre of the source
$z =$ Vertical transverse distance from the centre of the source
$Y =$ Width of source
$Z =$ Depth of source below water table
$C_o =$ Concentration of the source
$\alpha =$ Dispersivity for each coordinate direction
$t =$ Elapsed time
$v =$ Contaminant velocity.

It is convenient to express the concentration of a particular chemical parameter as a relative concentration, defined as C/C_o, where C is the calculated concentration in RES-2 and C_o is the source concentration. The concentration versus time relation at the well screen at RES-2 is known as the breakthrough curve. Contaminant migration in the Peterson Creek Aquifer has been simulated by taking into consideration the effects of advection and mechanical dispersion. The component of molecular diffusion was neglected since the analytical solution assumes that advection and dispersion dominate contaminant transport in aquifers. Freeze and Cherry (1979) indicate the error introduced by neglecting the molecular diffusion process within aquifers[2] is small.

2.3.2. Pulse Source Model

Seepage from the EMRSF pond to RES-2 was simulated as a sudden release from a single source in the subsurface. The following equation, derived by Baetsle (1969) for a pulse-source in 3D, was arranged to solve for relative concentration as above:

$$\frac{C(x,y,z,t)}{C_o} = \frac{V_o}{8(\pi t)^{3/2}(DxDyDz)^{1/2}} exp\left\{-\frac{(x-v_x t)^2}{4D_x t} - \frac{(y)^2}{4D_y t} - \frac{(z)^2}{4D_z t} - \lambda t\right\}$$

Where:

$V_o =$ Original volume of the spill
$D_x =$ Coefficient of dispersion in the x-direction
$D_y =$ Coefficient of dispersion in the y-direction
$D_z =$ Coefficient of dispersion in the z-direction
$\lambda =$ First order decay rate

The original volume of the spill (V_o) was estimated to be 25% of the total volume of the proposed pond. This assumes a liner tear would be noticed and repaired before the total volume of the pond passed to the subsurface.

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[2] In this context, the term aquifers implies a hydraulic conductivity, K, that is typically greater than or equal to 1 x 10^{-6} m/s; at K < 10^{-6} m/s diffusion should be considered in transport calculations.

The coefficient of dispersion in the x, y and z directions (D_x, D_y and D_z, respectively) is related to the dispersivity (α) and the diffusion coefficient D* where:

$$D_x = \alpha_x v_x + D^*$$

$$D_y = \alpha_y v_x + D^*$$

$$D_z = \alpha_z v_x + D^*$$

$D^* = \omega D$ where ω is a coefficient that is related to tortuosity (Bear 1972), and D is the diffusion coefficient. The spreading of contaminant caused by molecular diffusion is assumed to be small relative to mechanical dispersion in groundwater movement and is ignored in this model. The term λt was also ignored for this analysis, assuming mass-conservative substances (i.e., $\lambda = 0$).

2.4. Sensitivity Analysis

A sensitivity analysis for the analytical models was performed using hydraulic conductivity, effective porosity, and dispersion parameters to determine how different parameter values would affect groundwater travel times and plume concentrations at RES-2. An overview of the analysis performed for each parameter is described in the subsections below, and results of the sensitivity analysis are presented in Section 3.0.

2.4.1. Hydraulic Conductivity

As discussed in Section 2.1, the average horizontal K of the Peterson Creek Aquifer is assumed to be 1.4 x 10^{-5} m/s (BGC 2015b). However, a recent constant rate discharge test completed within the Peterson Creek Aquifer (BGC 2015a) suggests that K may range between 1.8 x 10^{-5} m/s and 9.9 x 10^{-5} m/s. To test the upper range of probable K values, each analytical model was re-calculated with a K of 1.4 x 10^{-4} m/s by multiplying the velocity inferred from reverse particle tracking by the K ratio (i.e., 10/1.4).

2.4.2. Effective Porosity

The effective porosity (n) is associated with the interconnected pore space through which water can actually flow. Effective porosity is used to calculate the seepage velocity in the pore space (in the direction of groundwater flow), according to the following equation:

$$v_x = \frac{K}{n} \times \frac{dh}{dl}$$

Where:

$\mathrm{K} =$ Hydraulic conductivity
$\mathrm{dh/dl} =$ Hydraulic gradient

As specified in Section 2.1, an average value of 0.25 was chosen for the particle tracking work. Thus, for the sensitivity analysis, n was set to 0.10 and 0.40 by multiplying the velocity inferred from reverse particle tracking results from the groundwater flow model by the inverse n ratio (i.e. 25/10 and 25/40), and the analysis repeated.

2.4.3. Hydrodynamic Dispersion

The nature and influence of hydrodynamic dispersion is commonly described by a parameter called dispersivity (Bear 1972), which is a property of a porous medium and its capability to cause mechanical dispersion. Dispersivity has longitudinal (α_x), transverse (α_y) and vertical (α_z) components that are in the direction of flow, horizontal to flow and normal to flow, respectively. Dispersivity is scale-dependent. As a first approximation, α_x can be estimated by multiplying longitudinal distance from the centre of the source by 0.1; however, research has shown that the relationship between macroscopic dispersivity and scale is non-linear (Xu and Eckstein 1995). For long plumes, calculated dispersitivities become unreasonably large, and underestimate peak plume concentrations. Xu and Eckstein (1995) used a weighted least squares method to evaluate the relationship between dispersivity and field scale based on collected field data. The non-linear equation to estimate longitudinal dispersivity (α_x) is as follows:

$$\alpha_x = 0.83[\log_{10} x]^{2.414}$$

Longitudinal dispersion is significantly stronger than dispersion in the horizontal transverse direction; furthermore, vertical spreading is considered to be very weak, and controlled by local dispersion on par with molecular diffusion rates (Sudicky and Illman 2011). It is generally expected that longitudinal dispersivity exceeds transverse dispersivity by 1 to 2 orders of magnitude (Freeze and Cherry 1979). In a field study at Canadian Forces Base (CFB) Borden, the dispersivities to describe the contaminant plume in the Borden aquifer were found to vary by approximately 3 orders of magnitude between longitudinal and vertical transverse dispersivities (Frind and Hokkanen 1987). For this reason, transverse and vertical dispersivities were estimated as follows:

$$\alpha_y = 0.1\alpha_x$$

$$\alpha_z = 0.01\alpha_x$$

The equation to determine longitudinal dispersivity given by Xu and Eckstein (1995) was used to provide the base case values for dispersion. To review how sensitive the models were to the longitudinal dispersivity, solutions were carried out with a α_x that was 2 times and 0.5 times the original value.

3.0 RESULTS AND DISCUSSION

3.1. East Mine Rock Storage Facility Pond

Seepage from the EMRSF pond was simulated as an instantaneous, pulse source loading. Refer to Table 3-1 for base case input parameters and Section 2.4 for a discussion on the selection of the ranges of input values for the sensitivity analysis.

Table 3-1. Base case input data for a pulse source seepage simulation in the EMRSF Pond.

Parameter	Value	Units	Description
$x =$	1403	m	longitudinal distance from center of source
$y =$	0	m	lateral transverse distance from center of source
$z =$	0	m	vertical transverse distance from center of source
$V_o =$	7.9×10^3	m^3	initial source volume
$D_x =$	3.5×10^{-5}	m^2/s	the coefficient of hydrodynamic dispersion in the direction of flow
$D_y =$	3.5×10^{-6}	m^2/s	the coefficient of hydrodynamic dispersion in the horizontal transverse direction of flow
$D_z =$	3.5×10^{-7}	m^2/s	the coefficient of hydrodynamic dispersion in the vertical transverse direction of flow
$\alpha_x=$	13.2	m	dispersivity in the x direction
$\alpha_y=$	1.32	m	dispersivity in the y direction
$\alpha_z=$	0.13	m	dispersivity in the z direction
$n =$	0.25	(-)	effective porosity
$K =$	1.4×10^{-5}	m/s	hydraulic conductivity
$v_x=$	4.0×10^{-6}	m/s	contaminant velocity from particle tracking

Results of the simulation are presented in Figure 3-1 and Figure 3-2.

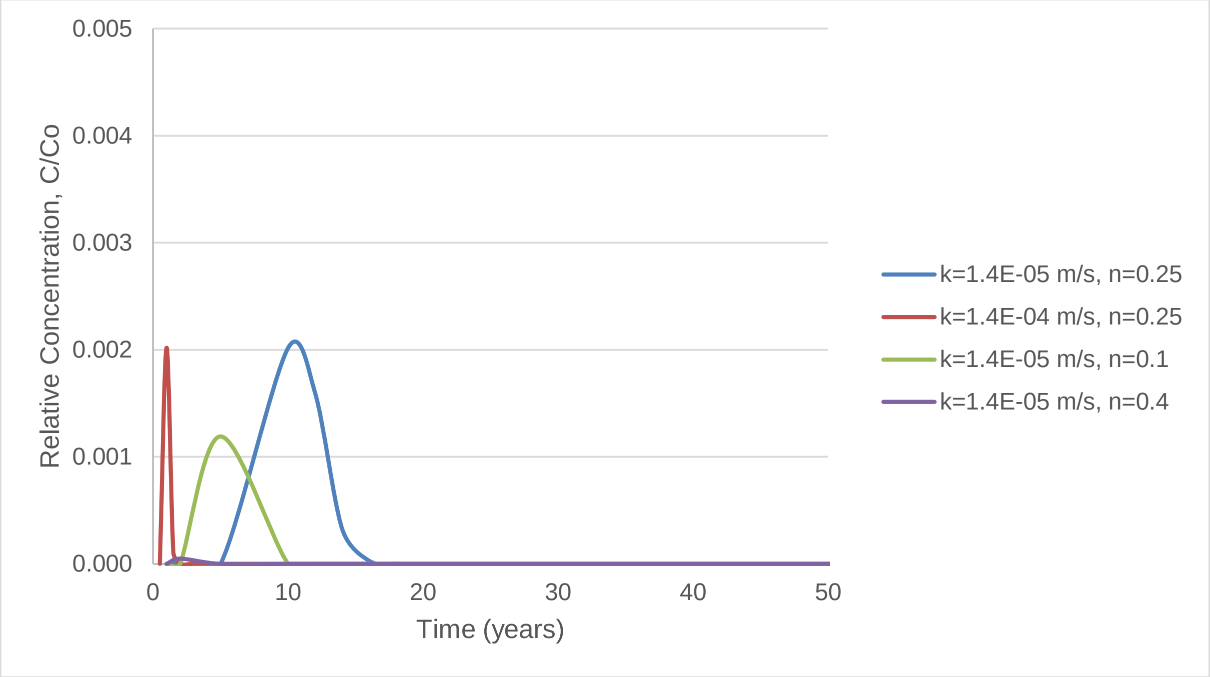

Figure 3-1. EMRSF pond 3D pulse source model demonstrating the range of hydraulic conductivity values (K) and effective porosity values (n).

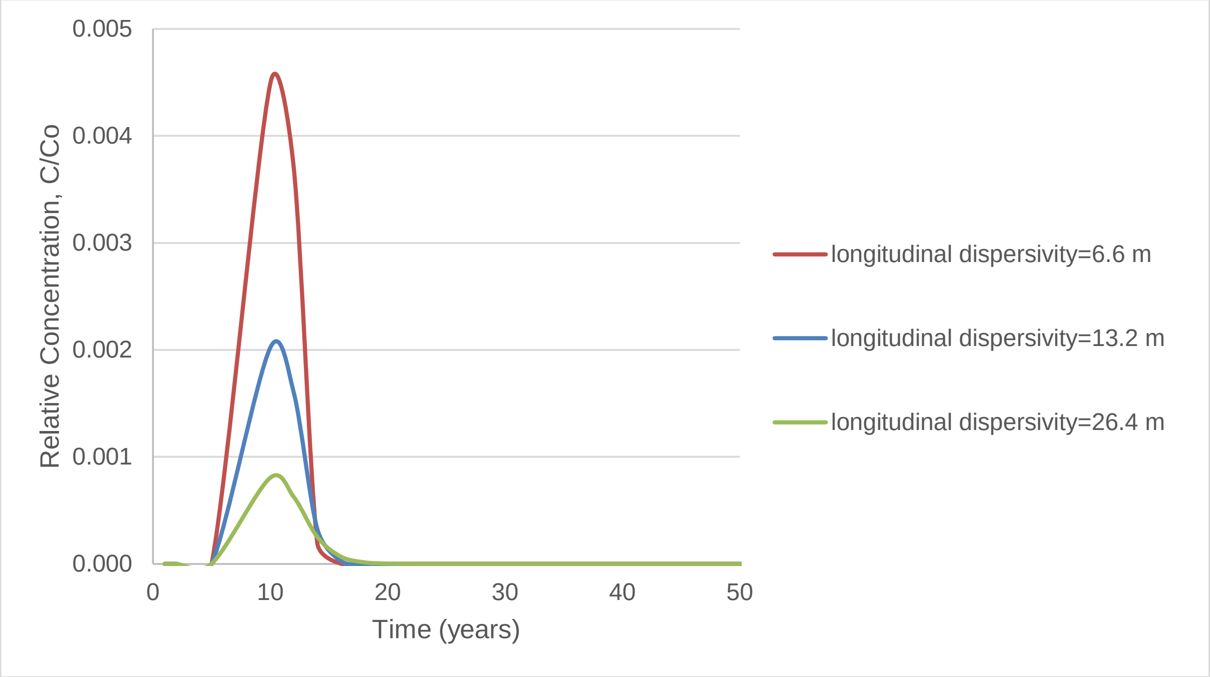

Figure 3-2. EMRSF pond 3D pulse source model demonstrating sensitivity to longitudinal dispersivity (α_x) values.

The peak relative concentration for the base case scenario was found to be 0.002, or 0.2% of the original source concentration. The analysis also reveals that an increase in K by an order of magnitude speeds up arrival time of a plume from the EMRSF to the vicinity of RES-2 by approximately 15 years (Figure 3-1). The range of effective porosity (Figure 3-1) and longitudinal dispersivity values (Figure 3-2) correspond to relative concentration differences of between 0 to 0.002 and 0.00081 to 0.0045, respectively.

3.2. East Mine Rock Storage Facility

Seepage from the EMRSF was simulated as a continuous source loading. Base case input parameters are specified in Table 3-2, input ranges for the sensitivity analysis are outlined in Section 2.4 and Figures 3-3 and 3-4 present the results of the analysis.

Table 3-2. Base case input data for a continuous source seepage simulation in the EMRSF.

Parameter	Value	Units	Description
$x =$	1762	m	longitudinal distance from center of source
$y =$	0	m	lateral transverse distance from center of source
$z =$	0	m	vertical transverse distance from center of source
$Y =$	1000	m	width of source[3]
$Z =$	1	m	depth of source below water table (estimated)
$\alpha_x =$	14.2	m	dispersivity in the x direction
$\alpha_y =$	1.42	m	dispersivity in the y direction
$\alpha_z =$	0.14	m	dispersivity in the z direction
$n =$	0.25	(-)	effective porosity
$K =$	1.4×10^{-5}	m/s	hydraulic conductivity
$v_x =$	5.1×10^{-6}	m/s	contaminant velocity from particle tracking

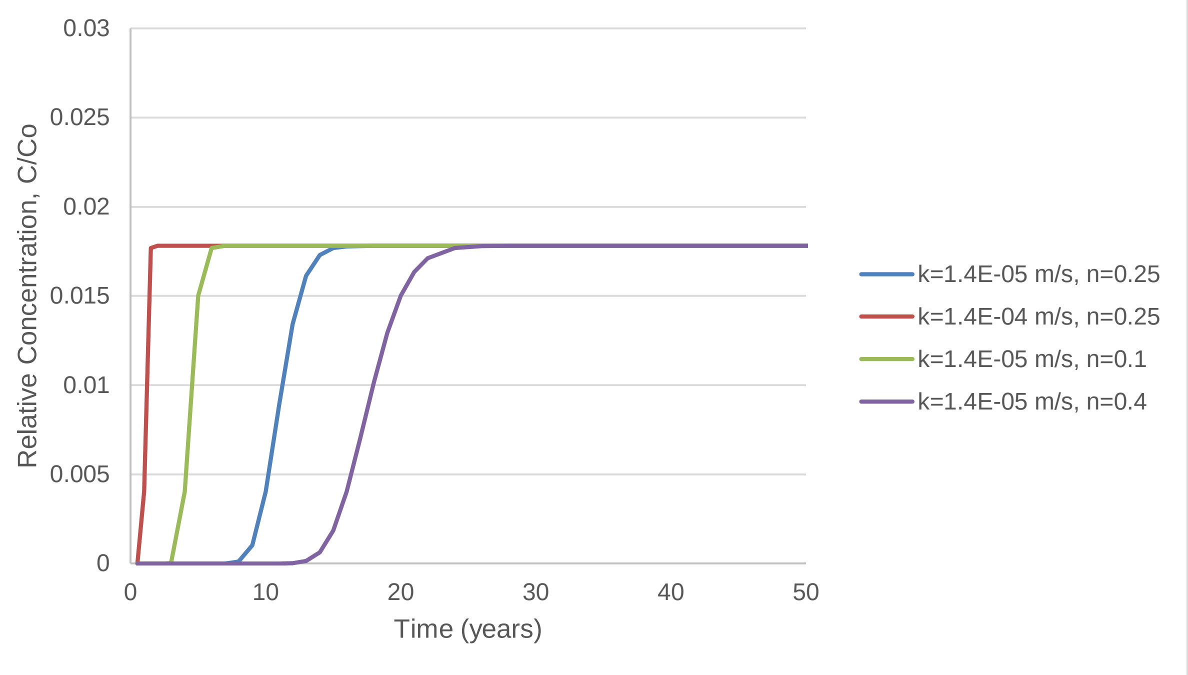

Figure 3-3. EMRSF 3D continuous source model demonstrating the range of hydraulic conductivity (K) and effective porosity (n) values.

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[3] The approximate width of the proposed EMRSF was obtained from the general arrangement map, dated March 13, 2015, prepared for KGHM Ajax Mining Inc. by Environmental Resources Management Group Inc. (ERM).

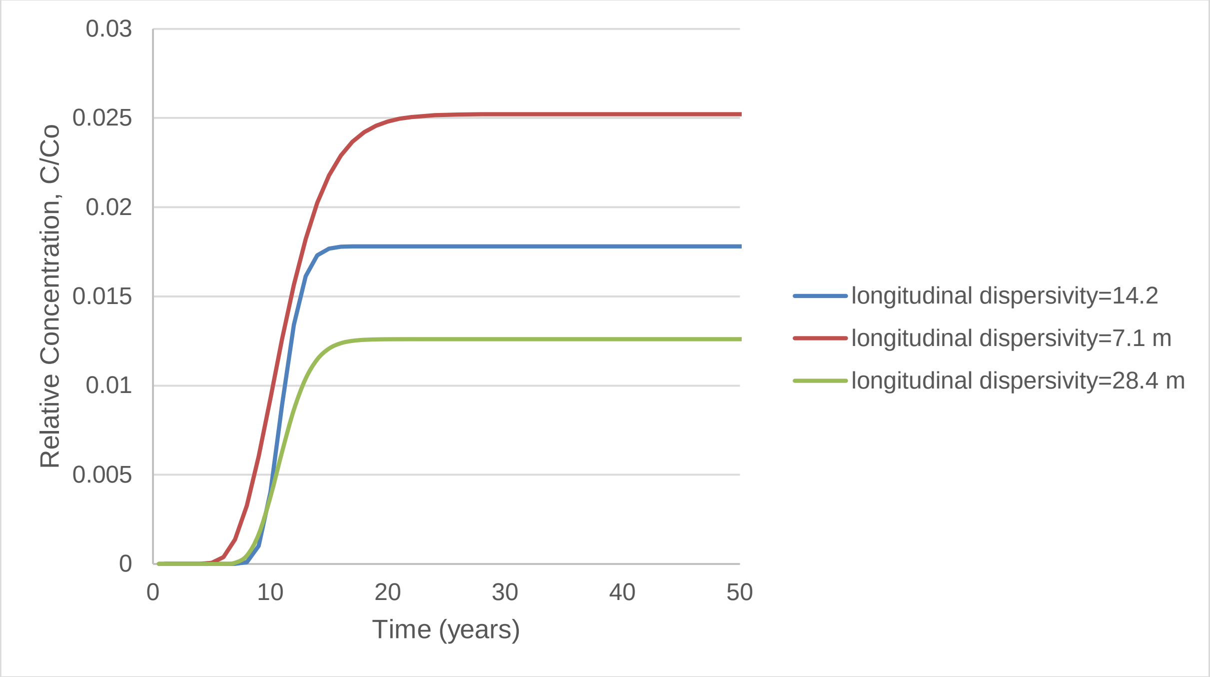

Figure 3-4. EMRSF 3D continuous source model demonstrating sensitivity to longitudinal dispersivity (α_x) values.

The peak relative concentration from modelling the EMRSF as a continuous source was found to be 0.018 for the base case, or 1.8% of the original source concentration. The analysis also reveals that an increase in K by an order of magnitude speeds up the plume arrival time from the EMRSF to the vicinity of RES-2 by approximately 12 years (Figure 3-3). The range of effective porosity (Figure 3-3) used in the sensitivity analysis demonstrates that for smaller values (i.e. n=0.1), breakthrough (when maximum concentrations are reached) occurs faster than when n is larger, and by varying n from 0.1 to 0.4, breakthrough times span a 20 year period. The variation in longitudinal dispersivity values (Figure 3-4) shows that the greater the value of α_x, the faster the breakthrough time, and the lower the peak concentration at breakthrough. Peak concentrations based on the α_x sensitivity analysis show a range between 0.013 and 0.025, or 1.3% to 2.5% of the source concentration.

3.3. Peterson Creek Downstream Pond

The Peterson Creek downstream dam will be constructed during the first year of construction (mine year -2), leading to the formation of the Peterson Creek Downstream Pond (PCDP). Stream flows are routed into and out of the Peterson Creek Downstream Pond (BGC 2015c). In the numerical groundwater model, the hydraulic head was set to the average operating level of 865.5 masl (Norwest 2015).

As with the EMRSF, the Domenico and Robbins (1985) solution was used to analyze the concentrations expected in RES-2 from a continuous source of contamination leaving PCDP. Table 3-3 present the base case inputs for the simulation.

Table 3-3. Base case input data for a continuous source seepage simulation in the PCDP.

Parameter	Value	Units	Description
$x =$	1501	m	longitudinal distance from center of source
$y =$	0	m	lateral transverse distance from center of source
$z =$	0	m	vertical transverse distance from center of source
$Y =$	130	m	width of source (Norwest 2015)
$Z =$	3.5	m	depth of source below water table (i.e. depth of pond at normal operating water elevation)
$\alpha_x =$	13.5	m	dispersivity in the x direction
$\alpha_y =$	1.35	m	dispersivity in the y direction
$\alpha_z =$	0.14	m	dispersivity in the z direction
$n =$	0.25	(-)	effective porosity
$K =$	1.4×10^{-5}	m/s	hydraulic conductivity
$v_x =$	8.6×10^{-7}	m/s	contaminant velocity from particle tracking

Results of the base case simulation and sensitivity analysis are presented in Figures 3-5 and 3-6.

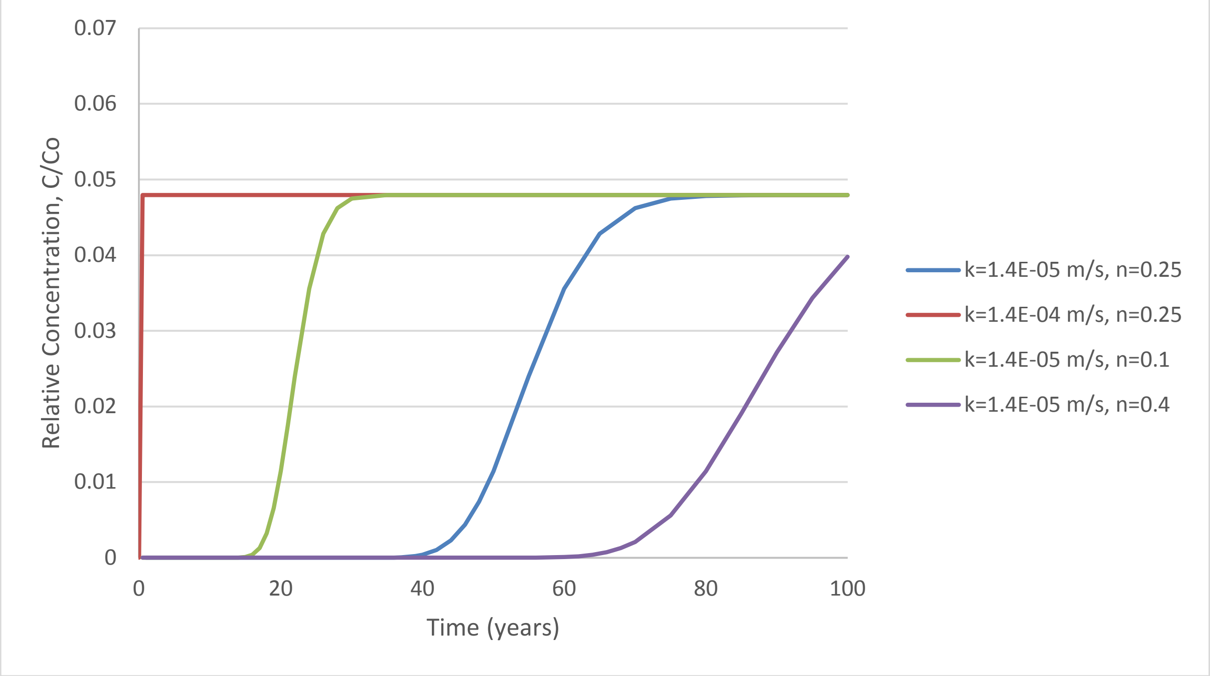

Figure 3-5. PCDP 3D continuous source model demonstrating the range of hydraulic conductivity (K) and effective porosity (n) values.

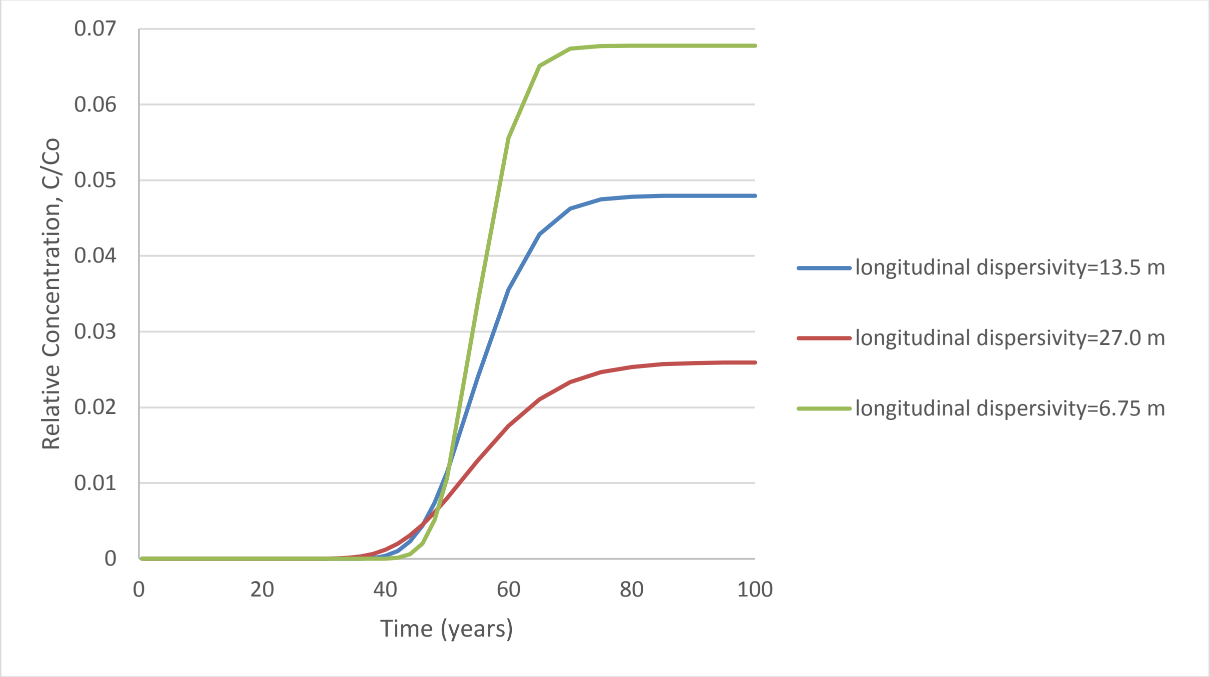

Figure 3-6. PCDP 3D continuous source model demonstrating sensitivity to longitudinal dispersivity (α_x) values.

The peak relative concentration from modelling the PCDP as a continuous source was found to be 0.068 (Figure 3-6), or 6.8% (as opposed to 1.8% for EMRSF) of the original source concentration. Similar to the EMRSF, the analysis also shows how an increase in K by an order of magnitude speeds up the plume arrival time from PCDP to RES-2 by approximately 23 years (Figure 3-5). The range in effective porosity from 0.1 to 0.4 corresponds to breakthrough times that differ by about 40 years. Peak concentrations based on the α_x sensitivity analysis (Figure 3-6) show a range between 0.026 and 0.068, or 2.6 to 6.8% of the source concentration.

3.4. Water Quality Analysis

Monthly source concentrations (C_o) for the EMRSF and the PCDP were output from the water quality mixing model that is currently in development for the project by Knight Piésold (received May 6, 2015). Additional work on source concentrations is currently underway, as is further refinement of the water quality mixing model; as such, source concentrations for the EMRSF and the PCDP are preliminary and subject to change. The same C_o expected from the EMRSF was applied to the EMRSF pond as no separate term for the EMRSF pond was provided.

The maximum C_o for each source was determined from examining the predicted source concentrations over the life of the mine and into closure for a range of chemical parameters[4]. To determine the maximum concentrations (C) expected in a seepage plume at RES-2,

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[4] Total time frame considered in the water quality model simulations was 200 years.

maximum C_o values emerging from the EMRSF, EMRSF pond and PCDP were first multiplied by their corresponding maximum C/C_o values expected at RES-2, including consideration for sensitivity results. Maximum C/C_o values from the EMRSF, the EMRSF pond and PCDP were 0.025, 0.0045 and 0.068, respectively (Table 3-4).

A summary of predicted total seepage concentrations at RES-2 is provided in Table 3-5. The total seepage represents the sum of the individual maximum seepage concentrations predicted at RES-2 for each of the three sources considered and for each chemical parameter. This representation reflects simultaneous arrival and mixing of plumes from the EMRSF, EMRSF pond and PCDP, but not the mixing of these plume concentrations with background water quality concentrations already present in RES-2.

Table B-1 in Appendix B provides the total concentration of each chemical parameter modeled as the sum of the seepage concentrations from the EMRSF, EMRSF pond and PCDP, combined with background RES-2 water concentrations. Background concentrations in RES-2 were provided by Knight Piésold.

The total seepage concentrations predicted in RES-2 (Table 3-5) as well as the total concentrations in RES-2 that consider background water quality (Table B-1) were compared to BC Ministry of Environment 30-day average and maximum drinking water guidelines and Health Canada drinking water quality guidelines.

Table 3-4. Maximum concentrations (C) in seepage based on maximum median source concentrations (C_o).

Parameter	EMRSF	EMRSF	EMRSF pond	PCDP	PCDP
	C_o (mg/L)	**C (mg/L)**	**C (mg/L)**	**C_o (mg/L)**	**C (mg/L)**
Modelled C/C_o	(-)	**0.025**	**0.0045**	(-)	**0.068**
Baseline Hardness (as $CaCO_3$)	no data	(-)	(-)	564	38
Modelled Hardness (as $CaCO_3$)	863	22	3.9	732	50
Bromide (Br^-)	0.49	0.012	0.0022	0.33	0.022
Chloride (Cl^-)	69	1.7	0.31	70	4.7
Fluoride (F^-)	0.34	0.0086	0.0015	0.31	0.021
Sulphate (SO_4^{2-})	634	16	2.9	316	21
Calcium (Ca)	263	6.6	1.2	127	8.6
Magnesium (Mg)	51	1.3	0.23	102	6.9
Potassium (K)	24	0.60	0.11	20	1.3
Sodium (Na)	83	2.1	0.37	71	4.8
Nutrients					
Ammonia (NH_4^+)	0.56	0.014	0.0025	0.14	0.0094
Nitrate (NO_3)	4.3	0.11	0.019	0.26	0.018
Nitrite (NO_2)	0.10	0.0025	0.00045	0.017	0.0011
Phosphorus - Dissolved (P)	0.0042	0.00011	0.000019	0.091	0.0062
Dissolved Metals					
Aluminum (Al)	0.0035	0.00009	0.000016	0.020	0.0014
Antimony (Sb)	0.021	0.00052	0.000094	0.00057	0.000039
Arsenic (As)	0.022	0.00055	0.00010	0.0035	0.0002403
Barium (Ba)	0.054	0.0013	0.00024	0.090	0.0061
Beryllium (Be)	0.000053	0.0000013	0.00000024	0.000064	0.0000044
Boron (B)	0.16	0.00405	0.00073	0.045	0.0031
Cadmium (Cd)	0.000034	0.00000085	0.00000015	0.000015	0.0000010
Chromium (Cr)	0.0018	0.000046	0.0000083	0.0014	0.00009
Cobalt (Co)	0.0008	0.000021	0.0000037	0.00040	0.000027
Copper (Cu)	0.0063	0.00016	0.000028	0.0061	0.00041
Iron (Fe)	0.089	0.0022	0.00040	0.094	0.0064
Lead (Pb)	0.000074	0.0000019	0.00000033	0.00017	0.000012
Lithium (Li)	0.017	0.00042	0.000075	0.0085	0.00058
Manganese (Mn)	0.098	0.0024	0.00044	0.17	0.0116
Mercury (Hg)	0.000049	0.0000012	0.00000022	0.000020	0.0000014
Molybdenum (Mo)	0.15	0.0037	0.00067	0.044	0.0030
Nickel (Ni)	0.012	0.00029	0.000053	0.0032	0.00022
Selenium (Se)	0.024	0.00060	0.00011	0.0018	0.00012
Silicon (Si)	10	0.26	0.046	13	0.86
Silver (Ag)	0.000014	0.00000034	0.000000062	0.0000068	0.00000046
Strontium (Sr)	1.7	0.043	0.0078	0.97	0.066
Thallium (Tl)	0.00010	0.0000026	0.00000047	0.000012	0.0000008
Tin (Sn)	0.00014	0.0000034	0.00000061	0.00011	0.0000074
Uranium (U)	0.0029	0.00007	0.000013	0.0029	0.00019
Vanadium (V)	0.0053	0.00013	0.000024	0.0056	0.00038
Zinc (Zn)	0.016	0.00040	0.000072	0.0035	0.00024

Table 3-5. Comparison of predicted seepage concentrations at RES-2 to BC Ministry of Environment and Health Canada drinking water guidelines.

Parameter	**Units[2]**	**BC MOE Drinking Water Guidelines[1]**		**Health Canada Drinking Water Guidelines[3]**	**Predicted Seepage Concentration at RES-2[4]**
		30-day average	**maximum**		
Baseline Hardness (as $CaCO_3$)	mg/L	(-)	(-)	(-)	38
Modelled Hardness (as $CaCO_3$)	mg/L	(-)	(-)	(-)	75
Bromide (Br^-)	mg/L	(-)	(-)	(-)	0.037
Chloride (Cl^-)	mg/L	(-)	250	AO ≤ 250	6.8
Fluoride (F^-)	mg/L	1	1.5	1.5	0.031
Sulphate (SO_4^{2-})	mg/L	(-)	500	AO ≤ 500	40
Calcium (Ca)	mg/L	(-)	(-)	(-)	16
Magnesium (Mg)	mg/L	(-)	(-)	(-)	8.4
Potassium (K)	mg/L	(-)	(-)	(-)	2.1
Sodium (Na)	mg/L	(-)	(-)	AO ≤ 200	7.3
Nutrients					
Ammonia (NH_4^+)	mg/L	(-)	(-)	(-)	0.026
Nitrate (NO_3)	mg/L	(-)	10	10	0.14
Nitrite (NO_2)	mg/L	(-)	1	1	0.0041
Phosphorus - Dissolved (P)	mg/L	(-)	(-)	(-)	0.0063
Dissolved Metals					
Aluminum (Al)	mg/L	(-)	0.2	(-)	0.0015
Antimony (Sb)	mg/L	(-)	(-)	0.006	0.00065
Arsenic (As)	mg/L	(-)	0.025	0.01	0.00089
Barium (Ba)	mg/L	(-)	(-)	1	0.0077
Beryllium (Be)	mg/L	(-)	0.004	(-)	0.0000059
Boron (B)	mg/L	(-)	5	5	0.0078
Cadmium (Cd)	mg/L	(-)	(-)	0.005	0.0000020
Chromium (Cr)	mg/L	(-)	(-)	0.05	0.00015
Cobalt (Co)	mg/L	(-)	(-)	(-)	0.000052
Copper (Cu)	mg/L	(-)	0.5	AO ≤ 1.0	0.00060
Iron (Fe)	mg/L	(-)	(-)	AO ≤ 0.3	0.0090
Lead (Pb)	mg/L	(-)	0.05	0.01	0.000014
Lithium (Li)	mg/L	(-)	(-)	(-)	0.0011
Manganese (Mn)	mg/L	(-)	(-)	AO ≤ 0.05	0.014
Mercury (Hg)	mg/L	(-)	0.001	0.001	0.0000028
Molybdenum (Mo)	mg/L	(-)	(-)	0.25	0.0074
Nickel (Ni)	mg/L	(-)	(-)	(-)	0.00056
Selenium (Se)	mg/L	(-)	0.01	0.05	0.00084
Silicon (Si)	mg/L	(-)	(-)	(-)	1.2
Silver (Ag)	mg/L	(-)	(-)	(-)	0.00000087
Strontium (Sr)	mg/L	(-)	(-)	(-)	0.12
Thallium (Tl)	mg/L	(-)	0.002	(-)	0.0000039
Tin (Sn)	mg/L	(-)	(-)	(-)	0.000011
Uranium (U)	mg/L	(-)	(-)	0.02	0.00028
Vanadium (V)	mg/L	(-)	(-)	(-)	0.00054
Zinc (Zn)	mg/L	(-)	5	AO ≤ 5.0	0.00071

Notes: 1. (-) denotes no guideline; 2. mg/L denotes milligrams per litre; 3. AO denotes aesthetic objective; 4. Predicted seepage concentration at RES-2 = ∑ predicted seepage concentrations from EMRSF, EMRSF pond and PCDP; note that background concentrations are not included.

4.0 SUMMARY

A preliminary assessment of potential plume migration pathways to residential well 2 (RES-2) and resulting seepage concentration predictions was done in support of the HHERA being completed by Stantec for the Ajax Project Environmental Assessment.

To evaluate which seepage sources may reach well RES-2, forward and reverse particle tracking simulations were performed using a finite difference groundwater flow model. Particle tracking found that only particles leaving PCDP reached RES-2; particles migrating from the EMRSF and EMRSF pond passed just north of RES-2 by approximately 50 to 150 m.

Maximum relative concentrations determined from either continuous source or pulse-source analytical models were then used to determine estimates of contaminant concentrations in RES-2. Some maximum concentrations were revealed by assessing select parameter sensitivities to model outputs. Maximum source concentration values for the EMRSF and PCDP were then used to estimate concentrations at, or in the vicinity of, RES-2 should seepage from EMRSF, EMRSF pond or PCDP occur. A comparison of estimated maximum seepage concentrations in RES-2 to BC Ministry of Environment 30-day average and maximum drinking water guidelines and Health Canada drinking water quality guidelines reveals that no exceedances are expected from seepage only. Calculated total concentrations (i.e. seepage + background concentrations) at RES-2 are provided in Appendix B; results indicate that aesthetic objectives for sulphate and iron, 500 mg/L and 0.3 mg/L respectively, may be exceeded at RES-2 with a projected total concentration of 1050 mg/L for sulfate and 0.323 mg/L for iron. However, note that the baseline concentrations in RES-2 for sulphate and iron are above the aesthetic objectives at 1010 mg/L, and 0.314 mg/L to begin with.

5.0 CLOSURE

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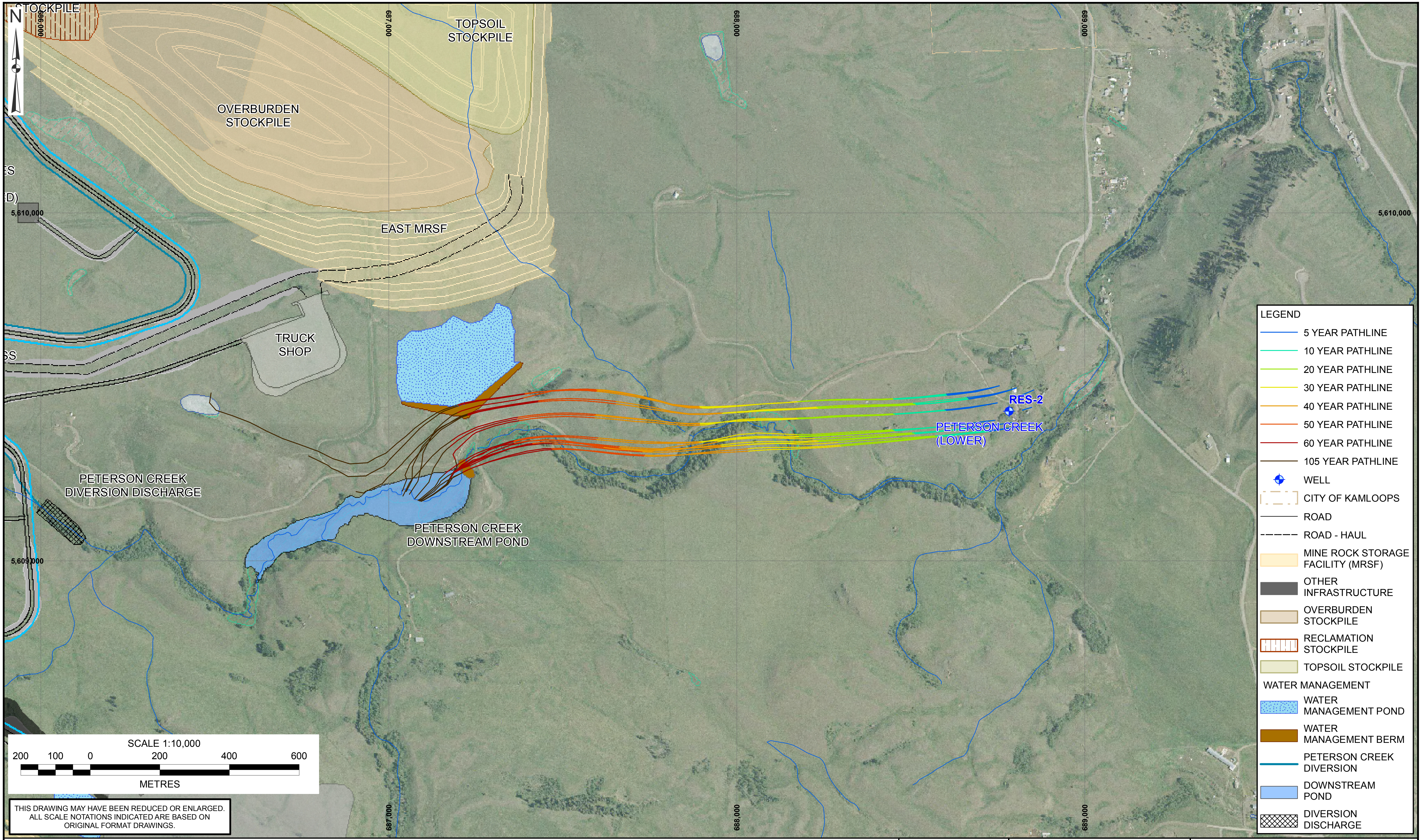
DRAWINGS



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AJAX PROJECT ENVIRONMENTAL ASSESSMENT -
PLUME MIGRATION ANALYSES TO RES-2

TITLE:
RES-2 REVERSE
PARTICLE TRACKING RESULTS
(CLOSURE CONDITIONS)

PROJECT No.:	DWG No:
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APPENDIX A
SOURCE TERM CONCENTRATIONS

Monthly source term concentrations for Peterson Creek downstream pond, East Mine Rock Storage Facility and East Mine Rock Storage Facility pond for the life of the mine through closure are not provided here, however can be provided electronically upon request.

APPENDIX B

PREDICTED MAXIMUM TOTAL CONCENTRATIONS AT RES-2

Table B-1. Comparison of predicted seepage concentrations at RES-2 and predicted maximum concentrations at RES-2 to BC MoE and Health Canada Drinking Water Guidelines.

Parameter	Units	BC MOE Drinking Water Guidelines		Health Canada Drinking Water Guidelines	Predicted Maximum Change in Concentration at RES-2	Baseline RES-2	Predicted Maximum Concentration at RES-2
		30-day average	maximum			October 2014	
Baseline Hardness (as $CaCO_3$)	mg/L	(-)	(-)	(-)	38	1100	1138
Modelled Hardness (as $CaCO_3$)	mg/L	(-)	(-)	(-)	75	1100	1175
Bromide (Br^-)	mg/L	(-)	(-)	(-)	0.037	0.500	0.537
Chloride (Cl^-)	mg/L	(-)	250	AO ≤ 250	7	14	21
Fluoride (F^-)	mg/L	1	1.5	1.5	0.031	0.317	0.348
Sulphate (SO_4^{2-})	mg/L	(-)	500	AO ≤ 500	40	1010	1050
Calcium (Ca)	mg/L	(-)	(-)	(-)	16	242	258
Magnesium (Mg)	mg/L	(-)	(-)	(-)	8	121	129
Potassium (K)	mg/L	(-)	(-)	(-)	2.1	13.9	16.0
Sodium (Na)	mg/L	(-)	(-)	AO ≤ 200	7	82	89
Nutrients							
Ammonia (NH_4^+)	mg/L	0.131-2.08	0.681-28.7	(-)	0.026	0.003	0.028
Nitrate (NO_3)	mg/L	3	33	10	0.14	0.05	0.19
Nitrite (NO_2)	mg/L	0.02	0.06	1	0.004	0.010	0.014
Phosphorus - Dissolved (P)	mg/L	(-)	(-)	(-)	0.0063	0.0025	0.0088
Dissolved Metals							
Aluminum (Al)	mg/L	(-)	0.2	(-)	0.0015	0.0015	0.0030
Antimony (Sb)	mg/L	0.014	(-)	0.006	0.0007	0.0001	0.0008
Arsenic (As)	mg/L	(-)	0.025	0.01	0.0009	0.0009	0.0018
Barium (Ba)	mg/L	(-)	(-)	1	0.008	0.029	0.037
Beryllium (Be)	mg/L	(-)	0.004	(-)	0.0000059	0.0000500	0.0000559
Boron (B)	mg/L	(-)	5	5	0.008	0.172	0.180
Cadmium (Cd)	mg/L	(-)	(-)	0.005	0.0000020	0.0000150	0.0000170
Chromium (Cr)	mg/L	(-)	(-)	0.05	0.00015	0.00011	0.00026
Cobalt (Co)	mg/L	(-)	(-)	(-)	0.00005	0.00012	0.00017
Copper (Cu)	mg/L	(-)	0.5	AO ≤ 1.0	0.00060	0.09130	0.09190
Iron (Fe)	mg/L	(-)	(-)	AO ≤ 0.3	0.009	0.314	0.323
Lead (Pb)	mg/L	(-)	0.05	0.01	0.000014	0.000519	0.000533
Lithium (Li)	mg/L	(-)	(-)	(-)	0.0011	0.0109	0.0120
Manganese (Mn)	mg/L	(-)	(-)	AO ≤ 0.05	0.014	0.037	0.051
Mercury (Hg)	mg/L	(-)	0.001	0.001	0.0000028	0.0000050	0.0000078
Molybdenum (Mo)	mg/L	(-)	(-)	0.25	0.007	0.016	0.023
Nickel (Ni)	mg/L	(-)	(-)	(-)	0.0006	0.0019	0.0025
Selenium (Se)	mg/L	(-)	0.01	0.05	0.0008	0.0001	0.0009
Silicon (Si)	mg/L	(-)	(-)	(-)	1.2	11.4	12.6
Silver (Ag)	mg/L	(-)	(-)	(-)	0.0000009	0.0000050	0.0000059
Strontium (Sr)	mg/L	(-)	(-)	(-)	0.12	2.98	3.10
Thallium (Tl)	mg/L	(-)	0.002	(-)	0.000004	0.000005	0.000009

Parameter	**Units**	**BC MOE Drinking Water Guidelines**		**Health Canada Drinking Water Guidelines**	**Predicted Maximum Change in Concentration at RES-2**	**Baseline RES-2** **October 2014**	**Predicted Maximum Concentration at RES-2**
		30-day average	**maximum**				
Tin (Sn)	mg/L	(-)	(-)	(-)	0.000011	0.000050	0.000061
Uranium (U)	mg/L	(-)	(-)	0.02	0.00028	0.00179	0.00207
Vanadium (V)	mg/L	(-)	(-)	(-)	0.00054	0.00180	0.00234
Zinc (Zn)	mg/L	(-)	5	AO ≤ 5.0	0.0007	0.0484	0.0491

Notes:
(-) denotes no guideline.
Mg/L denotes milligrams per litre.
AO denotes aesthetic objective.