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Technical Memorandum

To: Stuart Arkley, MDNR
From: Jeré Mohr, Tina Pint, Don Richard
Subject: Plant Site Groundwater Impacts Predictions
Date: November 12, 2008
Project: 23/69-862
c: Jim Scott, PolyMet Mining, Inc.

1.0 Introduction

1.1 Purpose and Objectives

The purpose of this memorandum is to assess the potential impacts at the NorthMet Plant Site for the Tailings Basin Geotechnical Mitigation on the groundwater quality downgradient of the Tailings Basin. This work was done at the request of the MDNR following the preliminary review of RS74B Draft 02.This memorandum summarizes the methodology used to predict potential groundwater impacts at the Plant Site and the results of the predictive simulations. The intent of this work is to provide a conservative, defensible prediction of groundwater impacts. To the extent possible, simplifying conservative assumptions were used to make predictions of potential groundwater impacts, with additional complexity added only when needed. A multi step process as outlined below was used to make predictions of potential groundwater impacts. The methodology used in this work is the same methodology that was used in the evaluation of the Mine Site – Proposed Action and Mine Site – Reasonable Alternative RA1, which is presented in RS74A Draft 02.

1.2 General Modeling Approach

The same general modeling approach is used for the evaluation of the potential Plant Site groundwater impacts predictions as was used for the Mine Site (RS74A Draft 02). A “screening level model” was prepared to determine what the dissolved constituents of concern were for the Plant Site. In the screening level model, the most conservative simplifying assumptions were made. If the dissolved constituents being evaluated were not predicted to exceed groundwater evaluation criteria under these assumptions, those constituents were not carried forward to the next phase of modeling. More detailed modeling was conducted for those constituents that showed potential exceedances of groundwater evaluation criteria using the screening level model. Because of the heightened concern regarding sulfate concentration as it relates to mercury, sulfate was carried forward to the next phase of modeling regardless of whether the screening level model predicted groundwater concentrations in excess of criteria.

1.3 Organization of Technical Memorandum

This memorandum is organized into seven sections, including this introduction. Section 2 provides a brief discussion of the Tailings Basin and the groundwater evaluation criteria used in this memorandum. The general modeling methodology is presented in Section 3. Section 4 presents the results of the screening level models. Results of the more detailed transient simulations are presented in Section 5. Any changes in the modeling methodologies from the work that was presented for the Mine Site – Proposed Action and Mine Site – RA1 (RS74A Draft 02) will be documented as appropriate in Sections 4 and 5. Section 6 discusses additional transport modeling of arsenic that was conducted. A summary of results is presented in Section 7.

2.0 Background Information

[This section contains the same text that is found in RS74B Draft 02 in Sections 2.1.5, 2.1.6, and 3.2. It is repeated here for completeness.]

2.1 Quaternary and Bedrock Geology

Much of the area is covered by peat bogs or open wetlands, with the remaining area covered by rolling to undulating Wisconsin aged Rainey Lobe drift, lacustrine materials, and outwash. In the region, it appears that only the Embarrass River sub-watershed north of the LTVSMC tailings impoundments has significant quantities of outwash (sand and gravel), with thicknesses greater than 100 feet (Jirsa et al., 2005). Elsewhere, the Quaternary deposits form a thin blanket (0-30 feet) over the bedrock.

Rainey Lobe drift is generally a bouldery till with high clay content. While site-specific geological studies of the drift have not been conducted, information on the quaternary deposits has been gathered during engineering and hydrogeologic investigations in the area. At the Tailings Basin, test pits for preliminary PolyMet engineering studies and informal observations of sumps and other small excavations indicate that the Quaternary geology in this area is similar. Most areas at the Tailings Basin consist of unsorted sand/silt/clay with cobbles and boulders. Boulders on surface can be greater than 10 feet in size and there may be a boulder lag horizon just below the ground surface in some areas. The till has been described as heterogeneous clayey to silty sand with fine to medium grained sand and some gravel and boulders (Sitka, 1995).

In the vicinity of the tailings basins, the uppermost bedrock unit is the Giants Range batholith, including quartz monzonite, monzodiorite and monzogranite. In the southeast corner of Cell 1E in the Tailings Basin, the uppermost bedrock is sedimentary schist with a seam of volcanic schist.

2.2 Hydrogeology

The Rainy Lobe drift forms the major surficial aquifer in the region that encompasses the Tailings Basin. Underlying the drift deposits are Precambrian crystalline and metamorphic bedrock. This material is assumed to have a significantly lower hydraulic conductivity (i.e., several orders of magnitude) than the drift and as such, acts as an aquitard. In some locations, peat deposits have been encountered between the tailings and the drift. These deposits are likely discontinuous and can be ignored at the scale at which the Tailings Basin is being evaluated for this analysis. On top of the drift deposits are numerous wetlands and minor surface-water drainages. These features are assumed to represent surficial expressions of the water table.

Regionally, groundwater flows primarily northward, from the Embarrass Mountains to the Embarrass River. At the southern end of the Tailings Basin, there is some flow to the south, forming the headwaters of Second Creek. As the Tailings Basin was built up over time, a groundwater mound formed beneath the basin due to seepage from the various basins, which altered local flow directions and rates. Seeps have been identified on the south, west, and north sides of the Tailings Basin. The east side of the Tailings Basin is bounded by low-permeability bedrock uplands and there is likely little or no water that seeps out in this direction. In addition to the visible seeps, groundwater likely flows out from beneath the tailing basin into the surrounding drift to the south, west, and north of the basin.

2.3 Groundwater Evaluation Criteria

The groundwater quality standards that the NorthMet Project will be required to meet and the compliance locations will be established during the permitting process. However, in order to evaluate potential groundwater impacts, it is helpful to compare deterministic groundwater quality predictions to groundwater standards. Groundwater quality standards are promulgated rules that are enforceable by the MPCA. Groundwater quality standards are published in Minnesota Rules 4717.7500 Table of Health Risk Limits (HRLs). If the groundwater were used as a water source for a public water system, then the water delivered to the tap would need to meet the National Primary Drinking Water Regulations (also known as maximum contaminant levels (MCLs)) published at 40 CFR Part 141.

The USEPA has also established national secondary drinking water regulations that set non-mandatory water quality goals for 15 constituents. These secondary MCLs are not enforceable but are established as guidelines to assist public water system operators in managing their drinking water for aesthetic considerations such as taste, color and odor. The constituents are not considered to present an adverse affect to human health at the secondary MCL. The water quality standards for the constituents being evaluated as part of this study are summarized in Table 2-1. The lower of the groundwater standards referenced above was selected as the target groundwater evaluation criteria for use in this evaluation.

3.0 General Modeling Methodology

This discussion of the general modeling methodology follows the same format as the general modeling methodology sections in RS74A Draft 02, with information in these sections updated to reflect the specific issues related to the Tailings Basin.

The source of potential groundwater impacts evaluated in this memorandum is groundwater seepage from the northern edge of the Tailings Basin that flows toward the Embarrass River. Several residential wells are located between the Tailings Basin and the Embarrass River, shown on Figure 3-1. A groundwater flow path originating at the Tailings Basin and ending at the Embarrass River was selected for evaluation of potential groundwater impacts. The shortest path from the Tailings Basin to the residential wells and the Embarrass River was selected to evaluate a "worst-case" scenario. Figure 3-1 shows the flow path selected for evaluation of potential impacts from the Tailings Basin.

Potential impacts along the flow path were assessed using a simple cross-sectional model. Three-dimensional solute transport in groundwater in a one-dimensional flow field is described by the following equation, termed the advection-dispersion-reaction equation:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} + D_z \frac{\partial^2 C}{\partial z^2} - \frac{q}{n}\frac{\partial C}{\partial x} - R\lambda C \qquad \textbf{(Eq. 1)}$$

Where

C = Dissolved concentration [M/L^3]

t = Time [T]

D_x, D_y, D_z = Dispersion coefficients [L^2/T]

q = Darcy flux [L/T]

n = Saturated water content [unitless]

R = Retardation factor [unitless]

λ = Decay coefficient [T^{-1}]

Because the model used in this study is a two-dimensional cross-section model (i.e. lateral flow into or out of the cross-section is assumed to be zero), the "y" terms drop out of the equation. In addition, potential decay (i.e. radioactive decay or chemical precipitation) was not accounted for as part of this evaluation. By ignoring these terms, this analysis provides a conservative estimate of groundwater concentrations. Under these assumptions, the advection-dispersion-reaction equation simplifies to the following:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_z \frac{\partial^2 C}{\partial z^2} - \frac{q}{n}\frac{\partial C}{\partial x} - RC \qquad \textbf{(Eq. 2)}$$

There are a number of published solutions to the advection-dispersion equation, including analytical and numerical solutions. Analytical solutions are attractive because of their relative simplicity; however, these solutions have more limitations on how the solute source may be represented and generally cannot explicitly simulate seepage into the aquifer from above, which was needed at for the Mine Site modeling presented in RS74A Draft 02. For maximum flexibility, a numerical solution to the advection-dispersion equation was utilized for this analysis. Specifically, the program MT3DMS (Zheng and Wang, 1999) was used to numerically solve the advection-dispersion equation. MT3DMS is a modular program that solves the advection-dispersion equation numerically and is designed to work with the industry standard finite-difference groundwater modeling code MODFLOW (McDonald and Harbaugh, 1988). Solute transport modeling was completed in two steps: first, a simple cross-sectional groundwater flow model was constructed using MODFLOW. Then, the groundwater flow field generated using MODFLOW was used in MT3DMS to predict solute concentrations downgradient of the source. The graphical user interface (GUI) Groundwater Vistas (version 5.22 Build 4) was used to complete the MODFLOW and MT3DMS modeling.

At the Plant Site, predicted groundwater concentrations were evaluated at four points along the flow path as shown on Figure 3-1. The first evaluation location is a point midway between the toe of the Tailings Basin and the property boundary. The second evaluation location is located at the property boundary. The third evaluation location is located adjacent to the closest domestic well downgradient of the Tailings Basin. The fourth evaluation location is the Embarrass River. The four evaluation locations are approximately 575 meters, 1150 meters, 2575 meters, and 4725 meters from the toe of the Tailings Basin, respectively.

3.1 Model domain and discretization

Figure 3-2 shows schematics of the MODFLOW model layout and input parameters. The x-axis is oriented along the groundwater flow path, with the origin located at the northern edge of the Tailings Basin. Model cell dimensions were set to minimize numerical dispersion and computation time for each scenario. The following cell dimensions were used for all simulations where applicable:

Table 3-1: Cell Dimensions

Δx	25 meters
Δy	10 meters
Δz	1 meter

The model consists of 5 layers (simulating an average thickness of 5 meters for the surficial deposits).

3.2 Hydraulic conductivity values

Hydraulic conductivity values were obtained from the groundwater model of the Plant Site presented in RS13B Draft 01. A hydraulic conductivity of 20 m/day was used.

3.3 Boundary conditions

A specified flux boundary condition is located at the upgradient edge of the flow path model. The flux was determined using the predicted groundwater flow out of the Tailings Basin to the north of Cell 2E presented in Table 8-7 of RS74B. The discharge applied to each upgradient model cell was calculated as follows:

$$Q_{cell} = Q_{tb} * \left(\frac{A_{cell}}{A_{tb}} \right) \quad \textbf{(Eq. 3)}$$

where

Q_{cell} = Specified discharge on model cell [L^3/T]

Q_{tb} = Groundwater flow out of Tailings Basin to the north of Cell 2E [L^3/T]

A_{cell} = Area of model cell perpendicular to groundwater flow direction [L^2]

A_{tb} = Aquifer area perpendicular to groundwater flow north of Tailings Basin [L^2]

For the screening level model, the maximum predicted flux, which occurs in Year 20, was used. Substituting values from Year 20 gives:

$$Q_{cell} = (1950\ \text{gal/min}) * \left(\frac{10\ \text{m} * 1\ \text{m}}{2042\ \text{m} * 5\ \text{m}} \right) = 1.9\ \text{gal/min} = 10.4\ \text{m}^3 / \text{day}$$

A constant head boundary is located at the downgradient edge of the flow path model, with a specified head value equal to the elevation of the Embarrass River at the downgradient end of the model (436.2 meters). The upgradient and downgradient boundary conditions used for the flow path model are shown on Figure 3-2.

3.4 Recharge

The Recharge Package in MODFLOW was used to simulate the infiltration of precipitation within the model domain and was applied to the uppermost model layer. The three-dimensional groundwater flow model of the Tailings Basin presented in RS13B used a recharge rate for the area between the Tailings Basin and the Embarrass River of 8 inches per year based on literature rates. However, in order to provide a conservative estimation of groundwater impacts, it was recommended by the Agencies that a lower recharge rate be used. Therefore, recharge was set equal to the recharge value (1.5 inches per year) used in the Mine Site groundwater model presented RS22 and RS74A.

3.5 Dispersion

After the flow field was calculated using the MODFLOW model, MT3DMS was used to predict solute fate and transport and concentrations at the evaluation locations. MT3DMS requires values for the dispersion coefficients D_x, D_y, and D_z. Since there was assumed to be no flow in the y-direction (transverse to the flow path), a value for D_y was not required. The following relationships were used to estimate these parameters (Wiedemeier et al., 1999):

$$D_x = 0.83(\log_{10} L_p)^{2.414} \quad \textbf{(Eq. 4)}$$

$$D_z = 0.05 D_x \quad \textbf{(Eq. 5)}$$

Where

L_p = flow path length (i.e distance from source to discharge area) [L]

Table 3-2 summarizes the dispersion coefficients used for the cross-sectional model.

Table 3-2: Dispersion Coefficients

Model	**D_x (m)**	**D_z (m)**
Tailings Basin	19.2	0.96

3.6 Sorption

MT3DMS allows for simulation of retardation due to sorption onto soil particles and decay of constituents. Neither of these was simulated in the screening level model presented in Section 4. However, sorption was included in the simulations presented in Section 5.

Sorption is the process by which dissolved constituents are removed from solution and immobilized in or on the solid matrix of the porous medium by electrostatic or chemical forces. Sorption includes both adsorption and absorption, which includes both surface adhesion of the constituent and entering of the constituent into the bulk phase (i.e., solid phase). Sorption reactions are commonly included in modeling the potential impacts to surface and groundwater associated with leaching of heavy metals from waste sources. Sorption acts as a sink for heavy metals and is included in the retardation factor of the general advection-dispersive reactive equation (see Eq. 1 and 2).

Several isotherms have been developed to describe the ability of a particular constituent to be sorbed onto a particular porous medium. These isotherms include liner, Langmuir, Freundlich, and others. For this analysis, the equilibrium-based sorption and a liner sorption isotherm were assumed. Sorption is controlled by the partition (distribution) coefficient, K_d. K_d is defined by the following equation:

$$K_d = \frac{C_{sorbed}}{C_{solution}} \quad \textbf{(Eq. 6)}$$

Where C_{sorbed} is the equilibrium concentration of the constituent sorbed onto the surface of the porous medium and $C_{solution}$ is the equilibrium concentration of the constituent remaining in the solution.

Higher partition coefficients represent higher sorption capacity. K_d, which has units of L^3M^{-1}, is dependent on both the nature of the constituent and the properties of the porous medium. Thus, it is both site-specific and constituent-specific. Sorption parameters used in the cross-section model are discussed in Section 5. Additional information on the sorption of metals at the Mine Site can be found in the Technical Memorandum "Attenuation of Inorganics in Groundwater at the NorthMet Mine Site," which is Appendix C to RS74A Draft 02.

3.7 Recharge concentrations

As was done in the Mine Site transport models presented in RS74A Draft 02, background groundwater concentrations were assumed to be representative of recharge concentrations and the recharge concentration was set equal to the background concentration in the model. For this work, the median groundwater concentrations determined as part of RS74B Draft 02 (presented in Section 5.1.3.2 and Table 5-2) were used. These values came from the Regional Copper-Nickel Study when available (Siegel and Ericson, 1980). If data for that parameter was not included in this study, values were calculated from groundwater data collected in the Embarrass River watershed by the MPCA (MPCA, 1999). The recharge concentrations used in the model are shown on Table 4-1.

3.8 Tailings Basin concentrations

Concentrations of seepage from the Tailings Basin – Geotechnical Mitigation were presented in RS74B Draft 02 in Tables 4-5 and 8-8. Predicted concentrations of Tailings Basin seepage were applied to the upgradient specified flux boundary of the cross-sectional model. For the screening level model presented in Section 4, the highest predicted concentrations for each constituent were used. For the more detailed model presented in Section 5, time-varying source area concentrations were incorporated.
Actual concentrations used in the model are shown in Tables 4-1 and 5-2.

4.0 Screening Level Model

4.1 Methodology

A "screening level model" was prepared to determine what the potential constituents of concern are for the Tailings Basin flow path. In this model, the most conservative assumptions were made; these simulations included only advection and dispersion in a steady-state model using the maximum predicted

Tailings Basin seepage rate (from Year 20) and the maximum predicted seepage concentrations (typically from closure). In the screening level model, the only mechanism for reduction of constituent concentrations prior to reaching the Embarrass River is mixing with recharge from precipitation.

The results from the screening level model were scaled to predict the concentrations of individual constituents, avoiding the need to complete a separate model run for each constituent to be evaluated. The following relationship was used to predict concentrations of individual constituents:

$$C = p_s C_s + p_r C_r \qquad \textbf{(Eq. 7)}$$

Where

C = concentration of constituent of interest
p_s = proportional contribution to groundwater flow from Tailings Basin
C_s = concentration of constituent of interest in Tailings Basin seepage
p_r = proportional contribution to groundwater flow from recharge
C_r = concentration of constituent of interest in recharge inflow

The proportional contributions from the Tailings Basin and from recharge were determined by completing a model run with the concentration of one flow component set equal to 1 and the concentration of the other component equal to 0 and evaluating what percentage of that input concentration reached the evaluation location .

4.2 Simulation Results

Table 4-1 summarizes the results of the screening level simulation for the Tailings Basin flow path. This table also presents the source area and background concentrations used for the screening level model. Predicted groundwater concentrations are compared to groundwater evaluation criteria presented Section 2.5. Potential exceedances of the groundwater evaluation criteria are highlighted on Table 4-1.

Predicted beryllium and thallium concentrations exceed evaluation criteria in the screening level simulation. However, the beryllium and thallium concentrations predicted for the source areas are affected by scale-up of humidity cell test data and are not meaningful. As such, these parameters are not included in the transient modeling presented in Section 5. Many of the potential constituents of concern have been eliminated using the simple, conservative screening level models. The following constituents were carried forward to the next phase of modeling:

- Aluminum (Al);
- Arsenic (As);
- Fluorine (F);
- Manganese (Mn);
- Antimony (Sb); and
- Sulfate (SO_4).

5.0 Transient Models

5.1 Methodology

An additional phase of groundwater modeling was undertaken to further evaluate the constituents of concern for which potential exceedances of evaluation criteria were identified through use of the screening level models (Section 4.2). In this phase of modeling, the previously steady state model was converted to a transient model, which allowed for the Tailings Basin seepage concentrations and seepage rates to vary with time.

A total of eleven stress periods were used in the transient models. Stress periods are summarized in Table 5-1. Transient seepage concentrations are presented in RS74B Draft 02 Tables 4-5 and 8-8. Input concentrations for each constituent being simulated for each model stress period are shown on Table 5-2. Transient seepage rates are presented in RS74B Draft 02 Table 8-7.

Table 5-1 Transient Model Stress Period Set-Up

Stress Period	Duration (Days)	Period Simulated
1	730	Year 1 – Year 2
2	730	Year 3 – Year 4
3	730	Year 5 – Year 6
4	730	Year 7 – Year 8
5	730	Year 9 – Year 10
6	730	Year 11 – Year 12
7	730	Year 13 – Year 14
8	730	Year 15 – Year 16
9	730	Year 17 –Year 18
10	730	Year 19 – Year 20
11	722700	Year 21 –Year 2000

5.2 Sorption

In order to better understand what actual groundwater impacts may be associated with the Plant Site, the transient cross-sectional model was run both with and without sorption. Equilibrium-based sorption and a liner sorption isotherm were assumed. Liner isotherms use a partition coefficient (K_d) to relate the concentration of a sorbed constituent to the concentration of the constituent in solution. General K_d values can be used in screening-level/risk assessment analysis to determine the impact of heavy metals on groundwater in the absence of site-specific geochemical or isotherm data (U.S. EPA, 1996a)

The United States Environmental Protection Agency (EPA) published a 2005 report titled *Partition Coefficients for Metals in Surface Water, Soil, and Waste* (U.S. EPA, 2005). The goal of the report was to "develop metal partition coefficients…for screening-level human and ecological risk assessments for chronic exposure to chemicals released from land-based waste management units…" The report summarized a search of published documents on the topic of partition coefficients. It summarized the results of many different studies and provided the ranges of values that were reported for conditions that are likely to represent a natural environment (did not include studies of pure mineral phase or treated soils, very low or high pH, etc.). Also presented in the publication are the values recommended by the EPA for use in developing risk-based soil screening levels for contaminants in soils (U.S. EPA, 1996b). Table 5-3 summarizes the K_d values presented in the EPA reports and the values that were used in this analysis. Sorption is only considered for those parameters listed in Table 5-3.

Table 5-3: K_d Parameters from EPA References

Constituent	Results from Literature Study (U.S. EPA, 2005)			EPA Recommended Values (U.S. EPA, 1996b) (L/kg)	Values used in Cross-Section Models (L/kg)
	Minimum K_d (L/kg)	Maximum K_d (L/kg)	Mean K_d (L/kg)		
Arsenic	2	20,000	16,000	25-31	25
Antimony	1.3	500	200	45	45

In addition to K_d values, the inclusion of sorption in the transport simulation requires a bulk density for the soil. An average bulk density of 1.4 tons/yd^3 (1.65 kg/L) was used. This value represents the average bulk density for the soils at the Plant Site as reported in the U.S. Department of Agriculture's St. Louis County Soil Survey Geographic Database.

5.3 Results

Results from the transient models are presented on Figures 5-1 through 5-8 and are summarized below and in Table 5-4:

- **Arsenic:** The concentration of arsenic in groundwater is predicted to be above the groundwater standard with and without the inclusion of sorption at all four of the evaluation locations.
- **Antimony:** The concentration of antimony in groundwater is predicted to be below the groundwater standard with the inclusion of sorption at all four of the evaluation locations. When sorption is not simulated, the concentration of antimony in groundwater is predicted to be above the groundwater standard for a period during operations and closure (less than 50 years).
- **Aluminum:** The concentration of aluminum in groundwater is predicted to be above the groundwater standard at all four of the evaluation locations.
- **Fluoride:** The concentration of fluoride in groundwater is predicted to be below the groundwater standard at all four of the evaluation locations, and below the sMCL at the residential well and Embarrass River evaluation locations. The concentrations are predicted to be temporarily above the sMCL at the property boundary (second evaluation location) and the first evaluation location
- **Manganese:** The concentration of manganese in groundwater is predicted to be above the groundwater standard and the sMCL at all four of the evaluation locations.
- **Sulfate:** The concentration of sulfate in groundwater is predicted to be below the sMCL at all four of the evaluation locations.

The transient groundwater transport models predict potential exceedances of arsenic, aluminum, fluoride and manganese. The potential arsenic exceedance is further addressed below in Section 6. Fluoride was predicted to be below the groundwater standards at all evaluation locations and below the sMCL at the third and fourth evaluation locations but to exceed the sMCL at the first evaluation location and the property boundary (second evaluation location). The high fluoride concentrations were discussed in RS74B Draft 02 Section 8.2 and that discussion is repeated here:

> *"As shown on Table 8-8, groundwater standards are predicted to be exceeded for fluoride in Years 1 through 6. Due to the conservative manner in which these predictions are made, for these years, the predicted quality of water leaving the basin is equal to the quality of water in the pond in Year 1 (i.e. there are no other source areas included). The pond water quality at start-up is essentially equal to the current water quality in the LTVSMC ponds, which has elevated fluoride concentrations (RS64). High fluoride concentrations are also observed in*

> *down-gradient monitoring wells (see analytical data for wells GW-006 and GW-007 in Table 8-9). During PolyMet operations, the fluoride concentration in the pond is predicted to decrease, and by Year 2 is predicted to be below the surface water standard (pond water quality predictions are shown in Table 8-5 and will be discussed in detail in a subsequent SRK memorandum or report). As such, the high fluoride concentrations should be considered a remnant of LTVSMC operation that will improve through time."* [RS74B Draft 02 page 81]

Aluminum concentrations are predicted to reach a maximum concentration of 0.6 mg/L at the first evaluation location and 0.54 mg/L at the residential well evaluation location (second evaluation location). While these concentrations are above the sMCL, they are well below the existing aluminum concentrations. Table 8-9 from RS74B Draft 02 (included in at the back of this memorandum) shows the water quality measured in the existing wells at the basin. Well GW-001, which is located at the toe of the Tailings Basin, very near the cross-section being modeled, has an average aluminum concentration of 12.9 mg/L. The maximum predicted concentration for seepage leaving the PolyMet Tailings Basin is 0.62 mg/L. A similar condition exists for manganese; Tailings Basin seepage is predicted to have a maximum manganese concentration of 0.24 mg/L. Well GW-001 has an average manganese concentration of 2.35 mg/L. It should also be noted that while a HRL was promulgated for manganese, due to research that has become available since the HRLs were promulgated, the MDH no longer recommends the HRL value (Richard Clark, personal communication). For aluminum and manganese, seepage under the Geotechnical Mitigation will improve the existing groundwater in the vicinity of the Tailings Basin.

6.0 PHREEQC Modeling of Arsenic

Because arsenic is an inorganic element (not a metal), the sorptive behavior of arsenic in the subsurface is different than most metals. In the groundwater environment arsenic is predominantly present as an oxyanion (negative charge) rather than a cation in the form of either arsenate ($H_2AsO_4^-$) or arsenite ($H_2AsO_3^-$). The location of arsenic on the periodic table (directly below phosphorous) also helps to explain why these elements behave similarly, with both being adsorbed onto iron oxides when they are present. Like phosphorous, arsenic can be released into solution in strongly reducing or acidic conditions, where iron oxides become less stable. However, in strongly reducing conditions where iron and sulfide are present, arsenic is again removed from solution by coprecipitation with iron as arsenopyrite. Given the wide variety of factors, including both pH and oxidation-reduction potential, it is understandable that the potential range of sorptive values for arsenic in soil would be very broad. The wide variability of potential sorption values for arsenic was confirmed by the U.S. EPA in their recent review of partition coefficients for metals (U.S. EPA, 2005).

Because the sorptive behavior of arsenic is variable across a range of pH and redox values, the use of a low K_d from the range of published values is likely to be very conservative. Even with a conservative value, the preliminary ‘screening level’ modeling of arsenic migration in the groundwater suggests that the potential concentration of arsenic in the groundwater down gradient of the Tailings Basin exceeds the groundwater standard by less than a factor of three. More representative modeling of arsenic adsorptive behavior, as described below, has demonstrated that the preliminary screening was indeed conservative, perhaps by an order of magnitude (i.e. factor of ten), and that the long term increase in arsenic concentrations in the groundwater are not expected to exceed groundwater standards at the evaluation locations.

6.1 PolyMet Tailings Basin Arsenic Adsorption Modeling Protocol

Arsenic transport through native till was modeled using a one-dimensional advective transport model with dispersion and adsorption to native till material. PHREEQC, a geochemical modeling software program developed by the USGS (http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/), and which is a publicly-available, was used to develop the model.

6.2 Adsorption Model Description and Calibration

Adsorption to native till was modeled using the two-layer surface complexation model for hydrous ferric oxides described by Dzombak and Morel (1990). The model was calibrated to account for the amount of iron in the till that was available for adsorption of arsenic. Calibration of the model was accomplished using the adsorption isotherms presented in Carillo and Drever (1998). Input for adsorption model calibration included initial solution composition and total iron dose as ferrihydrite. The pH was varied by NaOH addition, ferrihydrite was allowed to dissolve or precipitate, and arsenic was allowed to adsorb/desorb at the ferrihydrite surface. Initial solution pH was assumed to be neutral and redox was assumed to be positive (pe = 4). The densities of strong and weak adsorption sites (moles/gram), as well as the specific surface area (m^2/gram) were adjusted to reproduce the adsorption isotherm reported by

Carillo and Drever. The calibrated model isotherm is compared to the isotherm presented by Carillo and Drever in Figure 6-1.

The transport model was set-up to have the same fraction of iron available for arsenic adsorption in the till as that reported by Carillo and Drever (natural aquifer material). The approximate gradation of the aquifer material described by Carillo and Drever is 65 percent 0.15-0.25 mm and 35 percent <0.15 mm. This is similar to the gradation of the Rainy Lobe till as was measured at the Mine Site. Additionally, the PHREEQC model was constrained to only allow dissolution of iron oxyhydroxides (no precipitation of iron in the till matrix), which is also a conservative assumption.

6.3 Transport Model Description

The PHREEQC transport model was constructed with the following assumptions:

1. Grid spacing = 50 m, number of cells = 51
2. Longitudinal dispersivity = 19.2 m
3. Flux boundary conditions at inlet and outlet cells
4. Porosity = 0.3
5. Width of flow zone = 2,042 m
6. Depth of flow zone = 5 m
7. Distance to property boundary = 1,150 m
8. Distance to wells = 2,575m

With the exception of the grid spacing, all the assumptions described above are the same as those used in the MODFLOW-MT3DMS model described in Section 3. For the arsenic transport modeling, the grid spacing was increased from 25m to 50m in order to reduce computational complexities that occur in PHREEQC when the grid size is similar to the longitudinal dispersivity. The initial iron content of the till was approximated using the available data for iron in the till at the Mine Site. From a total of 25 overburden till samples that were analyzed for iron, the 5th percentile of the available iron data was approximately 1.9 mg/Kg. This conservative value was used to represent the iron content of the till.

Iron content of each cell was computed as the minimum measured iron content of Mine Site overburden (1.9 percent, wt.) multiplied by the bulk density (1.65 kg/L), multiplied by cell volume (50 m^3). This iron content, expressed as moles ferrihydrite per cell, was equilibrated with pore water (15,000 L), having chemistry as measured in the Tailings Basin well GW-007 (see Table 8-9 from RS74B Draft 02 included at the end of this memorandum) prior to the transport simulation.

Drainage flux, in terms of shifts (pore volumes) was computed for the simulated time interval, and a corresponding time step was computed such that #shifts x time step = simulated time interval (2,000 years). The simulation assumed the worst-case water quality (post-closure arsenic concentration = 27.9 µg/L) and the maximum (Year 20) flux. This is similar to what was used in the screening level models presented in Section 4. These maximum flux and water quality values were assumed to remain constant during the entire 2000 year period being simulated, which is very conservative. The pH value for influent flux was assumed to be 7 (SRK, 2008) and the redox was assumed to be mildly reducing (pe = -4). These are also conservative assumptions because arsenic adsorption is less efficient under non-acidic and reducing conditions.

6.4 Modeling Results

The results of the 2,000-year simulation of arsenic transport through the groundwater near the Tailings Basin are shown in Figure 6-2. The initial arsenic concentration was 4.2 µg/L (groundwater samples from GW-007). The arsenic concentration in the system decreased initially due to enhanced adsorption at the less alkaline pH of the tailings basin drainage. The arsenic concentration increased thereafter, reaching a maximum concentration of 4.1 µg/L at the property boundary and residential well (the second and third evaluation locations) in Years 360 and 700, respectively.

To assess the additional conservatism of the model, an additional arsenic transport simulation was performed using a density of adsorptive sites that was one order of magnitude less than the initial model calibration. As shown in Figure 6-3, decreasing the density of adsorption sites by an order of magnitude increases the maximum observed arsenic concentrations. However, the arsenic concentrations observed in this simulation are still well below the groundwater standard of 10 µg/L. The fact that a constant (maximum modeled) arsenic load and a maximum flux for 2,000 years does not result in an exceedance of the drinking water standard for arsenic at the property boundary even with one order of magnitude less iron adsorption sites than the conservative (5th percentile) initial value used in the model is a further demonstration that the actual, transient, load from the Tailings Basin would not result in an exceedance of standards for arsenic at the property boundary or any of the down gradient well locations.

7.0 Conclusions

Potential impacts from the Tailings Basin – Geotechnical Mitigation on the groundwater quality downgradient of the Tailings Basin were evaluated using simplifying, conservative assumptions, with additional complexity added only when needed, as in the case of arsenic which is described in Section 6. The impact evaluation was completed using a two-step process, with the first step consisting of a steady-state screening level model that identified potential dissolved constituents of concern, and the second step consisting of two sets of transient models for dissolved constituents that showed the potential for groundwater criteria exceedances during the first step modeling. Additional modeling of the sorption of arsenic was also conducted.

The screening level models identified five potential constituents of concern: arsenic, antimony, aluminum, fluoride, manganese (sulfate was also considered a potential constituent of concern even though it did not fail the screening level model). Of these, transient modeling presented in Section 5 showed that concentrations of antimony (when sorption was included), and sulfate were predicted to be below the applicable groundwater standards or sMCL at all four evaluation locations. Fluoride was predicted to be below the groundwater standards at all evaluation locations and below the sMCL at the third and fourth evaluation locations but to exceed the sMCL at the first evaluation location and the property boundary (second evaluation location). As discussed in RS74B Draft 02, the high fluoride concentrations are the result of the existing basin water quality which is above the groundwater standard and do not relate to the proposed PolyMet operations.

As noted in Section 6, because the sorptive behavior of arsenic is different than most metals and may not be adequately represented by a linear isotherm with a conservative K_d value from literature, a more detailed sorption model was used. Instead, a one-dimensional advective transport model with dispersion and arsenic adsorption to iron present in the native till material was used. The results of this model showed that the till has excess capacity to adsorb arsenic and prevent migration to the property boundary or nearby wells that would result in concentrations above the potential groundwater quality standard

Aluminum concentrations are predicted to reach a maximum concentration of 0.6 mg/L at the first evaluation location and 0.55 mg/L at the residential well evaluation location (second evaluation location). While these concentrations are above the sMCL, they are well below the existing aluminum concentrations. Table 8-9 from RS74B Draft 02 (included in at the back of this memorandum) shows the water quality measured in the existing wells at the basin. Well GW-001, which is located at the toe of the

Tailings Basin, very near the cross-section being modeled, has an average aluminum concentration of 12.9 mg/L. The maximum predicted concentration for seepage leaving the PolyMet Tailings Basin is 0.62 mg/L. A similar condition exists for manganese; Tailings Basin seepage is predicted to have a maximum manganese concentration of 0.24 mg/L. Well GW-001 has an average manganese concentration of 2.35 mg/L. This means that for aluminum and manganese, seepage under the Geotechnical Mitigation will improve the existing groundwater in the vicinity of the Tailings Basin.

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Table 2-1 Groundwater Quality Standards (concentrations in µg/L)

		GW Standards		
		EPA	MDH	EPA
		MCL	HRL	sMCL
Antimony	µg/L	6	6	--
Arsenic	µg/L	10	--	--
Barium	µg/L	2,000	2,000	--
Beryllium	µg/L	4	0.08	--
Boron	µg/L	--	600	--
Cadmium	µg/L	5	4	--
Calcium		--	--	--
Chromium, total	µg/L	100	--	--
Chromium Hexavalent	µg/L	--	100	--
Chromium Trivalent	µg/L	--	20,000	--
Cobalt	µg/L	--	--	--
Copper	µg/L	1,300	--	1,000
Iron	µg/L	--	--	300
Lead (TT)	µg/L	15	--	--
Magnesium		--	--	--
Manganese	µg/L	--	*100**	50
Mercury	µg/L	2	--	--
Nickel	µg/L	--	100	--
Selenium	µg/L	50	30	--
Silver	µg/L	--	30	100
Thallium	µg/L	2	0.6	--
Tin	µg/L	--	4,000	--
Vanadium	µg/L	--	50	--
Zinc	µg/L	--	2,000	5,000
Other Parameters				
Sulfate	µg/L	--	--	250,000
Alkalinity		--	--	--
Chloride	µg/L	--	--	250,000
Fluoride	µg/L	4,000	--	2,000
Hardness		--	--	--
Potassium		--	--	--
Sodium		--	--	--
Nitrogen as nitrate	µg/L	10,000	10,000	--
Nitrogen as ammonia		--	--	--
Aluminum	µg/L		--	50 to 200
Molybdenum	µg/L	--	--	--

Groundwater Criteria:

sMCL - Secondary MCLs (40 CFR 143) based on aesthetics.
MCL - Maximum Contaminant Levels (40 CFR 141)
HRLs - Health Risk Limits - (MN Rules 4717.7500)

* While a HRL was promulgated for this chemical, due to research that has become available since the HRLs were promulgated, the MDH no longer recommends the HRL value.

Table 4-1 Predicted Groundwater Concentrations - Screening Level Model - Tailings Basin

Source Proportional Contribution

	Eval Pt #1	Property Boundary	Residential Well	Embarrass River
Cell 2E Tailings Basin	0.988	0.977	0.95	0.914
Recharge/Background	0.012	0.023	0.05	0.086

Parameter	Units	GW Standard	EPA sMCL	Seepage Concentration (mg/L)	Recharge Concentration (mg/L)	Predicted concentration (mg/L), Eval Pt #1	Predicted concentration (mg/L), Property Boundary	Predicted concentration (mg/L), Residential Well	Predicted concentration (mg/L), Embarrass River
Ag	mg/L	0.030	0.10	0.0012	0.000008	0.0012	0.0012	0.0011	0.0011
Al	mg/L	--	0.05	0.615	0.025	0.608	0.601	0.586	0.564
As	mg/L	0.010	--	0.028	0.003	0.028	0.027	0.027	0.026
B	mg/L	0.600	--	0.161	0.021	0.160	0.158	0.154	0.149
Ba	mg/L	2	--	0.055	0.068	0.055	0.055	0.055	0.056
Be	mg/L	8.0E-05	--	0.020	0.00002	0.019	0.019	0.019	0.018
Ca	mg/L	--	--	109	19	108	107	105	102
Cd	mg/L	0.004	--	0.0012	0.0003	0.0012	0.0012	0.0012	0.0011
Cl	mg/L	--	250	15.3	1.8	15.1	14.9	14.6	14.1
Co	mg/L	--	--	0.0027	0.0011	0.0027	0.0027	0.0026	0.0026
Cu	mg/L	1.3	1.00	0.014	0.004	0.014	0.014	0.014	0.013
F	mg/L	4	2.00	2.9	0.4	2.9	2.8	2.8	2.7
Fe	mg/L	--	0.30	0.099	0.035	0.099	0.098	0.096	0.094
Hardness	mg/L	--	--	402	88	398	395	386	375
K	mg/L	--	--	21.3	1.6	21.1	20.8	20.3	19.6
Mg	mg/L	--	--	56.0	10.7	55.5	55.0	53.7	52.1
Mn	mg/L	--	0.05	0.24	0.19	0.24	0.24	0.24	0.24
Na	mg/L	--	--	53.0	4.9	52.4	51.8	50.5	48.8
Ni	mg/L	0.100	--	0.027	0.007	0.026	0.026	0.026	0.025
Pb	mg/L	0.015	--	0.0036	0.0012	0.0036	0.0035	0.0035	0.0034
Sb	mg/L	0.006	--	0.012	0.0015	0.012	0.012	0.011	0.011
Se	mg/L	0.030	--	0.0033	0.0030	0.0033	0.0033	0.0033	0.0033
SO_4	mg/L	--	250	245	9	242	240	233	225
Tl	mg/L	6E-04	--	0.0011	0.000004	0.0011	0.0011	0.0010	0.0010
Zn	mg/L	2	5	0.082	0.012	0.081	0.080	0.078	0.076

▨	Groundwater standard exceedance
⬚	EPA sMCL exceedance
--	No applicable standard

Table 5-2 Input Concentrations - Transient Model - Tailings Basin

Stress Period	Year	As (mg/L)	Sb (mg/L)	Al (mg/L)	F (mg/L)	Mn (mg/L)	SO4 (mg/L)
1	2	0.0068	0.0080	0.010	2.903	0.240	190.0
2	4	0.0068	0.0080	0.010	2.903	0.240	190.0
3	6	0.0068	0.0080	0.010	2.903	0.240	190.0
4	8	0.0097	0.0105	0.189	0.549	0.198	191.1
5	10	0.0094	0.0117	0.125	0.507	0.158	223.1
6	12	0.0100	0.0113	0.139	0.529	0.167	225.5
7	14	0.0101	0.0085	0.205	0.531	0.211	182.4
8	16	0.0082	0.0099	0.086	0.637	0.196	194.2
9	18	0.0081	0.0087	0.102	0.612	0.228	174.6
10	20	0.0075	0.0088	0.069	0.599	0.231	163.3
11	Post-Closure	0.0279	0.0012	0.615	1.137	0.144	176.5
Recharge Concentration		0.00273	0.0015	0.025	0.385	0.188	8.5

Table 5-4. Summary of maximum concentrations predicted using the transient groundwater model

	Evaluation Location 1 (mg/L)	Property Boundary (mg/L)	Residential Wells (mg/L)	Embarrass River (mg/L)
Arsenic without Sorption				
Max during Operations	0.010	0.010	0.009	0.003
Max in Closure	0.027	0.027	0.025	0.023
Final Value	0.027	0.026	0.025	0.023
Arsenic with Sorption				
Max during Operations	0.003	0.003	0.003	0.003
Max in Closure	0.027	0.026	0.025	0.023
Final Value	0.027	0.026	0.025	0.023
Antimony without Sorption				
Max during Operations	0.0116	0.0113	0.0098	0.0015
Max in Closure	0.0087	0.0085	0.0085	0.0069
Final Value	0.0012	0.0012	0.0012	0.0013
Antimony with Sorption				
Max during Operations	0.0015	0.0015	0.0015	0.0015
Max in Closure	0.0030	0.0025	0.0021	0.0019
Final Value	0.0012	0.0012	0.0012	0.0019
Aluminum				
Max during Operations	0.20	0.20	0.16	0.03
Max in Closure	0.60	0.58	0.54	0.49
Final Value	0.60	0.58	0.54	0.49
Fluoride				
Max during Operations	2.85	2.76	1.74	0.38
Max in Closure	1.11	1.08	1.00	0.91
Final Value	1.10	1.07	1.00	0.91
Manganese				
Max during Operations	0.24	0.23	0.19	0.19
Max in Closure	0.23	0.22	0.20	0.16
Final Value	0.14	0.14	0.13	0.12
Sulfate				
Max during Operations	222	217	188	8
Max in Closure	172	167	166	142
Final Value	171	166	155	142

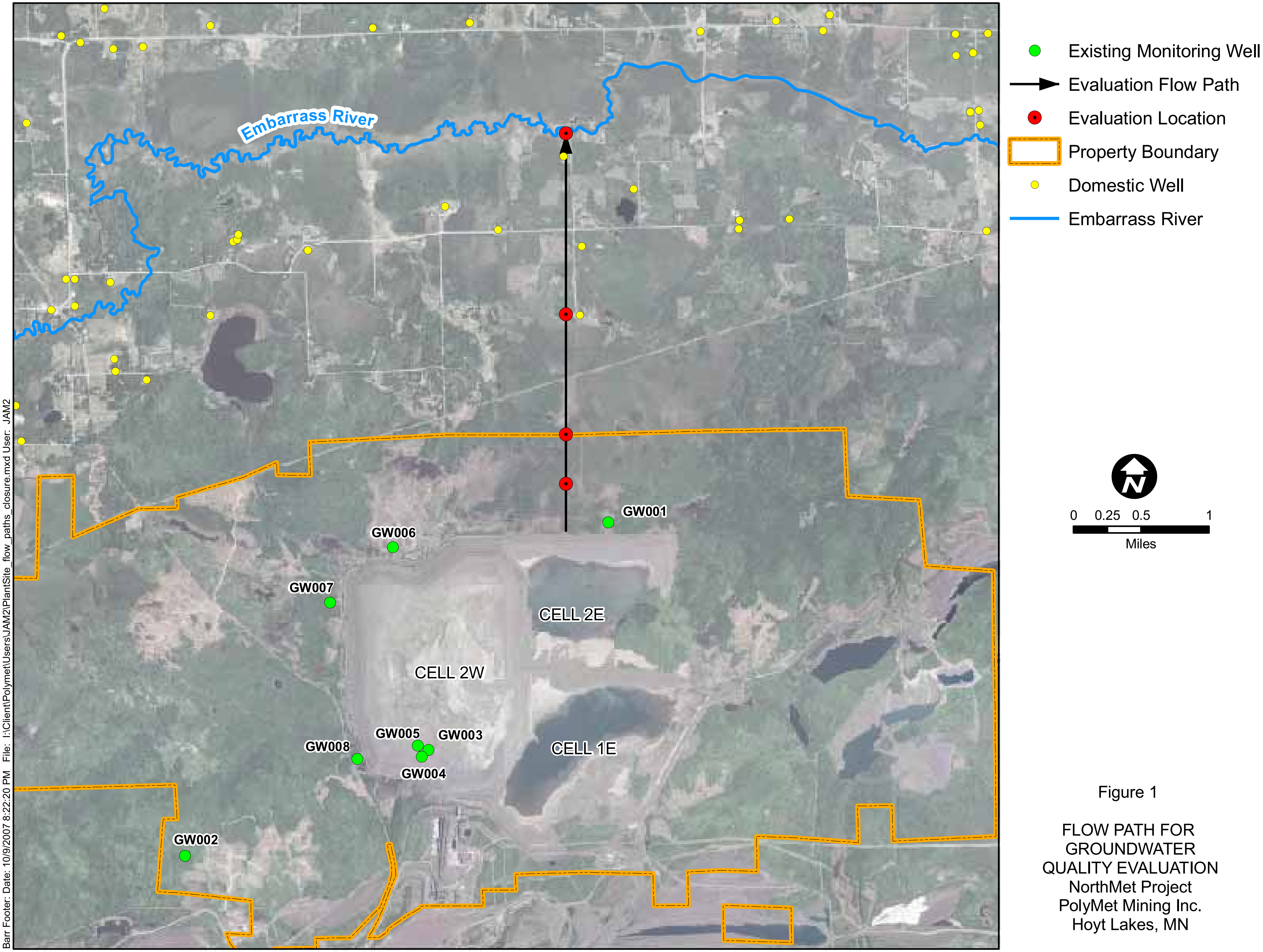
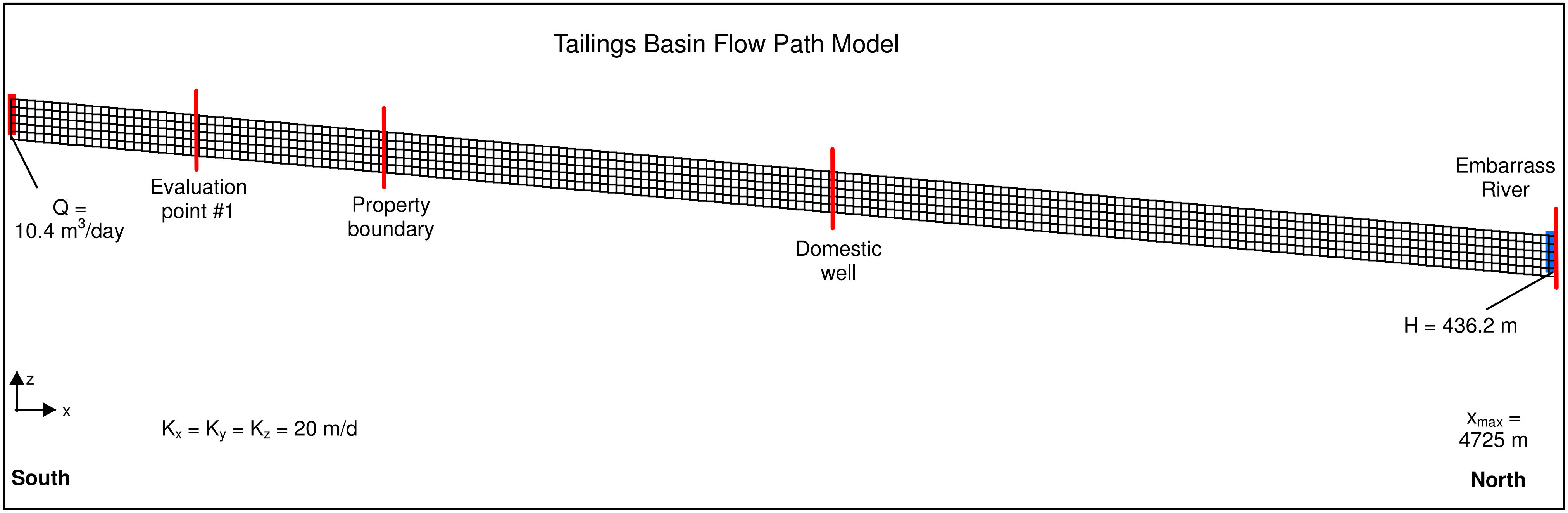


Figure 1

FLOW PATH FOR GROUNDWATER QUALITY EVALUATION
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



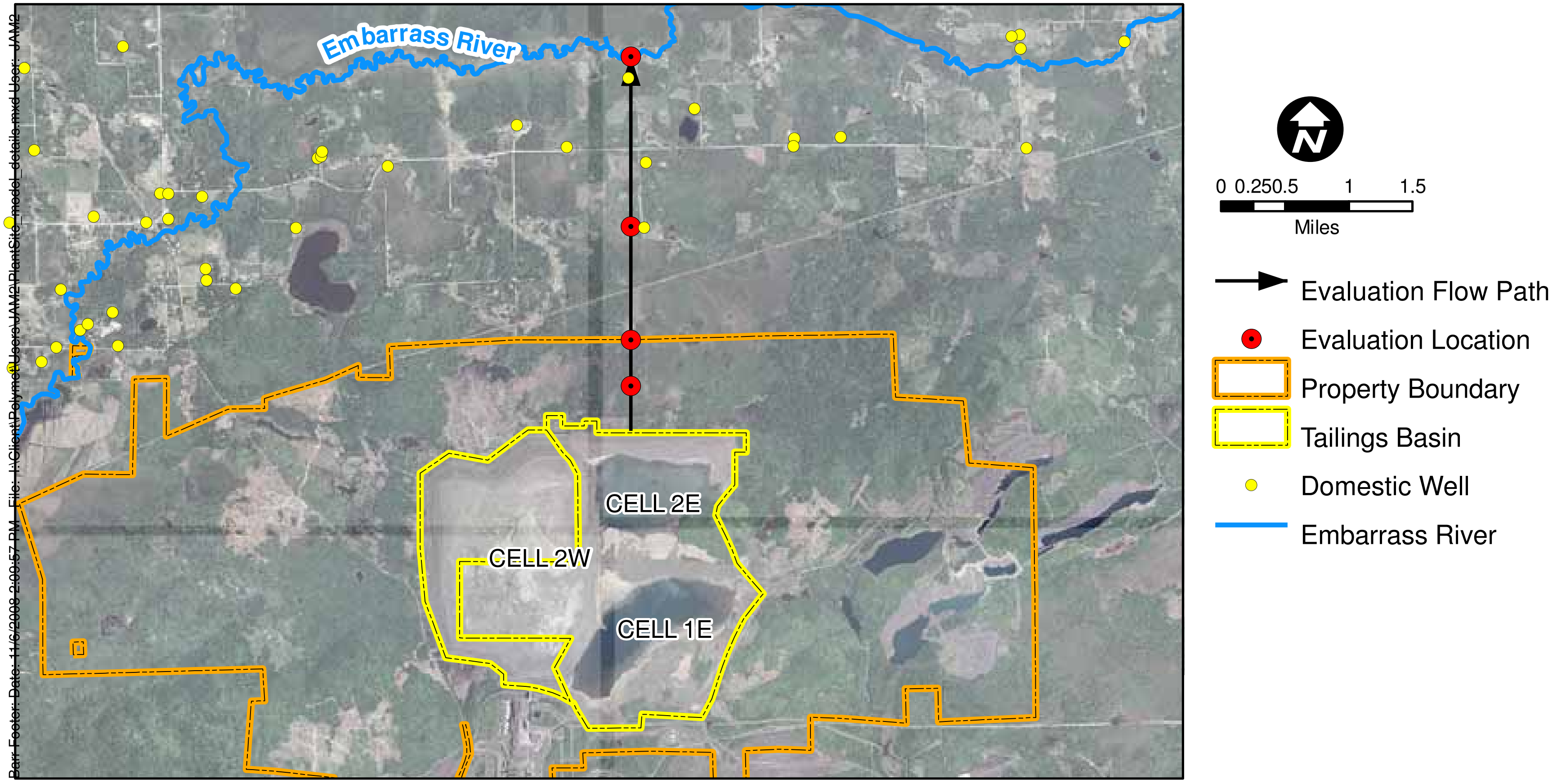


Figure 3-2

FLOW PATH
MODEL DETAILS
PLANT SITE
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Figure 5-1
Tailings Basin Transient Model
Arsenic Concentrations Without Sorption

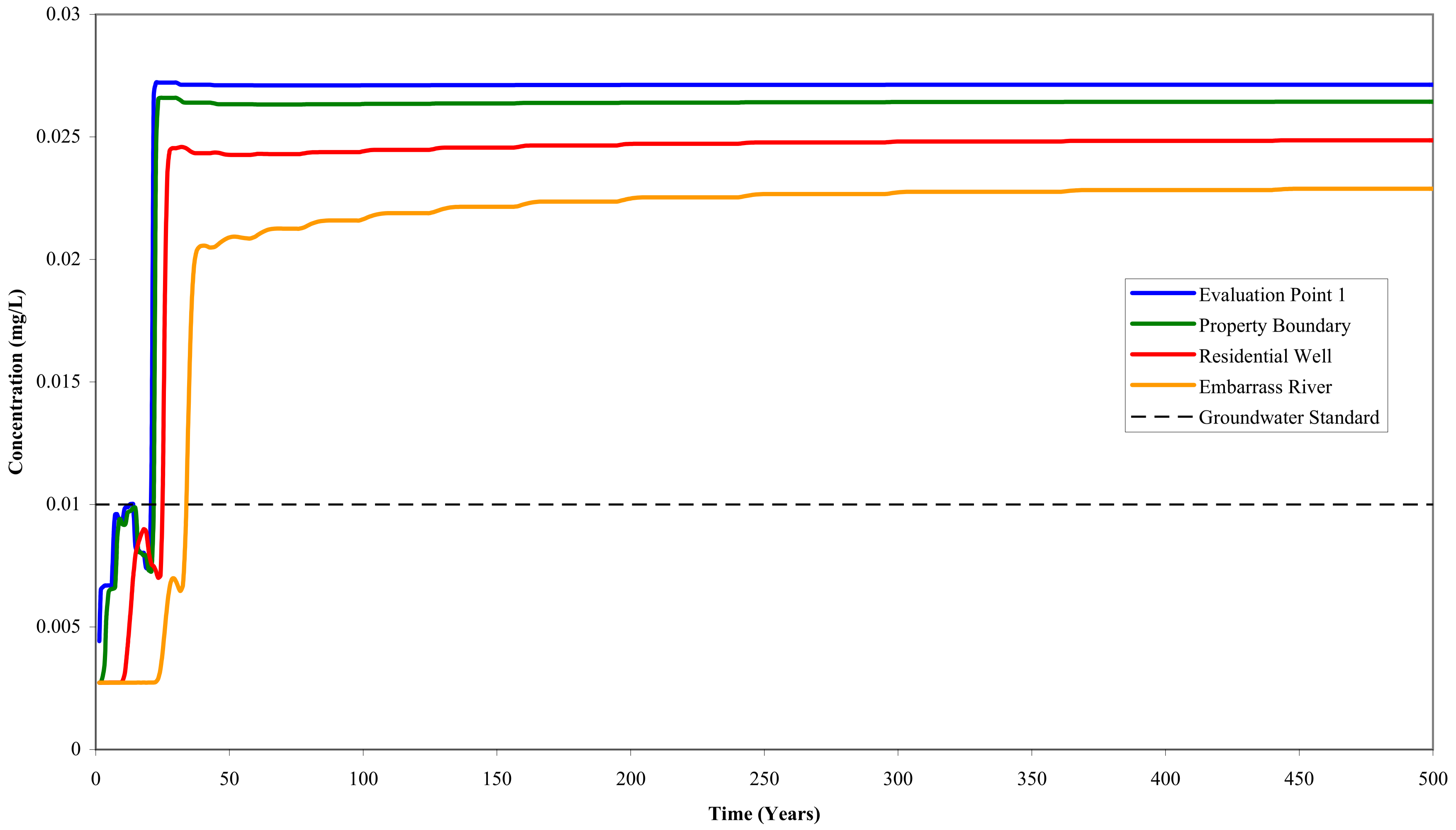


Figure 5-2
Tailings Basin Transient Model
Arsenic Concentrations With Sorption

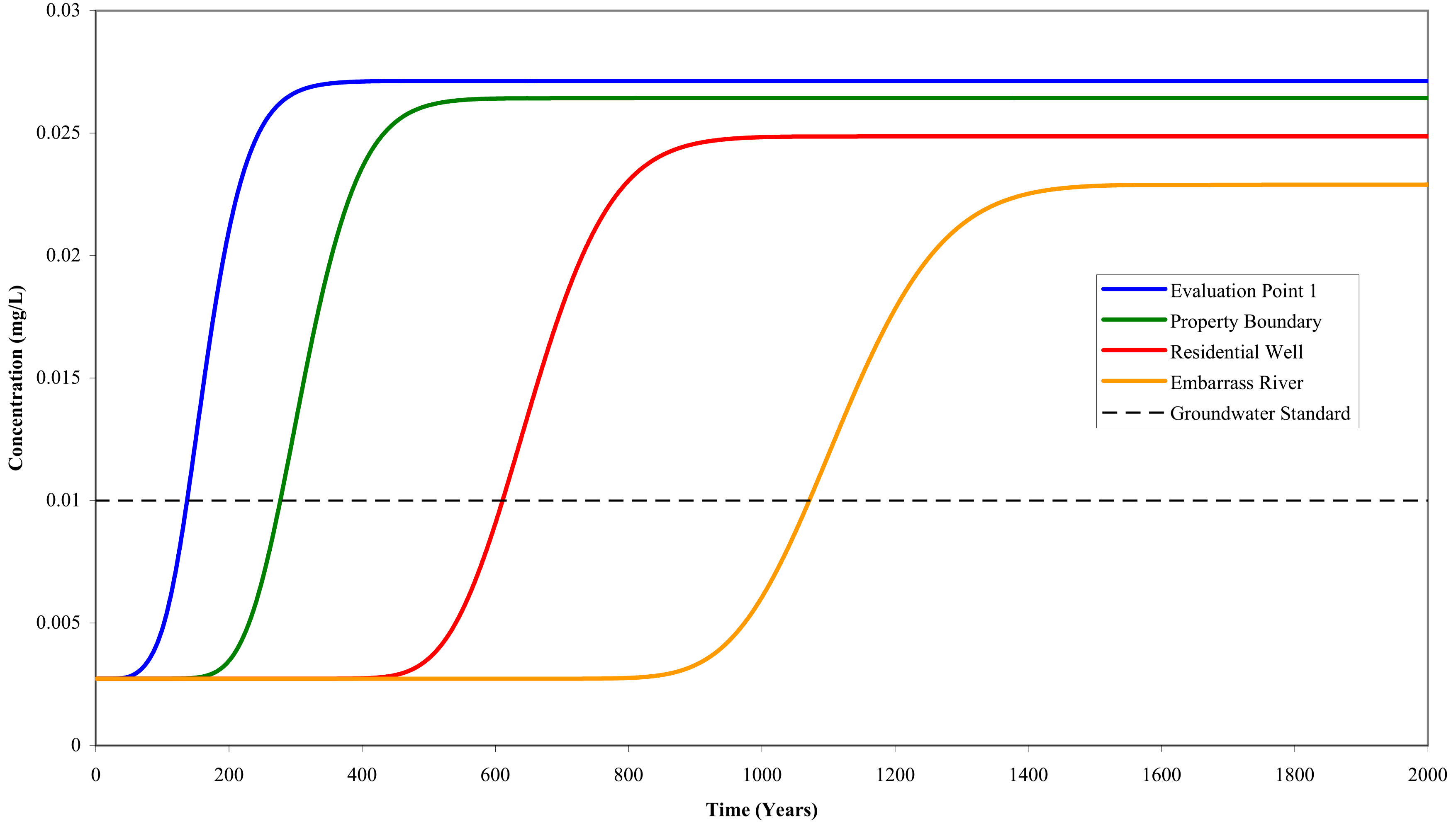


Figure 5-3
Tailings Basin Transient Model
Antimony Concentrations Without Sorption

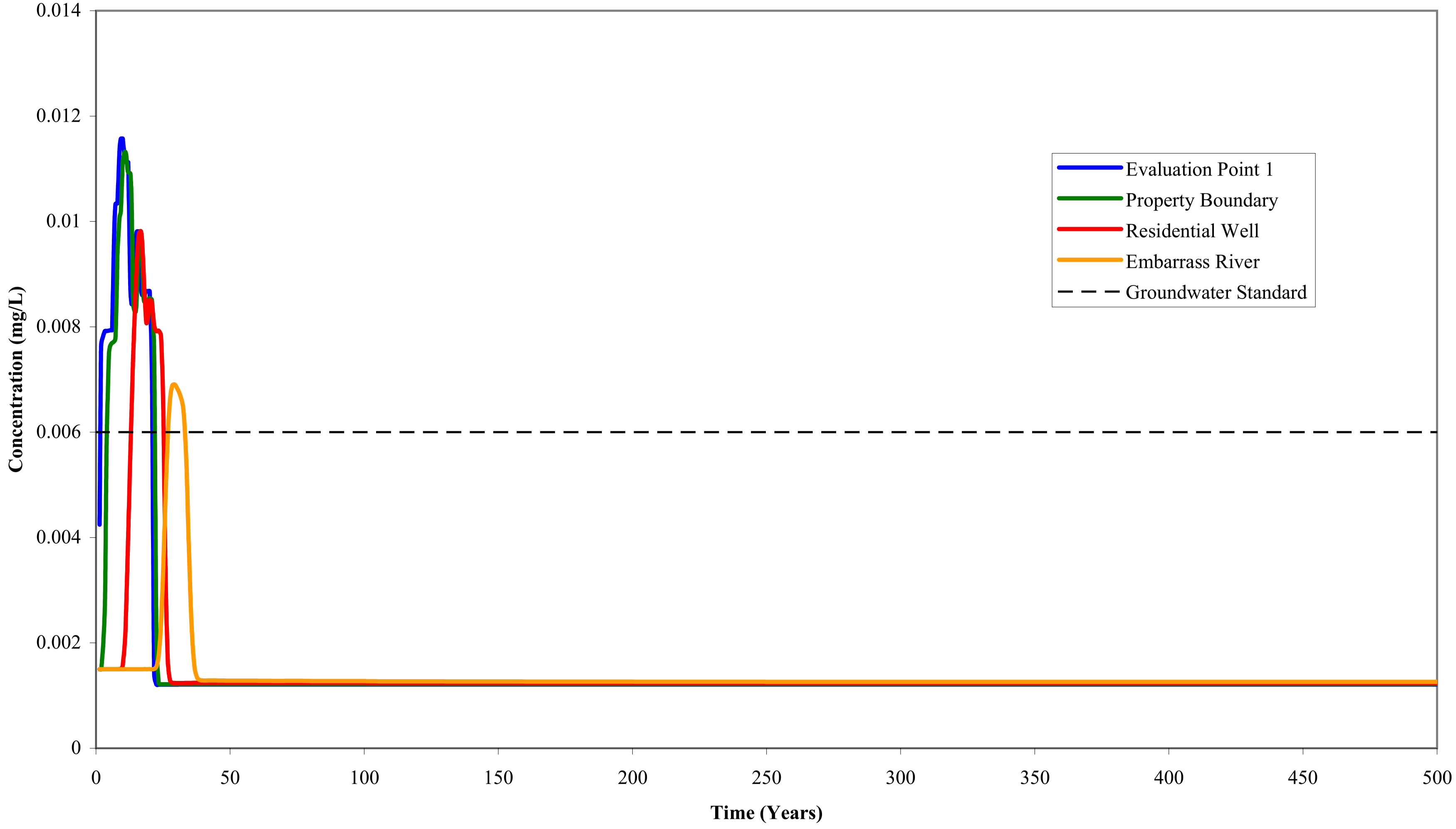


Figure 5-4
Tailings Basin Transient Model
Antimony Concentrations With Sorption

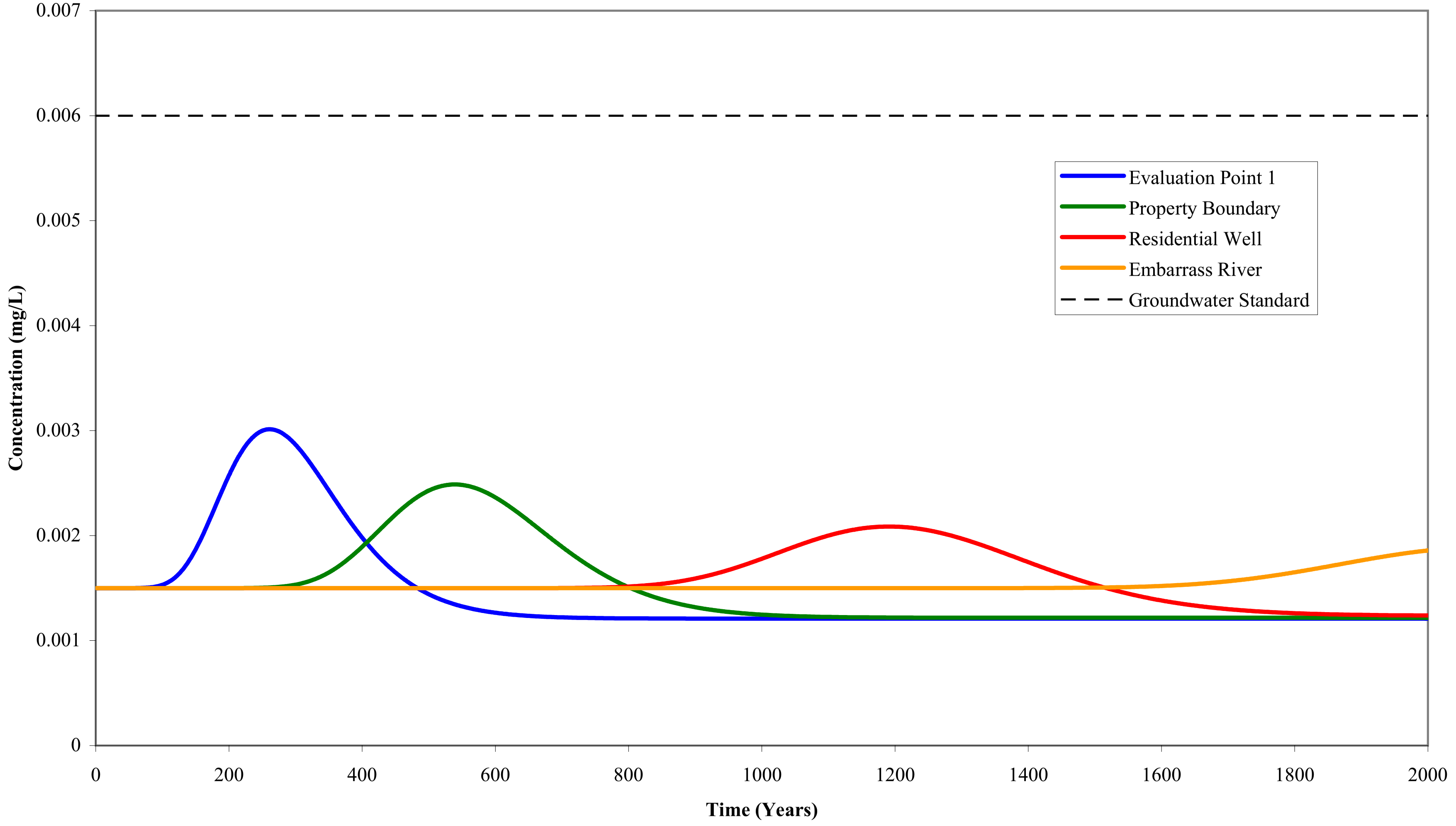


Figure 5-5
Tailings Basin Transient Model
Aluminum Concentrations

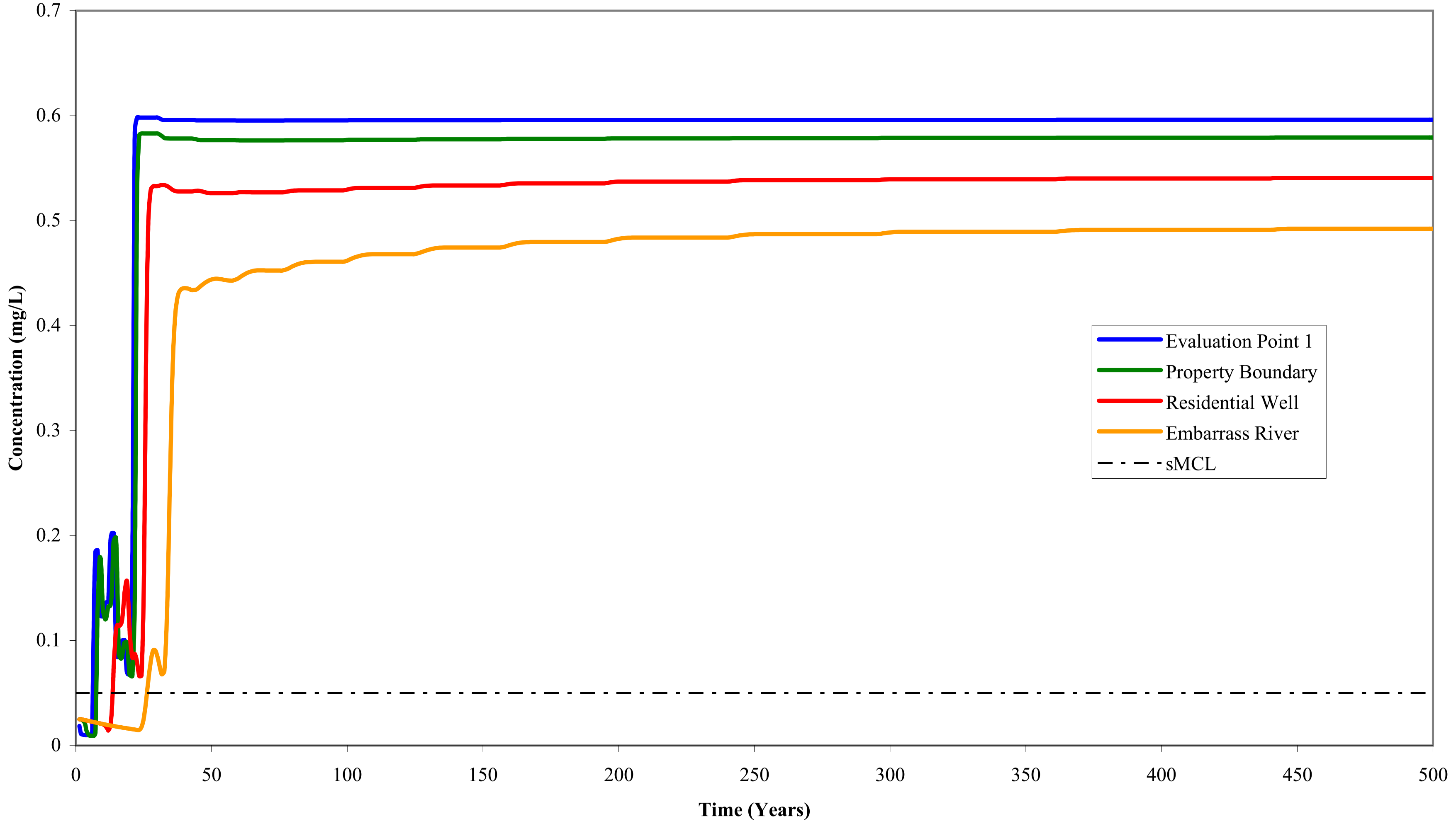


Figure 5-6
Tailings Basin Transient Model
Fluoride Concentrations

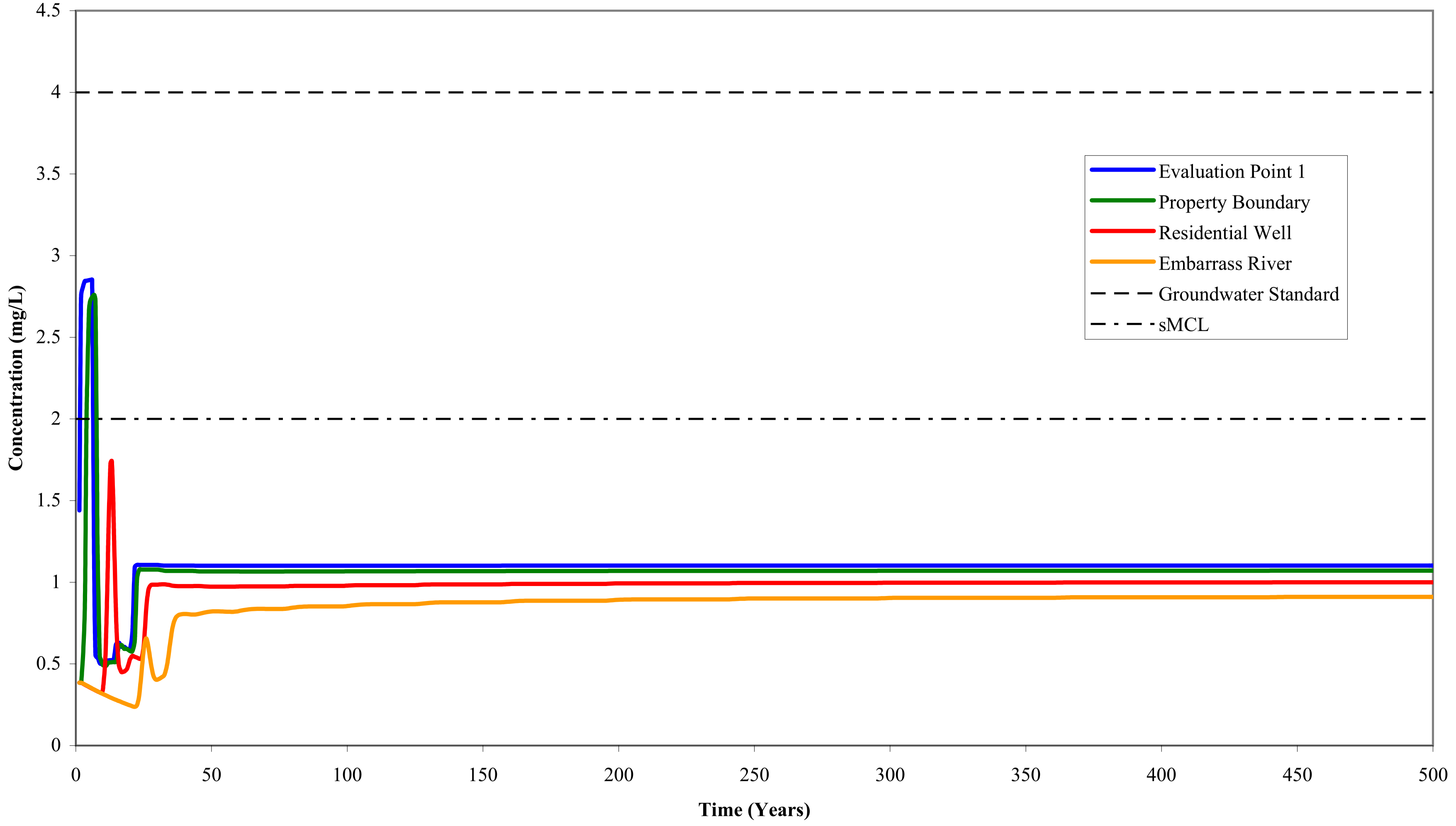


Figure 5-7
Tailings Basin Transient Model
Manganese Concentrations

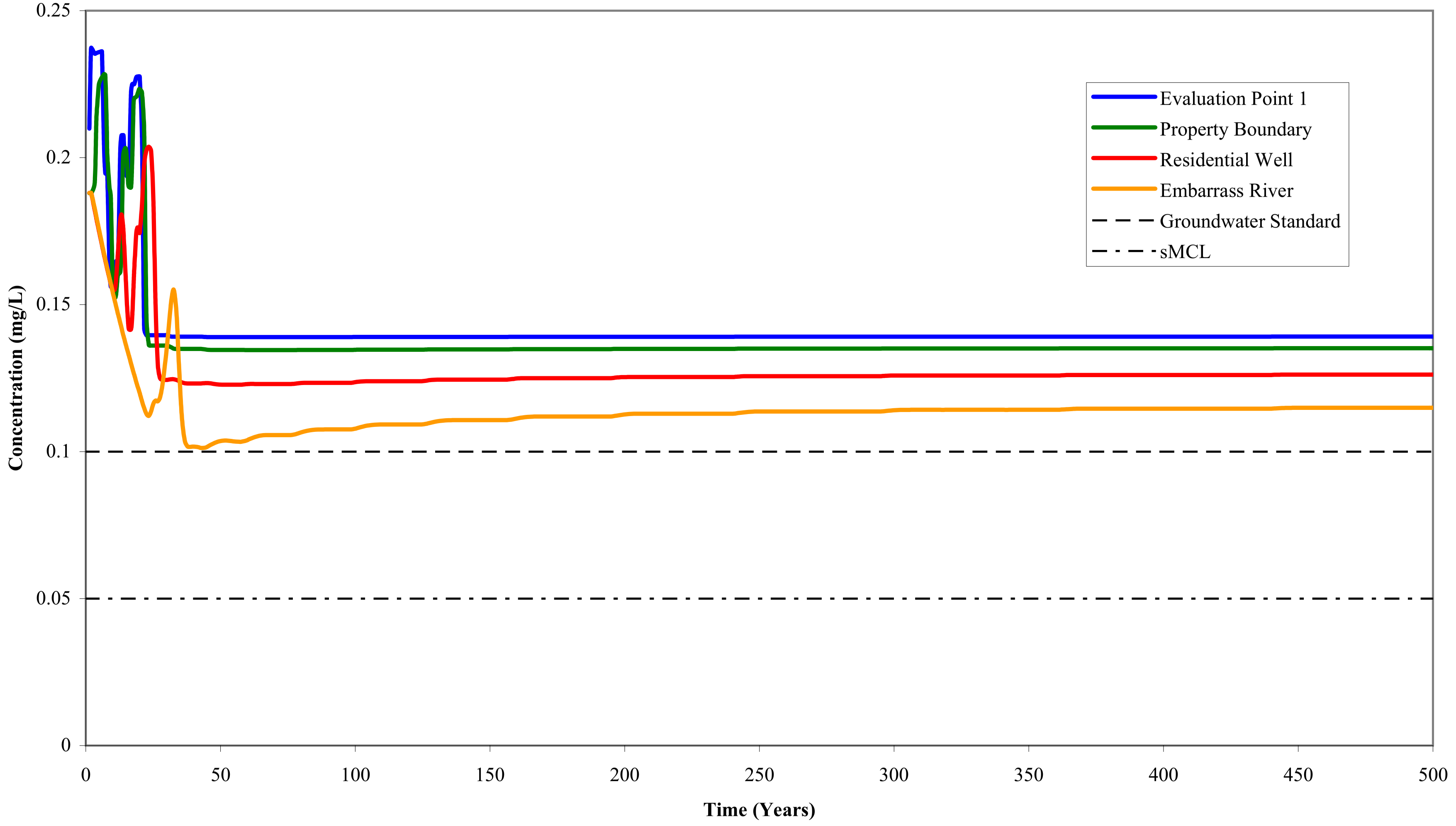


Figure 5-8
Tailings Basin Transient Model
Sulfate Concentrations

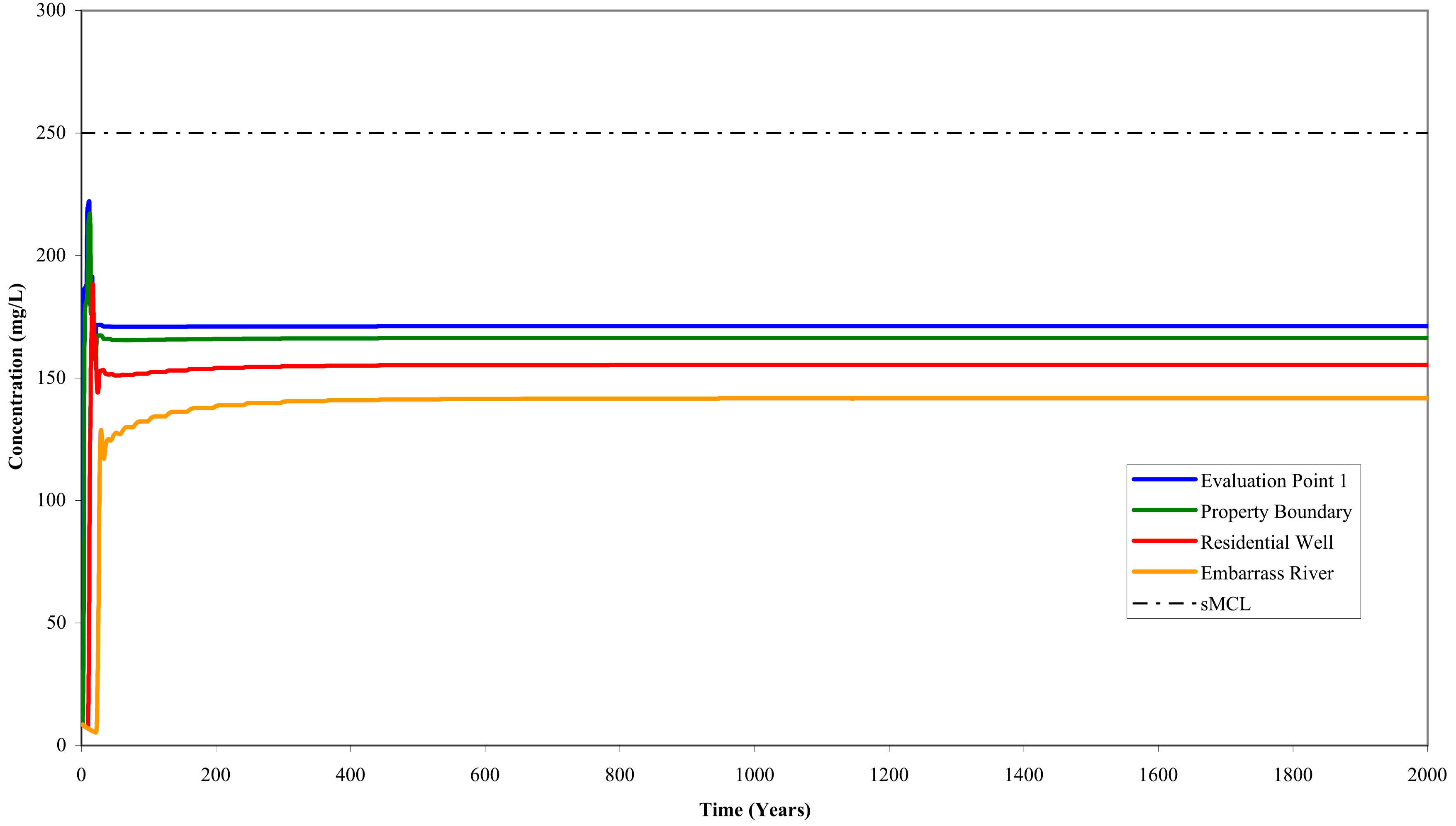


Figure 6-1
Arsenic Adsorption Isotherm

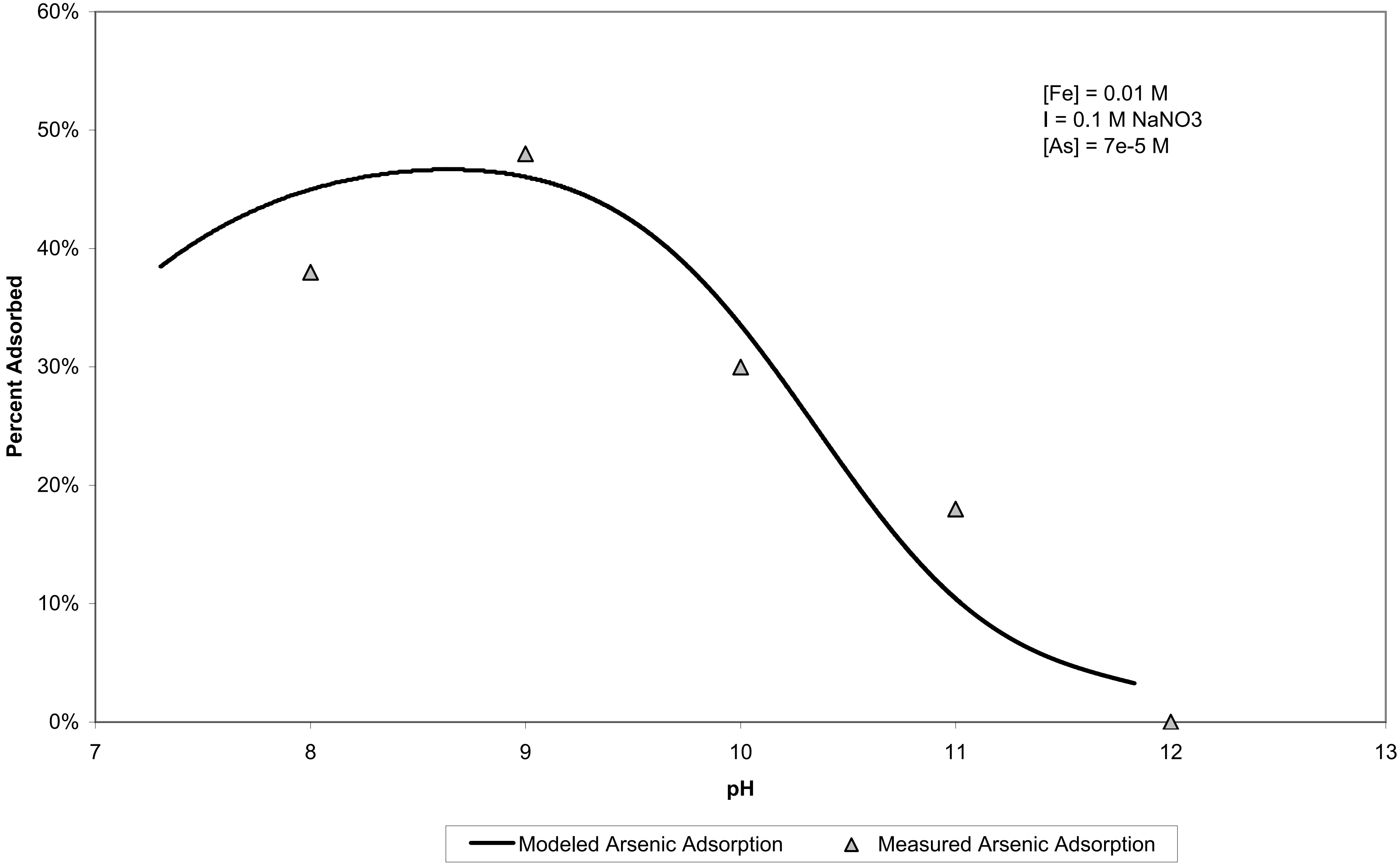


Figure 6-2
PHREEQC Modeling
Arsenic Concentration vs. Time

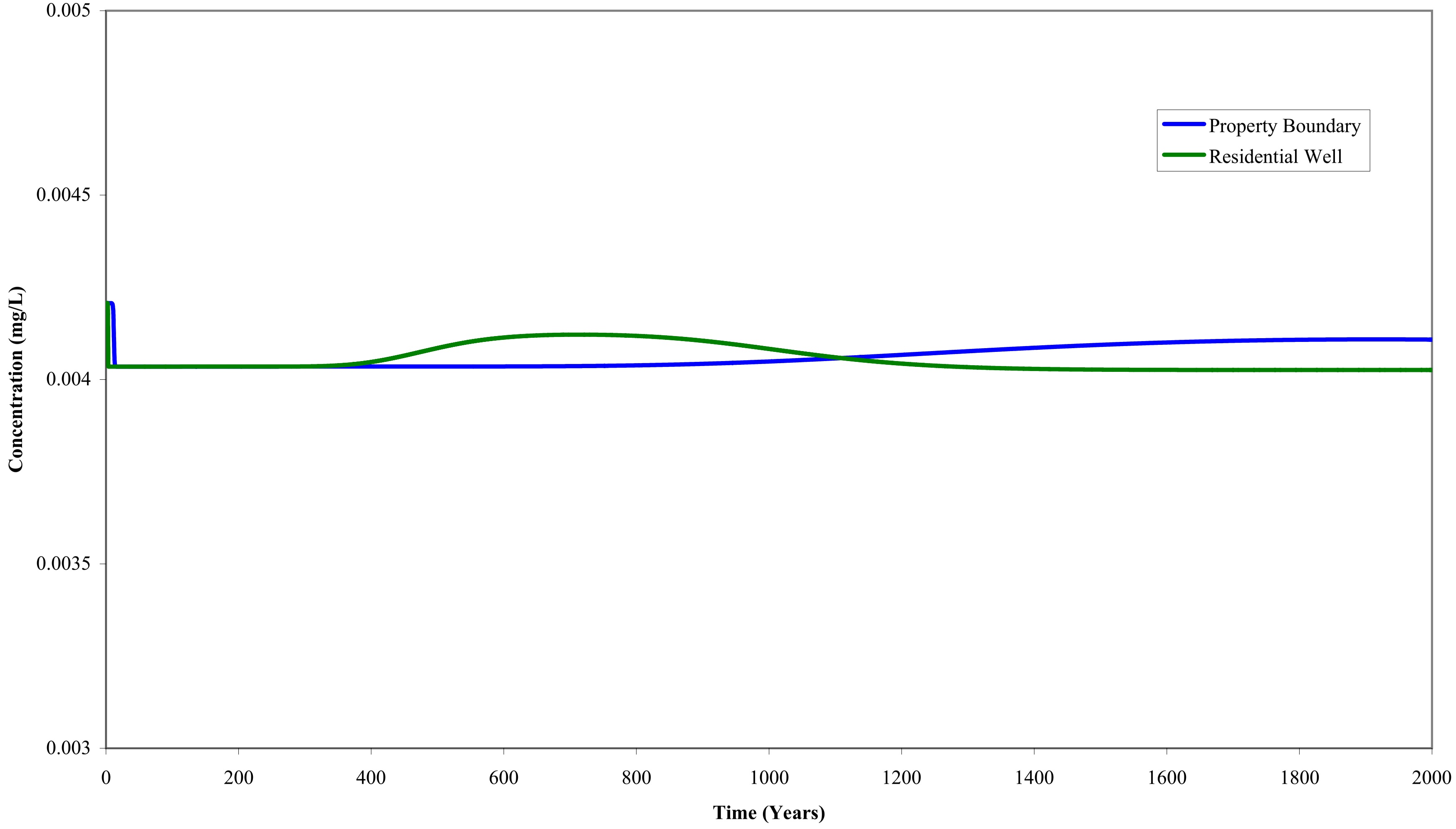
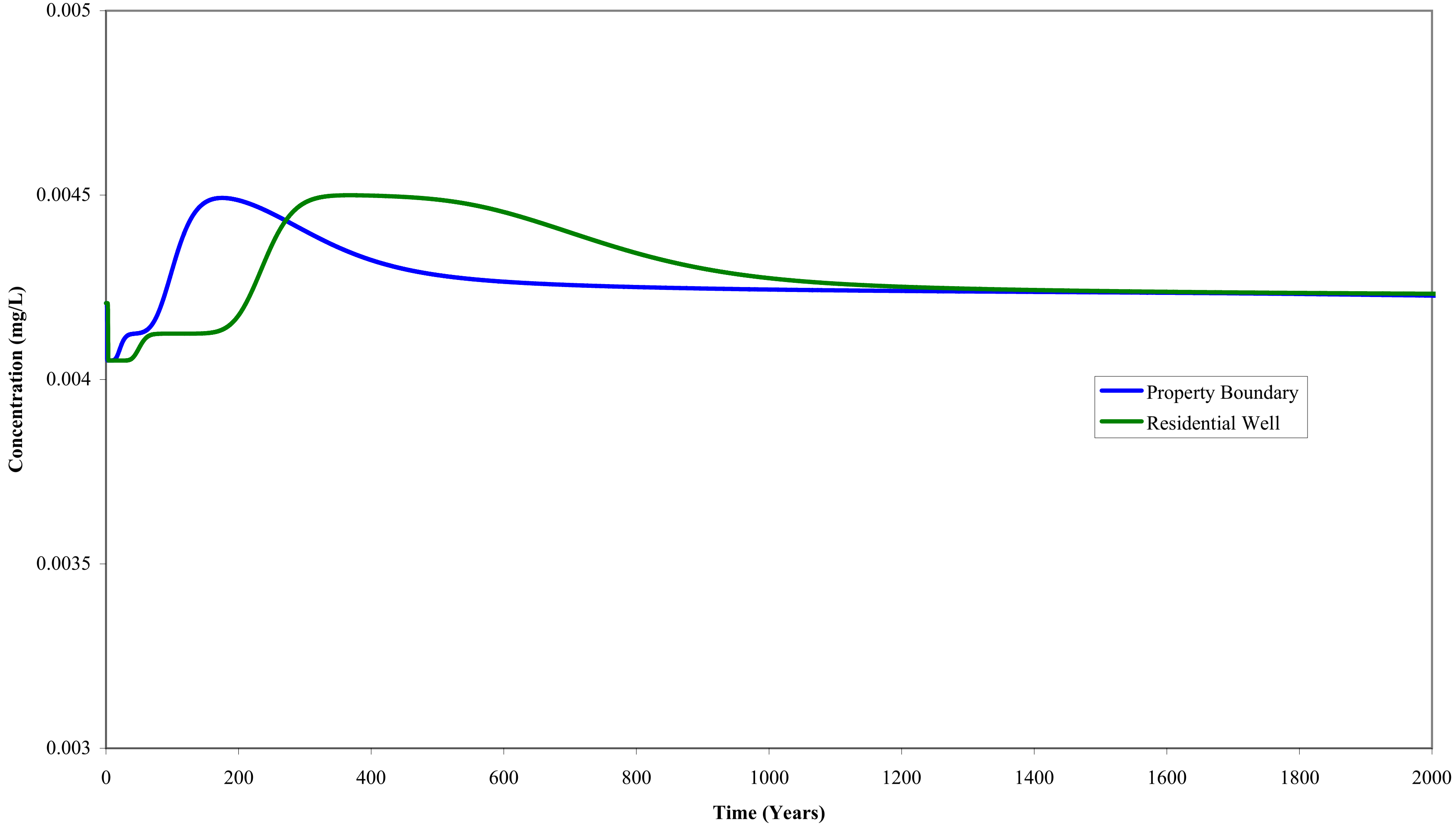


Figure 6-3
PHREEQC Modeling
Arsenic Concentration vs. Time
One order of magnitude fewer adsorption sites



Referenced Tables from RS74B Draft 02

Table 4-5. Water Chemistry of Cells 1E and 2E Seepage to Groundwater for Tailings Basin - Geotechnical Mitigation

		Cells 1E and 2E Percolate to Groundwater under Geotechnical Mitigation						
Parameter	**Units**	**Year 1**	**Year 5**	**Year 10**	**Year 15**	**Year 20**	**Closure**	**Post-Closure**
Ag	mg/L	0.0009	0.0009	0.0008	0.0009	0.0009	0.0012	0.0012
Al	mg/L	0.0100	0.0100	0.1251	0.0874	0.0688	0.6149	0.6149
As	mg/L	0.0068	0.0068	0.0094	0.0078	0.0075	0.0279	0.0279
B	mg/L	0.1378	0.1378	0.1500	0.1535	0.1587	0.1506	0.1506
Ba	mg/L	0.0505	0.0505	0.0492	0.0500	0.0540	0.0195	0.0195
Be	mg/L	0.0004	0.0004	0.0006	0.0005	0.0005	0.0013	0.0013
Ca	mg/L	77.3	77.3	107.3	81.6	65.2	68.7	68.7
Cd	mg/L	0.0003	0.0003	0.0006	0.0006	0.0005	0.0012	0.0012
Cl	mg/L	15.2	15.2	5.1	5.7	5.9	4.0	4.0
Co	mg/L	0.0015	0.0015	0.0016	0.0019	0.0022	0.0027	0.0027
Cu	mg/L	0.0068	0.0068	0.0070	0.0091	0.0114	0.0141	0.0141
F	mg/L	2.9034	2.9034	0.5070	0.5631	0.5994	1.1369	1.1369
Fe	mg/L	0.0040	0.0040	0.0397	0.0386	0.0217	0.0994	0.0994
Hardness	mg/L	374.3	374.3	310.8	254.7	218.2	402.1	402.1
K	mg/L	9.3	9.3	8.0	6.7	6.2	21.3	21.3
Mg	mg/L	44.0	44.0	10.4	12.4	13.4	56.0	56.0
Mn	mg/L	0.2403	0.2403	0.1585	0.1938	0.2308	0.1435	0.1435
Na	mg/L	52.9	52.9	31.4	26.0	22.2	26.6	26.6
Ni	mg/L	0.0191	0.0191	0.0248	0.0222	0.0236	0.0055	0.0055
Pb	mg/L	0.0009	0.0009	0.0030	0.0027	0.0023	0.0010	0.0010
Sb	mg/L	0.0080	0.0080	0.0117	0.0093	0.0088	0.0012	0.0012
Se	mg/L	0.0011	0.0011	0.0016	0.0015	0.0014	0.0033	0.0033
SO_4	mg/L	190.0	190.0	223.1	183.9	163.3	176.5	176.5
Tl	mg/L	0.0009	0.0009	0.0010	0.0010	0.0010	0.0001	0.0001
Zn	mg/L	0.0182	0.0182	0.0636	0.0666	0.0587	0.0128	0.0128

Table 5-2. Input Concentrations Used in the Embarrass River Mass-Balance Model

Parameter	Units	Surface Runoff Concentration	Median Groundwater Concentration	Pre-PolyMet Seepage from Cell 2W	Area 5 Pit NW Discharge
Ag	mg/L	0.00011	0.000008	0.0001	0.00016
Al	mg/L	0.1	0.025	1.5788	0.0133
As	mg/L	0.00075	0.00273	0.002905	0.0013
B	mg/L	0.012	0.0212	0.33	0.132
Ba	mg/L	0.011	0.0681	0.09298	0.0044
Be	mg/L	0.0001	0.000023	0.00075	0.0001
Ca	mg/L	13	19	59.78	95.4
Cd	mg/L	0.00008	0.0003	0.000188	0.0001
Cl	mg/L	10	1.8	21.54	5.95
Co	mg/L	0.0006	0.0011	0.001556	0.00055
Cu	mg/L	0.0015	0.004	0.004555	0.0035
F	mg/L	0.1	0.385	1.55	0.125
Fe	mg/L	2.9	0.035	4.594	0.038
Hardness	mg/L	70	87.5	436.6	943
K	mg/L	3.7	1.6	7.77	53.8
Mg	mg/L	6	10.65	69.97	271
Mn	mg/L	0.3	0.188	1.183	0.485
Na	mg/L	3.5	4.9	44.31	120
Ni	mg/L	0.0012	0.007	0.00688	0.0052
Pb	mg/L	0	0.0012	0.0012	0.0003
Sb [1]	mg/L	0.00002	0.0015	0.00025	0.00025
Se	mg/L	0.0003	0.00295	0.00109	0.0016
SO_4	mg/L	4	8.5	152.4	1046
Tl	mg/L	0.0002	0.000004	0.0002	0.0006
Zn	mg/L	0.016	0.0115	0.01435	0.003

[1] Antimony was not measured in the MPCA or the Copper Nickel Study, therefore the groundwater value from the Partridge River watershed was used for the median groundwater concentration.

Table 8-7. Predicted groundwater flow out of the Tailings Basin to the north of Cell 2E - Tailings Basin - Geotechnical Mitigation

Year	gpm
1	1570
2	1610
3	1640
4	1680
5	1710
6	1750
7	1780
8	1800
9	1810
10	1830
11	1840
12	1860
13	1870
14	1890
15	1900
16	1910
17	1920
18	1930
19	1940
20	1950

Table 8-8. Predicted Total Concentrations Cell 2E Tailings Basin - Geotechnical Mitigation

Prediction	SO4	Sb	As	Co	Cu	Ni	Zn	F	Cl	Al	Ba	Be	B	Cd	Ca	Fe	Pb	Mg	Mn	K	Se	Ag	Na	Tl	Hardness
Year	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
GW Standard	250	0.006	0.01	--	1	0.1	2	2	250	0.05	2	8.00E-05	0.6	0.004	--	0.3	0.015	--	0.05	--	--	0.03	--	0.0006	--
SW Standard	--	0.031	0.053	0.005	0.024	0.132	0.306	--	230	0.125	--	--	--	0.006	--	--	0.013	--	--	--	--	0.001	--	0.00056	--
1	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
2	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
3	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
4	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
5	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
6	190	0.00805	0.00677	0.00150	0.00681	0.01914	0.01821	2.90335	15.24697	0.01000	0.05046	0.00038	0.13784	0.00033	77.28098	0.00400	0.00089	44.02811	0.24035	9.30705	0.00111	0.00086	52.94899	0.00091	374
7	187	0.01063	0.00653	0.00153	0.00735	0.02653	0.02503	0.74660	5.41693	0.01000	0.04796	0.00046	0.13543	0.00051	93.96505	0.00400	0.00112	15.48190	0.20899	6.15520	0.00122	0.00076	19.22317	0.00085	298
8	191	0.01049	0.00972	0.00155	0.00838	0.02516	0.02841	0.54898	4.63454	0.18909	0.04900	0.00069	0.13562	0.00059	99.95855	0.04516	0.00123	13.31180	0.19774	8.46787	0.00147	0.00082	16.01842	0.00089	304
9	174	0.01016	0.00679	0.00136	0.00689	0.02303	0.02729	0.46751	4.42685	0.07219	0.04758	0.00050	0.13286	0.00059	99.92731	0.03579	0.00121	10.21950	0.18361	6.05729	0.00131	0.00079	15.03050	0.00089	292
10	223	0.01173	0.00943	0.00163	0.00698	0.02482	0.06357	0.50704	5.09065	0.12514	0.04921	0.00059	0.14997	0.00065	107.27244	0.03972	0.00300	10.43427	0.15849	7.97846	0.00157	0.00084	31.36633	0.00103	311
11	245	0.01205	0.01229	0.00177	0.00787	0.02496	0.07567	0.55961	5.55699	0.22969	0.05112	0.00074	0.15891	0.00067	109.30312	0.04842	0.00358	12.29341	0.15620	10.20968	0.00181	0.00091	37.09655	0.00109	324
12	225	0.01127	0.01000	0.00163	0.00701	0.02298	0.07001	0.52900	5.56481	0.13872	0.05064	0.00059	0.15832	0.00060	101.23511	0.04211	0.00335	11.75210	0.16730	8.33318	0.00168	0.00089	35.16079	0.00108	301
13	181	0.00862	0.00952	0.00136	0.00755	0.01657	0.04978	0.51639	6.21731	0.18882	0.05445	0.00060	0.16053	0.00045	78.60652	0.04683	0.00241	13.43220	0.22117	8.11694	0.00167	0.00099	26.71499	0.00109	252
14	182	0.00853	0.01013	0.00137	0.00772	0.01673	0.05002	0.53085	5.98399	0.20544	0.05210	0.00063	0.15681	0.00045	79.20806	0.04873	0.00241	14.15260	0.21066	8.63844	0.00170	0.00095	27.03131	0.00104	256
15	184	0.00929	0.00783	0.00193	0.00905	0.02217	0.06657	0.56315	5.66230	0.08737	0.04996	0.00049	0.15353	0.00057	81.61110	0.03860	0.00270	12.36098	0.19382	6.68053	0.00153	0.00089	26.02499	0.00103	255
16	194	0.00993	0.00822	0.00249	0.01147	0.02640	0.08163	0.63740	5.86357	0.08568	0.05195	0.00053	0.15944	0.00069	85.73298	0.02378	0.00295	12.87000	0.19649	6.95112	0.00161	0.00093	25.32803	0.00108	267
17	180	0.00900	0.00871	0.00225	0.01140	0.02400	0.06558	0.61732	6.16023	0.13287	0.05454	0.00058	0.16125	0.00057	75.21797	0.02727	0.00239	14.15859	0.22702	7.41637	0.00161	0.00099	21.57378	0.00108	246
18	175	0.00870	0.00810	0.00218	0.01104	0.02345	0.06204	0.61199	6.04044	0.10176	0.05336	0.00053	0.15954	0.00054	72.27612	0.02560	0.00226	14.48484	0.22822	6.90292	0.00158	0.00096	20.94284	0.00104	240
19	178	0.00917	0.00723	0.00233	0.01116	0.02477	0.07010	0.60844	6.05610	0.05931	0.05358	0.00048	0.16082	0.00060	76.20966	0.02113	0.00252	13.10784	0.21986	6.17127	0.00153	0.00097	21.91684	0.00108	244
20	163	0.00878	0.00745	0.00219	0.01143	0.02357	0.05869	0.59938	5.85490	0.06879	0.05400	0.00047	0.15866	0.00050	65.23767	0.02172	0.00230	13.43794	0.23079	6.22836	0.00143	0.00095	22.21623	0.00100	218

Table 8-9. Analytical Data Summary, Polymet Mining Company (units as noted)

Location	GW-001	GW-001	GW-002	GW-002	GW-006	GW-006	GW-007	GW-007	GW-007	GW-007	GW-008	GW-008
Date	8/17/2007	10/11/2007	8/17/2007	10/10/2007	8/17/2007	10/10/2007	8/17/2007	8/17/2007	10/10/2007	10/10/2007	8/17/2007	10/10/2007
Dup								DUP		DUP		
<u>General Parameters, mg/L (unless noted otherwise)</u>												
Alkalinity, total	394	387	46.5	34.1	576	521	274	279	280	281	158	135
Chemical Oxygen Demand	48.0	43	<10	38	23.0	10	27.0 *	95.4 *	10	8	<10	18
Chloride	26.9	27.3	0.65	0.74	22.7	8.26	30	30	28.6	28.7	1.16	1.02
Cyanide, ug/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Hardness, total	367	352	66	73.9	933	757	390	392	416	408	184	167
Nitrogen Nitrate	<0.1 h	--	<0.1 h	--	<0.1 h	--	<0.1 h	<0.1 h	--	--	<0.1 h	--
Nitrogen Nitrite	<0.05 h	--	<0.05 h	--	<0.05 h	--	<0.05 h	<0.05 h	--	--	<0.05 h	--
Nitrate + Nitrite	--	0.11	--	<0.1	--	<0.1	--	--	<0.1	<0.1	--	<0.1
Nitrogen, ammonia as N, ug/L	150	130 b	<100	<100	110	<100	<100	<100	<100	<100	<100	<100
Phosphorus total	<0.1	<0.1	0.37	0.41	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	0.12	0.12
Sulfate	36.8	36.8	7.74	6.39	430	217	161	158	169	166	23.5	21.3
Fluoride	<0.1	0.11	<0.1	<0.1	2.56	1.67	1.79	1.79	1.89	1.89	<0.1	<0.1
pH, standard units	7.1	7.2	7.4	7.4	7.5	7.4	7.8	7.8	7.7	7.8	7.1	7.0
Carbon, total organic	8.6	9.1	1.9	7.4	2.8	2.4	1.6	1.7	1.9	1.9	1.8	1.6
<u>Metals, ug/L (unless noted otherwise)</u>												
Aluminum	1600	1100	9800	16000	89	33	<40	<40	12	14	6300	6600
Antimony	<0.5	<0.50	<0.5	<0.50	<0.5	<0.50	<0.5	<0.5	<0.50	<0.50	<0.5	<0.50
Arsenic	<10	<0.50	<10	2.2	4.3	2.0	4.2	4.4	3.3	3.6	<2.0	<2.0
Barium	300	280	59	110	110	66	4.2	4.5	4.0	4.1	76	81
Beryllium	<1.0	<2.0	<1.0	<2.0	<1.0	<2.0	<1.0	<1.0	<2.0	<2.0	<1.0	<2.0
Boron	300	260	<200	<200	540	330	430	430	410	400	<200	<200
Cadmium	<0.20	0.98	0.44	0.46	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Calcium, mg/L	76	71.7	15.0	16.6	110	81.9	49.0	50	51.4	50.3	31	26.5
Chromium	<5.0	7.7 b	17	31	<1.0	<2.0	<1.0	<1.0	<2.0	<2.0	9.5	15 b
Cobalt	1.4	1.1	4.2	7.9	1.9	1.6	0.96	1.0	1.0	1.0	2.5	3.1
Copper	7.9	7.5	17	32	1.4	1.7	0.86	0.99	1.2	1.3	9.7	13
Iron	14000	13000	12000	18000	3000	830	290	290	360	370	6700	7100
Lead	1.2	5.6	2.6	4.0	<0.60	<0.60	<0.60	<0.60	<0.60	<0.60	1.5	1.9
Magnesium, mg/L	43	42	7.0	7.88	160	134	65.0	67	69.7	68.5	26	24.5
Manganese	2400	2300	230	340	1200	580	1200	1200	1100	1100	530	220
Mercury, ng/L	--	4.6	--	7.7	--	1.4	--	--	1.0	0.9	--	8.5
Mercury methyl, ng/L	--	<0.05	--	<0.05	--	<0.05	--	--	<0.05	<0.05	--	<0.05
Molybdenum	8.7	8.0	0.33	0.48	47	30	35 *	34 *	32	31	0.43	0.33
Nickel	6.6	7.6	15	32 b	5.8	7.0	2.5	2.6	3.9	3.8	11	18 b
Palladium	<0.3	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Platinum	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium	4000	3500	2700	4000	16000	9600	9700	9800	9400	9100	3300	3300
Selenium	<10	1.3	<5.0	<1.0	<1.0	<1.0	1.1	<1.0	<1.0	<1.0	<1.0	<1.0
Silver	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Sodium	65000	61000	5500	5400	80000	33000	48000	48000	47000	46000	7800	7300
Strontium	250	240	92	110	550	350	310	310	330	330	130	110
Thallium	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
Titanium	57	40	820	720	6.8	4.1	<2.0	<2.0	3.0	2.7	150	240
Zinc	<30	33	<30	48	<30	6.5	<30	<30	<6.0	<6.0	<30	23
<u>Dissolved Metals, ug/L</u>												
Aluminum, dissolved	<10	<10	56	110	<10	<10	<10	<10	<10	<10	25	16
Cadmium, dissolved	<0.20	<0.20	<0.20	<0.20	0.34 b	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Chromium, dissolved	<1.0	<2.0	1.7	<2.0	<1.0	<2.0	<1.0	1.5	<2.0	<2.0	2.1	2.9
Copper, dissolved	0.92 b	0.93	1.9 b	4.7	1.4 b	11	0.76 b	<0.70	<0.70	0.78	1.8 b	1.9
Molybdenum dissolved	8.6 b	8.0	<0.30	<0.30	45 b	30	34 b	<0.30	30	30	0.30 b	0.31
Nickel, dissolved	3.1 b	4.4	1.1 b	2.0	5.2 b	7.0	2.5 b	<0.60	3.9	4.0	1.7 b	2.5
Selenium, dissolved	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Silver, dissolved	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Zinc, dissolved	17	16	<30	<6.0	<30	12	<30	<30	6.8	7.9	<30	7.1

-- Not analyzed.

* Estimated value, QA/QC criteria not met.

b Potential false positive value based on blank data validation procedure.

DUP Duplicate sample.

h EPA sample extraction or analysis holding time was exceeded.