Appendix B
Groundwater Modeling of the NorthMet Mine Site
Draft-03

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List of RS Documents Referenced

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RS10 Draft-02 Hydrogeological – Drill hole monitoring and data collection – Phase 2

RS10A Draft-01 Hydrogeological – Drill hole monitoring and data collection – Phase 3

RS14 Draft-02 Wetlands Delineation

RS18 Draft-02 Mine Design and Schedule for Backfill Alternative

RS22 Draft-02 Mine Waste Water Management

RS25 Draft-02 Mine Diking/Ditching Effectiveness Study

RS49 Draft-02 Stockpile Design

RS52 Draft-01 Closure Plan

RS73 Draft-02 Cumulative Streamflow Impacts. This was separated into two documents:

- RS73A Streamflow and Lake Level Changes: Model Calibration Report
- RS73B Streamflow and Lake Level Changes: Model Results

RS78 Draft-01 Report on Mine Block Model – Ore and Waste

1.0 Introduction

The purpose of this report is to describe the technical approach, rationale, and scope for the groundwater flow modeling that was conducted to support the Mine Waste Water Management Plan for the PolyMet NorthMet Mine Site (RS22). This report describes the objectives of the modeling, the site conceptual model, the methodologies that were used, and the modeling results. The following description of the technical approach for this modeling was based on the current understanding of the Mine Site conditions and the proposed mine plan. The modeling results presented here are based on the Mine Site conceptual model and the Mine Site Proposed Action. While this work directly relates to the Mine Site Proposed Action, it is also applicable to the Mine Site – Reasonable Alternative 1. These results may not be applicable if there are significant changes to the conceptual model or the mine plan.

1.1 Objectives

The primary objectives of this study are to predict the amount of groundwater inflow that can be expected into the PolyMet mine pits during operations and pit filling and to determine the groundwater flow conditions following pit closure. To meet these objectives, a series of numerical groundwater flow models of the Mine Site were developed. These models were designed to simulate current conditions, conditions during mining and conditions in closure.

1.2 Background

The mine plan, which is presented in RS18 Draft-02, defines the proposed pit designs. In these designs, the pits are located primarily in the Duluth Complex, with a portion of the East Pit intersecting the Virginia Formation. Diking and trenching is proposed around the pits as addressed in the Mine Diking/Ditching Effectiveness Study (RS25 Draft-02).

Three hydrogeologic investigations have been conducted at the Mine Site. The Phase I investigation (RS02 Draft-02) characterized the hydrogeologic properties of the surficial sediment and the Duluth Complex. The Phase II investigation (RS10 Draft-02) characterized the hydrogeologic conditions of the Virginia Formation. The Phase III investigation (RS10A Draft-01) characterized the connection of the Virginia Formation and the overlaying wetlands. Results from these studies were incorporated into a groundwater model of the Mine Site.

1.3 Report Organization

This report is organized into five sections, including this introduction. Section 2 presents the conceptual model of the Mine Site. Section 3 discusses the modeling approach. Model results and sensitivity analysis are presented in Section 4. A report summary and conclusions are presented in Section 5. Appended to this report is a technical memorandum discussing NorthMet bedrock groundwater elevation measurements.

2.0 Conceptual Model

A *hydrogeologic conceptual model* is a schematic description of how water enters, flows, and leaves the groundwater system. Its purpose is to define the major sources and sinks of water, the division or lumping of hydrostratigraphic units into aquifers and aquitards, the direction of groundwater flow, the interflow of groundwater between aquifers, and the interflow of water between surface waters and groundwater. The hydrogeologic conceptual model is both scale-dependent (i.e. local conditions may not be identical to regional conditions) and dependent upon the questions being asked. It is important when developing a conceptual model to strive for parsimony: the model should be kept as simple as possible while still adequately representing the system for the purposes of analyzing the problem at hand.

2.1 Geologic Units

2.1.1 Bedrock

The proposed mine pits will be located primarily within the Duluth Complex, with a portion of the East Pit intersecting the Virginia Formation. Underlying the Virginia Formation is the Biwabik Iron-Formation (BIF). The site bedrock geology is shown on Figure 2-1. Cross sections through the proposed mine pits that show the relationship between the various units are presented on Figures 2-2 and 2-3. The BIF is generally considered to be the most permeable unit, locally acting as a water source for residential and community wells, with the Virginia Formation and Duluth Complex being less permeable (Siegel and Ericson, 1980).

Aquifer tests were conducted at the Mine Site to determine aquifer properties of the Duluth Complex and the Virginia Formation. Four pumping tests were conducted in new monitoring wells placed within the Virginia Formation. The hydraulic conductivity values measured in these wells ranged from 0.0024 ft/day to 1.0 ft/day (RS10 Draft-02). The geometric mean of the values is 0.17 ft/day. Aquifer tests were conducted using exploratory drill holes within the Duluth Complex. Hydraulic conductivity values measured in these drill holes ranged from 0.00026 ft/day to 0.041 ft/day, with a geometric mean of 0.0024 ft/day (RS02 Draft-02). As a comparison, the average hydraulic conductivity determined from specific capacity tests is 1 ft/day for the BIF and 0.03 ft/day for the Giants Range batholith (Siegel and Ericson, 1980).

2.1.2 Surficial Deposits

Geomorphically, the Mine Site is part of the Superior Upland Province and is characterized by bedrock hills and ridges which are interspersed with peat bogs and wetlands (Olcott and Siegel, 1978). At the Mine Site, the bedrock surface appears to be hummocky. Much of the Mine Site is covered by peat/wetland deposits, with the remaining area covered by rolling to undulating topography formed from Wisconsin age Rainey Lobe drift. Rainey Lobe drift is generally a bouldery till with high clay content. In the region, it appears that only the Embarrass River basin northwest of the Mine Site and the Dunka River basins northeast of the Mine Site have significant quantities of outwash (sand and gravel), with thicknesses greater than 100 feet (Olcott and Siegel, 1978). Elsewhere in the region, including the Mine Site, the surficial deposits form a thin cover over the bedrock.

The bouldery drift of the Rainy Lobe that covers the Mine Site has an estimated hydraulic conductivity range of 0.1 to 30 ft/day (Siegel and Ericson, 1980). Based on test trenches and drill core from the site, the surficial deposits at the Mine Site consist primarily of silty sand that is interbedded with clay and silt. Lab permeameter tests on the silty sand found the hydraulic conductivity values to be 0.00043 to 0.0081 ft/day, while field testing of the various unconsolidated deposits found a range in hydraulic conductivity values of 0.012 ft/day to 31 ft/day (RS02 Draft-02). The ability of this unit to transmit water is highly dependent on the thickness of the sediments (Adams et al., 2004; Siegel and Ericson, 1980). At the Mine Site, the thickness of the deposits average approximately 12 feet. They are generally less than 25 feet thick, with local depths over 50 feet.

2.2 Sources and Sinks for Water

Sources of water to the saturated flow system include:

- Infiltration of precipitation;
- Groundwater seepage from wetlands and losing segments of streams;
- Seepage from nearby mine-pit lakes.

Sinks that remove water from the saturated system include:

- Discharge to streams, rivers and wetlands;
- Discharge to local mine pits that are currently being dewatered or are in the process of filling.

Evaporation from soil and free-water surfaces is assumed to be accounted for in the recharge component (i.e., recharge from precipitation includes losses from evaporation).

2.3 Local Flow System

Saturated conditions exist within the unconsolidated deposits at the Mine Site. Groundwater divides in this area generally coincide with surface-water divides. However, groundwater flow is interrupted by bedrock outcrops, which cause divisions in the groundwater flow field (Siegel and Ericson, 1980). Regionally, groundwater within the surficial deposits flows primarily to the south, from the Embarrass Mountains to the Partridge River. Figure 2-4 shows water levels measured in the wetland piezometers installed at the Mine Site. At the Mine Site, groundwater flow is generally towards the Partridge River, a major discharge point for the area. Because of the shallow nature of the aquifer, flow paths are generally thought to be short, with the recharge areas being very near the discharge areas.

Groundwater flow within the bedrock is primarily through fractures and other secondary porosity features, as the rocks have low primary hydraulic conductivity. Near the surface, water in the bedrock is believed to be hydraulically connected with the overlying surficial aquifers, resulting in similar flow directions. Recharge to the bedrock aquifers is by infiltration of precipitation in outcrop areas and leakage from the overlying surficial aquifers (Siegel and Ericson, 1980). According to Siegel and Ericson (1980), the interaction between the surficial deposits and the bedrock aquifers is assumed to be insignificant due to the low permeability of the bedrock. Groundwater contours within the bedrock units are shown on Figure 2-5. These contours are based on water levels collected from bedrock monitoring wells and exploratory drill holes during December 2006 (see Attachment A). In general, groundwater in the bedrock flows from northwest to southeast.

2.4 Hydrologic Model Selection

Groundwater flow within fractured bedrock, such as at the Mine Site, is more challenging to simulate and predict than flow in unconsolidated deposits. The available fracture-based modeling codes require detailed characterization of the geometry and hydraulic properties of individual fractures. At a large scale (such as the scale of this study) the fractures can reliably be assumed to be sufficiently interconnected that the fractured rock medium behaves similar to a porous medium. By assuming that the aquifer acts as an equivalent porous medium at the scale of the study, it is possible to use conventional porous media modeling codes such as MODFLOW (McDonald and Harbaugh, 1988; Harbaugh et al., 2000) to predict the general direction and magnitude of groundwater flow. This assumption was used to predict groundwater inflow into the mine pits at the various stages of pit development.

MODFLOW simulates three-dimensional, steady-state and transient groundwater flow (saturated) using finite-difference approximations of the differential equation of groundwater flow:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

where:

K_{xx}, K_{yy}, and K_{zz}: three principal directions of the hydraulic conductivity tensor

W: sources and sinks

S_s: specific storage

h: hydraulic head

t: time

For steady-state simulations, the partial derivative of head with respect to time is zero and the right side of Laplace’s equation, above, equals zero.

MODFLOW was developed by the U.S. Geological Survey and is in the public domain. It is widely used and accepted. The version used in the study is MODFLOW 2000. The MODFLOW model was developed using the GUI Groundwater Vistas (Version 5) (Environmental Simulations, Inc., 2004).

3.0 Modeling Approach

An approach called Telescopic Mesh Refinement (TMR) (Ward et al., 1987) was used for the Mine Site models. The TMR approach uses a local-scale model that is embedded in a regional model. The regional model is used to define the boundary conditions for the local-scale model. This approach is useful for sites were physical or hydraulic boundaries of the aquifer lie outside of the area of interest. At the Mine Site, it was not possible to determine *a priori* what the aquifer boundaries are for the bedrock units. The TMR approach was used to account for uncertainty in the location of boundaries.

3.1 Regional Model

A single-layer Regional Model of the area surrounding the Mine Site was constructed. This model provided the boundary conditions for the smaller, Local-Scale Model that was used to make the predictions of groundwater inflow rates into the pits.

3.1.1 Model Grid and Layers

A single flat-lying model layer, covering approximately 1000 square miles was used to simulate groundwater flow within the various bedrock units (Figure 3-1). The bottom elevation of the model was set below the maximum depth of the proposed pits at an elevation of 640 feet above mean sea level (MSL). The model grid was rotated 45 degrees in order to better align with the axis of the mine. A uniform grid with a spacing of 500 meters (1,640 feet) was used.

3.1.2 Boundary Conditions

Internal boundary conditions were used to represent surface-water features. Major rivers and lakes were simulated as either river cells or constant head cells. River and lake stage information was obtained from 7.5 minute U.S. Geological Survey quadrangle maps. Boundary conditions are shown on Figure 3-2.

The upper model boundary was simulated as a specified-flux boundary that represents recharge to the bedrock aquifers. A single recharge zone was used. The value of recharge was allowed to vary during model calibration within expected upper and lower ranges.

Perimeter model boundaries were set as no-flow boundaries in the regional model. The model perimeter was set sufficiently far from the Mine Site so that the no-flow boundaries would not affect groundwater flow predictions at the Mine Site.

3.1.3 Hydraulic Conductivity Distribution

Hydraulic conductivity distribution was based on the bedrock geology of the area (Jirsa and Chandler, 2005). Four zones were used, with a single zone representing each of the four major bedrock formations: the BIF, Giants Ridge Formation, the Duluth Complex, and the Virginia Formation. Hydraulic conductivity values for the BIF and the Giants Range batholith were set using literature values (Siegel and Erickson, 1980). The hydraulic conductivity of the Duluth Complex and the Virginia Formation was set as the geometric mean of values calculated as part of the Phase I and Phase II Hydrogeologic Investigations, respectively. Hydraulic conductivity values used in the Regional Model are shown in Table 3-1.

Table 3-1 Hydraulic Conductivity Values used in the Regional Model

	Hydraulic Conductivity (ft/day)
Duluth Complex	0.0014
Virginia Formation	0.33
BIF	0.72
Giants Range batholith	0.029

3.1.4 Calibration

The Regional Model was calibrated to water levels measured within the wetland areas at the Mine Site. Approximately 25 water-level targets were used, as shown on Figure 2-4. During model calibration, recharge was adjusted until there was an acceptable match between measured and simulated heads. The model was calibrated using the automated calibration capabilities of MODFLOW-2000 (Hill et al., 2000). The results of the model calibration are shown on Figure 3-3. The optimized recharge value for the model is 0.001 inches/year (7.3×10^{-8} m/day). This low recharge rate is consistent with information from regional studies which indicate that there is likely little interaction between the surficial deposits and the bedrock aquifers due to the low permeability of the bedrock (Siegel and Ericson, 1980).

3.2 Local-Scale Model

3.2.1 Model Grid and Layers

A grid covering an area of approximately 100 square miles was extracted from the Regional Model and used for the Local-Scale Model (Figure 3-1). The model grid was further refined at the Mine Site, with the final grid coarser at the boundaries and outside of the area of interest (cells of approximately 100-200 meters on a side) and more refined at the Mine Site (cell size of 10 to 30 meters) (Figure 3-4). The Local-Scale Model was vertically discritized into eight layers; seven layers simulating the various bedrock units and one layer simulating the surficial deposits. Vertical discritization was needed to accurately simulate the footwall and headwall geology of the pit at various stages of pit development.

The bottom of Layer 1 was set equal to the bedrock-surface elevation as defined in RS49 Draft-02. The bottom elevations were modified slightly in some locations to prevent portions of the layer from going dry during model simulations. Bottom elevations for Layers 2-7 were set to correspond to the elevations of major benches in the mine pits and pit bottom elevations at various stages of development. The bottom elevation for Layer 8 was set at -65 feet MSL, which corresponds roughly to the estimated bottom elevation of the BIF at the Mine Site. Model layer bottom elevations are shown in Table 3-2.

Table 3-2 Model Layer Bottom Elevations

	Bottom Elevation (ft MSL)
Layer 1	1400 – 1585
Layer 2	1350
Layer 3	1270
Layer 4	1050
Layer 5	890
Layer 6	700
Layer 7	330
Layer 8	-65

3.2.2 Boundary Conditions

The lateral model boundaries were extracted from the regional model as constant head cells, with head values corresponding to the regional model's simulated values at these locations. Internal boundaries from the Regional Model were further refined near the Mine Site due to the finer grid cells in this area. Additional boundaries, such as constant head cells simulating the water levels in the Peter Mitchell Pits, were added during the calibration process. Figure 3-4 shows the final boundary conditions in Layer 1.

Drain cells were used to simulate the mine pits during periods when the pits are being dewatered. Drain cells are similar to river cells, but only interact with the aquifer if the simulated head exceeds the specified drain elevation. Drain cell elevations were set at the elevation of the pit wall or floor (depending on location). Drain cell conductance was set several orders of magnitude higher that the hydraulic conductivity of the aquifers, while still maintaining a stable solution with low mass-balance error. Pit extent and elevations were based on CAD drawings of the pits presented in the RS18 Draft-02 at Years 1, 5, 10, 15, and 20.

During Years 12-20, the East Pit will no longer be dewatered and will be filled with waste rock. The water level in this pit will rise as a result of the cessation of pit dewatering. For the Year 12, Year 15 and Year 20 model realizations, the East Pit was simulated using river cells. River cells were used rather than drain cells to allow for the option of the pits to loose water to groundwater if the head in the pit is higher than in the surrounding aquifer. The river cell heads were set equal to the level of the water in the pit, as determined as part of RS22 Draft-02. The conductance of the river cells was set equal to the conductance of the drain cells that were used to simulate the pits.

3.2.3 Hydraulic Conductivity Distribution

Five hydraulic conductivity zones were used to simulate the bedrock units in the local-scale model: one zone for the Duluth Complex, two zones for the Virginia Formation, one zone for the BIF and one zone for the Giants Range batholith. Specific capacity tests conducted as part of the Phase III Hydrogeologic Investigation (RS10A Draft-01) show that the upper portion of the Virginia Formation is approximately twice as permeable as the lower portion. As such, one hydraulic conductivity zone was used to represent the upper portion of the formation (Layers 2-4) and one zone was used to represent the lower portion of the formation (Layers 5-8). For the various layers, the boundary between the zones representing the Virginia Formation and the Duluth Complex and the boundary between the zones representing the Virginia Formation and the BIF was based on the location of these contacts at the elevation of the center of each layer. A three-dimensional picture of these contacts was developed by PolyMet (RS78 Draft-01) and was used in this study. Two hydraulic conductivity zones were used to simulate the surficial deposits in Layer 1: one zone to simulate wetland deposits and one zone to simulate glacial deposits. Boundaries of the wetland deposits were based on the wetland delineation presented in RS14. An additional low hydraulic conductivity zone was used to simulate the cutoff barrier that will be installed north of the East Pit between the Category 1/2 stockpile and the Category 3 stockpile as described in RS25 Draft-02. Hydraulic conductivity zones for each model layer are shown on Figure 3-5.

Hydraulic conductivity values for the zones representing the unconsolidated deposits were allowed to vary during model calibration. For these two zones, hydraulic conductivity was assumed to be laterally isotropic and vertically anisotropic. Values for the remaining zones were based on hydraulic conductivity information presented in Section 2.1.1. Hydraulic conductivity of these zones was assumed to be isotropic. Table 3-3 shows the final hydraulic conductivity values used in the Local-Scale model.

Table 3-3 Hydraulic Conductivity Values used in Local-Scale Model

	Kx=Ky (ft/day)	Kz (ft/day)
Wetland Deposits	9.3	0.0000033
Glacial Drift	2.6	0.0000033
Duluth Complex	0.0024	0.0024
Virginia Formation – Upper Portion	0.34	0.34
Virginia Formation – Lower Portion	0.085	0.085
BIF	0.98	0.98
Giants Range batholith	0.029	0.029
Cuttoff barrier (predictive models only)	0.0028	0.0028

3.2.4 Recharge Distribution

The same two zones that were used to represent the hydraulic conductivity of the surficial deposits were used to represent recharge in the Local-Scale Model (see Figure 3-5). Recharge values were allowed to vary during model calibration. The final recharge values used in the Local-Scale Model are as follows:

- Recharge to wetland deposits = 0.3 inches per year
- Recharge to the glacial deposits = 1.5 inches per year

These recharge rates are consistent with the groundwater recharge rate that was predicted by the XP-SWMM model of the mine site area. The XP-SWMM model, which was calibrated to stream flow data in the Partridge River (see RS73A Draft-02), has an average recharge rate of 0.84 inches per year.

For the predictive simulations, an additional recharge zone was used to simulate leakage through the stockpile liners. During operations, a leakage rage of 0.029 in/year was applied to each stockpile footprint. During closure, a leakage rate of 0.0003 in/yr was used. The exception to this is for the Category 1/2 stockpile where recharge was kept equal to the background recharge. These rates are at the high end of expected linear leakage rates[1] and provide a general prediction of the effects of the stockpiles on regional water levels.

3.2.5 Storage Parameters

Two storage zones were used in the groundwater model: one zone for the unconsolidated deposits in Layer 1 and one zone for the bedrock units in Layers 2-8. Storage values are only used in transient simulations. The storage parameters used in the model are shown in Table 3-4.

Table 3-4 Storage parameters used in the Local-Scale model

	Specific Yield	Specific Storage
Unconsolidated Deposits	0.25	1×10^{-5}
Bedrock Units	0.05	1×10^{-5}

Specific storage values are consistent with calculated values for the Virginia Formation, as reported in RS10 Draft-02, as well as with literature values for fractured rock ($7\times10^{-5} – 3\times10^{-6}$)(Anderson and Woessner, 1992). The specific yield of the unconsolidated deposits was set based on an average literature value for sand and silt (Anderson and Woessner, 1992).

3.2.6 Model Calibration

The Local-Scale Model was recalibrated using a combination of traditional trial-and-error methods and automated calibration methods. Automated calibration was conducted using MODFLOW-2000 (Hill et al., 2000). The baseline conditions model, which was used for calibration, was a steady-state model. During model calibration, the only parameters that were allowed to vary were hydraulic conductivity of the surficial deposits, recharge, and conductance of the river cells simulating the Partridge River.

The model was calibrated to the same water-level data in the unconsolidated deposits that were used to calibrate the Regional Model, plus additional water-level data measured in bedrock wells and exploratory drill holes during December 2006 (Attachment 1). Head calibration targets are shown on

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[1] As of the publish date for RS22 Appendix B Draft-03 the references for the linear leakage rates are the Barr Memorandums “Changes to Water Quality Model of the Partridge River Watershed – PolyMet RS-74, Mine Site-Proposed Action”, dated May 27, 2008 and “Water Quality Model of the Partridge River Watershed – PolyMet RS-74, Mine Site-Reasonable Alternative 1 (RA1)” dated June 2, 2008. Eventually, this information will be provided in RS-74 Draft-02.

Figures 2-4 and 2-5. All bedrock head targets were located in model layer 2. In addition to head targets, the model was also calibrated to a prediction of baseflow in the north branch of the Partridge River just upstream of the confluence with the south branch of the Partridge River, monitoring station SW004 (Figure 3-5). The XP-SWMM model presented in RS73 Draft-02 predicted that baseflow at this location under current conditions is approximately 1.43 cfs. For this purpose, baseflow is defined as the groundwater contribution to streamflow.

Calibration results are shown on Figures 3-6 and 3-7. The baseline conditions model matches the general flow directions in both the unconsolidated deposits and the bedrock. In general, model simulated heads were higher than measured heads in layer 1. In layer 2, the model simulated gradient was slightly flatter than observed in the field, resulting in high heads simulated lower than measured and low heads simulated higher than measured. The predicted baseflow in the Partridge River was 1.49 cfs, compared to the target baseflow of 1.43 cfs. Overall, the calibration was determined to be acceptable given the modeling objectives. The residual mean and absolute residual mean of the head targets were 0.02 meters and 1.57 meters respectively. The range of observed heads is 17 meters.

3.3 Assumptions and Limitations of the Model

The groundwater flow models that were constructed and calibrated for this evaluation are a necessary simplification of groundwater flow in the vicinity of the Mine Site. Several limitations to the model need to be acknowledged. These limitations are the result of assumptions and simplifications that are inherent to any groundwater modeling. The assumptions and limitations include:

- The use of a conventional porous media modeling code can accurately simulate flow within the bedrock units at the Mine Site, which is assumed to be primarily through interconnected fractures, at the scale of this study. It is assumed that the fractures are sufficiently interconnected such that the fractured rock medium behaves similar to a porous medium.

- The bedrock units at the Mine Site are assumed to be homogeneous in terms of hydraulic conductivity. In reality, all geologic material has variations resulting in heterogeneity. The assumption of homogeneity is considered appropriate given the modeling objectives for this evaluation.

- The model will not simulate any off-site well pumping or pit dewatering. The Peter Mitchell Pits, located north of the Mine Site, have historically been dewatered periodically. However, future operation of these pits cannot be anticipated and was not simulated.   Affects of dewatering at the Peter Mitchell Pits was not evaluated as part of this work.

- The validity of the modeling results is based on the assumption that the conceptual model is a reasonable representation of the groundwater flow system. The conceptual model, in turn, is based on the data that are collected at the Mine Site and the interpretation of those data. Errors in the data or data interpretation that affect the groundwater flow model's conceptualization may result in errors in the flow simulation.

The groundwater flow model was designed with the specific goal of predicting groundwater flow rates into the mine pits during operation and closure. If the model is to be used for other purposes, the validity of the model for that purpose must be carefully evaluated.

4.0 Model Simulations and Results

4.1 Mine Operation

4.1.1 Simulations

Five model realizations were used to simulate conditions during mine operations. All model realizations were transient simulations. Model realizations are as follows:

- The first realization simulated Years 1-10, during which time both the East Pit and the West Pit are to be mined and dewatered. Linear interpolation was used to determine pit elevations in years for which no pit design was available. The Years 1-10 Model had ten stress periods, each 365 days long, with five time steps per stress period. Initial heads were taken from the baseline conditions model.

- The second model realization simulated Year 11, when the East Pit is at its maximum extent. This realization had one stress period 365 days long with 5 time steps. The Year 11 Model used the final heads from the Years 1-10 Model as initial conditions.

- The third model realization simulated Year 12, when the East Pit is first backfilled with waste rock. This realization had one stress period 730 days long with 5 time steps. The Year 12 Model used the final heads from the Year 11 Model as initial conditions.

- The fourth model realization simulated Year 15, where the East Pit is partially filled with rock and water and the West Pit is still being mined and dewatered. The Year 15 model had one stress periods, 730 days long, with 10 time steps. The final heads from the Year 12 Model were used as the initial conditions for the Year 15 model.

- The final model realization simulated Year 20, where the East Pit is filled with rock and water and the West Pit is at its maximum extent. The Year 20 Model had one stress period 1825 days long with 10 time steps. The final heads from the Year 15 Model were used as the initial conditions for the Year 20 Model.

In the Year 12, Year 15 and Year 20 models, the head in the East Pit was defined using pit filling information presented in RS22 Draft-02.

4.1.2 Results

These model realizations were used to predict the amount of groundwater that can be expected to flow into the mine pits during operations. Table 4-1 shows the predicted groundwater inflow rates.

Table 4-1 Predicted Groundwater Flow Rates during Mine Operations

	East Pit		Central Pit		West Pit	
	GW Inflow	GW Outflow	GW Inflow	GW Outflow	GW Inflow	GW Outflow
	gpm	gpm	gpm	gpm	gpm	gpm
Year 1	180	0	--	--	20	0
Year 5	820	0	--	--	80	0
Year 10	880	0	--	--	160	0
Year 11	930	0	--	--	140	0
Year 12	870	0	--	--	150	0
Year 15	750	0	70	0	320	0
Year 20	20	130	20	10	810	0

[Note for DRAFT-03: Total annual flows in Table 4-1 changed by less than 10gpm from DRAFT-02. Because of the relatively insignificance of the changes, no reports that use the groundwater flow rates were updated to reflect these new numbers.]

Groundwater inflow into the East Pit increases during Years 1 through 11 as the pit expands laterally and vertically. Starting in Year 12, backfill of the pit with rock and water will begin and dewatering of this pit will cease. By Year 20, the East Pit is predicted to lose more water to the groundwater system that it receives. This is due in large part to the continued dewatering of the West Pit, which creates a cone of depression that extends beyond the East Pit.

The Central Pit, which will eventually become part of the East Pit, will be mined from Year 12 to Year 13. Starting in Year 14, the pit will be filled with rock and water and dewatering ceases. The filling of the Central and East Pits is described in RS22 Draft-02. Similar to the East Pit, the Central pit is predicted to have both groundwater inflow and outflow by Year 20. Groundwater inflow into the West Pit is predicted to increase during Years 1 through 20 as the pit expands laterally and vertically. Predicted water levels in Year 20 are shown on Figures 4-1 and 4-2.

4.2 West Pit Filling

4.2.1 Simulations

Following the completion of mining of the West Pit in Year 20, the dewatering of the pit will cease and additional water will be discharged into the pit (see future release of RS74 Draft-02 or references provided in footnote 1 on page 12). As the West Pit fills with water, the groundwater flow into the pit will decrease. Several model simulations were run in order to predict groundwater inflow rates into the West Pit at various stages of pit filling. For each model simulation, the elevation of the water in the pit was set using the River Package, as discussed in Section 3.2.2. Model simulations were run as steady-state and used Doherty's dry-cell correction (Doherty, 2001) to improve model stability.

4.2.2 Results

Groundwater inflow rates into the West Pit during filling were predicted for various water levels in the West Pit. Simulation results are shown in Figure 4-3. As expected, groundwater inflow rates decrease as the pit fills with water.

4.3 Long Term Closure

A constructed wetland will be built within the area of the former East Pit to provide additional treatment of the stockpile drainage water. This system is described in greater detail in RS52 Draft-01, but is discussed here as it pertains to the closure scenario models. The wetland treatment system will be a passive system, with an inflow area along the eastern boundary and an outflow structure to the West Pit along the western boundary. The wetland will be constructed above the waste rock fill in the East Pit and will be separated from the waste rock by a layer constructed of compacted glacial till overburden. The invert of the outlet structure connecting the East Pit to the West Pit will be at an elevation of approximately 1,592 ft-MSL.

The West Pit is predicted to fill in approximately 40-50 years. Prior to the completion of pit filling, an outlet structure will be constructed on the southeastern side of the West Pit at an elevation of 1,581 ft-MSL near the natural overflow location. Details on pit filling and the outlet structure are provided in RS52 Draft-01 and the March 3, 2008 Memorandum from Christie Kearney (Barr Engineering) to John Borovsky (Barr Engineering) which was provided to Stuart Arkley (DNR).

4.3.1 Simulations

A final model realization was constructed to predict final groundwater conditions at post-closure (i.e. once the system has reached equilibrium). In this simulation, the West Pit is simulated using river cells, with the head set at the outlet elevation of 1,581 ft-MSL. The portion of the East Pit that is backfilled with waste rock was simulated in model layers 2-5 as a high hydraulic conductivity zone (K = 33 ft/day). The constructed wetland above the waste rock was simulated in model layer 1using the River Package with a head set equal to the outlet elevation of 1,592 ft-MSL. The vertical hydraulic conductivity of the wetland was assumed to be equal to the vertical hydraulic conductivity of the native material.

4.3.2 Results

Groundwater contours in the surficial deposits and bedrock at final closure (i.e. when the system has reached steady state) are shown in Figures 4-4 and 4-5. With the proposed outlet elevations, both pits are predicted to have groundwater flow into the pit along a portion of the pit perimeter and groundwater flows out of the pit over a portion of the pit perimeter. Predicted seepage rates are shown below in Table 4-2.

Table 4-2 Predicted groundwater inflow and outflow rates for the pits in post-closure

		Groundwater Inflow (gpm)	Groundwater Outflow (gpm)
West Pit	Surficial Aquifers	80	20
	Bedrock Aquifers	30	<5
East Pit	Surficial Aquifers	30	10
	Bedrock Aquifers	20	<5

Both pits are expected to have a net positive flux of groundwater. Both pits are predicted to lose water to the surficial aquifer to the south in the case of the West Pit and to the south and east in the case of the East Pit.

4.4 Predicted Impacts

4.4.1 Impacts to Groundwater Levels

Drawdowns were computed within the surficial deposits and within the bedrock at Year 11 (maximum extent of mining in the East Pit), Year 20 (maximum extent of mining in the West Pit) and in Post-Closure when the system has reached a new equilibrium. Drawdowns in model Layer 2, the uppermost layer simulating the bedrock, were used to create the bedrock drawdown figures. Within the surficial deposits, changes in the water table elevation are caused by the dewatering of the pits and the placement of the stockpiles (shown on Figures 4-6, 4-8 and 4-10). During operations, the cone of depression in the surficial aquifer expands with time. In closure, the model predicts that water levels at the Mine Site will reach a new equilibrium below current water levels, as shown in Figure 4-10. There is predicted to be a slight rise in water levels east of the East Pit. It is important to note that the models likely provide a very conservative estimate of predicted water level impacts. Results from the Phase III Hydrogeologic Investigation (RS10A) showed a poor connection between the bedrock and the surficial deposits. Information presented in the "Indirect Wetland Impacts at the Mine Site" memorandum (Barr, May 4, 2008) further supports this conclusion. The high predictions of drawdown in the surficial aquifer are likely caused by the deposits being simulated in the models as a single layer. Furthermore, leakage from the Category 1/2 stockpile was simulates at a much lower rate than is currently being predicted (see future release of RS74 Draft-02 or references provided in footnote 1 on page 12). Actual observed drawdowns should be less than what is presented here.

Predicted drawdowns in the bedrock units are shown on Figures 4-7, 4-9 and 4-11. The cone of depression within the bedrock continues to expand with time as the pits grow laterally and vertically. Water levels near the East Pit start to rebound after Year 11 when mining of this pit ceases and it is backfilled with waste rock. Predicted drawdowns in the bedrock within the Mine Site itself are controlled in part by the thickness of the overlaying surficial deposits. Within the model, site data was used to define overburden thicknesses for the area near the pits and stockpiles, while outside the Mine Site a uniform thickness was used due to a lack of site specific data. This results in non-uniform drawdowns within the bedrock within the Mine Site, while there are relatively uniform drawdowns predicted for areas further from the Mine Site.

4.4.2 Impacts to Partridge River

The mine operations models were also used for prediction of impacts to the baseflow in the Partridge River. Although not a primary objective of the groundwater modeling, the model realizations can be used to predict average groundwater discharge rates to the Partridge River during pre-mining condition, during mine operations and during post-mining conditions.

The groundwater models predict baseflow reductions as a result of pit dewatering at the three locations shown on Figure 3-5. Results are summarized in Table 4-3.

Table 4-3 Predicted Percent Reduction in Partridge River Baseflow

	Location		
	SW002	SW003	SW004
Year 1	4%	3%	1%
Year 5	8%	6%	4%
Year 10	13%	9%	6%
Year 15	14%	9%	5%
Year 20	22%	15%	10%
Closure	20%	13%	8%

Baseflow impacts shown in Table 4-2 are total impacts at each location for each time period shown. For example, the total baseflow reduction at SW003 in Year 10 is 9%. This includes the 13%

reduction in baseflow predicted at SW002; that is, reductions do not need to be summed. Baseflow impacts to the Partridge River increase as mining progresses and the pit dewatering increases. A detailed assessment of water quantity impacts to the Partridge River is provided in RS73B Draft-02. It should be noted that the baseflow reductions for closure do not include any baseflow that will be added after the West Pit has filled and is discharging.

Surface water monitoring station SW-001 is located very near the headwaters of the Partridge River. Headwater portions of streams typically fluctuate between gaining and loosing water to the groundwater system seasonally, especially in a wetland dominated environment like Hundred Mile Swamp (Brooks et al., 1997). Thus, during periods with high groundwater levels (e.g. after complete soil defrost during spring) the stream will gain water and during periods with low groundwater levels (e.g. by the end of summer or early fall) the stream will loose water. This seasonal reversal of flow between groundwater and the stream can not accurately be captured by the groundwater model, which is steady-state. As such, the furthest upstream that baseflow reductions were predicted with some confidence are at surface water monitoring station SW-002, where the stream is likely a gaining stream for most of the year. The baseflow reductions predicted using the groundwater model at SW-002 takes into account aquifer drawdowns in the entire watershed up-gradient of the monitoring location; that is, it includes average annual gains or losses at SW-001. In addition, the groundwater model could not predict baseflow reductions at station SW-004a because the entire watershed for that portion of the stream is not included in the model.

4.5 Sensitivity Analysis

The model sensitivity analysis was not redone for Draft-03 of this report. Readers should refer to Draft-02 for a discussion of model sensitivity.

5.0 Summary and Conclusions

A major component of the Mine Site water balance is the groundwater flow into the mine pits. Groundwater inflows from surficial deposits, the Duluth Complex, and the Virginia Formation were predicted using the industry standard finite difference groundwater modeling code MODFLOW. A three-dimensional model was constructed for the 100-square mile area encompassing the proposed mine pits. Data collected as part of the Phase I, Phase II, and Phase III Hydrogeologic Investigations, which provided information on the hydraulic conductivity of the Duluth Complex, the Virginia Formation and the surficial deposits, was incorporated into the model (see RS02, RS10 and RS10A). The model was calibrated to groundwater levels in both the bedrock aquifers and the surficial deposits.

Several transient model realizations simulating the pits in various stages of development were constructed based on the proposed mine plan. Groundwater inflow rates to the pits were predicted in each model realization. In addition to predicting groundwater flow rates into the pits during operations, the groundwater model was used to predict impacts to the Partridge River during operations and closure, predict groundwater flow rates during pit filling, and predict groundwater flow at closure.

The following conclusions can be drawn from the work presented here:

- Groundwater flow into the East and West Pits will increase from 200 gpm to 1070 gpm between Year 1 and Year 11 as the pits expand laterally and vertically. Groundwater flow into the East Pit will begin to decrease starting in Year 12 as the pit is backfilled with rock and water. Groundwater flow into the West Pit will continue to increase through Year 20, reaching a maximum predicted inflow rate of 810 gpm.

- As a result of pit dewatering, baseflow in the Partridge River is predicted to be reduced by a maximum of between 10% and 22% at the three locations examined.

- In closure, both the East Pit and the West Pit are predicted to have a net positive flux of groundwater into the pits. The East Pit is predicted to lose a small amount water (10 gpm) to both the surficial aquifer; the West Pit is predicted to loss 20 gpm to the surficial aquifer.

6.0 References

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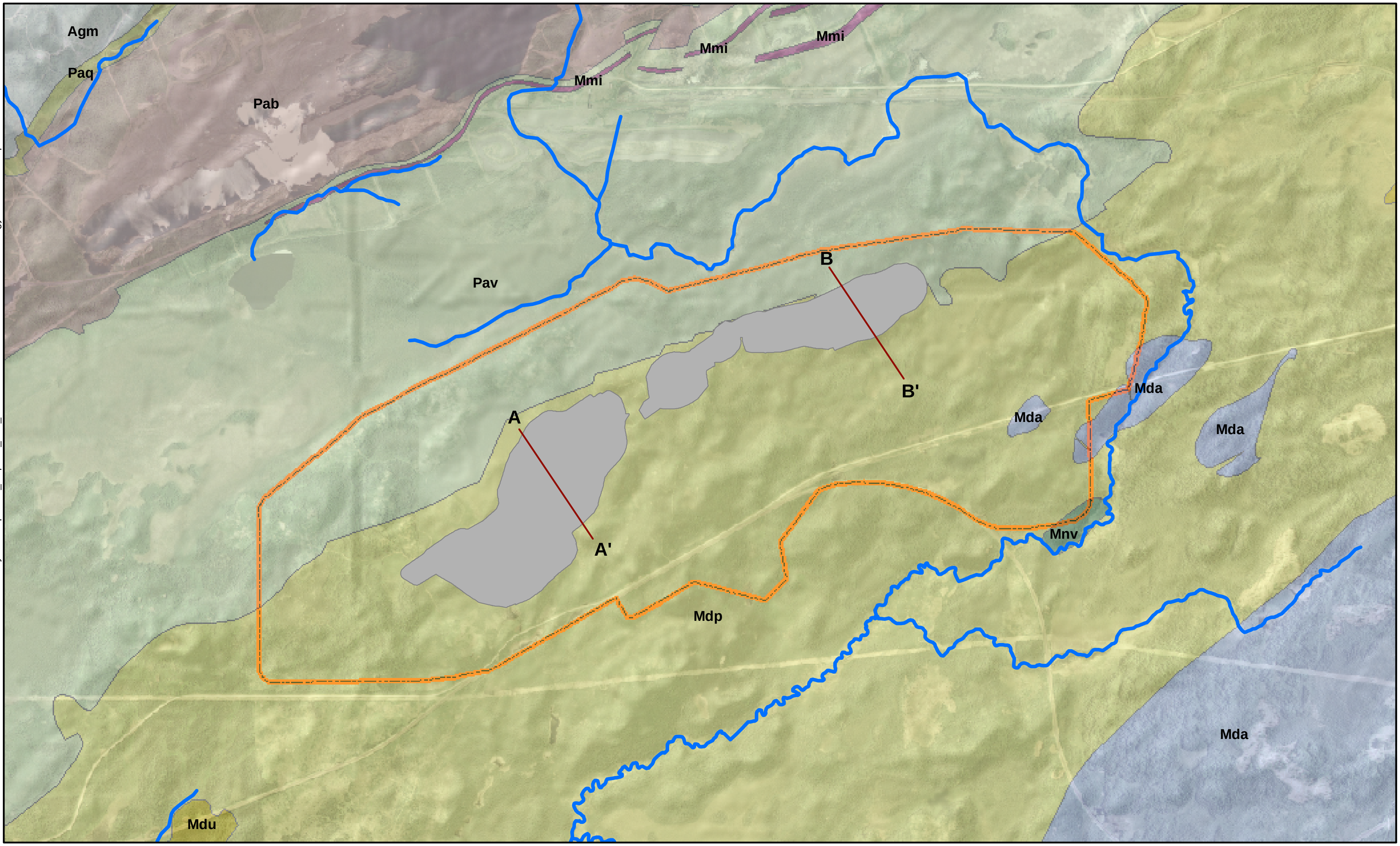


Geology Data from Jirsa, M.A., V.W. Chandler, and R.S. Lively, 2005. Bedrock Geology of the Mesabi Iron Range, Minnesota. Miscellaneous Map Series map M-163

Bedrock Geology

Mesoproterozoic - Duluth Complex

- Mda Anorthositic Series Substitute of the Duluth Complex
- Mdg Gabbro
- Mdp Partridge River Intrusion
- Mdu Ultramafic, Oxide-rich Intrusions
- Mmi Mafic Intrusions
- Mnv North Shore Volcanic Group

Paleoproterozoic

- Pab Biwabik Iron Formation
- Paq Pokegama Quartzite
- Pav Virginia Formation

Neoarchean - Giants Range batholith

- Agm Quartz Monzontie and Monzodiorite

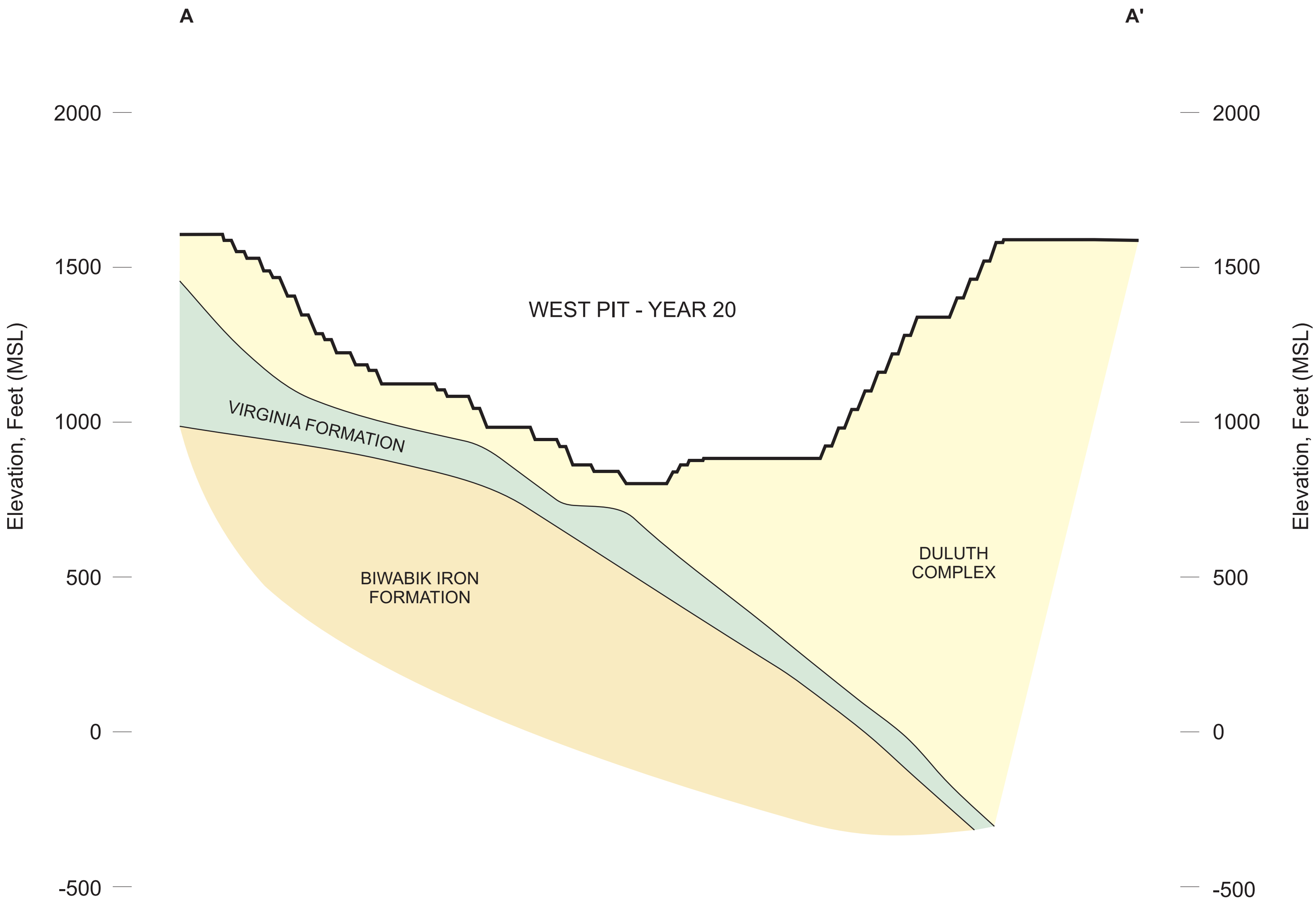
- Mine Site
- Mine Pits
- River or Stream
- X-Section Location

0 1,0002,000 4,000
Feet

Figure 2-1

MINE SITE
BEDROCK GEOLOGY

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



0 500
Horizontal Scale, Feet

Figure 2-2

CROSS SECTION A-A'

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

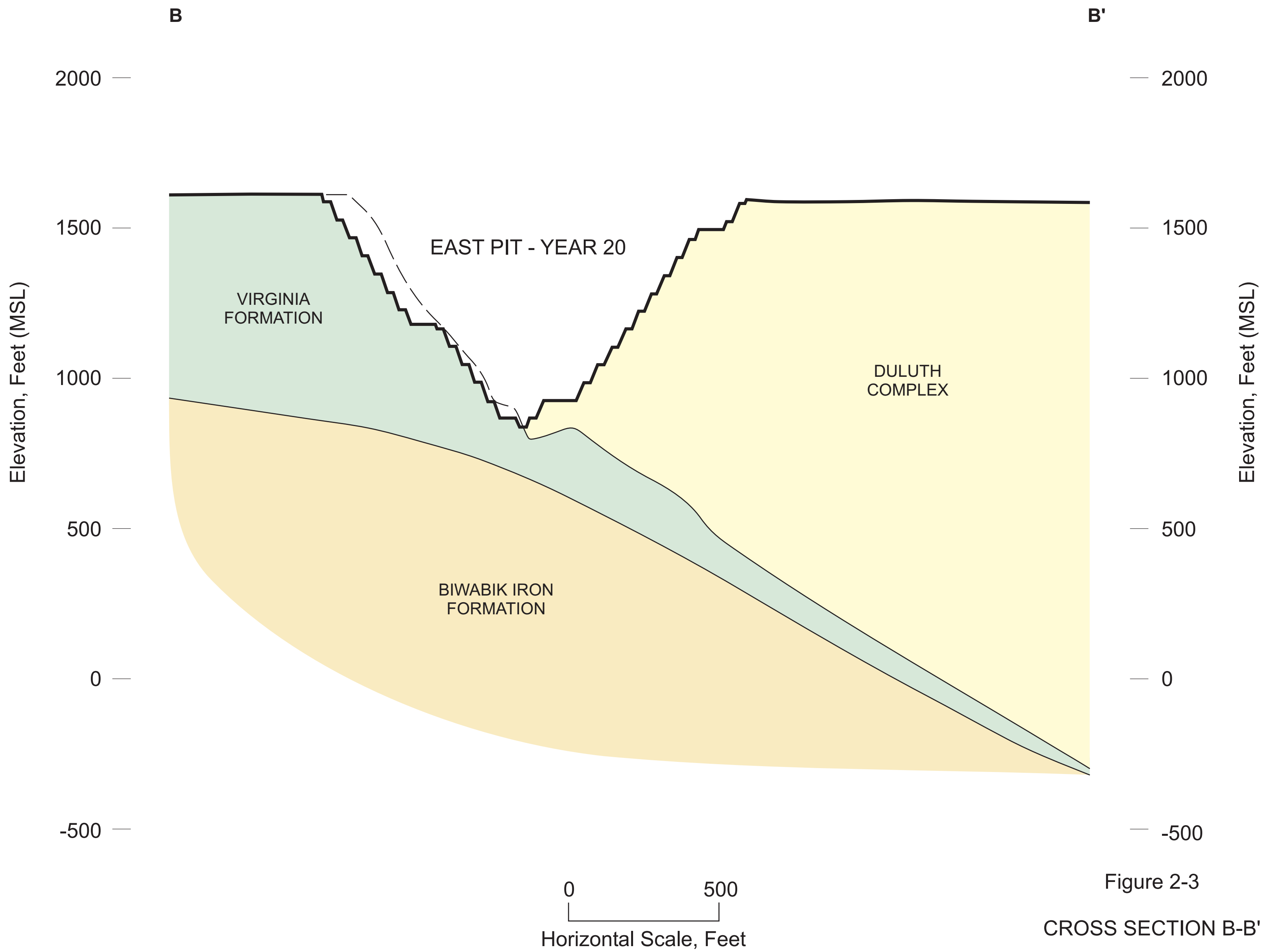
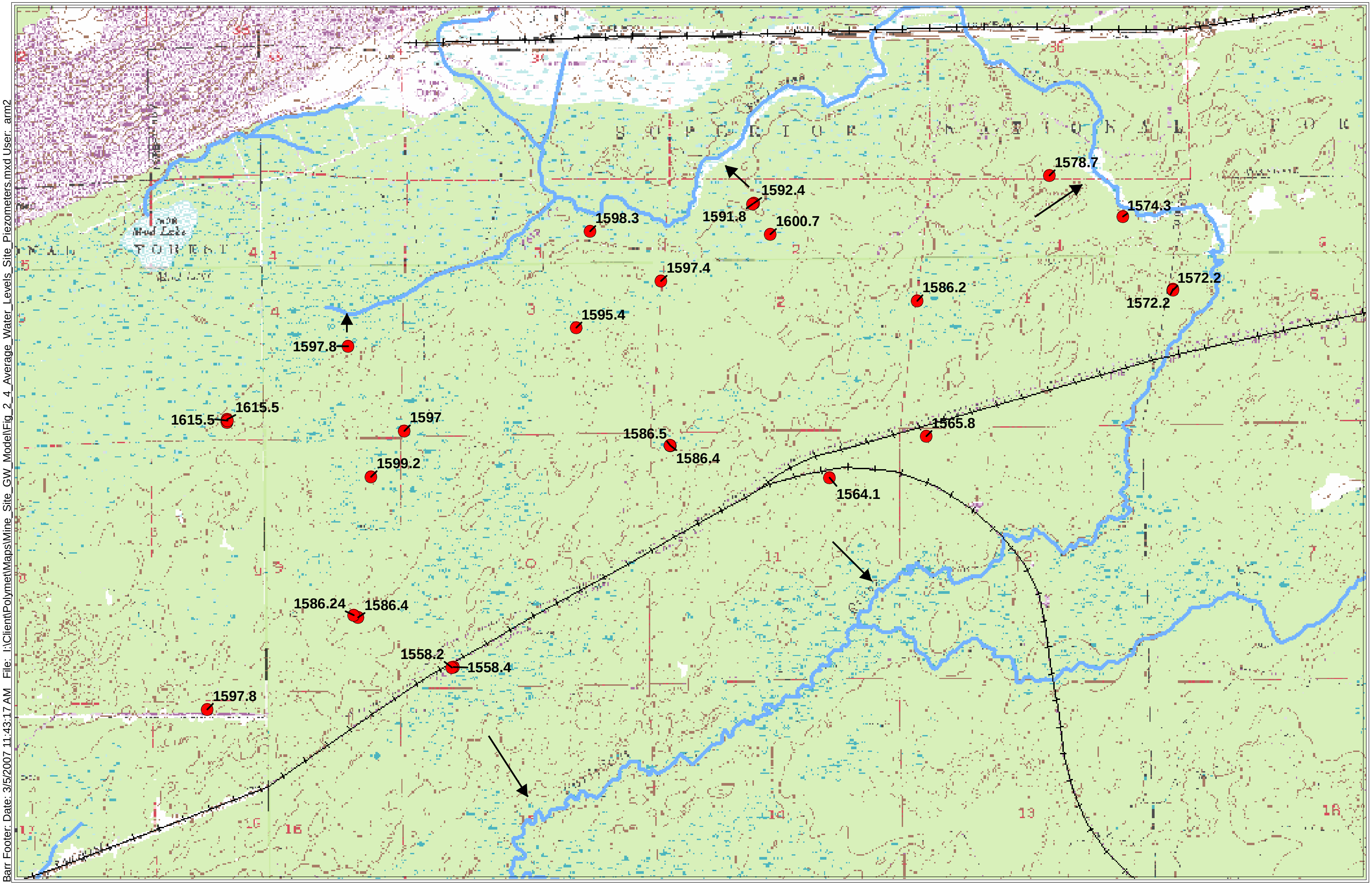


Figure 2-3

CROSS SECTION B-B'

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Wetland Monitoring Locations

Flow Direction

0 2,500 5,000
Feet

Figure 2-4

AVERAGE WATER LEVELS
MEASURED IN SITE PIEZOMETERS

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

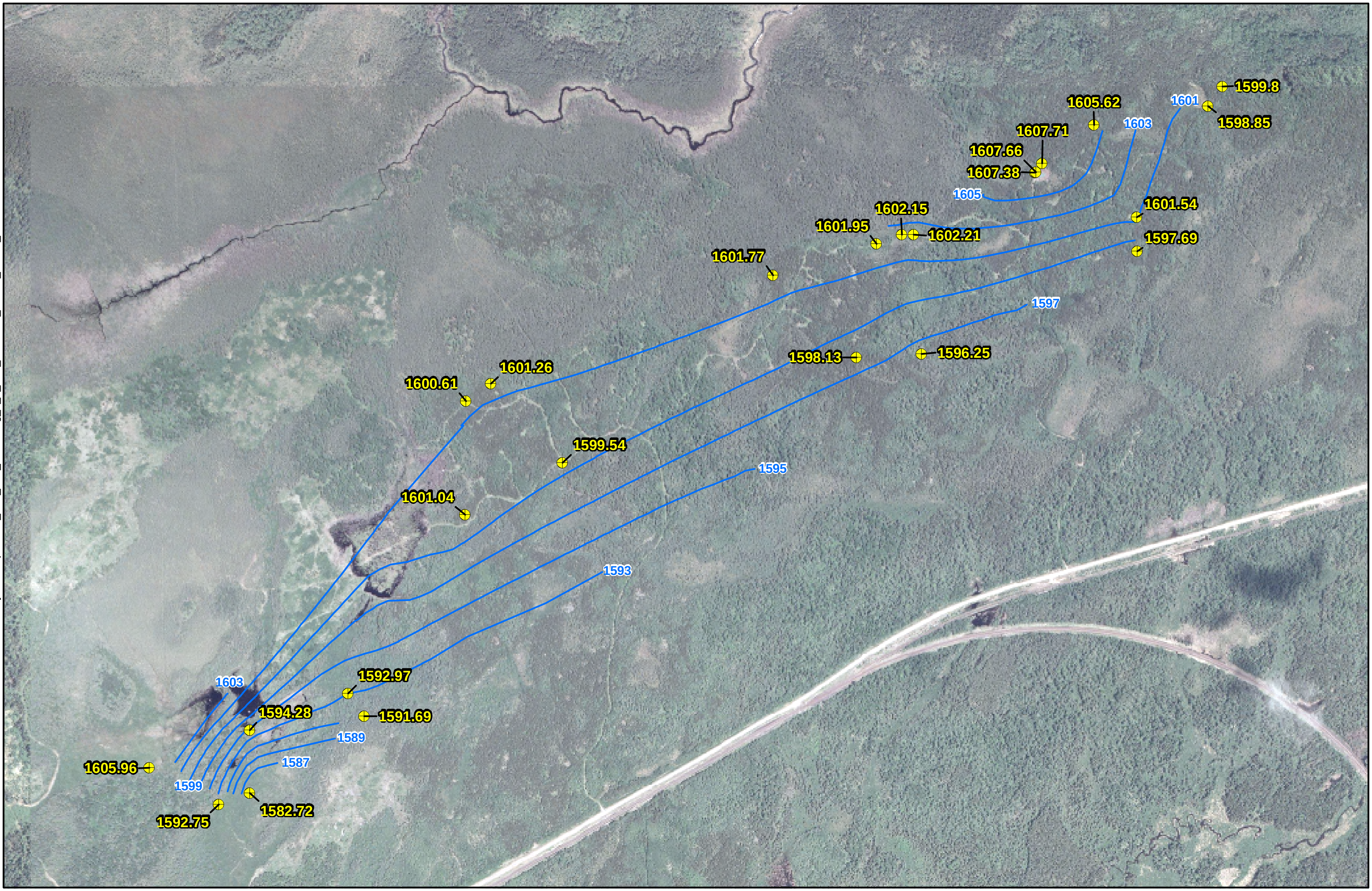


Figure 2-5

Groundwater Elevation Measurement Used for Contouring-Feet MSL

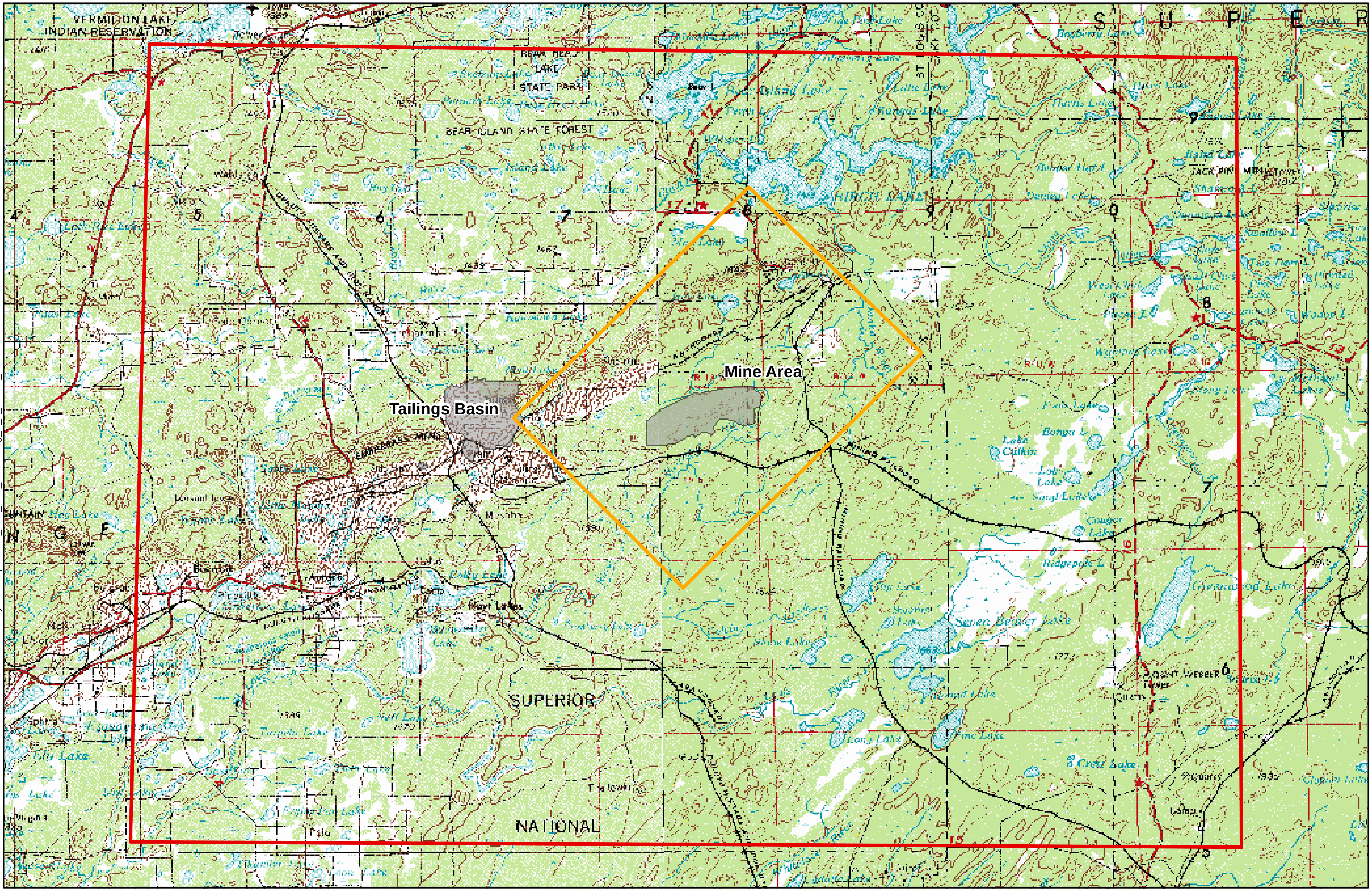
Groundwater Contour-Feet MSL (contour interval = 2ft)

0 500 1,000 2,000 3,000

Feet

GROUNDWATER CONTOURS AND HEADS WITHIN THE BEDROCK AT THE NORTHMET MINE SITE

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Legend

- Regional Model Area
- Local-Scale Model Area
- Project Areas

0 2.5 5 10

Miles

Figure 3-1

MODEL AREAS

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

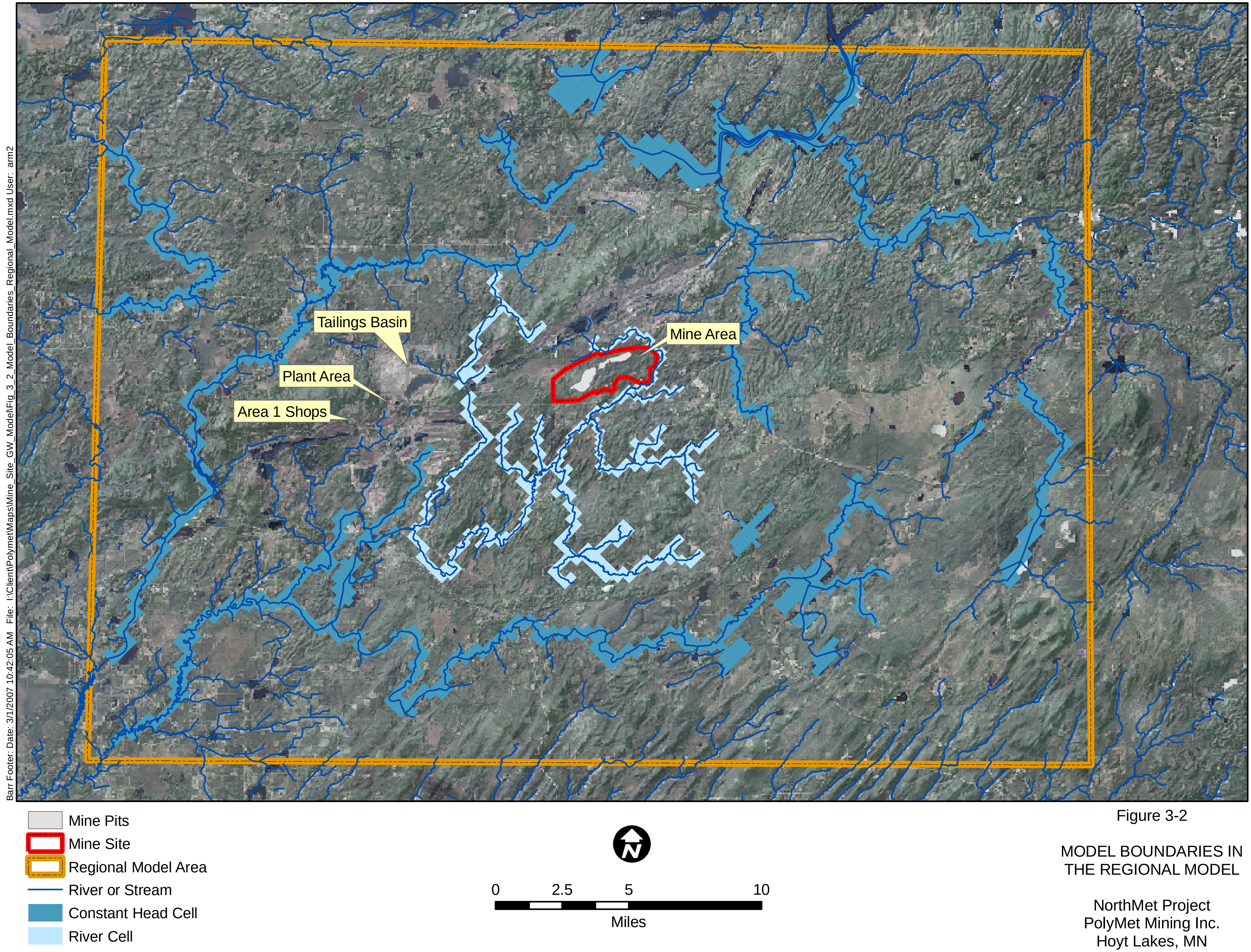
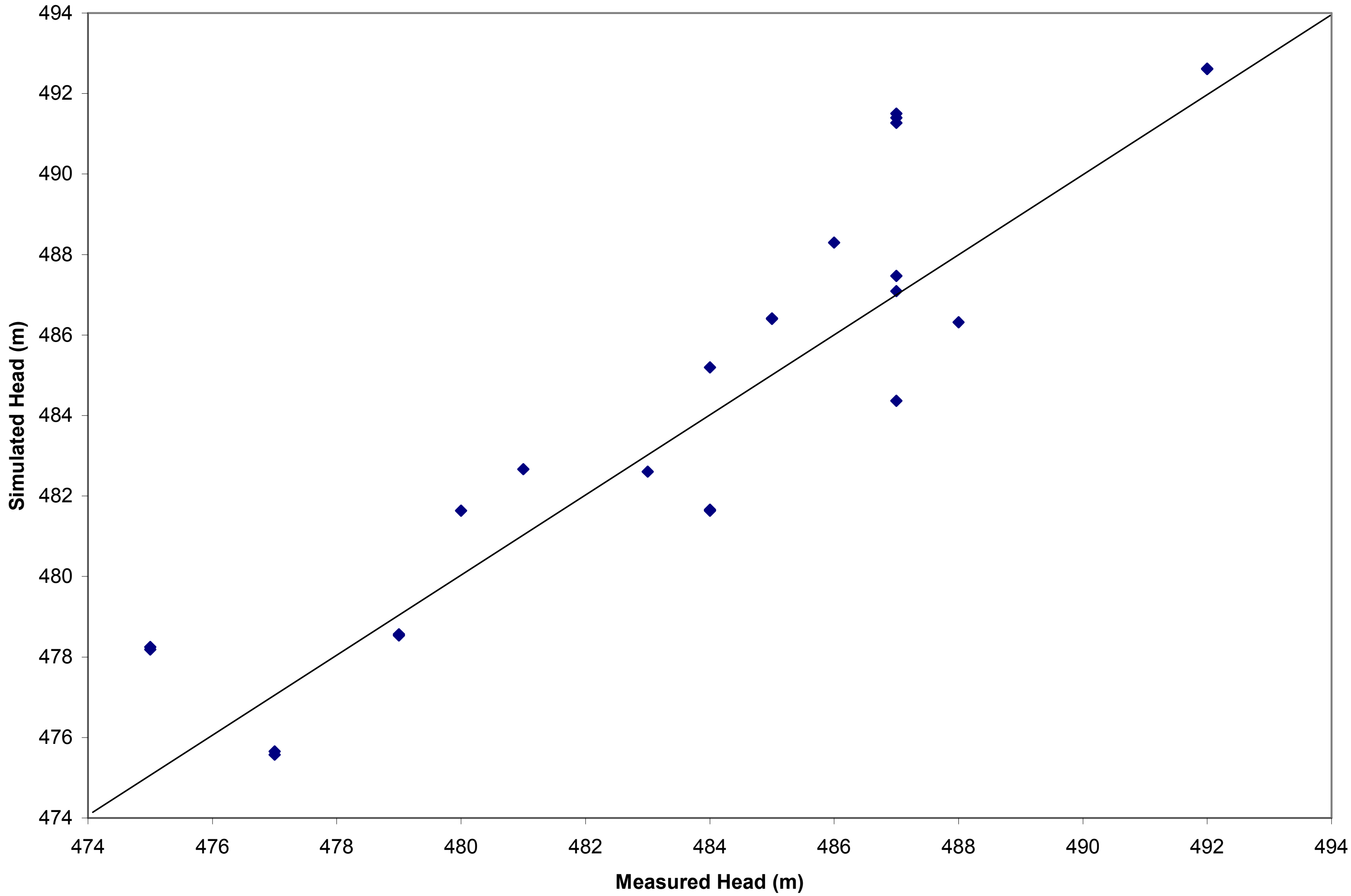


Figure 3-2

MODEL BOUNDARIES IN THE REGIONAL MODEL

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Figure 3-3 Regional Model Calibration Results



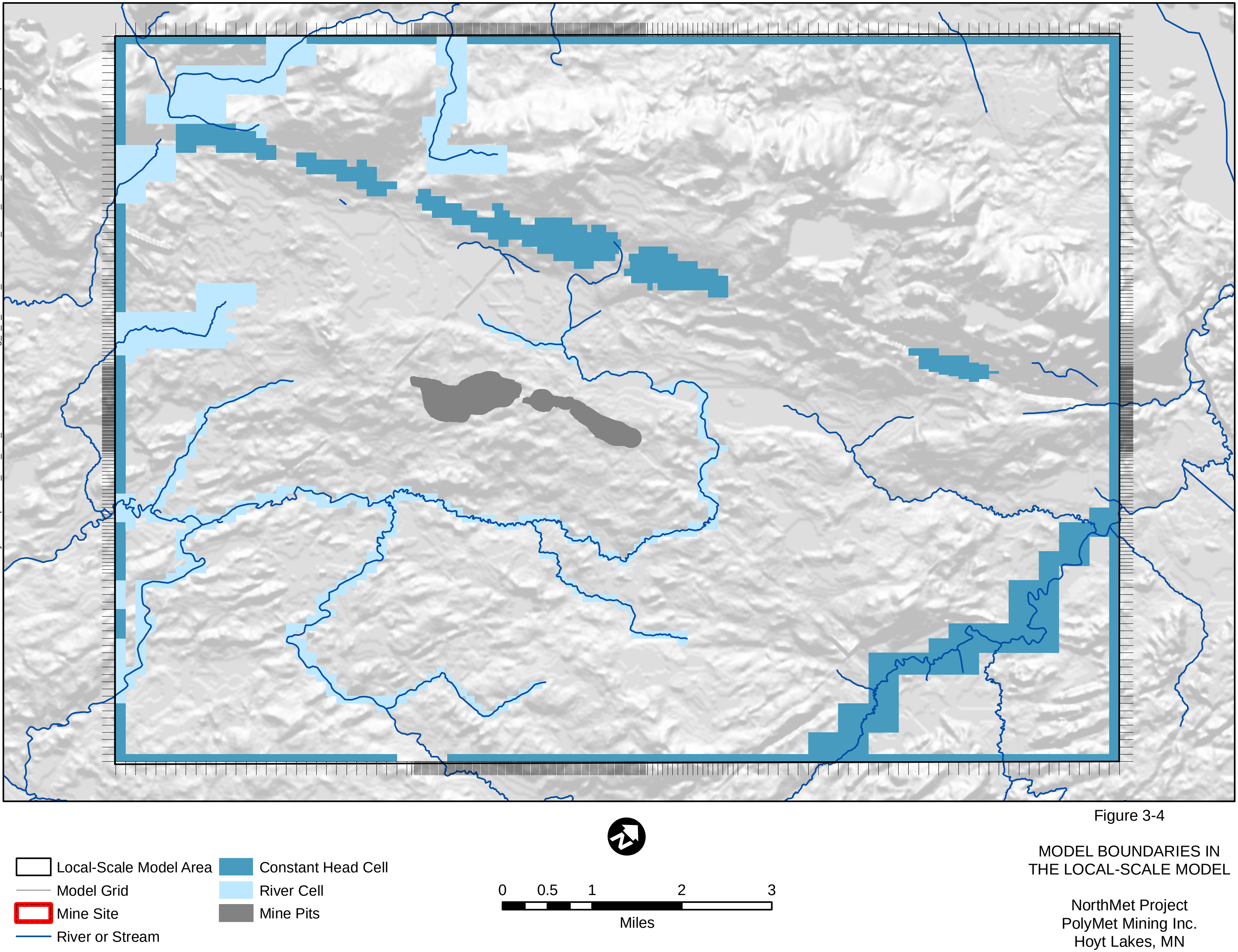
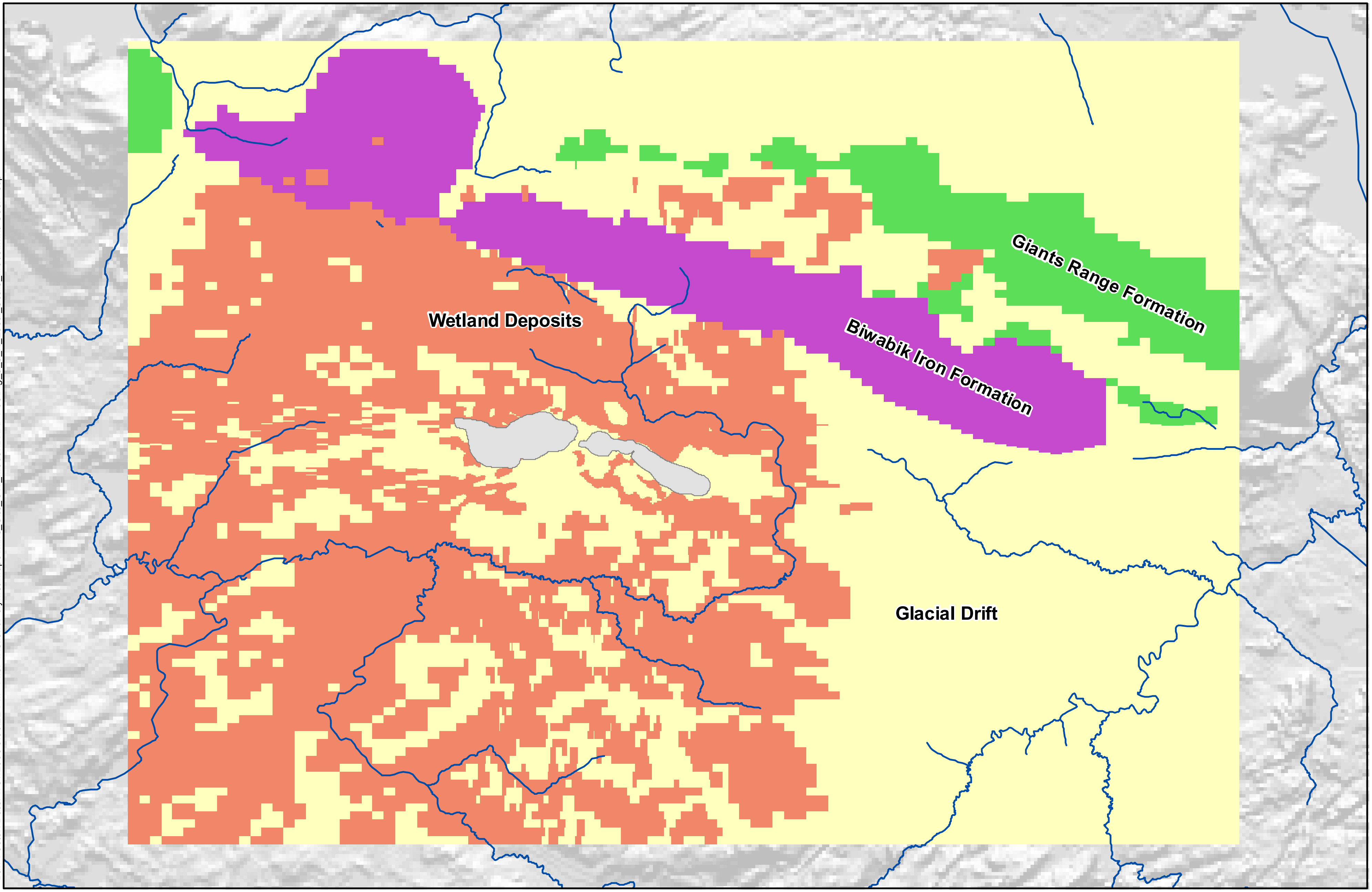


Figure 3-4

MODEL BOUNDARIES IN THE LOCAL-SCALE MODEL

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

0.0089

0.3

0.79

3.03

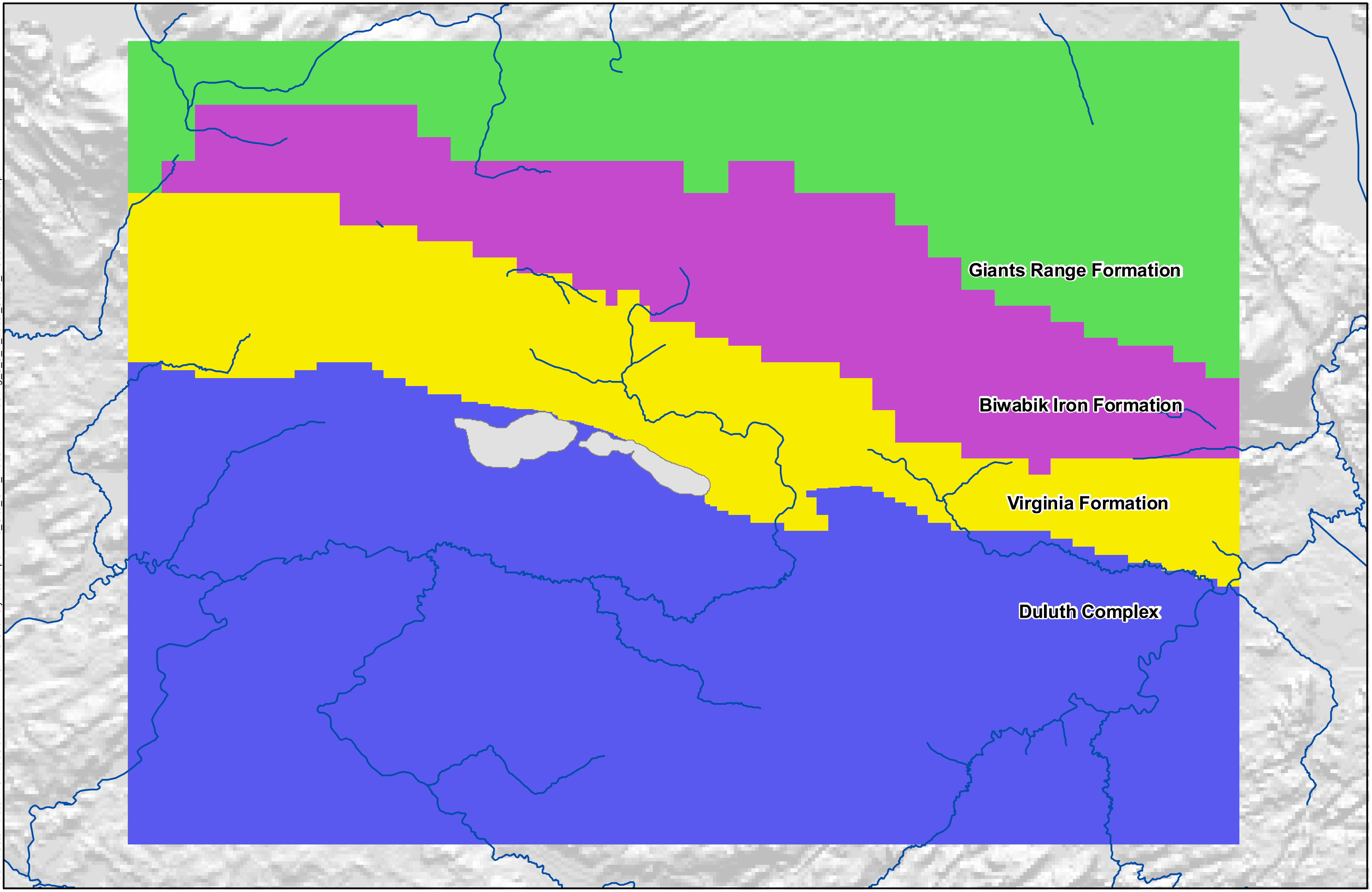
0 0.5 1 2 3

Miles

Figure 3-5a

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 1

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

0.00073

0.0089

0.104

0.3

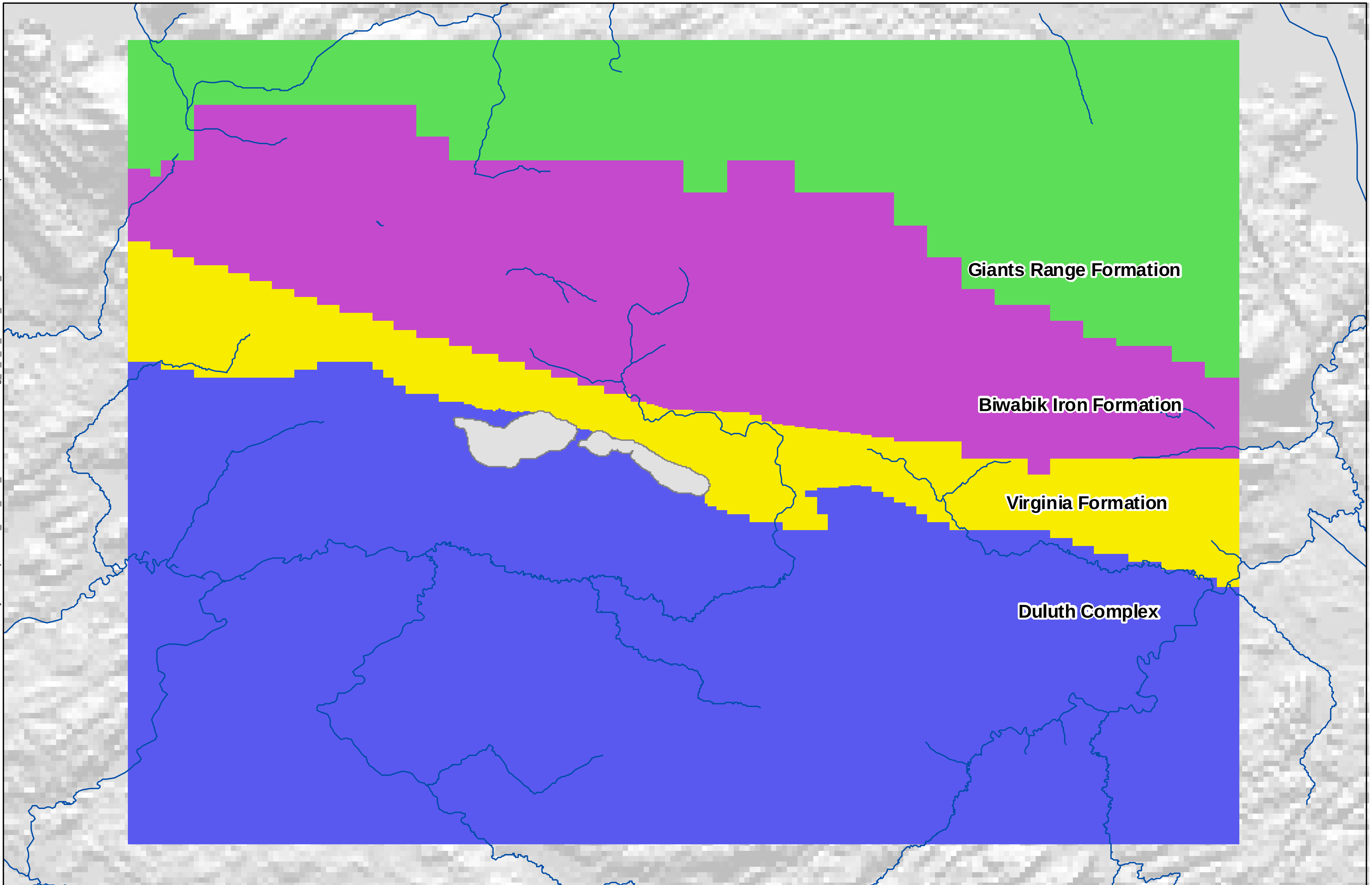
0 0.5 1 2 3

Miles

Figure 3-5b

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 2

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

- 0.00073
- 0.0089
- 0.104
- 0.3

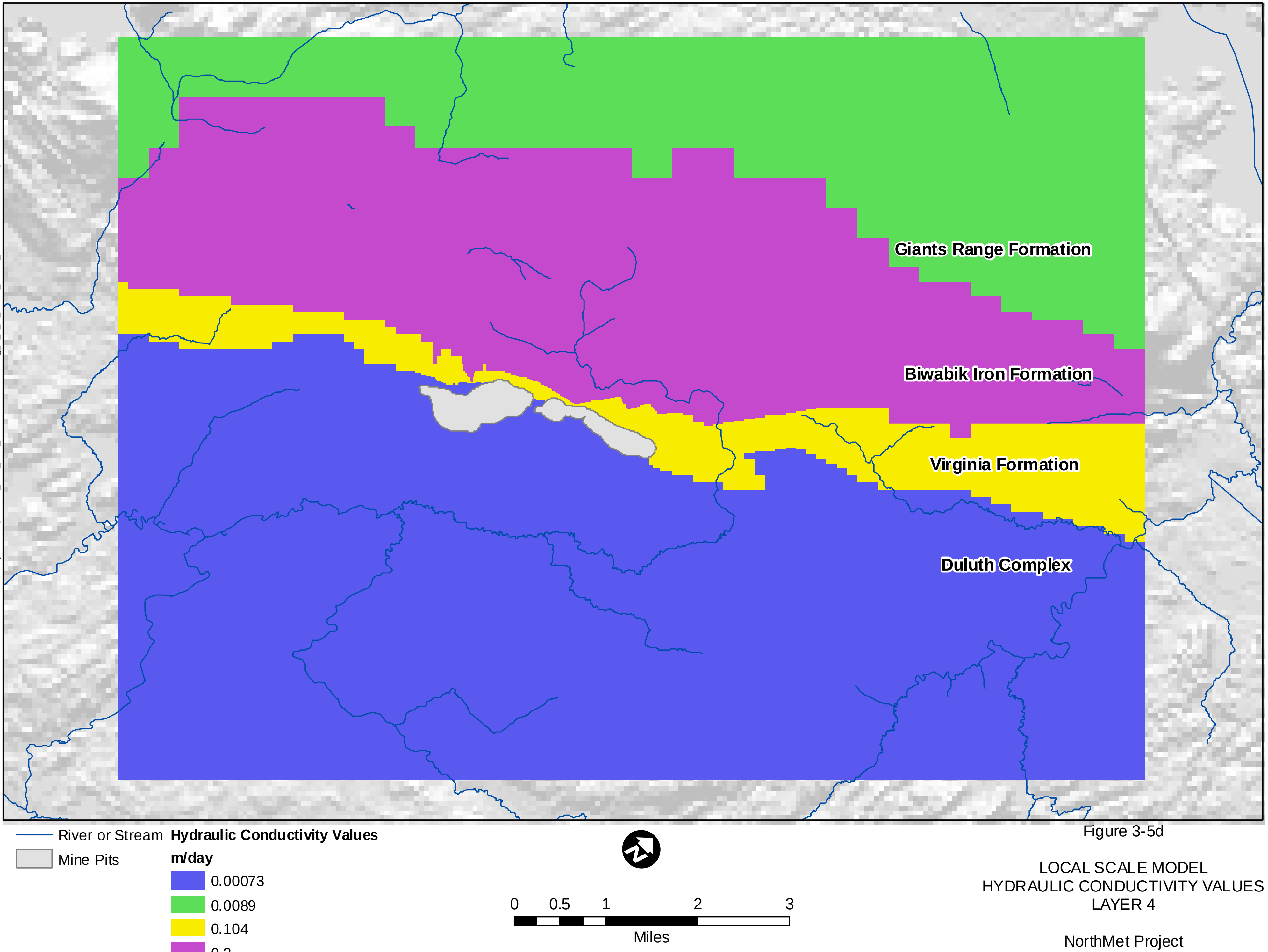
0 0.5 1 2 3

Miles

Figure 3-5c

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 3

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

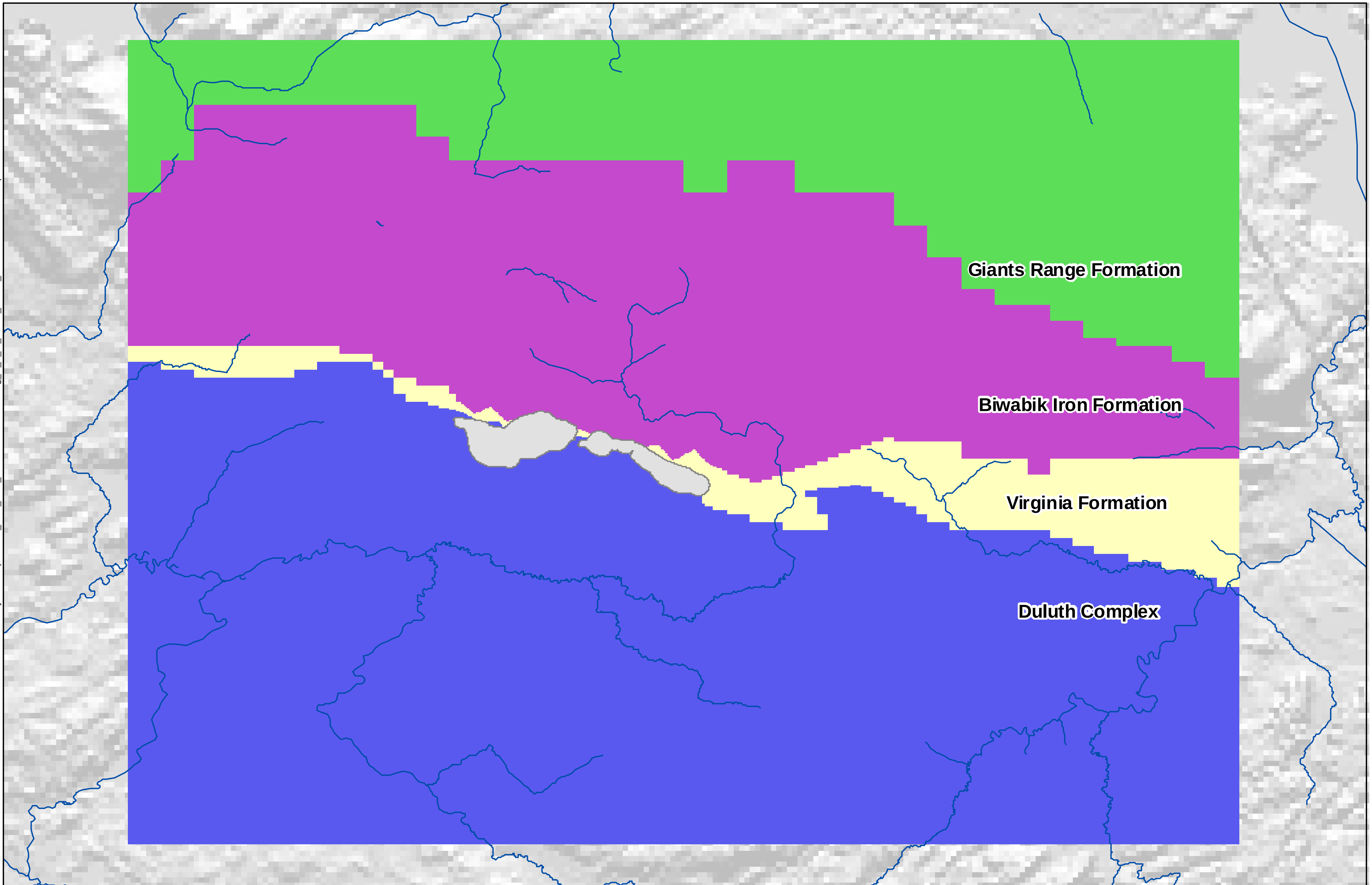
m/day

- 0.00073
- 0.0089
- 0.104
- 0.3

Figure 3-5d

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 4

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

0.00073

0.0089

0.026

0.3

0 0.5 1 2 3

Miles

Figure 3-5e

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 5

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

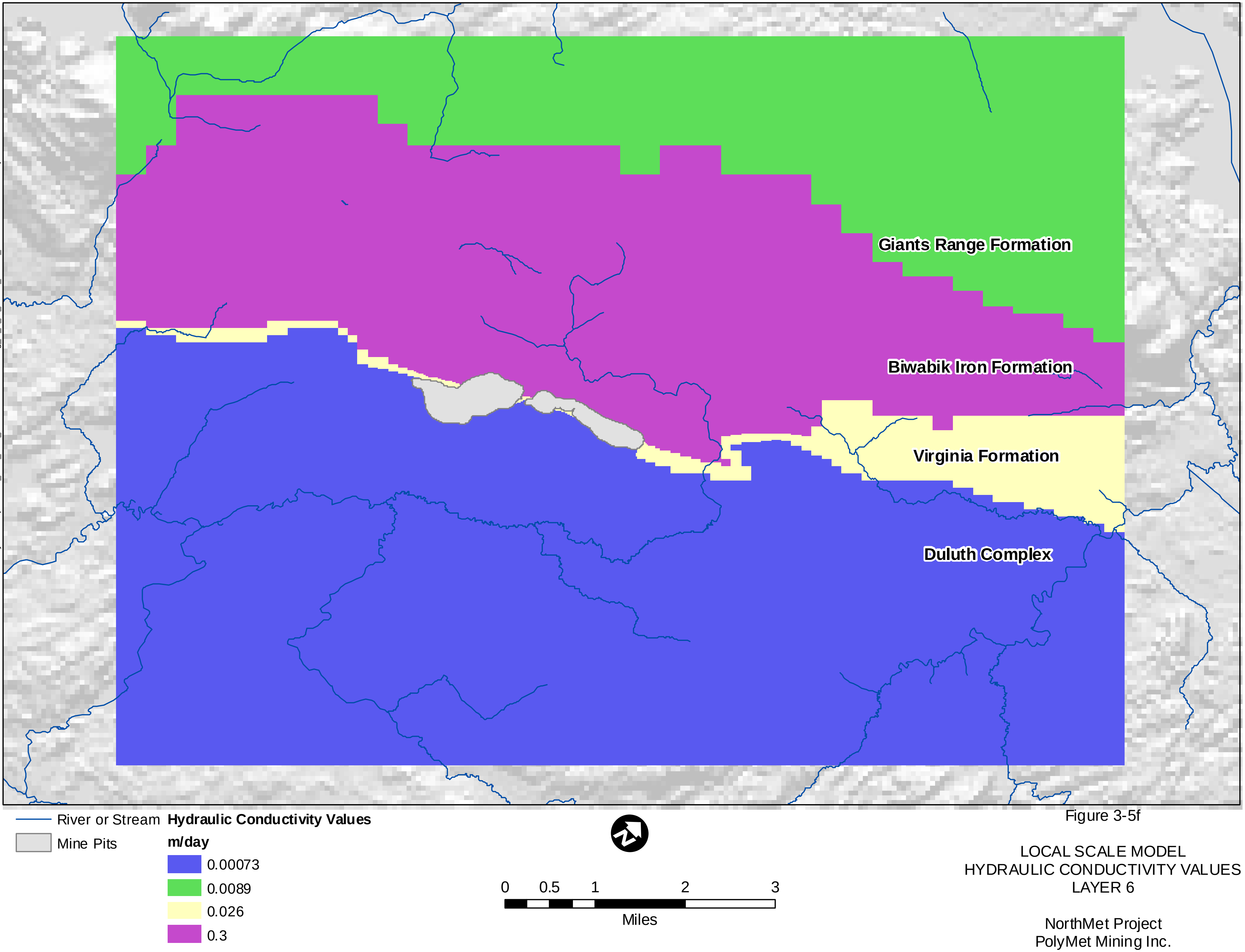
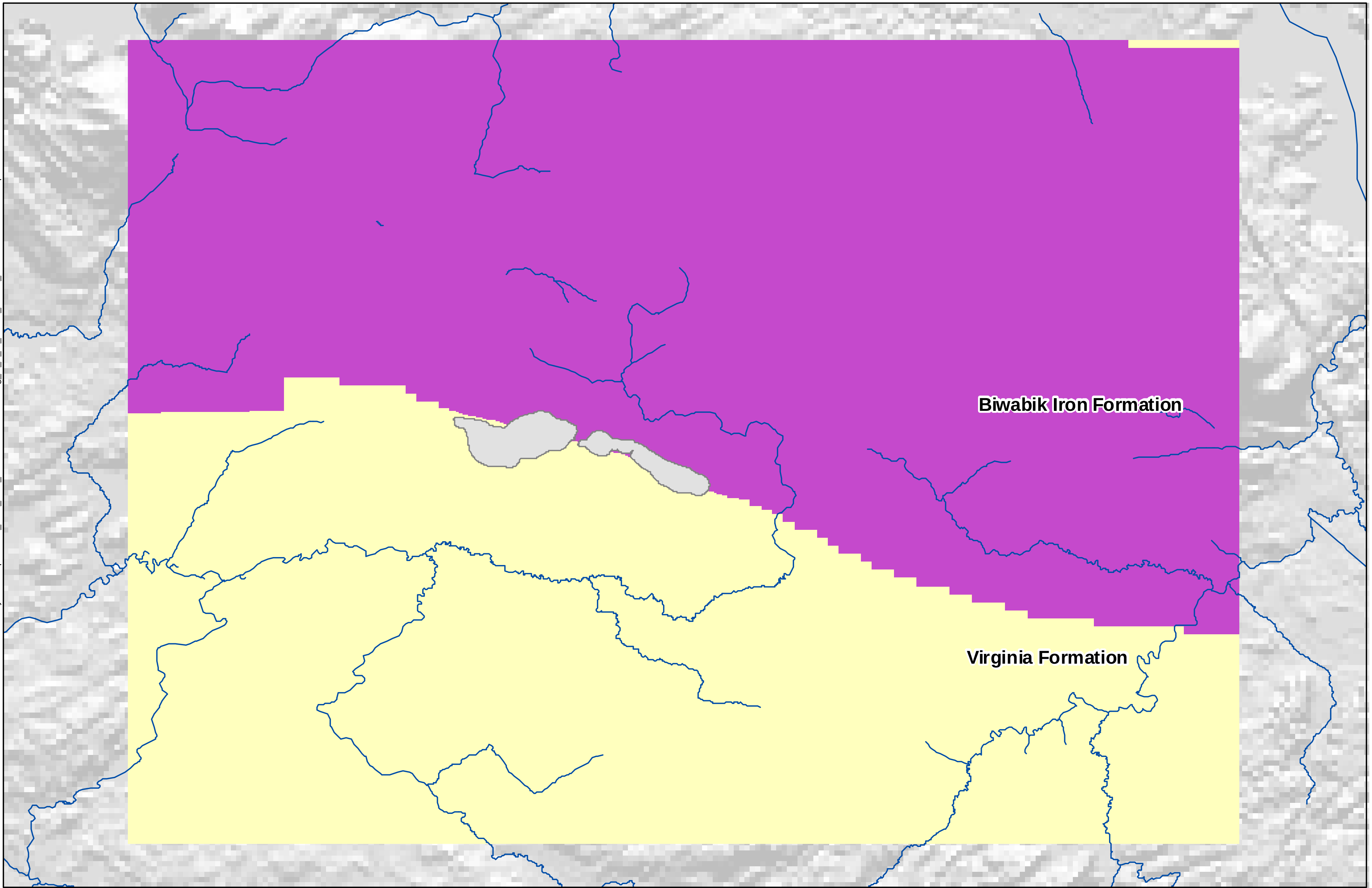


Figure 3-5f

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 6

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

0.00073

0.0089

0.026

0.3

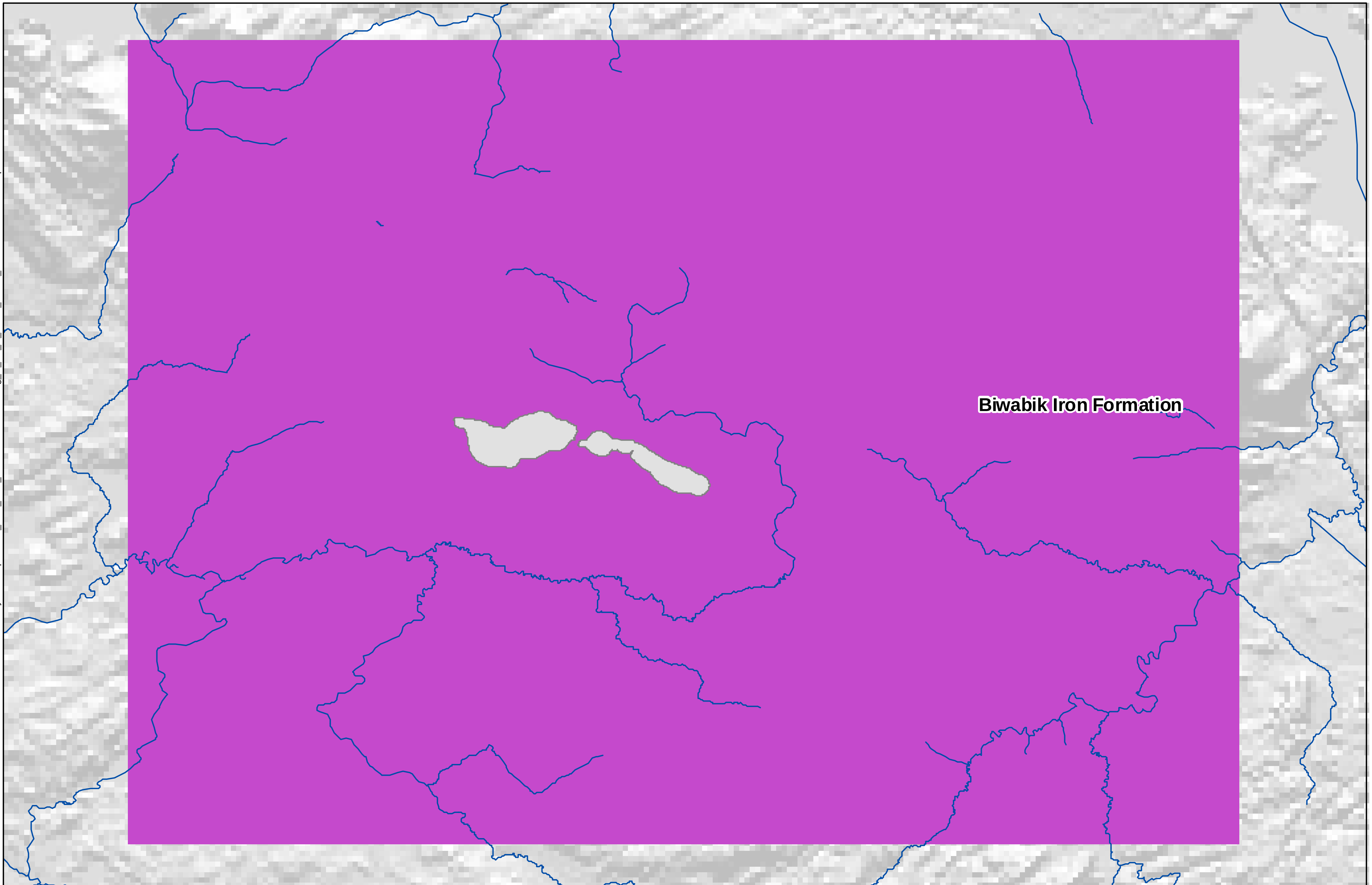
0 0.5 1 2 3

Miles

Figure 3-5g

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 7

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



River or Stream

Mine Pits

Hydraulic Conductivity Values

m/day

0.00073

0.0089

0.026

0.3

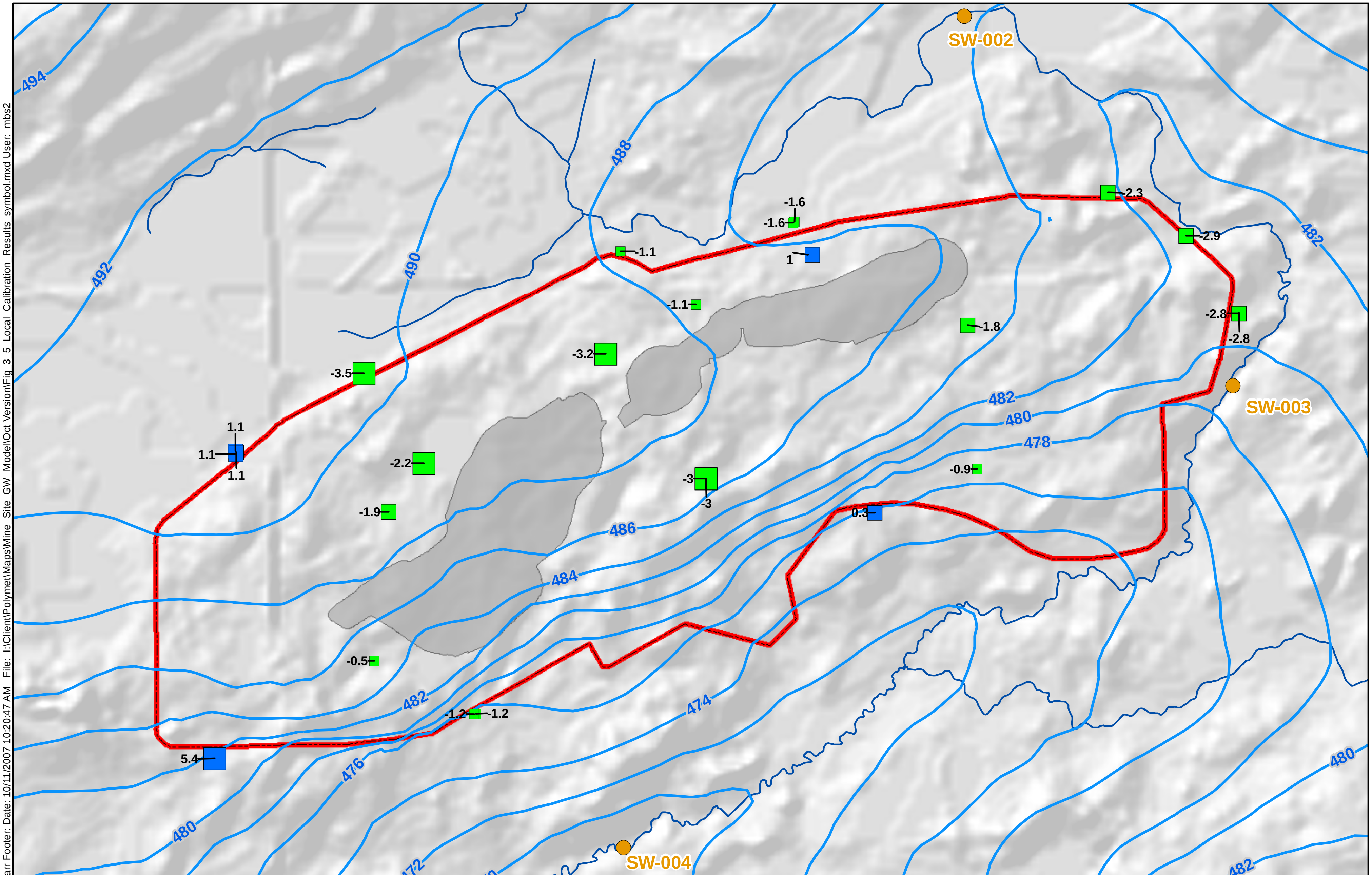
0 0.5 1 2 3

Miles

Figure 3-5h

LOCAL SCALE MODEL
HYDRAULIC CONDUCTIVITY VALUES
LAYER 8

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Barr Footer: Date: 10/11/2007 10:20:47 AM File: I:\Client\Polymet\Maps\Mine Site GW Model\Oct Version\Fig 3_5 Local Calibration Results symbol.mxd User: mbs2

- Monitoring Location
- River or Stream
- Mine Pits
- Mine Site
- Simulated Water Table (meters) Contour Interval 2 meters

Layer 1 Calibration Residuals

- > 2.00 meters
- 1.00 - 1.99 meters
- 0.00 - 0.99 meters
- 0.00 - -0.99 meters
- -1.00 - -1.99 meters
- < -2.00 meters

0 1,000 2,000 4,000
Feet

Figure 3-6

LOCAL-SCALE MODEL CALIBRATION RESULTS - SURFICIAL AQUIFER

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

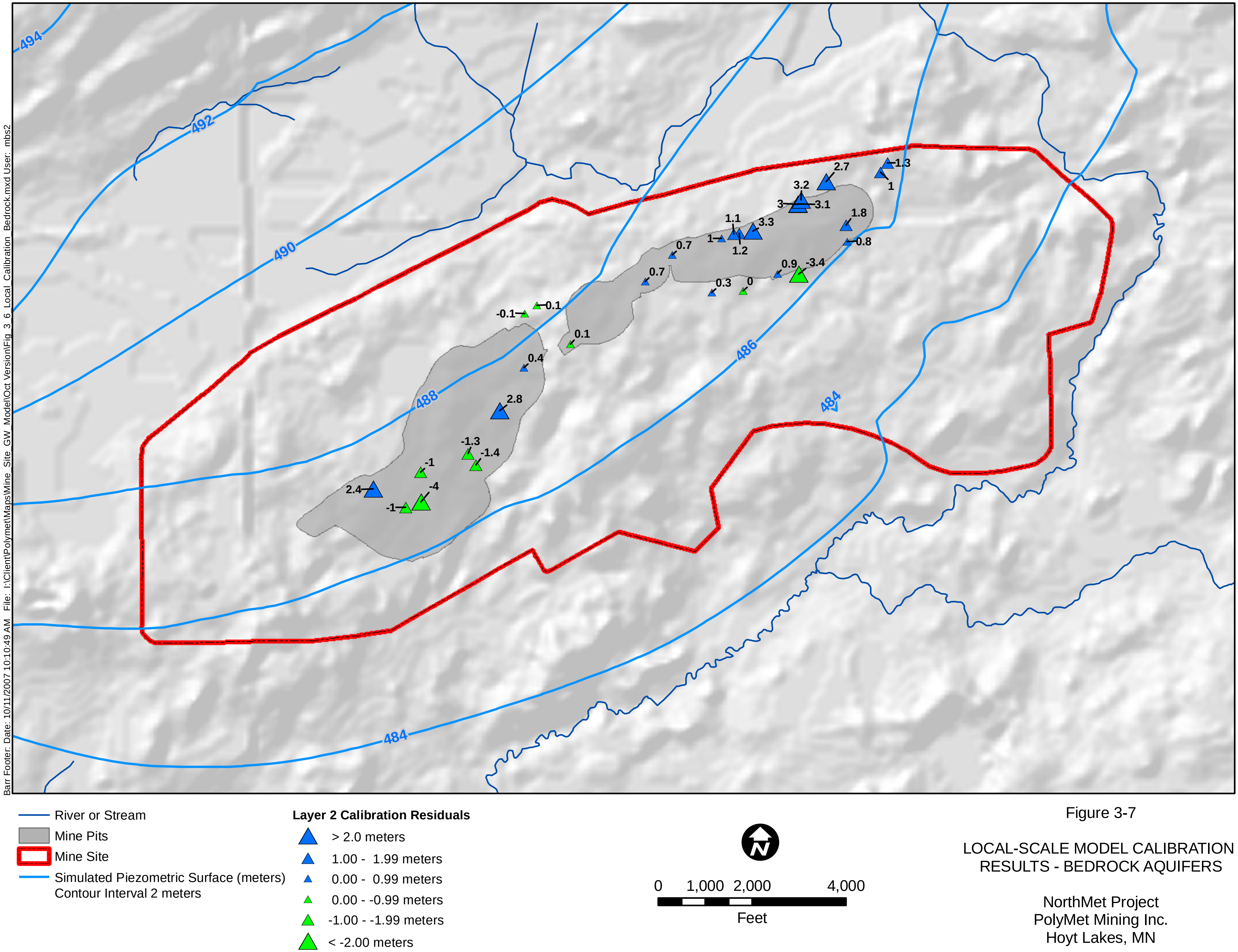
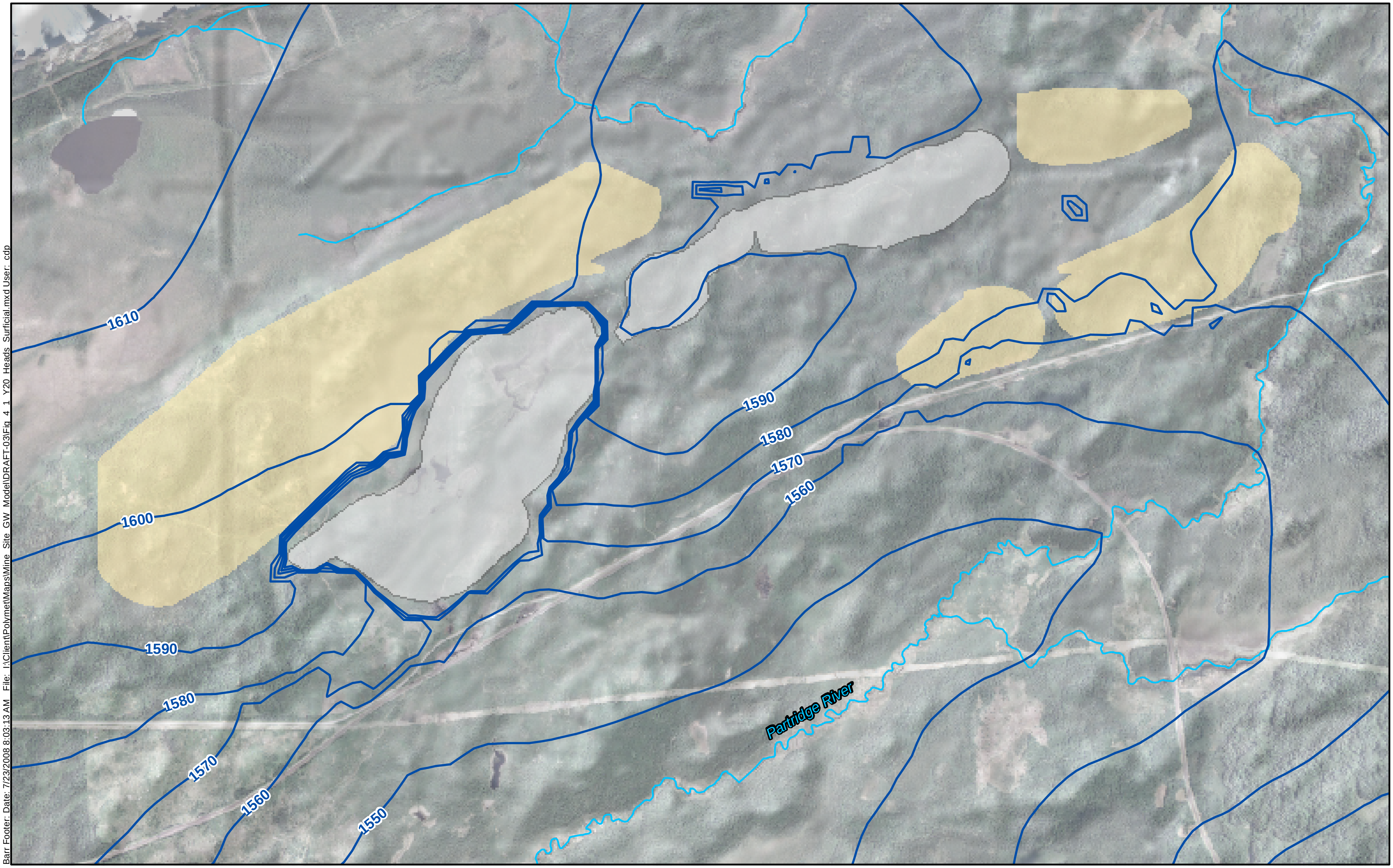


Figure 3-7

LOCAL-SCALE MODEL CALIBRATION RESULTS - BEDROCK AQUIFERS

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Barr Footer: Date: 7/23/2008 8:03:13 AM File: I:\Client\Polymet\Maps\Mine Site GW Model\DRAFT-03\Fig 4 1 Y20 Heads Surficial.mxd User: cdp

Figure 4-1

Simulated Water Table (feet)
Contour Interval = 10 feet

Stockpile Footprints at Closure

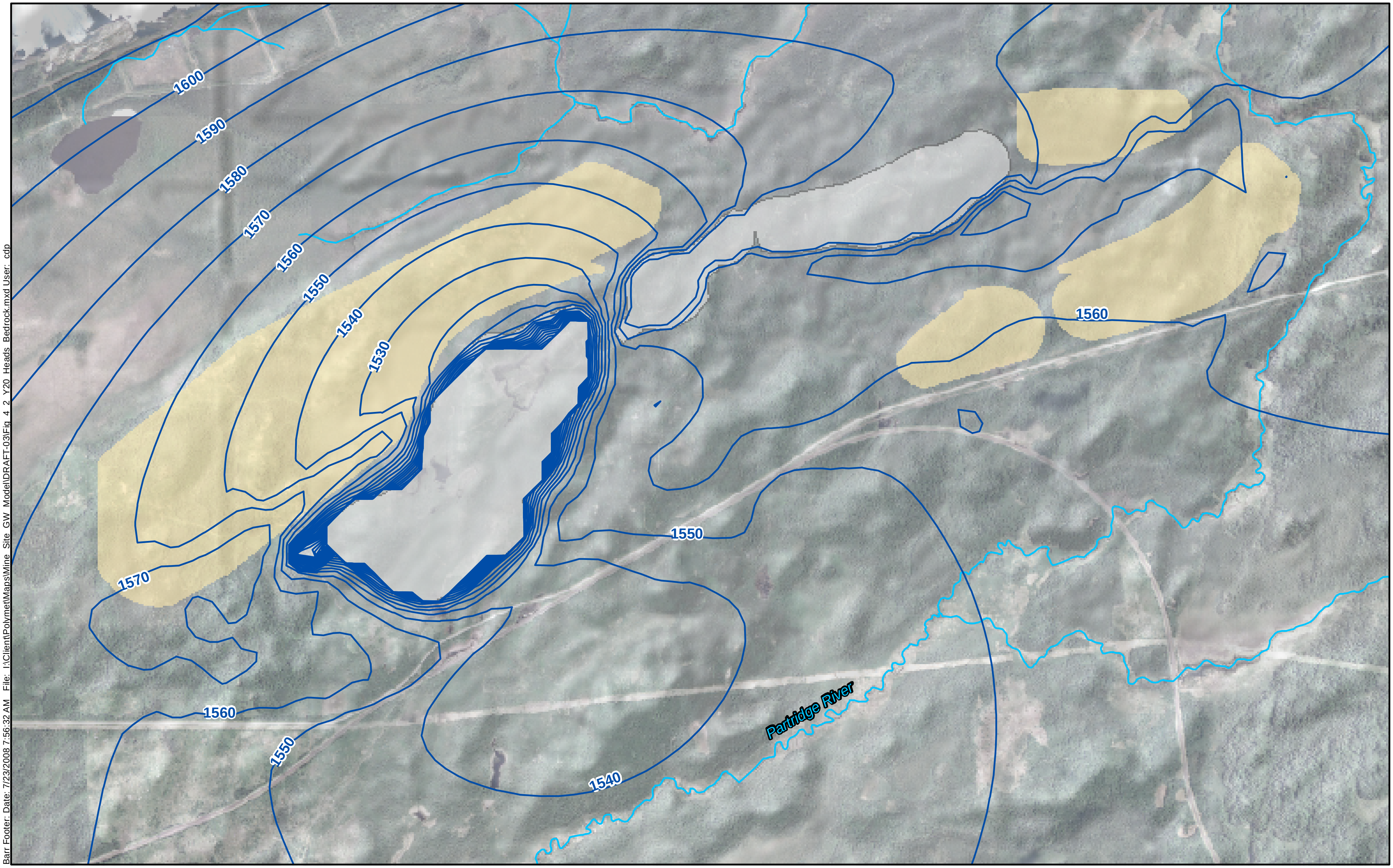
Year 20 Mine Pits

2,250 1,125 0 2,250

Feet

PREDICTED GROUNDWATER LEVELS
WITHIN SURFICIAL AQUIFER - YEAR 20

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Simulated Piezometric Surface (feet)
Contour Interval = 10 feet

Stockpile Footprints at Closure

Year 20 Mine Pits

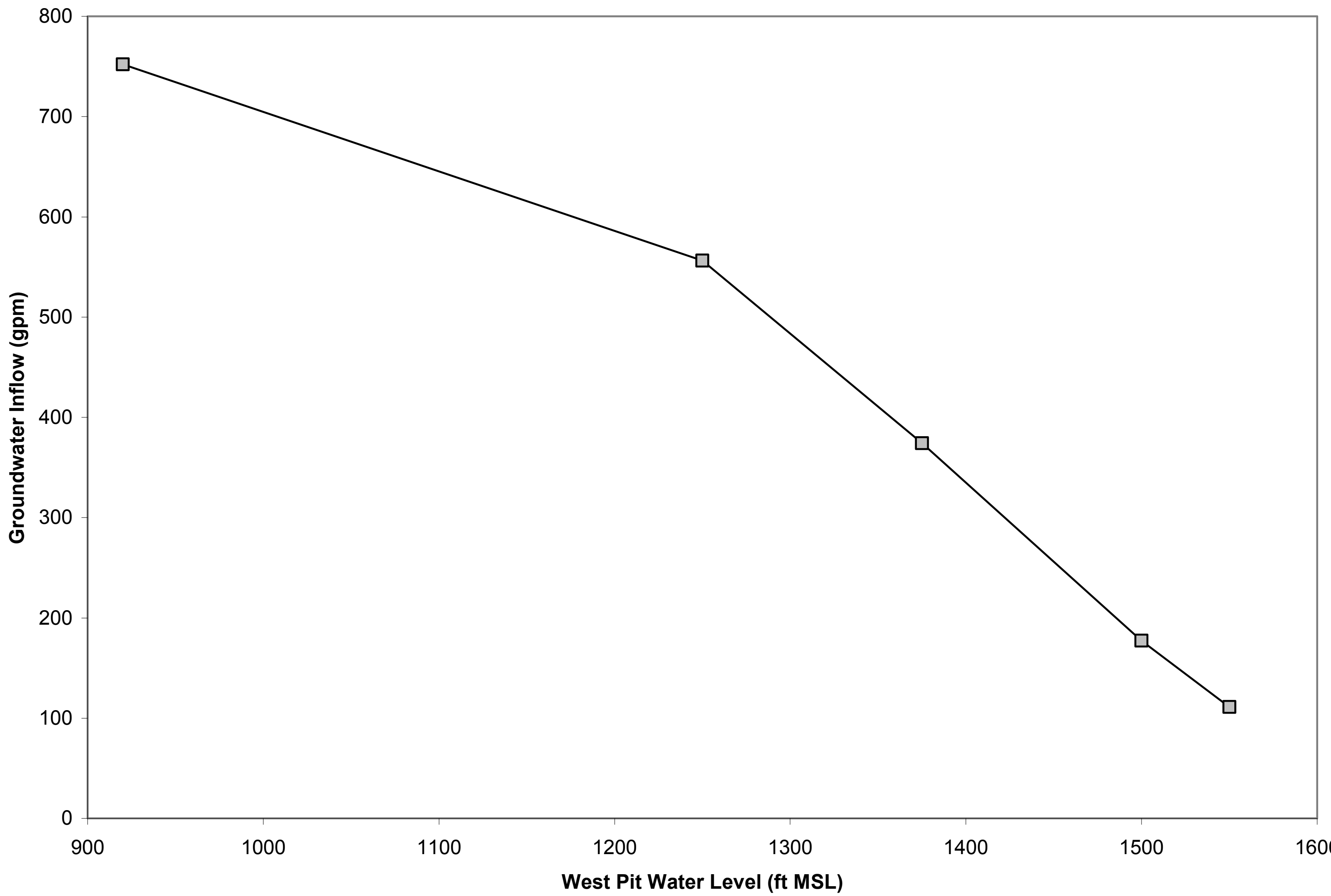
2,250 1,125 0 2,250

Feet

Figure 4-2
PREDICTED GROUNDWATER LEVELS
WITHIN BEDROCK- YEAR 20

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Figure 4-3 Predicted Groundwater Inflow Rates During West Pit Filling



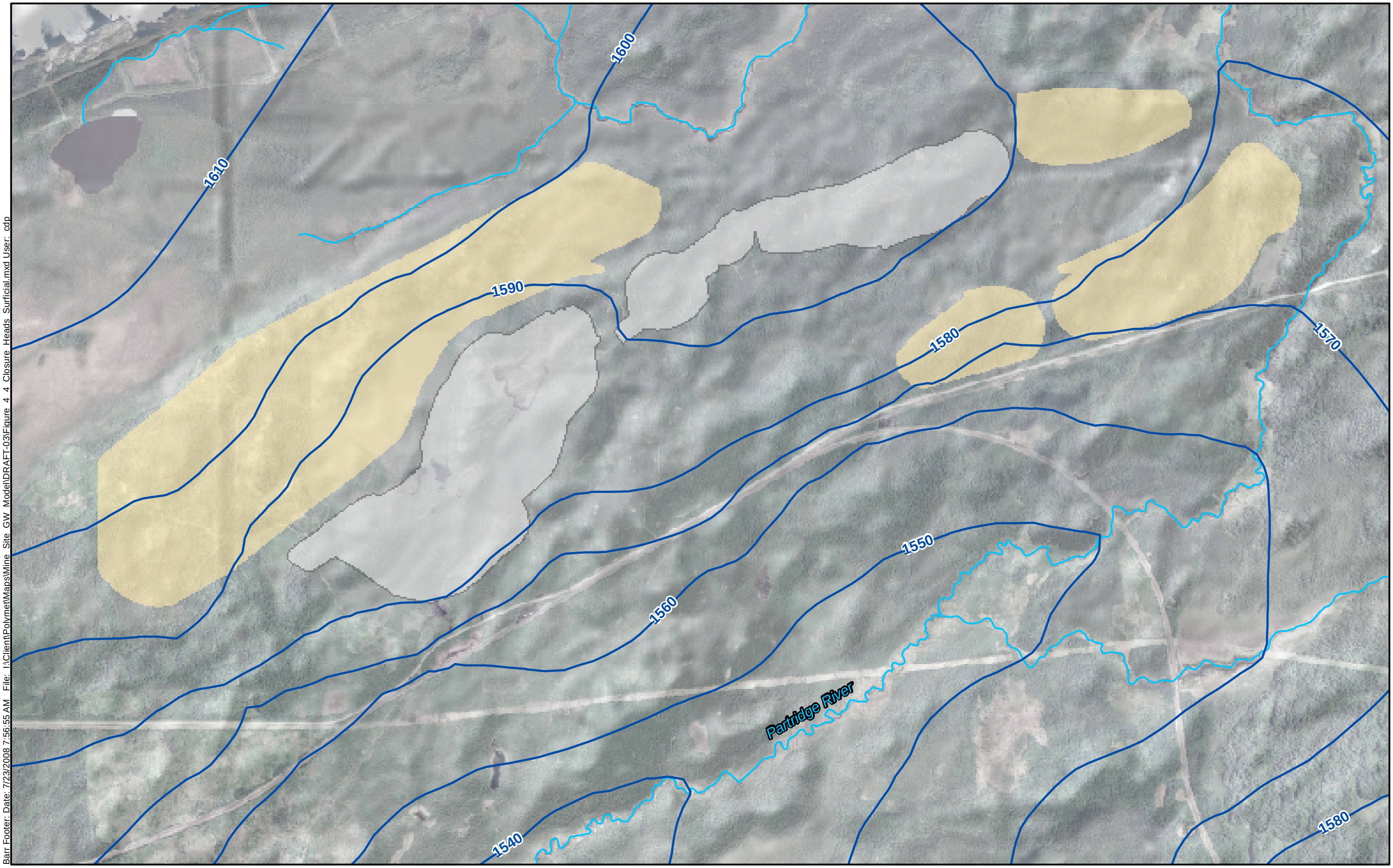


Figure 4-4

PREDICTED GROUNDWATER LEVELS
WITHIN SURFICIAL AQUIFER- POST CLOSURE

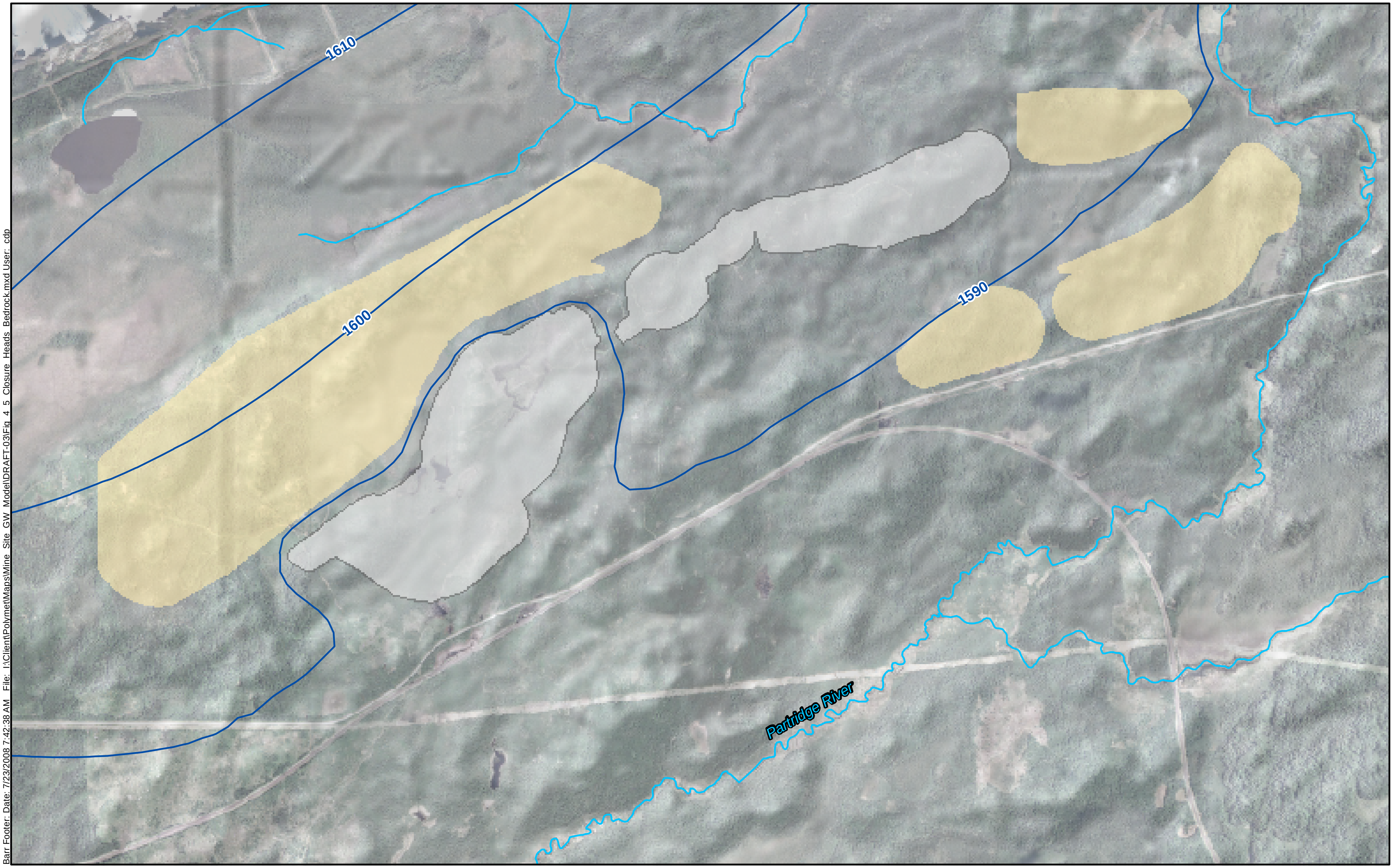
NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Simulated Water Table (feet)
Contour Interval = 10 feet

Stockpile Footprints at Closure

Year 20 Mine Pits

2,250 1,125 0 2,250
Feet



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Simulated Piezometric Surface (feet)
Contour Interval = 10 feet

Stockpile Footprints at Closure

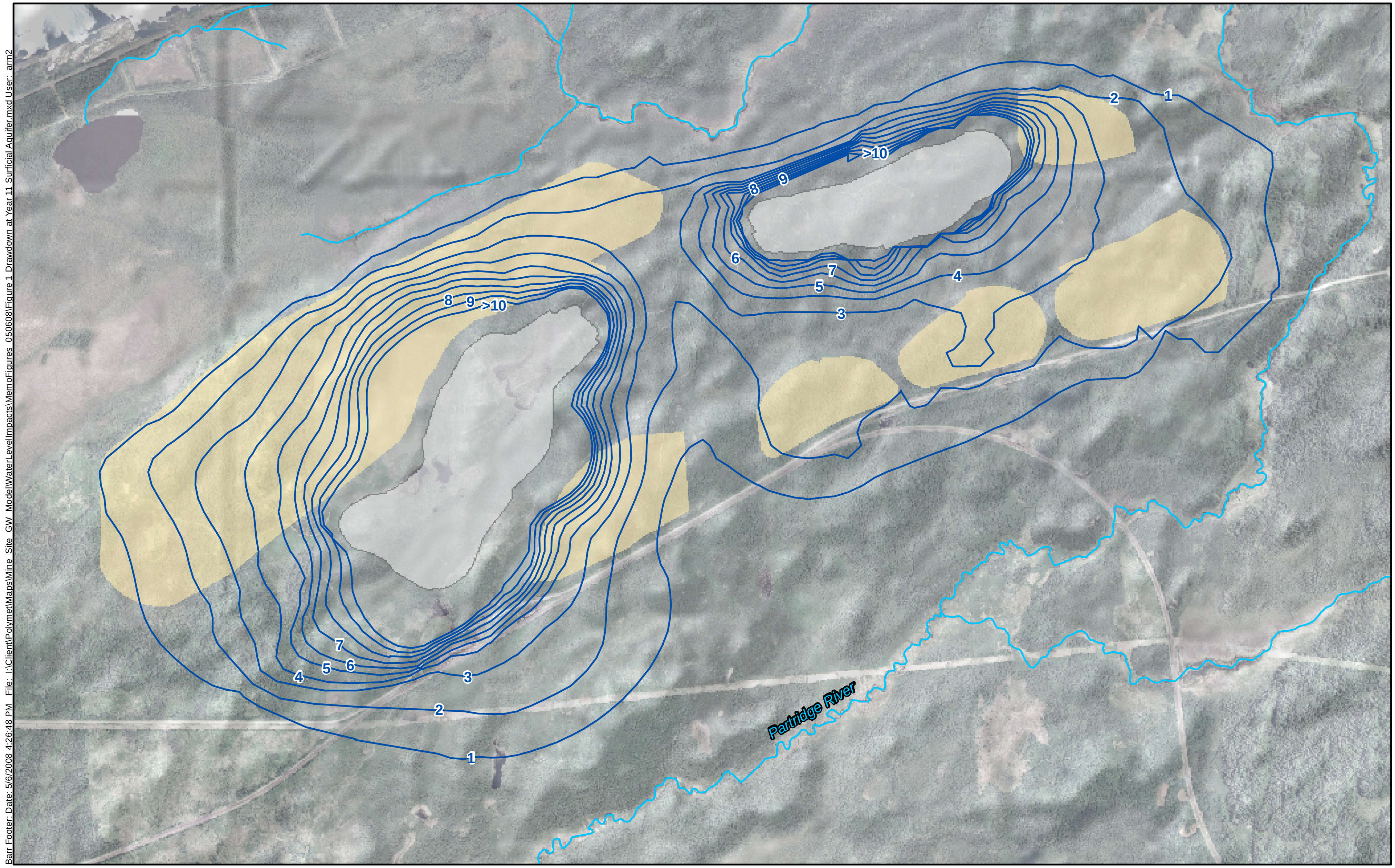
Year 20 Mine Pits

N

2,250 1,125 0 2,250
Feet

Figure 4-5
PREDICTED GROUNDWATER LEVELS
WITHIN BEDROCK- POST CLOSURE

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Water Table Drawdown, ft
Contour Interval = 1 ft

Year 10 Stockpile Footprints

Year 10 Mine Pits

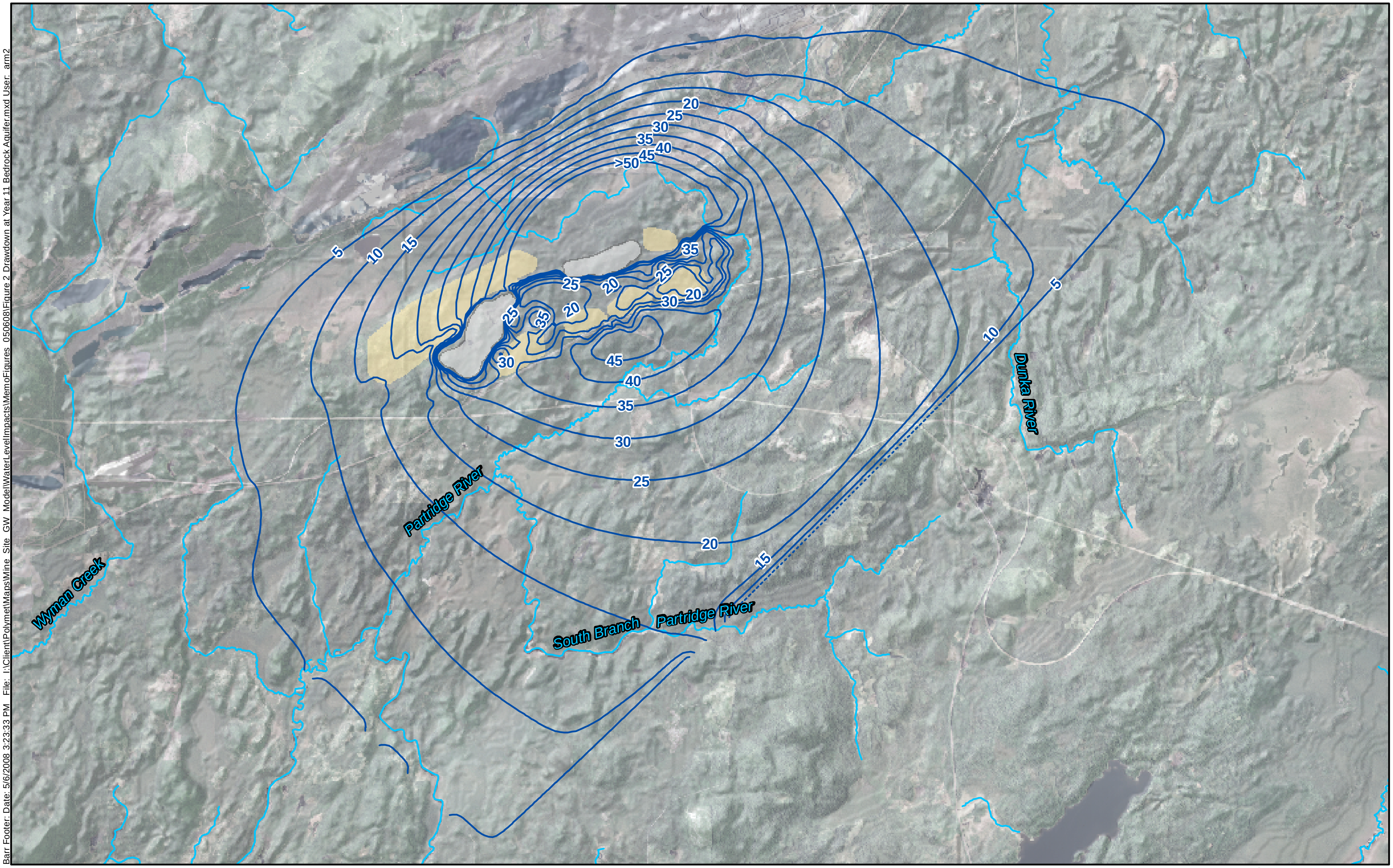
2,250 1,125 0 2,250

Feet

Figure 4-6

DRAWDOWN AT YEAR 11
SURFICIAL AQUIFER

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Water Table Drawdown, ft
Contour Interval = 5 ft

Year 10 Stockpile Footprints

Year 10 Mine Pits

N

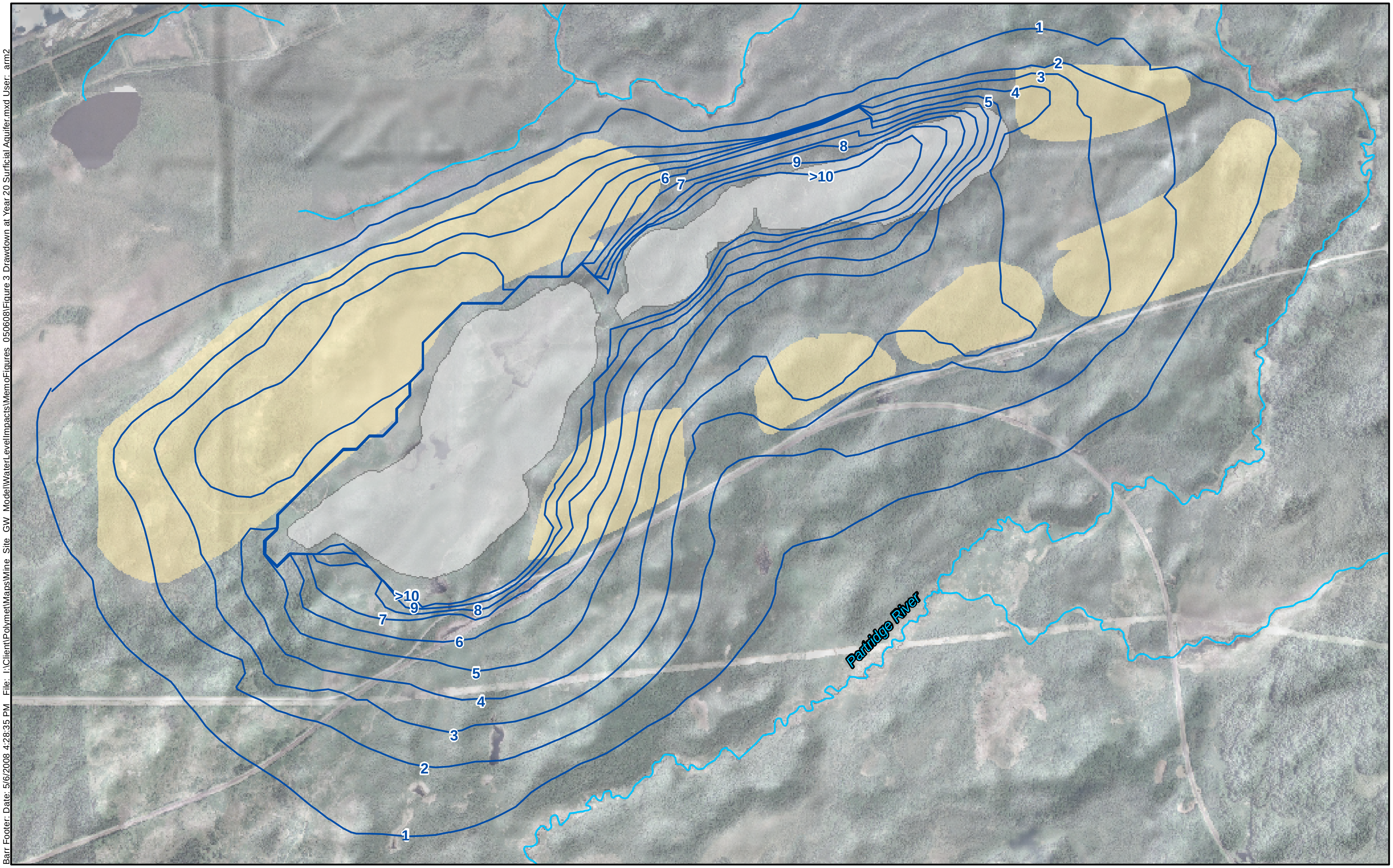
7,500 3,750 0 7,500

Feet

Figure 4-7

DRAWDOWN AT YEAR 11
BEDROCK AQUIFER

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Water Table Drawdown, ft
Contour Interval = 1 ft

Year 20 Stockpile

Year 20 Mine Pits

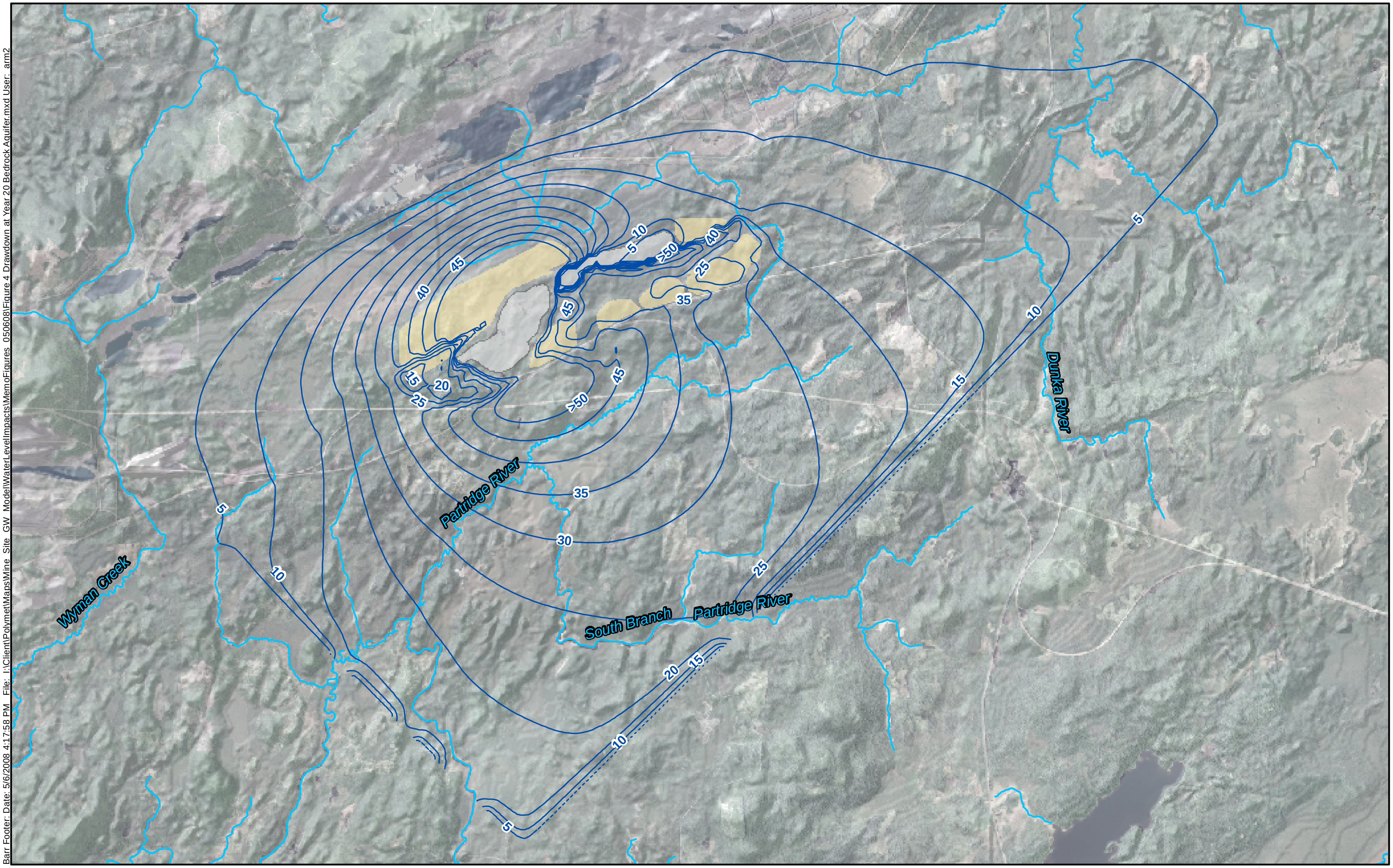
2,250 1,125 0 2,250

Feet

Figure 4-8

DRAWDOWN AT YEAR 20
SURFICIAL AQUIFER

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN



Water Table Drawdown, ft
Contour Interval = 5 ft

Year 20 Stockpile Footprints

Year 20 Mine Pits

7,500 3,750 0 7,500
Feet

Figure 4-9

DRAWDOWN AT YEAR 20
BEDROCK AQUIFER

NorthMet Project
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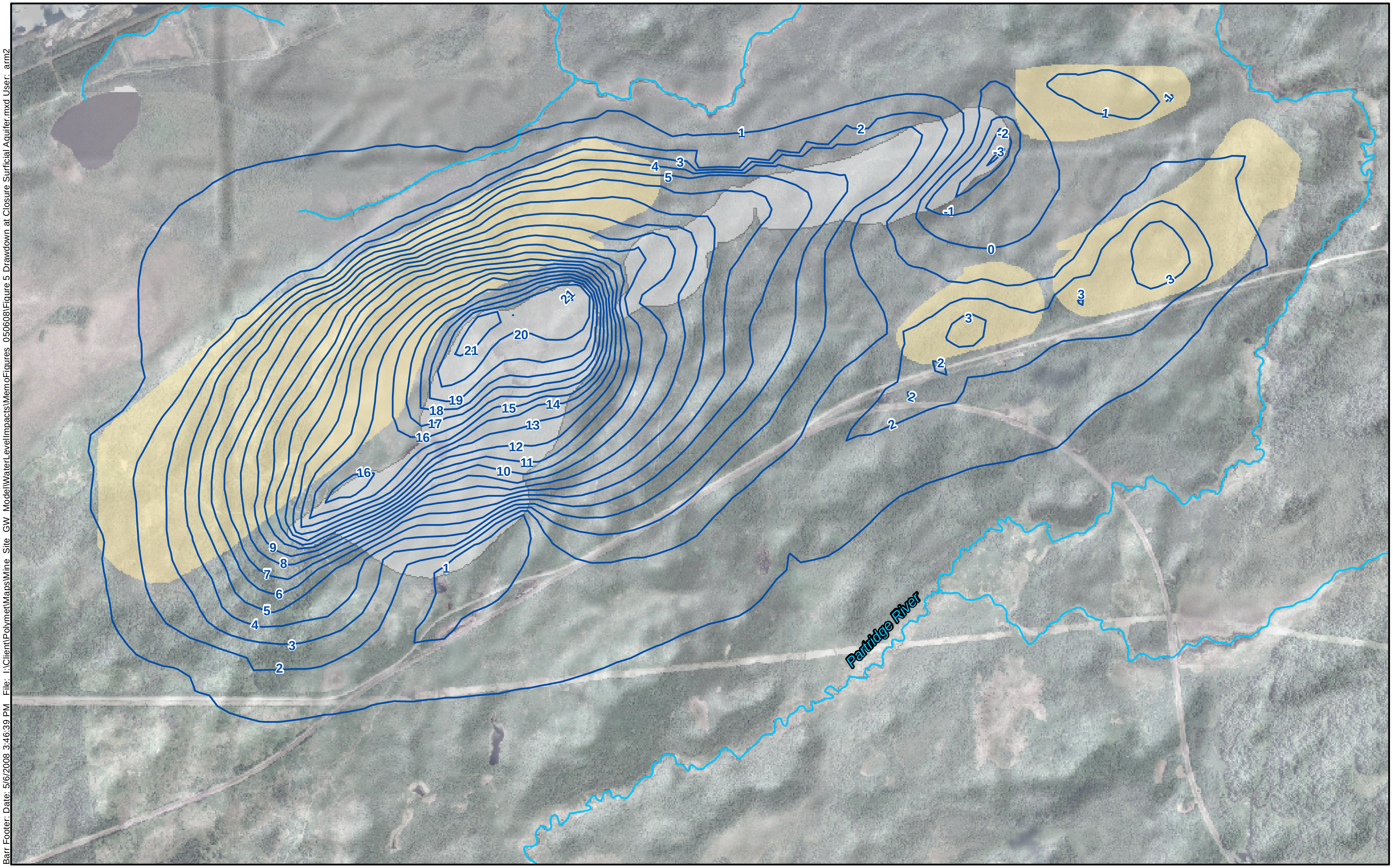

Figure 4-10

Water Table Drawdown, ft
Contour Interval = 1 ft

Year 20 Stockpile

Year 20 Mine Pits

2,250 1,125 0 2,250

Feet

DRAWDOWN AT CLOSURE
SURFICIAL AQUIFER

NorthMet Project
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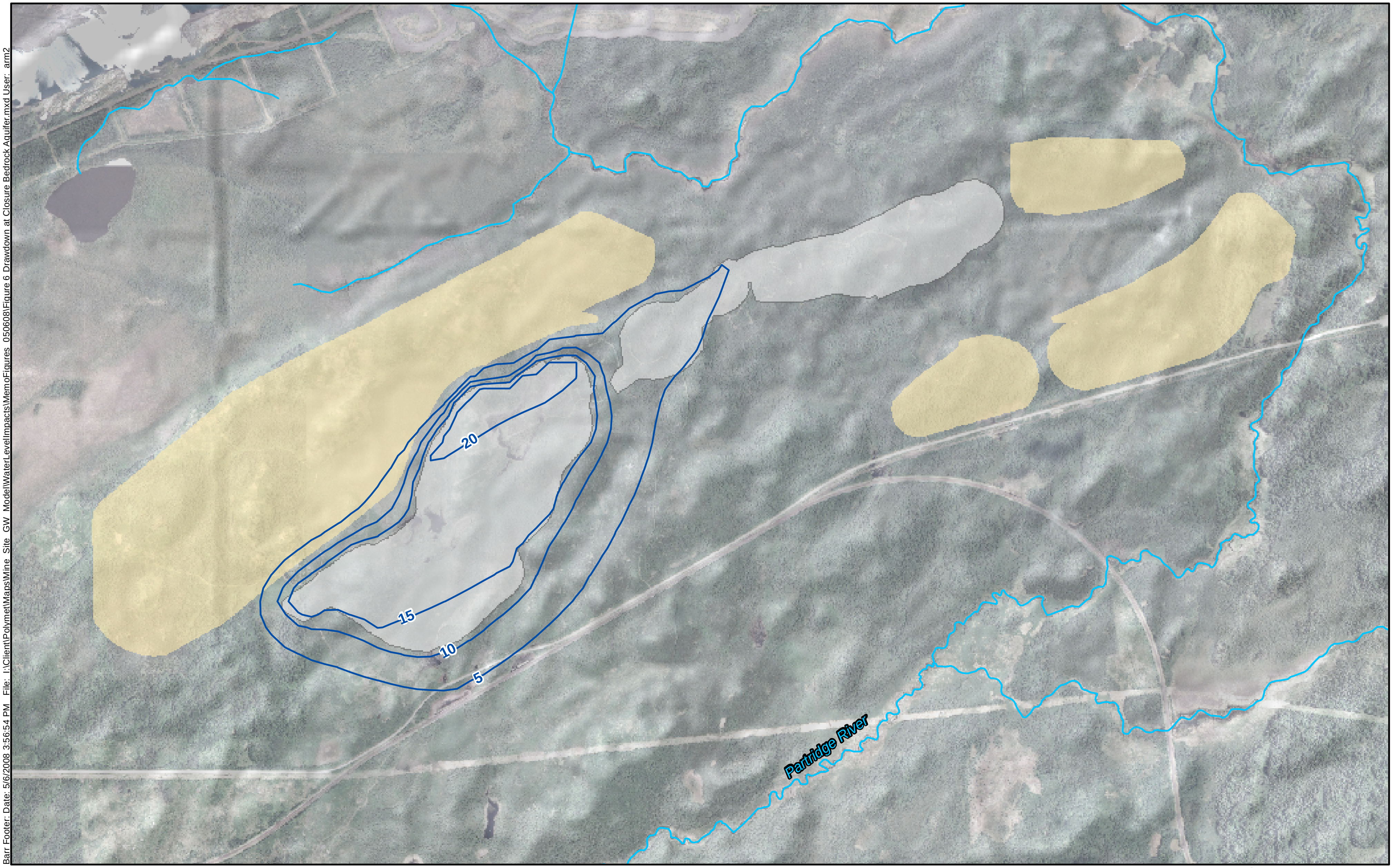

Figure 4-11

Bedrock Aquifer Drawdown, ft
Contour Interval = 5 ft

Year 20 Stockpile

Year 20 Mine Pits

2,250 1,125 0 2,250

Feet

DRAWDOWN AT CLOSURE
BEDROCK AQUIFER

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Attachment 1

Barr Engineering Company
332 West Superior Street, Suite 600 • Duluth, MN 55802
Phone: 218-727-5218 • Fax: 218-727-6450 • www.barr.com *An EEO Employer*

Minneapolis, MN • Hibbing, MN • Duluth, MN • Ann Arbor, MI • Jefferson City, MO

Technical Memorandum

To: Project File
From: Jeré Mohr and Tina Pint
Subject: NorthMet Bedrock Groundwater Elevation Measurements
Date: January 11, 2006
Project: 23/69-862 007 02D

This memorandum summarizes field activities and data analysis conducted to evaluate groundwater elevations and flow direction at the NorthMet Mine Site (Site). These results will be used for calibration of the groundwater model for the Site.

Proposed groundwater elevation measurement locations were selected to provide relatively uniform coverage across the Site. Groundwater levels were measured on December 13-14, 2006. Due to access issues, final groundwater elevation measurement locations were selected in the field. A total of 31 water levels were measured. The majority of measurements (19) were taken from PolyMet 2005 exploratory drill hole locations, as these were the easiest locations to access and open. Two measurements were collected from 1970s US Steel drill holes. The remainder of the measurements (10) were taken from Barr wells, which were installed in 2005 as part of Phase II of the Hydrogeologic Investigation. Borehole locations and measuring point elevations were surveyed by Northern Lights Surveying and Mapping of Virginia, MN between December 18 and December 29, 2006. The survey was completed using a real-time kinematic GPS survey system. Elevation measurements were referenced to mean sea level (MSL) and x,y coordinates were provided in both UTM (Zone 15 North, NAD83) and State Plane coordinate systems. Depth to groundwater measurements taken in angled boreholes were corrected to vertical depths in order to calculate groundwater elevations at these locations. Measurement locations and groundwater elevations are summarized in Table 1.

In order to check the accuracy of the survey data, the x,y coordinates of each location were compared to x,y coordinates supplied by PolyMet. Apparently, two locations were surveyed incorrectly, as there are large discrepancies (>50 ft) between the surveyed location and the PolyMet provided location. These two locations were removed from Table 1 and are not shown on Figure 1. By comparing the surveyed coordinates to the comprehensive list of borings provided by PolyMet, it believed that the location surveyed as 05-433M is actually 26128 and the location surveyed as 05-442N is actually 05-441. The surveyed ground surface elevations at each location were also compared to TIN elevation data provided by PolyMet. Except for the two locations mentioned previously, surveyed and estimated elevations appeared to generally coincide. As a final check, the casing stick up measured in the field at each location was compared to the stick up calculated using the survey data.

Groundwater elevation measurement locations and contoured groundwater elevations are shown in Figure 1. Groundwater elevations at 05-449N, 05-472N, 50-499N, 05-500Q, and 05-506H appeared to be anomalous and were not used for contouring. Groundwater appears to flow from northwest to southeast, which is generally consistent with the conceptual regional hydrogeologic model.

Table 1
Groundwater Elevations - December 13-14, 2006
PolyMet Mining, Inc.

Boring/Well	UTM Coordinates (m)		State Plane Coordinates (ft)		Dip (deg)	Borehole length (ft)	Vertical depth (ft)	Ground Elevation (ft)		Surveyed measuring point elevation (ft)	Measured distance to groundwater (ft)	Vertical depth to groundwater (ft)	Groundwater elevation (ft)	Comments
	x	y	x	y				Estimated from TIN	Surveyed					
26054	576265.1	5273526.7	2899614.0	735167.3	90	776	776.0	1598.2	1598.0	1600.32	6.04	6.04	1594.28	
26141	576169.1	5273296.6	2899299.7	734411.7	90	1585	1585.0	1592.4	1592.5	1595.12	2.37	2.37	1592.75	
05-405N	575952.8	5273409.7	2898589.4	734781.8	72	769	731.4	1606.8	1606.2	1607.29	1.40	1.33	1605.96	
05-414N	576265.1	5273331.4	2899614.7	734526.2	65	1438	1297.9	1592.5	1592.7	1593.64	12.10	10.92	1582.72	water level rising
05-424N	576571.1	5273641.3	2900617.4	735544.7	66	1087	992.3	1594.3	1593.6	1595.33	2.59	2.36	1592.97	
05-434N	576621.9	5273570.5	2900784.6	735312.5	65	729	662.8	1593.2	1592.6	1593.44	1.92	1.75	1591.69	
05-447G	577239.3	5274359.2	2902807.2	737903.5	46	499	359.0	1603.6	1605.3	1605.79	8.69	6.25	1599.54	water level rising
05-449N	578719.5	5274808.1	2907662.8	739383.2	64	1136	1016.2	1603.0	1601.7	1602.15	20.19	18.07	1584.08	
05-456Q	579027.4	5275016.7	2908672.1	740068.9	63	1169	1042.1	1598.9	1598.0	1599.47	2.00	1.78	1597.69	
05-472N	578578.1	5274808.2	2907198.6	739382.7	65	925	837.7	1603.9	1605.4	1606.42	8.11	7.34	1599.08	
05-473G	579026.5	5275122.8	2908668.8	740417.3	64	1059	954.2	1612.1	1609.4	1609.49	8.82	7.95	1601.54	
05-487N	578153.6	5274687.2	2905806.2	738983.7	65	906	821.3	1605.4	1604.6	1604.87	7.43	6.74	1598.13	
05-490N	577893.3	5274942.7	2904950.7	739821.4	45	218	154.1	1608.7	1609.5	1609.92	11.53	8.15	1601.77	
05-495N	578356.5	5274697.6	2906472.0	739018.9	66	1208	1100.1	1601.5	1599.8	1600.11	4.24	3.86	1596.25	
05-498N	576935.1	5274197.4	2901809.5	737371.3	66	598	544.2	1604.6	1610.7	1610.94	10.88	9.90	1601.04	
05-499N	576952.1	5273956.0	2901866.4	736579.0	65	908	821.6	1617.9	1620.7	1621.00	7.13	6.45	1614.55	
05-500Q	576775.7	5273922.2	2901287.7	736467.6	64	838	755.1	1614.7	1614.3	1614.64	7.86	7.08	1607.56	
05-505H	578331.7	5275068.9	2906388.8	740237.3	89	298	297.9	1608.4	1609.4	1609.62	7.41	7.41	1602.21	
05-506H	578420.4	5275083.1	2906680.0	740284.3	71	329	311.4	1617.5	1618.9	1619.23	10.98	10.39	1608.84	
OB-1	576938.8	5274551.3	2901820.1	738532.7	90	100	100.0	1610.2	1611.1	1613.21	12.60	12.60	1600.61	
OB-2	578216.3	5275040.0	2906010.4	740141.9	90	100	100.0	1609.0	1608.7	1610.70	8.75	8.75	1601.95	
OB-3	578710.1	5275261.2	2907629.7	740870.1	90	100	100.0	1615.9	1616.1	1617.85	10.47	10.47	1607.38	
OB-3A	578711.5	5275263.2	2907634.5	740876.5	90	50	50.0	1615.8	1615.8	1617.05	9.39	9.39	1607.66	
OB-4	578893.1	5275409.5	2908229.6	741357.3	90	100	100.0	1618.7	1619.5	1620.94	15.32	15.32	1605.62	
OB-5	579292.7	5275528.9	2909540.5	741750.9	90	100	100.0	1609.0	1609.3	1611.73	11.93	11.93	1599.80	
P-1	577016.0	5274605.2	2902073.2	738709.9	90	610	610.0	1614.1	1616.9	1617.79	16.53	16.53	1601.26	
P-2	578294.3	5275068.9	2906266.2	740237.3	90	610	610.0	1606.2	1606.3	1607.85	5.70	5.70	1602.15	
P-3	578730.5	5275289.7	2907696.7	740963.5	90	610	610.0	1615.4	1615.0	1619.57	11.86	11.86	1607.71	
P-4	579248.2	5275468.8	2909394.6	741553.5	90	485	485.0	1607.0	1608.2	1609.66	10.81	10.81	1598.85	

0 750 1,500
Feet

Groundwater elevation contour (ft MSL)
Contour interval = 2 ft

Groundwater elevation measurement used for contouring (ft MSL)

Groundwater elevation measurement not used for contouring (ft MSL)

Figure 1

GROUNDWATER ELEVATIONS
DECEMBER 13-14, 2006
PolyMet Mining Co.
Hoyt Lakes, MN