

Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, CO USA 80228
Telephone: (303) 980-0540
Fax: (303) 985-2080
www.golder.com



REPORT ON

BEDROCK HYDROGEOLOGICAL MODELING TO ASSESS INFLOW TO PROPOSED EAGLE PROJECT

Submitted to:

Kennecott Eagle Minerals Company

DISTRIBUTION:

- 1 Copy - Kennecott Eagle Minerals Company
- 2 Copies - Golder Associates Ltd.
- 1 Copy - Golder Associates Inc.

February 10, 2006

05-3236-2c

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 INTRODUCTION.....	1
1.1 Work Flow.....	1
1.2 Report Format	2
2.0 GEOLOGY	3
2.1 Quaternary Geology of the Project Area	3
2.2 General Bedrock Geology – Yellow Dog Plains, Marquette County, Michigan	3
3.0 PRELIMINARY CONCEPTUAL MODEL BASED ON PHASE I BEDROCK HYDROGEOLOGIC INVESTIGATION.....	4
3.1 Alluvium	4
3.2 Upper Bedrock Hydrostratigraphic Unit	4
3.3 Lower Bedrock Hydrostratigraphic Unit	4
3.4 Incorporation of the Preliminary Conceptual Model into the Preliminary Numerical Model.....	5
4.0 MINE SCHEDULE.....	7
5.0 PRELIMINARY NUMERICAL MODEL	8
5.1 Numerical Code Selection	8
5.2 Finite Element Mesh.....	9
5.3 Values of Model Parameters	9
5.4 Boundary Conditions and Initial Conditions.....	10
5.5 Verification of Inflow from Single Water Conductive Feature	11
6.0 INFLOW PREDICTIONS WITH THE PRELIMINARY NUMERICAL MODEL.....	13
6.1 Predicted Inflows – Preliminary Numerical Model	13
7.0 NEW DATA SINCE DEVELOPMENT OF THE PRELIMINARY NUMERICAL MODEL	14
7.1 2005 Phase II Bedrock Investigation	14
7.2 Borehole Orientation versus Fracture Orientation	16
7.3 Correlation between Geologic Structures and Groundwater Flow	16
7.4 Conclusions and Recommendations for Model Refinement.....	17
8.0 REVISION OF THE NUMERICAL HYDROGEOLOGIC MODEL	18
8.1 Model Calibration to the 04EA-84 Pumping Test	18
8.2 Base Case and Upper Bound Case Models.....	20
9.0 REVISED INFLOW PREDICTIONS	22
10.0 RECOMMENDATIONS.....	23
11.0 CLOSURE	24
12.0 REFERENCES.....	25

LIST OF TABLES

Table 4.1	15 February 2005 Mine Development Schedule
Table 5.1	Values of Hydrogeologic Parameters used in the Model
Table 7.1	Comparison of Structure Data with Hydrogeologic Data
Table 7.2	Flow Anomalies Associated with Packer Tests
Table 9.1	Predicted Mine Inflow – Base Case and Upper Bound Case

LIST OF FIGURES

Figure 1.1	Regional Overview
Figure 1.2	Work Flow Used to Develop the Bedrock Numerical Model
Figure 3-1	Preliminary Conceptual Model – East-West Cross Section
Figure 3-2	Preliminary Conceptual Model – Plan View-Simplified Representation of Spatial Distribution of Water Conductive Features within Lower Bedrock
Figure 4.1	15 February 2005 Mine Plan - Northwest Isometric View
Figure 5.1	FEFLOW Finite Element Mesh
Figure 5.2	Hydraulic Properties for Bulk of the Rock Mass
Figure 5.3	Representation of Water Conductive Features within the Lower Bedrock
Figure 5.4	Boundary Conditions – Typical Cross-Section
Figure 6.1	Predicted Hydraulic Heads at the end of Mining: Preliminary Model
Figure 6.2	Predicted Drawdown at the end of Mining: Preliminary Model
Figure 7.1	Trace of AMEX Study Fault and Relation to Hydrogeologic Boreholes
Figure 7.2	Borehole 04EA-47 Major Structures Compared to Hydrogeologic Data
Figure 7.3	Borehole 04EA-54 Major Structures Compared to Hydrogeologic Data
Figure 7.4	Borehole 04EA-73 Major Structures Compared to Hydrogeologic Data
Figure 7.5	Borehole 04EA-77 Major Structures Compared to Hydrogeologic Data
Figure 7.6	Borehole 04EA-83 Major Structures Compared to Hydrogeologic Data
Figure 7.7	Borehole 04EA-84 Major Structures Compared to Hydrogeologic Data
Figure 8.1	Measured vs. Simulated Drawdown – Preliminary Model – 04EA-84 Pumping Test
Figure 8.2	Measured vs. Simulated Pressure Derivative – Preliminary Model – 04EA-84 Pumping Test
Figure 8.3	Measured vs. Simulated Drawdown – Revised Model – 04EA-84 Pumping Test
Figure 8.4	Adjustment of Water Conductive Feature Length – Measured vs. Simulated Drawdown – 04EA-84 Pumping Test
Figure 8.5	Measured vs. Simulated Drawdown – Observation Wells – Revised Model – 04EA-84 Pumping Test
Figure 8.6	Representation of Water Conductive Features within the Lower Bedrock – Revised Model
Figure 9.1	Predicted Inflow to Proposed Mine
Figure 9.2	Predicted Hydraulic Heads at the End of Mining – Base Case
Figure 9.3	Predicted Hydraulic Heads at the End of Mining – Upper Bound Case
Figure 9.4	Predicted Drawdown at the End of Mining – Base Case
Figure 9.5	Predicted Drawdown at the End of Mining – Upper Bound Case

1.0 INTRODUCTION

On behalf of Kennecott Minerals Company (KMC), Golder Associates Ltd. (Golder) developed a numerical hydrogeologic model to simulate groundwater flow in the bedrock in the area of the Eagle Project (Project) in Michigan's Upper Peninsula (Figure 1.1). The primary objective of the model is to provide a reliable predictive tool for mine inflows to assist in the ongoing mine planning. This report represents the chronological development of the model.

The model does not include a rigorous simulation of the overburden sediments, as this is not considered necessary to meet the above objectives. A separate more comprehensive model of the overburden and shallow bedrock is being developed for the Project by Fletcher Driscoll in conjunction with North Jackson Company (Fletcher Driscoll, 2006).

All depths are reported as measured along borehole in meters (m) unless otherwise noted.

1.1 Work Flow

The work flow was an iterative process of hydrogeologic data collection, geotechnical data evaluation and numerical modeling as illustrated in Figure 1.2. In general, the work flow consisted of the following well established steps for the development of a reliable predictive tool (Anderson and Woessner, 1992):

- Data collection;
- Development of a Preliminary Conceptual and Preliminary Numerical Model;
- Identification of additional data needs;
- Additional data collection; and,
- Refinement of the hydrogeological model based on the additional data.

1.2 Report Format

This report has the following format:

- Section 2: describes site geology;
- Sections 3: reviews the Preliminary Conceptual Model that was developed after the Phase I Bedrock Hydrogeologic Investigation;
- Section 4: summarizes the mine schedule assumed in the model;
- Section 5: describes the development of the Preliminary Numerical Model;
- Section 6: discusses the mine inflow estimates based on the Preliminary Numerical Model;
- Section 7: reviews the data that was collected since the development of the preliminary models;
- Section 8: compares the recent data to the parameters used in the preliminary models and provides recommendations for model refinement;
- Section 9: provides mine inflow estimates based on the refined hydrogeologic models; and,
- Section 10: provides recommendations for continued model development as additional data is collected.

2.0 GEOLOGY

2.1 Quaternary Geology of the Project Area

Regional geologic maps for the Project Area indicate that the site is covered by surficial deposits of unconsolidated, Quaternary glacial outwash and post-glacial Quaternary deposits. The thickness of these deposits generally ranges from 18 to 54 m (North Jackson Company, 2005). Further information on the Quaternary Geology of the Project Area can be found in the Eagle Project Environmental Baseline Study Stage 1 Hydrology Report (North Jackson Company, 2005).

2.2 General Bedrock Geology – Yellow Dog Plains, Marquette County, Michigan

The Yellow Dog Plains in northern Marquette County is composed of Precambrian rocks overlain by glacial and post-glacial Quaternary sediments. The bedrock beneath the plains is mostly metasedimentary rocks of the Michigamme Formation, part of the Marquette Range Supergroup of Proterozoic age rocks (roughly 2 billion years old). These metasedimentary rocks are contained in an east-west trending structural trough known informally as the Baraga Basin (Klasner, *et al.*, 1979). This trough is flanked on the north, south and east by gneiss and greenstone Archean basement rocks, older than 2.5 billion years. Because of the extensive Quaternary deposit cover on the plains, very little exposure of the Michigamme Formation exists in this area. The Archean basement rocks have numerous outcrop exposures surrounding the Baraga Basin.

The Michigamme Formation beneath the Yellow Dog Plains consists of fine-grained clastic rocks, predominately black slate and argillite as indicated by core drilling (Klasner, *et al.*, 1979). These rocks were deformed and metamorphosed to greenschist facies about 1.9 billion years ago, during the Penokean orogenic event.

Emplaced into the Michigamme Formation are east to west-trending diabase dikes of early Keweenaw age, intruded about 1.1 billion years ago. The Yellow Dog Peridotite is present in the central Yellow Dog Plains, and is known from two outcrops located in T50N, R29W, Section 11 and 12, along one of these dike trends. The Eagle nickel mineralization prospect is located within the Peridotite near the outcrop located in Section 11. The Peridotite is generally undeformed and only moderately serpentinized (Klasner, *et al.*, 1979). The higher-grade mineralization either post dates or is syn-deformation. The deformation event is best characterized as a WNW-ESE trending dextral shear couple with evidence of dilation. The event may have been responsible for the location of, and controls the shape of, the intrusive units including the massive and semi-massive sulfide mineralization. Major structures could exist on the edges or contacts of the earlier intrusions, including gabbros, pyroxenites and peridotites containing disseminated sulfides.

3.0 PRELIMINARY CONCEPTUAL MODEL BASED ON PHASE I BEDROCK HYDROGEOLOGIC INVESTIGATION

A Preliminary Conceptual Model was developed previously based on the 2004 Field Program, referred to as Phase I, and it is presented in Golder (2005). The Preliminary Conceptual Model consists of two main hydrostratigraphic units – an Upper Bedrock and a Lower Bedrock - and these will be discussed in the following sections. The results of tests and monitoring conducted in overburden sediments during the Phase I investigation will also be discussed; however, as presented above, the overburden material was not explicitly simulated in this model as it was not considered necessary to meet the study objectives.

3.1 Alluvium

The main focus of the Phase I hydrogeologic investigation was the bedrock; Golder collected very little data on the overburden sediments during field investigations. A well was installed in alluvial sediments in the vicinity of the collars of boreholes in which packer testing was conducted within the bedrock. During these packer tests, no response was observed in this alluvium well (Golder, 2005). A slug test was performed in the well and a hydraulic conductivity of 4.1×10^{-7} m/s was calculated from this test. The well was completed within a sandy unit (located between 7.92 and 9.45 m) which was underlain by silty clay located between 9.45 m and the top of the bedrock at 11.28 m.

3.2 Upper Bedrock Hydrostratigraphic Unit

The upper section of the bedrock was found to have a higher hydraulic conductivity compared to the bedrock at depth. Based on the results of packer tests conducted in four boreholes (Golder, 2005), the Upper Bedrock is estimated to extend from the bottom of the overburden material down to approximately 90 mTVD (true vertical depth) or approximately 345 m geodetic elevation. The geometric mean average hydraulic conductivity from tests performed within this interval is approximately 2×10^{-8} m/s.

3.3 Lower Bedrock Hydrostratigraphic Unit

The Lower Bedrock is considered to be located from 90 mTVD to at least 323 mTVD , which is the depth of the deepest borehole in the Phase I investigation (Golder, 2005). The Lower Bedrock is further subdivided into two hydrostratigraphic units: relatively unfractured bedrock (rock mass) and water conductive features (joints, fractures, fractured rock zones, etc. that have significant hydraulic conductivity above the matrix/background fracture network).

The relatively unfractured bedrock has a very low hydraulic conductivity with a geometric average of 5×10^{-10} m/s based on testing in four boreholes. This hydraulic conductivity value is consistent with published values for relatively unfractured bedrock (Freeze and Cherry, 1979). It likely represents the hydraulic conductivity of intact rock mass with some minor poorly connected fractures (also generally referred to as matrix/background fracture network).

Two localized zones of relatively moderate hydraulic conductivity within an otherwise low hydraulic conductivity rock mass were identified in two boreholes below 90 mTVD (approximately 345 m geodetic elevation). These localized zones are attributed to flow in discrete features such as fractures and/or fractured rock zones and hereafter will be referred to as water conductive features. The largest flow anomaly in borehole 04EA-84 was also isolated for hydraulic testing and a transmissivity value of 3×10^{-6} m²/s was estimated from the analysis (Golder, 2005). As the saturated thickness of such features is unknown, but likely less than the testing interval of 3 m, the transmissivity, which is the hydraulic conductivity times the saturated thickness, will be reported for these features.

3.4 Incorporation of the Preliminary Conceptual Model into the Preliminary Numerical Model

A schematic for the Preliminary Conceptual Model that provides the basis for the Preliminary Numerical Model is presented in Figures 3.1 and 3.2 and the components of this model are described below:

- Upper Bedrock: bottom of overburden down to 90 mTVD with a hydraulic conductivity of 2×10^{-8} m/s;
- Lower Bedrock: >90 mTVD with a hydraulic conductivity of 5×10^{-10} m/s and comprises the majority of rock mass; and,
- Water Conductive Features within Lower Bedrock: >90 mTVD that are sparsely distributed in the rock mass with a transmissivity of 3×10^{-6} m²/s.

The simplifying assumptions for representing the geometry and spatial distribution of the water conductive features within the otherwise low hydraulic conductivity Lower Bedrock are summarized below:

- The water conductive features at depth are assumed to be vertical and terminate at the Upper Bedrock/Lower Bedrock contact. The reason for this latter assumption is that the calculated hydraulic conductivity values for all the boreholes tested in the Phase I Investigation (Golder, 2005) were found to be significantly higher in the Upper Bedrock than the Lower Bedrock. This higher hydraulic conductivity is attributed to higher intensity of open fractures that result from ground surface related effects and expected to decrease in intensity with depth. Ground surface-related fractures may develop during unloading, release of stored stress and strain, creation of free surfaces or unsupported boundaries and from weathering in general (Nelson, 2001). In contrast, the water conductive features at depth are probably not surface related, are not found in all boreholes and appear to be sparsely distributed. Because of the difference in distribution and origin, the Upper Bedrock is considered to be one hydrostratigraphic unit and the Lower Bedrock consists of two subunits – the relatively unfractured bedrock that comprises the majority of the rock mass and the water conductive features at depth. If the water conductive features at depth were extended into the Upper Bedrock, then the bulk hydraulic conductivity value for the Upper Bedrock would need to be lowered.
- The water conductive features are assumed to have a transmissivity of $3 \times 10^{-6} \text{ m}^2/\text{s}$ based on one test in a water conductive feature in borehole 04EA-84 (Golder, 2005), which was the largest flow anomaly of the six boreholes in which flow logging was performed.
- The thickness of the water conductive features is unknown but for simplicity a thickness of 1 m is assumed to represent these features in the numerical model.
- The spatial distribution for the water conductive features is simplified to an orthogonal pattern (consistent with a regional fracture system) with an east-west direction and a north-south direction.
- The spacing for the east-west trending water conductive features is assumed to be 226 m based on one water conductive feature per 226 m equivalent horizontal length in boreholes 04EA-47, 04EA-73, 04EA-77 and 04EA-83. These boreholes are orientated north-south (azimuth 180°; Golder, 2005).
- The spacing for the north-south trending water conductive features is assumed to be 120 m based on one water conductive feature observed over an equivalent horizontal length of 120 m in borehole 04EA-84. This borehole is orientated east-west (azimuth 100°; Golder, 2005).

4.0 MINE SCHEDULE

KMC provided Golder with a mine schedule, referred to as the 15 February 2005 Mine Development Schedule, which was prepared by McIntosh Engineering. The schedule indicates that the orebody would be mined using underground mining methods over a period of 10 years, and that the total production would be approximately 3,675,000 tons. Table 4.1 and Figure 4.1 present yearly production rates and information on the proposed mine workings.

In general, mining would consist of the following steps:

- Year -2: Construction of a decline from the ground surface to 263 m elevation;
- Year -1: Construction of a decline from 263 m geodetic elevation to 143 m elevation;
- Year 1 to 3: Mining from 143 m geodetic elevation to 263 m elevation;
- Year 4 to 6: Construction of an incline from 263 m geodetic elevation to 383 m elevation; and,
- Year 4 to 8: Mining from 263 m geodetic elevation to 383 m elevation.

5.0 PRELIMINARY NUMERICAL MODEL

5.1 Numerical Code Selection

The appropriate numerical code to be applied to the site must be capable of simulating all of the hydrogeological conditions identified in the conceptual model. These conditions include:

- Flow of groundwater in relatively unfractured rock which could be represented as an equivalent porous media;
- Potential presence of discrete and thin water conductive features;
- Changes of hydrogeological properties with depth; and,
- Complex boundary conditions resulting from mine development over a 10-year period.

Although not required at this stage of the Project, the selected numerical code should be sufficiently flexible to allow, if necessary, expanding the model domain for simulation of shallow groundwater flow in the overburden.

Considering the above, the three-dimensional model of groundwater flow was developed using FEFLOW, a numerical code from WASY Institute in Germany (Diersch, 2004). FEFLOW is capable of simulating density-dependent groundwater and heat flow in three-dimensions in heterogeneous and anisotropic porous media using the method of finite elements. This modeling code has been continuously updated since its initial development in 1979. It has been extensively tested, and has been applied to numerous sites worldwide. FEFLOW was chosen over MODFLOW, a finite difference modeling code from the United States Geological Survey (Harbaugh et al., 2000), for the following reasons:

- Capability of simulating discrete features, like fractured rock zones and faults: In addition to simulation of porous media type flow, FEFLOW includes 1D and 2D discrete feature elements. These elements can be placed at arbitrary orientations within the model mesh, along the alignment of permeable fractures or faults. Thus, FEFLOW allows simultaneous simulation of equivalent porous media flow in relatively unfractured rock and flow in a discrete network of fractures or water conductive features. MODFLOW was designed to simulate porous media type flow, and cannot readily represent fracture type flow along thin conductive features.

- Capability for representing the details of mine workings and site hydrostratigraphy: FEFLOW uses the finite element method to solve the equations governing groundwater flow and transport. Triangular finite element meshes can better represent complex geometries and boundary conditions that arise when mine workings are simulated in the groundwater model. This is because the dimensions of finite elements in areas of interest can be significantly refined without the need to carry this finer element spacing to the edges of the model domain. MODFLOW uses the finite difference method that is based on a rectangular grid. Any refinements to grid spacing near the mine workings need to be transferred to the entire grid rows and/or columns. This results in elongated gridblocks along the model perimeter that can lead to model instability. Typically, the number of gridblocks used by MODFLOW when compared to the number of finite elements used by FEFLOW is much larger for a given application. A smaller number of elements reduces the duration of an individual simulation and consequently the FEFLOW model is generally more efficient.

5.2 Finite Element Mesh

The extent of the model domain is presented in Figure 5.1. The horizontal extent of the model is identical to the extent of the MODFLOW model that is being developed for the overburden by Fletcher Driscoll in conjunction with North Jackson Company. The domain covers an area of approximately 87 km² from 427100 m E to 440500 m E and from 5172700 m N to 5182900 m N.

The finite element mesh consists of over 180,000 triangular elements. In the horizontal direction the average size of the elements varies from approximately 25 m near the proposed mine workings to 200 m along the perimeter of the model domain. Vertically the model is divided into 14 layers that are horizontally uniform. The model top is set at 413 m geodetic elevation, which represents the average elevation of the top of bedrock in the vicinity of the proposed mine. Layers 1 to 9 are spaced every 30 m extending to the bottom of the mine workings at 143 elevation. The thicknesses of the remaining layers are gradually increased with the bottom of layer 14 located at -250 m geodetic elevation. This mesh design provides model resolution that is considered sufficient to adequately represent groundwater flow conditions near the proposed mine.

5.3 Values of Model Parameters

The values of hydrogeologic parameters used in the Preliminary Numerical Model are based on the Preliminary Conceptual Model discussed above and are presented in Table 5.1 and Figure 5.2. A hydraulic conductivity of 2×10^{-8} m/s was assigned to model layers 1 and 2 that represent the Upper Bedrock. Specific yield and specific storage of

this unit were set to 0.01 (m/m) and 1×10^{-5} 1/m, respectively. Model layers 3 to 14 which represent the Lower Bedrock were assigned a hydraulic conductivity of 5×10^{-10} m/s, specific yield of 0.005 (m/m), and specific storage of 1×10^{-6} 1/m. Values of storage parameters correspond to the mid-range of storage parameters for igneous and metamorphic rocks as presented in Maidment (1992).

The two-dimensional discrete fracture elements were used to simulate the water conductive features in the vicinity of the proposed mine workings (Figure 5.3). These features were assigned a transmissivity of 3×10^{-6} m²/s, specific yield of 0.1 (m/m), and specific storage of 1×10^{-5} 1/m. In the east-west direction the features are spaced every 120 m, and in the north-south direction the spacing is 225 m. The features extent at least 500 m from the mine workings, and their overall length varies from 1 km to 2 km. In the vertical direction all features extend from the top of the Lower Bedrock (layer 3) to the model bottom (layer 14). At greater horizontal distance from the proposed mine the water conductive features are not simulated under the assumption that these features would not likely be well connected and transmissive over distances greater than 1 to 2 km. Experience from other mine sites suggests that only major fractured rock zones, not identified at the site during recent field investigation, could be conductive and transmissive on the scale of several kilometres.

5.4 Boundary Conditions and Initial Conditions

Figure 5.4 presents boundary conditions used in the Preliminary Numerical Model. Two types of boundary conditions were assigned to the model mesh: specified head and no-flow (zero flux) boundaries.

A specified head boundary was applied to the top of model mesh and assigned a uniform value of 433 m geodetic elevation, which corresponds to the average watertable elevation in the overburden above the proposed mine. This boundary represents leakage from the overburden to bedrock that is assumed to occur in response to mine dewatering. Specified heads provide an infinite source of leakage, thus using this type of boundary is considered to provide conservatively high estimates of leakage from the overburden sediments. In reality, at locations where low-permeability till underlies a surficial aquifer the leakage from the overburden may be less than simulated by the model. No response was observed in the alluvium to the short-term testing performed in the bedrock (Golder, 2005), which suggests that the hydraulic connection between the bedrock and the alluvium is relatively weak within the zone influenced by the tests. Although this boundary condition simulates the leakage from the overburden, the model does not explicitly represent the overburden flow conditions. However, this method of representing the overburden is considered to have relatively little affect on the model predicted inflows.

Specified heads were also used to represent the proposed mine workings. Mesh nodes along declines, ramps, and stopes were assigned specified heads equal to node elevation, and were constrained to allow only inflow into the mine. These boundaries were sequentially activated during model runs to simulate the progress of mining as outlined in the mine schedule.

A no flow boundary was assigned to the model bottom at an elevation of -250 m geodetic elevation, or approximately 400 m below the base of the proposed mine. Considering that the bulk hydraulic conductivity likely decreases with depth, it was assumed that groundwater inflow to the mine from beneath -250 elevation would be negligible compared to inflow originated from above this elevation. No flow boundaries were also assigned along the model perimeter in layers 2 to 14. Preliminary analytical calculations and model simulations suggested that the cone of depression resulting from mine dewatering does not extend to this distance.

Initial hydraulic head conditions for the simulation of mine dewatering were assumed to be hydrostatic across the Project Area. Hydrostatic conditions imply that the hydraulic head does not vary in space and, in the absence of hydraulic gradient, groundwater flow is essentially nil. This was represented in the model by assigning an initial head of 433 m geodetic elevation (approximate elevation of watertable above the proposed mine) to all mesh nodes. Recent site data (Golder, 2006) suggest that the vertical hydraulic gradient is relatively small. Some horizontal flow of groundwater in bedrock likely occurs under natural conditions, however, considering that the hydraulic stresses imposed by the planned mine dewatering are expected to be significantly larger than those of the natural flow conditions, the inflow resulting from natural groundwater flow is expected to be negligible.

5.5 Verification of Inflow from Single Water Conductive Feature

The predictive capabilities of the Preliminary Numerical Model were verified against order-of-magnitude inflow estimates provided by Golder (2005). The idea behind this verification was to ensure that the numerical model was capable of reproducing these initial estimates. The order-of-magnitude estimates utilized an analytical model for flow in a confined aquifer, and were based on following assumptions:

Underground opening was represented by a 150 m long tunnel with effective radius of 1.5 m;

- The tunnel intersected one permeable feature over its length. The transmissivity of this feature was set at $3 \times 10^{-6} \text{ m}^2/\text{s}$; and,

- The tunnel was located near the base of the proposed mine workings. The inflow to the tunnel was calculated using the analytical solution to be approximately $90 \text{ m}^3/\text{day}$ (16 US gallons per minute – USgpm) 1,000 days after tunnel construction (Golder, 2005).

A similar underground opening was simulated in the Preliminary Numerical Model by assigning a specified head boundary in a permeable feature near the based of the proposed mine. The model was then run in transient mode for a period of 1000 days. The corresponding inflow was approximately $110 \text{ m}^3/\text{day}$ (20 USgpm). This slightly higher value is likely the result of the single water conductive feature in the Preliminary Numerical Model intersecting the tunnel as well as a network of similar features, whereas the analytical model did not incorporate such a network. Consequently it was concluded that the Preliminary Numerical Model was in good agreement with analytical solution.

6.0 INFLOW PREDICTIONS WITH THE PRELIMINARY NUMERICAL MODEL

The Preliminary Numerical Model was used to predict inflows over the life of the proposed mine. All simulations were based on the following assumptions:

- The mine will be developed over a period of 10 years based on the 15 February 2005 Mine Development Schedule;
- Once completed, all mine workings will remain open until the end of mining. No backfilling will take place; and,
- Grouting ahead of decline advancement, or other measures to mitigate localized inflows, will not be implemented.

The latter two assumptions are considered conservative because they will result in a higher estimate of inflow, as backfilling is planned and mitigation measures may be implemented to reduce mine inflow.

6.1 Predicted Inflows – Preliminary Numerical Model

Figures 6.1 and 6.2 present the hydraulic heads and drawdowns predicted at the end of mining using the Preliminary Model. The model results suggest that the average annual inflow will increase to approximately 1,000 m³/day (180 USgpm) in year 3 and then decrease slightly later in mine life. The drawdown cone in bedrock, defined by the 1 m drawdown contour, is predicted to extend radially away from the proposed mine to a distance of approximately 1,400 m.

7.0 NEW DATA SINCE DEVELOPMENT OF THE PRELIMINARY NUMERICAL MODEL

This section describes the data that was assessed and collected since the development of the Preliminary Numerical Model and provides recommendation for refinement of the Preliminary Numerical Model based on the new data.

7.1 2005 Phase II Bedrock Investigation

A summary of the results of the 2005 Phase II Bedrock Investigation (Golder, 2006) is provided in the following:

- Majority of the overlapping fixed-interval double-packer tests in borehole 05EA-107 were performed in the Upper Bedrock hydrostratigraphic unit. The geometric mean hydraulic conductivity from these tests of 1.4×10^{-08} m/s shows good consistency with the geometric mean value of 2×10^{-08} m/s for the Upper Bedrock hydrostratigraphic unit based on the Phase I investigation (Golder, 2005b).
- The bottom portion of borehole 04EA-084 was isolated with a packer with the majority of flow controlled by a water conductive feature. This water conductive feature showed the largest flow anomaly (257.54 to 260.29 m) of the six boreholes with flow logging records and analysis of the short duration test performed in 2004 resulted in an estimated transmissivity of 3.1×10^{-06} m²/s (Golder, 2005b). A seven day pumping test and a seven day recovery test was performed to assess the large-scale properties for the water conductive feature.
- Based on the analysis of the source zone data from the borehole 04EA-084 pumping test, the estimates for local transmissivity matched to early time data shows a range between 2.0×10^{-06} and 3.7×10^{-06} m²/s while the relatively large scale transmissivity derived from the late time data shows a variation between 2.1×10^{-07} and 2.8×10^{-07} m²/s. The decrease in transmissivity away from the well is attributed to transition from flow in a water conductive feature in early time to flow in a lower transmissivity matrix/background fracture network in late time. The decrease in transmissivity indicates that the water conductivity feature is limited in extent and poorly connected to other water conductive features. Analysis for estimates of the length of the water conductive feature and sensitivity analysis shows an estimated range between 96 and 320 m.

- Based on the analysis of two of the four responding observation zone data from the borehole 04EA-084 pumping test, the estimates for transmissivity vary between 1.3×10^{-07} and $2.6 \times 10^{-07} \text{ m}^2/\text{s}$, consistent with the values derived from the late time data from the analysis of the source zone. From the time match, storativity values of 2.5×10^{-06} and 1.6×10^{-05} were derived from the analyses. The remaining two responding zones were poorly connected to the source zone, based on the low diffusivity estimates, and no analysis was performed.
- Three water samples were collected from a relatively shallow depth, an intermediate depth and a relatively deep depth with respect to the proposed mining. Prior to sampling, a minimum of six system volumes were removed from the intervals and field parameters were relatively stable at the time of sampling. The shallow water sample is characterized as sodium-bicarbonate water while the intermediate and deep samples are characterized as sodium-chloride type water. The TDS increases with depth. For the relatively deep sample collected from the bottom of borehole 04EA-084, the TDS concentrations showed a variation between 3,500 and 4,000 mg/L, which is considered moderately saline, and was relatively stable throughout the pumping test.
- In order to calculate the environmental water head to evaluate vertical gradients at the Project site it was necessary to determine both the static formation pressure and the groundwater density profile. Regression on the two deep samples intercepts the freshwater density/salinity line at about 95 mTVD (approximately 340 m geodetic elevation). The more saline water with depth indicates poorer hydraulic communication between the alluvium aquifer and the deeper bedrock and attributed to decreasing hydraulic conductivity with depth, consistent with the conceptual model for the site. The analyses concluded that the overall trend indicates a negligible average vertical gradient for the Project site.
- The alluvium wells that were monitored during testing in the bedrock showed no response to testing with one exception. A subdued and delayed response was observed in one alluvium well during consecutive slug test #2. As the lag time was 30 hours between the start of the test in the bedrock and the first measured response, and considering the relatively small distance between the top of the test interval and the alluvium (about 4 m), the response is consistent with relatively low hydraulic conductivity bedrock that attenuates the vertical propagation of the pressure transients. In addition, the water conductive feature isolated for testing in borehole 04EA-84 shows distinct differences in water quality (higher TDS in particular) compared to the alluvium and confirms the poor hydraulic communication with the alluvium sediments. Overall, as the bedrock contains relatively low hydraulic conductivity, and lower than the alluvium sediments, the relatively poor hydraulic communication between the alluvium and the bedrock groundwater systems is attributed to the relatively low hydraulic conductivity of the bedrock.

7.2 Borehole Orientation versus Fracture Orientation

In general, two major joint sets have been defined (2005 Geotechnical Data Base); a near horizontal and a near vertical set. The trends of the joints are quite varied and no distinct sets were identified based on trend alone. As mentioned above, the Preliminary Conceptual Model was based on measurements in six boreholes. These boreholes varied in azimuth between 0° and 180° and varied in inclination between vertical and -56°. As these boreholes were likely to have intersected both the near horizontal and the near vertical joint sets, it appears that the hydraulic properties that were measured from the boreholes provide a representative data base.

7.3 Correlation between Geologic Structures and Groundwater Flow

The hydraulic properties of geologic structures can vary between localized conductors of flow to barriers to flow. To evaluate the hydraulic properties of structures at the Eagle Project, the known geologic structures were correlated to the hydraulic testing results and flow logging data.

A discrete fault plane was identified by an AMEC study (personal communication, KMC, January 2006) and located between 431520 and 431560 Easting and the estimated strike of the fault plane is 010 degrees/190 degrees azimuth and the dip is sub-vertical. Figure 7.1 shows that the fault trace intersects one of the boreholes with testing and flow logging data - borehole 04EA-84 between approximately 170 and 180 m. No significant flow anomalies were correlated with this depth (Figure 7.7) and the hydraulic conductivity for this zone of 9.5×10^{-9} m/s is relatively low.

Several other structures were identified from the 2005 Geotechnical Data Base for the boreholes with hydraulic testing and/or flow logging data. The depth of the structures is shown on the hydrogeologic synthesis plots (Figures 7.2 to 7.7). A summary of the comparison between geologic structures and hydrogeologic data is shown in Table 7.1. No significant flow anomalies were associated with any of the structures. A flow anomaly is defined as “kick” or local deflection in the temperature, fluid resistivity/fluid conductivity and the heat pulse flow meter. The structures that were located within intervals that were packer tested contain relatively low hydraulic conductivity values between 1.5×10^{-10} and 5.1×10^{-8} m/s (Table 7.1).

In the Phase I Investigation, several flow anomalies were isolated with a relatively small spacing between packers to obtain discrete data. The largest flow anomaly was identified between 257.74 to 260.29 m in borehole 04EA-84 (Figure 7.7) with local deflections in the temperature, fluid resistivity/fluid conductivity, fluid temperature, caliper and heat pulse flow meter. The hydraulic conductivity derived from the analysis was 5.2×10^{-7} m/s. In comparison, a hydraulic conductivity of 4.6×10^{-6} m/s was derived from a larger test interval that included the more discrete test interval (Table 7.2). This comparison suggests that the major flow anomaly contains an enhanced localized hydraulic conductivity compared to the background rock properties. This localized feature was selected for further hydraulic testing to evaluate large properties and connectivity away from the borehole in the Phase II Investigation.

Two other heat pulse flow anomalies were isolated for a more discrete packer test in the Phase I investigation (Table 7.2). However, in both of these tests, a smaller hydraulic conductivity was derived from the more discrete packer test compared to the larger interval packer test.

7.4 Conclusions and Recommendations for Model Refinement

The estimates for hydraulic parameters, geophysical borehole logging data, geologic setting and water quality data suggest a consistent conceptual model with a relatively low hydraulic conductivity for the bedrock that decreases with depth. In comparison between the preliminary model and the new data, the following conclusions and recommendations are made:

- The additional testing in borehole 04EA-107, performed predominantly in the Upper Bedrock, shows a geometric mean hydraulic conductivity (1.4×10^{-8} m/s) similar to the geometric mean hydraulic conductivity (2×10^{-8} m/s) from the Phase I investigation (Golder, 2005). Therefore, the hydraulic conductivity of 2×10^{-8} m/s in the Preliminary Numerical Model is recommended to be unchanged.
- The analysis of the 04EA-84 pumping test, which isolated a water conductive feature, suggests this feature is of limited extent (10's to 100's of meters). In the late portion of the test, a much lower transmissivity was derived from the analysis and attributed to recharge from the matrix/background fracture network.
- The 04EA-84 pumping test data should be simulated in the Preliminary Numerical Model. Based on this comparison, the model should be adjusted to match both the early time transmissivity (thought to represent the properties for the water conductive feature connected to the borehole) and the late time transmissivity (thought to represent the properties for the matrix/background fracture network).

8.0 REVISION OF THE NUMERICAL HYDROGEOLOGIC MODEL

The Preliminary Numerical Model described in preceding sections was revised based on hydrogeologic data collected during the Phase II investigation (Golder, 2006). This included calibration of the model to the hydrogeologic response observed during pumping test that was conducted in borehole 04EA-84. Following this calibration, the revised model was used to provide updated predictions of groundwater inflow to the proposed mine.

8.1 Model Calibration to the 04EA-84 Pumping Test

The pumping test conducted in borehole 04EA-84 (Golder, 2006) was simulated in the Preliminary Numerical Model under the assumption that most of the discharge measured in this well originated from one of the water conductive features incorporated in the model mesh. Pumping was simulated using a variable flux boundary assigned to a node that intersected one of these features at an elevation of 203 m, which corresponds to an approximate elevation where such feature was intersected by 04EA-84. The pumping rate assigned to this boundary was varied throughout the simulation based on values measured during the test. The hydrogeologic model was run in transient model for a period of 350 hours that comprised pumping and recovery periods. It was assumed that, initially, groundwater conditions were hydrostatic. Due to superposition, this assumption is considered to have negligible affect on predicted drawdown.

To check the large scale hydrogeologic properties of bedrock and water conductive features assigned in the Preliminary Numerical Model within the influence zone of the pumping test, the measured drawdown was directly compared, in Cartesian coordinates, to the simulated drawdown (Figure 8.1). The drawdown predicted by the Preliminary Numerical Model was found to be less than that measured during the test, suggesting that the transmissivity and/or the extent of the water conductive features assigned to the model mesh were likely too high.

To provide a direct comparison of formation responses, the pressure derivative of the measured and simulated recovery data collected during the pumping test were plotted on a transmissivity normalized plot (Enachescu *et. al.*, 2004), as presented on Figure 8.2. The merging of pressure derivative data in early time suggests a consistent local scale transmissivity between the simulated and pumping test data at approximately 2×10^{-6} to $3 \times 10^{-6} \text{ m}^2/\text{s}$. In late time the pressure derivative data of the two data sets show different trends. The simulated data from the model shows a negative slope in the pressure derivative data or an increase in the effective transmissivity away from the well. The measured pumping test data shows a positive slope or a reduction in the effective transmissivity away from the well.

The analytical analysis of the pumping data used a single water conductive feature of limited extent (96 to 320 m) connected to the borehole to match the data (Golder, 2006). This model was consistent with the reduction in transmissivity away from the wellbore as transition from flow in a water conductive feature in early time to recharge from the lower hydraulic conductivity matrix/background fracture network. This limited extent of these features was consistent with previous studies that suggest these water conductive features are sparsely distributed in the Lower Bedrock (Golder, 2005). The overestimation of the late time transmissivity in the Preliminary Numerical Model was attributed to an overestimation of the connectivity of the water conductive features. Accordingly, as the Preliminary Numerical Model overestimates the late time hydraulic properties of the formation, this model would likely provide an upper bound for mine inflow predictions.

To improve the match between drawdown predicted using the numerical model and that observed during the pumping test, the connectivity, length and transmissivity of the water conductivity features incorporated into the model was varied until a reasonable match was achieved. A good fit between model prediction and field data (Figure 8.3) was obtained by reducing the feature length to 145 m, eliminating connections between individual features, and lowering their transmissivity to $1 \times 10^{-6} \text{ m}^2/\text{s}$. In addition, to improve the match, the specific storage assigned to the Lower Bedrock was reduced to 1×10^{-7} 1/m (a factor of 10 decreased from the preliminary value) and the specific storage assigned to water conductive features was reduced to 1×10^{-6} 1/m (a factor of 10 decrease from the preliminary value). To provide a direct comparison of formation responses, the pressure derivative of the measured and simulated pumping test recovery data were plotted on a transmissivity normalized plot, as presented on Figure 8.4. The merging of the measured and simulated data for a feature length of 145 m indicates a consistent late time transmissivity.

The measured radius of influence observed during testing in 04EA-84 was constrained between 203 and 230 m (Golder 2005) and shows good agreement to the simulated drawdown of 200 to 250 m. Figure 8.5 shows the measured and simulated drawdown both parallel (dominated by the properties of the water conductive feature) and perpendicular to the water conductive feature (dominated by the properties of the matrix/background fracture network). The responding zone with the highest measured diffusivity (Golder, 2005), indicating good communication or close proximity to the water conductive feature, plots proximal to the drawdown response in the feature. The two responding zones with the lowest measured diffusivity (Golder, 2006), indicating attenuation by the relatively low hydraulic conductivity matrix/background fracture network, plot proximal to the simulated drawdown for the matrix. The final responding monitoring zone had a moderate measured diffusivity and plots between the simulated drawdown for the matrix and the simulated drawdown for the feature. Overall, the measured and simulated drawdown for the revised model shows good agreement.

As the match to the measured data for the borehole 04EA-84 pumping test (Golder 2005) was improved by reducing the connectivity of the water conductive features and reducing their length to 145 m, the same general pattern was used to revise the spacing and the length for the water conductive features throughout the Revised Model (Figure 8.6). The properties for all the water conductive features in the model are conservatively assumed to be proximal to the largest flow anomaly in the six boreholes with hydraulic information (Golder, 2005). As the Revised Model shows good agreement to the measured pumping test data, it was considered appropriate to provide the a more accurate estimate of mine inflows than the Preliminary Model and is hereafter referred to as the Base Case. The Preliminary Numerical Model is hereafter referred to as the Upper Bound Case based on the discussion above.

8.2 Base Case and Upper Bound Case Models

The predictions of groundwater inflow to the proposed mines were revised based on data collected during the 04EA-84 pumping test (Golder, 2006) and subsequent model recalibration. The inflows were predicted for two scenarios:

- **Base Case:** In this scenario a Revised Model (as described in the preceding section) with 145 m long water conductive features not connected to each other was used. This scenario is considered to provide most likely inflows that could be encountered throughout the mine life; and,
- **Upper Bound Case:** In this scenario the Preliminary Model (as described in Section 5) with relatively long, well-connected water conductive features was used. This scenario is considered to provide a reasonable upper bound of future mine inflows.

The modeling methodology and assumptions used in both simulations were the same as the one used to provide preliminary estimates of inflow, as discussed in Section 6. As in the preliminary analysis, grouting or other measures to mitigate inflow and/or backfilling of mined-out areas were not incorporated into the model. This is considered conservative as backfilling is planned and inflow mitigative measures could be implemented.

Two additional modifications were made in the models used to provide the Base Case and the Upper Bound Case predictions of inflow. The first modification considered the boundary condition used to represent overburden. The specified head boundary originally assigned to the model top was replaced by a head-dependent boundary. The conductance values assigned to this boundary were calculated based on the hydraulic conductivity and thickness of lower-most hydrostratigraphic unit incorporated into MODFLOW overburden model concurrently developed by Fletcher Driscoll in

conjunction with North Jackson Company. This modification allowed for a more realistic prediction of drawdown in the Upper Bedrock immediately beneath the overburden, thus allowing for better coupling of bedrock model and overburden model. For example, in the areas where thick lower-permeability sediments directly overlying bedrock the model with head-dependent boundary will predict more drawdown than in the areas where thin higher-permeability sediments are present. Conversely, a model with specified head boundary would predict similar drawdown in both areas. With regards to mine inflow, modification of the upper model boundary was found to have negligible influence on predicted inflow quantities. This is because the hydraulic conductivity assigned to Upper Bedrock is, in general, significantly lower than that assigned to overburden.

The second modification considered potential affects of rock dilation on predicted inflows. Rock dilation, resulting from stress relief associated with excavation of underground workings, and associated effects of blasting, may increase the degree of fracturing and/or increase the aperture size of existing fractures in the immediate vicinity of the mine. This in turn could create a zone of increased hydraulic conductivity surrounding the mine. In both the Base Case and the Upper Bound Case, the potential affects of dilation were simulated by increasing the hydraulic conductivity of both bedrock units and water conductive features by a factor of 3 from the original values (Golder, 1999) within 15 m radius from the underground openings. This assumption is considered conservative, especially along the main decline, where the radius of the dilation zone would likely be less due to smaller effective radius of the decline when compared to that of stopes and accesses.

9.0 REVISED INFLOW PREDICTIONS

Figure 9.1 presents the model predicted inflow to the underground workings for the Base Case and Upper Bound Case scenarios, and Figures 9.2 and 9.3 present the corresponding hydraulic heads at the end of mining. Figure 9.4 and 9.5 provide the predicted drawdowns at the end of mining for both scenarios. As presented in Table 9.1, the model results suggest that in the Base Case the average annual inflow will increase to approximately 410 m³/day (75 USgpm) towards the end of mine life. The drawdown cone in the Lower Bedrock, defined by the 1.0 m drawdown contour, is predicted in the Base Case to extend radially away from the proposed mine to a distance of approximately 1,300 m.

In the Upper Bound Case, average annual inflow is predicted to reach approximately 1,180 m³/day (215 USgpm) in year three, and then remain at that level later in mine life. The corresponding drawdown cone, defined by the 1.0 m contours, is predicted to extend radially away from the workings to a distance of about 1,500 m. The relatively small difference in the extent of drawdown cone predicted for the Base Case and Upper Bound Case is related to a strong hydrogeologic boundary, relative to the hydrogeologic properties of bedrock, that is assigned to the model top and represents leakage from overburden.

10.0 RECOMMENDATIONS

The present data provide a range of possible inflow quantities and it is expected that the actual inflows will fall within the range of model predictions. Monitoring of the groundwater regime in the early stage of mining, especially during the construction of main decline, can be used together with the hydrogeologic model to confirm the predicted range of possible future inflows. It is therefore recommended that the mine inflow, as well as the response recorded in nearby monitoring wells, be rigorously monitored and reviewed on a continuous basis as the mine is being deepened. These early-time monitoring data will be extremely valuable as a basis for comparison with the present model predictions. If necessary, the data should be used to refine the hydrogeologic model and update inflow predictions. Through regular re-calibration of the model against new data, any significant deviations between predicted and actual inflows can be incorporated into the model at a relatively early stage. This information can be used to guide the mining operation to mitigate inflow rates through grouting or other means to prevent potential impacts from any potential deviations.

11.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

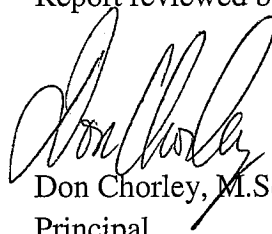
GOLDER ASSOCIATES LTD.

Report prepared by:

FOR 

John Wozniewicz, M.Sc.
Associate

Report reviewed by:


Don Chorley, M.Sc., P.Geo.
Principal



Willy Zawadzki, M.Sc., P.Geo.
Associate

JW/WZ/DC/cap
Attachments

N:\Final\2005\3000\05-3236-2c\Rep 0210 Final Gw Modeling\Rep 020906 Draft Gw Modeling.Doc

12.0 REFERENCES

- Anderson, M. P., and W.M. Woessner. 1992. *Applied Groundwater Modeling, Simulation of Flow and Advective Transport*. Academic Press, New York.
- Diersch, H.G. 2004. *FEFLOW v. 5.1 Finite Element Subsurface Flow and Transport Simulation System*. WASY Institute for Water Resources Planning and System Research Ltd., Berlin, Germany.
- Freeze, Allan R., and Cherry, John A. 1979. *Groundwater*. Prentice Hall, Inc.
- Enachescu, Christian, Bernd Frieg and John Wozniwicz. 2004. A New Visual Synthesis Tools for Transient Tests. Presented at the 2004 U.S. EPA/NGWA Fractured Rock Conference.
- Fletcher Driscoll Associates, Inc. 2006. *Predictive Assessment Modeling of the Quaternary Alluvium Hydrogeology - Eagle Project*. Submitted to Kennecott Minerals Company, February 2006.
- Golder, 1999. *Report on Hydrogeological Modelling of Feasibility Mine Plan, Diavik Diamond Mine Project, NWT*. Submitted to Diavik Diamond Mines Inc.
- Golder, 2005. *Eagle Project Hydrogeologic Bedrock Investigation*. Submitted to Kennecott Minerals Company, April 2005.
- Golder, 2006. *Eagle Project Phase II Bedrock Hydrogeologic Investigation*. Submitted to Kennecott Eagle Minerals Company, February 2006.
- Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000. *MODFLOW-2000, the U.S. Geological Survey modular ground-water model - User guide to modularization concepts and the Ground-Water Flow Process*. Open-File Report 00-92. U.S. Geol. Surv.
- Klasner, JS, Snider, DW, Cannon, WF, Slack, JF, 1979. The Yellow Dog Peridotite and a Possible Buried Igneous Complex of Lower Keweenaw Age in the Northern Peninsula of Michigan, *Report of Investigation 24*. Michigan Department of Natural Resources, Geological Survey Division, Lansing, Michigan.
- Maidment, David R. 1992. *Handbook of Hydrology*. McGraw-Hill, New York.

Mikkelsen, Erik P. and Gordon E. Green, 2003. Piezometers in Fully Grouted Boreholes. FMGM 2003, *Field Measurements in Geomechanics*, Oslo, Norway, September, 2003.

Nelson, Ronald A. 2001. *Geologic Analysis of Fractured Reservoirs*. 2nd Edition, Gulf Professional Publishing

North Jackson Company, 2005. *Eagle Project Environmental Baseline Study Stage 1 Hydrology Report*. Submitted to Kennecott Minerals Company and Golder Associates, Inc, September 2005.

Table 4.1- 15 February 2005 Mine Development Schedule

Item	Drift Dimensions (m)	Total Length (m)	Productivity (m/d)	Duration (days)	Year -2 (m)	Year -1 (m)	Year 1 (m)	Year 2 (m)	Year 3 (m)	Year 4 (m)	Year 5 (m)	Year 6 (m)	Year 7 (m)	Year 8 (m)	Totals (m)
Days	(m)	(m)	(m/d)	(days)	126	365	365	365	365	365	365	365	365	365	
<i>Lateral Development</i>															
Decline - Surface to 263 Level	5m x 5m	1,383	6	230	759	624	0	0	0	0	0	0	0	0	1,383
Decline - 263 Level to 143 Level	5m x 5m	1,080	6	180	0	1,080	0	0	0	0	0	0	0	0	1,080
Incline - 263 Level to 383 Level	5m x 5m	1,080	6	180	0	0	0	0	0	500	250	330	0	0	1,080
143 Level Development	5m x 5m	113	6	19	0	113	0	0	0	0	0	0	0	0	113
173 Level Development	5m x 5m	374	6	62	0	374	0	0	0	0	0	0	0	0	374
203 Level Development	5m x 5m	382	6	64	0	0	382	0	0	0	0	0	0	0	382
233 Level Development	5m x 5m	464	6	77	0	0	464	0	0	0	0	0	0	0	464
263 Level Development	5m x 5m	572	6	95	0	0	0	0	572	0	0	0	0	0	572
293 Level Development	4.5m x 4.5m	178	7	25	0	0	0	0	0	178	0	0	0	0	178
323 Level Development	4.5m x 4.5m	179	7	26	0	0	0	0	0	0	179	0	0	0	179
353 Level Development	4.5m x 4.5m	234	7	33	0	0	0	0	0	0	234	0	0	0	234
383 Level Development	4.5m x 4.5m	251	7	36	0	0	0	0	0	0	0	251	0	0	251
Sub-total		6,290			759	2,191	846	0	572	678	663	581	0	0	6,290
<i>Raise Development</i>															
Main Exhaust Raise	4m Diameter	277	10	28	0	277	0	0	30	30	30	30	0	0	397
Orepass - 383 Level to 263 Level	4m Diameter	120	10	12	0	0	0	0	0	0	0	0	0	0	0
Sub-total					0	277	0	0	30	30	30	30	0	0	397

Table 5.1 - Values of Hydrogeologic Parameters Used in the Preliminary Model

Hydrostratigraphic Unit	Elevation Interval (m)	Hydraulic Conductivity (m/s)	Specific Yield (-)	Specific Storage (1/m)
Upper Bedrock	413 - 353	2×10^{-8}	0.01	1×10^{-5}
Lower Bedrock (Bulk of Rock Mass)	353 - -250	5×10^{-10}	0.005	1×10^{-6}
Water Conductive Fractures in Lower Bedrock	353 - -250	3×10^{-6}	0.1	1×10^{-5}

Table 7.1: Comparison of Structure Data with Hydrogeologic Data

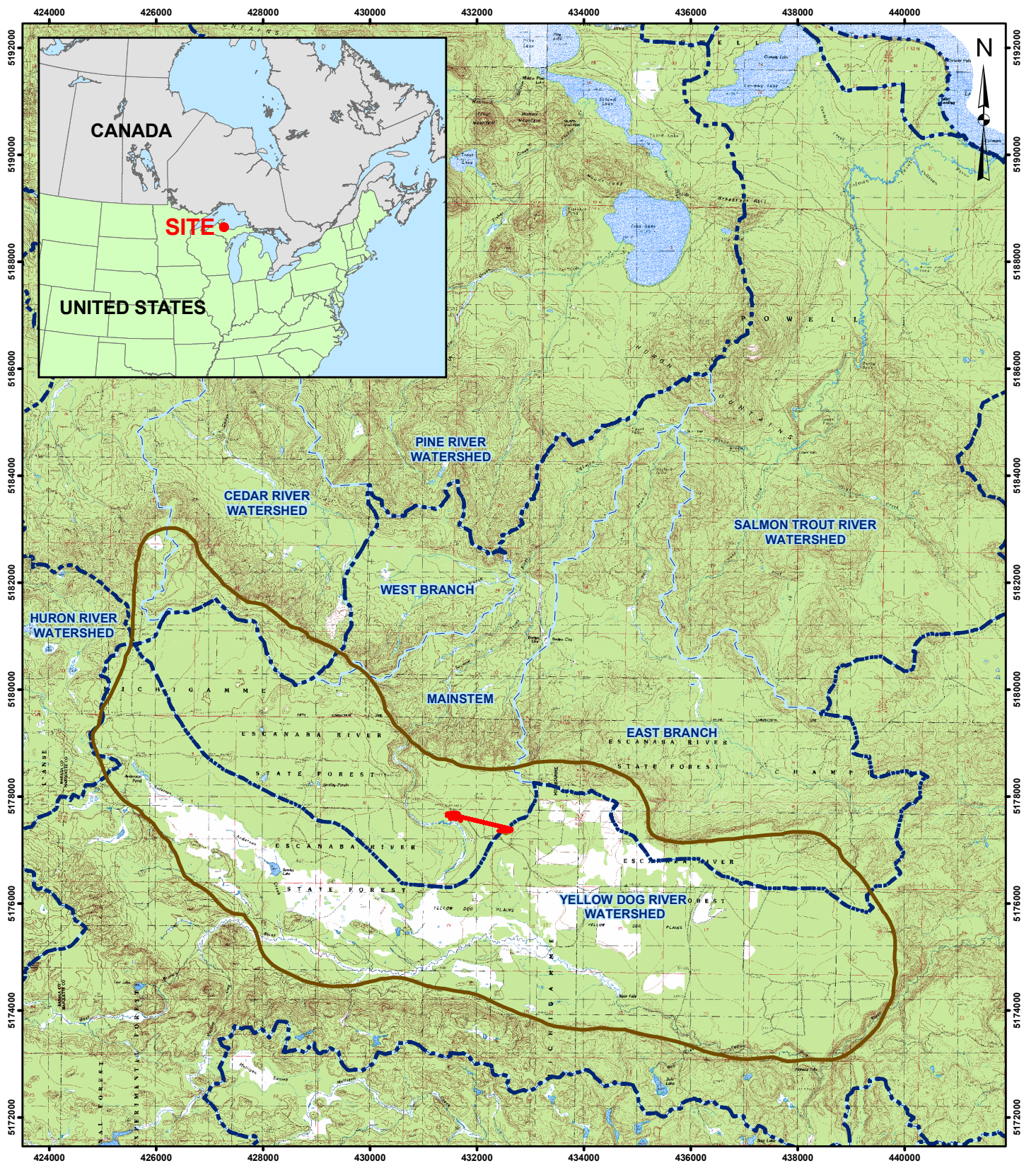
Borehole	Depth [m]	Length [m]	Structure	Temp/Fluid Conductivity/Heat Pulse/ Caliper Local Deflection	Hydraulic Conductivity [m/s]
04EA-47	14.21	0.4	broken	no	not measured
04EA054	18.29	0.72	sheared	no	not measured
	60.27	0.13	sheared	no	not measured
	114.48	1.1	sheared	no	not measured
	261.5	2.64	broken	no	not measured
04EA-73	113.3	0.95	gouge	no	2.00E-09
	120.2	3.3	sheared	no	2.00E-09
	137.75	0.56	sheared	no	2.00E-09
	141.92	4.35	sheared	no	2.00E-09
	148.65	0.65	sheared	no	2.00E-09
	217.22	1.33	broken	no	1.50E-10
04EA083	26.23	0.15	sheared	no	5.10E-08
04EA084	55.13	0.25	sheared	no	1.10E-08
	139.26	0.77	gouge	no	9.50E-09
	167.22	2.32	sheared	no	9.50E-09
	170	10	AMEC FAULT	no	9.50E-09
	175.35	0.21	sheared	no	9.50E-09
	276	3.2	broken	no	4.60E-08

Table 7.2: Flow Anomalies Isolated with Packers

	Flow Anomaly		Description of Local Deflection				Dicrete Packer Test	Larger Interval Packer Test		
Borehole	Top [m]	Bottom [m]	Temp	Fluid Conductivity	Heat Pulse Flowmeter	Caliper	Hydraulic Conductivity [m]	Top [m]	Bottom [m]	Hydraulic Conductivity [m/s]
04EA-83	41.45	44.19	Minor	Minor	Minor	No	1.20E-09	15.54	79.55	5.10E-08
04EA-84	109.72	112.8	Minor	No	No	No	3.10E-09	100.88	302.04	9.50E-09
04EA-84	257.74	260.29	Major	Major	Major	Major	5.20E-07	213.65	302.04	4.60E-06

Table 9.1 - Predicted Mine Inflow

Year	Predicted Mine Inflow (m ³ /day)	
	Base Case	Upper Bound Case
1	330	730
2	360	990
3	390	1180
4	390	1180
5	390	1180
6	380	1180
7	370	1180
8	400	1180
9	410	1180
10	410	1180



LEGEND

- STATE DEFINED SURFACE WATERSHED BOUNDARY
- PRELIMINARY SURFACE SUB-WATERSHED BOUNDARY
- PROPOSED MINE WORKINGS
- ORE BODY
- OUTCROP
- YELLOW DOG PLAINS

REFERENCE

DRG provided by Michigan DNR. Ground and surface water data from North Jackson Company. Sub-watersheds delineated by Golder Associates Ltd. from Michigan DNR digital elevation model. Watersheds provided by Michigan DNR. Datum: NAD 83 Projection: Transverse Mercator Coordinate System: UTM Zone 16

5,000 0 5,000
SCALE: 1:100,000 FEET

PROJECT

EAGLE PROJECT
KENNECOTT MINERALS COMPANY

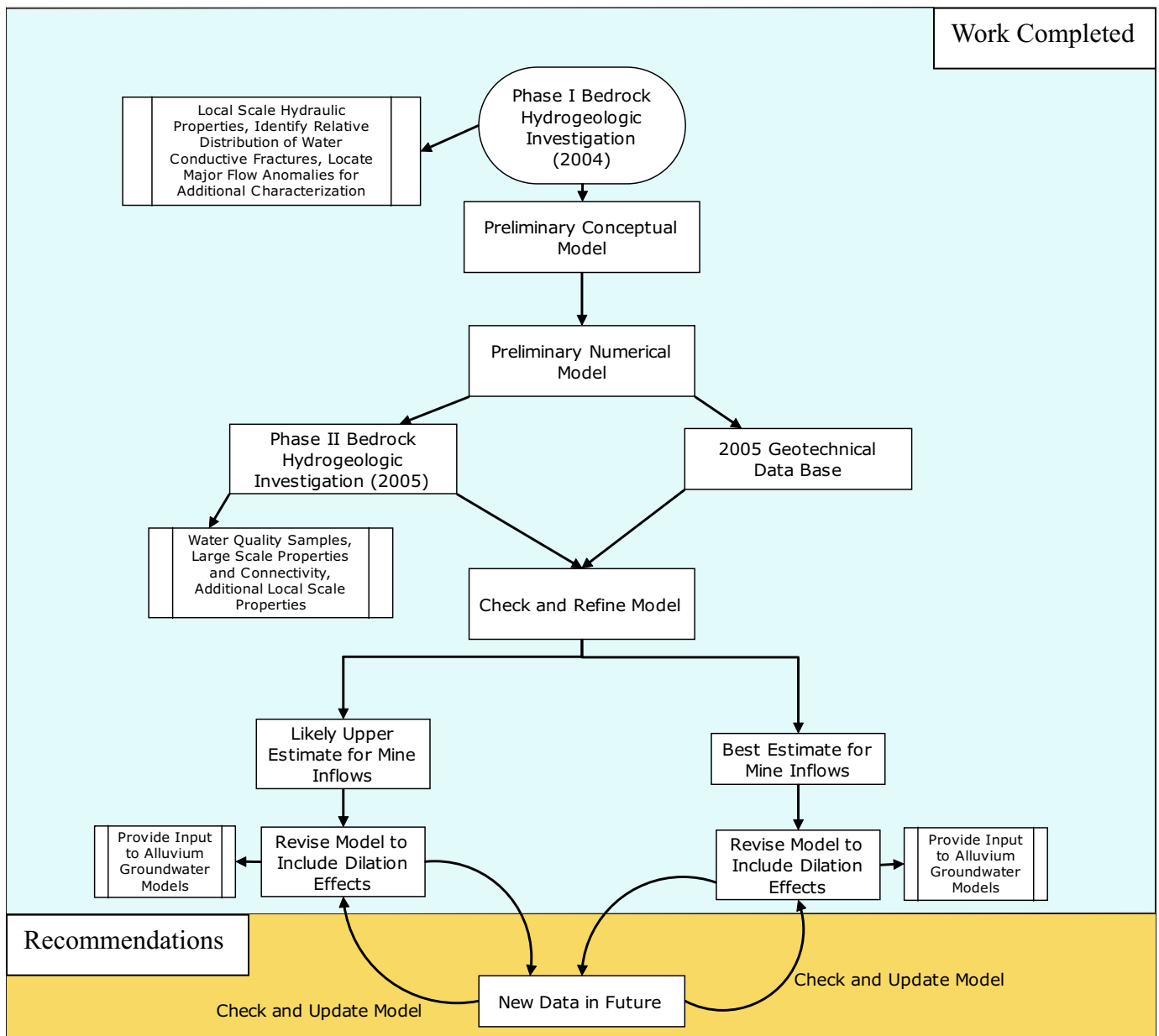
TITLE

REGIONAL OVERVIEW



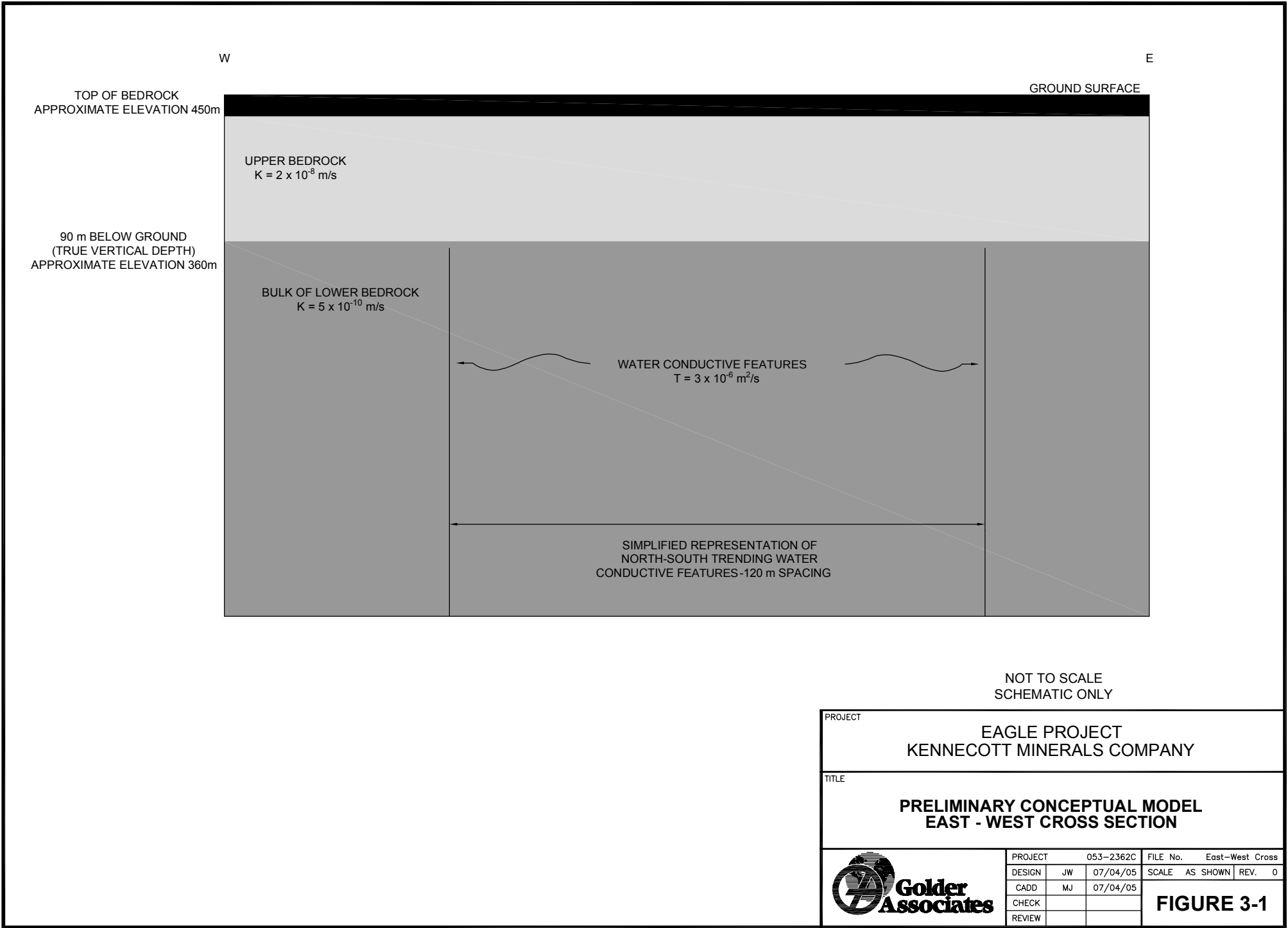
PROJECT No.	05-3236-2c	SCALE AS SHOWN	REV. 1
DESIGN	KG	17 May 2004	
GIS	TN/CDB	18 Apr. 2005	
CHECK	CT	18 Apr. 2005	
REVIEW			

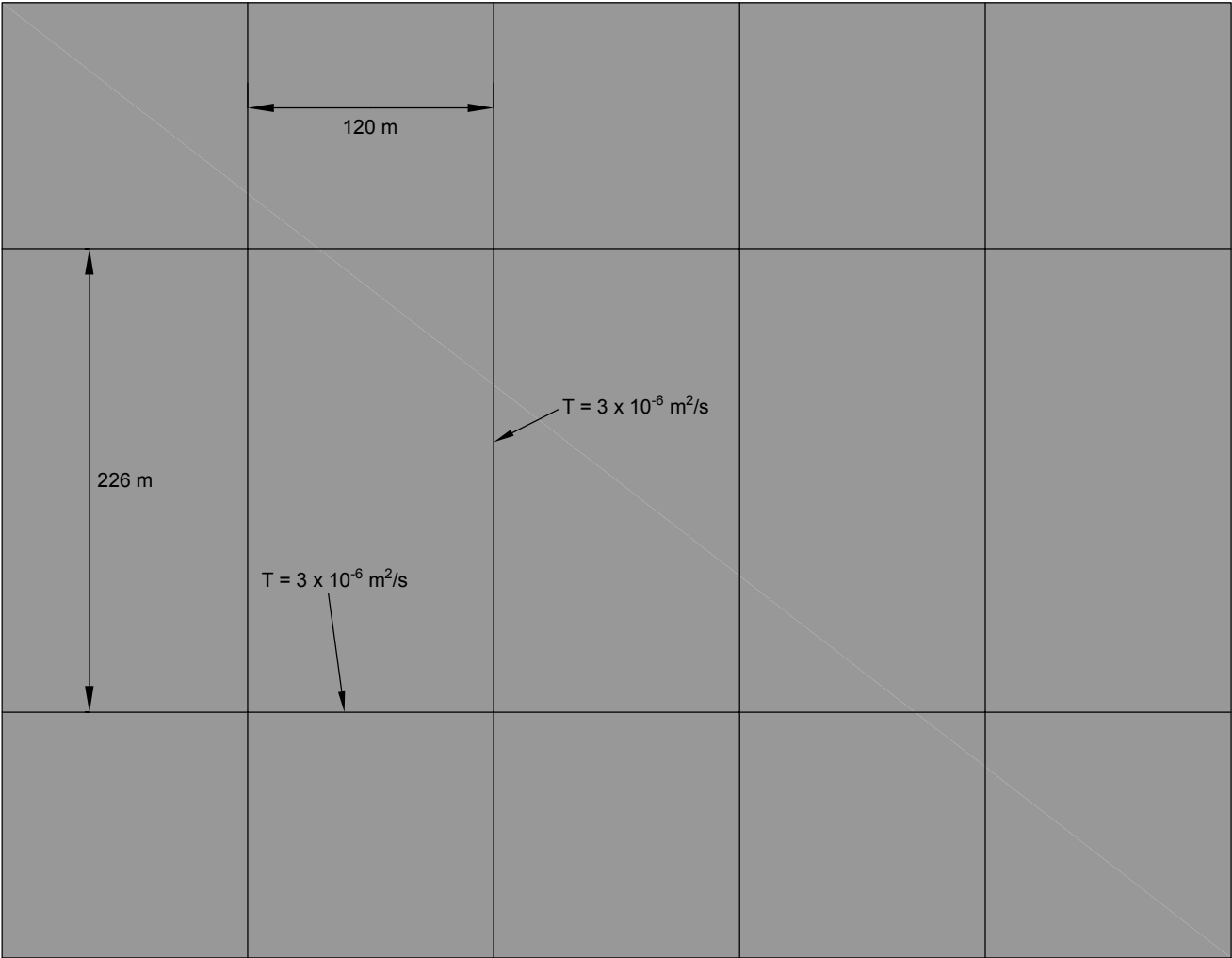
FIGURE 1.1



PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
WORK FLOW USED TO DEVELOP THE BEDROCK NUMERICAL MODEL				
PROJECT No.		05-3236-2C	FILE No.	
DESIGN	WZ	03FEB06	SCALE	NTS
CADD	SS	03FEB06	FIGURE 1.2	
CHECK	WZ	03FEB06		
REVIEW				

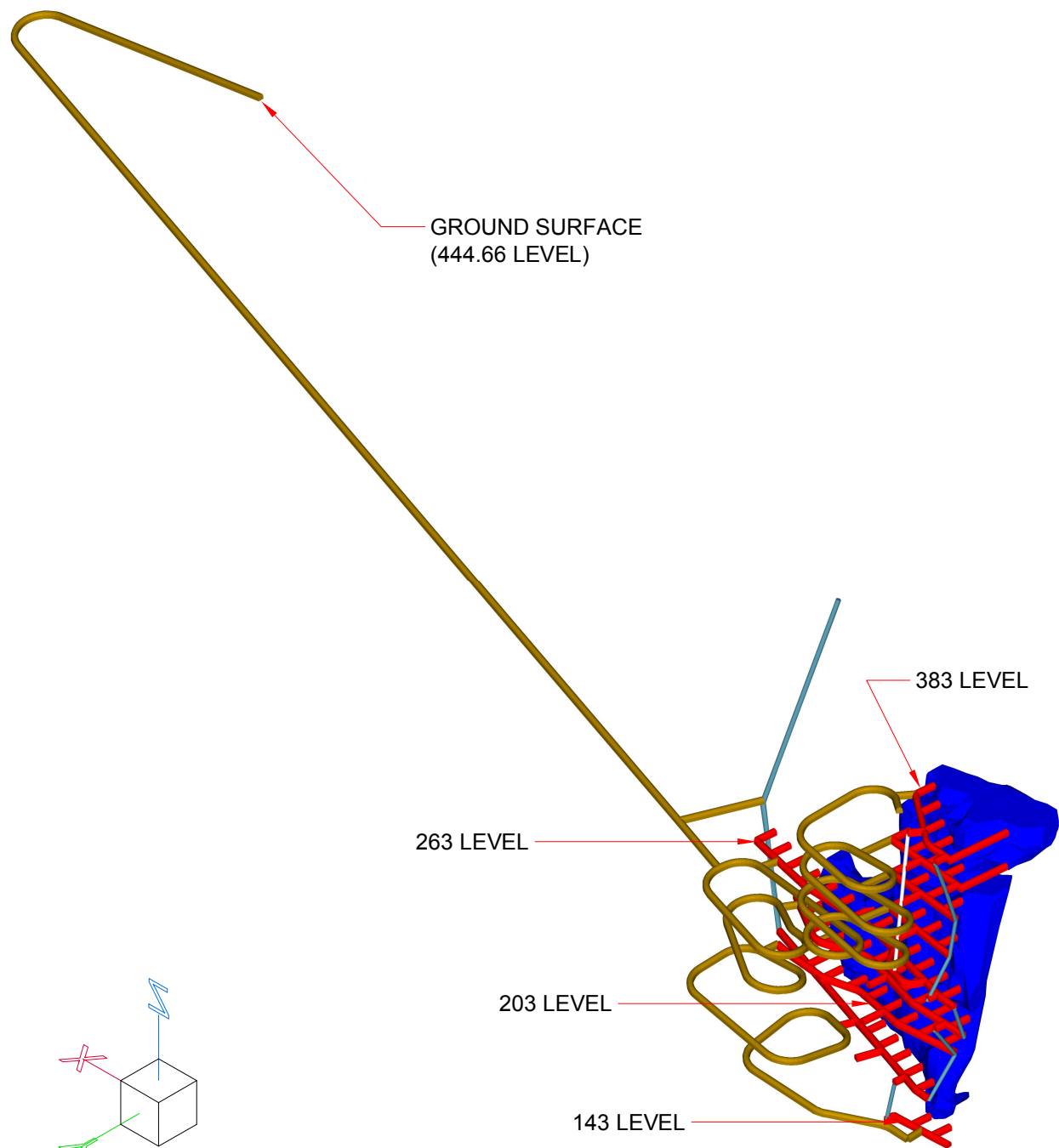






NOT TO SCALE
SCHEMATIC ONLY

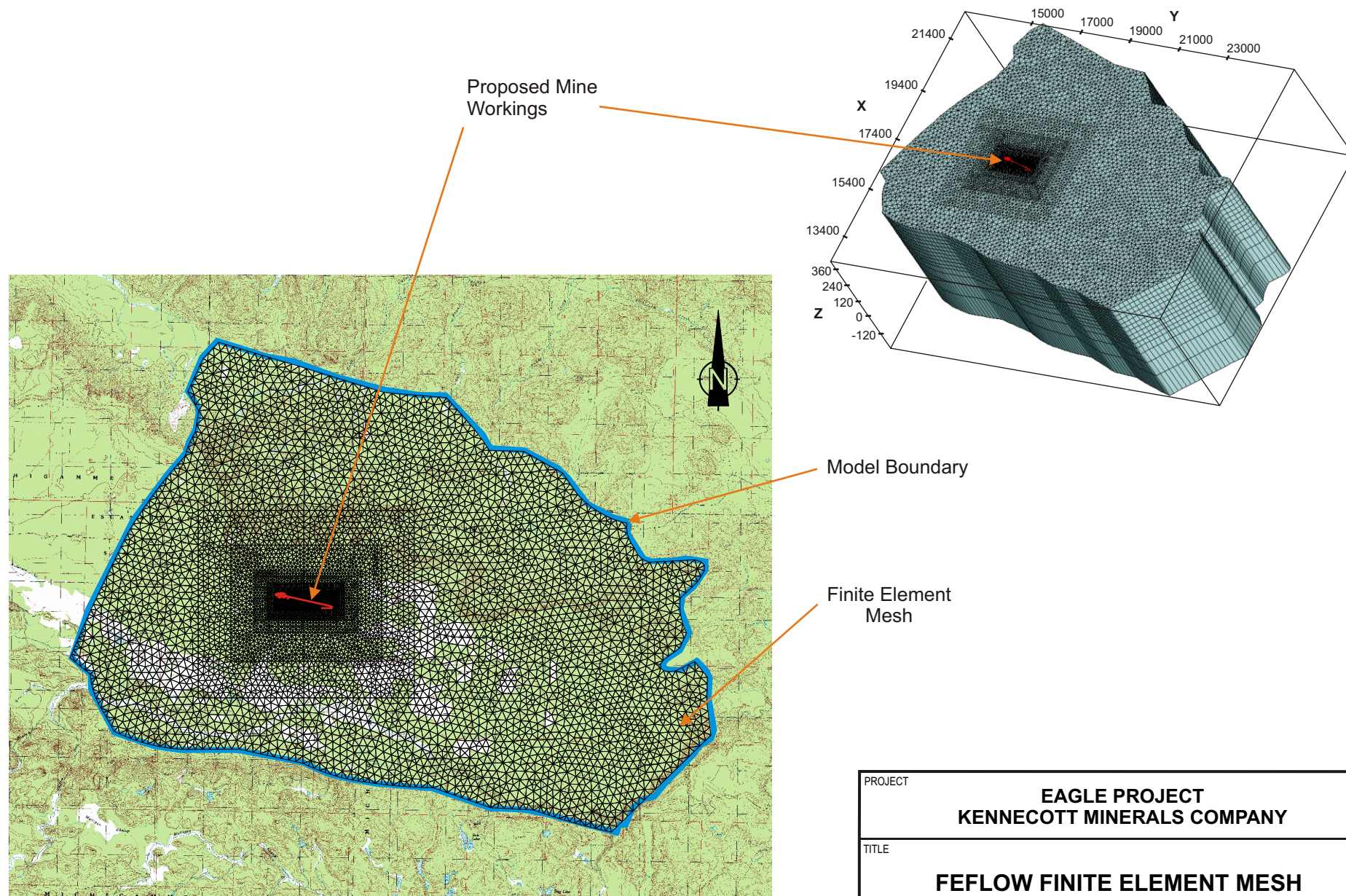
PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY			
TITLE		PRELIMINARY CONCEPTUAL MODEL PLAN VIEW - SIMPLIFIED REPRESENTATION OF SPATIAL DISTRIBUTION OF WATER CONDUCTIVE FEATURES WITHIN LOWER BEDROCK			
		PROJECT	053-2362C	FILE No.	Plan View
		DESIGN	JW	07/04/05	SCALE AS SHOWN
		CADD	MJ	07/04/05	REV. 0
		CHECK			FIGURE 3-2
		REVIEW			



LEGEND

- █ Levels
- Ore Pass
- █ Exhaust
- █ Main Ramp
- █ Stopes

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY					
TITLE		15 FEBRUARY 2005 MINE PLAN NORTHWEST ISOMETRIC VIEW					
	PROJECT No.		0532362C		FILE No.	0532362C_SK01	
	DESIGN				SCALE	NTS	REV. A
	CADD	RCR	18APR2005		FIGURE 4.1		
	CHECK						
	REVIEW						

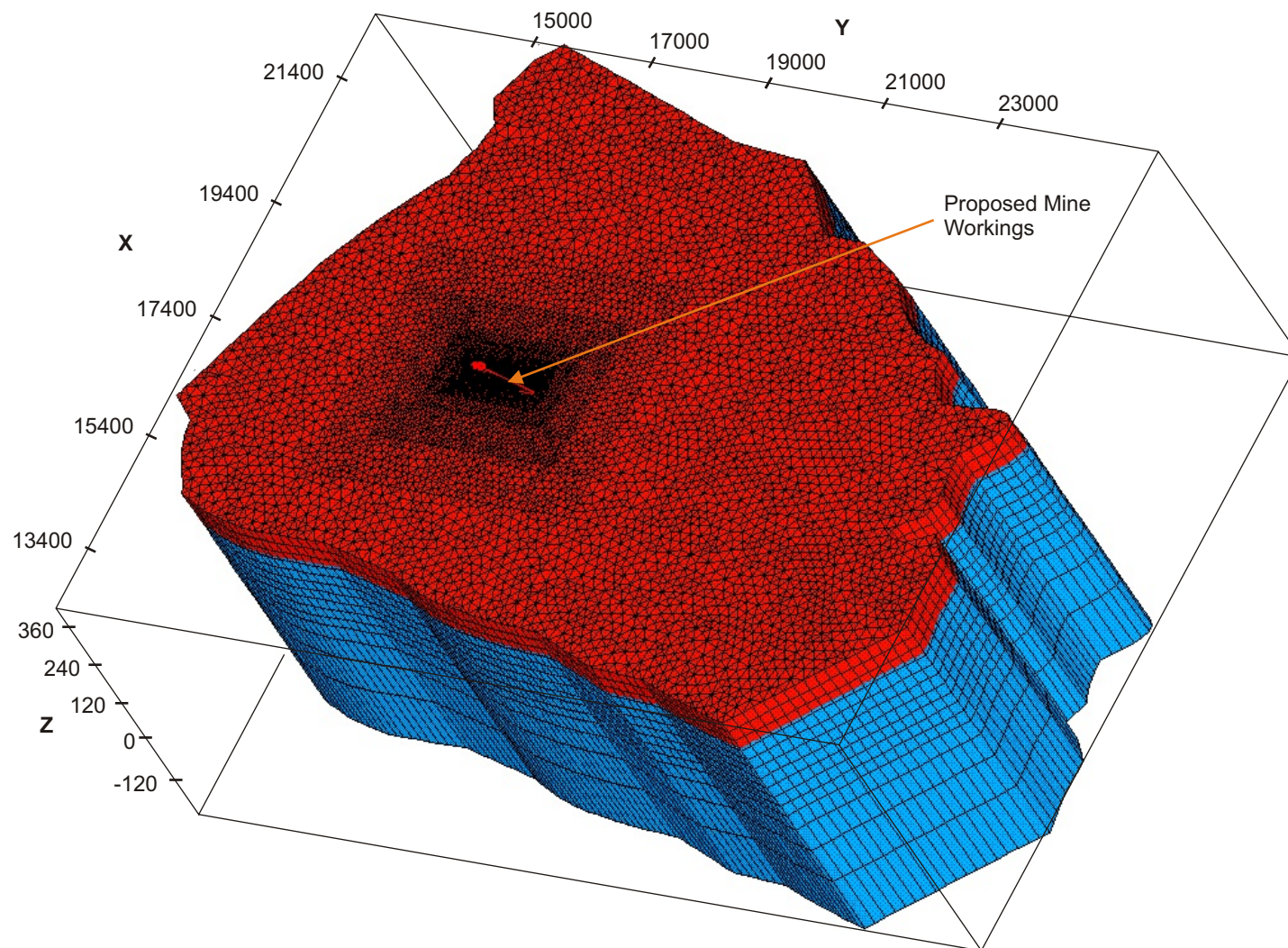


NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

0 m 4000 m

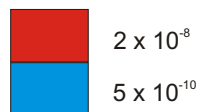
PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY			
TITLE		FEFLOW FINITE ELEMENT MESH			
		PROJECT No.	05-3236-2c	FILE No.	hydrogeo1
		DESIGN	WZ	01FEB06	SCALE NTS
		CADD	GG	01FEB06	REV.
		CHECK	WZ	01FEB06	FIGURE 5.1
		REVIEW			



NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

Hydraulic Conductivity (m/s)



PROJECT

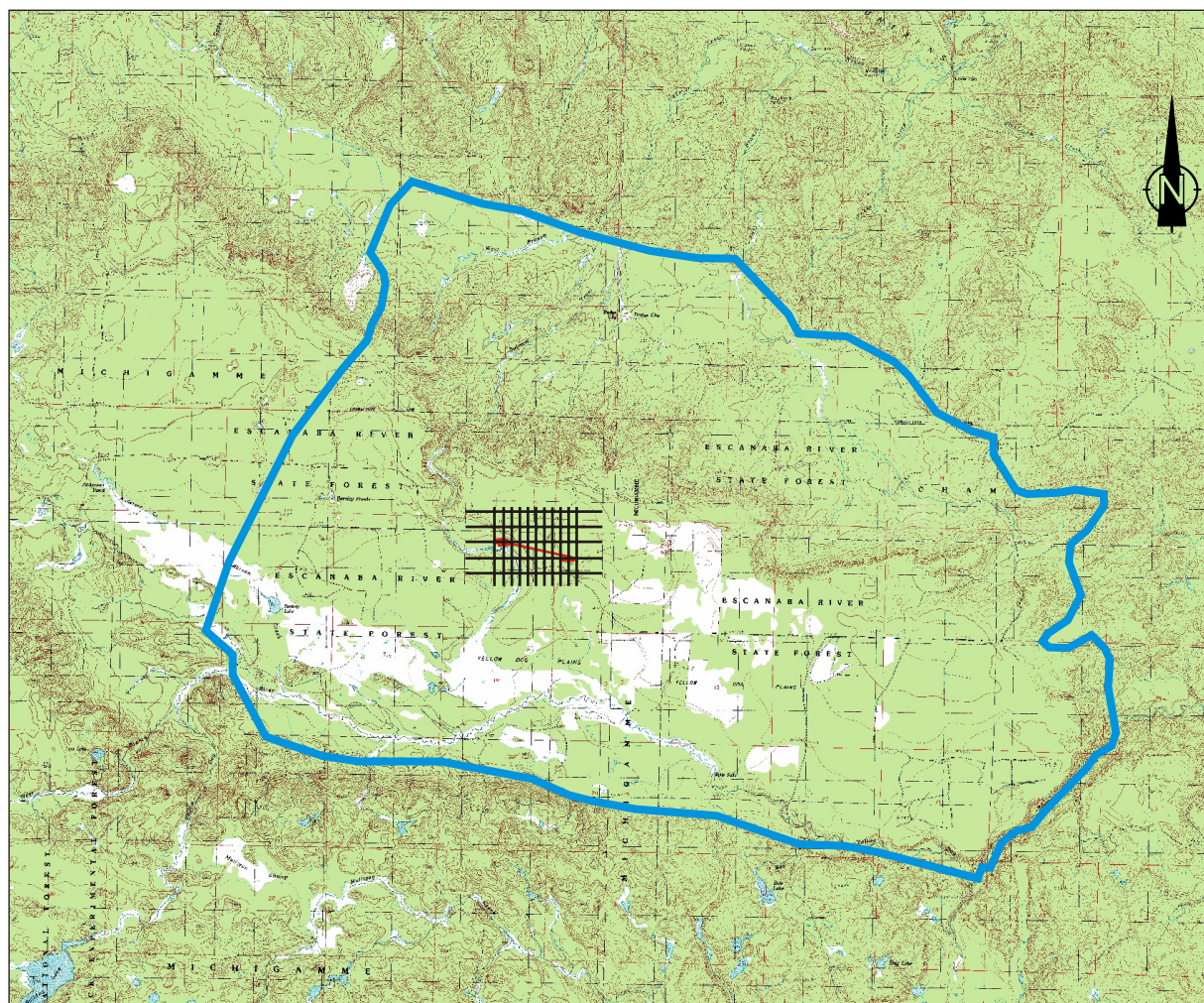
**EAGLE PROJECT
KENNECOTT MINERALS COMPANY**

TITLE

**HYDRAULIC PROPERTIES FOR
BULK OF THE ROCK MASS**



PROJECT No. 05-3236-2c			FILE No. hydrogeo1	
DESIGN	WZ	01FEB06	SCALE NTS	REV.
CADD	GG	01FEB06	FIGURE 5.2	
CHECK	WZ	01FEB06		
REVIEW				



0 4000 m

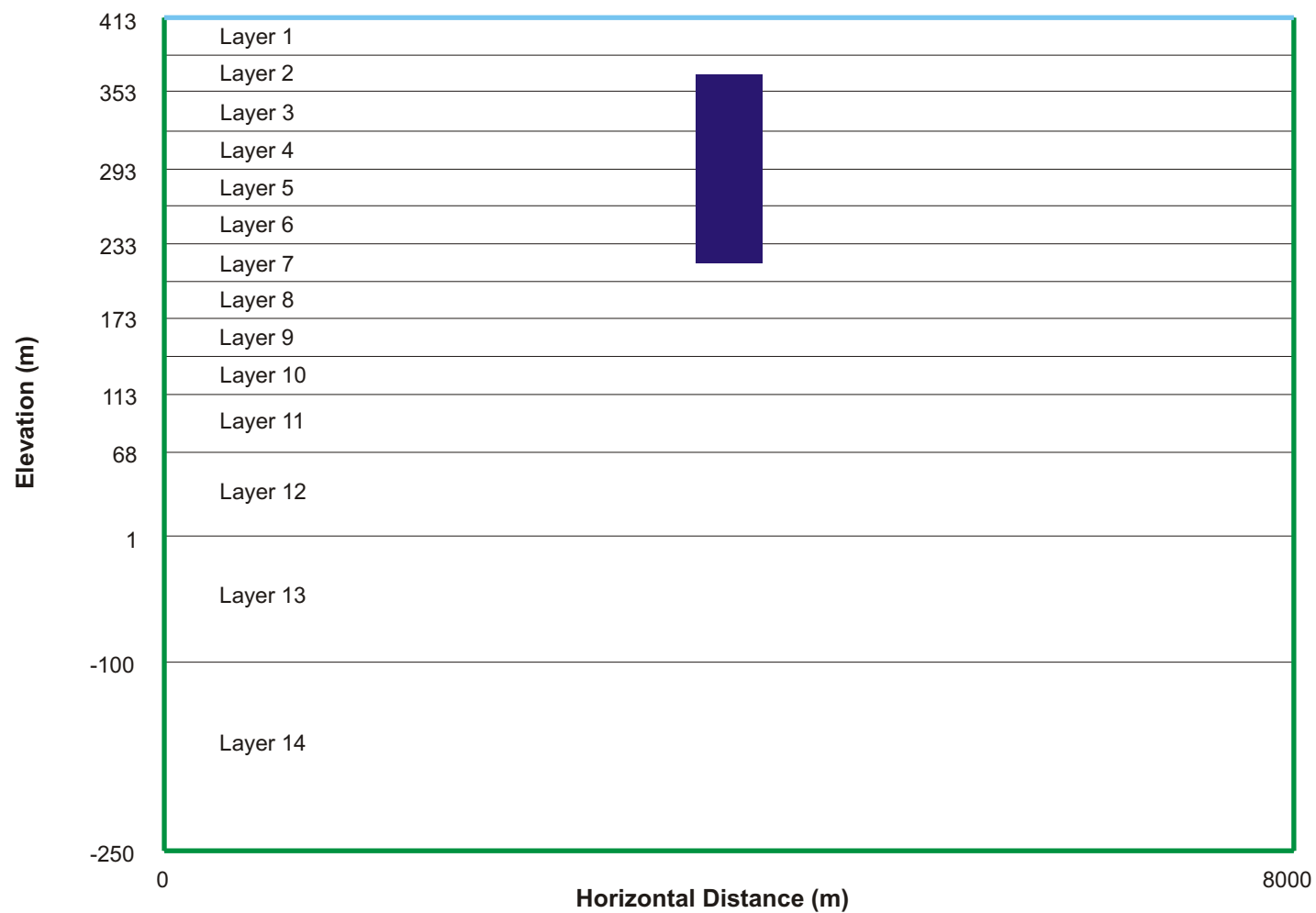
LEGEND

- Water Conductive Feature
- Proposed Mine Workings
- Model Boundary

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY			
TITLE		REPRESENTATION OF WATER CONDUCTIVE FEATURES WITHIN THE LOWER BEDROCK - PRELIMINARY MODEL			
		PROJECT No.	05-3236-2c	FILE No.	hydrogeo1
		DESIGN	WZ 01FEB06	SCALE	NTS
		CADD	GG 01FEB06	REV.	
		CHECK	WZ 01FEB06	FIGURE 5.3	
		REVIEW			

**NOTE**

Schematic only. Not to scale.

LEGEND

-  Specified Head Boundary (Preliminary Model)
-  Head Dependant Boundary (Revised Model)
-  No Flow
-  Specified Head - Mine Workings (time dependent)

PROJECT

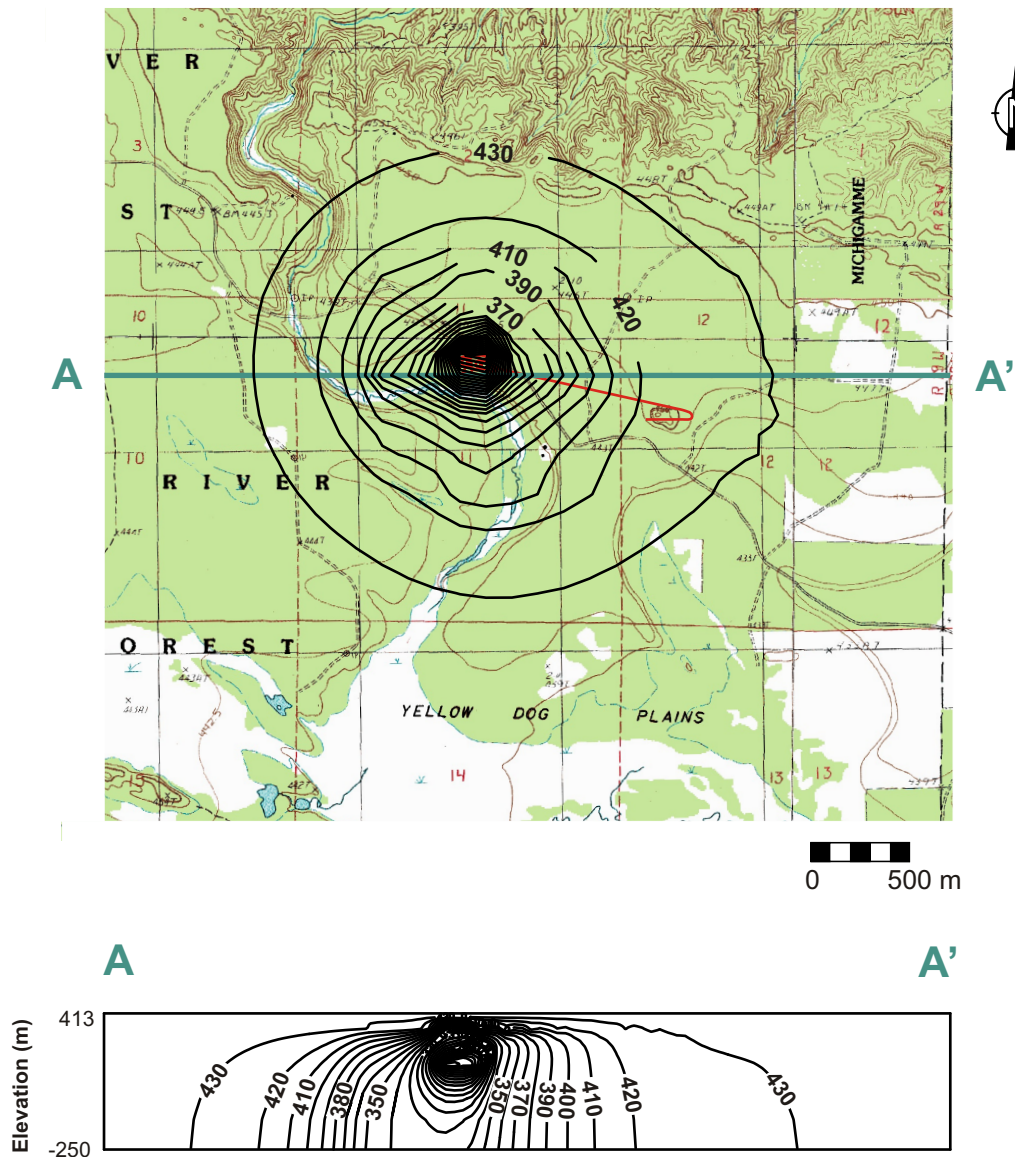
EAGLE PROJECT
KENNECOTT MINERALS COMPANY

TITLE

BOUNDARY CONDITIONS
TYPICAL CROSS-SECTION



PROJECT No. 05-3236-2c		FILE No. hydrogeo1	
DESIGN	WZ	01FEB06	SCALE NTS
CADD	GG	01FEB06	REV.
CHECK	WZ	01FEB06	FIGURE 5.4
REVIEW			



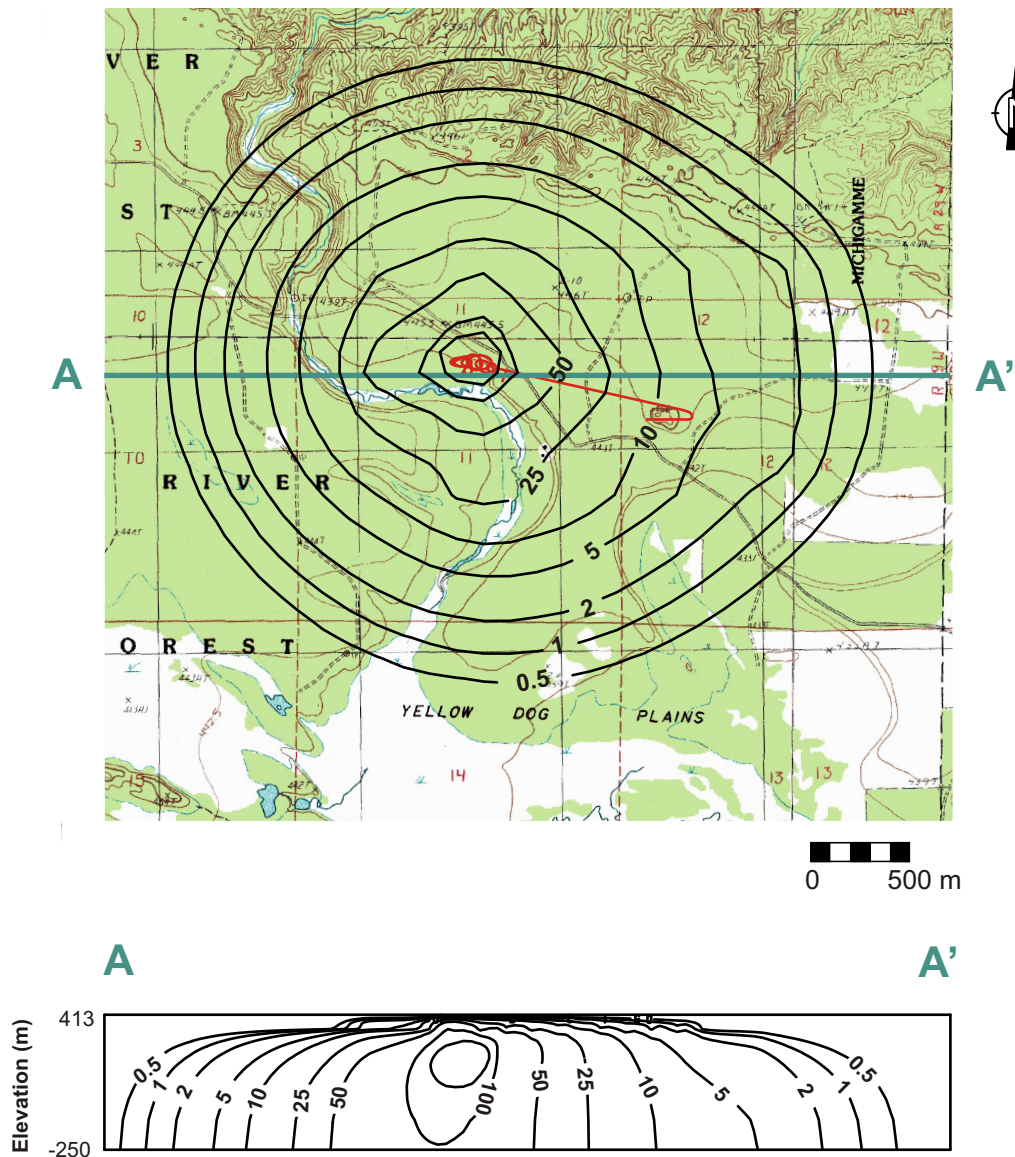
LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT		
		KENNECOTT MINERALS COMPANY		
TITLE		PREDICTED HYDRAULIC HEADS AT THE END OF MINING PRELIMINARY MODEL		
		PROJECT No.	05-3236-2c	FILE No. hydrogeo2
		DESIGN	WZ 01FEB06	SCALE NTS
		CADD	GG 01FEB06	REV.
		CHECK	WZ 01FEB06	
		REVIEW		
				FIGURE 6.1



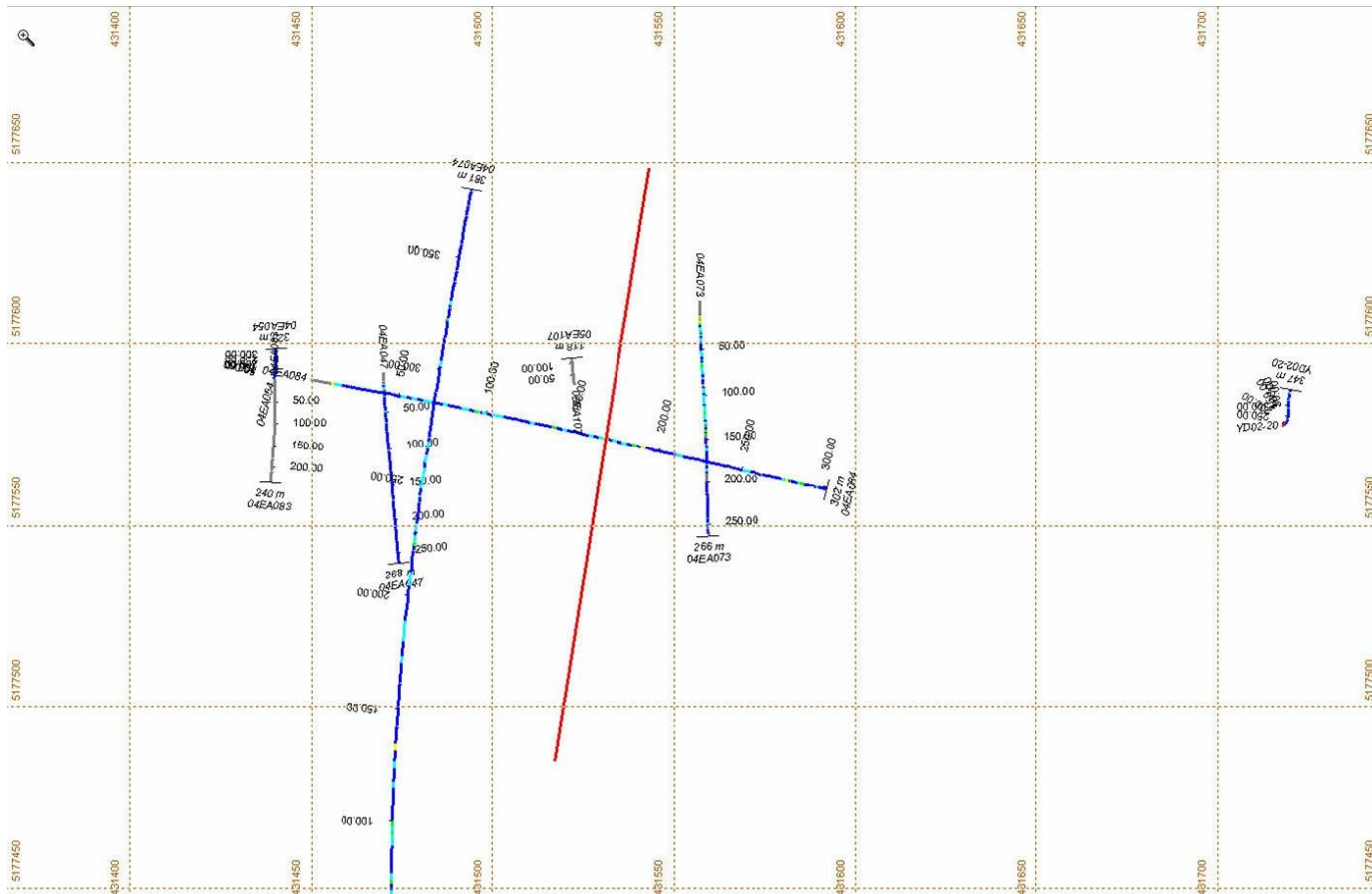
LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY		
TITLE		PREDICTED DRAWDOWN AT THE END OF MINING PRELIMINARY MODEL		
		PROJECT No.	05-3236-2c	FILE No. hydrogeo2
		DESIGN	WZ 01FEB06	SCALE NTS
		CADD	GG 01FEB06	REV.
		CHECK	WZ 01FEB06	
		REVIEW		
				FIGURE 6.2



NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT

**EAGLE PROJECT
KENNECOTT MINERALS CORPORATION**

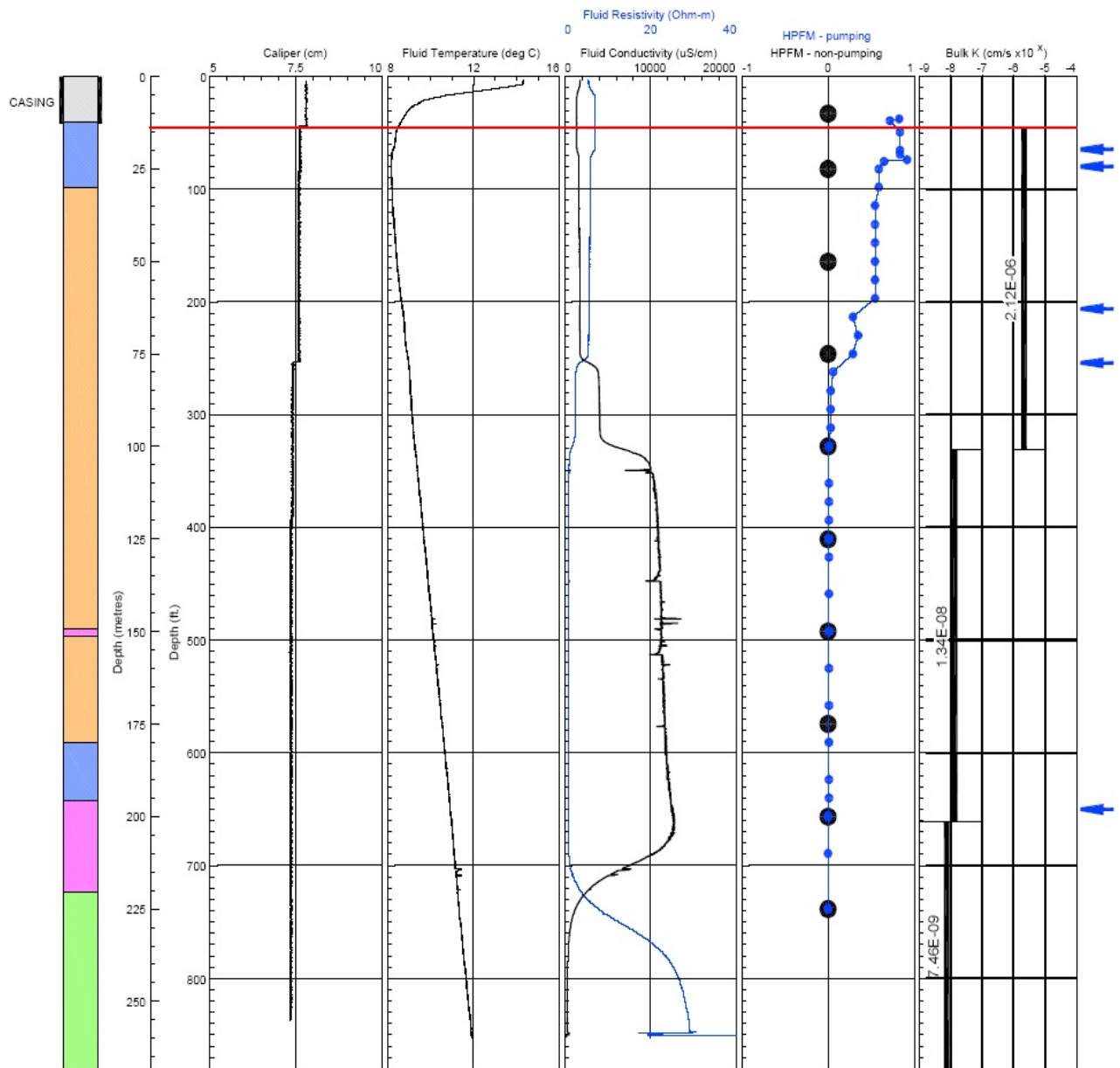
TITLE

**TRACE OF AMEC STUDY FAULT AND
RELATION TO HYDROGEOLOGIC BOREHOLES**
(provided by KMC)



PROJECT No.	05-3236-2C	FILE No.	hydrogeo3
DESIGN	WZ	03FEB06	SCALE NTS
CADD	SS	03FEB06	REV.
CHECK	WZ	03FEB06	
REVIEW			

FIGURE 7.1



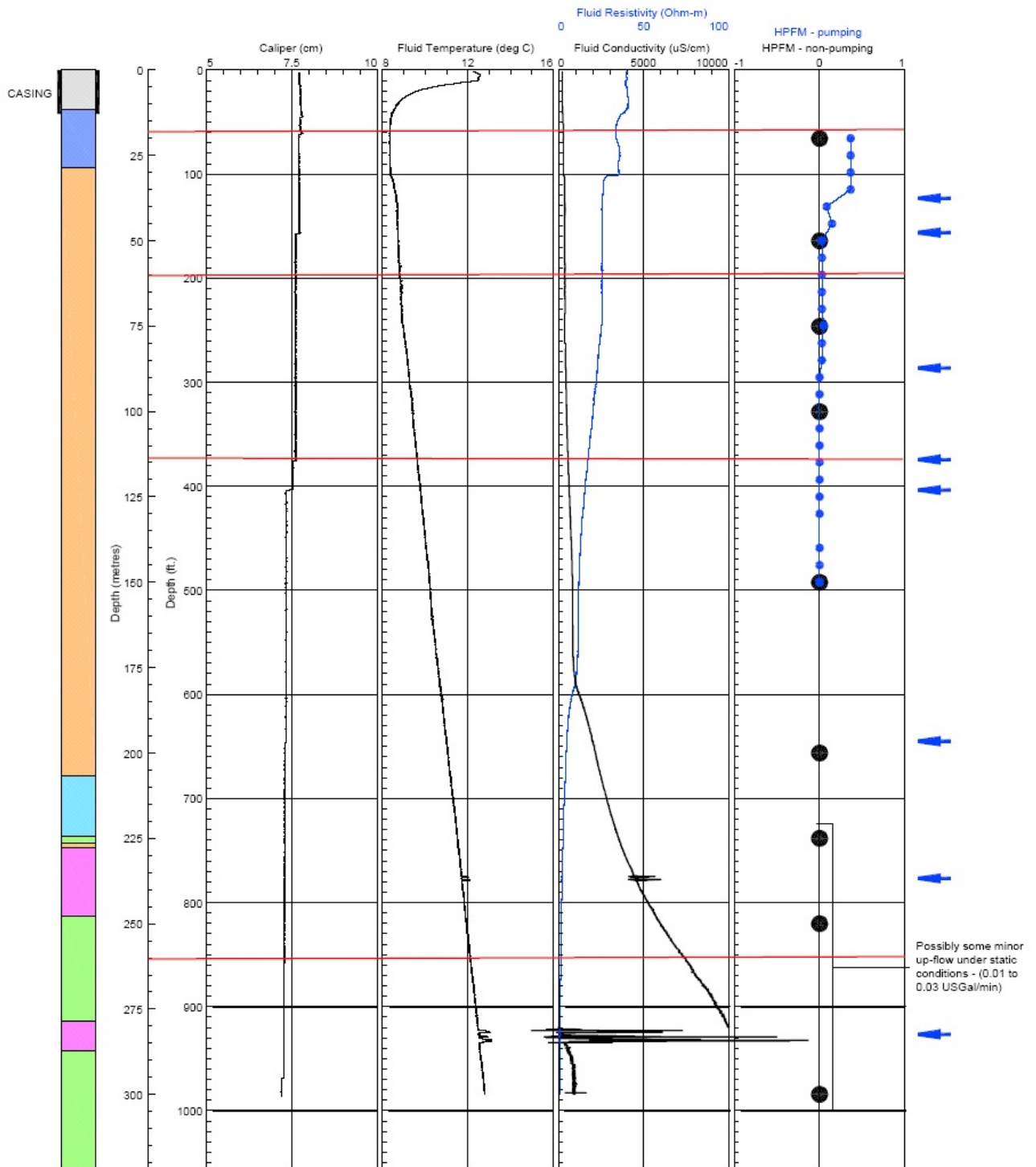
(from Golder, 2005)

— Major Structure (2005 Geotechnical Data Base)

PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
BOREHOLE 04EA-47 MAJOR STRUCTURES COMPARED TO HYDROGEOLOGIC DATA				
PROJECT No.		05-3236-2C	FILE No.	
DESIGN	WZ	03FEB06	SCALE	NTS
CADD	SS	03FEB06	REV.	
CHECK	WZ	03FEB06	FIGURE 7.2	
REVIEW				



DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr



(from Golder, 2005)

— Major Structure (2005 Geotechnical Data Base)

PROJECT

**EAGLE PROJECT
KENNECOTT MINERALS CORPORATION**

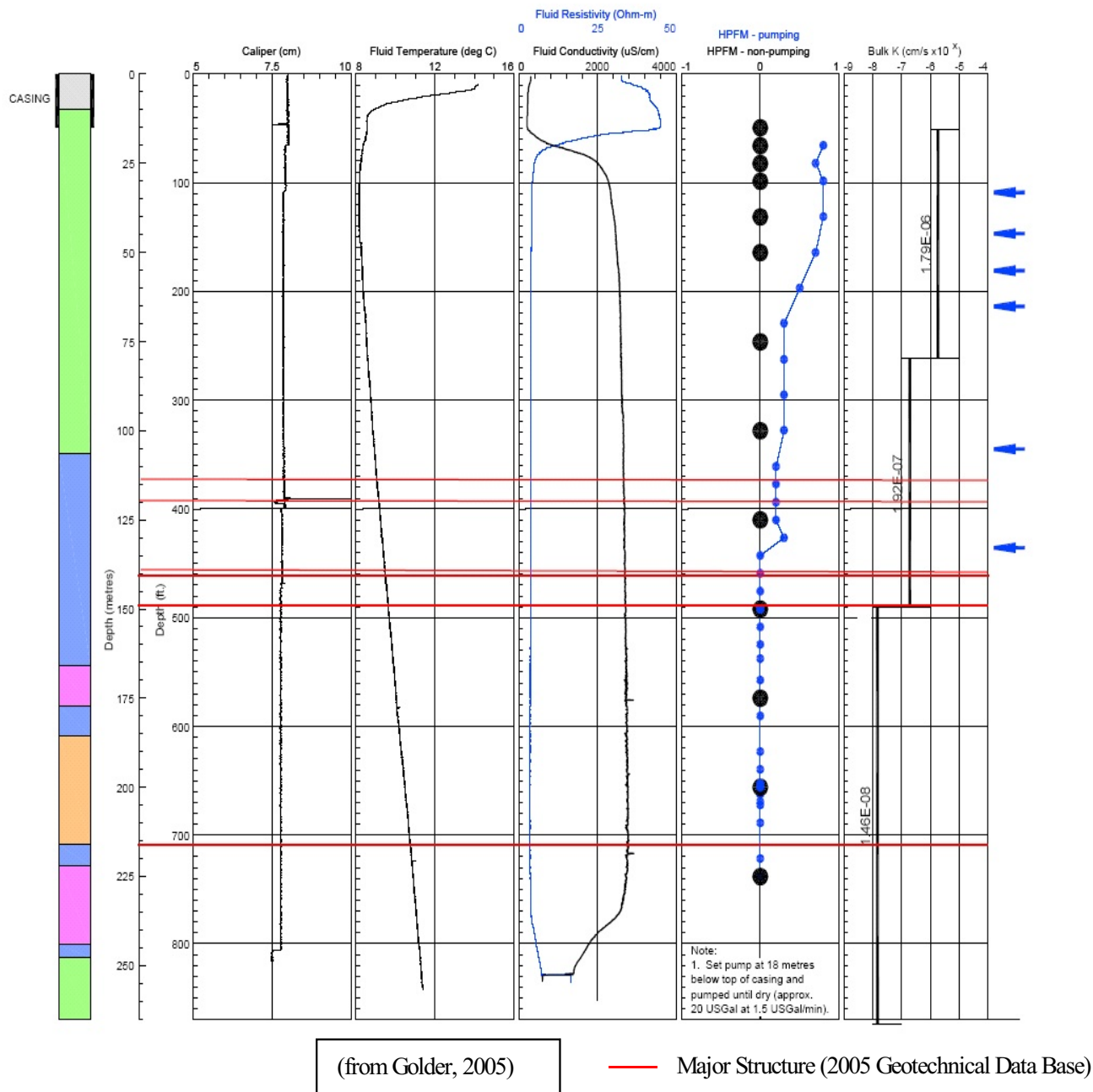
TITLE

**BOREHOLE 04EA-54
MAJOR STRUCTURES COMPARED TO
HYDROGEOLOGIC DATA**



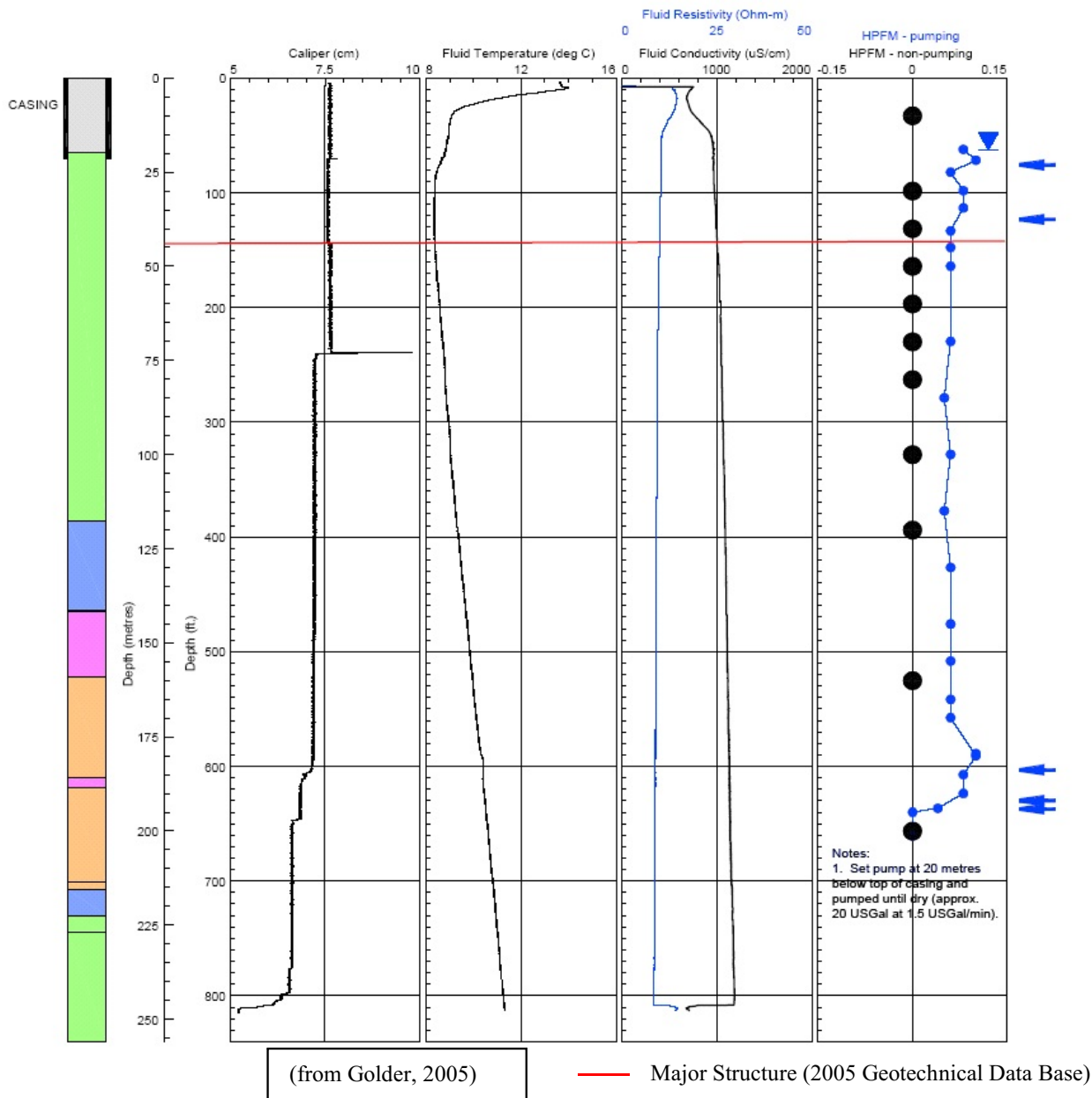
PROJECT No. 05-3236-2C			FILE No. hydrogeo3		
DESIGN	WZ	03FEB06	SCALE	NTS	REV.
CADD	SS	03FEB06	FIGURE 7.3		
CHECK	WZ	03FEB06			
REVIEW					

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\hydrogeo3.cdr



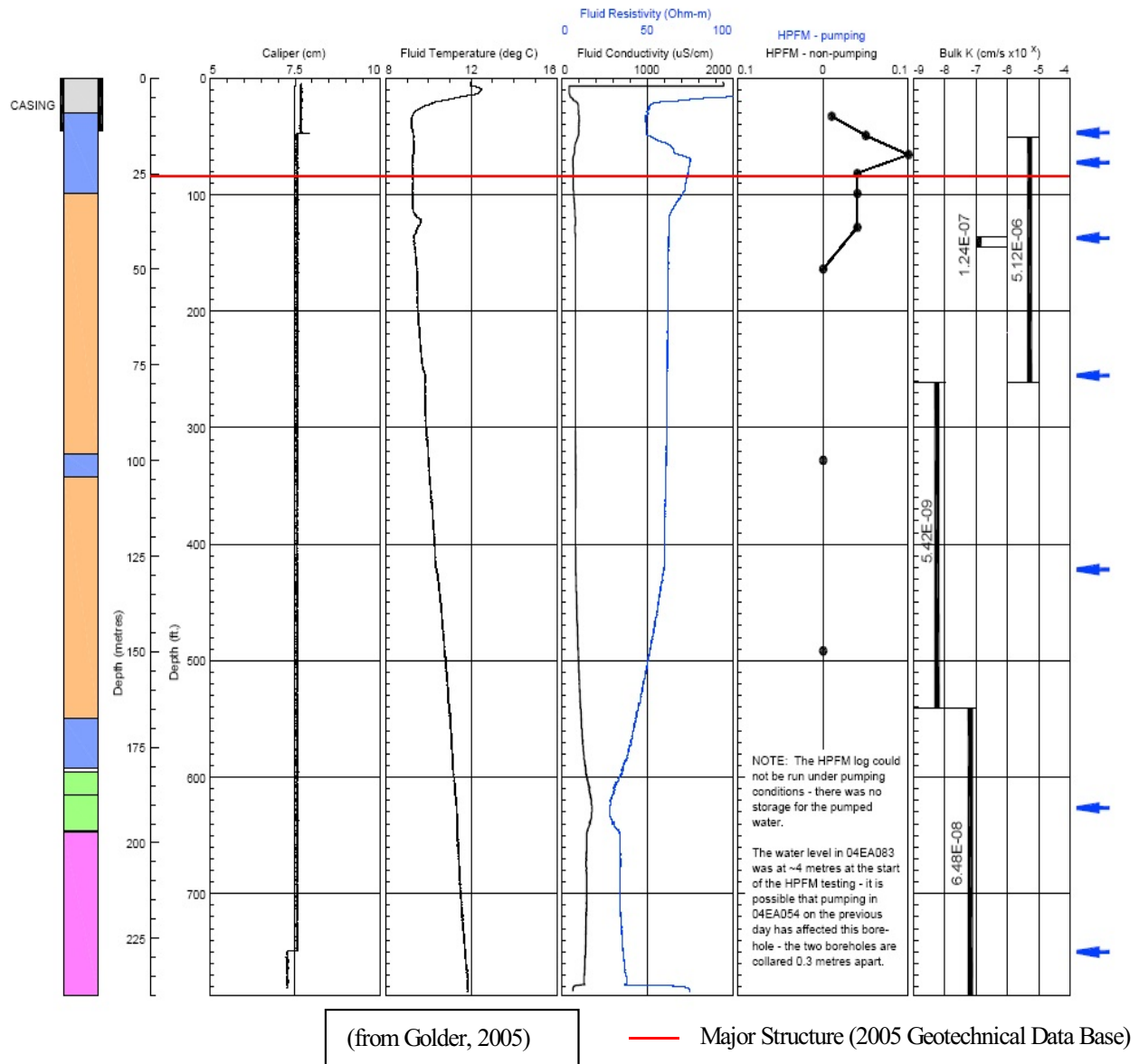
PROJECT					
EAGLE PROJECT KENNECOTT MINERALS CORPORATION					
TITLE					
BOREHOLE 04EA-73 MAJOR STRUCTURES COMPARED TO HYDROGEOLOGIC DATA					
		PROJECT No.	05-3236-2C	FILE No.	hydrogeo3
		DESIGN	WZ	03FEB06	SCALE NTS
		CADD	SS	03FEB06	REV.
		CHECK	WZ	03FEB06	
		REVIEW			
					FIGURE 7.4

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\hydrogeo3.cdr



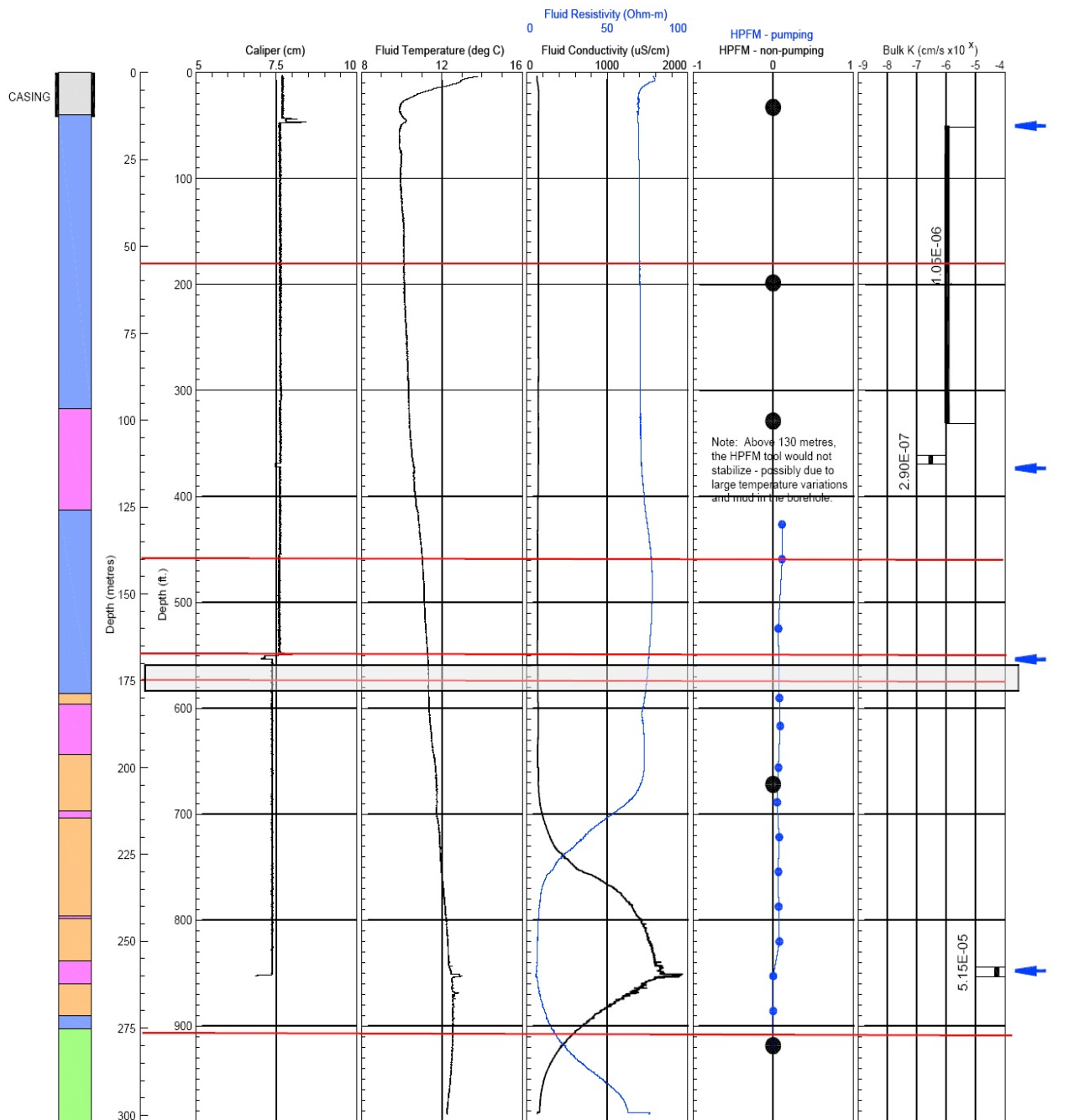
PROJECT	EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE	BOREHOLE 04EA-77 MAJOR STRUCTURES COMPARED TO HYDROGEOLOGIC DATA				
	PROJECT No.	05-3236-2C	FILE No.	hydrogeo3	
	DESIGN	WZ	03FEB06	SCALE	NTS
	CADD	SS	03FEB06	REV.	
	CHECK	WZ	03FEB06	FIGURE 7.5	
	REVIEW				

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\hydrogeo3.cdr



PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
BOREHOLE 04EA-83 MAJOR STRUCTURES COMPARED TO HYDROGEOLOGIC DATA				
		PROJECT No.	05-3236-2C	FILE No. hydrogeo3
		DESIGN	WZ	03FEB06
		CADD	SS	03FEB06
		CHECK	WZ	03FEB06
		REVIEW		
			SCALE	NTS
			REV.	
FIGURE 7.6				

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr



(from Golder, 2005)

Major Structure (2005 Geotechnical Data Base)

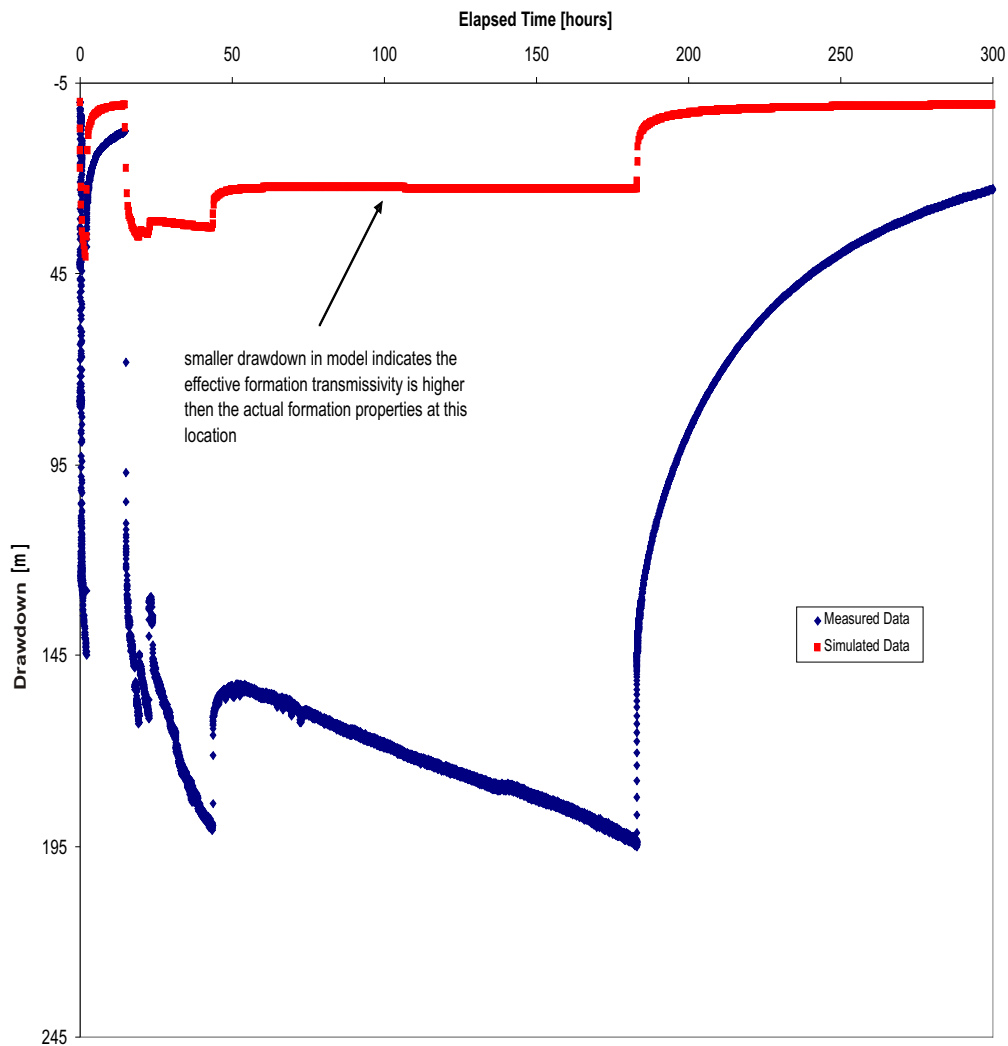


AMEC Study Fault

PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
BOREHOLE 04EA-84 MAJOR STRUCTURES COMPARED TO HYDROGEOLOGIC DATA				
PROJECT No.		05-3236-2C	FILE No.	
DESIGN	WZ	03FEB06	SCALE	NTS
CADD	SS	03FEB06	REV.	
CHECK	WZ	03FEB06	FIGURE 7.7	
REVIEW				

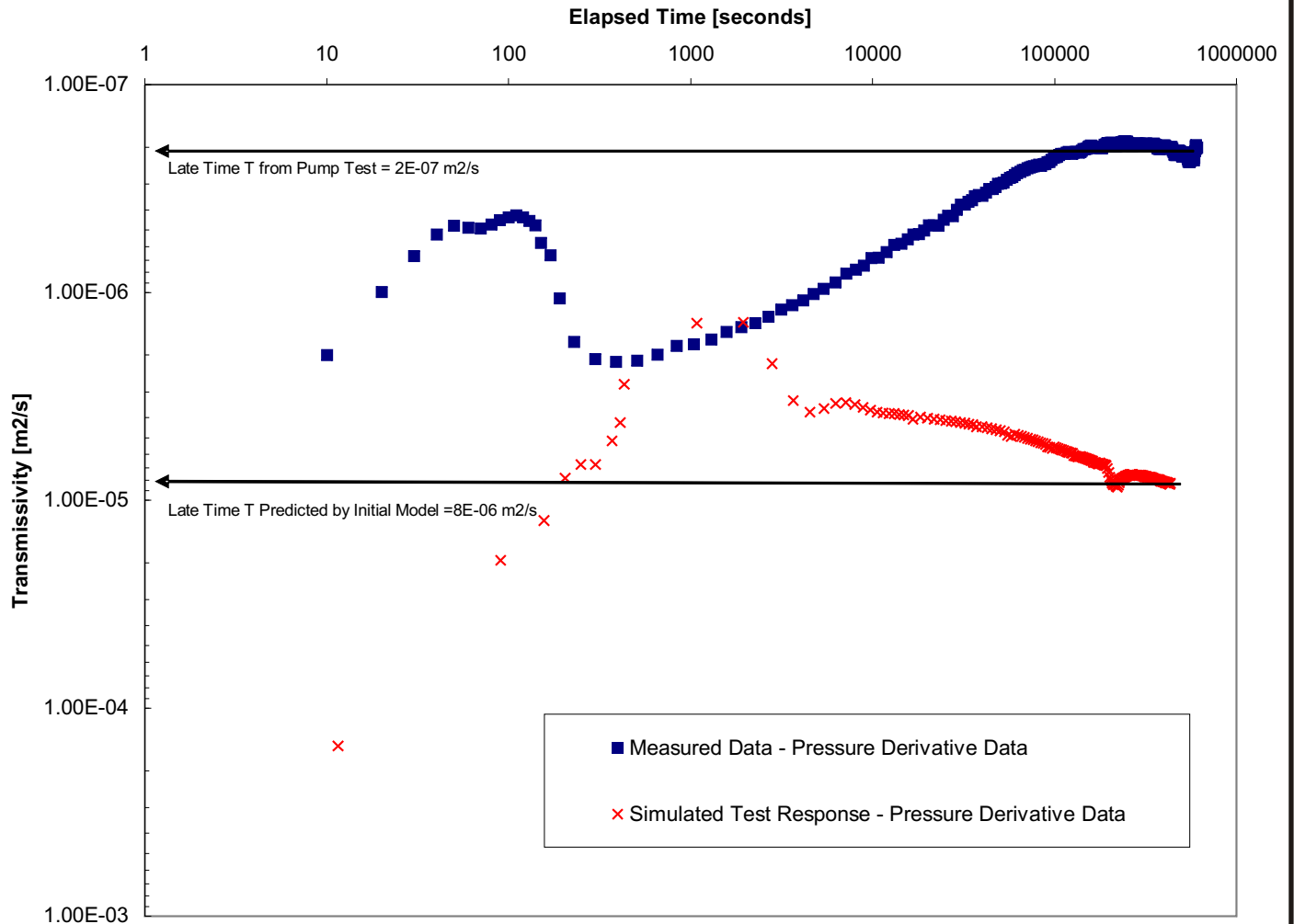


DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr



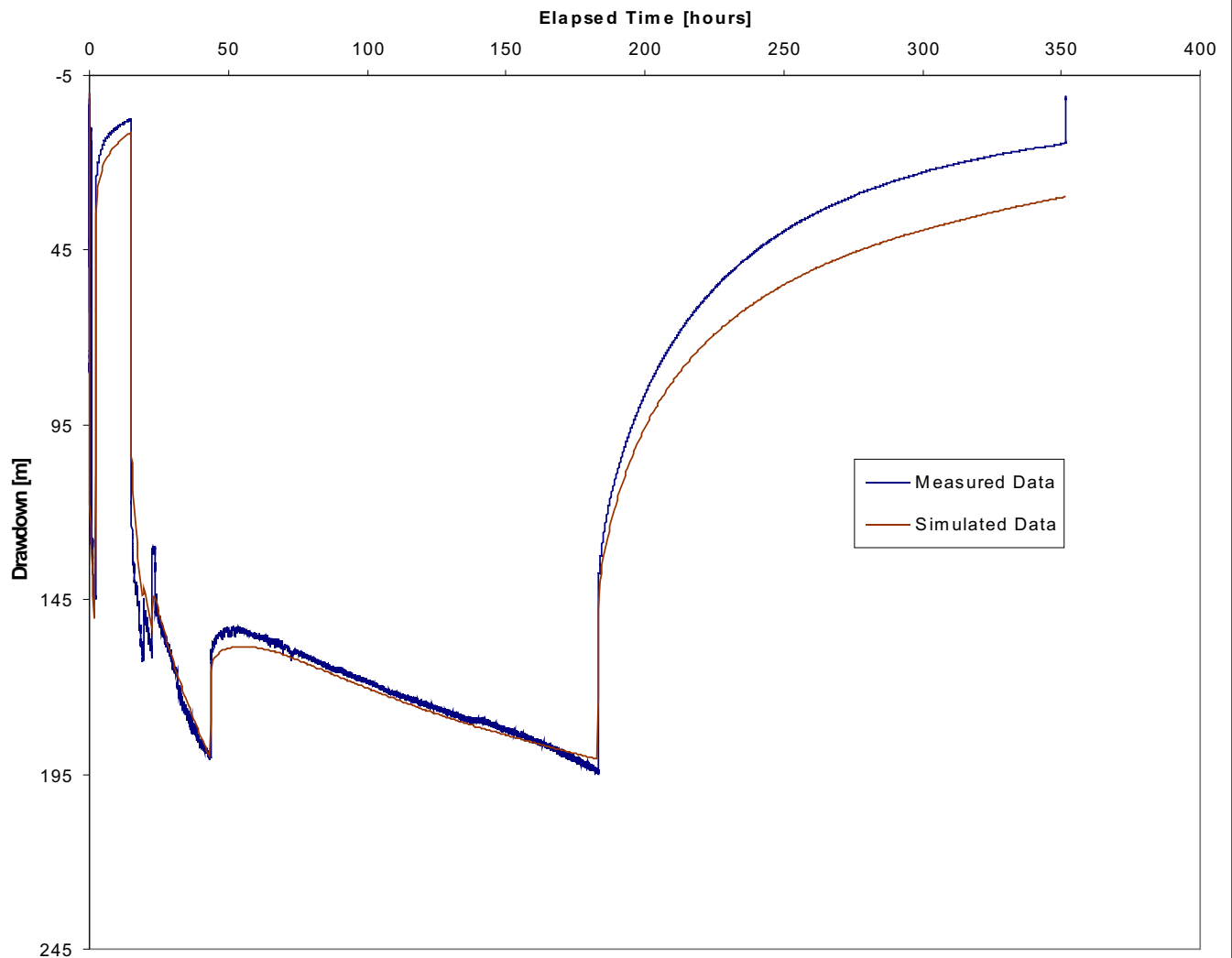
PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
MEASURED vs. SIMULATED DRAWDOWN PRELIMINARY MODEL 04EA-84 PUMPING TEST				
		PROJECT No.	05-3236-2C	FILE No. hydrogeo3
		DESIGN	WZ	03FEB06
		CADD	SS	03FEB06
		CHECK	WZ	03FEB06
		REVIEW		
				SCALE NTS
				REV.
FIGURE 8.1				

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr



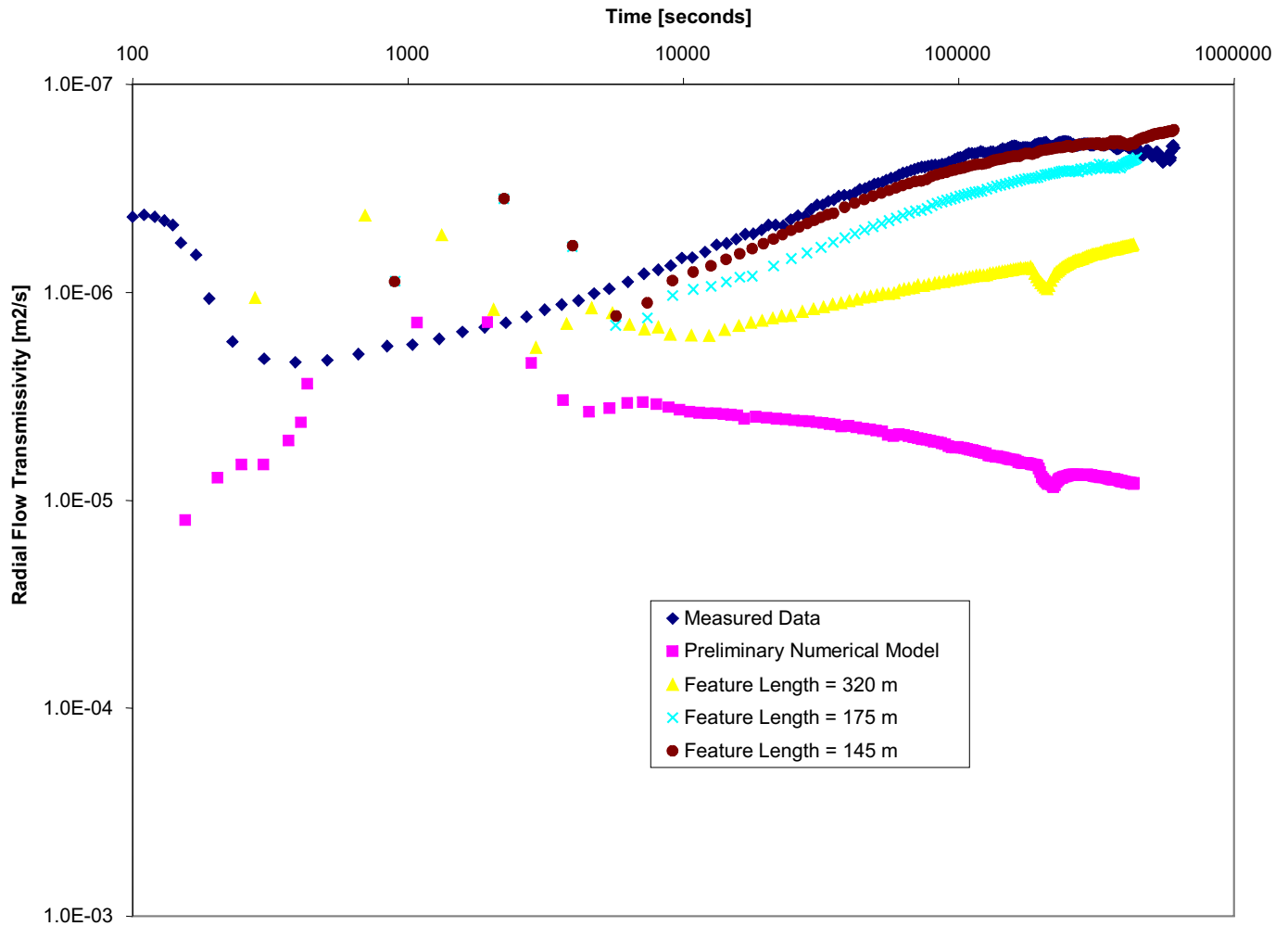
PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
MEASURED vs. SIMULATED PRESSURE DERIVATIVE PRELIMINARY MODEL 04EA-84 PUMPING TEST				
		PROJECT No.	05-3236-2C	FILE No. hydrogeo3
		DESIGN	WZ	03FEB06
		CADD	SS	03FEB06
		CHECK	WZ	03FEB06
		REVIEW		
				SCALE NTS
				REV.
FIGURE 8.2				

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr

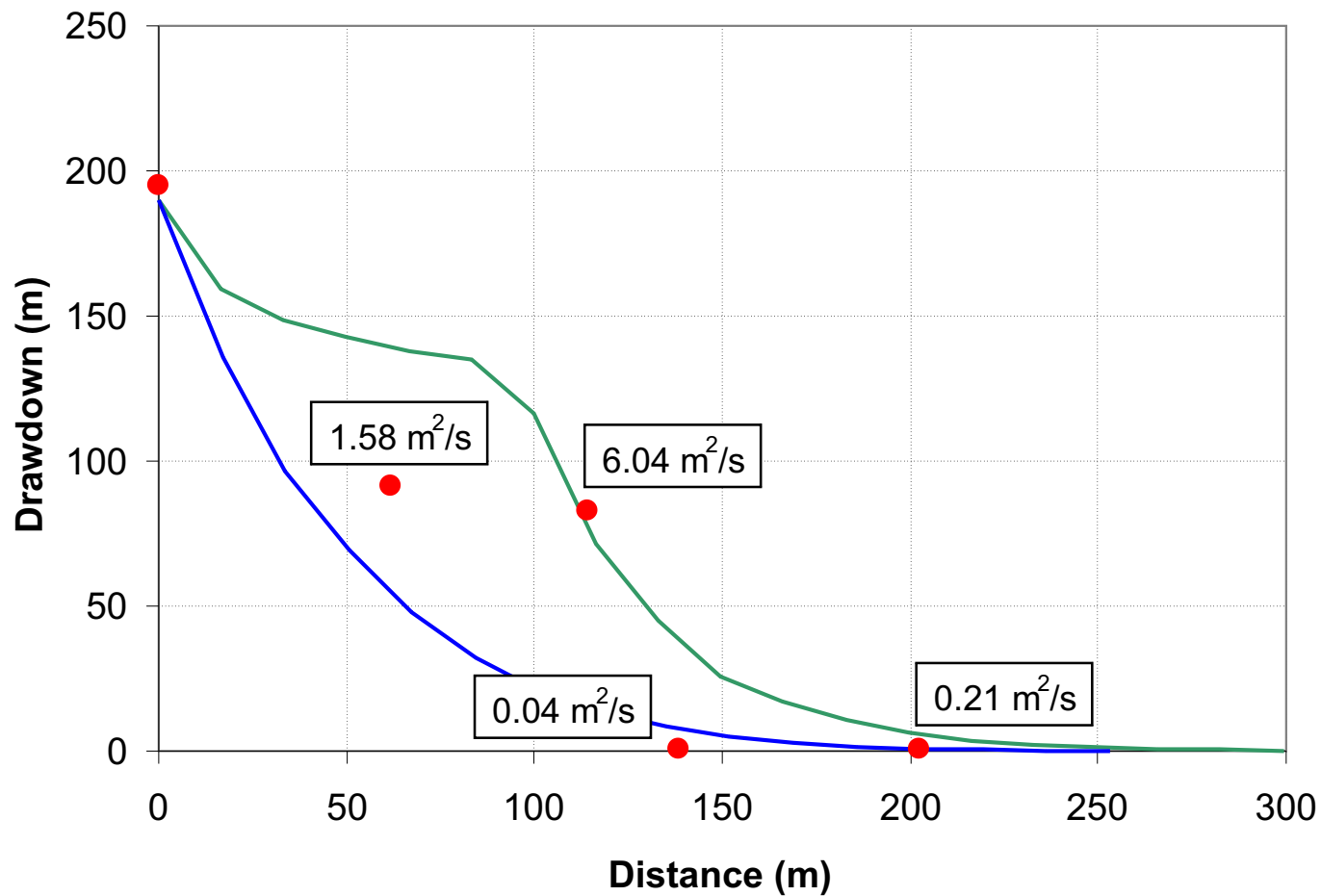


PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
MEASURED vs. SIMULATED DRAWDOWN REVISED MODEL 04EA-84 PUMPING TEST				
		PROJECT No.	05-3236-2C	FILE No. hydrogeo3
		DESIGN	WZ	03FEB06
		CADD	SS	03FEB06
		CHECK	WZ	03FEB06
		REVIEW		
SCALE NTS				REV.
FIGURE 8.3				

DRAWING DATE: 06-Feb-06 COREL FILE: N:\Bur-Graphics\Projects\2005\3000\05-3236-2C\Drafting\corel\hydrogeo3.cdr



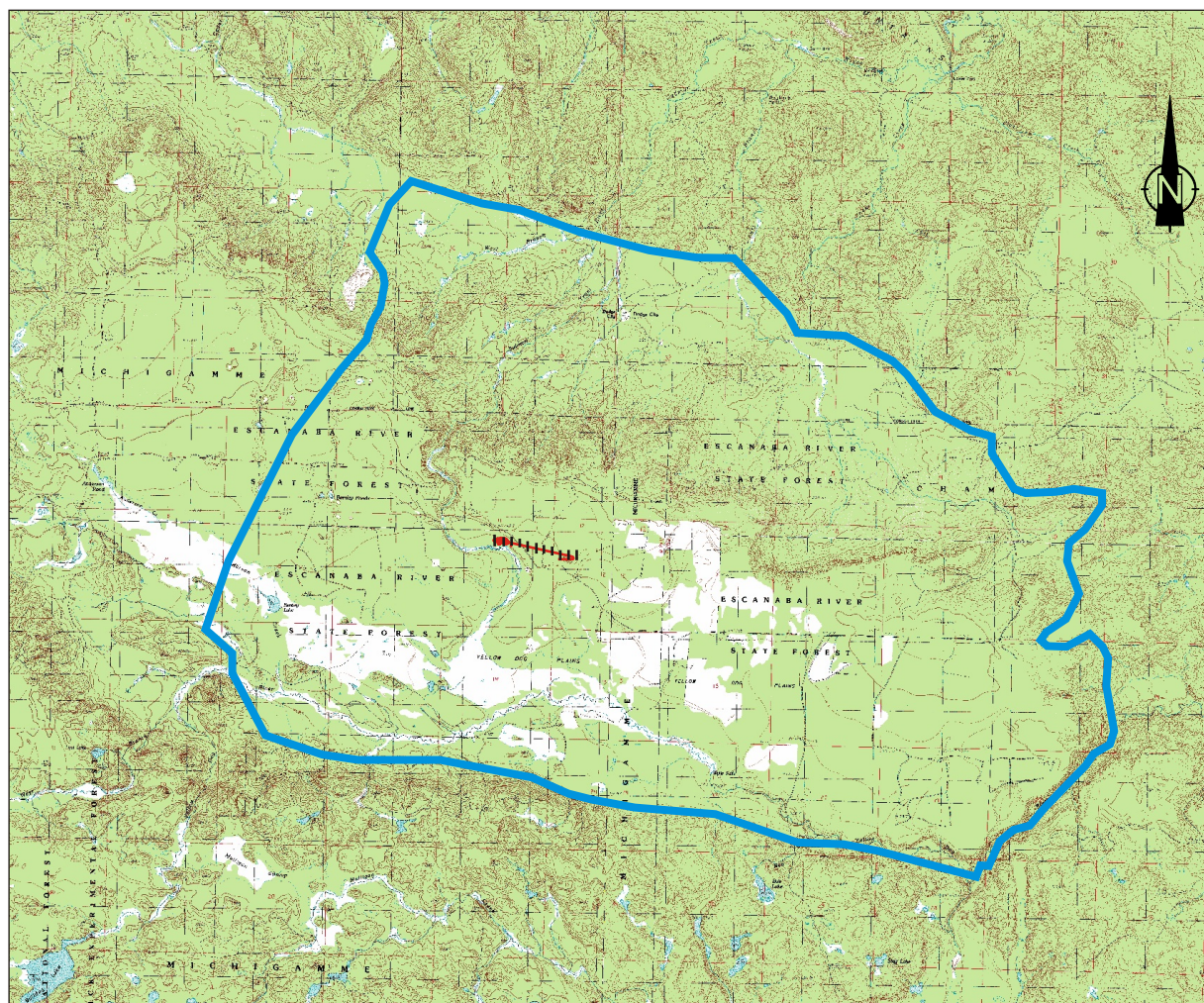
PROJECT				
EAGLE PROJECT KENNECOTT MINERALS CORPORATION				
TITLE				
ADJUSTMENT OF WATER CONDUCTIVE FEATURE LENGTH MEASURED vs. SIMULATED DRAWDOWN NORMALIZED TRANSMISSIVITY PLOT 04EA-84 PUMPING TEST				
		PROJECT No.	05-3236-2C	FILE No. hydrogeo3
		DESIGN	WZ	03FEB06
		CADD	SS	03FEB06
		CHECK	WZ	03FEB06
		REVIEW		
				SCALE NTS
				REV.
FIGURE 8.4				



● Measured — Predicted - Along FRZ — Predicted - Prependicular to FRZ

1.58 m²/s Diffusivity

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY			
TITLE		MEASURED vs. SIMULATED DRAWDOWN OBSERVATION WELLS - REVISED MODEL PUMPING TEST IN 04EA-84			
		PROJECT No. 05-3236-2c		FILE No. hydrogeo1	
		DESIGN	WZ	01FEB06	SCALE NTS
		CADD	GG	01FEB06	REV.
		CHECK	WZ	01FEB06	FIGURE 8.5
		REVIEW			



0 4000 m

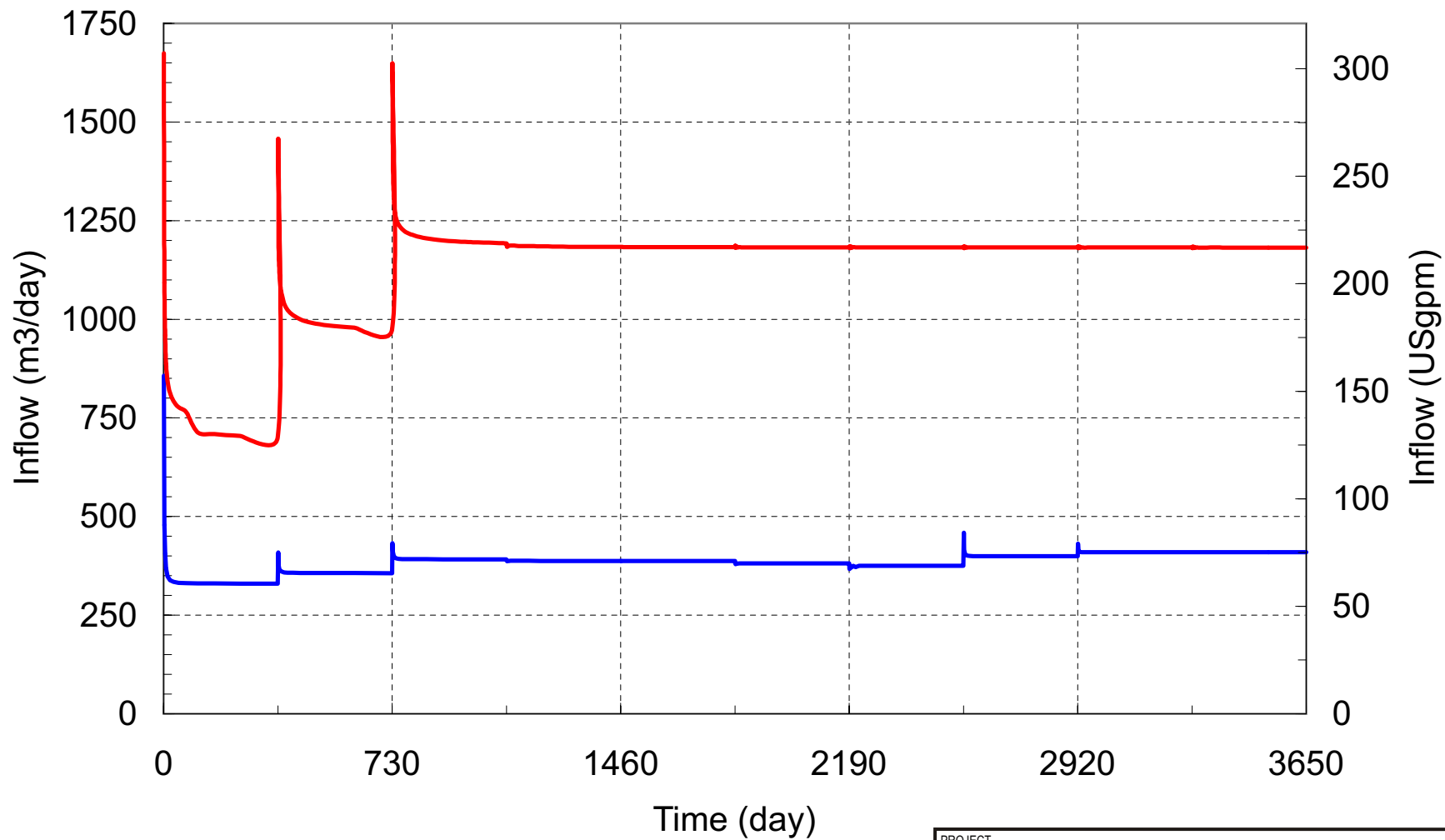
LEGEND

- Water Conductive Feature
- Proposed Mine Workings
- Model Boundary

NOTES

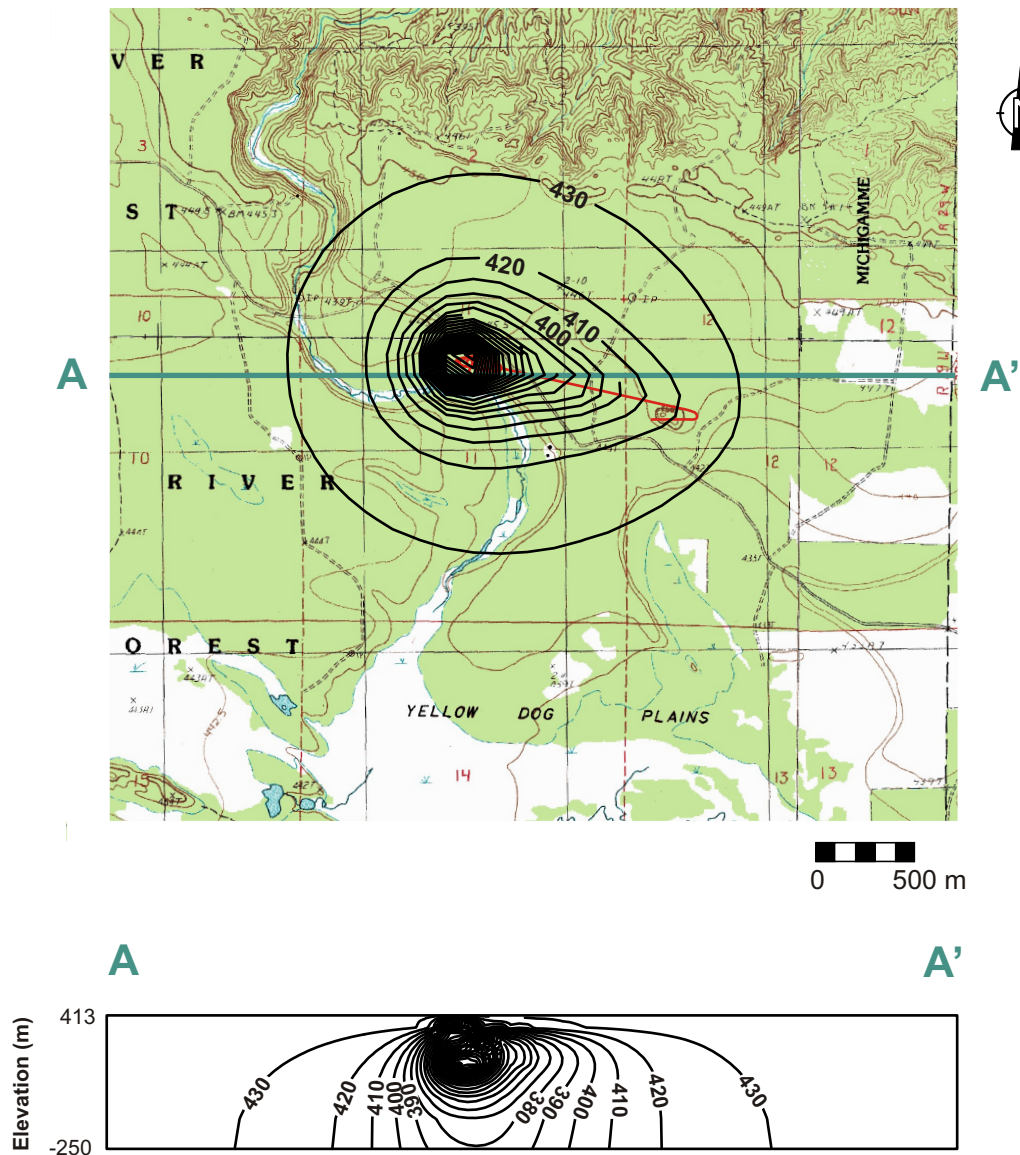
1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY			
TITLE		REPRESENTATION OF WATER CONDUCTIVE FEATURES WITHIN THE LOWER BEDROCK - REVISED MODEL			
		PROJECT No.	05-3236-2c	FILE No.	hydrogeo1
		DESIGN	WZ 01FEB06	SCALE	NTS
		CADD	GG 01FEB06	REV.	
		CHECK	WZ 01FEB06	FIGURE 8.6	
		REVIEW			



— Base Case Total
— Upper Case Total

PROJECT				
EAGLE PROJECT KENNECOTT MINERALS COMPANY				
TITLE				
PREDICTED INFLOW TO PROPOSED MINE				
		PROJECT No. 05-3236-2c		FILE No. hydrogeo1
		DESIGN	WZ	01FEB06
		CADD	GG	01FEB06
		CHECK	WZ	01FEB06
		REVIEW		
SCALE NTS				REV.
FIGURE 9.1				



LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT

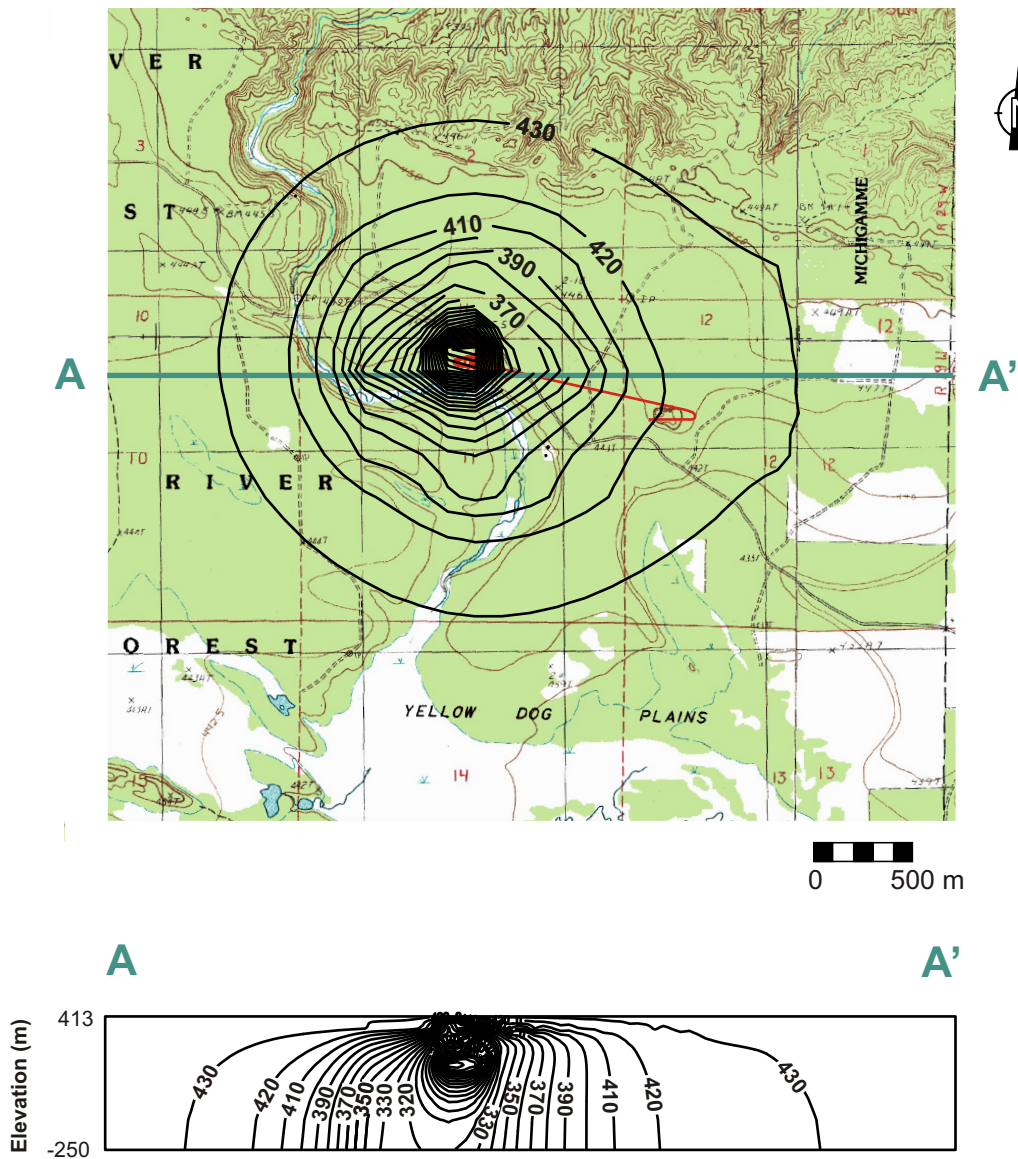
**EAGLE PROJECT
KENNECOTT MINERALS COMPANY**

TITLE

**PREDICTED HYDRAULIC HEADS
AT THE END OF MINING
REVISED BASE CASE**



PROJECT No. 05-3236-2c			FILE No. hydrogeo2		
DESIGN	WZ	01FEB06	SCALE	NTS	REV.
CADD	GG	01FEB06	FIGURE 9.2		
CHECK	WZ	01FEB06			
REVIEW					



LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT

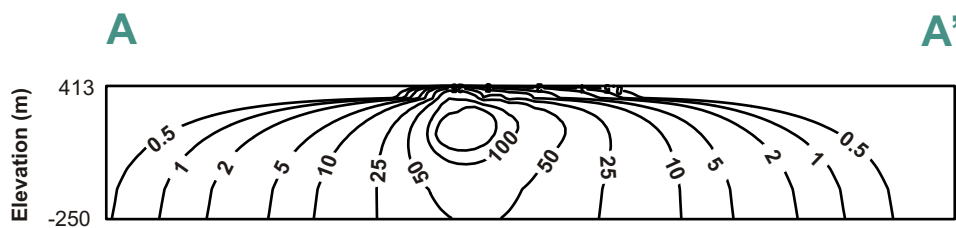
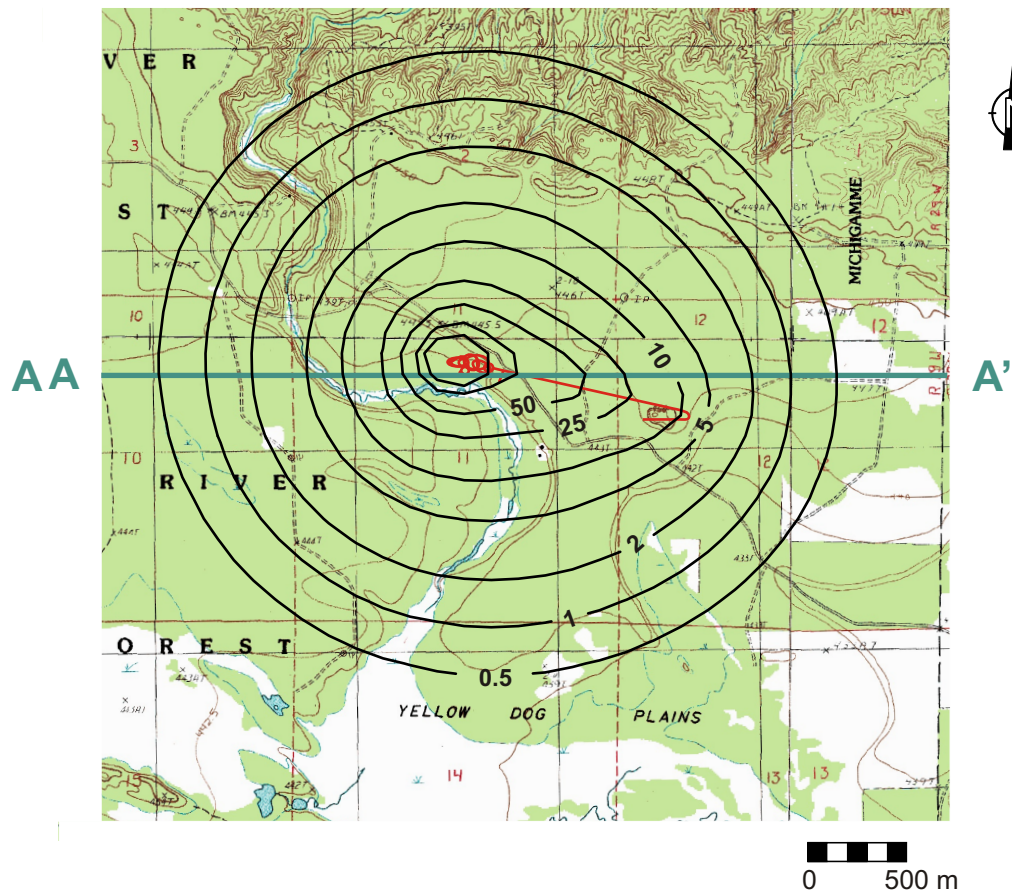
**EAGLE PROJECT
KENNECOTT MINERALS COMPANY**

TITLE

**PREDICTED HYDRAULIC HEADS
AT THE END OF MINING
UPPER BOUND CASE**



PROJECT No. 05-3236-2c			FILE No. hydrogeo2	
DESIGN	WZ	01FEB06	SCALE NTS	REV.
CADD	GG	01FEB06	FIGURE 9.3	
CHECK	WZ	01FEB06		
REVIEW				



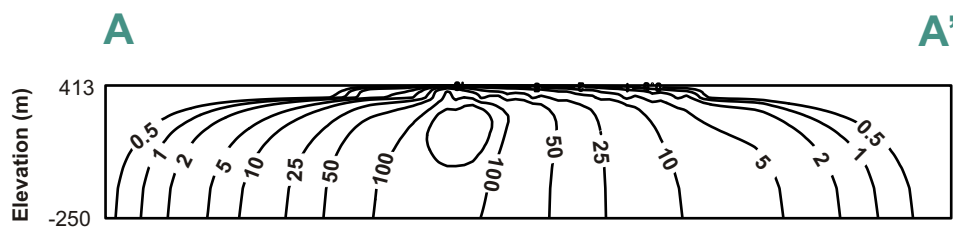
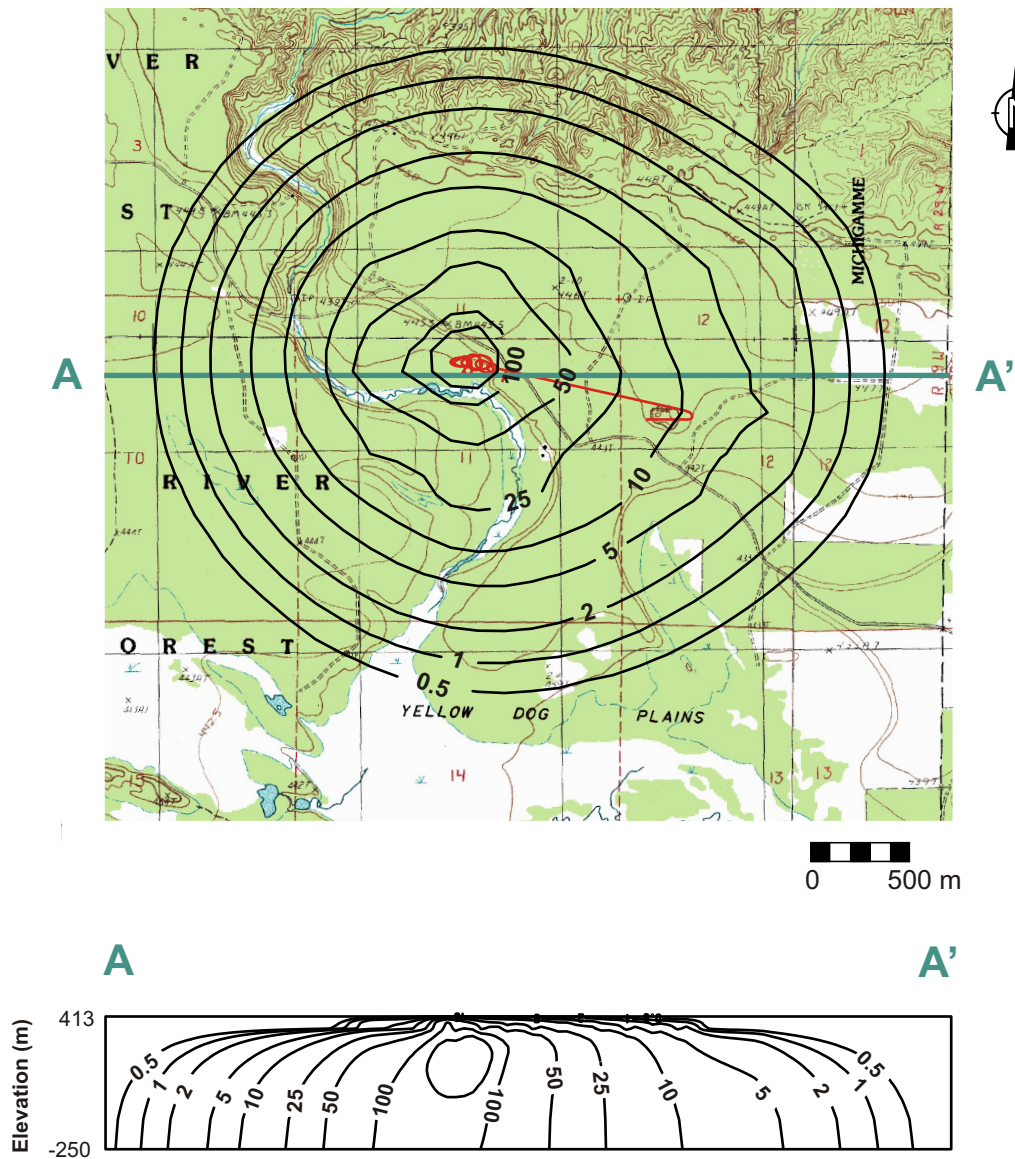
LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY		
TITLE		PREDICTED DRAWDOWN AT THE END OF MINING REVISED BASE CASE		
		PROJECT No.	05-3236-2c	FILE No. hydrogeo2
		DESIGN	WZ 01FEB06	SCALE NTS
		CADD	GG 01FEB06	REV.
		CHECK	WZ 01FEB06	
		REVIEW		
FIGURE 9.4				



LEGEND

- Hydraulic Head Contour (m)
- Proposed Mine Workings

NOTES

1. Schematic only. Not to scale.
2. All distances are in metres.

PROJECT		EAGLE PROJECT KENNECOTT MINERALS COMPANY		
TITLE		PREDICTED DRAWDOWN AT THE END OF MINING UPPER BOUND CASE		
		PROJECT No.	05-3236-2c	FILE No. hydrogeo2
		DESIGN	WZ 01FEB06	SCALE NTS
		CADD	GG 01FEB06	REV.
		CHECK	WZ 01FEB06	
		REVIEW		
FIGURE 9.5				