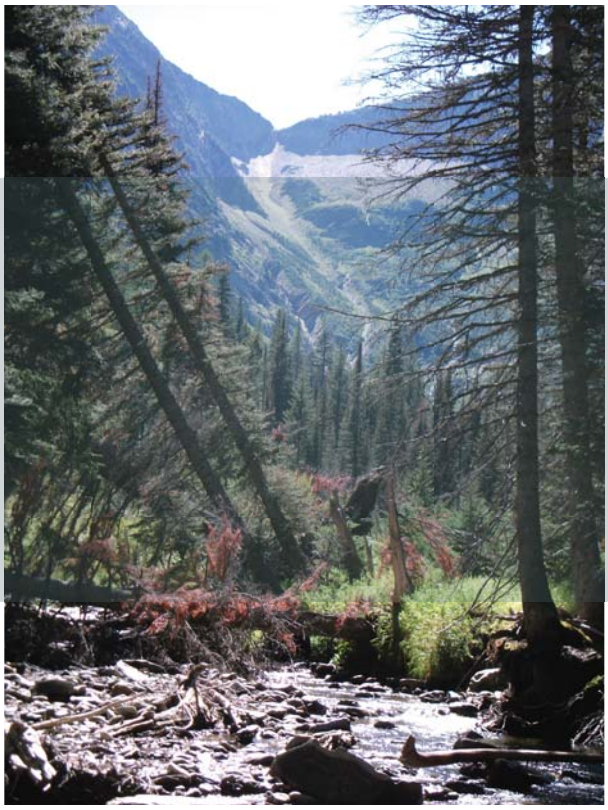
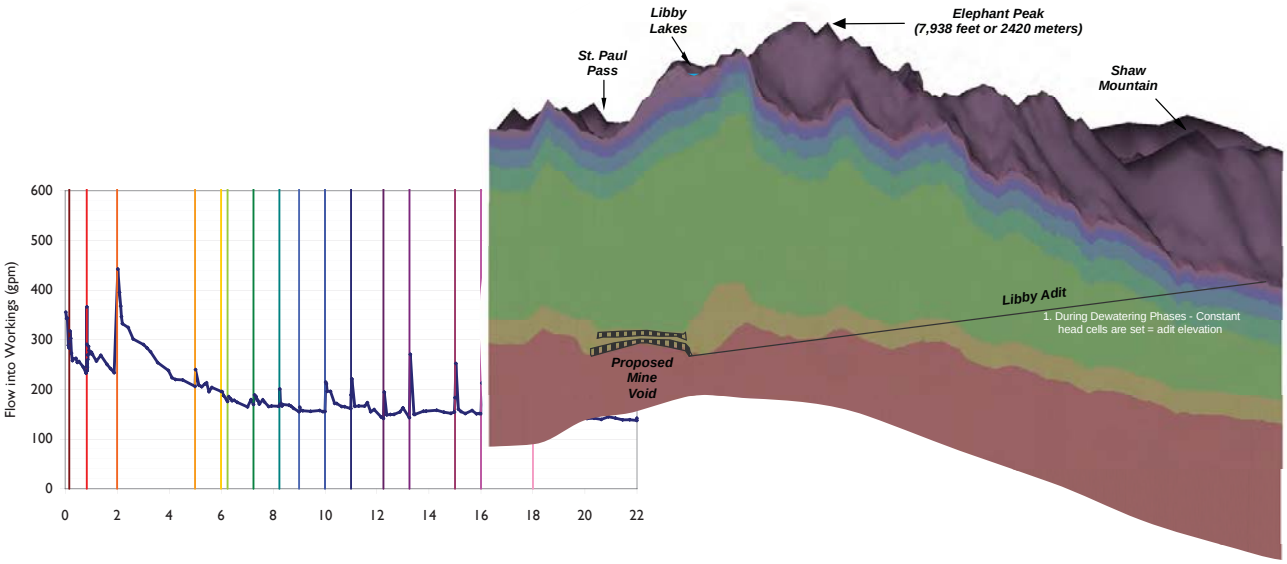


FINAL NUMERICAL GROUNDWATER MODEL DEVELOPMENT, CALIBRATION, AND PREDICTIONS

Montanore Mine Project
Sanders and Lincoln Counties, Montana



AMEC Geomatrix

DECEMBER 2010
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FINAL
Numerical Groundwater Model Development, Calibration, and Predictions

Montanore Mine Project
Sanders and Lincoln Counties, Montana

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1.0 INTRODUCTION

This report describes development of a three-dimensional numerical groundwater flow model of the Montanore Mine project area located in northwest Montana (**Figure 1**) by AMEC Geomatrix (AMEC). The purpose of developing this three-dimensional numerical groundwater flow model is to provide an advanced tool for estimating flows into existing and proposed mine workings and to help assess potential impacts to surrounding water resources. Figures for this report are contained in **Appendix A**.

The Montanore Minerals Corporation (MMC) Mine site is located approximately 18 miles south of Libby in the Cabinet Mountains of northwest Montana. The mine targets a silver and copper ore body located beneath the Cabinet Mountains Wilderness Area. All access and surface facilities will be located east of the wilderness boundary. The permit area is contained within Township 28N, Range 31W and Township 27N, Range 31W in Lincoln and Sanders counties (**Figure 1**).

Proposed underground mine facilities consist of the existing Libby Adit, two additional adits semi-parallel and proximal to the Libby Adit, and two parallel layered mine voids in the ore zone. The adits and mine workings will extend beneath the Cabinet Mountains, with the ore body dipping to the northwest from an elevation range of approximately 4900 feet above mean sea level (msl) beneath the Rock Lake area (500 feet below ground surface), to about 6000 feet msl beneath the St. Paul Lake area (3,700 feet below ground surface). The previous permittee (Noranda Minerals Corp.) constructed the first 14,000 feet of Libby Adit in the early 1990s. Approximately 3,000 feet more of adit construction is required for completion of the Libby Adit into the ore zone. Following completion, evaluation, and exploration of the Libby Adit, the two new Libby Adits will be constructed; after which the underground mine workings (voids) will be developed.

The Libby Adit, which Noranda began constructing in 1989 under Montana Exploration Permit No. 06-002, was advanced approximately 14,000 feet by November 1991 when construction ceased prior to reaching the target ore zone. From November 1991 to May 1994, water pumping rates from the adit ranged from 170 to 240 gallons per minute (gal/min). Adit pumping was suspended in October 1995 when the pumping rate had stabilized at about 150 gal/min for 15 months.

In 1996, much of the Libby Adit site was temporarily closed and interim reclamation completed, including fitting the adit opening with a concrete bulkhead. Noranda was granted Montana Pollutant Discharge Elimination System (MPDES) Permit No. MT-0030279 in November 1997 to allow discharge of Libby Adit water to local groundwater and/or surface water (i.e., Libby Creek).

The Montanore project currently is in the process of undergoing an environmental review under the National Environmental Policy Act (NEPA) and Montana Environmental Policy Act (MEPA), with a Draft Environmental Impact Statement (EIS) issued in February 2009 (USFS/MDEQ 2009). A previous EIS for the Montanore project was completed in 1992 (USFS et al. 1992).

ERO Resources, Inc. (ERO 2009) completed a two-dimensional groundwater flow model of the full-scale Montanore Mine operation. Results of this model are summarized in the 2009 Draft EIS. Predicted steady-state mine/adit discharge for this model is about 450 gal/min. Impacts predicted by the model include a decrease in natural base flow for Libby Creek, Ramsey Creek, Rock Creek, and East Fork Bull River during full-scale mining operations. Ramsey Creek and East Fork Bull River are predicted by ERO (2009) to increase in base flow for post-mining conditions when the Montanore mine workings fill with groundwater, which would take about 47 years. Baseflow conditions generally occur over a period of about 1 to 2 months (mid-July to early October); similar conditions may occur during the winter season.

2.0 CONCEPTUAL MODEL

Geomatrix Consultants, Inc. (Geomatrix 2006a), ERO (2009), and the Draft EIS (USFS/MDEQ 2009) describe conceptual models of the physical groundwater flow system at the Montanore project site. The study area for the groundwater flow model includes all hydrologic features potentially affected by mine dewatering. The study area comprises the southern end of the Cabinet Mountains and extends from the Montanore project area northward to Big Cherry Creek and North Fork Bull River, eastward to Swamp Creek and Fisher River, southward to Silver Butte Fisher River, and westward to Bull River and Clark Fork River (**Figure 1**). Total area within the study area or model boundary shown on **Figure 1** is approximately 371 square miles. Key components of the conceptual model are described below.

The region surrounding the Montanore project area has the greatest annual precipitation in Montana. Precipitation within the study area ranges from 23 to 81 inches per year (in/yr), with a spatial average of 44 in/yr (1971-2000 PRISM data).

The project area lies within the Cabinet Mountains. The Cabinet Mountains are composed of complexly folded and faulted Precambrian-age metasedimentary bedrock (primarily quartzite with some argillite, siltite, and mudstone). The region retains a structural fabric trending to the north or northwest. The hard brittle metasedimentary rocks with complex fracture systems can store and transport groundwater. Glacial deposits mantling the flanks of the Cabinet Mountains support shallow groundwater systems. Valleys with streams draining the mountains contain unconsolidated colluvial and alluvial deposits that also transmit shallow groundwater. All of these water-bearing units eventually discharge to major river valleys, including the Kootenai and Clark Fork rivers.

The Libby Adit portal is at an elevation of about 4000 feet msl in the upper Libby Creek drainage. Rock Lake and St. Paul Lake in the Cabinet Mountains are at elevations of 4960 and 4715 feet msl, respectively. The elevation of St. Paul Pass is 6085 feet msl, and nearby Elephant Peak is at 7940 feet msl. The Clark Fork River and Kootenai River near the study area are at about 2175 and 2065 feet msl, respectively.

The Libby Adit begins in the Prichard Formation, then enters the Burke Formation, and ends in the lower member of the Revett Formation where the ore body is located. The current extent of the Libby Adit, at approximately 14,000 feet in length, is at the transition zone between the Burke Formation and lower Revett Formation. The ore body is located in the Revett Formation on the east side of the Rock Lake Fault within a syncline truncated by the fault.

The two mineralized zones are identified as the B and B-1 zones. The B zone averages 35 feet in thickness; whereas the overlying B-1 zone has an average thickness of 30 feet. Between the B and B-1 zones is a low-grade barren zone of disseminated galena ranging in thickness from more than 200 feet on the west of the mine area to approximately 18 feet on the east (USFS et al. 1992).

Information on groundwater occurrence in the proposed mine area was developed, in part, using results of drill holes and monitoring wells completed for the Montanore project and adjacent Rock Creek project, and data obtained while constructing and monitoring flows from the Libby Adit. Exploration drill holes completed in the Cabinet Mountains Wilderness Area averaged 1,000 feet in depth, and groundwater reportedly was encountered at various depths. The amount of groundwater encountered during drilling of the exploration holes was not reported.

The Rock Lake Fault extends along the alignment of Rock Lake and St. Paul Lake. The Montanore ore body is truncated by the Rock Lake Fault, limiting potential mining through the fault zone. The Montanore ore body outcrops at the north end of Rock Lake, dipping approximately 15 degrees northwest.

Groundwater is recharged at higher elevations and flows in shallow and deep bedrock systems (**Figure 2**). Shallow local groundwater flow systems occur in the headwaters of drainages as snowmelt infiltrates into talus and weathered bedrock, and discharges to cirque lakes, springs, and streams. Intermediate and deep regional groundwater flow systems also are recharged in the mountains, with flow discharging to glacial and valley fill deposits and ultimately the major streams and rivers.

According to Gurrieri (2001), "The local flow system is the upper shallow portion of the bedrock aquifer that interacts with the lakes. The regional flow systems recharge at major water table highs and discharge to major lows. Under unstressed conditions, groundwater flow occurs mostly in local flow systems, with recharge occurring by infiltration of snowmelt and rainfall, and discharge occurring in nearby streams, lakes, and wetlands." In addition, Gurrieri (2001) states "Where surface water bodies are isolated from the underlying groundwater system by low conductivity rock units at intervening depths, or are perched on low permeability unconsolidated materials at the surface, much of the recharge would continue to follow the pre-mining path flowing laterally to discharge in surface water sinks."

Figure 3 displays the general potentiometric surface based on limited water level observations and stream elevations. Bedrock groundwater discharges to streams and rivers within the study area, including Libby Creek, Rock Creek, and East Fork Bull River. Discharge areas at the margins of the model domain include the Bull River, Clark Fork River, and Fisher River. Some bedrock groundwater from deeper flow systems probably exits the study area as underflow, both west toward Lake Pend Oreille and north toward the Kootenai River.

Unfractured bedrock has minimal primary porosity and is relatively impermeable. As a result, groundwater flow in bedrock is primarily through interconnected fractures. Fractures that are not well connected can store water, but transmit little to no groundwater. If these fracture zones are intercepted by voids, water can initially drain from storage, but long-term water yield would be low. Site-specific data indicate that near-surface bedrock, which is subject to freeze/thaw and may be experiencing unloading (as evidenced by talus slopes), is more highly fractured than the deeper bedrock.

The weathered and highly fractured near-surface bedrock is expected to transmit water more rapidly via secondary porosity or fracture flow. The Libby Adit intercepts multiple water-bearing fracture zones. Historic flow rates in the larger water-bearing zones typically decrease with depth. **Appendix B** presents historic data for the Libby Adit including a 1992 memo describing inflow rates in water-bearing zones, photographs of intercepted fractures, and cross-sections for the Libby Adit that show fracture occurrence and water yielding intervals measured in 1991. Groundwater inflow rates recorded on the Libby Adit cross-sections in **Appendix B** suggest over 50 percent of the total flow entering the adit from bedrock occurred in the first 3,200 feet along the decline. Converting the locations of water yielding zones into depth below ground surface establishes that approximately the upper 600 feet of bedrock yields 50 percent of the water (**Figure 4**).

Geologic structure may play a significant role in groundwater flow in bedrock. Faults can act as conduits to flow, barriers to flow, or both. The hydraulic characteristics of major structures, such as the Rock Lake Fault (**Figure 2**), have not been directly investigated. However, Noranda obtained some information regarding the hydraulic behavior of fractured rock during advancement of the Libby Adit, and MMC obtained additional information by performing hydraulic tests in discrete fracture intervals. The information obtained by Noranda and MMC indicates that permeability of the fractured rock decreases with depth.

2.1 GROUNDWATER BALANCE

One key element of the conceptual model is the water budget. This section discusses water balance components for the groundwater system including recharge and discharge. The generalized groundwater balance equation is: Inflow = Outflow ± Change in Storage.

As part of the three-dimensional numerical flow model, AMEC developed a steady-state groundwater balance for the study area using a set of hydrologic inputs that represent a period when the system receives the least stress, to provide a basis for simulating steady-state flow conditions in the numerical groundwater model. The late summer-early fall period is a time when stresses are typically at a minimum and should be most representative of steady-state conditions. The August-September period is the time of low rainfall, low stream discharge, and low groundwater elevations based on historic precipitation records, stream flow records, and depth to groundwater measurements. **Table 1** summarizes estimated flow rates for each component of the groundwater budget.

Table 1. Groundwater Balance

Source	Low Estimate (ft^3/day)	High Estimate (ft^3/day)	Low Estimate (m^3/day)	High Estimate (m^3/day)
INFLOW				
Infiltrating Precipitation (R)	7,931,649	18,511,358	224,607	524,202
% of Total Precipitation	8%	18%	8%	18%
Total INFLOW	7,931,649	18,511,358	224,607	524,202
OUTFLOW				
Discharge as Baseflow (BF)	7,912,510	18,490,683	224,066	523,617
Underflow (GW_{out})	15.5	1551.2	0.4	43.9
Evapotranspiration (ET_G)	19,123.5	19,123.5	541.5	541.5
Total OUTFLOW	7,931,649	18,511,358	224,607	524,202

Note: ft^3/day = cubic feet per day; m^3/day = cubic meters per day. Average annual precipitation for model area = 44 inches per year (in/yr) = 104,300,000 ft^3/day over an area of about 10,357,000,000 square feet (ft^2).

The steady-state groundwater balance equation can be expressed in terms of the sources of recharge and discharge:

$$R = BF + GW_{out} + ET_G$$

Where:

R = recharge due to infiltrating precipitation and runoff
BF = groundwater discharged to streams as baseflow
GW_{out} = groundwater discharged downgradient of the study area via underflow
ET_G = evapotranspiration directly from near surface saturated zones

2.1.1 Areal Recharge

Areal recharge from precipitation can be estimated through soil moisture water balances, using stable isotopes, or calculating recharge as part of a water balance. A water balance approach to estimate groundwater recharge from precipitation was used for this study. The water balance (**Table 1**) provides estimates of recharge ranging from approximately 7,932,000 to 18,511,000 cubic feet per day (ft^3/day).

Annual precipitation across the study area varies significantly from a low of 21 inches near the town of Libby to a high of 73 inches in the peaks of the Cabinet Mountain Wilderness (1971-2000 PRISM). The spatial average annual precipitation over the study area is 44 inches. The estimated range of recharge (7,932,000 to 18,511,000 ft^3/day) is equivalent to 8 to 18 percent of average annual precipitation.

2.1.2 Baseflow

Groundwater discharges to Libby Creek, Rock Creek, Swamp Creek, Big Cherry Creek, Bull River, Clark Fork River, Fisher River, and their tributaries as baseflow within the study area. Available stream flow data were examined to estimate baseflow to streams within the model domain. **Appendix C** presents stream and river flow data and the calculated baseflow. Estimated total baseflow ranges from approximately 7,913,000 to 18,491,000 ft^3/day.

2.1.3 Groundwater Underflow

Some groundwater is assumed to exit the study area as underflow in the valleys of the Clark Fork River, Bull River, Libby Creek, and Fisher River. Underflow rates were estimated using Darcy's Law and hydraulic conductivity (K) values from literature. Hydraulic gradient was calculated using the elevation of surface water at the model boundary and the elevation to assumed down-gradient discharge points: Lake Pend Oreille (underflow to west) and Kootenai River (underflow to north and east). A range of literature values for hydraulic conductivity of lithified rock was used (10^{-8} to 10^{-6} centimeters per second (cm/sec)), resulting in an estimated total groundwater underflow leaving the study area ranging from 15 to 1,550 ft^3/day. This is a minor component relative to the overall water balance (**Table 1**); therefore, uncertainty regarding this regional groundwater underflow does not have a notable effect on model results.

2.1.4 Evapotranspiration

Evapotranspiration (ET) in the groundwater balance includes only direct ET from groundwater; thus, it is limited to ET from surface and near-surface expressions of groundwater. For purposes of the steady-state groundwater balance, the estimate for ET was calculated using the mapped area covered by wetlands in the Rock Creek Meadows area, which totals 2,282,300 ft^2. A potential evapotranspiration rate of 0.0084 ft/day (Chen Northern 1989) was used to estimate ET water loss of 19,100 ft^3/day for the water balance. This is a minor component relative to the overall water balance (**Table 1**).

3.0 CODE SELECTION AND MODEL DESIGN

The finite element code FEFLOW developed by WASY, Inc. (Diersch 2005) was selected for model development. FEFLOW allows simulation of three-dimensional groundwater flow and contaminant transport. The model has been verified and used successfully to simulate groundwater flow and chemical transport in many mining environments (Diersch et al. 1995 and 1997; Kaden 1997; O'Hare 2007; Rapantova et al. 2007; Renz et al. 2009; Schätzl et al. 2008; and Sena and Molinero 2009).

The numerical groundwater model was designed based on the conceptual model summarized above. The model encompasses approximately 371 square miles in and surrounding the Cabinet Mountains (**Figure 1**). The model domain includes hydrologic features of interest and is large enough that the aquifer stresses simulated within the model domain are not affected by the boundaries of the model. The model domain is bound to the north by the North Fork Bull River and Big Cherry Creek, to the east by Swamp Creek and Fisher River, to the south by Silver Butte Fisher River, and to the west by Bull River and Clark Fork River (**Figure 1**). The model domain includes the entire Montanore project site.

Design elements of the numerical model for the Montanore project include the following:

- The model has a variably spaced finite element mesh with elements ranging in size from approximately 1,140 to 3,445,000 ft^2.
- The finite element mesh is refined near drainages, existing and proposed mine workings, Rock Lake Fault, and other geologic structures.
- The model represents groundwater flow from a base elevation of 328 feet msl to the water table. The model thickness ranges from 1,750 feet at the river boundaries to 8,360 feet beneath the peaks of the Cabinet Mountains (**Figure 5**).
- The model has a total of 1,225,574 elements and 709,704 nodes (**Figure 6**).
- The model is divided into seven vertical layers (**Figure 5**).
    - Layer 1 represents the highly weathered and fractured bedrock zone and the alluvial and glacial deposits, and is 98 feet (30 meters) thick.
    - Layer 2 represents the moderately weathered and fractured bedrock, and is 147 feet (45 meters) thick.
    - Layer 3 represents minimally fractured bedrock, and is 246 feet (75 meters) thick.
    - Layers 4 through 7 represent competent bedrock. Layers 4 through 7 have varying thicknesses. Near the planned underground workings, the top of Layer 7 and the bottom of Layer 6 is at an elevation corresponding to the base of the mine void.

Vertical discretization was necessary to capture the conceptual model of decreasing permeability with depth. The seven model layers achieve the desired vertical discretization. Moreover, the relatively thin upper layers (Layers 1, 2 and 3) comprise the first 500 feet of depth where the greatest inflow rates were recorded in the Libby Adit.

FEFLOW allows for a fully deformable mesh, in which the upper slice of the model is allowed to move with the water table through the fixed stratigraphic structure of the model. The upper slice of the model is, therefore, defined (in the model code) as "unconfined, free and movable." This assignment allows the water table to move below the bottom of Layer 1 without causing numerical instability in the model. Layers 2 and 3 are set as "unspecified"; if the layer above is set as "free and movable", the unspecified layer will move with the upper layer. This assignment again allows the water table to move through and below these layers. Layers 4 through 7 are set as "fixed" which indicates the model structure in these layers is rigid and non-deformable.

3.1 BOUNDARY CONDITIONS

Model boundary conditions include areal recharge, head dependant flux (transfer boundaries), and constant head and constant flux boundaries (**Figures 7** and **8**).

Areal recharge is simulated across the model at varying rates based on precipitation distribution from the PRISM (2008) database. The spatially averaged recharge rate is 4.6 in/yr or 10.5 percent of annual average precipitation (44 in/yr) in the model domain. The calibrated recharge distribution is equivalent to 2 percent of PRISM precipitation in areas with slopes greater than 30 percent, and 14 percent of the PRISM precipitation in areas where slopes are less than 30 percent. The infiltration rates range from 0.5 to 11 in/yr **(Figure 9)**.

Head dependant (transfer) nodes with varying transfer rates simulate flow between groundwater and major streams and rivers in the model domain. River stage was input based on the U.S. Geological Survey (USGS) digital elevation model (USGS 2000a). Constant head nodes simulate exchange between groundwater and Noxon and Cabinet Gorge reservoirs. The stage of the reservoirs was set based on the USGS (2000a) digital elevation model. Constant flux nodes simulate assumed regional underflow to the west toward Lake Pend Orielle, and to the north and east toward the Kootenai River. As previously mentioned, however, these assumed deeper regional groundwater flow systems and regional discharge points that are incorporated into the model are a minor component of the overall water balance for the study area.

3.2 INITIAL PARAMETERS

Initial hydraulic conductivity estimates were based on a range of reasonable literature values. According to Domenico and Schwartz (1990), unfractured to fractured metamorphic rock can have hydraulic conductivity values ranging from 3×10^{-12} to 3×10^{-2} cm/sec. Geological mapping of the area indicates that several major faults traverse the region (USGS 2000b; USFS/MDEQ 2001; maps prepared by MMC) (**Figure 10**). Minor faults and fracture zones are represented by the bulk permeability of the model. Hydraulic characteristics of major faults in the study area have not been investigated. Movement along faults can often create fractures that become preferential flow paths for water; however, recrystallization and fault gouge sometimes result in the opposite effect (i.e. barrier to flow).

The model incorporates the conservative assumption that major faults and those near the Montanore mine site have greater permeability than the surrounding bedrock. Faults incorporated into the model include the Moyie Thrust System (including Rock Lake Fault), Hope Fault, Snowshoe Fault and primary splay, Libby Lakes Fault and primary splay, Copper Lake Fault, and Moran Fault (**Figure 10**). Based on findings in the Libby Adit and the principles of lithostatic loading, the entire fault permeability was

assigned decreasing permeability values with depth. The fault widths vary somewhat based on element size, but in general are between 50 and 100 meters in width. This is considered representative of the fault core and adjacent damage zone based on geologic mapping of the surface and Libby Adit completed for the project. Where information was available, faults were simulated in the model with a plunging angle; otherwise, the faults were simulated as vertical and extending through all layers. Approximate plunge angles were taken from a cross-section along the Libby Adit for the Snowshoe Fault (53°) and Libby Lakes Fault (45°) (Geomatrix 2006a). Initial values for compressible and drainable storage were assigned based on literature values from Driscoll (2003) and adjusted during calibration.

4.0 MODEL CALIBRATION

The model was calibrated to steady-state and transient conditions. The following subsections describe calibration methods and results.

4.1 CALIBRATION METHODS

There are 115 steady-state head targets in the model, including 93 wells obtained from Montana's Ground Water Information Center (GWIC), eight Montanore monitoring wells, three Montanore exploratory boreholes, and 11 Rock Creek Mine Project monitoring wells. Head targets for the eight Montanore wells are based on surveyed elevations and depth to groundwater measured in October 1988 (Chen-Northern Inc. 1989). These water levels were measured during a period of seasonally low water and representative of steady-state conditions. Head targets in three exploratory boreholes (HR-19, HR-26 and HR-29) are approximate because they are based on water levels noted in driller's comments (Chen Northern Inc. 1989; Geomatrix 2006a and 2006b). Head targets for the 11 wells from the Rock Creek Mine Project (MW-84 and MW-85 series) are based on July 1986 measurements (USFS/MDEQ 2001).

Head targets selected from the GWIC database include wells that have a minimum location accuracy of quarter section. These wells were then plotted on a digital elevation model with 98-ft (30-meter) resolution to estimate the surface elevation of each well. The static water level measurement recorded on the well log was then subtracted from the ground surface elevation to determine the groundwater elevation. Error associated with head target values includes uncertainty in the precise well location and elevation, and uncertainty associated with seasonal changes in groundwater elevation. A well located only to the quarter section could actually be located as far away as a quarter mile (1,320 feet or 402 meters) in both the x and y direction from its recorded location.

The digital elevation model introduces potential interpolation error due to its resolution. Location and interpolation uncertainty introduces greater error in the higher elevations where topography changes dramatically over short distances. In addition, targets that are based on single water level measurements may not be representative of steady-state conditions. Although the cumulative uncertainty associated with head target is appreciable, the large range in target groundwater elevations of 4,423 feet (1,348 meters) makes the GWIC targets relevant. In the higher elevations, potential error associated with head target values is estimated to be as great as 164 feet (50 meters). Near major drainages, the estimated potential error is approximately 33 feet (10 meters).

Calibration goals were established to demonstrate the model could produce groundwater elevations, fluxes, flow directions, and gradients similar to those based on existing data. Residual is the difference between simulated and target values. Based on the estimates of error associated with head target elevations, a calibration goal was established to have all head residuals less than 164 feet (50 meters). Another goal was to have residual standard deviation divided by range in target values be small (<5%). According to Anderson and Woessner (1992) and Rumbaugh (1998), the residual standard deviation should be a small portion (<10%) of the total range in head across the model domain. Another goal was for the model to produce simulated fluxes within the target ranges or be within ±25 percent of single value flux estimates.

The model was also calibrated to transient conditions to verify the model's ability to simulate groundwater flow under a variety of conditions. Following steady-state calibration, the model was subsequently calibrated to hydraulic testing performed in the Libby Adit that is described in **Appendix D** (AMEC Geomatrix 2009) and to dewatering rates measured in the Libby Adit between January 1991 and September 1995. Transient simulations of hydraulic tests in boreholes 3680RR and 5220RR were executed to match time-drawdown data from the hydraulic tests. Boreholes 3680RR and 5220LR were simulated using well (specified flux) boundaries with flow rates measured at each borehole.

Finally, a transient simulation was executed to match flow rates observed during construction and dewatering of the Libby Adit. The adit installation and dewatering simulation matches the period between January 1991 and September 1995. Adit dewatering was simulated with constrained transfer (head dependent flux) boundaries cells (only allowing water to exit the model) set at the adit elevation along the entire extent of the adit (14,000 feet) during dewatering periods (**Figure 11**). Transfer (head dependent flux) boundaries were used for the Libby Adit in order to assign transfer rates along the adit corresponding to grouted locations. The transfer rate in grouted areas was set to represent a 5-meter zone of grout with a permeability of 1×10^{-8} cm/sec. Flow rates recorded during the dewatering period ranged from 135 to 239 gal/min and were used as transient targets.

During model calibration, inputs such as hydraulic conductivity, recharge, boundary conditions, and storage parameters were adjusted iteratively until residuals were minimized, and calibration goals were achieved. Output from each run was examined to see if the changes improved the match to potentiometric surface based on target values, to the estimated groundwater balance, and to head and flux targets.

4.2 CALIBRATION RESULTS

Calibration goals were achieved by the model because the model adequately produced heads, flow directions, gradients and fluxes matching those based on available data. **Appendix E** presents calibration residuals and statistics. **Figure 12** is a plot of observed vs. simulated heads demonstrating that observed and simulated heads are randomly distributed on either side of the regression line, which indicates that the model is well calibrated (Anderson and Woessner 1992). One observation point had a residual outside of the calibration goal (171 feet or 52 meters). The residual standard deviation divided by range of observed heads is 1.7 percent and the absolute residual mean is 46 feet (13 meters). **Figure 13** displays the target residuals posted across the site; positive (blue) and negative (red) residuals are distributed randomly suggesting heads are not spatially biased. The simulated potentiometric surface (**Figure 14**) generally matches the observed potentiometric surface (**Figure 3**).

Simulated flux rates are within the estimated range and are close to the average estimated values (**Table 2**). Calibrated baseflow to streams is within the range or close to the single estimate baseflow value for all streams, except Bull River and Rock Creek (**Table 3**). The simulated flux representing baseflow to Bull River was 40 ft^3/sec, which is slightly below the estimated target range of 47 to 75 ft^3/sec. Simulated flux from groundwater to Rock Creek is 7.7 ft^3/sec, which is slightly above the target range of 3 to 7 ft^3/sec.

Table 2. Model Water Balance

Source	Low Estimate (ft^3/day)	High Estimate (ft^3/day)	Low Estimate (m^3/day)	High Estimate (m^3/day)	Model Simulated Water Balance (ft^3/day)	Model Simulated Water Balance (m^3/day)
INFLOW						
Infiltrating Precipitation	7,931,649	18,511,358	224,607	524,202	10,727,770	303,788
Total INFLOW	**7,931,649**	**18,511,358**	**224,607**	**524,202**	**10,727,770**	**303,788**
OUTFLOW						
Discharge as Baseflow	7,912,510	18,490,683	224,065.5	523,617	10,740,739	304,155
Underflow	15.5	1,551.2	0.4	43.9	141	4
Evapotranspiration	19,123.5	19,123.5	541.5	541.5	22,318	632
Total OUTFLOW	**7,931,649**	**18,511,358**	**224,607**	**524,202**	**10,763,198**	**304,791**
ERROR						0.3%

Note: ft^3/day = cubic feet per day; m^3/day = cubic meters per day.

Table 3. Modeled Stream Baseflow and Estimated Baseflow

Drainage	Low Estimated Baseflow to Drainage in Model Domain (ft^3/sec)	High Estimated Baseflow to Drainage in Model Domain (ft^3/sec)	Model Simulated Baseflow (ft^3/sec)
Bull River	47	75	40
Fisher River	15	51	23
Swamp Creek	6.7 [1]		8.2
Libby Creek	4	58	20
Rock Creek	3	7	7.7
Clark Fork River	10.4 [2]		14
Big Cherry Creek	5.5 [2]		4.7
Total Baseflow Exiting Model	91.6	213.6	117.6
Stream Baseflows Tributary to Baseflows of Larger Rivers and Streams (tabulated above)			
East Fork Bull River	10 [1]		11
West Fisher Creek	8	16	11
Rock Lake(difference between Inflow and Outflow)	0.54 [3]		0.14
Rock Lake Inflow (above Rock Lake)	0.22 [3]		0.15
Rock Lake Outflow	0.76 [3]		0.29

Note: Appendix B presents data and calculations of baseflow estimates. ft^3day = cubic feet per day.
[1] No range was provided; baseflow number from ERO Resources (2009).
[2] Estimated from a discharge to catchment area approach (Appendix C).
[3] Only one low flow measurement available (used as a magnitude target; not a calibration target).
Source: Geomatrix 2006a.

The calibrated model is able to generally match observed time-drawdown resulting from hydraulic testing in Libby Adit. **Figures 15** and **16** compare simulated and observed drawdown inside the Libby Adit at the observation bores for the hydraulic tests at 3680RR and 5220RR, respectively. To be able to reproduce the lack of drawdown like that observed at 4500LR (**Figure 16**) required parameterization of very low permeability outside the fracture sets. This very low permeability represents unfractured rock.

The calibrated model is capable of matching measured dewatering rates for the Libby Adit between January 1991 and September 1995. Simulated dewatering rates required to keep the Libby Adit dewatered during the initial simulation range from 250 gal/min initially to 150 gal/min after 4 years of dewatering (**Figure 17**). Actual dewatering rates in the Libby Adit during this period ranged from 239 to 135 gal/min, with a stabilized rate of about 150 gal/min during the last 15 months of dewatering.

4.2.1 Calibrated Parameter Distribution

Figures 18 through **23** display the calibrated hydraulic conductivity (K) distribution. The bulk hydraulic conductivity in bedrock within the calibrated model ranged from a minimum of 6×10^{-8} cm/sec in Layers 6 and 7, to a maximum of 4×10^{-4} cm/sec in the Wallace Formation in Layer 1. During calibration, it became evident that greater permeability was necessary in portions of the bedrock to achieve the estimated flows in the Bull River. Since the Wallace Formation contains limestone and dolomite, both of which weather more readily than argillite and quartzite, the Wallace Formation was assigned higher hydraulic conductivity values in the shallower layers. Alluvial and fluvial-glacial materials were assigned hydraulic conductivity values ranging from 4.5×10^{-4} cm/sec to 1×10^{-2} cm/sec.

Hydraulic conductivity of the fracture and fault zones in the mine area was determined during calibration to the hydraulic tests at Libby Adit boreholes 3680RR and 5220RR. To adequately match the time-drawdown data and the lack of drawdown during simulations of hydraulic tests at 3680RR and 5220RR, elevated hydraulic conductivity values that decreased with depth were assigned to regions representing fractured rock (where boreholes 3680RR and 5220RR were finished), surrounded by reduced hydraulic conductivity representing unfractured rock.

When modeling large-scale bedrock aquifers, it is common practice to simulate the mass as an equivalent porous medium. This means that on a large scale, the series of fractures transmit water in a similar manner to porous material. This is an appropriate assumption for the regional system modeled around Montanore. However, on a smaller scale, it is more appropriate to simulate discrete fractures within relatively impermeable material (assuming there is information regarding the nature and location of the fractures). In and around the proposed mine workings, a greater degree of fault mapping has been conducted. Since the Libby Adit data are the best representation of the hydraulic behavior of water-bearing features at depth, the higher permeability fractures separated by low permeability competent bedrock was extrapolated from the calibrated fracture regions in the Libby Adit to the mapped faults in areas immediately surrounding the proposed mine.

In addition to the hydraulic test data, mapping of the Libby Adit **(Appendix B)** shows a pattern of short intervals of water-bearing fractures followed by large intervals with an absence of water-bearing fractures. Observed zones of non-water-bearing material up to 2000 feet in extent justify the use in the model of zones of competent bedrock between zones of fractures. **Figures 20** through **23** display the fracture and fault zone hydraulic conductivity values surrounded by competent rock with lower

hydraulic conductivity. These low permeability zones do not represent bedrock that is of lower permeability than the surrounding bedrock, they represent the unfractured bedrock surrounding fracture locations.

The mapped faults are assumed to not be the only locations where fractures are present; thus, the low permeabilty zones were simulated to be only a few elements wide around the high permeability mapped fault zones. The remaining bedrock areas were simulated using background permeability values (equivalent porous media). Hydraulic conductivity values assigned to faults outside the immediate mine area have values intermediate between fracture zones in the mine area and bedrock outside the mine area. **Figures 18** through **23** show hydraulic conductivity distribution for faults in the various model layers.

Calibration results suggest the hydraulic conductivity values assigned to fracture zones in the model are reasonable based on extrapolation from data in the Libby Adit fractures, and on stream flow data which indicate cross-basin flow from the Rock Creek and Swamp Creek drainages toward the Bull River drainage and Big Cherry Creek. However, the actual permeability of fault zones has not been quantified and may vary from the values assigned above.

The compressible storage per unit thickness (specific storage) and drainable storage (specific yield) values were calibrated during transient simulations of both the hydraulic tests and Libby Adit dewatering. The calibrated specific storage and specific yield values are presented in **Table 4**.

Table 4. Storage Parameterization in Model

Layer	Specific Storage (dimensionless)	Specific Yield (dimensionless)
1	1×10^{-6}	0.10
2	1×10^{-6}	0.05
3	1×10^{-6}	0.02
4	1×10^{-6}	0.005
5	1×10^{-6}	0.005
6	1×10^{-6}	0.005
7	1×10^{-6}	0.005

5.0 PREDICTIVE SCENARIOS

The calibrated model was used to predict the effects of mining during the following four stages:

Stage 1 – Exploration: includes extension of the Libby Adit and completion of the three drifts at the end of the adit – period is 0 to 2 years.

Stage 2 – Construction and Initial Mining: includes completion of "New Libby Adits" plus the first six blocks of mine void – period is 2 to 8 years.

Stage 3 – Final Mining: includes mining of entire mine void – period is 8 to 22 years.

Stage 4 – Post-Mining: period following active mining – up to 1,150 years.

Table 5 summarizes simulated dewatering periods for each mine feature, and **Figure 24** displays a map view of these features. Calibrated steady-state heads were used as the initial condition. The existing Libby Adit was again simulated using transfer boundaries to account for grouted locations. The transfer boundaries were assigned constrained heads set at the adit elevation. All other mine features were simulated as constrained constant heads set to the adit elevations or the floor of the B-zone (Bed 4) mining void. The mine void nodes were simulated one node over from the high permeability fault zone, which was generally around 50 meters. The simulation was modeled with 18 discrete time-steps representing the periods each successive block or set of blocks will be mined for the expected mining period of 22 years. Each new mine feature was simulated as being completely dewatered at the beginning of the time step in which it would be mined. This design results in a slight simplification since in actuality each mine feature will be expanded over time.

Figure 25 presents the predicted dewatering rates through the entire mining period. Due to the simplification of assuming the entire mine feature is completely dewatered at the beginning of the time step when mining is initiated, results in the model simulate a large flux to the mine workings at the beginning of each time step. This initial large flux shows up as peaks coincident with the timing of additional mine features on **Figure 25**. The volume of water that the model predicts will be pumped during this initial period represents the water in storage in the portion of the dewatered feature. In actual implementation, this volume of water would not be released all at once, but rather would be released slowly as the mine feature was fully expanded.

The graph of dewatering rates through time (**Figure 25**) shows several periods with notable changes in flux. From initiation to year 2, flow rates fluctuate with the extension of the adit and drilling of exploration drifts. Beginning in year 2, the flux increases substantially with the expansion of the two new Libby Adits, declining to about year 5. From year 5 to year 20, the flux undulates with the addition of each new block of underground mine void. Finally, from year 20 to year 22 when no additional mine expansion occurs but mine dewatering is maintained, the flux stabilizes. **Table 6** presents average dewatering rates during each of these periods (0-2 yrs, 2-5 yrs, 5-20 yrs, and 20-22 yrs) and, additionally, presents the stabilized flow rate at the end of each of the three modeled mining stages (0-2 yrs, 2-8 yrs, and 8-22 yrs).

Table 5. Full Mine Model Design

Stage	Time step	Mine Feature	Mining/ Construction Days	Start to Mine*/ Construct Date (dewatered starting now)	Finish Mine/ Construct Date	Day in Model Dewatering in Region Begins (mining simulation starts 1/1/2010)	Day in Model Dewatering is Finished (mining continues to 12/31/2031)
Stage 1 Exploration	1	Hydraulic Exploration Libby Adit	180	1/1/2010	6/30/2010	**0**	**8034**
	2	Libby Adit Extension	180	3/1/2010	8/28/2010	**59**	**8034**
	3	Libby Adit Drifts	180	11/1/2010	4/30/2011	**304**	**8034**
Stage 2 Construction /Initial Mining	4	New Libby Adits	800	1/1/2012	3/11/2014	**730 (2 yr)**	**8034**
	5	Block 1	510	1/1/2015	5/25/2016	**1826**	**8034**
		Block 2	391	1/1/2015	1/27/2016	**1826**	**8034**
	6	Block 4	394	1/1/2016	1/29/2017	**2191**	**8034**
	7	Block 6	392	4/1/2016	4/28/2017	**2282**	**8034**
	9	Block 8	415	4/1/2017	5/21/2018	**2647**	**8034**
		Block 10	406	4/1/2017	5/12/2018	**2647**	**8034**
Stage 3 Final Mining	10	Block 12	367	4/1/2018	4/3/2019	**3012 (8 yr)**	**8034**
		Block 14	348	4/1/2018	3/15/2019	**3012**	**8034**
	11	Block 16	230	1/1/2019	8/19/2019	**3287**	**8034**
		Block 18	118	1/1/2019	4/29/2019	**3287**	**8034**
		Ventilation Adit	np	np	np	**3652**	**8034**
	12	Block 3	395	1/1/2020	1/30/2021	**3652**	**8034**
		Block 5	422	1/1/2020	2/26/2021	**3652**	**8034**
	13	Block 7	380	1/1/2021	1/16/2022	**4018**	**8034**
		Block 9	434	1/1/2021	3/11/2022	**4018**	**8034**
	14	Block 11	449	4/1/2022	6/24/2023	**4473**	**8034**
		Block 13	499	4/1/2022	8/13/2023	**4473**	**8034**
	15	Block 15	516	4/1/2023	8/29/2024	**4838**	**8034**
		Block 17	556	4/1/2023	10/8/2024	**4838**	**8034**
	16	Block 19	541	1/1/2025	6/26/2026	**5479**	**8034**
		Block 21	501	1/1/2025	5/17/2026	**5479**	**8034**
	17	Block 23	429	1/1/2026	3/6/2027	**5844**	**8034**
		Block 25	416	1/1/2026	2/21/2027	**5844**	**8034**
	18	Block 27	710	1/1/2028	12/11/2029	**6574**	**8034**
Total Simulation Time:						**8034 days or 22 years**	

* Start date of 1/1/2010 is an artificial start date to base the timing of the mine schedule.
Each block will be dewatered to elevations from the planned base of the B-zone.
np: data not provided; ventilation adit may or may not be needed - if it is needed, it will likely be installed 10 or more years into the mining process (personal communication E. Klepfer 2010).

Table 6. Predicted Dewatering Rates from Calibrated Model

Average Predicted Dewatering Rates (Flux) during Mining Simulation			
Period	Average Dewatering Rate in Adits (gal/min)	Average Dewatering Rate in VOID/Exploration Bores (gal/min)	Average Dewatering Rate for all Mine Workings (gal/min)
0-2 years (exploration)	226	31	257
2-5 years (construction & initial mining)	445	29	474
5-20 years (mining)	267	115	382
20-22 years (end of mining)	203	166	369

Stabilized Dewatering Rates (Flux) at End of Simulated Mining Stage		
Stage	Time After Initiation of Exploration (years)	Stabilized Dewatering Rate (gal/min)
Stage 1 – Exploration	2	250
Stage 2 – Construction / Initial Mining	8	360
Stage 3 – Final Mining	22	370

Note: gal/min = gallons per minute.

5.1 STAGE 1 - EXPLORATION

The model predicts that groundwater discharge to the entire Libby Adit and drifts during the exploration phase (years 0-2) will average 257 gal/min and will stabilize at 250 gal/min at the end of Stage 1 (year 2) (**Figure 25** and **Table 6**). During this period, the drawdown area or cone-of-depression expands from the adit preferentially outward along fractures and faults. **Figure 26** shows that the zone of influence of adit dewatering predicted at the water table is restricted to near the adit opening and along the faults and fracture zones in the vicinity of the Libby Adit.

The model was used to predict streamflow depletions in the Cabinet Mountains. Specific drainages investigated include Libby Creek, Rock Creek, East Fork Rock Creek, East Fork Bull River, Ramsey Creek, and Poorman Creek. Predicted changes in baseflow to Libby Creek, Rock Creek, and East Fork Bull River were calculated for the entire stream (except Libby Creek is segment above Highway 2), for the reach of each stream within the Wilderness Area, and at a few established stream monitoring locations (Libby Creek at LB-50 & LB-300; East Fork Rock Creek at EFRC-50; and East Fork Bull River at EFBR-300) (**Figure 27**). Calculations for Ramsey and Poorman creeks were made only for the reaches within the Wilderness Area (**Figure 27**). This regional-scale model was not designed to accurately predict impacts to the uppermost reaches of these streams where baseflows are low and variable, and where there is lack of data regarding groundwater/surface water interaction in these areas for which the model can be calibrated. Therefore, predicted changes in baseflows at LB-50, EFRC-50, and EFBR-300 have a high degree of uncertainty.

The model predicts minimal streamflow depletion to Cabinet Mountain streams during the exploration stage. **Table 7** presents resulting changes in stream and river baseflow predicted by the model at the end of exploration. Predicted changes to stream baseflow are less than 4 percent of the modeled baseflow, and are within the estimated normal range of variability of baseflow (±20%) in the study area

(Wegner 2007). The 20 percent variability is estimated from Cabinet Mountain streamflow data obtained from gaging stations at the edge of the model domain; variability may be more or less in the upper watersheds. These predicted changes are also within the range of streamflow measurement error of 6 to 19 percent under typical conditions (Harmel et al. 2006). Some adit/mine water may be discharged to Libby Creek during the exploration phase of the project, thus reducing baseflow impacts to this stream.

Table 7. Predicted Changes to Baseflow - Stage 1 (Exploration; Year 2)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Stage 1	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.32	-0.02
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	4.36	0.00
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.29	0.00
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.69	-0.01
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.28	-0.01
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.04	0.00
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.81	-0.02
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.19	-0.02
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.54	0.00
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.28	0.00
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.375	0.00
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.12	0.00

[1] Natural baseflow variability determined by USFS (Wegner 2007).

Note: ft^3/sec = cubic feet per second. The predicted adit dewatering rate at the end of Stage 1 (year 2) is approximately 250 gallons per minute (gal/min).

In order to assess impacts to Rock Lake, a water balance for the lake was developed. The water balance was calculated independent of the numerical model since this model does not keep track of surface water flow and storage. **Table 8** presents the estimated annual water balance for Rock Lake assuming no net change in volume over a 1-year period. **Appendix F** presents calculations and assumptions.

The model predicts a net reduction influx from groundwater to Rock Lake of 3 acre-ft/yr and no reduction in baseflow to the stream flowing into Rock Lake. Assuming that precipitation, surface water inflow, overland flow, and evaporation remain the same, the Rock Lake water balance was revised with a reduced net flux into the lake of 3 acre-ft/yr or an annual average of 2 gal/min. This results in a net loss to the average downgradient "surface water out" component, indicating the primary impact to Rock

Lake will be a reduction in the "surface water out" from an annual average of 6,947 acre-ft/yr to 6,944 acre-ft/yr (less than 0.1 percent change) (**Table 8**).

Table 8. Rock Lake Water Balance and Predicted Water Balance - Stage 1

Source	Annual Rock Lake Water Balance		Predicted Annual Rock Lake Water Balance Stage 1	
	Average (acre-ft/yr)	Error [1] (acre-ft/yr)	Average (acre-ft/yr)	Error [1] (acre-ft/yr)
Precipitation	334	±29	334	±29
Surface Water In	4,042	±562	4,042	±562
Net Groundwater In	954	---	951 [2]	---
Overland Flow	1,743	±119	1,743	±119
TOTAL IN	7,073	±711	7,070	±711
Evaporation	126	±15	126	±15
Surface Water Out	**6,947**	±1,041	**6,944**	±1,041
TOTAL OUT	7,073	±1,093	7,070	±1,093

[1] See Appendix F for Error calculations.
[2] "Net Groundwater In" reduced by 3 acre-ft/yr or 2 gal/min annual average.
Note: acre-ft/yr = acre-feet per year; gal/min = gallons per minute.

5.2 STAGE 2 - CONSTRUCTION AND INITIAL MINING

Predicted groundwater discharge to the adits and the first six blocks of the mine void stabilize at approximately 360 gal/min at the end of Stage 2 (year 8), with an average dewatering rate of 474 gal/min predicted for years 2-5 (**Table 6** and **Figure 25**). Groundwater drawdown at this time has continued to expand from the adits and Blocks 1, 2, 4, 6, 8 and 10 preferentially outward along fractures and faults up toward the water table. **Figure 28** shows that the predicted zone of influence for water table drawdown at the end of Stage 2 surrounds most of the adit and extends along the faults near the mine void.

The model predicts minimal streamflow depletion in the Wilderness Area and downstream areas in Stage 2. Predicted changes in baseflow were calculated for Libby Creek, Rock Creek, East Fork Rock Creek, East Fork Bull River, Ramsey Creek, and Poorman Creek. **Table 9** presents resulting changes in baseflow predicted by the model at Stage 2 (year 8). Predicted changes to stream baseflow are less than 12 percent of the modeled baseflow, and are within the estimated normal range of variability of baseflow (±20%) in the study area (Wegner 2007). These predicted changes are also within the range of streamflow measurement error of 6 to 19 percent under typical conditions (Harmel et al. 2006).

Some adit/mine water may be discharged to Libby Creek during the construction phase of the project, thus reducing baseflow impacts to this stream. During the mining operational phase, no water is expected to be discharged to Libby Creek, with some additional effects to lower Libby Creek baseflow potentially occurring from interception of surface water runoff in the tailings impoundment and interception of groundwater from pump-back wells located at the impoundment site.

Table 9. Predicted Changes to Baseflow - Stage 2 (Construction/Initial Mining; Year 8)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Stage 2	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.31	-0.03
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	4.36	0.00
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.29	0.00
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.68	-0.02
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.28	-0.01
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.04	0.00
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.66	-0.17
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.09	-0.13
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.49	-0.05
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.27	-0.01
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.356	-0.02
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.12	0.00

[1] Natural baseflow variability determined by USFS (Wegner 2007).

Note: ft^3/sec = cubic feet per second. The predicted dewatering rate in the adits and first six mine blocks at the end of Stage 2 (year 8) is approximately 360 gallons per minute (gal/min).

The model predicts a net reduction in flux from groundwater for Rock Lake of 9 acre-ft/yr during Stage 2 and no reduction in baseflow to the stream flowing into Rock Lake. Assuming that precipitation, surface water in, overland flow, and evaporation remain the same, the Rock Lake water balance was revised with a reduced net flux into the lake of 9 acre-ft/yr or an annual average of 6 gal/min. This results in a net loss to the average downgradient "surface water out" component, indicating the primary impact to Rock Lake will be a reduction in the "surface water out" from an annual average of 6,947 acre-ft/yr to 6,938 acre-ft/yr (less than 0.2 percent change) (**Table 10**).

5.3 STAGE 3 - FINAL MINING

Predicted groundwater discharge to the entire mine void and adits, including the ventilation adit, averages and stabilizes at about 370 to 380 gal/min during and at the end of final mining and Stage 3 (year 22) (**Table 6** and **Figure 25**). **Figure 29** shows the area of influence for water table drawdown predicted by the model at the end of the mining period, which would be primarily limited to the mined region and extending along the faults. **Figure 30** presents the potentiometric surface for Stage 3 in cross-section along the length of the mine void at the end of mining. **Figure 31** shows the water table surface for the same cross-section for pre-mining and end-of-mining (Stage 3) conditions.

Table 10. Rock Lake Water Balance and Predicted Water Balance - Stage 2

Source	Annual Rock Lake Water Balance		Predicted Annual Rock Lake Water Balance Stage 2	
	Average (acre-ft/yr)	Error [1] (acre-ft/yr)	Average (acre-ft/yr)	Error [1] (acre-ft/yr)
Precipitation	334	±29	334	±29
Surface Water In	4,042	±562	4,042	±562
Net Groundwater In	954	---	945 [2]	---
Overland Flow	1,743	±119	1,743	±119
TOTAL IN	7,073	±711	7,064	±711
Evaporation	126	±15	126	±15
Surface Water Out	**6,947**	±1,041	**6,938**	±1,041
TOTAL OUT	7,073	±1,093	7,064	±1,093

[1] See Appendix F for Error calculations.
[2] "Net Groundwater In" reduced by 9 acre-ft/yr or 6 gal/min annual average.
Note: acre-ft/yr = acre-feet per year; gal/min = gallons per minute.

The model predicts that following full mine build-out, some streamflow depletion will occur. Again, the specific drainages investigated include Libby Creek, Rock Creek, East Fork Rock Creek, East Fork Bull River, Ramsey Creek, and Poorman Creek. **Table 11** shows resulting changes to baseflow predicted by the model at the end of Stage 3 (year 22). Predicted changes to baseflow are 20 percent or less of the modeled baseflow. Streamflow depletion at a few locations equals the 20 percent estimated normal range of variability of baseflow (Wegner 2007), and the 6 to 19 percent range in streamflow measurement error (Harmel et al. 2006). This includes upper East Fork Rock Creek at EFRC-50, East Fork Rock Creek at the Wilderness boundary, and upper Libby Creek at the Wilderness boundary.

As previously discussed, model predictions in upper reaches of the drainages have considerable uncertainty because of the low and variable baseflow conditions, and lack of data regarding groundwater/surface water interaction in these areas for which the model can be calibrated. During the mining operational phase, no water is expected to be discharged to Libby Creek, with some additional effects to lower Libby Creek baseflow potentially occurring from interception of surface water runoff in the tailings impoundment and interception of groundwater from pump-back wells located at the impoundment site.

The model predicts a net reduction in flux from groundwater for Rock Lake of 24 acre-ft/yr during the mining phase and a reduction in baseflow to the stream flowing into Rock Lake of 23 acre-ft/yr. Assuming that precipitation, overland flow, and evaporation remain the same, the Rock Lake water balance was revised with a reduced net flux into the lake of 47 acre-ft/yr or an annual average of 29 gal/min. This results in a net loss to the downgradient "surface water out" from an annual average of 6,947 acre-ft/yr to 6,900 acre-ft/yr (less than 1 percent change) (**Table 12**).

Table 11. Predicted Changes to Baseflow - Stage 3 (Final Mining; Year 22)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Stage 3	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.25	-0.09
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	4.29	-0.07
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.24	-0.05
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.64	-0.06
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.23	-0.06
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.03	-0.01
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.56	-0.27
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.02	-0.20
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.43	-0.12
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.24	-0.04
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.34	-0.04
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.11	-0.01

[1]Natural baseflow variability determined by USFS (Wegner 2007).

Note: ft^3/sec = cubic feet per second. The predicted dewatering rate in the adits and all mine blocks at the end of Stage 3 (year 22) is approximately 370 gallons per minute (gal/min).

Table 12. Rock Lake Water Balance and Predicted Water Balance – Stage 3

Source	Annual Rock Lake Water Balance		Predicted Annual Rock Lake Water Balance Stage 3	
	Average (acre-ft/yr)	Error [1] (acre-ft/yr)	Average (acre-ft/yr)	Error [1] (acre-ft/yr)
Precipitation	334	±29	334	±29
Surface Water In	4,042	±562	4,019 [2]	±562
Net Groundwater In	954	---	930 [3]	---
Overland Flow	1,743	±119	1,743	±119
TOTAL IN	7,073	±711	7,026	±711
Evaporation	126	±15	126	±15
Surface Water Out	**6,947**	±1,041	**6,900**	±1,041
TOTAL OUT	7,073	±1,093	7,026	±1,093

[1] See Appendix F for Error calculations.
[2] "Surface Water In" reduced by 23 acre-ft/yr or 14 gal/min annual average.
[3] "Net Groundwater In" reduced by 24 acre-ft/yr or 15 gal/min annual average.

Note: acre-ft/yr = acre-feet per year; gal/min = gallons per minute.

5.4 STAGE 4 – POST MINING

To simulate the post-mining period, the mine void was assigned increased permeability and storage parameters. Model layers within the mine footprint were assigned increased permeability and storage values to represent the actual open volume in mined layers.

Hydraulic conductivity of the mine void for Stage 4 is roughly six orders of magnitude greater than the surrounding bedrock. Constant head boundaries that were used to simulate mine dewatering were removed and the model was run for a period of 1,150 years in order to show the long-term simulated recovery of groundwater for the entire mine void area.

Figure 32 is a graph showing predicted hydrographs of groundwater recovery during and after mining. The mine is filled-up to Block 1 (elevation 3462 feet msl; mid-area of mine void) after 3 days; however, filling to Block 18 (elevation 4691 feet msl) at the upper end of the mine void takes about 426 years. The model predicts that it will take up to about 493 years to fill the entire mine void to an elevation of 4800 feet msl. Additional groundwater recovery will occur after this time where water table elevations approach pre-mining levels. Heads in the mine void eventually recover to approximately 5300 feet msl. Heads above the upgradient end of the mine void do not fully recover, but heads above the downgradient end of the mine void stabilize at elevations slightly higher than pre-mining levels. This is because the mine void creates a highly conductive conduit within the bedrock mass and flattens the groundwater gradient within the void. Greatest residual drawdown at the water table after the end of Stage 4 is predicted near the upgradient end of the mine void overlying Blocks 16 and 18 (**Figures 33** and **34**). Residual drawdown near the upgradient end of the mine is propagated somewhat along the Rock Lake Fault, Libby Lakes Fault, and Snowshoe Fault.

5.4.1 Post Mining - 16 Years After Closure

The recovery trend (**Figure 32**) suggests water levels near the upgradient end of the mine at the water table actually decline for several years following closure, and that around 16 years after closure or 38 years following the start of mining, the lowest water table elevations in this region will occur (**Figure 33**). At this stage of closure, some streamflow depletion is predicted to occur. **Table 13** shows resulting changes to baseflow predicted by the model 16 years following closure. Predicted changes to the upper reaches of East Fork Bull River and East Fork Rock Creek are relatively high; however, as previously discussed, model predictions in upper reaches of the drainages have considerable uncertainty because of the low and variable baseflow conditions (modeled baseflow = 0.04 to 0.29 ft^3/sec), and lack of data regarding groundwater/surface water interaction in these areas for which the model can be calibrated.

Rock Creek (East Fork) at the Wilderness boundary is showing a negative value in the **Table 13** column "Modeled Groundwater Contributing to Surface Water – 16 Years Following Closure" because Rock Lake is part of the stream reach at that simulation point which would provide a source of recharge water to the groundwater drawdown area, assuming that lake water would move down to the subsurface if the water table declines.

Table 13. Predicted Changes to Baseflow – Stage 4 (16 Years After Closure or 38 Years Since Start of Mining)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) 16 Years After Closure Stage 4	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.08	-0.26
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	3.98	-0.38
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.02	-0.27
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.05	-0.65
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.00 (-0.15) [2]	-0.29 (-0.44) [2]
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.00	-0.04
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.72	-0.11
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.10	-0.12
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.47	-0.07
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.24	-0.04
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.361	-0.01
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.12	0

[1] Natural streamflow variability determined by USFS (Wegner 2007).

[2] The modeled groundwater contributing to surface water at East Fork Rock Creek at wilderness boundary 16 years following closure is -0.15 ft^3/sec, the negative value means water is moving from the surface water (Rock Lake) into the groundwater system. The difference between the pre-exploration groundwater contributing to surface water (0.29 ft^3/sec) and the 16-year post-mine surface water contribution to groundwater -0.15 ft^3/sec, results in a net change to baseflow of -0.44 ft^3/sec.

Note: ft^3/sec = cubic feet per second. Shaded values are >20% change predicted in baseflow (i.e., outside estimated natural variability in modeled baseflow).

Approximately 16 years after closure, the model predicts a net reduction in flux from groundwater for Rock Lake of 209 acre-ft/yr, and a reduction in baseflow to the stream flowing into Rock Lake of 109 acre-ft/yr. Assuming that precipitation, overland flow, and evaporation remain the same, the Rock Lake water balance was revised with a reduced net flux into the lake of 318 acre-ft/yr or an annual average of 198 gal/min. This results in a net loss to the downgradient "surface water out" from an annual average of 6,947 acre-ft/yr to 6,629 acre-ft/yr (less than 5 percent change) (**Table 14**).

Table 14. Rock Lake Water Balance and Predicted Water Balance – Stage 4 (16 Years After Closure or 38 Years Since Start of Mining)

Source	Annual Rock Lake Water Balance		Predicted Annual Rock Lake Water Balance Stage 4 (16 yrs after closure)	
	Average (acre-ft/yr)	Error [1] (acre-ft/yr)	Average (acre-ft/yr)	Error [1] (acre-ft/yr)
Precipitation	334	±29	334	±29
Surface Water In	4,042	±562	3,933 [2]	±562
Net Groundwater In	954	---	745 [3]	---
Overland Flow	1,743	±119	1,743	±119
TOTAL IN	7,073	±711	6,755	±711
Evaporation	126	±15	126	±15
Surface Water Out	**6,947**	±1,041	**6,629**	±1,041
TOTAL OUT	7,073	±1,093	6,755	±1,093

[1] See Appendix F for Error calculations.
[2] "Surface Water In" reduced by 109 acre-ft/yr or 68 gal/min annual average.
[3] "Net Groundwater In" reduced by 209 acre-ft/yr or 130 gal/min annual average.
Note: acre-ft/yr = acre-feet per year; gal/min = gallons per minute.

5.4.2 Post Mining - Stabilized/Recovered Conditions

Once groundwater elevations stabilize, there would still be some residual drawdown at the water table, primarily above the mine void area and major fault structures (**Figure 34**). The model predicts baseflow in Rock Creek and the upper reaches of East Fork Bull River may be slightly lower after this recovery period than prior to mining. In contrast, baseflow to the lower East Fork Bull River may be slightly greater. **Table 15** shows resulting changes to baseflow predicted by the model after 1,150 years of recovery (1,172 years since the start of mining). These persistent changes to baseflow are due to the mine void crossing a hydraulic divide. Since the void results in a highly conductive conduit that flattens the groundwater gradient in that area, and since the void crosses a hydraulic divide, it results in slightly reducing the groundwater catchment area for Rock Creek and slightly increasing the groundwater catchment area for East Fork Bull River. For stabilized conditions, the model predicts that flow at the mouth of East Fork Bull River increases slightly over pre-mine conditions; however, flow at and above the Wilderness Boundary is slightly depleted. This occurs due to the mine void acting as a conduit supplying water to the deep regional flow system within the flow paths reporting to the lower reaches of East Fork Bull River and because a minor amount of residual drawdown persists in the upper drainage of East Fork Bull River.

Predicted changes to baseflow may exceed the natural range or variability in stream baseflow (±20 percent) in the uppermost reach of the East Fork Rock Creek drainage above Rock Lake where the model predicts greater impacts (**Table 15**). As previously discussed, model predictions in upper reaches of the drainages have a high degree of uncertainty because of the low and variable baseflow conditions. Modeled baseflow in this area is only 0.04 ft^3/sec.

Table 15. Predicted Changes to Baseflow - Stage 4 (Post-Mining/Recovery; 1,150 Years After Closure or 1,172 Years Since Start of Mining)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) 1,150 Years After Closure Stage 4	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.39	+0.05
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	4.35	-0.01
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.27	-0.02
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.67	-0.03
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.26	-0.03
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.02	-0.02
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.83	0.00
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.22	0.00
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.54	0.00
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.28	0.00
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.375	0.00
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.12	0.00

[1] Natural streamflow variability determined by USFS (Wegner 2007).

Note: ft^3/sec = cubic feet per second. Shaded values are >20% change predicted in baseflow (i.e., outside estimated natural variability in modeled baseflow).

Following recovery, the model predicts a net reduction in flux from groundwater for Rock Lake of 3 acre-ft/yr, and a reduction in baseflow to the stream flowing into Rock Lake of 21 acre-ft/yr (**Table 16**). Assuming that precipitation, surface water in, overland flow, and evaporation remain the same, the Rock Lake water balance was revised with a reduced net flux into the lake of 24 acre-ft/yr or an annual average of 15 gal/min. This results in a net loss to the average downgradient "surface water out" component, indicating the primary impact to Rock Lake will be a reduction in the "surface water out" from an annual average of 6,947 acre-ft/yr to 6,923 acre-ft/yr (less than 0.5 percent change) (**Table 16**).

Table 16. Rock Lake Water Balance and Predicted Water Balance - Stage 4 (Post-Mining/Recovery; 1,150 Years After Closure or 1,172 Years Since Start of Mining)

Source	Annual Rock Lake Water Balance		Predicted Annual Rock Lake Water Balance Stage 4 (1,150 yrs after closure)	
	Average (acre-ft/yr)	Error [1] (acre-ft/yr)	Average (acre-ft/yr)	Error [1] (acre-ft/yr)
Precipitation	334	±29	334	±29
Surface Water In	4,042	±562	4,021 [2]	±562
Net Groundwater In	954	---	951 [3]	---
Overland Flow	1,743	±119	1,743	±119
TOTAL IN	7,073	±711	7,049	±711
Evaporation	126	±15	126	±15
Surface Water Out	**6,947**	±1,041	**6,923**	±1,041
TOTAL IN	7,073	±1,093	7,049	±1,093

[1] See Appendix F for Error calculations.
[2] "Surface Water In" reduced by 21acre-ft/yr or 13 gal/min annual average.
[3] "Net Groundwater In" reduced by 3 acre-ft/yr or 2 gal/min annual average.
Note: acre-ft/yr = acre-feet per year; gal/min = gallons per minute.

5.5 SIMULATED MITIGATION

During mining operations and following mining, MMC will likely perform operations that may mitigate impacts to the surface water systems. Grouting of water-bearing fractures during mining operations, and installation of bulkheads following mining operations, are both likely mitigation measures. In order to assess these possible mitigation measures, two primary mitigation scenarios were simulated in the model: (1) grouting in the upper mine blocks (Blocks 14, 16 and 18) during mining; and (2) installing bulk heads in the mine workings after mining ceases. **Appendix G** describes the model setup and results for these mitigation simulations.

Simulation of grouting the backside of Blocks 14, 16, 18, and corresponding access ramps during mining operations, resulted in some reductions to predicted streams impacts (**Table 17**). Model predictions in the table show that during the dewatering period (through year 22), the grouting simulation resulted in reduced impacts predicted to East Fork Rock Creek, Libby Creek, Ramsey Creek, and Poorman Creek at the wilderness boundary at the end of the mining period, as compared to previous "standard" unmitigated model simulations. The "standard" model run shows three model points where changes to stream baseflow exceed 20 percent; whereas, only one model point exceeded 20 percent for the grouting scenario. It is noted that the three locations that had greater than 20 percent change are in the upper reaches of Libby Creek and East Fork Rock Creek where modeled baseflows are low (0.04 to 0.54 ft^3/sec).

Table 17. Predicted Changes to Baseflow from Standard and Grouting Model Runs During Mining

	Pre-Mine	STANDARD MODEL RUN						MITIGATION MODEL RUN (grouting)					
	Baseflow (ft^3/sec)	Simulated Baseflow (ft^3/sec)		Change in Baseflow (ft^3/sec)		Percent Change in Baseflow		Simulated Baseflow (ft^3/sec)		Change in Baseflow (ft^3/sec)		Percent Change in Baseflow	
	0 yrs	8 yrs	22 yrs	8 yrs	22 yrs	8 yrs	22 yrs	8 yrs	22 yrs	8 yrs	22 yrs	8 yrs	22 yrs
East Fork Bull River at Mouth	11.34	11.31	11.25	-0.03	-0.09	-0.3%	-0.8%	11.32	11.27	-0.02	-0.07	-0.2%	-0.6%
East Fork Bull River at Wilderness Boundary	4.36	4.36	4.29	0.00	-0.07	0%	-1.6%	4.36	4.29	0.00	-0.07	0%	-1.6%
East Fork Bull River at EFBR-300	0.29	0.29	0.24	0.00	-0.05	0%	-17%	0.29	0.24	0.00	-0.05	0%	-17%
Rock Creek at Mouth	7.70	7.68	7.64	-0.02	-0.06	-0.26%	-0.78%	7.69	7.64	-0.01	-0.06	-0.1%	-0.78%
Rock Creek (East Fork) at Wilderness Bndry (below lake)	0.29	0.28	0.23	-0.01	-0.06	-3.4%	-21%	0.28	0.24	-0.01	-0.05	-3.4%	-17%
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	0.04	0.03	0.00	-0.01	0%	-25%	0.04	0.03	0.00	-0.01	0%	-25%
Libby Creek at Highway 2	19.83	19.66	19.56	-0.17	-0.27	-0.9%	-1.4%	19.66	19.57	-0.17	-0.26	-0.9%	-1.3%
Libby Creek at LB-300	1.22	1.09	1.02	-0.13	-0.20	-11%	-16%	1.09	1.02	-0.13	-0.20	-11%	-16%
Libby Creek at Wilderness Boundary	0.54	0.49	0.43	-0.05	-0.12	-9%	-22%	0.49	0.430	-0.05	-0.11	-9%	-20%
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	0.27	0.24	-0.01	-0.04	-4%	-14%	0.27	0.25	-0.01	-0.03	-4%	-11%
Ramsey Creek at Wilderness Boundary	0.38	0.36	0.34	-0.02	-0.04	-5%	-9%	0.37	0.35	-0.01	-0.03	-3%	-7%
Poorman Creek at Wilderness Boundary	0.12	0.12	0.11	0.00	-0.01	0%	-8%	0.12	0.12	0.00	0.00	0%	0%

Note: ft^3/sec = cubic feet per second. Shaded cells show >20% change predicted in baseflow. Time period of 8 years coincides with Stage 2 (construction and initial mining); 22 years coincides with Stage 3 (end of mining).

Simulation of bulkheads installed in Blocks 1 and 8 after cessation of mining show reduced predicted impacts to surface water during the post-mining period and long-term flow conditions. In this mitigation scenario, less post-mine drawdown is propagated to the water table near the south end of the mine void. The lowest water table elevation over Block 18 at the south end of the mine void occurs 2.8 years after closure, or 25 years after the start of mining (**Appendix G**). This compares to the "standard" unmitigated model run where the lowest water table elevation over Block 18 occurs about 16 years after closure, or 38 years after the start of mining. Groundwater recovery in this mitigation scenario stabilizes after approximately 1,300 years (1,322 years since start of mining).

Table 18 presents the simulated baseflow and change to baseflow between the unmitigated "standard" model run and the model run simulating mitigation using grouting and bulk heads. The mitigation run predicted less impacts to water in the Rock Creek, East Fork Rock Creek, and East Fork Bull River drainages. The two uppermost East Fork Rock Creek stations and the upper East Fork Bull River station still show relatively high percentages of change to baseflow 3 to 16 years after mining ceases (25 to 38 years since start of mining). However, these three locations have low and variable baseflows (0.04 to 0.29 ft^3/sec).

Table 18. Predicted Changes to Baseflow from Standard and Mitigation Model Runs Post-Mining

	Pre-Mine	STANDARD MODEL RUN									MITIGATION MODEL RUN (bulk heads and grouting)								
	Base-flow (ft^3 / sec)	Simulated Baseflow (ft^3/sec)			Change in Baseflow (ft^3/sec)			Percent Change in Baseflow			Simulated Baseflow (ft^3/sec)			Change in Baseflow (ft^3/sec)			Percent Change in Baseflow		
	0 yr	38 yrs*	25 yrs	1172 yrs	38 yrs*	25 yrs	1172 yrs	38 yrs*	25 yrs	1172 yrs	38 yrs	25 yrs*	1322 yrs	38 yrs	25 yrs*	1322 yrs	38 yrs	25 yrs*	1322 yrs
East Fork Bull River at Mouth	11.34	11.08	11.22	11.39	-0.26	-0.12	+0.05	-2.3%	-1.1%	+0.4%	11.09	11.25	11.33	-0.25	-0.09	-0.01	-2.2%	-0.8%	-0.1%
East Fork Bull River at Wilderness Boundary	4.36	3.98	4.20	4.35	-0.38	-0.16	-0.01	-8.7%	-3.7%	-0.2%	3.99	4.21	4.35	-0.37	-0.15	-0.01	-8.5%	-3.4%	-0.2%
East Fork Bull River at EFBR-300	0.29	0.02	0.17	0.27	-0.27	-0.12	-0.02	-93%	-41.4%	-7%	0.03	0.18	0.27	-0.26	-0.11	-0.02	-90%	-37%	-7%
Rock Creek at Mouth	7.70	7.05	7.51	7.67	-0.65	-0.19	-0.03	-8.4%	-2.5%	-0.4%	7.55	7.54	7.71	-0.15	-0.16	+0.01	-1.9%	-2.1%	+0.1%
Rock Creek (East Fork) at Wilderness Bndry (below lake)	0.29	-0.15	0.11	0.26	-0.44	-0.18	-0.03	>100%[1]	-62.1%	-10%	0.12	0.14	0.29	-0.17	-0.15	0.00	-59%	-51%	0%
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	0.00	0.00	0.02	-0.04	-0.04	-0.02	-100%	-100%	-50%	0.00	0.00	0.03	-0.04	-0.04	-0.01	-100%	-100%	-25%
Libby Creek at Highway 2	19.83	19.72	19.58	19.83	-0.11	-0.25	0.00	-0.6%	-1.3%	0%	19.73	19.58	19.83	-0.10	-0.25	0.00	-0.5%	-1.3%	0%
Libby Creek at LB-300	1.22	1.10	1.03	1.22	-0.12	-0.19	0.00	-10.2%	-15.6%	0%	1.10	1.04	1.22	-0.12	-0.18	0.00	-9.8%	-14.8%	0%
Libby Creek at Wilderness Boundary	0.54	0.47	0.44	0.54	-0.07	-0.10	0.00	-12.2%	-18.5%	0%	0.48	0.44	0.54	-0.06	-0.10	0.00	-11.1%	-18.5%	0%
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	0.24	0.24	0.28	-0.04	-0.04	0.00	-13.8%	-14.3%	0%	0.25	0.25	0.28	-0.03	-0.03	0.00	-10.7%	-10.7%	0%
Ramsey Creek at Wilderness Boundary	0.38	0.36	0.35	0.38	-0.01	-0.03	0.00	-3.8%	-6.7%	0%	0.36	0.35	0.38	-0.02	-0.02	0.00	-4.0%	-6.7%	0%
Poorman Creek at Wilderness Boundary	0.12	0.12	0.12	0.12	0.00	0.00	0.00	-3.7%	0%	0%	0.12	0.12	0.12	0.00	0.00	0.00	0%	0%	0%

Note: ft^3/sec = cubic feet per second. Yellow shaded cells show >20% change predicted in baseflow. * Time period with an asterisk is when maximum groundwater drawdown occurs over model Block 18.

[1] Percent change greater than 100% for East Fork Rock Creek below Rock Lake at Wilderness Boundary indicates there is a net flow of lake water (recharge) contributing to groundwater at this site (assuming lake is well-connected to groundwater system).

5.6 CUMULATIVE PREDICTIONS

Rock Creek Mine is a proposed underground mine that is located in close proximity to the proposed Montanore Mine. Since both mines are within similar catchments in the Cabinet Mountains, a simulation of both mines was completed to assess cumulative impacts to water resources with both mines in operation.

The cumulative mine simulation required several assumptions regarding design of the Rock Creek Mine. Information from the Rock Creek Mine EIS (USFS/MDEQ 2001) was used to simulate the mine in the model. Maps from the EIS were used to determine the approximate areal extent of the mine, and cross-sections were used to determine the elevation of ore that will be mined. The cumulative mine simulation used the same design for the Montanore Mine described above and, in addition, included constrained constant head boundaries set in the locations and elevations extrapolated from the Rock Creek Mine EIS. The Rock Creek Mine void is entirely with Layer 5 of the numerical model.

Since no schedule was available describing when each section of the Rock Creek mine would be opened, the same time steps were used that were already defined for the Montanore Mine beginning with an area closest to the Rock Creek Adit. Thus, the cumulative mine simulation had both the Montanore Mine and the Rock Creek Mine expanding simultaneously, and both mines reached full build-out at 22 years. The Rock Creek EIS states that Sterling Mining Company plans to leave a large barrier on either side of the Copper Lake Fault. This was simulated in the model by leaving a minimum 150-ft gap on either side of the Copper Lake Fault.

The model predicts that the peak cumulative groundwater inflow from both mines would be approximately 1,000 gal/min, although the Rock Creek EIS predicted a maximum inflow rate of about 2,700 gal/min into the Rock Creek mine based on an analytical approach (USFS/MDEQ 2001). Simultaneous dewatering of the Rock Creek Mine and Montanore Mine will result in separate water table drawdown areas at the end of mining (**Figure 35**).

Drawdown associated with the Rock Creek Mine is most significant in the St. Paul Peak area and the Copper Creek drainage, which is not influenced by the Montanore Mine. Copper Creek is a tributary to Bull River and, therefore, changes to baseflow were evaluated for the Bull River.

Table 19 lists changes in baseflow predicted by the model after Stage 3 (22-year cumulative mine development and operational period). Comparison of **Table 19** to **Table 11** indicates that the cumulative effect of mining at the Rock Creek and Montanore mines could be an increase in streamflow depletion to the lower Rock Creek drainage, but no cumulative effect on other streams in the study area. Predicted changes to baseflow for all streams in **Table 19** are about 20 percent or less of the modeled baseflow. Most of the cumulative effects are observed in East Fork Bull River and in the lower reaches of Rock Creek; a minor cumulative effect is predicted for East Fork Rock Creek within the wilderness boundary. The minor cumulative decrease in baseflow to Rock Creek within the wilderness area suggests that at least the shallowest portions of groundwater drawdown resulting from the Rock Creek mine void will extend under Rock Peak.

Since the most significant impacts to water resources from the Montanore Mine are predicted to occur 16 years following closure (for unmitigated scenario), the cumulative impact assessment included analysis of both mines closing and flooding simultaneously. To simulate the flooding of the mine voids following closure, the storage and hydraulic conductivity of the numerical model was increased both in the region of the Montanore mine and in layer 5 within the footprint of the Rock Creek Mine. In addition, head boundaries simulating dewatering were removed.

Figure 36 presents the cumulative drawdown 16 years following closure. Simultaneous dewatering of the Rock Creek Mine and Montanore Mine may result in coalescing drawdown areas at the water table for a period following mining.

Table 20 lists changes in baseflow predicted by the model 16 years following closure of both mines. Comparison of **Table 20** to **Table 13** indicates that the cumulative effect of mining at the Rock Creek and Montanore mines could be an increase in stream flow depletion to Rock Creek and East Fork Bull River drainage, but no cumulative effect on streams east of the divide.

Table 19. Predicted Changes to Baseflow - Stage 3 – Cumulative (Final Mining; Year 22)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) At End of Cumulative Mining Period	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.24	-0.10
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	4.28	-0.08
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.24	-0.05
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.49	-0.21
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.22	-0.07
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.03	-0.01
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.56	-0.27
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.02	-0.20
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.43	-0.12
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.24	-0.04
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.30 - 0.45)	0.34	-0.04
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.11	-0.01
Bull River	39.95	±7.99 (31.96 - 47.94)	39.61	-0.34

[1] Natural baseflow variability determined by USFS (Wegner 2007)

Note: ft^3/sec = cubic feet per second. The predicted cumulative dewatering rate at the end of Stage 3 is approximately 1,000 gallons per minute (gal/min).

Table 20. Predicted Changes to Baseflow – Cumulative (16 Years After Closure)

Drainage	Modeled Groundwater Contributing to Surface Water (ft^3/sec) Pre-Exploration	Estimated Variability in Modeled Baseflow at ±20% [1] (ft^3/sec)	Modeled Groundwater Contributing to Surface Water (ft^3/sec) 16 Years After Closure	Modeled Baseflow Change (ft^3/sec)
East Fork Bull River at Mouth	11.34	±2.27 (9.07 - 13.61)	11.05	-0.29
East Fork Bull River at Wilderness Boundary	4.36	±0.87 (3.49 - 5.23)	3.90	-0.46
East Fork Bull River at EFBR-300	0.29	±0.06 (0.23 - 0.35)	0.00	-0.29
Rock Creek at Mouth	7.70	±1.54 (6.16 - 9.24)	7.02	-0.68
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	±0.06 (0.23 - 0.35)	0.00 (-0.15) [2]	-0.29 (-0.44) [2]
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	±0.008 (0.032 - 0.048)	0.00	-0.04
Libby Creek at Highway 2	19.83	±4.03 (16.13 - 24.19)	19.72	-0.11
Libby Creek at LB-300	1.22	±0.24 (0.98 - 1.46)	1.10	-0.12
Libby Creek at Wilderness Boundary	0.54	±0.11 (0.43 - 0.65)	0.47	-0.07
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	±0.06 (0.22 - 0.34)	0.24	-0.04
Ramsey Creek at Wilderness Boundary	0.375	±0.075 (0.3 - 0.45)	0.361	-0.01
Poorman Creek at Wilderness Boundary	0.12	±0.024 (0.096 - 0.144)	0.12	0
Bull River	39.95	±7.99 (31.96 - 47.94)	39.47	-0.48

[1] Natural baseflow variability determined by USFS (Wegner 2007)

[2] The modeled groundwater contributing to surface water at East Fork Rock Creek at wilderness boundary 16 years following closure is -0.15 ft^3/sec, the negative value means water is moving from the surface water (Rock Lake) into the groundwater system. The difference between the pre-exploration groundwater contributing to surface water (0.29 ft^3/sec) and the 16-year post-mine surface water contribution to groundwater -0.15 ft^3/sec, results in a net change to baseflow of -0.44 ft^3/sec.

Note: ft^3/sec = cubic feet per second.

6.0 UNCERTAINTY

In any modeling exercise, there is a degree of uncertainty. Minimal site-specific data are available to quantify hydraulic conductivity of the rock mass. An uncertainty analysis was performed to estimate uncertainty in predictions that could result from hydraulic conductivity estimates. To assess the uncertainty, hydraulic conductivity of the entire model domain was both increased and decreased by an order of magnitude, and the model was executed in steady-state to establish initial conditions. Both models were subsequently run through Stage 3 to assess the effects of changes in hydraulic conductivity on predictions of stream flow depletion. Following completion of this standard uncertainty analysis, a subsequent uncertainty run was developed and executed using additional changes in hydraulic conductivity as described in Section 6.2 and **Appendix H**.

6.1 STANDARD UNCERTAINTY ANALYSIS

The steady-state model runs for both standard uncertainty analyses resulted in poor calibrations. Calibration goals were to have all residuals less than 50 meters, and have the "standard deviation divided by range" less than 5 percent. Further, the residual mean should be close to zero to indicate the model is not biased toward heads that are too high or too low. Both uncertainty models had large residual mean values.

In general, the uncertainty model with increased hydraulic conductivity had simulated heads lower than observed heads. This simulation had nine target wells with residuals greater than 50 meters and a "standard deviation divided by range" of 2.5 percent. The absolute residual mean was 62 feet and the residual mean was 42 feet. Furthermore, simulated streamflows in the upper drainages with the increased hydraulic conductivity model were very low to non-existent.

The uncertainty model with decreased hydraulic conductivity generally had heads that were much higher than observed heads. This simulation had 30 wells with residuals greater than 50 meters and a "standard deviation divided by range" of 4.6 percent; the absolute residual mean and residual mean were 133 feet and -129 feet, respectively. Streamflows with the reduced hydraulic conductivity model were within calibration ranges.

The uncertainty analysis suggests the stabilized flow rates to the mine workings may range from 130 to 1,800 gal/min. **Figures 37** and **38** show predicted flows to the mine workings during the 22-year simulation period for the order of magnitude increased and decreased uncertainty simulations, respectively.

Table 21 summarizes uncertainty in the predicted streamflow depletion at Stage 3 (year 22). The model with an order of magnitude higher hydraulic conductivity shows that resulting changes in baseflow are within the natural range (±20%) for the East Fork Bull River drainage, but greater than the natural range for upper Libby Creek drainage and Rock Creek drainage. Since the pre-exploration baseflow in the Wilderness Area is calculated to be relatively low with this uncertainty analysis, the predicted change in baseflow within the Wilderness Area may not be meaningful. The model with an order of magnitude lower hydraulic conductivity predicts minor reductions in streamflow, less than 12 percent of modeled baseflow.

Table 21. Predicted Changes to Baseflow - Standard Uncertainty Analysis

Drainage	Calibrated Model			10 x Uncertainty Model			0.1 x Uncertainty Model		
	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change
	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)
East Fork Bull River at Mouth	11.34	11.25	-0.09	10.89	10.20	-0.69	11.79	11.24	-0.55
East Fork Bull River at Wilderness Boundary	4.36	4.29	-0.07	3.90	3.46	-0.44	4.33	4.19	-0.14
East Fork Bull River at EFBR-300	0.29	0.24	-0.05	0.00	0.00	0.00	1.11	1.05	-0.05
Rock Creek at Mouth	7.70	7.64	-0.06	7.67	4.86	-2.81	7.64	7.64	0.00
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	0.23	-0.06	0.00	0.00	0.00	0.43	0.43	0.00
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	0.03	-0.10	0.00	0.00	0.00	0.10	0.10	0.00
Libby Creek at Highway 2	19.83	19.56	-0.27	19.61	17.03	-2.58	19.37	19.12	-0.25
Libby Creek at LB-300	1.22	1.02	-0.20	0.96	0.15	-0.81	1.19	1.05	-0.14
Libby Creek at Wilderness Boundary	0.54	0.43	-0.12	0.34	0.00	-0.34	0.56	0.54	0.02
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	0.24	-0.04	0.15	0.13	-0.03	1.31	1.23	-0.08
Ramsey Creek at Wilderness Boundary	0.375	0.34	-0.04	0.00	0.00	0.00	0.38	0.38	0.00
Poorman Creek at Wilderness Boundary	0.12	0.11	-0.01	0.00	0.00	0.00	0.29	0.29	0.00

Note: ft^3/sec =cubic feet per second. Pre-Exploration flow rates for the two uncertainty models were generated from steady-state simulations under the revised hydraulic conductivity parameterization; therefore, these values are not the same as the calibrated model flow rates, especially in the Wilderness Area.

6.2 SUBSEQUENT UNCERTAINTY ANALYSIS

Due to the uncertainty of parameterization of the fault zones, particularly the Rock Lake Fault, a third model configuration was developed for the uncertainty analysis. The calibrated hydraulic conductivity distribution presented in Section 4.2.1 was modified by removing zones of low permeability simulated adjacent to fractures and faults. The model was then executed and compared to calibration targets, and predictive runs were executed with the modified model.

Hydraulic conductivity values in zones representing virtually unfractured bedrock simulated in Layers 3 through 7 adjacent to fractures and faults were replaced with the background hydraulic conductivity values for each respective layer. **Table 22** presents the original and replaced hydraulic conductivity for the low permeability zones in each layer.

Table 22. Adjusted Hydraulic Conductivity - Subsequent Uncertainty Model Configuration

Layer	Hydraulic Conductivity Calibrated Model (cm/sec)	Adjusted Hydraulic Conductivity (cm/sec)
3	3×10^{-8}	4×10^{-7}
4 and 5	3×10^{-9}	9×10^{-8}
6 and 7	3×10^{-9}	6×10^{-8}

Note: cm/sec = centimeters per second.

Increasing the hydraulic conductivity in zones adjacent to fractures resulted in a poorer calibration to both the steady-state head data and to the transient Libby Adit calibration data. Statistics indicate that the residuals increase a little in the modified model parameterization. This simulation had two wells with residuals greater than 50 meters, "standard deviation divided by range" of 1.8 percent, absolute residual mean of 43 feet, and a residual mean of -5 feet. Since hydraulic conductivity values were changed in a small area, only a few target locations were noticeably affected. Residuals at wells HR-19, HR-26, and HR-29 increased by 121, 13, and 20 feet, respectively. The modified model generally under-predicts drawdown from hydraulic tests at boreholes 3650 and 5220 within the fracture sets, but over-predicts drawdown across the fracture sets. Finally, the modified model parameterization results in historic adit dewatering rates that are generally over-predicted by 35 gal/min or more.

Comparing the average dewatering rates for the various mining periods predicted by the calibrated and the modified model (**Tables 6** and **23**, respectively), shows that the increase in hydraulic conductivity values adjacent to fracture sets yields predicted dewatering rates 11 to 35 percent higher than calibrated model predictions.

The modified model predicts greater depletion in flow in nearby streams than the calibrated model. **Table 24** presents the predicted impacts to streams from both models. This table shows that the modified model predicts baseflow depletions that are greater than the calibrated model, except in the Poorman and Ramsey creek drainages. The predicted changes in baseflow with this model are greater than the natural range (±20%) for upper drainages of Libby Creek, Rock Creek (East Fork), and East Fork Bull River.

Table 23. Predicted Dewatering Rates and Percent Increase - Subsequent Uncertainty Analysis

Period	Average Dewatering Rate in Adits (gal/min)	% Increase	Average Dewatering Rate in VOID/exploration bores (gal/min)	% Increase	Average Dewatering Rate for all Mine Workings (gal/min)	% Increase
0-2 years	226 (calibrated) 309 (modified)	37%	31 (calibrated) 40 (modified)	29%	257 (calibrated) 348 (modified)	35%
2-5 years	445 (calibrated) 485 (modified)	9%	29 (calibrated) 41 (modified)	41%	474 (calibrated) 526 (modified)	11%
5-20 years	267 (calibrated) 310 (modified)	16%	115 (calibrated) 168 (modified)	46%	382 (calibrated) 478 (modified)	25%
20-22 years	203 (calibrated) 277 (modified)	36%	166 (calibrated) 210 (modified)	27%	369 (calibrated) 487 (modified)	32%

Note: gal/min = gallons per minute. See Table 6 for calibrated dewatering rates.

Table 24. Predicted Changes to Baseflow - Subsequent Uncertainty Analysis

Drainage	Calibrated Model			Modified Parameterization		
	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change
	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)
East Fork Bull River at Mouth	11.34	11.25	-0.09	11.36	11.17	-0.19
East Fork Bull River at Wilderness Boundary	4.36	4.29	-0.07	4.37	4.22	-0.15
East Fork Bull River at EFBR-300	0.29	0.24	-0.05	0.29	0.19	-0.10
Rock Creek at Mouth	7.70	7.64	-0.06	7.70	7.57	-0.13
Rock Creek (East Fork) at Wilderness Boundary (below lake)	0.29	0.23	-0.06	0.29	0.16	-0.13
Rock Creek (East Fork) at EFRC-50 (above lake)	0.04	0.03	-0.01	0.04	0.01	-0.03
Libby Creek at Highway 2	19.83	19.56	-0.27	19.87	19.48	-0.39
Libby Creek at LB-300	1.22	1.02	-0.20	1.24	0.97	-0.27
Libby Creek at Wilderness boundary	0.54	0.43	-0.11	0.56	0.39	-0.17
Libby Creek at LB-50 (above Wilderness Boundary)	0.28	0.24	-0.04	0.28	0.22	-0.06
Ramsey Creek at Wilderness Boundary	0.38	0.34	-0.04	0.38	0.34	-0.04
Poorman Creek at Wilderness Boundary	0.12	0.11	-0.01	0.12	0.11	-0.01

Note: ft^3/sec = cubic feet per second.

7.0 CONCLUSIONS

The regional-scale numerical model developed for the Montanore Project is capable of simulating groundwater flow in the model area within a reasonable range of error. Inherent in any modeling effort is a degree of uncertainty. There is substantial uncertainty associated with the hydraulic properties of the bedrock and faults (i.e., hydraulic conductivity and storage), especially for the Rock Lake Fault which is located near the proposed mine void. Predictions of mine inflows and impacts to water resources are sensitive to permeability of major fault zones. The model was not designed to accurately predict impacts to the uppermost reaches of streams where baseflows are low and variable, and where groundwater/surface water interaction is not well defined, nor can be calibrated in the model. The uncertainty analyses performed in this study capture a range of uncertainty in predictions caused by the hydraulic parameterization.

Model predictions represent a range of possible impacts to streams and lakes in the Cabinet Mountains, including the Wilderness Area. Predictions from the calibrated model suggest that impacts to streams will be less than the estimated normal range of natural stream baseflow variability (±20%) through the exploration, construction, and initial mining phases (through year 8). During the remaining period of mining (through year 22), the upper reaches of three streams (Libby Creek, East Fork Rock Creek, and East Fork Bull River) at the Wilderness boundary are predicted to have baseflows reduced up to 25 percent. Baseflows that occur for a relatively short period of time each year in these upper stream reaches are low and variable (typically <0.3 ft^3/sec). Maximum reductions in streamflow to Rock Creek (including Rock Lake) and East Fork Bull River are predicted to occur at about 16 years after mine closure.

In general, reductions in stream baseflow, where they are predicted to occur, are larger downstream. This occurs because dewatering in the mine workings intercepts both local and regional flow paths that report to upper and lower reaches of drainages, respectively. Similarly, the model indicates that for long-term closure, flow in lower East Fork Bull River increases slightly; whereas, flow farther upstream above the Wilderness Boundary is slightly reduced. This occurs due to the mine void acting as a conduit supplying water to the deep regional flow system within the flow paths reporting to the lower reaches of East Fork Bull River.

Maximum steady-state dewatering rates during mining of the ore body are predicted to reach about 350 to 500 gal/min. The uncertainty analysis with an order of magnitude higher hydraulic conductivity for all areas shows mine inflow rates up to 1,800 gal/min. These values assume fractures in the mine void will not be grouted to reduce mine inflows, which is estimated to be up to about 1,400 gal/min.

Dewatering rates could decrease significantly with grouting. Grouting during underground mining is a common practice and will likely be used at Montanore to limit inflows to that required for process makeup water. After cessation of mining, construction of bulkheads underground also could reduce long-term effects on groundwater levels and stream baseflows. The two mitigation measures of grouting during mining and installing bulkheads after mining were simulated to evaluate their potential to reduce impacts to surface water. Both mitigation scenarios suggest some decrease in predicted impacts to the surface water system. Modeling the mitigation scenarios has some limitations with respect to using a regional-scale model with relatively small-scale mitigations to predict changes to surface water impacts.

During the mining operation, other areas may be grouted in addition to those simulated; thus, even greater reductions to impacts could occur.

Uncertainty in model predictions for dewatering rates and impacts to streams is highest during the later years of mining when the mine voids increase substantially in area and extent, and when mining gets closer to Rock Lake and the Rock Lake Fault. During the first 8 years of exploration, construction, and initial mining, predicted changes to stream baseflow from the model are less than 12 percent. When additional characterization of underground hydraulic properties is completed as planned during the first 2 years (and subsequent construction and mining period), the model's uncertainty for predicting inflows and water resource impacts for later years will be greatly reduced based on the empirical data obtained from underground testing. Such testing will better characterize both fractured and unfractured rock, including fault zones. Since the surface trace of the Rock Lake Fault is in the Cabinet Mountains Wilderness Area, completing wells/borings in the fault will be most feasible from inside the mine void.

Results from the model runs described herein capture a feasible range of impacts and dewatering rates. With the data currently available, these are the best estimates of impacts and associated uncertainty that can be obtained using the FEFLOW model. When the groundwater flow model is refined and rerun after data from the first 1 to 2 years of underground testing are incorporated into the model, the predicted longer-term impacts to surface water resources in the project area will have greater certainty, including simulation of mitigation measures. The water resources monitoring program can be adapted as necessary to match the revised impact predictions. Additional mitigation measures can be designed and implemented, if needed, to address these potential impacts.

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APPENDIX A

FIGURES

APPENDIX B

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APPENDIX C

BASEFLOW CALCULATIONS AND DATA

APPENDIX D

HYDRAULIC TESTING MEMORANDUM

APPENDIX E

MODEL CALIBRATION STATISTICS AND RESIDUALS

APPENDIX F

ROCK LAKE WATER BALANCE

APPENDIX G

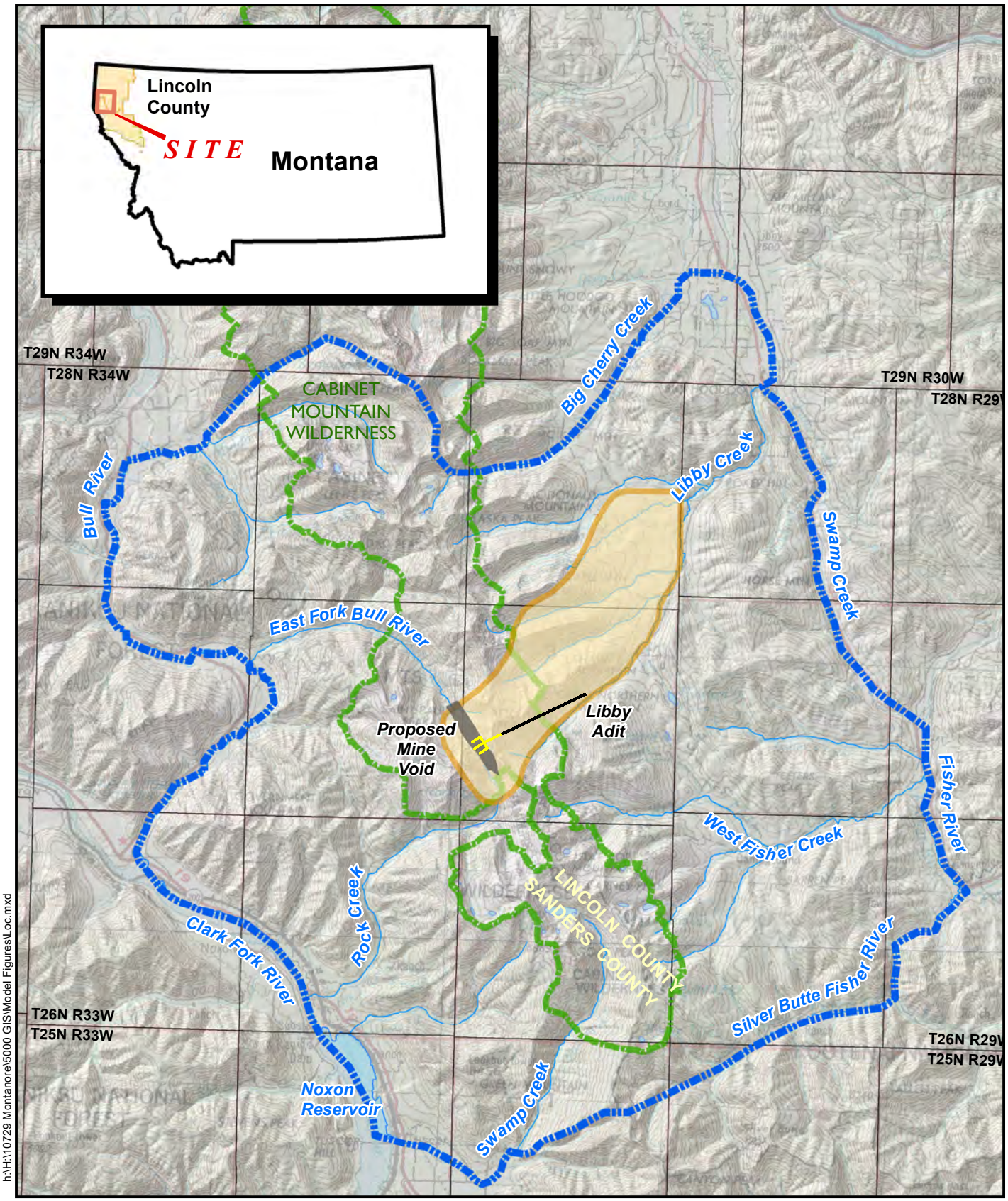
MODEL PREDICTIONS OF MITIGATION MEASURES MEMORANDUM

APPENDIX H

MODEL PARAMETERIZATION ADJUSTMENT MEMORANDUM

APPENDIX A

FIGURES



h:\H:\10729 Montanore\5000 GIS\Model Figures\Loc.mxd

Source: USGS 100K Montana Quadrangle

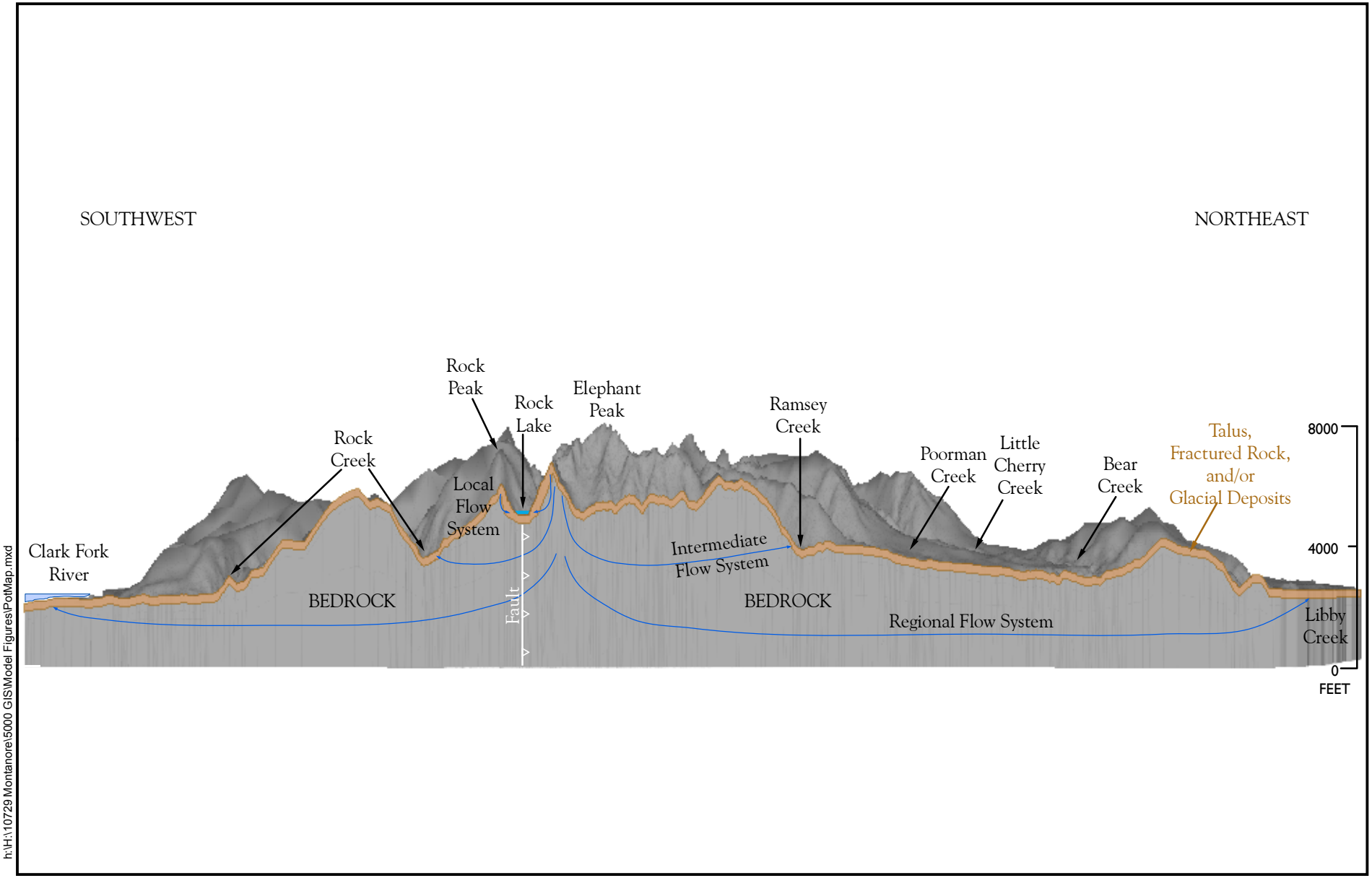
N

0 20,000
Feet

AMEC Geomatrix

Proposed Libby Adit Expansion
Project Area
Study Area/Model Boundary
Cabinet Mountain Wilderness Area

Project Area and Study Area Location Map
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 1



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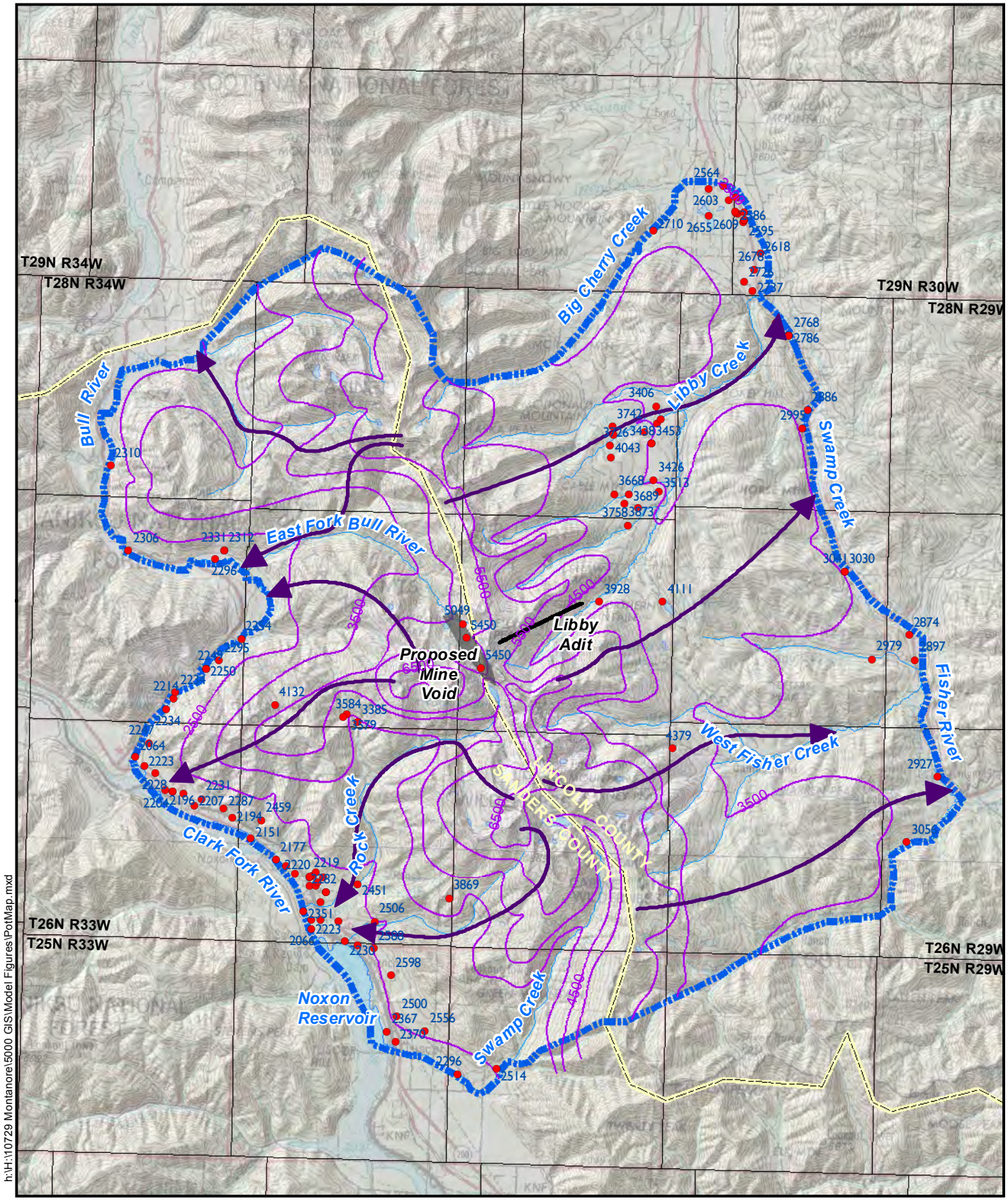
Conceptual Model Cross Section
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 2

AMEC Geomatrix



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

0 20,000
Feet

AMEC Geomatrix

Groundwater Flow Line
Potentiometric Contours (feet msl)
Study Area/Model Boundary
Well static water elevation (feet)

Potentiometric Surface
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 3

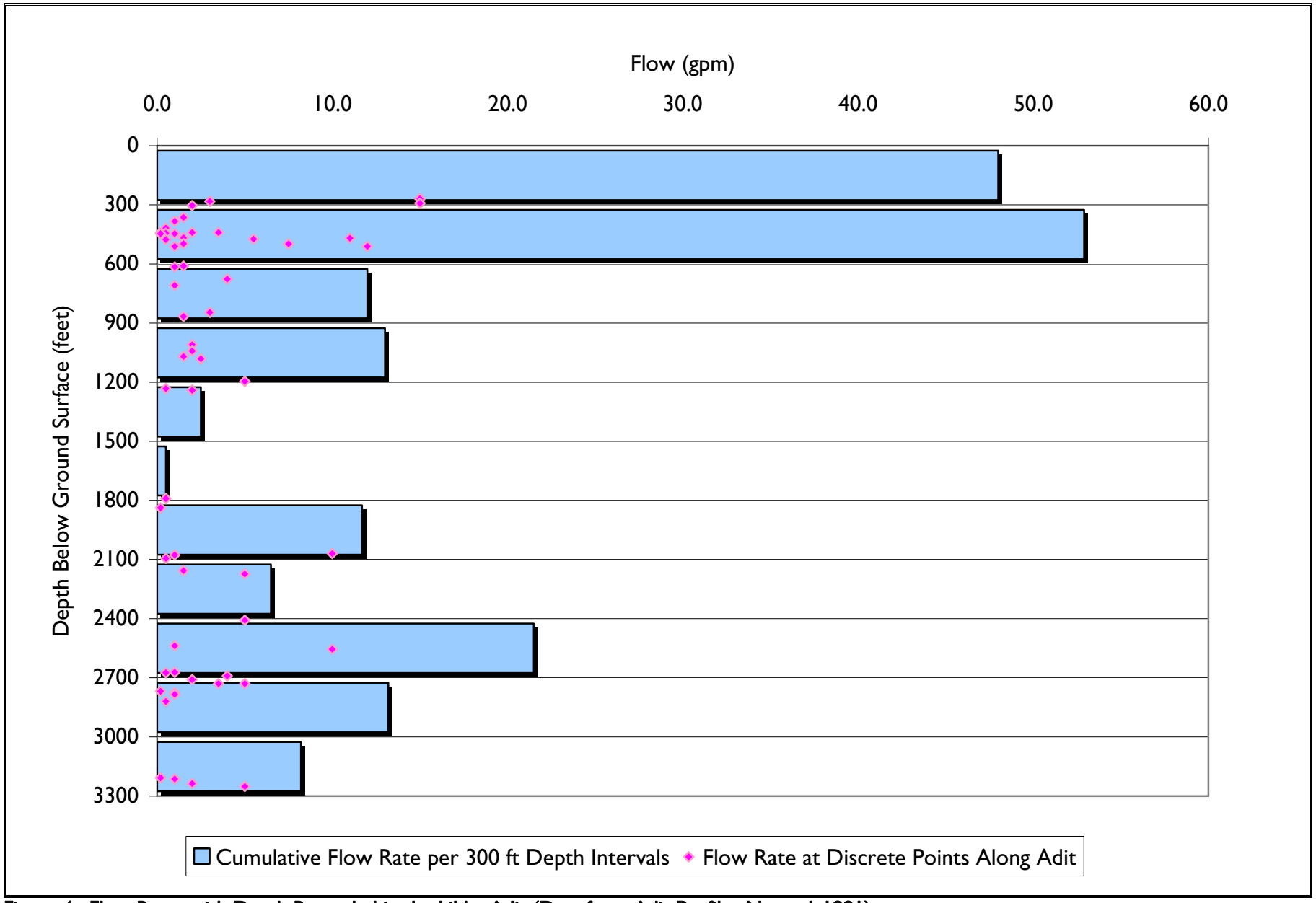
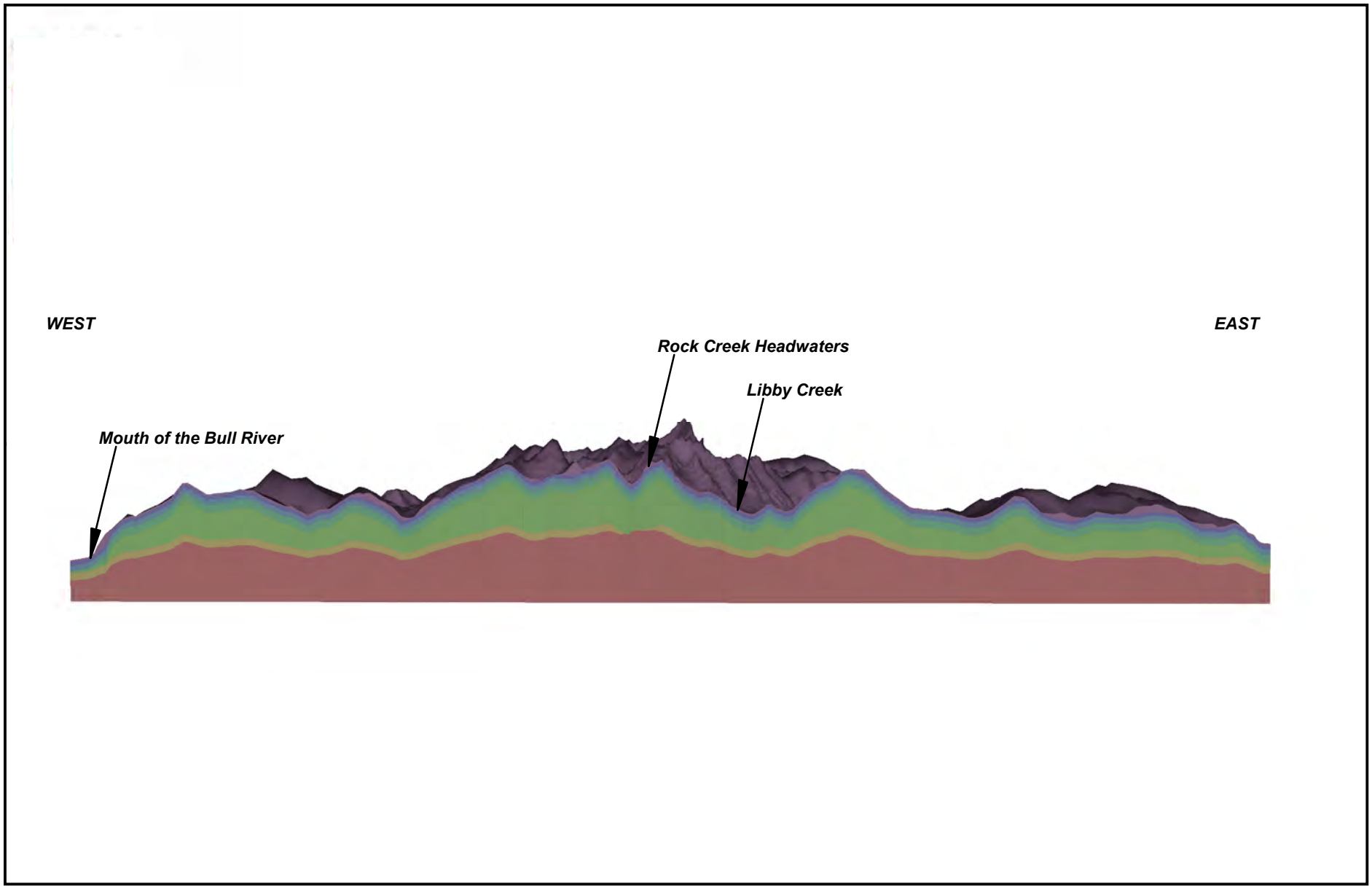


Figure 4. Flow Rates with Depth Recorded in the Libby Adit (Data from Adit Profiles Noranda1991)



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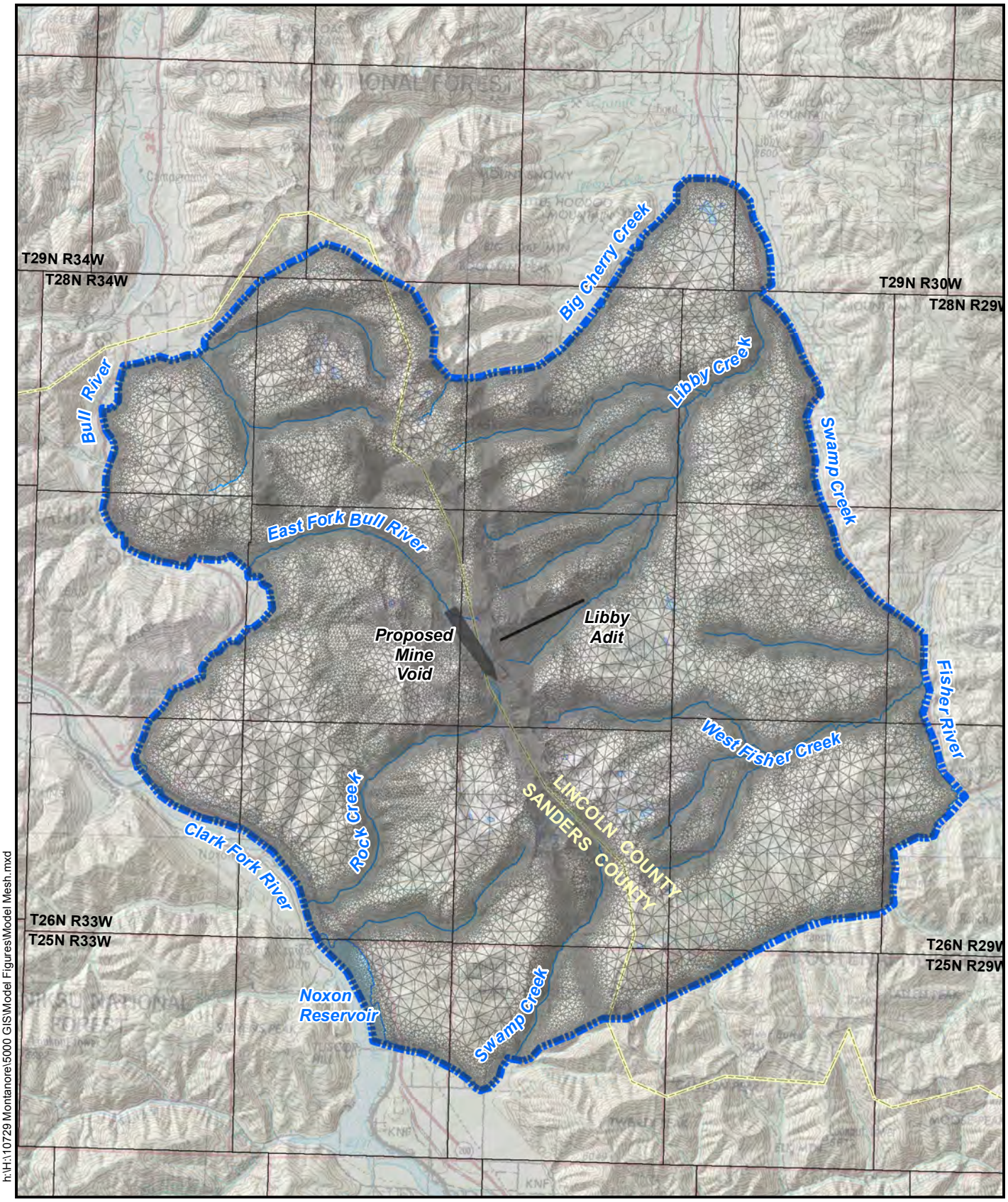
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7

Vertical Exaggeration - 1"=6000'

0 7
Miles

AMEC Geomatrix

Model Cross Section
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 5



Source: USGS 100K Montana Quadrangle

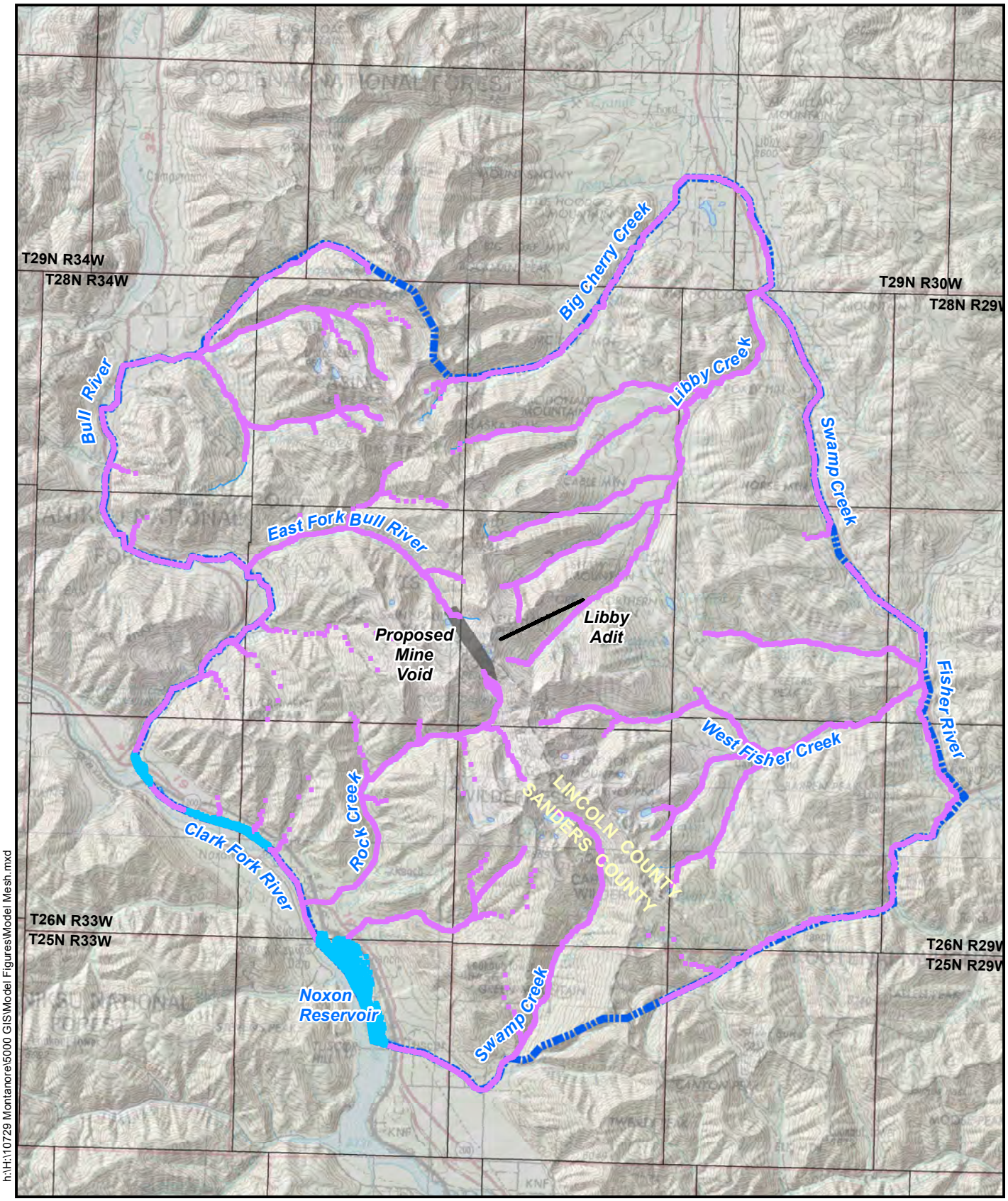
h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000
Feet

Study Area/Model Boundary

AMEC Geomatrix

Model Mesh
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 6



h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

Source: USGS 100K Montana Quadrangle

N

0 20,000
Feet

AMEC Geomatrix

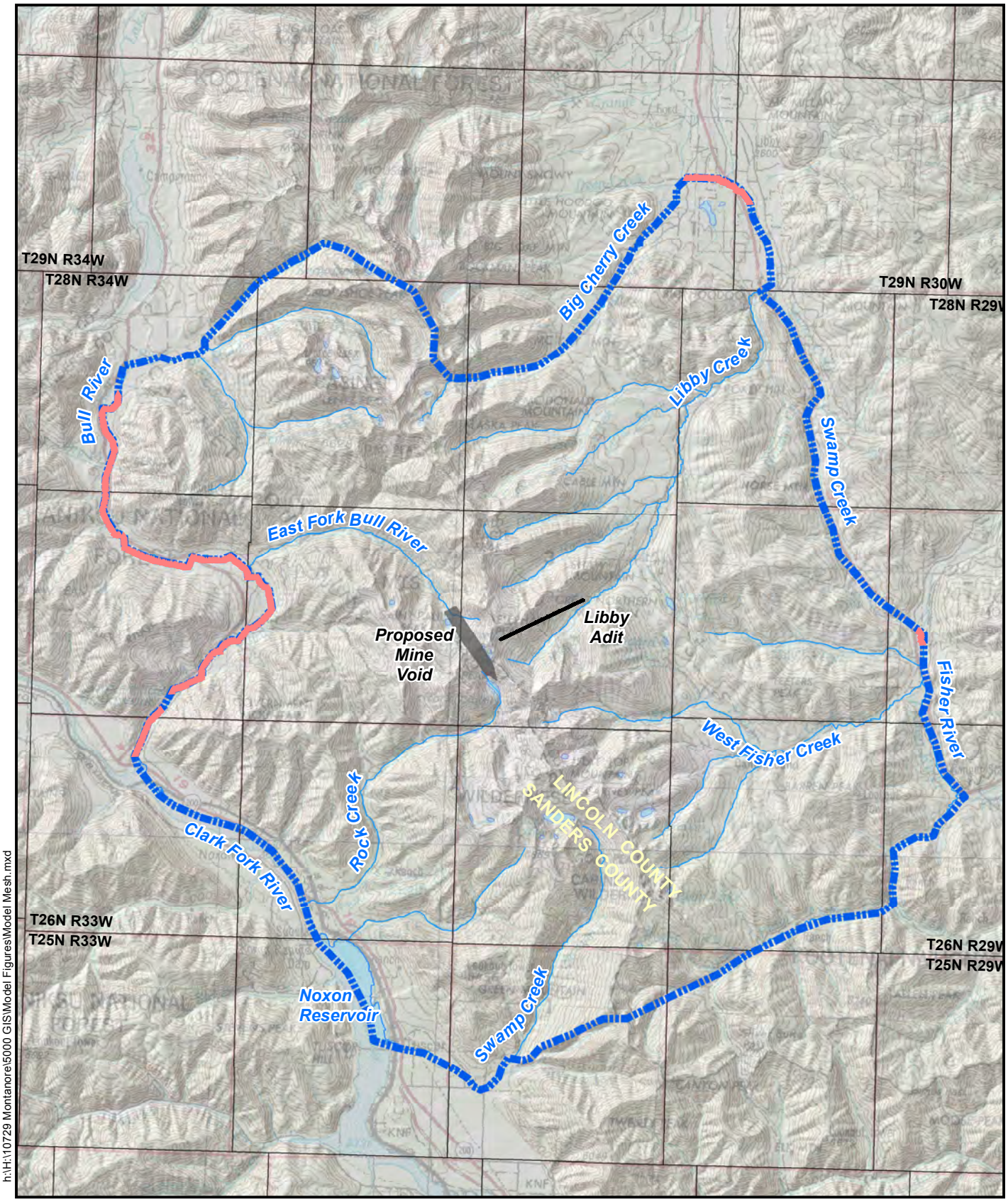
Study Area/Model Boundary

Layer1 & 2 Boundaries

Transfer Boundaries

Constant Head Boundaries

Boundary Conditions - Layer 1
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 7



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000
Feet

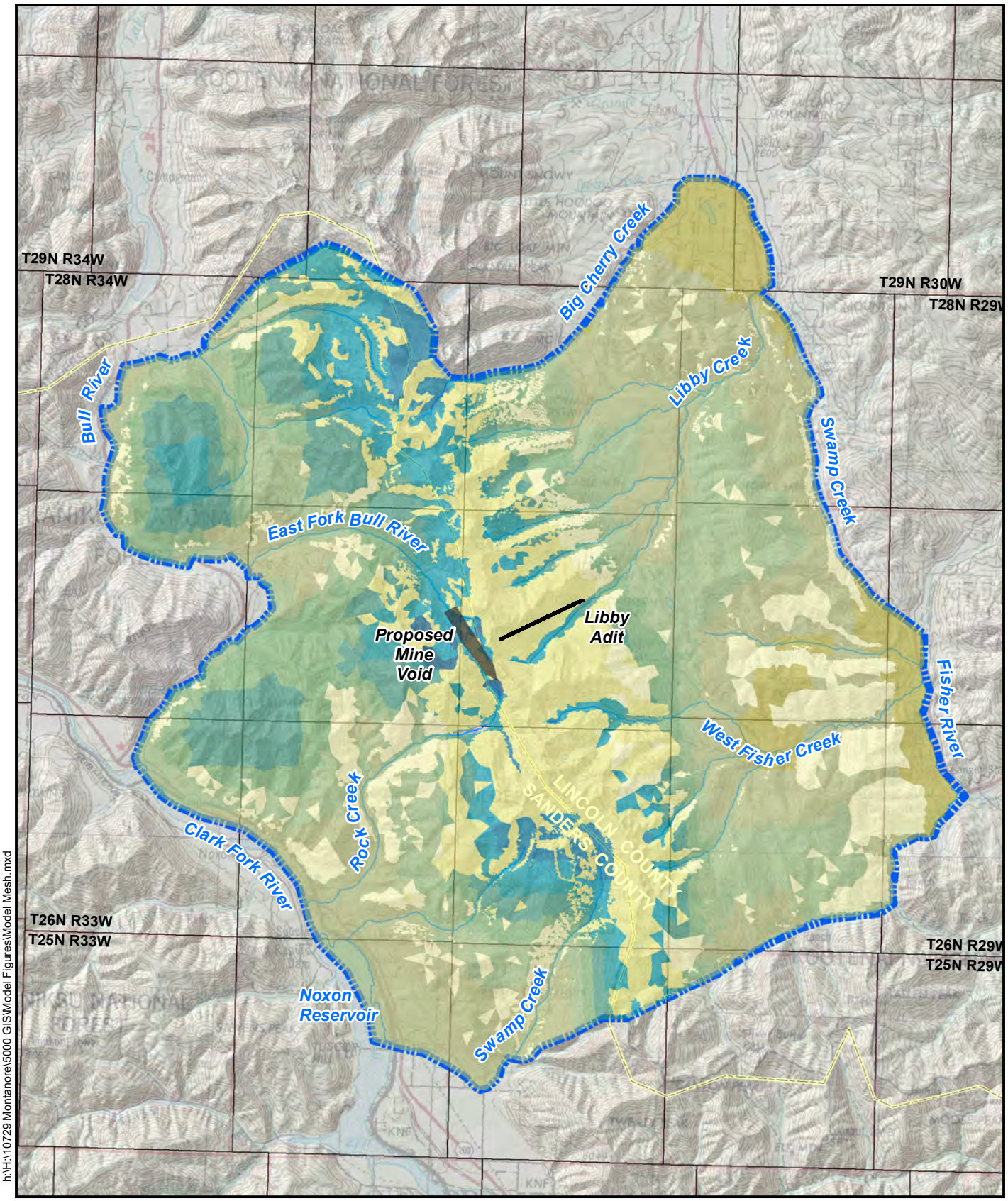
Study Area/Model Boundary

Boundaries Layers 3-7

Constant Flux Boundaries

AMEC Geomatrix

Boundary Conditions - Layers 3 through 7
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 8



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

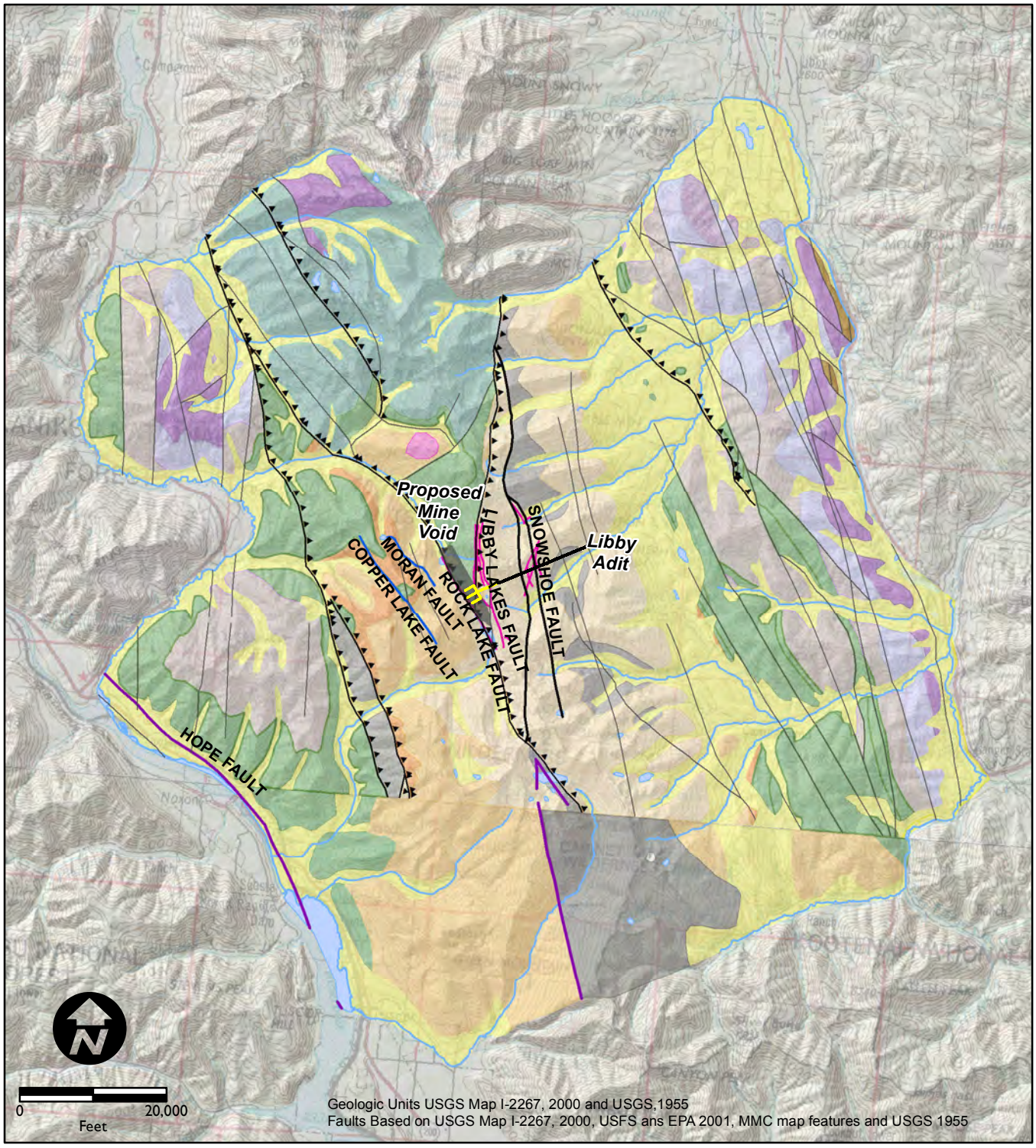
0 20,000 Feet

AMEC Geomatrix

Recharge in/year

0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 11.5

Recharge Distribution
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 9



Faults USGS 2267, 2000

- Minor
- Thrust System
- Major

- Faults Rock Creek EIS
- Faults USGS 1955
- Faults Mines Management

Geology USGS I-2267, 2001

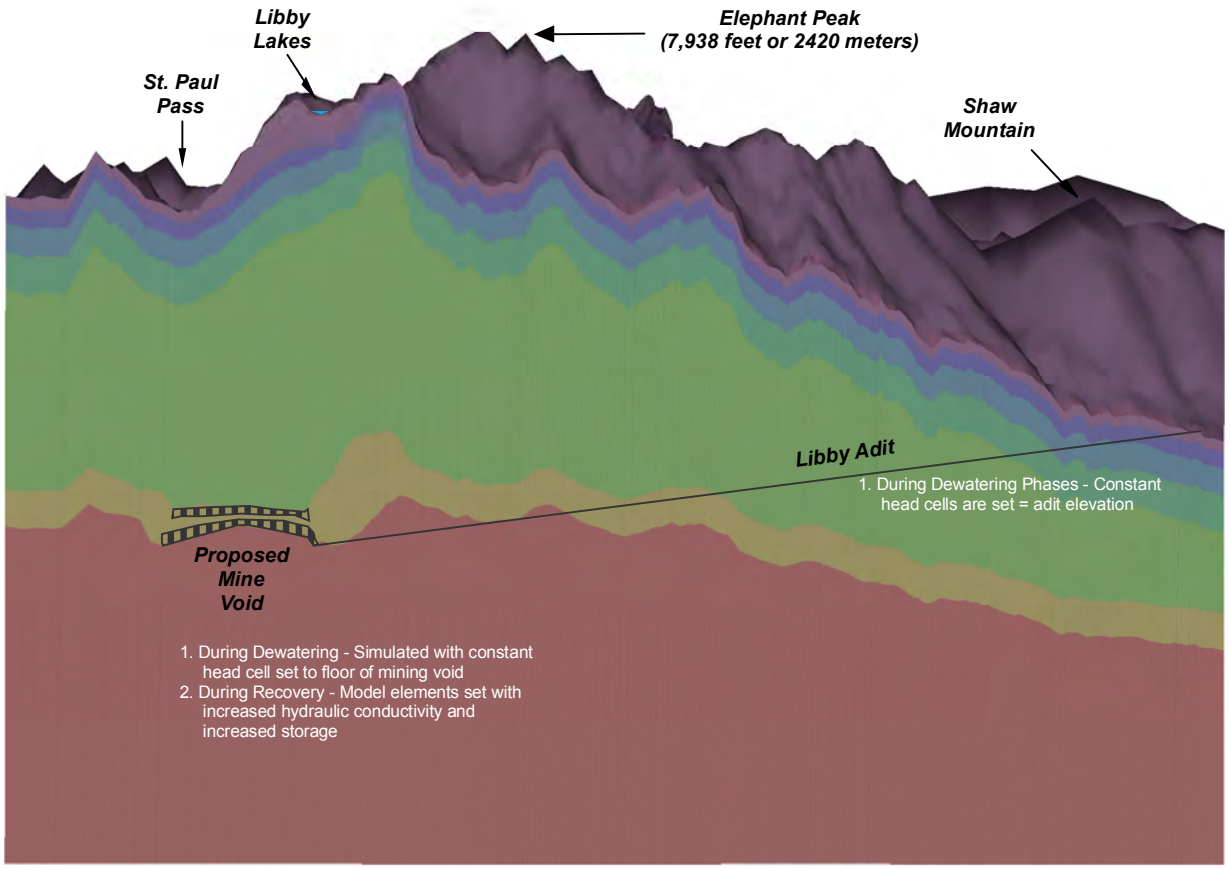
- Cu-Middle Cambrian Sedimentary
- Kg-Felsic Plutons
- Qal-Alluvial Deposit
- Qg- Glacial and Fluvial Glacial Deposit
- Ql-Glacial Lake Deposit
- Ybo, Ylu-Libby
- Yms, Ymsu-MountSheilds
- Ysh-Sheppard
- Ysn, Ysng-Snowslip
- Ypt, Ypu-Prichard
- Yb-Burke
- Yr-Revette
- Ysr-St Regis
- Ysw-Sheppard & Wallace
- Yw, Ywl, Ywm, Ywu-Wallace

Geology USGS, 1955

- Qal-Alluvial Deposit
- pCp Belt Series-Prichard Formation
- pCr Belt Series-Ravalli Group
- pCw Belt Series- Wallace Formation

AMEC Geomatrix

Geologic Map
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 10



Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7

Vertical Exaggeration - 1"=2500'

0 1.5
Miles

AMEC Geomatrix

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

Adit and Mine Conceptualization
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 11

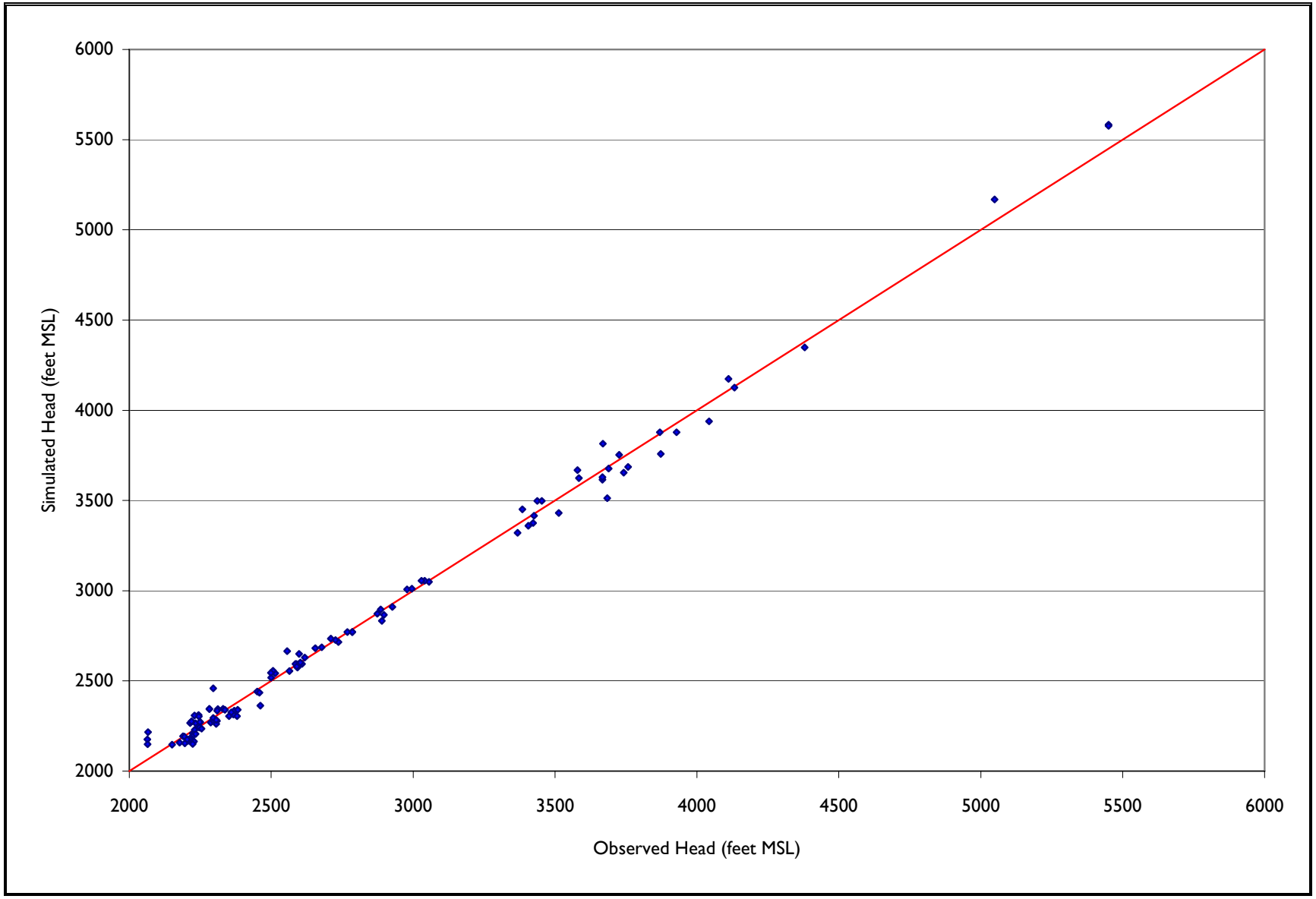
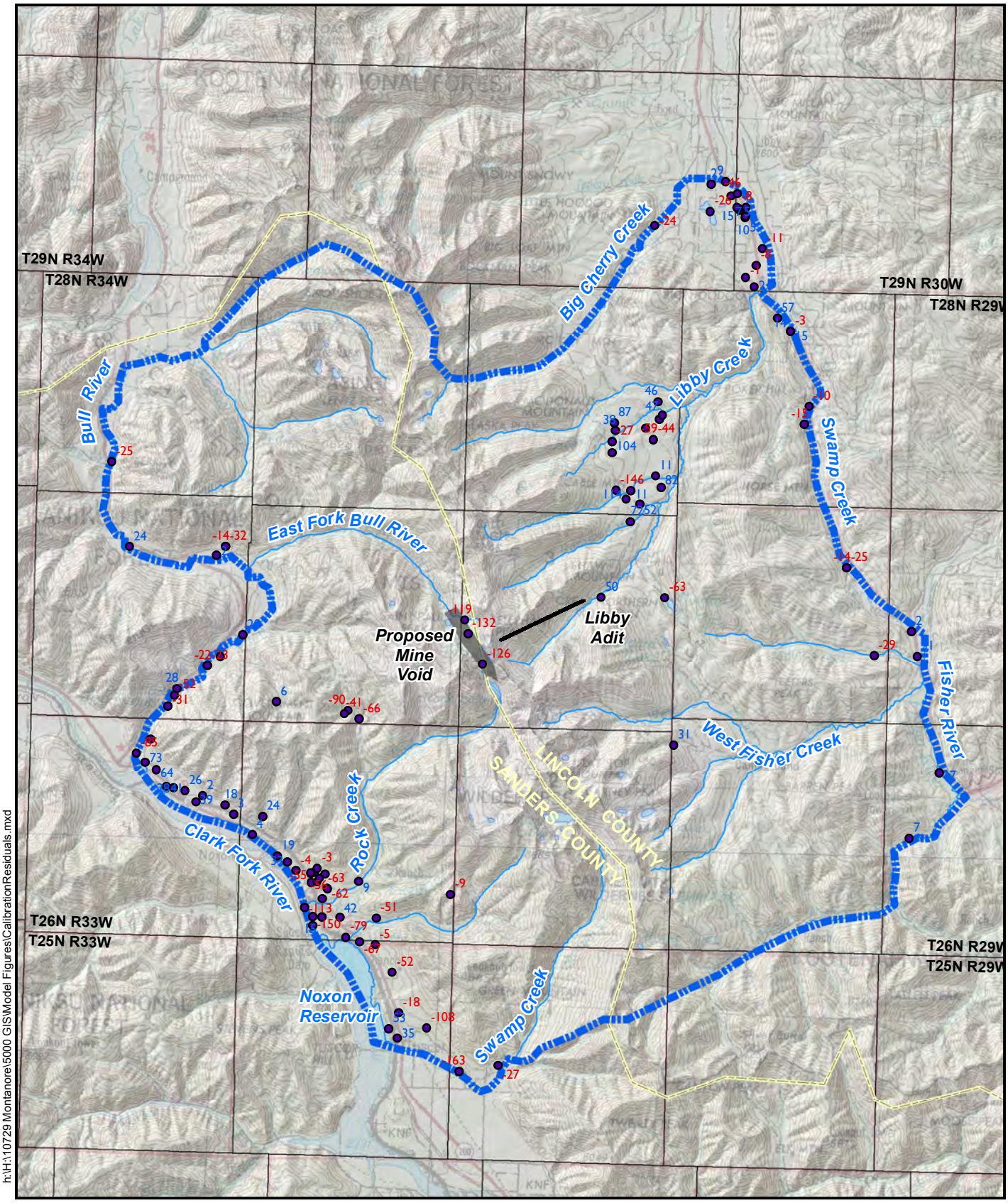


Figure 12. Observed Versus Simulated Heads



Source: USGS 100K Montana Quadrangle

0 20,000 Feet

Study Area/Model Boundary

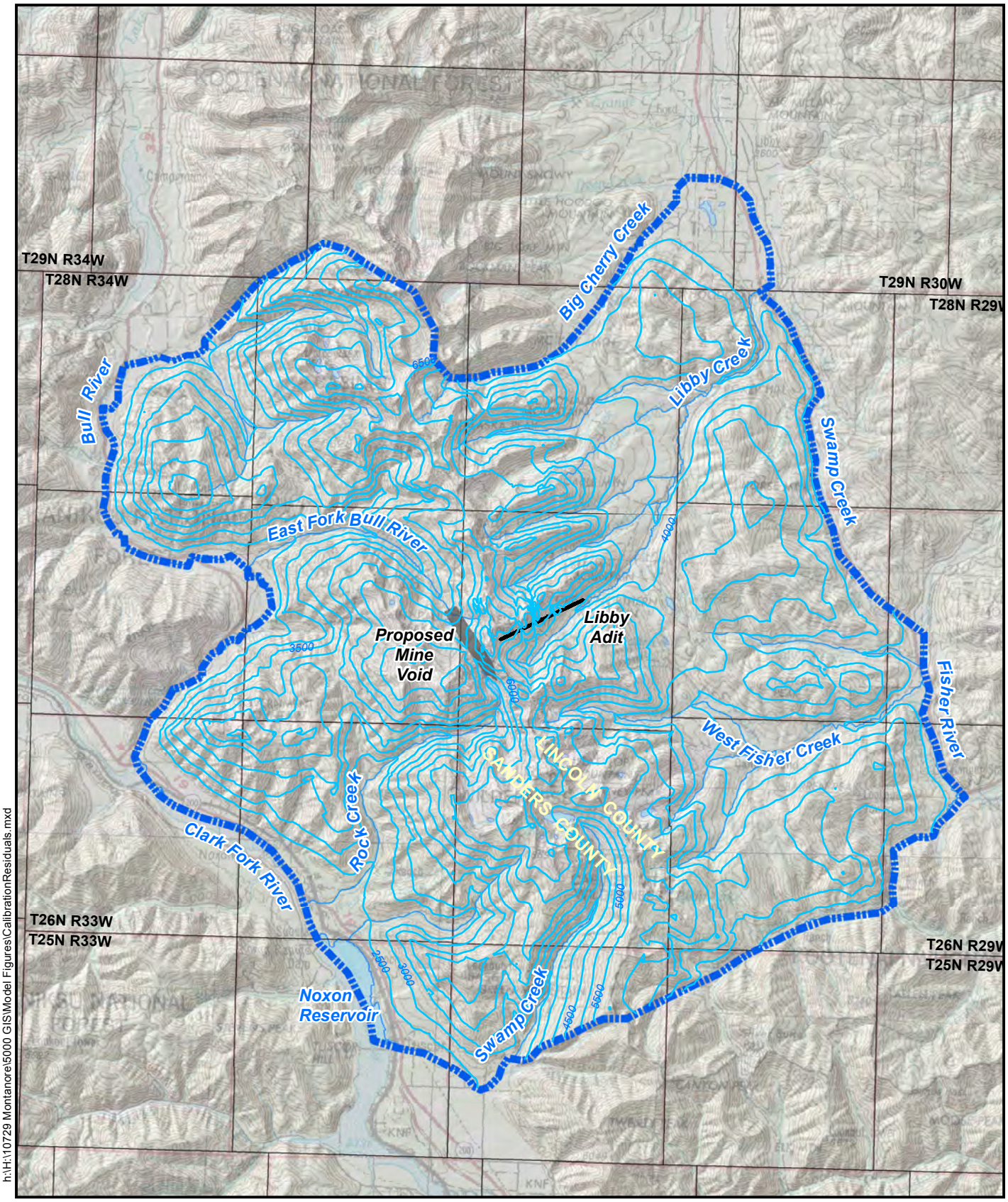
Groundwater Targets

-65 Residual (feet)

AMEC Geomatrix

h:\H:\10729 Montanore\5000 GIS\Model Figures\CalibrationResiduals.mxd

Calibration Residuals
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 13



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\CalibrationResiduals.mxd

N

0 20,000
Feet

AMEC Geomatrix

Study Area/Model Boundary

Watertable Contours (ft msl)

Simulated Potentiometric Surface
Layer 1 (Water Table)
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 14

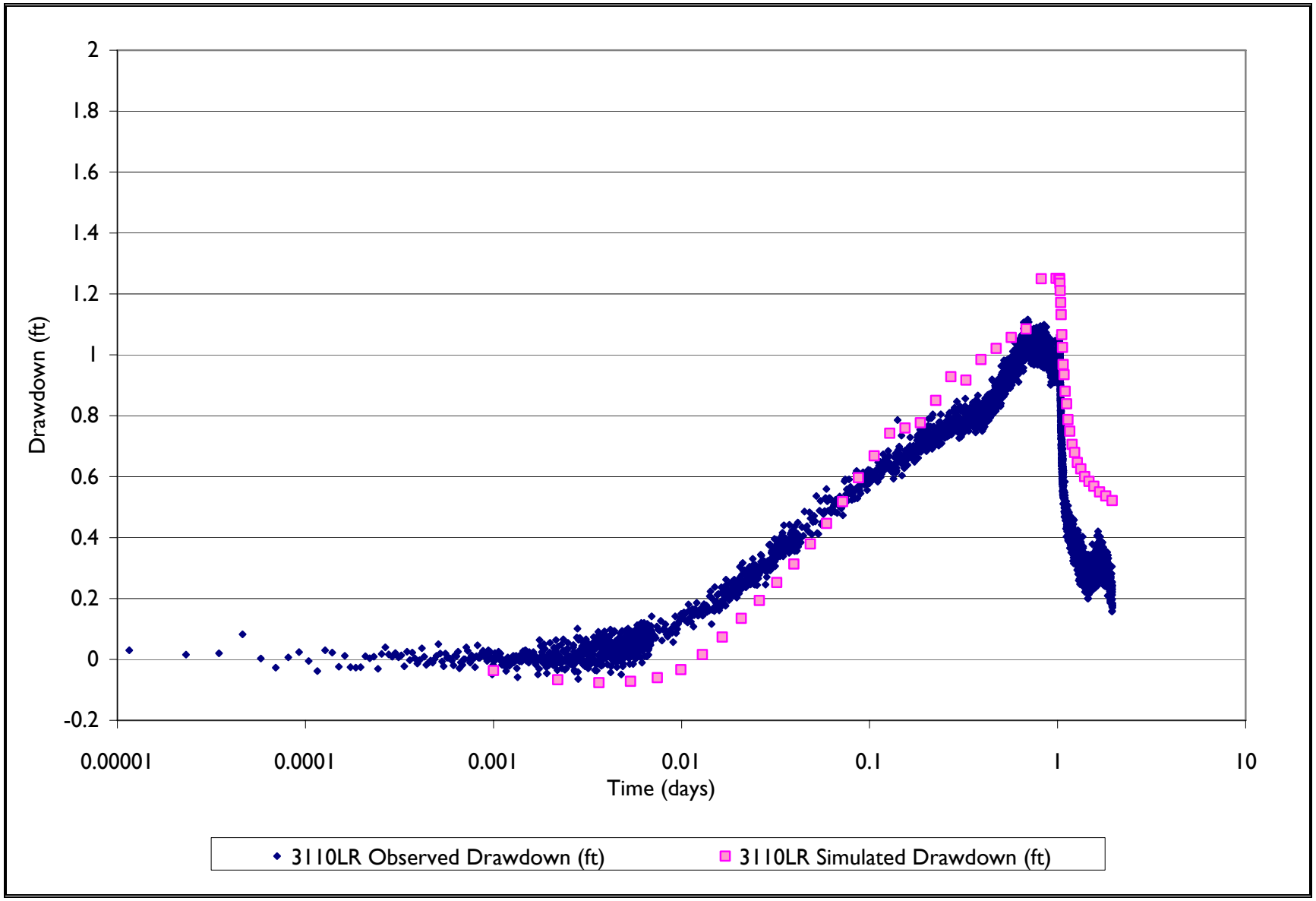


Figure 15. Simulated and Observed Drawdown at 3110LR during Test of 3660RR

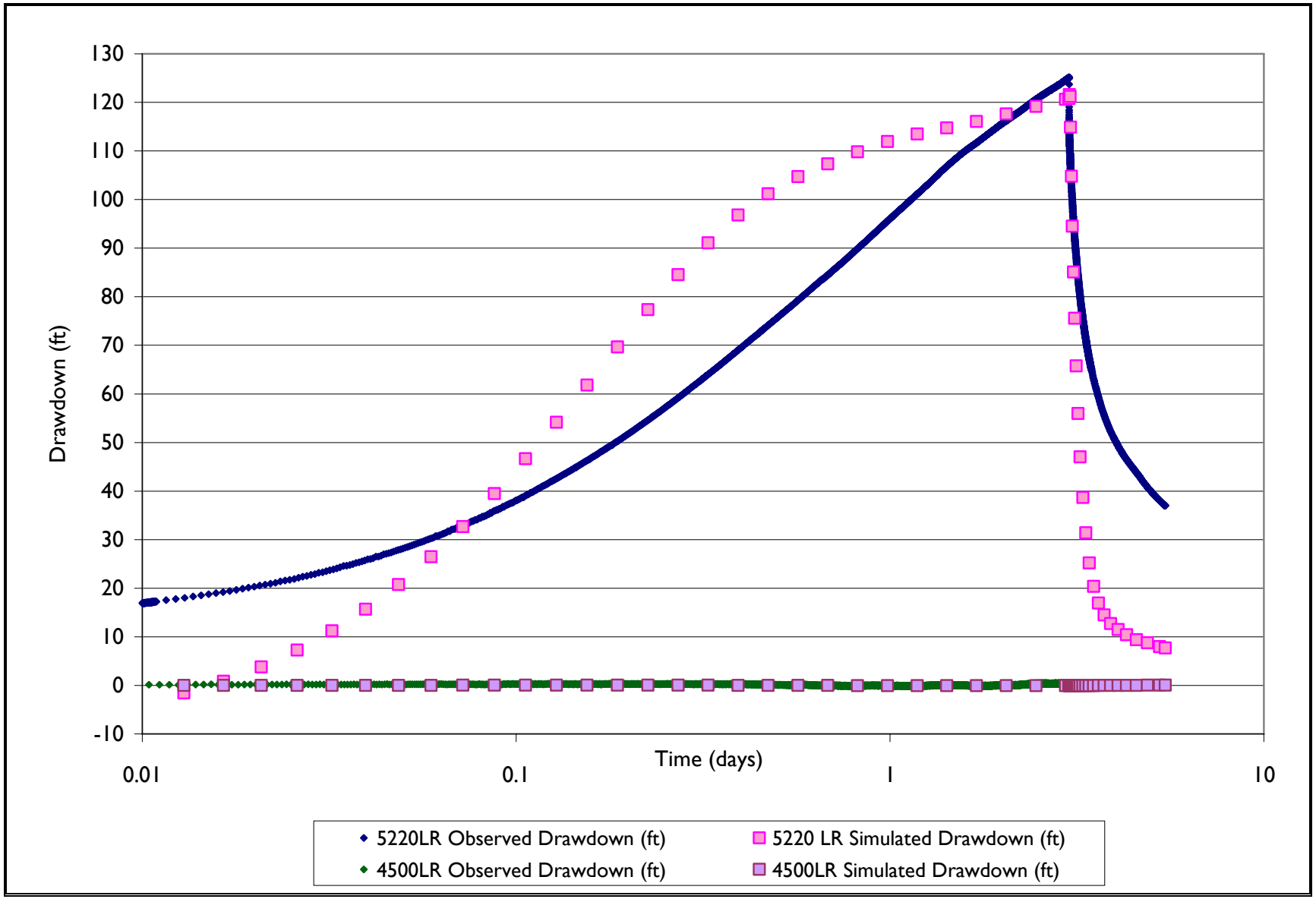


Figure 16. Simulated and Observed Drawdown at 5220LR and 4500LR during the Test of 5220LR

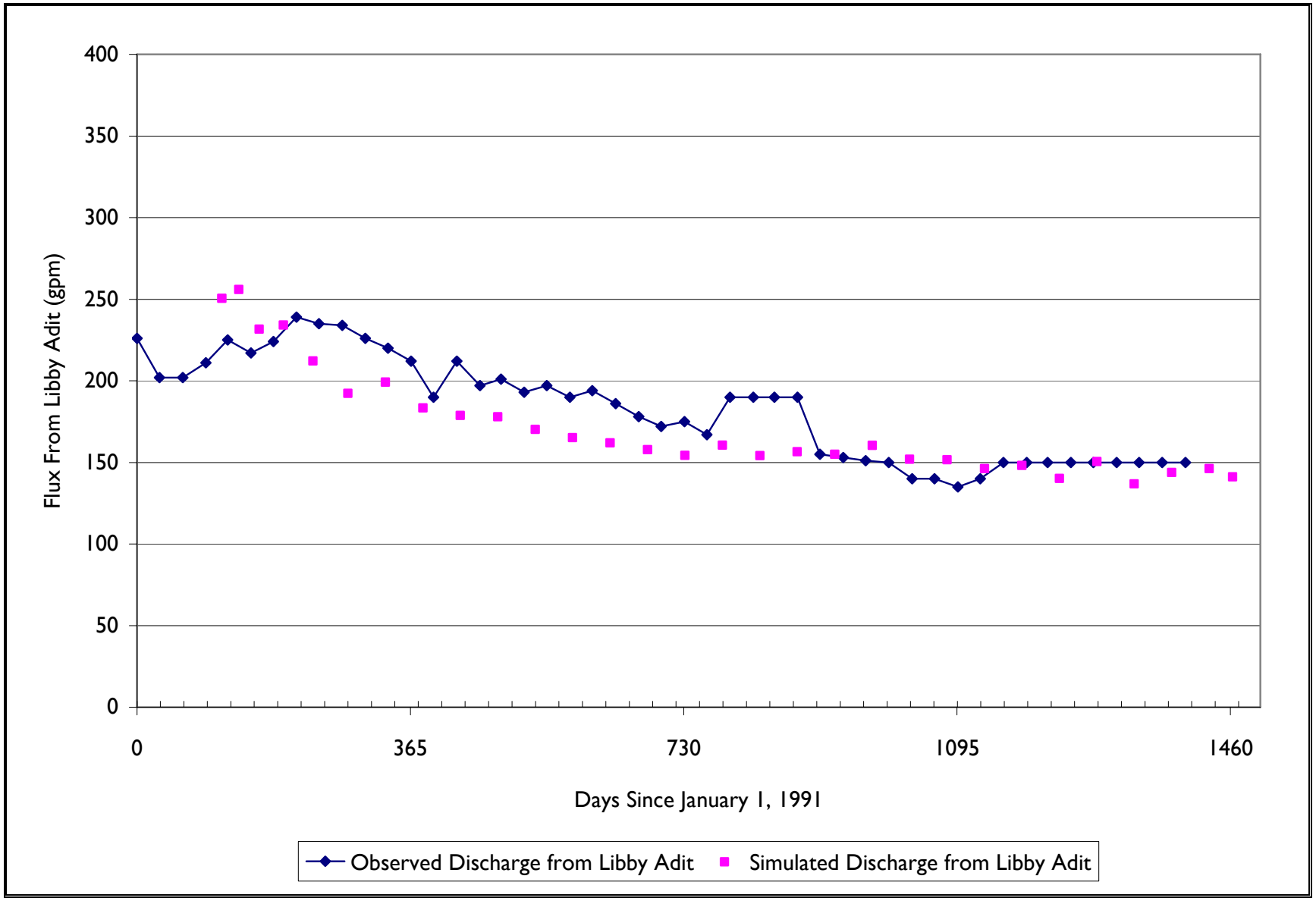
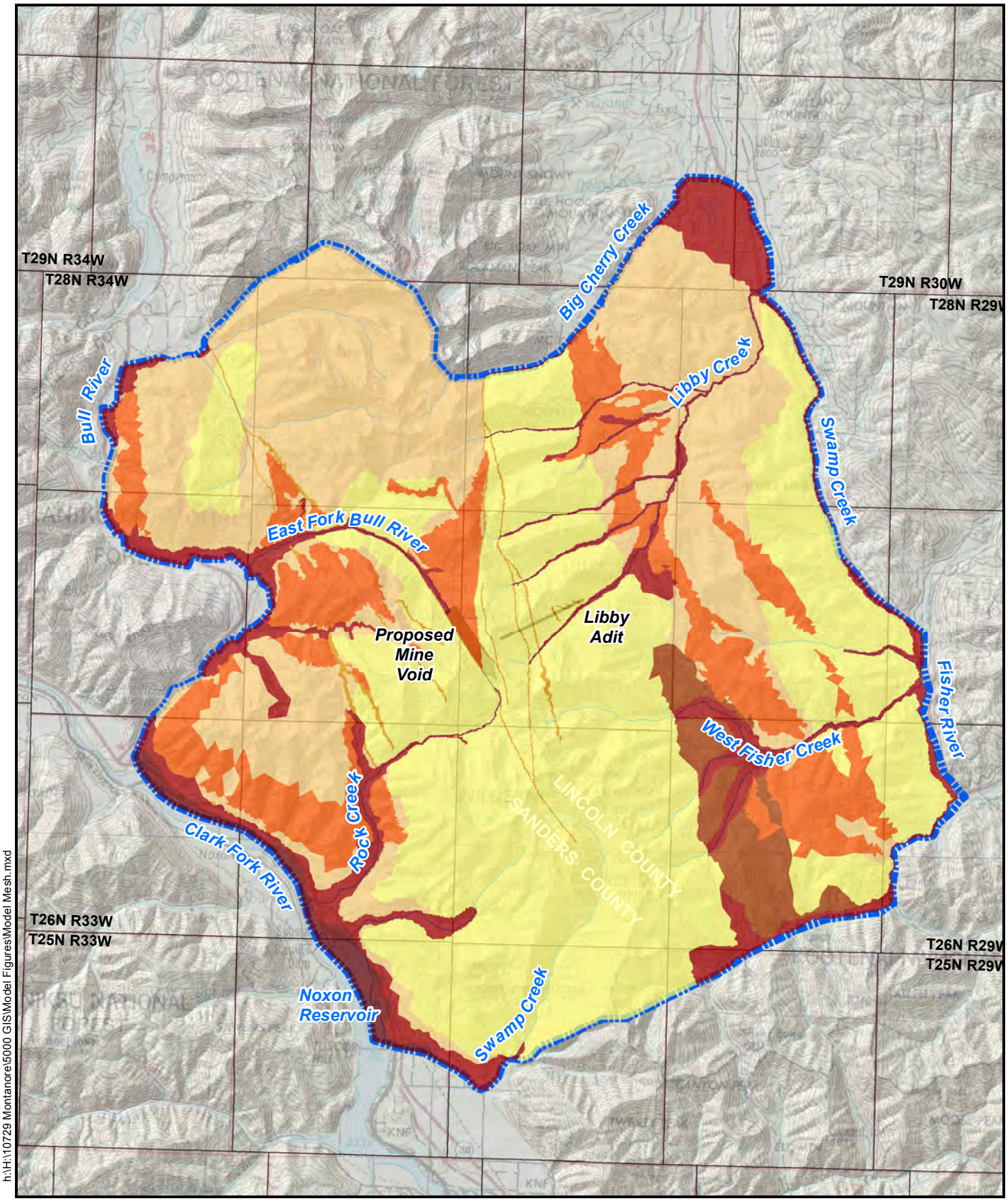


Figure 17. Simulated Discharge Rate to Maintain Dewatered Adit



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000 Feet

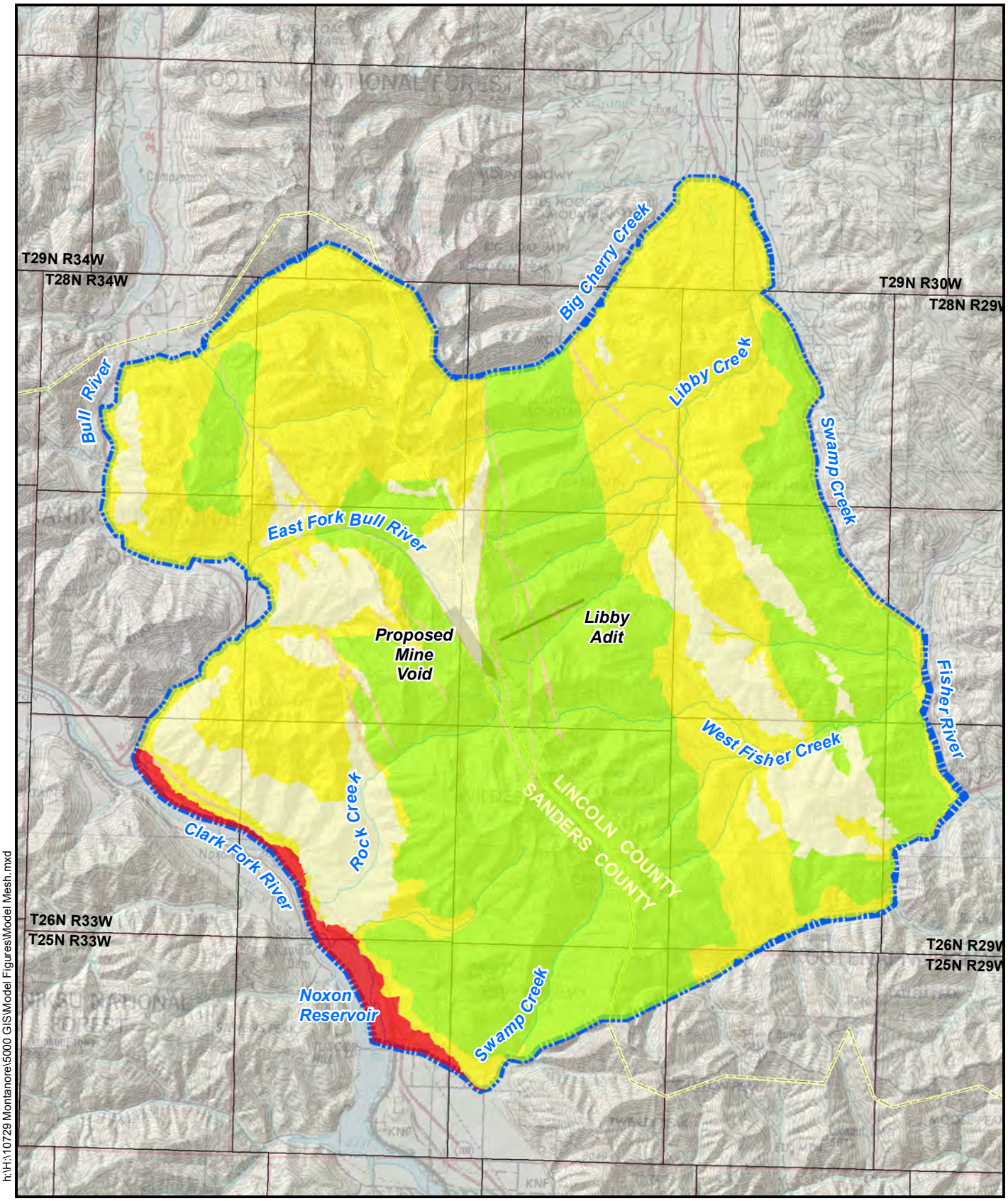
AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layer-1 (cm/s)

5E-05
1.5E-04
2E-04
4E-04
4.5E-04
5E-04
2E-03
1E-02

Hydraulic Conductivity Distribution Layer-1
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 18



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000 Feet

AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layer-2 (cm/s)

3E-06

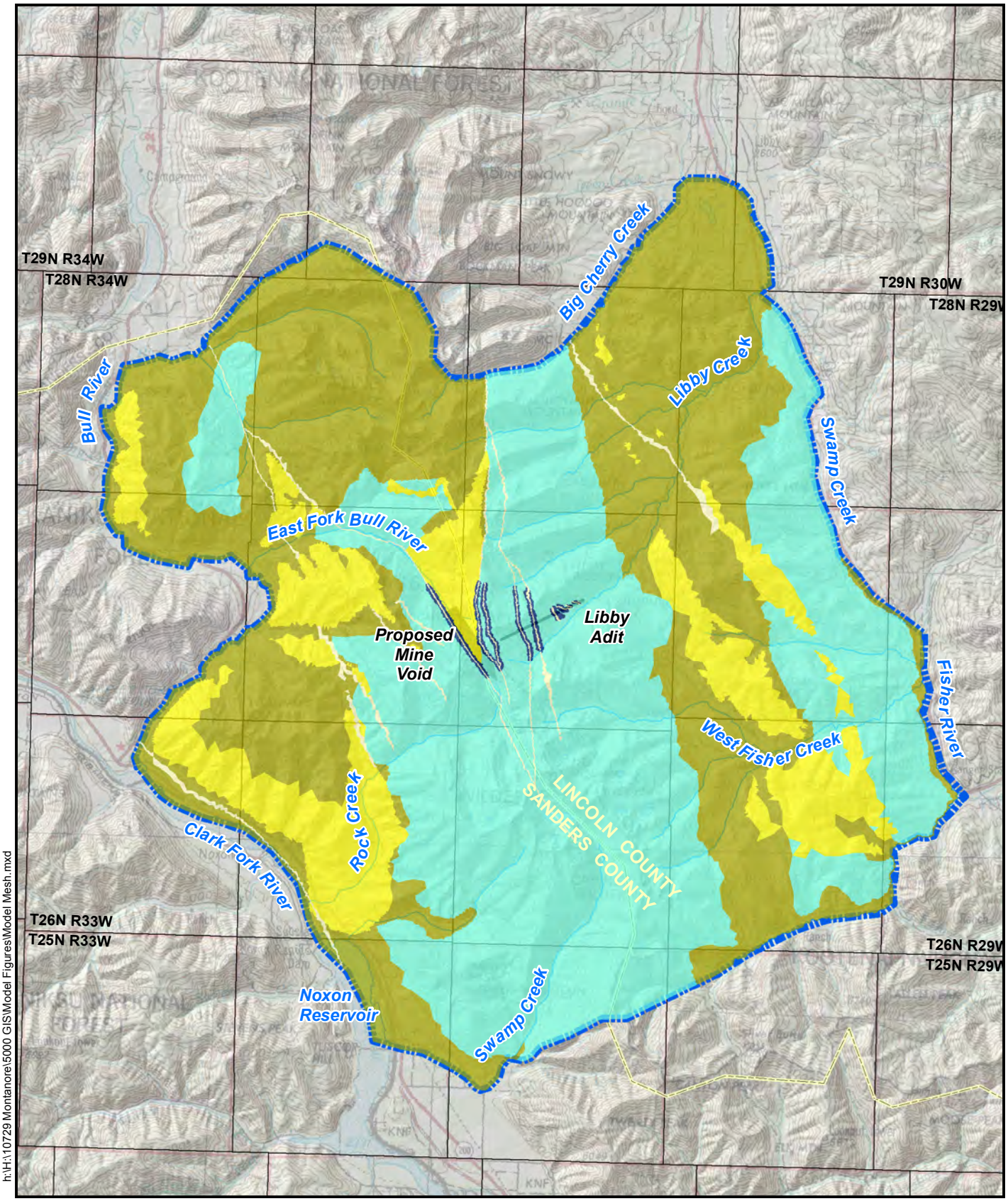
3E-05

9E-05

1.5E-04

6E-04

Hydraulic Conductivity Distribution Layer-2
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 19



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000 Feet

AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layer-3 (cm/s)

3E-08

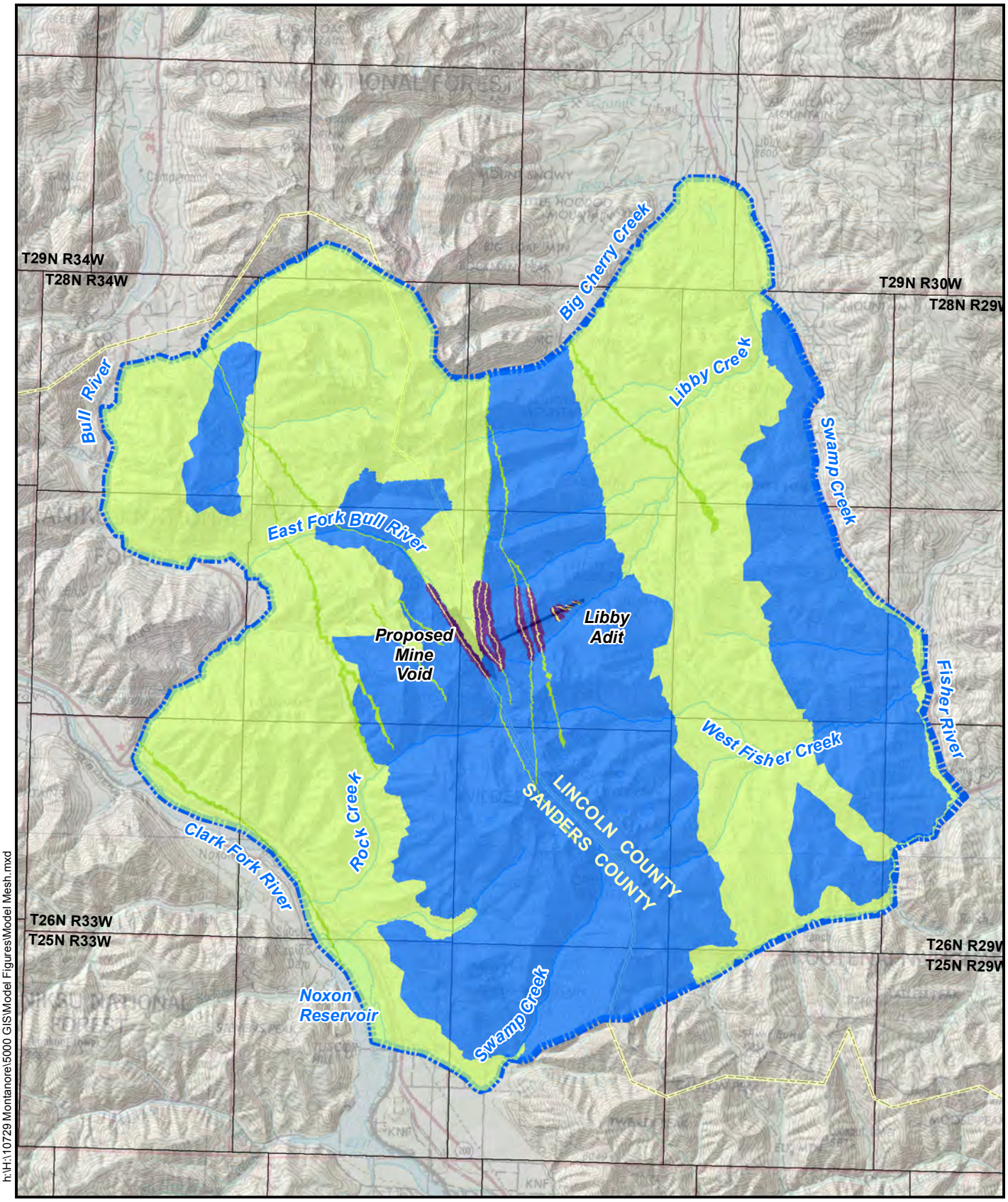
4E-07

1E-5

3E-05

1.2E-04

Hydraulic Conductivity Distribution Layer-3
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 20



Source: USGS 100K Montana Quadrangle

0 20,000 Feet

AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layer-4 (cm/s)

3E-09

9E-08

1E-06

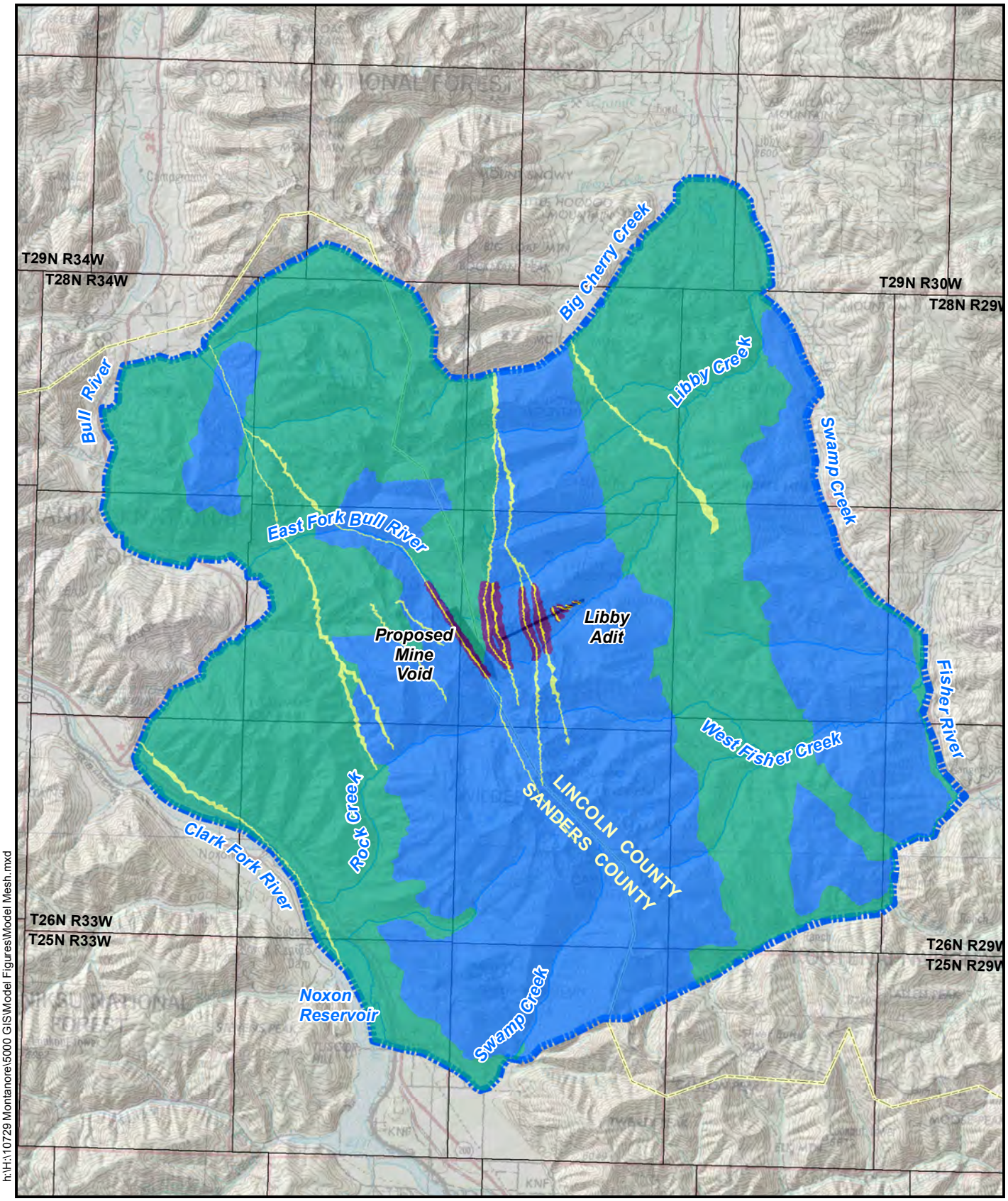
5E-06

1E-05

5E-05

Hydraulic Conductivity Distribution Layer-4
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 21

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000
Feet

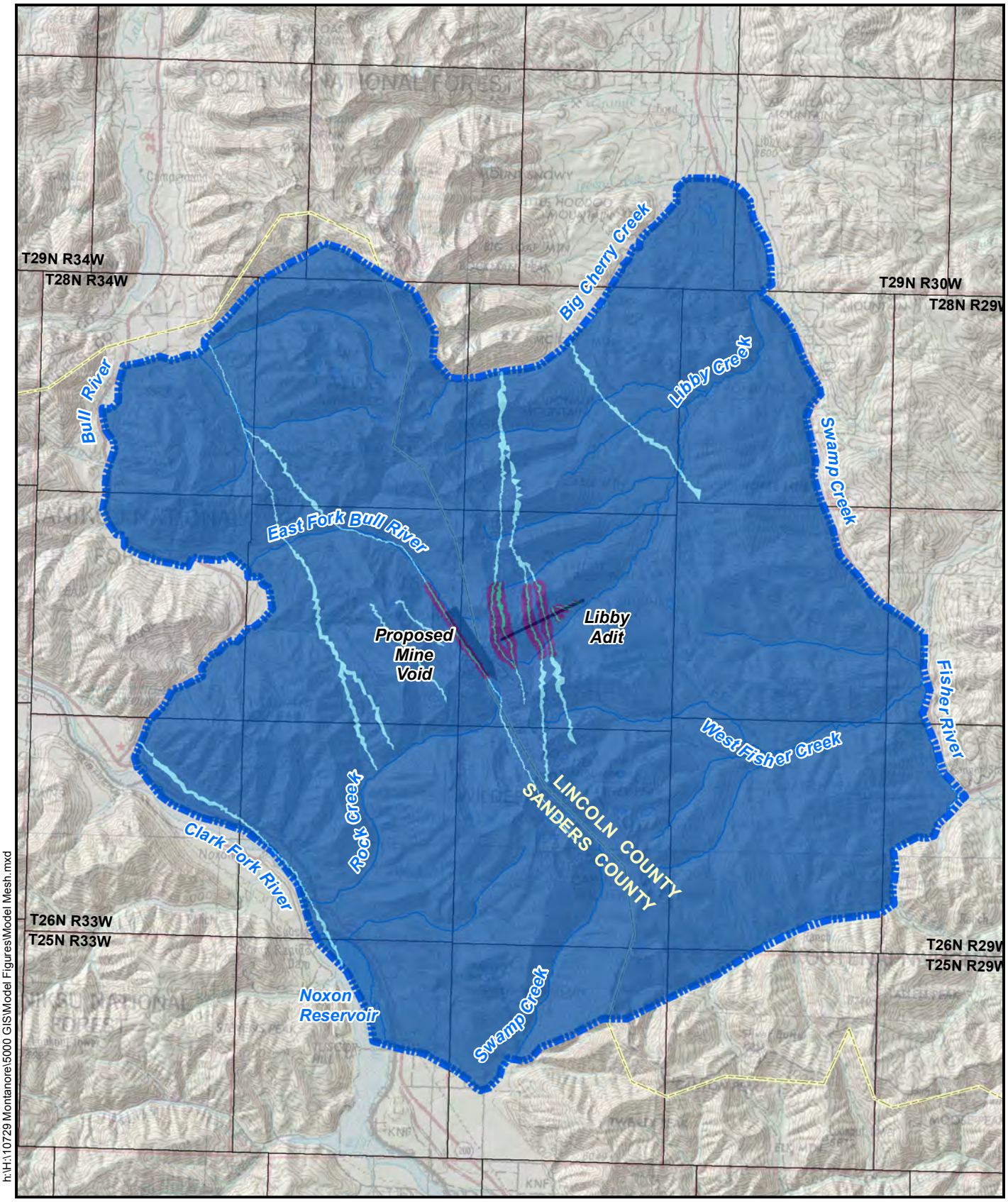
AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layer-5 (cm/s)

- 3E-09
- 9E-08
- 2E-07
- 1E-06
- 3E-05

Hydraulic Conductivity Distribution Layer-5
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 22



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\Model Mesh.mxd

0 20,000 Feet

AMEC Geomatrix

Study Area/Model Boundary

K Distribution Layers 6 & 7 (cm/s)

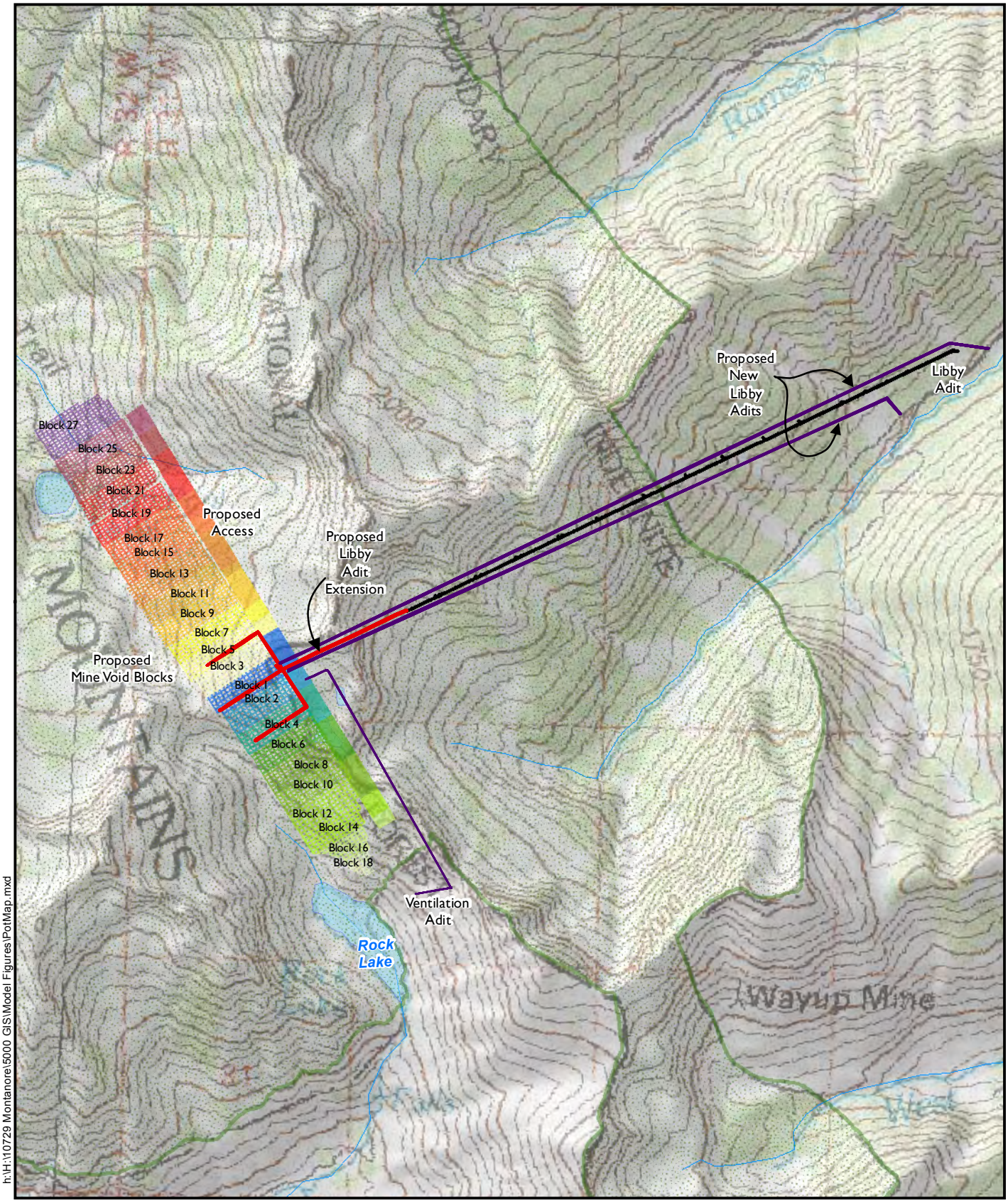
3E-09

6E-08

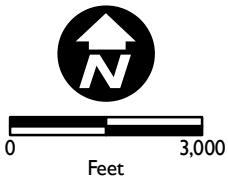
1E-07

2E-07

Hydraulic Conductivity Distribution Layers 6 & 7
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 23



Source: USGS 100K Montana Quadrangle



Cabinet Mountain Wilderness Area

AMEC Geomatrix

Simulated Mine Feature Locations
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 24

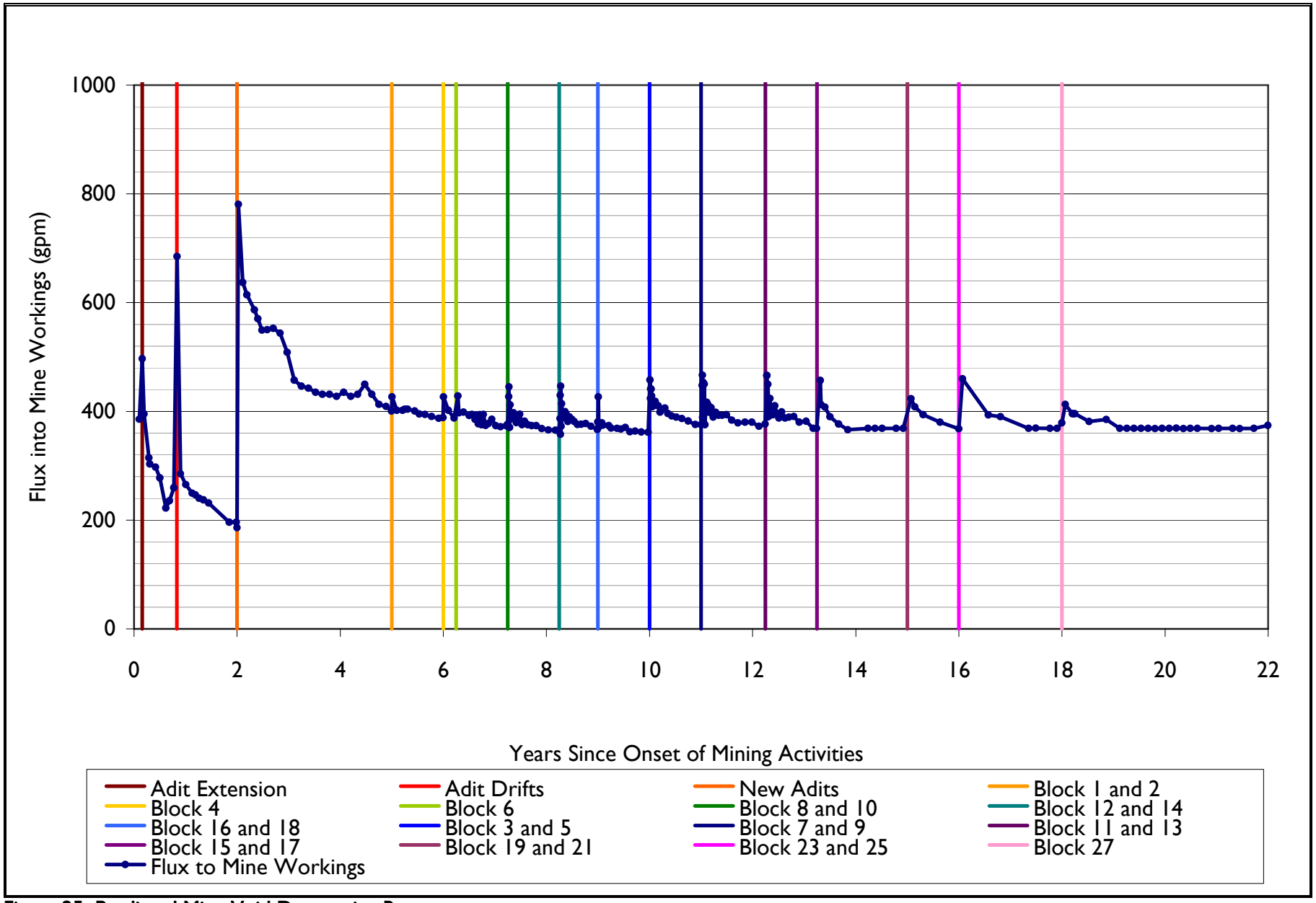
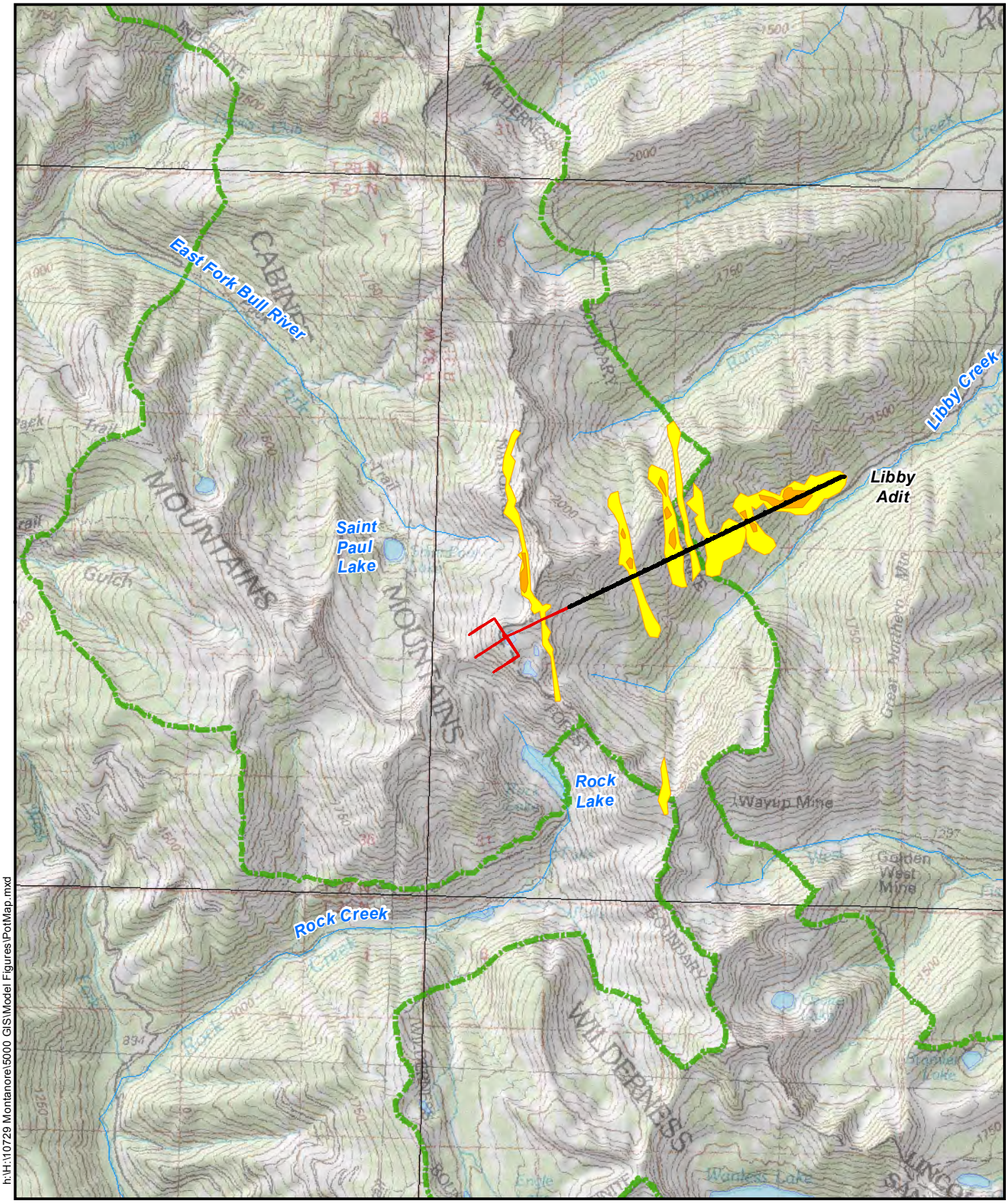


Figure 25 Predicted Mine Void Dewatering Rates.



Source: USGS 100K Montana Quadrangle

Proposed Libby Adit Expansion

Cabinet Mountain Wilderness Area

Greater than 10 ft Drawdown

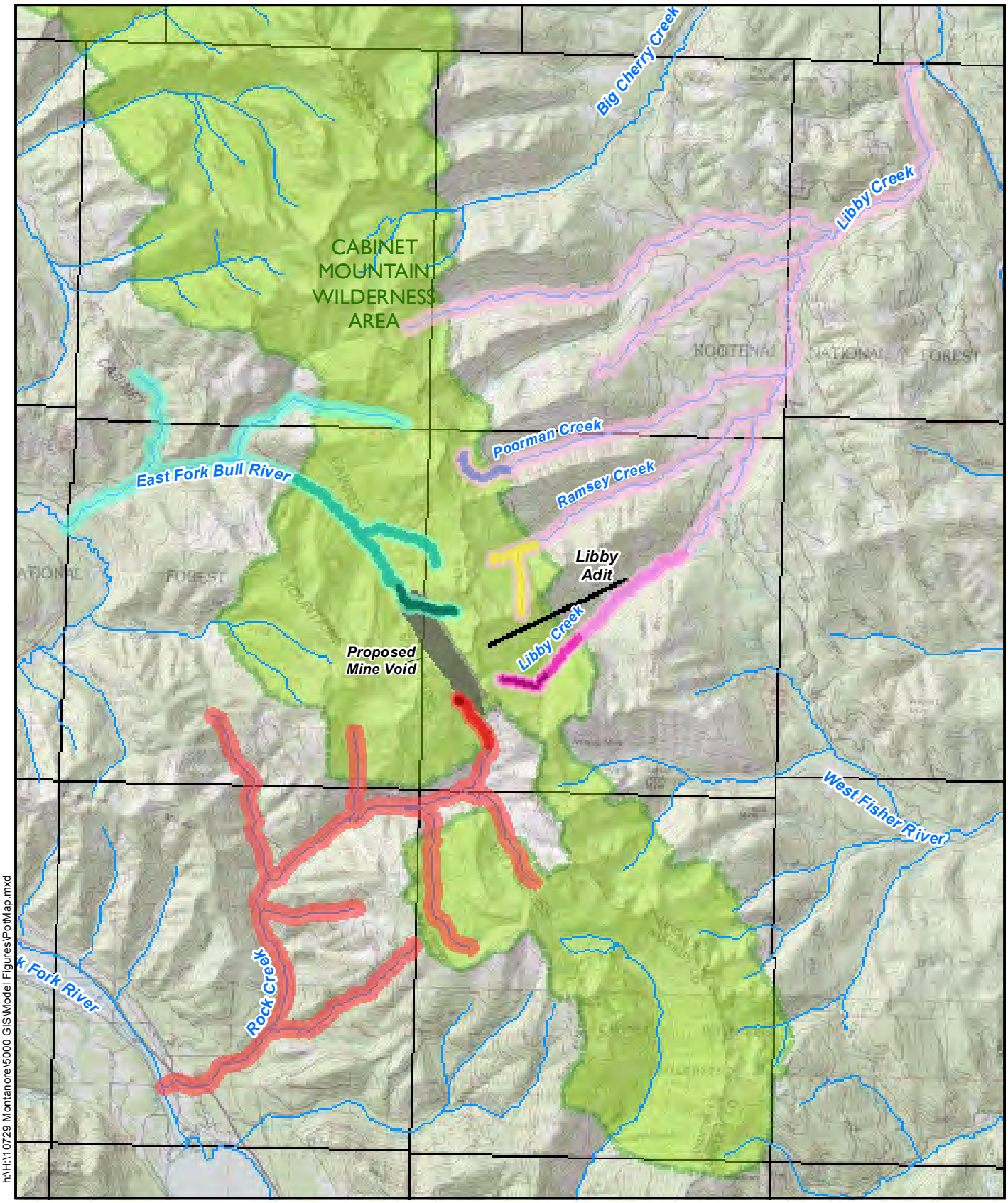
Greater than 100 ft Drawdown

0 6,000
Feet

AMEC Geomatrix

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

Water Table Drawdown
End of Exploration Phase
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 26



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

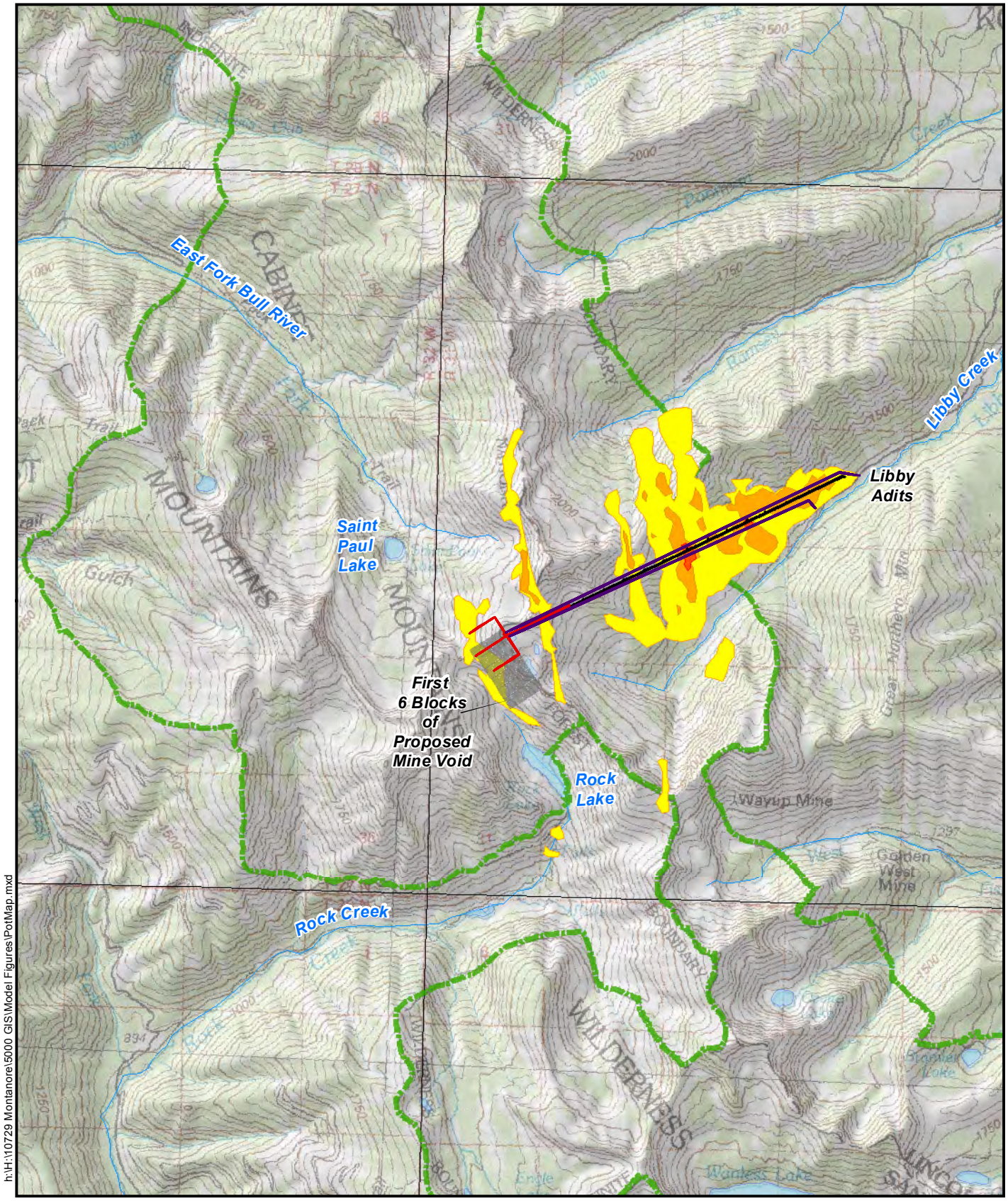
N

0 12,000
Feet

AMEC Geomatrix

- Libby Creek LB-50
- Poorman Creek at Wilderness Boundary
- Ramsey Creek at Wilderness Boundary
- Libby Creek at Wilderness Boundary
- Libby Creek LB-300
- Libby Creek
- East Fork Bull River EFBR-300
- East Fork Bull River at Wilderness
- East Fork Bull River
- Rock Creek EFRC-50
- Rock Creek at Wilderness Boundary
- Rock Creek

Reporting Regions for Groundwater Contribution to SurfaceWater
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 27



h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

Source: USGS 100K Montana Quadrangle

Proposed Libby Adit Expansion

Cabinet Mountain Wilderness Area

Greater than 10 ft Drawdown

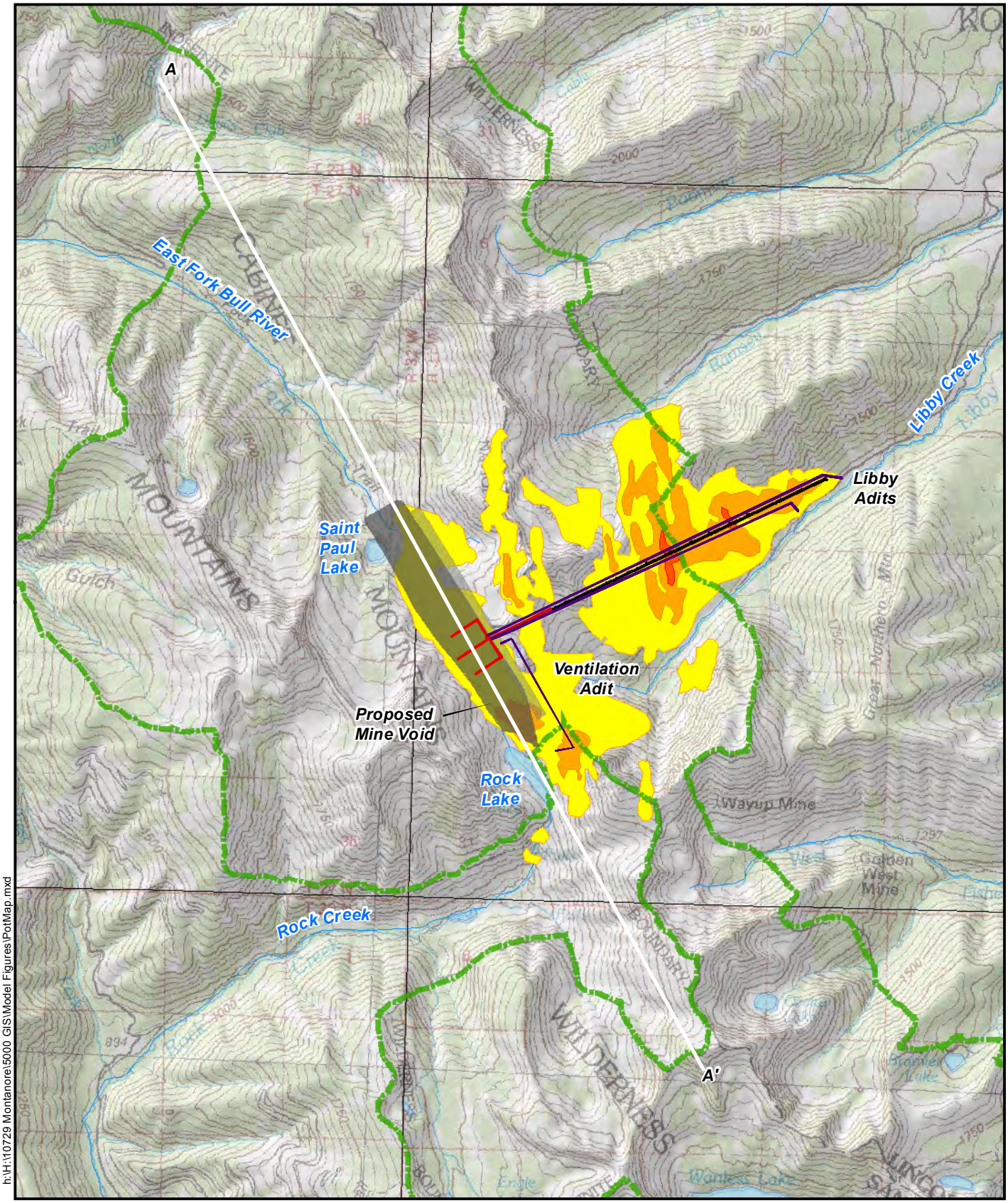
Greater than 100 ft Drawdown

Greater than 500 ft Drawdown

0 6,000 Feet

AMEC Geomatrix

Water Table Drawdown
End of Construction Plus 3 Years of Mining
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 28



h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

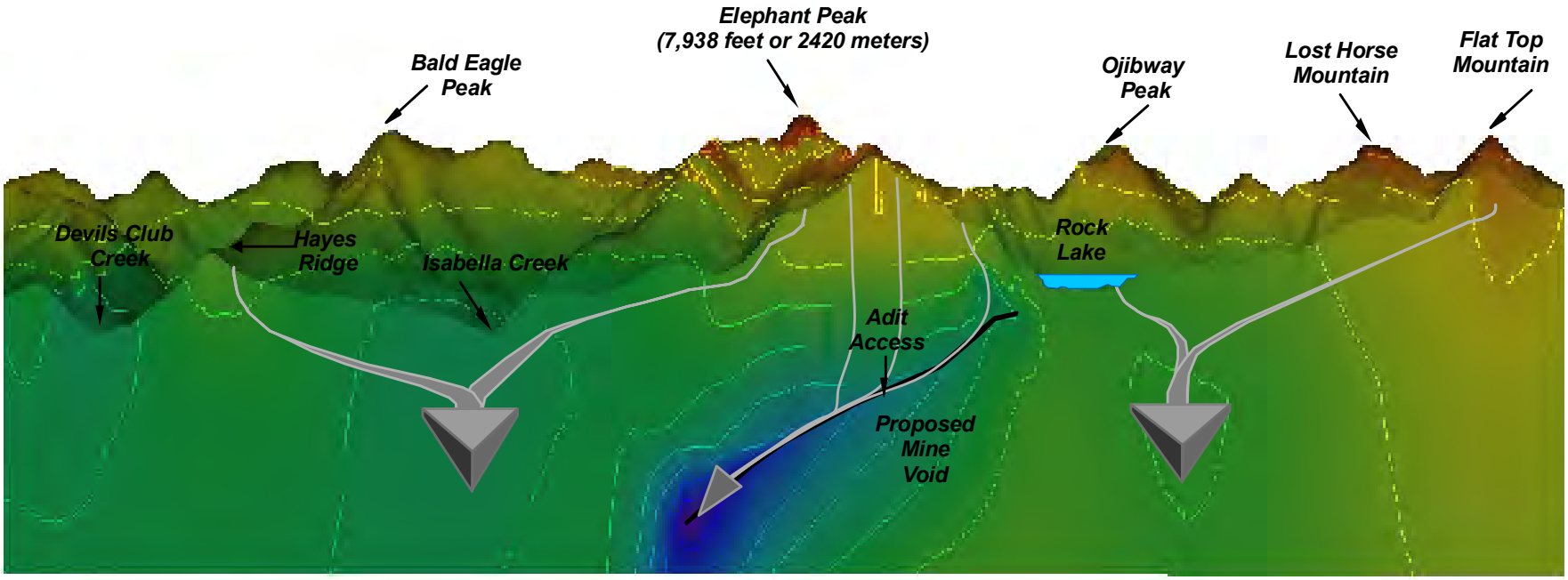
Source: USGS 100K Montana Quadrangle

0 6,000
Feet

AMEC Geomatrix

Proposed Libby Adit Expansion
Cabinet Mountain Wilderness Area
Greater than 10 ft Drawdown
Greater than 100 ft Drawdown
Greater than 500 ft Drawdown

Water Table Drawdown
End of Mining
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 29



Vertical Exaggeration - 1"=2750'

0 5500
Feet

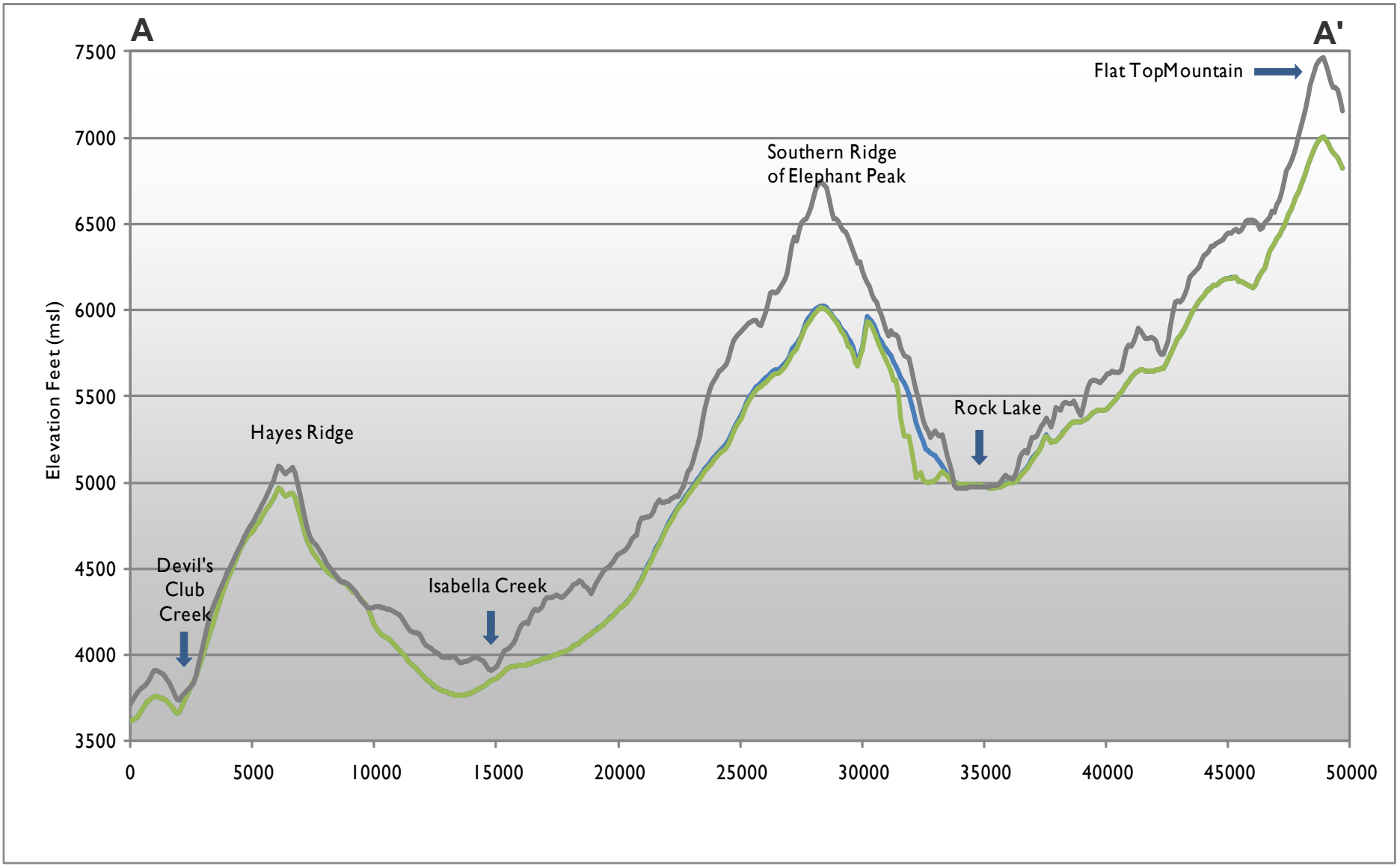
Direction of Groundwater Flow

Potentiometric Head (ft msl)

7440	4960	2480
6820	4340	1860
6200	3720	1240
5580	3100	620

AMEC Geomatrix

Potentiometric Cross Section End of Mining
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 30



Water Table at End of Mining

Pre Mine Water Table

AMEC Geomatrix

Water Table Pre Mining and At the End of Mining
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 31

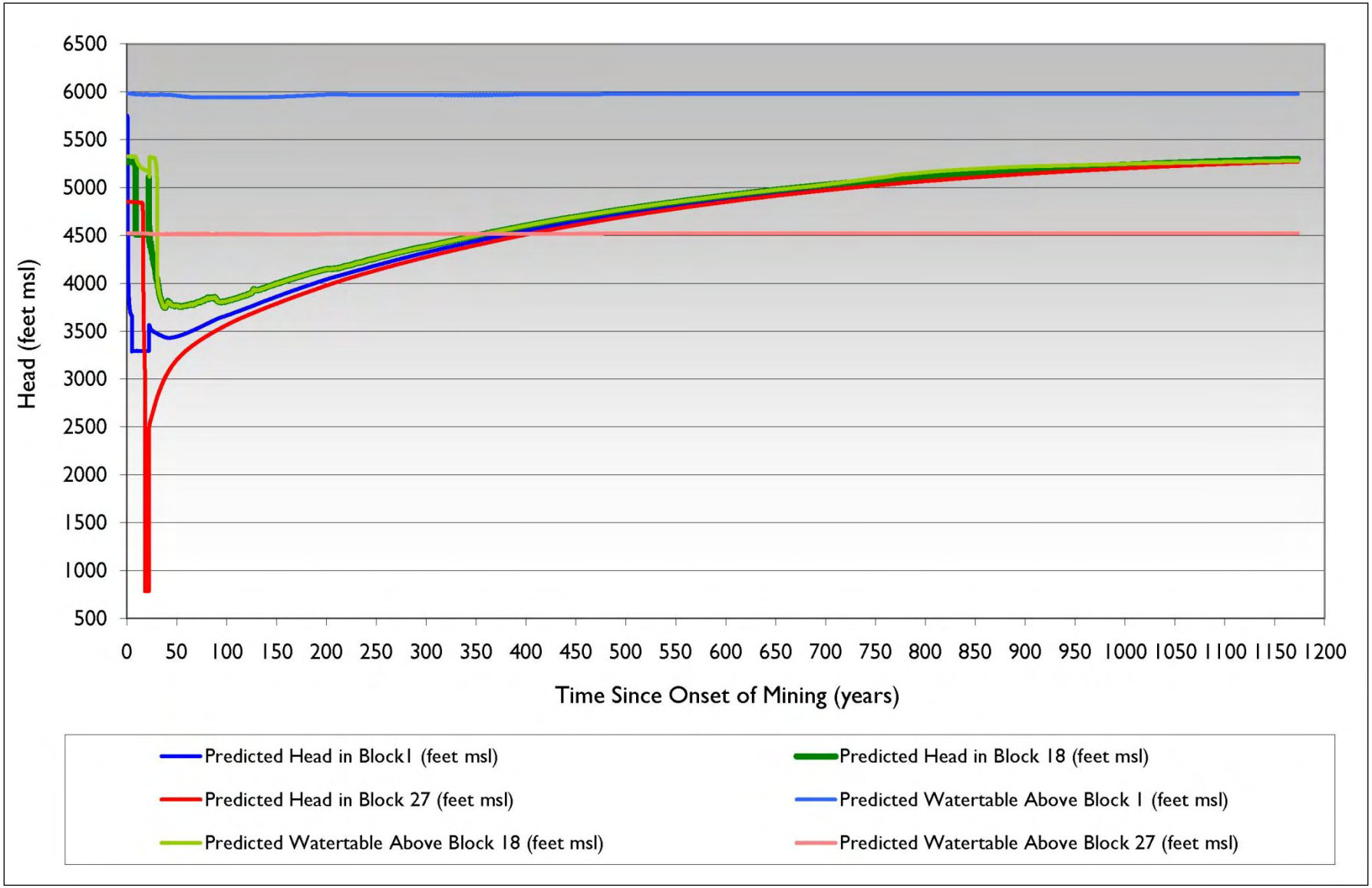
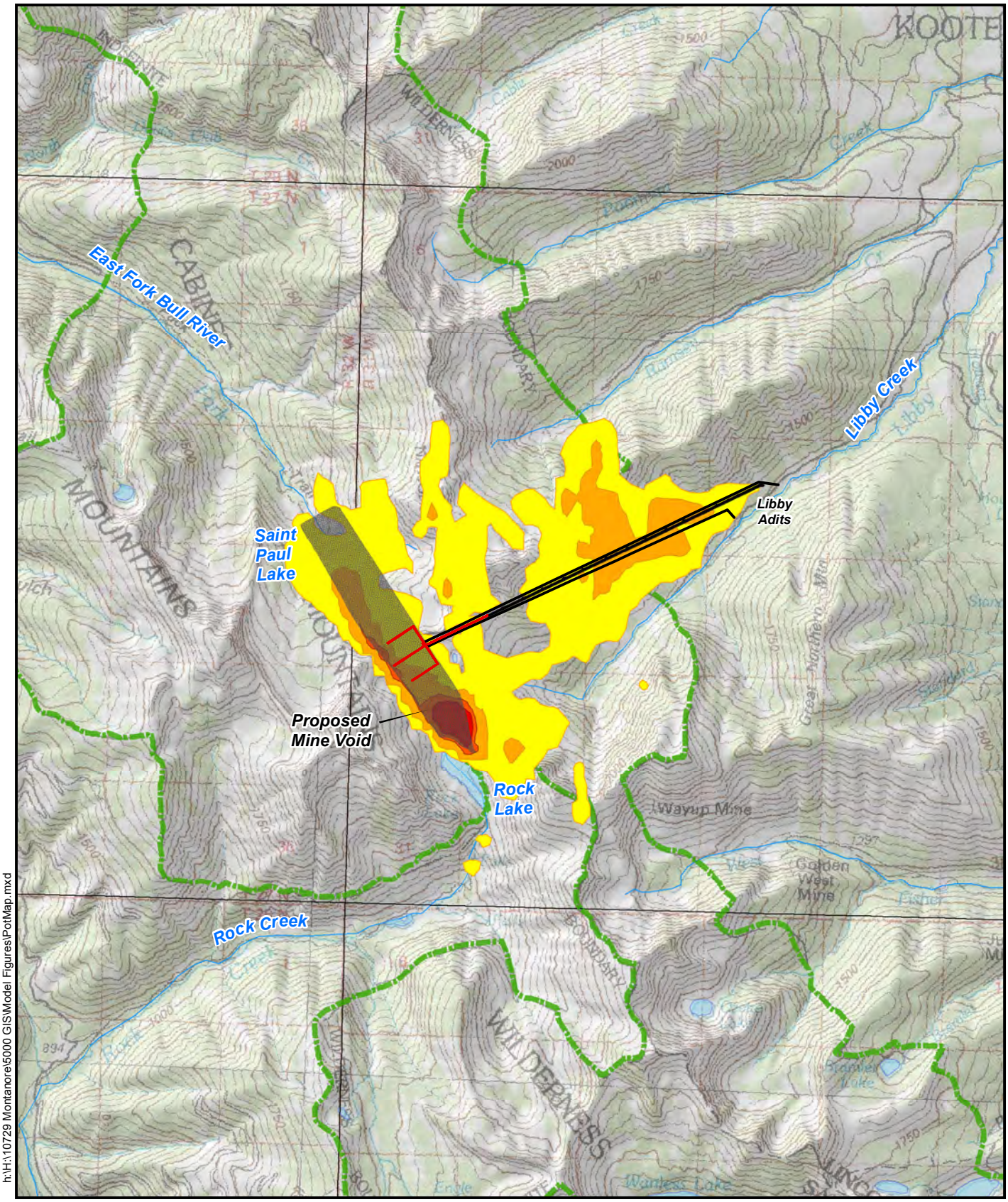


Figure 32. Predicted Hydrographs During Mining and Recovery



Source: USGS 100K Montana Quadrangle

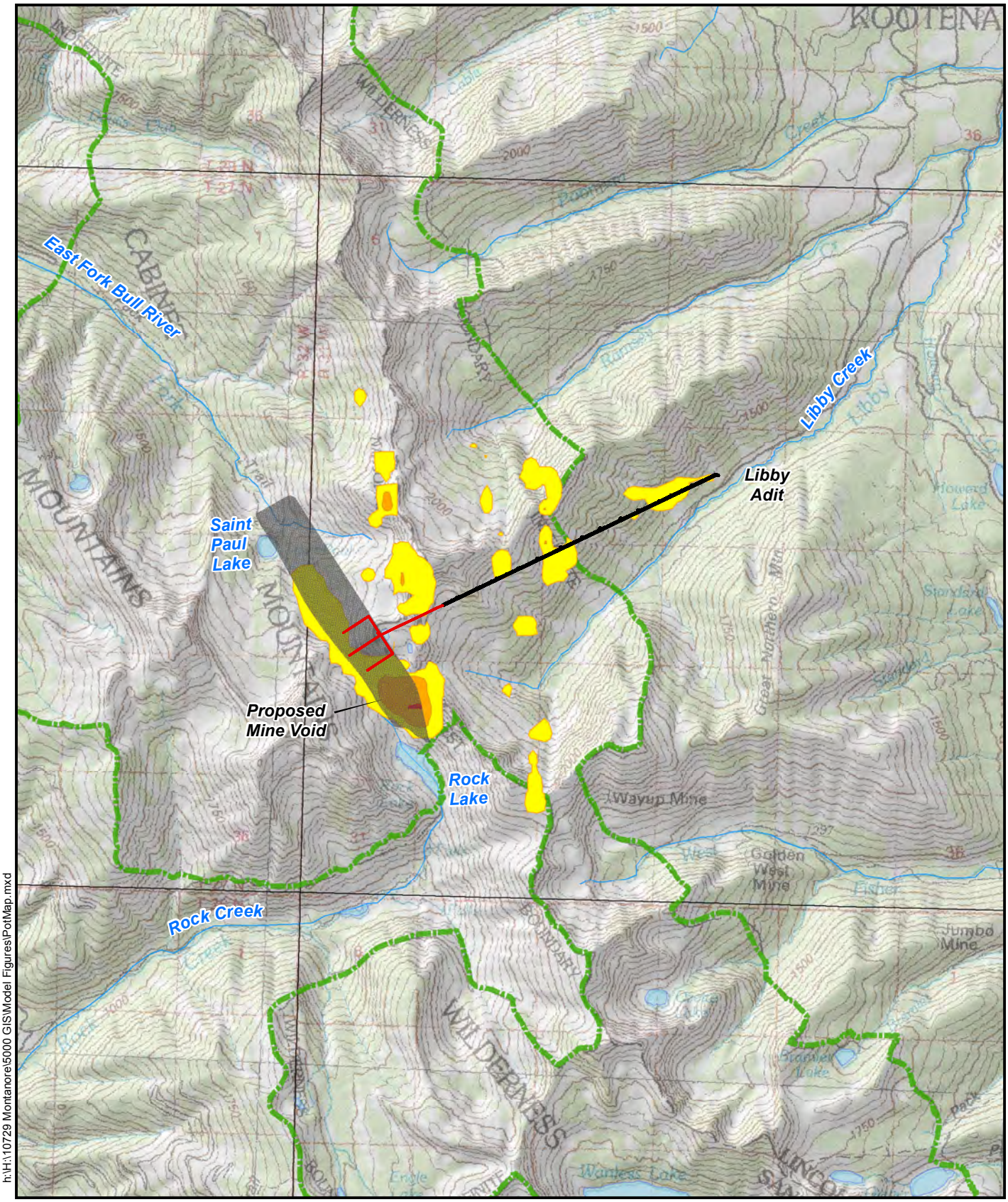
0 6,000 Feet

AMEC Geomatrix

- Cabinet Mountain Wilderness Area
- Greater than 10 ft Drawdown
- Greater than 100 ft Drawdown
- Greater than 500 ft Drawdown
- Greater than 1000 ft Drawdown

Water Table Drawdown
16 years Post Mining
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 33

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd



Source: USGS 100K Montana Quadrangle

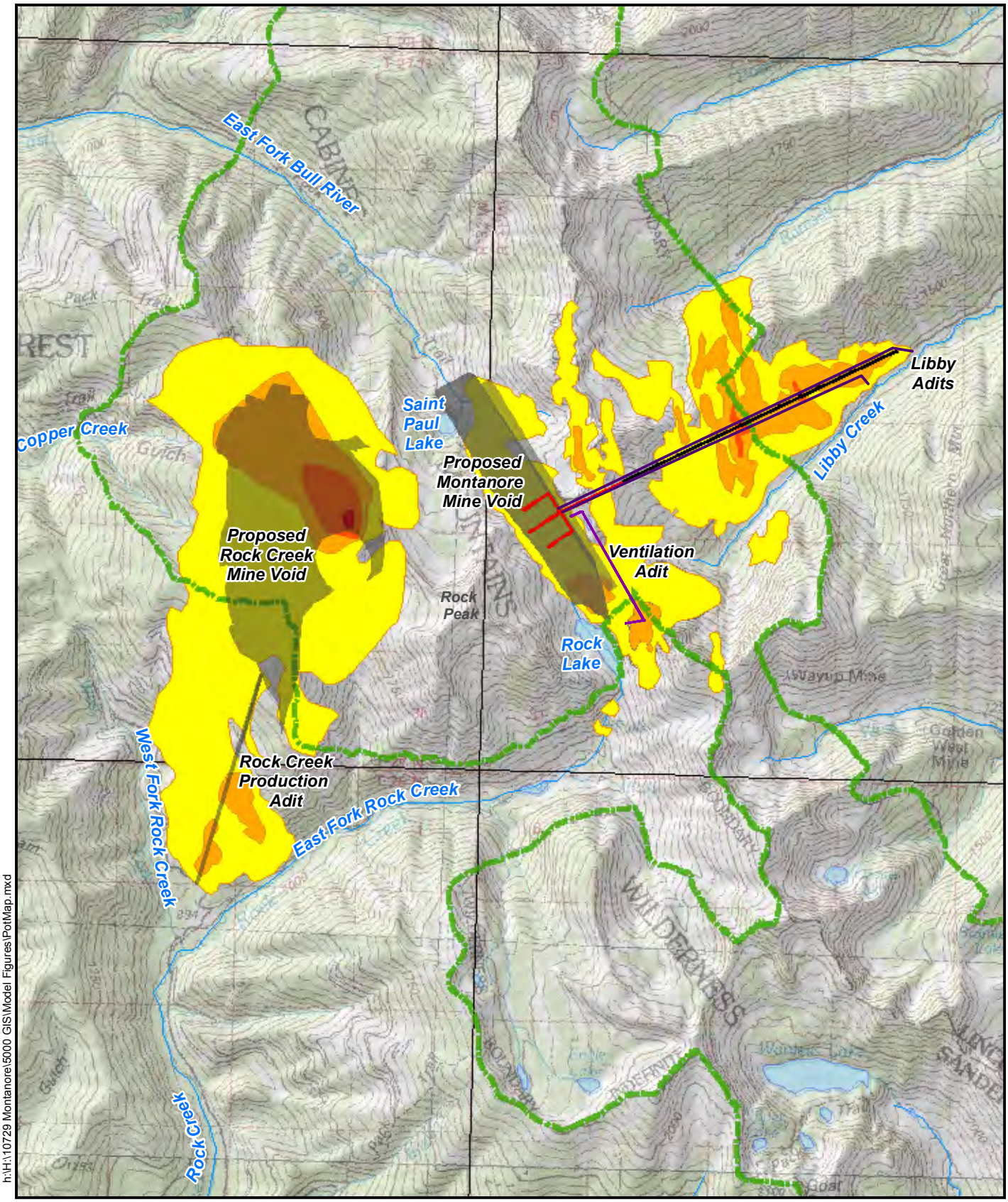
0 6,000
Feet

AMEC Geomatrix

Proposed Libby Adit Expansion
Cabinet Mountain Wilderness Area
Greater than 10 ft Drawdown
Greater than 100 ft Drawdown
Greater than 500 ft Drawdown

Residual Water Table Drawdown Following Recovery
(1150 years after end of mining)
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 34

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

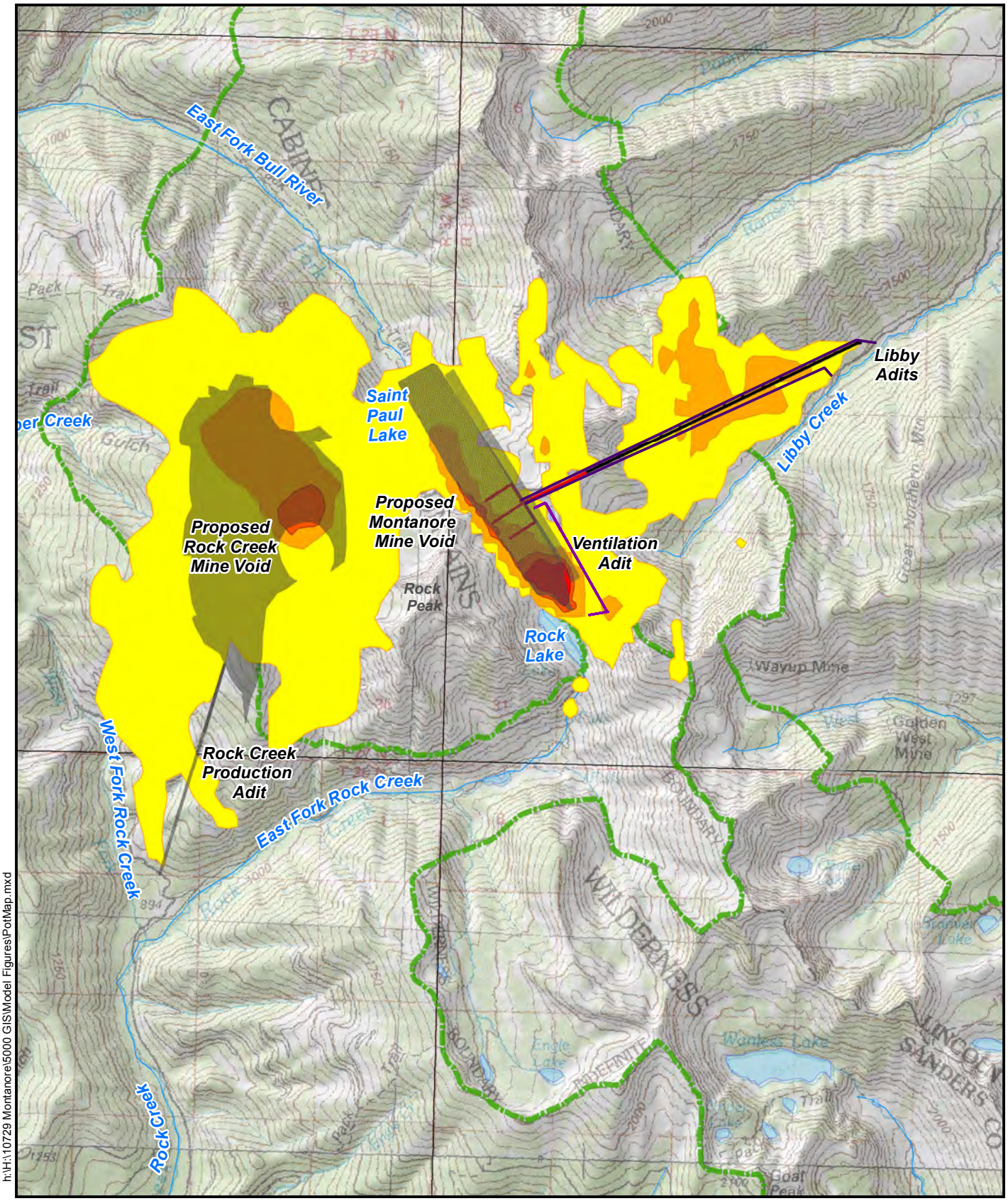
N

0 6,000
Feet

AMEC Geomatrix

Proposed Libby Adit Expansion
Cabinet Mountain Wilderness Area
Greater than 10 ft Drawdown
Greater than 100 ft Drawdown
Greater than 500 ft Drawdown
Greater than 1000 ft Drawdown

Cumulative Water Table Drawdown
End of Mining at Montanore and Rock Creek
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 35



Source: USGS 100K Montana Quadrangle

h:\H:\10729 Montanore\5000 GIS\Model Figures\PotMap.mxd

0 6,000
Feet

AMEC Geomatrix

- Cabinet Mountain Wilderness Area
- Greater than 10 ft Drawdown
- Greater than 100 ft Drawdown
- Greater than 500 ft Drawdown
- Greater than 1000 ft Drawdown

Cumulative Water Table Drawdown
16 Years Post Mining at Montanore and Rock Creek
Montanore Groundwater Model
Lincoln and Sanders Counties, Montana
FIGURE 36

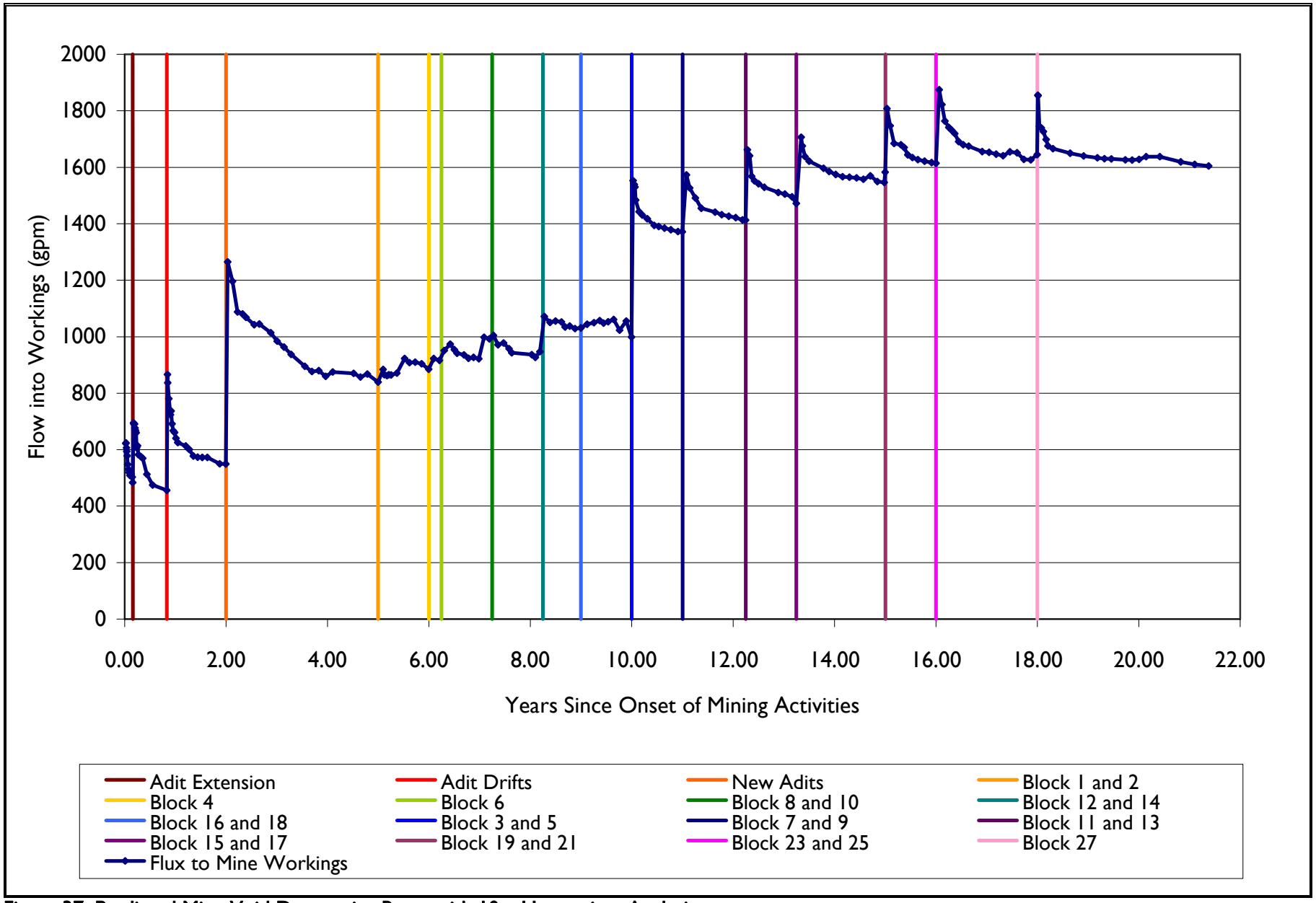


Figure 37 Predicted Mine Void Dewatering Rates with 10 x Uncertainty Analysis .

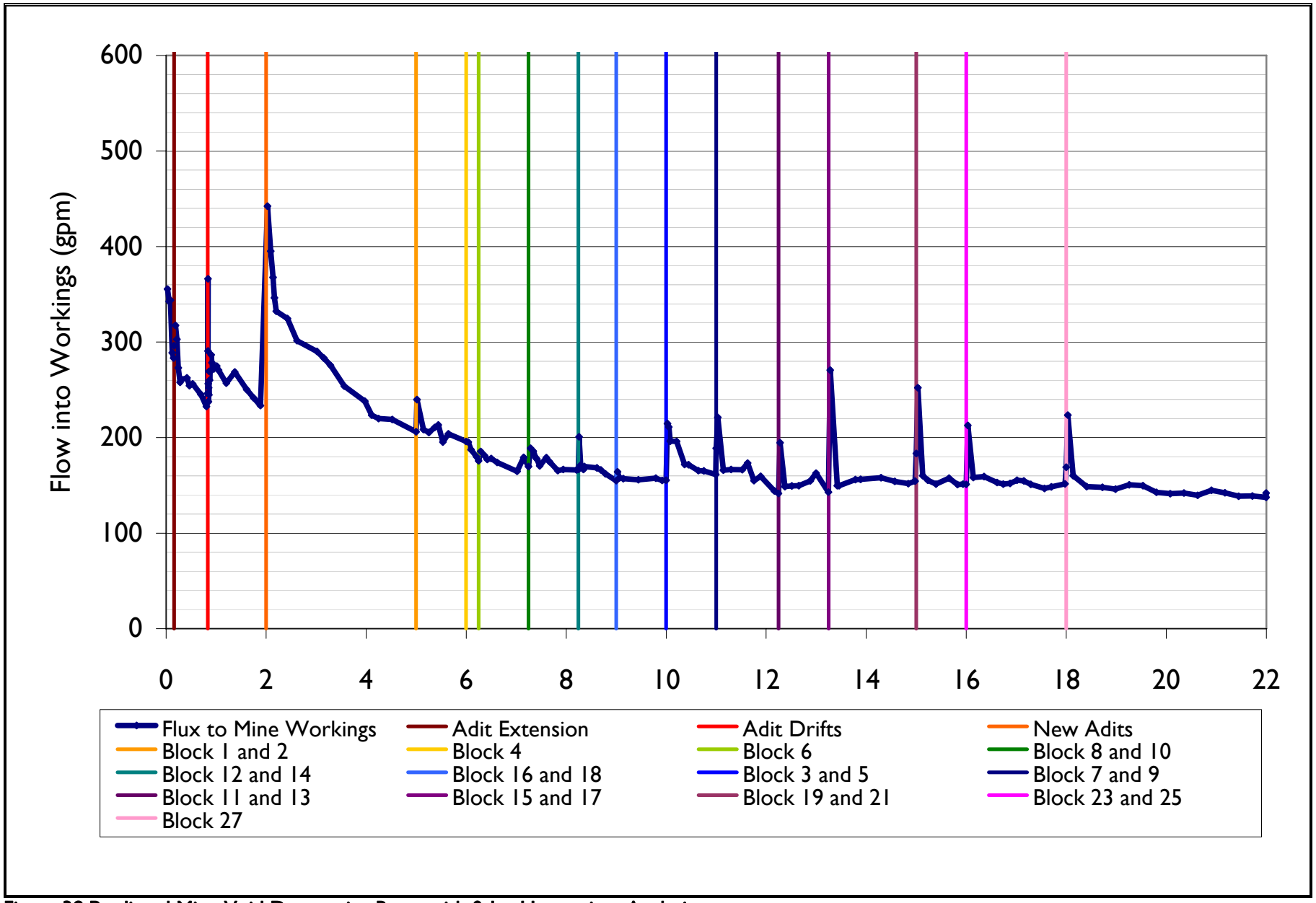


Figure 38 Predicted Mine Void Dewatering Rates with 0.1 x Uncertainty Analysis .

APPENDIX B

HISTORIC LIBBY ADIT DATA

MPL-03-04

Noranda Minerals Corp.

MONTANORE PROJECT

January 6, 1992

MEMO TO: Mark Petersmeyer

FROM: Tony Adkins

cc: Denise Saunders
John Stoiazzo
Doug Parker

SUBJECT: **Recent Hydrohole Drilling Results**

Pursuant to your request in mid-December for additional hydroholes in the decline, ten holes were drilled into water-bearing zones by Gilbert/Dynatec crews between 27 Dec 91 and 4 Jan 92. Eight of the holes are listed in my 20 Dec 91 letter to Jim Morris, with remaining two located late in the program. The program had two objectives: 1) investigate a number of the water-bearing zones in the decline for hydrologic characteristi and 2) to discover good water sources for potential mine water dilution.

To summarize the results; two holes hit appreciable water inflows (180 gpm total), two hole hit minor amounts of water (16 gpm total), and six of the holes were dry. The two high gpm holes were flow tested for a minimum of one hour. Total new water inflow available is about 196 gpm. All the holes were drilled into fault and/or fracture zones. Two holes were abandoned well before reaching their slated T.D. because of stuck drill steel. The individual hole results are listed below:

Table 1: Results of the Hydrohole Drilling

Location (RR=Rt Rib) (LR=Lft Rib)	Bearing (Grid North)	Angle (Deg)	T.D. (Ft)	Target	H2O Inflow (gpm)/PSI
PR+3590 RR	N76W	+10	92	fault/frac.	60/100
MB+5300 RR*	N45E	+5	132	fault	120/160
PR+7945 LR	S85E	+5	104	fault	8/NA
PR+8005 RR	N53E	+10	168	fault	0
PR+8953 RR	N49E	+1	108	fault	0
PR+9300 RR	N50E	+15	84	fault	0
PR+9343 LR	S48W	+10	108	fault/frac.	0

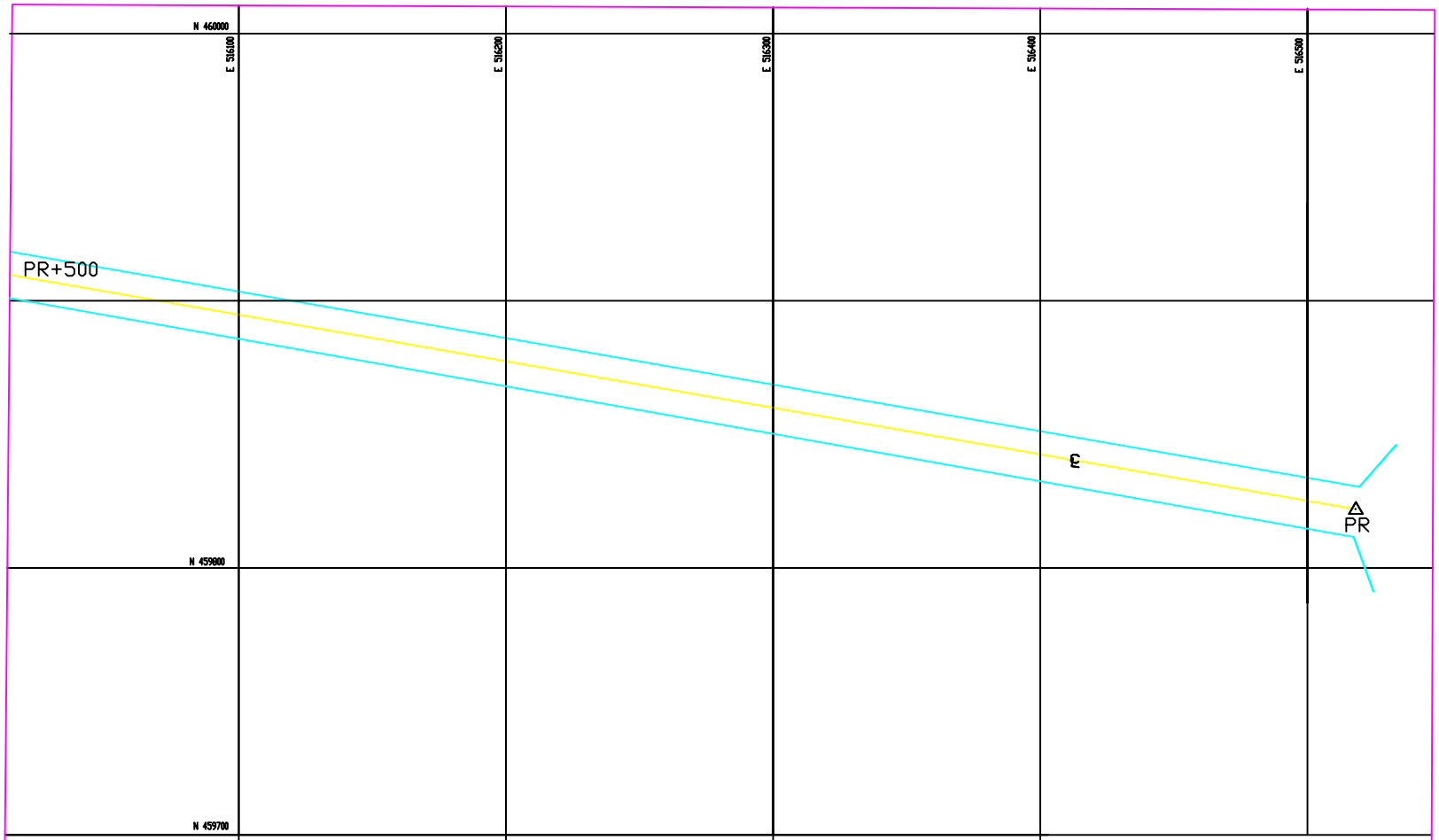
PR+9520 RR	S80W	+5	96 (orig. T.D. @ 140,stuck steel @ 96)	fault	8/250
PR+10843	N54E	+5	156	fractures	0
PR+12800	N51E	+5	118 (orig. T.D. @ 150, stuck steel @ 118)	fault/frac.	0
Totals:10 Holes	------	----	1,166 ft	---------	196gpm/ ---
* Offset hole from WI-3 (approx. 40 gpm @ 165 psi)					

It's interesting to note that several of the holes (ie. PR+7945, PR+8005 & PR+9300), designed to penetrate discrete zones with substantial water inflows, failed to yield significant amounts of water. What appears to be happening is that the within each particular zone, water conduits have developed, either in response to superimposed fracture patterns, or defined by conditions unique to the individual zones. The conduits may have been further modified by lithostatic loading or tectonic forces.

According to this hypotheses, if the decline penetration of a water-bearing zone coincided with a water course, the decline made water. However, a probe hole drilled into the zone 50 or 60 feet adjacent to the decline would be dry if it did not hit either the same or another water course. This would explain why the decline occasionally went through damp, broken ground that looked like it should have presented a water problem. Supporting evidence comes from the MB+5300 hydrohole drilled this last go-round. This hole, which made 120 gpm, is an offset of WI-3 (40 gpm). The MB+5300 hole hit the water-bearing target zone about 30 feet north of the WI-3 piercepoint. Flow testing done on the two holes indicated that there was a slight but detectable level of communication between them. I think the MB+5300 hole hit the same water-course, but in a more permeable area.

There may be other explanations as to why a dry probe hole can be drilled into a water-bearing zone, but the above seems quite valid.

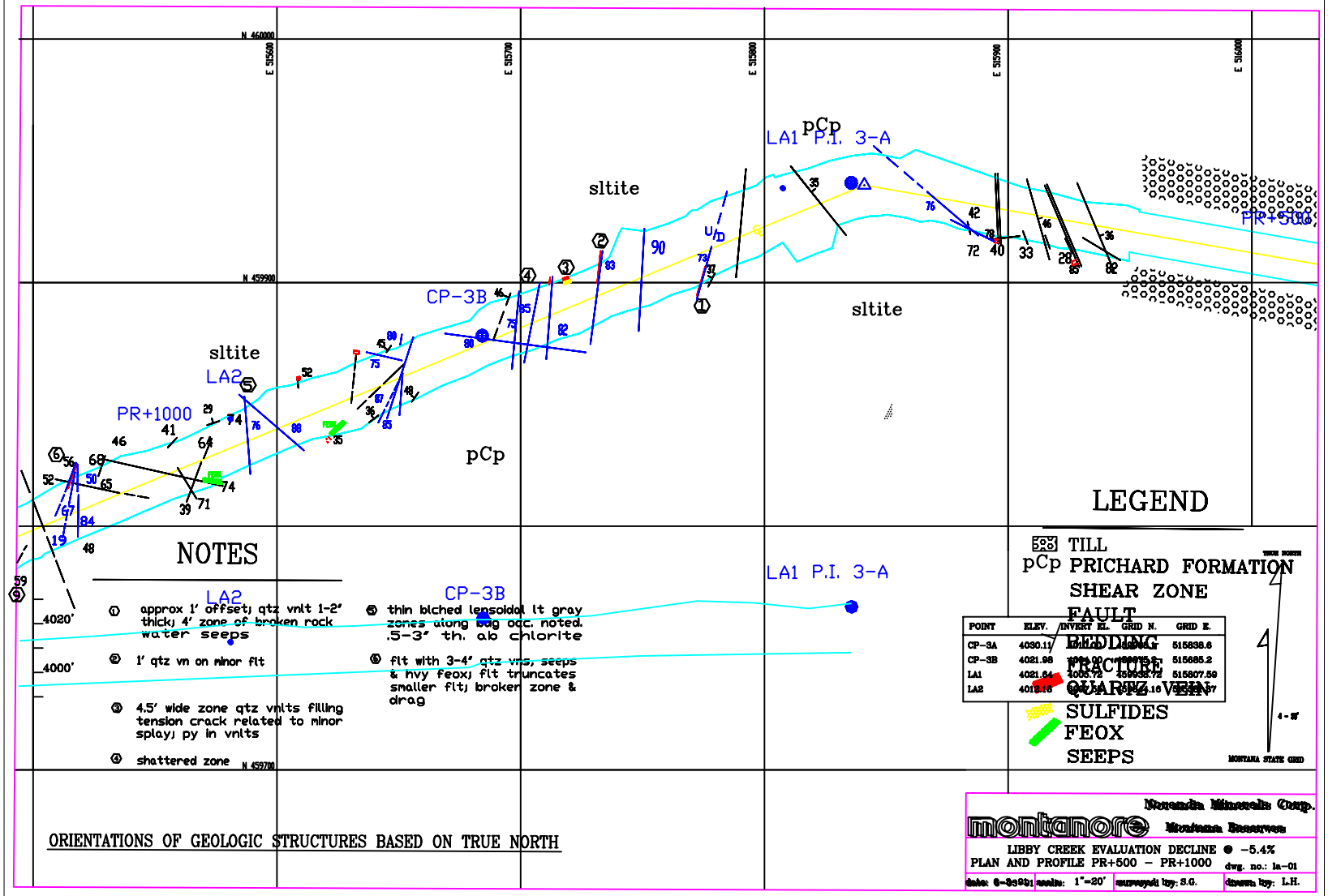
Based on the drilling, I would say that the water-bearing areas down decline from PR+5200 probably have relatively widely spaced conduits with poor permeability, most likely as a result of lithostatic loading. The potential for significant water inflow in these areas is low. The portion of the decline from the steel sets at about PR+3070 to PR+5200, which is characterized by a probable higher water-course density and less lithostatic compression, currently has the best potential for water if additional gain is desired.



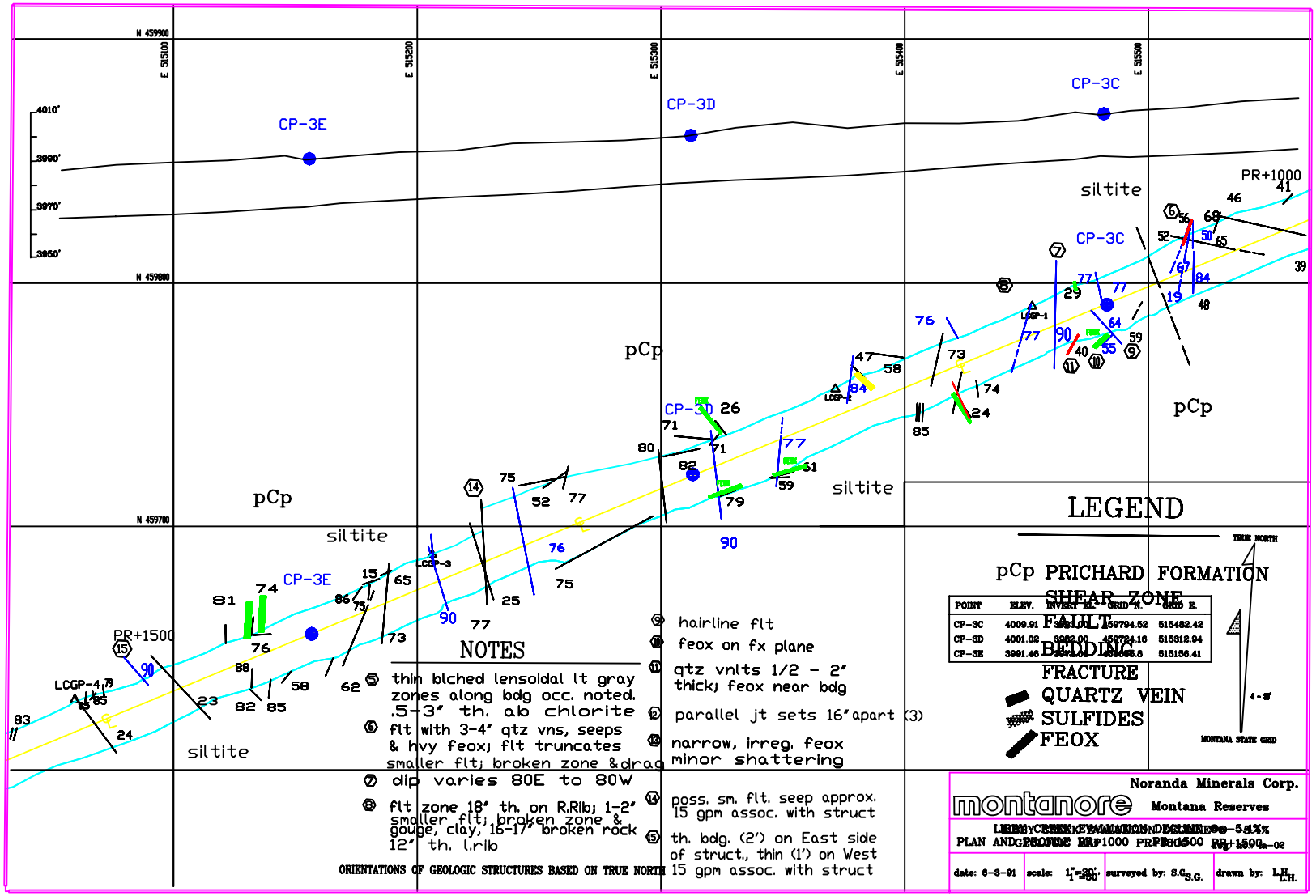
Noranda Minerals Corp.

montanore Montana Reserves

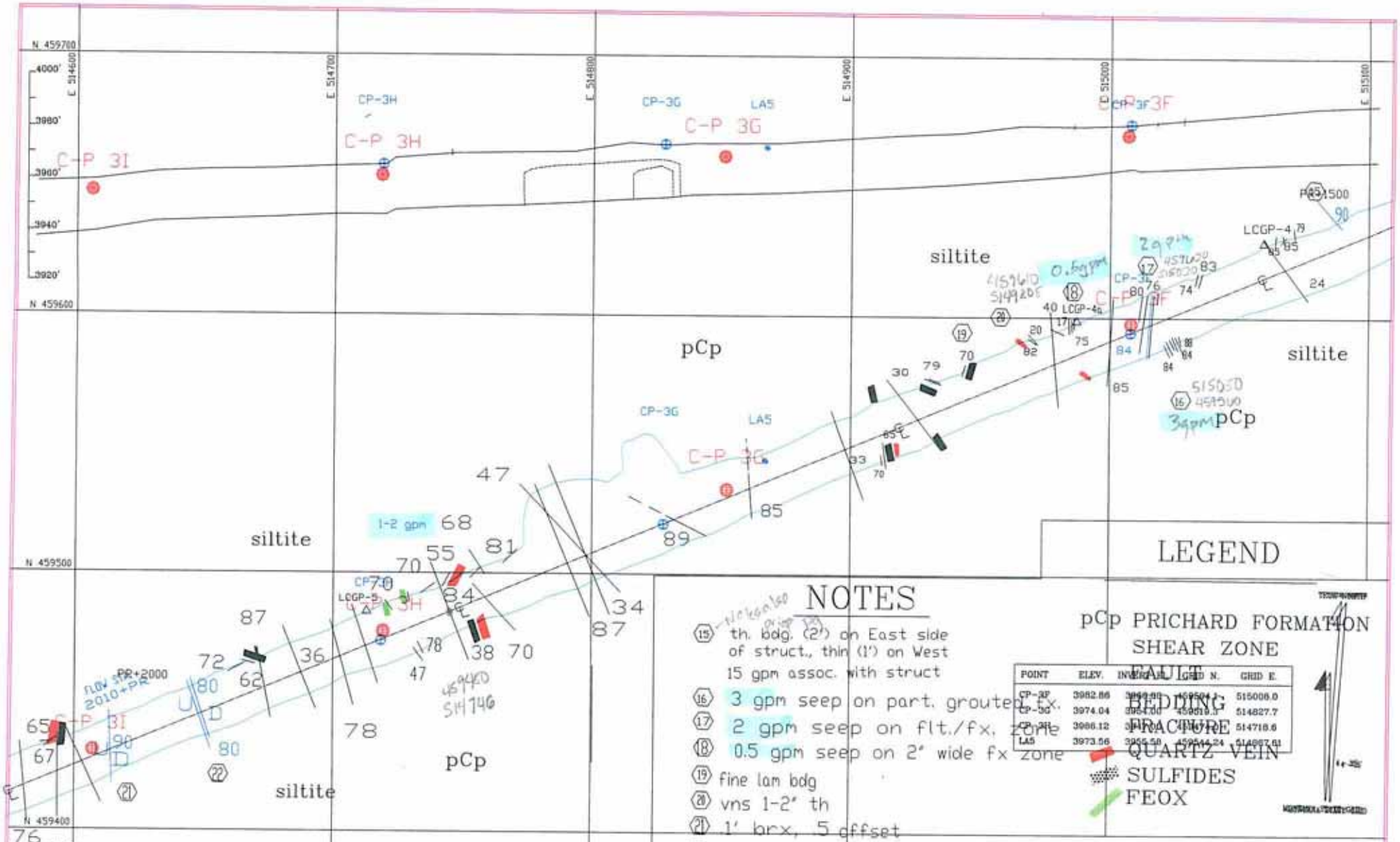
date: scale: drawn by:

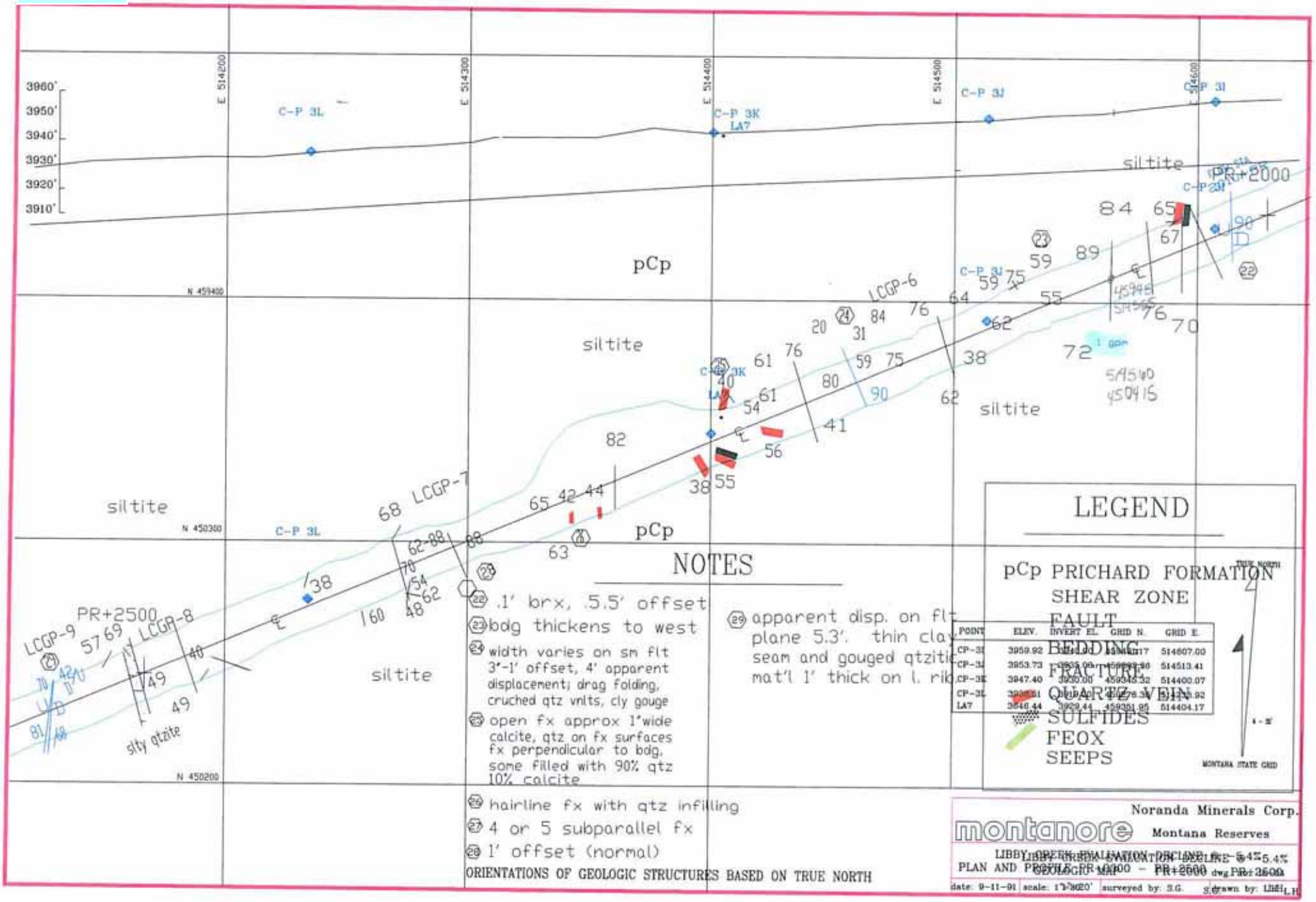


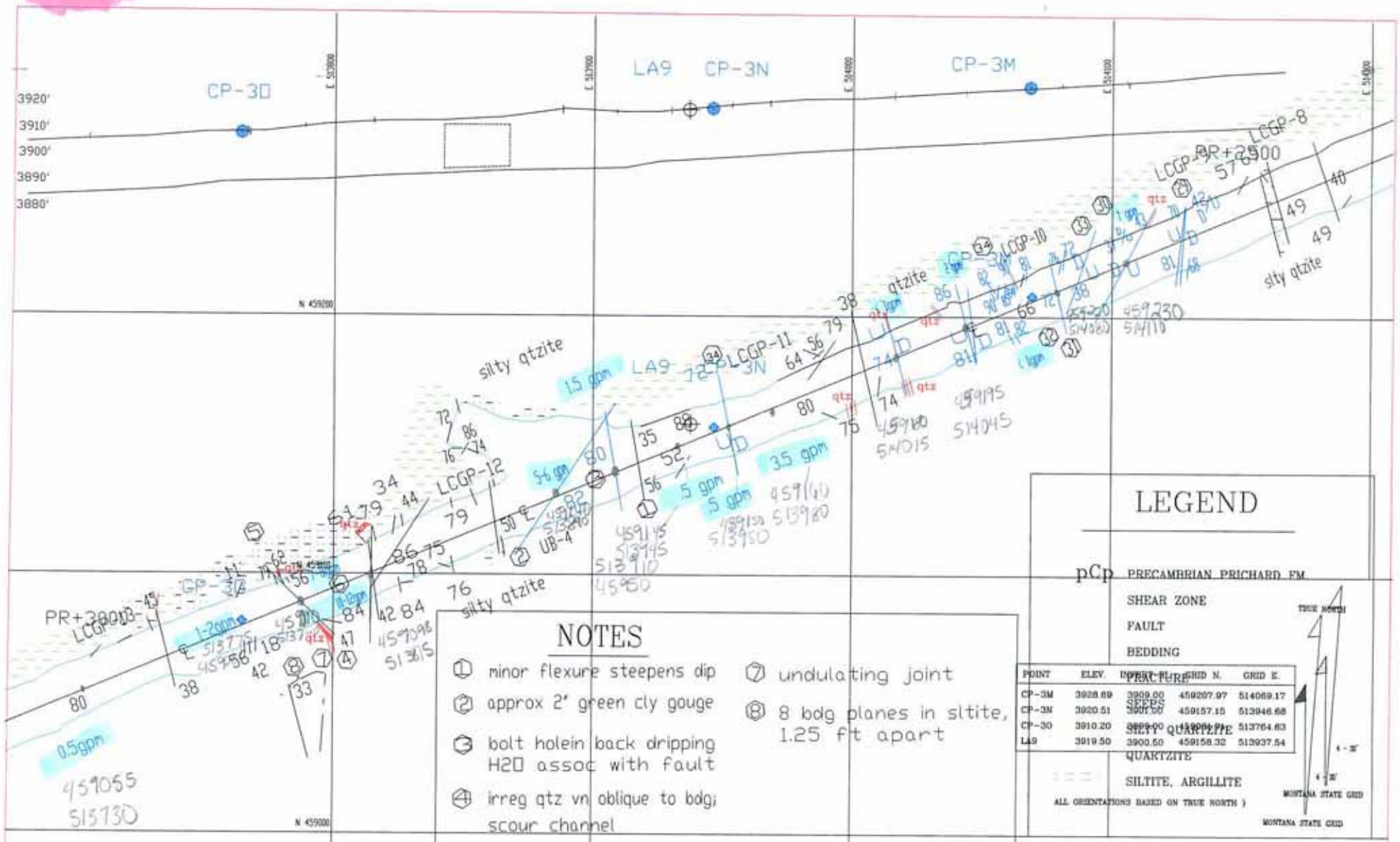
POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-3A	4030.11	[illegible]	[illegible]	515638.6
CP-3B	4021.98	[illegible]	[illegible]	515685.2
LA1	4021.64	4005.72	459938.72	515807.59
LA2	4012.16	[illegible]	[illegible]	[illegible]



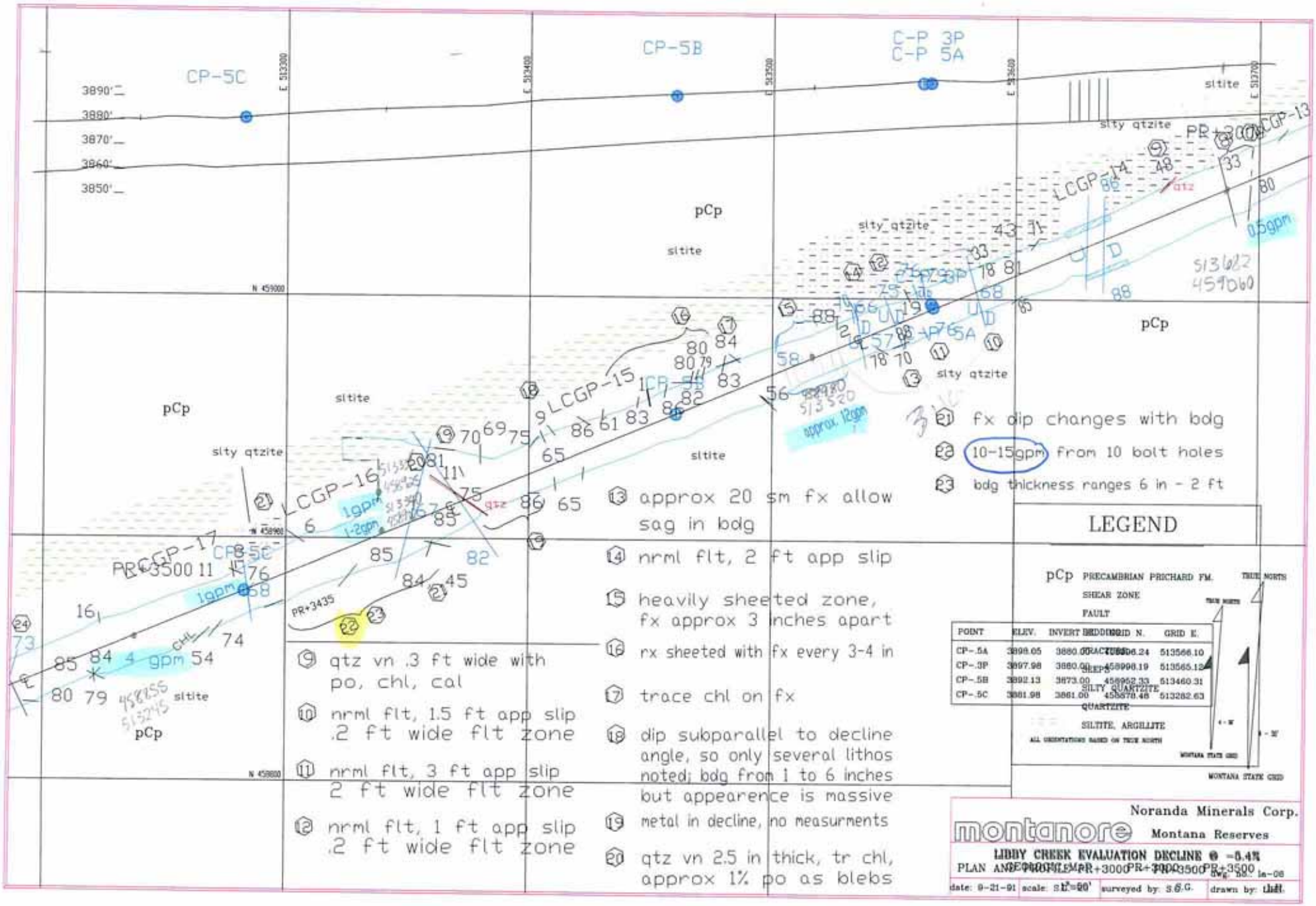
POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-3C	4009.91	[illegible]	459794.52	515482.42
CP-3D	4001.02	[illegible]	459724.16	515312.94
CP-3E	3991.46	[illegible]	[illegible]	515156.41

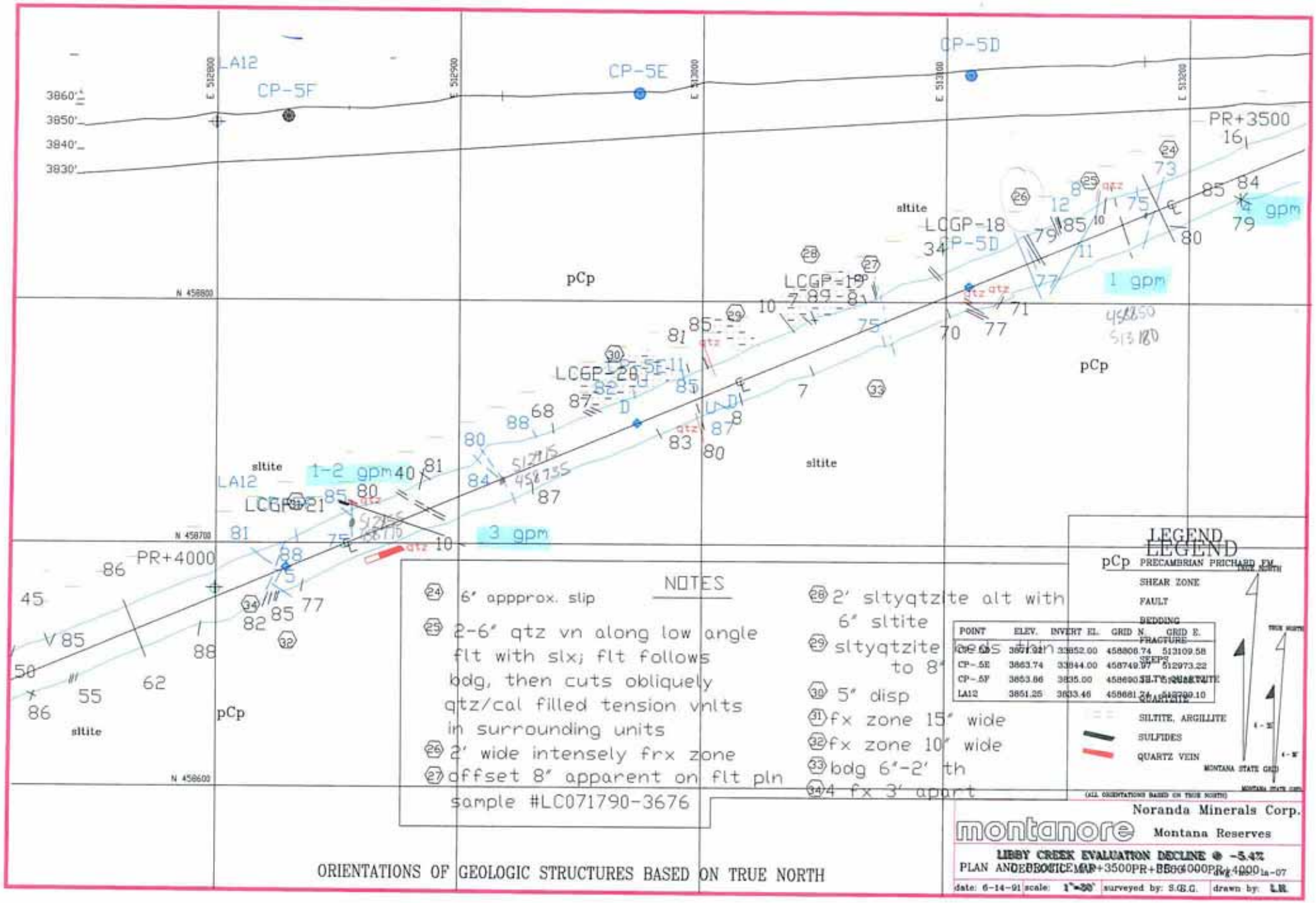

N. 459700
N 459600
N 459500
N 459400
E 514600
E 514700
E 514800
E 514900
E 515000
E 515100
4000'
3980'
3960'
3940'
3920'
C-P 3I
CP-3H
C-P 3H
CP-3G
LA5
C-P 3G
CP-3F
C-P 3F
LCGP-4
LCGP-5
siltite
pCp
1-2 gpm
0.5gpm
2 gpm
3gpm
LEGEND
pCp PRICHARD FORMATION
SHEAR ZONE
FAULT
BEDDING
FRACTURE
QUARTZ VEIN
SULFIDES
FEOX
NOTES
(15) th. bdg. (2') on East side of struct., thin (1') on West 15 gpm assoc. with struct
(16) 3 gpm seep on part. grouted fx.
(17) 2 gpm seep on flt./fx. zone
(18) 0.5 gpm seep on 2' wide fx zone
(19) fine lam bdg
(20) vns 1-2' th
(21) 1' brx, .5 offset
(22) .9' offset thin seam along fault plane, trace H2O
ORIENTATIONS OF GEOLOGIC STRUCTURES BASED ON TRUE NORTH
POINT | ELEV. | GRID N. | GRID E.
CP-3F | 3982.86 | 515006.0
CP-3G | 3974.04 | 514827.7
CP-3H | 3986.12 | 514718.6
LA5 | 3973.56 | 3955.58 | 459544.24 | 514867.61
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DRILLING
PLAN AND GEOLOGIC MAP 1500 - PR+1000 - PR+2000
date: 8-3-91 scale: 1"=20' surveyed by: S.G. drawn by: S.G.


3960'
3950'
3940'
3930'
3920'
3910'
E 514200
E 514300
E 514400
E 514500
E 514600
C-P 3L
C-P 3K
LA7
C-P 3J
C-P 3I
siltite
PR+2000
pCp
N 459400
LCGP-6
LCGP-7
LCGP-8
LCGP-9
PR+2500
N 450300
N 450200
sity qtzite
NOTES
.1' brx, .5.5' offset
bdg thickens to west
width varies on sm flt 3'-1' offset, 4' apparent displacement; drag folding, cruched qtz vnlts, cly gouge
open fx approx 1'wide calcite, qtz on fx surfaces fx perpendicular to bdg, some filled with 90% qtz 10% calcite
apparent disp. on flt plane 5.3'. thin clay seam and gouged qtzitic mat'l 1' thick on l. rib
hairline fx with qtz infilling
4 or 5 subparallel fx
1' offset (normal)
ORIENTATIONS OF GEOLOGIC STRUCTURES BASED ON TRUE NORTH
LEGEND
pCp PRICHARD FORMATION
SHEAR ZONE
FAULT
BEDDING
FRACTURE
QUARTZ VEIN
SULFIDES
FEOX
SEEPS
TRUE NORTH
MONTANA STATE GRID
POINT
ELEV.
INVERT EL.
GRID N.
GRID E.
CP-3I
3959.92
514607.00
CP-3J
3953.73
514513.41
CP-3K
3947.40
514400.07
CP-3L
514404.17
LA7
3946.44
3929.44
459351.85
514404.17
montanore
Noranda Minerals Corp.
Montana Reserves
LIBBY CREEK EVALUATION DECLINE
PLAN AND PROFILE FOR CROSS CUT 4000 - PR+2500
GEOLOGIC MAP
date: 9-11-91
scale: 1"=20'
surveyed by: S.G.
drawn by: LHH

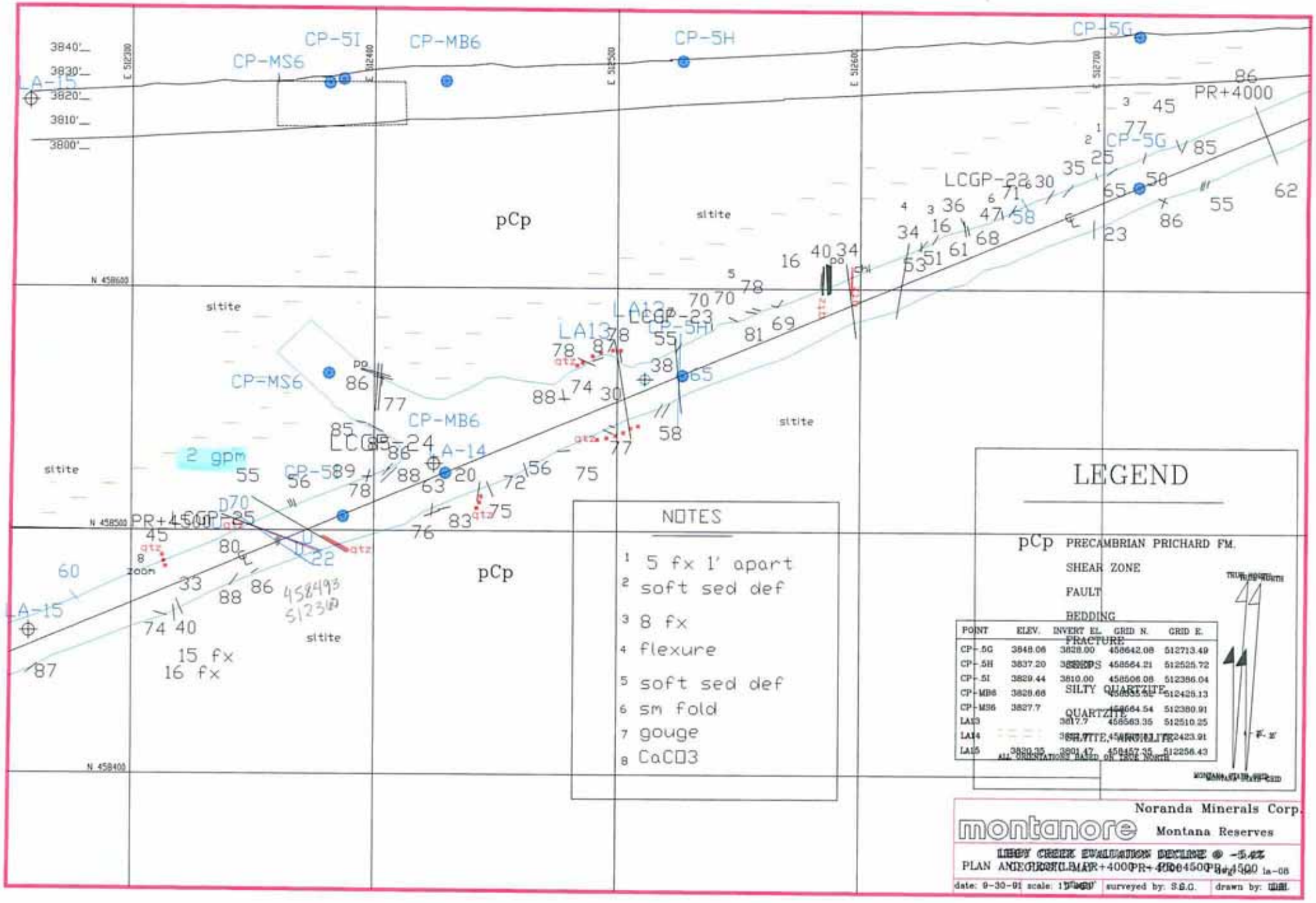


POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-3M	3928.69	3909.00	459207.97	514069.17
CP-3N	3920.51	3907.00	459157.15	513946.68
CP-3O	3910.20	[illegible]	[illegible]	513764.63
LA9	3919.50	3900.50	459158.32	513937.54

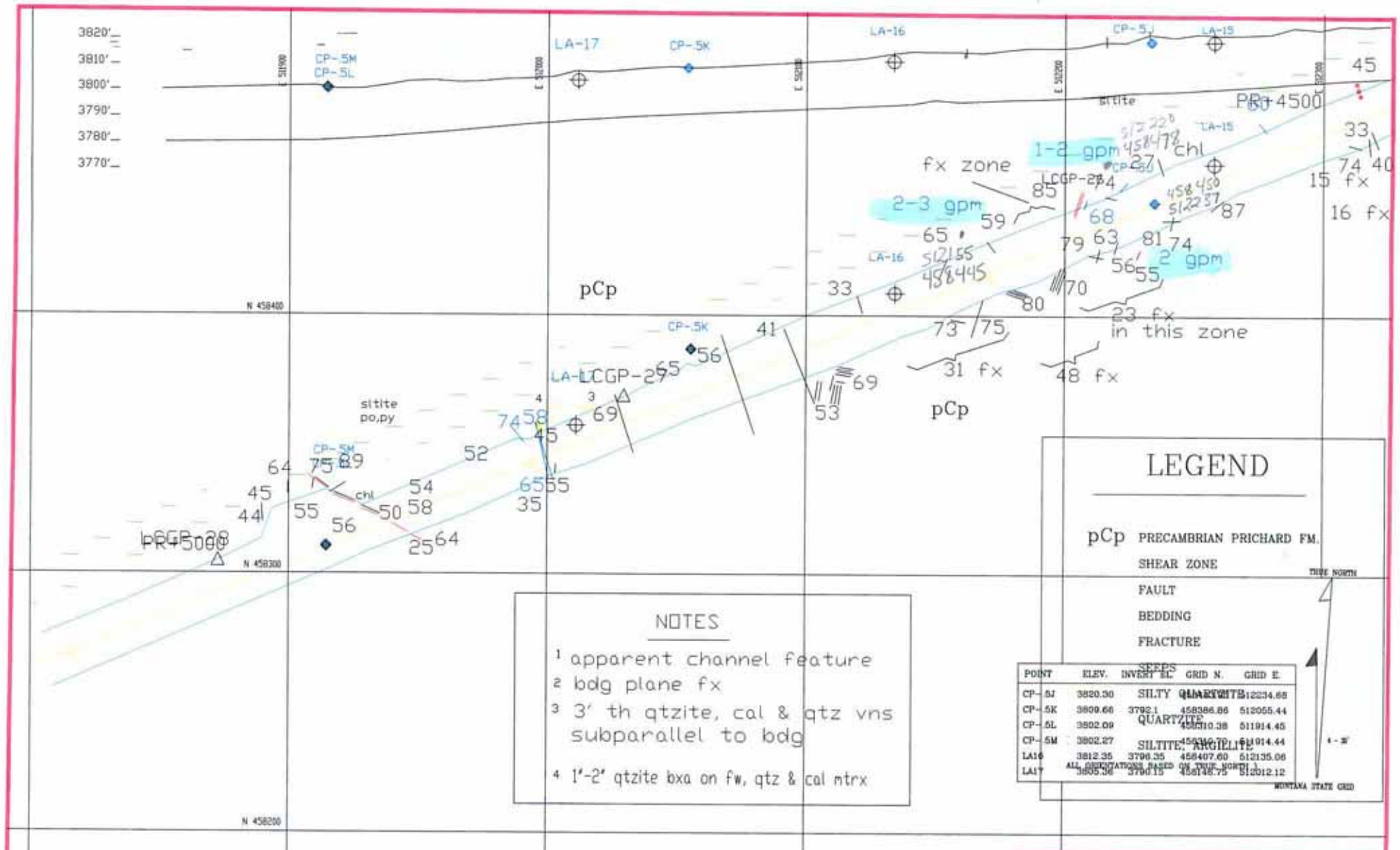

CP-5C
CP-5B
C-P 3P
C-P 5A
3890'
3880'
3870'
3860'
3850'
E 513300
E 513400
E 513500
E 513600
E 513700
N 459000
N 458900
N 458800
pCp
sitite
slty qtzite
LCGP-13
LCGP-14
LCGP-15
LCGP-16
LCGP-17
PR+3500
PR+3435
PR+3300
qtz
0.5gpm
approx. 12gpm
1gpm
1-2gpm
4 gpm
513682
459060
513520
458855
513245
fx dip changes with bdg
10-15gpm from 10 bolt holes
bdg thickness ranges 6 in - 2 ft
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
TRUE NORTH
MONTANA STATE GRID
POINT
ELEV.
INVERT
GRID N.
GRID E.
CP-.5A 3898.05 3880.00 458906.24 513566.10
CP-.3P 3897.98 3880.00 458998.19 513565.12
CP-.5B 3892.13 3873.00 458952.33 513460.31
CP-.5C 3861.98 3861.00 458878.48 513282.63
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
ALL ORIENTATIONS BASED ON TRUE NORTH
approx 20 sm fx allow sag in bdg
nrml flt, 2 ft app slip
heavily sheeted zone, fx approx 3 inches apart
rx sheeted with fx every 3-4 in
trace chl on fx
dip subparallel to decline angle, so only several lithos noted; bdg from 1 to 6 inches but appearence is massive
metal in decline, no measurments
qtz vn 2.5 in thick, tr chl, approx 1% po as blebs
qtz vn .3 ft wide with po, chl, cal
nrml flt, 1.5 ft app slip .2 ft wide flt zone
nrml flt, 3 ft app slip 2 ft wide flt zone
nrml flt, 1 ft app slip .2 ft wide flt zone
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
PLAN AND PROFILE
PR+3000
PR+3500
date: 9-21-91
scale: 1"=20'
surveyed by: S.G.G.
drawn by: DHH



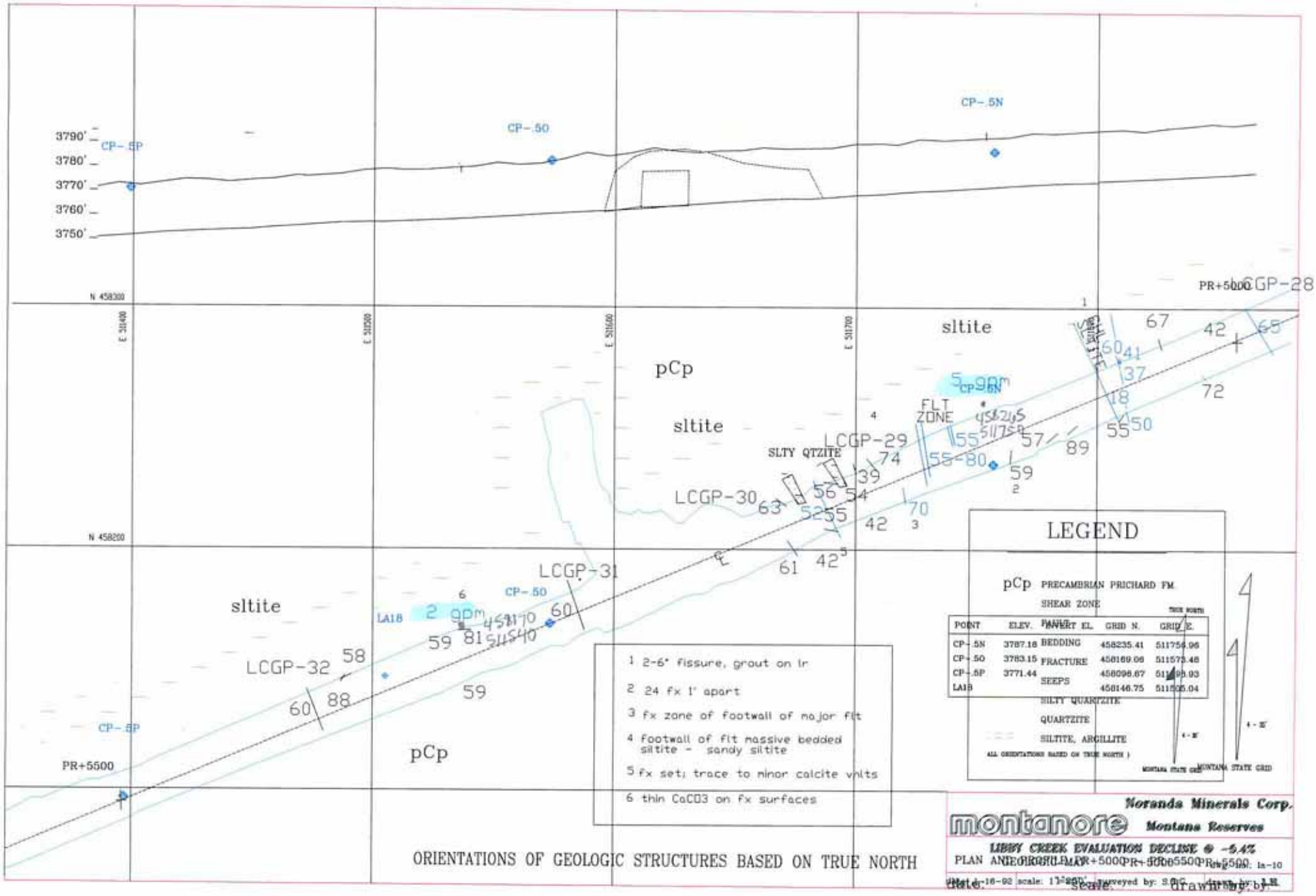
ORIENTATIONS OF GEOLOGIC STRUCTURES BASED ON TRUE NORTH

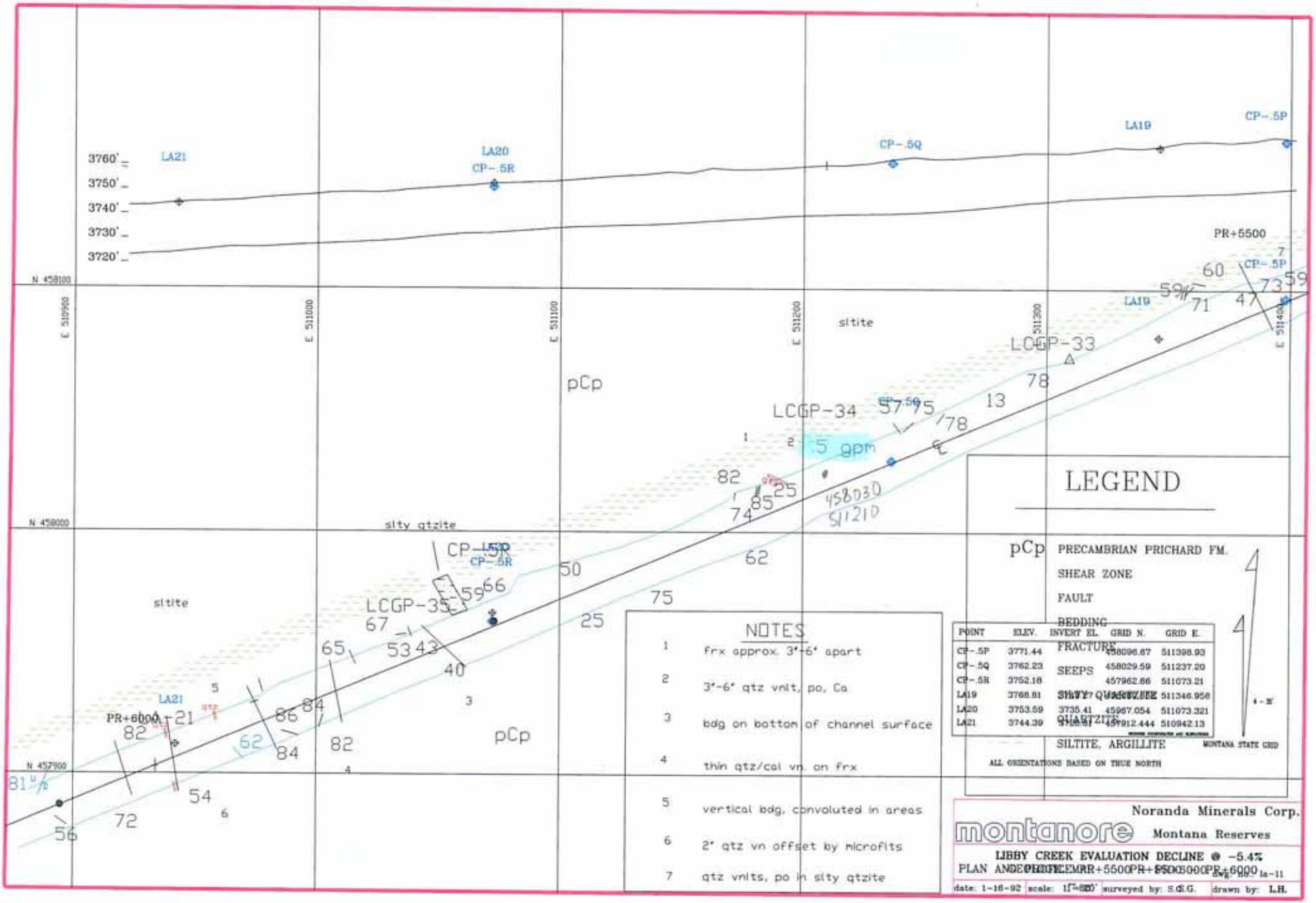


POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-5G	3848.06	3828.00	458642.08	512713.49
CP-5H	3837.20	[illegible]	458564.21	512525.72
CP-5I	3829.44	3810.00	458506.08	512386.04
CP-MB6	3828.68	[illegible]	[illegible]	512426.13
CP-MS6	3827.7	[illegible]	458664.54	512380.91
LA13	[illegible]	3817.7	458563.35	512510.25
LA14	[illegible]	[illegible]	[illegible]	512423.91
LA15	3820.35	3801.47	458457.35	512256.43

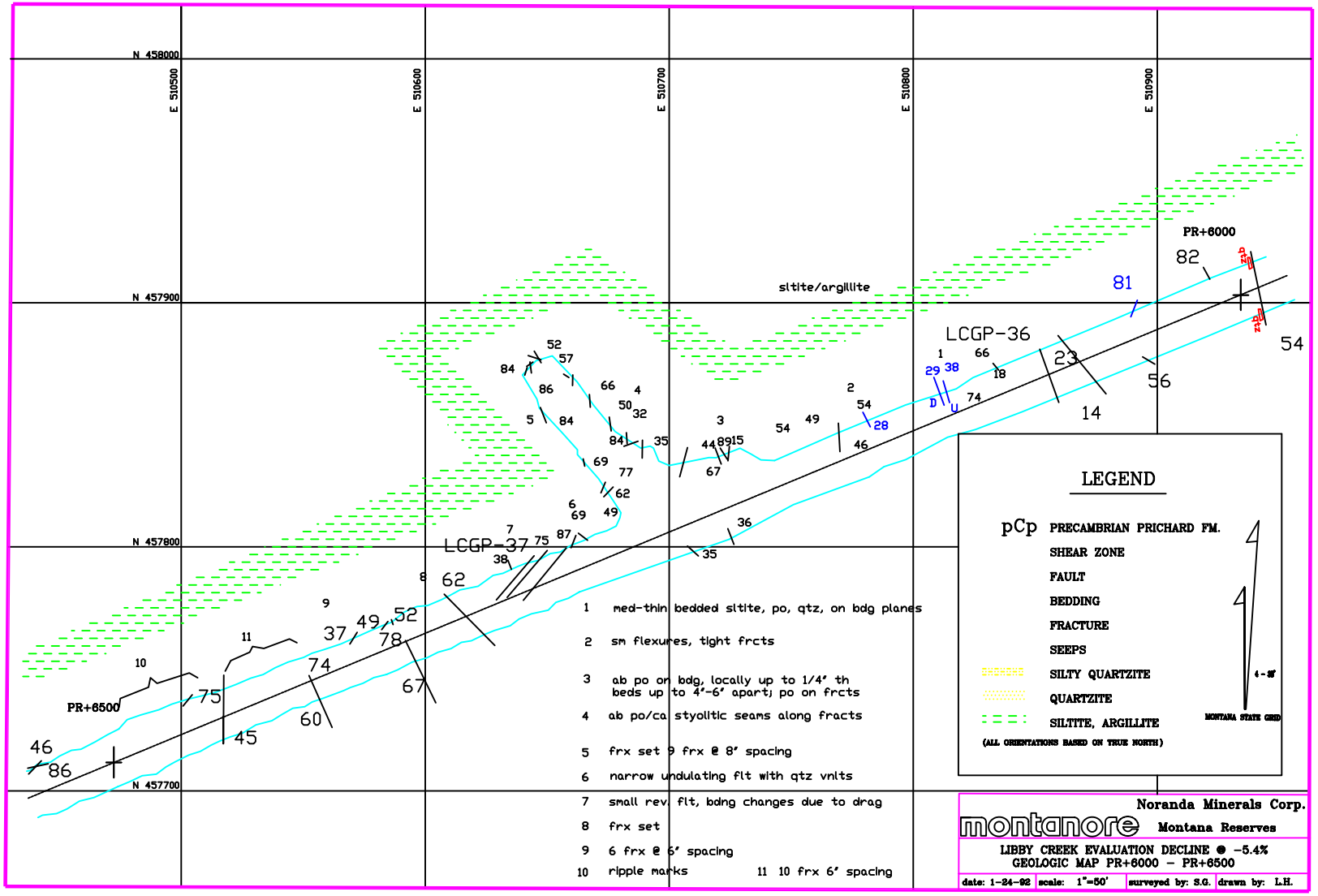


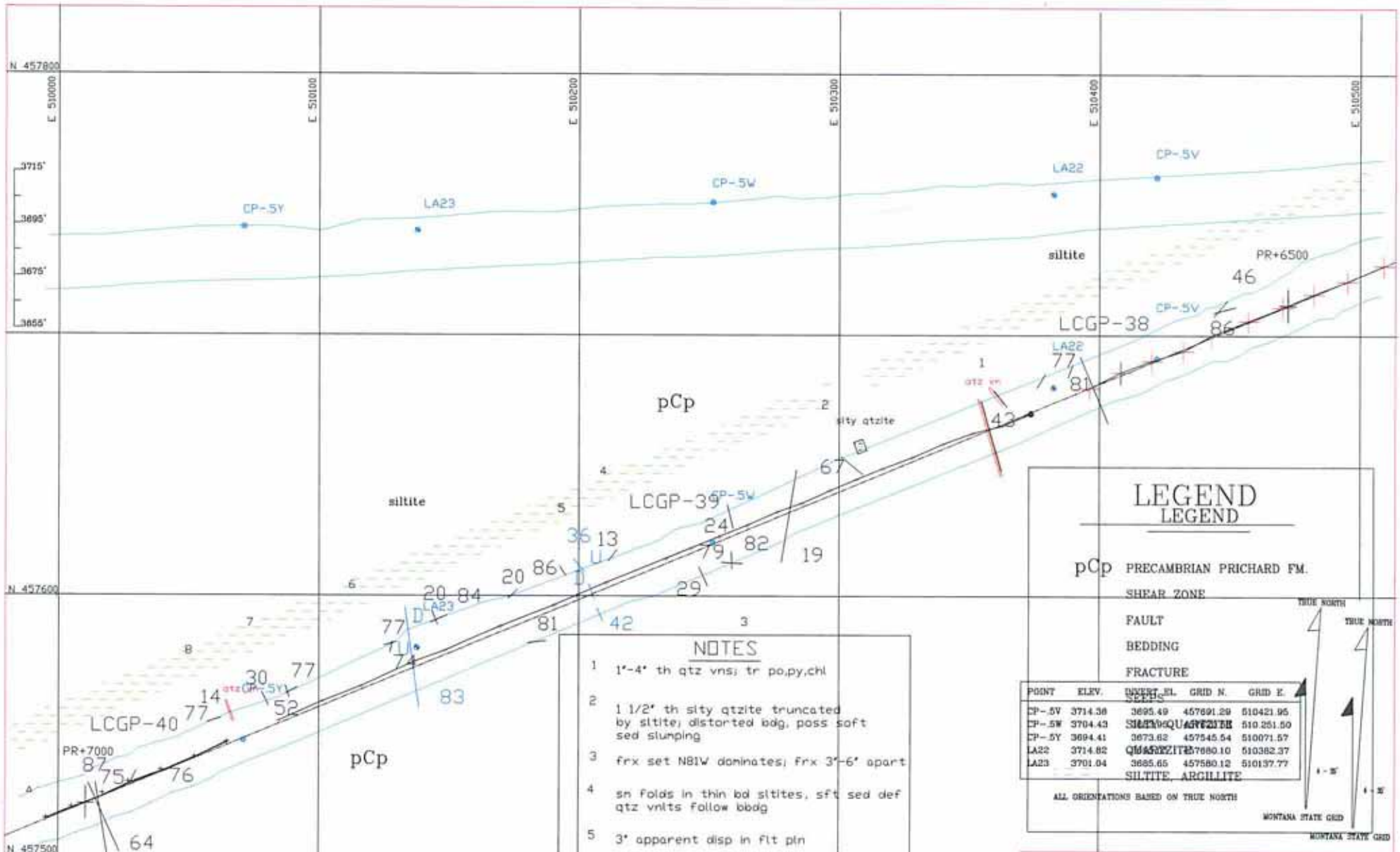
ORIENTATIONS OF GEOLOGIC STRUCTURES BASED ON TRUE NORTH

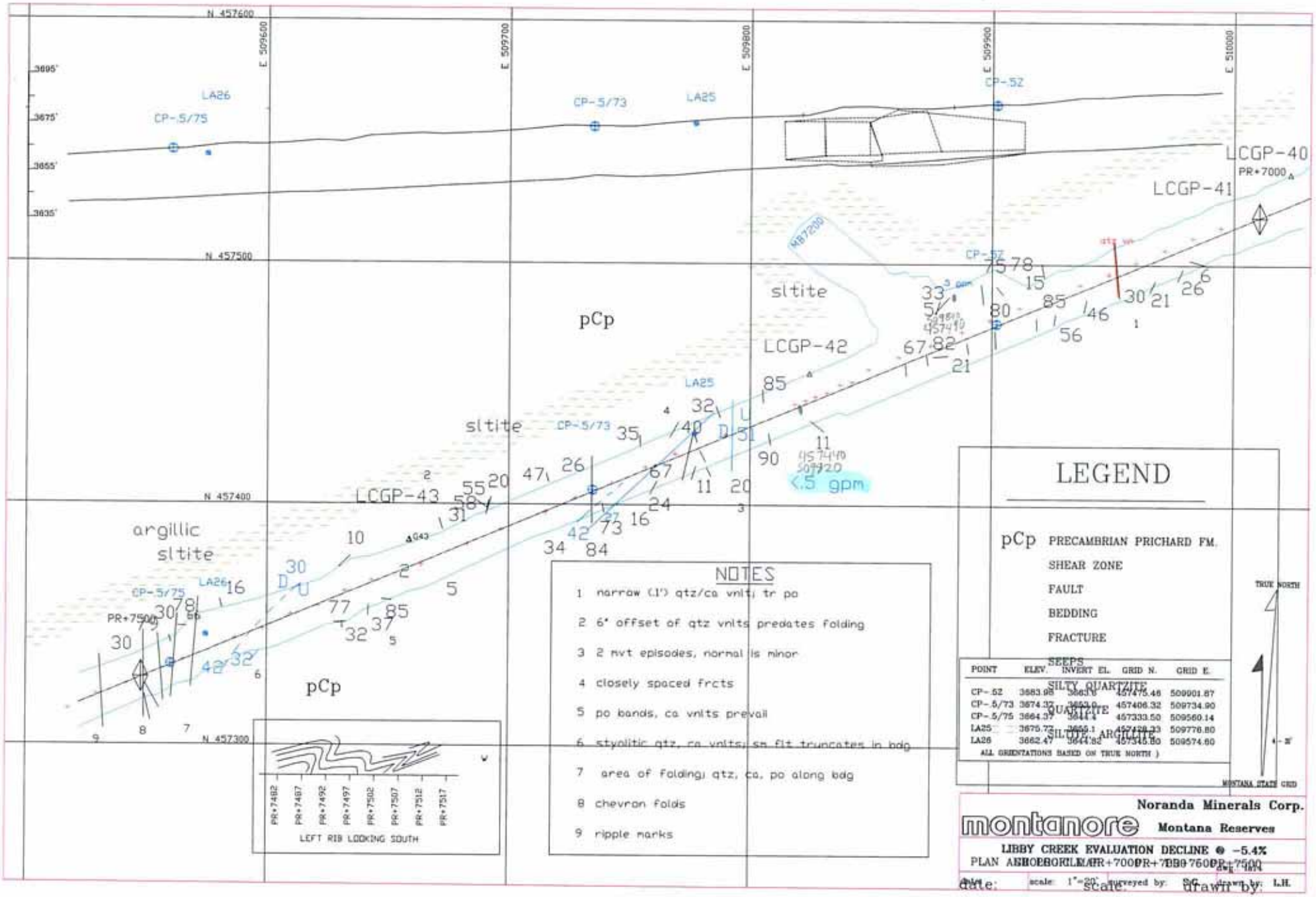

3790'
3780'
3770'
3760'
3750'
CP-.5P
CP-.50
CP-.5N
N 458300
N 458200
E 501400
E 501600
E 501700
PR+5000
LCGP-28
sltite
pCp
sltite
FLT ZONE
LCGP-29
SLTY QTZITE
LCGP-30
LCGP-31
LCGP-32
LA18
CP-.50
CP-.5P
PR+5500
pCp
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
(ALL ORIENTATIONS BASED ON TRUE NORTH)
TRUE NORTH
MONTANA STATE GRID
1 2-6" fissure, grout on lr
2 24 fx 1' apart
3 fx zone of footwall of major flt
4 footwall of flt massive bedded siltite - sandy siltite
5 fx set; trace to minor calcite vnlts
6 thin CaCO3 on fx surfaces
ORIENTATIONS OF GEOLOGIC STRUCTURES BASED ON TRUE NORTH
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
PLAN AND PROFILE
Date:
Scale:
Drawn by:

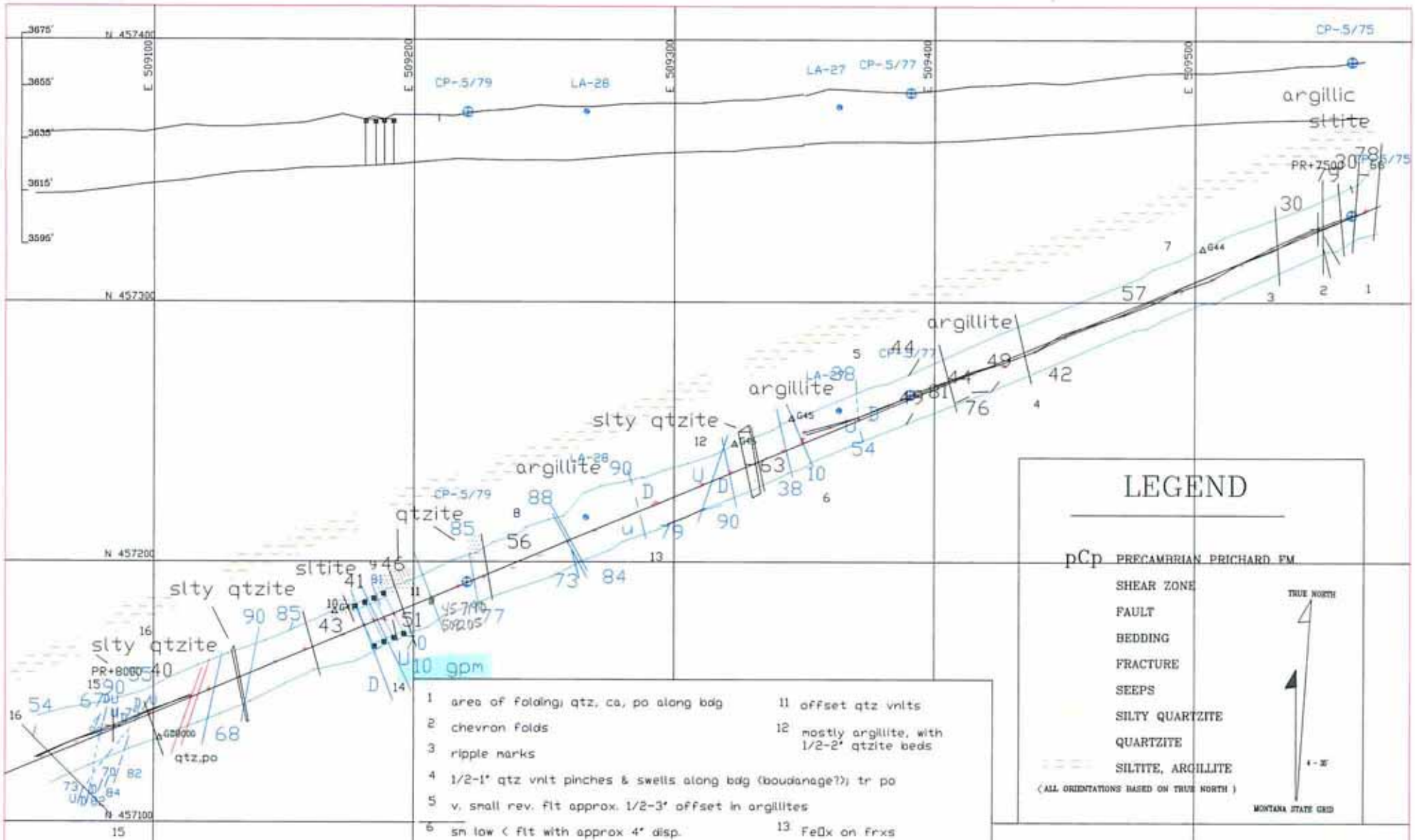


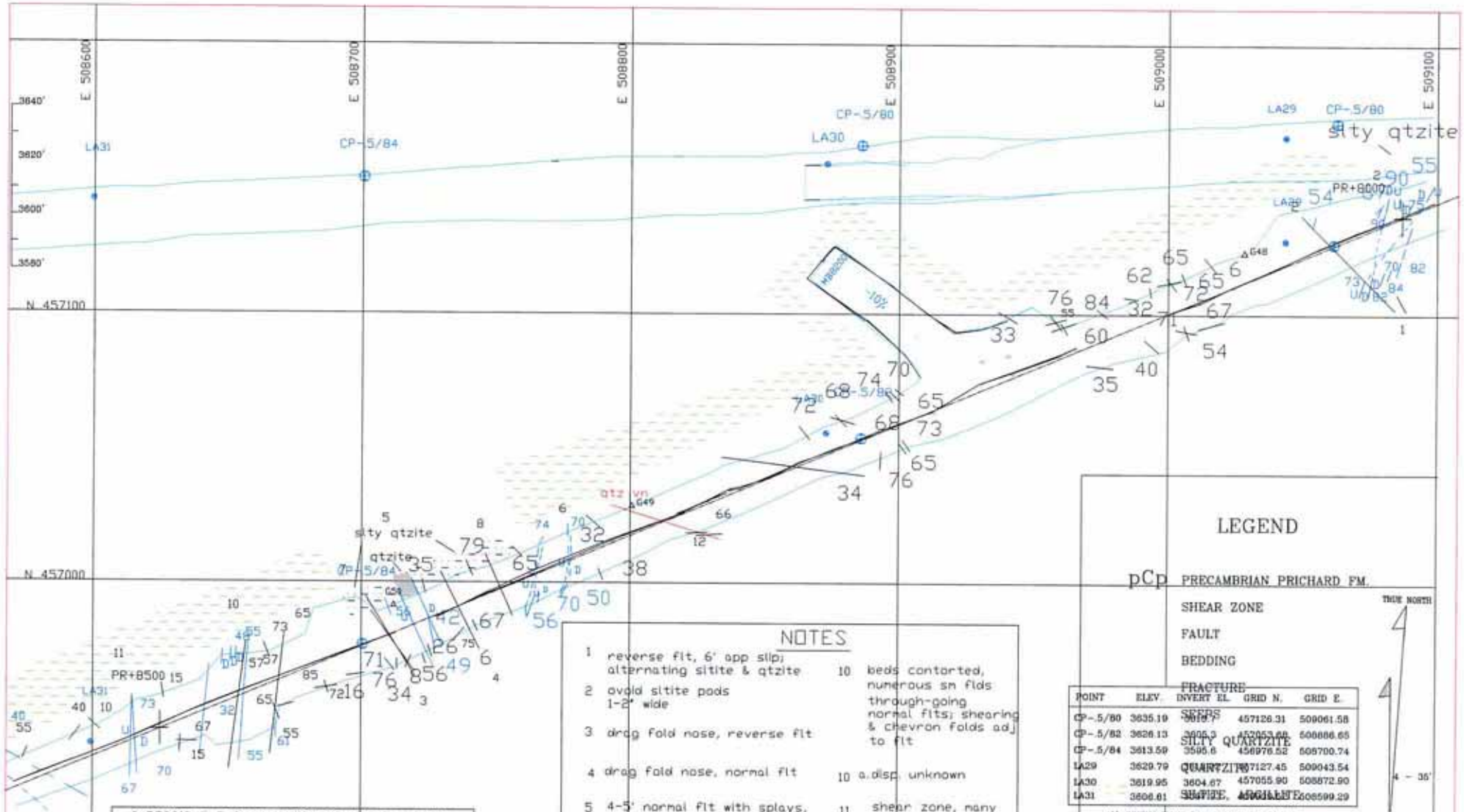
POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5P	3771.44		458096.67	511398.93
CP-.5Q	3762.23		458029.59	511237.20
CP-.5R	3752.18		457962.66	511073.21
LA19	3768.81	[illegible]	[illegible]	511346.958
LA20	3753.59	3735.41	45967.054	511073.321
LA21	3744.39	[illegible]	457912.444	510942.13


N 458000
N 457900
N 457800
N 457700
E 510500
E 510600
E 510700
E 510800
E 510900
PR+6000
PR+6500
LCGP-36
LCGP-37
siltite/argillite
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
(ALL ORIENTATIONS BASED ON TRUE NORTH)
MONTANA STATE GRID
1 med-thin bedded siltite, po, qtz, on bdg planes
2 sm flexures, tight frcts
3 ab po on bdg, locally up to 1/4' th beds up to 4'-6' apart; po on frcts
4 ab po/ca styolitic seams along fracts
5 frx set 9 frx @ 8' spacing
6 narrow undulating flt with qtz vnlts
7 small rev. flt, bdng changes due to drag
8 frx set
9 6 frx @ 6' spacing
10 ripple marks
11 10 frx 6' spacing
Noranda Minerals Corp.
montanore Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
GEOLOGIC MAP PR+6000 - PR+6500
date: 1-24-92
scale: 1"=50'
surveyed by: S.G.
drawn by: L.H.


N 457800
N 457600
N 457500
E 510000
E 510100
E 510200
E 510300
E 510400
E 510500
3715'
3695'
3675'
3655'
CP-5Y
LA23
CP-5W
LA22
CP-5V
siltite
PR+6500
LCGP-38
pCp
silty qtzite
LCGP-39
LCGP-40
PR+7000
qtz vn
NOTES
1 1"-4" th qtz vns; tr po,py,chl
2 1 1/2" th silty qtzite truncated by siltite; distorted bdg, poss soft sed slumping
3 frx set N81W dominates; frx 3"-6" apart
4 sn folds in thin bd siltites, sft sed def qtz vnlts follow bbdg
5 3" apparent disp in flt pln
6 soft sed def, styolotic qtz vnlts
7 med to thin bd siltite
8 dominant joint set
LEGEND
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
QUARTZITE
SILTITE, ARGILLITE
POINT ELEV. DOWNT. EL. GRID N. GRID E.
CP-.5V 3714.38 3695.49 457691.29 510421.95
CP-.5W 3704.43 3673.23 457673.18 510.251.50
CP-.5Y 3694.41 3673.62 457545.54 510071.57
LA22 3714.82 457680.10 510382.37
LA23 3701.04 3685.65 457580.12 510137.77
ALL ORIENTATIONS BASED ON TRUE NORTH
TRUE NORTH
MONTANA STATE GRID
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE
PLAN AND PROFILE MAP
PR+6500 PR+6500 PR+7000 PR+7000
dwg. no.: la-013
date: 2-20-91
scale: 1"=20'
surveyed by: S.G. E.G.
drawn by: L.H. L.H.


N 457600
N 457500
N 457400
N 457300
E 509600
E 509700
E 509800
E 509900
E 510000
3695'
3675'
3655'
3635'
LA26
CP-5/75
CP-5/73
LA25
CP-52
LCGP-40
PR+7000
LCGP-41
LCGP-42
LCGP-43
pCp
sltite
argillic sltite
PR+7500
<.5 gpm
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTY ARGILLITE
NOTES
1 narrow (.1') qtz/ca vnlts; tr po
2 6" offset of qtz vnlts predates folding
3 2 mvt episodes, normal is minor
4 closely spaced frcts
5 po bands, ca vnlts prevail
6 stylolitic qtz, ca vnlts; sm flt truncates in bdg
7 area of folding; qtz, ca, po along bdg
8 chevron folds
9 ripple marks
POINT ELEV. INVERT EL. GRID N. GRID E.
CP-52 3683.98 3663.0 457475.46 509901.87
CP-5/73 3674.32 3653.0 457406.32 509734.90
CP-5/75 3664.37 3644.4 457333.50 509560.14
LA25 3675.77 3655.1 457428.23 509776.80
LA26 3662.47 3644.82 457345.80 509574.60
ALL ORIENTATIONS BASED ON TRUE NORTH)
TRUE NORTH
MONTANA STATE GRID
PR+7482
PR+7487
PR+7492
PR+7497
PR+7502
PR+7507
PR+7512
PR+7517
LEFT RIB LOOKING SOUTH
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
PLAN AERIAL VIEW
PR+7000
PR+7500
date:
scale: 1"=20'
surveyed by: S.G.
drawn by: L.H.
scale:
drawn by:


3675'
3655'
3635'
3615'
3595'
N 457400
N 457300
N 457200
N 457100
E 509100
E 509200
E 509300
E 509400
E 509500
CP-5/79
LA-28
LA-27
CP-5/77
CP-5/75
argillic
siltite
PR+7500
argillite
slty qtzite
qtzite
sltite
PR+8000
qtz,po
10 gpm
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
(ALL ORIENTATIONS BASED ON TRUE NORTH)
TRUE NORTH
MONTANA STATE GRID
1 area of folding; qtz, ca, po along bdg
2 chevron folds
3 ripple marks
4 1/2-1" qtz vnlt pinches & swells along bdg (boudanage?); tr po
5 v. small rev. flt approx. 1/2-3" offset in argillites
6 sm low ∠ flt with approx 4" disp.
7 soft sed def too small to map
8 erratic discontinuous qtz vnlts; tr po
9 1x3" ovoid & lenticular sltite pods in qtzite
10 thrusting, shearing apparent
11 offset qtz vnlts
12 mostly argillite, with 1/2-2" qtzite beds
13 FeOx on frxs
14 reverse flt, 6' app slip; alternating sltite & qtzite
15 ovoid sltite pods 4-8" long 1-2" wide
16 sltite,slty qtzite alternate
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
GEOLOGIC MAP PR+7500 - PR+8000
Date:
scale: 1"=20'
Surveyed by: SIC
drawn by: L.H.
Scale:
Drawn by:



LEGEND

pCp PRECAMBRIAN PRICHARD FM.

SHEAR ZONE

FAULT

BEDDING

FRACTURE

SEEPS

SILTY QUARTZITE

QUARTZITE

SILTITE, ARGILLITE

TRUE NORTH

4 - 35'

MONTANA STATE GRID

POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5/80	3635.19	[illegible]	457126.31	509061.58
CP-.5/82	3626.13	3605.3	457053.68	508886.65
CP-.5/84	3613.59	3595.6	456976.52	508700.74
LA29	3629.79	[illegible]	457127.45	509043.54
LA30	3619.95	3604.67	457055.90	508872.90
LA31	3606.61	[illegible]	[illegible]	508599.29

ALL ORIENTATIONS BASED ON TRUE NORTH

NOTES

1 reverse flt, 6' app slip; alternating siltite & qtzite

2 ovoid siltite pods 1-2' wide

3 drag fold nose, reverse flt

4 drag fold nose, normal flt

5 4-5' normal flt with splays, min 6' offset

6 normal flt, 4' offset

7 normal drag fold nose high on rt rib

8 overturned drag fold anticline assoc. with reverse flt

9 LCA040901 8370&8425 - chip samples on 5' qtz vns with po, chl, tr py

10 beds contorted, numerous sm flds through-going normal flts; shearing & chevron folds adj to flt

10 a. disp. unknown

11 shear zone, many discont. qtz vnlts

12 normal flt, 6' apparent slip

2 POSSIBLE EXPLANATIONS FOR FOLD/FAULTING

1. reverse flt reactivated as normal flt
2. normal flt cutting trough a series of overturned East dipping folds

Noranda Minerals Corp.

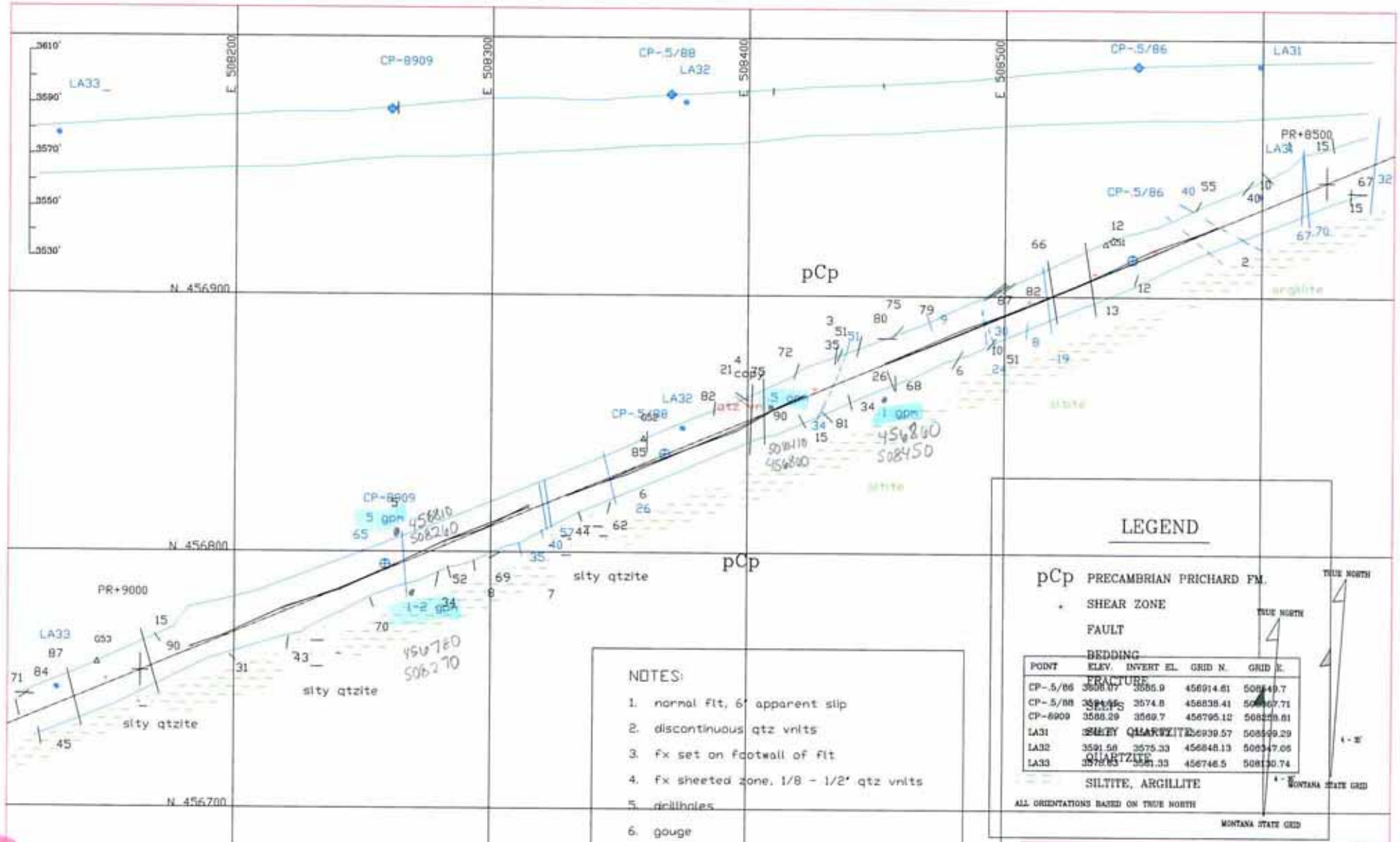
montanore Montana Reserves

LIBBY CREEK EVALUATION DECLINE @ -5.4%

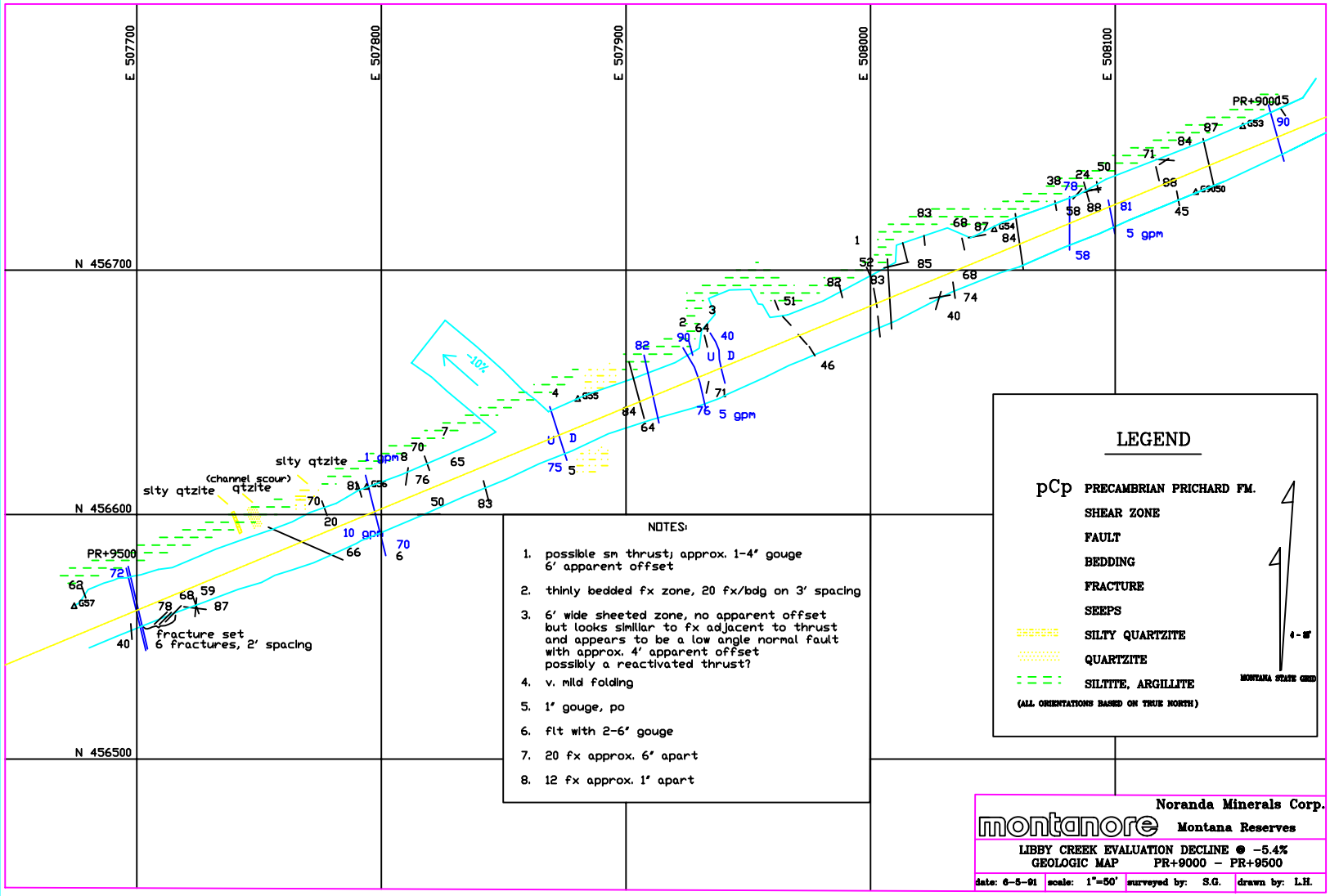
PLAN AND GEOLOGY PR+8000 PR+8500

dwg no. la-16

date: 5-30-91 scale: 1"=20' surveyed by: SG. drawn by: LH.



POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5/86	3556.07	3555.9	456914.61	508549.7
CP-.5/88	3584.45	3574.8	456838.41	508467.71
CP-8909	3566.29	3569.7	456795.12	508259.81
LA31	[illegible]	[illegible]	456939.57	508599.29
LA32	3591.56	3575.33	456848.13	508347.06
LA33	[illegible]	[illegible]	456746.5	508130.74



NOTES:

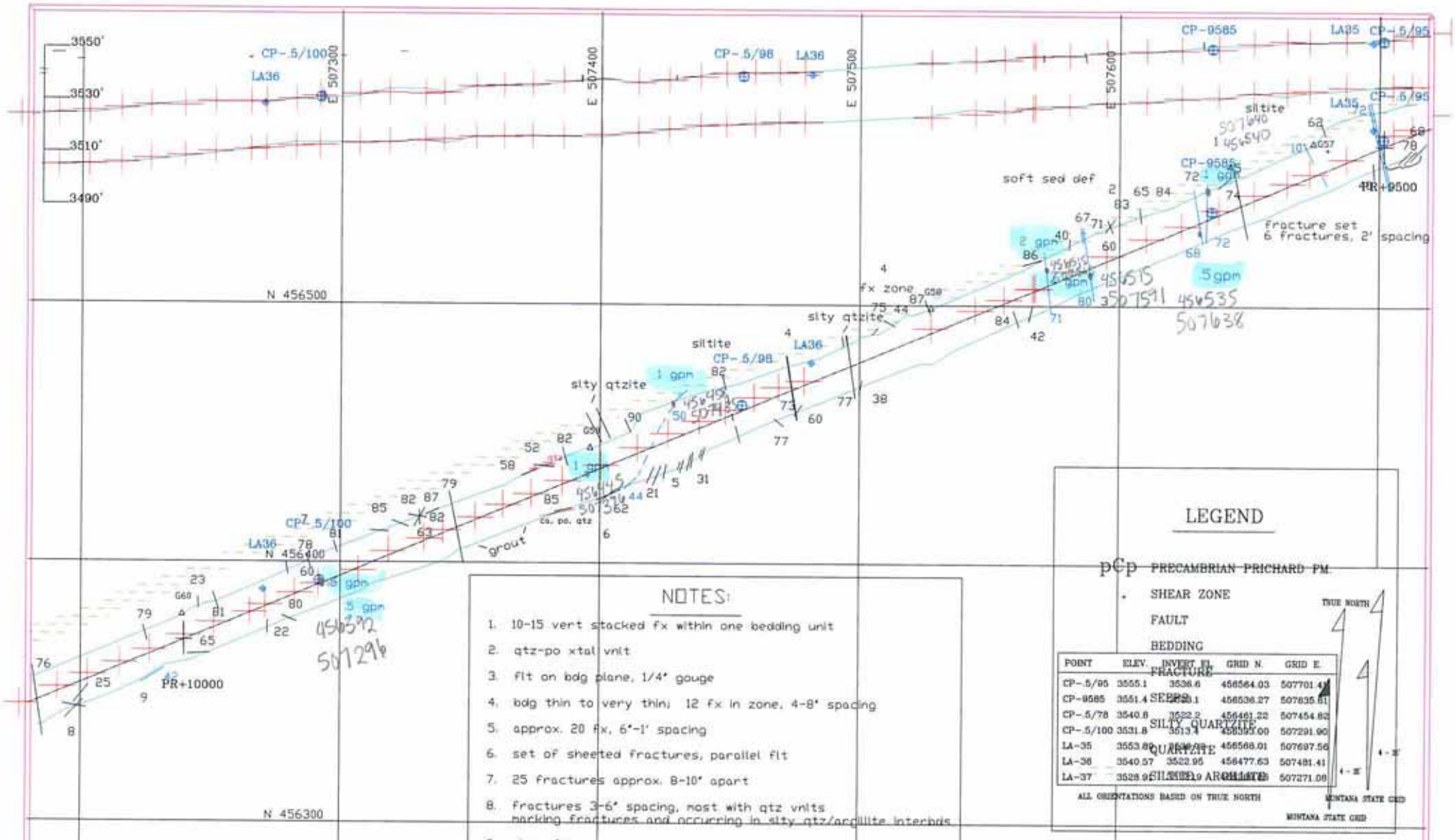
1. possible sm thrust; approx. 1-4' gouge 6' apparent offset
2. thinly bedded fx zone, 20 fx/bdg on 3' spacing
3. 6' wide sheeted zone, no apparent offset but looks similar to fx adjacent to thrust and appears to be a low angle normal fault with approx. 4' apparent offset possibly a reactivated thrust?
4. v. mild folding
5. 1' gouge, po
6. flt with 2-6' gouge
7. 20 fx approx. 6' apart
8. 12 fx approx. 1' apart

Noranda Minerals Corp.

montanore Montana Reserves

LIBBY CREEK EVALUATION DECLINE @ -5.4%
GEOLOGIC MAP PR+9000 - PR+9500

date: 6-5-91	scale: 1"=50'	surveyed by: S.G.	drawn by: L.H.



NOTES:

1. 10-15 vert stacked fx within one bedding unit
2. qtz-po xtal vnlt
3. flt on bdg plane, 1/4" gouge
4. bdg thin to very thin; 12 fx in zone, 4-8" spacing
5. approx. 20 fx, 6"-1' spacing
6. set of sheeted fractures, parallel flt
7. 25 fractures approx. 8-10" apart
8. fractures 3-6" spacing, most with qtz vnlts marking fractures and occurring in silty qtz/argillite interbds
9. minor flts, poss thrust

LEGEND

pCp PRECAMBRIAN PRICHARD FM.

SHEAR ZONE

FAULT

BEDDING

FRACTURE

SERPS

SILTY QUARTZITE

QUARTZITE

SILTITE, ARGILLITE

TRUE NORTH

POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5/95	3555.1	3536.6	456564.03	507701.41
CP-9585	3551.4	[illegible]	456536.27	507635.61
CP-.5/78	3540.8	3522.2	456461.22	507454.82
CP-.5/100	3531.8	3513.4	456395.00	507291.90
LA-35	3553.80	[illegible]	456568.01	507697.56
LA-36	3540.57	3522.95	456477.63	507481.41
LA-37	3528.9[illegible]	[illegible]	[illegible]	507271.06

ALL ORIENTATIONS BASED ON TRUE NORTH

MONTANA STATE GRID

MONTANA STATE GRID

Noranda Minerals Corp.

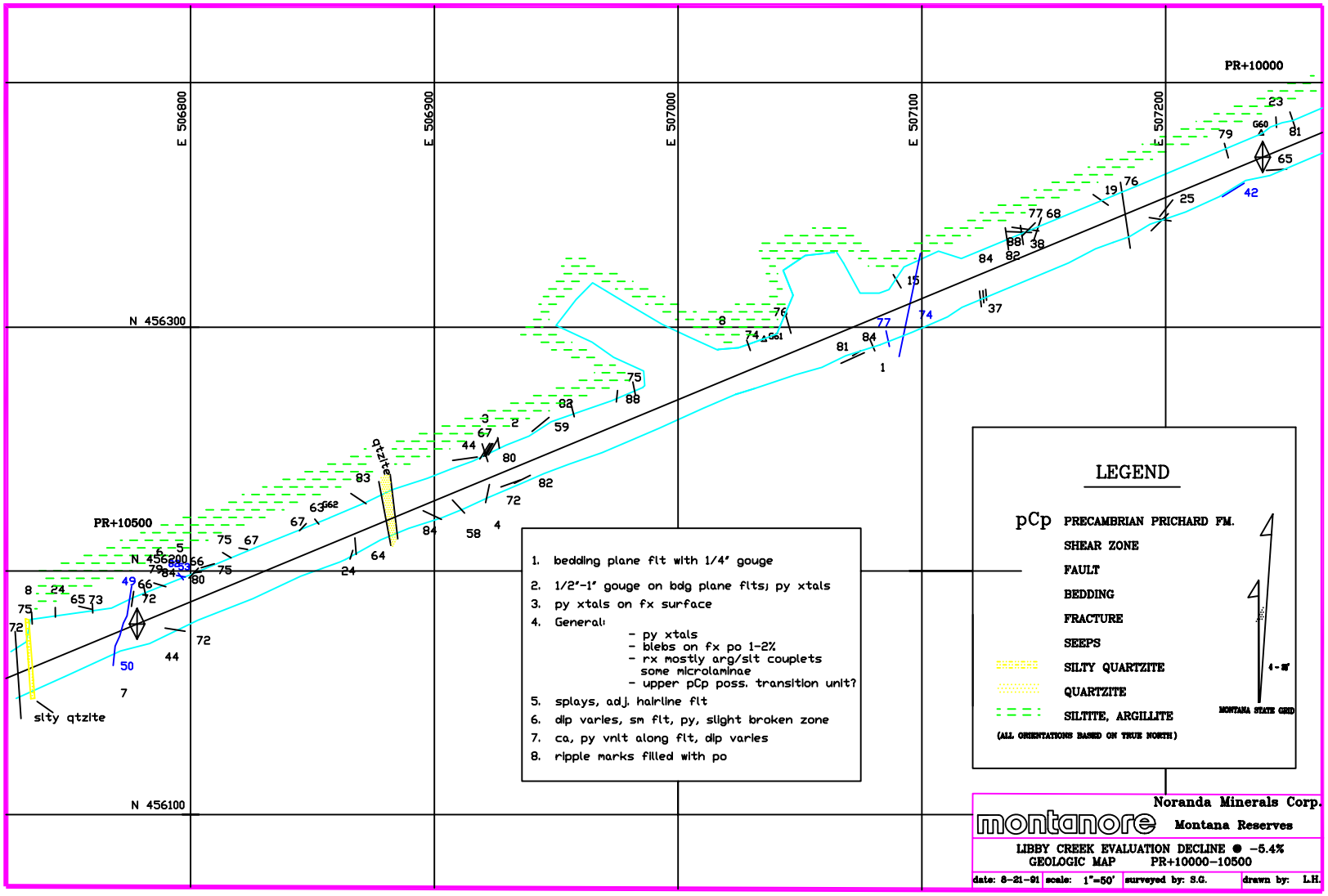
montanore Montana Reserves

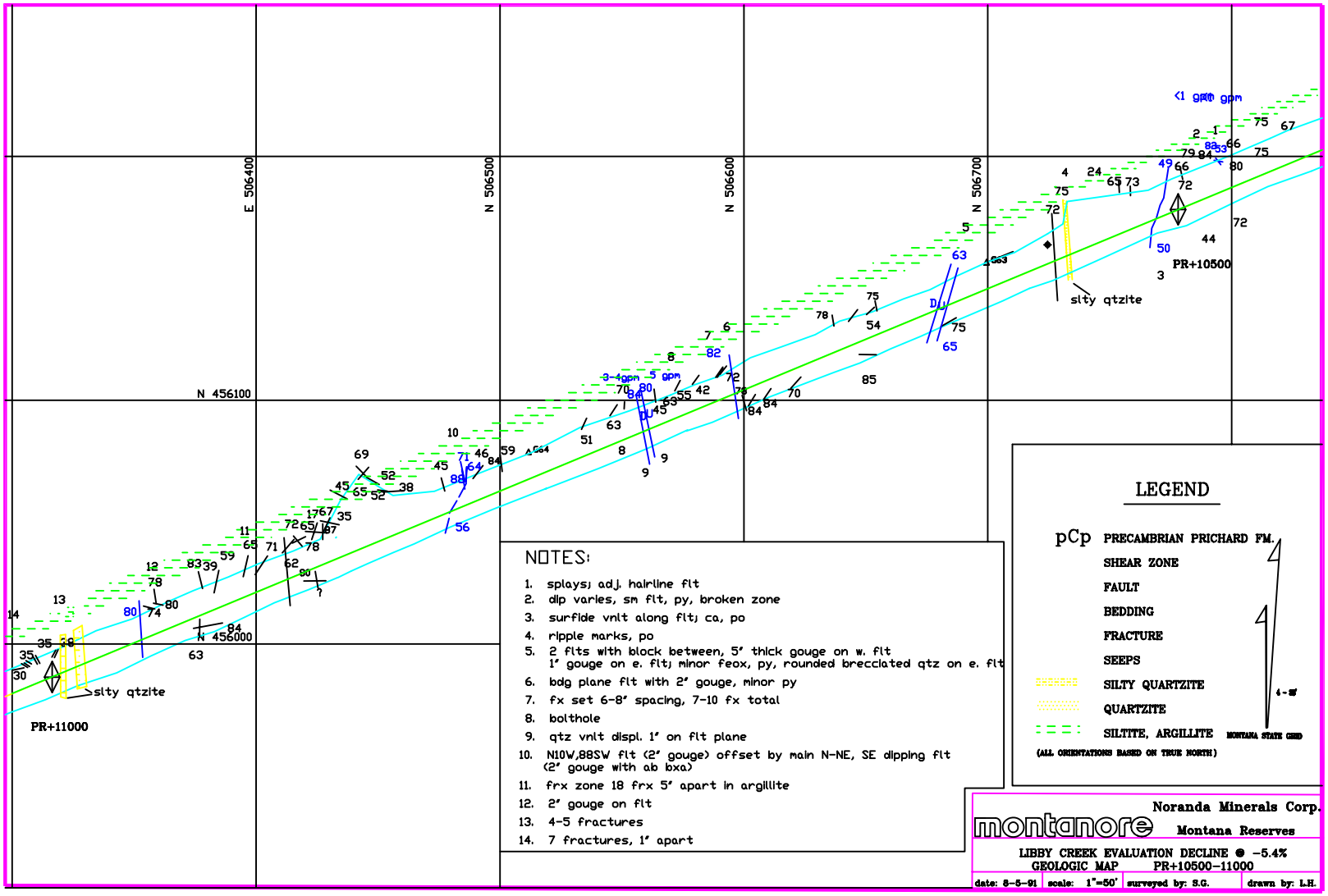
LIBBY CREEK EVALUATION DECLINE @ -5.4%

PLAN AND PROFILE MAP PR+9500 TO PR+10000

date: 7-18-91 scale: 1"=20' surveyed by: S.G. drawn by: LMH.

dwg. no.: la-19


PR+10000
PR+10500
E 506800
E 506900
E 507000
E 507100
E 507200
N 456300
N 456200
N 456100
qtzite
slty qtzite
G60
G61
G62
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
(ALL ORIENTATIONS BASED ON TRUE NORTH)
MONTANA STATE GRID
1. bedding plane flt with 1/4" gouge
2. 1/2"-1" gouge on bdg plane flts; py xtals
3. py xtals on fx surface
4. General:
- py xtals
- blebs on fx po 1-2%
- rx mostly arg/slt couplets some microlaminae
- upper pCp poss. transition unit?
5. splays, adj. hairline flt
6. dip varies, sm flt, py, slight broken zone
7. ca, py vnlt along flt, dip varies
8. ripple marks filled with po
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE ● -5.4%
GEOLOGIC MAP PR+10000-10500
date: 8-21-91
scale: 1"=50'
surveyed by: S.G.
drawn by: L.H.



NOTES:

1. splays; adj. hairline flt
2. dip varies, sm flt, py, broken zone
3. surfide vnlt along flt; ca, po
4. ripple marks, po
5. 2 flts with block between, 5' thick gouge on w. flt
   1' gouge on e. flt; minor feox, py, rounded brecciated qtz on e. flt
6. bdg plane flt with 2' gouge, minor py
7. fx set 6-8' spacing, 7-10 fx total
8. bolthole
9. qtz vnlt displ. 1' on flt plane
10. N10W,88SW flt (2' gouge) offset by main N-NE, SE dipping flt
    (2' gouge with ab bxa)
11. frx zone 18 frx 5' apart in argillite
12. 2' gouge on flt
13. 4-5 fractures
14. 7 fractures, 1' apart

LEGEND

pCp PRECAMBRIAN PRICHARD FM.

SHEAR ZONE

FAULT

BEDDING

FRACTURE

SEEPS

SILTY QUARTZITE

QUARTZITE

SILTITE, ARGILLITE

MONTANA STATE GRID

(ALL ORIENTATIONS BASED ON TRUE NORTH)

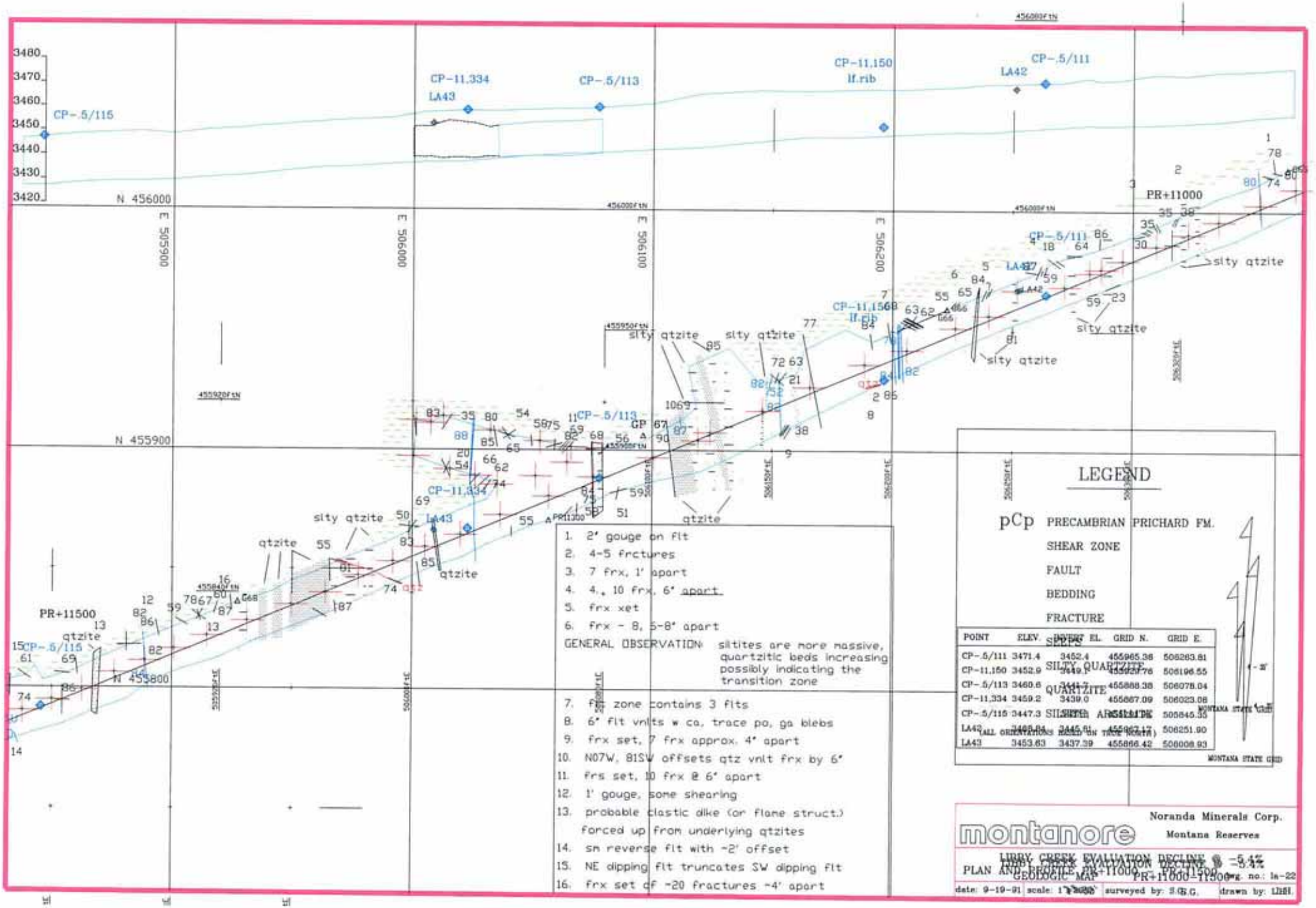
Noranda Minerals Corp.

montanore Montana Reserves

LIBBY CREEK EVALUATION DECLINE @ -5.4%

GEOLOGIC MAP PR+10500-11000

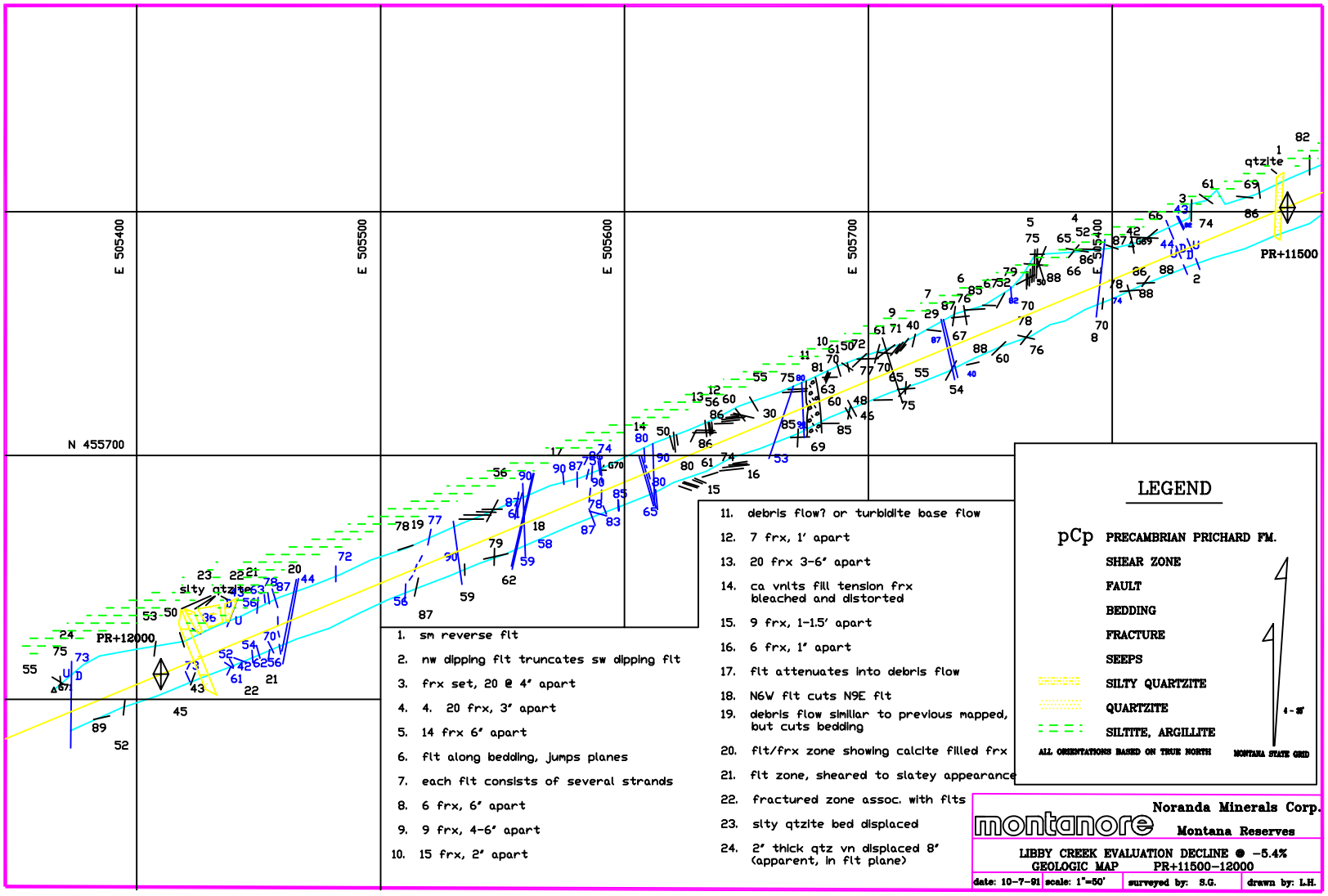
date: 8-5-91	scale: 1"=50'	surveyed by: S.G.	drawn by: L.H.



POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5/111	3471.4	3452.4	455965.38	506283.81
CP-11.150	3452.9	3449.1	455925.76	506196.55
CP-.5/113	3460.6	3441.7	455888.38	506078.04
CP-11.334	3459.2	3439.0	455867.09	506023.08
CP-.5/115	3447.3	[illegible]	[illegible]	505845.35
LA42	[illegible]	3445.61	455967.17	506251.90
LA43	3453.63	3437.39	455866.42	506008.93

ALL ORIENTATIONS BASED ON TRUE NORTH

MONTANA STATE GRID



1. sm reverse flt
2. nw dipping flt truncates sw dipping flt
3. frx set, 20 @ 4' apart
4. 4. 20 frx, 3' apart
5. 14 frx 6' apart
6. flt along bedding, jumps planes
7. each flt consists of several strands
8. 6 frx, 6' apart
9. 9 frx, 4-6' apart
10. 15 frx, 2' apart
11. debris flow? or turbidite base flow
12. 7 frx, 1' apart
13. 20 frx 3-6' apart
14. ca vnlts fill tension frx bleached and distorted
15. 9 frx, 1-1.5' apart
16. 6 frx, 1' apart
17. flt attenuates into debris flow
18. N6W flt cuts N9E flt
19. debris flow similar to previous mapped, but cuts bedding
20. flt/frx zone showing calcite filled frx
21. flt zone, sheared to slatey appearance
22. fractured zone assoc. with flts
23. silty qtzite bed displaced
24. 2' thick qtz vn displaced 8' (apparent, in flt plane)

LEGEND

pCp PRECAMBRIAN PRICHARD FM.

SHEAR ZONE

FAULT

BEDDING

FRACTURE

SEEPS

SILTY QUARTZITE

QUARTZITE

SILTITE, ARGILLITE

ALL ORIENTATIONS BASED ON TRUE NORTH

MONTANA STATE GRID

1 - 25'

montanore

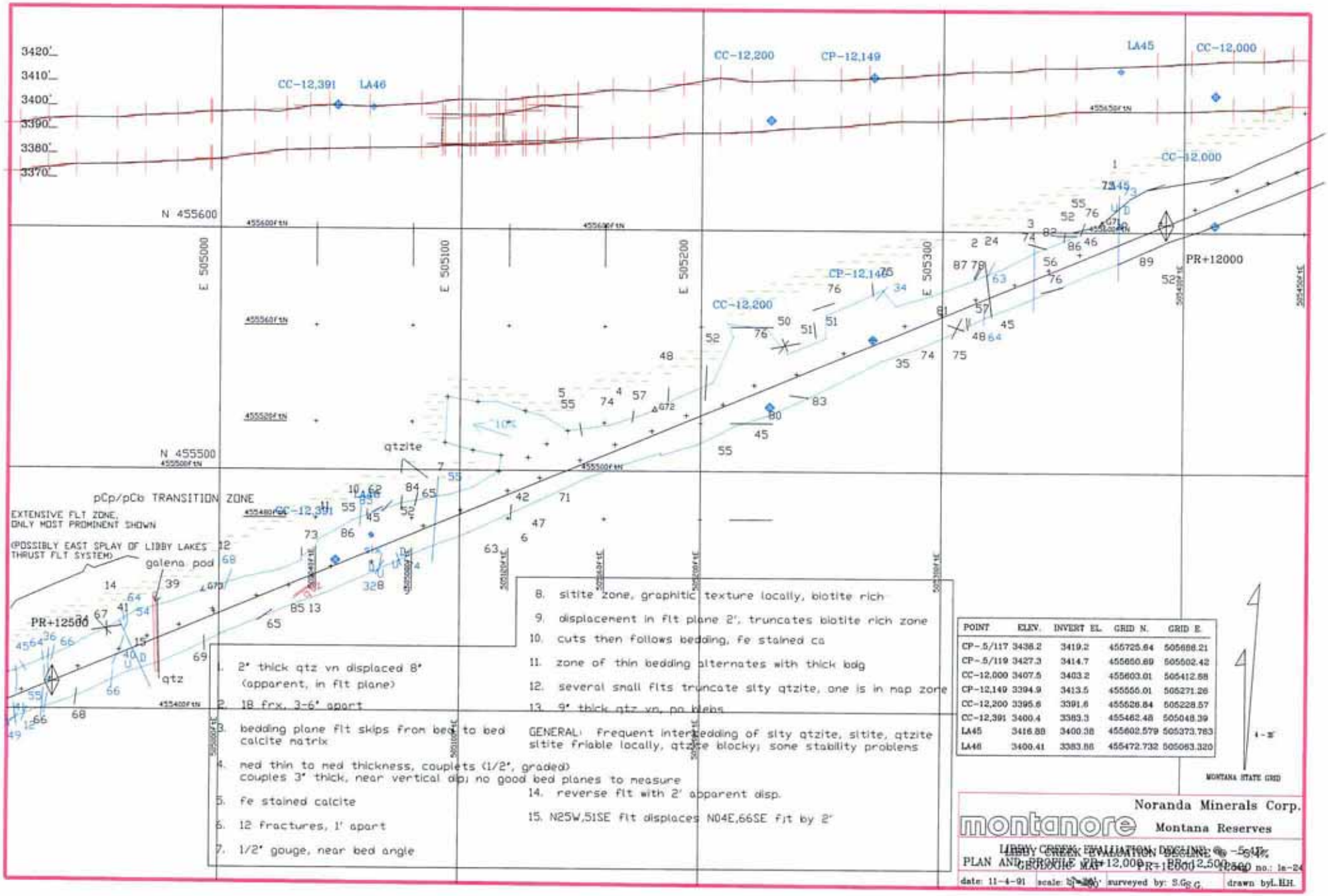
Noranda Minerals Corp.

Montana Reserves

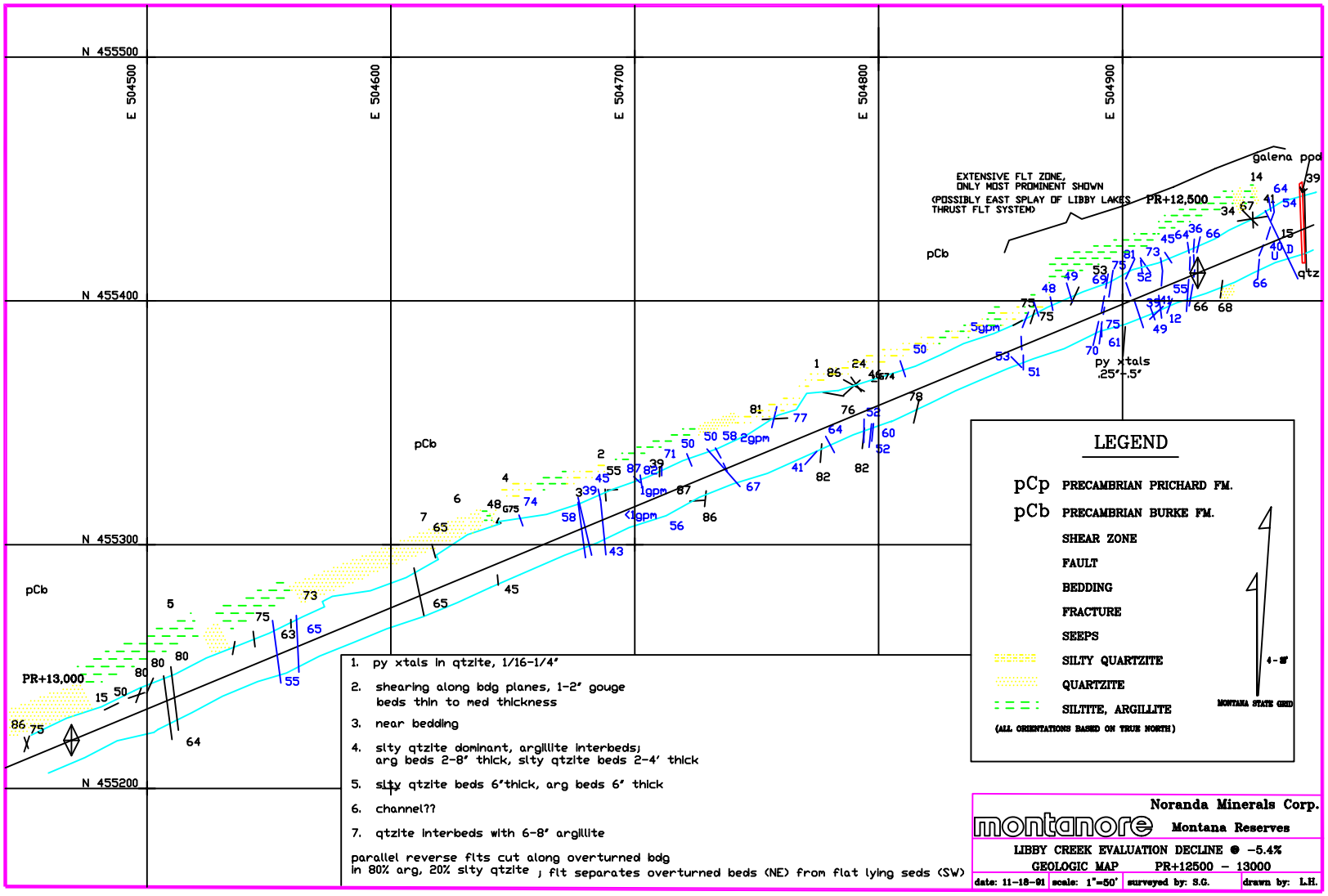
LIBBY CREEK EVALUATION DECLINE @ -5.4%

GEOLOGIC MAP PR+11500-12000

date: 10-7-91	scale: 1"=50'	surveyed by: S.G.	drawn by: L.H.



POINT	ELEV.	INVERT EL.	GRID N.	GRID E.
CP-.5/117	3436.2	3419.2	455725.64	505698.21
CP-.5/119	3427.3	3414.7	455650.69	505502.42
CC-12,000	3407.5	3403.2	455603.01	505412.58
CP-12,149	3394.9	3413.5	455555.01	505271.26
CC-12,200	3395.6	3391.6	455526.84	505228.57
CC-12,391	3400.4	3383.3	455462.48	505048.39
LA45	3416.88	3400.38	455602.579	505373.783
LA46	3400.41	3383.86	455472.732	505063.320



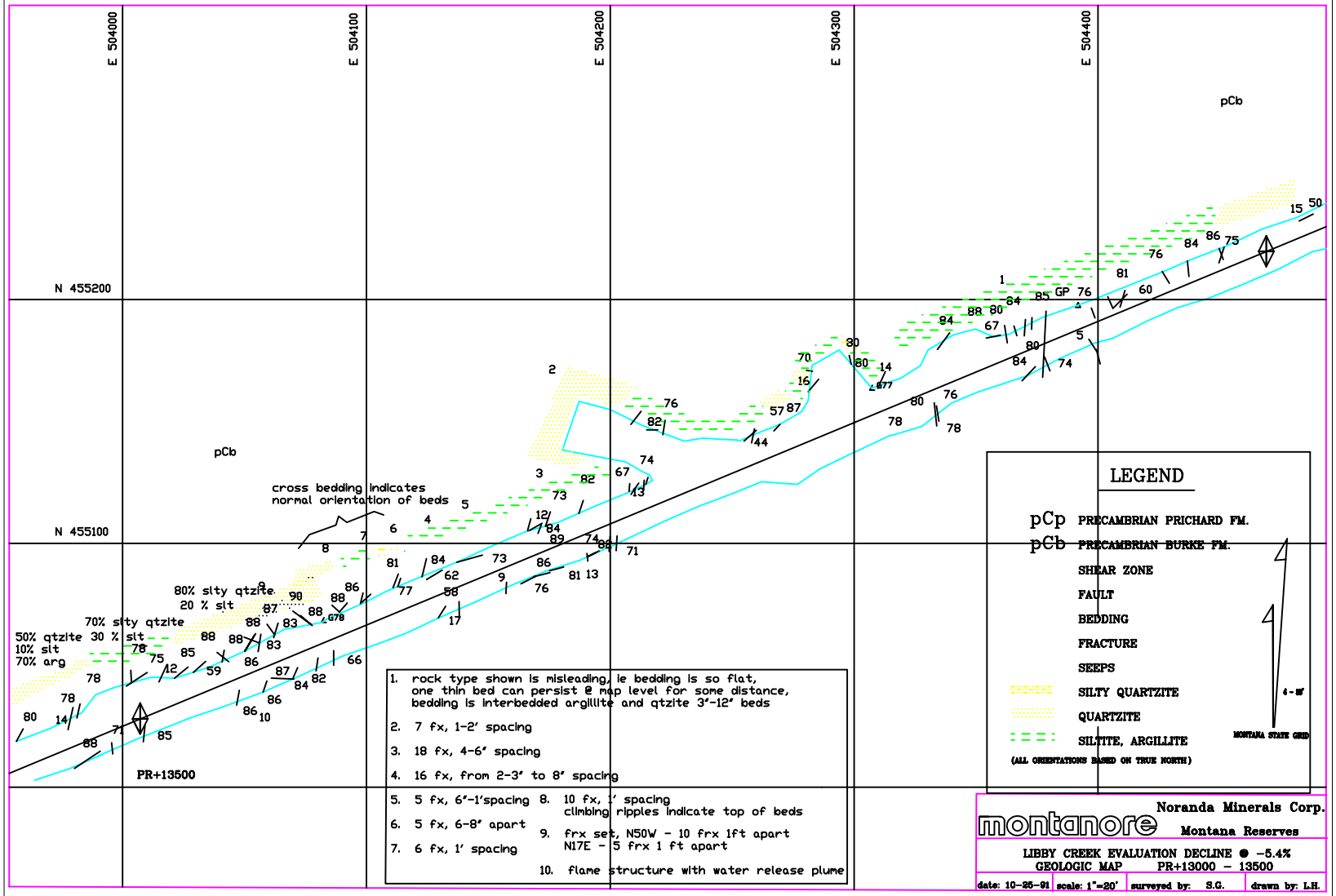
1. py xtals in qtzite, 1/16-1/4"
2. shearing along bdg planes, 1-2' gouge
   beds thin to med thickness
3. near bedding
4. silty qtzite dominant, argillite interbeds;
   arg beds 2-8' thick, silty qtzite beds 2-4' thick
5. silty qtzite beds 6'thick, arg beds 6' thick
6. channel??
7. qtzite interbeds with 6-8' argillite

parallel reverse flts cut along overturned bdg
in 80% arg, 20% silty qtzite ; flt separates overturned beds (NE) from flat lying seds (SW)

Noranda Minerals Corp.
montanore Montana Reserves

LIBBY CREEK EVALUATION DECLINE ● -5.4%
GEOLOGIC MAP PR+12500 – 13000

date: 11-18-01	scale: 1"=50'	surveyed by: S.G.	drawn by: L.H.

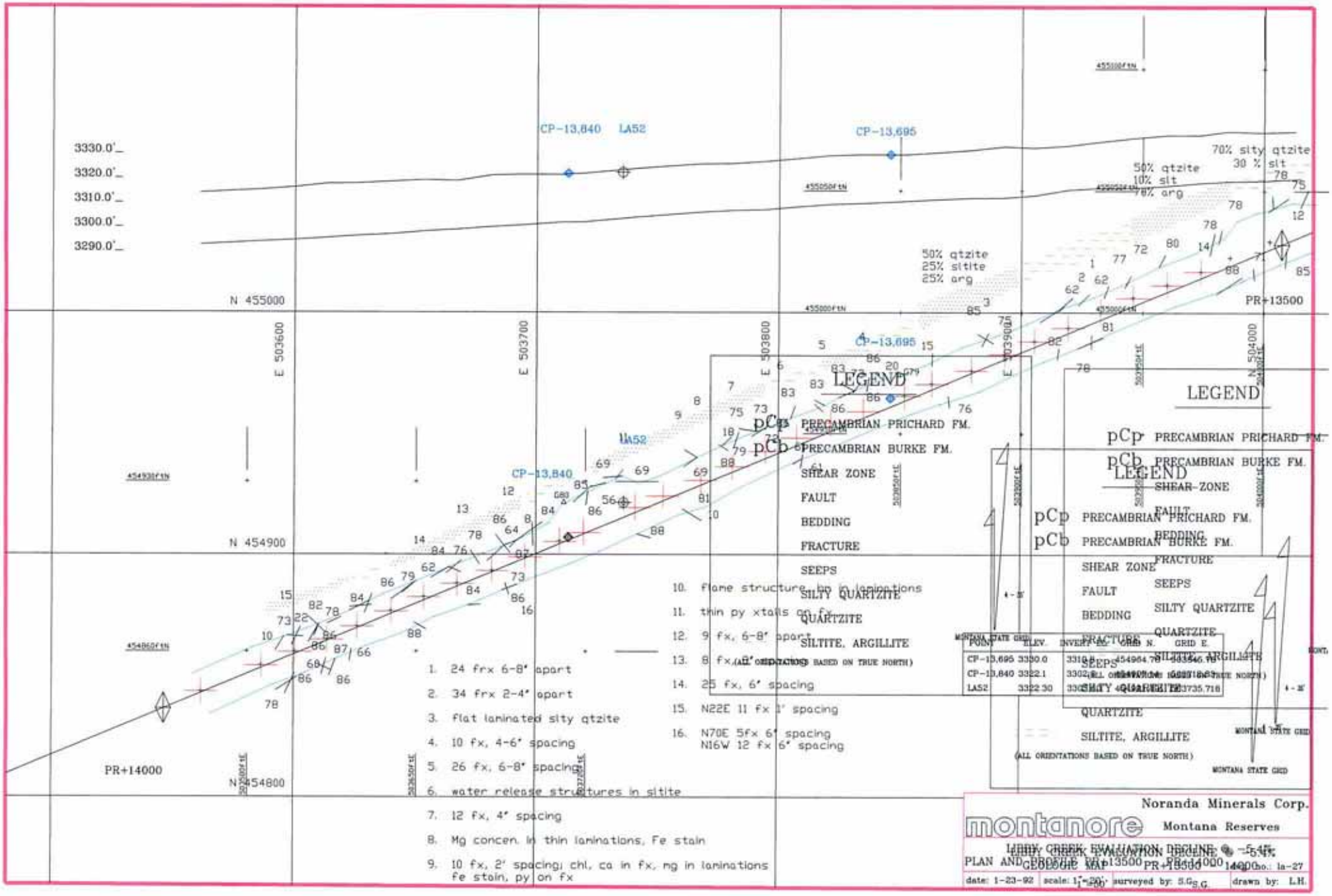


1. rock type shown is misleading, ie bedding is so flat, one thin bed can persist @ map level for some distance, bedding is interbedded argillite and qtzite 3'-12' beds
2. 7 fx, 1-2' spacing
3. 18 fx, 4-6' spacing
4. 16 fx, from 2-3' to 8' spacing
5. 5 fx, 6'-1'spacing
6. 5 fx, 6-8' apart
7. 6 fx, 1' spacing
8. 10 fx, 1' spacing climbing ripples indicate top of beds
9. frx set, N50W - 10 frx 1ft apart N17E - 5 frx 1 ft apart
10. flame structure with water release plume

Noranda Minerals Corp.
montanore Montana Reserves

LIBBY CREEK EVALUATION DECLINE @ -5.4%
GEOLOGIC MAP PR+13000 - 13500

date: 10-25-91	scale: 1"=20'	surveyed by: S.G.	drawn by: L.H.


3330.0'
3320.0'
3310.0'
3300.0'
3290.0'
CP-13,840
LA52
CP-13,695
N 455000
N 454900
N 454800
E 503600
E 503700
E 503800
E 503900
N 504000
PR+14000
PR+13500
50% qtzite
10% slt
70% arg
70% silty qtzite
30 % slt
50% qtzite
25% siltite
25% arg
LEGEND
pCp PRECAMBRIAN PRICHARD FM.
pCb PRECAMBRIAN BURKE FM.
SHEAR ZONE
FAULT
BEDDING
FRACTURE
SEEPS
SILTY QUARTZITE
QUARTZITE
SILTITE, ARGILLITE
(ALL ORIENTATIONS BASED ON TRUE NORTH)
1. 24 frx 6-8" apart
2. 34 frx 2-4" apart
3. flat laminated silty qtzite
4. 10 fx, 4-6" spacing
5. 26 fx, 6-8" spacing
6. water release structures in sitite
7. 12 fx, 4" spacing
8. Mg concen. in thin laminations, Fe stain
9. 10 fx, 2" spacing; chl, ca in fx, mg in laminations fe stain, py on fx
10. flame structure, no in laminations
11. thin py xtalls on fx
12. 9 fx, 6-8" apart
13. 8 fx
14. 25 fx, 6" spacing
15. N22E 11 fx 1" spacing
16. N70E 5fx 6" spacing
N16W 12 fx 6" spacing
MONTANA STATE GRID
Noranda Minerals Corp.
montanore
Montana Reserves
LIBBY CREEK EVALUATION DECLINE @ -5.4%
PLAN AND PROFILE MAP
date: 1-23-92
scale: 1"=20'
surveyed by: S.G.
drawn by: L.H.

APPENDIX C

BASEFLOW CALCULATIONS AND DATA

APPENDIX C
BASEFLOW CALCULATIONS AND DATA

INTRODUCTION

This appendix describes development of the steady-state baseflow portion of the water balance for the Montanore conceptual groundwater flow model. **Table C-1** presents estimates of inflow and outflow components of the groundwater water balance. The following sections discuss development of the baseflow estimates.

Table C-1. Water Balance for Montanore Model

	Low Estimate (ft^3/d)	High Estimate (ft^3/d)	Low Estimate (m^3/d)	High Estimate (m^3/d)
INFLOW				
Infiltrating Precipitation	7,931,649	18,511,358	224,607	524,202
% of Total Precipitation	8%	18%	8%	18%
Total INFLOW	7,931,649	18,511,358	224,607	524,202
OUTFLOW				
Discharge as Baseflow to Streams/Rivers	7,912,510	18,490,683	224,066	523,617
Underflow	15.5	1551	0.4	44
Evapotranspiration (ET)	19,124	19,124	542	542
Total OUTFLOW	7,931,649	18,511,358	224,607	524,202

Note: ft^3/d = cubic feet per day; m^3/d = cubic meters per day.

BASEFLOW

Groundwater contributes to the baseflow of streams throughout the model domain. Various data sources provided stream discharge or stream baseflow estimates for streams within the model domain. Seven streams; Bull River, Fisher River, Swamp Creek, Libby Creek, Rock Creek, Clark Fork River, and Big Cherry Creek were identified as major drainages within the model domain(**Table C-2**).

Bull River

Ten years of monthly averaged discharge data are available from the USGS Gage 12391550 on Bull River near Noxon Reservoir. The data extend from October 1972 through September 1982 (**Table C-3**). Flows recorded during the month of October were chosen to be representative of baseflow conditions, with the exception of the October 1975. October 1975 was abnormally wet for October according to precipitation data for the region (**Table C-4**) (PRISM 1970-2000). This results in an estimated baseflow range for the Bull River of 71 to 114 ft^3/sec, reducing to 47 to 75 ft^3/sec for the portion of Bull River within the model domain.

Table C-2. Baseflow Estimated for Each Drainage Leaving Model Domain

Stream	Low Estimate Low Flow (ft^3/sec)	High Estimate Low Flow (ft^3/sec)	Drainage Area Above Gage (ft^2)	Drainage Area Above Gage in Model (ft^2)	% of Drainage Basin Above Gage in Model Domain	Low Estimate Baseflow to Drainage in Model Domain (ft^3/sec)	High Estimate Baseflow to Drainage in Model Domain (ft^3/sec)
Bull River	71.1	114.1	3875097600	2561182753	66%	**47**	**75**
Fisher River based on Fisher River at Jennings	128	237	21745152000	2546151672	12%	**15**	28
Fisher River based on West Fisher Creek	9	23	1142257340	2546151672	223% [1]	**20**	**51**
Swamp Creek	10		836352000	557568000	67%	**6.7**	**6.7**
Libby Creek at Highway 2	4	58	1875392598	1875392598	100%	**4**	20
Libby Creek at LB-3000	16	58	1772194457	1772194457	100%	16	**58**
Rock Creek	3	7	919987200	919987200	100%	**3**	**7**
Clark Fork River						**10.4**	**10.4**
Big Cherry Creek						**5.5**	**5.5**
Total Baseflow						**91.6**	**214.3**

[1] baseflow for West Fisher Creek was extrapolated to the entire catchment area of Fisher River within the model domain

Table C-3. Mean Monthly Discharge Data at USGS Gage 12391550 Bull River Near Noxon MT

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1972										111.2	100.9	150.9
1973	236.2	136.9	197	289.4	783.7	591.4	215.6	97.2	86.8	105.1	355.5	413.1
1974	903.7	384.4	416	779.8	1,252	2,241	663.8	212	114.7	82.4	111	136.7
1975	155.8	161.2	231	313.4	1,044	1,442	600.9	173	134.2	139.1	235.9	555.2
1976	293.2	247.9	233	624.9	1,372	930.3	480	235	135.3	95.1	103	95.5
1977	84.7	96.7	142	449.3	610.8	354.7	123.5	79.7	106	110.7	152	421.6
1978	183.8	145.8	364	646.7	1,116	1,013	369.6	170	157.3	103.8	99.5	77.3
1979	60.4	104.5	311	425.5	1,255	663.9	224.8	116	80	71.1	72.9	112.8
1980	133.7	128.2	240	702.2	1,039	604.9	248.8	126	153.8	114.1	213.1	658.3
1981	428.6	372.6	323	552.7	1,163	1,047	452.3	165	104.4	99.5	124.5	200.6
1982	132.4	685	543	523.9	1,192	1,441	579.9	179	111.1			
Mean monthly Discharge	261	246	300	531	1,080	1,030	396	155	118	103	157	282

Latitude 48°02'50", Longitude 115°50'01" NAD27 Gage datum 2202.4 feet above sea level NGVD29
Drainage area 139 square miles
All flows in cubic feet per second (ft^3/sec)

Table C-4. 1972-1982 October Cumulative Precipitation in Bull River Catchment (PRISM 1970-2000)

Year	Month	Precipitation (inches)
1972	10	1.66
1973	10	1.38
1974	10	0.05
1975	10	4.91
1976	10	1
1977	10	1.49
1978	10	0.42
1979	10	2.48
1980	10	1.26
1981	10	1.87
1982	10	2.53

Longitude -115.806, Latitude 48.112
Grid Resolution: 2.5min Elevation: 959 meters

Fisher River

Nineteen years of monthly averaged discharge data were available from USGS gage 12302000 on the Fisher River near Jennings, Montana (**Table C-5**). Lowest flows for this river were recorded generally during the month of September. However, the considerable number of surface water diversions on the Fisher River upstream of the gage suggest these data are not representative of baseflow. Instead, the 19-year mean September flow was presumed to be a low end estimate of baseflow. The 19-year mean January flow (a period when minimal diversions occur and the majority of precipitation falls as snow) was used as the high-end estimate of baseflow. Resulting estimates for baseflow in the entire Fisher River range from 128 to 237 ft^3/sec, and from 15 to 28 ft^3/sec within the model domain.

Estimated baseflow in West Fisher Creek was extrapolated to the entire Fisher River catchment within the model domain as an additional baseflow estimate. The USFS-Libby Range District has collected flow data in West Fisher Creek from 2001 through 2009 (**Table C-6**). August flow rates at this gage appear to be most representative of baseflow conditions. The August flow rates range from 9 to 23 ft^3/sec. Extrapolating this baseflow to the entire Fisher River catchment area within the model domain gives baseflow values for the Fisher River ranging from 20 to 51 ft^3/sec. Coupling both the Jennings and the West Fisher Creek estimates gives a baseflow range of 15 to 51 ft^3/sec for the Fisher River within the model domain

Swamp Creek

Verifiable sources of data for flows in Swamp Creek could not be identified. ERO (2008) reported a baseflow estimate of 10 ft^3/sec for Swamp Creek, reportedly provided by the Kootenai National Forest Service. Reducing this value by the area of Swamp Creek within the model domain yields an estimated baseflow of 6.7 ft^3/sec. In the absence of additional data, no range was estimated.

Table C-5. Mean Monthly Discharge Data at USGS Gage 12302000
Fisher River, near Jennings, MT

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951	353.5	955.5	406.6	1,738	2,440	783.7	352.4	172.1	163.4	335.4	294.6	299.4
1952	247.8	229	240.5	2,097	1,326	512	233	118.3	93.9	84.2	83.2	92.6
1953	371.8	598.4	307.7	991.4	1,647	984.4	288.8	131.3	94.1	93	131.1	172.9
1954	153.3	237.5	400.6	1,791	3,243	1,266	571.8	206	177.3	194.3	246.8	197.4
1955	135.3	149.2	157.8	495.9	1,922	1,387	399.4	151.7	110.8	239	393.3	501.7
1956	375.6	243.4	510	3,265	3,070	1,086	330.9	160.6	135.7	157.3	160.6	250.7
1957	123.5	168.9	298	1,143	2,423	687	227.5	124.6	103.6	134.7	134.1	143.1
1958	144	224	393.4	1,135	1,507	460.5	184.3	96.7	91	109.7	307.6	362.8
1959	487.1	309.4	385.6	2,145	2,117	1,335	359.8	161.8	235.6	336.6	468.3	361.5
1960	240.6	234.8	620.4	1,663	1,392	933.4	271.1	157.8	118.6	117.8	167	131.9
1961	154.3	574.3	467.4	957.2	2,297	1,054	250.6	121.1	120.4	137.8	113.6	142.1
1962	168.1	288.3	207.5	1,624	1,457	723.9	226.2	124.9	104.8	146.3	259.1	339.5
1963	197.1	479.2	350.3	834.4	959.7	508.9	200.9	91.4	82.5	89.7	128.6	140.5
1964	122.9	111.7	127.5	702.2	1,748	1,304	333.5	150.8	129.1	163.2	170.8	435.7
1965	321.7	363.1	457.5	1,953	1,600	861.8	295	152.2	143.7	125.3	160.3	174.9
1966	163.1	133.1	319.9	1,389	1,364	867	252.4	125.8	102.2	107	147.4	214.3
1967	233.1	376.1	358.8	1,003	2,390	1,646	355.2	142.1	102.5	172.3	267.2	191.7
1968	229.8	493.1	699.5	589.9	1,182	691	212	115.9	201.5	243.9	294.1	225.6
1969	283.5	254.3	323	2,666	1,841	809	369.2	131.4	116.4			
Mean monthly Discharge	237	338	370	1,480	1,890	942	301	139	128*	166	218	243

Latitude 48°14'50", Longitude 115°17'30" NAD27 Gage datum 2433.94 feet above sea level NGVD29
Drainage area 780 square miles

All flows in cubic feet per second (ft^3/sec)
* there are substantial diversions from Fisher River upstream of the gage

Libby Creek

Frequent stream gaging was conducted on Libby Creek at Highway 2 between 1999 and 2009 by the USFS-Libby Range District. The station at Highway 2, which is located farthest downstream, was used to estimate baseflow in Libby Creek within the model domain. **Table C-7** presents discharge data collected at the Highway 2 station. The August data appear most representative of baseflow conditions (4 to 20 ft^3/sec). Oolder data (1988 -1993) for station LB-3000 located approximately 1 mile upstream of the Hiway 2 station suggests flow rates for Libby Creek have declined slightly in recent years. **Table C-8** presents the flow data at the LB-3000 station. The August data suggest baseflow estimates for Libby Creek at this station may range from 16 to 58 ft^3/sec. Since the entire catchment of Libby Creek above both of these gages is within the model domain, the estimated baseflow to Libby Creek within the model is 4 to 58 ft^3/sec.

Rock Creek

Similar to Swamp Creek, verifiable sources of data for Rock Creek flows could not be identified. ERO (2008) reported baseflow estimates ranging from 3 to 7 ft^3/sec for Rock Creek provided by the Kootenai National Forest Service. The entire catchment of Rock Creek lies with in the model domain.

Table C-6. Discharge Data Collected at West Fisher Creek

Date	Month	Discharge @ West Fisher Creek	Colleted by
18-Mar-08		31	USFS Erickson
23-Mar-05		42	USFS Boyd Rainey
22-Mar-04	March	116	USFS Boyd Hooper
17-Apr-08		93	USFS Erickson
18-Apr-02	April	272	USFS Hooper Wegner
12-May-05		185	USFS Boyd Thompson
10-May-06		195	USFS Boyd Wegner
29-May-07		209	USFS Gillan, Reckin, May
12-May-04		216	USFS Boyd Wegner
17-May-07		358	USFS Boyd, Gillan
9-May-08		396	USFS Erickson, Tralles
27-May-03		417	USFS Thompson Jungst Ague
22-May-08		669	USFS Boyd, Gier, May
21-May-02	May	892	USFS Hooper Jungst
28-Jun-07		60	USFS Erickson, Gillan
21-Jun-05		85	USFS Ague, Jungst
15-Jun-07		92	USFS Boyd, Erickson
9-Jun-04		138	USFS Boyd Thompson
26-Jun-06		146	USFS May, Rowan, Reckin
17-Jun-03		161	USFS Ague Pfeifer
9-Jun-03		272	USFS Thompson Pfeifer Kujawa
1-Jun-04		359	USFS Ague Jungst Thompson
13-Jun-08		363	USFS Erickson, May, Reckin
15-Jun-06	June	560	USFS Boyd, Reckin
18-Jul-05		21	USFS Jungst, Ague
9-Jul-07	July	37	USFS Erickson, May
6-Aug-07		9	USFS Gillan, Reckin
28-Aug-07		10	USFS J. Gillan, Reckin
16-Aug-07		10	USFS Gillan, Reckin, Erickson
28-Aug-02		14	USFS Jungst
12-Aug-04		18	USFS Thompson Jungst
19-Aug-09		19	USFS Erickson, Geber
25-Aug-08	August	23	USFS Gillan, Reckin
21-Sep-09	September	9	USFS Geber
1-Oct-01	October	9	USFS Hooper Wegner
16-Nov-05	November	41	USFS Boyd
12-Dec-04	December	560	USFS Boyd Wegner

Table C-7. Discharge Data Collected at the Highway 2 Station on Libby Creek

Date	Month	Discharge @ Highway 2 (f^3/sec)	Colleted by
23-Mar-99	March	195	USFS Hooper Wegner Shu
22-Mar-00		63	USFS Hooper Wegner
19-Mar-04		230	USFS Boyd Wegner
23-Mar-05		53	USFS Boyd, Rainey
13-Mar-06		61	USFS Boyd
18-Mar-08		37	USFS Erickson
15-Apr-99	April	116	USFS Hooper Mineau Shu
24-Apr-99		504	USFS Hooper Mineau Shu
28-Apr-99		548	USFS Hooper Shu Boyd
27-Apr-01		420	USFS Hooper Wegner
15-Apr-08		227	USFS Erickson
26-May-99	May	974	USFS Hooper Mineau Shu
26-May-99		971	USFS Hooper Mineau Shu
28-May-99		619	USFS Hooper Boyd Shu
4-May-00		585	USFS Hooper Monty
18-May-00		446	USFS Hooper
14-May-01		476	USFS Hooper Boyd
20-May-02		946	USFS Hooper Pfeifer Everett Jungst Ague
22-May-02		1076	USFS Jungst Pfeifer
28-May-03		483	USFS Jungst Thompson Wegner
18-May-04		190	USFS Boyd Wegner
12-May-05		202	USFS Boyd, Thompson
25-May-06		564	USFS Boyd, Rowan, Reckin
17-May-07		412	USFS Boyd, Gillan
29-May-07		245	USFS Gillan, Reckin, May
15-May-09		492	USFS Gillan, Erickson
13-Jun-00	June	620	USFS Hooper Boyd
9-Jun-03		332	USFS Kujawa Pfeifer Thompson
30-Jun-03		93	USFS Ague Thompson
1-Jun-04		365	USFS Thompson Jungst Ague
2-Jun-04		261	USFS Boyd Thompson Jungst
20-Jun-05		113	USFS thompson, may, jungst
19-Jun-06		256	USFS Erickson, Reckin, May
4-Jun-07		250	USFS Gillan, Reckin, May
28-Jun-07		77	USFS Erickson, Gillan
13-Jun-08		363	USFS Erickson, May, Reckin
25-Jun-08		340	USFS Gillan, May
8-Jun-09		339	USFS Erickson, Martin
16-Jun-09		308	USFS Erickson, Barnett, Martin
27-Jul-01	July	12	USFS Thompson Jungst Pfeifer
11-Jul-06		38	USFS Erickson, May
19-Jul-07		36	USFS Reckin
14-Jul-08		117	USFS Erickson, Reckin, May
14-Jul-09		101	USFS Barnett, Gillan, Martin
12-Aug-04	August	17	USFS Thompson Jungst
6-Aug-06		4	USFS Erickson, Reckin
13-Aug-07		9	USFS Gillan, Reckin
29-Aug-07		7	USFS Reckin, J.Gillan
19-Aug-08		20	USFS Reckin, Gillan, Erickson
19-Aug-09		16	USFS Erickson, Geber
21-Sep-09	September	7	USFS Geber
11-Dec-04	December	549	USFS Boyd, Wegner

Table C-8. Discharge Data Collected at Station LB-3000 on Libby Creek

Date	Month	Libby Creek Discharge at LB-3000 (f^3/sec)	Source
26-Jan-89	January	69	Chen-Northern, Inc., 1990 (Table 2-4).
19-Feb-90		36	Chen-Northern, Inc., April 1991.
19-Feb-91	February	204	Chen-Northern, Inc., May 1992.
30-Mar-89		155	Chen-Northern, Inc., 1990 (Table 2-4).
1-Mar-93	March	96	Huntingdon Chen-Northern, Inc., February 1994.
28-Apr-88		155	Montanore Permit Application, June 23, 1989 (Table 3-2).
12-Apr-89		270	Chen-Northern, Inc., 1990 (Table 2-4).
1-Apr-92	April	118	Chen-Northern, Inc., April 1993.
25-May-88		319	Montanore Permit Application, June 23, 1989 (Table 3-2).
9-May-89	May	748	Chen-Northern, Inc., 1990 (Table 2-4).
8-Jun-88		154	Montanore Permit Application, June 23, 1989 (Table 3-2).
22-Jun-88		139	Montanore Permit Application, June 23, 1989 (Table 3-2).
7-Jun-89		419	Chen-Northern, Inc., 1990 (Table 2-4).
22-Jun-89		154	Chen-Northern, Inc., 1990 (Table 2-4).
1-Jun-91	June	38	Chen-Northern, Inc., May 1992.
20-Jul-88		44	Montanore Permit Application, June 23, 1989 (Table 3-2).
17-Jul-89	July	105	Chen-Northern, Inc., 1990 (Table 2-4).
17-Aug-88		16	Montanore Permit Application, June 23, 1989 (Table 3-2).
14-Aug-89		33	Chen-Northern, Inc., 1990 (Table 2-4).
1-Aug-91		17	Chen-Northern, Inc., May 1992.
1-Aug-92		18	Chen-Northern, Inc., April 1993.
1-Aug-93	August	58	Huntingdon Chen-Northern, Inc., February 1994.
14-Sep-88		11	Montanore Permit Application, June 23, 1989 (Table 3-2).
21-Sep-89	September	23	Chen-Northern, Inc., 1990 (Table 2-4).
19-Oct-88		160	Montanore Permit Application, June 23, 1989 (Table 3-2).
1-Oct-92		33	Chen-Northern, Inc., April 1993.
1-Oct-93	October	30	Huntingdon Chen-Northern, Inc., February 1994.
30-Nov-88	November	69	Montanore Permit Application, June 23, 1989 (Table 3-2).
15-Dec-88	December	93	Montanore Permit Application, June 23, 1989 (Table 3-2).

Clark Fork River

Discharge data for the Clark Fork River were not available downstream of Noxon. Since a large section of the model has flow entering the Clark Fork downstream from Noxon, a discharge to catchment area relationship approach was used to estimate baseflow. To estimate baseflow reporting to the Clark Fork River within the model domain, baseflow per catchment area was calculated and averaged for two nearby drainages (Rock Creek and East Fork Bull River). The resulting baseflow per catchment area value (9.62×10^{-9} $ft^3/sec/ft^2$) was multiplied by the catchment area reporting to the Clark Fork River minus the areas reporting to Swamp Creek and Rock Creek. The resultant estimated baseflow to the Clark Fork River in the model domain is 10.4 ft^3/sec (**Table C-9**).

Table C-9. Calculation of Baseflow to the Portion of Clark Fork River in Model Domain

	Estimated Baseflow (ft^3/sec)	Drainage Area (ft^2)	Baseflow per Catchment Area (ft^3/sec/ft^2)
Rock Creek	5[a]	919,987,200	5.43E-09
East Fork Bull River	10[b]	724,838,400	1.38E-08
Average Baseflow per Catchment Area			9.62E-09
Drainage Area of the Clark Fork Excluding Swamp C. Rock C.		108,630,9794	
Clark Fork Area x Average Baseflow per Catchment Area (Baseflow)	10.4		

[a] average of values reported by ERO 2009

[b] value reported by ERO 2009

Big Cherry Creek

Similar to the Clark Fork River, no discharge data for Big Cherry Creek were available. To estimate baseflow reporting to Big Cherry Creek within the model domain, baseflow per catchment area was calculated and averaged for three nearby drainages (West Fisher Creek, Little Cherry Creek, and Libby Creek). The resulting baseflow per catchment area value (1.72×10^{-8} ft^3/sec/ft^2) was multiplied by the catchment area reporting to Big Cherry Creek. Estimated baseflow to Big Cherry Creek is 5.5 ft^3/sec (**Table C-10**).

Table C-10. Calculation of Baseflow to the Portion of Big Cherry Creek in Model Domain

	Estimated Baseflow (ft^3/sec)	Drainage Area (ft^2)	Baseflow per Catchment Area (ft^3/sec/ft^2)
West Fisher Creek	12[a]	1198771200	1.00E-08
Little Cherry Creek	1.5[b]	52968960	2.78E-08
Libby Creek L3000	16.9[c]	1230932486	1.37E-08
Average Baseflow per Catchment Area			1.72E-08
Drainage Area of Big Cherry within Model Domain		321202864	
Big Cherry Creek Area x Average Baseflow per Catchment Area	5.5		

[a] average of values reported by ERO 2009

[b] estimated September Flow Table 2.10 Klohn Crippen 2005

[c] average of September Flows Measured in Libby Creek LB-3000

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APPENDIX D

HYDRAULIC TESTING MEMORANDUM

Technical Memorandum

To Eric Klepfer, Kelpfer Mining Services;
Mike Galloway and Richard Trenholme, ERO
From Amelia Tallman and Cam Stringer, AMEC Geomatrix
Tel (406) 542-0129
Fax (406) 542-0130
Date December 15, 2009
Subject Analysis of Underground Hydraulic Test Data, Libby Adit, Montanore Project

1.0 INTRODUCTION

Montanore Minerals Corp. (MMC) completed seven hydraulic tests in the Libby Adit between September and November of 2009 to characterize the hydraulic properties of underground fracture systems. AMEC Geomatrix analyzed the hydraulic test data as presented in this Memorandum. Hydraulic testing methods and results of analysis are discussed below. Referenced tables and figures are attached.

The Libby Adit is located at the Montanore Mine Project site in northwestern Montana. The Libby Adit extends approximately 14,000 feet into bedrock, with the first 7200 feet of adit currently dewatered. MMC has drilled across several water producing fracture systems in the first 7200 feet of adit and instrumented them for hydraulic testing.

2.0 TEST HOLE INSTALLATION AND CONSTRUCTION

MMC named test holes based on the approximate length from the Adit Portal (**Figure 1**). Fracture sets located 3110, 3680, 4500 and 5220 feet down the portal were grouted and plumbed in order to monitor and manage groundwater inflow. The fracture sets were plumbed as described by MMC below.

> *Typical test hole installation consists of drilling a 3¼-inch diameter pilot hole 6 to 7 feet into bedrock. Five feet of 2½-inch (ID) steel casing is then inserted into the pilot hole. The casing is slotted at one end and has a continuous steel bead welded (spiraled) along the entire length to assist with grouting around the casing and annulus of the hole. The casing is secured to the adit surface or rib with a steel plate and 9-ft split sets. Grout is then pumped into the casing and forced out through the slots to the annulus of the pilot hole. The grout hardens for at least 24 hours, then the inside of the casing is drilled and pressure checked before proceeding with further drilling. After drilling is completed, a 3-inch stainless steel ball valve is installed at the threaded collar (**Figure 2**).*

At the 3110 fracture set, test holes were completed on either side of the adit rib referred to as 3110RR (Right Rib) and 3110LR (Left Rib). Similarly at site 5220, test holes were completed on either side of the adit (5220RR and 5220LR). **Table 1** presents test hole locations and completion information for the six locations monitored during the hydraulic tests.

3.0 HYDRAULIC TEST SETUP AND RESPONSE

Single flow tests were conducted at sites 3110LR, 3680RR, and 4500LR. Two tests were conducted at sites 3110RR and 5220RR. The hydraulic tests were conducted by opening the pressure release valve (**Figure 2**) on the test hole to permit water to flow, while pressure transducers collect pressure head data at either the flowing test hole and/or at nearby shut-in test holes. Shut-in test holes have the pressure release valve closed allowing the pressure transducer (installed at the Quick Couple [**Figure 2**]) to collect pressure readings. Forty-eight hours of background pressure data were collected at each test hole location prior to the test to obtain natural pressure head trends. Background pressure head data did not necessitate trend correction of test data except for the drawdown and recovery data collected at 3680RR during the test of 3110LR.

Table 2 summarizes the test set up, monitored locations, and test duration for each test. Since the test holes are obliquely angled and drilled into the side-wall of the adit, the approximate midpoint where water was intercepted in the test hole was used to determine the radial distance between the flowing test hole and observation test hole.

3110RR

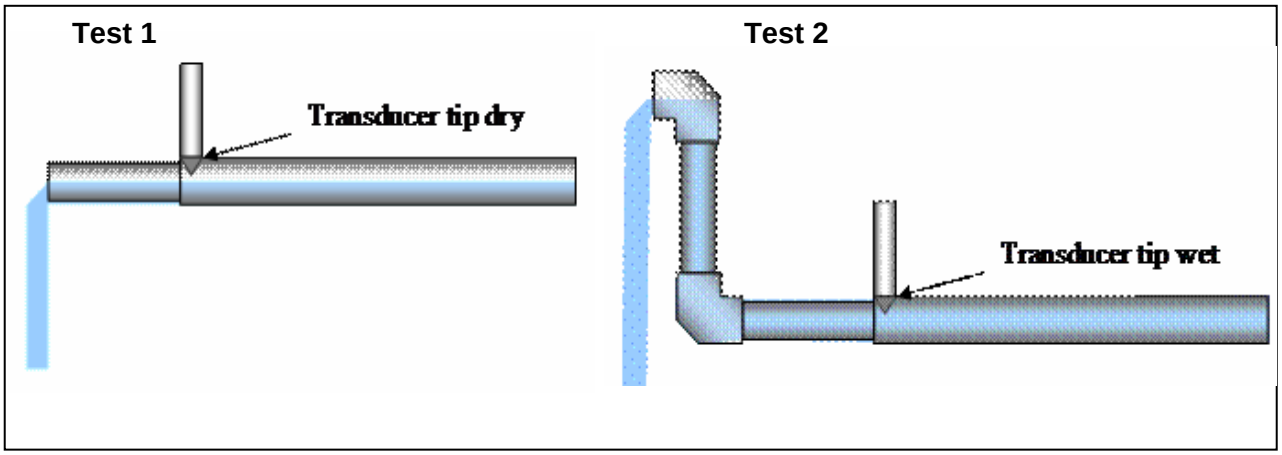
Test hole 3110RR was tested twice. The first and second tests were conducted between September 18 and 21 and November 2 and 3, respectively. During the first test, 3110RR flowed at approximately 1.44 gallons per minute (gpm), while shut-in pressures at 3110LR (49 feet away) and 3680RR (471 feet away) were monitored. Prior to shut-down, a transducer was installed on 3110RR for collection of recovery data. For the second test, the 3110RR pipe outlet was plumbed such that, if the flow rate was not high enough to maintain a full pipe, the transducer would not go dry as displayed in **Diagram 1**. The second 3110RR test had a flow rate of 1.37 gpm. Only the flowing test hole was instrumented for the second test since no drawdown was observed at either of the nearest test hole locations during the first test.

No drawdown was observed at either monitoring location during the first test (**Figure 3**), suggesting the fractures at 3110RR are not connected to the nearby fractures at 3110LR nor the more distant fractures at 3680RR. Despite the modified plumbing efforts for the second test, the transducer began measuring barometric pressures soon after the valve on 3110RR was opened (**Figure 4**). This result suggests insufficient flow from the groundwater system was supplied to the fracture system around the test hole resulting in desaturation.

3110LR

Test hole 3110LR was tested at an average flow rate of 2.36 gpm between October 26 and 27. During this test, flowing test hole 3110LR and shut-in test hole 3680RR, located a distance of 480 feet from 3110LR, were instrumented with transducers. The fractures monitored by test hole 3110LR became desaturated during the test (**Figure 5**), similar to the tests at 3110RR. The background pressure head data collected at 3680RR displayed a declining trend. To correct for the trend a straight line was fit to the pressure head data from the beginning of the background to the end of recovery. The straight line had a slope of -0.000079 feet per minute. After correcting for the declining trend at 3680RR, a total drawdown of 0.324 foot was observed (**Figure 6**). The communication between 3110LR and 3680RR suggests the fracture systems at these locations are hydraulically connected. However, as indicated above for the first test of hole 3110RR, the fractures at 3110LR do not appear to be hydraulically connected to 3110RR located only 49 feet away.

Diagram 1. Plumbing of Test Hole and Transducer Installation



3680RR

Test hole 3680RR was tested between October 19 and 20 with an average flow rate of 9.3 gpm. Both flowing test hole 3680RR and shut-in test hole 3110LR pressures were monitored during the test. Again despite plumbing efforts, the fractures associated with the flowing test hole became desaturated shortly after the valve was opened. A maximum pressure head drawdown of 1.09 feet was observed at test hole 3110LR, located 480 feet from 3680RR (**Figure 7**).

4500LR

Test hole 4500LR was tested at an average flow rate of 0.49 gpm from September 30 to October 1. This test was conducted simultaneously with the first test at 5220RR (see below). Because these tests were conducted simultaneously, the drawdown and recovery data from both tests may be affected.

However, during the second test at 5220RR (see below), stable pressure heads at 4500LR (located 780 feet away) suggest no hydraulic communication between the fracture systems. During the test at 4500LR, the flowing test hole became desaturated (**Figure 8**).

5220RR

Test hole 5220RR was tested twice, with the first test conducted at an average flow rate of 88.7 gpm from September 30 to October 1, and the second test conducted at an average flow rate of 85.25 gpm from October 5 to 8. During the first test, only shut-in test hole 5220LR, which is located 96 feet from the 5220RR was monitored. During the second test at 5220RR, pressure heads were monitored at both shut-in test holes 5220LR and 4500LR.

During the first test, a maximum pressure head drawdown of 94.48 feet was observed at 5220LR after 24 hours (**Figure 9**). During the second test, after 72 hours, a maximum of 125.97 feet of pressure head drawdown was observed at 5220LR and no drawdown was observed at 4500LR (780 feet away) (**Figure 10**). The lack of communication with 4500LR during this high flowing test suggests the fracture system at 5220RR, which is relatively permeable, is isolated by very low permeability rock perpendicular to its trend.

4.0 HYDRAULIC TEST ANALYSES

Time-drawdown and recovery data from both the flowing location and an observation location are generally analyzed to determine hydraulic properties of a water-bearing rock system. Results of the testing and data analysis are summarized in **Table 3**. During the Libby Adit tests, drawdown data for the flowing test holes was not available, since desaturation occurred in the fracture systems, resulting in the transducer at the flowing test hole recording only barometric pressures. Because of this condition, only recovery data were available for analysis at the flowing test holes. Time-drawdown data were collected at observation shut-in test holes during four of the seven tests.

Determining the most appropriate analysis method for the time-drawdown data from the observation test holes required formulation of a conceptual model. In the Cabinet Mountains, primary faults and fractures generally follow a northwest-southeast fabric; thus the conceptual model consists of a series of generally parallel fractures. Time-drawdown data from the hydraulic tests most resembled type curves of the "confined fractured aquifer of double porosity type" (Kruseman and de Ridder, 1991). Furthermore, the assumptions associated with these type curves fit our conceptual model. The Moench (1984) Slab-Shaped Block analytical method, a specific solution for double porosity fractured aquifers, was chosen as the most appropriate method for estimating the hydraulic conductivity and specific storage of both the fracture systems and the rock matrix. **Table 3** summarizes results of the analyses, and **Attachment 1** presents all of the straight-line and curve matches.

Where only recovery data were available, the data were analyzed using the Theis Recovery (1946) method. This straight-line method allows for estimates of the combined transmissivity of the fracture and matrix system intercepted by the flowing test hole. Many of the assumptions in the analytic equations for the Theis Recovery method were not met in this system, including the assumptions that the aquifer has infinite areal extent, is homogeneous, isotropic and of a uniform thickness. However, use of this method allows for estimation of relative hydraulic properties.

The following summarizes calculated hydraulic properties from the various tests (**Table 3**):

3110 RR: Based on recovery data, the combined hydraulic conductivity of the fracture system and rock matrix intercepted by test hole 3110RR is approximately 6.3×10^{-3} ft/d (feet per day) or 2.2×10^{-6} cm/s (centimeters per second).

3110LR: Hydraulic conductivity of the fracture system at test hole 3110LR is approximately 2.4 ft/d (8.5×10^{-4} cm/s). The rock matrix in this region is approximately five orders of magnitude lower at 1.1×10^{-5} ft/d or 3.9×10^{-9} cm/s. The combined hydraulic conductivity of the fracture system and rock matrix based on the recovery data at 3110LR is 3.7×10^{-3} ft/day or 1.3×10^{-6} cm/s. The specific storage in this fracture set and the surrounding rock matrix is estimated to be 1.6×10^{-9} and 6.3×10^{-6}, respectively.

3680RR: Hydraulic conductivity of the fracture system at 3680RR is approximately 2.2 ft/d or 7.7×10^{-4} cm/s, with a rock matrix roughly six orders of magnitude lower (1.9×10^{-6} ft/d or 6.6×10^{-10} cm/s). The combined hydraulic conductivity of the fracture system and rock matrix based on the recovery data at 3680RR is 4.12×10^{-2} ft/day or 1.5×10^{-5} cm/s. The specific storage in this fracture set and the surrounding rock matrix is estimated to be 2.9×10^{-7} and 5.9×10^{-6}, respectively.

4500LR: The hydraulic conductivity of the fracture system and rock matrix intercepted by test hole 4500LR of 2.3×10^{-6} ft/d or 8.2×10^{-10} cm/s suggests that the permeability of this set of fractures is low compared with the other fracture systems tested.

5220RR: Hydraulic conductivity of the fracture system between 5220RR and 5220LR is approximately 9.7×10^{-2} ft/d or 3.4×10^{-5} cm/s, with a rock matrix hydraulic conductivity roughly five orders of magnitude lower (5.9×10^{-6} ft/d or 2.1×10^{-9} cm/s). The combined hydraulic conductivity of the fracture system and rock matrix based on the recovery data at 5220LR is 1.2×10^{-1} ft/day or 4.2×10^{-5} cm/s. The specific storage in this fracture set and the surrounding rock matrix is approximately 8.3×10^{-9} and 1.1×10^{-6}, respectively.

Below is a summary of geometric mean hydraulic conductivity (K) values calculated using all recovery and drawdown test results presented in **Table 3**:

- K (fractures/rock matrix) using recovery data = 5.7×10^{-3} ft/d or 2.0×10^{-6} cm/s
- K (fractures) using drawdown data = 4.7×10^{-1} ft/d or 1.7×10^{-4} cm/s
- K (rock matrix) using drawdown data = 5.2×10^{-6} ft/d or 1.8×10^{-9} cm/s

Another way to assess the test results is based on distance from the test location underground to ground surface (using geometric mean K values):

<u><1000 feet below ground surface (sites 3110 and 3680)</u>

- K (fractures/rock matrix) using recovery data = 8.8×10^{-3} ft/d or 3.1×10^{-6} cm/s
- K (fractures) using drawdown data = 2.3 ft/d or 8.1×10^{-4} cm/s
- K (rock matrix) using drawdown data = 4.6×10^{-6} ft/d or 1.6×10^{-9} cm/s

<u>>1000 feet below ground surface (site 5220)</u>

- K (fractures/rock matrix) using recovery data = 3.2×10^{-3} ft/d or 1.1×10^{-6} cm/s
- K (fractures) using drawdown data = 0.1 ft/d or 3.4×10^{-5} cm/s
- K (rock matrix) using drawdown data = 5.9×10^{-6} ft/d or 2.1×10^{-9} cm/s

5.0 APPLICATION OF HYDRAULIC TEST DATA TO NUMERICAL MODEL

The information obtained during hydraulic testing in the Libby Adit will be used to further refine the design of the 3-D groundwater flow model for the Montanore Mine Project. In particular, the model will be calibrated to the time-drawdown data observed during the tests at 3680RR and 5220RR. In addition, the general hydraulic conductivity of the model may be adjusted with respect to the average rock fracture and matrix hydraulic conductivity and specific storage values determined during the tests.

Specific changes to be evaluated for the groundwater model include:

- Perform another calibration step by iteratively adjusting hydraulic conductivity values and storage parameters in the Libby Adit at the test locations until drawdown is matched.
- The calibrated hydraulic property distribution around the fracture sets will be used to assess the assignment of hydraulic properties throughout the remainder of the model domain for fracture and fault zones and overall rock matrix. This more detailed assessment will focus on areas within and immediately surrounding the adits and underground mine workings.
- The assignment of hydraulic properties also will incorporate an assessment of depth below ground surface as discussed above in Section 4.0.

In general, it is expected that the revised model will incorporate more known fracture and fault zones, with variable hydraulic conductivity values according to depth below ground surface. In addition, the rock matrix may have reduced hydraulic conductivity values between the known fracture and fault zones compared with rock matrix values used in the previous model.

6.0 REFERENCES

Kruseman, G. P., and N.A. de Ridder 1991. Analysis and Evaluation of Pumping Test Data 2nd Ed. International Institute for Land Reclamation and Improvement. Publication #47. The Netherlands.

Moench, A.F., 1984. Double-Porosity Models for a Fissured Groundwater Reservoir with Fracture Skin. Water Resources Research, vol. 20, no. 7, pp. 831-846.

TABLES

Table 1. Test Hole Locations and Completion

Test Hole ID	Collar Location	Collar X	Collar Y	Collar Z	Test Hole Azimuth	Test Hole Plunge (dip)	Test hole length (ft)	Test Hole Diameter (in)	Date Drilled	Approx. Distance (ft) to H2O	Approx. Midpoints of H_2O Intersect X	Approx. Midpoints of H_2O Intersect Y	Approx. Midpoints of H_2O Intersect Z	Rate (gpm)
3110RR	PR + 3144'	513568.5	459006.1	3875.7	270°	(+) 11°	63	1 7/8	8/5/2009	60	513507.2	459001.2	3887.5	1.94
3110LR	PR + 3268'	513461.2	458941.2	3867.4	81°	(+) 19°	75	1 7/8	8/28/2009	68	513530.7	458957.9	3890.6	3.16
3680RR	PR + 3620'	513128.6	458824.2	3861.2	275°	(+) 13°	66	1 7/8	8/28/2009	60	513066.5	458834.6	3875.4	10.00
4500LR	PR + 4524'	512300.8	458460.8	3813.2	80°	(+) 17°	155	1 7/8	8/28/2009	146	512446.5	458498.6	3857.2	0.63
5220LR	PR + 5220'	511658.9	458191.5	3771.9	75°	(+) 17°	100	1 7/8	7/29/2009	93	511753.8	458208.9	3800.1	40.00
5220RR	PR + 5220'	511621.0	458214.9	3769.2	43°	(+) 9°	150	?	1991 ?	?	511699.6	458286.8	3785.9	75.00

Notes: X and Y are in mine coordinates

ft: feet

in: inches

gpm: gallons per minute

?: unknown

Table 2. Hydraulic Test Set Up and Implementation

Flowing Test Hole	Observation Pipe	Distance (ft)	Average Flow Rate (gpm)	Duration (hr)	Maximum Drawdown (ft)
3110RR	3110LR	49.31	1.44	72.3	nm
	3680RR	471.26	1.44		nm
	3110 RR	0.078	1.44		Only Recovery
3110RR	3110RR	0.078	1.37	24.7	Desaturated
3110LR	3110LR	0.078	2.36	24.6	Desaturated
	3680RR	480.52	2.36		0.324
3680RR	3110LR	480.52	9.3	24.5	1.09
	3680RR	0.078	9.3		Desaturated
4500LR	4500LR	0.078	0.489	26.1	Desaturated
5220RR	5220LR	95.9	88.7	24.3	94.48
5220RR	5220LR	95.9	85.25	72.3	125.97
	4500LR	779.6	85.25		nm

notes:

ft: feet

gpm: gallons per minute

hr: hours

Table 3. Summary of Hydraulic Test Results

Flowing Test Hole	Observation Test Hole	Distance (ft)	Average Flow Rate (gpm)	Duration (hr)	Maximum Drawdown (ft)	ANALYSIS	Estimated Aquifer Thickness (ft)	T_1 (ft^2/d)	K_0 (fracture/ matrix) (ft/d)	K_1 (fracture) (ft/d)	K_2 (matrix) (ft/d)	Ss_1 (fracture)	Ss_2 (matrix)	K_0 (fracture/ matrix) (cm/s)	K_1 (fracture) (cm/s)	K_2 (matrix) (cm/s)
3110RR	3110RR	0.078	1.44	72.3	Desaturated	Theis Recovery	150	1.1	7.13E-03	-	-	-	-	2.52E-06	-	-
3110RR	3110RR	0.078	1.37	24.7	Desaturated	Theis Recovery	150	0.8	5.53E-03	-	-	-	-	1.95E-06	-	-
3110LR	3110LR	0.078	2.36	24.6	Desaturated	Theis Recovery	150	0.56	3.73E-03	-	-	-	-	1.32E-06	-	-
	3680RR	480.52			0.324	Moench (slab blocks)	150	-	-	2.41E+00	1.12E-05	1.57E-09	6.25E-06	-	8.52E-04	3.93E-09
3680RR	3110LR	480.52	9.3	24.5	1.09	Moench (slab blocks)	181	-	-	2.22E+00	1.87E-06	2.97E-07	5.93E-06	-	7.82E-04	6.60E-10
	3680RR	0.078			Desaturated	Theis Recovery	181	7.5	4.12E-02		-	-	-	1.45E-05	-	-
4500LR	4500LR	0.078	0.489	26.1	Desaturated	Theis Recovery	301	0.0007	2.33E-06	-	-	-	-	8.20E-10	-	-
5220RR	5220LR	95.9	88.7	24.3	94.48	Theis Recovery	450	46.3	1.03E-01	-	-	-	-	3.63E-05	-	-
						Moench (slab blocks)		-	-	1.06E-01	5.97E-06	1.63E-08	8.56E-07	-	3.73E-05	2.11E-09
5220RR	5220LR	95.9	85.25	72.3	125.97	Moench (slab blocks)	450	-	-	8.83E-02	5.76E-06	3.02E-10	1.29E-06	-	3.12E-05	2.03E-09
						Theis Recovery		59.5	1.32E-01	-	-	-	-	4.66E-05	-	-
Geomean									5.69E-03	4.73E-01	5.18E-06	6.92E-09	2.53E-06	2.01E-06	1.67E-04	1.83E-09

Notes:

T: Transmissivity

K: Hydraulic Conductivity

Ss: Specific Storage

ft: feet

gpm: gallons per minute

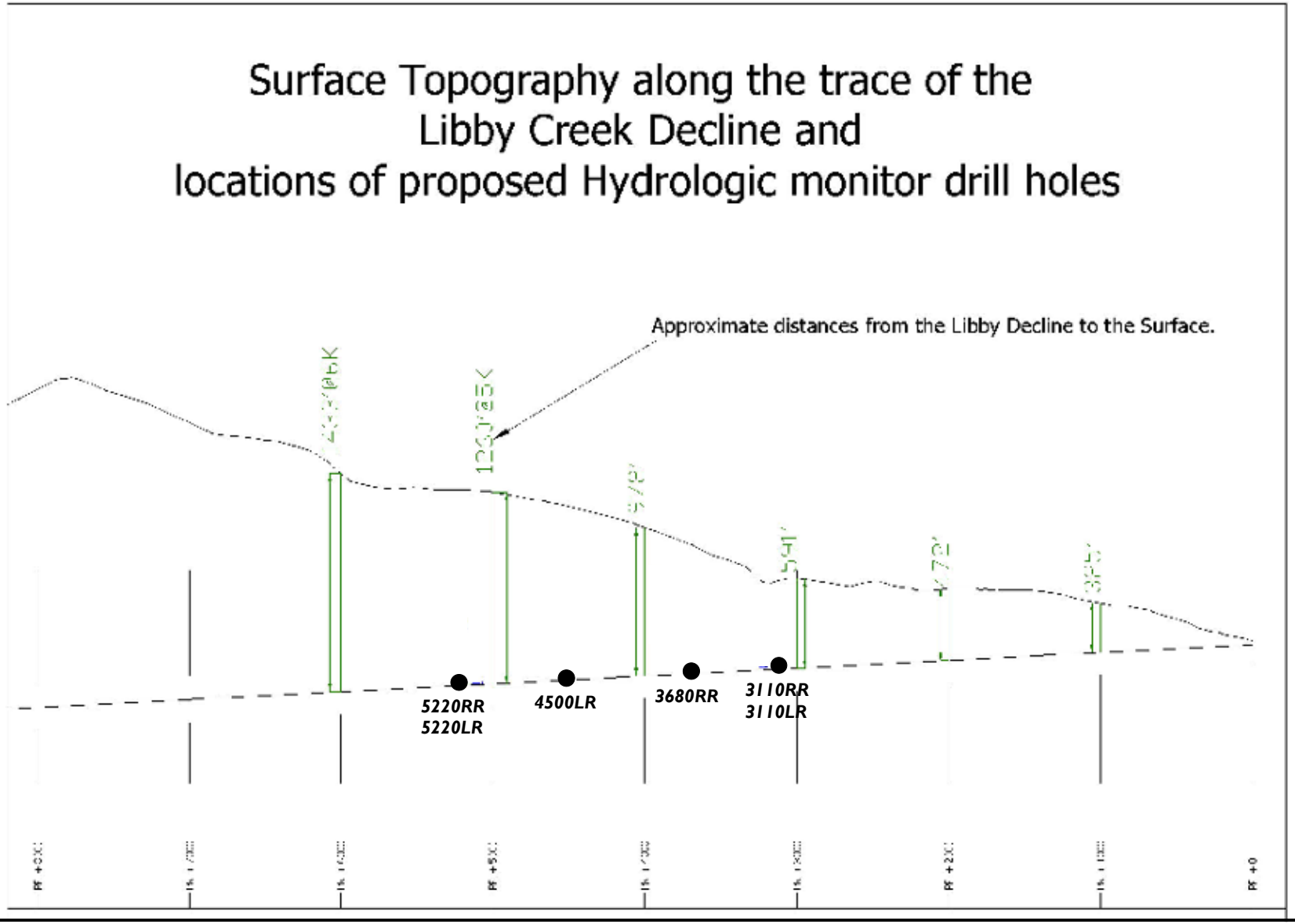
hr: hours

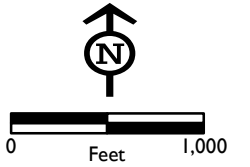
ft2/d: square feet per day

ft/d: feet/ perday

cm/s: centimeters per second

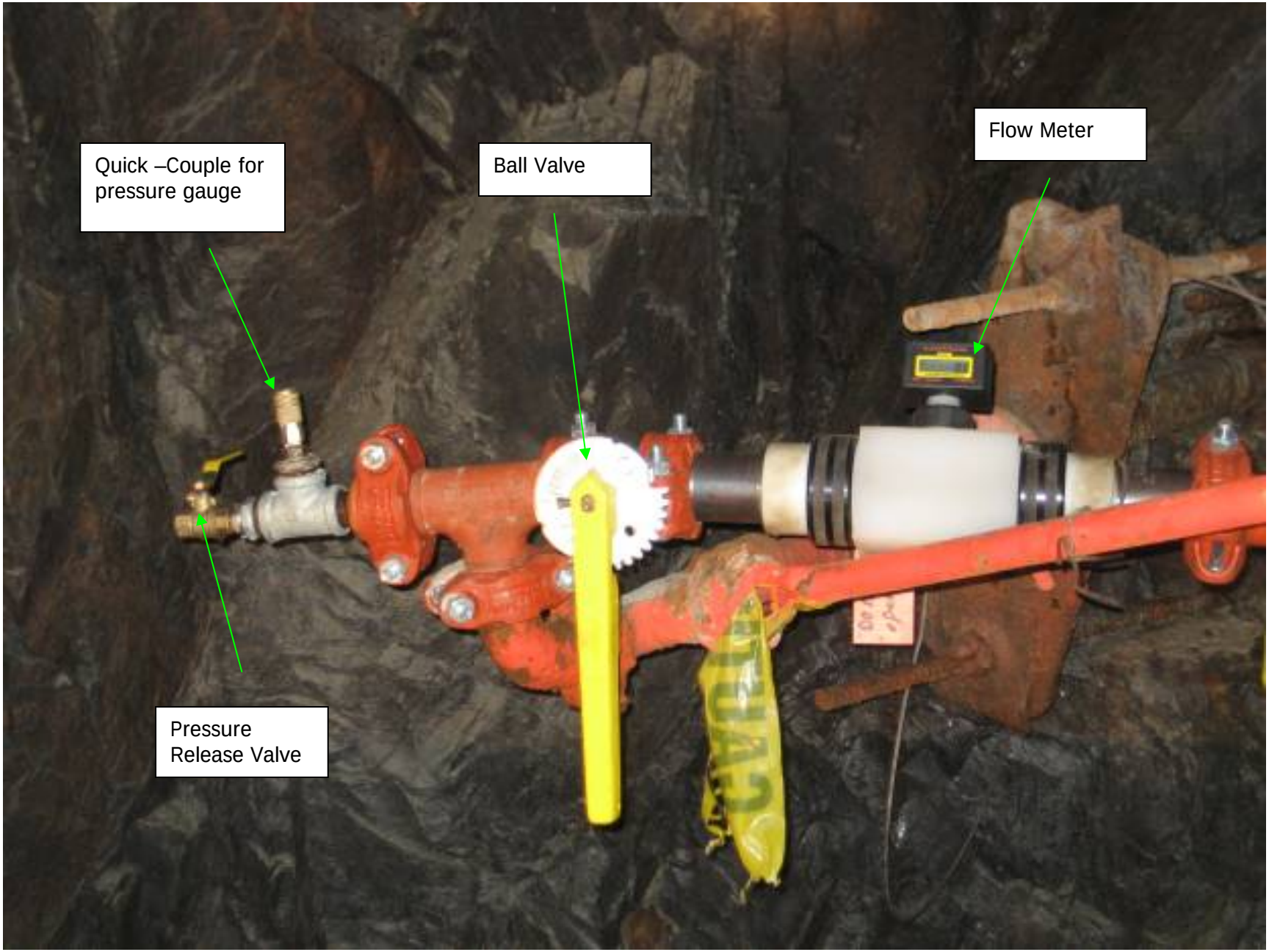
FIGURES





AMEC Geomatrix

Test Hole Locations
Montanore Mine
Lincoln County, Montana
FIGURE 1



Test Hole Plumbing Setup
Montanore Mine
FIGURE 2

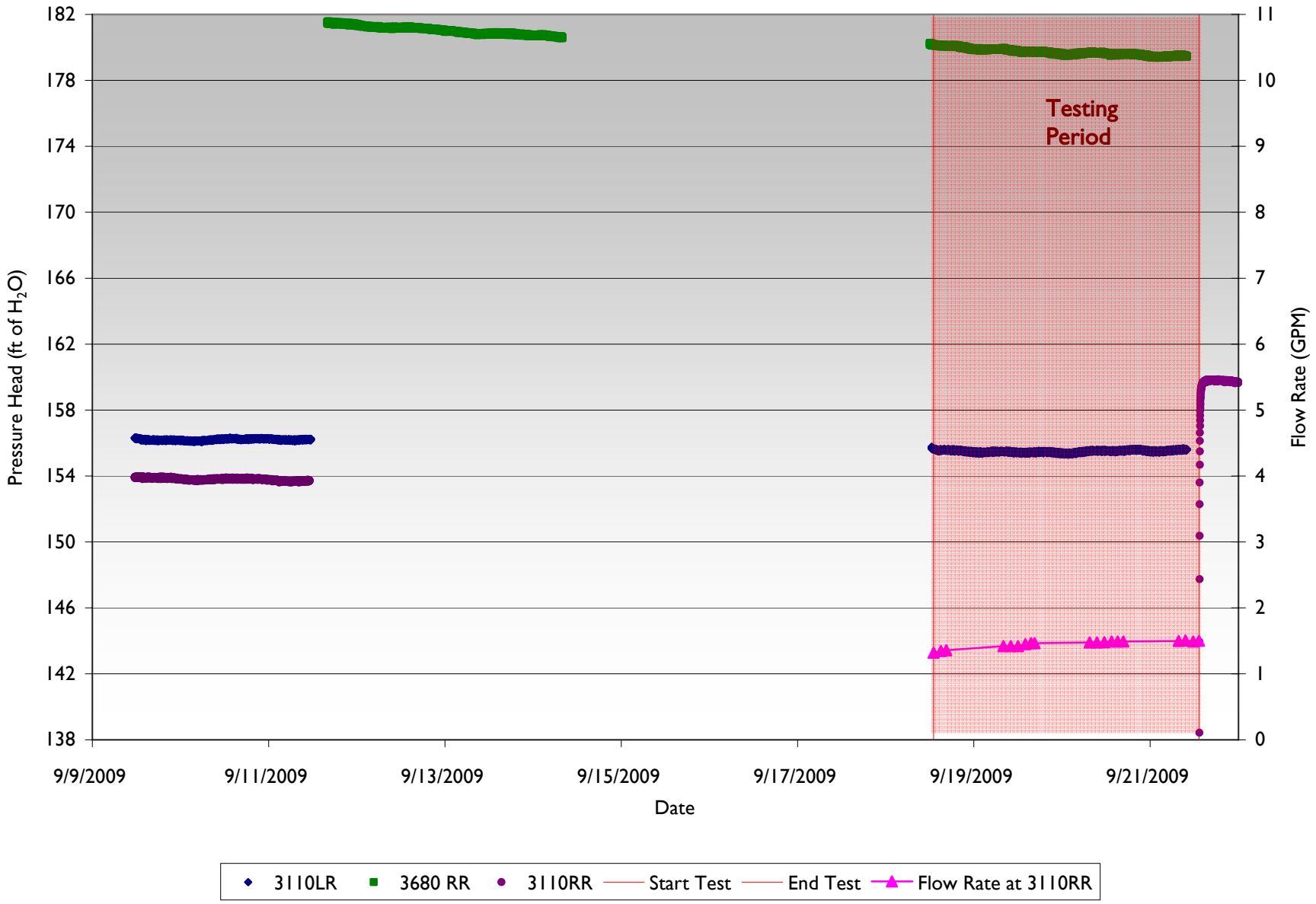


FIGURE 3
Background and Test at 3110RR (9/18/09 through 9/21/09)

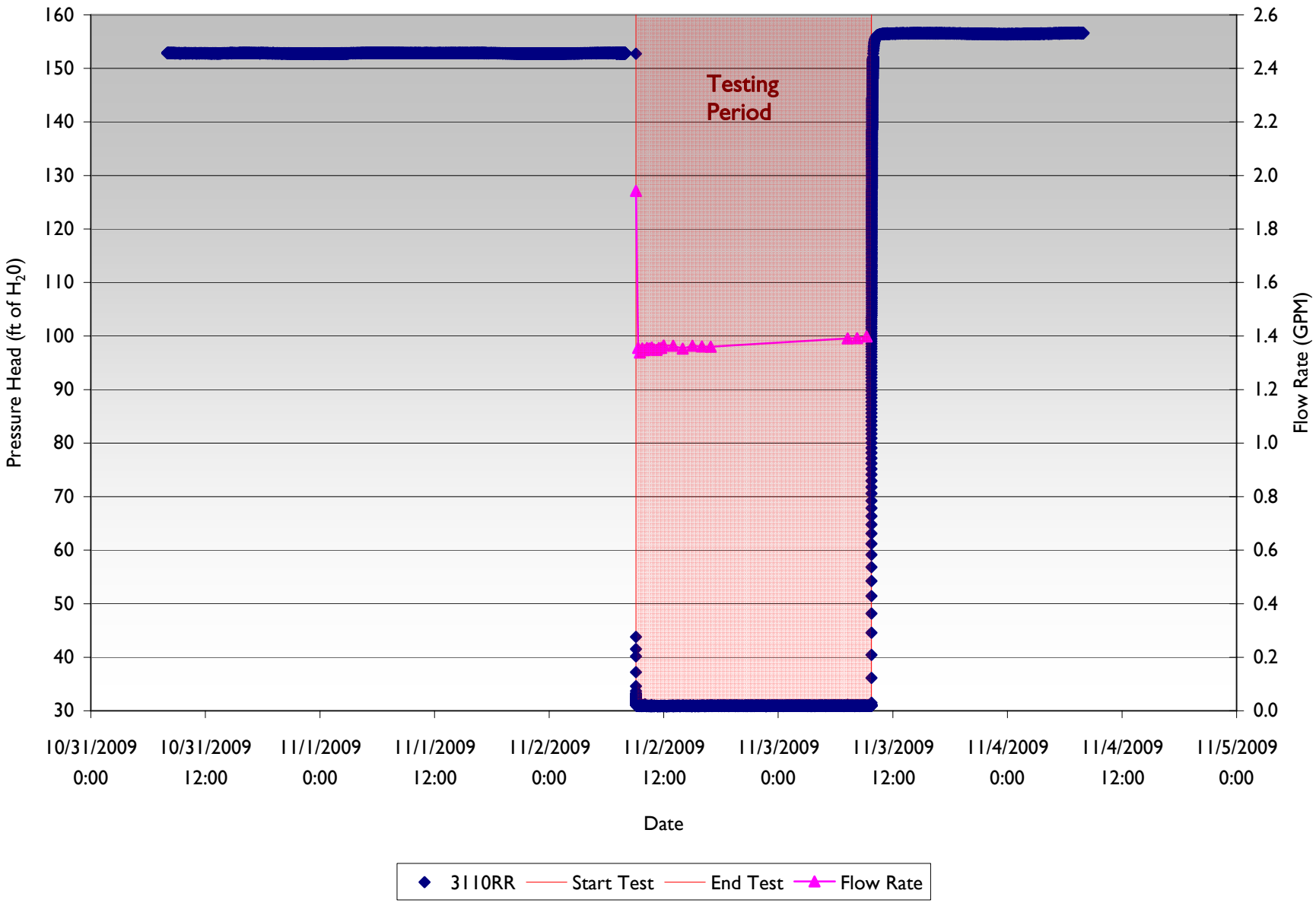


FIGURE 4
Test at 3110RR (11/2/09 through 11/3/09)

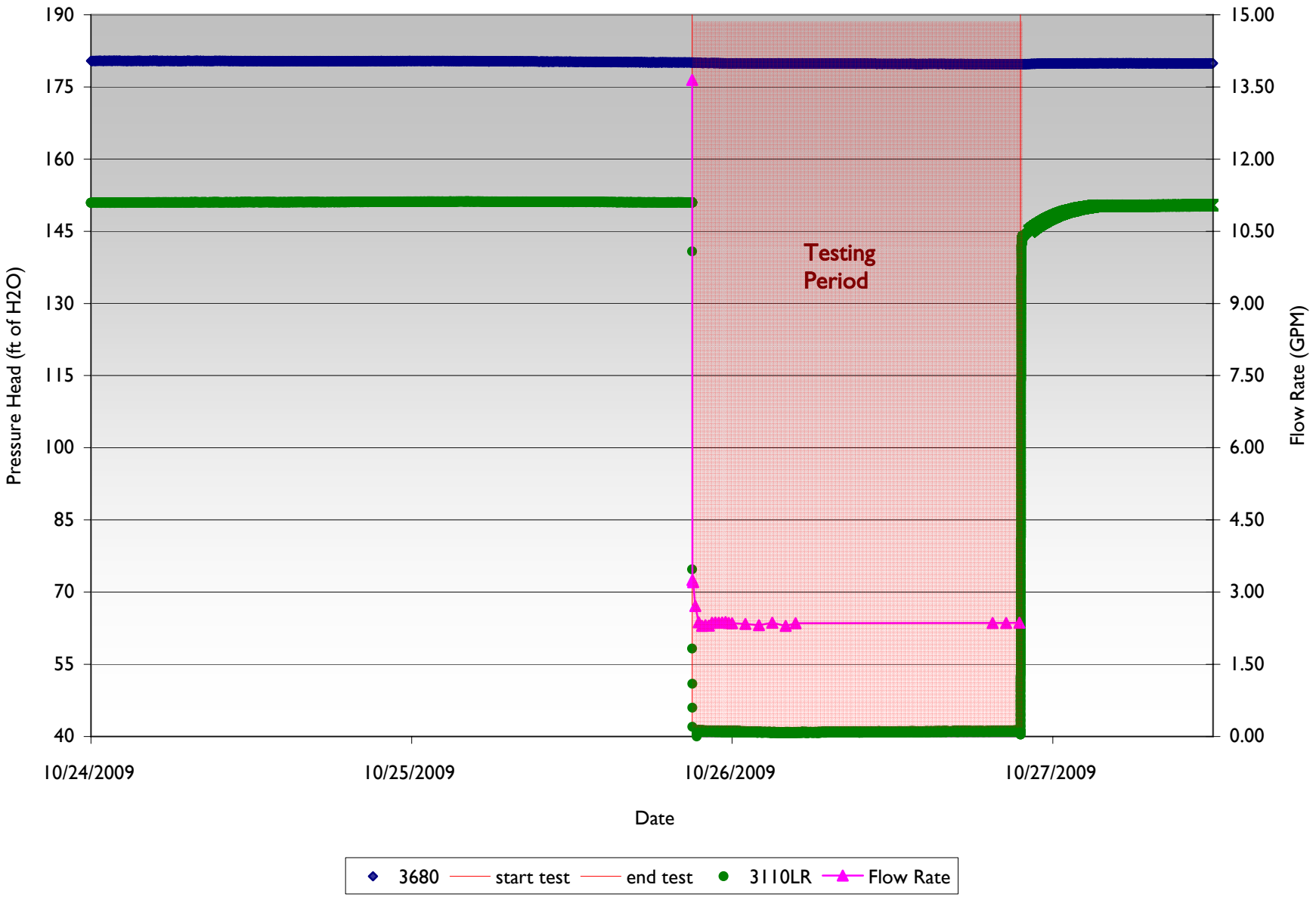


FIGURE 5
Test at 3110LR (10/26/09 through 10/27/09)

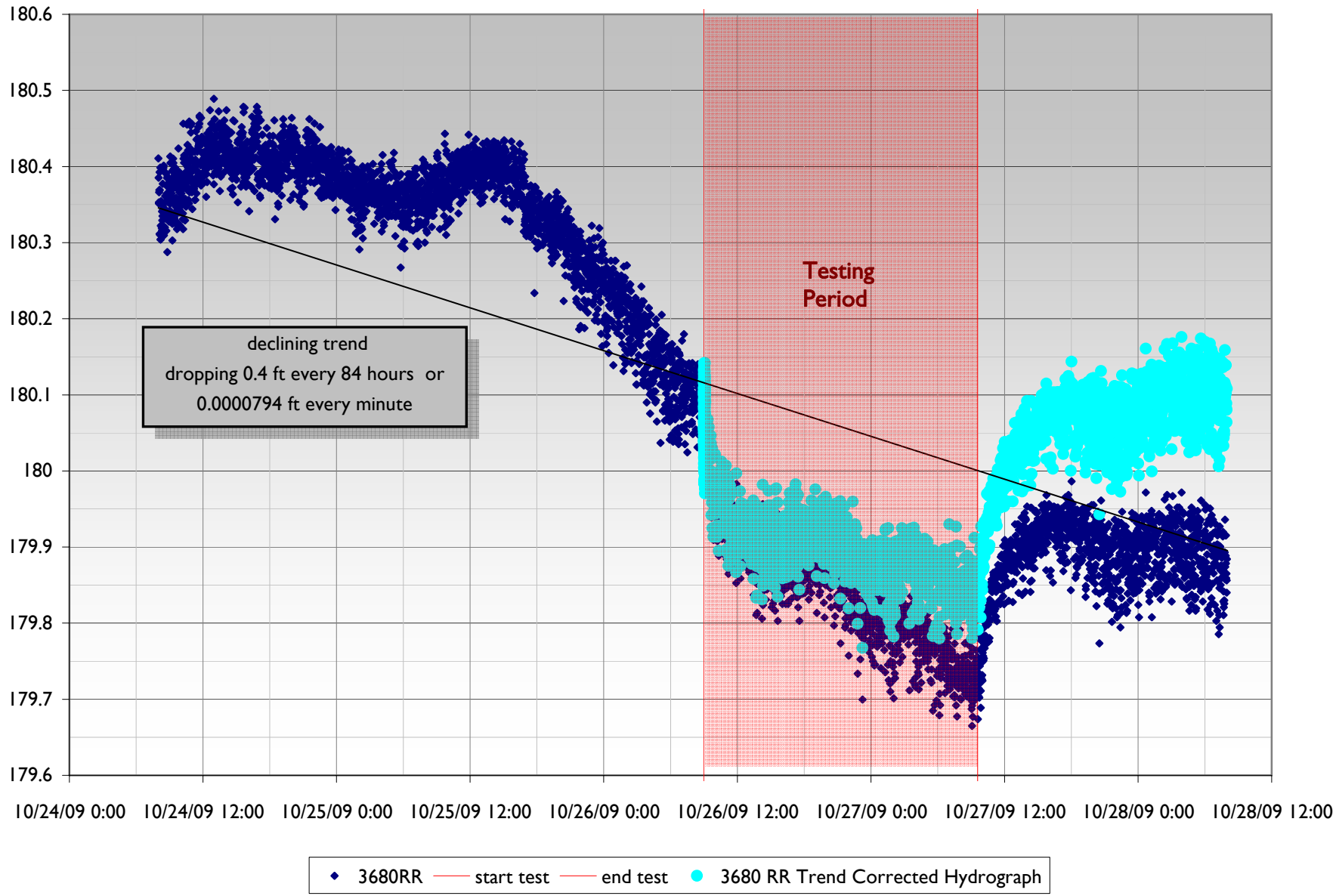


FIGURE 6
Observed and Trend Corrected Hydrograph at 3680RR during Test at 3110LR (10/26/09 through 10/27/09)

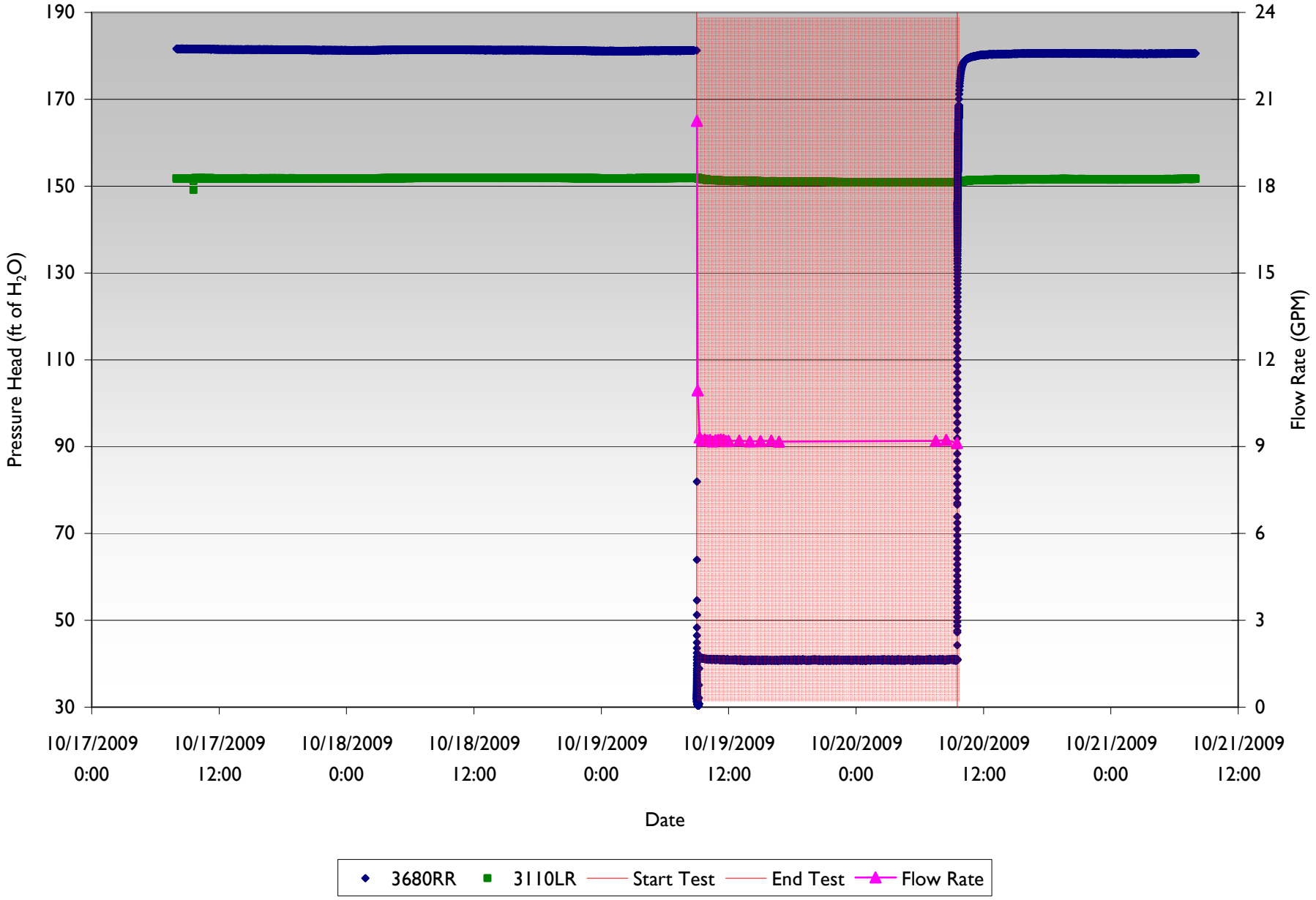


FIGURE 7
Test at 3680RR (10/19/09 through 10/20/09)

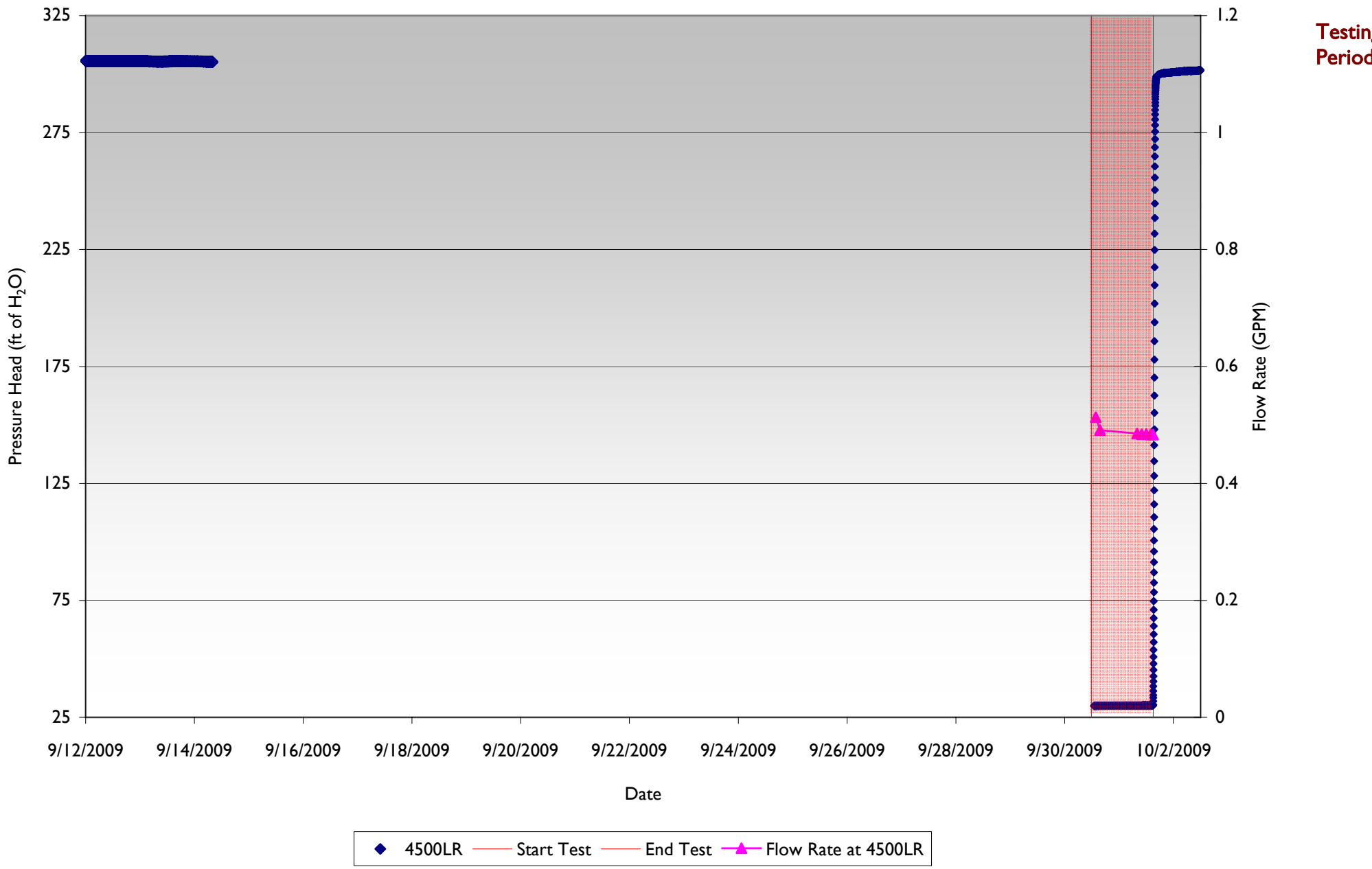


FIGURE 8
Background and Test at 4500LR (10/30/09 through 10/1/09)

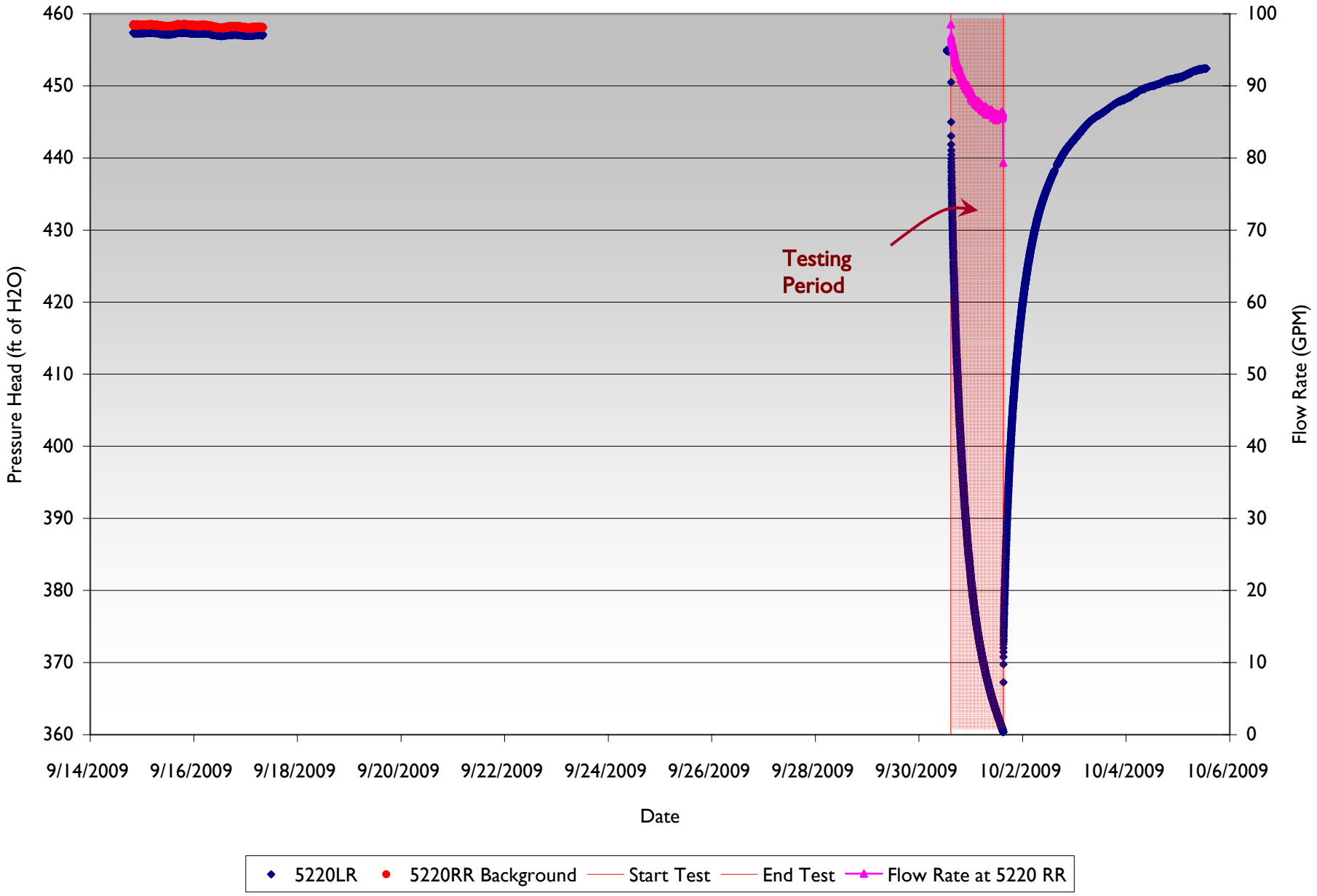


FIGURE 9
Background and Test at 5200RR (10/30/09 through 10/1/09)

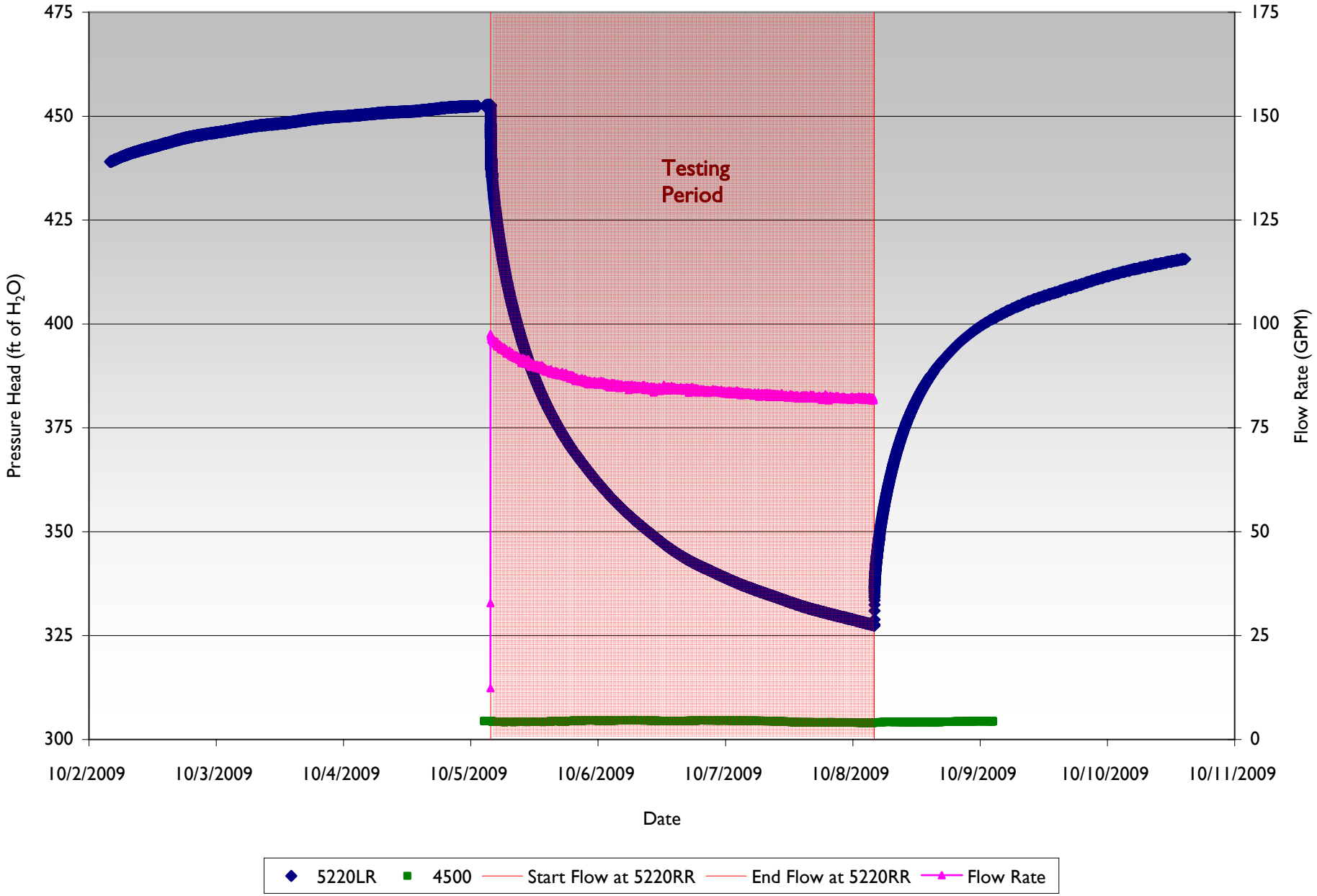
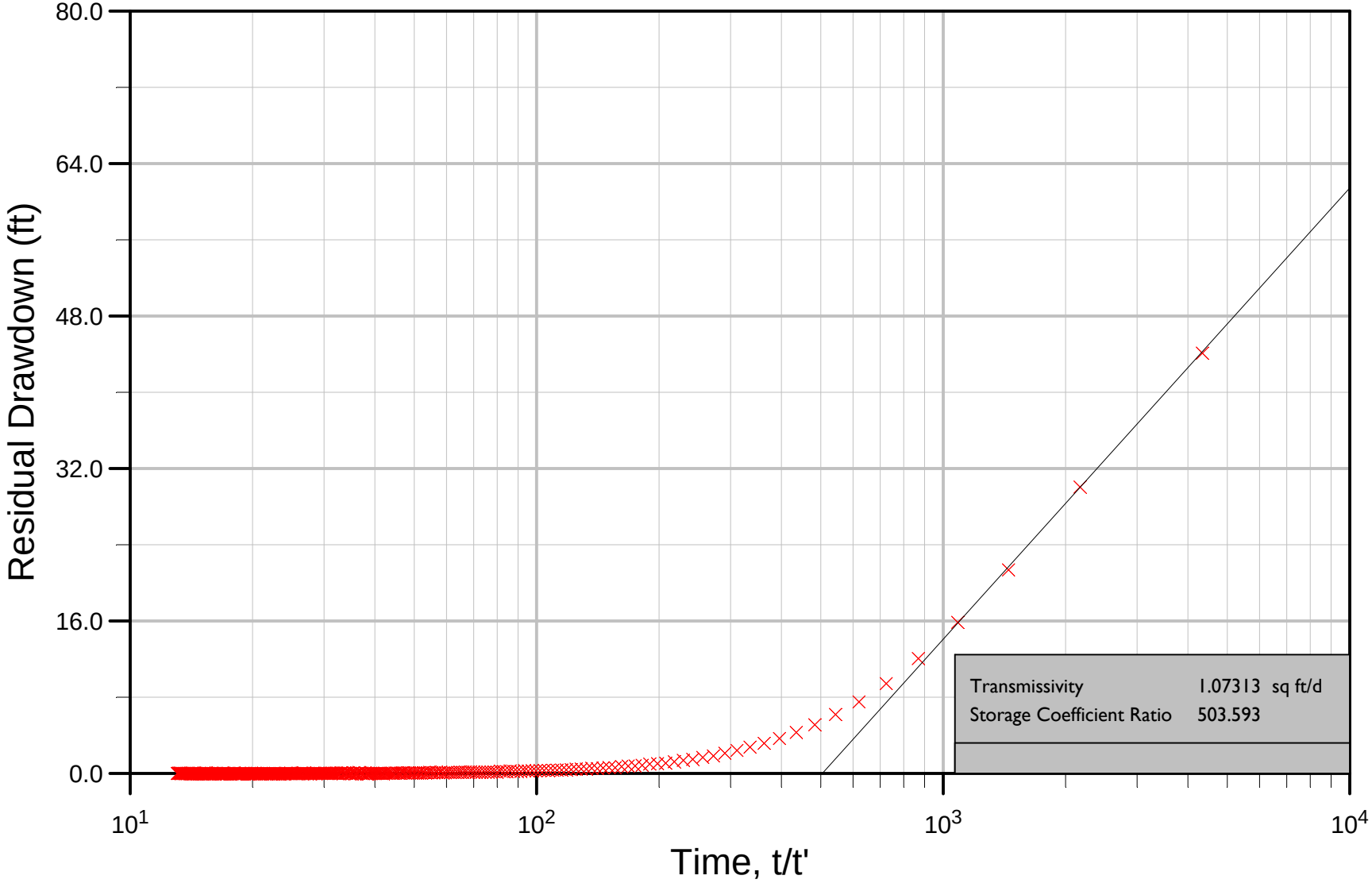


FIGURE 10
Test at 5220RR (10/5/09 through 10/8/09)

ATTACHMENT 1

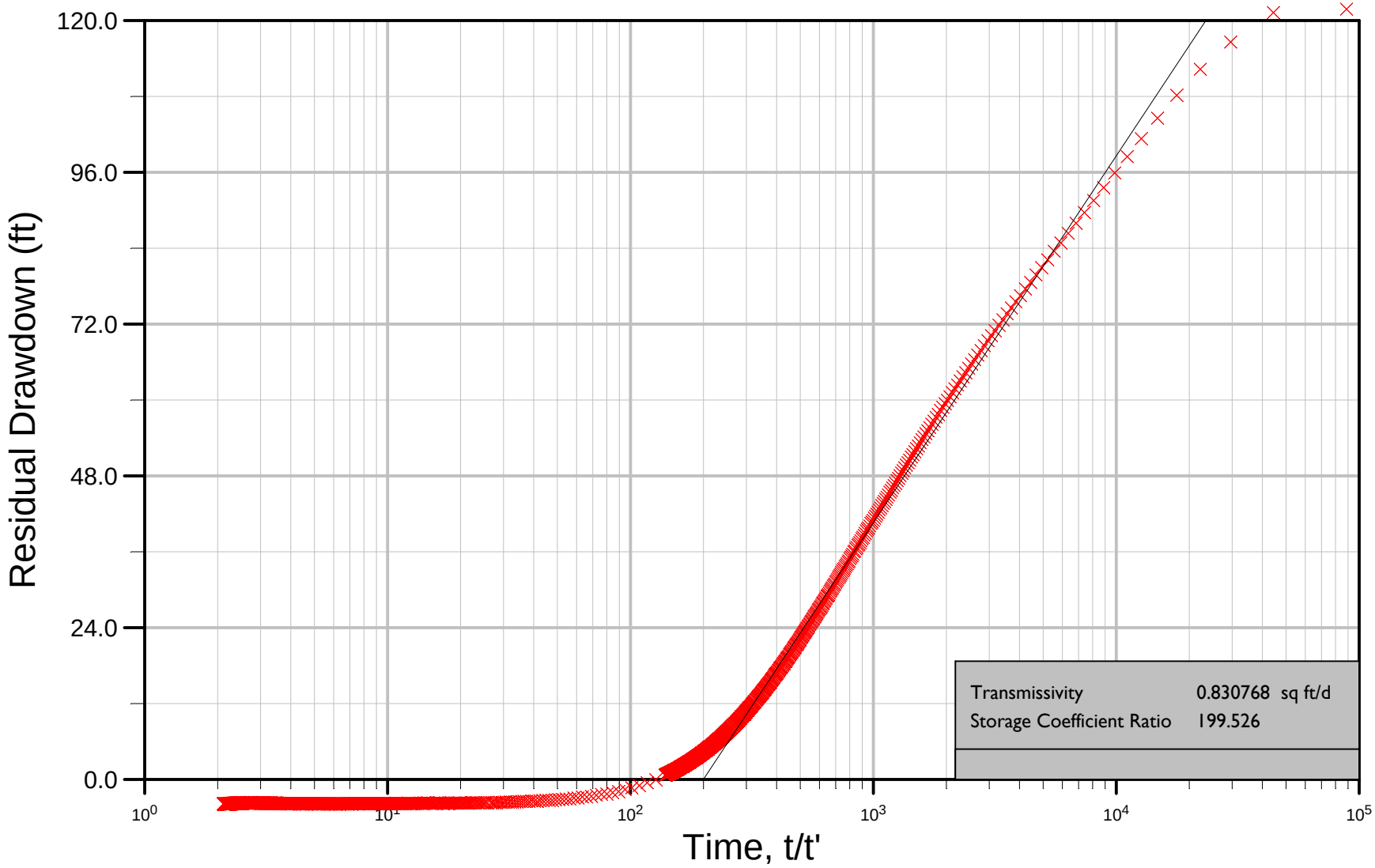
Recovery of 3110RR After Flow of 3110RR on 9/18/2009

Theis Recovery



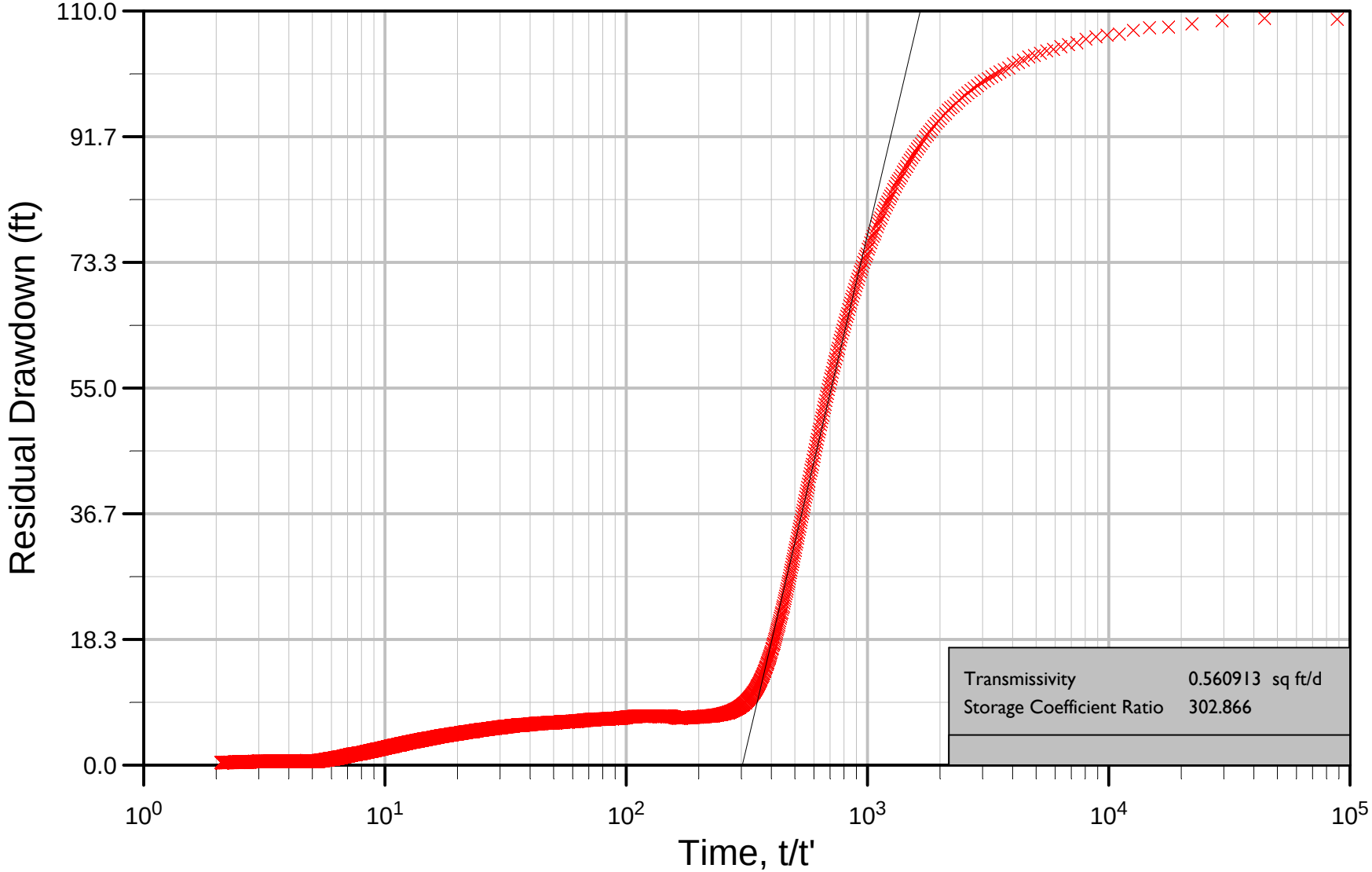
Recovery of 3110RR After Flow of 3110RR on 11/02/2009

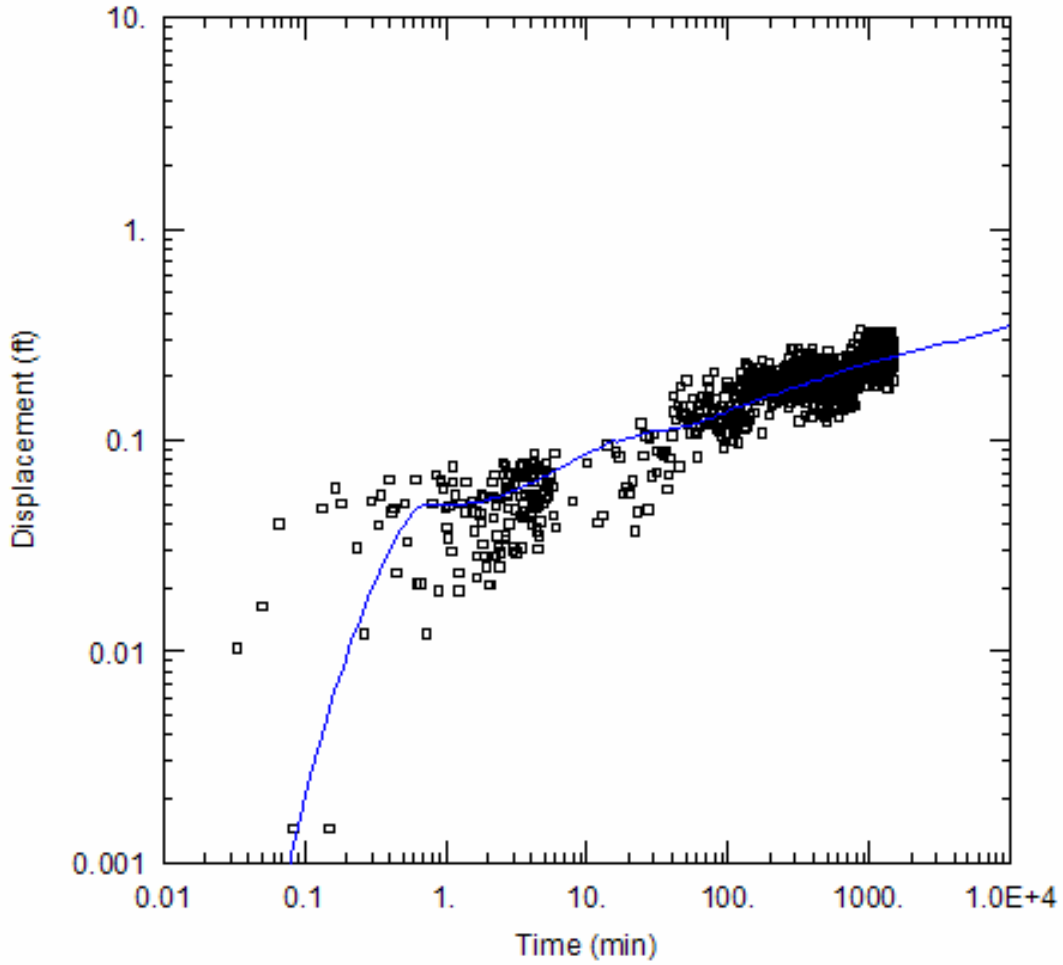
Theis Recovery



Recovery of 3110LR After Flow of 3110LR

Theis Recovery





WELL TEST ANALYSIS

Data Set:
Date: 11/04/09 Time: 12:39:59

PROJECT INFORMATION

Company: AMEC Geomatrix
Client: MMC
Project: 10729
Location: Montanore
Test Well: 3110LR
Test Date: 10/26/2009

AQUIFER DATA

Saturated Thickness: 150. ft Slab Block Thickness: 10. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
3110LR	0	0

Observation Wells

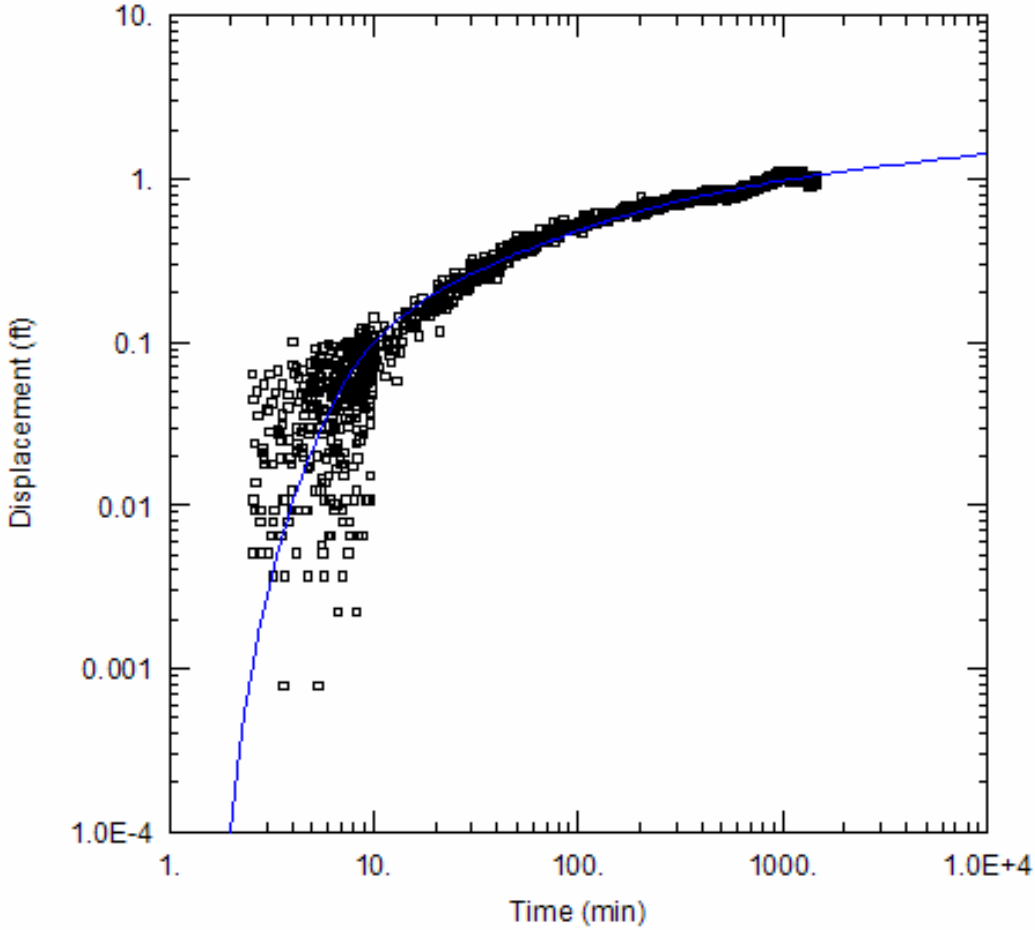
Well Name	X (ft)	Y (ft)
▫ 3680RR	0	480.52

SOLUTION

Aquifer Model: Fractured Solution Method: Moench w/slab blocks

K = 2.414 ft/day
K' = 1.115E-5 ft/day
Sw = 0.
r(w) = 0.078 ft

Ss = 1.565E-9 ft^{-1}
Ss' = 6.245E-6 ft^{-1}
Sf = 0.
r(c) = 0.078 ft



WELL TEST ANALYSIS

Data Set:
Date: 11/02/09 Time: 10:47:26

PROJECT INFORMATION

Company: AMEC Geomatrix
Client: MMC
Project: 10729
Location: Montanore
Test Well: 3680
Test Date: 10/19/2009

AQUIFER DATA

Saturated Thickness: 182. ft Slab Block Thickness: 10. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
3680	0	0

Observation Wells

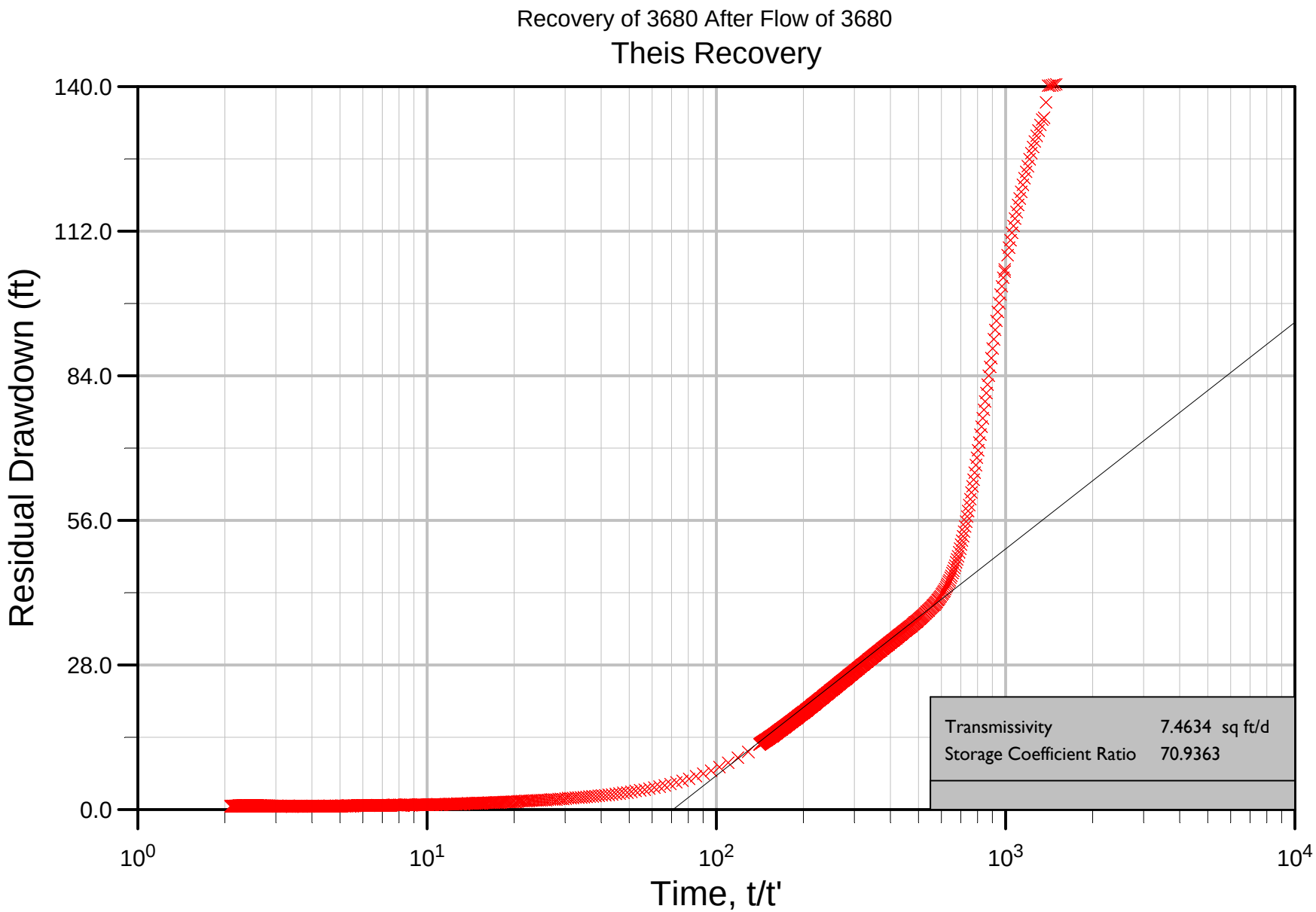
Well Name	X (ft)	Y (ft)
▫ 3110LR	0	480.5277

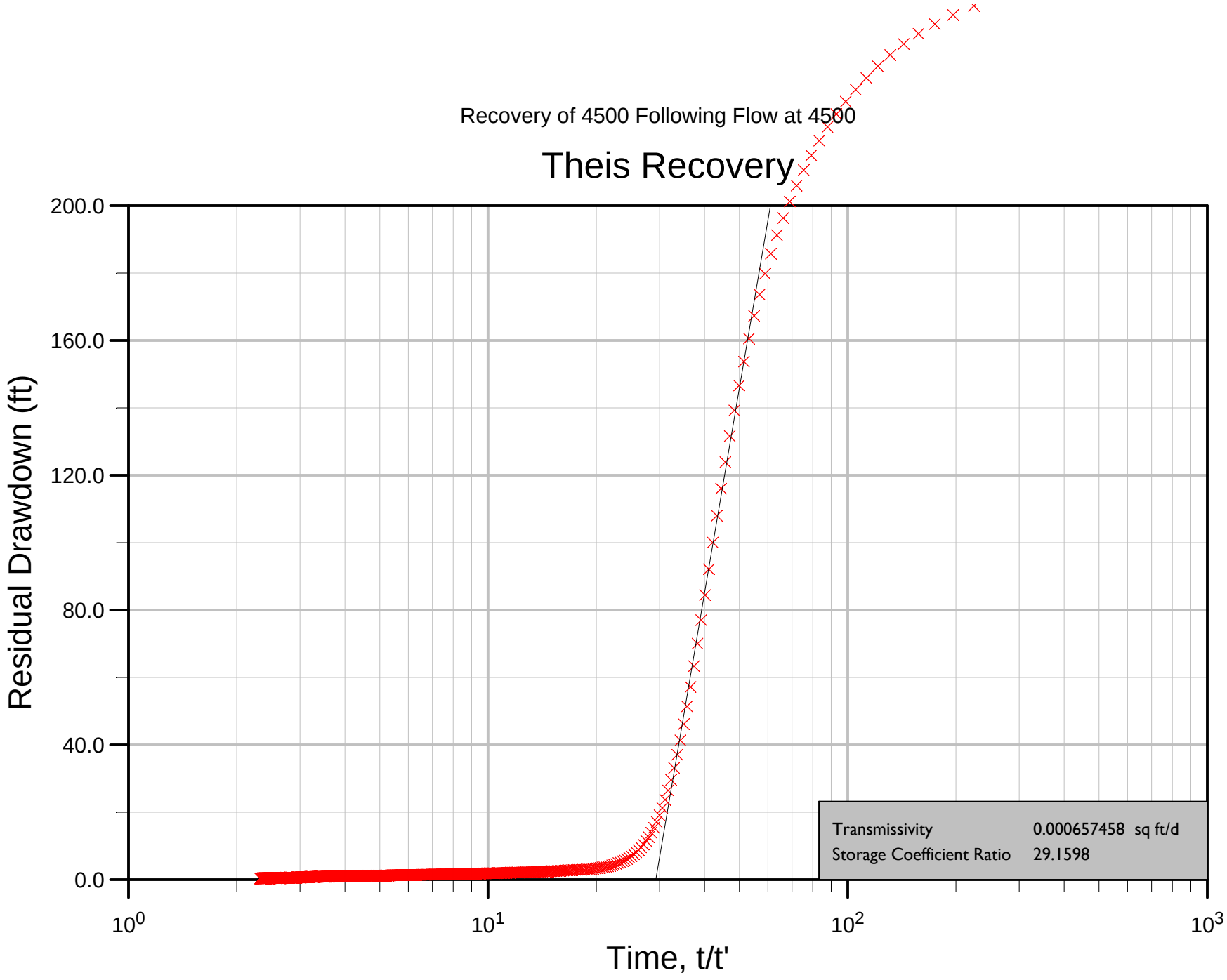
SOLUTION

Aquifer Model: Fractured
Solution Method: Moench w/slab blocks

K = 2.217 ft/day
K' = 1.871E-6 ft/day
Sw = 0.825
r(w) = 0.078 ft

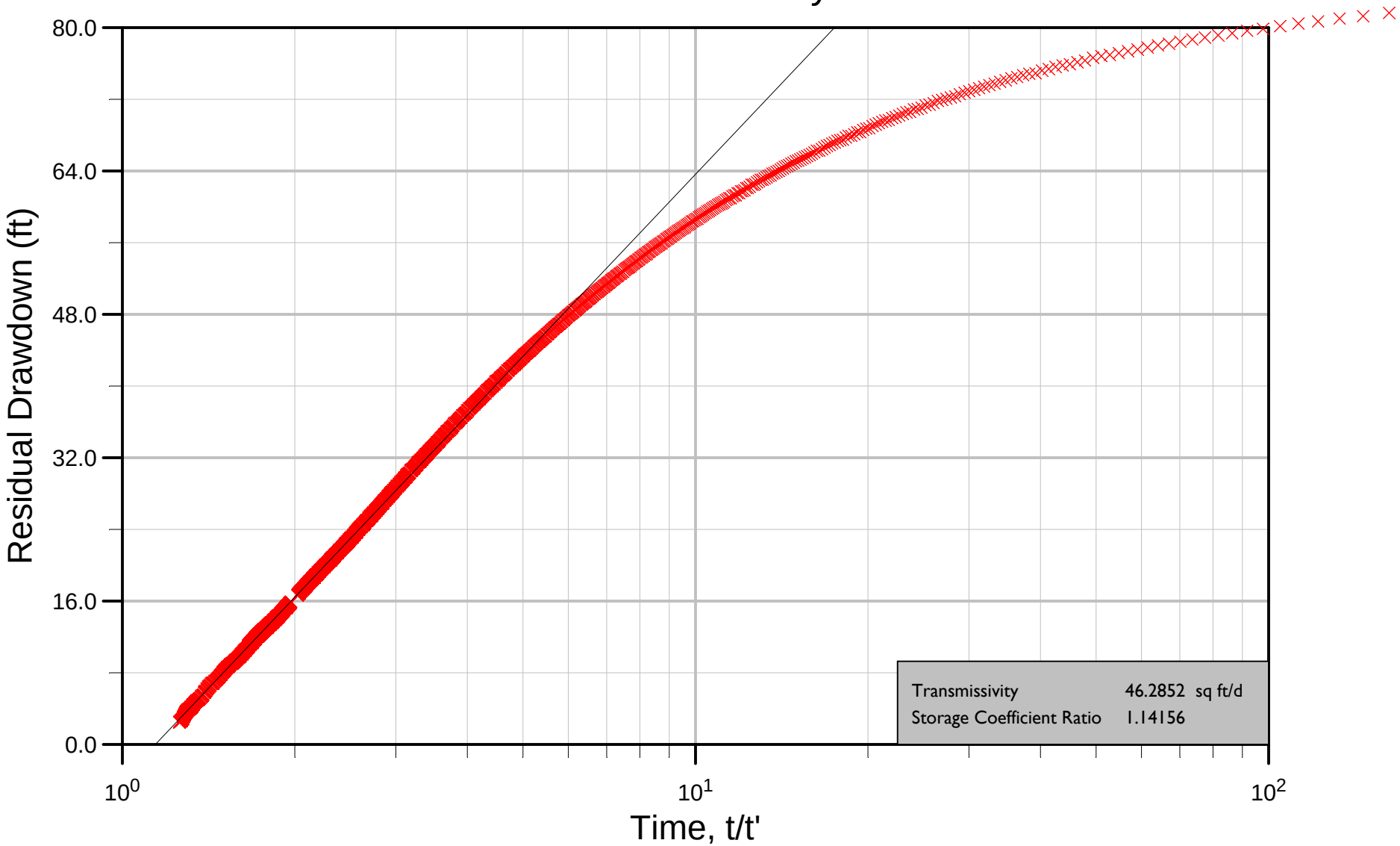
Ss = 2.971E-7 ft^{-1}
Ss' = 5.927E-6 ft^{-1}
Sf = 0.
r(c) = 0.078 ft

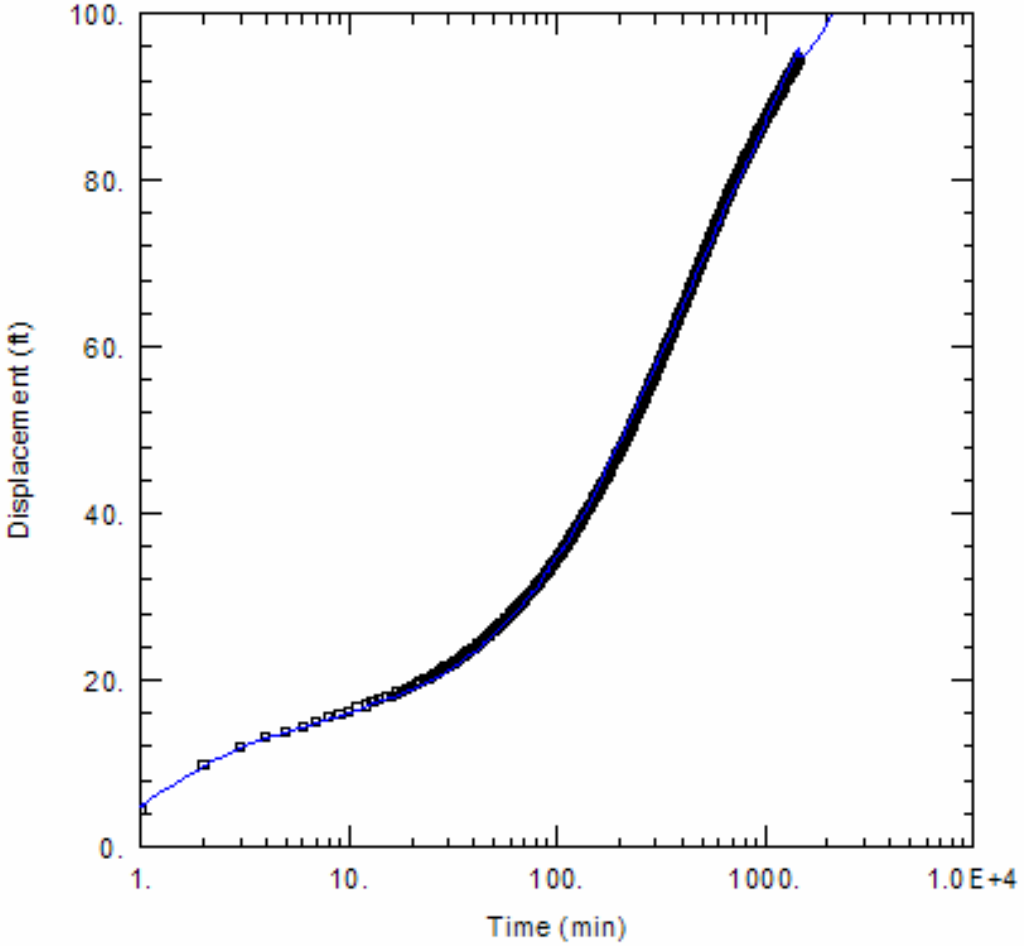

Recovery of 3680 After Flow of 3680
Theis Recovery
Residual Drawdown (ft)
140.0
112.0
84.0
56.0
28.0
0.0
10^0
10^1
10^2
10^3
10^4
Time, t/t'
Transmissivity 7.4634 sq ft/d
Storage Coefficient Ratio 70.9363


Recovery of 4500 Following Flow at 4500
Theis Recovery
Residual Drawdown (ft)
200.0
160.0
120.0
80.0
40.0
0.0
10^0
10^1
10^2
10^3
Time, t/t'
Transmissivity 0.000657458 sq ft/d
Storage Coefficient Ratio 29.1598

Drawdown of 5220LR During Flow of 5220RR 9/30- 10/1

Theis Recovery





WELL TEST ANALYSIS

Data Set:
Date: 11/09/09 Time: 16:31:53

PROJECT INFORMATION

Company: AMEC Geomatrix
Client: MMC
Project: 10729
Location: Montanore
Test Well: 5220RR
Test Date: 9/30/2009

AQUIFER DATA

Saturated Thickness: 450. ft Slab Block Thickness: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
5220RR	0	0

Observation Wells

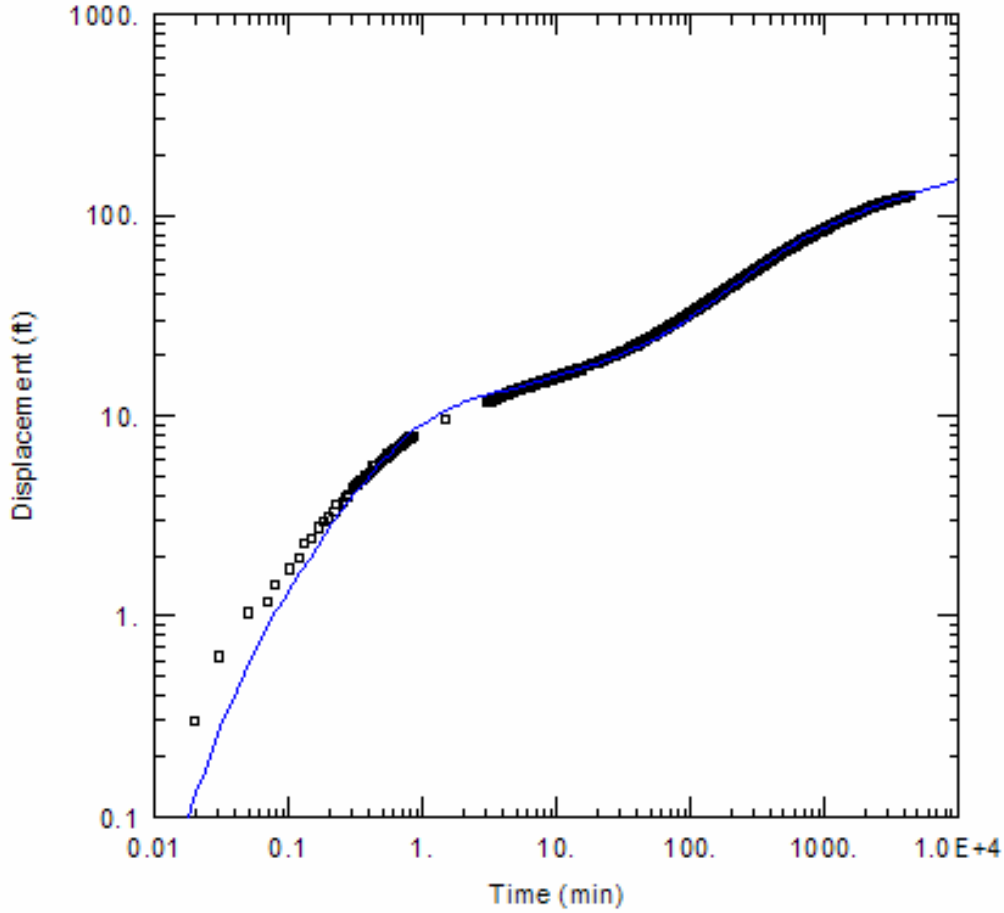
Well Name	X (ft)	Y (ft)
▫ 5220LR	0	95.9

SOLUTION

Aquifer Model: Fractured Solution Method: Moench w/slab blocks

K = 0.1056 ft/day
K' = 5.973E-6 ft/day
Sw = 0.1
r(w) = 0.078 ft

Ss = 1.63E-8 ft^{-1}
Ss' = 8.557E-7 ft^{-1}
Sf = 0.65
r(c) = 0.078 ft



WELL TEST ANALYSIS

Data Set:
Date: 11/09/09 Time: 16:43:08

PROJECT INFORMATION

Company: AMEC Geomatrix
Client: MMC
Project: 10729
Location: Montanore
Test Well: 5220RR
Test Date: 10/05/2009

AQUIFER DATA

Saturated Thickness: 450. ft Slab Block Thickness: 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
5220RR	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
5220LR	0	95.9

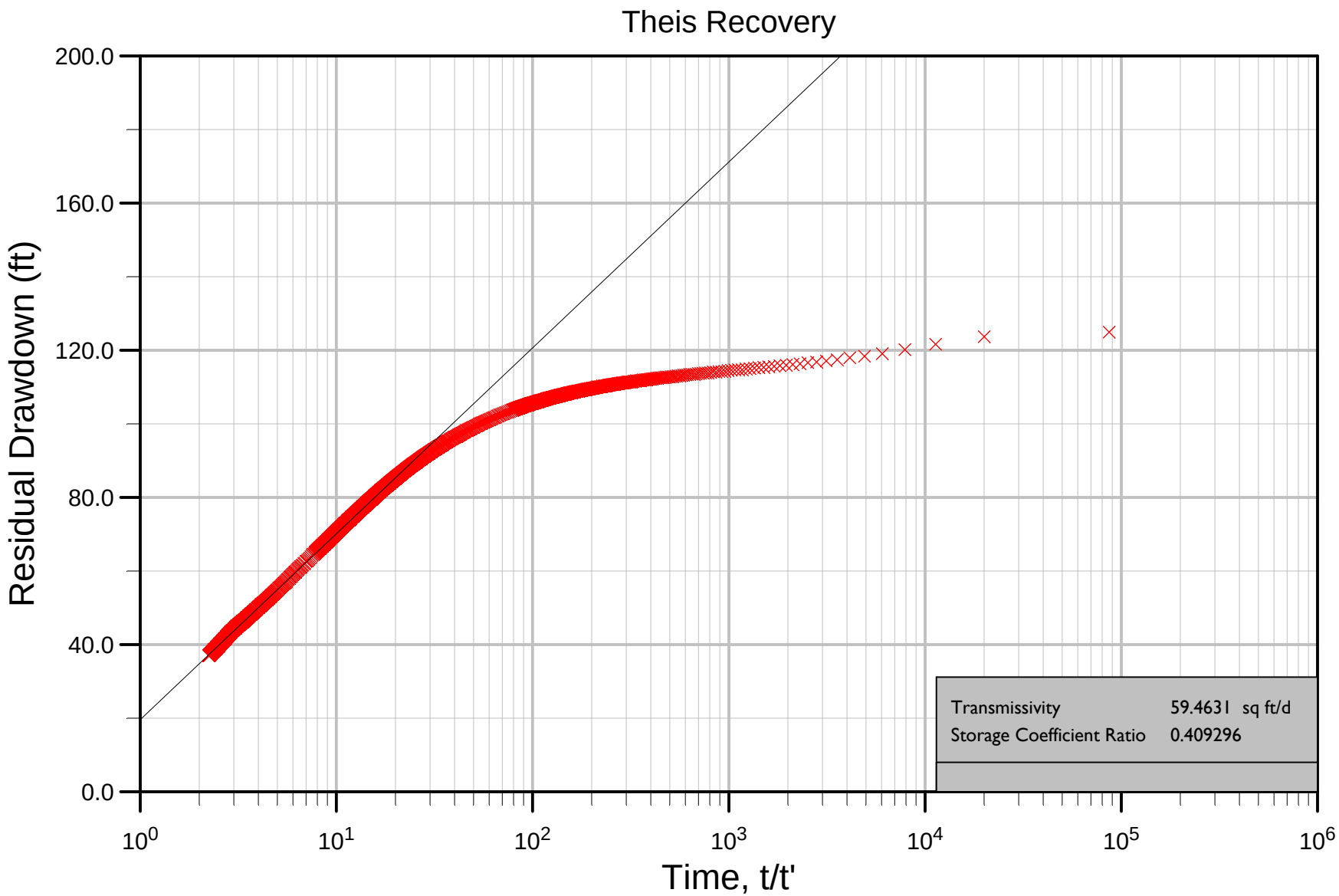
SOLUTION

Aquifer Model: Fractured Solution Method: Moench w/slab blocks

K = 0.08832 ft/day
K' = 5.761E-6 ft/day
Sw = 0.1
r(w) = 0.078 ft

Ss = 3.021E-10 ft^{-1}
Ss' = 1.296E-6 ft^{-1}
Sf = 0.65
r(c) = 0.078 ft

Drawdown of 5220LR During Flow of 5220RR 10/5-10/8



APPENDIX E

MODEL CALIBRATION STATISTICS AND RESIDUALS

Appendix E

Model Calibration Statistics and Residuals

ID	Data Source	Easting (SP meters)	Northing (SP meters)	Layer	Observed Head (meters msl)	Simulated Head (meters msl)	Residual (meters)	Observed Head (feet msl)	Simulated Head (feet msl)	Residual (feet)
141525	GWIC	141171.70	424564.80	3	699.88	749.48	-50	2296.2	2458.9	-163
160571	GWIC	142922.00	424724.20	2	766.34	774.68	-8	2514.2	2541.6	-27
79344	GWIC	138495.30	426178.10	2	722.37	711.83	11	2369.9	2335.4	35
221309	GWIC	139822.80	426590.40	3	779.16	812.08	-33	2556.3	2664.3	-108
177487	GWIC	138127.80	426626.20	3	721.35	705.23	16	2366.6	2313.7	53
79345	GWIC	138599.19	427318.43	4	761.93	767.53	-6	2499.7	2518.1	-18
79341	GWIC	138426.00	429145.20	2	791.87	807.68	-16	2598.0	2649.9	-52
230519	GWIC	137725.00	430407.10	3	788.88	790.51	-2	2588.2	2593.5	-5
79343	GWIC	137024.70	430564.90	2	684.14	704.43	-20	2244.5	2311.1	-67
146861	GWIC	136436.50	430811.70	2	679.67	703.77	-24	2229.9	2308.9	-79
130551	GWIC	134971.60	431408.50	3	629.79	675.64	-46	2066.2	2216.7	-150
187725	GWIC	137826.10	431599.60	3	763.83	779.26	-15	2506.0	2556.6	-51
120080	GWIC	136205.40	431717.00	1	726.01	713.09	13	2381.9	2339.5	42
120088	GWIC	135404.40	431780.80	2	703.82	694.20	10	2309.1	2277.5	32
175101	GWIC	135003.90	431812.70	2	677.68	673.03	5	2223.3	2208.1	15
212839	GWIC	134644.80	432244.00	5	629.00	663.30	-34	2063.6	2176.2	-113
80015	GWIC	141204.50	432478.30	1	1179.40	1182.02	-3	3869.4	3878.0	-9
159184	GWIC	135460.70	432587.30	2	716.73	702.30	14	2351.4	2304.1	47
120079	GWIC	137137.40	433281.70	1	747.02	744.18	3	2450.8	2441.5	9
80017	GWIC	135013.20	433342.80	3	702.87	689.26	14	2306.0	2261.3	45
228666	GWIC	135160.80	433790.10	1	725.39	702.49	23	2379.8	2304.7	75
212595	GWIC	134361.50	433899.80	2	667.27	668.55	-1	2189.2	2193.4	-4
80004	GWIC	161814.80	433911.00	2	931.47	929.22	2	3056.0	3048.6	7
80014	GWIC	133994.90	434322.70	2	675.78	665.73	10	2217.1	2184.1	33
80013	GWIC	133563.70	434601.40	2	663.68	657.92	6	2177.4	2158.5	19
80009	GWIC	132492.90	435621.50	1	655.56	654.38	1	2150.7	2146.9	4
166515	GWIC	132989.90	436399.60	2	749.42	742.05	7	2458.7	2434.5	24
80070	GWIC	131711.50	436573.10	1	668.82	667.95	1	2194.3	2191.4	3
182184	GWIC	163312.70	436757.60	1	892.27	887.09	5	2927.4	2910.4	17
80069	GWIC	131339.90	437005.70	1	697.09	691.60	5	2287.0	2269.0	18
234438	GWIC	130043.50	437206.40	1	672.85	661.01	12	2207.5	2168.6	39
234317	GWIC	130372.80	437482.50	1	679.88	679.22	1	2230.6	2228.4	2
217911	GWIC	129582.60	437744.10	1	678.76	670.81	8	2226.9	2200.8	26
80066	GWIC	129089.20	437885.00	1	674.74	663.46	11	2213.7	2176.7	37
153139	GWIC	129089.20	437885.00	3	671.69	663.10	9	2203.7	2175.5	28
168767	GWIC	128761.60	437965.00	1	669.36	656.76	13	2196.0	2154.7	41
223741	GWIC	151531.40	438615.50	1	1334.86	1325.47	9	4379.4	4348.6	31
152852	GWIC	128356.30	438750.00	1	679.18	659.79	19	2228.3	2164.6	64
80059	GWIC	127879.60	439092.20	1	677.63	655.38	22	2223.2	2150.2	73
80038	GWIC	127511.90	439526.40	2	629.16	655.12	-26	2064.2	2149.3	-85
80037	GWIC	128167.40	440104.60	2	684.78	683.28	1	2246.6	2241.7	5
132426	GWIC	133872.20	441496.70	1	1259.52	1257.70	2	4132.2	4126.3	6
228391	GWIC	129021.00	441557.30	1	680.92	690.51	-10	2234.0	2265.4	-31
81353	GWIC	162609.60	442012.70	1	883.12	873.54	10	2897.3	2865.9	31
81392	GWIC	129338.60	442024.30	1	674.91	690.71	-16	2214.2	2266.1	-52

198908	GWIC	160683.50	442158.80	4	907.92	916.69	-9	2978.7	3007.5	-29
211479	GWIC	129464.40	442305.30	1	680.90	672.38	9	2233.9	2205.9	28
81352	GWIC	162402.90	443134.40	1	875.99	875.28	1	2873.9	2871.6	2
81383	GWIC	130882.20	443275.30	1	685.74	692.35	-7	2249.8	2271.5	-22
139476	GWIC	130882.20	443275.30	1	685.43	692.35	-7	2248.8	2271.5	-23
146210	GWIC	131488.70	443632.40	1	699.53	695.00	5	2295.0	2280.2	15
81379	GWIC	132538.00	444558.40	1	687.15	681.13	6	2254.4	2234.6	20
81360	GWIC	151460.90	445225.00	1	1253.01	1272.21	-19	4110.9	4173.9	-63
134273	GWIC	148624.10	445380.20	1	1197.30	1181.91	15	3928.1	3877.6	50
187783	GWIC	159661.00	446132.10	1	926.86	931.15	-4	3040.8	3054.9	-14
187782	GWIC	159661.00	446132.10	1	923.44	931.15	-8	3029.6	3054.9	-25
148731	GWIC	131537.30	448170.20	1	699.88	699.18	1	2296.2	2293.9	2
166629	GWIC	131969.20	448538.80	1	710.40	714.72	-4	2330.7	2344.9	-14
230008	GWIC	131969.20	448538.80	2	704.61	714.44	-10	2311.7	2343.9	-32
134271	GWIC	150096.00	448695.00	1	1145.34	1123.41	22	3757.6	3685.7	72
81369	GWIC	127686.20	448756.20	1	703.00	695.83	7	2306.4	2282.9	24
226962	GWIC	150565.70	449460.40	1	1117.62	1101.84	16	3666.7	3614.9	52
134266	GWIC	149968.00	449708.80	1	1180.40	1145.60	35	3872.7	3758.5	114
83271	GWIC	150203.50	450094.90	1	1124.28	1120.87	3	3688.5	3677.3	11
83273	GWIC	151560.50	450154.50	1	1070.91	1045.87	25	3513.4	3431.3	82
83270	GWIC	149463.10	451816.20	1	1232.26	1200.60	32	4042.8	3938.9	104
152947	GWIC	127086.30	452596.20	1	703.95	711.72	-8	2309.5	2335.0	-25
83262	GWIC	158111.10	452637.60	1	913.03	917.72	-5	2995.5	3010.8	-15
83265	GWIC	149648.30	452806.50	1	1117.76	1106.29	11	3667.1	3629.5	38
83267	GWIC	151016.60	452842.40	2	1122.98	1070.77	52.2	3684.3	3513.0	171
226967	GWIC	151634.50	453199.50	1	1043.41	1028.54	15	3423.2	3374.4	49
83261	GWIC	158373.10	453431.20	1	879.56	882.69	-3	2885.7	2895.9	-10
83256	GWIC	157720.70	456821.60	1	848.99	844.75	4	2785.4	2771.5	14
83257	GWIC	157720.70	456821.60	1	849.30	844.75	5	2786.4	2771.5	15
83258	GWIC	157720.70	456821.60	1	843.81	844.75	-1	2768.4	2771.5	-3
155294	GWIC	157158.00	457425.90	1	880.95	863.43	18	2890.2	2832.7	57
84854	GWIC	156202.20	458895.40	1	834.13	827.72	6	2736.6	2715.6	21
81357	GWIC	155839.80	459328.00	1	830.89	831.05	0	2726.0	2726.5	-1
84850	GWIC	156324.50	459847.50	1	816.31	818.66	-2	2678.2	2685.9	-8
235691	GWIC	156643.90	460579.80	1	798.07	801.35	-3	2618.3	2629.1	-11
84913	GWIC	151895.00	461853.20	2	826.16	833.37	-7	2710.5	2734.1	-24
84832	GWIC	155947.10	462004.50	1	793.76	790.73	3	2604.2	2594.2	10
84834	GWIC	155976.20	462055.70	1	791.55	789.56	2	2596.9	2590.4	7
164741	GWIC	155976.20	462055.70	2	790.94	789.55	1	2594.9	2590.3	5
121338	GWIC	155720.90	462356.30	2	791.97	790.57	1	2598.3	2593.7	5
84912	GWIC	154409.40	462372.00	5	809.27	817.15	-8	2655.1	2680.9	-26
121337	GWIC	155662.60	462432.70	3	795.19	790.52	5	2608.9	2593.5	15
84824	GWIC	156006.90	462456.90	1	790.32	784.55	6	2592.9	2573.9	19
148224	GWIC	155617.70	462486.70	1	788.10	790.60	-3	2585.6	2593.8	-8
225656	GWIC	155363.40	463004.10	1	789.58	786.33	3	2590.5	2579.8	11
172633	GWIC	155663.80	463088.40	2	761.58	775.58	-14	2498.6	2544.5	-46
84911	GWIC	154501.80	463574.00	3	793.37	792.81	1	2602.9	2601.1	2
84907	GWIC	155157.50	463665.00	2	781.52	778.71	3	2564.0	2554.8	9
PM-3	Chen N.	151345.98	450672.29	1	1044.32	1040.97	3	3426.2	3415.2	11

PM-2	Chen N.	149541.81	450138.76	1	1118.11	1162.76	-45	3668.3	3814.8	-146
LCTM-8	Chen N.	151791.46	453388.73	1	1026.52	1012.18	14	3367.8	3320.8	47
LCM-9	Chen N.	151620.29	453979.38	1	1038.07	1024.09	14	3405.7	3359.8	46
LCM-11	Chen N.	149630.40	453157.20	1	1140.61	1114.04	27	3742.1	3655.0	87
LCM-10	Chen N.	149480.10	452321.12	1	1135.64	1143.96	-8	3725.8	3753.1	-27
PLCM-6	Chen N.	151334.19	452316.63	1	1047.79	1065.90	-18	3437.6	3497.0	-59
PLCM-6	Chen N.	151334.19	452316.63	1	1052.61	1065.90	-13	3453.4	3497.0	-44
HR-29_5050	Chen N.	142481.51	444698.51	4	1539.00	1575.32	-36	5049.2	5168.3	-119
HR-26_5500	Chen N.	142599.86	444071.94	4	1661.18	1701.56	-40	5450.0	5582.5	-132
HR-19_5400	Chen N.	143167.25	442679.56	4	1661.18	1699.72	-39	5450.0	5576.4	-126
MW_84_1	Rock Creek EIS	137056.12	440933.82	1	1090.90	1118.25	-27	3579.0	3668.7	-90
MW_84_2	Rock Creek EIS	136889.24	440803.51	1	1092.40	1104.77	-12	3583.9	3624.5	-41
MW_85_15	Rock Creek EIS	137529.33	440531.48	1	1031.80	1051.92	-20	3385.1	3451.1	-66
MW_85_17	Rock Creek EIS	135322.85	433963.48	1	712.30	713.34	-1	2336.9	2340.3	-3
MW_84_12	Rock Creek EIS	135649.19	433684.12	1	750.40	719.98	30	2461.9	2362.1	100
MW_85_19	Rock Creek EIS	135273.24	433357.78	1	684.30	702.20	-18	2245.1	2303.8	-59
MW_85_27	Rock Creek EIS	135704.02	433042.66	1	695.60	714.53	-19	2282.1	2344.2	-62
MW_85_18	Rock Creek EIS	135012.17	433729.29	1	676.60	693.47	-17	2219.8	2275.1	-55
MW_84_7	Rock Creek EIS	135393.34	433515.21	1	719.30	708.89	10	2359.9	2325.7	34
MW_85_25	Rock Creek EIS	135009.56	433781.51	1	676.40	693.57	-17	2219.1	2275.5	-56
MW_85_21	Rock Creek EIS	135732.74	433019.16	1	695.60	714.94	-19	2282.1	2345.6	-63

Absolute Residual Mean	12.7	meters	Absolute Residual Mean	42	feet
Residual Mean	-0.9	meters	Residual Mean	-3	feet
Standard Deviation	17.2	meters	Standard Deviation	56	feet
Range	1032	meters	Range	3386	feet
Standard Deviation/Range	0.017	meters	Standard Deviation/Range	0.017	feet

APPENDIX F

ROCK LAKE WATER BALANCE

APPENDIX F

ROCK LAKE WATER BALANCE

INTRODUCTION

This appendix discusses a water balance developed for Rock Lake in northwest Montana. The water balance was prepared in support of conceptual and numerical modeling for the Montanore Mine project. Lakes are surface water features that store water and can act as both sources or sinks to the groundwater system. As site-specific data are sparse, the steady-state water balance was developed for Rock Lake based primarily on literature and assumed values. Error associated with water balance components is also estimated.

Gurrieri (2001) developed a transient water balance for Rock Lake using generally reasonable values for the water balance components. However, the water balance did not include an estimate of overland or poorly channelized flow entering the lake. Since Rock Lake is a cirque lake, runoff can enter from three sides of the lake, and this would be expected during snowmelt and major precipitation events. Ephemeral drainage channels distinguishable in aerial photos on the rock faces both east and west of the lake provide evidence that overland flow or poorly channelized flow contributes water to the lake. Since the water balance presented in Gurrieri (2001) did not include this component, the "Groundwater In" component presented in that report may be an overestimate during any period in which moderate precipitation or snowmelt may have occurred.

The following equation represents a steady-state water balance for Rock Lake:

$$P_{in} + SW_{in} + GW_{in} + OF_{in} = E_{out} + SW_{out} + GW_{out}$$

Where:

- P_{in}: Water entering the lake via direct precipitation onto the lake surface
- SW_{in}: Surface water entering the lake through the inlet
- GW_{in}: Groundwater seeping into the lake
- OF_{in}: Overland flow entering the lake
- E_{out}: Evaporation directly from the lake surface
- SW_{out}: Surface water leaving the lake through the outlet
- GW_{out}: Water leaving the lake via seepage into the groundwater system

Table F-1 summarizes the average contribution and estimated error for each component of the Rock Lake water balance. The following subsections describe how the calculated average and estimated error for each component of the Rock Lake water balance were determined.

Table F-1. Rock Lake Water Balance

INFLOW	Average (acre-ft/yr)	Estimated Error (acre-ft/yr)	Comments
Precipitation	334	29	Annual precipitation of 69 inches over lake area. *Error is based on an estimated 6 inch variability in precipitation.*
Surface Water In	4,042	562	Integrated surface water flow in. *Error is based on runoff occurring 20 days earlier or later than the regional average (based on Flower Creek [Gurrieri, 2001]).*
Net Groundwater In	954	-	Used to complete the water balance for Inflow and Outflow components.
Overland Flow	1,743	119	Precipitation (69 inches) - 17% infiltration into talus (11.7 inches) - 10% evapotranspiration (6.9 inches) over overland flow area. *Error is uncertainty in evaporation and infiltration rate estimated at 5% of precipitation.*
TOTAL INFLOW	**7,074**	**711**	
OUTFLOW			
Evaporation	126	15	Annual evaporation 26 inches over lake area. *Error is based on an estimated 3 inches variability in evaporation.*
Surface Water Out	6,947	1,041	Integrated surface water flow out. *Error is based on runoff occurring 20 days earlier or later than the regional average (based on Flower Creek [Gurrieri 2001]).*
Groundwater Out	0		Water balance shows net groundwater flow "In"; therefore, there is no groundwater outflow, on average.
TOTAL OUTFLOW	7,074	1,056	

Lake surface Area 58 acres (2,526,480 ft^2) (USGS 1997, Elephant Mountain MT 7.5 min Quadrangle)
Overland Flow Catchment Area 415 acres (18,092,845 ft^2) (USGS 1997, Elephant Mountain MT 7.5 min Quadrangle)
Annual Precipitation 69 inches (5.75 ft) (PRISM, 2000)
Annual Evaporation 26 inches (2.17 ft) (Gurrieri, 2001) up to 37 inches (3.06 ft) (Chen Northern)

PRECIPITATION

Precipitation was estimated by applying 69 inches of average annual precipitation falling on the lake surface over the lake area of 58 acres. This results in an annual average contribution to Rock Lake of 334 acre-ft/yr from precipitation directly falling on the Lake. Reviewing data from the Poorman Creek Snotel gage suggests an average of 6 inches of variability in the annual precipitation in this region, resulting in an estimated error of 29 acre-ft/yr (NRCS, 2008).

SURFACE WATER INFLOW

Surface water inflow and outflow data were available for a few months between October 7, 1989 and September 20, 1999. These data represented by the open circles on **Figure F-1** were extrapolated based on a 31-year average hydrograph for Flower Creek (**Figure F-2**) to obtain an average hydrograph for Rock Lake inflow and outflow. The red plot on **Figure F-1** represents the average annual inflow. The area under this plot was integrated to determine the annual contribution to the lake from surface water inflow (approximately 4,042 acre-ft/yr). To address uncertainty in this estimate due to lack of springtime data, the date of thaw was moved both forward and backward 20 days giving a range from 3,480 to 4,604, acre-ft/yr, or an average error of 562 acre-ft/yr.

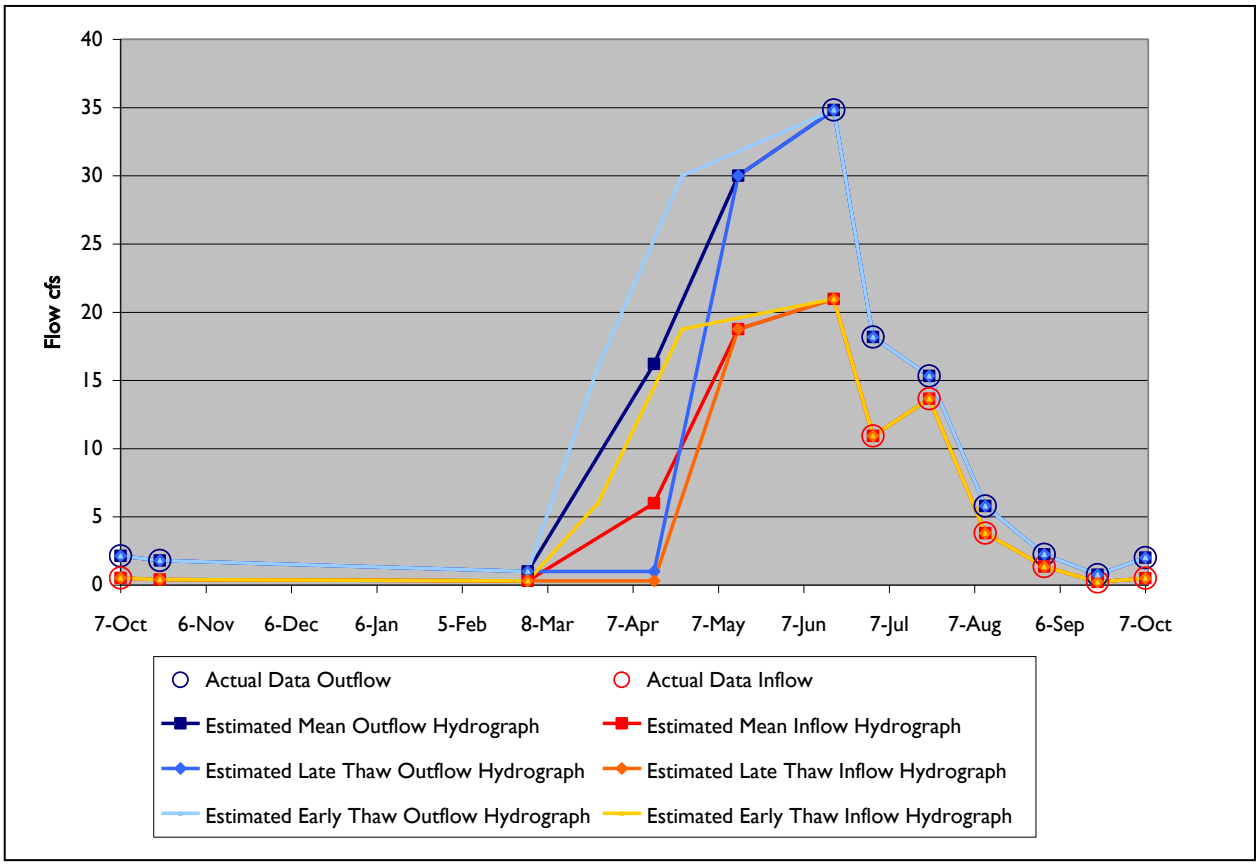


Figure F-1. Stream Flow Data and Extrapolated Hydrographs for Rock Lake Inflow and Outflow.

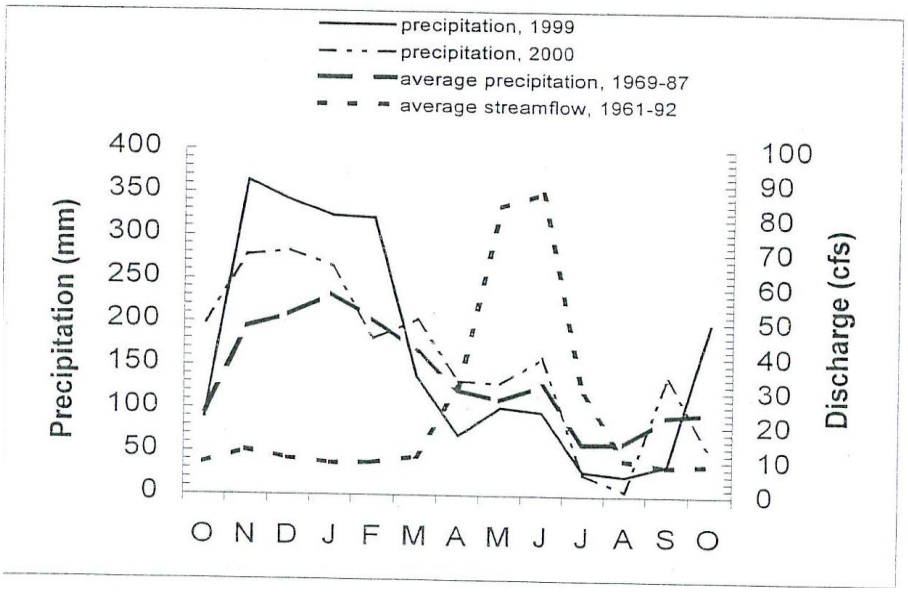


Figure F-2. Precipitation and Flower Creek Stream Flow Hydrographs (from Gurrieri [2001])

SURFACE WATER OUTFLOW

Surface water outflow was calculated in the same fashion as surface water in. The dark blue plot on **Figure F-1** represents the average annual outflow. The area under this plot was integrated to determine the annual surface outflow from the lake (approximately 6,947 acre-ft/yr). Again, to address uncertainty in this estimate, the date of thaw was moved forward and backward 20 days giving a range from 5,907 to 7,989 acre-ft/yr, or an average error of 1,041 acre-ft/yr.

OVERLAND FLOW

Several conservative assumptions were used that likely underestimate this component of the water balance, which would overestimate the contribution from groundwater.

There is a substantial catchment area for Rock Lake that does not contribute to the surface inlet channel above Rock Lake. The overland flow catchment area is approximately 415 acres. Precipitation falling in this area was reduced to account for infiltration into groundwater and direct evaporation from surface pools, sublimation and evapotranspiration. Since a portion of the overland flow area has talus slopes, a higher rate of infiltration (17% of precipitation or 11.7 inches) was applied. There is limited vegetation in this region with Rock Lake located at the tree line; thus, minimal evapotranspiration from vegetation is expected. Topography of the overland flow catchment area is very steep, with little water expected to pool and evaporate. Sublimation of snow and ice may occur for several months of the year. According to Chen Northern (1989), potential evaporation in the winter months in this region is quite low (November through February ET at 4400 feet elevation is approximately 2.6 inches). Each of these evaporative processes might add up to as much as 10 percent of annual precipitation (6.9 inches). This leaves approximately 50 inches of precipitation annually flowing from 415 acres; thus, the overland flow estimate is approximately 1,743 acre-ft/yr. Up to 5 percent of precipitation error may be associated with these estimates, yielding ± 119 acre-ft/yr to this estimate.

EVAPORATION

Evaporation directly off the lake surface was calculated by applying an evaporation rate to the area of the lake. Gurrieri (2001) provided an estimated lake evaporation rate for this region of 26 inches. This yields an average annual evaporation from the lake surface of 126 acre-ft/yr. To assess the error in this estimate, the potential annual evaporation rates for elevation 4400 feet (Chen Northern 1989) was used (29 in/yr). Based on these rates, there may be up to 3 inches of variability in the evaporation rate, yielding a lake evaporation error 15 acre-ft/yr.

NET GROUNDWATER FLUX

Adding up each of the inflows and outflows left a deficit of 954 acre-ft/yr for inflow, which is attributed to flux from groundwater (i.e., net groundwater inflow).

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APPENDIX G

MODEL PREDICTIONS OF MITIGATION MEASURES MEMORANDUM

Technical Memorandum

To: Eric Klepfer, Klepfer Mining Services

From: Amelia Tallman, Cam Stringer, & Doug Rogness
AMEC Geomatrix

Tel: (406) 542-0129

Fax: (406) 542-0130

Date: April 22, 2011

Subject: Updated 3D Model Predictions of Various Mitigation Measures; Montanore Project

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This Memo presents results of revised 3D groundwater model runs designed to simulate mitigation measures that may be adopted during operations in order to reduce impacts to surface water resources. Two primary mitigation scenarios were simulated that include: (1) grouting in the upper mine blocks (Blocks 14, 16 and 18) during mining; and (2) installing bulk heads in the mine workings after mining ceases.

MODEL MODIFICATION

Grouting was simulated along the back (south) side of Blocks 14, 16, and 18, and corresponding access ramps (**Figure 1**). These blocks are all simulated in layer 5 of the model. The grout was simulated as 10 feet thick with a hydraulic conductivity of 1×10^{-9} cm/sec. Since the elements in the model are approximately 30 meters wide in this region, the hydraulic conductivity was set such that it would be equivalent to 10 feet of 1×10^{-9} cm/sec material. The grouting was simulated in both the mining (dewatering) and post-mining (recovery) model simulations.

Simulation of bulk heads was conducted to determine the effectiveness of installing bulk heads in the southern end of the mine void (nearest to Rock Lake). The bulk heads were simulated to represent a 20-ft thick concrete pressure grouted wall with a mean hydraulic conductivity of 1×10^{-9} cm/sec. The bulk heads were simulated in the post-mining recovery simulation. Two different bulk head configurations were simulated, each having two simulated bulk heads. The first simulation had bulk heads in Blocks 8 and 14; the second simulation had bulk heads placed in Blocks 1 and 8 (see **Figure 1** for block locations). The model was used to determine the best location of bulk heads to reduce predicted impacts to surface water features (e.g. Rock Lake and Rock Creek).

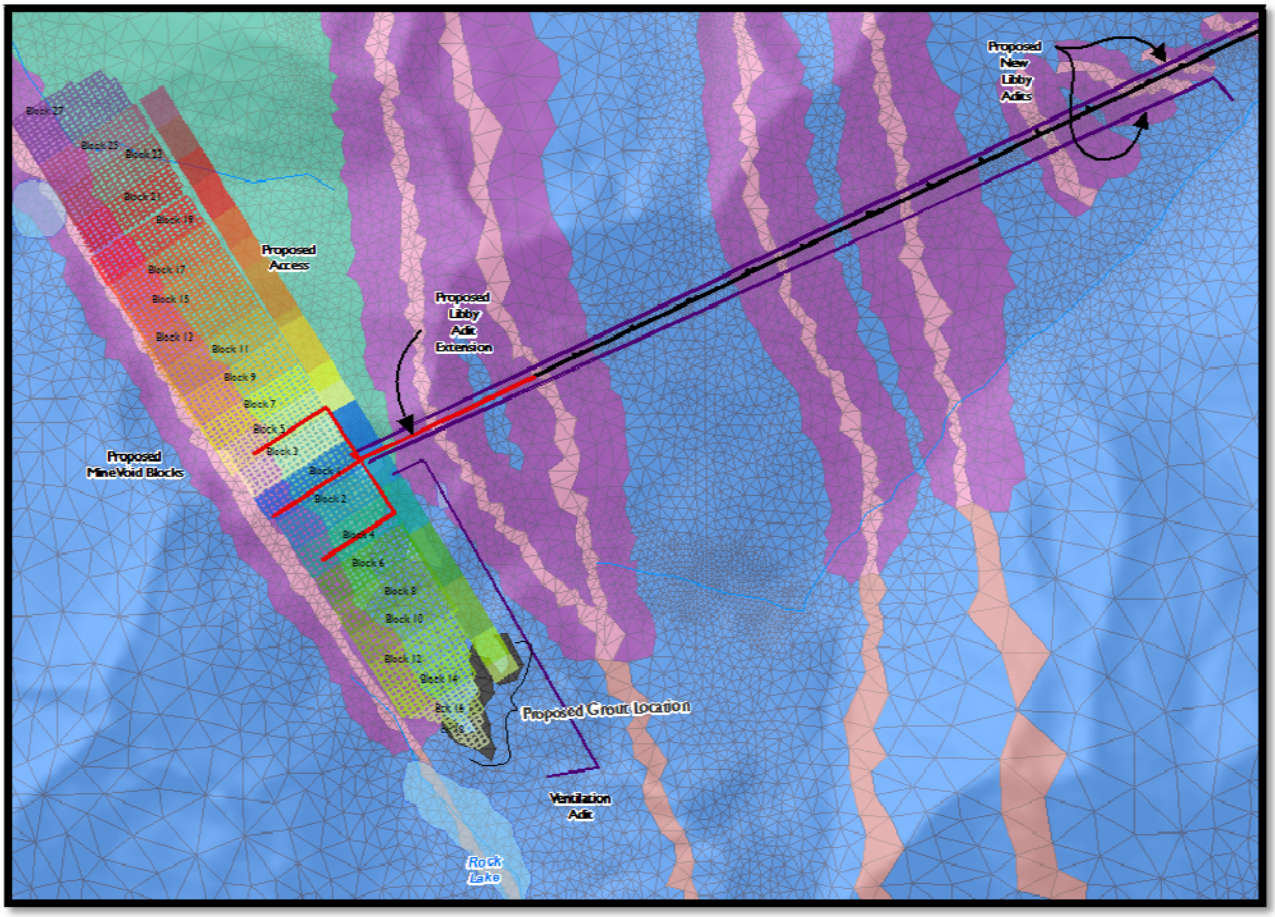

Figure 1. Proposed Grout Simulation Location

RESULTS

Simulation of grouting the back side of Blocks 14, 16, and 18, and corresponding access ramps resulted in minor reductions to predicted streams impacts (**Table 1**). This table shows that during the dewatering period, the grouting simulation resulted in notably reduced impacts predicted to Rock Creek, Ramsey Creek, and Poorman Creek at the wilderness boundary at the end of the mining period, and little or no changes to impacts predicted for the other drainages, as compared to previous "standard" model simulations. The "standard" model run also shows three locations where changes to stream baseflow exceed 20 percent; whereas, only one model point exceeded 20 percent for the grouting scenario. It is noted that the three locations that had greater than 20 percent change are in the upper reaches of Libby Creek and East Fork Rock Creek where baseflows are low (0.04 to 0.54 cfs).

Table 1. Predicted Changes to Baseflow from Standard and Grouting Model Runs During Mining

	Pre-Mine	STANDARD MODEL RUN						MITIGATION MODEL RUN (Grouting)					
	Base-flow (cfs)	Simulated baseflow (cfs)		Change in baseflow (cfs)		Percent change in baseflow		Simulated baseflow (cfs)		Change in baseflow (cfs)		Percent change in baseflow	
	0 yrs	8.4 yrs	22 yrs	8.4 yrs	22 yrs	8.4 yrs	22 yrs	8.4 yrs	22 yrs	8.4 yrs	22 yrs	8.4 yrs	22 yrs
E.Fk. Bull River at Mouth	11.34	11.31	11.25	-0.03	-0.09	-0.3%	-0.8%	11.32	11.27	-0.02	-0.07	-0.2%	-0.6%
E.Fk. Bull River at Wilderness Bndry	4.36	4.36	4.29	0.00	-0.07	0.0%	-1.6%	4.36	4.29	0.00	-0.07	0.0%	-1.6%
E.Fk. Bull River at EFBR-300	0.29	0.29	0.24	0.00	-0.05	0%	-17%	0.29	0.24	0.00	-0.05	0%	-17%
Rock Creek at Mouth	7.70	7.68	7.64	-0.02	-0.06	-0.26%	-0.78%	7.69	7.64	-0.01	-0.06	-0.1%	-0.78%
Rock Creek (E.Fk.) below Rock Lake at Wilderness Bndry	0.29	0.28	0.23	-0.01	-0.06	-3.4%	-21%	0.28	0.24	-0.01	-0.05	-3.4%	-17%
E.Fk. Rock Creek at EFRC-50 (above lake)	0.04	0.04	0.03	0.00	-0.01	0%	-25%	0.04	0.03	0.00	-0.01	0%	-25%
Libby Creek at Highway 2	19.83	19.66	19.56	-0.17	-0.27	-0.9%	-1.4%	19.66	19.57	-0.17	-0.26	-0.9%	-1.3%
Libby Creek at LB-300	1.22	1.09	1.02	-0.13	-0.20	-11%	-16%	1.09	1.02	-0.13	-0.20	-11%	-16%
Libby Creek at Wilderness Bndry	0.54	0.49	0.43	-0.05	-0.12	-9%	-22%	0.49	0.430	-0.05	-0.11	-9%	-20%
Libby Creek at LB-50 (inside Wilderness Bndry)	0.28	0.27	0.24	-0.01	-0.04	-4%	-14%	0.27	0.25	-0.01	-0.03	-4%	-11%
Ramsey Creek at Wilderness Bndry	0.38	0.36	0.34	-0.02	-0.04	-5%	-9%	0.37	0.35	-0.01	-0.03	-3%	-7%
Poorman Creek at Wilderness Bndry	0.12	0.12	0.11	0.00	-0.01	0%	-8%	0.12	0.12	0.00	0.00	0.0%	0.0%

Note: cfs = cubic feet per second. Shaded cells show >20% change predicted in baseflow.

In addition to grouting the back walls of the mine void, it is likely that the ceiling of the void could be grouted as well, where needed, to control inflows. In reality, grouting the ceiling would result in reduced hydraulic conductivity in all directions over a thin zone; however, simulation of this condition was not possible with the model configuration because the model layers are relatively thick resulting in no hydraulic conductivity contrast horizontally for the thinner grout zone. Therefore, an attempt was made to simulate grouting in the ceiling by reducing hydraulic conductivity in the vertical direction only. This reduced vertical conductance was simulated over Blocks 1, 2, 4, 5, 7, 9, 12, 14, 16 and 18 (i.e. south upper half of mine void), and over portions of the adits crossing fault zones. Results of this modification to the first grouting model run show some additional reductions in stream flow impacts along the upper Libby Creek drainage (e.g. changed from 20% down to 18% at wilderness boundary, and from 16% down to 14% at LB-300), and only minor changes to flow at some other stream points.

During actual mining conditions, it is likely that grouting would seal any major groundwater inflows occurring from discrete fault or fracture zones. Therefore, it is difficult to model this condition with a regional model when the locations of discrete inflow zones are not known at this time.

Of the two bulk head simulations, the one with bulk heads installed in Blocks 1 and 8 resulted in the lowest magnitude of predicted impacts to surface water during the post-mining period and long-term flow conditions. **Figure 2** presents modeled hydrographs for this scenario in various blocks of the mine and at the water table during the mining and post-mining period. Much less post-mining drawdown is propagated to the water table on the south end of the mine void in this mitigation scenario. The lowest water table elevation over Block 18 at the south end (**Figure 1**) occurs 2.8 years after closure, or 25 years after the onset of mining. This compares to the "standard" unmitigated model run where the lowest water table elevation over Block 18 occurs about 16 years after closure, or 38 years after the onset of mining. **Figure 1** also shows that groundwater recovery stabilizes after approximately 1,300 years (1,322 years after onset of mining); whereas, the "standard" unmitigated model run shows stabilized recovery after about 1,150 years (1,172 years after onset of mining).

Table 2 presents the simulated baseflow and change to baseflow between the unmitigated "standard" model run and the model run simulating mitigation using grouting and bulk heads. The mitigation scenario presented in this table includes the first grouting model run (where grouting is simulated along the back side of Blocks 14, 16, and 18, and corresponding access ramps), with the addition of bulk heads placed in Blocks 1 and 8 during the post-mining period. The mitigation run predicted reduced impacts to water in the Rock Creek, East Fork Rock Creek, and East Fork Bull River drainages. The two uppermost East Fork Rock Creek stations and the upper East Fork Bull River station still show relatively high percentages of change to baseflow 3 to 16 years after mining ceases. However, these three locations have low and variable baseflows (0.04 to 0.29 cfs).

The greatest impacts to Libby Creek and its tributaries occur at or soon after the end of mining (year 22). Following mining, impacts to this drainage begin to decrease. Since the bulk head mitigation simulation had the greatest surface system drawdown over the mine void 2.8 years following mining (25 years after start of mining), the predicted impacts to Libby Creek at that time are greater than the "standard" post-mining model run where the greatest surface system drawdown over the mine void occurred 16 years following mining (38 years since onset of mining onset).

It is noted that there are considerable uncertainties in model predictions of baseflow changes in the upper reaches of streams. Predicted flows at locations such as EFRC-50, EFBR-300, and LB-50, which each include only a few model nodes upstream from the point (only one model node in the case of EFRC-50), are particularly prone to exacerbate any uncertainty or error in the model (for instance elevation accuracy.) Uncertainties or errors in elevation accuracy are generally normalized when fluxes are analyzed across a longer stream reach. The model was initially calibrated to baseflows in the longer, lower reaches of streams; whereas, the accuracy of model predictions in the upper reaches of streams, where flows are low are variable, is unknown. As previously stated, most of the upper reaches of streams where the greatest percentage of flow reductions are predicted to occur have average baseflows of less than 0.3 cfs that occur for only a few months of each year. In addition, there is uncertainty regarding the interconnection of regional groundwater systems with flow in the high elevation upper reaches of mountain streams.

In general, we believe these model results should be considered conservative, or nearly "worst" case, with respect to predicting impacts to the upper reaches of modeled streams because of the way the model assume interconnection between groundwater and surface water. We have established the basic framework for a 3D groundwater flow model of the Montanore Mine and surrounding area; its best utility in predicting inflows and impacts will be when empirical data are obtained during further underground drilling and testing in and near the ore zone to obtain more reliable input data about rock and groundwater flow conditions. Future model updates will incorporate this information.

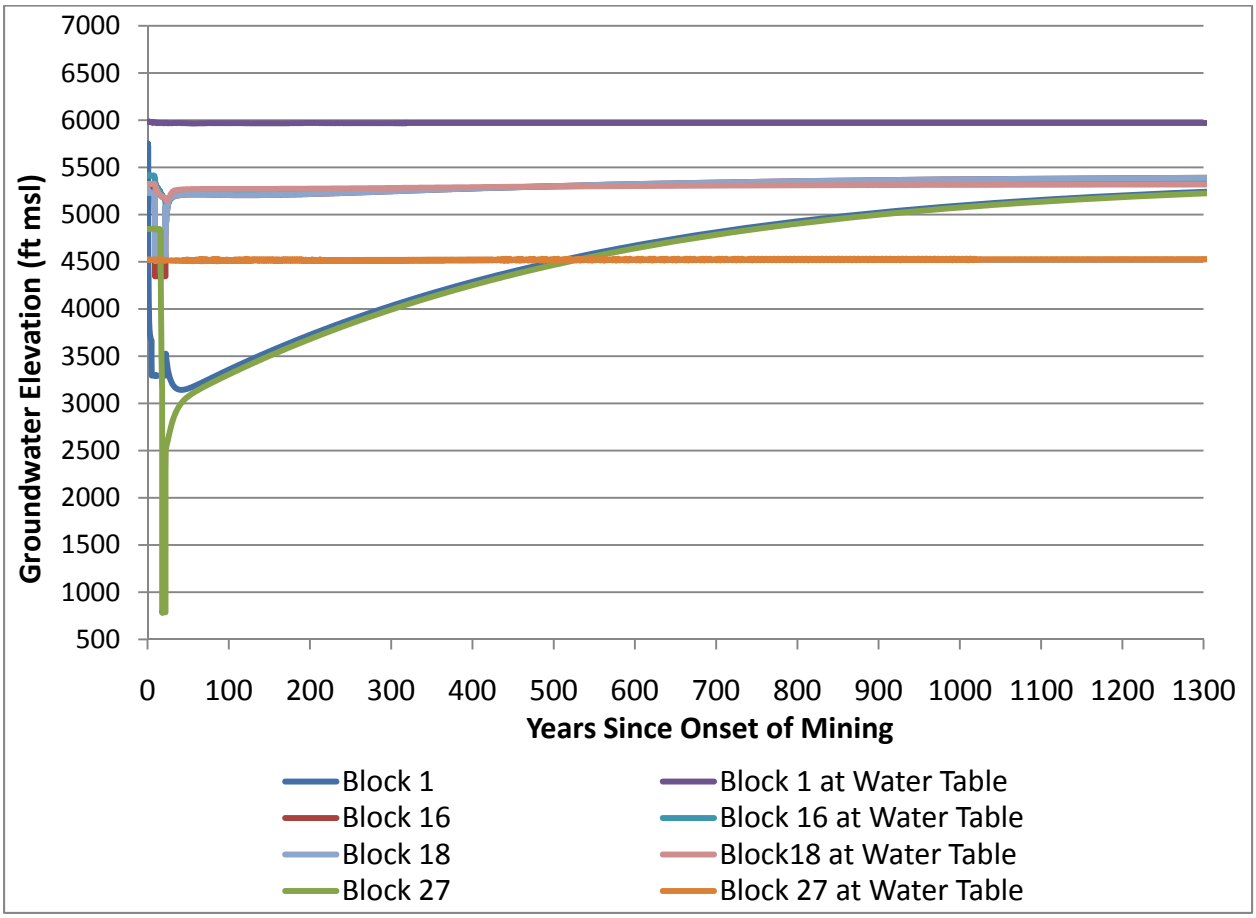

Figure 2. Predicted Groundwater Elevations During and After Mining with Mitigation

Table 2. Predicted Changes to Baseflow from Standard and Mitigation Model Runs Post-Mining

	Pre-Mine	STANDARD MODEL RUN									MITIGATION MODEL RUN (bulk heads and grouting)								
	Base-flow (cfs)	Simulated baseflow (cfs)			Change in baseflow (cfs)			Percent change in baseflow			Simulated baseflow (cfs)			Change in baseflow (cfs)			Percent change in baseflow		
	0 yr	38 yrs*	25 yrs	1172 yrs	38 yrs*	25 yrs	1172 yrs	38 yrs*	25 yrs	1172 yrs	38 yrs	25 yrs*	1322 yrs	38 yrs	25 yrs*	1322 yrs	38 yrs	25 yrs*	1322 yrs
E.Fk. Bull River at Mouth	11.34	11.08	11.22	11.39	-0.26	-0.12	+0.05	-2.3%	-1.1%	+0.4%	11.09	11.25	11.33	-0.25	-0.09	-0.01	-2.2%	-0.8%	-0.1%
E.Fk. Bull River at Wilderness Bndry	4.36	3.98	4.20	4.35	-0.38	-0.16	-0.01	-8.7%	-3.7%	-0.2%	3.99	4.21	4.35	-0.37	-0.15	-0.01	-8.5%	-3.4%	-0.2%
E.Fk. Bull River at EFBR-300	0.29	0.02	0.17	0.27	-0.27	-0.12	-0.02	-93%	-41.4%	-7%	0.03	0.18	0.27	-0.26	-0.11	-0.02	-90%	-37%	-7%
Rock Creek at Mouth	7.70	7.05	7.51	7.67	-0.65	-0.19	-0.03	-8.4%	-2.5%	-0.4%	7.55	7.54	7.71	-0.15	-0.16	+0.01	-1.9%	-2.1%	+0.1%
Rock Creek (E. Fork) below Rock Lake at Wilderness Bndry	0.29	-0.15	0.11	0.26	-0.44	-0.18	-0.03	>100%[1]	-62.1%	-10%	0.12	0.14	0.29	-0.17	-0.15	0.00	-59%	-51%	0%
E.Fk. Rock Creek at EFRC-50 (above lake)	0.04	0.00	0.00	0.02	-0.04	-0.04	-0.02	-100%	-100%	-50%	0.00	0.00	0.03	-0.04	-0.04	-0.01	-100%	-100%	-25%
Libby Creek at Mouth	19.83	19.72	19.58	19.83	-0.11	-0.25	0.00	-0.6%	-1.3%	0%	19.73	19.58	19.83	-0.10	-0.25	0.00	-0.5%	-1.3%	0%
Libby Creek at LB-300	1.22	1.10	1.03	1.22	-0.12	-0.19	0.00	-10.2%	-15.6%	0%	1.10	1.04	1.22	-0.12	-0.18	0.00	-9.8%	-14.8%	0%
Libby Creek at Wilderness Bndry	0.54	0.47	0.44	0.54	-0.07	-0.10	0.00	-12.2%	-18.5%	0%	0.48	0.44	0.54	-0.06	-0.10	0.00	-11.1%	-18.5%	0%
Libby Creek at LB-50 (inside Wilderness Bndry)	0.28	0.24	0.24	0.28	-0.04	-0.04	0.00	-13.8%	-14.3%	0%	0.25	0.25	0.28	-0.03	-0.03	0.00	-10.7%	-10.7%	0%
Ramsey Creek at Wilderness Bndry	0.38	0.36	0.35	0.38	-0.01	-0.03	0.00	-3.8%	-6.7%	0%	0.36	0.35	0.38	-0.02	-0.02	0.00	-4.0%	-6.7%	0%
Poorman Creek at Wilderness Bndry	0.12	0.12	0.12	0.12	0.00	0.00	0.00	-3.7%	0.0%	0%	0.12	0.12	0.12	0.00	0.00	0.00	0.0%	0%	0%

Note: cfs = cubic feet per second. Shaded cells show >20% change predicted in baseflow. * Time period with an asterisk is when maximum groundwater drawdown occurs over model Block 18.

[1] Percent change greater than 100% for East Fork Rock Creek below Rock Lake at Wilderness Boundary indicates there is a net flow of lake water (recharge) contributing to groundwater at this site (assuming lake is well-connected to groundwater system).

APPENDIX H

MODEL PARAMETERIZATION ADJUSTMENT MEMORANDUM

Technical Memorandum

To Eric Klepfer, Kelpfer Mining Services;
Mike Galloway and Richard Trenholme, ERO, Wayne Jepson USFS
From Amelia Tallman and Cam Stringer, AMEC Geomatrix
Tel (406) 542-0129
Fax (406) 542-0130
Date 10/26/2010
Subject Model Parameterization Adjustment Exercise

INTRODUCTION

At the request of the Agencies, the three dimensional MMC model was modified by removing zones of low permeability simulated adjacent to fractures and faults. The model was then executed and compared to calibration targets and predictive runs were run with the modified model. Results of these modified model runs should not replace the previously predicted model results presented by AMEC (2010) as this model parameterization provides a poorer calibration to steady state targets and Libby Adit data. These new results could be added to the previous results in the final report for the purposes of uncertainty analysis.

Sections below describe requested adjustments to the numerical model and resulting changes to calibrations and predicted impacts. In addition, we understand the justification for the low permeability parameterization may not have been adequately documented in the previous draft report. Therefore, the final section below (Proposed Documentation) includes text proposed for addition to the final model report that describes the justification of the model parameterization.

MODIFICATIONS TO NUMERICAL GROUNDWATER MODEL

Hydraulic conductivity values in zones representing virtually unfractured bedrock simulated in layers 3 through 7 adjacent to fractures and faults were replaced with the background hydraulic conductivity values for each respective layer. **Table 1** presents the original and replaced hydraulic conductivity for the low permeable zones in each layer.

Table 1. Adjusted Hydraulic Conductivity

Layer	Hydraulic Conductivity Calibrated Model (cm/sec)	Adjusted Hydraulic Conductivity (cm/sec)
3	$3x10^{-8}$	$4x10^{-7}$
4 and 5	$3x10^{-9}$	$9x10^{-8}$
6 and 7	$3x10^{-9}$	$6x10^{-8}$

EFFECT ON CALIBRATION

Increasing the hydraulic conductivity in zones adjacent to fractures resulted in a poorer calibration to both the steady state head data and to the transient Libby Adit calibration data (hydraulic tests and the long-term Libby Adit dewatering rate). **Table 2** presents the steady state calibration statistics of the adjusted model verses the calibrated model. Residual is the difference between the head value simulated by the model and the target head value. Statistics indicate that the residuals increase a little in the modified model parameterization. Since hydraulic conductivity values were changed in a small area, only a few target locations were noticeably affected. Residuals at wells HR-19, HR-26 and HR-29 increased by 121, 13, and 20 feet, respectively.

Table 2. Summary of Steady State Calibration Statistics for Calibrated and Adjusted Model Parameterizations

Statistic	Calibrated Model	Modified Model
Absolute Residual Mean (feet)	42	43
Residual Mean (feet)	-3	-5
Standard Deviation (feet)	56	60
Range (feet)	3386	3386
Standard Deviation/Range	0.017	0.018

Figures 1 and 2 are graphs showing simulated and measured drawdown vs. time for hydraulic tests at boreholes 3650 and 5220 respectively, for both the calibrated and modified model. These figures show that the modified model generally under-predicts drawdown within the fracture sets but over-predicts drawdown across the fracture sets (i.e. not enough drawdown at 3110LR and 5220LR and too much drawdown at 4500LR).

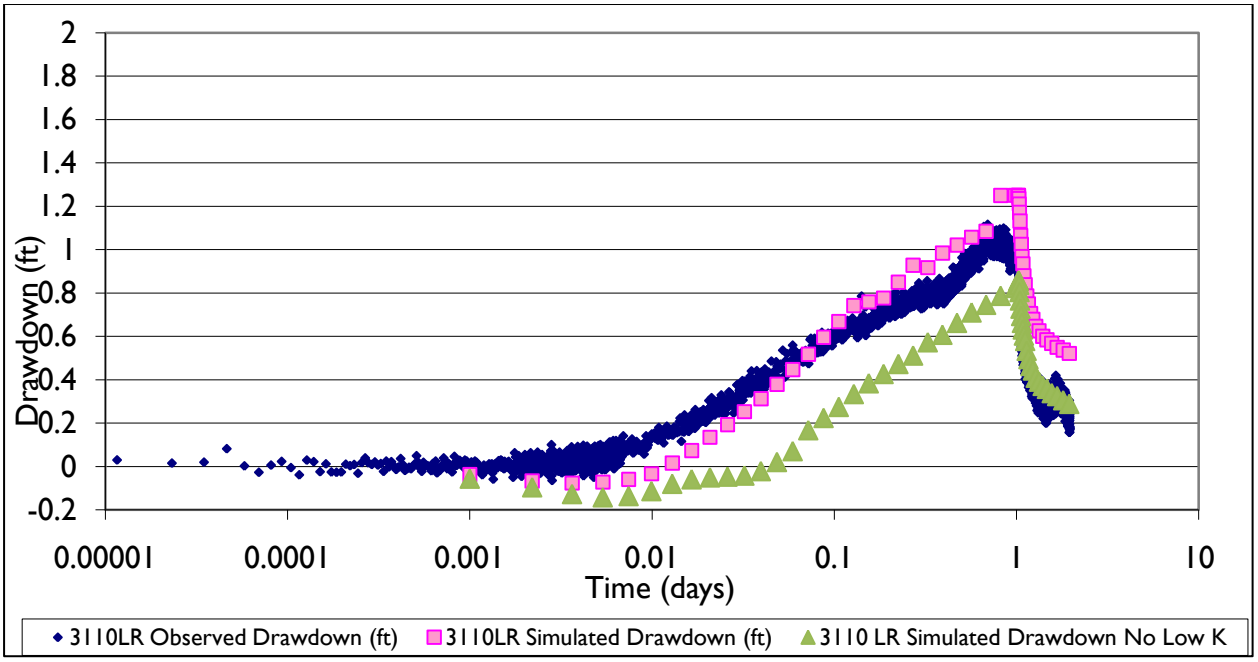

Figure 1. Observed and Simulated Time-Drawdown at 3110 LR During test at 3680RR in Libby Adit

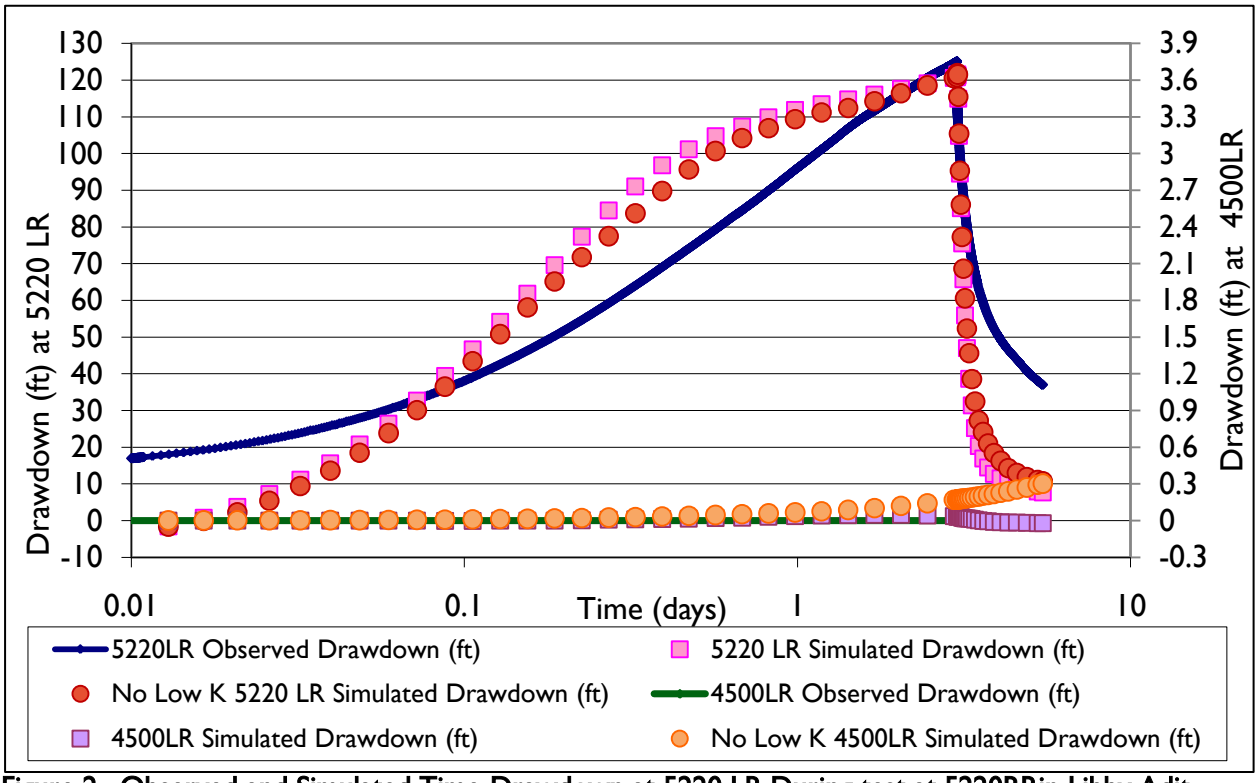

Figure 2. Observed and Simulated Time-Drawdown at 5220 LR During test at 5220RRin Libby Adit

Figure 3 presents the simulated long term (1991-1995) pumping rates in the Libby Adit for both the calibrated and modified models along with the observed dewatering rate. The modified model parameterization results in adit dewatering rates that are generally over-predicted by 35 gallons per minute or more.

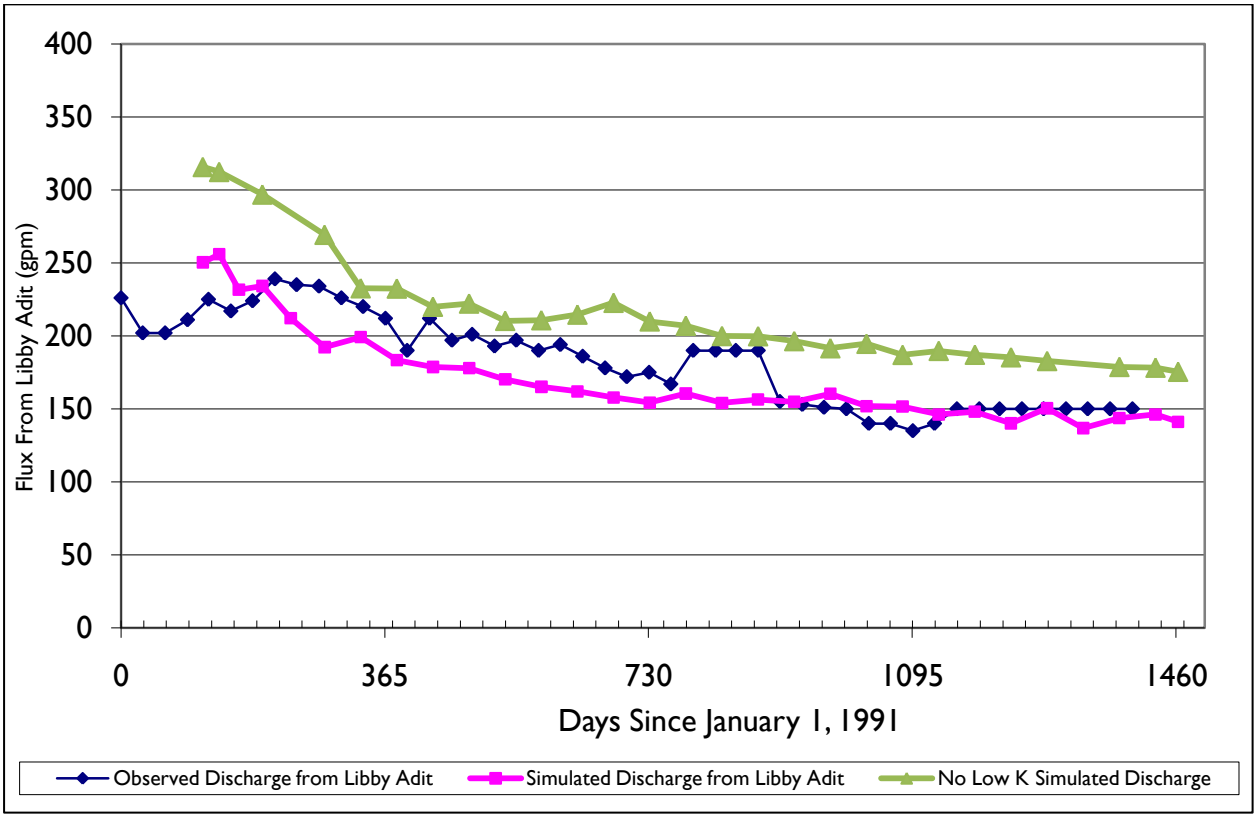

Figure 3. Observed and Simulated Libby Adit Discharge

PREDICTED DEWATERING RATES

The increase in hydraulic conductivity values adjacent to fracture sets yields predicted dewatering rates that are 11 to 35 higher than calibrated model predictions. The average dewatering rates for the various mining periods predicted by both the calibrated and modified models are presented in **Tables 3** and **4**, respectively.

Table 3. Calibrated Model Predicted Dewatering Rates

Period	Average Dewatering Rate in Adits (gpm)	Average Dewatering Rate in VOID/exploration bores (gpm)	Average Dewatering Rate for all Mine Workings (gpm)
0-2 years	226	31	257
2-5 years	445	29	474
5-20 years	267	115	382
20-22 years	203	166	369

Table 4. Adjusted Model Predicted Dewatering Rates and Percent Increase from Calibrated Model

Period	Average Dewatering Rate in Adits (gpm)	% Increase	Average Dewatering Rate in VOID/exploration bores (gpm)	% Increase	Average Dewatering Rate for all Mine Workings (gpm)	% Increase
0-2 years	309	37%	40	29%	348	35%
2-5 years	485	9%	41	41%	526	11%
5-20 years	310	16%	168	46%	478	25%
20-22 years	277	36%	210	26%	487	32%

PREDICTED STREAMLFOW DEPLETION

The modified model predicts greater depletion in flow in nearby streams than the calibrated model. **Table 5** presents the predicted impacts to streams from both models. This table shows that the modified model predicts baseflow depletions that are greater except in the Poorman and Ramsey Creek drainages.

Table 5. Predicted Impacts to Streams from Calibrated and Adjusted Model Parameterizations

Drainage	Calibrated Model			Adjusted Parameterization		
	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change	Modeled Groundwater Contributing to Surface Water		Modeled Baseflow Change
	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)	Pre-Exploration (ft^3/sec)	Stage 3 (ft^3/sec)	(ft^3/sec)
East Fork Bull River	11.34	11.25	-0.09	11.36	11.17	-0.19
East Fork Bull River at Wilderness Boundary	4.36	4.29	-0.07	4.37	4.22	-0.15
Rock Creek	7.70	7.64	-0.06	7.70	7.57	-0.13
Rock Creek at Wilderness Boundary (below lake)	0.29	0.23	-0.06	0.29	0.16	-0.13
Libby Creek	19.83	19.56	-0.27	19.87	19.48	-0.4
Libby Creek at Wilderness boundary	0.54	0.43	-0.12	0.56	0.39	-0.17
Ramsey Creek at Wilderness Boundary	0.375	0.34	-0.04	0.38	0.34	-0.04
Poorman Creek At Wilderness Boundary	0.12	0.11	-0.01	0.12	0.11	-0.01

PROPOSED TEXT

Hydraulic conductivity of the fracture and fault zones in the mine area was determined during the calibration to the hydraulic tests at Libby Adit boreholes 3680RR and 5220RR. To adequately match the time-drawdown data and the lack of drawdown during simulations of hydraulic tests at 3680RR and 5220RR, elevated hydraulic conductivity values that decreased with depth were assigned to regions representing fractured rock *(where boreholes 3680RR and 5220RR were finished),* surrounded by reduced hydraulic conductivity representing unfractured rock.

When modeling large scale bedrock aquifers, it is common practice to simulate the mass as an equivalent porous medium. This means that on a large scale the series of fractures transmit water in a similar manner to porous material. This is an appropriate assumption for the regional system modeled around Montanore. However, on a smaller scale it is more appropriate to simulate discrete fractures within relatively impermeable material (assuming there is information regarding the nature and location of the fractures). In and around the proposed mine workings, a greater degree of fault mapping has been conducted. Since the Libby Adit data are the best representation of the hydraulic behavior of water bearing features at depth, the pattern of higher permeability fractures separated by low permeable competent bedrock was extrapolated from the calibrated fracture regions in the Libby Adit to the

mapped faults in areas surrounding the proposed mine. In addition to the hydraulic test data, mapping of the Libby Adit shows a pattern of short intervals of water bearing fractures followed by large intervals with an absence of water bearing fractures. Observed zones of non-water-bearing material up to 2000 feet in extent justify the use in the model of zones of competent bedrock between zones of fractures. These low permeable zones do not represent bedrock that is of lower permeability than the surrounding bedrock, they represent the unfractured bedrock surrounding fracture locations.

We do not assume that the mapped faults are the only locations where fractures are present, thus we only simulated low permeabilty zones a few elements wide around the high permeable mapped fault zones and simulated the remaining bedrock areas with the background permeability values (equivalent porous media).