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FINAL
HYDROGEOLOGY TECHNICAL REPORT
MONTANORE MINE AREA

Prepared for—

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February 2009

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Executive Summary
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Montanore Mine Area

Mines Management, Inc. (MMI) proposes to develop an underground mine in the Cabinet Mountains of northwestern Montana. The ore body is beneath the Cabinet Mountains Wilderness (CMW). All access and surface facilities would be located outside of the CMW boundary. Montanore Minerals Corp. (MMC), a wholly owned subsidiary of Mines Management, Inc. (MMI), would be the project operator.

As part of an effort to prepare an EIS for the Montanore Project, ERO Resources Corporation (ERO) reviewed available data and conceptual models of the mine area hydrogeology and recommended that additional analysis be completed to evaluate mine area hydrology, and provide additional information where both models were deficient. ERO proposed to use a two-dimensional numerical model that was developed specifically to address mine inflow and mine impact situations (ABCFEM). As the analysis progressed, the various conceptual models were reduced to two basic models—the agencies' conceptual model and the revised MMC conceptual model. The agencies' conceptual model was selected for ongoing analysis because it was better supported by site data and observations and was the more conservative of the two models.

The primary objective of the conceptual model and the subsequent numerical model was to establish a hydrogeologic framework that can be used to evaluate potential mine impacts and develop possible impact mitigation. Given the limited data, the numerical model cannot provide precise answers to questions, but rather assist in developing the limits to any given issue and evaluate how different components of a conceptual model behave under different hydraulic stresses. The model was not intended to provide a detailed analysis of the hydrogeology for design or engineering purposes, but rather to test and refine an existing conceptual model. The model results have assisted in the development of a conceptual model that is consistent with observations and can duplicate certain quantitative data, such as adit outflows and stream base flow. Because the model was successfully calibrated against four independent hydrologic data, and was relatively insensitive to certain aspects of the conceptual model that are not as well constrained by actual data, the model has been useful in evaluating potential changes to the local hydrogeology in response to proposed mining activities. A list of specific conclusions regarding various aspects of the conceptual model is provided.

Modeling was performed in three phases. Phase I was the initial steady state model runs or scenarios that were based on an initial conceptual model. After the Phase I results were presented to the Hydrogeology Committee, the conceptual model was modified slightly, the numerical model recalibrated to a domain-wide water balance, and additional Phase II model runs were performed. Phase III modeling was conducted to investigate the timing of the predicted ground water drawdown.

For those areas where the fractured bedrock water table is currently some depth below ground surface (for all areas above 5,600 feet elevation), ground water drawdown, as

predicted by the model, would not have a direct effect on surface water occurring above this elevation. Because surface and ground water above 5,600 feet elevation appear to be not hydraulically connected, ground water drawdown would not result in decreases to surface water (creeks, springs, and lakes) in those areas. Infiltration of precipitation is controlled by the nature of the surface material and overall hydraulic conductivity and, therefore, the infiltration rate would not change in these areas as a result of a lower water table. It is possible that random fractures exist above elevations of 5,600 feet that are saturated between the fractured bedrock water table and the shallow ground water flow path, hydraulically connecting the two ground water flow paths. If this condition existed, drawdown of the fractured bedrock water table by mine dewatering could reduce flow to unidentified springs or affect lake levels associated with this type of fracture, such as the Libby Lakes. However, there are no observations, data or numerical model results to indicate this condition exists.

For those areas where ground water is either at the surface or connected hydraulically to shallow ground water flow systems (below an elevation of about 5,600 feet), drawdown due to mine dewatering would decrease the volume of water available to the surface water system, such as springs, lakes and creeks. In the agencies' conceptual model, ground water and surface water are hydraulically connected below elevations of about 5,600 feet and, therefore, surface water would be affected if ground water levels decreased due to mine dewatering.

The time to fill the mine void was calculated, using the available information for produced tonnage of waste rock, tonnage of ore, bulk density of the rock, and the mine/adit flow rate predicted by the Phase II modeling. Using assumptions for these variables, it would require about 47 years to refill the mine void and adits. After the mine void filled with water, the drawdown cone would begin to recover, but would require slightly more than 20 years to achieve steady state recovery, as defined by the Phase II results.

The agencies' numerical model predicted base flows for all model node locations along various creeks. The model does not consider what is possible to detect or measure. There are other factors that should be considered when reviewing and interpreting these data. For example, base flow at any one location along a creek may not be easily defined within the range of the model-predicted changes, but impacts from dewatering of the mine and adits may be expressed in other ways, such as changing the elevation at which creeks begin to flow. Mine dewatering (and resultant ground water drawdown) may cause this elevation to move down the drainage.

Another consideration in the ability to measure or detect changes in base flow due to mine dewatering is the annual variability in precipitation. In wet years, there may be sufficient precipitation and/or remaining snowpack to mask any changes in base flow that would otherwise be observable in late summer to early fall. Also, in the middle to lower reaches of the various drainages, there are sufficient thicknesses of alluvium or other surficial deposits that have the ability to store sufficient ground water. Ground water discharge from these deposits through dry periods would probably be sufficiently high to mask any changes in base flow resulting from mine dewatering. An example of this condition is at Rock Creek Meadows, located about 0.75 miles downstream from Rock Lake.

In contrast to the middle and lower reaches of the various creeks, the upper reaches in the higher elevation portions of these drainages have much thinner alluvial or surficial deposits with limited ground water storage capacity or no surficial deposits. Late season base flow is derived mostly from deeper ground water and may be subject to measurable changes from mine dewatering.

In determining whether surface water would be affected by mine dewatering, another consideration is to what degree the hydrogeology of the area is heterogeneous versus homogeneous. The agencies' numerical model assumed homogeneous conditions because of the lack of specific data on this issue. If ground water flow is dominantly controlled by heterogeneous conditions, then potential impacts to surface water would be focused along structural trends, rather than being distributed evenly among all drainages. It is not possible to predict how this condition might affect creek base flow with the currently available data.

Final
Hydrogeology Technical Report
Montanore Mine Area

INTRODUCTION

The Montanore Project is a proposed copper and silver underground mine and associated transmission line located about 18 miles south of Libby near the Cabinet Mountains of northwestern Montana(Figure 1; all figures are at the end of this report). The ore body is beneath the Cabinet Mountains Wilderness (CMW). All access and surface facilities would be located outside of the CMW boundary. Montanore Minerals Corp. (MMC), a wholly owned subsidiary of Mines Management, Inc. (MMI), would be the project operator. As proposed, the underground mine would be accessed via two adit declines, one of which (Libby Adit) was completed to within about 2,000 feet of the ore body in 1991. Twenty-four deep exploration core holes, generally located along the trend of the Rock Lake Fault, defined the approximate location of the ore body. Limited ground water data were collected during the exploration drilling program. Considerable ground water flow data were collected during the construction of the Libby Adit, including descriptions of structures associated with ground water discharge to the adit and overall flow (pumpage) from the adit during and after construction.

On behalf of MMI, Geomatrix developed a conceptual model of the mine area hydrogeology and presented it in a Hydrogeology Report, initially in 2005 and revised in 2006 (Geomatrix 2006a), and again in 2007 (Geomatrix 2007). Using water quality and flow data collected from surface water bodies, such as Rock Lake, and other experience in the proposed mine area, Gurrieri also presented a conceptual model of the mine area hydrogeology (Gurrieri 2001). Gurrieri's model was developed while employed by the Montana Department of Environmental Quality (DEQ) and during the agencies' preparation of an environmental impact statement (EIS) for the nearby Rock Creek Project. Gurrieri's report was to address concerns raised about the potential for adverse effects on wilderness lakes that overlie the deposits that would be mined by both projects.

As part of the effort to prepare an EIS on the Montanore Project, ERO Resources Corporation (ERO) reviewed available data and conceptual models of the mine area hydrogeology and recommended that additional analysis be completed to evaluate mine area hydrology, and provide additional information where both models were deficient. ERO proposed to use a two-dimensional numerical model that was developed specifically to address mine inflow and mine impact situations (ABCFEM). As the analysis progressed, the various conceptual models were reduced to two basic models—the agencies' conceptual model and the revised MMC conceptual model. The agencies' conceptual model was selected for ongoing analysis because it was better supported by site data and observations and was the more conservative of the two models.

The primary objective of the conceptual model and the subsequent numerical model was to establish a hydrogeologic framework that can be used to evaluate potential mine impacts and develop possible impact mitigation. Given the limited data, the numerical

model cannot provide precise answers to questions, but rather assist in developing the limits to any given issue and evaluate how different components of a conceptual model behave under different hydraulic stresses.

Initial Conceptual Model

A hydrogeology committee consisting of representatives from the Kootenai National Forest (KNF), DEQ, MMI, and ERO was established to guide the development of the numerical model. The numerical model was initially constructed using the following assumptions regarding a conceptual model for the Montanore mine area. The conceptual model was modified as the model progressed, as described in subsequent sections of this report. The underlying assumptions are:

- Metasedimentary rocks in the mine area have very low primary permeability (hydraulic conductivity).
- Fractures and other structures provide pathways for ground water movement.
- Fracture or secondary permeability is higher than primary permeability.
- Source of ground water is infiltration of precipitation.
- Static water levels measured in exploratory boreholes (in those containing water) were at an elevation of about 5,400 to 5,500 feet. Static water level in exploratory boreholes drilled near Rock Lake had a water surface elevation approximately the same as the lake.
- Springs consistently start at an elevation of about 5,400 to 5,500 feet. Springs that occur above this elevation are probably the result of isolated shallow flow cells controlled by local fracturing, bedding planes, or drainage from surficial material such as colluvium or talus.
- Base flow to creeks and springs is maintained by ground water discharge. Perennial flow in area streams begins at an elevation of about 5,400 to 5,500 feet.
- A ground water table exists at depths up to 500 feet below ground surface in the higher topographic areas and is at or near land surface in areas below elevations of 5,400 to 5,500 feet.

Model Description

The Finite Element Method Code (ABCFEM) is a computer code that allows flexible, powerful two- and quasi-three-dimensional ground water engineering flow and solute transport evaluations to be performed on personal computers (Brown and Hertzman 1994). ABCFEM is written in the C programming language, and is compiled using the Microsoft C version 5.1 compiler and linker.

Overview

ABCFEM has the following analytical capabilities:

- *Flow analysis*. Two-dimensional and quasi-three-dimensional (layered) finite-element ground water flow analysis, with moving phreatic surface, infiltration, stream interaction, and capability for plan, sectional, or radial analysis. The quasi-three-dimensional capability was not used because there were insufficient site-wide data to support its use.
- *Solute transport*. Random-walk solute transport analysis with retardation, dispersion, injection, and withdrawal of chemical mass, first-order linear decay, and chemical mass accounting.

The program can be used for the solution of flow problems, or it can be used to analyze flow and solute transport together in a single domain. The finite element method of analysis allows flow computations to be performed with flexibility. Actual locations of points of importance to the analysis and actual features of the problem may be modeled, such as impermeable boundaries, infiltration from the surface, interaction with streams, extraction from wells, flow from wetlands, seepage from waste disposal areas, and many other commonly encountered hydrogeologic situations. When detailed resolution is needed, the method allows detailed simulation of the existing conditions. Where the analytical needs are less demanding, the method allows increased efficiency through more approximate simulation of the real flow domain.

The program has certain limitations:

- It does not directly compute three-dimensional flows, except in problems with radial symmetry. The “connections” feature, however, may be used to perform quasi-three-dimensional layered analyses.
- It does not directly analyze flow in the vadose zone. ABCFEM instead uses simplifying assumptions to approximate reduced transmissivity in the vadose zone in quasi-three-dimensional layered analyses.

Features

ABCFEM has a number of features to make commonly encountered engineering situations amenable to analysis. These features include:

- *Flexible aquifer analysis*. ABCFEM provides the flexibility that is expected of finite element methods for analyzing transient or steady state ground water flow systems. The discretization can be fine when great detail is needed, or coarse when general trends or boundary settings are required.
- *Flexible boundary conditions*. Boundary conditions may be selected to match actual situations, including fixed flow, fixed head, forced inflow, infiltration, and swamping. Well extraction, injection, and other commonly encountered ground water engineering activities can be analyzed. The ability to specify arbitrary

conductive connections between nodes permits additional flexibility in defining an analysis domain.

- *Infiltration*. Most ground water systems receive much of their water from the ground surface. Accordingly, ABCFEM allows downward movement of infiltrating water, which it handles on an element-by-element basis, using infiltration rates set by the analyst.
- *Moving phreatic surface*. In many mining and water resource situations, the location of the ground water table changes over time, or in response to removal/injection scenarios. For this reason, ABCFEM includes the ability to allow the top of the zone of saturation (the phreatic surface) to move. If the analysis type is specified as "unconfined," ABCFEM tracks the location of the phreatic surface, and modifies the transmissivity (the saturated thickness multiplied by the hydraulic conductivity of the material) of the formation appropriately. Mixtures of confined and unconfined nodes are allowed in the same problem, as long as the confined portions of the aquifer remain fully saturated.
- *Swamping*. The ability for the phreatic surface to move creates the possibility for it to move above the ground surface. If this happens in an actual unconfined aquifer, ground water will emerge at the ground surface, forming a spring or a stream. This behavior can be modeled in ABCFEM. If the node boundary condition is set appropriately (to "swamping"), the head at the node may change without restraint as long as it is below the ground surface and above the base of the aquifer. If it is driven to move above the ground surface, the head stays at the ground surface, and water flows out of the ground water system at a rate determined by the flow imbalance at the node for that (temporarily) fixed head. If at any later time in the analysis the head is driven to decline below the ground surface, then the head drops and the outflow from that node to the surface system ceases. The swamping feature may be used in both confined and unconfined simulations.
- *Stream/aquifer interaction*. The capability to allow swamping also allows the opportunity to model the base flow in streams, and the interaction of flow in such streams with the ground water system. In actual conditions, if the ground water system beneath a flowing stream is at a head below the stream, and if infiltration is possible, then water will tend to infiltrate from the stream to the ground water system (a losing reach of the stream). Conversely, if the ground water head at a location is greater than the surface elevation, then ground water will flow (seep) into the stream bed (a gaining reach of the stream). ABCFEM accommodates this feature by allowing any water flowing out of a node to be directed to any other node. Chains of these linked nodes behave as "streams," gaining in flow where the ground water flow gradient is upward, and losing flow where the water table is beneath the surface. These stream networks can be defined automatically, or specified directly by the user. The result is a natural method of simulating the interaction between surface water and ground water.

- This feature does not directly model factors as bed resistivity or evapotranspiration. Such factors can be simulated by judicious model construction and flow extraction at nodes.

NUMERICAL MODEL OF MINE AREA

Modeling was performed in three phases. Phase I was the initial steady state model runs or scenarios that were based on the conceptual model described in the previous *Initial Conceptual Model* section. After presenting the Phase I results to the Hydrogeology Committee, the conceptual model was modified slightly, recalibrated to a domain-wide water balance, and additional Phase II model runs performed. Phase III modeling was conducted to investigate the timing of the predicted ground water drawdown.

Phase I Modeling

Model Set Up

Variables

The following variables were used in the initial calibration runs of the Phase I model. As discussed in the *Calibration* section, the variables were adjusted during the calibration process.

Infiltration: 10% of average precipitation.

Annual precipitation: 60 inches per year. Precipitation in the model area varies as a function of elevation and ranges from about 30 to more than 70 inches per year. The average elevation of the model domain was calculated and the precipitation reported for that elevation (60 inches) was used (Geomatrix 2006b).

Hydraulic conductivity: The following values have been reported in project documents and other references, as indicated.

From Gurrieri (2001): K_{fz} 3.5×10^{-2} cm/sec
K_r 1×10^{-6}
K_f 1×10^{-3}

From MMI: K_{ave} 2.35×10^{-5} (Chen Northern reduced K by one order of magnitude per 1,000 feet of depth in their analysis)

From Stober and Bucher (2000): K_{fg} 1×10^{-5} cm/sec

fz = fault zone
r = “rock mass” (page 5 of Gurrieri 2001)
f = “fracture zone” (page 5 of Gurrieri 2001)
ave = average
fg = fractured granite (for comparison)

The initial K value used in the model for the rock was 1×10^{-5} cm/sec.

Boundaries

Model boundaries were selected using two criteria (Figure 1). First, boundaries were defined sufficiently distant from the mine area so that activities at the mine area would not likely affect heads at the boundaries. During modeling, it was confirmed that the predicted drawdown cone from the mine did not reach the model boundary at any location.

Second, boundaries were defined in locations at which topography or hydrologic features permitted the reasonable assumption that a negligible amount of ground water would be expected to flow across the boundary, either into or out of the model domain. In this way, the model was designed with the reasonable assumption that essentially all inflow into the model domain was from infiltration of precipitation, and essentially all outflow was via surface water as base flow.

Boundaries were therefore defined on major drainages (the Clark Fork River and its reservoirs, the Bull River and its Middle Fork, Libby Creek, Silver Butte Fisher River), smaller surface water bodies distant from the mine area (Bighorn Creek, Cherry Creek, Silver Butte Creek, Swamp Creek), or, in a few cases, across high divides between surface water bodies, distant from the mine area and of minimal length.

The "bottom" limit of the model was set at an elevation of 2,000 meters (about 6,500 feet) below the ground surface elevation. Again, this thickness was selected so that the bottom boundary did not interact with the model at the deepest predicted drawdown of about 900 meters (about 3,000 feet). Minor fractures probably close with depth, reducing permeability. Fractures associated with major structures, however, can remain sufficiently open for ground water flow to significant depths.

All of these boundaries and all of the nodes in the model were defined as "swamping" nodes. Swamping nodes act as normal continuity nodes when the water table is at or below ground surface. However, when the water table is driven to rise above the ground surface, the nodes are temporarily fixed at the ground surface elevation and excess flow is directed as surface water to a topographically-downhill node. In this way, swamping nodes simulate the interaction between ground water and base flow in creeks or streams. Use of swamping nodes also allowed the calibration of the model to the known location of perennial springs and seeps. No constant head or constant flux nodes were used anywhere in the model domain. The only source of inflow to the model was infiltration to the model domain area. The only outflow from the model domain was surface water (base flow) from the nodes located where the major drainages exit the model domain. All streams were assumed to be in full connection with the underlying ground water system.

Domain Definition

Two hundred and seventy-eight nodes were plotted on a topographic map of the mine area to define the topography, including drainages, and the limits of the model domain (Figure 2). More nodes per unit area were used in the area around the proposed mine where either more data were available, better resolution was required, and/or specific structures were simulated, such as adits and the Rock Lake Fault. Fewer nodes per unit area were used in the periphery of the model. Coordinates and topographic elevation of each node were transferred to the model software directly from the topographic map software (Appendix A). Additional nodes were added to accommodate the cumulative

effects analysis of both the Montanore and Rock Creek projects for the Phase II and III modeling (see *Cumulative Effects Analysis* section, p. 24). Triangular elements were then defined automatically using the nodes as vertices, and corrected by hand where necessary to avoid excessively long and narrow elements (Figure 3). Figure 2 and Figure 3 include the nodes and elements, respectively, used in the Phase II and Phase III modeling. The Phase I modeling nodes and elements differ primarily in the area of the proposed Rock Creek mine, but because the Phase I modeling was superseded by the Phase II modeling, Phase I figures of the nodes and elements are not included in this report.

For those analyses that incorporated the Rock Lake Fault, the fault zone was defined using ABCFEM "connections" (Figure 4). The fault trace was based on regional geologic information (Harrison et al. 1992). A connection is an arbitrary flow path defined by the analyst between any two nodes. ABCFEM enforces flow through the connection in linear proportion to the head difference between the two nodes. The constant of proportionality (the "conductance") was calculated for each connection to simulate the desired hydraulic conductivity of the fault zone through the assumed cross-sectional area of the fault zone:

$$C = \frac{KA}{\Delta l}$$

where:

C = connection conductance
K = hydraulic conductivity
A = the simulated cross-sectional area of the fault
Δl = the distance between the two nodes

The proposed mine void, Libby Adit, and Ramsey Adits were simulated when appropriate by setting the ground surface elevation for corresponding nodes to the elevation of the adits or mine void at that location, and directing outflow generated when the nodes swamped to a "sink" (an ABCFEM feature that removes the flow from the model altogether, simulating the use of the water for industrial processes). The Heidelberg Adit was simulated using the same method, but its swamped outflow was allowed to flow into Rock Creek because MMC is not planning to use its outflow for process water.

The post-mining mine void was simulated by setting the swamping elevations of the corresponding nodes back to the actual topographic elevation, and setting the hydraulic conductivity of the elements within the mine void to a high value. The post-mining adits were simulated as being completely plugged by restoring their swamping elevations to ground surface level and relinking their swamp outflows to the natural stream system.

For those analyses that simulated a high-conductivity interconnection between fault and mine void, an ABCFEM connection was used to connect the mine void to the fault zone. This connection was defined between the northern end of the mine void (the end with the lowest elevation) and the nearest fault node.

Performance Criteria

Criteria for evaluating performance of the model are limited at this site. The Hydrogeology Committee expected that the model should be able to simulate various

observed conditions in the mine area. ERO established the following performance criteria:

1. Simulate approximate elevation (and location) at which creeks draining the proposed mine area become perennial (within about 100 feet).
2. Simulate measured flow from two existing adits (within 10%).
3. Simulate measured base flows at existing gaging stations (within 50%).
4. Consistent with bedrock head data. Depth to bedrock ground water exists in the area of the proposed Little Cherry Creek tailings impoundment and the proposed Rock Creek Mine. ERO reviewed the data and determined that the bedrock water levels are, in general, consistent with what would be predicted by the agency conceptual model. However, the water level data cannot be specifically compared to the numerical model-predicted ground water elevations because of the large contour interval (100 meters or about 300 feet) used in the model.

Calibration

For the Montanore mine area, three sources of hydrologic data were used to calibrate the model during Phase I:

- Empirical information concerning elevation of springs and the start of perennial creek flow (at an elevation of 5,400 to 5,500 feet) (Wegner, pers. comm. 2006 and USGS 1983). The elevation of perennial creek flow was the only head calibration attempted because of the lack of directly measured head data.
- Measured flow from the Libby Adit (steady state flow of 150 gallons per minute (gpm)) (Geomatrix 2006a).
- Steady state flow from the Heidelberg Adit in the East Fork Rock Creek drainage (45-135 gpm) (it is assumed that 45 gpm represents base flow to the adit and the higher flows represent periods of increased shallow ground water flow) (Gurrieri 2001). Flow from the adit was estimated to be in the 40 to 50 gpm range in September 2007 during a very dry period with little or no surface water runoff.

Surface water flow data are presented in two commonly used units; gallons per minute (gpm) and cubic feet per second (cfs). One cfs is equal to 448.8 gpm. Relatively low flows from adits and springs are reported in gpm and stream flows are reported in cfs.

Calibration proceeded along two simultaneous tracts—with a major fault (Rock Lake Fault) and without the fault. To calibrate the model (without the fault, initially), both the hydraulic conductivity (K) of the (fractured) rock and the infiltration rate had to be reduced from initial values. The initial values for K and infiltration resulted in too much water entering the system and relatively flat heads well below the suspected ground water elevation of 5,400 to 5,500 feet. Adit inflows also were substantially above observed values. The K value was decreased during subsequent calibration model runs to a value more likely to be representative of the effective permeability. Through several runs, the K value of the rock was reduced to 10^{-7} cm/sec. The infiltration rate then was reduced to 2% in subsequent runs to achieve calibration. The final infiltration value of 2% seemed

reasonable for the Phase I modeling, considering the overall steep nature of the area and subsequent rapid runoff.

Calibration without the fault was achieved with an infiltration rate of 2% and a rock hydraulic conductivity of 10^{-7} cm/sec. At calibration, nearly all streams started to flow (due to ground water discharge) at an elevation of about 5,400 feet. The Libby Adit "flowed" at 152 gpm and the Heidelberg Adit at 46 gpm (Table 1).

Table 1. Phase I modeling results.

		Hydraulic Conductivity											
Type	Conditions	Fault	Rock	Heidel-berg Adit	Libby Creek Adit	Ramsey Creek Adit	Mine Void	Total Montanore Inflow	East Fork Bull River (node 180)	Change from Pre Mine	Rock Creek (node 150)	Change from Pre Mine	Comment
		cm/sec	cm/sec	gpm	gpm	gpm	gpm	gpm	gpm	gpm	gpm	gpm	
Calibration	Fault/Ha/La	2.5 x 10-6	1 x 10-7	46	150	0	0		82		276		
Calibration	Ha/La	2.5 x 10-6	1 x 10-7	46	152	0	0		75		297		
Pre mine	Fault/Ha	2.5 x 10-6	1 x 10-7	46	0	0	0		42		300		
Pre mine	Ha	2.5 x 10-6	1 x 10-7	46	0	0	0		79		306		
Mine	Fault/Ha/La/Na/M	2.5 x 10-6	1 x 10-7	43	99	51	214	364	0	-42	230	-69	
Mine	Fault/Ha/La/Na/M-C	2.5 x 10-6	1 x 10-7	43	99	51	244	393	0	-34	229	-70	
Mine	La/Ha/Na/M	2.5 x 10-6	1 x 10-7	46	99	51	201	351	0	-35	245	-60	
Post Mine	Ha	2.5 x 10-6	1 x 10-7	55	0	0	0		152	117	275	-31	all adits plugged
Post Mine	Fault/Ha	2.5 x 10-6	1 x 10-7	37	0	0	0		104	70	276	-24	all adits plugged
Ha = Heidelberg Adit		**C = fault - mine void connection**											
La = Libby Creek Adit													
Na = Ramsey Creek Adit													
M = Mine void													

The Rock Lake Fault was added to the model, using an initial K value for the fault of 10^{-2} cm/sec. The model would not converge using this value. At 10^{-3} cm/sec, the model converged, but stream elevations and the Libby Adit flow were too low. At this K value, the fault was draining the area below the observed head values. The K value was incrementally reduced, ultimately to 2.5×10^{-6} cm/sec, before both the elevation of ground water base flow to creeks returned to about 5,400 feet and adit flows returned to observed values. Again, this K value is an effective permeability for a fault zone, assumed to be 500 feet wide and 6,500 feet thick (same as the rock). It is possible that individual fractures within the fault zone may have higher hydraulic conductivities over unknown distances. The final adit outflows for the calibrated version with the fault were 150 gpm for the Libby Adit and 46 gpm for the Heidelberg Adit (Table 1).

Reducing both the rate of infiltration and hydraulic conductivity of the fault and the rock resulted in a calibrated model for both cases (fault and no fault). As a check, a different set of values (higher K and infiltration) was tried. At higher rates of infiltration, a higher K value was necessary to maintain ground water elevations at 5,400 to 5,500 feet. However, this approach resulted in adit outflows larger than observed values. Therefore, these values not considered an improvement over the initial calibrated values.

Results

The calibrated model was used to simulate pre-mining, mining, and post-mining conditions for both versions of the model (fault and no fault). Using the calibrated version of the model, flow from the Libby Adit was removed to establish pre-mining conditions for initial ground water head, and provide an estimate of ground water contributions to the Rock Creek drainage below Rock Lake and the East Fork Bull River drainage below St. Paul Lake. The Heidelberg Adit was not removed from the model because it is a historical structure that currently discharges water.

For the mining period, a mine void and two adits were added (Libby and Ramsey Adits) to the model, using the maximum build-out for the mine, to simulate steady state conditions (Figure 5). The location and geometry of the mine void were taken from various drawings, including Figure 48 of the mine permit application (MMI 2005) and Figures 5 and 6 of Geomatrix (2006b). It was assumed the mine void would extend along the ore body northward to an area just south of St. Paul Lake. The exact northern extent of the proposed mine has not been defined by MMI.

For the third model run or scenario, the adits were plugged and no water was removed from the mine void, simulating a post-mining period. Using the fault and no fault versions, six model runs were performed. The various resultant ground water head configurations for the mine and post-mining periods were compared to pre-mining heads and ground water contribution to the two drainages recorded. Table 1 summarizes the results of these model scenarios.

An additional set of runs were performed to simulate a direct connection between the mine void and the Rock Lake Fault. To simulate a connection, a node along the fault was connected to a node within the mine void.

All model output is reported in metric units. For example, the head elevation and drawdown are in meters, as reported in the initial ground water head figures (such as

Figure 6) and the various drawdown figures (such as Figure 11). For simplicity, the text describes drawdown and head elevation in feet converted from the metric model output. The conversion from meters to feet is 100 meters equals 328.084 feet. The various values of drawdown and elevation reported in the text were rounded to the nearest foot, and in some cases, to the nearest 100 feet where the precision was insufficient to report more significant figures.

Observations

The steady state heads determined by the model in the two calibration scenarios were used to define "initial heads" used in the pre-mining, mining, and post-mining model periods for the purpose of calculating predicted drawdown. The "initial heads," as expected, mimic topography (Figure 6). The precision of the initial heads is related to the number of nodes used to define the topography. There would be some departure from the actual topography because the nodes are limited, relative to the generally steep relief in the area. Some of these departures were corrected during the Phase II modeling.

The Phase I analysis of the mining and post-mining periods resulted in a series of figures showing predicted drawdown, with and without the fault. Because the Phase II analysis superseded the Phase I analysis, head changes and drawdown are discussed in *Phase II Model Set Up*, and the Phase I results are not provided in this document. Qualitatively, the Phase I and Phase II drawdown results are essentially the same.

The model indicates that regardless of whether the fault is considered a preferential pathway for ground water, ground water flow from the mine and adits would create a steep drawdown cone beneath the mine area during the mining period. Ground water drawdown beneath land areas at elevations above 5,400 or 5,500 feet would have little direct effect on shallow springs and seeps located above this elevation because they are perched above the regional ground water system. However, ground water drawdown beneath land areas below an elevation of 5,400 to 5,500 feet would reduce available ground water that currently discharges as springs and seeps or discharges directly to the upper reaches of several drainages.

MMI proposes to plug all mine adits. After the mine and adits are plugged, the mine void would fill with ground water and heads would begin to return to pre-mining levels. The mine void would dip to the north, following the ore body, but because the topography decreases steeply to the north along the western edge of the ore body past St. Paul Pass, the mine void would not become increasingly deep below the drainage, depending on how far north the mine would extend. Based on the known extent of mineralized resources, the mine void would be about 3,000 feet below East Fork Bull River. However, because the mine void would create a large chamber of essentially infinite hydraulic conductivity, the head would be the same throughout the mine void. The elevation of the East Fork Bull River above the known extent of mineralized resources and the head in the mine void would be similar, about 4,200 feet. Consequently, the model indicates that water from the mine void would discharge to the East Fork Bull River drainage during the post-mining period. As a result of the increased discharge to the East Fork Bull River, the overall post-mining heads would be slightly lower than pre-mining heads, reducing flow slightly to the Rock Creek drainage. The model indicates that water from within the mine void would not reach Rock Lake because of the permanent downward gradient in the area of the lake created by the mine void.

Phase II Modeling

ERO met with the Hydrogeology Committee and other MMI and agency personnel to review the Phase I model results. The Hydrogeology Committee recommended the following changes to the model:

1. Establish a domain-wide water balance as confirmation that the model adequately simulates site conditions. The water balance consisted of using measured base flows at six USDA Forest Service gaging stations, located around the perimeter of the model domain for comparison to model-predicted base flows at the same locations. A drainage-specific water balance (upper East Fork Rock Creek) was provided in Gurrieri (2001).
2. Modify the model to accept a thin layer near the ground surface. This layer would have a higher hydraulic conductivity than the bedrock and would be designed to simulate a zone that includes surficial deposits such as soil and colluvium, and highly weathered and fractured shallow bedrock. Review the exploration boring logs to establish whether a thickness can be assigned to a suspected higher K zone near the surface.
3. With this "layer" in place, recalibrate the model using adit flows, spring elevations, and base flow values for surface flow in drainages at the periphery of the model domain. The objective of this modification is to improve the overall water balance of the model domain, as measured by actual streamflow measurements.
4. Modify the area along the trace of the Rock Lake Fault to accept infiltration at a rate higher than that used in the general model. This would probably require that the K of the fault zone be increased.
5. Using the modified model, insert low K material in the mine void to simulate bulkheads of some thickness.

Model Set Up

High K Layer

Based on Committee members' experience with the site, the Committee concluded that the site conceptual model should include a relatively thin layer of weathered rock at the ground surface of higher hydraulic conductivity rather than the unweathered fractured rock. ERO reviewed all exploration boring logs in the mine area provided by MMI, which identified a zone described as "highly weathered," highly "broken," or "overburden" in most of the logs. ERO assumed "overburden" included colluvium, soil, and very weathered bedrock. The depth to unweathered rock ranged from 3 to 51 feet and averaged 36 feet.

The model code that calculates transmissivity was modified to take into account different Ks in a deep and shallow slice. The two-dimensional model was modified to simulate a thin layer (12 meters or about 40 feet) near the surface as follows:

1. If the head at the node is below the elevation of the top of the deep slice (i.e., the shallow slice is completely unsaturated), then the transmissivity is calculated as before: (K_{Deep} X the saturated thickness in the deep slice).
2. If the head at the node is above the elevation of the top of the deep slice (i.e., the shallow slice is at least partially saturated), then the transmissivity is calculated as: (K_{Deep} X the full thickness of the deep slice + $K_{Shallow}$ X the saturated thickness of the shallow slice).

Water Balance

The KNF provided base flows from six gaging stations within the model area (Table 2). The gaging locations are located both on the periphery of the model domain and within the model area along the major drainages (Figure 7). One of the watersheds that included area outside the model domain was adjusted to report only flow from within the model. In Phase II, the domain-wide water balance was incorporated into the calibration process. Refer to base flow discussion in the calibration section and Table 2 for results of the water balance.

In addition to using measured base flow from the periphery of the model domain (domain-wide water balance), the total model water balance water was reviewed to confirm that the model internally handles applied water appropriately. The net infiltration of precipitation and the rate of water leaving the model as base flow were both 257,124.133 cubic meters/sec, which confirms that the model is correctly accounting for all water.

Calibration

The first model runs after making the appropriate modifications included the following conditions:

1. Thin high K layer, thickness = 12 meters (about 40 feet)
2. Thin high K layer, K = 10^{-5} to 10^{-4} cm/sec
3. Initial infiltration rate of 10% of average precipitation
4. The fault was initially turned off
5. Rock K = 10^{-7} cm/sec
6. Precipitation over model domain is 60 inches (based on average elevation in the domain)

The initial model run with a thin layer K value of 10^{-5} cm/sec and an infiltration rate of 10% resulted in too much water on the surface in higher elevation areas. The thin layer K value was increased to drain more of the infiltrating water to lower elevations, but the higher K did not significantly reduce heads in the higher areas. Rather than reducing infiltration, the fault was reintroduced and its K value progressively increased in an attempt to increase drainage away from the upper areas. Even with a fault K value of 10^{-3} cm/sec, not enough water could be removed from the upper areas. At an infiltration of 10%, flows from the two adits were much higher than observed flows. Flows from the

adits and heads in the upper areas were insensitive to changes in the K value of the thin layer.

In an attempt to decrease adit flow, the infiltration rate was reduced to 5%. Adit flow decreased, but as expected, the ground water contribution to the various drainages also decreased. At this point in the modeling, the various drainages were checked to make sure they were reasonable simulations of the actual topography and flow paths. The mesh in the downstream areas of Libby Creek was adjusted to correct a problem in the topography, which resulted in higher flow down that drainage. The other drainages appeared to be correct.

As a check, infiltration was reduced to the Phase I value of 2% and the adit flows returned to observed values, even with the thin high K layer. However, the ground water contribution to streamflow was much lower than the observed or calculated base flow values. At this point of the modeling, the following observations were made:

- Measured flow from the adits cannot be simulated with rates of infiltration higher than 2%, regardless of the K used for any feature, such as bedrock, the fault, or high K layer.
- An infiltration rate of about 10% was required for a reasonable water balance in drainages in the lower portions of the model domain.

Because of this calibration dilemma, infiltration was distributed on some basis. Initially, the infiltration was distributed on the basis of elevation, which resulted in a better overall fit to observed data. However, it was decided that it made more sense conceptually to distribute infiltration on the basis of slope, rather than elevation. Using a trial and error process, it was determined that a slope break of 30% resulted in a reasonable match to topographic “breaks in slope” observed on the topographic map.

A 2% net infiltration rate was used for areas (model elements) that have slopes greater than 30%, and a 10% infiltration rate was used for areas with slopes less than 30% (Figure 8). A 10% infiltration rate is consistent with the infiltration rate used by Klohn-Crippen in the modeling of the Little Cherry Creek impoundment area, which has slopes less than 30% (Klohn-Crippen 2005). This approach resulted in a good match with spring elevations, adit flows, and stream base flows. The calibration match for the adit flows was within a few gallons per minute of the measured flows. The model-predicted base flows at the gaging stations were within a few cubic feet per second (cfs) of the measured (and adjusted) values. Bull River base flow was within a factor of 4 of the reported value (Table 2). Given the size of the drainage area for Bull River and the amount of drainage outside of the model domain, this difference seems reasonable. The Committee agreed that the domain-wide water balance was satisfied by the model-predicted base flows.

Table 2. Summary of base flow data for model area drainages.

Watershed	Drainage Area (mi^2)	Drainage Area in Model Domain (mi^2)	KNF Low Flow (cfs)	Adjusted Low Flow (cfs)†	Model Predicted Flows (cfs)§
West Fisher Creek	43	43	8 – 16	8 – 16	15.4
Libby Creek	66	66	15 – 30	15 – 30	17.4
Rock Creek	33	33	3 – 7	3 – 7	9.6
Swamp Creek	30	20	10	6.7	9.1
East Fork Bull River	26	26	10	10	6.1
Bull River	139	80	130	40 – 80	9.8

†Adjusted for drainage area in model domain.
§Flows from calibration run with the fault.

Rock Lake Fault

At this point in the modeling, the fault was reintroduced and the hydraulic conductivity of the fault was incrementally increased until a calibration could no longer be achieved. The resulting K value for the Rock Lake fault carried forward through all subsequent analyses was 2.5 x 10^{-5} cm/sec. Using this K value, additional infiltration was added to the fault zone to establish whether the fault could convey additional ground water and if the mine and post-mining hydrology would change. Infiltration along the fault zone was increased in multiple steps, but the fault analysis was performed with a maximum infiltration rate to the fault zone of 12% to 20% (based on topographic slope). Infiltration rates higher than 20% are unlikely, so higher rates were not used. The modeling results indicated that fault K values higher than 10^{-5} cm/sec were not necessary to accept and convey infiltrating water within a reasonable range of infiltration rates.

The same modeling process was used in the high-infiltration-rate-to-the-fault scenario as with other scenarios. After calibration, the pre-mining and mining periods were run, including the fault-mine void connection. Because the results were not significantly different than other fault scenarios, it was not necessary to run the post-mining period. The primary conclusions of this scenario are:

- Increasing infiltration along the fault does not have a significant effect on any aspect of the site hydrology.
- With the higher rate of infiltration along the fault, the fault would contribute slightly more water to the Rock Creek and East Fork Bull River drainages, but the changes are not significant.
- During the mining period, the fault would contribute additional water to the mine void, but the change is not significant.
- Increased infiltration along the fault in the mine-void-fault-connection scenario does not result in significant changes to the overall water balance.

"Not significant" is defined as changes that are considered to be small relative to the range of the parameter in question. For example, if flows in a stream are measured to be

in the range of 15 to 30 cfs, changes of a cfs or less are considered to be not significant. Another criterion used is if changes are generally less than resolution of the model. For example, if head changes are reported to be on the order of a few meters, the model cannot precisely show changes in head of that magnitude.

Results

Once the Phase II model was considered to be calibrated and initial heads established (Figure 9), the pre-mining, mining, and post-mining scenarios were run. Additional runs included fault and no-fault versions, a mine-void-fault-connection scenario, and a post-mine-with-bulkhead scenario. Five model scenarios were run during the Phase II analysis. The five scenarios are:

1. Fault (Rock Lake fault has slightly higher hydraulic conductivity than adjacent bedrock)
2. No Fault (Rock Lake fault has same hydraulic conductivity as the adjacent bedrock)
3. Fault with higher infiltration (same as the fault scenario but with increased infiltration along the fault)
4. Fault-void connection (assumes mine void is connected to the Rock Lake fault and fault is more conductive that the bedrock)
5. Fault-void connection with higher infiltration (combination of number 3 and number 4)

The results of the five scenarios are similar (Table 3), and predict mine void/adit inflows between 427 and 625 gpm. In terms of calibration, the fault scenario produced the best fit with observed conditions, but the no fault and the fault with higher infiltration scenarios were not significantly different. For the purposes of on-going analyses, the fault scenario was selected as the representative scenario because of its calibration success, mid range results for mine void/adit inflows, and because this configuration best fits site observations. Although possible, there are no specific data to support additional infiltration along the fault. The connection scenarios assume that during mining the void becomes connected to the fault. As part of its mine plan, MMI intends to avoid connection with the fault. The connection scenarios were included in the analysis because inadvertent connections with the fault are possible via secondary fractures. Therefore, the transient and cumulative effects analyses were performed with only the fault scenario and tables 3, 6, and 7 report only fault scenario results.

Regardless of the model scenario, the mining period runs show drawdown in the area of the mine would exceed 900 meters (nearly 3,000 feet) (Figure 10 and Figure 11). Although all contours are not shown due to scale, in the area immediately above the mine and adits, drawdown was greater than 900 meters (nearly 3,000 feet). However, due to the relatively low hydraulic conductivity of the fractured rock, the drawdown cone was fairly steep and the 100-meter (approximately 300 feet) contour was generally limited to within 1 kilometer of the mine void, except in the area above the adits that extends several kilometers to the east (Figure 10 and Figure 11). The 1-meter (approximately 3 feet) drawdown contour extended a maximum of 5 kilometers (3 miles) from the mine

void. Within the resolution of the model, the 1-meter contour is considered to be equivalent to zero drawdown.

During the post-mining period, the drawdown cone would recover very little if the adits remained open. If the adits were plugged (assumed in most of the post-mining runs), ground water head would recover somewhat to pre-mining elevations (Figure 12 and Figure 13). With or without the fault, the area of 100-meter (about 300 feet) drawdown during the mining period would reduce from a diameter of about 5 kilometers (about 3 miles) (not considering the extended area of 100-meter drawdown in the area over the adits) to less than 3 kilometers (less than 2 miles) directly over the mine void during the post-mining period. The adit area would recover to within about 10 meters (about 30 feet) of the initial head elevation. The post-mining ground water elevations would not achieve pre-mining elevations because the mine void would transmit water (via infinitely high permeability compared to the fractured rock) from beneath areas of high ground surface elevation to areas of lower elevation. In other words, the ground water elevations beneath topographically high areas would be depressed because ground water would discharge at rates higher than pre-mining rates to drainages such as the East Fork Bull River to the north.

Mine Bulkhead

A bulkhead was added to the no-fault post-mining version by inserting a single low K area 100 meters (about 300 feet) thick in the middle of the mine void. A K value of 10^{-6} cm/sec was assigned to this zone. The introduction of a 100-meter-thick bulkhead reduced the post-mining ground water contribution from the mine void to the East Fork Bull River by 50%. However, the addition of the bulkhead increased flow to the Rock Creek drainage from the mine void, rather than reducing flow to that drainage without a bulkhead. The model predicted a bulkhead would increase post-mining heads in the upper end of the mine void and cause ground water to flow toward East Fork Rock Creek, rather than away from it. Heads in the lower portion of the mine void (below the bulkhead) would be lower than without the bulkhead, reducing ground water flow toward the East Fork Bull River (Table 3).

Table 3. Phase II modeling results.

		Hydraulic Conductivity													
Type	**Conditions**	**Fault**	**Rock**	**Thin Surface Layer**	**Infiltration Rate**	**Heidel-berg Adit**	**Libby Creek Adit**	**Ramsey Creek Adit**	**Mine Void**	**Total Montanore Inflow**	**East Fork Bull River (node 180)**	**Change from Pre Mine**	**Rock Creek (node 150)**	**Change from Pre Mine**	**Comment**
		cm/sec	**cm/sec**	**cm/sec**		**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	
Calibration	Fault/Ha/La	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	151								
Calibration	Ha/La		1×10^{-7}	1×10^{-4}	D	43	153								
Calibration	Fault/Ha/La-Inf	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D+10%	43	151								
Pre mine	Fault/Ha	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	0	0	0		1		631		
Pre mine	Ha		1×10^{-7}	1×10^{-4}	D	43	0	0	0		151		665		
Pre mine	Fault/Ha-Inf	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D+10%	43	0	0	0		11		666		
Mine	**Fault/Ha/La/Na/M**	**2.5×10^{-5}**	**1×10^{-7}**	**1×10^{-4}**	**D**	**39**	**93**	**61**	**298**	**452**	**0**	**-1**	**549**	**-82**	
Mine	Fault/Ha/La/Na/M-Inf	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D+10%	40	93	61	310	464	0	-11	572	-94	
Mine	Ha/La/Na/M		1×10^{-7}	1×10^{-4}	D	42	93	61	273	427	36	-115	596	-69	
Mine	Fault/Ha/La/Na/M - C	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	37	93	61	451	605	0	-1	231	-400	
Mine	Fault/Ha/La/Na/M - C-Inf	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D+10%	38	93	61	471	625	150	139	555	-111	
Post Mine	Fault/Ha	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	0	0	0		82	35	612	-19	all adits plugged
Post Mine	Ha	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	0	0	0		255	104	627	-38	all adits plugged
Post Mine	Fault/Ha - C	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	0	0	0		102	101	598	-33	all adits plugged
Post Mine	Ha - B	2.5×10^{-5}	1×10^{-7}	1×10^{-4}	D	43	0	0	0		206	55	673	8	all adits plugged

Bolded scenario used in subsequent analyses

Ha = Heidelberg Adit
La = Libby Creek Adit
Na = Ramsey Creek Adit
M = Mine void
D = Distributed infiltration (2%/10%)

D+10% = Distributed infiltration of 2 and 10% plus 10% (12 to 20%)
C = fault - mine void connection
B = Bulkhead (assume 100 meters thick at K = 10^{-6} cm/sec)
INF = Increased infiltration along fault

Streamflow

Rock Creek. The model indicates that the ground water contribution to the upper East Fork Rock Creek drainage (below Rock Creek Lake) would decrease by about 70 gpm during the mining period, relative to pre-mining contributions. If the fault were directly connected to the mine void, the ground water contribution would decrease by about 400 gpm during the mining period. During the post-mining period, the ground water contribution to this drainage is estimated to be about 20 or 40 gpm less (no fault and fault, respectively) than the pre-mining flows, assuming all adits were plugged.

East Fork Bull River. The model indicates that the ground water contribution to the East Fork Bull River would decrease by 1 to 115 gpm (with and without the fault, respectively) during the mining period. The model indicates that there would be no ground water contribution to the portion of the drainage within the area of drawdown resulting from the mining period. After the mine and adits are closed (post-mining), the ground water contribution to this drainage would be higher than pre-mining flows by about 35 gpm without the fault and 104 gpm with the fault.

Libby and Ramsey Creeks. Because the Libby and Ramsey Adits would originate in these respective drainages, the adits would intercept ground water that would otherwise be tributary to those drainages. During the mining phase, flow in Libby and Ramsey Creeks, as measured at the confluence of the two creeks, may decrease by 175 gpm for the fault scenario. The model indicates that during the post-mining period, the flow in the creeks would decrease by about 40 gpm. The post-mining period decrease would result from redirecting ground water flow along the infinitely high hydraulic conductivity mine void, assuming the mine were not backfilled or bulkheads placed in the void.

Final Phase II Modeling

During Phase III modeling (see *Cumulative Effects Analysis* section, p. 24), the model mesh was modified slightly to allow the modeling of the cumulative impacts of the Rock Creek and Montanore mines. Because of this change, all Phase II scenarios were rerun with the Phase III mesh to ensure comparability of the model reported stream base flows in both the Phase II and III modeling. The Phase II model configuration was also recalibrated with the Phase III mesh to ensure the mesh changes did not alter the original calibration. All Phase II values reported in the various tables of this document are from model runs using the Phase III mesh. Changes to the Phase III mesh did not significantly change the previous Phase II results.

Agency and MMI Review

During May and June 2006, ERO collaborated with the Hydrogeology Committee to review the Phase II model results. The modifications made to the model and the values used during the calibration process were described to the Committee. ERO prepared and distributed a draft report on the Phase I and Phase II model results and distributed it for review and comment to the KNF, DEQ and MMI. Based on the review of the draft report, the agencies requested ERO to conduct two additional analyses. Because the model assumed steady state conditions, the question was the length of time it would take to reach steady state conditions. A transient analysis was completed to address this issue. The second requested analysis was to address the cumulative effects of the Rock Creek and Montanore Projects. The additional modeling is described in the following sections.

Phase III Modeling

Transient Analysis

Methods

Using the calibrated Phase II model, a range of effective porosity values from literature were used to perform a transient analysis. Effective porosity is the only variable that is required for running a transient model, in addition to those required for the steady state Phase II model. Because effective porosity has not been measured at the site, a range of values from literature was used. Literature-reported values for fractured rocks characteristically similar to those at the Montanore site are listed below:

From Freeze and Cherry (1979)	Total porosity less than 2%
From Stober and Bucher (2000)	Effective porosity 0.2 to 0.5 % (test area) 0.1 to 2.1 % (Black Forest)
From Snow (1968)	Effective porosity 0.001 to 0.5 %

A transient analysis was performed using three effective porosity values, 0.01%, 0.1%, and 2%, representing a range of reported effective porosity values. The reported value of 0.001%, at the lowest end of the range, was not used because this value is from a site with relatively unfractured rock and, for the purpose and resolution of this analysis, there is not much discernable difference between the 0.001% and 0.01% results. An effective porosity value of 0.001% would result in water level changes measured in days. Defining water level changes on a daily basis is beyond the scope of this model and an unlikely scenario, given other uncertainties.

Transient analyses were performed using the Phase II mining and post-mining – fault scenarios for the Montanore mine area, and effective porosity values ranging from 0.01% to 2%. In this section, “steady state condition” is defined as the drawdown condition for the mining and post-mining periods as determined in the Phase II modeling, and depicted in Figure 10 and Figure 12. Contours of mining drawdown and post-mining residual drawdown at various time steps for an effective porosity value of 0.1% are shown in the attached figures (Figure 14 to Figure 20), and the results for all three effective porosity values are reported in Table 4.

The transient analysis did not consider advance of the mine void during the mining period. Rather, as in the steady state analysis, the model assumes the mine is at full build out at time zero. Implications of this assumption are addressed in the following *Discussion* section. Also, the transient analysis did not consider the time required to refill (with water) the mine void and adits after mining is completed. The time to fill the mine void was calculated separately, using the available information for produced tonnage of waste rock, tonnage of ore, bulk density of the rock, and the mine/adit flow rate predicted by the Phase II modeling. Using the assumptions listed in Table 5, it would require about 47 years to refill the mine void and adits.

Table 4. Estimated time in years to achieve steady state.

Condition	Effective Porosity		
	0.01% (0.0001)	**0.1% (0.001)**	**2% (0.02)**
Substantial steady state drawdown (assumes full mine build out)	1	5	>20
Mine and adit void filling	~47	~47	~47
Substantial steady state recovery-post-mining after void filling	5	>20	>100

"Substantial steady state" defines the 100-meter contours as nearly the same in both the steady state and transient analyses.

Table 5. Assumptions used in mine void inflow analysis.

Variable	Assumption	Source
Ore production	120,000,000 tons	Klohn-Crippen, June 15, 2006, p. 44
Waste rock production†	3,260,000 tons	Klohn-Crippen, November 10, 2005 Table 4.10, p. 63
Bulk density	165 lbs/ft^3	Tom Vandergrift (pers. comm. September 12, 2006)
Flow rate	450 gpm	Phase II fault scenario

†Includes only the portion of waste rock that would be used outside the mine, as opposed to that portion that would be stored underground.

Results

At the high end of the range of reported effective porosity values (2%), the transient analysis indicates that drawdown would not reach steady state during the mining period (within 20 years). If the average effective porosity were as high as 2%, drawdown created by mine and adit dewatering would affect a smaller area than predicted by the steady state analysis. However, the higher effective porosity would result in a drawdown cone that would not reach post-mining steady state for more than 100 years after mine closure (not including the time required to fill the mine void). Assuming a 2% effective porosity would decrease the maximum impact due to drawdown, but would increase the time over which the impact would be observed (Table 4).

The mid-range effective porosity value of 0.1% analysis indicates that drawdown resulting from mine and adit dewatering would substantially reach steady state within 5 years of time zero. "Substantially reach steady state" is defined as the 100-meter drawdown contours of the transient and steady state analyses are essentially the same. The drawdown would continue to expand slightly to full steady state conditions and remain at steady state as the mine void would fill with water over the next 47 years after mining ceases. After the mine void filled with water, the drawdown cone would begin to recover, but would require slightly more than 20 years to achieve steady state recovery, as defined by the Phase II results.

At an effective porosity of 0.01%, the mining phase would achieve steady state drawdown and the post-mining phase recovery more rapidly than the other scenarios. Steady state drawdown would be substantially achieved 1 year from time zero. The drawdown would continue to expand slightly to full steady state conditions during the mining period and remain at steady state as the mine void fills over the next 47 years. The post-mining steady state drawdown, as defined by the Phase II modeling, would be achieved within 5 years after void filling.

Discussion

Without measured values for effective porosity from the Montanore site, it is not possible to calibrate the transient analysis against known conditions. The literature values provide a reasonable range of effective porosity values that are expected for similar geologic settings. Site-specific effective porosity may vary a few orders of magnitude due to local faulting and fracturing, but an overall or average value for the entire area is likely to be within the reported range, particularly when considering the average hydraulic conductivity needed to calibrate the model.

Given the relatively rapid response of flows from the Libby Adit during construction and post construction, it seems unlikely that the average effective porosity value is as high as 2%. The results for the 2% effective porosity analysis are provided to establish a range of possible transient effects, but it is unlikely that they apply to this site. Flow data collected during the construction of the Libby Adit (Geomatrix 2006a) suggest that steady state flow conditions were achieved within a few years after completing the adit, consistent with the model response for effective porosity values in the range of 0.01% to 0.1%.

The transient analysis, combined with the time required to refill the mine void and adits, provides information as to the timing of any potential changes in ground water elevations and base flow to streams and creeks. Selecting the mid value for effective porosity (0.1%), it appears that the maximum drawdown predicted by the steady state analysis (Phase II) would be achieved during the mining period. This is also true for the lower effective porosity value (0.01%), but not the higher value of 2%. At the end of mining, the steady state drawdown cone would persist for about 47 years (based on the mine refilling calculation), before ground water levels would begin to recover. With an effective porosity value of 0.1%, steady state post-mining water levels would require slightly more than 20 years after the mine void is filled with water. If the effective porosity were 0.01%, steady state would be achieved within 5 years after the mine void is filled.

The model was not originally designed to provide an engineering-level transient analysis as the mine void advances. The steady state model assumed full build out of the mine starting at time zero and this assumption was used for the transient analysis. Certainly, the sequential advance of the mine would retard development of the drawdown cone. However, for the purposes of understanding how quickly the drawdown cone may develop and how long it may persist within an order of magnitude and given a range of effective porosities, introducing the advance of the mine void is not essential.

Development of the cone of depression would not be linear, as a function of the advance of the mine, because fractured rock beyond the mine void at any one time would begin to dewater before the mine advances into that area. As mining would progress, the incremental increase in drawdown would likely decrease. A possible contradiction to this generalization is that more permeable fractures may be encountered from time to time as the mine advances and drawdown may increase in some areas differentially.

The model configuration assumes full build out at time zero rather than starting the analysis at the end of the mine life. There is an inherent error in either assumption, but the former assumption results in a smaller error and more accurately simulates drawdown during the mining process, given the relatively low effective porosity of the area formations. In other words, because the time to reach steady state for reasonable values of effective porosity would be relatively short compared to the mining period and the time to refill the mine void/adits,

assuming full build out at time zero introduces a relatively small error. This is particularly true considering the order of magnitude accuracy of the transient analysis.

Cumulative Effects Analysis

Methods

To evaluate the potential for cumulative impacts due to construction of both the Montanore and adjacent Rock Creek mines, a cumulative effects analysis was performed using the Phase II model. The proposed Rock Creek mine would be located about 1 mile west of the proposed Montanore mine. The underground Rock Creek mine proposes to mine along the same ore body trend as Montanore and would use an evaluation adit and two development adits. The cumulative effects analysis used data from the Rock Creek Project Final EIS, which reports the general configuration of the mine at full build out, location of the adits, and expected dewatering rates from the mine void and adits (USDA Forest Service and Montana Department of Environmental Quality 2001).

A generalized Rock Creek mine void and adits were added to the Phase II calibrated Montanore model. The shape of the mine void was taken from Figure 3-2 (Rock Creek EIS), generalized by a rectangular polygon without including the small detail as shown in the figure. The addition of the Rock Creek mine void required the addition of nodes and elements in the area of the mine to simulate the generalized shape of the mine. The calibrated model was rerun to ensure these changes did not affect the Phase II results. Rather than use the dewatering values reported in the Rock Creek EIS, the same approach was used as was used for the Montanore mine. The hydraulic head within the footprint of the mine was lowered to the floor of the mine, simulating dewatering of the mine and adits. The resultant dewatering rate required to achieve this hydraulic head was reported by the model.

A second approach to simulate the calculated discharge rate from the Rock Creek mine and adits (1,089 gpm) was originally considered, but was not performed. The second approach would have used wells throughout the mine footprint pumping at the reported discharge rate (1,089 gpm), rather than fixing heads to the floor of the mine void. This approach would have been used if the modeled inflow exceeded the calculated inflow. The well approach could not be used because the modeled inflow did not exceed the calculated inflow and the controlling factor for water production is hydraulic conductivity. The model could have been used to simulate the calculated discharge rate in two ways.

One approach would require that a number of wells would have to be placed outside of the mine footprint in order to create a large enough drawdown cone to produce the reported discharge rate from the Rock Creek mine. Because of the relatively low hydraulic conductivity used in the calibrated model, the extent of the drawdown cone would be relatively limited and therefore the mine inflow rate would be limited.

The second approach, to simulate the reported higher discharge rate from the mine, would be to increase the hydraulic conductivity used in the model. However, this approach would not be consistent with the results of the calibrated model. Because increasing hydraulic conductivity and using wells outside the footprint of the mine would be unrealistic with respect to the physical situation as defined by the conceptual and numerical model, simulating the reported discharge rate was not performed.

After establishing the steady state drawdown that would result from the Rock Creek mine, the footprints of the two proposed mines were combined in one model run and the steady state cumulative drawdown cone was determined for the mining period (Figure 21). This analysis assumed that the mine voids of each mine would be fully developed at the same time. Steady state post-mining conditions were determined (Figure 22), assuming closure at about the same time and the plugging of all adits. Alternately, the cumulative post-mining drawdown, assuming the Rock Creek adits would not be plugged at completion of mining, is provided in Figure 23. Within the scope of the cumulative analysis, which neglects transient timing of the drawdown during the mining period, recovery during the post-mining period, and timing of the filling of the two mine voids, the assumption that the two mines would be closed at the same time does not affect the analysis.

Results

The model predicts that the combined drawdown from the Rock Creek and Montanore mines would merge in the area between the two mines (Figure 21). The model indicates that only the westernmost portion of the Montanore drawdown cone and the easternmost portion of the Rock Creek drawdown cone would be affected by dewatering at the other mine. The model predicts that there would be more drawdown in the area between the two mines, in response to dewatering activities at both mines, as opposed to drawdown created by a single mine. During the post-mining period, the steady state recovered drawdown cones of the two mines are predicted to merge in the area between the two mines (Figure 22 and Figure 23).

Other than ground water drawdown, potential impacts to ground water would be expressed by changes to ground water flow to creeks, streams, and springs. Because there is no comprehensive inventory of springs in the area, only ground water contribution to major streams and creeks was considered as a measure of the potential impact to ground water. The cumulative analysis predicts the base flow in Rock Creek and East Fork Bull River would decrease as a result of drawdown from the two mines (Table 7). No cumulative impacts would occur in Libby Creek or Ramsey Creek. It is not known whether the cumulative effect shown in Table 7 is an incremental cumulative effect or the direct effect of the Rock Creek mine. Although the model was calibrated to actual base flow data, the significance of this analysis is not the absolute values of flow reported for the various drainages, but rather the predicted changes in each drainage relative to the modeled base flow.

Sensitivity Analysis

During October and November 2006, ERO distributed the results of the transient and cumulative effects analysis to the KNF and DEQ for review and comment. The modifications made to the model and the values used during the calibration process were described. Based on the review of the transient and cumulative effects analyses, the agencies requested ERO to conduct sensitivity analysis of the model. The sensitivity analysis is described in the following section.

The variables used in the Montanore ground water model can be reduced to two basic variables, hydraulic conductivity and rate of infiltration. A single precipitation value (60 inches) was selected that represented the average annual precipitation for the average elevation of the model domain. The precipitation value was used throughout the model domain, and was not changed during the modeling process. Possible inaccuracies in distributing precipitation are compensated by varying the infiltration rate based on slope. Using a single precipitation value essentially reduces the two variables to a single variable – infiltration rate. It became obvious while

modeling that the model calibration was very sensitive to infiltration rate, limiting the range of possible values. Calibrating against measured stream base flow, elevation of perennial heads of streams, and adit outflows offered enough constraint on the model variables to greatly limit the range of those variables.

A simple sensitivity analysis was performed to strengthen the understanding of the possible range of variation in (a) the predicted base flows in each stream, and (b) in the location along each stream at which streamflow during or after mining is predicted to have changed by more than 10% compared to the pre-mining flow. Spreadsheets developed during the sensitivity analysis are provided in Appendix A.

Because previous analyses demonstrated that the predicted base flows and mine inflows did not vary much when considering variables such as a higher-K fault, a connection between the fault and the mine void, or a thin higher-K layer near ground surface, it was deemed sufficient to perform the sensitivity analysis using a single model configuration. The base case from previous rounds of analyses, including a higher-conductivity fault but no direct connection between it and the mine void, and a higher-K layer near the surface was selected.

The model was used to predict mine and adit inflows and stream base flows for the following five cases:

- Running the unchanged base case from previous rounds of modeling;
- Raising all infiltration values in the model by 20% (i.e., raising the infiltration on steeper slopes from 2% to 2.4%, and on the shallower slopes from 10% to 12%);
- Lowering all infiltration values in the model by 20%;
- Raising the basic hydraulic conductivity throughout the model by a factor of 3, without changing the fault conductivity; and
- Lowering the basic hydraulic conductivity throughout the model by a factor of 3, without changing the fault conductivity.

For each of the five cases, the following four time periods were used:

- Calibration scenario (in order to judge the quality of the calibration with the modified parameter);
- Pre-mining;
- Mining; and
- Post-mining.

The following conclusions were made:

1. The calibration is very sensitive to the infiltration value. Varying the infiltration up or down resulted in a near-proportional increase or decrease in the predicted flows in the Libby and Heidelberg adits. Therefore, it is unlikely that the actual infiltration varies as much as 20% from the baseline values.
2. The calibration is less sensitive to the hydraulic conductivity value, within a limited range. The predicted location of emergence of springs (the basic head calibration

criteria) did not change much in the lower-K calibration; it did begin to change adversely in the higher-K calibration. Therefore, it is possible that the actual average conductivity may be lower than the baseline value, but probably not much higher than the baseline value.

3. Changes in infiltration resulted in changes to the predicted base flow at the various nodes along the streams. However, because the base flow in the pre-mining period changed proportionally as the base flow in the mining and post-mining periods, the predicted difference in streamflow with and without mining did not change much between the various cases. In other words, the predicted location of a 10% change in base flow with mining did not change significantly in all five cases. Where the location of a 10% change in base flow changes, it changes by no more than one adjacent node.
4. Changes in hydraulic conductivity also resulted in changes to the predicted base flow at the various nodes along the streams. However, as with infiltration, the changes to the pre-mining period are more or less proportional to the changes in the mining and post-mining periods, so the percentage change at any one node remained approximately the same. However, the percentage change to base flow at any one node is more sensitive to the range of possible hydraulic conductivities than infiltration. For example, the location of a 10% change to base flow moves by up to two nodes in some cases.

Discussion and Interpretation

Limitations

Because there were insufficient site data to support a three-dimensional model, a two-dimensional model was selected to perform the analysis. Although the numerical precision of this two-dimensional model is limited by the relatively small amount of field data available for calibration, the model was configured to take advantage of the availability of a wide range of observation and measurement types. The predicted base flow for each creek at the margins of the model domain matched reasonably well with measured base flow values. Even though specific values for base flow at each node have some uncertainty, the changes in flow reported by the model for various time periods are more certain.

The use of a two-dimensional model does not permit the inclusion of detailed geologic layers, assuming the data exist, and as a result, surficial material along the creeks, such as alluvium, colluvium, and various glacial deposits, cannot be directly simulated. However, by using varying infiltration rates (as a function of slope), the likely contribution of the surficial deposits to base flow is simulated in the model. There is very little surficial material at the higher, steeper, elevations and what does occur at the higher elevations is relatively thin (Gurrieri, pers. comm. 2007 and agencies' field review in September 2007). As a result, it is unlikely that this material discharges significant volumes of ground water to creeks during late summer/early fall when base flow is the primary contributor to streamflow (Gurrieri, pers. comm. 2007; Montanore Minerals Corp. (MMC) 2006). In the lower elevation areas, however, surficial material can be hundreds of feet thick and probably does contribute ground water to creeks during the late season.

Although this model does not simulate ground water in thick sequences of surficial material, the selection of infiltration rates to match measured base flows accomplishes the simulation

indirectly. In other words, the higher infiltration rate used for lower elevations probably compensates for the higher permeability material not directly included in the model. If the lower elevations were only composed of bedrock, the infiltration rate would be lower and the base flow would also be lower. However, to calibrate with measured base flows, the infiltration rate had to be increased in these areas.

Discussion

In general, the Phase II results were similar to those generated during the Phase I modeling. The mine area hydrology proved to be very sensitive to infiltration rates, less sensitive to the existence of a high K layer near the surface, and insensitive to changes in the fault hydraulic conductivity and infiltration rate. In order to simulate adit flows and spring/creek elevations, the areas of steeper slope could not receive infiltration greater than 2%. However, to approximate measured "low" or base flows in the various drainages around the mine area, infiltration rates of about 10% were necessary. Consequently, infiltration rates were distributed based on topographic slope.

The primary difference between the Phase I and Phase II model results was the increase in ground water contribution to streams, both in the mine area and on the edges of the model domain. This was the result of increasing the infiltration rate over much of the area, while maintaining lower infiltration in steeper areas. The higher K layer may have helped distribute the increased infiltration, but overall the model was much less sensitive to this layer than infiltration. The ground water contribution to streams near the mine site were about two times higher than the Phase I results. The overall Phase II model water balance was good. The ground water contribution to streams was similar to the observed base flows. The fault tended to decrease flow to streams located near the mine site because it provided a conduit to convey water farther out into the model domain. However, the overall water balance was not affected by the addition of the fault.

The pre-mining and post-mining ground water contributions to two drainages in the vicinity of the mine (Rock Creek and East Fork Bull River) were similar to the Phase I modeling results. The flows were higher, but the magnitude of the increases and decreases in flow during the post-mining period were similar to the Phase I results. A direct connection between the mine void and the fault produced similar results to the fault version, although flow to the mine void was higher with the fault-mine void connection.

The conductive-fault-high-infiltration-rate scenario did not result in significant changes to the model results. The resulting higher rate of ground water flow along the fault (within reasonable limits of infiltration and hydraulic conductivity) resulted in slightly more flow to drainages directly connected to the fault and the mine void. However, the increased flow rates were not significant with respect to the total flow in these drainages.

The use of bulkheads (as simulated by one bulkhead 100 meters thick with a K value that was one order of magnitude higher than the rock) reduced post-mining contributions to the East Fork Bull River by 50% over the non-bulkhead version. However, as a result of increasing the head in the upper portion of the mine void with a bulkhead, the flow direction to East Fork Rock Creek reversed from the non-bulkhead version. With a single bulkhead, ground water would flow from the mine void toward East Fork Rock Creek at a higher rate than pre-mining conditions. In the non-bulkhead version, ground water would flow from East Fork Rock Creek toward the mine void. This result suggests that if bulkheads were to be used at mine closure, they should be

spaced throughout the mine void so that the recovering head would be distributed similar to the pre-mining heads, which would limit flow from the mine void.

NUMERICAL MODEL CONCLUSIONS

The two-dimensional model of the Montanore mine area has improved the overall understanding of the site hydrogeology and how the system may react to the proposed mining activities. The model was not intended to provide a detailed analysis of the hydrogeology for design or engineering purposes, but rather to test and refine an existing conceptual model. The model results have assisted in the development of a conceptual model that is consistent with observations and can duplicate certain quantitative data, such as adit outflows and stream base flow. Because the model was successfully calibrated against four independent hydrologic data, and proved to be relatively insensitive to certain aspects of the conceptual model that are not as well constrained by actual data, the model has been useful in evaluating potential changes to the local hydrogeology in response to proposed mining activities. The following list of specific conclusions deals with various aspects of the conceptual model. Conclusions regarding various conceptual model issues, confidence in numerical model predicted changes to the hydrogeology, and potential impacts to the environment is discussed in the next section of this report.

1. Calibration of the model with adit outflow, spring elevation, and stream base flows was not dependent on the existence of a high K layer near the surface. The high K layer assisted in distributing the higher rates of infiltration, but was not essential for achieving calibration.
2. Higher rates of infiltration (up to 20%) along the Rock Lake Fault did not significantly affect the area hydrology but did affect drainages along the fault.
3. Measured outflows from the Libby and Heidelberg adits could not be simulated with net infiltration rates greater than 2% in the mine area.
4. Net infiltration rates of about 10% over much of the model domain were necessary to achieve a reasonable water balance with measured stream base flows.
5. Infiltration rates distributed on the basis of percent slope (2% on slopes greater than 30%, and 10% on slopes less than 30%) resulted in a good calibration match with spring elevations, adit outflows, and stream base flows.
6. The Phase II model results were essentially the same as the Phase I results. The magnitude of the various flows was higher in the Phase II model, but the differences between model periods were similar to Phase I.
7. Bulkheads equivalent to the single simulated bulkhead reduced post-mining flow from the mine void to the East Fork Bull River by 50% compared to the non-bulkhead scenario. However, as simulated, the flow direction in the mine void toward East Fork Bull River Creek reversed in the upper areas of the void toward East Fork Rock Creek.
8. The fault scenario yielded results that were slightly closer to the observed values, but the fault version was not sufficiently “better” to conclude that the fault was an essential part of the system. This conclusion is based on the way this system is simulated and, therefore, it is possible that the fault may actually play a larger role

locally, depending on which specific fractures are interconnected. However, the approach taken in this model can be considered conservative from the perspective of not overestimating potential impacts of the mine because of invoking a larger role for the fault than the model suggests.

9. The results of the transient analysis indicate that the bulk effective porosity of the bedrock is about 0.1%.
10. Using the available information regarding volume of the final mine void and the void/adit inflow rate of about 450 gpm, the mine void and adits would require 47 years to fill with water. As a result, initiation of recovery from the mining period ground water drawdown would be delayed about 47 years.
11. The cumulative effects analysis indicates that drawdown created by both the Rock Creek and Montanore mines would overlap in the area between the two mine locations. The cumulative effects can best be expressed in changes in ground water contributions to surface water (base flow). Impacts to creeks on the east side of the divide appear to be related only to the Montanore mine, whereas creeks on the west side of the divide would experience changes related to both mines.

Final Conceptual Models

Conceptual models are a commonly used tool for extending knowledge beyond what is specifically known and allowing the predictions or estimates of what the system's response might be if conditions change in the future. For a hydrogeologic conceptual model to be useful, it must be internally consistent and explain most, if not all, observations or known facts. A model that is not internally consistent cannot be confidently used to predict responses to changes in conditions.

The following sections discuss two conceptual models of the site hydrogeology. The two models use the same basic geologic framework, but arrive at different conclusions regarding the hydraulic connection between the deeper ground water, shallow ground water, and surface water.

MMC Conceptual Model

MMC's conceptual model divides ground water flow in the Montanore project area into three general flow paths: (1) regional deep flow in bedrock; (2) local shallow flow in upper weathered and fractured bedrock; and (3) local shallow flow in surficial unconsolidated deposits. Ground water in these flow paths moves from higher to lower elevations. The deeper regional flow path is characterized by low hydraulic conductivity fractures, faults, and bedding planes that convey ground water from recharge areas at high elevations to areas of low elevation along the flanks of the Cabinet Range. Very little, if any, ground water moves through the unfractured rock matrix.

The shallow flow paths are characterized by localized recharge and discharge through near-surface fractured and weathered bedrock, fine-grained glacial lake beds (glaciolacustrine) of silt and clay, and poorly sorted glacial outwash deposits (glaciofluvial) of gravel, sand, silt, and clay. Shallow ground water also flows in alluvial deposits of sand and gravel that occurs in many of the valleys of the Cabinet Range (Geomatrix 2006a).

The Cabinet Mountains are composed of hard, brittle metasedimentary rocks with complex fracture systems that can store and transport ground water (Geomatrix 2006c). Glacial deposits

mantling the flanks of the mountains support shallow ground water systems. Valleys with streams draining the mountains contain unconsolidated colluvial and alluvial deposits that also support local ground water systems. In general, most ground water is recharged at higher elevations and moves downhill in both shallow and deep bedrock systems. The deep regional ground water moves down to the valleys where some of the water discharges to the glacial and valley fill deposits. Some of this water also discharges to streams and springs in the project area, but MMC anticipates that most ground water in the deeper fractures discharges to surface flow systems below an elevation of 4,000 feet and, therefore, is not well connected hydraulically to lakes, creeks, and springs in the vicinity of the proposed mine (Geomatrix 2007a) (Appendix B).

During mine development and the mining period, ground water would flow into the adits and mine void at rates estimated by MMC to be a short-term maximum rate of 1,200 gpm during dewatering of fractures. Using several different analytical methods, Geomatrix calculated a steady state inflow range of 600 to 800 gpm (Geomatrix 2007b). MMC developed a revised water balance reflecting a steady state inflow of 800 gpm (Geomatrix 2008). For the post-operational period, ground water intercepted by the mine workings would fill the mine workings. Geomatrix reports that no long-term discharge is expected from the adits because the Libby Adit has had no discharge since 1998.

Agencies' Conceptual Model

The agencies' conceptual model is based on the following key components of the hydrogeologic framework:

- Metasedimentary rocks in the mine area have very low primary permeability (hydraulic conductivity).
- Fractures and other structures provide pathways for ground water movement.
- Fractures or secondary permeability is higher than primary permeability.

The source of all surface and ground water in the Cabinet Mountains is precipitation that falls within the mountain range. There are no regional aquifers beneath the range that derive their source of water from outside the range. Ground water (shallow and deep) results from infiltration of precipitation at various rates, depending on the topography and geologic material exposed at the surface. Due to the topographic relief, occurrence of more permeable surficial geologic deposits and low overall hydraulic conductivity of the bedrock, different ground water flow paths have developed in shallow unconsolidated deposits and the deeper fractures of the bedrock. At the higher elevations (greater than about 5,600 feet), the surficial deposits are relatively thin and discontinuous, but they store and discharge infiltrated precipitation over the course of a year. In typical or dry precipitation years, it is likely that all ground water drains from these deposits by the end of the season. In wetter years, ground water may not fully drain by the end of the season. The net infiltration rate to deeper fractures in the steeper bedrock terrain is probably very low, as most precipitation would leave the area as runoff. The shallower, more fractured or weathered portions of the bedrock probably receive and transmit water at higher rates than the deeper fractures.

The contrast between the very low hydraulic conductivity of the deeper fractured bedrock and the higher hydraulic conductivity of the shallow weathered bedrock/surficial deposits and infiltration rates between the shallow and deeper fractured bedrock (and surficial material)

appears to result in two saturated zones with distinctly different flow characteristics. The shallow and deeper flow paths do not appear to be hydraulically connected above an elevation of about 5,600 feet. However, there is probably ground water leakage from the shallower flow path at low rates into unsaturated bedrock or randomly saturated vertical fractures that eventually reaches the deeper fractured bedrock flow path. Site observations during the exploration program, elevation of perennial creeks, and field observations concerning the location of springs indicates that a water table has developed in interconnected fractures at a depth of about 500 feet below the areas of highest elevation. The water table slopes toward the valleys and intersect the low areas at an elevation of about 5,400 to 5,600 feet, about at the same elevation that creeks become perennial (Figure 24). Springs exist above and below this 5,400 to 5,600 feet elevation range; those above this elevation are part of the shallow flow path and those below this elevation are connected to both flow systems. Below an elevation of between 5,400 and 5,600 feet, there are two distinct flow paths due to very different hydraulic conductivities, but the two flow paths are hydraulically connected.

Creek base flow in the upper reaches of each drainage is maintained by the deeper bedrock fractures during the driest part of each annual season. In the middle and lower reaches of the drainages, it is difficult to separate that portion of the "apparent" base flow resulting from the deeper system versus from residual shallow ground water. In the lower, flatter areas, ground water from thicker surficial deposits accounts for a much higher contribution to base flow than in the higher areas. During the year, there is probably an ever-changing ratio between shallow ground water and deeper bedrock ground water contributions to any one creek, as the season progresses. Depending on when precipitation starts in the fall, it may not be possible to know if or when a stream reaches true base flow, particularly with the limited available flow data for creeks in the analysis area.

The agencies' field review of the East Fork Rock Creek drainage during the driest season (September 2007) indicated that the only surface water flow in East Fork Rock Creek above Rock Lake was from discharge of ground water from bedrock springs. At that time, there was no surface water runoff or evidence that shallow springs maintained by snowmelt and/or recent rainfall contributed any water to the drainage. Precipitation records from the SNOTEL site near Bear Mountain, Idaho, indicate that the summer of 2007 had the second longest period (51 days) without precipitation since continuous precipitation data collection began in 1983. Bedrock springs from the Rock Lake fault zone along the East Fork Rock Creek drainage above Rock Lake accounted for 100 percent of the flow in the creek, which was estimated at 30 to 40 gpm. Ground water discharge to the creek started at an elevation of about 5,625 feet. At the time of the field review, bedrock ground water appeared to be the sole source of water to Rock Lake. Farther down the drainage, creek flow gradually increased from an estimated 40 to 50 gpm below Rock Lake to an estimated 1 cfs (480 gpm) within 0.5 mile and 2 cfs before the creek enters Rock Creek Meadows. These observations are consistent with the agencies' conceptual model that deeper bedrock ground water is connected to shallow ground water and surface water at elevations below about 5,600 feet.

Discussion of Model-Predicted Mining Effects on Mine Area Hydrology

Drawdown

At full build out of the mine, the water table within the footprint of the mine void is lowered (1,000 meters or about 3,300 feet) to the elevation of the mine void in the numerical model to simulate dewatering of the mine void. This simplifying assumption is necessary because of the use of a two-dimensional numerical model. Drawdown due to mine dewatering would extend about 2 miles from the mine void in all directions, but along the trend of the proposed adits, drawdown created by the mine void would merge with drawdown created by the adits (Figure 10). Given uncertainties described previously in this report, the model cannot precisely predict the final configuration of the drawdown cone around the mine, but the model does provide an indication of the catchment area required to supply approximately 450 gpm to the mine and adits on a steady state basis. If steady state inflow to the mine were higher, a larger catchment would be required to supply that water at the calibrated infiltration rates and hydraulic conductivity. For example, if the steady state inflow were in the range of 800 gpm, as indicated by Geomatrix (2007b), the catchment area would have to be about two times larger than predicted by the ground water model (using the assumptions inherent in the calibrated version of the model).

An example of the uncertainty in the final shape of the drawdown cone is due to the assumption in the agencies' numerical model that homogeneous conditions exist in the mine area. As a result of this assumption, the numerical model essentially distributes potential impacts from mine dewatering evenly in all directions. The actual site conditions may vary and ground water drawdown may be subject to some degree of heterogeneity, causing more drawdown along structural trends and less drawdown in other directions. There were insufficient data for the model to predict heterogeneous drawdown. Another example of uncertainty is the location of the 1-meter drawdown contour (assumed to represent zero drawdown) presented in the various figures in this document. The specific shape of the 1-meter contour is subject to influence by the size and location of the various elements used in the agencies' numerical model. To some extent, model elements control the geometric shape of the contours. Given the approximate nature of the agencies' numerical model, the location of all contours, including the 1-meter contour, should be considered approximate.

For those areas where the fractured bedrock water table is currently some depth below ground surface (for all areas above 5,600 feet elevation), ground water drawdown, as predicted by the model, would not have a direct effect on surface water occurring above this elevation. Because surface and ground water above 5,600 feet elevation appear to be not hydraulically connected, ground water drawdown would not result in decreases to surface water (creeks, springs, and lakes) in those areas. Infiltration of precipitation is controlled by the nature of the surface material and overall hydraulic conductivity and, therefore, the infiltration rate would not change in these areas as a result of a lower water table. It is possible that random fractures exist above elevations of 5,600 feet that are saturated between the fractured bedrock water table and the shallow ground water flow path, hydraulically connecting the two ground water flow paths. If this condition existed, drawdown of the fractured bedrock water table by mine dewatering could reduce flow to unidentified springs or affect lake levels associated with this type of fracture, such as the Libby Lakes. However, there are no observations, data or numerical model results to indicate this condition exists.

For those areas where ground water is either at the surface or connected hydraulically to shallow ground water flow systems (below an elevation of about 5,600 feet), drawdown due to mine dewatering would decrease the volume of water available to the surface water system, such as springs, lakes and creeks. In the agencies' conceptual model, ground water and surface water are hydraulically connected below elevations of about 5,600 feet and, therefore, surface water would be affected if ground water levels decreased due to mine dewatering.

In the MMC conceptual model, ground water is not connected to surface water in the vicinity of the mine and adits, but is connected to surface water at elevations below 4,000 feet. The MMC conceptual model states that streams, lakes, and springs overlying the mine would not be affected by ground water drawdown due to mine dewatering.

Mine/Adit Inflow

The numerical ground water model predicted that the total steady state inflow to the mine and adits at full build out would be about 450 gpm for the fault scenario. The extent of the numerical model-predicted drawdown is based on inflows to the mine and adits within this range of steady state inflows. The calculated reduction in base flow to creeks is also based on this range of steady state inflows. The 1992 Montanore Project Final EIS used steady state inflow of 1,200 gpm, based on estimates developed by Noranda Minerals Corp (USDA Forest Service et al 1992). MMC used a steady state inflow of 1,200 gpm in developing a project water balance (Mines Management, Inc. 2005), but reduced steady state inflow to 800 gpm after additional analysis (Geomatrix 2007b).

An attempt was made to use the agencies' model to produce inflow rates of 1,200 and 800 gpm on a steady state basis. The two basic variables (infiltration and hydraulic conductivity) were modified to achieve a total inflow of 1,200 gpm. With respect to infiltration, a net infiltration rate of 9% in the steeper areas and 45% in the flatter areas (compared to 2% and 10% in the calibrated model, respectively) was required to produce a total inflow of 1,200 gpm. As a result of this configuration, the Libby Adit flowed at 382 gpm, the Heidelberg Adit flowed at 96 gpm, and creeks became perennial at much higher elevations than observed. Raising hydraulic conductivity to achieve a total inflow of 1,200 gpm required an increase of about 20 times, and resulted in a Libby Adit flow of 704 gpm, Heidelberg Adit flow of 101 gpm, and creeks becoming perennial at much lower elevations than observed. An inflow of 800 gpm required similar but smaller changes and also resulted in much higher values for Libby and Heidelberg adit outflow than measured.

Although the resulting model configurations are unrealistic relative to known conditions and reasonable values of infiltration and hydraulic conductivity, inflows of 1,200 or 800 gpm were produced with the model. If it is assumed that the steady state inflow to the mine and adits would be 1,200 or 800 gpm, then the reduction in creek flow would be about three times and two times higher than predicted by the calibrated version of the model, respectively. Because the model cannot be calibrated at these inflows, it is not possible to use the model to determine how an inflow of 1,200 or 800 gpm would be distributed between the four major drainages leaving the mine area.

Changes in Creek Base Flow

The effects of ground water drawdown due to dewatering of the mine can best be expressed by estimating changes to base flow in creeks. As part of the numerical model calibration process,

the model results were compared to measured flows in various creeks that drain the area that are considered to be base flow. In general, streamflow measurements were from gaging stations located on the periphery of the numerical model domain (Figure 7). There were insufficient flow data from the upper reaches of the various creeks to determine actual creek base flow at these locations. Because the model was calibrated to flow data at the periphery of the model domain and to several other direct observations, including the elevation at which creeks tend to become perennial, the base flow predictions at various nodes along the creeks are considered to be reasonable estimates of base flow at these locations. The model results are also based on the assumption that the predicted base flow is representative of a typical precipitation year. The agencies' numerical model predicted base flow values for the various model nodes that are comparable to the 7Q10 values calculated for several locations along various creeks (see Surface Water Section of the EIS). A subsequent field review in September 2007 confirmed that base flows in the upper reaches of East Fork Rock Creek (above and just below Rock Lake) were similar to those predicted by the agencies' numerical model.

Using the fault scenario version of the model, base flow for the three periods (pre-mining, mining, and post-mining) were calculated for nodes along four streams (Libby, Ramsey, and Rock creeks, and East Fork Bull River) (Table 6). Using the pre-mining base flows as the baseline, the changes in flow and percentage changes were calculated for each node along the creeks for the mining and post-mining cases (Table 6). The same process was used for the cumulative analysis that included both the Rock Creek and Montanore mines (Table 7). Nodes along various drainages are provided in Figure 25.

Several factors should be considered in evaluating the significance of this analysis. In many cases, the predicted changes at any given node may appear to be large when considering only the percentage change, but the actual predicted flow change is very small, compared to typical creek flows and measurement precision. For example, the model predicts changes in nodes 124 and 125 in Libby Creek of 0.02 and 0.04 cfs, respectively, for the mining period. The actual predicted changes in flow are very small and it is unlikely that such changes could be measured or detected for two reasons. First, it is difficult to measure stream flow to an accuracy greater than plus or minus 10%, within the range of typical flows of creeks in the mine area using a stream flow meter (Wegner, pers. comm. 2007). Flow measurement error could be reduced to less than plus or minus 5 percent with the use of a flume or weir in low flow situations. Secondly, uncertainty in year-to-year base flow at the gaging station locations would result in a significantly higher range of values than the predicted changes. The model results are reported in Table 6 and Table 7. Professional judgment was used to identify possible environmental impacts as a result of mine dewatering.

To adequately judge the duration of the predicted base flow reduction, the agencies examined the relative contribution of ground water base flow and surface water runoff to a given creek. There are very little actual stream flow data from the upper reaches of most creeks draining the CMW. It is likely that during non-base flow periods, creek flows are probably much greater than the base flow period, but the actual flows are unknown. The agencies reviewed the hydrograph from three stream locations (Granite Creek and Flower Creek, located near Libby, Montana, and Boulder Creek, near Leonia, Idaho) where between 22 and 50 years of continuously recorded annual flow data exist. Based on these three streams, it appears that creeks in the area flow at base flow for about 1 to 2 months between mid July to early October (Figure 26). The creek

hydrographs indicate that periods of base flow may also occur during the winter months, but these base flow periods were not included in the base flow estimate of 1 to 2 months.

Libby and Ramsey Creeks

The agencies' numerical model-predicted changes in base flow in Libby and Ramsey creeks are small compared to the likely variability in determining base flow at any one location. Model-predicted changes in base flow of fractions of a cubic foot per second may occur due to mining, but the predicted changes in base flow for the four upstream-most nodes in Libby Creek are low enough that it is unlikely changes of this magnitude would be measurable. Any reduction in base flow due to mine dewatering would persist for up to 70 years after mine closure because the time for the mine void to refill and for recovery of ground water levels.

East Fork Rock Creek

The agencies' numerical model-predicted base flow for the upper reaches of East Fork Rock Creek (above and below Rock Lake) is consistent with creek base flow observed during a September 2007 site visit. In September 2007, no surface runoff or shallow ground water was contributing to the creek. All of the observed flow was from deep bedrock ground water discharge to the drainage. The flow rate out of Rock Lake was similar to the flow from East Fork Rock Creek above the lake. The agencies' numerical model predicted that changes in base flow due to mine inflow would reduce the deeper ground water contribution to East Fork Rock Creek above the lake to near zero (Table 6). The predicted changes would result in no flow into Rock Lake when base flow was the sole contribution of surface flow into Rock Lake, such as during late summer to early fall.

There may be some annual variability in base flow along the upper reaches of East Fork Rock Creek, but the variability is probably small compared to the predicted flow reductions (Table 6). About 0.75 mile below Rock Lake, East Fork Rock Creek enters a flat area with a considerable thickness of alluvium (Rock Creek Meadows). There is likely sufficient water storage in the alluvium to mask any potential reductions in base flow at this location and downstream. In other words, changes in base flow above Rock Creek Meadows would likely be measurable, but changes at or downstream of Rock Creek Meadows would not likely be measurable.

East Fork Bull River

The same effects predicted in the upper reaches of East Fork Rock Creek are predicted by the agencies' numerical model for the upper reaches of the East Fork Bull River drainage. The DEQ reported spring discharge in the East Fork Bull River above St. Paul Lake along the trace of the Rock Lake fault at about the same elevation observed in the East Fork Rock Creek drainage (McKay, pers. comm. 2007). During normal to dry years when winters snows have completely melted, deeper ground water discharge may be the only source of water to St. Paul Lake during late summer to early fall. Model-predicted reductions in base flow in the upper reaches of East Fork Bull River (above St. Paul Lake) may be a large portion of the total base flow (Table 6). Impacts may not be measurable when precipitation and/or remaining snow pack continue to be a source to spring and streamflow above the lake, but in drier years, impacts from mining may aggravate natural low-flow conditions. Based on the agencies' numerical model results, reduced base flow would persist during the post-mining period for a portion of the drainage until the mine void was refilled with water and the regional water table recovered. After the regional water table recovered, the agencies' numerical model predicts there may be a slight increase in ground

water contribution to portions of the East Fork Bull River compared to pre-mining conditions (Table 6).

Summary

The agencies' numerical model predicted base flows for all model node locations along various creeks. The model does not consider what is possible to detect or measure. There are other factors that should be considered when reviewing and interpreting these data. For example, base flow at any one location along a creek may not be easily defined within the range of the model-predicted changes, but impacts from dewatering of the mine and adits may be expressed in other ways, such as changing the elevation at which creeks begin to flow. Mine dewatering (and resultant ground water drawdown) may cause this elevation to move down the drainage.

Another consideration in the ability to measure or detect changes in base flow due to mine dewatering is the annual variability in precipitation. In wet years, there may be sufficient precipitation and/or remaining snowpack to mask any changes in base flow that would otherwise be observable in late summer to early fall. Also, in the middle to lower reaches of the various drainages, there are sufficient thicknesses of alluvium or other surficial deposits that have the ability to store sufficient ground water. Ground water discharge from these deposits through dry periods would probably be sufficiently high to mask any changes in base flow resulting from mine dewatering. An example of this condition is at Rock Creek Meadows, located about 0.75 mile downstream from Rock Lake.

In contrast to the middle and lower reaches of the various creeks, the upper reaches in the higher elevation portions of these drainages have much thinner alluvial or surficial deposits with limited ground water storage capacity or no surficial deposits. Late season base flow is derived mostly from deeper ground water and may be subject to measurable changes from mine dewatering.

Another consideration in determining whether surface water would be affected by mine dewatering is to what degree the hydrogeology of the area is heterogeneous versus homogeneous. The agencies' numerical model assumed homogeneous conditions because of the lack of specific data on this issue. If ground water flow were dominantly controlled by heterogeneous conditions, then potential impacts to surface water would be focused along structural trends, rather than being distributed evenly among all drainages. It is not possible to predict how this condition might affect creek base flow with the currently available data. Ground water monitoring in piezometers drilled from within the mine adits and/or mine void would provide information on the degree of heterogeneity of the fractured bedrock system that could be used to refine model observations.

Table 6. Model predicted changes in base flow - Montanore Mine only.

Creek/model node	Premining			Mining		Post Mining			Change - Premining-Mining	Percent Change	Change Premining-Post Mining	Percent Change
	m3/day	cfs	gpm	m3/day	cfs	m3/day	cfs		cfs		cfs	
Libby Creek												
125	344	0.14	63	284	0.12	462	0.19		-0.02	-17%	0.05	34%
124	715	0.29	131	623	0.25	990	0.40		-0.04	-13%	0.11	39%
122	3,974	1.62	728	3,152	1.29	3,698	1.51		-0.34	-21%	-0.11	-7%
121	6,511	2.66	1,194	5,689	2.32	6,235	2.55		-0.34	-13%	-0.11	-4%
120	12,348	5.04	2,264	11,404	4.66	12,134	4.96		-0.39	-8%	-0.09	-2%
92	35,990	14.70	6,598	35,046	14.31	35,776	14.61		-0.39	-3%	-0.09	-1%
Gage St. B		17.4	7,810									
Ramsey Creek												
117	414	0.17	76	321	0.13	460	0.19		-0.04	-23%	0.02	11%
118	773	0.32	142	650	0.27	832	0.34		-0.05	-16%	0.02	8%
119	1,904	0.78	349	1,777	0.73	1,965	0.80		-0.05	-7%	0.03	3%
Rock Creek												
177	24	0.01	4	0	0.00	0	0.00		-0.01	-100%	-0.01	-100%
147	283	0.12	52	0	0.00	186	0.08		-0.12	-100%	-0.04	-34%
148	379	0.15	70	0	0.00	270	0.11		-0.15	-100%	-0.04	-29%
145	343	0.14	63	<1	0.00	229	0.09		-0.14	-100%	-0.05	-33%
149	697	0.28	128	328	0.13	582	0.24		-0.15	-53%	-0.05	-16%
150	3,449	1.41	632	2,994	1.22	3,334	1.36		-0.19	-13%	-0.05	-3%
151	4,212	1.72	772	3,747	1.53	4,096	1.67		-0.19	-11%	-0.05	-3%
152	6,130	2.50	1,124	5,692	2.33	6,047	2.47		-0.18	-7%	-0.03	-1%
153	7,531	3.08	1,381	7,061	2.88	7,415	3.03		-0.19	-6%	-0.05	-2%
154	13,929	5.69	2,554	13,458	5.50	13,813	5.64		-0.19	-3%	-0.05	-1%
155	20,477	8.36	3,754	20,007	8.17	20,361	8.32		-0.19	-2%	-0.05	-1%
Gage St C 230	23,433	9.57	4,296	22,962	9.38	23,316	9.52		-0.19	-2%	-0.05	0%
East Fork Bull River												
180	7	0.00	1	-	0.00	444	0.18		0.00	-100%	0.18	100%
45	1,446	0.59	265	433	0.18	1,777	0.73		-0.41	-70%	0.14	23%
44	1,923	0.79	353	904	0.37	2,254	0.92		-0.42	-53%	0.14	17%
43	3,301	1.35	605	2,259	0.92	3,632	1.48		-0.43	-32%	0.14	10%
42	4,356	1.78	799	3,315	1.35	4,687	1.91		-0.43	-24%	0.14	8%
41	10,636	4.34	1,950	9,594	3.92	10,967	4.48		-0.43	-10%	0.14	3%
40	12,868	5.26	2,359	11,827	4.83	13,200	5.39		-0.43	-8%	0.14	3%
Gage St. E 39-26	14,844	6.06	2,721	13,802	5.64	15,175	6.20		-0.43	-7%	0.14	2%

Table 7. Model predicted changes in base flow - cumulative impacts (Montanore and Rock Creek Mines).

Creek/model node	Premining			Mining		Post Mining			Change - Premining-Mining	Percent Change	Change Premining-Post Mining	Percent Change
	m3/day	cfs	gpm	m3/day	cfs	m3/day	cfs		cfs		cfs	
Libby Creek												
125	344	0.14	63	284	0.12	462	0.19		-0.02	-18%	0.05	34%
124	715	0.29	131	622	0.25	990	0.40		-0.04	-13%	0.11	39%
122	3,974	1.62	728	3,152	1.29	3,698	1.51		-0.34	-21%	-0.11	-7%
121	6,511	2.66	1,194	5,689	2.32	6,235	2.55		-0.34	-13%	-0.11	-4%
120	12,348	5.04	2,264	11,403	4.66	12,134	4.96		-0.39	-8%	-0.09	-2%
92	35,990	14.70	6,598	35,046	14.31	35,776	14.61		-0.39	-3%	-0.09	-1%
Gage St. B												
Ramsey Creek												
117	414	0.17	76	321	0.13	460	0.19		-0.04	-23%	0.02	11%
118	773	0.32	142	651	0.27	832	0.34		-0.05	-16%	0.02	8%
119	1,904	0.78	349	1,777	0.73	1,965	0.80		-0.05	-7%	0.03	3%
Rock Creek												
177	24	0.01	4	0	0.00	0	0.00		-0.01	-100%	-0.01	-100%
147	283	0.12	52	0	0.00	184	0.08		-0.12	-100%	-0.04	-35%
148	379	0.15	70	0	0.00	268	0.11		-0.15	-100%	-0.05	-29%
145	343	0.14	63	0	0.00	227	0.09		-0.14	-100%	-0.05	-34%
149	697	0.28	128	325	0.13	580	0.24		-0.15	-53%	-0.05	-17%
150	3,449	1.41	632	3,001	1.23	3,329	1.36		-0.18	-13%	-0.05	-3%
151	4,212	1.72	772	3,758	1.53	4,086	1.67		-0.19	-11%	-0.05	-3%
152	6,130	2.50	1,124	5,252	2.15	5,830	2.38		-0.36	-14%	-0.12	-5%
153	7,531	3.08	1,381	6,454	2.64	7,194	2.94		-0.44	-14%	-0.14	-4%
154	13,929	5.69	2,554	11,904	4.86	13,290	5.43		-0.83	-15%	-0.26	-5%
155	20,477	8.36	3,754	18,452	7.54	19,838	8.10		-0.83	-10%	-0.26	-3%
Gage St C 230	23,433	9.57	4,296	21,408	8.74	22,793	9.31		-0.83	-9%	-0.26	-3%
East Fork Bull River												
180	7	0.00	1	-	0.00	39	0.02		0.00	-100%	0.01	>100%
45	1,446	0.59	265	210	0.09	1,362	0.56		-0.50	-85%	-0.03	-6%
44	1,923	0.79	353	403	0.16	1,721	0.70		-0.62	-79%	-0.08	-11%
43	3,301	1.35	605	1,688	0.69	3,021	1.23		-0.66	-49%	-0.11	-8%
42	4,356	1.78	799	2,726	1.11	4,058	1.66		-0.67	-37%	-0.12	-7%
41	10,636	4.34	1,950	9,007	3.68	10,334	4.22		-0.67	-15%	-0.12	-3%
40	12,868	5.26	2,359	11,241	4.59	12,557	5.13		-0.66	-13%	-0.13	-2%
Gage St. E 39-26	14,844	6.06	2,721	13,224	5.40	14,533	5.94		-0.66	-11%	-0.13	-2%

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Figures

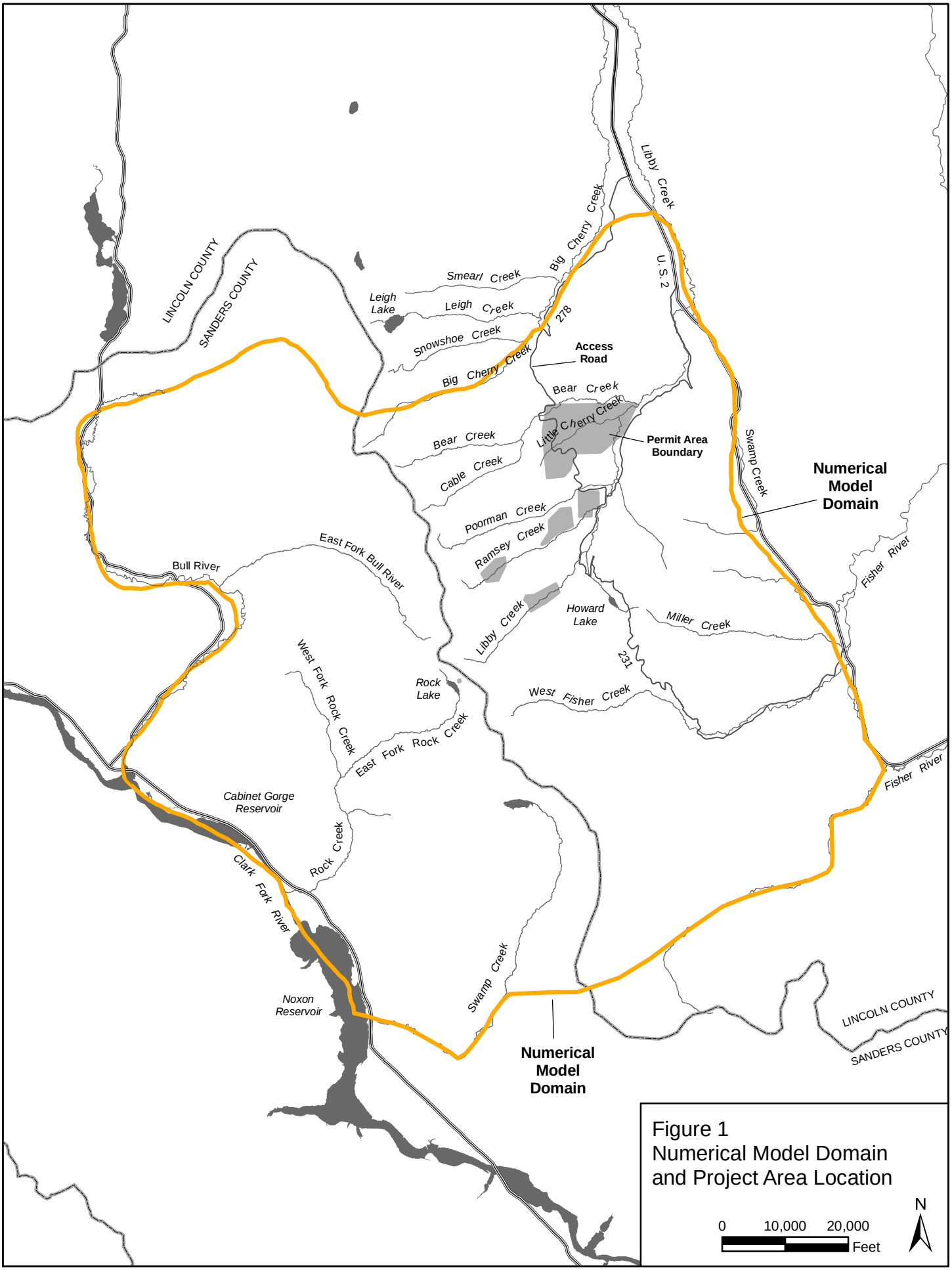


Figure 1
Numerical Model Domain and Project Area Location

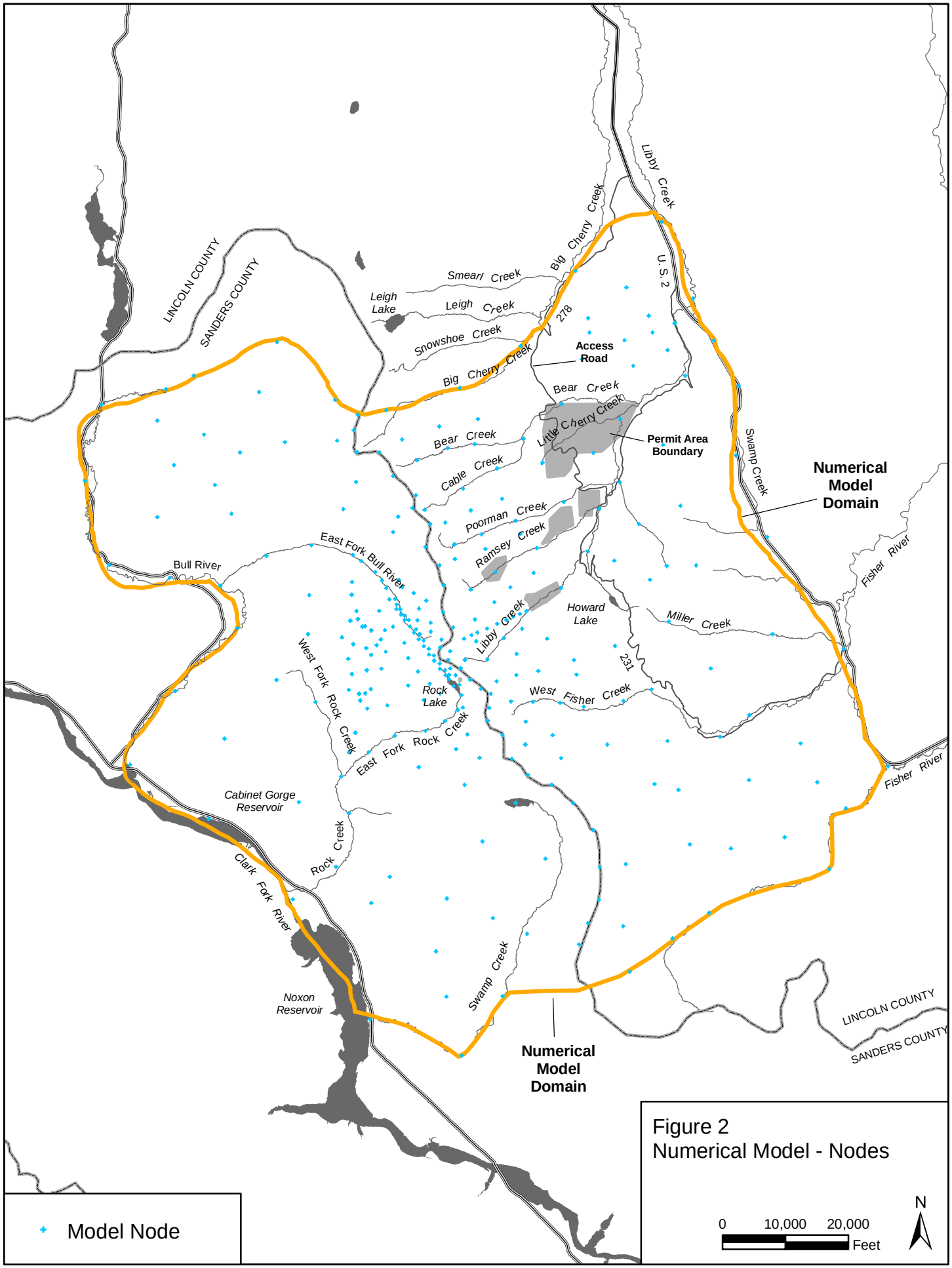


Figure 2
Numerical Model - Nodes

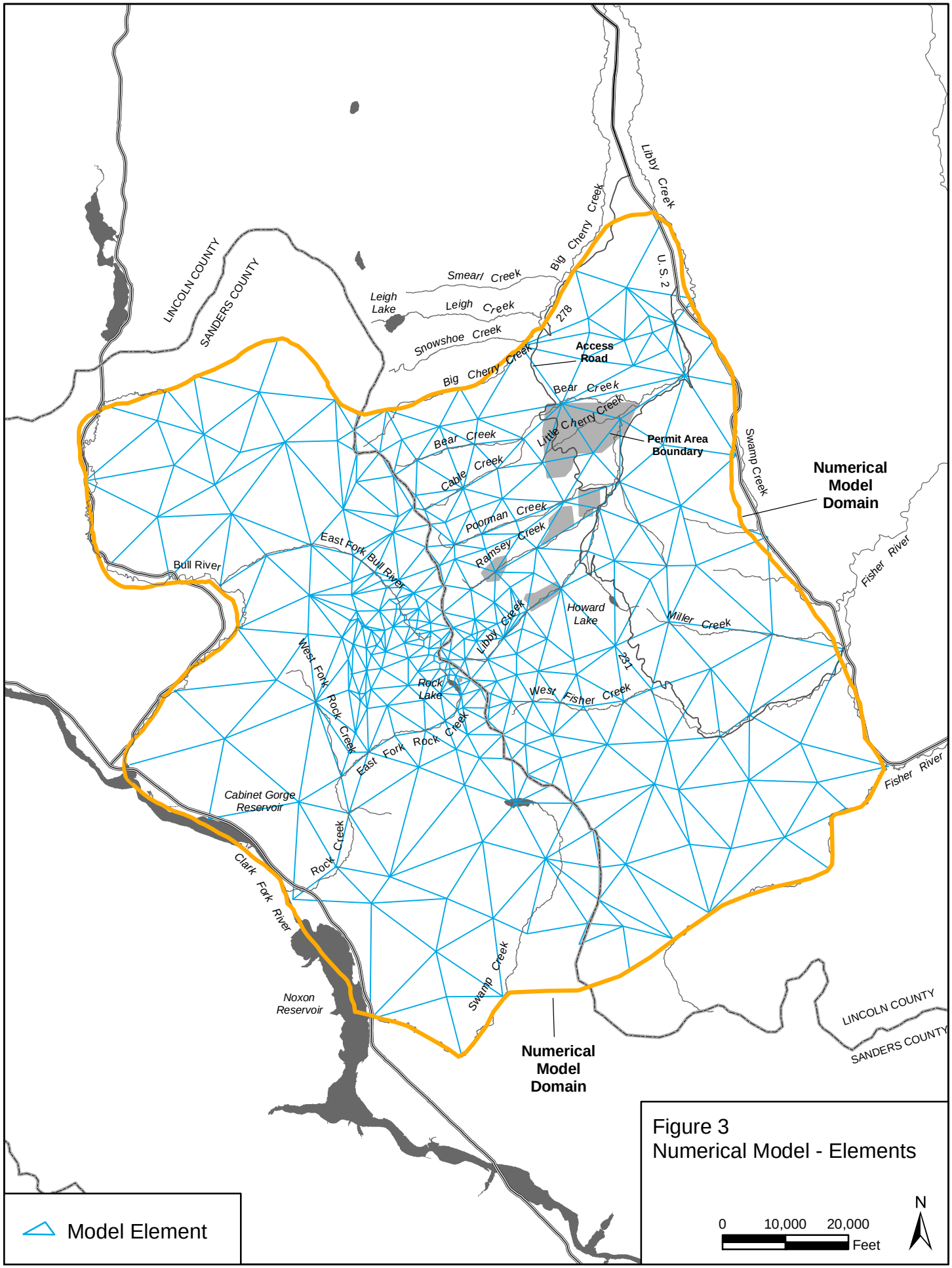


Figure 3
Numerical Model - Elements

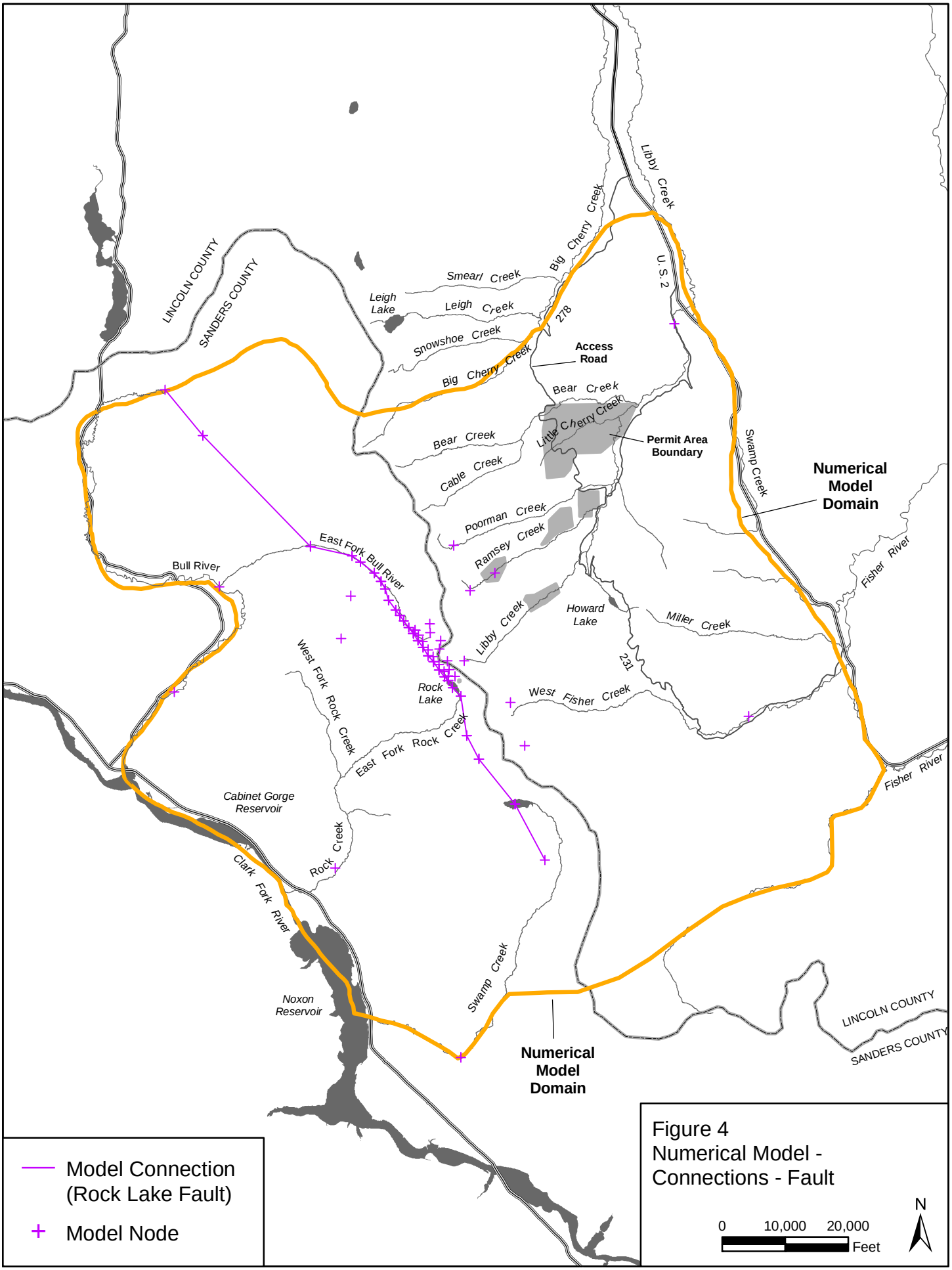


Figure 4
Numerical Model - Connections - Fault

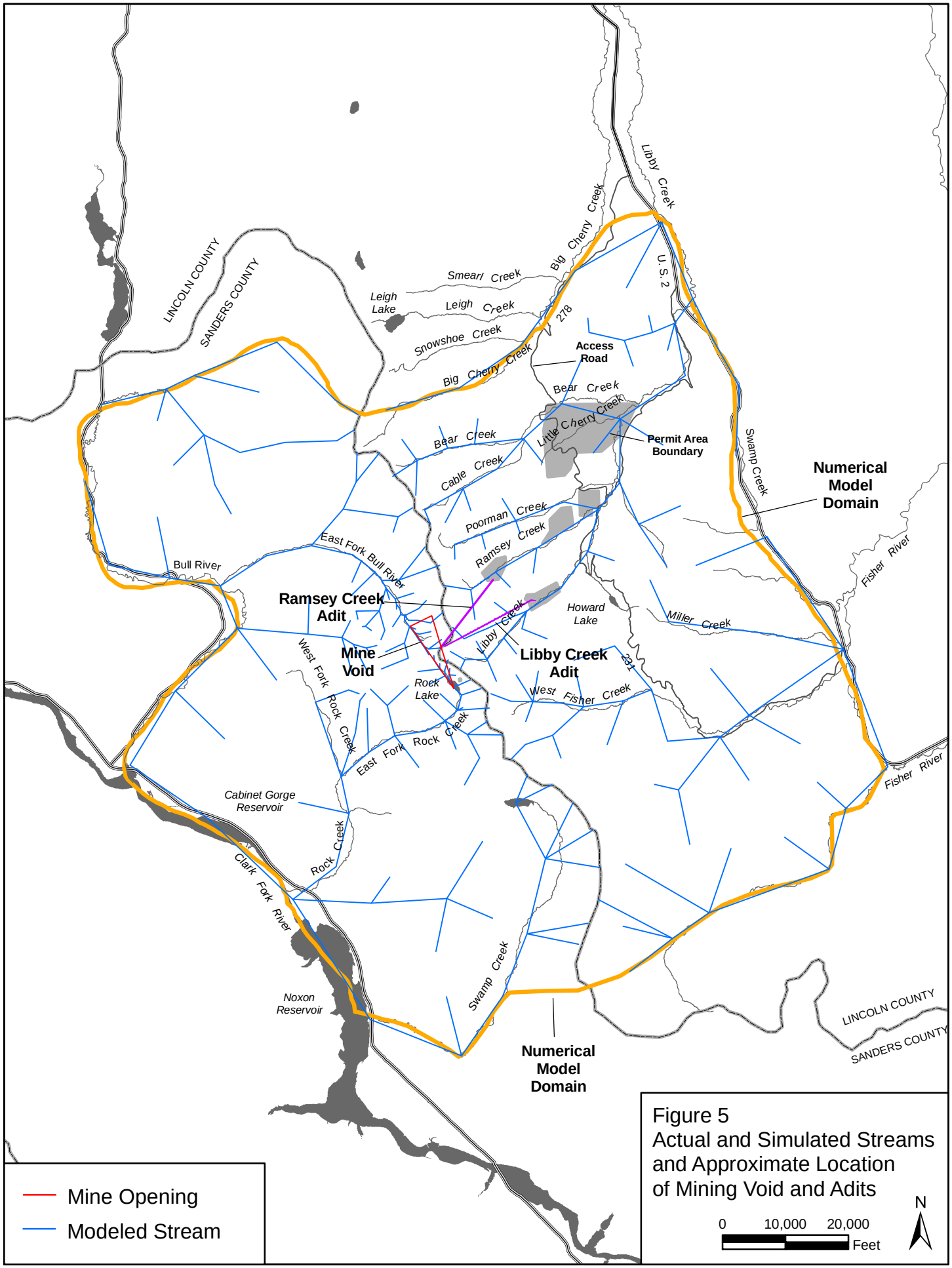
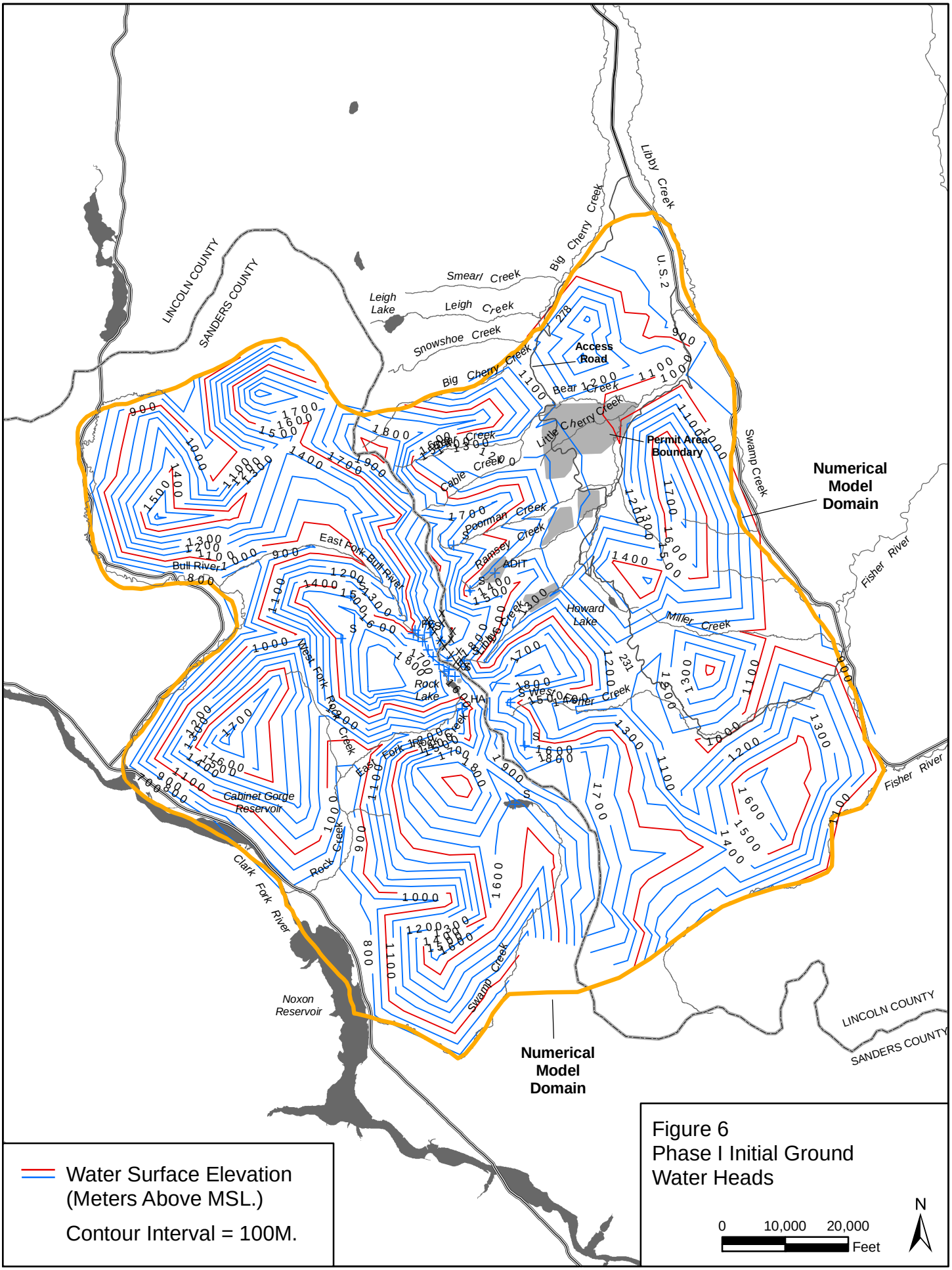


Figure 5
Actual and Simulated Streams and Approximate Location of Mining Void and Adits



Water Surface Elevation (Meters Above MSL.)

Contour Interval = 100M.

Figure 6
Phase I Initial Ground Water Heads

0 10,000 20,000 Feet

N

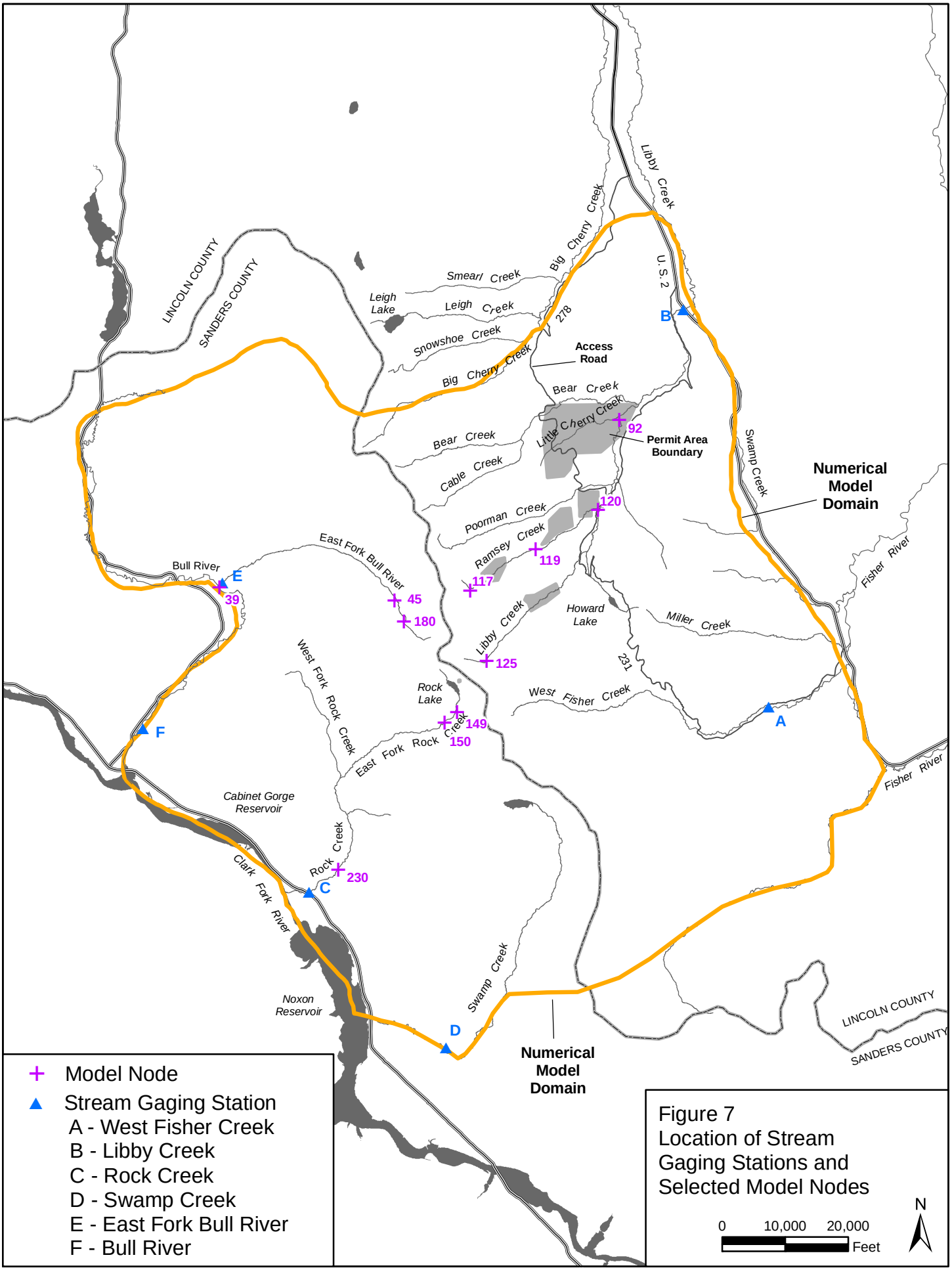


Figure 7
Location of Stream Gaging Stations and Selected Model Nodes

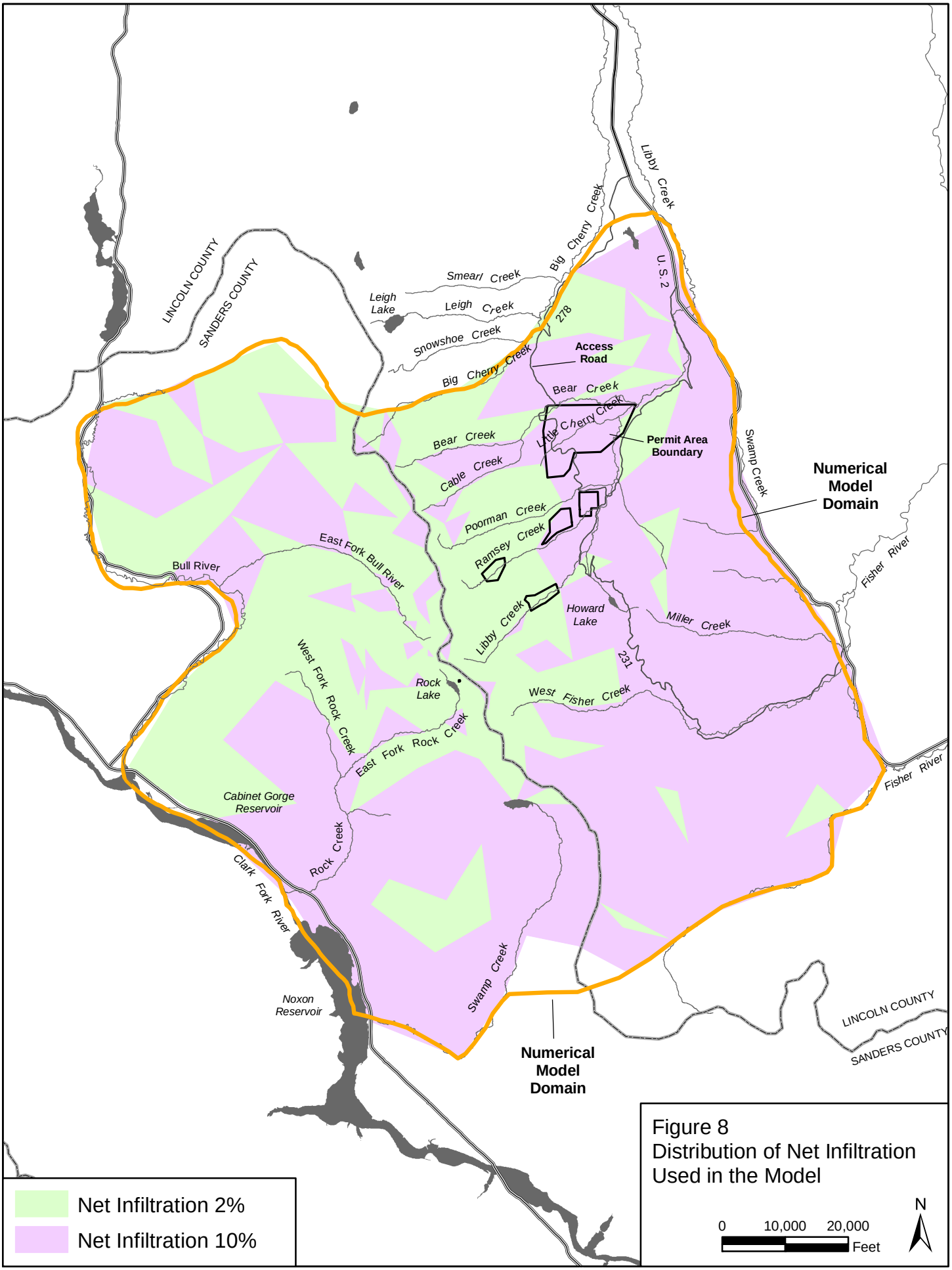
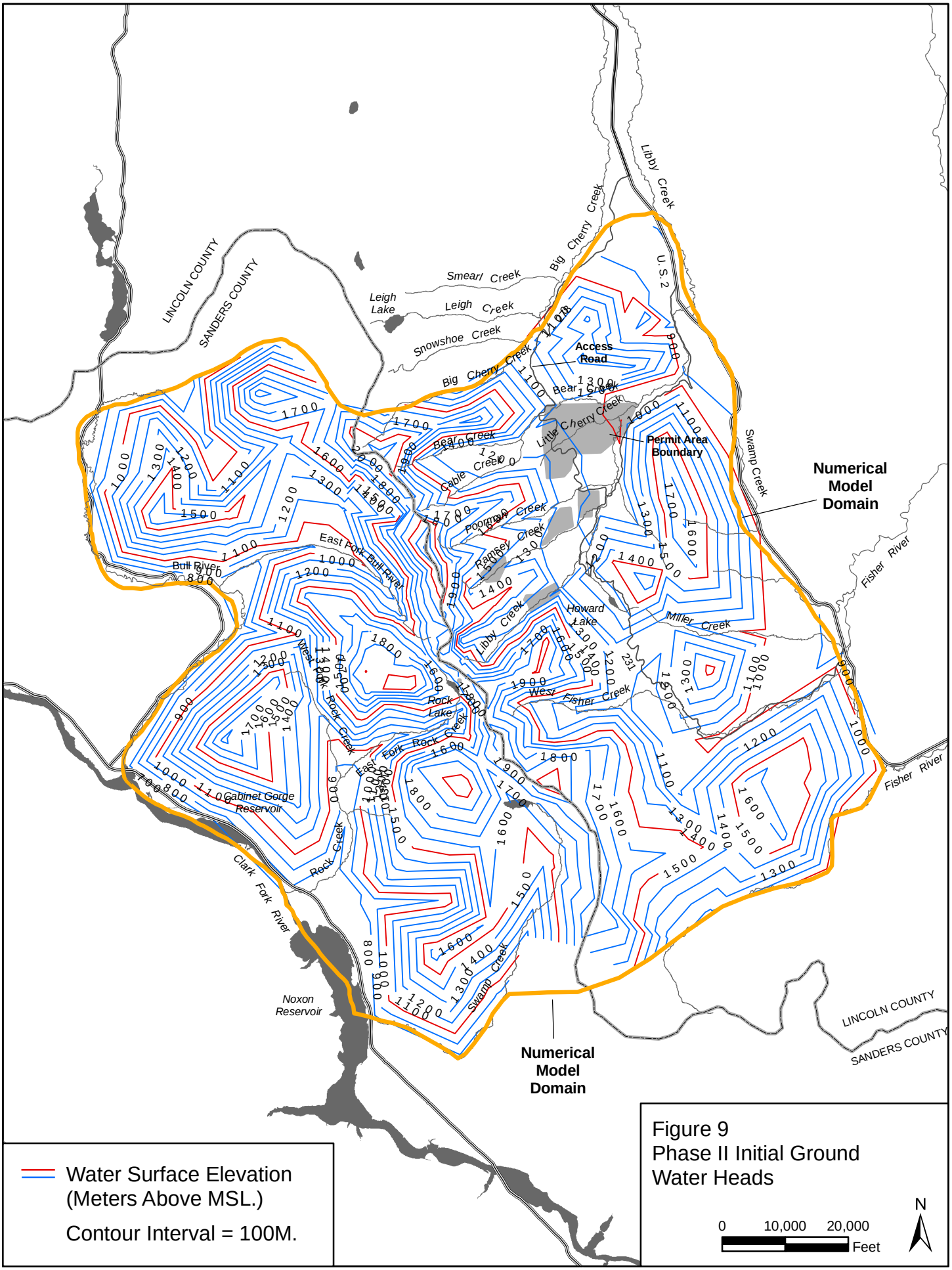


Figure 8
Distribution of Net Infiltration Used in the Model



Water Surface Elevation (Meters Above MSL.)

Contour Interval = 100M.

Figure 9
Phase II Initial Ground Water Heads

0 10,000 20,000 Feet

N

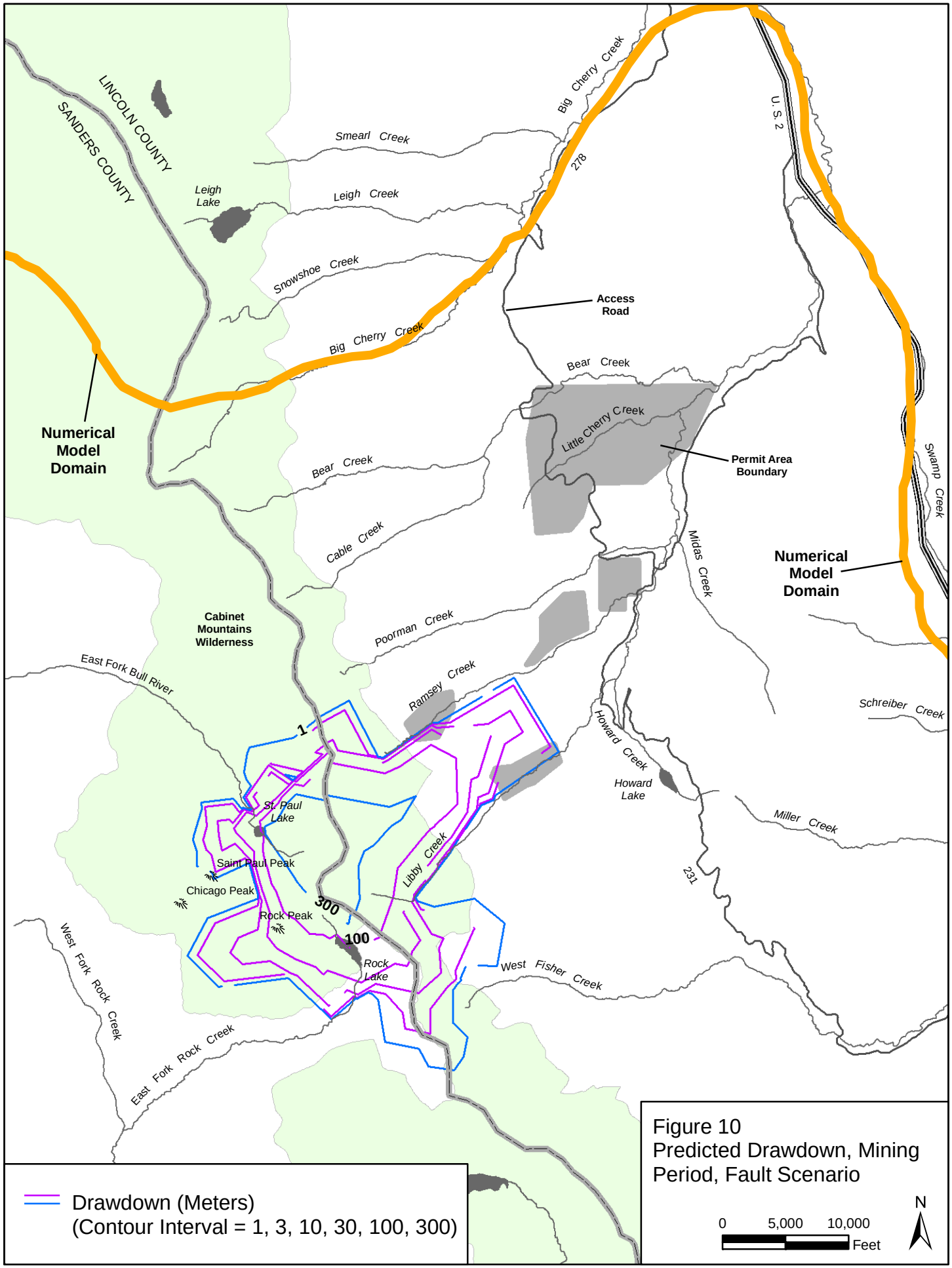


Figure 10
Predicted Drawdown, Mining Period, Fault Scenario

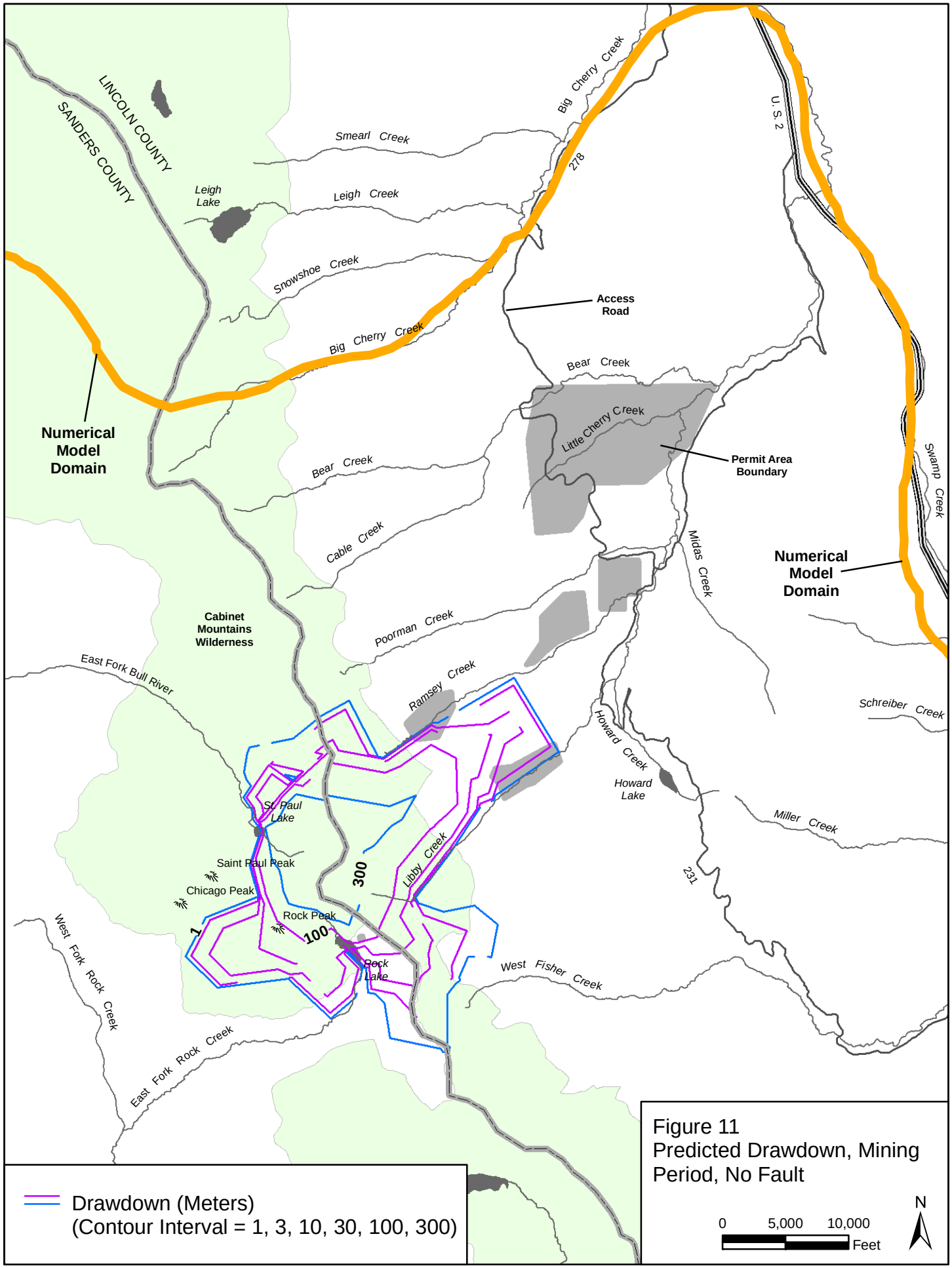


Figure 11
Predicted Drawdown, Mining Period, No Fault

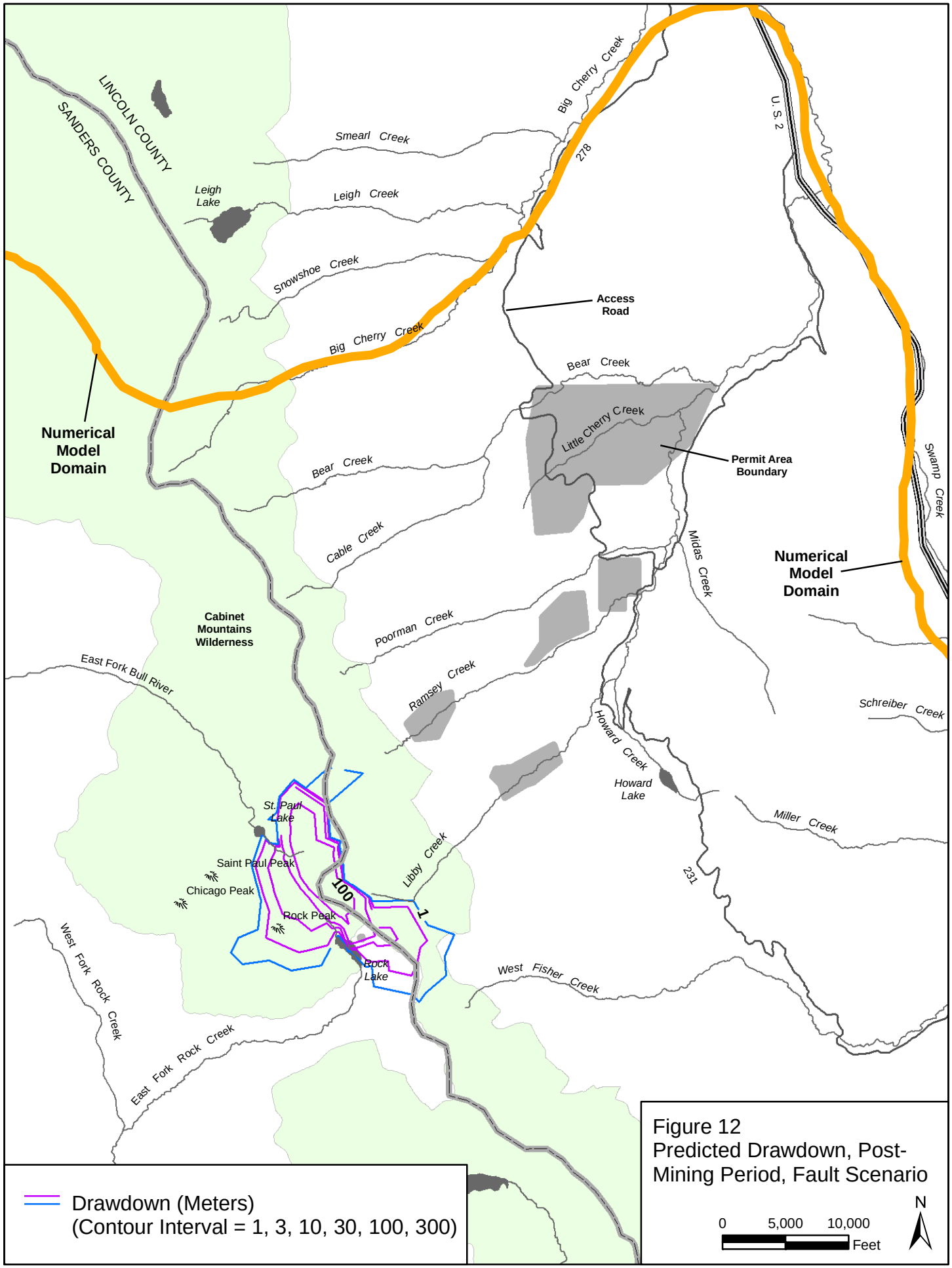


Figure 12
Predicted Drawdown, Post-Mining Period, Fault Scenario

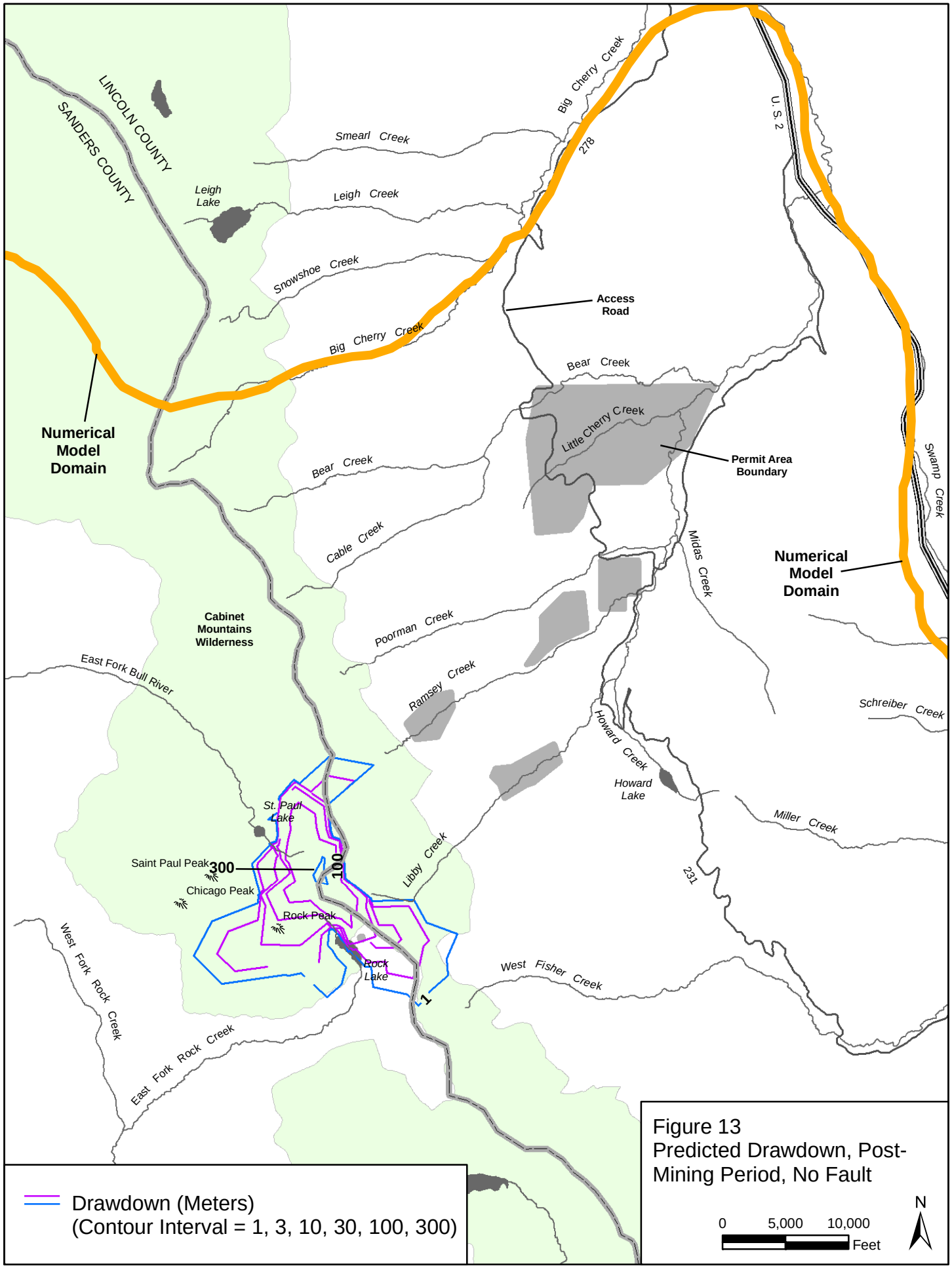


Figure 13
Predicted Drawdown, Post-Mining Period, No Fault

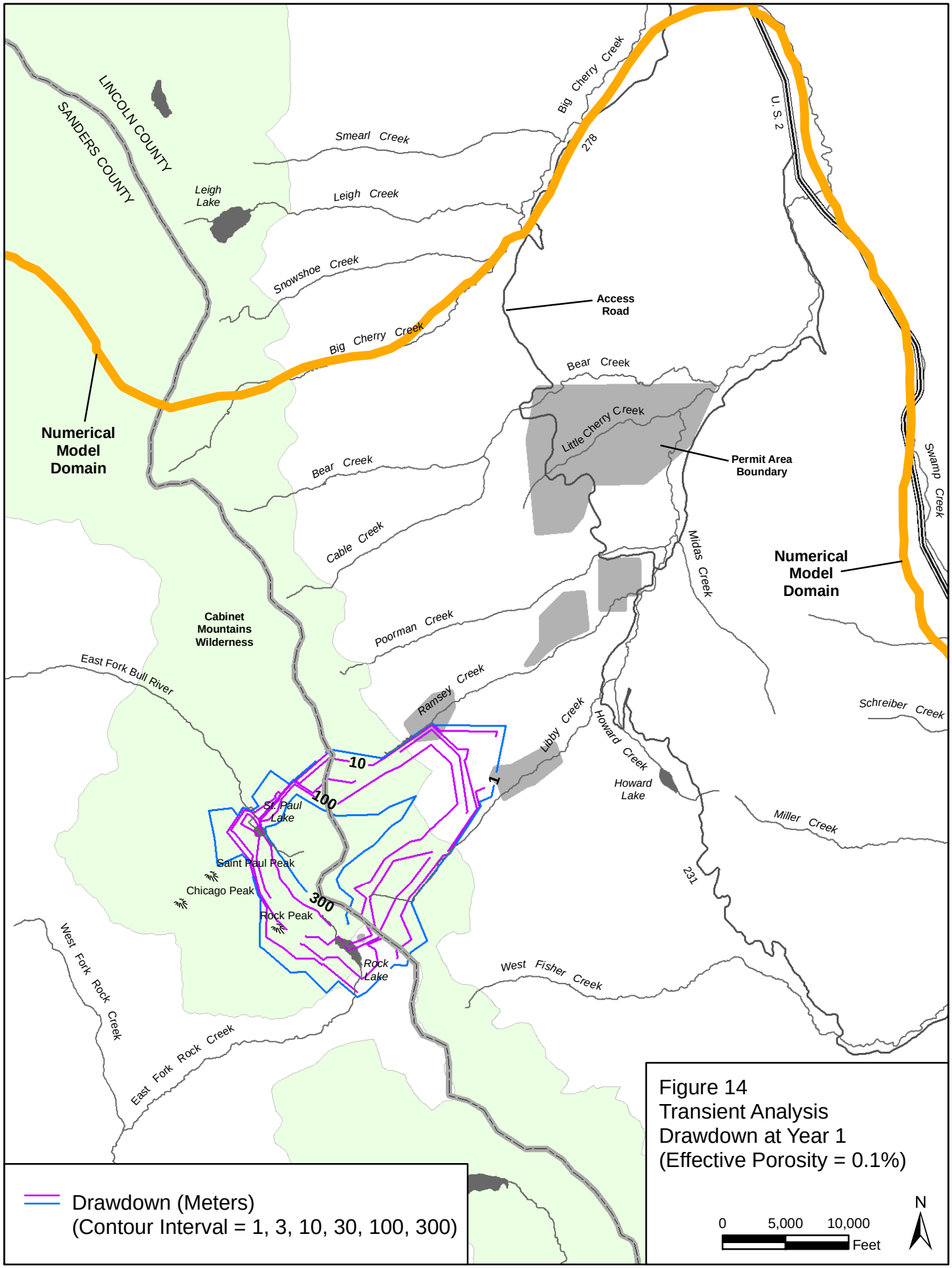


Figure 14
Transient Analysis
Drawdown at Year 1
(Effective Porosity = 0.1%)

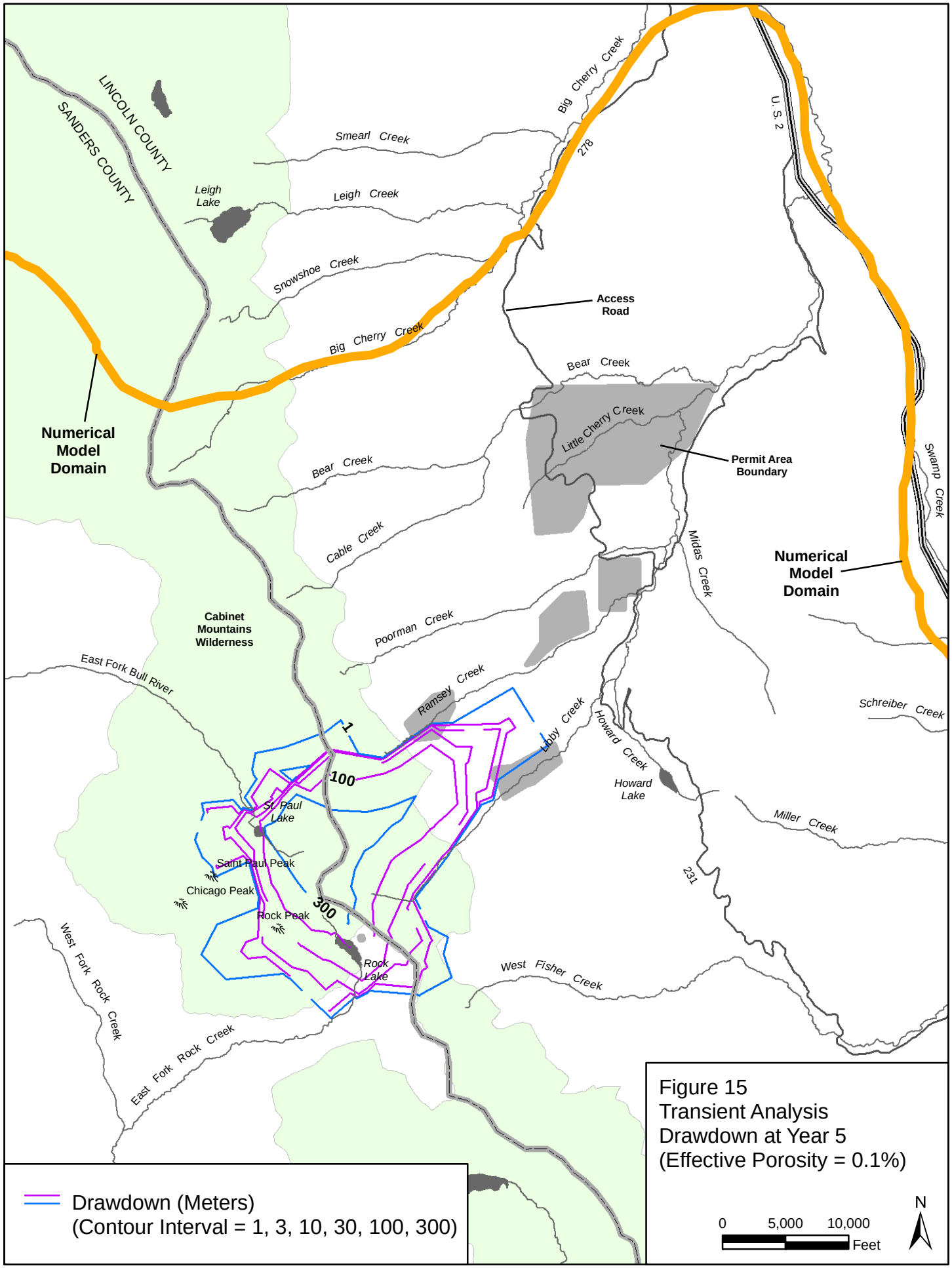


Figure 15
Transient Analysis
Drawdown at Year 5
(Effective Porosity = 0.1%)

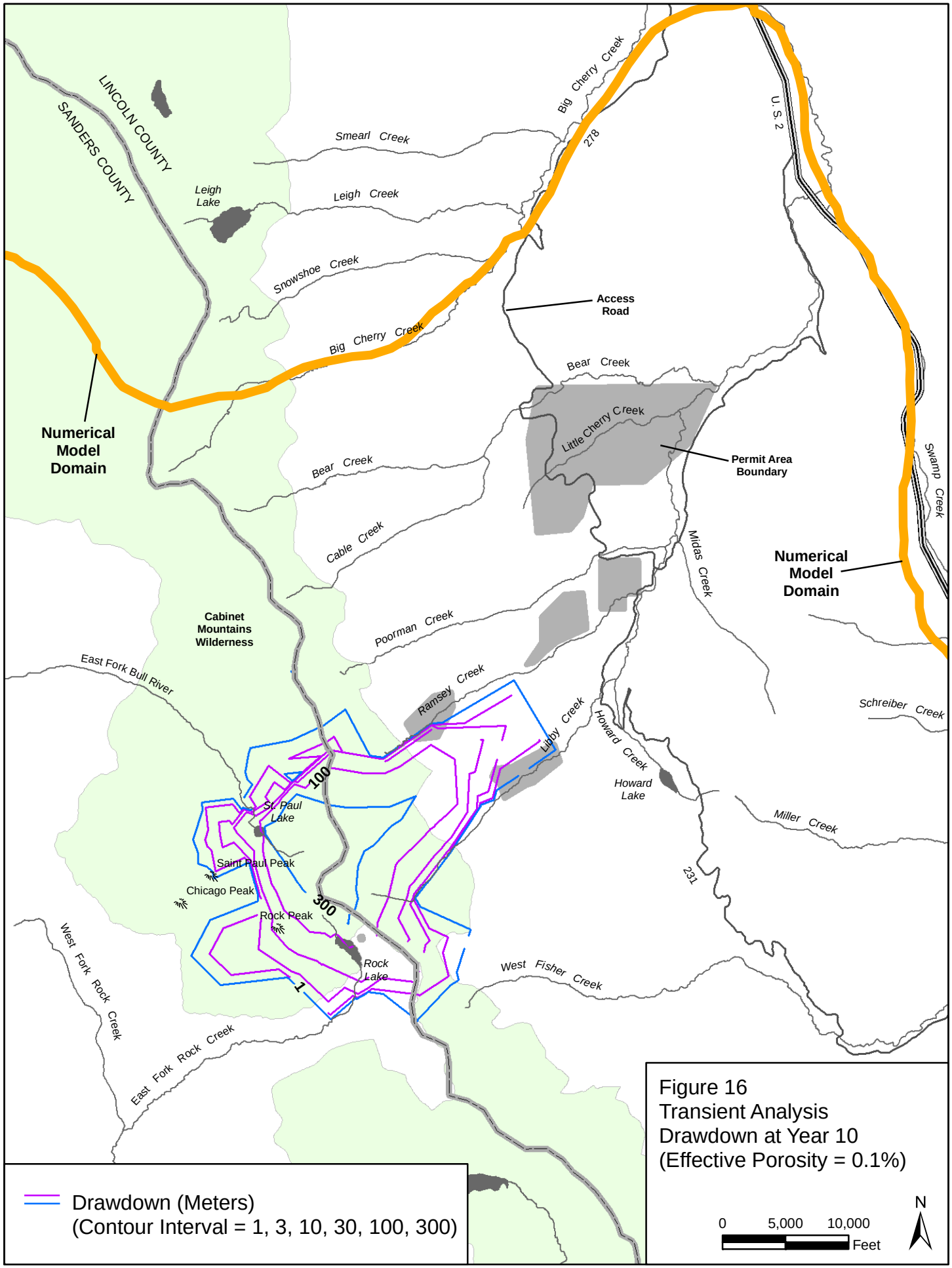


Figure 16
Transient Analysis
Drawdown at Year 10
(Effective Porosity = 0.1%)

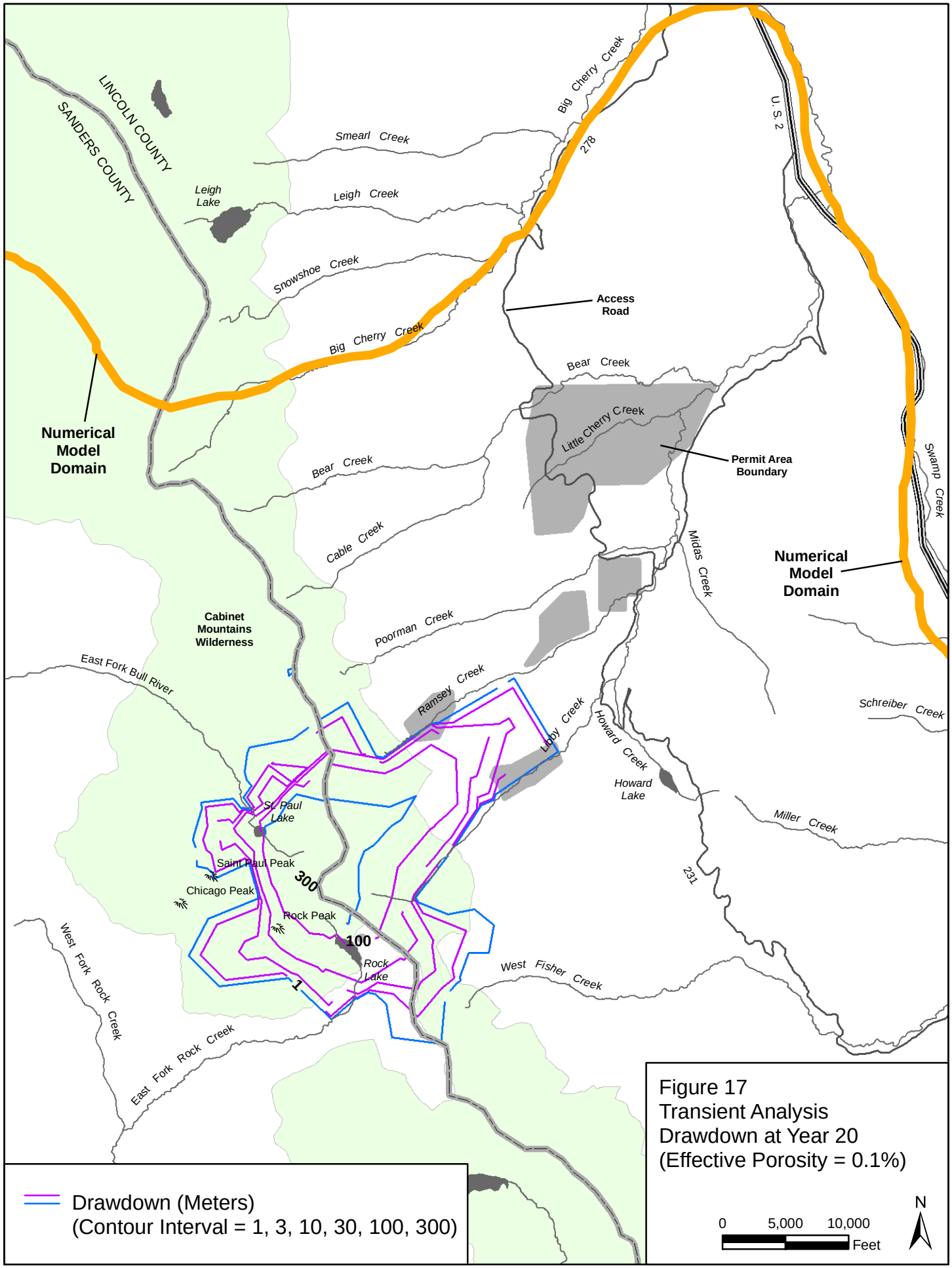


Figure 17
Transient Analysis
Drawdown at Year 20
(Effective Porosity = 0.1%)

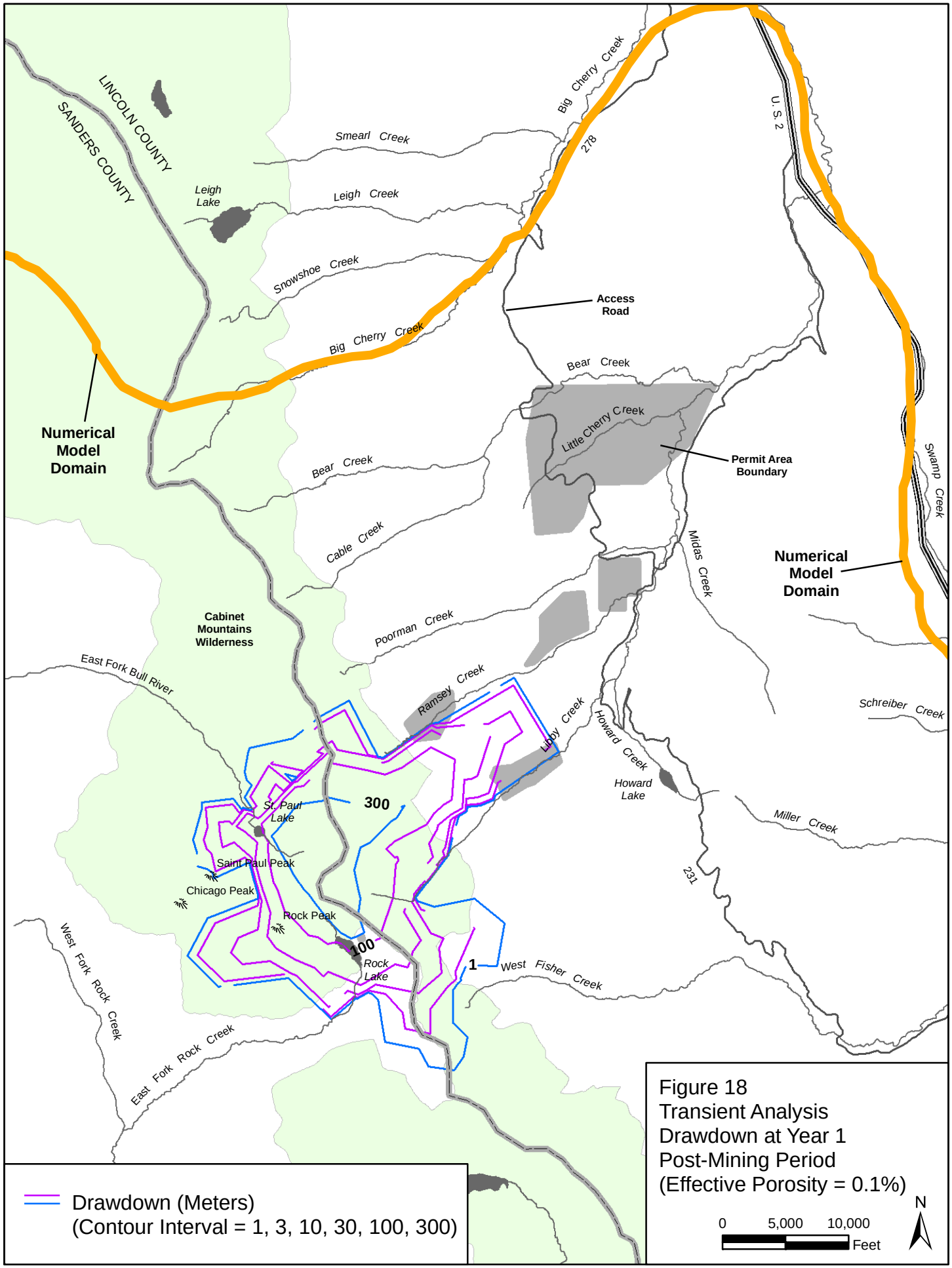


Figure 18
Transient Analysis
Drawdown at Year 1
Post-Mining Period
(Effective Porosity = 0.1%)

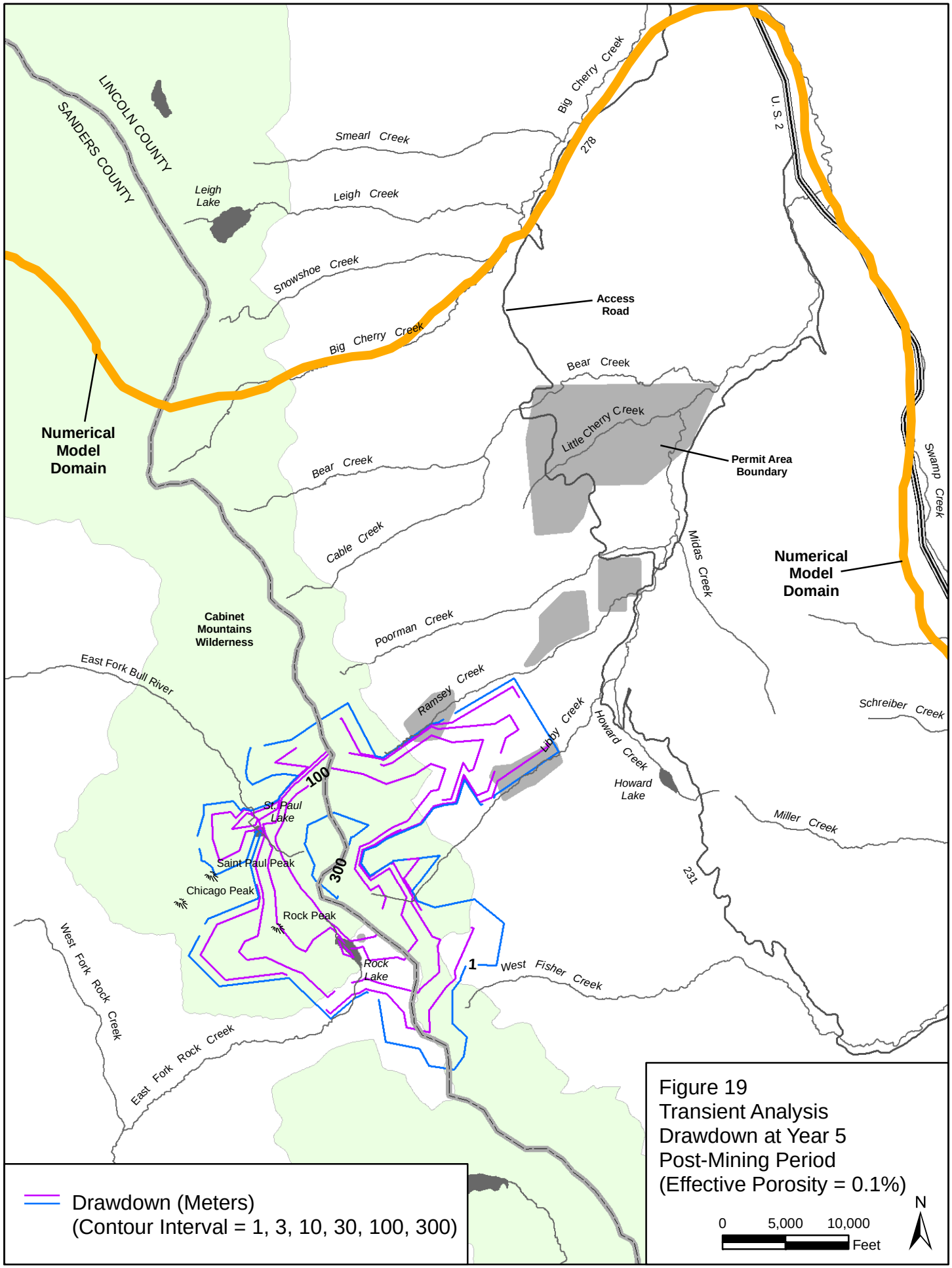


Figure 19
Transient Analysis
Drawdown at Year 5
Post-Mining Period
(Effective Porosity = 0.1%)

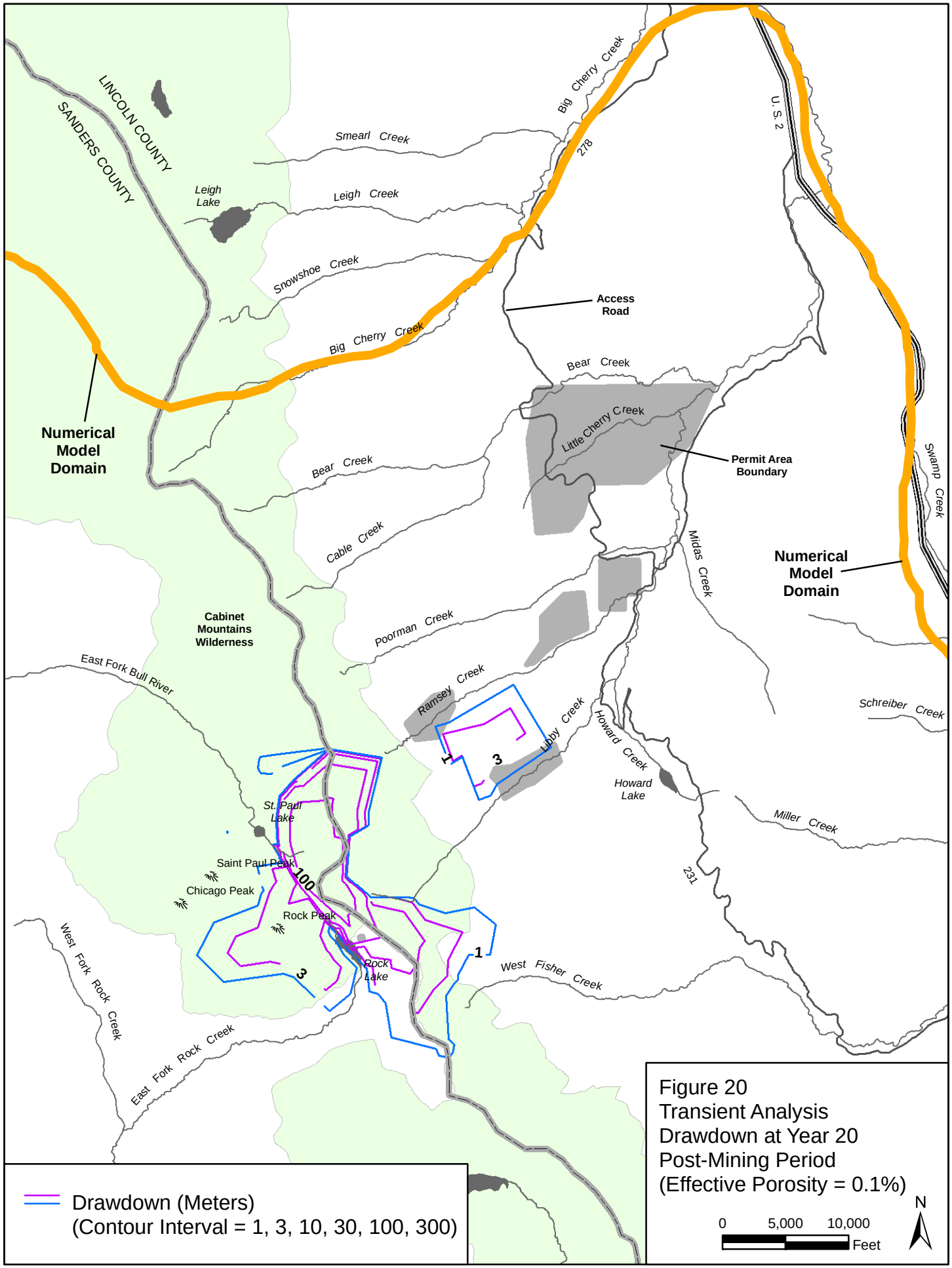


Figure 20
Transient Analysis
Drawdown at Year 20
Post-Mining Period
(Effective Porosity = 0.1%)

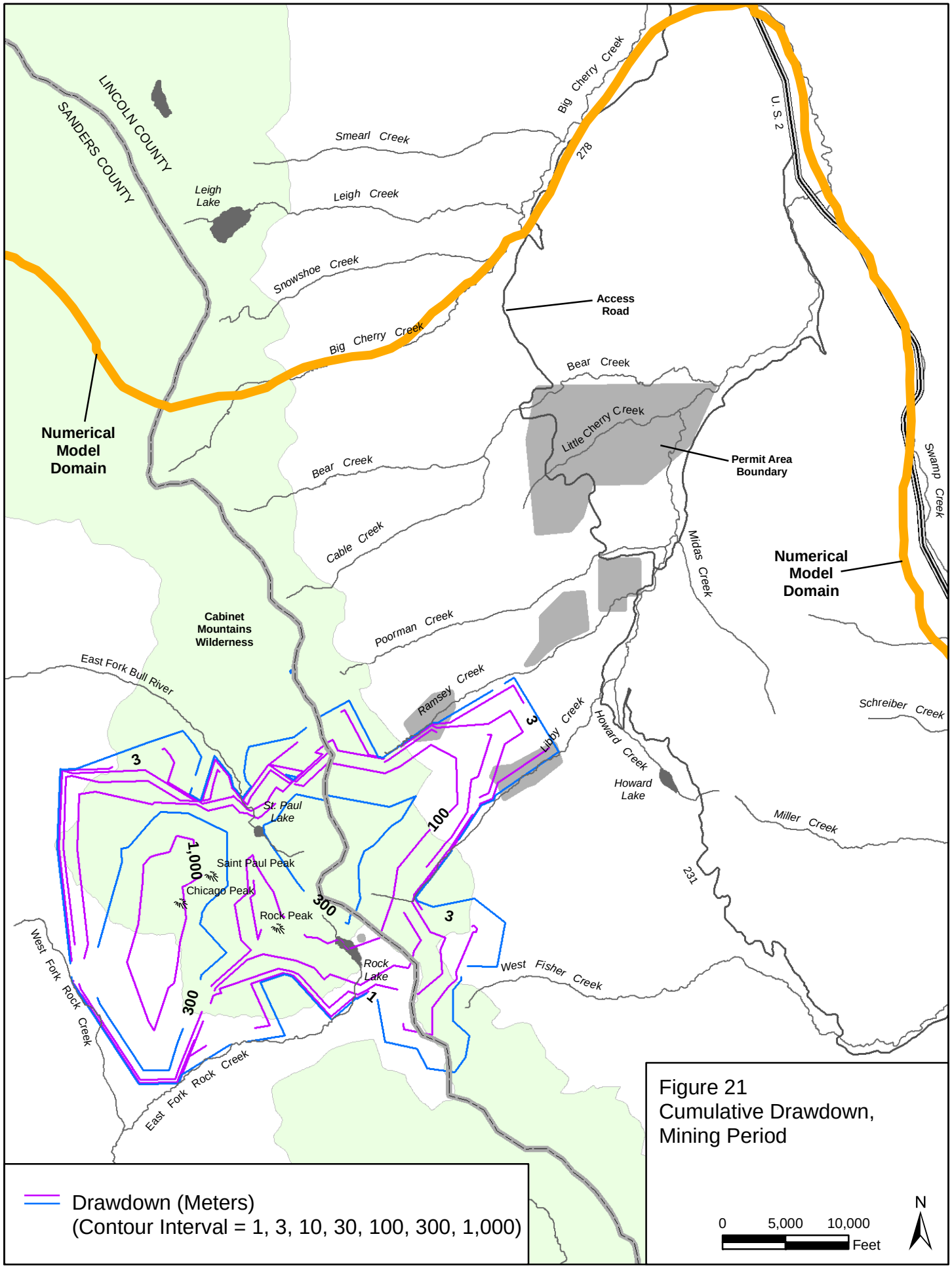


Figure 21
Cumulative Drawdown,
Mining Period

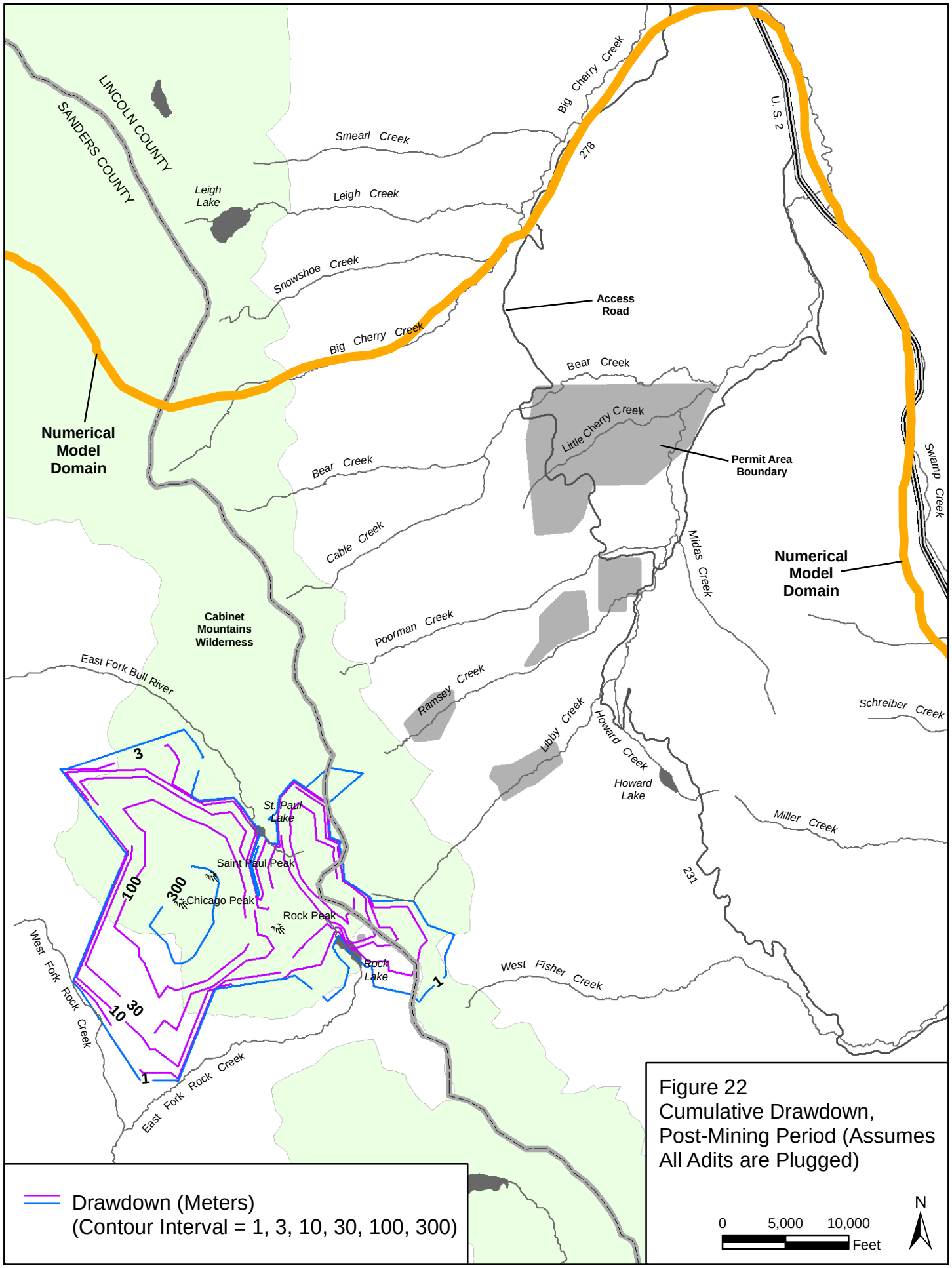


Figure 22
Cumulative Drawdown, Post-Mining Period (Assumes All Adits are Plugged)

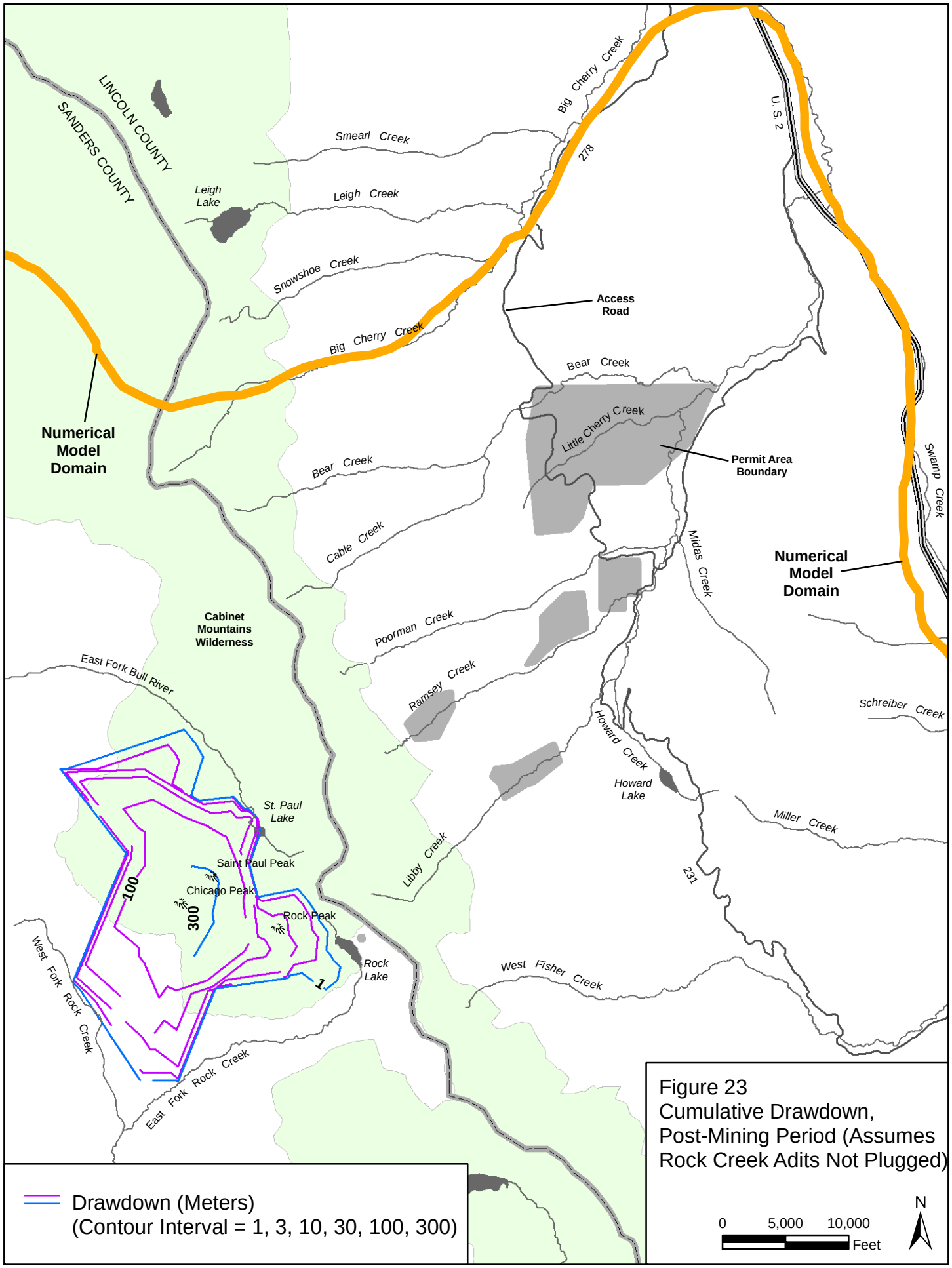


Figure 23
Cumulative Drawdown, Post-Mining Period (Assumes Rock Creek Adits Not Plugged)

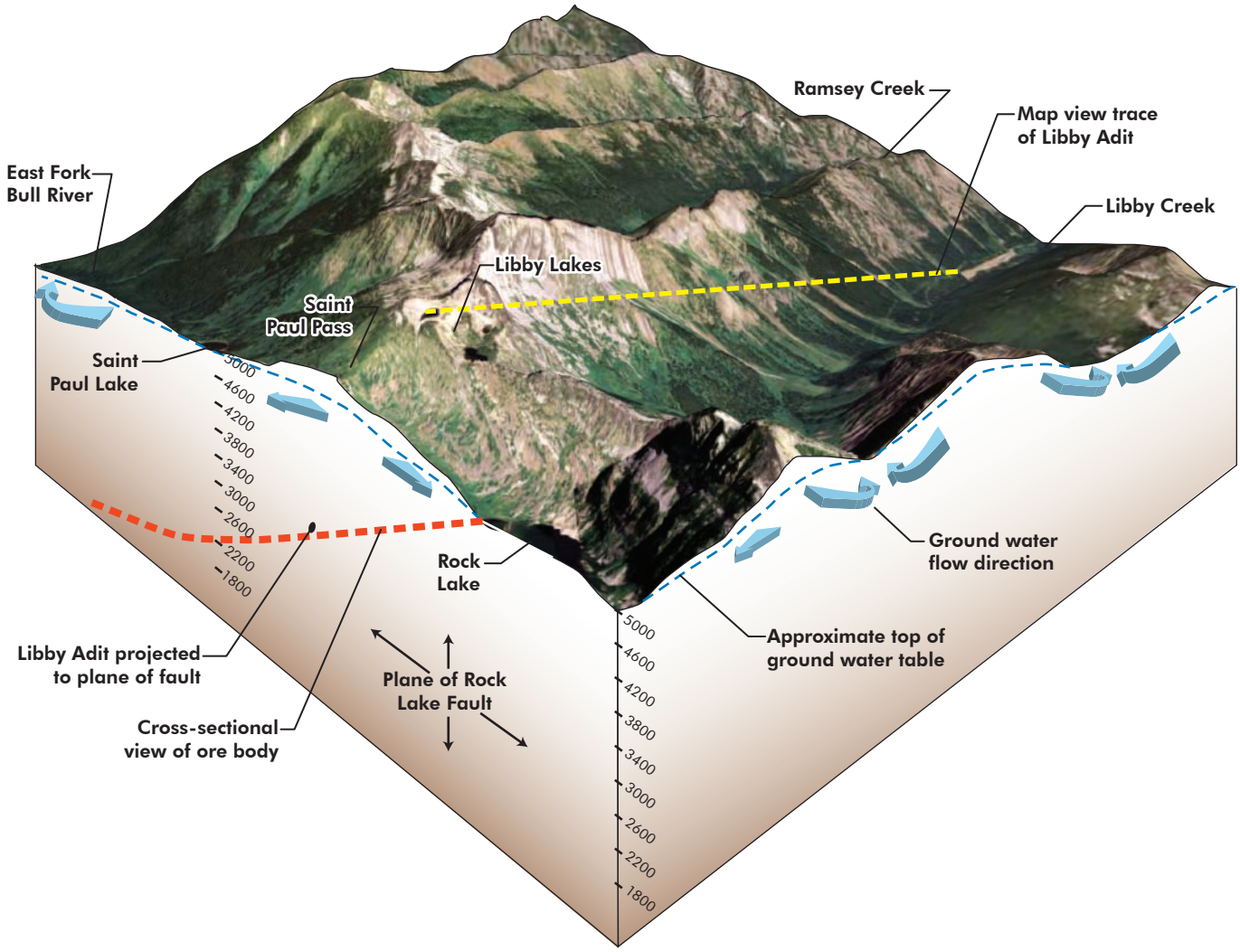


Figure 23
Three Dimensional Conceptual Hydrogeology of the Montanore Mine Area

0 0.5 1 Miles
Approximate Horizontal Scale

N

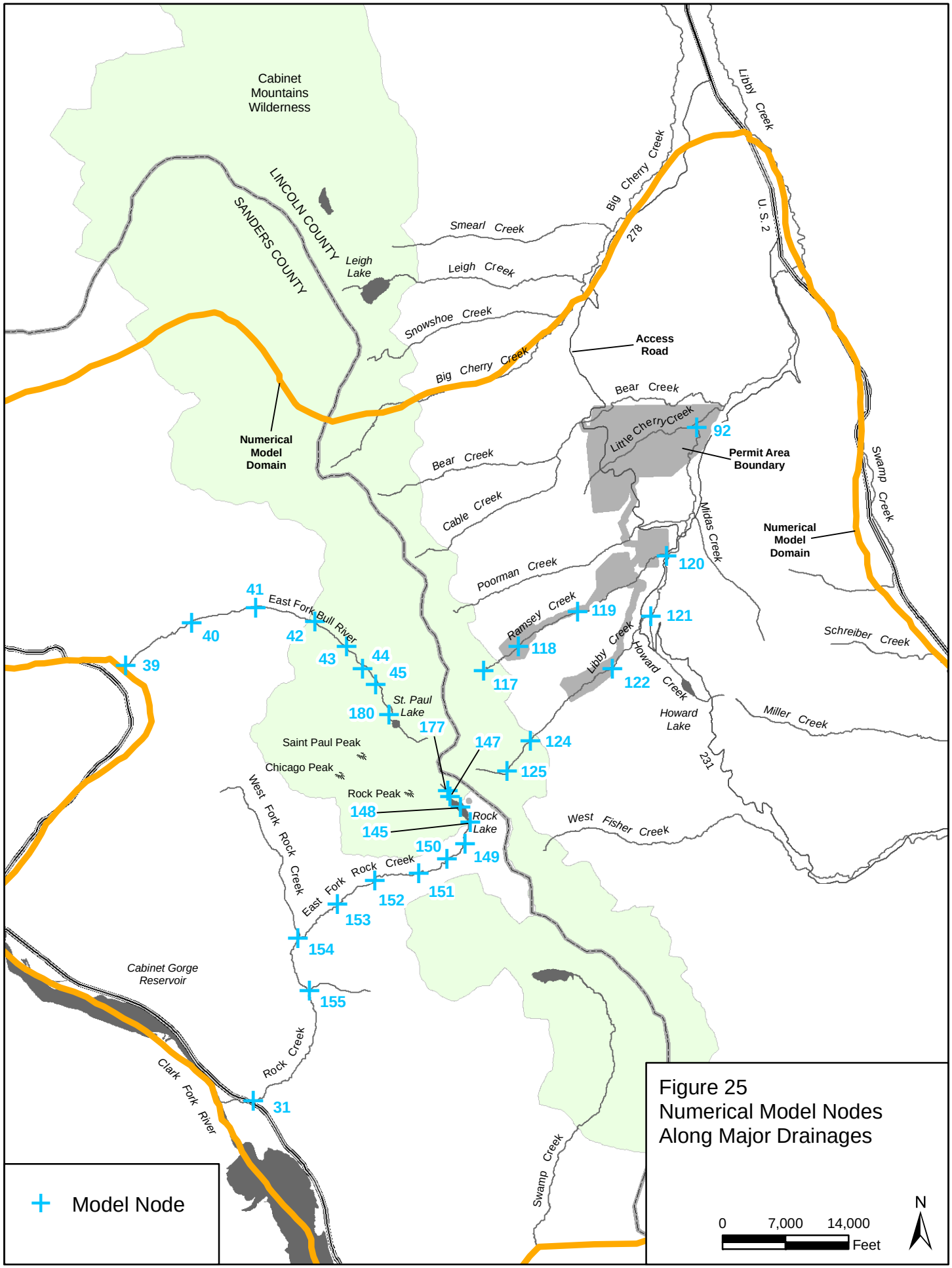
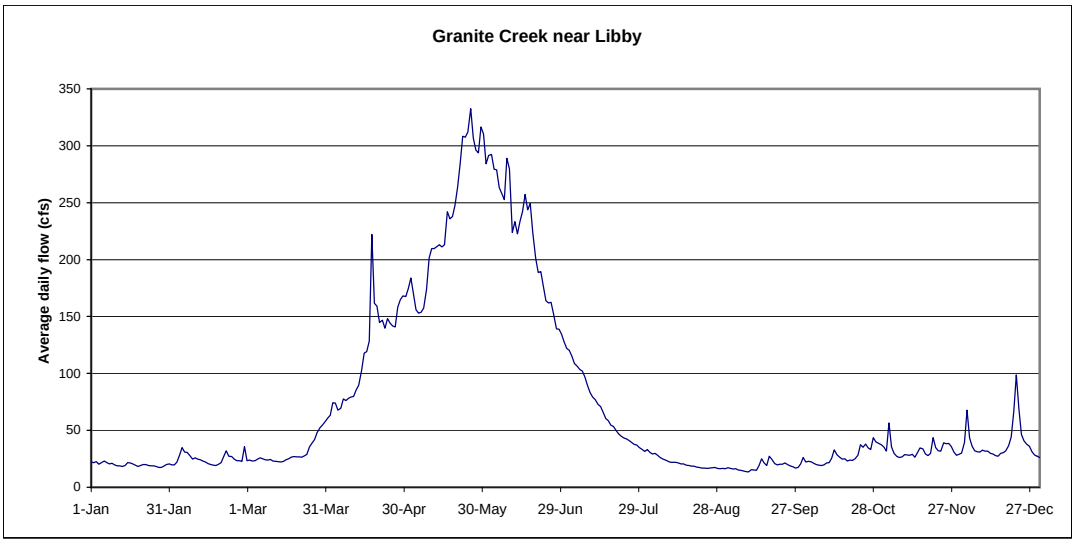
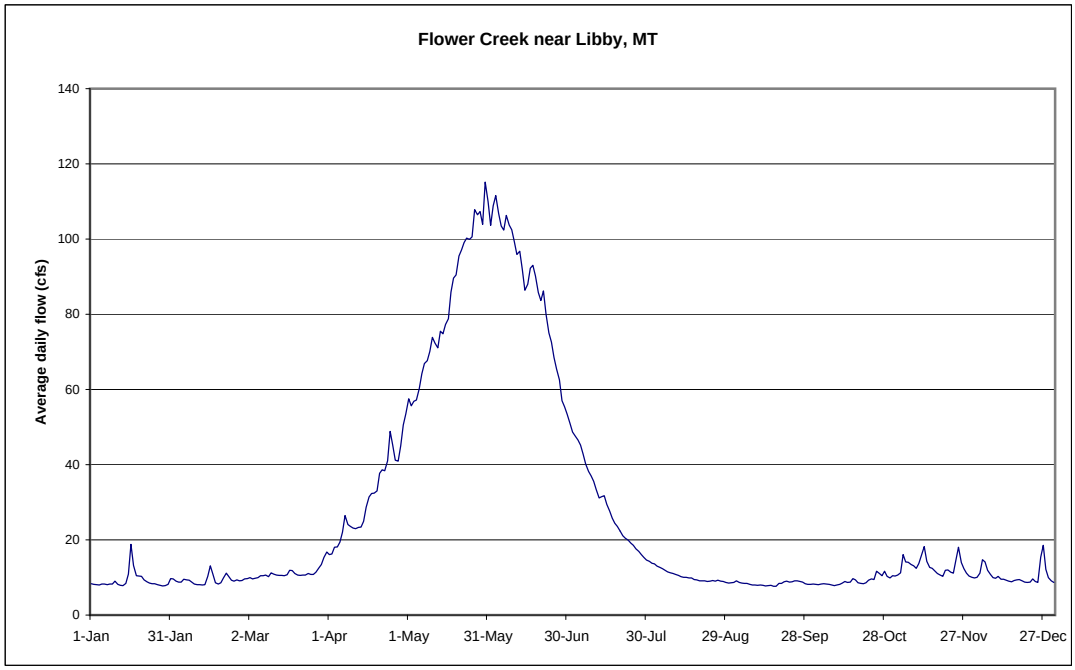
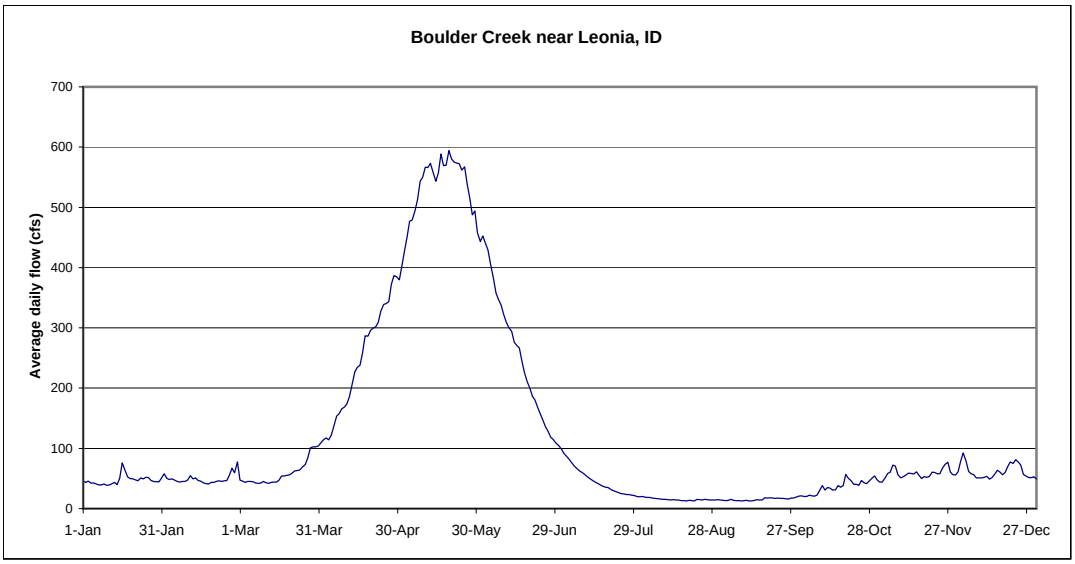


Figure 25
Numerical Model Nodes
Along Major Drainages

Figure 26. Hydrographs for Three Montanore Area Creeks







Appendices

Appendix A. Model Technical Details and Description of Model Files

This appendix supplements the description of modeling in the text of this report by documenting some of the specific modeling techniques used for the various analyses. In addition, it describes the modeling files that are included on the attached CD.

A.1 Modifications to Modeling Software

The Phase I modeling used the straight commercial version of ABCFEM (Brown and Hertzman 1994), simulating the domain as an unconfined two-dimensional aquifer in which the transmissivity for any given node's entry in the stiffness matrix is the product of the hydraulic conductivity and the saturated thickness:

$$T = K(h - z_{base})$$

where:

T	effective transmissivity
K	hydraulic conductivity
h	head at the node (never higher than ground surface, due to swamping boundary condition)
z_{base}	elevation of the base of the aquifer at the node (the bottom of the model domain)

For the Phase II and III modeling, the software was slightly modified in order to simulate two-dimensional flow through two horizontal layers of material, each with a different hydraulic conductivity. The modifications were effected to the calculation of transmissivity at each node made during construction of the nodal stiffness matrix. Specifically, the altered model calculates transmissivity differently depending on whether the shallow layer is completely unsaturated versus partially or completely saturated.

$$T = \begin{cases} K_{deep}\left(h - z_{base}\right) & \text{if } h \le z_{mid} \\ K_{deep}\left(z_{mid} - z_{base}\right) + K_{shallow}\left(h - z_{mid}\right) & \text{if } h > z_{mid} \end{cases}$$

where:

K_{deep}	hydraulic conductivity of the deep layer
$K_{shallow}$	hydraulic conductivity of the shallow layer
z_{base}	elevation of the base of the deep layer
z_{base}	elevation of the base of the shallow layer

The alterations were tested by exporting the model's transmissivity calculations to a spreadsheet and comparing them to equivalent calculations done by hand in the spreadsheet. In all cases, the model's calculated transmissivity matched the spreadsheet calculation.

The altered code demands input of three extra parameters (major and minor hydraulic conductivity[1] in the deep zone, and height of the contact between the two zones above the base of the aquifer) for each material type. Because no solute transport features were used for the Montanore model, parameters that are normally used only for solute transport were "borrowed" by the code to use as placeholders for input and storage of the extra parameters. Material parameters were therefore defined as shown in Table A-1.

Table A-1: Parameters used to enter material data in modified code

Physical parameter	ABCFEM variable used	Description
Shallow layer K	K_{major} and K_{minor}	Hydraulic conductivity of the shallow layer (major and minor are identical)
Deep layer K	$Dispersivity_{longitudinal}$ and $Dispersivity_{transverse}$	Hydraulic conductivity of the deep layer (major and minor are identical)
Thickness of deep layer	Retardation	The thickness of the deep layer

A.2 Method of Modeling Specific Features

The main text of the modeling report describes the alterations made for the various modeling scenarios. This section presents the method of applying each such change to the model. Actual values used for the various parameters are provided in the model input files on the attached CD.

A.2.1 Libby Adit

The Libby Adit was modeled as follows:

- For the calibration scenarios, in which the actual adit is open and pumped dry, the adit was modeled by setting the aquifer top of the nodes representing the adit to the elevation of the adit at the node, in effect setting the maximum head at each adit node to its own elevation. Each adit node's link (to which excess flow is directed if the node swamps) was set to –2, in effect removing the flow from the domain.
- For the pre-mining scenarios, in which the adit exists but is assumed plugged at the mouth so that heads inside the adit can rise above the adit elevation, the aquifer top of the adit nodes was set back up to the topographic ground surface and the nodes were relinked into the natural dendritic stream pattern. High-conductivity ABCFEM connections were then established between each node along the adit to simulate the very high effective conductivity of the open adit.
- For the mining scenarios, in which the adit is open and assumed to be pumped dry, the adit was simulated in the same manner as for the calibration scenario above.

[1] ABCFEM is capable of simulating horizontal anisotropy and, therefore, requires input of separate hydraulic conductivity values parallel to the major and minor axes of anisotropy. For the Montanore mine modeling, all analyses were isotropic and, therefore, identical values were entered for major and minor terms.

- For the post-mining scenario, it was assumed that the adit was completely backfilled and plugged. The model simulated this scenario by setting the aquifer maximum at each node to ground surface elevation, linking each node back into the natural dendritic stream pattern, and removing all connections used to represent the open adit.

A.2.2 Heidelberg Adit

The Heidelberg Adit was modeled similarly for all scenarios. Specifically, the nodes along the adit were defined as swamping nodes with a maximum elevation equal to the physical elevation of the adit at that node. The nodes were linked such that the link (surface) outflow within the adit was directed along the adit, finally emerging at the mouth of the adit into East Fork Rock Creek.

A.2.3 Ramsey Adits

The Ramsey Adits was modeled as follows:

- For the calibration and pre-mining cases, the adits were not modeled.
- For the mining scenarios, the adits were modeled by setting the aquifer top for each of the adit nodes to the elevation of the adit. Swamped outflow was directed to sink –3, removing it from the model domain completely.
- For the post-mining scenario, the adits were assumed to be completely plugged and backfilled. All nodes were returned to their pre-mining conditions: maximum elevation set to the ground surface elevation, and links set to the natural dendritic stream pattern.

A.2.4 Rock Lake Fault

For the scenarios that include a more highly conductive Rock Lake Fault, the fault was modeled using ABCFEM connections (a method to establish arbitrary flow paths between nodes for which the flow is proportionate to the head difference). Twenty six connections were used to link 27 nodes located along the mapped trace of the fault. A spreadsheet was used to define conductance (the constant of proportionality) for each in order to simulate a fault zone 2,000 meters deep by 60 meters wide. For each connection, the conductance was defined using the following two relationships:

$$Q = K \frac{\Delta h}{\Delta l} A \quad \text{(Darcy's Law)}$$

and

$$Q = C \Delta h \qquad \text{(Definition of conductance)}$$

Equating these two terms gives:

$$C = \frac{KA}{\Delta l}$$

where:

Q	Flow through connection
Δh	Head difference across connection
C	Conductance of connection
K	Simulated hydraulic conductivity of connection
A	Cross-sectional area of the connection (2,000 m x 60 m)
Δl	Distance between the two nodes

A spreadsheet was used to perform this calculation for each desired value of *K*. The resulting connections were then manually pasted into the model definition spreadsheet before the model was run for each different value of *K* used during calibration.

A.2.5 Montanore Mine Void

The Montanore mine void was simulated as follows:

- For the calibration and pre-mining scenarios, the void was not simulated.
- For the mining scenarios, the aquifer maximum for all nodes located within the footprint of the mine was set to the elevation of the mine void at the location of that node. Swamped outflow was directed to sink –4, effectively removing it from the model domain.
- For the post-mining scenarios, the aquifer maximum for void nodes was restored to the ground surface elevation and links were set to the natural dendritic stream pattern. All elements within the footprint of the mine void were set to a new material (#3) with hydraulic conductivity of 1 m/d, approximately 10^{-3} cm/sec. This value was chosen to be sufficiently higher than the rock conductivity of 10^{-7} cm/s to dominate flow through the mine void.

For transient scenarios, the mine void was not defined with increased specific yield relative to the rock. Instead, filling-time calculations for the mine void were performed externally to the model and added to the predicted recovery time.

A.2.6 Connection between Fault and Mine Void

For the scenarios that modeled the consequences of a high-permeability pathway between the mine void and the fault, the connection was modeled by using a single ABCFEM connection (#27) between nodes 163 and 165 (a node at the north end of the mine void and the nearest node on the fault) with a conductivity set to 10,000 m^2/day, a value high enough to allow sufficient flow between the two nodes to keep their heads within 1 meter of each other.

A.2.7 Rock Creek Mine Void

For the cumulative effects scenarios that included the Rock Creek Mine, the Rock Creek mine void was modeled in the same way that the Montanore mine was modeled (see section A.2.5 above):

- For the pre-mining scenarios, the void was not simulated.
- For the mining scenarios, the aquifer maximum for all nodes located within the footprint of the mine was set to the elevation of the mine void at the location of that node. Swamped outflow was directed to sink –5, effectively removing it from the model domain.
- For the post-mining scenarios, the aquifer maximum for void nodes was restored to the ground surface elevation and links were set to the natural dendritic stream pattern. All elements within the footprint of the mine void were set to a new material (#4) with hydraulic conductivity of 1 m/day.

A.2.8 Rock Creek Mine Adit

For the cumulative effects scenarios that included the Rock Creek Mine, its adit was modeled as follows:

- For the pre-mining cases, the adit was not modeled.
- For the mining scenarios, the adit was modeled by setting the aquifer top for each of the adit nodes to the elevation of the adit. Swamped outflow was directed to sink –5, removing it from the model domain completely.
- For the post-mining scenario, the adit was modeled in two ways. One run simulated the plugging and backfilling of the adit. For this run, all nodes were returned to their pre-mining conditions: maximum elevation set to the ground surface elevation, and links set to the natural dendritic stream pattern.

A second run simulated leaving the adit open and flowing. For this run during the mining scenario, the adit was modified by linking each of the adit nodes into a chain that eventually discharged to the surface at the mouth of the adit. The adit nodes were left with a maximum elevation equal to the elevation of the adit at the nodes location, so that swamped flow would flow down the adit and discharge to the surface at the mouth.

A.2.9 High-infiltration Zone on Rock Lake Fault

One set of runs modeled the effects of increasing infiltration along the Rock Lake Fault. This was performed as follows:

- The total length of the fault was allocated among the nodes comprising the fault by determining the distance between each adjacent fault node, and assigning one-half of that distance to each of the two adjacent nodes.

- The effective ground surface area of the fault zone was allocated to each node along the fault by multiplying (1) the effective length of the fault allocated in the previous step to each node by (2) 60 meters, the assumed width of the higher-infiltration zone corresponding to the fault.
- A direct inflow was applied to each of the fault nodes. The inflow was calculated by taking the product of the effective fault area of each node (from the previous step) and the desired extra infiltration rate (that portion of infiltration above and beyond the background infiltration applied to the entire model), in meters/day.

The above calculations were performed in a spreadsheet and copied to the model spreadsheet for each different value of extra infiltration that was modeled.

A.3 Sensitivity Analysis

A sensitivity analysis was performed in order to determine how sensitive to input parameters the predicted area of significant impact is to stream base flows. A total of 20 model runs were performed: five variations on the four basic model scenarios: (calibration, pre-mining, mining, and post-mining). The five variations included:

- Base case: identical to Phase II with-fault base case;
- High-infiltration: the infiltration to both infiltration zones (steep and flat) was increased by 20% of their base values. In other words, the infiltration to the steep elements was increased from 2% of average precipitation to 2.4%; the infiltration to the shallow elements was increased from 10% of average precipitation to 12%;
- Low-infiltration: the infiltration to both infiltration zones was reduced to 80% of the base case value.
- High-conductivity: The hydraulic conductivity of all elements (except for those representing the mine void in the post-mining scenario) was multiplied by 3 in both layers.
- Low-conductivity. The hydraulic conductivity of all elements (except for those representing the mine void in the post-mining scenario) was divided by 3 in both layers.

A.4 Description of Model Files on CD

ABCFEM stores all model information in a spreadsheet. The model files for the analyses are provided on the accompanying CD. The spreadsheets should be self-explanatory, bearing in mind the use of solute transport parameters discussed above in Table A-1.

Table A-2 lists the model files on the accompanying CD. All files are .wk1 files.

Table A-2. Model files

Folder	File Name	Series	Description
Phase I	FLTHALA CAL	Base fault	Calibration
	FLTHA PREMINE	Base fault	Pre-mining
	FLTMINE	Base fault	Mining
	FLTMNCO	Base fault	Mining with connection between void and fault
	FLTPOClosedAdits	Base fault	Post-mining with adits backfilled

Folder	File Name	Series	Description
	FLTPOSTOpenAdits	Base fault	Post-mining with adits left open and plugged at mouth
	NFLTHLA CAL	Base no fault	Calibration
	NFLTPREMINE	Base no fault	Pre-mining
	NFLTMINE	Base no fault	Mining
	NFLOTPOClosedAdits	Base no fault	Post-mining with adits backfilled
Phase II	FLTHALA CAL	Base fault	Calibration
	FLTPRE	Base fault	Pre-mining
	FLTMN	Base fault	Mining
	FLTMNCO	Base fault	Mining with connection between void and fault
	FLTPOST	Base fault	Post-mining
	FLTPOCO	Base fault	Post-mining with connection between void and fault
	NFLTHALA CAL	Base no fault	Calibration
	NFLTPRE	Base no fault	Pre-mining
	NFLTMN	Base no fault	Mining
	NFLTPOST	Base no fault	Post-mining
	NFLTBULKPOST	Base no fault	Post-mining with bulkhead in mine void
	FLTHIINFCAL	High infiltration along fault	Calibration
	FLTPREHIINF	High infiltration along fault	Pre-mining
	FLTMNHIINF	High infiltration along fault	Mining
	FMNCOHIINF	High infiltration along fault	Mining with connection between void and fault
Phase III Cumulative	CUMPRE	Cumulative effects	Pre-mining (same as Phase II pre-mining with fault)
	CUMMN	Cumulative effects	Mining, both mines
	MONTONLY	Cumulative effects	Mining, Montanore mine only (same as Phase II mining with fault)
	RCONLY	Cumulative effects	Mining, Rock Creek mine only
	POSTCUM	Cumulative effects	Post-mining, both mines, Rock Creek mine adit backfilled
	POSTMONT	Cumulative effects	Post-mining, Montanore mine only (same as Phase II post-mining with fault)
	POSTRC	Cumulative effects	Post-mining, Rock Creek mine only
	POSTCUMRC	Cumulative effects	Post-mining, both mines, Rock Creek mine adit left open
Phase III Transient[2]	MM0Y	Transient, S_Y = 0.1%	Transient drawdown, year 0 of mining (same as pre-mining phase II)
	MM1Y	Transient, S_Y = 0.1%	Transient drawdown, year 1
	MM5Y	Transient, S_Y = 0.1%	Transient drawdown, year 5
	MM10Y	Transient, S_Y = 0.1%	Transient drawdown, year 10
	MM20Y	Transient, S_Y = 0.1%	Transient drawdown, year 20
	MMSS	Transient, S_Y = 0.1%	Transient drawdown, final steady state (same as phase II mining)
	RECM0Y	Transient, S_Y = 0.1%	Transient recovery, year 0 (same as MMSS)
	RECM1Y	Transient, S_Y = 0.1%	Transient recovery, year 1
	RECM5Y	Transient, S_Y = 0.1%	Transient recovery, year 5
	RECM20Y	Transient, S_Y = 0.1%	Transient recovery, year 20
Sensitivity	CALBASE	Sensitivity, base	Calibration

[2] For brevity, the transient runs using specific yields of 0.01% and 2% are not provided on the CD. They are identical to the provided transient runs except for the specific yield on all materials.

Folder	File Name	Series	Description
	CALIN20	Sensitivity, +20% inf	Calibration
	CALIN-20	Sensitivity, -20% inf	Calibration
	CALK3	Sensitivity, x3 cond	Calibration
	CALK-3	Sensitivity, /3 cond	Calibration
	PREBASE	Sensitivity, base	Pre-mining
	PREIN20	Sensitivity, +20% inf	Pre-mining
	PREIN-20	Sensitivity, -20% inf	Pre-mining
	PREK3	Sensitivity, x3 cond	Pre-mining
	PREK-3	Sensitivity, /3 cond	Pre-mining
	MNBASE	Sensitivity, base	Mining
	MNIN20	Sensitivity, +20% inf	Mining
	MNIN-20	Sensitivity, -20% inf	Mining
	MNK3	Sensitivity, x3 cond	Mining
	MNK-3	Sensitivity, /3 cond	Mining
	POSBASE	Sensitivity, base	Post-mining
	POSIN20	Sensitivity, +20% inf	Post-mining
	POSIN-20	Sensitivity, -20% inf	Post-mining
	POSK3	Sensitivity, x3 cond	Post-mining
	POSK-3	Sensitivity, /3 cond	Post-mining

Appendix B. Geomatrix Conceptual Model of Groundwater Flow for Montanore Mine Site Groundwater Model (April 26, 2007)

Geomatrix

MEMORANDUM

To: Mike Galloway, ERO

From: Doug Rogness, Geomatrix

Cc: Eric Klepfer and Michele Savor, Mines Management
Richard Trendholme, ERO

Date: April 26, 2007

Re: Geomatrix Conceptual Model of Groundwater Flow for Montanore Mine Site Groundwater Model

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Based on an action item identified in the Montanore Project Hydrology Meeting in Missoula, MT on April 5-6, 2007, the following is a description of our alternate conceptual model of groundwater flow at the Montanore Project site. This description focuses on that portion of groundwater that flows in bedrock in and near the Cabinet Mountains Wilderness Area where the Montanore ore body is located. Much of the information presented in this Memo is obtained from the "Hydrologeology Report, Montanore Mine Project" (Geomatrix Consultants, October 2006).

In general, most groundwater is recharged in the higher elevations and moves in both shallow and deep bedrock systems. These groundwater flow paths are shown on attached **Figure 3** and **Figure 4** from Gurrieri's (2001) Technical Report "Hydrology and Chemistry of Wilderness Lakes and Evaluation of Impacts from Proposed Underground Mining, Cabinet Mountains Wilderness, Montana". On **Figure 4**, the shallow groundwater flow path is shown to move in bedrock that is relatively more fractured near ground surface, discharging to a lake and associated stream. The deep groundwater flow path extends into deeper, less-fractured bedrock, until this groundwater encounters a more highly-fractured fault zone and moves up to the same lake and associated stream (i.e., upward groundwater gradient). It is assumed that this lake is intended to be Rock Lake, even though it is not labeled on the figure.

According to information in the "Draft Final Numerical Model Report of the Montanore Mine Area Hydrogeology" (ERO March 2007), the regional groundwater flow system in bedrock is believed to intercept ground surface at an elevation range of 5400 to 5600 feet based on observations of elevations of springs and the start of perennial flow in area streams. Rock Lake is at an elevation of about 4960 feet; therefore, the regional water table would intersect ground surface approximately 500 feet above Rock Lake. This scenario is shown on a modified version of **Figure 3** from Gurrieri's (2001) report. On this figure, Rock Lake is in connection with the local groundwater flow system, but the regional flow system is shown to flow beneath the lake and assumed to discharge in the vicinity of Rock Creek Meadows.

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Another interpretation of this groundwater flow system, as presented on attached **Figure 3b** and **Figure 4b**, is that the deep or regional groundwater flow system in bedrock discharges to surface water at lower elevation regional discharge locations (i.e., approximately 4000 feet or less), and is not directly connected to surface water features in the Rock Lake area. On **Figure 3b**, the deep regional flow system is shown to be in contact with the local flow system; however, the regional flow path is assumed to be separate from the shallow flow system and does not supply water to surface water features at elevations above about 1,200 meters or 4,000 feet. The deep regional flow path, which goes through the proposed Montanore underground mine workings and deeper portions of adits, extends from the higher elevation mountains to the lower elevation valley bottoms as regional discharge areas.

Figure 4b shows a similar conceptual flow system where the deep groundwater flow path extends from the mountains to the valley bottoms (e.g., Rock Creek Meadows). An intermediate flow path is shown which coincides with the general notion of three groundwater flow systems in areas of topographic relief: local, intermediate, and regional (Freeze and Cherry, 1979). The shallow groundwater flow path affects high elevation surface water features such as Rock Lake.

If the regional flow system is lowered due to mine dewatering, then it is possible that an unsaturated zone could develop beneath a portion of the local flow system. This scenario is shown on **Figure 3c**. In this case, due to the significant difference in permeability of the shallow fractured bedrock flow system, and the underlying less-fractured intermediate and/or deep regional flow systems, a perched groundwater flow system could occur in the shallow local flow system. As shown on **Figure 3c**, groundwater would continue to flow in this shallow system following topography, with sufficient year-round recharge from snowmelt and rain events to maintain wilderness surface water features.

This conceptual model is supported by Gurrieri (2001) where he states "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 (Winter, 1981). 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" (Gburek et al., 1999). "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." (Gurrieri, 2001).

This alternate conceptual model of groundwater flow in bedrock at the Montanore Project site is supported by the following:

- Some springs and stream reaches between 4000 and 5400 feet elevation (and even at lower elevations) have highly variable and sometimes no flow during late summer and fall. This condition is typical of surface water features that are connected to shallow groundwater that responds to changes in precipitation. If the springs and streams were connected to the regional groundwater flow system, it would be expected that they would have a more consistent base flow condition. It is expected that many high

elevation springs and perennial streams do not consistently begin flowing at an elevation of about 5400 to 5600 feet.

- Depth to water measurements reported for exploration drill holes completed in the Cabinet Mountains Wilderness Area between Rock Lake and St. Paul Lake are highly variable. At two of the drill sites near Rock Lake (site no. 1) and St. Paul Lake (site no. 8), groundwater levels were observed to be near the lake levels (Chen-Northern, Inc. 1989; USFS et al., 1992). Other drill holes located between the two lakes and drilled to depths of 900 to 1,200 feet below lake level, had no apparent static water level (Chen-Northern, Inc., 1989). Some drill holes (HR-19 and HR-26) had reported static water levels at approximately 5400 to 5600 feet elevation, or about 500 feet below ground surface in those areas (Chen-Northern, Inc., 1989). These variable depth to groundwater conditions may represent unreliable readings from the water level probe; heterogeneous conditions; compartmentalization of groundwater in blocks of structural zones; seepage along the angle drill hole walls causing erroneous water level measurements; and/or non-static water level conditions.

- Oxidized zones were reported in exploration drill logs that extended well below the elevation of Rock Lake.

- Measured increases in Rock Lake outflow versus inflow rates in September 1999 and 2005 could be from shallow localized groundwater in talus deposits and fractured bedrock surrounding the lake, rather than from deep regional groundwater flow. It is believed that sufficient recharge occurs to these near-surface materials to supply water to Rock Lake on a year-round basis (see next bullet).

- Based on a Rock Lake watershed area of 740 acres (32.2 million ft^2), shallow bedrock aquifer thickness of 40 feet, and effective porosity of 0.1% for shallow bedrock, the total volume of water that could be held in shallow bedrock is about 9.6 million gallons. Using a total annual precipitation rate of 70 inches, and an infiltration rate into shallow bedrock aquifer of 5% annual precipitation, the amount of precipitation that could recharge this shallow aquifer is approximately 70 million gal/yr. This amount of water in the shallow bedrock aquifer appears to be sufficient to supply water year-round to Rock Lake.

- Water samples from Rock Lake outflow/inflow and upgradient spring SP-1R have similar water quality types (calcium bicarbonate), with very low concentrations of common ions. Water samples from the Heidelberg Adit and nearby spring SP-05/-3R have higher concentrations of most ions, especially calcium and bicarbonate. These differences may reflect a more intermediate groundwater flow path for water encountered at the Heidelberg Adit and nearby spring. Water from the Libby Adit shows notably greater ion concentrations, especially sodium and bicarbonate. The Libby Adit sample may represent the deep regional groundwater flow system and/or influences from different hydrostratigraphic units in the Montanore Project area.