Evaluation of Groundwater Flow Models Used to Simulate the Effects of Proposed Mining on the Groundwater–Surface Water System in the Vicinity of Crandon, Forest County, Wisconsin

Edited by James T. Krohelski and Christopher P. Carlson

Prepared through the cooperation of the
U.S. Geological Survey
Wisconsin Department of Natural Resources
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Contents

Figures

Tables

Appendixes

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	by	to obtain
Length		
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre (A)	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.4047	hectare
Volumetric flow rate		
Cubic feet per second (cfs)	448.83	gallons per minute (gpm)
Hydraulic conductivity*		
Feet per day (ft/day)	0.3048	meters per day (m/d)
Inches per year (in/yr)	0.0254	meters per year (m/yr)

* **Hydraulic conductivity:** The standard unit for hydraulic conductivity is cubic foot per day per square foot of aquifer cross-sectional area $(ft^3/day)/ft^2$. In this report, the mathematically reduced form, feet per day (ft/day), is used for convenience.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1927 (NGVD of 1927) a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929. (Note: msl = mean sea level.)

The stratigraphic nomenclature used in this report is that of the Wisconsin Geological and Natural History Survey and does not necessarily follow usage of the U.S. Geological Survey.

Section 1

Introduction

In May of 1995, the Crandon Mining Company (later changed to Nicolet Minerals Company [NMC]) submitted the first set of permit applications and supporting documents to the Wisconsin Department of Natural Resources (WDNR) for the proposed Crandon Mine in southern Forest County, Wisconsin (Foth and Van Dyke, 1995a) (figure 1). The company updated its permit applications and many supporting documents in late 1998 to reflect project modifications. Since then, the company has revised, updated and provided additional documents through mid-2003. A groundwater flow model is required by the WDNR to be included with the submittals.

A technical working group (TWG) consisting of hydrogeologists and hydrologists from WDNR, the Wisconsin Geological and Natural History Survey (WGNHS), RMT, and the U.S. Geological Survey (USGS) was assembled to assist the WDNR. The purpose of the TWG was to review and evaluate groundwater-related data, project submittals, and modeling, and to subsequently develop a final assessment of expected hydrologic impacts from the operation of the proposed mine.

1.1 Purpose and Scope

The purpose of this report is to describe the groundwater flow models resulting from the review by the TWG. This report provides information and serves as a reference document to support the Environmental Impact Statement to be written and distributed by the WDNR. Throughout this report, the groundwater model provided by the TWG is referred to as the "DNR model." The DNR model is distinct from other models of the site and is the result of review of NMC's model and hydrologic investigations and has its origin in the NMC model submitted in 1998 (GeoTrans, 1998a, 1998b, 1998c, 1998d and 1998e). This report provides a brief description of the geology and groundwater hydrology in the vicinity of the proposed mine. Additional details on the project area geology and hydrology can be found in Foth and Van Dyke reports from 1995 to 1998. The development of the groundwater flow model is presented from conceptualization through calibration. The simulation results that describe a range of potential hydrologic effects caused by mine dewatering and model sensitivity to various features are also presented. Additional details on model development and refinement prior to TWG modifications can be found in GeoTrans (1995a, 1996, 1998a, 1998b, 1998c, 1998d and 1998e).

Section 2

Geology

The geologic setting of the area of the proposed mine is described in detail in Section 3 of the applicant's Environmental Impact Report (EIR; Foth and Van Dyke, 1995a/1998). Therefore, only a summary is presented here.

2.1 Surficial Deposits

The bedrock in the area around the Crandon ore body is primarily covered by unconsolidated deposits of glacial drift (till and associated sand and gravel) with lesser deposits of aeolian, alluvial, colluvial, and organic material. The glacial deposits vary from 50 to 350 ft in thickness (Simpkins and others, 1987). Till is typically exposed at the surface in drumlins that are clustered on upland areas. Associated glacial meltwater sands and gravels have filled in low-lying areas in and around the uplands, forming pitted and unpitted outwash plains and aggraded meltwater channels. Locally, the drift is overlain by post-glacial sediments consisting of wind-blown silts and fine sand (loess), organic deposits and alluvium.

During the Pleistocene epoch (2 million to 10,000 years ago), the region was repeatedly covered by glaciers. Deposits from four major glacial advances have been recognized in the vicinity of the Crandon ore body. A majority of the Pleistocene

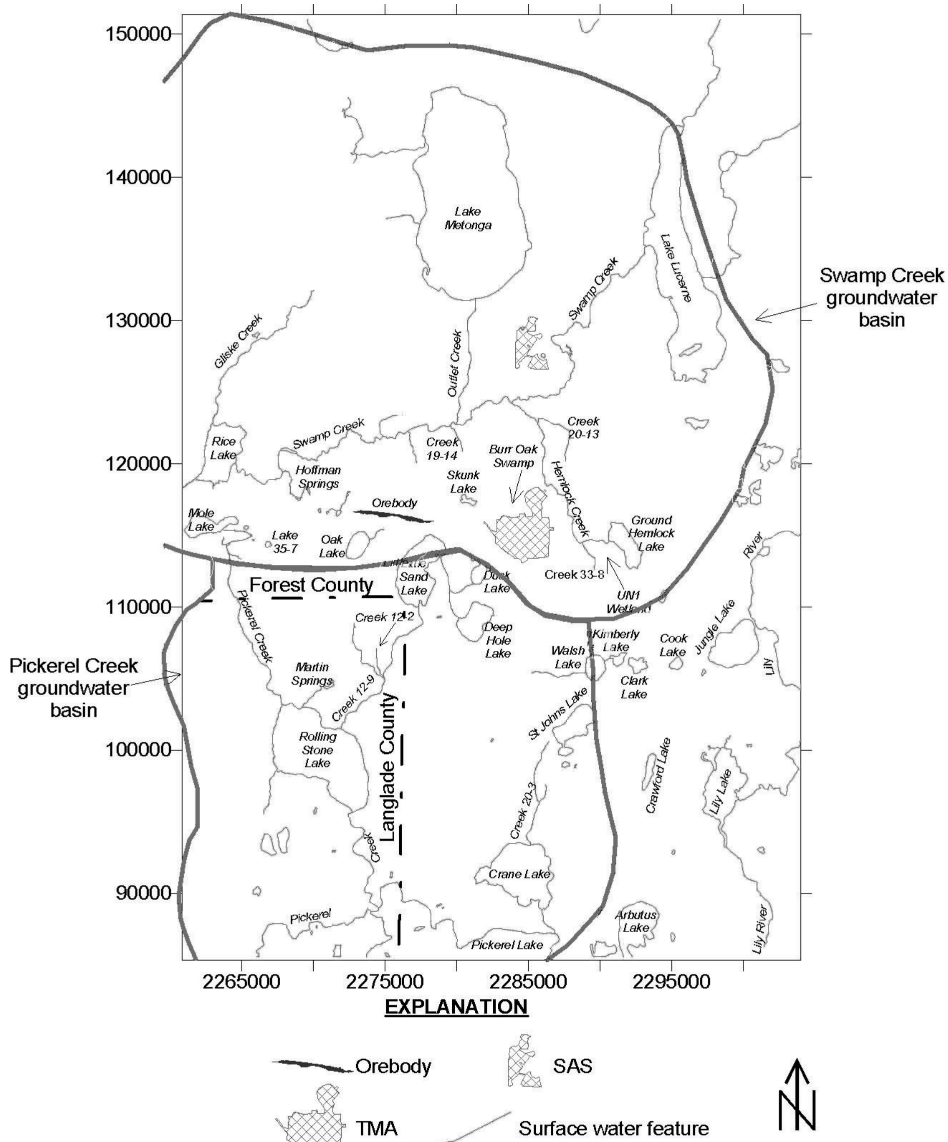


Figure 1. *Crandon area base map and Swamp and Pickerel Creek groundwater basins. Map coordinates are State Plane North, in feet (modified from Foth and Van Dyke, EIR, 1995). Boundary of groundwater basins are based on GFLOW model (Kelson and others, 2002) particle tracking from Cty M for the Swamp Creek basin and Hwy 55 for Pickerel Creek basin. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

deposits currently found in the area appear to be from the Late Wisconsin glaciation and are about 25,000 to 10,000 years old. In some locations, Pre-Wisconsin age sediments lie directly on top of the bedrock.

Southern Forest County is located along the margins of two lobes of the Wisconsin glacier, the Langlade Lobe and the Green Bay Lobe. During Late Wisconsin time, the region was over-ridden first by the Green Bay Lobe and subsequently by the Langlade Lobe. This has resulted in a complex and diverse near-surface glacial stratigraphy and a varying topography of drumlins and moraines separated by lowlands. With each glacial advance, the then-existing topography controlled deposition of near-continuous outwash in the lowlands and somewhat discontinuous deposition of outwash in the uplands (Dunning and others, 1997). The site of the proposed mine and associated operations is located mostly on a drumlin upland consisting of varying thicknesses of Late Wisconsin till and outwash underlain by Pre- to Early Wisconsin till and outwash. The Pre- to Early Wisconsin till formations generally contain less sand and more silt and clay than the younger, Late Wisconsin tills. Associated with the tills and outwash in the uplands are some ancient lacustrine deposits. Localized remnant loess deposits are present on hill sides in the drumlin upland. Accumulated sediments in lakes at the site consist of organics, silt, clay and sand. Wetlands at the site are underlain by accumulations of wetland sediments, consisting of organics, silt, and clay. The lowland areas adjacent to the drumlin uplands consist predominantly of alluvial and wetland sediments overlying Early Wisconsin outwash and Pre- to Early Wisconsin till.

2.2 Bedrock

The Crandon ore body is hosted in Early Proterozoic-age (late Precambrian time, between 1.8 and 1.9 billion years ago) bedrock of the Southern Province of the Canadian Shield. The bedrock at the site consists of metamorphosed submarine volcanic and associated marine sedimentary units. Deformation associated with the metamorphism resulted in the tilting of these originally horizontal layers to their present, near-vertical position between one and two billion years ago. To provide a simplified frame of reference, bedrock at the site is divided into three structural categories: hanging wall, Crandon Formation and foot wall. The zinc-rich ore (massive ore) is contained within the Crandon Formation. Everything that is stratigraphically beneath the Crandon Formation (to the south due to tilting) is called the foot wall. The foot wall is composed of volcanic tuff and breccia. It contains the copper-rich ore (stringer ore) originally emplaced beneath the zinc-rich ore. Everything above (to the north of) the Crandon Formation is referred to as hanging wall. The hanging wall is composed of a wide variety of fine- to coarse-grained volcanic rocks, including lava flows. There is some limited mineralization within the hanging wall, but no known ore.

During Late Proterozoic (from the time of deformation/metamorphism to 550 million years ago) and Phanerozoic (from 550 million years ago to the present) time, the bedrock was extensively weathered in the area of the ore body. Variability in bedrock weathering, along with structural trends (faults and fractures) and bedrock drainage patterns, produced the existing, irregular bedrock surface. The degree of weathering varies between the footwall, ore-bearing formations, and hanging wall due primarily to varying rock chemistry. The Crandon Formation contains a high percentage of easily weathered sulfide minerals, and as a result is more deeply weathered than either the foot wall or the hanging wall. The footwall and hanging wall are generally only moderately to weakly weathered except near their contacts with the Crandon Formation. To provide a simplified framework, bedrock at the site has been divided into five weathering categories: strong, moderate, low, weak, and unweathered (Rowe, 1984). In general, the degree of weathering decreases with depth below the bedrock surface. However, within and directly adjacent to the Crandon Formation the weathering does not consistently decrease with depth at many locations. Both physical and chemical weathering has resulted in mineral transformation into clays, oxides, enhanced fracturing, and material translocation. Investigations conducted in the 1980s described a layer of low permeability materials, termed the resistive layer, lying over the ore body (Rowe, 1984). Additional studies and reinterpretations of earlier data identified this layer as massive saprolite. Massive saprolite is a clay-rich, highly decomposed rock formed in place by chemical weathering of igneous, sedimentary and metamorphic rocks. At the project site the saprolite is directly overlain by the Pre- to Early Wisconsin till. The massive saprolite over the ore body varies from a thin sheet to as much as 80 ft in thickness. Below the massive saprolite is structured saprolite, which is rock that has been weathered to mostly clays, iron oxides and quartz, but still retains the original rock structure. In the area surrounding the ore body these two units vary in combined thickness from 30 to about 180 ft with an average thickness over the ore body of about 70 to 100 ft.

Section 3

Groundwater

On a regional scale, the hydrogeologic units in the project area consist of unsaturated and saturated unconsolidated (primarily glacially-derived) material overlying saturated crystalline bedrock. In this area, the major water-bearing units are sands and gravels within the glacial material. Groundwater flow occurs primarily within the surficial sediments, with the majority of flow focused within the more permeable outwash deposits.

Till deposits at the project site are extensive and contain sediments with a wide range of grain sizes. The nature of the glacial deposits is such that each of the units is regionally discontinuous and highly variable in composition. Till hydraulic conductivity ranges widely from about 0.0001 to 10 ft/day (Foth and Van Dyke, 1995a). Outwash, which was washed and sorted by glacial meltwater, consists of sandy and gravelly deposits with high hydraulic conductivity ranging from about 0.01 to 200 ft/day (Foth and Van Dyke, 1995a). In contrast, lenses of lacustrine silts or clays located beneath existing upland lakes and some wetlands, and also scattered within the outwash and till deposits from paleo-lakes, have low hydraulic conductivity ranging from about 0.00001 to 2 ft/day and impede the movement of water. The hydraulic conductivity of the bedrock is expected to be very low except along fractures and in substantially weathered zones. Though some water wells in the area are completed within the bedrock, the major source of water for most of those wells is probably drainage from the overlying glacial material to fractures in crystalline rock.

The Precambrian bedrock exhibits both primary and secondary porosity features. The effective porosity of intact metamorphic rock is typically less than two percent, as voids that make up that porosity are generally small and not well interconnected. Therefore, the primary porosity of the bedrock in the study area is assumed to be very small. The ability of the Precambrian bedrock to transmit water is governed by the presence of secondary porosity features. Secondary features, including weathered zones (such as the saprolite) and interconnected fractures, occur largely within the upper portions of the bedrock. The presence of the fractures is attributed to changes in the stress field caused by uplift, erosional removal of overlying material, and glaciation/deglaciation. The extent and intensity of bedrock weathering is highly variable over the site area.

The tilting of the originally horizontal layers in the bedrock means that the original vertical direction during deposition is now oriented along a north-south axis. It is probably coincident with the direction of minimum hydraulic conductivity. Layering and associated partings, originally horizontal, now constitute near-vertical planes along the east-west axis. It is probably coincident with the direction of maximum hydraulic conductivity. The third direction, originally north-south and now vertical, probably coincides with a direction of intermediate hydraulic conductivity.

In general, high water-table elevations occur within upland areas and around upland lakes and wetlands (as in the vicinity of the proposed Tailings Management Area [TMA] and around Little Sand Lake), and low water-table elevations occur in lowland areas associated with streams, wetlands or lakes (as in the area of Hemlock Creek) (figure 2). Groundwater recharge areas are typically associated with upland areas. Groundwater discharge

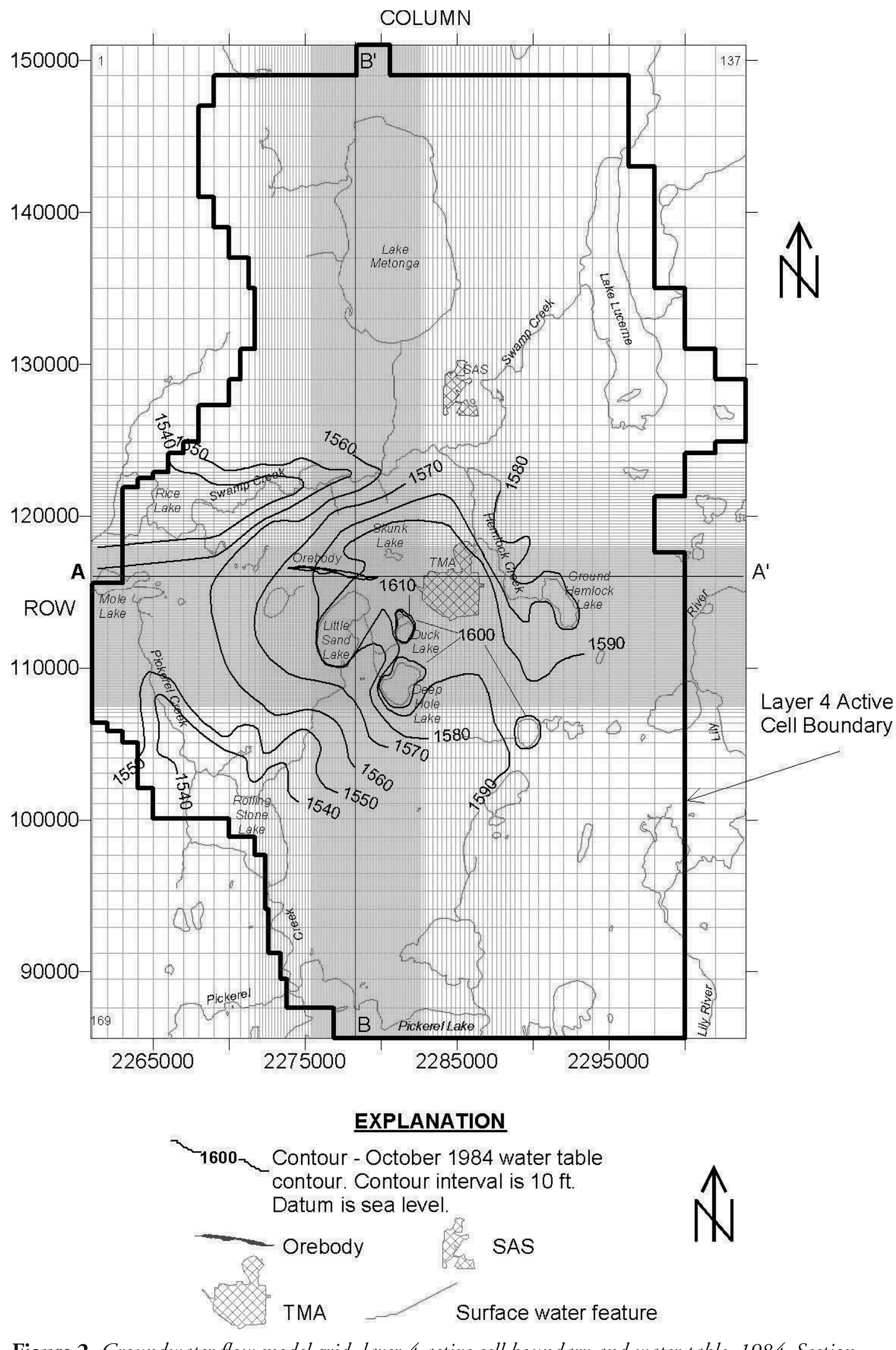


Figure 2. *Groundwater flow model grid, layer 4 active cell boundary and water table, 1984. Section A-A' is shown on figures 3 and 5 and section B-B' is shown on figures 4 and 6. Map coordinates are State Plane North, in feet. [Abbreviations: SAS, Soil Absorption Site; TMA, Tailings Management Area]*

areas are typically restricted to narrow bands along streams and around lowland wetlands and lakes. A water-table high of about 1,640 ft above sea level is located in the vicinity of Lake Lucerne. Water-table lows of about 1,532 ft above sea level are located near the outlets of Rice Lake and Pickerel Lake. The site of the proposed project is near the divide between the Swamp Creek and Pickerel Creek surface water and groundwater basins (figure 1).

3.1 Hydrostratigraphic Units

Hydrostratigraphic units are geologic deposits that are significant in characterizing the groundwater flow system of interest. These units may be entire formations or several formations together, or may be specific features within formations. The definition of hydrostratigraphic units in a particular area depends, in part, on the scale at which the groundwater system is being analyzed. For the work of the TWG, the hydrostratigraphic units for the site area have been identified as 1) the localized upland lakebed and wetland deposits, 2) the Late Wisconsin to present unconsolidated glacial or fluvial deposits (the recent unconsolidated deposits), 3) the Pre- to early Wisconsin-age till/massive saprolite, and 4) the Precambrian bedrock. These units, with some additional distinctions made, were used in constructing the groundwater model for this project area. More detail on the hydrostratigraphy can be found in the project EIR (Foth and Van Dyke, 1995a/1998) and the groundwater modeling reports in the EIR appendixes (GeoTrans 1996, 1998a, 1998b, 1998c, 1998e).

3.1.1 Upland Lakebed and Wetland Deposits

Upland lakebed and wetland deposits are localized hydrostratigraphic units important to the hydrologic behavior of the upland lakes and many of the larger upland wetlands near the project site. These deposits consist of low-hydraulic conductivity silts and clays, which have accumulated in basins in the upland areas. The lacustrine deposits are typically associated with the Late Wisconsin till and are likely formed in basins resulting from the melting of buried glacial ice blocks (known as kettles). Being local in nature, these deposits play a minor role in governing the overall regional flow of groundwater across the study area. However, they play a dominant role in controlling the local hydrologic interaction between the groundwater system and these upland lakes and wetlands. Examples are Little Sand, Duck, Deep Hole, Oak, and Skunk Lakes, Bur Oak Swamp, and the wetlands along Duck and Skunk Lakes. These lakes and wetlands primarily are mounded above the regional groundwater table and thus contribute minor amounts of recharge to the groundwater system.

3.1.2 Recent Unconsolidated Deposits

The upper-most unconsolidated deposits across the site area consist of glacial and post-glacial material. The post-glacial deposits are aeolian-, colluvial-, or alluvial-derived and present only at the land surface. The aeolian deposits consist of loess (fine sand and silt) deposited during the period immediately following the Late-Wisconsin glaciation. These deposits have subsequently been substantially modified by erosion and slope-processes. The colluvial deposits result from creep on upland slopes that modify the existing sediments. The alluvial deposits, located in the stream valleys, consist mostly of high-hydraulic conductivity stratified sand and gravel. Some overbank silt fines underlie many of the stream-side wetlands.

3.1.3 Glacial Unconsolidated Deposits

The glacial deposits consist mostly of the Late Wisconsin-age tills and associated outwash. The tills are unstratified to weakly stratified, and are composed of a wide variety of source rocks with a wide range of grain sizes, from silt and clay to gravel and boulders. Till hydraulic conductivity varies widely over the site area and is controlled by the local nature of the till deposit. The Late Wisconsin-age tills are laterally extensive, but their presence at the ground surface is limited primarily to the upland areas. Much of the recharge to the groundwater occurs through these upland till units. The outwash, deposited largely by pro- and sub-glacial meltwater streams, consists of high-hydraulic conductivity sand and gravel. The Late Wisconsin-age outwash deposits are also extensive, especially in the lowlands, but discontinuous across the uplands. Their surface presence is largely limited to the lowland areas and the upland areas from north of Skunk Lake south to Little Sand Lake and Rolling Stone Lake and from Mole Lake south to Rolling Stone Lake. Swamp, Hemlock, Outlet, and Pickerel Creeks and Creek 12-9 incise outwash through most of their lengths and receive groundwater discharge as their baseflow. Area lakes such as Rolling Stone, Crane, Pickerel, Ground Hemlock and Rice also sit primarily in the outwash deposits and receive discharge of groundwater.

3.1.4 Pre- to Early Wisconsin Till/Massive Saprolite

The Pre- to Early Wisconsin till and massive saprolite are geologic units with substantially different geneses that were grouped as a single hydrostratigraphic unit because of their juxtaposition in the stratigraphy and similar hydrologic characteristics. In the vicinity of the ore body, the Pre- to Early-Wisconsin-age tills reside stratigraphically on top of the massive saprolite. Together, at the scale of the study area, the massive saprolite and the Pre- to Early- Wisconsin till act as a single hydrologic unit with a moderate to low hydraulic conductivity. This unit appears to be present throughout the area of interest and lies between the younger unconsolidated sediments and the bedrock in the groundwater flow system.

3.1.5 Bedrock and Structured Saprolite

In the vicinity of the ore body, the bedrock has been differentiated into unweathered and weathered portions (the structured saprolite is part of the weathered bedrock). Secondary porosity features act as the principal conduit for groundwater movement within the bedrock. Therefore, three sub-hydrostratigraphic units were selected for the weathered bedrock based upon the extent of weathering as determined by Rowe (1984) through an examination of the drill core: 1) strongly weathered, 2) moderately and low weathered, and 3) weakly weathered. Hydraulic conductivity is assumed to increase with the degree of weathering.

The anisotropic fabric of the bedrock is assumed to exist everywhere except in the weathered bedrock at the unconsolidated-bedrock interface. The bedrock hydraulic conductivity in the east-west direction (maximum bedrock hydraulic conductivity) is assumed to be ten times greater than the hydraulic conductivity in the north-south direction (minimum bedrock hydraulic conductivity) (Rowe, 1984). The hydraulic conductivity in the vertical direction is assumed to be intermediate between that of the north-south and east-west directions.

3.2 Conceptual Model

Prior to development, groundwater in the site area flows from upland areas to lowland areas. Groundwater flow occurs predominantly in the unconsolidated glacial materials, with only relatively minimal flow in the bedrock. The majority of lateral groundwater flow occurs in the well-sorted, highly permeable outwash, even where the deposit is thin. Where the outwash is absent, lateral flow is predominantly through the less-permeable till deposits. Travel times from recharge to discharge areas in the glacial materials are generally on the order of decades. For example, using chlorofluorocarbon concentrations, Saad (1996) estimated travel time of about 30 years for water to move from the water table in the vicinity of the proposed TMA to a well near Hemlock Creek. Groundwater flow in the bedrock is primarily limited to highly weathered or fractured zones near the bedrock surface and along some fractures in the unweathered bedrock. The horizontal hydraulic conductivity of some of these zones, especially within the ore body, likely approaches that of the glacial materials. Groundwater flow through the beds of the lakes located in site uplands - Little Sand, Duck, Deep Hole, Skunk and Oak Lakes - is restricted by a layer of sediments composed mostly of lacustrine silt and clay. Some wetland beds in upland areas, such as Bur Oak Swamp and those around Duck and Skunk Lakes, also exhibit relatively low permeabilities due to silt and clay layers present beneath them. In contrast, lakes that receive groundwater discharge, such as Ground Hemlock, Rolling Stone, and Rice Lakes, are generally located in lowland areas of outwash and have higher hydraulic conductivity lake beds. Subsoils in wetlands in discharge areas, such as those along Swamp and Hemlock Creeks, are also consistently of a sandy nature with high permeabilities. Water enters the regional groundwater system through precipitation recharge and exits to groundwater discharge lakes and as baseflow in area streams such as Swamp and Pickerel Creeks and the Lily River.

Section 4

Computer Codes

Several computer programs (codes) were used to simulate the groundwater flow system in the vicinity of the Crandon mine. The use of each of these codes is described briefly below. The pre- and post- processor Groundwater Vistas (Rumbaugh and Rumbaugh, 1996) was used to visualize model input and output, and in some cases modify model input. Numerous FORTRAN programs were written to format data for model input and to process model results.

4.1 Computer Code MODFLOW

MODFLOW (McDonald and Harbaugh, 1984; Harbaugh and McDonald, 1996), a finite difference three-dimensional groundwater flow model code, was the primary tool used to assess potential effects of the proposed mine. Although several versions of the MODFLOW code were used over the period of review, the final calibration and predictive runs were made with MODFLOW96. A number of MODFLOW packages were used including Basic, Block Center Flow, Recharge, Well, Drain, River, Stream Routing, and Lake.

The original Lake Package (LAK1 - Cheng and Anderson, 1993) was modified (LAK2 - Council, 1999) and used to simulate Little Sand, Duck, Deep Hole and Skunk Lakes. The new lake package (LAK2) was reviewed and, with modifications to the lake precipitation and evaporation input, was found to accurately simulate lake stage for most steady-state problems (Hunt and Krohelski, 1998a; Hunt and Krohelski, 1998b; Krohelski and Hunt, 1998).

GeoTrans provided two versions of the MODFLOW code for solving the scenarios. The first, MODFLW96.EXE, corresponds to the MODFLOW96 code distributed by the USGS but adds the LAK2 package. The second, MODSHUNT.EXE, also adds a dry cell bypass option developed by GeoTrans to MODFLW96.EXE. It is used to shunt water vertically when dry cells would otherwise cause a no-flow boundary between layers. The objective of the option is to be sure that mine inflow is not underestimated owing to the presence of dry cells. It is described in a memo from GeoTrans (1995b). MODFLW96.EXE was applied to all Version 1 scenarios. MODSHUNT.EXE was applied to all Version 2 scenarios. Model Versions are described in a later section "Overview of Mining Scenarios."

4.2 Computer Code GFLOW

In addition to the DNR MODFLOW model, this review effort included construction of a two-dimensional regional analytic element model of the proposed mine area using the code GFLOW (Haitjema, 1995). The initial GFLOW model is discussed in detail in Haitjema and Kelson (1998); this model was slightly modified for use with parameter estimation and was reported by Hunt (1999). The purpose of the GFLOW model was to simulate an "area well beyond the domain of the applicant's model" (Haitjema and Kelson, 1998) to: 1) establish whether the boundary conditions used in the MODFLOW modeling were sufficient, and 2) obtain a regional groundwater recharge rate using an approach that more accurately simulates the entire watershed. The GFLOW model was coupled to UCODE (Poeter and Hill, 1998) to automate calibration and to estimate uncertainty in model results.

4.3 Computer Code UCODE

A recent advance in modeling involves using automated techniques, often called parameter estimation or inverse models, for calibration. Numerous publications detail the advantages of inverse models (e.g., Hill 1992, Poeter and Hill, 1997, Hill 1998). Briefly, the primary benefit of a properly constructed inverse model is its ability to calculate parameter values (e.g., hydraulic conductivity, recharge) that are the best fit between simulated model output and measured data (e.g., head, stream baseflow). Other benefits are also realized, such as the quantification of the quality of the calibration and a quantitative measure (i.e., confidence interval) of the uncertainty in the results of the optimized model. In addition, parameter correlation (e.g., hydraulic conductivity with recharge) and parameter sensitivity can be quantified and assessed.

Power and Barnes (1993) have suggested that the analytic element method is ideally suited for parameter estimation techniques because it is parsimonious (i.e., generally uses the minimum assumptions required for solution of the flow problem), is well posed by definition, has relatively few unknowns, and is linear in most of its coefficients. In this work, the GFLOW code was coupled to the inverse code UCODE (Poeter and Hill, 1998). A slight modification was made to the GFLOW code (the model output was expanded to include rate of streamflow) in order to make the optimization more efficient. This refined version of GFLOW was then calibrated with UCODE, using groundwater heads and stream fluxes measured on site as calibration targets (Hunt, 1999).

The UCODE model was also coupled to the DNR MODFLOW model to obtain the optimal values for global recharge and hydraulic conductivity of model layers 1 to 4 (the unconsolidated deposits).

Section 5

DNR MODFLOW Model

The DNR MODFLOW model was based on the applicant's MODFLOW model. Differences between these two versions of the model are discussed below and in Geo Trans (2000). Details on the applicant's model structure can be found in the modeling reports in the project Environmental Impact Report (EIR) (Foth and Van Dyke, 1995/1998, Appendix 4.2-3; GeoTrans, 1998a, 1998b, 1998c, 1998d and 1998e). The changes described below were discussed with the applicant at a number of meetings and are also documented in memoranda to the WDNR. The first memorandum provided details of the TWG's evaluation of the glacial stratigraphic framework used in model construction (Dunning and others, 1997). The second memorandum provided details of the reviewers' verification of model input for the glacial sediments (Dunning and Johnson, 1997a). The applicant responded to these two memoranda (Foth and Van Dyke, 1997) and proposed making a number of significant changes to their model. The TWG evaluated the applicant's proposed changes (Dunning and Johnson, 1997b). A subsequent memorandum (Dunning and Johnson, 1999a) provided details of the reviewers' evaluation of the applicant's representation of bedrock in the model (GeoTrans, 1998b). As a result of that review, a number of changes were incorporated into the DNR model (Dunning and Johnson, 1999b).

5.1 Model Domain

The domains and grids for both the applicant's and the DNR model are the same and were chosen such that the model boundaries were suitable hydrologic boundaries wherever possible. In addition, due to the important resources contained within the Swamp Creek basin, the entire basin upstream of Rice Lake was included in the model. The final model domain (figure 2) also included most of the Pickerel Creek basin upstream of Pickerel Lake, and a portion of the Lily River basin.

5.2 Discretization

The discretization of the DNR model is nearly identical to the applicant's; therefore, except for the brief overview of model discretization that follows, only changes or differences between the DNR and applicant's discretiztion are discussed in this report. The applicant's model discretization is described in detail in EIR Appendix 4.2-3, Section 2 of Addendum No. 1 of the Groundwater Modeling Report and GeoTrans (1998a).

The applicant's MODFLOW model-grid discretization was influenced by a number of physical considerations. Dimensions of rows and columns within the model extent were chosen to provide greater cell resolution at critical features, primarily lakes and streams closest to the proposed mine. The number of layers, as well as the position of layer tops and bottoms, were chosen by the applicant to largely reflect the proposed mine plan and the hydrogeology of the model domain. A layering scheme consisting of four unconsolidated layers and nine bedrock layers was selected by the applicant to represent the hydrostratigraphy and mine development. In addition, because of the complex interfingering of the glacial deposits and the bedrock weathering in the site area, bulk-averaging schemes were developed by the applicant to incorporate the variability in hydraulic conductivity rather than attempting to match each hydrostratigraphic unit with a particular model layer.

The grid covers an east-to-west distance of 43,000 ft and a north-to-south distance of 65,400 ft (figure 2). The model domain is roughly centered on the ore deposit, and is divided into 169 rows and 137 columns. The length and width of both rows and columns range from 100 to 2,000 ft. The smaller cells are in the center of the model domain to provide finer resolution near the proposed mine and critical surface-water features, the larger cells are at the model perimeter. The vertical dimension of the model is divided into 13 layers (figures 3 to 6). The rows, columns and layers combine to define a model domain with 300,989 cells of which 92 percent (277,049 cells) are active in the final DNR model, covering about 100 square miles.

The bottom elevation of the model is a uniform 450 ft below sea level, chosen to correspond to the greatest depth of the ore body at the center of the domain. The top elevation of the model (the top of layer 1) is based on the variable surface topography and is about 1,800 ft above sea level at its maximum. The upper-most four layers of the model represent the unconsolidated glacial deposits and the massive saprolite (figures 3 and 4). The combined thickness of layers one through four averages about 175 ft over the model domain and ranges from 15 ft to 390 ft. Over the ore body the minimum thickness is about 65 ft. The saturated thickness of the glacial units is less than the total thickness. It averages about 145 ft with a maximum of around 285 ft. The minimum saturated thickness over the ore body is on the order of 30 ft. Layer one generally represents the Late Wisconsin till, layers 2 and 3 generally represent the coarse and fine outwash materials of Early to Late Wisconsin age, and layer 4 generally represents the Early Wisconsin till. The massive saprolite is included in layer 4 (structured saprolite is included in layer 5). The bottom of layer 4 defines the top of the non-massive saprolite bedrock layers. The lower nine layers (layers five through 13) represent Precambrian bedrock, including the ore deposit (figures 5 and 6). The combined thickness of layers five through 13 ranges from about 1,800 to 2,000 ft. The three-dimensional model grid was created by intersecting the horizontal row and column grid with layer boundaries (tops and bottoms) as defined by layer elevation arrays.

Different bedrock model representations were created for the Zinc and Copper Phases of mining. This ensures that MODFLOW drain features are used appropriately within bedrock layers to

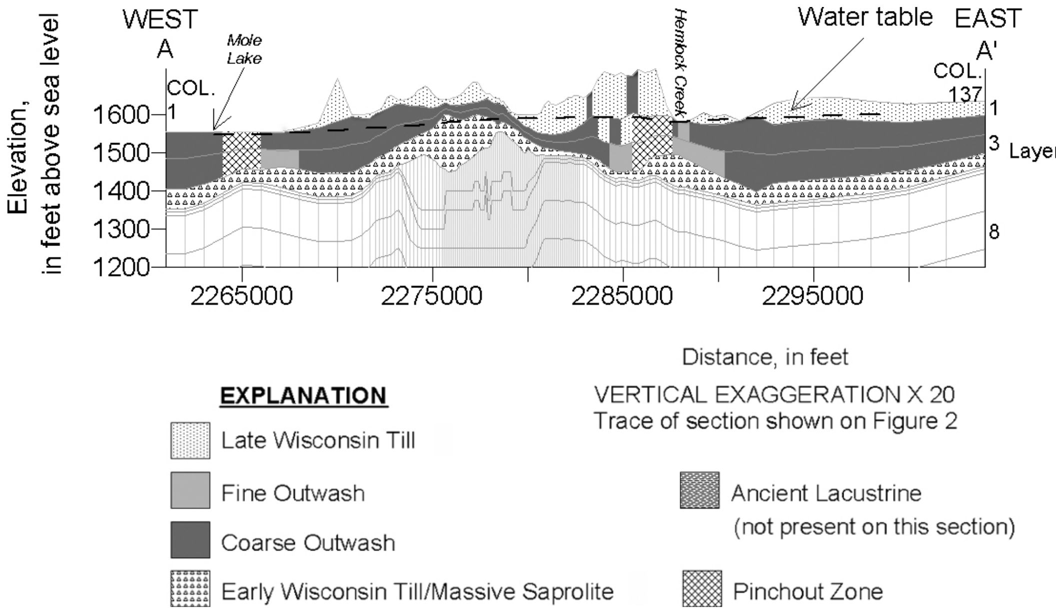


Figure 3. *Vertical distribution of unlithified deposits along row 60 of the Crandon regional groundwater-flow model. Model cells on the section are assigned a dominant deposit type using the highest percentage material present in the cell.*

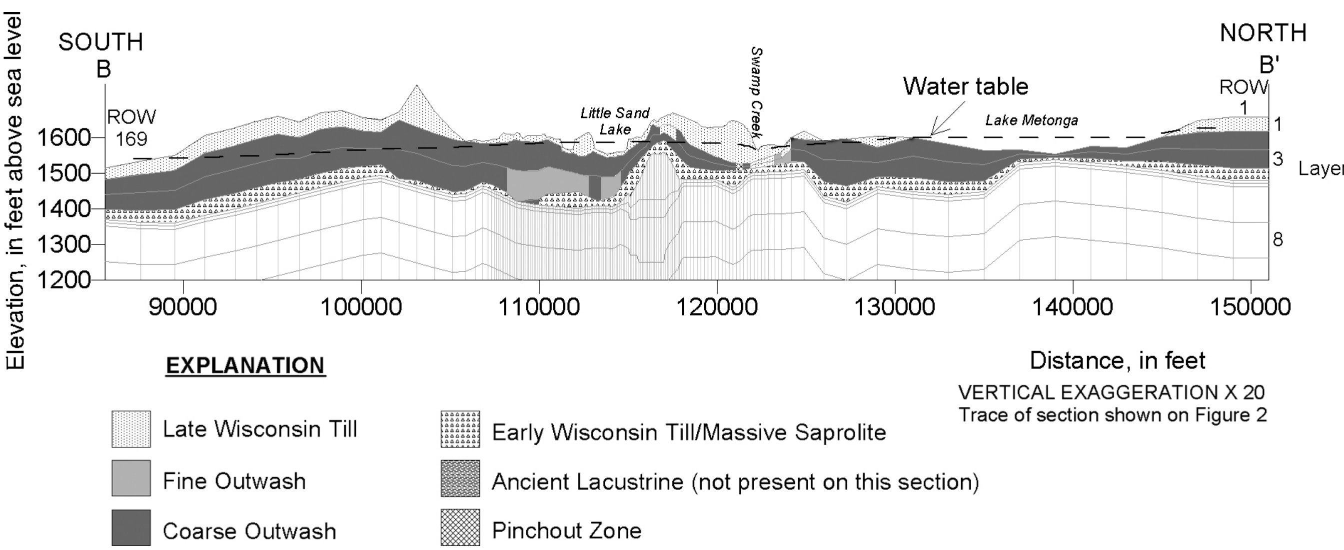


Figure 4. *Vertical distribution of unlithified deposits along Column 60 of the Crandon regional groundwater-flow model. Model cells on the section are assigned a dominant deposit type using the highest percentage material present in the cell.*

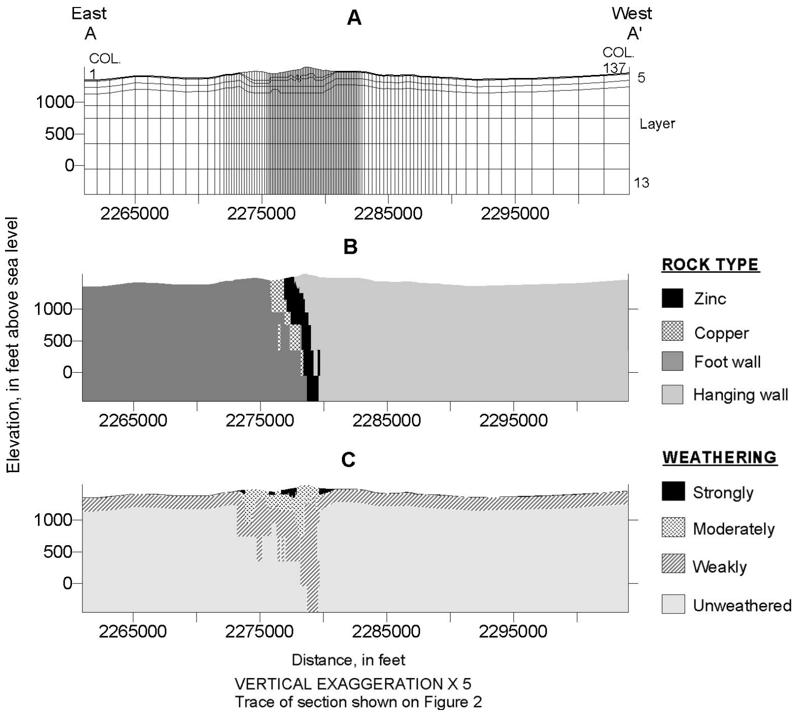


Figure 5. *Crandon regional groundwater-flow model bedrock cross sections showing along row 60 showing: A) finite-difference grid, B) rock type, and C) weathering. Model cells on the section are assigned a dominant rock type or weathering using the highest percentage material present in the cell.*

represent the removal of ore during each Phase of mining operations. As a result of changes made to the applicant's array of ore body cells in the DNR model, the contact between the hanging wall and foot wall was also adjusted to ensure that the contact remained in proper relation to the ore body.

To more fully represent the bedrock in the DNR model, the area of active model cells in glacial layer 4 was also used for the bedrock layers 5 through 13, thus increasing the volume of active bedrock nodes from the applicant's version of the model. Some of this newly activated bedrock in layers 5 through 13 was designated as "unweathered." For this revision, cells were designated as unweathered hanging wall or footwall bedrock, if the cell contained less than 30 percent weathered bedrock as designated on figures 11-48 of the GeoTrans memo (1998b). The weathered bedrock zones extend over the entire model domain. Below the top of the ore body, weathered bedrock surrounds the ore body thickness. This weathered zone extends about 2,000 ft north and south of the ore body. The exact extent of the weathered bedrock in any model layer was determined by interpolation routines applied to the data contained in the profiles constructed by Rowe (1984).

The DNR model includes two major changes to the weathering array. First, the representation of the weathering within the ore body was revised to explicitly include the deeper weathered zones of the Crandon Formation. The applicant's approach was to connect the depths of each weathering zone in the hanging wall and foot wall across their contacts with the ore body. The DNR revision was accomplished by overlaying a row-layer grid on the weathering cross-section diagrams (Rowe, 1984) and visually estimating the percentage of the weathering type falling within each ore body cell.

The second major change was to re-categorize the weathering interpretation. The weathering cross-section diagrams (Rowe, 1984) on which the interpretation is based present four weathering intensity categories – strong, moderate, low, and weak. The applicant's submittal included only 3 intensity categories for the weathering percentage arrays—strong, moderate and weak (the low and weak intensity areas on the diagrams were grouped together into the applicant's weak category). The low weathering intensity areas shown on the diagrams were grouped with moderate (rather than weak) areas to create a new moderate weathering designation for the DNR model (Dunning and Johnson, 1999a). As a result of these two major revisions, the strongly weathered and moderately weathered fractions generally increased and the weakly weathered fraction generally decreased for any given layer in the vicinity of the ore body. Combining the moderate and the low weathered zones also resulted in an increase in the continuity of the zones. Areas of strong and moderate weath-

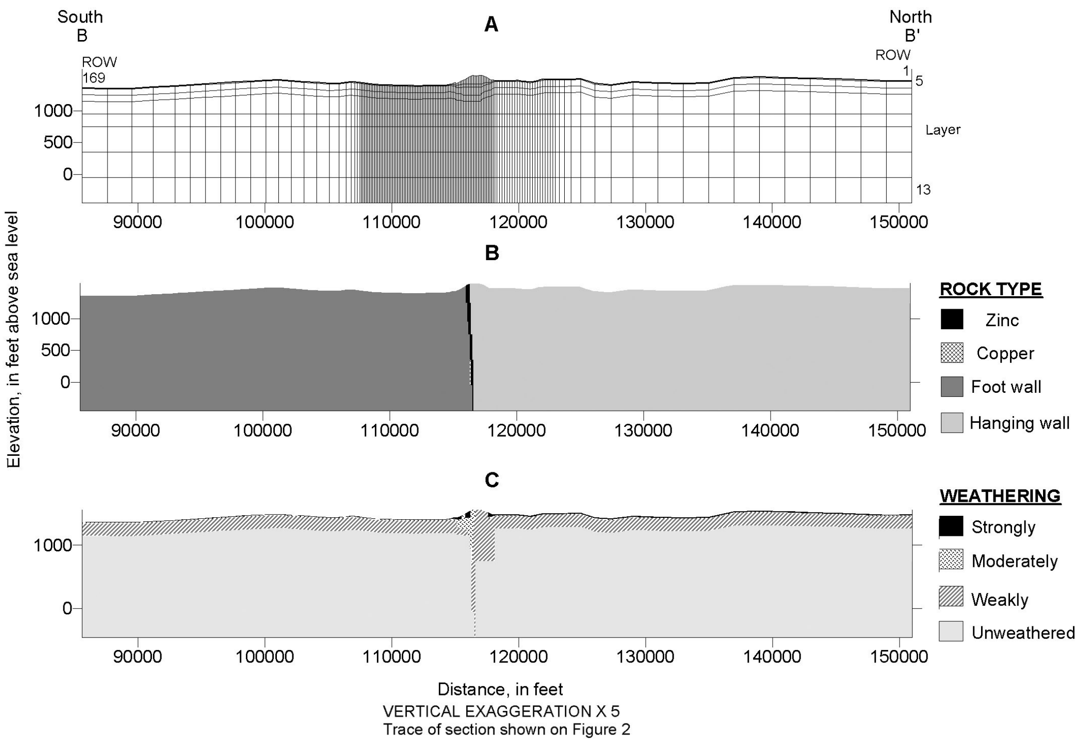


Figure 6. *Crandon regional groundwater-flow model bedrock cross sections along column 60 showing: A) finite-difference grid, B) rock type, and C) weathering. Model cells on the section are assigned a dominant rock type or weathering using the highest percentage material present in the cell.*

ering, which had been relatively isolated within the deeper layers that represent the ore body, were now more closely associated with weathered bedrock in the shallow layers. The vertical distribution of unconsolidated deposits and the bedrock and weathering are shown on figures 3, 4, 5 and 6.

5.3 Recharge and Hydraulic Conductivity of Unconsolidated Sediment

Model parameterization of recharge and of hydraulic conductivity for unconsolidated sediment can be discussed together because in a relatively homogeneous aquifer with head-specified boundary conditions, piezometric heads depend primarily on the ratio of recharge rate (R) to the aquifer transmissivity, the ability of the aquifer to transmit the water (Haitjema and Kelson, 1998). For the purposes of determining the parametric relationship, we can assume that the thickness of the system is constant, and therefore, the relation of interest is the ratio of recharge to hydraulic conductivity (K). Different values of R and K will result in a similar piezometric head distribution as long as the ratio of R/K is similar. Although the aquifer in the area of interest is not truly homogeneous and includes boundaries other than head-specified, the observed piezometric head distribution was consistently matched by the model using an R/K ratio of 5.1×10^{-5} (Haitjema and Kelson, 1998).

The initial values input to the DNR model for global recharge and unconsolidated sediment horizontal hydraulic conductivity were derived from the GFLOW-UCODE model work (Hunt, 1999) and the modeling of the pumping test conducted in the unconsolidated sediments (Feinstein, 1997). No field measurements have been made of the groundwater recharge rate to the underlying water table from seepage (recharge) wetlands and external upland lakes. However, using reasonable estimates, these sources are thought to comprise a small portion of the total amount of water input into the model (Feinstein, 1998a). Therefore, to simplify the model, the recharge rate assigned to these features was made equal to the global dryland recharge rate.

5.4 Outwash Pinchout Zone

Outwash is assumed to be absent along the margin of the drumlins that border the creek valleys of

Hemlock, Swamp, and Pickerel Creeks. Dunning and others (1997) describe possible stratigraphic outwash discontinuities between upland and lowland areas as reasons for the low hydraulic conductivity region referred to in this report as the outwash pinchout zone. The conceptual model for glacial deposition described in this memo results in largely continuous till layers and discontinuous outwash layers across the landscape, while the applicant's conceptual model assumes continuous outwash layers and discontinuous till layers. The outwash pinchout was incorporated into both the applicant's and DNR's groundwater flow models to be consistent with the conceptual geologic model of Dunning and others (1997). Hydraulic conductivity of the material within the zone was assumed to approximate that of till.

5.5 Bedrock Representation and Ore Body Configuration

Bedrock consists of weathered and unweathered portions; weathering occurs to varying degrees within weathered portions. In the applicant's model, unweathered bedrock away from the ore body was assumed to be impermeable (inactive model cells). Therefore, the unweathered bedrock away from the ore body in the applicant's model could not transmit water. In the DNR model the unweathered bedrock is assumed to have a low hydraulic conductivity and can transmit water.

As previously mentioned, the anisotropic fabric of the bedrock due to its near-vertical tilting is assumed to exist nearly everywhere. The lone exception is in the strongly weathered bedrock at the unconsolidated-bedrock interface, where due to the effects of pronounced weathering the bedrock is assigned isotropic values of hydraulic conductivity. The anisotropic fabric of the bedrock is assumed to originate with planes of weakness associated with depositional bedding planes and enhanced by subsequent metamorphism. These bedding planes were tilted from the original x-y orientation to the current x-z orientation (aligned along the near-east-west axis of the ore body) during tectonism. As a result, the hydraulic conductivity in the present x-z direction (east-west), Kx, is assumed to be higher than the conductivity in the present y-z direction (north-south), Ky. Due to the extensive weathering of the bedrock following tectonism and the vertical translocation of fines, the vertical hydraulic conductivity, Kz, is thought to be less than Kx. Review of pump test results showing elliptical drawdown with the major axis oriented east-west support the assumption that Kx is greater than Ky (Foth and Van Dyke, 1997). The hydraulic conductivity in the east-west direction is assumed to be ten times greater than in the north-south based upon trial and error work with the pump test results (Foth and Van Dyke, 1997). The vertical hydraulic conductivity is assumed to be 3.162 times greater than the north-south direction and 0.3162 times smaller than the east-west direction (GeoTrans, 1998a). These anisotropy ratios are assumed to pertain to the lowest 50 ft of the crown pillar, the zinc ore, the copper stringers, the weathered hanging wall, the weathered foot wall, and the unweathered bedrock (GeoTrans, 1998a).

Changes in the ore body configuration from that submitted by the applicant were incorporated to increase the continuity of the ore configuration in the model. A procedure was developed by the TWG for designating model cells as zinc or copper ore that differs from the applicant's procedure. The steps involved were detailed in a memorandum (Dunning and Johnson, 1999b). Although the new configuration increases the continuity of the ore body, it over-represents the volume of the ore body for both Zinc and Copper mining Phases. TWG work with the DNR model carries forward both configurations of the ore body – one maintaining ore body volume ("volume based") and one maintaining ore body continuity ("continuity based"). The ore body continuity configuration yields higher rates of mine inflow and greater drawdown than the ore body volume configuration.

5.6 Boundary Conditions

The specification of boundary conditions can have subtle effects on the parameterization of a groundwater flow model (e.g., Kelson and others, 2002). Perimeter boundary conditions in the DNR model near Pickerel Creek and Ground Hemlock Lake are discussed below, as well as the simulation of external and internal lakes. The external boundary conditions (the general head and no-flow boundaries) in the final submitted model are detailed in GeoTrans (1996, 1998a, 1998b, 1998c). Those boundary conditions have not been modified in this work. The internal boundary conditions (streams and lakes) are represented by a variety of head-dependent boundary conditions in the model, including MODFLOW STR, RIV, and LAK2 packages. Details are provided in GeoTrans (1996, 1998a, 1998b, 1998c). In this work, certain head-dependent internal boundary conditions were modified. Sections 5.6.1 – 5.6.4 in this report describe these modifications.

5.6.1 Boundary Conditions Near Pickerel Creek

The GFLOW model (Haitjema and Kelson, 1998) indicated that the simulated drawdowns due to mine operation have the potential to extend beyond the finite-difference model grid perimeter in only one area: between Mole Lake and Rolling Stone Lake on the west side of the model domain (west of upper Pickerel Creek) (figure 1). While the GFLOW model simulates drawdown in a small area west of the creek, the magnitude of the simulated drawdown is less than 1 foot. It is difficult to assess the actual magnitude of this potential boundary violation in the MODFLOW model by using the GFLOW model, because the GFLOW model only coarsely represents the hydrologic setting in the area adjacent to the proposed mine (the area that will help control how the cone of depression propagates out into the regional groundwater system) (Haitjema and Kelson, 1998). However, both the applicant's and the DNR's MODFLOW models use a no-flow boundary condition just to the west of Upper Pickerel Creek; therefore, both models will over predict drawdowns in the vicinity of the creek. This apparent lack of resolution is accepted in the MODFLOW model because drawdown of less than a foot is near the accuracy that can be reasonably expected from a regional flow model.

5.6.2 Boundary Conditions Near Ground Hemlock Lake

In the applicant's original model, the UN1 wetland located just west of Ground Hemlock Lake was represented as a large discharge wetland and simulated using drain nodes (figure 1). However, many of the UN1 wetland drains were inactive (Krohelski and Carlson, 1997) and the local direction of groundwater flow was not simulated correctly. Groundwater flow along the eastern model boundary in the vicinity of Walsh and Ground Hemlock Lakes, based on water table and lake elevations, should be roughly west to east (Hunt and Krohelski, 1995). The applicant's model simulated groundwater flow from north to south. In the DNR model, all drains representing the UN1 wetland were deleted and replaced with river nodes that simulate the extent of Creek 33-8, which drains the wetland, to obtain the correct direction of groundwater flow and to more closely represent the natural system in this area.

The conductance of the Ground Hemlock Lake bed was simulated using river nodes. In the DNR model the conductance of these river nodes was increased by an order of magnitude over the applicant's model. Prior to this increase, modeled surface-water flow from Ground Hemlock Lake was about 0.6 cfs, which was considerably lower than measured flow at the Ground Hemlock Lake outlet of 2.4 cfs. Simulated flow at the lake outlet after increasing the conductance was about 2.4 cfs. (Note: At a later date it was discovered that all conductances were not correctly updated. See Appendix III-3 for a detailed explanation.)

5.6.3 Internal Upland Lakes

Simulation with MODFLOW of the non-perched internal lakes (i.e., lake close to the ore body)—Little Sand, Duck, Deep Hole, and Skunk Lakes—requires estimates of lakebed hydraulic conductivity, surface-water outlet rating equation (except for Skunk Lake, which has no surface-water outlet), and runoff. Oak Lake, though located near the other internal lakes, is perched and is disconnected from the saturated groundwater system and thus not evaluated.

5.6.3.1 Lakebed Hydraulic Conductivity

An important set of inputs for the regional model is the average lakebed hydraulic conductivity (Kv) for each internal lake (Little Sand, Duck, Deep Hole and Skunk Lakes) since this parameter largely controls the seepage of lake water into the groundwater system. Kv can be estimated using an algebraic algorithm that constitutes the lake budget. The inverse form of this algorithm determines the average value for Kv as a function of daily stage, average groundwater level, daily precipitation, daily evaporation, average lakebed thickness, monthly rates of surface runoff, and daily rates of surface outflow. A Monte Carlo method was applied to the equation in order to determine the best-fit of the estimate and the uncertainty around the estimate for Kv as well as other random variables (for example, surface runoff and surface outflow). This method was performed separately on Little Sand Lake and Deep Hole Lake for three years of non-winter data (1977, 1985, 1994) and reported in Feinstein (1998b). Duck Lake was not analyzed and is assumed to behave similarly to Deep Hole Lake as discussed below.

The results of the Monte Carlo analysis proved very sensitive to the average potentiometric elevation beneath the lake because this controls the vertical hydraulic gradient, which combined with Kv determines the vertical flow rate. In the original analysis as described by Feinstein (1998b), more than one trial groundwater head value was applied to the calculation. Subsequent review of field data and model results suggest that the best estimate for the average vertical gradient across the lakebed is 0.70 for Little Sand Lake and 1.93 for Deep Hole Lake. Because the average lake stages are known for 1977, 1985, and 1994, these gradients imply an average groundwater head under the two lakes. When the updated head values were input to the Monte Carlo analysis for 1977 data, it yielded a value of Kv for Little Sand Lake equal to 0.0095 ft/day ± 0.0038 ft/day. The Kv value for Deep Hole Lake was equal to 0.0028 ft/day (rounded to 0.003 ft/day) ± 0.0015 ft/day. Duck Lake is more similar to Deep Hole Lake than Little Sand Lake both in terms of its size, its position in the watershed and its bottom sediments (Foth and Van Dyke, 1995a/98, Table 3.7-27). Therefore, the Kv value of 0.003 ft/day determined for Deep Hole Lake was also assigned to Duck Lake.

The use of the Kv values and the other random variables resulting from the Monte Carlo analyses in the forward application of the water-budget equation produced excellent fits to the stage measurements for the 1985 as well as the 1977 data, but a less good fit to the 1994 data; accurate field measurement of outflows at Duck, Deep Hole and Little Sand Lakes are very difficult to obtain due to outlet structures and beaver activity. The relatively poor fit to the 1994 data may be due to the difficulty in properly representing the surface water components of the lake balances in the model owing chiefly to the influence of beaver dams on the physical system. In 1977, the lake balances were dominated by groundwater outflow (seepage through the lake bed), while in 1985 and 1994 they were controlled by a combination of groundwater outflow and surface water outflow owing to higher average lake stages. The representation of surface-water components in the water budget is highly uncertain, and therefore, complicates the use of the budget to estimate Kv as a residual term. Consequently, it is reasonable to conclude that the good fit for 1977 data in the case of both Little Sand and Deep Hole Lakes implies reasonable estimates of Kv, while the poor fit in 1994 implies only that the surface water components are poorly understood.

The Kv for Skunk Lake, a relatively small lake that is characterized by a variable stage and no surface outlet, was not estimated through a water balance. Initially, the Kv estimate was based on observations that the lakebed sediment beneath the muck was relatively coarse (EIR, Appendix 3.5-8 and 3.5-10, Foth and Van Dyke, 1995a/1998). However, the suggested Kv value equal to 0.035 ft/day produces unrealistic simulated fluxes out of the lake into the groundwater system, a rate 10 to 30 times greater than that for the other internal lakes. Estimation of the contributing surface runoff area to Skunk Lake suggests that the surface runoff coefficient needed to satisfy the loss to groundwater at the rate simulated by the model is more than 100 percent of precipitation (Carlson, 1998). It is clear that the Kv value for Skunk Lake should, therefore, be less than 0.035 ft/day. Skunk Lake has a maximum area equal to about 6.5 acres (Carlson, 1998); the actual lake area fluctuates in its extent through wet and dry periods. The observation that Skunk Lake often shrinks to a small, but stable size in dry periods invites the hypothesis that the Kv of its lakebed can be characterized by two values. One relatively high value would be applied to about three quarters of the total area that is periodically inundated, while a lower value would be applied to the one quarter of the total area that remains inundated during dry periods. A second consideration was to select Kv values that imply a runoff coefficient for water entering the lake that is similar to the runoff coefficient for other internal lakes (about 15 percent of precipitation on its basin). To satisfy these requirements, nodes accounting for 75 percent of the area were assigned a Kv of 0.012 ft/day (slightly higher than the Little Sand Lake value), while nodes accounting for 25 percent of the area were assigned a Kv of 0.002 ft/day (slightly lower than the Deep Hole Lake value).

5.6.3.2 Surface-Water Outflow Rating

The LAK2 package in MODFLOW uses a functional relation between surface-water outflow and the lake stage. A plot of outflow versus lake stage field data for Little Sand Lake demonstrates that the same outflow occurs for different stages (Feinstein, 1998b). Consequently, the conventional form of the surface-water outflow rating equation used as part of the water-budget algorithm will likely be a poor predictor of surface-water outflow for any combination of rating parameters because it assumes a positive exponential relation between lake stage and surface outflow. It is also worth noting that because the rating equation is an exponential expression, it predicts very small surface-water outflows when the stage is less than one foot above the cutoff elevation. In reality, significant flows are possible at these stages because of the diffuse outlets (i.e., the outlet channels are poorly defined) that exist for Little Sand, Deep Hole and Duck Lakes (Skunk Lake has no outlet).

Therefore, we have chosen to effectively remove the rating equation from the LAK2 Package in MODFLOW by adjusting the parameters so that a constant surface water outflow occurs whenever the stage is above the cutoff elevation. The constant surface flow rates for the three internal lakes with outlets have been assigned on the basis of limited field measurements collected in 1996. The outflows from Duck Lake and Deep Hole Lake were set to 0.1 cfs and to 0.2 cfs, respectively. Available data from the Little Sand Lake outlet indicate that the average flow rate is greater than that at Deep Hole Lake. Because Little Sand Lake is about 2 times the size of Deep Hole Lake and integrates the upstream Deep Hole and Duck Lake basins, we elected to scale its surface outflow to 0.4 cfs.

In order to check the suitability of the assumption that surface-water outflow can be represented as a fixed value when the stage is above a lake's cutoff elevation, the water-budget calculations were run in forward mode for Little Sand Lake and Deep Hole Lake. The results indicated that the fit of simulated to observed lake stage was still quite good when the selected Kv values were combined with the selected fixed outflow for the years of record (1985 for Little Sand Lake, 1977 for Deep Hole Lake) in which the average lake stage is close to the assumed stages for the base model (corresponding to October 1984). The fit is less good for the other years of record for which the measured average stage is generally about 1 foot different than the October 1984 stage. These findings suggest that the use of fixed surface outflow is reasonable for calibration of the base model to October 1984 conditions, but that it might introduce some error for runs in which the simulated lakes respond to stresses, such as pumping from the mine.

5.6.3.3 Surface Runoff

It is also possible to check the reasonableness of the runoff values selected by using the MODFLOW model to solve for surface runoff to the lakes when the assumed values of Kv and surface-water outflow are inserted in the model. The LAK2 package in steady-state mode calculates the runoff values automatically for each lake as a deficit term to ensure mass balance. Two lines of evidence lead us to believe that the runoff coefficients should be about 15 percent of the precipitation that falls on the basin of each lake. First, a recent water budget conducted on a lake in similar terrain in northern Wisconsin based on 50 years of stage record yielded a runoff coefficient of 16 percent averaged over the entire year and 14 percent for October (Krohelski and others, 1999). Second, a Dames & Moore (1985) study computed runoff coefficients from streamflow measurements of Crandon site-area streams and concluded that non-winter runoff coefficients ranged from 16 percent for May to 9 percent for August, with 15 percent for October.

In fact, the base DNR model consistently produces runoff coefficients between 14 percent and 16 percent for the internal lakes (including Skunk Lake) when the selected lake parameters are used as discussed. These runoff values would not be as close to the target of about 15 percent if the average surface outflows used in the model (0.1 cfs for Duck Lake, 0.2 cfs for Deep Hole Lake and 0.4 cfs for Little Sand Lake) were greatly in error. The runoff results are moderately sensitive to the assumed outflow rates. For example, if outflow rates of one-half of the selected rates were used, the implied runoff coefficients would range between 9 percent and 13 percent. If twice the outflow rates were used, the implied runoff coefficients would range between 22 percent and 23 percent.

5.6.4 External Upland Lakes, Groundwater Discharge Lakes, and Wetlands

External upland lakes are lakes that located in drumlin uplands distant from the ore body and not along the model perimeter. Feinstein (1998a) determined that the use of head-dependent boundaries to simulate external upland lakes resulted in unrealistic amounts of recharge (seepage in excess of amounts available to the lakes from precipitation) from the lakes to the groundwater system. In order to constrain the amount of recharge, the head-dependent boundaries were deleted and dryland recharge rates were applied to model cells simulating these lakes. A study of Lake Lucerne, the largest of the external upland lakes, using a GFLOW model found that simulation of this lake did not to affect the model solution, because it was not a large source of water to the ground-water system (Hunt, 1999). Results of the GFLOW study are presented in table 1 of this report. This supports use of the dryland recharge rate of Lake Lucerne in the MODFLOW model.

Groundwater discharge lakes are those that receive appreciable water from the groundwater system. All groundwater discharge lakes, wherever they are located in the model domain, are explicitly included in the model solution by means of a stage and a conductance term representing the resistance of the lakebed. The net precipitation to these lakes is equated with the excess of precipitation over evapotranspiration at the latitude of the study area (about 5.8 in/yr). The model reported flow leaving the lake is the balance between the net precipitation leaving the lake and the groundwater

Table 1. Calibration information for the high and low recharge analytic element models both with and without explicit representation of Lake Lucerne. [abbreviations: ft, feet; ft/day, feet per day; cfd, cubic feet per day; in/yr, inches per year; MA, mean absolute; RMS, root mean squared]

Simulation	Lake Lucerne	Hydraulic Conductivity k1 (ft/day)	k2 (ft/day)	k3 (ft/day)	Recharge (in/yr)	Flux Calibration Swamp Cr. @ Hwy. 55 Residual[a] (cfd)	Error[b] (%)	Head Calibration Average Residual[a] (ft)	MA Residual[a] (ft)	RMS Residual[a] (ft)	Residual[a] Range (ft)
Low Recharge Case (Q80)	In	35.0	20.0	11.1	7.52	1.6E+4	0.93%	-0.71	2.91	4.56	-19.1–12.1
High Recharge Case (Q50)	In	48.5	27.9	14.9	10.57	-3.3E+4	-1.35%	-0.78	2.93	4.62	-19.5–11.8
Low Recharge Case (Q80)	Out	32.7	19.2	10.7	7.16	6.8E+2	0.04%	-0.88	3.02	4.92	-20.6–11.6
High Recharge Case (Q50)	Out	47.9	27.5	13.6	10.15	1.4E+3	0.05%	-0.74	3.05	4.93	-20.6–11.7

[a] *The residual was calculated with the following equation: residual = simulated - measured.*

[b] *The error was calculated in the following manner: error (%) = (residual / measured) * 100.*

discharge that enters it.

The recharge-discharge relations between wetlands and the groundwater system are very difficult to estimate without intensive field study. The interplay of sediment, vegetation, and seasonal precipitation patterns make it difficult to predict how much water a given wetland releases or absorbs over time. In the applicant's model, recharge wetlands (a wetland that releases water to the groundwater system) were only represented if located near the project site, while discharge wetlands (a wetland that receives water from the groundwater system) were represented as low-recharge areas. Analysis of the applicant's model results show that excessive amounts of water move from the recharge wetlands to the groundwater (Feinstein, 1998a). Given the great uncertainty in evaluating these features, in the DNR model we applied the dryland recharge rate to all wetlands in the model domain.

5.7 Model Calibration

The DNR model was calibrated using a variety of approaches, taking into account the applicant's previous work (Foth and Van Dyke, 1995a/1998; GeoTrans, 1998a, 1998b, 1998c, 1998d and 1998e). As part of calibration the applicant performed extensive sensitivity analyses that provided sufficient insight so that the TWG could focus efforts on selected features of the model. The calibration of the DNR model to steady-state conditions and calibration of the glacial pumping test model to shallow stressed conditions provide virtually no information on parameters controlling flow in the deeper units of the groundwater system (the Early Wisconsin till at the base of the unconsolidated material and the weathered bedrock/ore body beneath this till). In order to quantify the hydraulic conductivity of these deeper units, it was necessary to calibrate the MODFLOW model to three bedrock pumping tests (213, 211, and PWAR pumping tests) that stressed the deeper bedrock portions of the flow system.

During October 1984, streamflow at Swamp Creek was at a Q_{50} flow duration (the amount of flow exceeded 50 percent of the time) indicating a baseflow condition. Groundwater elevations and flow directions at that time are presented in figure 2, and are assumed for the work herein, to represent steady-state groundwater and surface water conditions. The October 1984 conditions were used for steady-state calibration.

5.7.1 Unconsolidated Deposit Calibration

Three approaches were used to obtain calibration of the upper unconsolidated sediments: finite-difference MODFLOW modeling of a pumping test in glacial sediments (Feinstein, 1997), GFLOW modeling of the regional Swamp and Hemlock

Creek watersheds (Haitjema and Kelson, 1998; Hunt, 1999), and UCODE optimization of the final regional MODFLOW model.

5.7.1.1 Glacial Pumping Test Calibration

In July 1980, a predecessor company to the applicant ran a pumping test for 24 days near the proposed TMA area. The test, conducted at about 1,420 gpm, stressed the unconsolidated deposits. An analysis of the pumping tests results, based on a stratigraphic interpretation of the sediments reported by the applicant (GeoTrans, 1996) is contained in Feinstein (1997). The test was simulated using an inset MODFLOW model derived from the regional MODFLOW model of the mine area. The refined grid, consisting of 11 layers and finely spaced rows and columns, allowed the model to take close account of the screen intervals of the pumping well and observation wells, an important consideration when dealing with a partially penetrating pumping well and heterogeneous deposits.

The results of the analysis indicate that the best estimates for the horizontal hydraulic conductivity of the coarse outwash sand and fine outwash sand as depicted by the applicant are 80 ft/day and 20 ft/day respectively. A 10:1 horizontal to vertical anisotropy ratio is reasonable for these two units. The analysis is insensitive to the hydraulic conductivity values assigned to the till units in the model (notably the Early-Wisconsin till directly above the bedrock) because the horizontal flux through these units to the pumping well was so small.

5.7.1.2 GFLOW Model Calibration

The parameters chosen for optimization in the GFLOW model (Haitjema and Kelson, 1998; Hunt, 1999) included the global hydraulic conductivity (K1), the hydraulic conductivity of a larger inhomogeneity that extends from Swamp Creek to St. John's Lake (K2), the hydraulic conductivity of a small inhomogeneity that extends from north of the ore body to Swamp Creek (K3), the global recharge (R1), and the resistance of the stream sediment, originally assigned values of 0.3 days and 1.0 days (S1 and S2, respectively) (figure 7). Initial runs on parameter sensitivity showed the model was relatively insensitive to changes in S1 and S2; that is, the observations used in the optimized calibration did not contain enough information to constrain these parameters. As a result, all subsequent runs were made with fixed values of S1 and S2 (set to their original values) and optimizing the remaining four parameters (K1, K2, K3 and R1). Optimized models with similar calibration statistics were obtained for both a high baseflow (Q_{50}) and a low baseflow (Q_{80}) case (table 1). The unweighted GFLOW head calibration statistics are also shown in table 1 for comparison. The simulated Q_{50} streamflow was obtained using a basinwide recharge equal to 10.2 inches per year; the simulated Q_{80} streamflow was obtained using a recharge equal to 7.2 inches per year. From the discussion in Haitjema and Kelson (1998), the R/K1 ratio is near 5×10^{-5} and proportional changes in optimized conductivity values and recharge yielded similar calibration statistics (table 1). This demonstrates that the problem is non-unique; additional flux measurements are necessary to estimate the recharge rate independent of hydraulic conductivity. The available field evidence with respect to hydraulic conductivity is consistent with the parameterization in the models, given that the hydraulic conductivity values for outwash units derived from the glacial pumping test (20 ft/day and 80 ft/day) bracket the global hydraulic conductivity values used in the GFLOW simulations (ranging from 33 to 48 ft/day).

5.7.1.3 UCODE DNR Model Optimization

The UCODE optimization code was coupled to the DNR MODFLOW model to obtain optimized values for global recharge and hydraulic conductivity of the glacial sediments. The U2DREL multiplier (McDonald and Harbaugh, 1988), which changes parameters uniformly across the model were varied for the following arrays: 1) recharge, 2) the arrays associated with the upper four model layers corresponding to the horizontal hydraulic

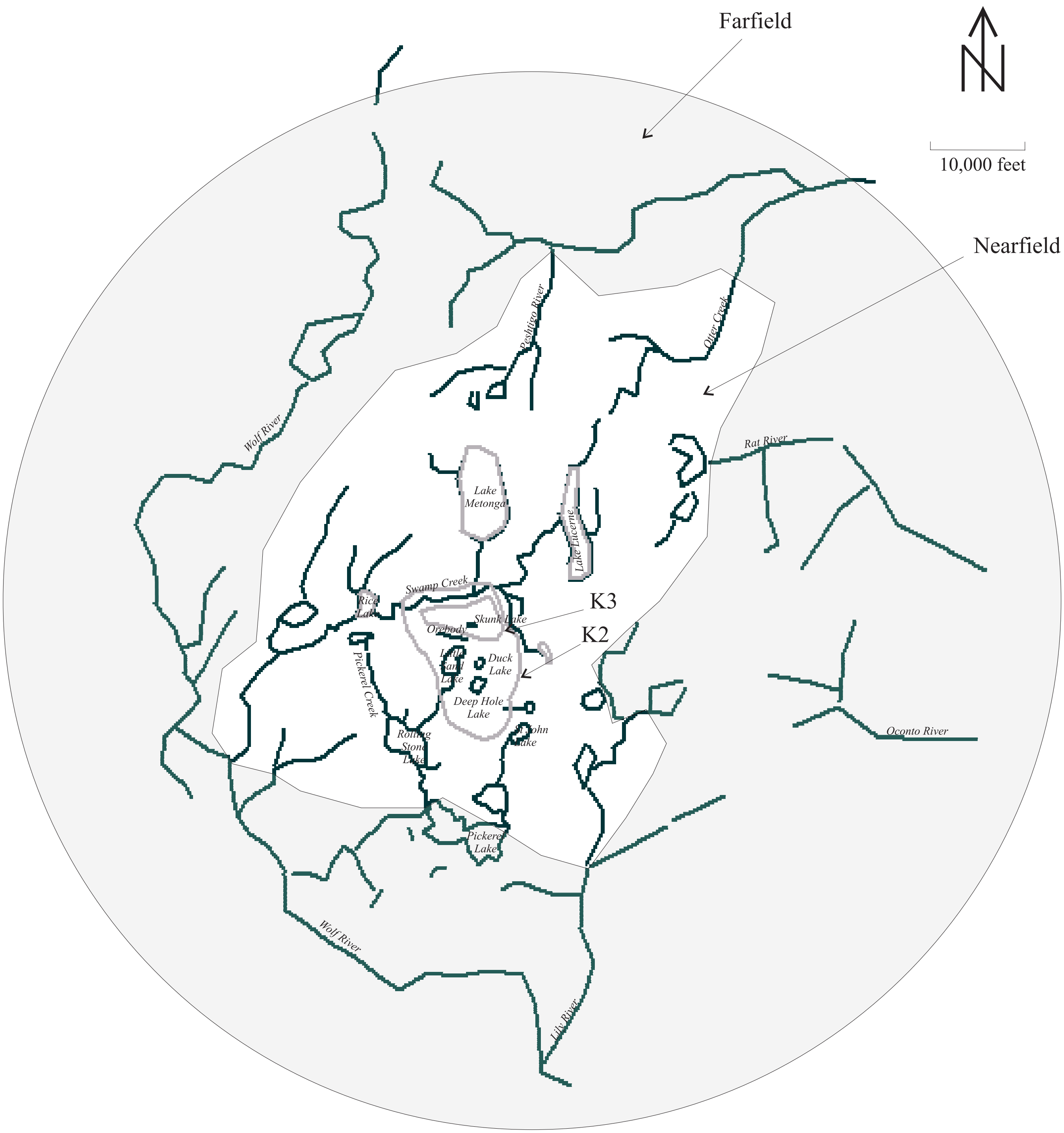


Figure 7. *Simulated hydrologic features with analytic elements. The parameters chosen for optimization in the GFLOW model (Haitjema and Kelson, 1998) included the global hydraulic conductivity (K1), the hydraulic conductivity of the larger inhomogeneity that extends from Swamp Creek to St. John's Lake (K2), the hydraulic conductivity of the small inhomogeneity that extends from north of the ore body to Swamp Creek (K3), the global recharge (R1) within the large circle (applied to both the near and far fields, and the resistance of the stream sediment originally assigned values of 0.3 day and 1.0 day.*

conductivity and 3) VCONT, the vertical hydraulic connection of the unconsolidated sediments. The VCONT values for layers 4-5 were not varied, nor were any of the bedrock parameters. Reasons for not varying these parameters are discussed in the section "Evaluation of Calibration."

5.7.1.4 Outwash Pinchout Zone

The outwash pinchout zone is depicted in areas north and east of the proposed mine site, roughly along the margin of drumlins where the upland terrain meets the lowlands. The outwash pinchout imposes low-hydraulic-conductivity material in layers representing unconsolidated deposits to simulate the absence of outwash in a setting that over glacial time remained unfavorable for deposition of coarse material from meltwater running off retreating glaciers. The effect of varying the representation of the outwash pinchout on the model calibration is demonstrated in Appendix II.

5.7.2 Bedrock Calibration Using Bedrock Pumping Tests

In 1981, extensive pumping tests were conducted on boreholes penetrating the eastern part of the ore body (the 213 borehole) and the western part of the ore body (the 211 borehole). In 1994, a pumping test was also conducted on the shallow bedrock (the PWAR borehole). The pumping rates and durations for the three tests were 560 gpm for 7 days at the 213 borehole, 225 gpm for 7 days at the 211 borehole, and 78 gpm for 16 days at the PWAR borehole.

The two 1981 tests have been analyzed with the regional model as reported by Feinstein (1999) and the applicant (GeoTrans, 1999). The GeoTrans document also contains the results of an analysis of the smaller-scale PWAR 1994 test using an inset model prepared by GeoTrans based on their regional model (Foth and Van Dyke, 1995b). The following are among the conclusions of Feinstein (1999):

• The 213 pumping test can be successfully simulated using the regional model. The PWAR test can be successfully simulated with an inset model. Efforts to simulate the 211 pumping test with the regional model are only marginally successful, probably because it is difficult to simulate the dewatering of the bedrock within the eastern part of the ore body that occurred during that test.

• Final hydraulic conductivity estimates from the analyses of the 213 pump test use the continuity-based configuration of the ore body.

• Final hydraulic conductivity estimates from analyses of the PWAR test used the volume-based ore body configuration.

• The calibrations of all three tests are very sensitive to the vertical hydraulic conductivity (Kv) of the Early-Wisconsin till – it is the most important parameter in controlling the amount of the water that can be pumped by a well in the ore body or that must be pumped to dewater an excavation in the ore body.

• Analysis of model fluxes suggests that the pumping tests differ with respect to the areas that they stress and the size of those areas – it appears that the 213 test induced vertical flow through the till at a significant distance from the trace of the ore body.

• A Kv value of 0.075 ft/day for the Early-Wisconsin till best matches the PWAR test, but it does not provide a good match to the 213 test.

• A Kv value of 0.6 ft/day for the Early-Wisconsin till best matches the 213 test, but it does not provide a good match to the PWAR test.

• The difference in the two Kv values for the Early-Wisconsin till is attributable to the scale of the PWAR and 213 tests – they define a "Low End" Case and a "High End" Case that can be used for prediction of the effects of the proposed mine on local water conditions.

• The High End value assigned to the Kv value of the Early-Wisconsin till in the model calibration of the 213 test is correlated to a High End value for the weakly-weathered hanging wall equal to 0.05 ft/day. The pumping test analyses also served to quantify the Low End and the High End values for the hydraulic conductivity of the various bedrock units tabulated in Feinstein (1999).

5.7.3 Solver Options

The DNR model is not highly sensitive to the type of solver employed or to solver parameters. The SIP and PCG solvers converge to nearly identical solutions for a convergence criterion of 0.001 ft. The WET/DRY option in MODFLOW is active in the simulations, but in the absence of transient stresses it has only a small influence on the outcome.

5.7.4 High End and Low End DNR Models

Changes, as previously described, in the ore body configuration, bedrock representation and weathering, along with associated hydraulic conductivities have resulted in two "Cases" of the DNR model (Low End and High End). The Low End Case model uses the volume-based ore body configuration and hydraulic conductivities derived from the PWAR test, while the High End Case model uses the continuity-based ore body configuration and hydraulic conductivities derived from the 213 test. The most significant difference between the High End and Low End Case models arises from the value assigned to the vertical hydraulic conductivity of the early Wisconsin till and the value assigned to the hydraulic conductivity of the weakly-weathered hanging wall. The vertical hydraulic conductivity of the Early Wisconsin till and the geometric mean of the horizontal hydraulic conductivity of the weakly weathered bedrock for the Low End Case are 0.075 and 0.00094 ft/day, respectively. The values are 0.600 and 0.05000 ft/day for the High End Case, respectively.

5.7.5 Evaluation of Calibration of DNR Model

The calibration of the High End and Low End Case Base models to steady-state (October 1984) conditions is not sensitive to the lower till or bedrock hydraulic conductivity parameters (that is, to the values derived from the bedrock pumping tests for the Early Wisconsin till, ore body, weathered hanging wall, weathered footwall and unweathered bedrock). Accordingly, these values were left fixed during the parameter estimation procedure. The calibration is sensitive to the horizontal (Kh) and vertical hydraulic (Kv) conductivity of the glacial deposits and to the global recharge rate. Figure 8 shows the calibrated steady-state water table configuration, which compares favorably to the October 1984 water table shown in figure 2.

Preliminary calibration to October 1984 head and flux data produced a good fit with a dryland recharge value close to 10 inches per year and with the hydraulic conductivity values in table 2 (column labeled "Starting"). Optimization of parameters with UCODE includes both head and the flux targets so that it can better constrain the solution with respect to both recharge and the hydraulic conductivity of the glacial deposits. Flux targets included Swamp Creek at Highway 55, Hemlock Creek near the confluence with Swamp Creek, Outlet Creek near Lake Metonga, and the outlet of Ground Hemlock Lake. The flux targets were weighted according to the quality of the data set, with Swamp Creek at Highway 55 considered the best quality data for calibration, and therefore, given the most weight of any of the flux targets. As already noted, individual parameters are not estimated, rather a single multiplier is applied to the "Starting" Kh/Kv values and another multiplier to the original recharge rate. The results are listed in table 2 (column labeled "Updated"). In all cases they are very similar to the values listed under "Starting."

The calibration results and statistics for the High End and Low End Case Base Runs in table 3 indicate the overall quality of the match between the

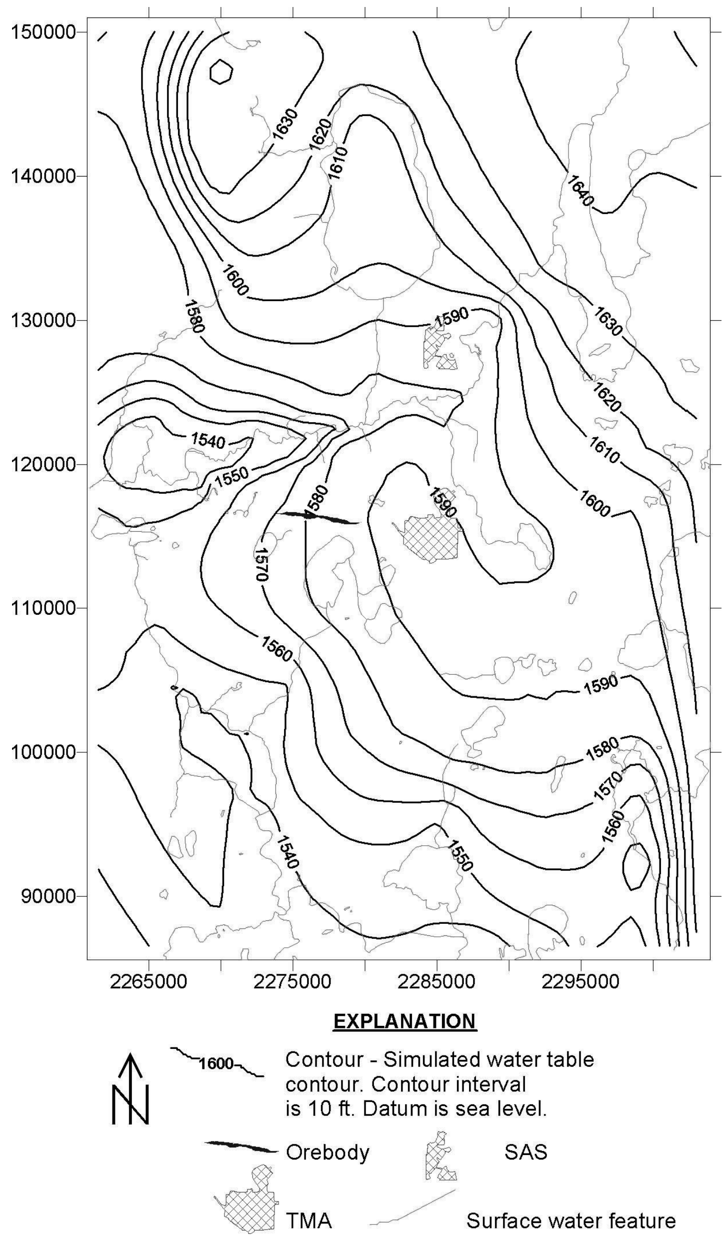


Figure 8. *Calibrated steady-state water table. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

observed and simulated heads at 212 locations. The error is defined to equal the observed minus the simulated head. Mean error (ME) is a measure of the bias in the error (negative values indicate that observed values are on average smaller than simulated values by the given amount). Mean absolute error (MAE) is a measure of the goodness-of-fit. A value of 2 ft indicates that the average absolute value of the error is 2 ft. Root mean square error (RMS) is a measure of the influence of outliers with large error. A value close to the MAE indicates that the number of targets with large error is small. The Low End and High End Case Base models have similar calibration statistics.

The calibration results were also evaluated by examining the spatial distribution of error for each run. The 212 head calibration targets are segregated by subdomain according to the pattern shown in figure 9. The calibration statistics are calculated for each subdomain and presented in table 3.

In all cases, the calibration statistics for the "Transition" area and for the "North" area are not as good as the statistics for the other areas. The Transition area defines a region that rims the ore body and includes only 6 target wells. The North area constitutes a large region between Skunk Lake and Swamp Creek and encompasses 37 calibration targets. Although the mean error is decidedly negative, some of the target wells in the North area also have large positive errors. Any simple change to the hydraulic conductivity or recharge of this area that tends to raise or lower the head would improve the fit for some wells but worsen it for others, resulting in a similarly poor overall fit. Only a detailed field investigation of this area could produce the detailed zonation of hydraulic conductivity data necessary to reduce the error to the levels achieved in the "Inner," the "Internal Lakes" and the "South" areas.

A final category of output for High End and Low End calibrated base models is the behavior of the internal lakes. They are evaluated in terms of the rate of flow from the lakes to groundwater (i.e., the "recharge" rates of the lakes) and the implied surface runoff coefficient as a fraction of basin precipitation. Recall that the surface water outflow is treated as a constant value independent of lake stage.

Examination of table 4 shows that the recharge rates from the lakes and the runoff rates into the lakes are very similar for the High End and Low End models. The runoff rates are all close to 15

Table 2. Model parameters for the Low End and High End Case Calibration Runs. [abbreviations: in/yr, inches per year; ft/day, feet per day; Kh, uniform horizontal hydraulic conductivity; Kx, horizontal hydraulic conductivity in the x-direction of the grid; Ky, horizontal hydraulic conductivity in the y-direction of the grid; Kv, vertical hydraulic conductivity]

Low End Case Parameters

	Recharge (in/yr)	
	Starting	Updated
Dryland and Seepage Lakes	9.7	9.93
Discharge Lakes	5.7	5.83

	Hydraulic Conductivity (ft/day)			
	Kh		Kv[a]	
	Starting	Updated	Starting	Updated
Unconsolidated:				
Late Wisconsin Till	0.8	0.77	0.4	0.385
Fine Outwash	20	19.3	2	1.93
Coarse Outwash	80	77.2	8	7.72
Early Wisconsin Till/Massive Saprolite	2	1.93	0.075	0.075
Pinch-out Zone Outwash	6	5.79	0.6	0.579
Bedrock:				
Strongly Weathered Footwall			0.23	
Moderately Weathered Footwall			0.028	
Weakly Weathered Footwall			0.012	
Unweathered Footwall			0.001	
Strongly Weathered Orebody (Zinc)			8	
Moderately Weathered Orebody (Zinc)			1.7	
Weakly Weathered Orebody (Zinc)			1.7	
Strongly Weathered Orebody (Copper)			0.23	
Moderately Weathered Orebody (Copper)			0.028	
Weakly Weathered Orebody (Copper)			0.012	
Strongly Weathered Hanging Wall			0.048	
Moderately Weathered Hanging Wall			0.014	
Weakly Weathered Hanging Wall			0.001	
Unweathered Hanging Wall			0.001	

[a] *The Kh values for the bedrock can be determined from the following equations:*

*Kx = 3.162 * Kv; Ky = Kv / 3.162*

High End Case Parameters

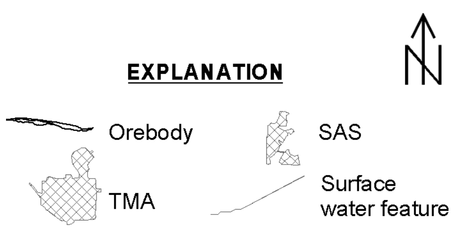
	Recharge (in/yr)	
	Starting	Updated
Dryland and Seepage Lakes	9.7	9.92
Discharge Lakes	5.7	5.83

	Hydraulic Conductivity (ft/day)			
	Kh		Kv[a]	
	Starting	Updated	Starting	Updated
Unconsolidated:				
Late Wisconsin Till	0.8	0.75	0.4	0.375
Fine Outwash	20	18.6	2	1.85
Coarse Outwash	80	74.6	8	7.46
Early Wisconsin Till/Massive Saprolite	3	2.8	0.6	0.6
Pinch-out Zone Outwash	6	5.6	0.6	0.56
Bedrock:				
Strongly Weathered Footwall			0.2	
Moderately Weathered Footwall			0.1	
Weakly Weathered Footwall			0.05	
Unweathered Footwall			0.005	
Strongly Weathered Orebody (Zinc)			7	
Moderately Weathered Orebody (Zinc)			1.5	
Weakly Weathered Orebody (Zinc)			0.05	
Strongly Weathered Orebody (Copper)			0.2	
Moderately Weathered Orebody (Copper)			0.1	
Weakly Weathered Orebody (Copper)			0.05	
Strongly Weathered Hanging Wall			0.05	
Moderately Weathered Hanging Wall			0.05	
Weakly Weathered Hanging Wall			0.05	
Unweathered Hanging Wall			0.005	

Table 3. DNR model calibration statistics by area for the High End and Low End Case Calibration Runs.

Simulation	Area	Number of Targets	Mean Error (feet)	Mean Absolute Error (feet)	Root Mean Square Error (feet)
Low End Case Calibration Run (UC-8)	Entire Model	212	-0.088	1.841	2.605
	Zone*				
	Inner	26	-0.254	1.713	2.389
	Transition	6	3.418	3.897	4.441
	TMA	26	0.148	1.419	1.600
	Internal Lake	19	-0.087	1.350	1.815
	North	37	-0.996	3.180	4.189
	South	98	0.022	1.451	2.005
High End Case Calibration Run (UC-78)	Entire Model	212	-0.078	1.881	2.642
	Zone*				
	Inner	26	0.549	1.561	2.316
	Transition	6	3.430	3.906	4.456
	TMA	26	0.279	1.546	1.733
	Internal Lake	19	-0.275	1.422	1.875
	North	37	-1.032	3.199	4.223
	South	98	-0.155	1.522	2.061

** See figure 7 for location of the zones.*



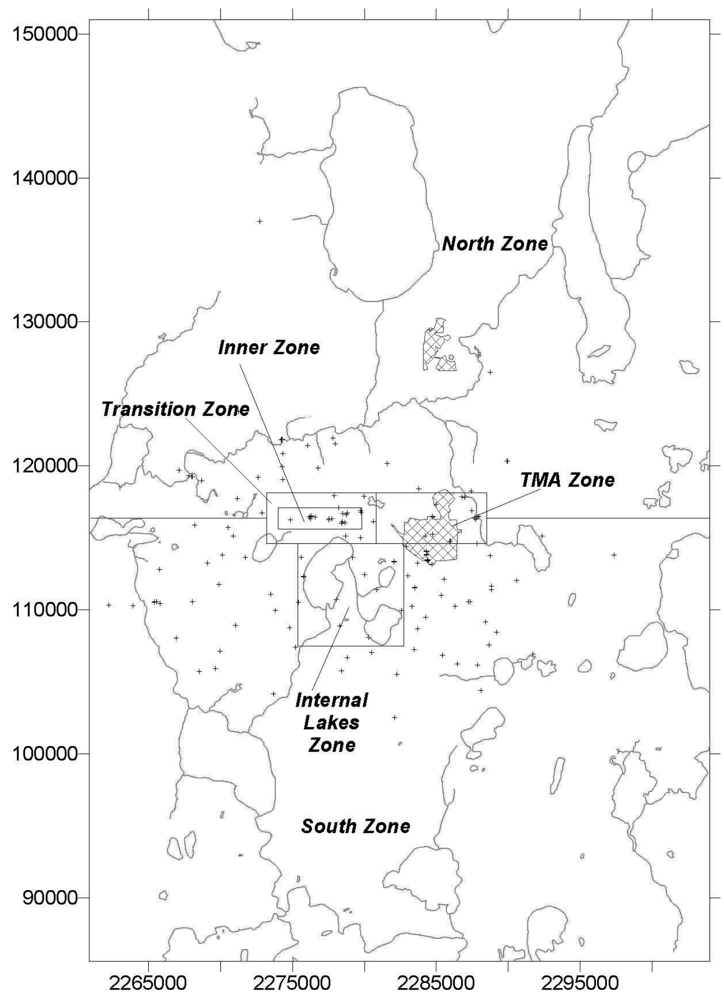


Figure 9. *Calibration targets grouped by zone. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

Table 4. Internal lake budgets from the DNR model calibration for the High End and Low End Calibration Runs. [abbreviation: cfs, cubic feet per second]

Simulation	Lake	Seepage Rate (inches/year)	Surface Outflow (cfs)	Watershed Runoff Fraction
Low End Case	Deep Hole	33.8	0.2	0.163
Calibration Run	Duck	23.8	0.1	0.138
(UC-8)	Little Sand	30.3	0.4	0.161
	Skunk	59.2	0	0.150
High End Case	Deep Hole	33.3	0.2	0.161
Calibration Run	Duck	23.6	0.1	0.138
(UC-78)	Little Sand	29.7	0.4	0.159
	Skunk	60.6	0	0.154

percent. The recharge rates for the three larger lakes, all between 23 and 33 in/yr, are reasonable rates of seepage. The Skunk Lake rate of 60 in/yr is anomalously high and may be overestimated. Nevertheless, because the lake is such a small feature, it represents a very small flux with respect to the water balance of the entire model area.

Section 6

Simulation of the Hydrologic Effects of Mine Dewatering

Though the DNR model is reasonably calibrated, there remains significant uncertainty in input parameter values and model predictions. Uncertainty may be addressed using several methods. A range may be used for a given parameter (e.g., lakebed hydraulic conductivity) or more than one configuration of a hydrogeologic unit (e.g., the ore body) may be used. The end result is a *set* of simulations that capture the range of reasonably possible hydrologic effects (e.g., reduction in baseflow, lake stage change) due to mine dewatering.

A range of hydrologic effects due to mine dewatering was simulated using combinations of hydraulic conductivity/bedrock configuration (the Low End and High End Cases previously described), mining sequence (Zinc and Copper Phases) and mine/grouting plans (Versions 1 and 2). Determining the range of possible effects of mine dewatering also includes an analysis of the effect of mine workings depictions, grout configurations, Soil Absorption Site discharge rates, recharge rates and, lakebed hydraulic conductivities. For each scenario, a series of runs (simulations) including calibration, background, base, sensitivity, revised calibration, and revised background were made. A description of each of these types of runs is provided in table 5.

Drains are used to simulate removal of water from a model cell for simulations of mine operation. To simulate atmospheric conditions, both the applicant's and the DNR's model place drain heads at the center of each ore cell. A sensitivity analysis using the DNR model indicated that model results are insensitive to drain elevation as long as the elevation is less than the cell top and greater than the cell bottom.

6.1 Overview of Mining Scenarios

The mining scenarios consist of High End and Low End Cases of both the Zinc and Copper Phases of mining. The High End and Low End Cases differ with respect to the hydraulic conductivity values assigned to various hydrostratigraphic units as well as the configuration of the ore body (volume-based and continuity-based, see section 5.5). Higher hydraulic conductivities and more continuous ore in the High End simulations favor greater mine inflow and greater stress on surface water bodies.

The Zinc Phase is simulated as a single step of

Table 5. Major types of DNR MODFLOW simulations.

Simulation Type	Description
Calibration Run	Runs that simulate the two selected bedrock configurations and associated parameter sets (High End and Low End Cases; see Tables 2, 3, and 4). These runs are the optimized "best fit" to selected head and flux targets.
Background Run	Runs that simulate background conditions immediately prior to mining (the pre-mining situation) using the same bedrock configurations/parameter sets as the Calibration runs (High End and Low End Cases). Base runs are compared to the appropriate Background run to assess changes due to the conditions simulated in the Base run. The primary difference between a Background run and a Calibration run involves the inclusion of a proposed outflow measurement structure on Little Sand Lake.
Base Run	Runs that simulate the mining phase (zinc, copper, or post-mining), mine workings (absence, presence, extent), grout configuration (extent and characteristics), and soil adsorption site representation (discharge) for a particular bedrock configuration (see Table 6). These runs are the same as Background runs, but have included features related to mining.
Sensitivity Run	Runs that simulate modifications or adjustments to the Calibration, Background, and/or Base runs made to better understand the models or the existing hydrologic system. These changes made to the models can involve unit hydraulic conductivity, mining phase, mine workings, grout configuration, soil adsorption site representation, etc. These runs sometimes require revised Calibration and Background runs to incorporate the effects of input changes on pre-mining conditions.

complete mining of the massive ore, and is simulated under long-term (effectively steady-state) conditions. Thus, model cells associated with all zinc stopes identified in the mining plan are allowed to receive mine inflow simultaneously. Similarly, the Copper Phase is modeled as a second long-term (effectively steady-state) stress with all planned stringer ore activated simultaneously. Four mining scenarios are defined by the combination of Cases and Phases.

In addition there are two Versions of the model. Version 1 of the model corresponds to the understanding of the mining plan presented by the applicant prior to 2001. Version 2 corresponds to the most recent update of these plans, including more extensive grouting (summer of 2001). These Versions are distinguished by:

- Differences in the extent of mine workings,
- Differences in the extent of the grout ceiling in the crown pillar overlying the ore body and,
- The presence or absence of a grout curtain placed on the outside of the major mine workings and keyed to the grout ceiling.

The more extensive the mine workings, the greater is the resulting mine inflow. Conversely, the more extensive the grout element, the smaller is the resulting mine inflow.

Version 1 of the model is characterized by limited representation of mine workings, a grout ceiling that is located only directly above the ore body, and no grout curtain. Version 2 is characterized by a full representation of the mine workings, a grout ceiling that extends beyond the subcrop of the ore to the edge of the access drifts, and a vertical grout curtain that extends downward from the grout ceiling in the crown pillar into the rock surrounding the ore body. Both Versions are subjected to the four scenarios defined by the combination of the Cases and Phases.

An additional set of runs in support of the solute transport modeling at the Tailings Management Area (TMA) simulates the Post Mine Phase, wherein groundwater levels recover following the cessation of mine dewatering. High End and Low End simulations of this third Phase have been performed for both Version 1 and Version 2 of the model. Table 6 summarizes and lists these "Base Run" simulations.

6.2 Construction of Mining Scenarios

GeoTrans, on behalf of the applicant, first developed almost all the features of the model discussed in this section. In this report, the TWG documents testing of these features in order to produce reasonable bounds of uncertainty around the model results.

Table 6. List of Base Run simulations used to assess the hydrologic system, analyze the sensitivity of the models and estimate the effects of the mine on the site area hydrology. [abbreviations: HW, hanging wall; FW, footwall; K, hydraulic conductivity; gpm, gallons per minute]

Model Version	Mining Phase	Bedrock Case	Simulation Name	Mine Workings Depiction[a]	Grout Configuration[b]	Soil Absorption Site Representation
1	Zinc	High End	**ZINC2A**	HW Drains	Limited Ceiling, High K	Discharge = 1500 gpm
1	Zinc	Low End	**ZINC1A**	HW Drains	Limited Ceiling, High K	Discharge = 525 gpm
1	Copper	High End	**COPPER2A**	HW Drains	Limited Ceiling, High K	Discharge = 1500 gpm
1	Copper	Low End	**COPPER1A**	HW Drains	Limited Ceiling, High K	Discharge = 525 gpm
1	Post	High End	**POST2A**	HW High K	Limited Ceiling, High K	—
1	Post	Low End	**POST1A**	HW High K	Limited Ceiling, High K	—
2	Zinc	High End	**HHZN1B**	HW & FW Drains	Extended Ceiling, Limited Curtain, Medium K	Discharge = 1500 gpm
2	Zinc	Low End	**LLZN1B**	HW & FW Drains	Extended Ceiling, Limited Curtain, Medium K	Discharge = 525 gpm
2	Copper	High End	**HHCU1B**	HW & FW Drains	Extended Ceiling, Limited Curtain, Medium K	Discharge = 1500 gpm
2	Copper	Low End	**LLCU1B**	HW & FW Drains	Extended Ceiling, Limited Curtain, Medium K	Discharge = 525 gpm
2	Post	High End	**POSTHH**	HW & FW High K, with Additional Vertical Shafts	Extended Ceiling, Limited Curtain, Medium K	—
2	Post	Low End	**POSTLL**	HW & FW High K, with Additional Vertical Shafts	Extended Ceiling, Limited Curtain, Medium K	—

[a] *The mine workings in all Version 1 mining simulations were represented by 366 drains in the hanging wall; there were no footwall workings simulated. The hanging wall mine workings in the Version 2 mining simulations were represented by 478 drains; the footwall mine workings in the Version 2 Copper Phase simulations were represented by 264 drains. The post mining simulations included no mine workings drains, rather the same cells with drains contained high K zones.*

[b] *The ceiling grout was located in the crown pillar directly above the thickest portion of the zinc ore; the limited configuration consisted of 18 acres of grouted bedrock, the extended configuration consisted of 69 acres. The curtain grout was located in the hanging wall and footwall between the mine workings, where present, or ore body and the surrounding bedrock; the limited curtain extended from the level of the ceiling grout down 260 feet. The hydraulic conductivity of the grouted bedrock was assigned to be 0.028 ft/day for High K and 0.0028 ft/day for Medium K.*

The MODFLOW model runs designed to predict the influence of the proposed Crandon mine on the groundwater and surface-water systems incorporate changes to the High End and Low End Case Base models of background conditions. Each change listed below is discussed with more detail in turn. Where appropriate, reference is made to appendixes that contain figures showing spatial extent or schematic drawings with sample calculations.

1. Insertion of MODFLOW drain cells that represent mine stopes (Appendixes I-1 and I-2).
2. Insertion of drain cells that represent grouted mine workings (Appendixes I-3 and I-4).
3. Modification of the leakance arrays to represent the grout ceiling (Appendixes I-5 and I-6).
4. Insertion of MODFLOW horizontal flow

barriers along the outer edge of the lateral mine workings to represent the vertical grout curtain (only for Version 2 of the model) (Appendixes I-7 and I-8).

5. Modification of the recharge array to represent water transferred from the mine and infiltrated at the Soil Absorption Site (SAS) and the reduction of recharge at the TMA (Appendix I-9).
6. Modification of surface runoff to internal lakes reflecting the influence of the TMA.
7. Introduction of Little Sand Lake structure to control surface outflow.
8. Insertion of a well for water supply at the mine (Appendix I-10).

Copper Phase runs and Post Mine runs contain additional elements:

9. Insertion of low-conductivity cells to represent backfilling with a paste of wasterock.
10. Updating of lake stages at the internal lakes based on results from previous mining Phase simulations.

For the Post Mine runs, there is a final set of modifications to circulate water downward during the Post Mine Phase as outlined in the Reflooded Mine Management Plan (Foth and Van Dyke, 2000) (Version 2 only):

11. Replacement of mine-workings drains with high conductivity cells, and
12. Insertion of high-conductivity cells to represent open vertical shafts.

6.2.1 Mine Stopes

Mine stopes are portions of ore that are to be removed and then backfilled with paste tailings. Because the stopes are emptied during mining, they cannot be modeled in terms of rock material properties, but only as internal boundary conditions, such as drains, to the model. The cells containing these boundary conditions correspond to zinc ore or copper ore slated for mining. They are found in layers 7 through 13 of the model. The arrangement of stopes is different for the High End and Low End Case scenarios due to the differing bedrock configurations.

One way to model an internal boundary condition that accepts water is to use MODFLOW drains. In this application, each drain element represents a mined chamber in terms of an estimated water level in the chamber that controls the gradient between the surrounding rock and the stope, and a conductance term that controls the flow between the remaining rock in the cell and the inside of the chamber. The drain water level is estimated by assuming it is equal to the elevation midway along the vertical extent of the model cell corresponding to the stope. That is, surface atmospheric conditions (zero pressure head) are assumed to exist within the cell and to have an average head value equal to the mid-elevation of the cell. Appendix I-1 contains a detailed description and example of the estimation of conductance. The method selected to estimate drain conductance tends to produce large conductance terms that maximize the water that can flow into the drain (stope) from the surrounding rock in the model.

The High End Case of the model contains 309 zinc stope cells and 198 copper stope cells. The Low End Case contains 272 zinc stope cells and 203 copper stope cells. Appendix I-2 contains figures that show the location of these cells by layer for both cases. Appendix I-2 also contains figures that show the vertical extent of the zinc and copper stopes for the two cases at selected sections. Mine stopes active in the Zinc Phase are backfilled with low-hydraulic conductivity paste tailings for the Copper Phase. Mine stopes active for the Copper Phase are backfilled for the Post Mine Phase.

6.2.2 Mine Workings

Mine workings refer to the drifts, cross cuts and ramps (tunnels) that are excavated in the rock in order to access the ore. Again they can be represented as internal boundary conditions in the form of MODFLOW drains with water levels set at the middle elevation of cells. However, unlike the stope chambers, these openings are best conceptualized as long cylinders that run through model cells. The conductance term is a function of the surface area of the cylinder. It is also a function of the leakance through the surrounding material, where leakance is a hydraulic conductivity divided by a thickness. For Version 1 of the model, the surface area corresponds to a cylinder with a radius equal to 10 ft and a length equal to the appropriate lateral dimension of the model cell; the hydraulic conductivity corresponds to the vertical hydraulic conductivity of the surrounding rock in the cell; and the thickness is equated with one-quarter the thickness of the cell. In effect, the resistance to flow into the mine workings is conceptualized as a function of the surrounding rock properties. For Version 2 of the model, the surface area corresponds to a cylinder with a radius equal to 8 ft and a length equal to the appropriate lateral dimension of the model cell, the hydraulic conductivity corresponds to an assumed grout conductivity equal to 0.003 ft/day (1e-6 cm/sec) and the thickness corresponds to an assumed grout penetration of 10 ft. In this instance the resistance to flow into the mine workings is conceptualized as a function of the grout injected into the wall during mining operations. It should be noted that the method used in Version 2 yields on average conductance values equal to about one-quarter the value used in Version 1.

Layers 7 through 10 of the model are assumed to contain one level of mine workings per model layer. Layers 11 through 13 (thicker than the overlying model layers) are assumed to contain two levels per layer, and therefore, calculated conductance values are doubled for model input because in MODFLOW, each model cell may only contain a single drain element (Appendix I-4).

The configuration of mine workings is limited to the hanging wall (northern) side of the mine in Version 1 for both the Zinc and Copper Phases. For Version 2, the mine workings are limited to the hanging wall side for the Zinc Phase, but also include the footwall side for the Copper Phase. The drains representing the mine workings are eliminated in the Post Mine Phase and replaced with high-conductivity cells meant to simulate the availability of low-resistance pathways. The total number of drain cells that represent mine workings depends on the model version (table 6): Version 1, 366 drains in the hanging wall only; Version 2, 478 drains in the hanging wall and 264 drains in the footwall. Schematic figures and sample calculations of drain conductances are provided for both Versions 1 and 2 of the model in Appendix I-3. The locations of the drains are superimposed over maps of the workings by layer in figures contained in Appendix I-4. One set of figures corresponds to Version 1 of the model and one set to Version 2. Note that the depiction of the 300 ft mine level in the DNR model does not correspond to current mine plans; it corresponds to an earlier version of the mine plan provided by NMC.

6.2.3 Grout Ceiling

The mining plan contains provisions for a 25-foot thick grout ceiling in the crown pillar. In the MODFLOW model, its location corresponds to the top half of layer 6. The ceiling is represented mathematically through a reduction in the vertical leakance term that controls flow between layers 5 and 6 of the model. The leakance term is equal to K'/b', where K' is the assumed vertical hydraulic conductivity of the grouted zone and b' is the assumed thickness equal to 25 ft. For every mining scenario, the leakance term used to simulate premining conditions is reduced to reflect the insertion of grout. In addition, the lateral transmissivity of model layer 6 is approximately halved to reflect the reduced flow in this 50-ft layer.

In Version 1 of the model, the grouted zone hydraulic conductivity is set to 0.03 ft/day (1e-5 cm/sec). The extent of the grout ceiling is assumed to be coincident with the extent of the subcrop of the zinc ore for the Zinc Phase (about 18 acres) and coincident with the combined subcrop of the zinc ore and copper ore for the Copper Phase (about 26 acres).

In Version 2 of the model, the grouted zone hydraulic conductivity is set to be substantially lower, at 0.003 ft/day (1e-6 cm/sec) based upon the more detailed grouting plan provided by the applicant (TRC, 2000; TRC and Whetstone Associates, 2001). The grout ceiling is assumed to extend beyond the subcrop of the ore body to just beyond the long east to west drifts that constitute the main mine workings in the hanging wall and footwall. The same configuration of the grout ceiling is used for both the Zinc and Copper Phases. The areal extent of the ceiling is about 60 acres. For all Post Mine scenarios, the grout ceiling is assumed to remain in place with the same characteristics. Appendix I-5 provides a schematic figure of the grout ceiling and a sample leakance calculation. Appendix I-6 shows the location of the grout ceiling for the various scenarios.

6.2.4 Grout Curtain

The updated grouting plan (TRC, 2000; TRC and Whetstone Associates, 2001) calls for the insertion of grout along vertical segments to inhibit flow from the hanging wall and footwall toward the mine if necessary to control mine inflow. It was incorporated in both High and Low Cases to estimate conditions using the version of the applicant's grouting plan detailed below.

The combined effect of the grout injection is assumed to produce a horizontal flow barrier that is 25 ft thick and reduces rock hydraulic conductivity to 0.003 ft/day (1e-6 cm/sec). This curtain joins the grout ceiling that extends just beyond the lateral drifts. The grout curtain is only present in Version 2 of the model and was incorporated to explore the full range of conditions. The depth to which the curtain extends is an important variable. Given the difficulty in physically implementing the curtain, for this work it is assumed to have only a limited depth associated with the mining levels that extend approximately 260 ft below the crown pillar in the DNR model. This interval corresponds to model layers 6, 7, and 8.

The MODFLOW horizontal flow barrier (Hsieh and Freckleton, 1993) is well suited to simulating the grout curtain. It incorporates the conductance term based on the assumed thickness and grout hydraulic conductivity. A schematic drawing and sample conductance calculation is provided in Appendix I-7. Appendix I-8 contains figures showing the location of the grout curtain for Version 2 scenarios that depict the curtain relative to the ore body and the mine workings. The grouting plan calls for the grout to be placed beyond the external wall of the stopes or drifts that extend furthest into the hanging wall or footwall. Accordingly, the curtain should fit like a glove around these openings and follow them in staircase fashion from model layer to model layer as the ore body dips to the north. However, to simplify the model input, the curtain was simulated as a strictly vertical element. Along the footwall, the curtain is keyed vertically to the southernmost stopes or workings in layer 7. Along the hanging wall, the curtain is keyed vertically to the northernmost stopes or workings in layer 8. In this way the curtain accommodates the inclination of the ore body, but, as shown by the second figure in Appendix I-8, it does not necessarily abut a drain cell. Because the curtain only extends from layer 6 to layer 8 in the base runs for Version 2 of the DNR model, the error in the placement of the grout curtain is always small—typically no more than one cell. The separation between the drain cells and the barrier cells would be more pronounced should a deeper curtain be simulated with this model.

6.2.5 Modification of Recharge Array

Simulation of two features of the mining plan call for adjusting the background average recharge rate at two locations. The first involves an infiltration gallery at the Soil Absorption Site (SAS) where treated water pumped during mine operations is released. The SAS is proposed to be located on the north side of Swamp Creek (Appendixes I-9 and I-10). The total area of the system corresponds to 6 model cells, limiting the ability of the model to yield detailed results in the area of the SAS. Except where noted, infiltration applied at the SAS is assumed to total roughly 100 gpm less than the simulated mine inflow to both stopes and mine workings. This quantity of water is partitioned between the model cells at the SAS as a function of the system area in each cell. The resulting infiltration rate is added to the background recharge rate (approximately 10 in/yr). A sample partitioning calculation is provided in Appendix I-9. The 100 gpm was chosen to accommodate consumptive use of water in the project (such as evaporation from TMA and reclaim pond and residual moisture in the ore concentrates shipped off the site for processing).

The second adjustment to recharge involves the Tailings Management Area (TMA). By the end of the Zinc Phase, about 67 acres of the TMA will be covered with a nearly impermeable liner, resulting in a reduction in recharge to the groundwater system equal to 33 gpm. By the end of the Copper Phase, about 167 acres of the TMA will be lined, resulting in a reduction of recharge equal to 86 gpm. The cells at the lined locations are assigned a zero recharge for each Phase. The figure in Appendix I-10 shows the location of the TMA liner for the two mining Phases.

For Post Mine scenarios, no additional recharge beyond the model-wide dryland rate is added to the SAS cells, but recharge is still excluded from the full extent of the TMA, accurately reflecting the plan of operations for the mine.

6.2.6 Modification of Surface Runoff

The MODFLOW lake package (LAK2) utilized to simulate the effect of mining on the four internal lakes (Deep Hole, Duck, Little Sand and Skunk) requires surface runoff into each lake as one set of inputs. The surface changes at the mine site and at the TMA are expected to change the basin area contributing to three of the four internal lakes, and therefore, the amount of surface runoff. Based on analyses conducted by Foth and Van Dyke (1998b) and the assumption that for Little Sand Lake a reduction of surface-water inflow from Duck and Deep Hole Lakes due to loss of water to the groundwater system must be accounted for (GeoTrans, 1998a and 1998d), the percent changes to basin area are estimated to be -2.3 percent for Deep Hole Lake basin, +0.5 percent for Duck Lake basin, -9.0 percent for Little Sand Lake basin and, no change for Skunk Lake basin. A -9.0 percent reduction for Little Sand Lake basin is assumed for both the High End and Low End Cases given that the outflow from Duck and Deep Hole Lakes was fixed to the same amount in both Cases. The surface runoff rates required for mass balance in the base mining runs are detailed in table 7.

The reduction in surface runoff is significant for Little Sand Lake because the drawdown effect of the mine on the lake level will be accentuated in the model by the simultaneous loss of runoff inflow.

6.2.7 Little Sand Lake Structure

The mining plan includes construction of a structure at the outlet to Little Sand Lake to measure surface water outflow (Foth and Van Dyke, 1996/1998). By the nature of its design, it will constrict outflow to some degree, thereby influencing the response of lake level to pumping from the mine. The structure is represented by a three-step rating curve that is documented in a series of model runs performed by the applicant (Foth and Van Dyke, 1998c). This structure is assumed to be active during mining and post mine scenarios. When the lake level falls below the minimum elevation of the structure, all surface outflow is assumed to cease. Deep Hole Lake and Duck Lake maintain the same fixed surface outflow used in the background runs. However, the response to mining typically causes the stage to fall below the assumed

Table 7. Changes due to mining operations in watershed surface runoff assigned to interior lakes for the Version 1, Zinc Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfd, cubic feet per day; %, percentage]

Simulation	Lake	Change in Input Surface Runoff Relative to Pre-Mine Phase (negative values indicate net decrease) (cfd)	(gpm)	percentage
Low End	Deep Hole	-1018	-5.3	-2.3%
	Duck	65	0.3	0.5%
	Little Sand	-8304	-43.2	-9.0%
	Skunk	0	0	—
High End	Deep Hole	-1008	-5.2	-2.3%
	Duck	65	0.3	0.5%
	Little Sand	-8186	-42.6	-9.0%
	Skunk	0	0	—

outflow elevation in these two lakes whereupon the surface outflow ceases.

6.2.8 Water Supply Wells

NMC plans to install a water supply well in the glacial deposits south of the ore body (see location figure in Appendix I-10). The well is modeled as penetrating layer 2 of the model and discharging a small amount of water (25 gpm). In addition, a well is proposed for the TMA for mitigation purposes. The TMA well is not simulated because it is expected to operate for a limited time during construction. The mitigation well proposed for the access road right of way was also not simulated due to the coarseness of the model grid at that location.

6.2.9 Backfilling of Stopes

The 309 zinc stopes in the High End Case Zinc Phase would be backfilled at the beginning of the subsequent Copper Phase runs. Similarly, the 272 zinc stopes in the Low End Case Zinc Phase would be backfilled at the beginning of the corresponding Copper Phase runs. The backfilling is simulated by replacing the vertical hydraulic conductivity of the zinc ore at each cell with a single value equal to 0.0003 ft/day (1e-7 cm/sec) (Golder Paste Technology, 1998). For simplicity, the assumed anisotropy ratios for all of the bedrock is assumed to hold and results in a horizontal hydraulic conductivity equal to 0.0009 ft/day (3e-7 cm/sec) in the east–west direction and 0.00009 ft/day (0.3e-7 cm/sec) in the north–south direction. The same method is used to simulate the backfilling of the 198 High End or 203 Low End copper stopes at the beginning of the corresponding Post Mine scenarios. The model results are insensitive to the assumption of horizontal anisotropy in the hydraulic conductivity of the paste.

6.2.10 Updating of Lake Stages

Lake stages in the four internal lakes respond to the simulated mining activity during the Zinc Phase. New lake stages are entered into updated lake budget inputs for the subsequent Copper Phase. Similarly, the response to copper mining results in new lake stages for the Post Mine Phase simulations.

6.2.11 Replacement of Mine Workings Drains with High-Conductivity Cells in Post Mine Phase

The drains representing the mine workings are eliminated in the Post Mine Phase and replaced with high-conductivity cells meant to simulate the availability of preferential pathways through the open workings. For example, the long east-to-west drifts in the hanging wall are represented as a line of high-conductivity cells in layers 7 through 13. However, it is worth noting that because these pathways are not connected to any major source, or sink, of water, they have minimal effect on the regional flow field.

In all scenarios, the vertical hydraulic conductivities in mine workings cells (Version 1, 366 cells; Version 2, 746 cells) are converted from their original values to 1,000 ft/day. This implies Kv values of 3,162 ft/day in the east-west direction and 316 ft/day in the north-south direction. These values ares selected to simulate a condition of negligible resistance to flow in these cells.

6.2.12 Insertion of Open Vertical Shafts During the Post Mine Phase (Version 2 Only)

As part of the closure plan for the mine, NMC has proposed opening certain vertical shafts after mining to enhance downward circulation of uncontaminated shallow groundwater and dilution of potentially contaminated deeper groundwater at mining levels (Foth and Van Dyke, 2000). This concept is simulated by converting the vertical hydraulic conductivity to 1,000 ft/day at 5 shaft locations extending from the top of the crown pillar (layer 5) to the deepest mining levels (layers 12 and 13). The shaft locations by layer are shown in Appendix I-11. In all, 50 cells are used to represent the shafts. The change to the vertical hydraulic conductivity is only applied to the Post Mine scenarios for Version 2 of the model.

6.3 Solution Techniques for Mining Scenarios

NMC and the TWG adopted a steady-state approach to modeling the Zinc and Copper Phases. Rather than attempting to simulate the response of the system though time to each stage of mining, the entire zinc portion of the mine is opened "at once" in the model and the long-term response to the complete emptying of stopes and mine workings is simulated. Similarly, the entire copper portion of the mine is opened "at once." This approach was adopted for simplicity and probably overestimates to a limited extent the mine inflow that would occur if the multiple stages included in the mining plan for the zinc and copper phases were explicitly simulated in sequential order by the model. A sensitivity run reported later in this report partly addresses the effect of this simplification.

Owing to the complexity of the model and the strength of the stress represented by the mine, it is not possible to achieve a steady-state solution directly. Instead, the long-term condition is approached using a transient solution that is run long enough so that a steady-state solution is closely approached. For all practical purposes a steady-state solution is attained when the rate that water enters and leaves storage in the MODFLOW mass balance is very small (a few gallons per minute).

A transient runtime of 40 years was used for all Zinc Phase scenarios and 20 years for all Copper Phase scenarios because these runtimes are sufficient to produce solutions where storage plays a negligible role in the mass balance. The times themselves have no physical meaning relative to mine operations. Rather, they are a function of the storage coefficients assigned to the model and the parameters applied to the SIP solver.

The two types of storage coefficients used in the model are "specific yield," which controls the release of water from drainage of the aquifer due to a declining water table, and "specific storage," which controls the release of water from consolidation of the rock matrix and expansion of water due to a declining potentiometric surface. These coefficients determine the rate at which falling water levels approach a new equilibrium condition in the presence of a long-term stress like the mine. In this model application, the values given to the storage parameters are used primarily to control the rate at which the numerical solution approaches a final equilibrium state rather than to simulate conditions as the system approaches that state. By slowing down the rate at which the computer approaches the long-term steady-state solution, the storage parameters allow a stable convergence.

The SIP solver itself requires an additional set of input parameters. They consist of the head change threshold that defines convergence during an iteration, the seed used to initiate the solver, the acceleration parameter which controls the rate at which it converges to a solution, and the number of iteration parameters involved in the solution. The values adopted for mining simulations are: head tolerance of 0.01 ft, seed of 0.006, acceleration parameter of 0.60, and number of iteration parameters of 5.

The most important characteristic of a good MODFLOW solution is that the value of the mass balance error is small. Each of the eight Base runs has a small mass balance error. The maximum error is -0.03 percent and the absolute value of the average error is 0.01 percent.

The High End Case runs and the Copper Phase Low End Case runs (Versions 1 and 2) not only have low mass balance error, but meet the head change threshold (that is, no cell suffers a head change greater than 0.01 ft during the last iteration). The two Zinc Phase Low End Case runs do not converge to the head change criteria (0.01 ft) despite achieving a low mass balance error. In that situation, the results are taken after the iteration limit is reached.

Because the Post Mine scenarios do not contain the stress of mine dewatering, they can be solved directly in steady-state mode. Therefore, the results of these runs represent groundwater conditions after all the effects of the mine have dissipated, but with the grout ceiling still in place. This potentially gives rise to increased groundwater levels over the ore body relative to pre-mining conditions. Recharge excluded from the full extent of the TMA (potentially giving rise to decreased groundwater levels in its vicinity relative to pre-mining conditions), and the mine workings are open and represented as high conductivity zones.

The LAK2 package complicates the solution of all scenarios. The model must not only seek mass balance for the groundwater system, but also for each of the internal lakes. The balance for three of the internal lakes (Deep Hole, Duck and Little Sand) depends partly on the surface water outflow term (as well as the rates of net precipitation, surface runoff, and groundwater seepage). Outflow occurs when the stage is above the prescribed surface outlet elevation and ceases when the stage falls below that elevation. This mechanism allows lake stages to oscillate around the outlet elevation in the presence of a stress that tends to reduce the stage to the elevation of the outflow, but is not strong enough to cause it to continue to drop once the outflow is cut off. This occurs at Deep Hole Lake and Duck Lake where the mine stress causes the level to drop below the outlet and the removal of surface outflow in turn causes the level to rise and reactivates the outlet. Therefore, the results for any single iteration of the model are misleading and can suffer from mass balance errors of several percent. This oscillation does not occur for Little Sand Lake because even when lake stage drops below the outflow elevation, the stage continues to drop in response to mine operation.

To overcome the oscillation problem for the internal lakes, the results at the end of a number of iterations are averaged. The iterations corresponding to the final year or half year of the total 40-year or 20-year simulation (when the model is close to steady state) are used to generate the average lake stage, average lake area, and average groundwater seepage rate reported here. In this way, the mass balance error for the lakes falls below 1 percent.

The LAK2 package is employed in transient mode for the Zinc and Copper Phases. Because it is applied in steady-state mode for Post Mine conditions, no averaging is needed.

6.4 Modeling Results and Sensitivity to Selected Features

Simulation results are presented for the High End and Low End Cases and Zinc and Copper Phases of model Versions 1 and 2. Figures are presented primarily by Version. Version 1 figures include simulated drawdown, delineation of mine capture areas and graphs of cumulative distributions of simulated travel time to the mine from the water table (figures 10 through 15). Equivalent figures are presented for Version 2 (figures 16 through 21). Capture areas were delineated using forward particle tracking. For the Post Mine runs (Versions 1 and 2) figures are limited to a contour map showing residual long-term drawdown at the water table below the TMA owing to reduced recharge and to residual long-term drawup at the water table over the ore body owing to the presence of the grout ceiling (figures 22 and 23). Summaries of simulation results for the High End and Low End Cases and Zinc and Copper Phases of model Versions 1 and 2 are also presented in tables (tables 8 through 18). Results of sensitivity analyses showing the effect of varying selected model features on the results are presented in tables 19 through 27. Table 28 summarizes the simulated transient response of the groundwater system and table 29 summarizes the effect of mine inflow on the reduction in the extent of Little Sand Lake and Pickerel Creek basin baseflow. Tables 30 to 35 provide results concerning internal lakes and stream mitigation and tables 36 and 37 address simulation results using an alternative representation of Duck Lake which is discussed in section 6.4.3.4.3 and Appendix IX-3a and b.

6.4.1 Range of Results

Comparing a High End Zinc or Copper Phase run to a Low End Zinc or Copper Phase run provides an estimate of the minimum and maximum effect of mine dewatering on system components and an estimate of the uncertainty in the range of effects. It is instructive to review the range of results in terms of the effect on the following components of the hydrologic system:

- mine inflow,
- drawdown at the water table,
- the zone of capture around the mine,
- change in internal lake conditions, and
- change in baseflow to streams.

6.4.1.1. Mine Inflow

For a given pair of scenarios related to the same Phase of mining and same Version of the model, the High End mine inflow averages about 4 times more than the Low End. In general, the Low End runs predict mine inflow rates equal to or less than the 600 gpm mine operation threshold proposed by the applicant, while the High End runs exceed this value. For Version 2 of the model, the range is from approximately one-half 600 gpm to approximately two times 600 gpm. This range of values is one way of gauging the uncertainty in the results. The more extensive use of grouting elements in Version 2 tends to produce smaller overall effects than Version 1, despite the presence of a much greater extent of mine workings in Version 2.

6.4.1.2 Drawdown

The High End runs as compared to the Low End runs indicate greater water-table drawdown. In the vicinity of the ore body, maximum water-table drawdown for the Version 1, High End Case, Zinc and Copper Phases is 109 ft while the minimum for the Version 1, Low End Case, Zinc and Copper Phases is 46 ft. Version 2 runs indicate considerably less drawdown than Version 1 in the vicinity of the ore body, and range from 69 ft for the High End Case, Zinc Phase to 17 ft for the Low End, Copper Phase. The areal extent of the drawdown is greatest for the Version 1, High End Case, Zinc Phase run and smallest for the Version 2, Low End Case, Zinc Phase run. The one-foot drawdown contour for most scenarios extends westward close to the vicinity of Mole Lake.

The range of effects predicted by the Post Mine scenarios is very small. The drawdown at the TMA is indifferent to Cases because the reduction of recharge at the TMA is the same for all scenarios—the expected drawdown is 2 ft. The presence of the open vertical shafts in the Version 2 scenarios has very little effect on this residual response. The predicted drawup over the grouted mine is negligible.

6.4.1.3 Mine Capture Zone

All the model simulations indicate that the mine will capture recharge to the water table from a smaller area than it will influence in terms of decreased water levels and altered flow rates. Even if the mine is assumed to operate in perpetuity (as is simulated by the near steady-state result obtained at the end of the mine operation simulations), the zone of capture under all scenarios remains largely

Figure 10. *Simulated water-table change from background for Version 1, Zinc Phase A) High End Case Base Run with 1579 gpm mine withdrawal rate and B) Low End Case Base Run with 602 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

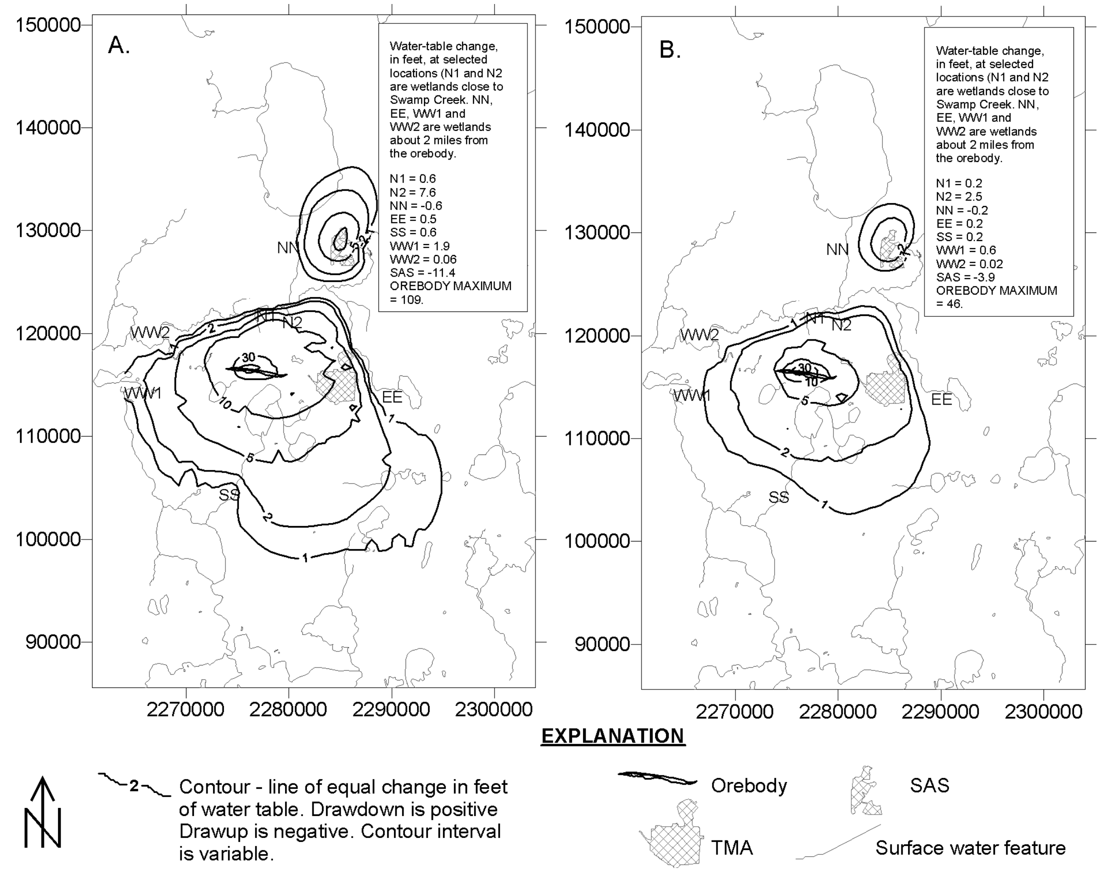
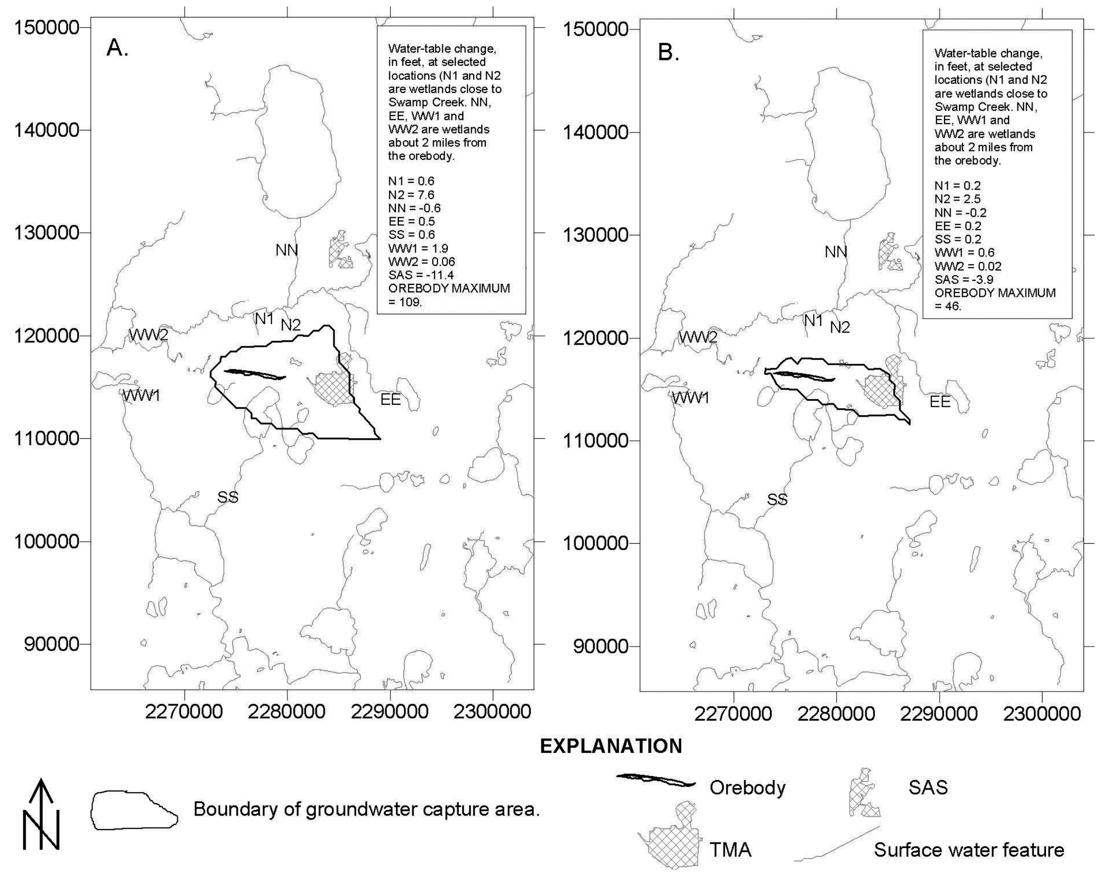


Figure 11. *Simulated mine capture areas for Version 1, Zinc Phase A) High End Case Base Run with 1579 gpm mine withdrawal rate and B) Low End Case Base Run with 602 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*



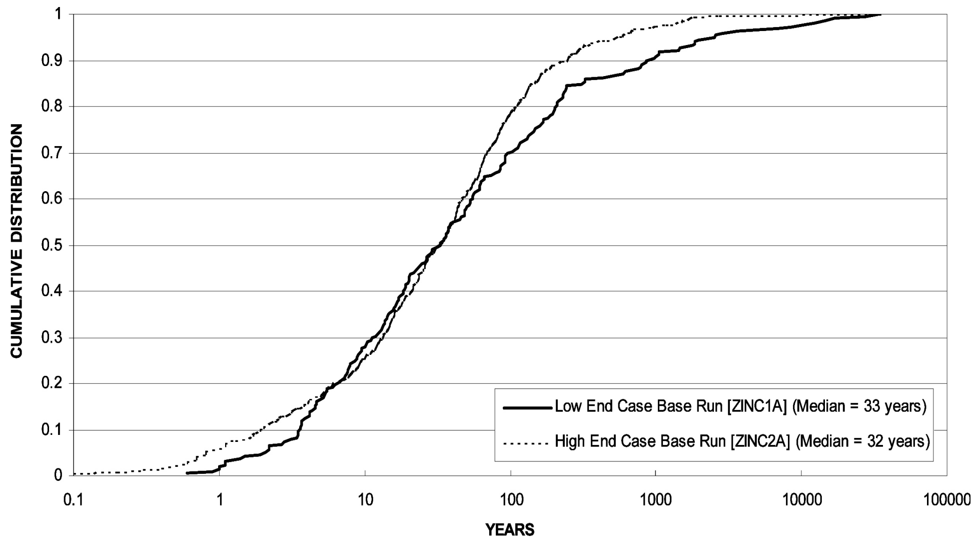


Figure 12. *Cumulative distributions of simulated travel times to the mine from the water table using the Version 1, Zinc Phase, High End and Low End Case Base Run models. The cumulative distribution curves that show predicted travel times from the water table to the mine were calculated by applying the particle tracking code PATH3D (Zheng, 1991) to the MODFLOW head results assuming the following effective porosity values: Layer 1 (mostly Late Wisconsin Till)=0.1, Layer 2 (mostly outwash)=0.3, Layer 3 (mostly outwash)=0.3, Layer 4 (mostly Early Wisconsin Till)=0.1, Layers 5 and 6 (saprolite or crown pillar)=0.04, Layers 7 through 13 (fractured bedrock)=0.02.*

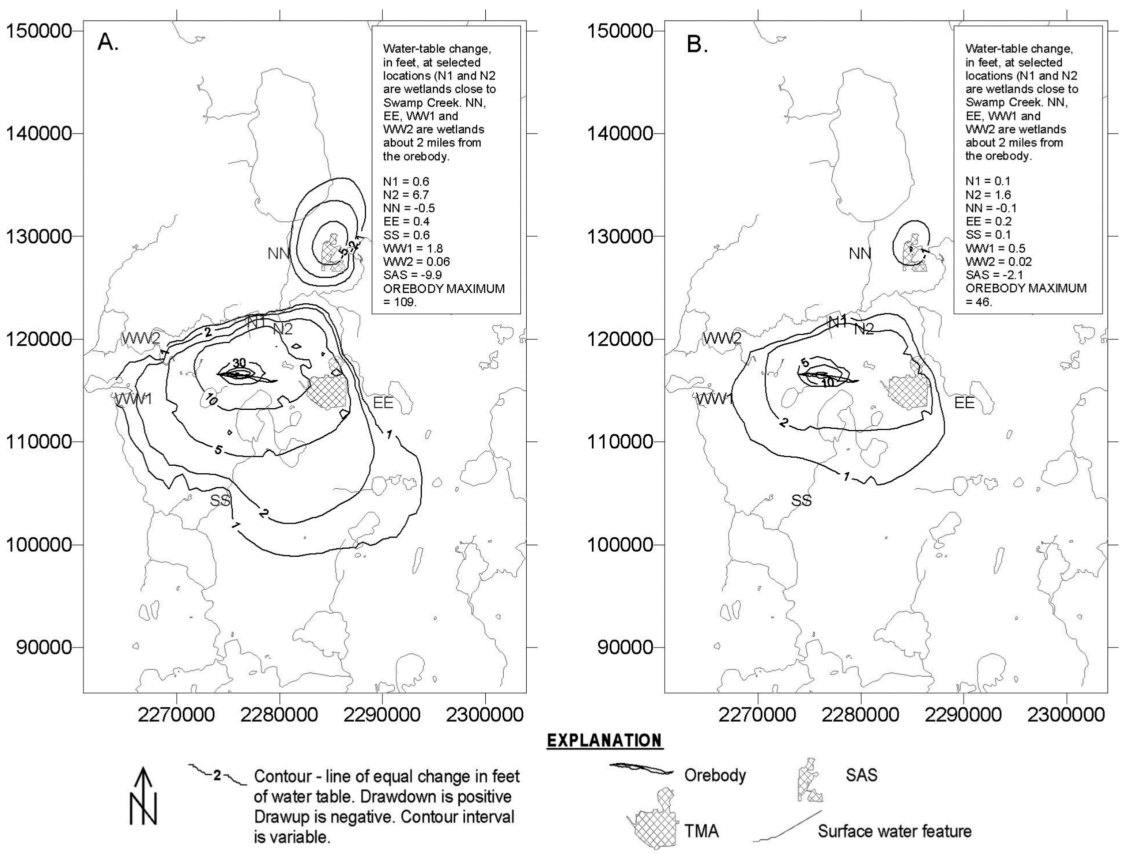


Figure 13. *Simulated water-table change from background for Version 1, Copper Phase A) High End Case Base Run with 1392 gpm mine withdrawal rate and B) Low End Case Base Run with 349 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

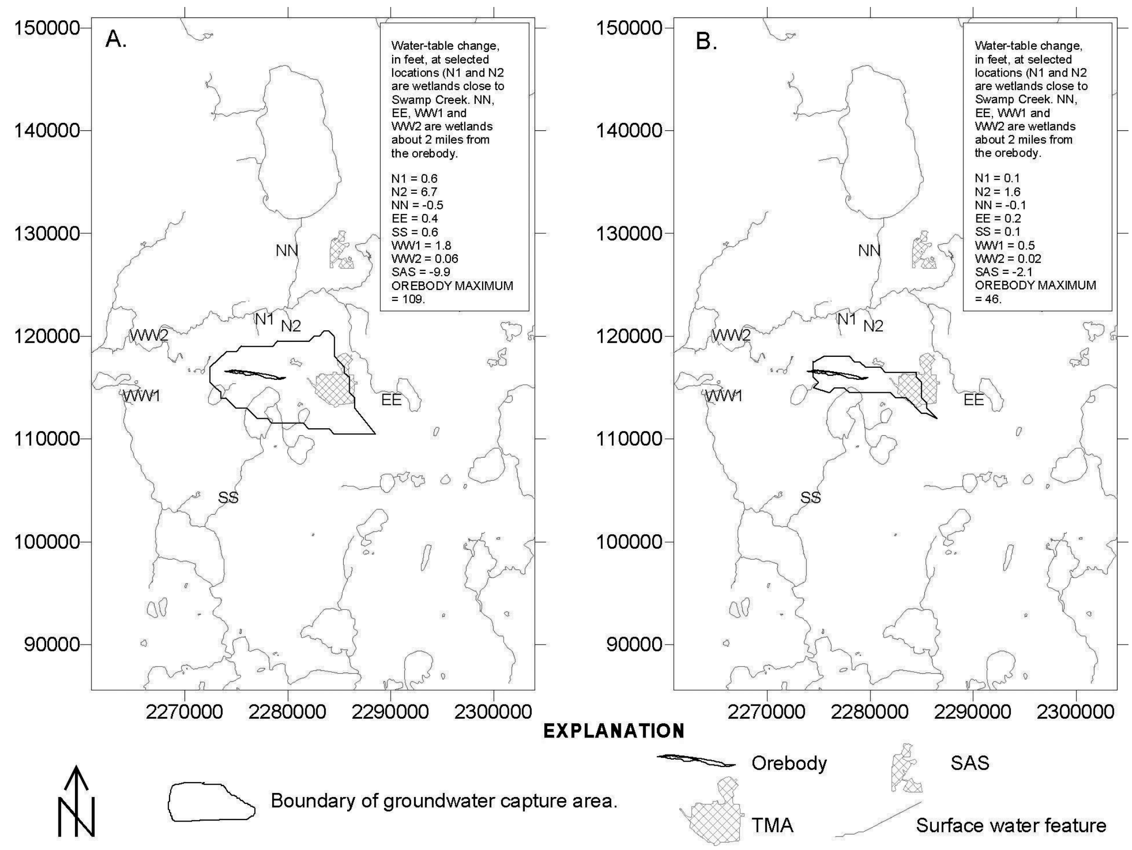


Figure 14. *Simulated mine capture areas for Version 1, Copper Phase A) High End Case Base Run with 1392 gpm mine withdrawal rate and B) Low End Case Base Run with 349 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute].*

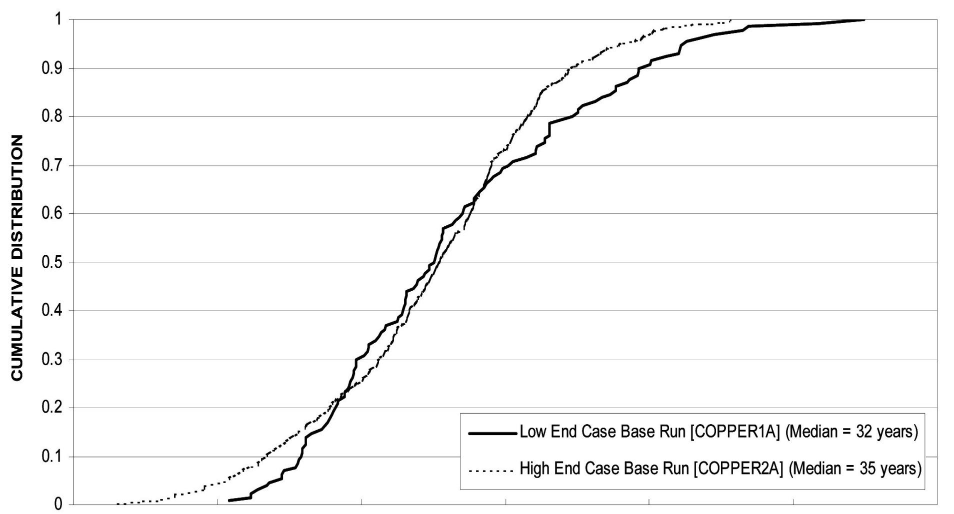


Figure 15. *Cumulative distributions of simulated travel times to the mine from the water table using the Version 1, Copper Phase, High End and Low End Case Base Run models. The cumulative distribution curves that show predicted travel times from the water table to the mine were calculated by applying the particle tracking code PATH3D (Zheng, 1991) to the MODFLOW head results assuming the following effective porosity values: Layer 1 (mostly Late Wisconsin Till)=0.1, Layer 2 (mostly outwash)=0.3, Layer 3 (mostly outwash)=0.3, Layer 4 (mostly Early Wisconsin Till)=0.1, Layers 5 and 6 (saprolite or crown pillar)=0.04, Layers 7 through 13 (fractured bedrock)=0.02.*

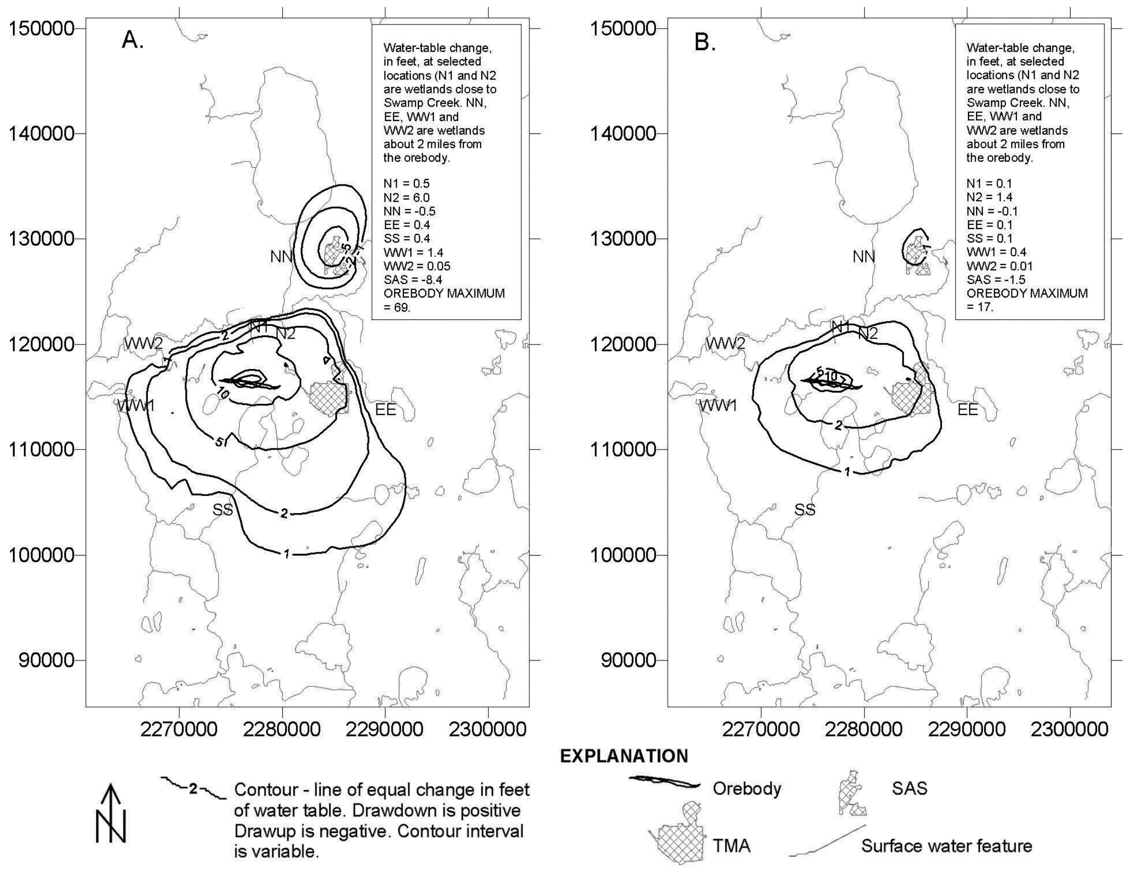


Figure 16. *Simulated water-table change from calibration for Version 2, Zinc Phase A) High End Case Base Run with 1176 gpm mine withdrawal rate and B) Low End Case Base Run with 285 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

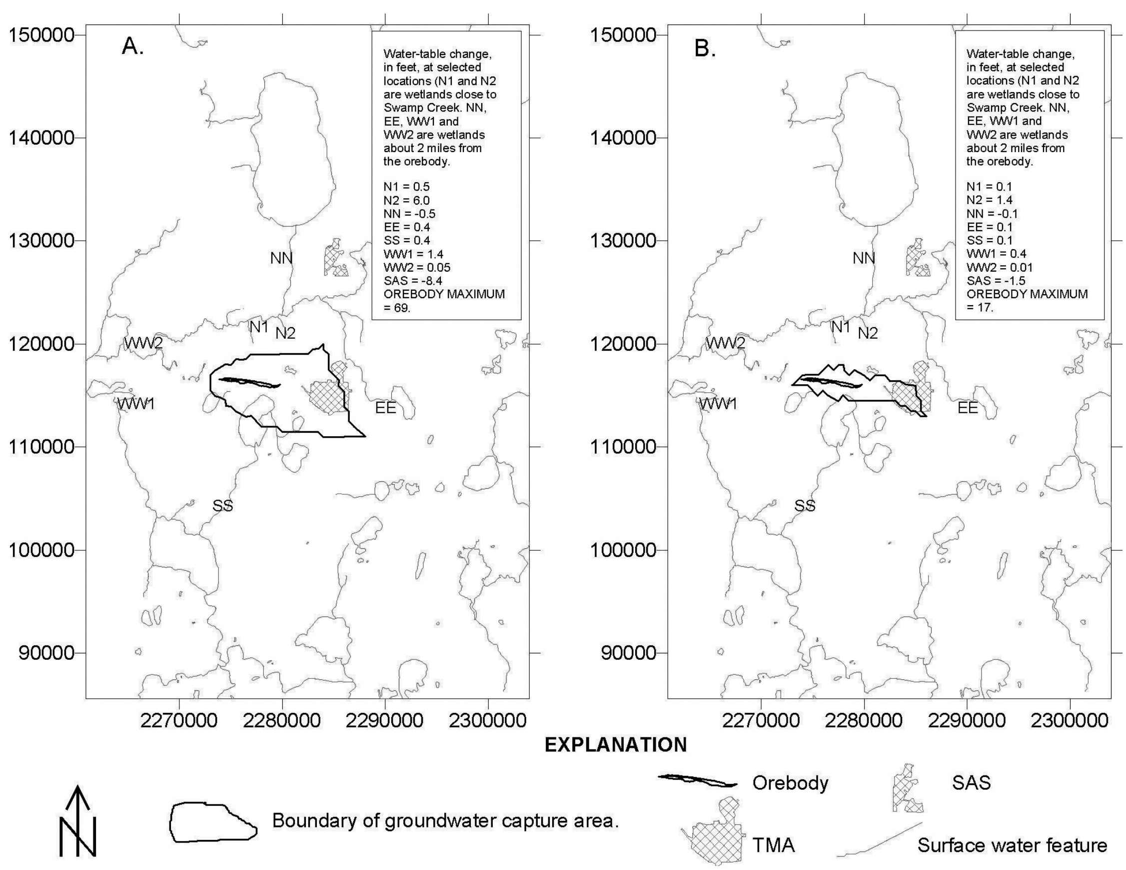


Figure 17. *Simulated mine capture areas for Version 2, Zinc Phase A) High End Case Base Run with 1176 gpm mine withdrawal rate and B) Low End Case Base Run with 285 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

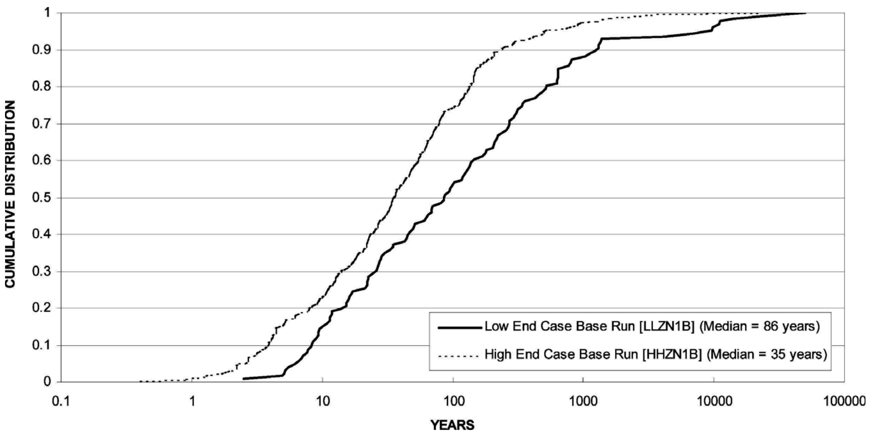


Figure 18. *Cumulative distributions of simulated travel times to the mine from the water table using the Version 2, Zinc Phase, High End and Low End Case Base Run models. The cumulative distribution curves that show predicted travel times from the water table to the mine were calculated by applying the particle tracking code PATH3D (Zheng, 1991) to the MODFLOW head results assuming the following effective porosity values: Layer 1 (mostly Late Wisconsin Till)=0.1, Layer 2 (mostly outwash)=0.3, Layer 3 (mostly outwash)=0.3, Layer 4 (mostly Early Wisconsin Till)=0.1, Layers 5 and 6 (saprolite or crown pillar)=0.04, Layers 7 through 13 (fractured bedrock)=0.02.*

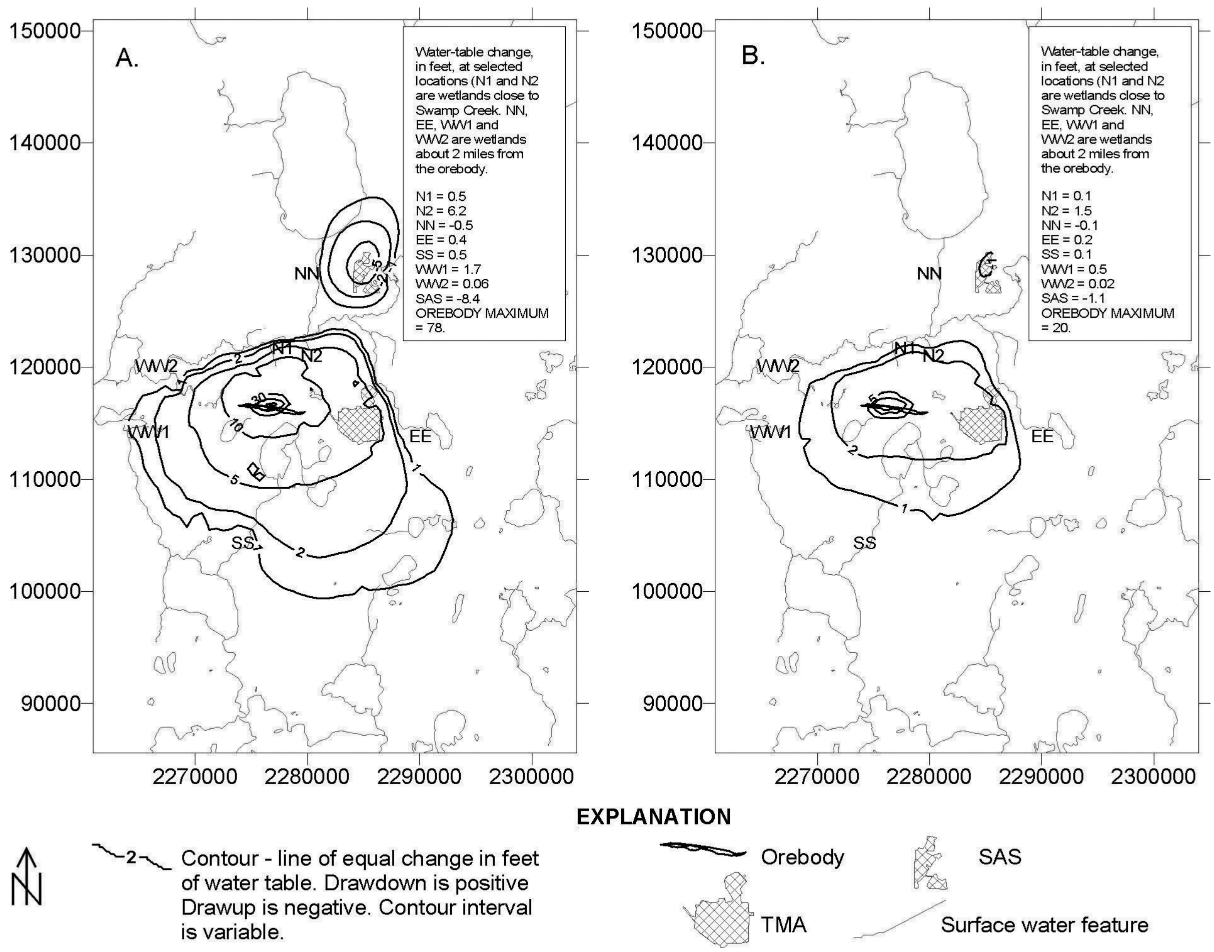


Figure 19. *Simulated water-table change from calibration for Version 2, Copper Phase A) High End Case Base Run with 1250 gpm mine withdrawal rate and B) Low End Case Base Case with 290 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

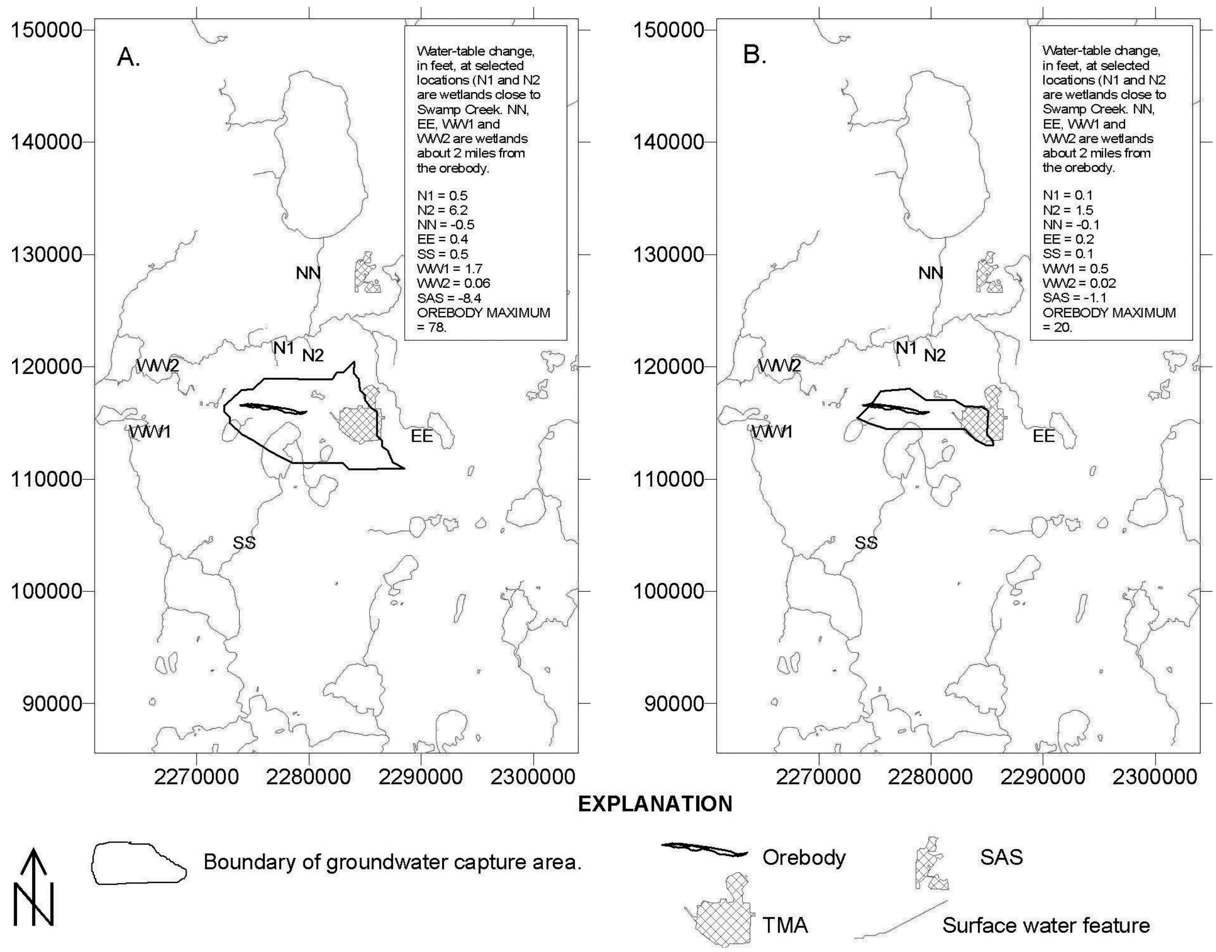


Figure 20. *Simulated mine capture areas for Version 2, Copper Phase A) High End Case Base Run with 1250 gpm mine withdrawal rate and B) Low End Case Base Run with 290 gpm mine withdrawal rate. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site; gpm, gallons per minute]*

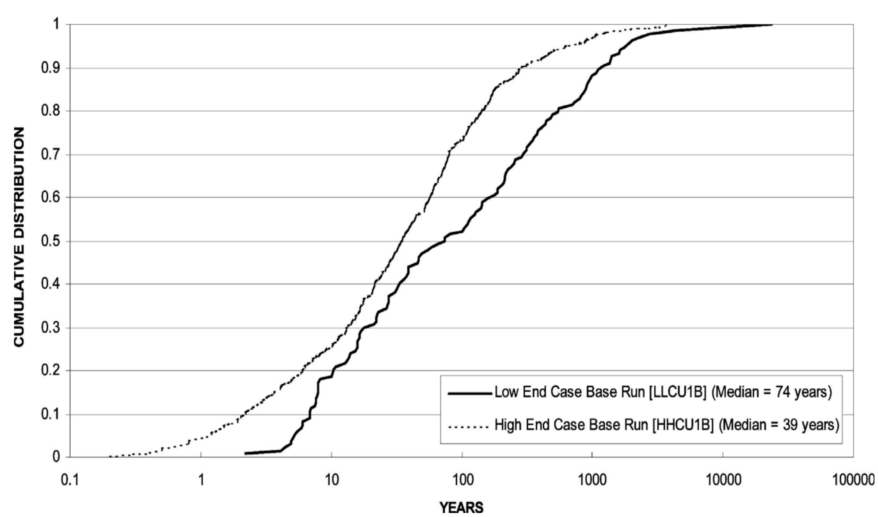


Figure 21. *Cumulative distributions of simulated travel times to the mine from the water table using the Version 2, Copper Phase, High End and Low End Case Base Run models. The cumulative distribution curves that show predicted travel times from the water table to the mine were calculated by applying the particle tracking code PATH3D (Zheng, 1991) to the MODFLOW head results assuming the following effective porosity values: Layer 1 (mostly Late Wisconsin Till)=0.1, Layer 2 (mostly outwash)=0.3, Layer 3 (mostly outwash)=0.3, Layer 4 (mostly Early Wisconsin Till)=0.1, Layers 5 and 6 (saprolite or crown pillar)=0.04, Layers 7 through 13 (fractured bedrock)=0.02.*

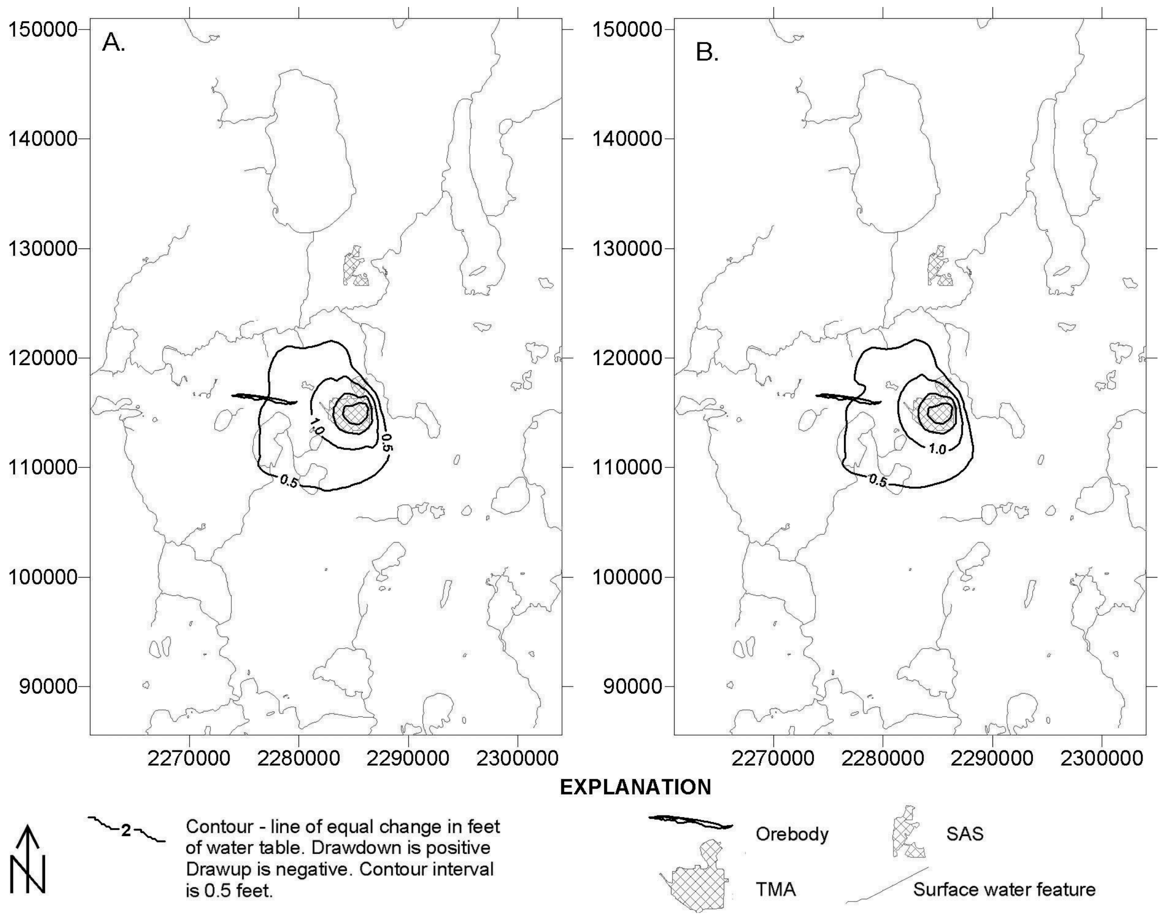


Figure 22. *Simulated water-table change from calibration for Version 1, Post mining A) High End Case Base Run and B) Low End Case Base Run. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

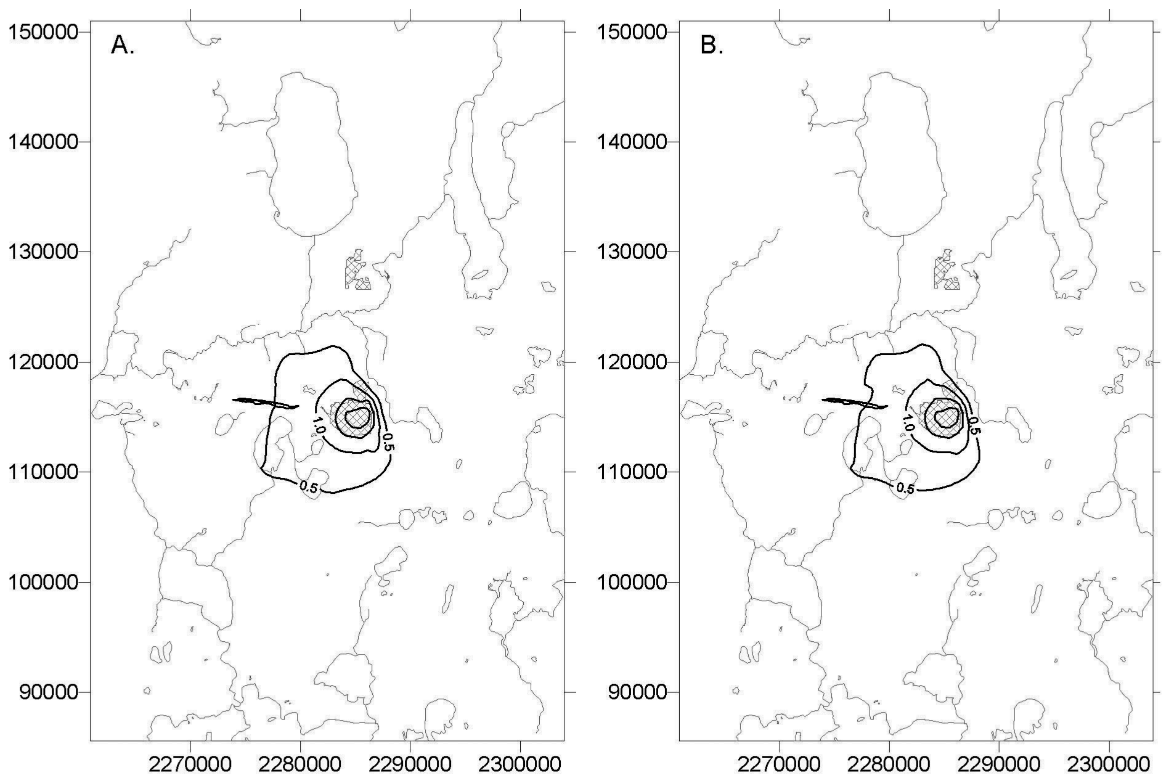


Figure 23. *Simulated water-table change from calibration for Version 2, Post mining A) High End Case Base Case and B) Low End Case Base Case. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

Table 8. Simulated mine inflow and the change in the stage, area and seepage of internal lakes and baseflow of selected streams from the Base Runs using the Version 1, Zinc Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Simulation	Number of Dry Bedrock Nodes	Mine Inflow Locale	Amount of Mine Inflow (gpm)	Amount of Mine Inflow (cfs)	Lake	Lake Stage Change (feet)	Lake Area Change (acres)	Lake Seepage Change (gpm)	Lake Seepage Change (cfs)	Net Baseflow Change (negative values indicate net decrease) Watershed[a]	(gpm)	(cfs)	percent
Low End Case	15	Stopes	515	1.147	Deep Hole	0.23	0.1	11	0.024	Swamp Cr.[b]	240	0.534	1.8%
Base Run		Workings	87	0.194	Duck	0.20	0.0	4	0.008	Pickerel Cr.	-192	-0.427	-2.9%
(ZINC1A)		Total	601.9	1.341	Little Sand	0.09	1.9	146	0.326	Lily River	-15	-0.034	-0.9%
					Skunk[c]	0.44	0.7	—	—				
High End Case	2	Stopes	1147	2.556	Deep Hole	0.24	0.1	28	0.062	Swamp Cr.[b]	654	1.456	4.9%
Base Run		Workings	433	0.965	Duck	0.20	0.0	9	0.020	Pickerel Cr.	-544	-1.211	-8.1%
(ZINC2A)		Total	1579	3.518	Little Sand	3.97	39.5	148	0.329	Lily River	-40	-0.089	-2.5%
					Skunk[c]	0.44	0.5	—	—				

[a] *The net change in baseflow for Swamp Creek is very small or positive due to the simulated discharge of treated wastewater at the Soil Absorption Site.*

[b] *Swamp Creek upstream of Highway 55.*

[c] *The lake package mass balance error precludes estimation of lake seepage change.*

Table 9. Simulated changes to surface waters from the Base Runs using the Version 1, Zinc Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Water Body	Low End Case Base Run[a]			High End Case Base Run[b]		
	Change in Base Flow[c]		Change from Base Case[c]	Change in Base Flow[c]		Change from Base Case[c]
Streams	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Upper Pickerel Creek	-72.6	-0.162	-5.7%	-200.5	-0.447	-15.7%
Martin Springs/Creek 11-4	-16.4	-0.037	-5.4%	-43.2	-0.096	-14.4%
Creek 12-2[d]	-36.7	-0.082	-12.1%	-86.8	-0.193	-28.8%
Creek 12-9	-34.3	-0.076	-2.4%	-131.6	-0.293	-9.4%
Lower Pickerel Creek	-4.8	-0.011	-0.6%	-12.2	-0.027	-1.6%
Creek 20-3	-14.5	-0.032	-1.9%	-37.2	-0.083	-5.0%
Swamp Creek System						
Hemlock Creek	-52.7	-0.117	-3.5%	-152.8	-0.340	-10.0%
Creek 20-13	-0.5	-0.001	-0.5%	-1.5	-0.003	-1.7%
Creek 33-8	-1.5	-0.003	-4.1%	-4.1	-0.009	-10.8%
Outlet Creek	116.1	0.259	13.1%	333.5	0.743	37.8%
Creek 19-14	-10.6	-0.024	-39.4%	-23.2	-0.052	-92.7%
Hoffman Springs/Creek	-22.5	-0.050	-8.4%	-67.3	-0.150	-24.9%
Swamp Creek	180.1	0.401	2.9%	473.6	1.055	7.6%
Swamp Cr. above Outlet Cr.	*309.7*	*0.690*	*10.6%*	*873.4*	*1.946*	*29.8%*
Swamp Cr. below Outlet Cr.	*-129.6*	*-0.289*	*-4.0%*	*-399.8*	*-0.891*	*-12.2%*
Lily River System						
Lily River	-2.4	-0.005	-0.4%	-6.3	-0.014	-1.1%

External Lakes	Change in Seepage[c] (gpm)	Change in Seepage[c] (cfs)	Change from Base Case[c]	Change in Seepage[c] (gpm)	Change in Seepage[c] (cfs)	Change from Base Case[c]
Pickerel Creek System						
Rolling Stone Lake	-6.5	-0.014	-1.1%	-16.7	-0.037	-3.0%
Crane Lake	-3.6	-0.008	-0.5%	-9.3	-0.021	-1.2%
Pickerel Lake	-2.4	-0.005	-0.4%	-6.0	-0.013	-1.1%
Swamp Creek System						
Ground Hemlock Lake	-17.6	-0.039	-1.6%	-46.6	-0.104	-4.2%
Lake Metonga	53.7	0.120	1.8%	156.7	0.349	5.1%
Rice Lake[e]	-1.4	-0.003	-1.3%	-4.1	-0.009	-3.7%
Mole Lake[e,f]	-3.6	-0.008	-180%	-10.5	-0.023	-1500%
Lily River System						
Jungle Lake	-6.5	-0.014	-48.2%	-17.0	-0.038	-79.8%
Lily Lake	-6.4	-0.014	-0.6%	-16.6	-0.037	-1.7%

[a] *Low End Case (ZINC1A): inflow simulated at 602 gpm, SAS infiltration assumed equal to 525 gpm.*

[b] *High End Case (ZINC2A): inflow simulated at 1579 gpm, SAS infiltration assumed equal to 1500 gpm.*

[c] *A negative value indicates an decrease in flow to the water body.*

[d] *Due to oversight, Creek 12-2 was simulated by Creeks 12-12a and 12-12d as on the USGS Mole Lake quad map.*

[e] *Portions of Mole Lake and Rice Lake are located outside the model domain and are not simulated.*

[f] *Mole Lake is a groundwater flow through lake that is a small net loser of water to groundwater under existing conditions, making the percentage change due to mining large.*

Table 10. Simulated mine inflow and the change in the stage, area and seepage of internal lakes and baseflow of selected streams from the Base Runs using Version 1, Copper Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

	Number of Dry Bedrock Nodes	Mine Inflow Locale	Amount of Mine Inflow			Lake Stage Change	Lake Area Change	Lake Seepage Change		Net Baseflow Change (negative values indicate net decrease)			
Simulation			**(gpm)**	**(cfs)**	**Lake**	**(feet)**	**(acres)**	**(gpm)**	**(cfs)**	**Watershed[a]**	**(gpm)**	**(cfs)**	**percent**
Low End Case	10	Stopes	309	0.688	Deep Hole	0.23	0.1	6	0.014	Swamp Cr.[b]	48	0.107	0.4%
Base Run		Workings	40	0.089	Duck	0.19	0.0	2	0.005	Pickerel Cr.	-146	-0.324	-2.2%
(COPPER1A)		Total	349	0.778	Little Sand	0.06	1.1	85	0.188	Lily River	-12	-0.026	-0.7%
					Skunk[c]	0.44	0.7	—	—				
High End Case	4	Stopes	773	1.722	Deep Hole	0.24	0.1	24	0.053	Swamp Cr.b	495	1.103	3.7%
Base Run		Workings	620	1.381	Duck	0.20	0.0	8	0.017	Pickerel Cr.	-482	-1.074	-7.2%
(COPPER2A)		Total	1392	3.101	Little Sand	2.64	29.8	150	0.334	Lily River	-35	-0.078	-2.2%
					Skunk[c]	0.44	0.5	—	—				

[a] *The net change in baseflow for Swamp Creek is very small or positive due to the simulated discharge of treated wastewater at the Soil Absorption Site.*

[b] *Swamp Creek upstream of Highway 55.*

[c] *The lake package mass balance error precludes estimation of lake seepage change.*

Table 11. Simulated changes to surface waters from the Base Runs using the Version 1, Copper Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Water Body	Low End Case Base Run[a]			High End Case Base Run[b]		
	Change in Base Flow[c]		Change from Base Case[c]	Change in Base Flow[c]		Change from Base Case[c]
Streams	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Upper Pickerel Creek	-55.1	-0.123	-4.3%	-191.9	-0.428	-15.0%
Martin Springs/Creek 11-4	-10.7	-0.024	-3.6%	-39.3	-0.088	-13.1%
Creek 12-2[d]	-14.3	-0.032	-4.7%	-76.0	-0.169	-25.2%
Creek 12-9	-44.6	-0.099	-3.1%	-104.8	-0.233	-7.5%
Lower Pickerel Creek	-3.0	-0.007	-0.4%	-10.5	-0.023	-1.3%
Creek 20-3	-9.9	-0.022	-1.3%	-31.7	-0.071	-4.3%
Swamp Creek System						
Hemlock Creek	-44.9	-0.100	-2.9%	-137.3	-0.306	-9.0%
Creek 20-13	-0.5	-0.001	-0.5%	-1.4	-0.003	-1.5%
Creek 33-8	-1.3	-0.003	-3.6%	-3.7	-0.008	-9.9%
Outlet Creek	60.6	0.135	6.8%	288.7	0.643	32.7%
Creek 19-14	-7.6	-0.017	-28.4%	-21.4	-0.048	-85.2%
Hoffman Springs/Creek	-18.9	-0.042	-7.0%	-68.0	-0.152	-25.1%
Swamp Creek	49.9	0.111	0.8%	357.4	0.796	5.8%
Swamp Cr. above Outlet Cr.	158	0.352	5.4%	756.7	1.686	25.8%
Swamp Cr. below Outlet Cr.	-108.2	-0.241	-3.3%	-399.3	-0.890	-12.2%
Lily River System						
Lily River	-1.9	-0.004	-0.3%	-5.6	-0.012	-1.0%

	Change in Seepage[c]		Change from Base Case[c]	Change in Seepage[c]		Change from Base Case[c]
External Lakes	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Rolling Stone Lake	-4.0	-0.009	-0.7%	-14.6	-0.033	-2.6%
Crane Lake	-2.5	-0.006	-0.3%	-8.0	-0.018	-1.1%
Pickerel Lake	-1.6	-0.004	-0.3%	-5.2	-0.012	-0.9%
Swamp Creek System						
Ground Hemlock Lake	-13.9	-0.031	-1.3%	-41.1	-0.092	-3.7%
Lake Metonga	28.8	0.064	0.9%	136.3	0.304	4.4%
Rice Lake[e]	-1.2	-0.003	-1.1%	-4.1	-0.009	-3.7%
Mole Lake[e,f]	-2.9	-0.006	-145%	-10.3	-0.023	-1471%
Lily River System						
Jungle Lake	-4.8	-0.011	-35.8%	-14.8	-0.033	-69.3%
Lily Lake	-4.7	-0.010	-0.5%	-14.4	-0.032	-1.4%

[a] *Low End Case (COPPER1A): inflow simulated at 349 gpm, SAS infiltration assumed equal to 275 gpm.*

[b] *High End Case (COPPER2A): inflow simulated at 1392 gpm, SAS infiltration assumed equal to 1300 gpm.*

[c] *A negative value indicates an decrease in flow to the water body.*

[d] *Due to oversight, Creek 12-2 was simulated by Creeks 12-12a and 12-12d as on the USGS Mole Lake quad map.*

[e] *Portions of Mole Lake and Rice Lake are located outside the model domain and are not simulated.*

[f] *Mole Lake is a groundwater flow through lake that is a small net loser of water to groundwater under existing conditions, making the percentage change due to mining large.*

Lake	Number of Model Cells[a]	Groundwater Drawdown (ft) Average[b]	Minimum	Maximum
Zinc Phase, Low End Case Base Run (ZINC1A)				
34-1*	4	0.64	0.63	0.65
35-7*	6	0.94	0.89	1.19
Clark	6	0.50	0.48	0.54
Cook	5	0.39	0.37	0.42
Kimberly	4	0.64	0.60	0.68
St. Johns/16-6	25	0.58	0.44	0.74
Walsh	11	0.76	0.68	0.86
Zinc Phase, High End Case Base Run (ZINC2A)				
34-1*	4	1.82	1.79	1.84
35-7*	6	2.68	2.53	3.38
Clark	6	1.29	1.21	1.37
Cook	5	1.00	0.94	1.08
Kimberly	4	1.63	1.54	1.74
St. Johns/16-6	25	1.47	1.12	1.88
Walsh	11	1.93	1.74	2.20
Copper Phase, Low End Case Base Run (COPPER1A)				
34-1*	4	0.52	0.51	0.53
35-7*	6	0.77	0.72	0.96
Clark	6	0.37	0.35	0.40
Cook	5	0.29	0.28	0.31
Kimberly	4	0.47	0.44	0.50
St. Johns/16-6	25	0.41	0.31	0.53
Walsh	11	0.55	0.49	0.63
Copper Phase, High End Case Base Run (COPPER2A)				
34-1*	4	1.80	1.77	1.82
35-7*	6	2.64	2.49	3.33
Clark	6	1.11	1.05	1.18
Cook	5	0.87	0.82	0.94
Kimberly	4	1.40	1.32	1.50
St. Johns/16-6	25	1.26	0.96	1.61
Walsh	11	1.65	1.49	1.88

[a] *The number of model cells (both complete and partial) located within the area of the lake.*

[b] *The area weighted average based on the portion of each model cell located within the area of the lake.*

* *A groundwater flow through lake.*

Table 12. Simulated groundwater drawdown beneath external lakes not explicitly represented in the Version 1, Zinc and Copper Phase, High End and Low End Case Base Runs. [abbreviation: ft, feet]

Table 13. Simulated mine inflow and the change in the stage, area and seepage of internal lakes and baseflow of selected streams from the Base Runs using Version 2, Zinc Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Simulation	Number of Dry Bedrock Nodes	Mine Inflow Locale	Amount of Mine Inflow (gpm)	(cfs)	Lake	Lake Stage Change (feet)	Lake Area Change (acres)	Lake Seepage Change (gpm)	(cfs)	Net Baseflow Change (negative values indicate net decrease) Watershed[a]	(gpm)	(cfs)	percent
Low End Case	41	Stopes	208	0.463	Deep Hole	0.23	0.1	4	0.010	Swamp Cr.[b]	47	0.105	0.4%
Base Run	(Dry Cell Bypass Active: Flow = 34 gpm)	Workings	77	0.172	Duck	0.20	0.0	2	0.004	Pickerel Cr.	-103	-0.230	-1.5%
(LLZN1B)		Total	285	0.635	Little Sand	0.05	0.7	69	0.153	Lily River	-8	-0.017	-0.5%
					Skunkc	0.44	0.7	—	—				
High End Case	30	Stopes	742	1.653	Deep Hole	0.23	0.1	20	0.045	Swamp Cr.[b]	457	1.018	3.4%
Base Run	(Dry Cell Bypass Active: Flow = 24 gpm)	Workings	435	0.969	Duck	0.20	0.0	6	0.014	Pickerel Cr.	-369	-0.823	-5.5%
(HHZN1B)		Total	1176	2.620	Little Sand	1.74	19.6	153	0.342	Lily River	-27	-0.061	-1.7%
					Skunk[c]	0.44	0.5	—	—				

[a] *The net change in baseflow for Swamp Creek is very small or positive due to the simulated discharge of treated wastewater at the Soil Absorption Site.*

[b] *Swamp Creek upstream of Highway 55.*

[c] *The lake package mass balance error precludes estimation of lake seepage change.*

Table 14. Simulated changes to surface waters from the Base Runs using the Version 2, Zinc Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Water Body	Low End Case Base Run[a]			High End Case Base Run[b]		
	Change in Base Flow[c]		Change from Base Case[c]	Change in Base Flow[c]		Change from Base Case[c]
Streams	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Upper Pickerel Creek	-37.1	-0.083	-2.9%	-144.7	-0.322	-11.3%
Martin Springs/Creek 11-4	-7.8	-0.017	-2.6%	-30.4	-0.068	-9.9%
Creek 12-2[d]	-10.8	-0.024	-3.6%	-65.9	-0.147	-21.9%
Creek 12-9	-32.5	-0.072	-2.3%	-72.9	-0.162	-5.2%
Lower Pickerel Creek	-2.2	-0.005	-0.3%	-8.3	-0.018	-1.1%
Creek 20-3	-7.1	-0.016	-0.9%	-25.3	-0.056	-3.4%
Swamp Creek System						
Hemlock Creek	-30.7	-0.068	-2.0%	-114.5	-0.255	-7.5%
Creek 20-13	-0.3	-0.001	-0.4%	-1.2	-0.003	-1.3%
Creek 33-8	-0.8	-0.002	-2.2%	-2.9	-0.006	-7.7%
Outlet Creek	44.0	0.098	5.0%	243.8	0.543	27.6%
Creek 19-14	-6.3	-0.014	-23.6%	-19.7	-0.044	-78.4%
Hoffman Springs/Creek	-11.8	-0.026	-4.5%	-49.9	-0.111	-18.5%
Swamp Creek	44.9	0.100	0.7%	330.4	0.736	5.3%
Swamp Cr. above Outlet Cr.	113.6	0.253	3.9%	638.6	1.423	21.8%
Swamp Cr. below Outlet Cr.	-68.7	-0.153	-2.1%	-308.2	-0.687	-9.4%
Lily River System						
Lily River	-1.1	-0.002	-0.2%	-4.3	-0.010	-0.7%
	Change in Seepage[c]		Change from Base Case[c]	Change in Seepage[c]		Change from Base Case[c]
External Lakes	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Rolling Stone Lake	-3.0	-0.007	-0.5%	-11.5	-0.026	-2.1%
Crane Lake	-1.7	-0.004	-0.2%	-6.3	-0.014	-0.8%
Pickerel Lake	-1.1	-0.002	-0.2%	-4.1	-0.009	-0.7%
Swamp Creek System						
Ground Hemlock Lake	-9.2	-0.020	-0.8%	-32.4	-0.072	-3.0%
Lake Metonga	19.9	0.044	0.7%	114.0	0.254	3.7%
Rice Lake[e]	-0.8	-0.002	-0.7%	-3.1	-0.007	-2.8%
Mole Lake[e,f]	-1.9	-0.004	-95.0%	-7.6	-0.017	-1086%
Lily River System						
Jungle Lake	-3.3	-0.007	-24.3%	-11.6	-0.026	-54.7%
Lily Lake	-3.2	-0.007	-0.3%	-11.3	-0.025	-1.1%

[a] *Low End Case (LLZN1B): inflow simulated at 602 gpm, SAS infiltration assumed equal to 525 gpm.*
[b] *High End Case (HHZN1B): inflow simulated at 1176 gpm, SAS infiltration assumed equal to 1100 gpm.*
[c] *A negative value indicates an decrease in flow to the water body.*
[d] *Due to oversight, Creek 12-2 was simulated by Creeks 12-12a and 12-12d as on the USGS Mole Lake quad map.*
[e] *Portions of Mole Lake and Rice Lake are located outside the model domain and are not simulated.*
[f] *Mole Lake is a groundwater flow through lake that is a small net loser of water to groundwater under existing conditions, making the percentage change due to mining large.*

Table 15. Simulated mine inflow and the change in the stage, area and seepage of internal lakes and baseflow of selected streams from the Base Runs using Version 2, Copper Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Simulation	Number of Dry Bedrock Nodes	Mine Inflow Locale	Amount of Mine Inflow (gpm)	Amount of Mine Inflow (cfs)	Lake	Lake Stage Change (feet)	Lake Area Change (acres)	Lake Seepage Change (gpm)	Lake Seepage Change (cfs)	Net Baseflow Change (negative values indicate net decrease) Watershed[a]	(gpm)	(cfs)	percent
Low End Case	18	Stopes	93	0.207	Deep Hole	0.23	0.1	5	0.012	Swamp Cr.[b]	-44	-0.097	-0.3%
Base Run	(Dry Cell Bypass	Workings	198	0.441	Duck	0.20	0.0	2	0.004	Pickerel Cr.	-126	-0.281	-1.9%
(LLCU1B run)	Active: Flow = 12 gpm)	Total	290	0.646	Little Sand	0.05	1.1	74	0.165	Lily River	-10	-0.023	-0.6%
					Skunk[c]	0.44	0.7	—	—				
High End Case	21	Stopes	385	0.858	Deep Hole	0.24	0.1	22	0.049	Swamp Cr.[b]	382	0.852	2.9%
Base Run	(Dry Cell Bypass	Workings	866	1.929	Duck	0.20	0.0	7	0.015	Pickerel Cr.	-427	-0.952	-6.4%
(HHCU1B run)	Active: Flow = 15 gpm)	Total	1250	2.785	Little Sand	2.16	23.9	152	0.339	Lily River	-31	-0.069	-1.9%
					Skunk[c]	0.44	0.5	—	—				

[a] *The net change in baseflow for Swamp Creek is very small or positive due to the simulated discharge of treated wastewater at the Soil Absorption Site.*

[b] *Swamp Creek upstream of Highway 55.*

[c] *The lake package mass balance error precludes estimation of lake seepage change.*

Table 16. Simulated changes to surface waters from the Base Runs using the Version 2, Copper Phase, High End and Low End Case models. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage]

Water Body	Low End Case Base Run[a]			High End Case Base Run[b]		
	Change in Base Flow[c]		Change from Base Case[c]	Change in Base Flow[c]		Change from Base Case[c]
Streams	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Upper Pickerel Creek	-47.0	-0.105	-3.7%	-170.1	-0.379	-13.5%
Martin Springs/Creek 11-4	-9.4	-0.021	-3.1%	-34.8	-0.078	-11.6%
Creek 12-2[d]	-13.1	-0.029	-4.3%	-73.3	-0.163	-24.3%
Creek 12-9	-37.9	-0.084	-2.7%	-86.7	-0.193	-6.2%
Lower Pickerel Creek	-2.7	-0.006	-0.3%	-9.2	-0.020	-1.2%
Creek 20-3	-8.9	-0.020	-1.2%	-28.4	-0.063	-3.8%
Swamp Creek System						
Hemlock Creek	-43.8	-0.098	-2.9%	-128.1	-0.285	-8.4%
Creek 20-13	-0.5	-0.001	-0.6%	-1.3	-0.003	-1.5%
Creek 33-8	-1.3	-0.003	-3.4%	-3.4	-0.008	-9.1%
Outlet Creek	32.8	0.073	3.7%	243.6	0.543	27.6%
Creek 19-14	-6.9	-0.015	-25.7%	-20.0	-0.045	-79.9%
Hoffman Springs/Creek	-15.5	-0.035	-5.8%	-59.8	-0.133	-22.1%
Swamp Creek	-7.5	-0.017	-0.1%	287.3	0.640	4.6%
Swamp Cr. above Outlet Cr.	*79.7*	*0.178*	*2.7%*	*636*	*1.417*	*21.7%*
Swamp Cr. below Outlet Cr.	*-87.2*	*-0.194*	*-2.7%*	*-348.7*	*-0.777*	*-10.7%*
Lily River System						
Lily River	-1.6	-0.004	-0.3%	-4.8	-0.011	-0.8%

	Change in Seepage[c]		Change from Base Case[c]	Change in Seepage[c]		Change from Base Case[c]
External Lakes	(gpm)	(cfs)		(gpm)	(cfs)	
Pickerel Creek System						
Rolling Stone Lake	-3.5	-0.008	-0.6%	-13.0	-0.029	-2.3%
Crane Lake	-2.2	-0.005	-0.3%	-7.1	-0.016	-0.9%
Pickerel Lake	-1.4	-0.003	-0.2%	-4.6	-0.010	-0.8%
Swamp Creek System						
Ground Hemlock Lake	-12.9	-0.029	-1.2%	-37.3	-0.083	—
Lake Metonga	15.4	0.034	0.5%	114	0.254	3.7%
Rice Lake[e]	-1.0	-0.002	-0.9%	-3.7	-0.008	-3.3%
Mole Lake[e,f]	-2.4	-0.005	-120%	-9.1	-0.020	-1300%
Lily River System						
Jungle Lake	-4.4	-0.010	-32.5%	-13.2	-0.029	-62.1%
Lily Lake	-4.2	-0.009	-0.4%	-12.8	-0.029	-1.3%

[a] *Low End Case (LLCU1B): inflow simulated at 290 gpm, SAS infiltration assumed equal to 150 gpm.*

[b] *High End Case (HHCU1B): inflow simulated at 1250 gpm, SAS infiltration assumed equal to 1100 gpm.*

[c] *A negative value indicates an decrease in flow to the water body.*

[d] *Due to oversight, Creek 12-2 was simulated by Creeks 12-12a and 12-12d as on the USGS Mole Lake quad map.*

[e] *Portions of Mole Lake and Rice Lake are located outside the model domain and are not simulated.*

[f] *Mole Lake is a groundwater flow through lake that is a small net loser of water to groundwater under existing conditions, making the percentage change due to mining large.*

Table 17. Simulated groundwater drawdown beneath external lakes not explicitly represented in the Version 2, Zinc and Copper Phase, High End and Low End Case Base Runs. [abbreviation: ft, feet]

Lake	Number of Model Cells[a]	Groundwater Drawdown (ft)		
		Average[b]	Minimum	Maximum
Zinc Phase, Low End Case Base Run (LLZN1B)				
34-1*	4	0.34	0.34	0.35
35-7*	6	0.51	0.48	0.64
Clark	6	0.27	0.25	0.28
Cook	5	0.21	0.20	0.22
Kimberly	4	0.34	0.32	0.36
St. Johns/16-6	25	0.30	0.23	0.39
Walsh	11	0.40	0.36	0.46
Zinc Phase, High End Case Base Run (HHZN1B)				
34-1*	4	1.34	1.32	1.36
35-7*	6	1.97	1.85	2.48
Clark	6	0.89	0.84	0.94
Cook	5	0.69	0.65	0.75
Kimberly	4	1.12	1.06	1.20
St. Johns/16-6	25	1.01	0.77	1.30
Walsh	11	1.33	1.20	1.52
Copper Phase, Low End Case Base Run (LLCU1B)				
34-1*	4	0.44	0.43	0.45
35-7*	6	0.65	0.61	0.81
Clark	6	0.34	0.32	0.37
Cook	5	0.27	0.25	0.29
Kimberly	4	0.43	0.41	0.46
St. Johns/16-6	25	0.38	0.29	0.49
Walsh	11	0.51	0.46	0.58
Copper Phase, High End Case Base Run (HHCU1B)				
34-1*	4	1.59	1.57	1.62
35-7*	6	2.34	2.20	2.95
Clark	6	1.00	0.95	1.06
Cook	5	0.78	0.74	0.84
Kimberly	4	1.26	1.19	1.35
St. Johns/16-6	25	1.13	0.86	1.45
Walsh	11	1.49	1.34	1.71

[a] *The number of model cells (both complete and partial) located within the area of the lake.*

[b] *The area weighted average based on the portion of each model cell located within the area of the lake.*

**A groundwater flow through lake.*

Table 18. Simulated range of effects from the proposed mine on representative components of the hydrologic system from the Version 1 and Version 2, Zinc and Copper Phase, High End and Low End Case Base Runs. [abbreviations: gpm, gallons per minute; %, percentage]

Version 1 Representative Hydrologic System Component	Minimum Effect Low End Copper (COPPER1A)	Maximum Effect High End Zinc (ZINC2A)
Mine Inflow (gpm)	349	1579
Extent of Capture Zone (acres)	746	2686
Maximum Drawup at the Soil Absorption Site (feet)	2.1	11.4
Drawdown Beneath Lake 35-7 (feet)	0.8	2.7
Reduction in Little Sand Lake Area	0.5%	17.1%
Pickerel Creek Basin Baseflow Reduction	2.8%	10.6%
Swamp Creek Baseflow Reduction Below Outlet Creek	3.3%	12.2%

Version 2 Representative Hydrologic System Component	Minimum Effect Low End Zinc (LLZN1B)	Maximum Effect High End Copper (HHCU1B)
Mine Inflow (gpm)	285	1250
Extent of Capture Zone (acres)	723	2261
Maximum Drawup at the Soil Absorption Site (feet)	1.5	8.4
Drawdown Beneath Lake 35-7 (feet)	0.5	2.3
Reduction in Little Sand Lake Area	0.3%	10.4%
Pickerel Creek Basin Baseflow Reduction	2.0%	8.4%
Swamp Creek Baseflow Reduction Below Outlet Creek	2.1%	10.7%

Table 19. Selected results from sensitivity simulations on parameters that control groundwater-surface water interaction using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A). [abbreviations: MAE, mean absolute error; K, hydraulic conductivity; gpm, gallons per minute; SAS, Soil Absorption Site; %, percentage; RIV, MODFLOW River Package; STR, MODFLOW Stream Routing Package]

Simulation	Description of the Simulation	Change in Background Run MAE[a]	Model Convergence	Quality of Mass Balance[b]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[c]	Change in Base Flow[c]	
							Pickerel Creek Basin	Swamp Creek Basin
ZINC2A	Base Run information for comparison	—	Yes	Good	1579	-17.1%	-8.1%	5.1%
SA0	Reduced internal lakebed K by 50%	20%	Yes	Good	1547	-6.4%	-8.1%	5.2%
SA1	Increased internal lakebed K by 50%	8%	Yes	Good	1602	-23.2%	-8.1%	5.0%
SA28	Duck lakebed K increased, no outlet	1%	Yes	Good	1582	0.0%	-8.2%	5.0%
SA30	Outlet flow reduced at internal lakes	0%	Yes	Good	1562	-30.7%	-8.8%	4.9%
SA6	Implementation of outlet rating curves	0%	Yes	Good	1581	-16.9%	-8.0%	5.1%
SA11	No Little Sand Lake outlet structure	0%	Yes	Good	1579	-19.2%	-8.3%	5.0%
SA7	Reduced conductances in RIV/STR packages by 5x	234%*	Yes	Good	1660	-23.3%	-9.0%	4.9%
SA8	Increased conductances in RIV/STR packages by 5x	16%	Yes	Good	1556	-16.8%	-7.5%	5.0%
SA12	Reduced SAS infiltration of 714 gpm	0%	Yes	Good	1579	-17.1%	-8.1%	-0.9%
SB12	Reduced SAS infiltration of 0 gpm	0%	Yes	Good	1579	-17.1%	-8.1%	-6.3%
SA18	Elimination of the "pinchout zone"	84%*	Yes	Good	1658	-15.0%	-7.1%	3.4%
SB18	Elimination of the "pinchout zone" with reduced SAS infiltration of 0 gpm	84%*	Yes	Good	1658	-15.0%	-7.1%	-7.6%

[a] *Change in calibration illustrated by change in MAE; positive values indicate an increase (a worsening), zero values indicate no change.*

[b] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes.*

[c] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site.*

* *These simulations are considered to be out of calibration.*

Table 20. Selected results from sensitivity simulations on parameters that control mine configuration using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: K, hydraulic conductivity; ft, feet; gpm, gallons per minute; SAS, Soil Absorption Site; %, percentage]

Simulation	Description of the Simulation	Model Convergence	Quality of Mass Balance[a]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[b]	Change in Base Flow[b]	
						Pickerel Creek Basin	Swamp Creek Basin
ZINC2A	Base Run information for comparison	Yes	Good	1579	-17.1%	-8.1%	5.1%
SC3	First stage zinc with limited mine workings & grout	No	Good	1527	-17.5%	-8.0%	3.8%
S3	First stage zinc with no mine workings/ limited grout	No	Good	1366	-16.1%	-7.3%	4.6%
ZINC2	Elimination of mine workings	Yes	Good	1482	-16.1%	-7.7%	5.6%
SA2	Elimination of grout ceiling	No	Good	1699	-21.0%	-9.0%	4.6%
ZN-NOGR1	Elimination of grout (ceiling and mine workings)	Yes	Good	1746	-21.7%	-9.2%	4.4%
SA16	Elimination of grout and mine workings with reduced SAS infiltration of 0 gpm	Yes	Good	1614	-19.7%	-8.7%	-6.3%
SC16	Elimination of grout (ceiling and mine workings) with reduced SAS infiltration of 0 gpm	No	Good	1699	-21.0%	-9.0%	-6.7%
ZINC2AEL	Lowered mine stopes & workings drains to 1ft above layer bottom	Yes	Good	1587	-16.8%	-8.1%	5.0%
COPPER2A	Copper Phase High End Case Base Run information for comparison	Yes	Good	1392	-12.9%	-7.2%	3.9%
CU-NOGR1	Copper: Elimination of grout (ceiling and mine workings)	Yes	Good	1446	-13.4%	-7.4%	3.6%
SA5	Copper: Increased K of backfill of zinc stopes	Yes	Good	1444	-14.0%	-7.6%	3.7%
ZINC1A	Zinc Phase Low End Case Base Run information for comparison	No	Good	602	-0.8%	-2.8%	1.8%
SA19	Low End Zinc: Elimination of grout ceiling	No	Good	775	-3.9%	-3.8%	1.2%
SA17	Low End Zinc: Elimination of grout and mine workings with reduced SAS infiltration of 0 gpm	No	Good	712	-2.8%	-3.5%	-2.5%

[a] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes.*

[b] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site, except as follows: 1300 gpm for first stage zinc and Copper Phase simulations, and 525 gpm for Low End simulations.*

Table 21. Selected results from sensitivity simulations on parameters to approximate drought using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: K, hydraulic conductivity; gpm, gallons per minute; %, percentage]

Simulation	Description of the Simulation	Model Convergence	Quality of Mass Balance[a]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[b]	Change in Base Flow[b]	
						Pickerel Creek Basin	Swamp Creek Basin
ZINC2A	Base Run information for comparison	Yes	Good	1579	-17.1%	-8.1%	5.1%
PRE-SA4	3 year drought in absence of mine (extension of background run)	Yes	-6.9%, 0.0%	—	-3.2%	-22.3%	-22.7%
PRE-SC4	3 year drought in absence of mine with no Little Sand Lake structure (extension of background run)	Yes	-7.3%, 0.1%	—	-6.9%	-22.5%	-22.8%
SA4	3 year drought in presence of mine	Yes	-1.0%, 0.0%	1463	-43.8%	-32.2%	-19.4%
SA9	3 year drought in presence of mine with reduced internal lakebed K by 50%	Yes	-1.1%, -0.1%	1445	-14.0%	-31.9%	-19.2%
SA10	3 year drought in presence of mine with increased internal lakebed K by 50%	Yes	0.4%, 0.0%	1479	-51.8%	-32.2%	-19.5%

[a] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes. For simulations that did not meet the "good" criteria, the model mass balance and Little Sand Lake mass balance errors, respectively, are reported as the two percentages.*

[b] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site.*

Table 22. Selected results from sensitivity simulations on bedrock representation using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: MAE, mean absolute error; K, hydraulic conductivity; gpm, gallons per minute; %, percentage]

Simulation	Description of the Simulation	Change in Background Run MAE[a]	Model Convergence	Quality of Mass Balance[b]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[c]	Change in Base Flow[e]	
							Pickerel Creek Basin	Swamp Creek Basin
ZINC2A	Base Run information for comparison	—	Yes	Good	1579	-17.1%	-8.1%	5.1%
SA13	Increased unweathered Kz by 2x	0%	Yes	Good	1723	-19.3%	-8.9%	4.4%
SA15	Changed bedrock configuration to Low End (keeping same parameters)	0%	Yes	Good	1500	-16.6%	-7.7%	5.4%
S15	Changed bedrock configuration to Low End with no mine workings	0%	Yes	Good	1318	-14.5%	-6.9%	4.8%
GAB2-ZN	Included gabbro dike in bedrock	0%	Yes	Good	1570	-16.8%	-8.1%	5.1%
COPPER2A	Copper Phase High End Base Run information for comparison	—	Yes	Good	1392	-12.9%	-7.2%	3.9%
GAB2-CU	Copper: Included gabbro dike in bedrock	0%	Yes	Good	1389	-12.8%	-7.2%	3.9%

[a] *Change in calibration illustrated by change in MAE; positive values indicate an increase (a worsening), zero values indicate no change.*

[b] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes.*

[c] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site, except as follows: 1300 gpm for run S15 and the Copper Phase runs.*

Table 23. Selected results from sensitivity simulations on the MODFLOW dry cell bypass option using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: gpm, gallons per minute; %, percentage]

Simulation	Description of the Simulation	Model Convergence	Quality of Mass Balance[a]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[b]	Change in Base Flow[b]	
						Pickerel Creek Basin	Swamp Creek Basin
ZINC2A	Base Run information for comparison	Yes	Good	1579	-17.1%	-8.1%	5.1%
ZINC2B	Activated dry cell bypass option	Yes	Good	1579	-17.1%	-8.1%	5.1%
Z2A-NOV	No vertical flow between stacked water tables	Yes	Good	1432	-14.2%	-7.2%	5.6%
ZINC1A	Zinc Phase Low End Case Base Run for comparison	No	Good	602	-0.8%	-2.8%	1.8%
ZINC1B	Low End Case: Activated dry cell bypass option	No	Good	619	-0.8%	-2.9%	1.8%
Z1A-NOV	No vertical flow between stacked water tables	Yes	Good	211	-0.3%	-1.2%	3.1%

[a] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes.*

[b] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site, except as follows: 525 gpm for Low End simulations.*

Table 24. Selected results from sensitivity simulations on parameters that define the "pinchout zone" using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: ft, feet; MAE, mean absolute error; K, hydraulic conductivity; gpm, gallons per minute; SAS, Soil Absorption Site; %, percentage]

Simulation	Description of the Simulation	Background Run Mean Error[a] (ft)	Change in Background Run MAE[b]	Model Convergence	Quality of Mass Balance[c]	Mine Inflow (gpm)	Change in Area of Little Sand Lake[d]	Change in Base Flow[d] Pickerel Creek Basin	Change in Base Flow[d] Swamp Creek Basin
ZINC2A	Base Run information for comparison	-0.08	—	Yes	Good	1579	-17.1%	-8.1%	5.1%
SA18	Elimination of the "pinchout zone"	2.39	84%*	Yes	Good	1658	-15.0%	-7.1%	3.4%
10PINC2A	Inclusion of about 10% random gaps in the "pinchout zone"	0.46	11%	Yes	Good	1574	-16.0%	-7.7%	4.8%
11PINC2A	Inclusion of about 10% random gaps in the "pinchout zone"—alternate realization	0.32	7%	Yes	Good	1576	-16.3%	-7.8%	4.9%
KINC2A	Revised narrow "pinchout zone" along Hemlock Creek with reduced zone K by 50%	-0.20	8%	No	Good	1592	-17.3%	-8.4%	5.1%
ZINC1A	Zinc Phase Low End Case Base Run information for comparison	-0.09	—	No	Good	602	-0.8%	-2.8%	1.8%
KINC1A	Low End Zinc: Revised narrow "pinchout zone" along Hemlock Creek with reduced zone K by 50%	-0.31	8%	Yes	Good	606	-0.8%	-2.9%	1.9%

[a] *A negative mean error indicates that the model-estimated heads are higher than the calibration targets; a positive mean error indicates that the model-estimated heads are lower than the calibration targets.*

[b] *Change in calibration illustrated by change in MAE; positive values indicate an increase (a worsening), zero values indicate no change.*

[c] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes.*

[d] *Changes in lake area and base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration of 1500 gpm at the Soil Absorption Site.*

* *These simulations are considered to be out of calibration.*

Table 25. Summary of the most important sensitivity analyses with respect to mine inflow, Little Sand Lake area, and Pickerel Creek basin baseflow, as compared to the Version 1, Zinc Phase, High End Case Base Run results. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second; %, percentage; K, hydraulic conductivity; RIV, MODFLOW River Package; STR, MODFLOW Stream Routing Package]

MINE INFLOW

Sensitivity Analyses Affecting Simulated Results by More than 5% [Background Run mine inflow = 0 gpm]	Mine Inflow (gpm)	Change from Base Run
ZINC2A - Base Run information for comparison	1579	—
SA7* - Reduced conductances in RIV/STR packages by 5x	1660	5%
SA18* - Elimination of the "pinchout zone"	1658	5%
ZINC2 - Elimination of mine workings	1482	-6%
SA2 - Elimination of grout ceiling	1699	8%
ZN-NOGR1 - Elimination of grout (ceiling and mine workings)	1746	11%
SA4[a] - 3 year drought in presence of mine	1463	-7%
SA9[a] - 3 year drought in presence of mine w/ lowered lakebed K	1445	-8%
SA10[a] - 3 year drought in presence of mine w/ raised lakebed K	1479	-6%
SA13 - Increased unweathered Kz by 2x	1723	9%
SA15 - Changed bedrock configuration to Low End	1500	-5%
Z2A-NOV - No vertical flow between stacked water tables	1432	-9%

LITTLE SAND LAKE AREA

Sensitivity Analyses Affecting Simulated Results by More than 20% [Background Run lake area = 231 acres]	Reduction in Lake Area (acres)	Change from Base Run
ZINC2A - Base Run information for comparison	39	—
SA0 - Reduced internal lakebed K by 50%	15	-63%
SA1 - Increased internal lakebed K by 50%	53	35%
SA30 - Outlet flow reduced at internal lakes	71	79%
SA7* - Reduced conductances in RIV/STR packages by 5x	54	36%
SA2 - Elimination of grout ceiling	48	23%
ZN-NOGR1 - Elimination of grout (ceiling and mine workings)	50	27%
SA4[a] - 3 year drought in presence of mine	105	166%
SA10[a] - 3 year drought in presence of mine w/ raised lakebed K	123	212%

PICKEREL CREEK BASIN BASEFLOW

Sensitivity Analyses Affecting Simulated Results by More than 20% [Background Run baseflow = 14.9 cfs]	Reduction in Baseflow (cfs)	Change from Base Run
ZINC2A - Base Run information for comparison	1.2	—
SA8 - Increased conductances in RIV/STR packages by 5x	0.9	-22%
SA4[a] - 3 year drought in presence of mine	4.8	296%
SA9[a] - 3 year drought in presence of mine w/ lowered lakebed K	4.7	286%
SA10[a] - 3 year drought in presence of mine w/ raised lakebed K	4.9	302%

[a] *Part of the effect on the lake area or stream flow in this simulation is attributable to the drought conditions alone.*

* *These simulations are considered to be out of calibration.*

Table 26. Selected results from sensitivity simulations on the configuration of the grout using the Version 1, Zinc Phase, High End Case Base Run. [abbreviations: K, hydraulic conductivity; ft/day, feet per day; gpm, gallons per minute]

	Grout Ceiling		Grout Curtain								
Simulation*	Area (acres)	Ceiling K[a] (ft/day)	Height[b] (feet)	Curtain K[a] (ft/day)	Mine Workings[c]	Workings Cover Grout K[d] (ft/day)	Dry Cell Bypass (Shunt Flow)	Number of Dry Cells Below Ceiling	Shunt Flow (gpm)	Inflow into Mine Workings (gpm)	Total Mine Inflow[e] (gpm)
No Grout											
ZN-NOGR1	—	—	—	—	present	—	inactive	11	—	663	1746
Limited High K Grout											
ZINC2A	18	2.8E-2	—	—	present	2.8E-3	inactive	2	—	433	1579
ZINC2B	18	2.8E-2	—	—	present	2.8E-3	active	2	1	433	1579
ZINC2	18	2.8E-2	—	—	absent	—	inactive	2	—	—	1482
ZINC2M	18	2.8E-3	—	—	present	2.8E-3	active	22	11	500	1470
ZINC2N	18	2.8E-3	—	—	present	2.8E-4	active	23	12	178	1392
Extended High K Grout											
ZINC4G	69	2.8E-2	—	—	present	2.8E-3	active	2	1	432	1572
ZINC4D	69	2.8E-2	260	2.8E-2	present	2.8E-3	active	2	2	430	1547
ZINC4E	69	2.8E-2	260	2.8E-3	present	2.8E-3	active	2	2	425	1498
ZINC44	69	2.8E-2	260	2.8E-3	absent	—	active	2	2	—	1396
Extended Medium K Grout											
ZINC4X	69	2.8E-3	—	—	present	2.8E-3	active	30	22	443	1306
ZINC4A	69	2.8E-3	260	2.8E-3	present	2.8E-3	active	31	25	407	1140
ZINC4B	69	2.8E-3	670	2.8E-3	present	2.8E-3	active	32	26	394	1083
ZINC4C	69	2.8E-3	1860	2.8E-3	present	2.8E-3	active	32	26	394	1071
ZINC4	69	2.8E-3	260	2.8E-3	absent	—	active	30	25	—	1004
Extended Low K Grout											
ZINC6X	69	2.8E-4	—	—	present	2.8E-4	active	56	4	173	1092
ZINC6A	69	2.8E-4	260	2.8E-4	present	2.8E-4	active	95	8	165	811
ZINC6	69	2.8E-4	260	2.8E-4	absent	—	active	91	7	—	758
ZINC6B	69	2.8E-4	670	2.8E-4	present	2.8E-4	active	109	9	151	557
ZINC6C	69	2.8E-4	1860	2.8E-4	present	2.8E-4	active	110	10	140	455
Extended Low K Grout with Ceiling Expanded into Footwall											
Ceiling expanded 100 feet:											
ZN6X-1	81	2.8E-4	—	—	present	2.8E-4	active	67	5	174	979
Ceiling expanded 200 feet:											
ZN6X-2	93	2.8E-4	—	—	present	2.8E-4	active	69	5	174	927
Ceiling expanded 500 feet:											
ZN6X-3	128	2.8E-4	—	—	present	2.8E-4	active	71	6	173	855

[a] *The thickness of the grout ceiling and the grout curtain was simulated as 25 feet based on documentation provided by the applicant.*

[b] *The vertical extent of the grout curtain in the model: 260 feet = layers 6-8; 670 feet = layers 6-10; 1860 feet = layers 6-13.*

[c] *Mine workings consist only of the hanging wall portion of the workings (366 drain nodes).*

[d] *Mine workings cover grout thickness was 5 feet except where indicated.*

[e] *Total mine inflow includes inflow from mine workings and stopes*

* *All simulations include Soil Absorption Site infiltration of 1500 gpm (infiltration at the Soil Absorption Site has negligible effect on mine inflow results).*

Table 27. Selected results from sensitivity simulations on the configuration of the grout using the Version 1, Zinc Phase, Low End Case Base Run. [abbreviations: K, hydraulic conductivity; ft/day, feet per day; gpm, gallons per minute]

	Grout Ceiling		Grout Curtain								
Simulation*	Area (acres)	Ceiling Ka[a] (ft/day)	Height[b] (feet)	Curtain K[a] (ft/day)	Mine Workings[c]	Workings Cover Grout K[d] (ft/day)	Dry Cell Bypass (Shunt Flow)	Number of Dry Cells Below Ceiling	Shunt Flow (gpm)	Inflow into Mine Workings (gpm)	Total Mine Inflow (gpm)
Limited Grout											
ZINC1B[e]	18	2.8E-2	—	—	present	8.4E-4	active	15	37	86	619
ZINC1A[e]	18	2.8E-2	—	—	present	8.4E-4	inactive	15	—	87	602
Extended Grout											
ZINC3B[e]	69	2.8E-2	260	2.8E-2	present	8.4E-4	active	13	36	86	609
ZINC3X[e]	69	2.8E-3	—	—	present	8.4E-4	active	41	30	56	443
ZINC5X	69	2.8E-4	—	—	present	2.8E-4	active	78	5	44	363
ZINC3A[e]	69	2.8E-3	260	2.8E-3	present	8.4E-4	active	43	37	57	274
ZINC5A	69	2.8E-4	260	2.8E-4	present	2.8E-4	active	99	7	44	144

[a] *The thickness of the grout ceiling and the grout curtain was simulated as 25 feet based on documentation provided by the applicant.*

[b] *The vertical extent of the grout curtain in the model: 260 feet = layers 6-8; 670 feet = layers 6-10; 1860 feet = layers 6-13.*

[c] *Mine workings consist only of the hanging wall portion of the workings (366 drain nodes).*

[d] *Mine workings cover grout thickness was 5 feet except where indicated.*

[e] *The mine workings cover grout K reported for these simulations is an average of the cell-specific conductivity used in each mine working cells.*

* *All simulations include Soil Absorption Site infiltration of 525 gpm (infiltration at the Soil Absorption Site has negligible effect on mine inflow results).*

Table 28. Simulated transient response of the groundwater system using a variant of the Version 1, Zinc Phase, High End Case Base Run[a]. [abbreviation: gpm, gallons per minute; ft^3, cubic feet]

Model Response	Simulated Long-term Value[b]	Time to Reach 90% of Long-term Value (years)	Time to Reach 95% of Long-term Value (years)
Total Mine Inflow	1569 gpm	2.7	4.0
Volume of Dewatered Glacial Material (model layers 1–4)	3.2E+09 ft^3	6.5	8.6
Volume of Dewatered Bedrock Material at or Above Crown Pillar Level (model layers 5–6)	3.6E+08 ft^3	3.9	5.5
Volume of Dewatered Bedrock Material Below Crown Pillar Level (model layers 7–13)	1.1E+09 ft^3	3.0	4.3
Storage Release	2 gpm	6.8[c]	8.9[c]

[a] *Run name: ZINC2AS1. The modification from the Base Run (ZINC2A) consisted of changing the storage coefficients as follows: glacial unit, 0.1; bedrock unit, 0.04.*

[b] *The long-term rates are based upon extended execution of run ZINC2AS1 without the use of the Dry Cell Bypass.*

[c] *The time to reach long-term storage release was approximated by comparing simulated mine-related water deficits (mine inflow + service well pumping + TMA recharge reduction) with the simulated long-term mine-related water deficit (1627 gpm).*

Table 29. Mine inflow and reduction in Little Sand Lake area and stage and Pickerel Creek basin baseflow from the Version 1 and 2, Zinc and Copper Phase, High End and Low End Case Base Runs. [abbreviations: gpm, gallons per minute; cfs, cubic feet per second]

Simulation	Mine Inflow (gpm)	Reduction in Little Sand Lake Area[a] (acres)	Reduction in Little Sand Lake Stage[b] (feet)	Reduction in Pickerel Creek Basin Baseflow[c] (cfs)
Version 1				
ZINC2A - Zinc, High End	1579	39.5	3.97	1.2
ZINC1A - Zinc, Low End	602	1.9	0.09	0.5
COPPER2A - Copper, High End	1392	29.8	2.64	1.1
COPPER1A - Copper, Low End	349	1.1	0.06	0.3
Version 2				
HHZN1B - Zinc, High End	1176	19.6	1.74	0.8
LLZN1B - Zinc, Low End	285	0.7	0.05	0.2
HHCU1B - Copper, High End	1250	23.9	2.16	1.0
LLCU1B - Copper, Low End	290	1.1	0.05	0.3

[a] *The unstressed (background) simulated lake area for all Base Runs is 230.5 acres.*
[b] *The unstressed (background) simulated lake stage with the proposed outlet structure is 1591.61 feet above sea level.*
[c] *The unstressed (background) simulated baseflow is 14.9 cfs.*

Table 30. Simulated flows to groundwater from internal lakes under Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; in/yr, inches per year]

		Flux from Internal Lakes to Groundwater				Rate of Seepage from Internal Lakes to Groundwater[a]			
Simulation	Mine Inflow (gpm)	Skunk[b] (gpm)	Duck (gpm)	Deep Hole (gpm)	Little Sand (gpm)	Skunk[b] (in/yr)	Duck (in/yr)	Deep Hole (in/yr)	Little Sand (in/yr)
Low End Cases:									
Background, pre-mining (UD-8)[c]	—	—	29.4	168.6	345.2	—	23.7	33.8	29.0
Version 1, Zinc Phase (ZINC1A)	602	—	33.0	179.5	491.6	—	26.6	36.0	41.6
Version 1, Copper Phase (COPPER1A)	349	—	31.5	174.8	429.7	—	25.4	35.0	36.3
Version 2, Zinc Phase (LLZN1B)	285	—	31.1	173.0	414.0	—	25.1	34.7	34.9
Version 2, Copper Phase (LLCU1B)	290	—	31.3	174.0	419.1	—	25.2	34.9	35.4
High End Cases:									
Background, pre-mining (UD-78)[c]	—	—	29.2	166.3	338.7	—	23.5	33.3	28.5
Version 1, Zinc Phase (ZINC2A)	1579	—	38.2	194.3	486.4	—	30.8	39.0	49.3
Version 1, Copper Phase (COPPER2A)	1392	—	36.6	190.3	488.4	—	29.5	38.2	47.2
Version 2, Zinc Phase (HHZN1B)	1176	—	35.5	186.7	492.0	—	28.6	37.4	45.2
Version 2, Copper Phase (HHCU1B)	1250	—	36.0	188.4	490.7	—	29.0	37.8	46.0

[a] *The rate of seepage is a function of both the simulated groundwater level beneath the lake and the final simulated area of the lake.*
[b] *The lake package mass balance error precludes estimation of lake seepage change.*
[c] *Background Runs include the proposed Little Sand Lake outlet structure.*

Table 31. Assessment of internal lake mitigation necessity under Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; ft, feet; MSL, mean sea level; MMMS, Metallic Mining Minimum Stage]

Simulation	Mine Inflow (gpm)	Result	Internal Lakes: Skunk	Duck	Little Sand	Deep Hole
MMMS[a] (ft MSL)			1597.01	1610.59	1591.41	1605.25
Low End Case						
Pre-mine Background Run [UD-8] (ft MSL)			1597.52	1611.82	1591.61	1605.63
Version 1:						
Zinc Phase	602	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1591.52	1605.40
(ZINC1A)		Mitigation necessary?[b]	No	No	No	No
Copper Phase	349	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.63	1591.55	1605.40
(COPPER1A)		Mitigation necessary?[b]	No	No	No	No
Version 2:						
Zinc Phase	285	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1591.56	1605.40
(LLZN1B)		Mitigation necessary?[b]	No	No	No	No
Copper Phase	290	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1591.56	1605.40
(LLCU1B)		Mitigation necessary?[b]	No	No	No	No
High End Case						
Pre-mine Background Run [UD-78] (ft MSL)			1597.52	1611.82	1591.61	1605.63
Version 1:						
Zinc Phase	1579	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1587.64	1605.39
(ZINC2A)		Mitigation necessary?[b]	No	No	Yes	No
Copper Phase	1392	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1588.97	1605.39
(COPPER2A)		Mitigation necessary?[b]	No	No	Yes	No
Version 2:						
Zinc Phase	1176	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1589.87	1605.40
(HHZN1B)		Mitigation necessary?[b]	No	No	Yes	No
Copper Phase	1250	Lake stage under mining conditions, no mitigation (ft MSL)	1597.08	1611.62	1589.45	1605.39
(HHCU1B)		Mitigation necessary?[b]	No	No	Yes	No

[a] *For lakes with seasonal MMMS values, the largest seasonal value was used as the mitigation trigger. For an explanation of the MMMS, see narrative Section 6.4.3.3, Mitigation of Surface Water.*

[b] *Forthe purposes of this report, mitigation need was determined based upon a similated lake stage reduction due to mining of 0.1 ft or greater below the MMMS.*

Table 32. Assessment of internal lake mitigation necessity under select Versions 1 and 2, Low End and High End Case mining scenarios with drought conditions. [abbreviations: gpm, gallons per minute; ft, feet; MSL, mean sea level]

Simulation	Inflow (gpm)	Result	Internal Lakes: Skunk	Duck	Little Sand	Deep Hole
Low End Case with Drought						
Pre-mine Background Run with Drought [PRE-SLA4] (ft MSL)			1596.68	1611.60	1590.75	1605.06
Version 1:						
Zinc Phase	570	Lake stage under mining conditions, no mitigation (ft MSL)	1596.66	1611.59	1588.20	1604.59
(SLA4)		Mitigation necessary?[a]	No	No	Yes	Yes
High End Case with Drought						
Pre-mine Background Run with Drought [PRE-SA4] (ft MSL)			1596.81	1611.60	1590.92	1605.12
Version 1:						
Zinc Phase	1463	Lake stage under mining conditions, no mitigation (ft MSL)	1596.80	1611.60	1584.95	1604.29
(SA4)		Mitigation necessary?[a]	No	No	Yes	Yes
Version 2:						
Copper Phase	1218	Lake stage under mining conditions, no mitigation (ft MSL)	1596.80	1611.60	1586.14	1604.38
(CA4)		Mitigation necessary?[a]	No	No	Yes	Yes

[a] *For the purposes of this report, mitigation need was determined based upon a similated lake stage reduction due to mining of 0.1 ft or greater based upon a comparison of a mining run with the corresponding pre-mine background run with drought.*

Table 33. Results from simulations assessing internal lake mitigation needs under select Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute]

Simulation	Internal Lake Mitigation: Skunk (gpm)	Duck (gpm)	Little Sand (gpm)	Deep Hole (gpm)
High End Case				
Version 1:				
Zinc Phase (ZINC2AM4)	0	0	175	0
Version 2:				
Copper Phase (HHCU1BM4)	0	0	90	0
Low End Case with Drought				
Version 1:				
Zinc Phase (SLA4M4)	0	0	188	14
High End Case with Drought				
Version 1:				
Zinc Phase (SA4M6)	0	0	380	24
Version 2:				
Copper Phase (CA4M2)	0	0	293	20

Table 34. Assessment of stream mitigation needs under three mitigation thresholds using Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; %, percentage]

Simulation	Water Body	Pre-mine Baseflow (gpm)	Without Lake Mitigation: Loss[a] (gpm)	Without Lake Mitigation: Loss[a] percentage	Without Lake Mitigation: Mitigation[b] (gpm)	Including Lake Mitigation: Loss[a] (gpm)	Including Lake Mitigation: Loss[a] percentage
Mitigation Threshold = 10% Reduction in Baseflow (Q50), equivalent to about Q60:							
Low End Case							
Version 1:							
Zinc Phase (ZINC1A)	Creek 12-2	303.8	-36.7	-12.1%	6.3	—	—
	Creek 19-14	26.8	-10.6	-39.4%	7.9	—	—
Copper Phase (COPPER1A)	Creek 19-14	26.8	-7.6	-28.4%	4.9	—	—
Version 2:							
Zinc Phase (LLZN1B)	Creek 19-14	26.8	-6.3	-23.6%	3.7	—	—
Copper Phase (LLCU1B)	Creek 19-14	26.8	-6.9	-25.7%	4.2	—	—
High End Case							
Version 1:							
Zinc Phase (ZINC2A)	Upper Pickerel Creek	1280.0	-200.5	-15.7%	72.5	-177.2	-13.8%
	Martin Springs/Creek 11-4	301.0	-43.2	-14.4%	13.1	-36.6	-12.2%
	Creek 12-2	301.4	-86.8	-28.8%	56.7	-77.7	-25.8%
	Creek 33-8	37.8	-4.1	-10.8%	0.3	—	—
	Creek 19-14	25.1	-23.2	-92.7%	20.7	-22.6	-90.1%
	Hoffman Springs/Creek	270.7	-67.3	-24.9%	40.2	-62.1	-23.0%
Copper Phase (COPPER2A)[c]	Upper Pickerel Creek	1280.0	-191.9	-15.0%	63.9	—	—
	Martin Springs/Creek 11-4	301.0	-39.4	-13.1%	9.3	—	—
	Creek 12-2	301.4	-76.1	-25.2%	45.9	—	—
	Creek 19-14	25.1	-21.4	-85.2%	18.8	—	—
	Hoffman Springs/Creek	270.7	-67.9	-25.1%	40.9	—	—
Version 2:							
Zinc Phase (HHZN1B)[c]	Upper Pickerel Creek	1280.0	-144.7	-11.3%	16.7	—	—
	Martin Springs/Creek 11-4	301.0	-30.4	-10.1%	0.2	—	—
	Creek 12-2	301.4	-65.9	-21.8%	35.7	—	—

[a] *Loss is reported for a stream only if the loss in flow due to mining is above the threshold reduction for mitigation.*

[b] *Mitigation flows are estimated based upon the amount of water needed to return the water body to the threshold level both with and without any needed lake mitigation. Mitigation flow calculation: mitigation flow = (%Loss - %Mitigation Threshold) x Pre-mine Baseflow - for example: (12.1% - 10%) * 303.8 gpm = 6.3 gpm.*

[c] *Though lake mitigation would be necessary for this simulation, the evaluation of the effect of lake mitigation on stream mitigation was not completed.*

Table 34 (cont.). Assessment of stream mitigation needs under three mitigation thresholds using Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; %, percentage]

			Without Lake Mitigation			Including Lake Mitigation		
		Pre-mine Baseflow	Loss[a]		Mitigation[b]	Loss[a]		Mitigation[b]
Simulation	**Water Body**	**(gpm)**	**(gpm)**	**percentage**	**(gpm)**	**(gpm)**	**percentage**	**(gpm)**
Version 2 *(cont.)*:								
Zinc Phase (HHZN1B)[c]	Creek 19-14	25.1	-19.7	-78.4%	17.2	—	—	—
	Hoffman Springs/Creek	270.7	-50.0	-18.5%	22.9	—	—	—
Copper Phase (HHCU1B)	Upper Pickerel Creek	1280.0	-170.1	-13.3%	42.1	-156.1	-12.2%	28.1
	Martin Springs/Creek 11-4	301.0	-34.8	-11.6%	4.7	-31.4	-10.4%	1.3
	Creek 12-2	301.4	-73.3	-24.3%	43.1	-64.9	-21.5%	34.8
	Creek 19-14	25.1	-20.0	-79.9%	17.5	-19.6	-78.1%	17.1
	Hoffman Springs/Creek	270.7	-59.8	-22.1%	32.7	-56.6	-20.9%	29.5
Mitigation Threshold = 25% Reduction in Baseflow (Q50), equivalent to about Q75:								
Low End Case								
Version 1:								
Zinc Phase (ZINC1A)	Creek 19-14	26.8	-10.6	-39.4%	3.9	—	—	—
Copper Phase (COPPER1A)	Creek 19-14	26.8	-7.6	-28.4%	0.9	—	—	—
Version 2:								
Copper Phase (LLCU1B)	Creek 19-14	26.8	-6.9	-25.7%	0.2	—	—	—
High End Case								
Version 1:								
Zinc Phase (ZINC2A)	Creek 12-2	301.4	-86.8	-28.8%	11.5	-77.7	-25.8%	2.3
	Creek 19-14	25.1	-23.2	-92.7%	17.0	-22.6	-90.1%	16.3
Copper Phase (COPPER2A)[c]	Creek 12-2	301.4	-76.1	-25.2%	0.7	—	—	—
	Creek 19-14	25.1	-21.4	-85.2%	15.1	—	—	—
	Hoffman Springs/Creek	270.7	-67.9	-25.1%	0.3	—	—	—
Version 2:								
Zinc Phase (HHZN1B)[c]	Creek 19-14	25.1	-19.7	-78.4%	13.4	—	—	—
Copper Phase (HHCU1B)	Creek 19-14	25.1	-20.0	-79.9%	13.8	-19.6	-78.1%	13.3

[a] *Loss is reported for a stream only if the loss in flow due to mining is above the threshold reduction for mitigation.*

[b] *Mitigation flows are estimated based upon the amount of water needed to return the water body to the threshold level both with and without any needed lake mitigation. Mitigation flow calculation: mitigation flow = (%Loss - %Mitigation Threshold) x Pre-mine Baseflow - for example: (39.4% - 25%) * 26.8 gpm = 3.9 gpm.*

[c] *Though lake mitigation would be necessary for this simulation, the evaluation of the effect of lake mitigation on stream mitigation was not completed.*

Table 34 (cont.). Assessment of stream mitigation needs under three mitigation thresholds using Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; %, percentage]

			Without Lake Mitigation			Including Lake Mitigation		
		Pre-mine Baseflow	Loss[a]		Mitigation[b]	Loss[a]		Mitigation[b]
Simulation	**Water Body**	**(gpm)**	**(gpm)**	**percentage**	**(gpm)**	**(gpm)**	**percentage**	**(gpm)**
Mitigation Threshold = 35% Reduction in Baseflow (Q50), equivalent to about Q85:								
Low End Case								
Version 1:								
Zinc Phase (ZINC1A)	Creek 19-14	26.8	-10.6	-39.4%	1.2	—	—	—
High End Case								
Version 1:								
Zinc Phase (ZINC2A)	Creek 19-14	25.1	-23.2	-92.7%	14.5	-22.6	-90.1%	13.8
Copper Phase (COPPER2A)[c]	Creek 19-14	25.1	-21.4	-85.2%	12.6	—	—	—
Version 2:								
Zinc Phase (HHZN1B)[c]	Creek 19-14	25.1	-19.7	-78.4%	10.9	—	—	—
Copper Phase (HHCU1B)	Creek 19-14	25.1	-20.0	-79.9%	11.3	-19.6	-78.1%	10.8

[A] *Loss is reported for a stream only if the loss in flow due to mining is above the threshold reduction for mitigation.*

[B] *Mitigation flows are estimated based upon the amount of water needed to return the water body to the threshold level both with and without any needed lake mitigation. Mitigation flow calculation: mitigation flow = (%Loss - %Mitigation Threshold) x Pre-mine Baseflow - for example: (39.4% - 35%) * 26.8 gpm = 1.2 gpm.*

[C] *Though lake mitigation would be necessary for this simulation, the evaluation of the effect of lake mitigation on stream mitigation was not completed.*

Table 35. Assessment of stream mitigation needs under three mitigation thresholds using select Versions 1 and 2, Low End and High End Case mining scenarios with drought conditions. [abbreviations: gpm, gallons per minute; %, percentage]

			Without Lake Mitigation			Including Lake Mitigation		
			Loss[a]			Loss[a]		
Simulation	**Water Body**	**Pre-mine Baseflow (gpm)**	**(gpm)**	**percent-age**	**Mitigation[b] (gpm)**	**(gpm)**	**percent-age**	**Mitigation[b] (gpm)**
Mitigation Threshold = 10% Reduction in Estimated Background Flow Under Drought Conditions:								
Low End Case with Drought								
Version 1:								
Zinc Phase (SLA4)	Creek 12-2	203.3	-37.3	-18.3%	17.0	-30.9	-15.2%	10.6
	Creek 19-14	12.6	-7.0	-55.6%	5.7	-6.8	-54.5%	5.6
	Hoffman Springs/Creek	218.6	-27.0	-12.3%	5.1	-25.0	-11.4%	3.1
High End Case with Drought								
Version 1:								
Zinc Phase (SA4)	Upper Pickerel Creek	907.4	-179.6	-19.8%	88.9	-154.0	-17.0%	63.3
	Martin Springs/Creek 11-4	231.2	-49.6	-21.5%	26.5	-40.7	-17.6%	17.6
	Creek 12-2	206.1	-84.3	-40.9%	63.7	-60.5	-29.4%	39.9
	Creek 12-9	1215.6	-220.2	-18.1%	98.7	-169.3	-13.9%	47.7
	Creek 20-3	512.1	-54.4	-10.6%	3.2	—	—	—
	Creek 33-8	27.7	-5.3	-19.3%	2.6	-4.9	-17.5%	2.1
	Creek 19-14	12.6	-12.6	-100%	11.3	-12.6	-100%	11.3
	Hoffman Springs/Creek	225.4	-75.0	-33.3%	52.4	-66.9	-29.7%	44.4
	Hemlock Creek System	2143.8	-271.4	-12.7%	57.0	-260.4	-12.1%	46.0
Version 2:								
Copper Phase (CA4)	Upper Pickerel Creek	907.4	-154.7	-17.0%	63.9	-126.9	-14.0%	36.1
	Martin Springs/Creek 11-4	231.2	-42.1	-18.2%	19.0	-34.3	-14.8%	11.2
	Creek 12-2	206.1	-64.6	-31.4%	44.0	-52.3	-25.4%	31.7
	Creek 12-9	1215.6	-175.8	-14.5%	54.3	-136.5	-11.2%	14.9
	Creek 33-8	27.7	-4.5	-16.4%	1.8	-4.1	-14.7%	1.3
	Creek 19-14	12.6	-12.6	-100%	11.3	-12.6	-100%	11.3
	Hoffman Springs/Creek	225.4	-67.4	-29.9%	44.9	-61.2	-27.2%	38.7
	Hemlock Creek System	2143.8	-233.5	-10.9%	19.1	-216.2	-10.1%	1.8

[a] *Loss is reported for a stream only if the loss in flow due to mining is above the threshold reduction for mitigation.*

[b] *Mitigation flows are estimated based upon the amount of water needed to return the water body to the threshold level both with and without any needed lake mitigation. Mitigation flow calculation: mitigation flow = (%Loss - %Mitigation Threshold) x Pre-mine Baseflow - for example: (18.3% - 10%) * 203.3 gpm = 17.0 gpm.*

Table 35 (cont.). Assessment of stream mitigation needs under three mitigation thresholds using select Versions 1 and 2, Low End and High End Case mining scenarios with drought conditions. [abbreviations: gpm, gallons per minute; %, percentage]

			Without Lake Mitigation			Including Lake Mitigation		
		Pre-mine	Loss[a]		Mitigation[b]	Loss[a]		Mitigation[b]
Simulation	Water Body	Baseflow (gpm)	(gpm)	percent-age	(gpm)	(gpm)	percent-age	(gpm)
Mitigation Threshold = 25% Reduction in Estimated Background Flow Under Drought Conditions:								
Low End Case with Drought								
Version 1:								
Zinc Phase (SLA4)	Creek 19-14	12.6	-7.0	-55.6%	3.8	-6.8	-54.5%	3.7
High End Case with Drought								
Version 1:								
Zinc Phase (SA4)	Creek 12-2	206.1	-84.3	-40.9%	32.8	-60.5	-29.4%	9.0
	Creek 19-14	12.6	-12.6	-100%	9.4	-12.6	-100%	9.4
	Hoffman Springs/Creek	225.4	-75.0	-33.3%	18.6	-66.9	-29.7%	10.6
Version 2:								
Copper Phase (CA4)	Creek 12-2	206.1	-64.6	-31.4%	13.1	-52.3	-25.4%	0.8
	Creek 19-14	12.6	-12.6	-100%	9.4	-12.6	-100%	9.4
	Hoffman Springs/Creek	225.4	-67.4	-29.9%	11.0	-61.2	-27.2%	4.9
Mitigation Threshold = 35% Reduction in Estimated Background Flow Under Drought Conditions:								
Low End Case with Drought								
Version 1:								
Zinc Phase (SLA4)	Creek 19-14	12.6	-7.0	-55.6%	2.6	-6.8	-54.5%	2.5
High End Case with Drought								
Version 1:								
Zinc Phase (SA4)	Creek 12-2	206.1	-84.3	-40.9%	12.2	-60.5	-29.4%	—
	Creek 19-14	12.6	-12.6	-100%	8.2	-12.6	-100%	8.2
Version 2:								
Copper Phase (CA4)	Creek 19-14	12.6	-12.6	-100%	8.2	-12.6	-100%	8.2

[a] *Loss is reported for a stream only if the loss in flow due to mining is above the threshold reduction for mitigation.*

[b] *Mitigation flows are estimated based upon the amount of water needed to return the water body to the threshold level both with and without any needed lake mitigation. Mitigation flow calculation: mitigation flow = (%Loss - %Mitigation Threshold) x Pre-mine Baseflow - for example: (55.6% - 25%) * 12.6 gpm = 3.8 gpm.*

Table 36. Results from simulations incorporating an alternate representation for Duck Lake under select Versions 1 and 2, Low End and High End Case mining scenarios. [abbreviations: gpm, gallons per minute; ft, feet; %, percentage]

Simulation	Mine Inflow (gpm)	Pickerel Creek Baseflow Change (percent)	Duck Lake Area Change (percent)	Duck Lake Stage Change (ft)
Low End Case				
Version 1: Zinc Phase -				
ZINC1A for comparison	602	-3.7%	0.0%	-0.20
SL28	612	-3.7%	-4.9%	-1.03
High End Case				
Version 1: Zinc Phase -				
ZINC2A for comparison	1579	-10.6%	0.0%	-0.20
SA28	1582	-10.8%	-15.7%	-2.16
Version 2: Copper Phase -				
HHCU1B for comparison	1250	-8.4%	0.0%	-0.20
HC28	1252	-8.4%	-11.0%	-1.70

Table 37. Results from simulations assessing internal lake mitigation needs under Version 1, Zinc Phase, High End Case mining scenarios incorporating the alternate representation of Duck Lake. [abbreviation: gpm, gallons per minute]

	Internal Lake Mitigation			
Simulation	Skunk (gpm)	Duck (gpm)	Little Sand (gpm)	Deep Hole (gpm)
High End Case				
Version 1:				
Zinc Phase (SA28M2)	0	9	175	0
High End Case with Drought				
Version 1:				
Zinc Phase (SA29M4)	0	23	380	24

within the area between the ore body and the TMA. The zone of influence at the water table is larger, but it is blocked from extending far to the north because the pressure wave spreading from the mine stops where Swamp Creek forms a vertical hydrologic boundary.

6.4.1.4 Internal Lakes—Area, Stage and Seepage

The High End simulations of the mine for both Version 1 and Version 2 of the model result in significant reductions in the stage and area of Little Sand Lake. For example, the High End Zinc and Copper Phases yield on average a 12 percent reduction in Little Sand Lake area and a 2.6 ft drop in stage. All the Low End simulations show a much smaller effect on Little Sand Lake, yielding an average reduction of 0.5% in lake area and 0.06 ft in stage. For High End runs, the pre-mine groundwater seepage out of the lake is 339 gpm and the average increase for runs in the presence of mining is 19 percent above the pre-mine level. For Low End runs, the pre-mine groundwater seepage out of the lake is 345 gpm and the average increase for runs under mining conditions is 0.5 percent.

The simulated influence of the mine on Deep Hole and Duck Lake area, stage and seepage is small for all base runs, both High End and Low End. Both lakes fall no lower than their surface water outlet elevations under any mining scenarios. In contrast, the influence of mining on the already small area of Skunk Lake is significant for all scenarios, yielding across all base runs an average reduction of 9 percent corresponding to a 0.44 ft drop in stage. The behavior of Skunk Lake is controlled by the presence in the model of fine-grained sediments over part of the lakebed that limit the drop in stage caused by mining. Difficulties in resolving mass balance for Skunk Lake do not allow the change in groundwater seepage caused by mining to be accurately quantified.

6.4.1.5 Baseflow to Surface Water Basins

The reductions in baseflow to surface water bodies in the Pickerel Creek Basin are significantly greater for High End Zinc and Copper simulations then for Low End simulations. The combined baseflow to Pickerel Creek water bodies is about 6700 gpm under both High End and Low End pre-mine conditions. The average reduction for the set of High End mining scenarios is approximately 7% of this total, or about 450 gpm. The average Low End reduction is approximately 2%, or about 140 gpm.

The effect of mining on baseflow to Swamp Creek Basin water bodies is offset by the release of water to the SAS. This addition to the groundwater circulates to streams as added baseflow, off setting the reductions to baseflow caused by mining. In both High End and Low End Base cases, the net effect of the mine and the SAS is to collectively increase baseflow to Swamp Creek water bodies. The increase is less if account is taken of the need to mitigate baseflow by transferring groundwater from the Swamp Creek Basin (by means of a well) to streams in the Pickerel Creek Basin. Analysis shows that a mitigation well in the Swamp Creek Basin will lower baseflow to its streams, but not enough to reduce the total quantity below pre-mine levels (see report section 6.4.3.3.3). For findings regarding decreases or increases of baseflow to individual streams and lakes in surface-water basins, refer to Tables 9, 11, 14 and 16.

6.4.1.6 Summary of Results

In order to summarize the results of the effect of the mining, we report mine inflow, and we evaluate drawdown in terms of a single representative point marked N2 located just south of Swamp Creek. The point N2 was arbitrarily chosen from the points shown of figures 10, 13, 16, and 19. We evaluate internal lake changes in terms of the reduction in the area of Little Sand Lake, and we evaluate change in baseflow in terms both of the change in groundwater flow to streams in the Pickerel Creek Basin located south of the ore body and the change in groundwater flow to Swamp Creek below Outlet Creek (that is, along a segment of Swamp Creek located below where it is strongly affected by SAS infiltration). Table 38 lists the minimum and maximum effect on various model components in model Versions 1 and 2.

For Version 1, the Zinc Phase simulation results in the maximum effect because there are more zinc stopes than copper stopes, while the extent of mine workings is limited in the model to the hanging wall for both Phases. For Version 2, the Copper Phase run results in the maximum effect because of the large increase in the extent of mine workings along the footwall anticipated for that Phase in the updated mining plan.

6.4.2 Effect of High End versus Low End Cases on Results

The High End and Low End Cases of the model are differentiated from each other chiefly by four elements:

- the vertical hydraulic conductivity of the Early Wisconsin Till/Massive Saprolite,
- the hydraulic conductivity of the weathered bedrock in the Hanging Wall,
- the hydraulic conductivity of the unweathered bedrock north and south of the ore body, and
- the continuity of the ore body configuration.

An analysis evaluating the relative contribution of each element to the difference between the Cases is presented in Appendix II. It shows that approximately 40 percent of the increase in mine inflow registered by the High End relative to the Low End versions is due to the higher value for the vertical hydraulic conductivity of the Early Wisconsin Till/Massive Saprolite. The Hanging Wall hydraulic conductivity accounts for about 30 percent of the difference and the remainder is split between the hydraulic conductivity of the unweathered bedrock and the configuration of the ore body.

The High and Low End Cases not only produce different rates of mine inflow, but also different capture zones for the mine. In particular the area over which groundwater flows downward and circulates to the mine is significantly larger for the High End simulations (see Appendix II). The flow patterns are also distinguished by the area over which “stacked” water tables develop above the mine. Stacked water tables occur when simulated head in a model cell is less than the elevation of the top of the cell. Both the capture zone pattern and the influence of solver options on the presence of multiple water tables are investigated in Appendix II for the High End and Low End Cases of the model.

6.4.3 Sensitivity Simulations

In order to determine how results change when uncertain parameters are varied, a series of simulations were made and compared to the results for the High End Case, Zinc Phase, Version 1 run (run ZINC2A). These sensitivity analyses were conducted using the applicant’s sensitivity analyses as guidance (GeoTrans, 1998a, 1998b, 1998c, 1998d and 1998e). The conditions modified in these simulations pertain to: groundwater/surface water interactions, reduced recharge owing to drought, mine configuration (that is, the number and location of stopes and access mine workings), bedrock representation (that is, the volume and continuity of the ore body), and absence or presence of the dry cell bypass in the solver. Tables 19 to 27 list the results while Appendixes III through IX present more details and discussion of the sensitivity simulations. Examination of these tables and appendixes show that the model is particularly sensitive to lakebed conductivity, the presence of the outwash pinchout zone, the incidence of drought, and the hydraulic conductivity of the unweathered bedrock. A few sensitivity simulations were variations of the Low End Zinc or High End Copper Base Runs. In every instance, however, the simulations were made using Version 1 of the model. As noted earlier, though the project as currently proposed (2003) is more accurately represented by Version 2 of the model, the project changes that resulted in Version 2 were not made by the applicant until late in the review process (summer 2001). Since the two Versions of the model

Table 38. Minimum and maximum effects on components of Versions 1 and 2.

VERSION 1 (limited grout ceiling, no grout curtain, limited mine workings):

	Minimum Effect	*Maximum Effect*
	Low End Copper	**High End Zinc**
Mine inflow	**349 gpm**	**1579 gpm**
Water-table drawdown just south of Swamp Creek (N2)	1.6 ft	7.6 ft
Extent of mine capture zone	746 acres	2686 acres
Reduction of Little Sand Lake area	0.5%	17.1%
Pickerel Basin baseflow reduction	2.2%	8.1%
Swamp Creek baseflow reduction below Outlet Creek[1]	3.3%	12.2%

VERSION 2 (extended grout ceiling, limited grout curtain, extended mine workings):

	Low End Zinc	**High End Copper**
Mine inflow	**285 gpm**	**1250 gpm**
Water-table drawdown just south of Swamp Creek (N2)	1.4 ft	6.2 ft
Extent of mine capture zone	723 acres	2261 acres
Reduction of Little Sand Lake area	0.3%	10.4%
Pickerel Basin baseflow reduction	1.5%	6.4%
Swamp Creek baseflow reduction below Outlet Creek[1]	2.1%	10.7%

[1] *This entry corresponds to reduction in groundwater discharge to a segment of Swamp Creek rather than it entire length. The reason for isolating this segment is to better understand the effect of mining on baseflow considering a segment where the effect of the SAS is small.*

have only limited differences with respect to mine workings and grout, results of sensitivity simulations investigating the effects of varying uncertain parameters completed on Version 1 are expected to be applicable to Version 2.

6.4.3.1 Effect of Selected Model Features

The sensitivity of the model to grout parameters, SAS infiltration, drains, outwash pinchout zone, and other selected features are discussed below. Table 25 groups together the simulations showing the most sensitivity.

6.4.3.1.1 Grout Parameters

An important element of the mining plan is the expected distribution of grout. Three areas of grouting are simulated: a sub-horizontal grout ceiling, grouted mine workings, and a near-vertical grout curtain (Version 2 only). Because these features have such a large influence on mine inflow, a particular analysis was made of the sensitivity of the High End Case to the following factors:

1. The absence of grout in any form;
2. The assumed hydraulic conductivity of the grout in the ceiling, mine workings and curtain of 0.03 ft/day, 0.003 ft/day or 0.0003 ft/day (1e-5 cm/sec, 1e-6 cm/sec or 1e-7 cm/sec, respectively);
3. The extent of the grout ceiling;
4. The depth of the grout curtain; and
5. The substitution of the Low End model for High End model.

Tables 26 and 27 and Appendix IV collect a series of Low End and High End Case runs that represent many permutations of the grout factors. It should be noted that the SAS infiltration was maintained at 1500 gpm for all runs even though some runs produced mine inflow much less than 1500 gpm. This anomaly is not a concern for this analysis because the rate of SAS infiltration has virtually no effect on the magnitude of mine inflow.

Many of these grout sensitivity runs include a mine representation involving mine workings and a grout curtain configuration that is similar, but not identical, to that used in Version 2 of the model. The grout sensitivity runs were performed before the revised grout and mining plans were finalized (summer 2001), and as a result, the tabulated runs with extended mine workings and vertical curtain were revisions based on an earlier version of the plan.

The extent of grout represented in the model has a large influence on mine inflow (and on associated phenomena such as lake drawdown and baseflow reduction) (tables 26 and 27). This effect can be compared to the completely ungrouted run, ZN-NOGR1, which yields a mine inflow rate of 1746 gpm. The High End Case, Zinc Phase, Version 1 run produces only a small reduction in mine inflow, to 1579 gpm, because the modeled hydraulic conductivity of the grout is relatively high at 0.03 ft/day (1e-5 cm/sec) and because the grouting configuration employs a relatively small grout ceiling and no grout curtain.

The most important factors controlling mine inflow are the assumed hydraulic conductivity of the grouted zones and the vertical extent of the grout curtain. For example, consider runs ZINC6A and ZINC6B. Grouting is assumed to penetrate 5 ft into the rock yielding a final hydraulic conductivity equal to 0.003 ft/day (1e-6 cm/sec). Then in the company of an extended grout ceiling and a vertical curtain extending 260 ft below the crown pillar, the model predicts a near halving of the mine inflow relative to the completely ungrouted case. If the vertical curtain is assumed to penetrate 670 ft below the crown pillar (from layer 6 to layer 10 of the model), then there is about a two-thirds reduction in mine inflow from the ungrouted rate.

6.4.3.1.2 SAS Infiltration

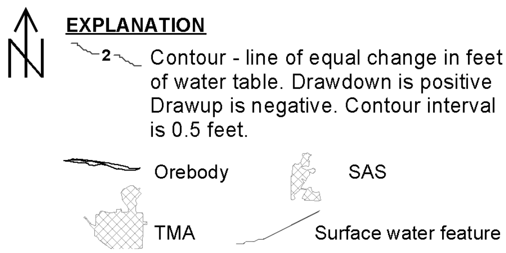
Comparison of figure 25 with figure 10a shows that simulated water table drawdown for the run with zero SAS infiltration (run SB12) is indistinguishable from the water table simulated for the reference run with 1500 gpm SAS infiltration (run ZINC2A). The agreement occurs despite the fact that in the absence of the SAS the baseflow in Swamp Creek basin drops by 8 percent rather than increasing by 5 percent). These results imply that Swamp Creek acts as a barrier to the propagation of the drawdown curve even in the absence of infiltration at the SAS.

As shown in Figures 10, 13, 16, and 19, the SAS infiltration causes a rise, or drawup, in the local water table. The drawup varies between 2.1 ft and 11.1 ft for Version 1 mining scenarios. It varies between 1.0 and 7.5 ft for Version 2 mining scenarios. In evaluating these results, it must be kept in mind, first, that these model results are approximate because of the relatively large size of the nodes in the SAS area and, second, that the amount of drawup is directly related to the SAS infiltration rate input in the model.

6.4.3.1.3 Drains

Model results (in terms of mine inflow) are sensitive to the location and configuration of drains, rather than the overall number of drains. A cluster of stopes is redundant from the point of view of mine inflow because the cells with drains that are surrounded by cells with drains have negligible effect on the flow field. These results suggest that a key control on the magnitude of impacts is the “surface area” of the mine, including the mine workings.

The results are sensitive to the elevation of the drain within a mine layer for the Version 1, Low End Case. This elevation for both stope and mine working model cells is set to the middle elevation of the cell for all Version 1 and Version 2 scenarios. To test the importance of this assumption, we performed a series of Zinc runs in which the drain elevation was lowered to one foot above the bottom elevation of the cell. For High End simulations, the change in elevation causes a small increase in mine inflow (0.5 percent increase for Version 1 run, 2.9 percent increase for Version 2 run). For Low End simulations the elevation change causes a



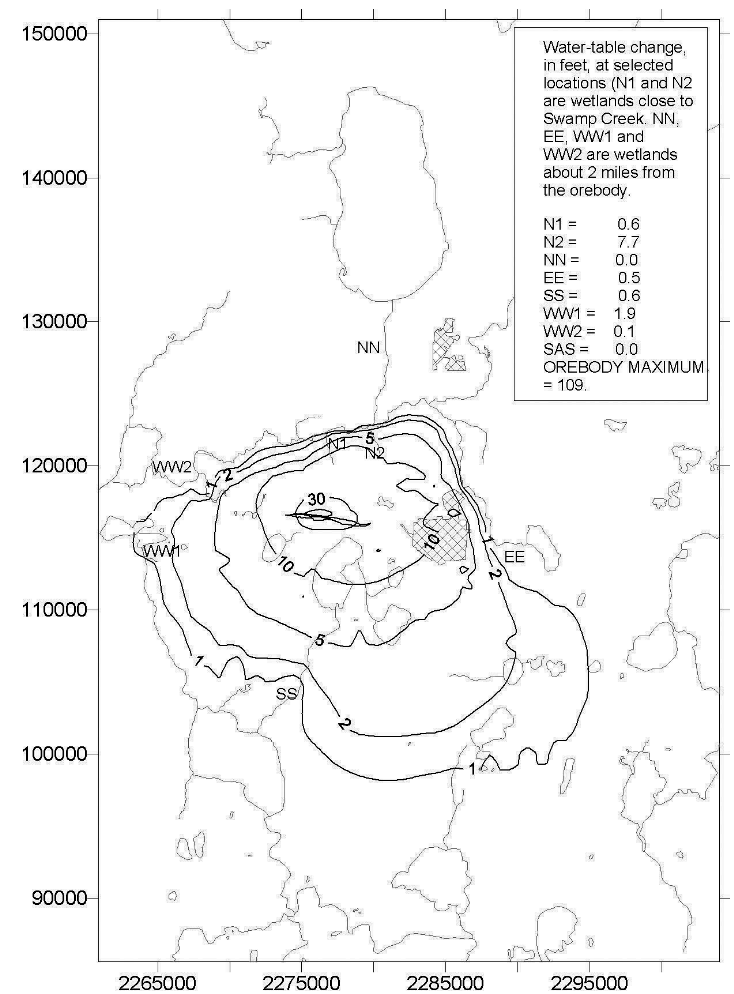


Figure 24. *Simulated water-table change from calibration for Version 1, Zinc Phase, High End Case Base Run without SAS infiltration. Compare this figure to figure 10A. Map coordinates are State Plane North, in feet. [Abbreviations: TMS, Tailings Management Area; SAS, Soil Absorption Site]*

decrease in mine inflow (-15.4 percent for Version 1 run, -2.0 percent for Version 2 run).

6.4.3.1.4 Outwash Pinchout Zone

We tested the effect of eliminating or modifying the configuration of the pinchout zone in a series of simulations. Appendix V tabulates the results in terms of the effect on model calibration and on the hydrologic response to mining. In particular, we examined the effect on drawdown at selected locations below wetlands. For the scenarios tested, the tables show that the model results in terms of mine inflow and drawdown are moderately sensitive to eliminating the outwash pinchout zone altogether and fairly insensitive to modifying it by simulating discontinuities in the form of gaps. However, as previously discussed, the pinchout zone is important to model calibration.

6.4.3.1.5 Gabbro Dike

There is geologic evidence that a low-hydraulic conductivity gabbro dike is present in the bedrock south of the ore body. To test the effect of such a dike, we inserted a low-conductivity zone that penetrates the entire bedrock section into the Version 1, High End Case, Zinc simulation. Despite the potential for the dike to act as a barrier to flow, the model simulation with the dike differs very little from run without the dike with respect to mine inflow or other measures of impact. The location of the dike was estimated from a figure in the EIR (Foth and Van Dyke, 1995a/1998a; figure 3.5-13) and is shown in plan view in figure 25 of this report.

6.4.3.1.6 Anisotropy in Bedrock

One part of the conceptual model underlying the construction of the regional flow model involves the assumed large-scale anisotropy of the bedrock with respect to planes of weakness, and, by extension, with respect to hydraulic conductivity. While the conceptual model is plausible on geological grounds and is supported by available core data (Foth and Van Dyke, 1995c; Agapito, 1997; TRC and Whetstone, 2001), the available aquifer tests do not allow us to precisely quantify the degree of bedrock anisotropy for model input. We addressed the uncertainty of this parameter by revisiting the pumping test that most strongly stressed the bedrock. The 213 pumping test, from which we obtained the High End Case hydraulic conductivity values, was calibrated assuming anisotropy ratios of Kx:Ky:Kz=10.00 : 3.16 : 1.00 for all bedrock units below the strongly-weathered bedrock in model layer 5. These same anisotropy ratios were assumed for all base runs and sensitivity runs presented in this report, except for those in Appendix VI.

Appendix VI contains two sets of simulations. The first set varies the bedrock anisotropy ratios in the context of the 213 pumping test to test the sensitivity of these changes to the match between simulated and observed drawdown. This procedure provides information on the uncertainty of the assumed ratios. The second set carries forward the ratios that preserve good calibration to the predictive runs that simulate the zinc phase of mining. The results listed in Appendix VI suggest that the overall response of the groundwater system is sensitive to the choice of bedrock anisotropy ratios even when the choice is constrained by the requirement that the ratios yield good calibration to the pumping test.

6.4.3.1.7 Other Model Features

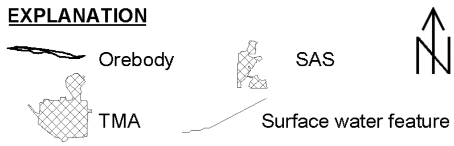
A number of simulations designed to evaluate the effects of selected model features do not appear in any of the tables or figures because they affected the results very little. They include:

1. replacing the fixed surface outflow equation for the internal lakes by an exponential rating curve;
2. reducing the full set of zinc stopes (309 drains) to only those that are expected to be opened during the first stage of the zinc mine (72 drains);
3. modifying the algorithm for assigning conductance to the mine workings drains so that it does not depend on the rock properties, but rather on an assumed 5 ft penetration of grout with final hydraulic conductivity equal to 0.003 ft/day (1e-6 cm/sec) (Appendix VII);
4. changing the drain elevations for stopes and mine workings from the middle elevation of the cell to 1 ft above the bottom of the layer; and
5. use of the dry-cell bypass in the solver.

6.4.3.2 Response Time of Stressed System

We have noted that the storage input to the various mining scenarios acts as a solver parameter decelerating the solution, rather than as a physical control on flow. However, in order to improve the understanding of the evolution of the response of the groundwater system to mining, we have varied the storage input in order to give it a more realistic physical significance. In particular, we inserted a specific yield values that varied by rock type: 0.10 for unconsolidated materials including the massive saprolite, 0.04 for the crown pillar rocks in layers 5 and 6, and 0.02 for the lower bedrock in layers 7 through 13. These values, identical to the effective porosity values used in the particle-tracking simulations, reflect the expectation that the pore space in the glacial material will release more water by draining than will rocks characterized largely by degrees of fracture porosity. They imply that under the same stress, groundwater in the bedrock tends to a steady-state equilibrium condition more quickly than groundwater in the glacial material. The Version 1, High End Case, Zinc scenario (ZINC2A) was selected for analysis. The transient output from this special set of runs with realistic specific yield values can be understood as an estimate of the response through time of the system due to the simultaneous opening of all zinc stopes.

Initial attempts to apply specific yield values that were equivalent to the effective porosities applied in the particle tracking simulations failed to achieve a stable solution. In particular, the use of a specific yield value equal to 0.02 for the bedrock below the crown pillar appeared to cause numerical instability. Instead, a simpler approach was adopted in which the specific yield for all glacial layers (1-4) was set uniformly to 0.10 and the specific yield for all bedrock layers (5-13) was set uniformly to 0.04 (compared to 0.02 in fractured bedrock that was used in particle tracking). The new run, ZINC2AS1, converged with low mass balance error. It yields a mine inflow rate of 1569 gpm after the full 40-year simulation (compared to 1579 gpm for ZINC2A). By saving the head and



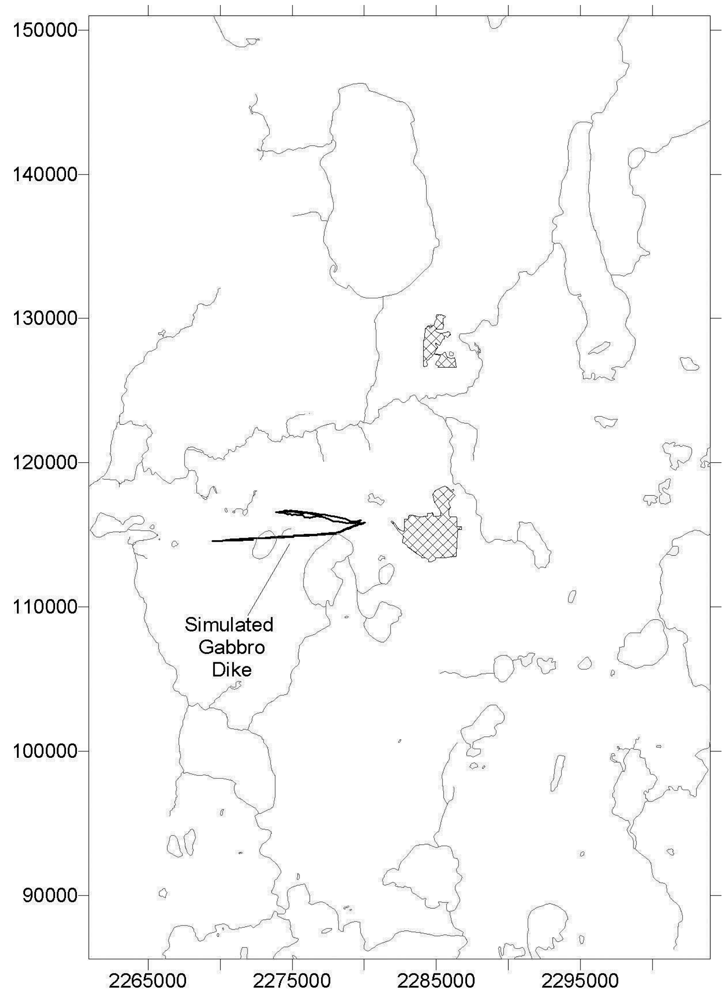


Figure 25. *Simulated gabbro dike location. Map coordinates are State Plane North, in feet. [Abbreviations: TMA, Tailings Management Area; SAS, Soil Absorption Site]*

flux output at frequent time steps over the 40-year run, it was possible to track the transient response.

The response time of the system is measured by computing the number of years necessary to achieve certain thresholds:

1. The time necessary to achieve 90 to 95 percent of the long-term mine inflow rate of 1569 gpm;
2. The time necessary to dewater 90 to 95 percent of the long-term dewatered volume of the glacial layers (3.15e9 ft^3);
3. The time necessary to dewater 90 to 95 percent of the long-term dewatered volume of the crown pillar, layers 5 and 6 (3.61e8 ft^3);
4. The time necessary to dewater 90 to 95 percent of the long-term dewatered volume of the bedrock, layers 7 through 13 (1.06e9 ft^3); and
5. The time necessary for the storage release rate to decrease to 10 to 5 percent of the discharge to model sinks (defined as the sum of the mine inflow [1569 gpm], the service well discharge [25 gpm], and the reduction in TMA recharge [33 gpm]). Note that the long-term storage release rate after 40 years is 2 gpm, or 0.1% of sink discharge.

The time necessary to achieve the 90 percent threshold for the various measures is between 3 and 7 years, while the time necessary to achieve the 95 percent threshold is between 4 and 9 years (table 28). The response of the shallow system is at the upper end of each range of years. Therefore, full development of drawdown from the mine under conditions of complete dewatering would be expected to take somewhat less than 10 years. Appendix VIII contains figures that track the transient response year by year for the five measures.

6.4.3.3 Mitigation of Surface Water

The four internal lakes and the streams and lakes within the Pickerel and Swamp Creek Basins may be subject to mitigation to reverse or reduce the effect of mining on water availability. Specifically, a mitigation plan is aimed at maintaining the internal lakes at specified stages and maintaining baseflow in streams at target levels. These target levels, known as the Metallic Mining Minimum Stage (MMMS) for lakes and the Metallic Mining Minimum Flow (MMMF) for streams, are established by the WDNR to protect public rights to the resources. Of particular interest is the effect that the combined stress of drought coincident with mining would have on the internal lakes and on the baseflow to streams, both with and without mitigation. Sensitivity of these results to the inputs used to characterize the surface-water bodies is also assessed.

6.4.3.3.1 Mitigation of Internal Lakes

Through repeated trial-and-error runs, the Crandon groundwater flow model can be used to estimate the mitigation flux necessary to restore an internal lake to a specified level. The mitigation flux applied to the lake is added to the natural inflow as part of the lake runoff term in the model LAK2 package. The MMMS target levels established by the WDNR for the internal lakes are listed below (for MMMS values that are seasonally based, the highest seasonal value is presented and used on subsequent analyses).

	Deep Hole	Duck Lake	Little Sand	Skunk
MMMS (ft MSL)	1606.25	1610.59	1591.41	1597.01

These levels are about 0.5 foot below the October 1984 levels used in calibration for Deep Hole, Little Sand and Skunk Lake. In the case of Duck Lake, the MMMS is 1.35 ft below the October 1984 level.

Comparison of the output of mining simulations with MMMS levels determines if a lake is expected to require mitigation under a particular scenario. Across the entire range of Base simulations, only Little Sand Lake ever falls below its MMMS level. This occurs in Little Sand Lake under the High End, but not the Low End, scenarios. The stage in Deep Hole and Duck Lakes never fall below the surface water outlet elevations, which are above their MMMS. Skunk Lake stage also remains above the MMMS, which we attribute to the low hydraulic conductivity sediments that constitute part of the lakebed.

Table 31 shows how the stages of internal lakes change under the following scenarios based upon the Base Runs:

- High End Pre-Mine
- High End Mining Scenarios
- Low End Pre-Mine
- Low End Mining Scenarios
- Mitigated High End Mining Scenarios

There is no need to simulate mitigated Low End mining scenarios because Little Sand Lake only drops below its MMMS for High End mining scenarios.

The rates of mitigation to Little Sand Lake depend on the particular scenario tested. To restore the lake to its MMMS under Version 1, High End, Zinc Phase conditions requires that 175 gpm be applied to the water body. To restore the lake under Version 2, High End, Copper Phase conditions requires that 90 gpm be applied. Version 1, High End, Copper Phase conditions would require less mitigation than 175 gpm because it has less mine inflow that the corresponding zinc phase. Similarly, Version 2, High End, Zinc Phase requires less mitigation than 90 gpm because it has less mine inflow than the corresponding copper phase.

More details on the inputs and outputs to the non-mitigated and mitigated simulations are provided in Appendix IX-1 (Cases 1 and 2). It should be noted that the analysis provided in Appendix IX-1 treats mitigation in one aspect only: restoring the lakes to a desired stage through the addition of water.

6.4.3.3.2 Lake Mitigation under Drought Conditions

From 1987 to 1989, precipitation to the Crandon study area fell to about two-thirds its normal level during a recognized regional drought period. These three years are used to define “drought conditions” for the purposes of this report. The low levels of precipitation are represented in the model with recharge rates that are two-thirds normal rates and in rates of runoff to the internal lakes that are two-thirds normal rates.

Drought by itself will cause lower lake levels and baseflow levels than would occur under normal conditions. In combination with mining, drought would cause lower lake and baseflow levels than would occur with mining under normal conditions. As a result, rates of mitigation under drought conditions would be higher than they would be for normal recharge. However, it is not reasonable to base mitigation rates during drought on long-term average lake levels or on MMMS levels. Instead, it is more reasonable to simulate the lake levels that would occur during drought in the absence of mining and then apply those levels as mitigation targets in place of the MMMS.

Appendix IX-1 reports on simulations for pre-mine conditions under drought, for mining scenarios under drought conditions, and for mining with mitigation during drought (see Cases 3, 4 and 5). For all drought cases examined, Deep Hole and Little Sand Lakes require mitigation over the length of the 3-year drought period to maintain their levels at the *end* of the 3-year drought period at the same level they would be without mining. Evidently, these calculations are sensitive to the severity and length of the drought. Different fluxes would be required to mitigate lakes to target levels at the end of a 4-year drought with three-quarters normal recharge. The results in Appendix IX-1 give an indication of the extent to which drought will change the amount of water needed for mitigation.

Table 31 summarizes the effect of simultaneous drought and mining on lake levels. Across the High End and Low End simulations evaluated, the mitigation water needed for Deep Hole Lake ranges between 14 and 24 gpm, the water needed for Little Sand Lake ranges between 188 and 380 gpm. Recall that under non-drought conditions, no mitigation was needed for Deep Hole Lake and the mitigation for Little Sand Lake ranged up to 175 gpm.

6.4.3.3.3 Baseflow Mitigation

Some mitigation may be needed to protect streams in the presence of mining so that stream flow does not fall below the MMMF when the stream is under baseflow conditions. The groundwater model solves for groundwater discharge into the surface-water features as a part of the simulation. As of this writing, the MMMF has not been established for each stream. In order to estimate mitigation quantities, we consider three baseflow-reduction thresholds (equivalent to 10%, 25% and 35% below average long-term rates) to provide a range that will include the MMMF determined for each stream.

Average long-term baseflow for a stream is defined here as its Q_{50} flow duration (i.e., stream flow that is exceeded 50% of the time). For the purposes of the flow modeling work, average baseflow is that simulated in the pre-mine regional model calibrated to the Q_{50} flow duration for Swamp Creek. For example, suppose that the simulated pre-mine baseflow to Hemlock Creek is 1532 gpm and that the MMMF corresponds to a 10% reduction threshold. Baseflow mitigation to Hemlock Creek would then be predicted as needed if the mine reduced the creek's baseflow by more than 153 gpm to below 1379 gpm. If for a given mining scenario the baseflow were reduced by 160 gpm, then the mitigation rate needed to allow no more than a 10% reduction would be 7 gpm for Hemlock Creek.

Table 34 stream mitigation needs for selected mining simulations. The results are grouped for MMMF thresholds corresponding to 10% reduction, 25% reduction and 35% reduction. Additional detail for a wider range of simulations is provided in Appendix IX-2.

The results of the analyses indicate that the *total* baseflow mitigation required for Base Run mine scenarios ranges up to 204 gpm for the 10% reduction threshold, up to 28 gpm for the 25% reduction threshold, and up to 14 gpm for the 35% reduction threshold. When lake mitigation is added to a scenario, then less water is required for baseflow mitigation because part of the water added to lakes eventually discharges to streams, and also mitigates the effect of the mine on the stream. Under drought conditions, more water is needed to restore baseflow to MMMF levels than under non-drought conditions. For example, the

10% threshold value under drought conditions is 286 gpm for Version 1, High End, Zinc Phase with lake mitigation, while under non-drought conditions with lake mitigation the corresponding value is 158 gpm.

The applicant has proposed to mitigate baseflow by extracting groundwater from Swamp Creek Basin and transferring it to surface waters in both the Swamp Creek and Pickerel Creek Basins. This approach assumes that infiltration to the SAS not only eliminates the need for baseflow mitigation in Swamp Creek, but also increases baseflow sufficiently to keep Swamp Creek baseflow at or above pre-mine levels despite water transfer out of the basin.

The mining plan proposes withdrawals of groundwater from the Swamp Creek Basin for mitigation by pumping a well open to the outwash. The well would be located approximately 1.5 miles west of Outlet Creek and 0.75 miles north of Swamp Creek. The source of almost all the water pumped from the mitigation well is groundwater that would otherwise discharge to streams, a quantity called "captured baseflow." Model simulations (using the Version 1, High End, Zinc Phase model) show that nearly all the well discharge originates as "captured baseflow" from the Swamp Creek Basin. From a mass balance viewpoint, baseflow mitigation would result in increasing Pickerel Creek Basin surface water flows at the expense of baseflow in Swamp Creek Basin, which in turn has been augmented by SAS infiltration.

Generally speaking, as long as the baseflow mitigation flux to the Pickerel Creek Basin is less than the SAS flux, then the Swamp Creek Basin will not suffer a reduction of baseflow relative to its pre-mining condition. The difference between the estimated SAS flux after lake mitigation (which incorporates a net usage of water by the mine and mill of about 100 gpm) and the baseflow mitigation routed to Pickerel Creek Basin from the mitigation well is an estimate of the expected net increase in Swamp Creek Basin baseflow during mining. While this expected net increase is a measure of the overall flow conditions to the Creek due to groundwater discharge, it does not account for the redistribution of baseflow along sections of the Creek and the possibility that some stretches, especially downgradient of Outlet Creek, could experience reduced ground-water discharge through the creek bed.

6.4.3.4 Alternative Surface Water Representation

Surface water representation in the DNR model is different from the applicant's model due to several modifications. Additional changes, such as replacement of Creeks 12-12a and 12-12d by Creek 12-2, assignment of a constant internal lake surface water outlet flow, and an alternative Duck Lake representation, were also evaluated.

6.4.3.4.1 Effect of Creek 12-2 Representation on Flow Conditions Around Martin Springs

During the initial stages of model development, the applicant used the USGS Mole Lake, WI, quadrangle map to digitize the perennial streams into the MODFLOW model. As indicated on the quad map, this resulted in the inclusion of Creek 12-12a and Creek 12-12d as tributaries to Creek 12-9. However, through project-site field work by personnel from DNR, it was recognized several years into the groundwater modeling process that representation of Creeks 12-12a and 12-12d on the USGS Mole Lake, WI, quadrangle map were not accurate representations of the surface water flow conditions in the area on the west side of Creek 12-9. Rather, the only perennial flow in that area occurred in a different channel system, Creek 12-2. What had been called Creeks 12-12a and 12-12d appear to correspond to a single ephemeral tributary to Creek 12-2 just upstream of its confluence with Creek 12-9.

Creeks 12-2 and 12-9 are close to the Martin Springs Wildlife Area, which also contains another water body, Creek 11-4. Because of the importance of the Wildlife Area, a sensitivity analysis was completed in which the model representation of Creeks 12-12a and 12-12d were removed from the MODFLOW stream package (STR) and an estimate of the location of Creek 12-2 based upon field visits, aerial photographs, and the Mole Lake quadrangle map was incorporated instead. Appendix X-1 contains figures that compare the original and alternate model representations of these streams. The appendix also contains a table that compares calibration statistics and model output for the two versions of the model. The table shows that the changes to the representation of Creek 12-2 has virtually no effect on model calibration or on forecasts of mine inflow, reduction in area of lakes around the ore body, or changes to baseflow at the regional scale.

At the local scale, the more accurate representation of the stream network near Martin Springs does influence model results. Figures in Appendix X-1 show that the original and revised versions of the model yield a different configuration of the simulated capture zone for Martin Springs/Creek 11-4 at its upgradient end near Little Sand Lake for both pre-mine and mining conditions. Under the revised version of the model, mining has the effect not only of reducing the capture zone, but also of shifting the upgradient end of the capture zone to the south. This implies a reduced flow of groundwater to the spring.

The final table in Appendix X-1 compares the reduction in base flow to various water bodies caused by mining under the original and revised versions of the model. The results indicate that the more accurate stream representation yields a slightly bigger baseflow reduction for Martin Springs/Creek 11-4 (15.0 percent reduction compared to 14.4 percent for the original representation), for Creek 12-2 (33.4 percent reduction compared to 28.8 percent for the original representation), and for Creek 12-9 (11.0 percent reduction compared to 9.4 percent for the original representation).

6.4.3.4.2 Internal Lake Surface Outlet Flow

All the Base Runs presented herein assign the same outlet flow for each of the four internal lakes. The stream outflow values used are 0.4 cfs for Little Sand Lake, 0.2 cfs for Deep Hole Lake, 0.1 cfs for Duck Lake, and 0 cfs for Skunk Lake, which has no outlet. For both high-end and low-end pre-mine simulations, these rates imply runoff to precipitation ratios (RO/PPT) in the range of 0.14 to 0.16, as suggested by available studies (Dames and Moore, 1985; Krohelski and others, 1999). However, this value like many others in the modeling is uncertain. Given uncertainty in the available outlet flow data and in the correct RO/PPT ratio, there is uncertainty about the correct surface (stream) outflow for Little Sand Lake, Deep Hole Lake and Duck Lake since the two quantities are linked in the lake water budgets. The lower the assumed ratio of overland runoff to dryland precipitation, the lower is the surface outflow needed to keep the lakes in balance under natural conditions. Observation suggests that the long-term average outflow from Duck Lake might be close to zero, while it is possible that the outflow for Little Sand Lake and Deep Hole Lake, while not zero, is significantly smaller than what has been assumed in the Base Runs (for example, by 1/2). Appendix X-2 provides a detailed assessment of the changes in effects on the internal lakes of reducing the lake outlet flow. In summary, the analysis indicates 1) that the assumed reduction of the Deep Hole Lake outlet rate has virtually no effect on the lake because the stage stays above the cutoff elevation during mining, 2) that the assumed reduction of the Little Sand Lake outlet rate drives its stage further below the cutoff elevation than before and magnifies the effect of the mine, and 3) the assumed absence of outlet flow from Duck Lake has a large effect because it allows the stage to fall below the cutoff elevation in the presence of mining. The analysis of Duck Lake is carried further in Appendix X-3A and X-3B.

6.4.3.4.3 Alternative Duck Lake Representation

For all the Base Runs presented in this document, Duck Lake is assigned the same lakebed hydraulic conductivity as Deep Hole Lake (0.003 ft/d) and a fixed surface water outlet flux (equal to 0.1 cfs). Both of these inputs are uncertain.

While the lakebed hydraulic conductivity of Deep Hole Lake and Little Sand Lake (0.0095 ft/d) are based on the Monte Carlo analysis of natural conditions for these lakes in 1977, 1984, and 1994 (Feinstein, 1998b), no equivalent analysis was performed on Duck Lake. In the Base Runs, Duck Lake is assigned the same lakebed hydraulic conductivity as Deep Hole Lake based on similar geomorphologic conditions. However, the possibility that the actual hydraulic conductivity of its lakebed is higher, and close in value to that of Little Sand Lake cannot be dismissed. Implementing this change would be important because of the large average thickness of Duck Lake sediments (averaging 13 ft). This thickness, in conjunction with the relatively low lakebed hydraulic conductivity of Deep Hole Lake, contributes so much resistance that the effect of the mine is buffered in the model and the lake never falls below its surface outlet elevation for the Base Case runs, even under drought conditions. Substitution of the relatively high value for lakebed hydraulic conductivity of Little Sand Lake would produce a substantially greater simulated response to mining.

In addition, from observation it is clear that the surface water outflow from Duck Lake, unlike that from Deep and Little Sand Lake, is intermittent and very small. In order to fully evaluate the potential effects of mining on this lake, it is reasonable to test a negligible outflow. Removal of the outlet from the model would also influence the response to the mine because of its effect on the overall lake water budget.

In Table 36, model runs with an alternative representation of Duck Lake are compared to Base Runs with the original representation (see Appendix X-3a for additional details). The alternative representation is subjected to an important check: the ratio of runoff into the lake to basin precipitation. The calibration runs for the High End and Low End cases of the model generate runoff needed to insure mass balance for the lakes. The runoff calculated by the model depends on the other lake parameters, including the lakebed hydraulic conductivity and surface water outflow. Studies conducted at the Crandon site and elsewhere in northern Wisconsin suggest that the runoff should amount to 0.16 of the total precipitation to the dryland area of the lake basin over a typical year (Dames and Moore, 1985; Krohelski and others, 1999). In constructing the base runs, we adjusted input lake parameters to produce ratio values close to 0.16 for each of the internal lakes. In the case of Duck Lake, the original representation (relatively low lakebed hydraulic conductivity, outflow equal to 0.1 cfs) produces a ratio equal to 0.138 for both High End and Low End calibration runs. The alternative representation produces a ratio of 0.16 for the High End calibration run and a ratio of 0.162 for the Low End run. Therefore, at least in the context of the runoff calculated by the model, the assumptions of lakebed hydraulic conductivity equal to 0.0095 ft/d and surface water outflow equal to 0.0 cfs are reasonable. It should be noted that there are additional data sets for Duck Lake for which this alternative assumption regarding the lakebed hydraulic conductivity have not been checked.

Table 36 lists the effect of the alternative representation on simulated reductions in the area and stage of Duck Lake. While the Base Run representation yields virtually no change caused by mining, the alternative representation for the Version 1, Zinc Phase, High End yields a 16% area reduction and more than 2 ft of stage drop. The corresponding Low End simulation yields a 5% area reduction and 1 ft of stage drop.

Table 36 summarizes the effect of the alternative representation of Duck Lake on lake levels for the Version 1, Zinc Phase, High End simulation. It is noteworthy that Duck Lake falls 2.16 ft below its long-term average level and 0.93 ft below the MMMS. Table 37 includes the results of the lake mitigation simulation for this scenario. The model indicates that under Version 1, Zinc Phase, High End conditions, 9 gpm are required to raise the lake 0.93 ft and restore it to the MMMS level.

Appendix X-3b provides more detail on mitigation of Duck Lake under the alternative representation for both non-drought and drought conditions. The results for drought conditions are summarized in Table 37 for the Version 1, Zinc Phase, High End simulation only. The model indicates that for this scenario in the presence of drought, Duck Lake would fall about 2.5 ft more with mining than without mining. The corresponding mitigation simulation for this scenario indicates that the amount needed to recover the 2.5 ft at the end of the 3-yr drought is about 23 gpm.

6.4.3.4.4 Effect of Adding Heterogeneity to the Representation of the Little Sand Lake Lakebed

The effect of the mine on the water level and area of nearby lakes is linked closely to the hydraulic resistance of the lakebed. The greater the resistance, the more blunted is the effect of mining. A major control on the resistance is the thickness of the bed. This variable was quantified for several lakes including Little Sand Lake as part of a geophysical study conducted on behalf of the mining company (Subsurface Detection Investigation 1994) Questions have been raised if the survey was conducted at a resolution sufficient to rule out the possibility that there are small areas where the generally fine-grained lakebed is absent. In particular, there is concern that "windows" in the lakebed under Little Sand Lake could undercut the resistance of the bed and cause the effects of mine dewatering on lake levels to be greater than simulated by model runs.

A series of runs were conducted to explore the effect of possible windows on the behavior of Little Sand Lake during the pre-mine and mining phases. Feinstein (2002) provides detail on the modeling approach adopted and the results generated. The rest of this section summarizes that memorandum.

Windows of virtually no resistance were inserted in the high-end version of the flow model at three node locations where the geophysical survey indicated thin lakebed - one in the northern, one in the central, and one in the southern part of Little Sand Lake. The total window area represented 0.3% of total lake area. By itself, incorporation of heterogeneity in the form of lowered resistance degraded the calibration of the flow model significantly. To offset this effect, the hydraulic conductivity of the lakebed at all other lakebed nodes was lowered by 20% (from 0.0095 ft/day to 0.0076 ft/day).

For pre-mine conditions, the combined effect of heterogeneity windows and lowered lakebed permeability left high-end model results unchanged except for the spatial distribution of the seepage from the lake to the groundwater. The three windows passed 21% of the total seepage in locations where just a fraction of 1% passed before. Adding more windows to the Lake would have accentuated this preferential flow effect to what we believe would be unrealistic levels given that high flux zones tend to seal up with silt carried by the seepage. Even the insertion of only three windows probably represents an extreme representation of possibility heterogeneity.

The presence of heterogeneity windows under mining conditions had virtually no effect on the overall results of the model, but it did affect the simulated behavior of Little Sand Lake:

	Base Run Without Windows	**Run With Windows**
Mine Inflow	1579.1 gpm	1579.9 gpm
Little Sand Lake Stage Change	-3.97 ft	-4.46 ft
Little Sand Lake Area Change	-39 acres	-46 acres
Percent of Seepage	0.6%	26.3%
Flux Occurring Across Window Nodes Under Mining Conditions		

The analysis shows that an extreme amount of heterogeneity introduced into the lakebed sediments in the model increases the simulated effect of the mine on Little Sand Lake by causing a moderate drop in lake stage and area relative to the homogeneous case while concentrating a quarter of the seepage flux through 0.3% of the lakebed area.

6.4.3.5 Summary of Base and Sensitivity Simulations

The High End and Low End cases yield significantly different results with respect to the predicted mine inflow, the predicted reduction in the area of Little Sand Lake, and the predicted reduction in the overall baseflow in the Pickerel Creek basin. For a given pair of scenarios related to the same phase of mining and same version of the model, table 39 shows that the High End mine inflow averages about 4 times more than the Low End, the High End Little Sand Lake area reduction averages about 25 times more than the Low End, and the High End reduction in Pickerel Creek baseflow averages about 3 times more than the Low End:

1. Versions 1 and 2 of the mining scenario model differ in the magnitude of effects they predict. The more extensive use of grouting elements in Version 2 tends to produce smaller overall effects than Version 1 despite the presence of the much greater extent of mine workings in Version 2.
2. Even if the mines are assumed to operate in perpetuity, their zones of capture under all scenarios are limited largely to the area between the ore body and the TMA. Their zones of influence at the water table are blocked from extending far to the north by the action of Swamp Creek. The one-foot drawdown contour for most scenarios extends westward, close to Mole Lake.
3. The range of simulated mine inflow rates can be compared to the 600 gpm threshold written into the draft permit. In general the Low End runs predict mine inflow rates equal to or less than the 600 gpm threshold, while the High End runs significantly exceed this value. For Version 2 of the model the range is from approximately half 600 gpm to approximately two times 600 gpm. This range of predicted effects is one measure of the uncertainty in the results.

Table 38. Summary results of base and sensitivity simulations

Case	Phase	Run	Mine Inflow (gpm)	Little Sand Lake Area Reduction[1] (acres)	Pickerel Creek Basin Baseflow Reduction (percent)
VERSION 1 (limited grout ceiling, no grout curtain, limited mine workings):					
High End	Zinc	ZINC2A	1597	39.5	8.1
Low End	Zinc	ZINC1A	602	1.9	2.8
High End	Copper	COPPER2A	1392	29.8	7.2
Low End	Copper	COPPER1A	349	0.7	2.2
VERSION 2 (extended grout ceiling, limited grout curtain, extended mine workings):					
High End	Zinc	HHZN1B	1176	19.6	5.5
Low End	Zinc	LLZN1B	285	0.7	1.5
High End	Copper	HHCU1B	1250	23.9	6.4
Low End	Copper	LLCU1B	290	1.1	11.9

[1] *Area reduction from an unstressed area of 230.5 acres.*

4. The sensitivity analysis provides another approach to evaluating uncertainty. The model shows particular sensitivity to assumptions regarding lakebed conductivity, the presence of the outwash pinchout zone, the incidence of drought, and the hydraulic conductivity of the unweathered bedrock.
5. A separate category of sensitive parameters involves the emplacement of grout. In particular, the model indicates that if the injected grout achieves a hydraulic conductivity equal to 0.0003 ft/day (1e-7 cm/sec) along the grout ceiling and grout curtain, then even under High End assumptions the mine inflow approaches a value of 60 gpm. If only 0.03 ft/day (1e-5 cm/sec) hydraulic conductivity is achieved, then the grout has little effect on limiting mine inflow or mitigating effects on surface water bodies.

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Appendix I-1

Calculation of Drain Conductance for Stope Cells

Water flowing toward the open chambers in the zinc and copper ore must overcome the resistance of the unmined rock before entering the stopes. We conceptualize any model cell that contains a stope as consisting partly of rock and partly of open chamber. A water table is assumed to exist inside the chamber at the mid-elevation of the cell. The ambient groundwater head in the rock surrounding the chamber is higher than the water table inside the chamber because the stope is a groundwater sink. The amount of flow that enters the stope is the product of the head difference between the rock and the stope and the conductance of the rock. No head loss occurs inside the stope because it has zero resistance.

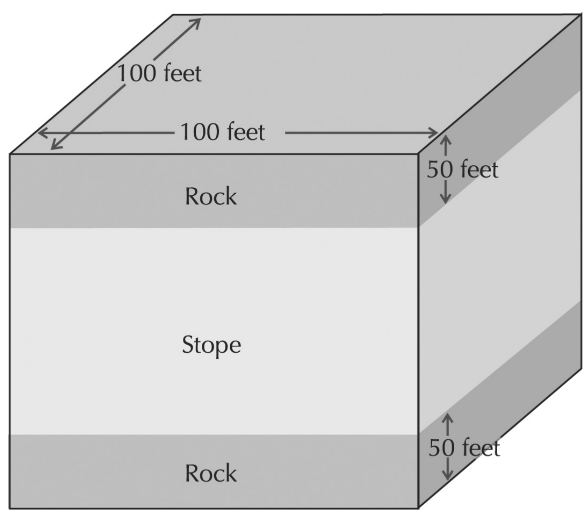
MODFLOW cannot directly simulate voids in rock. However, it can simulate the exchange between groundwater in the rock and a drain with an assumed stage or head. The drain is characterized by a conductance term that quantifies how much resistance the water must overcome to move from the rock into the drain. In this case we identify that resistance with the rock itself. In a sense we are "double counting" the rock resistance because it already enters into the groundwater equation through its hydraulic conductivity. However, model stability requires that the drains representing the stopes contribute some resistance to flow.

The head difference between the rock and stope water table equals the difference between the MODFLOW head solution for the cell and the specified water table in the stope at the mid-elevation of the cell. Model results are largely insensitive to the assumed water table elevation in the stope. Consider, for example, the Version 2 zinc simulation. With the water table at the cell mid-elevation, the mine inflow is 1176 gpm. With the water table 1 foot above the bottom of the cell, the mine inflow increases only to 1184 gpm.

The conductance of the rock is the product of two factors: the rock hydraulic conductivity divided by its thickness and the rock surface area containing the stope. We visualize the stope as occupying the middle volume of the cell with rock above and below it. Therefore, the rock thickness bordering the chamber is equal to one-quarter of the cell thickness, while the rock surface area is equal to twice the plan-view area of the cell (to take account of both the floor and roof of the stope). The accompanying schematic and sample conductance calculation show these relations. The input to MODFLOW for each stope cell consists of the drain stage equal to the cell mid-elevation and the drain conductance calculated as shown.

The conceptualization of the stope as the middle volume of the model cell is a convenient way to generate the input needed for the MODFLOW drain package. Other conceptualizations are possible, but sensitivity simulations show that this method tends to yield large conductance values be-

Schematic model cell (not to scale):



Sample calculation:

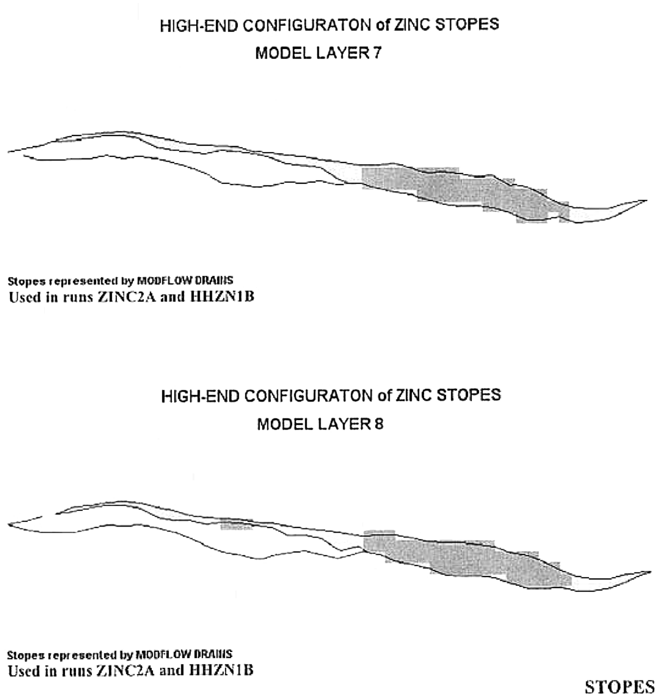
Cell plan view area =100ft x 100ft
K rock=1ft/d (typical value for relatively weathered zinc ore)
Cell thickness=200ft

Upper and lower stope surface area= 2x 100ft x 100ft-20000ft^2
Thickness of rock above and below stope=50ft
Conductance= (Kx surface area)/thickness=(1 ft/d x 20000ft^2)/ 50ft=400ft^2/d

cause of the large surface area assumed. It also tends to allow for the maximum mine inflow to the stopes. If conductance values are made even higher than the values yielded by this method, sensitivity runs show that the simulated mine inflow changes very little because it is limited by the permeability of the surrounding bedrock. For example, the Version 2 zinc simulation run yields mine inflow equal to 1176 gpm while a corresponding run with stope conductances increased by 10x yields mine inflow equal to 1168 gpm.

Appendix I-2

Location of Stope Cells



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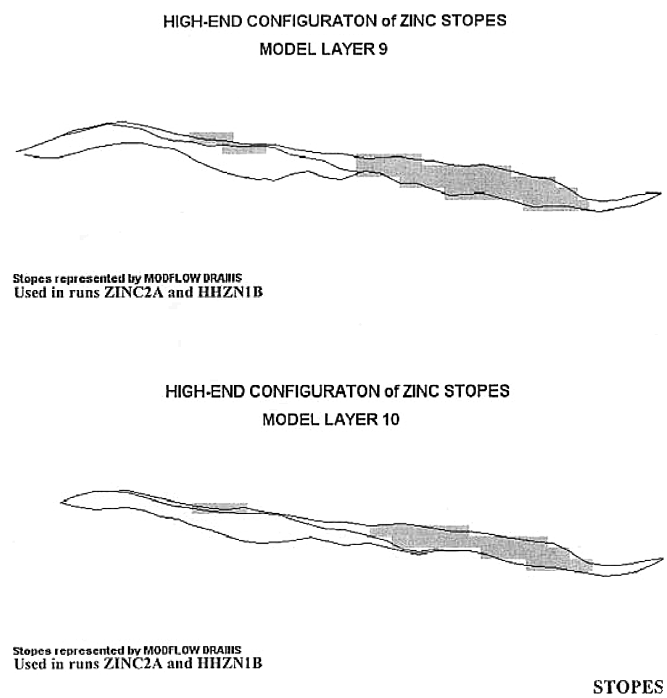

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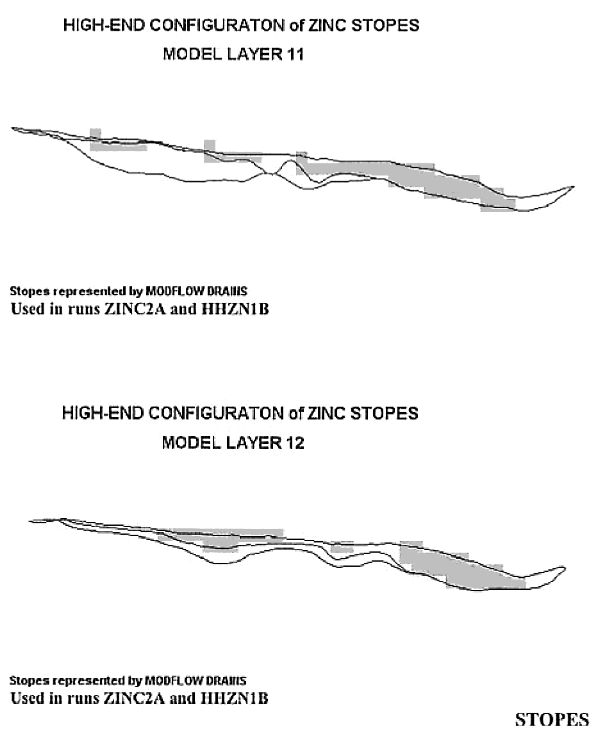

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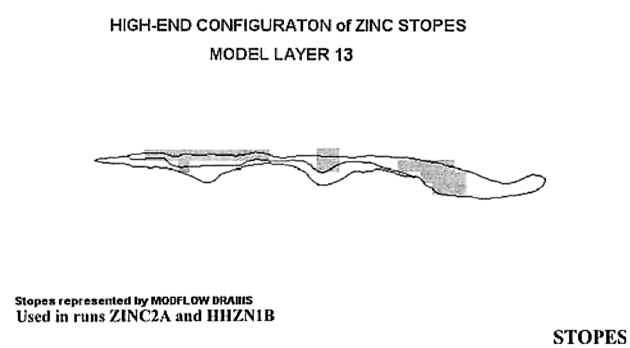

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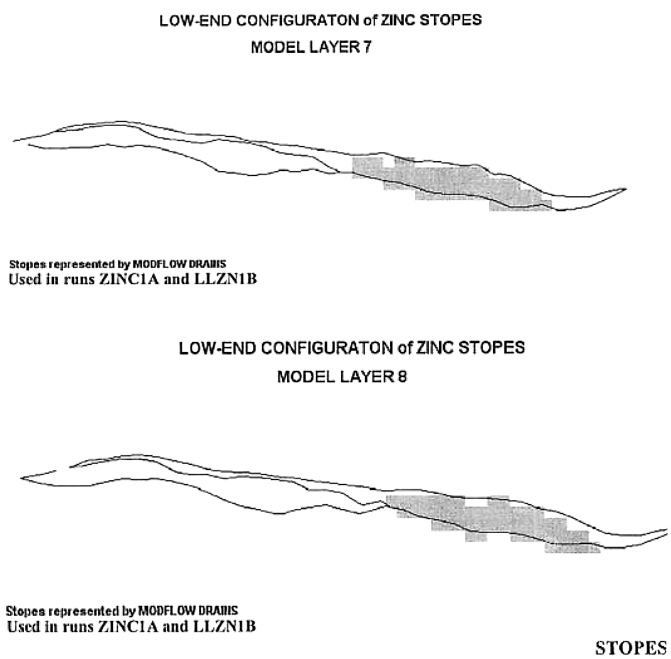

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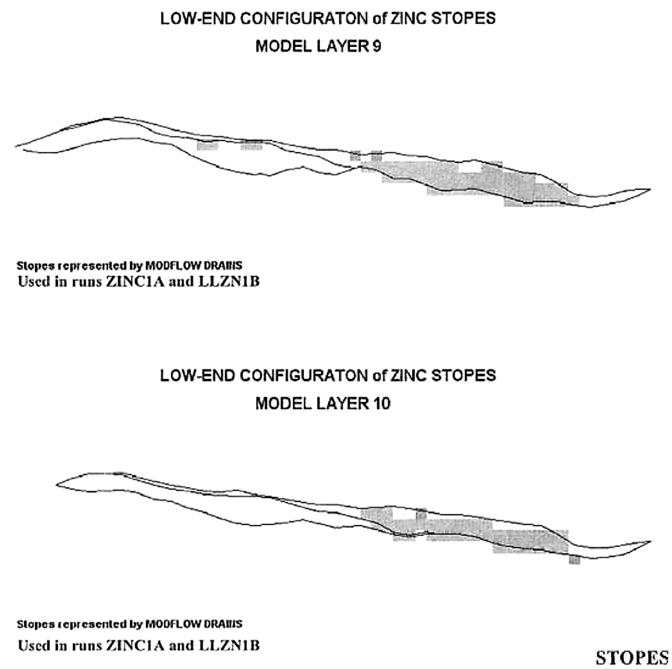

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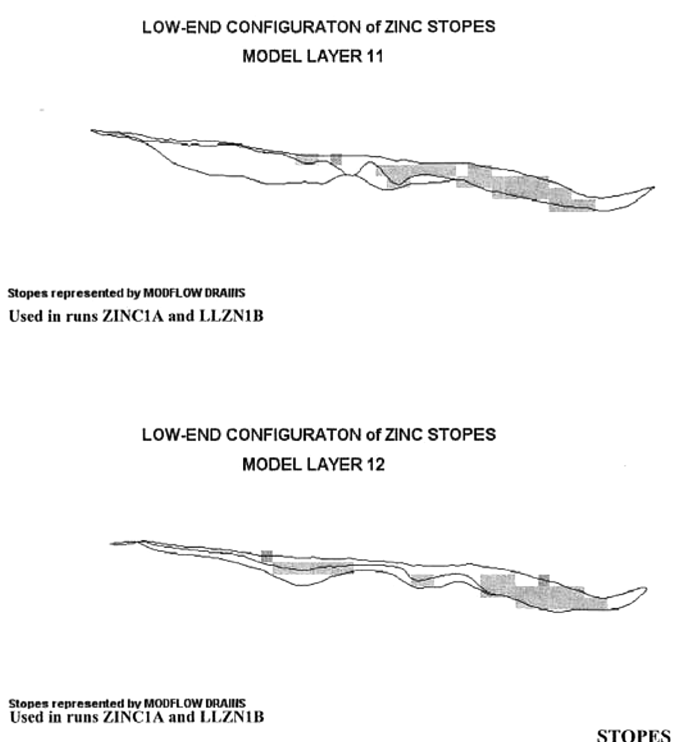

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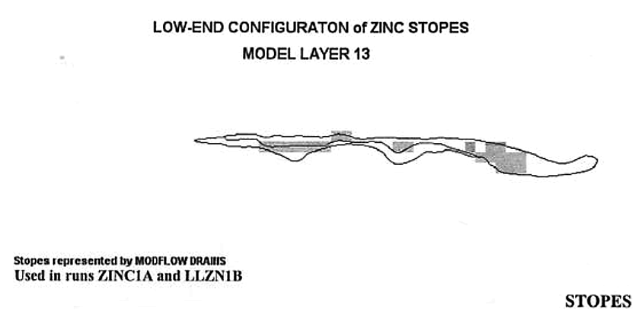

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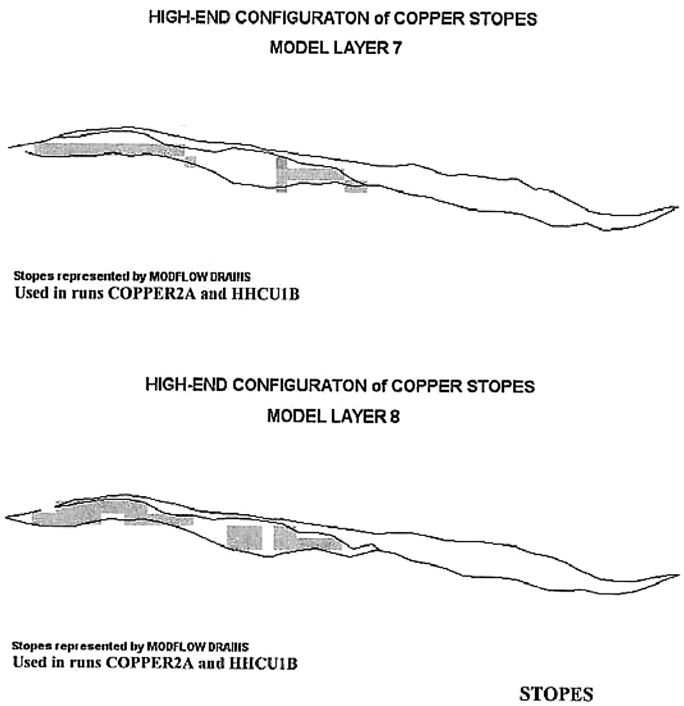

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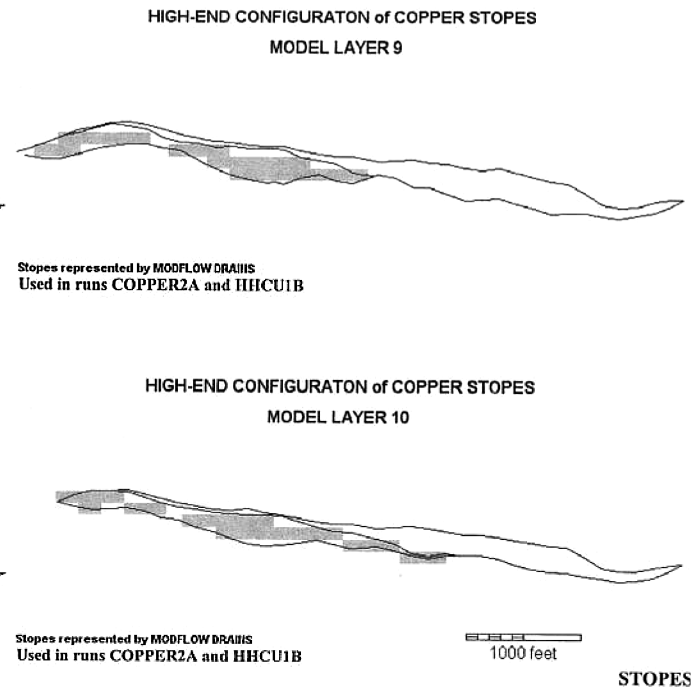

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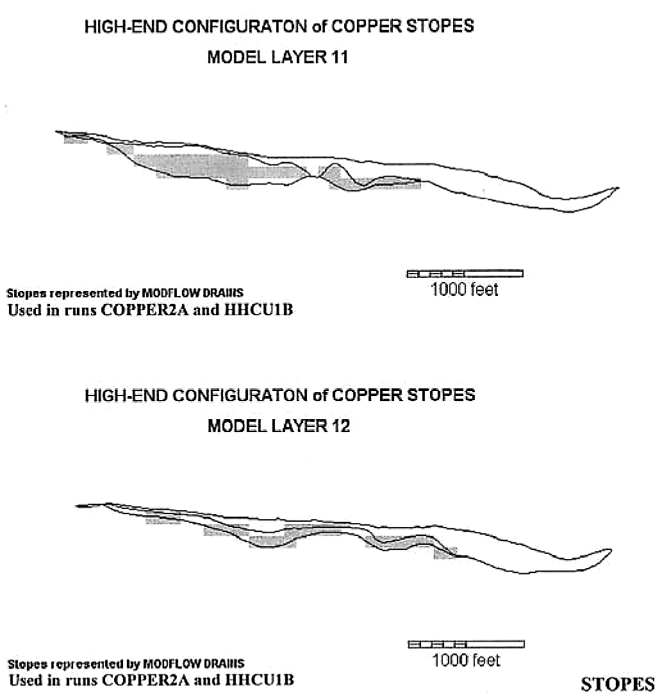

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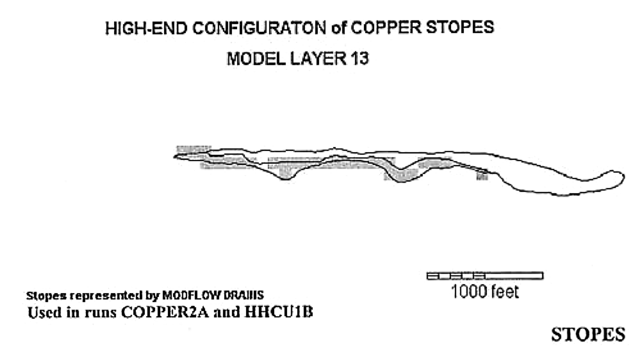

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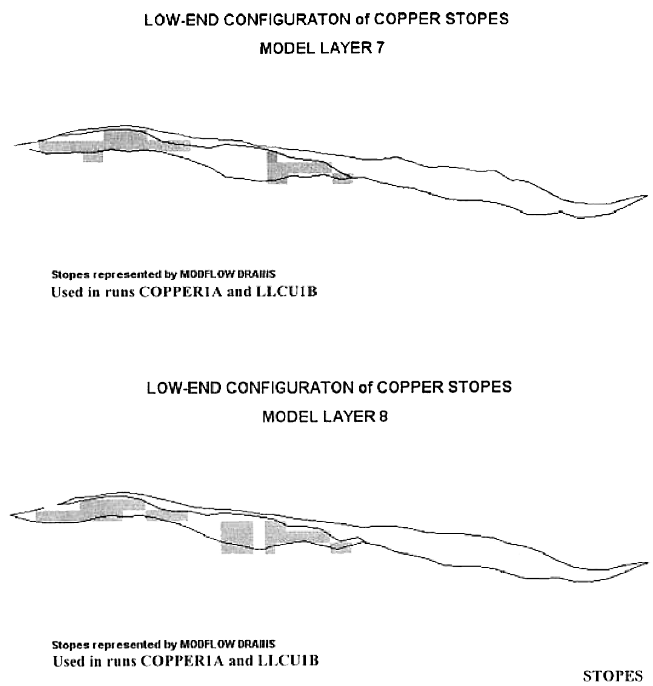

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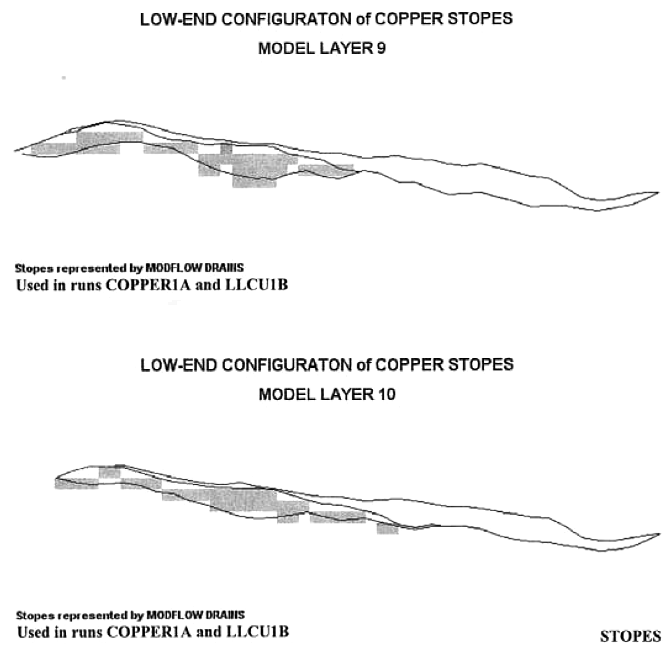

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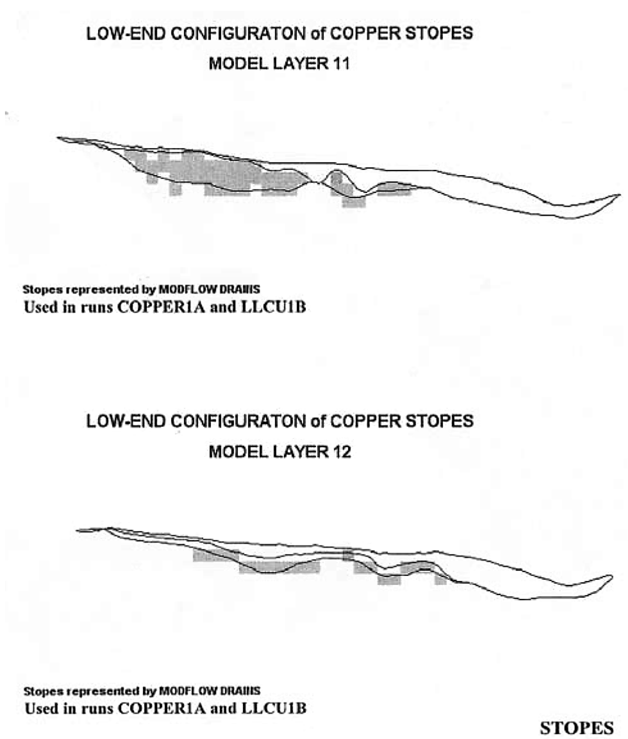

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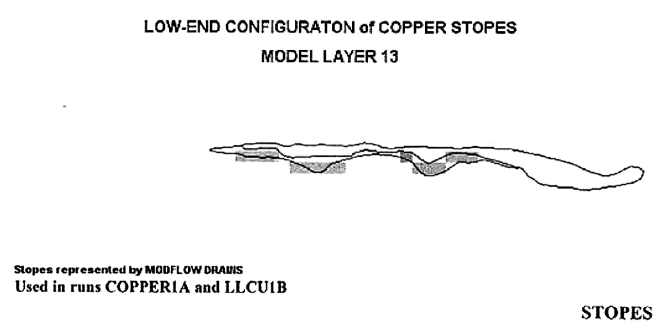

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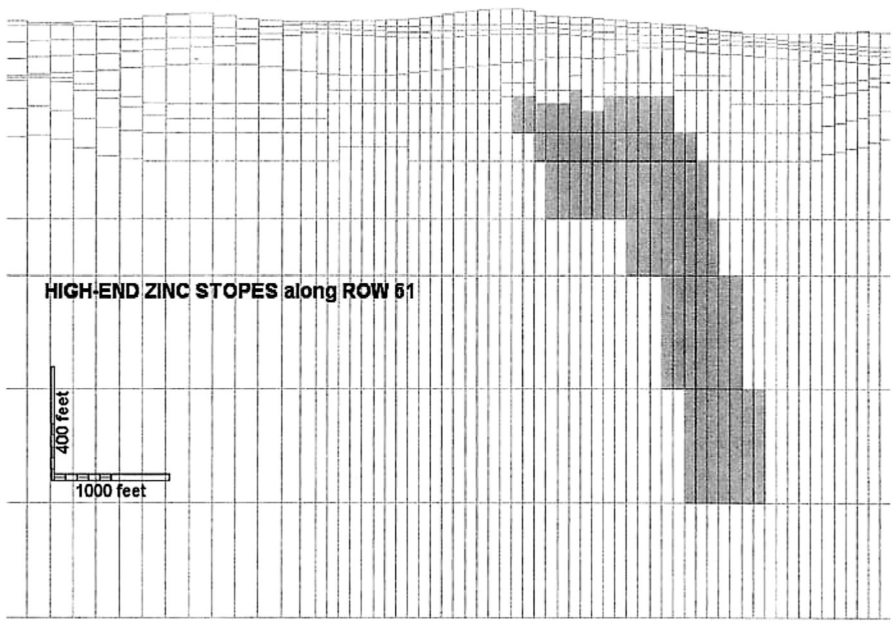

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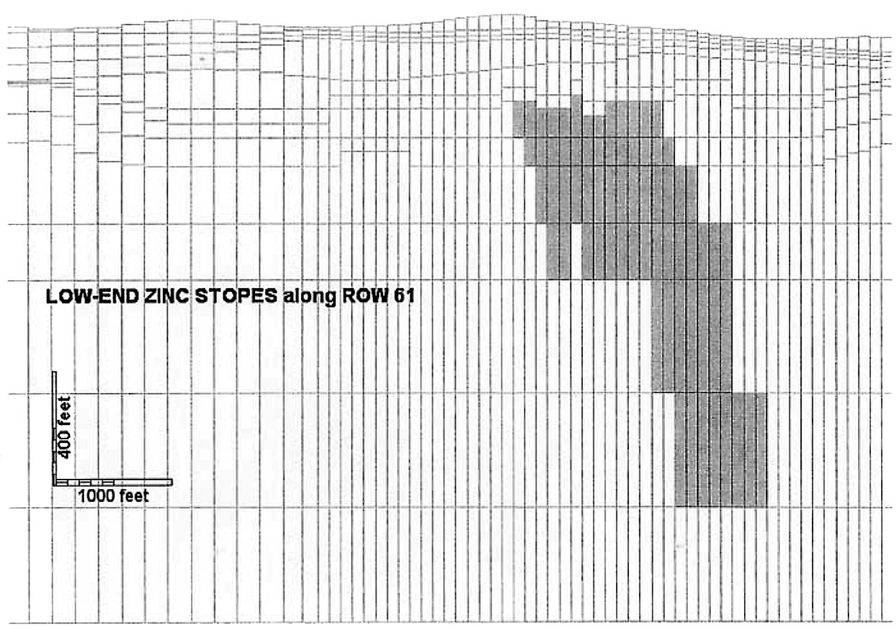

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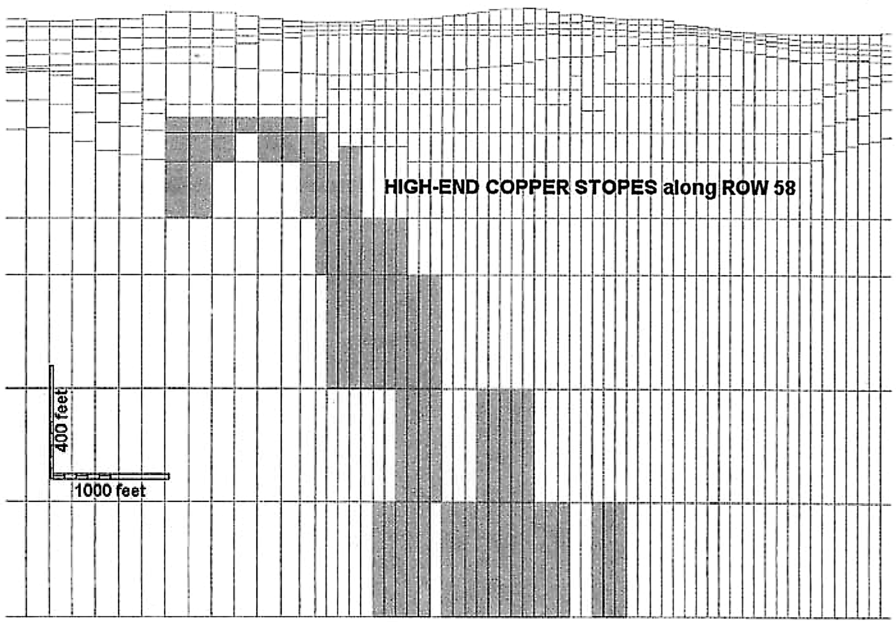

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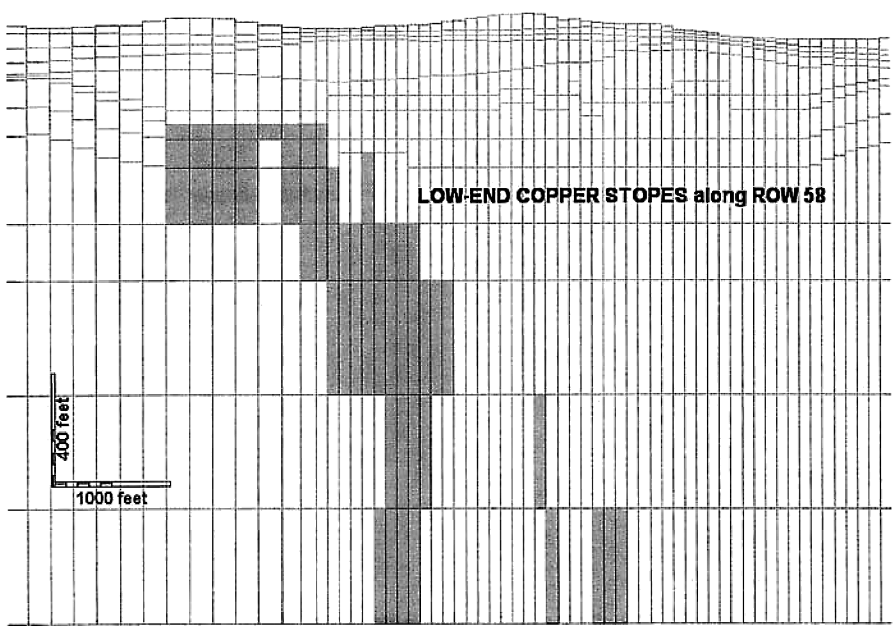


Figure AI-2-20.

Appendix I-3

Calculation of Drain Conductance for Mineworking Cells

The proposed mineworkings are drifts in the form of horizontal cylinders that provide access to the stopes at different depths within the mine. The drifts run alongside the ore body but are located mostly in the Hanging Wall. According to the mining plan put forward by NMC, the average diameter of the drifts is expected to be 16 ft. The plan also provides for grouting to minimize water inflow. That is, whenever the mineworkings act as an important groundwater sink, they would be grouted to add resistance. The mining engineers expect to reduce the hydraulic conductivity of the hanging wall to 1e-6 cm/sec in wet areas by injecting the grout 10 ft into the surrounding rock.

The cylinders run east to west, or less frequently, north to south through model cells in layers 7 through 18. They are represented as model drains in the form of cylinders. The flow into the cylinders is dictated in part by the head difference between the surrounding rock and the head at the inside walls of the drifts. The MODFLOW solution provides the ambient head. We assumed the head inside the cell to be equal to the mid-elevation of any cell intersected by a drift. Model results show small sensitivity to the assumed value for the inside head. Consider the Version 2 zinc simulation. If the stope water table is assumed to be 1 ft above the bottom of the cell (see Appendix I-1), but the mineworking elevation is assumed to be at the mid-elevation, the simulated mine inflow is 1184 gpm. If both the stope and mineworking drain head elevations are assumed to be 1 foot above the cell bottom, the simulated mine inflow increases to 1212 gpm.

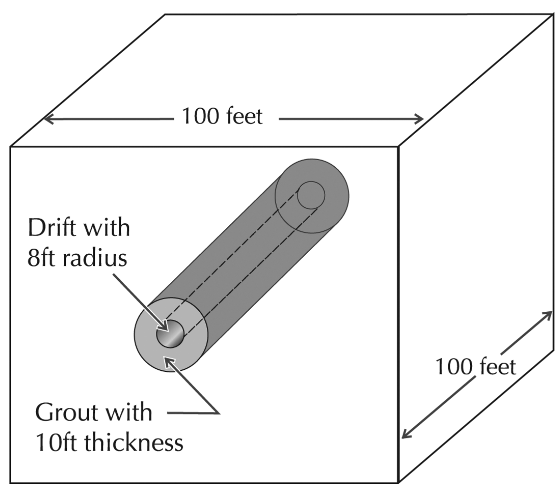
We used the expected radius of 8 ft, the expected grout thickness of 10 ft and the expected grout hydraulic conductivity of 1e-6 cm/sec to calculate drain conductances for all model nodes containing mineworkings. The conductance is equal to the product of two factors: the grout conductivity divided by the grout thickness and the surface area of the cylinder. The surface area of the cylinder is equal to 2π multiplied by the radius of the cylinder and by its length. The length is assumed to be the east/west or north/south dimension of the cell depending on the orientation of the drift.

Because layers 11, 12 and 13 are thicker than overlying layers, they contain two levels of mineworkings in the mine plan. For this reason, the conductance of the mineworking drain cells in these layers is doubled to account for the additional surface area for inflow.

The model results have small sensitivity to the mineworkings conductance. If the Version 2 zinc simulation is rerun with the assumed grout conductivity increased by 2.5x to 2.5e-6 ft/day, the mine inflow increases from 1176 gpm to 1216 gpm. If the assumed grout conductivity is increased by 10x to 1e-5 ft/day, the mine inflow increases from 1184 gpm to 1242 gpm.

The schematic figure below contains a sample calculation of drain conductance for a mineworking cell.

Schematic model cell (not to scale):

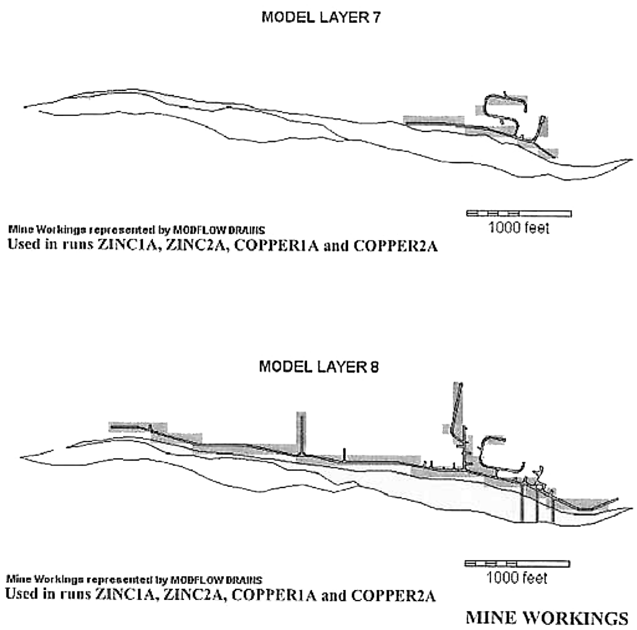


Sample calculation:

Kgrout=0.0028ft/d (1e-6cm/sec)
Depth of grout penetration=10ft/d
Drift length=100ft
Average drift radius=8ft
Cylinder surface area =2 x radius x length=5026ft^2
Conductance= (Kgrout x surface area)/grout thickness
Conductance =(0.0028ft/d x 5026ft^2)/10ft=1.41ft^2/d

Appendix I-4

Location of Mine Workings Cells



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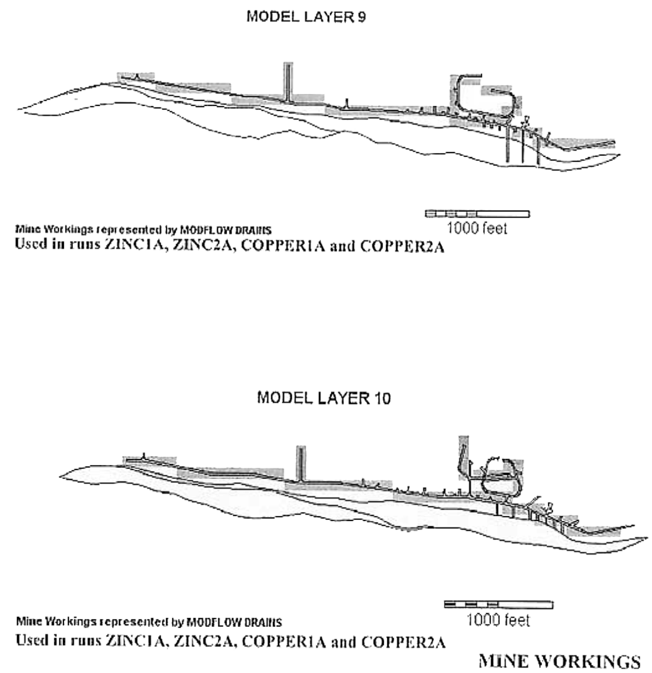

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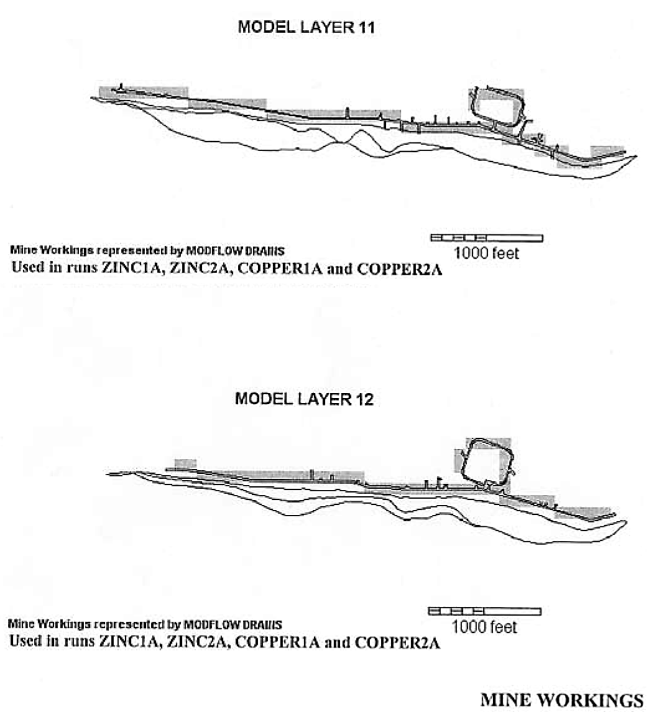

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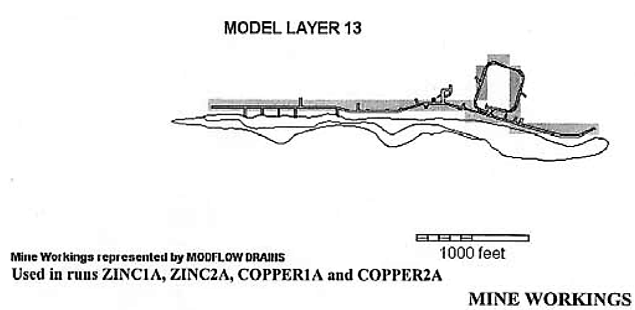

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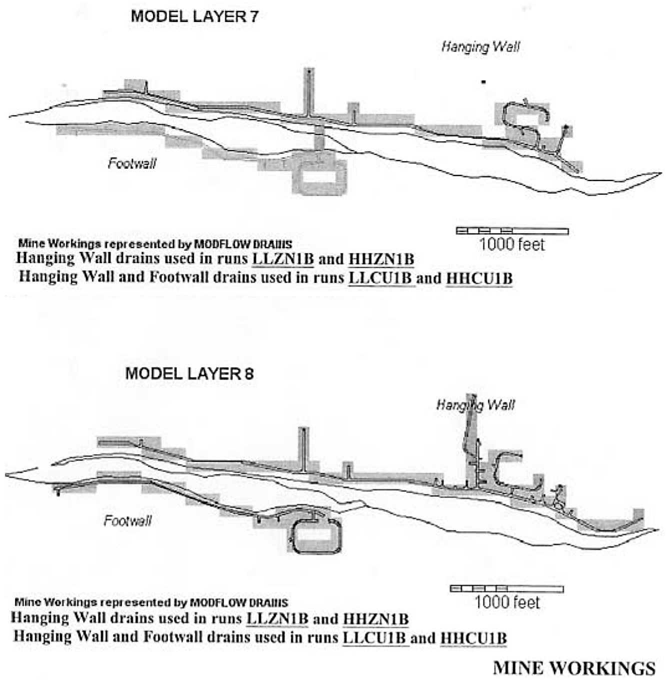

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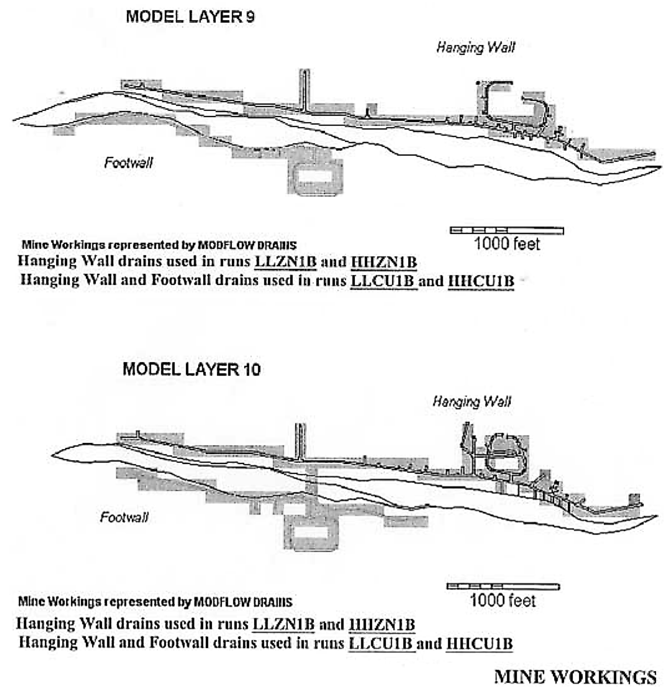

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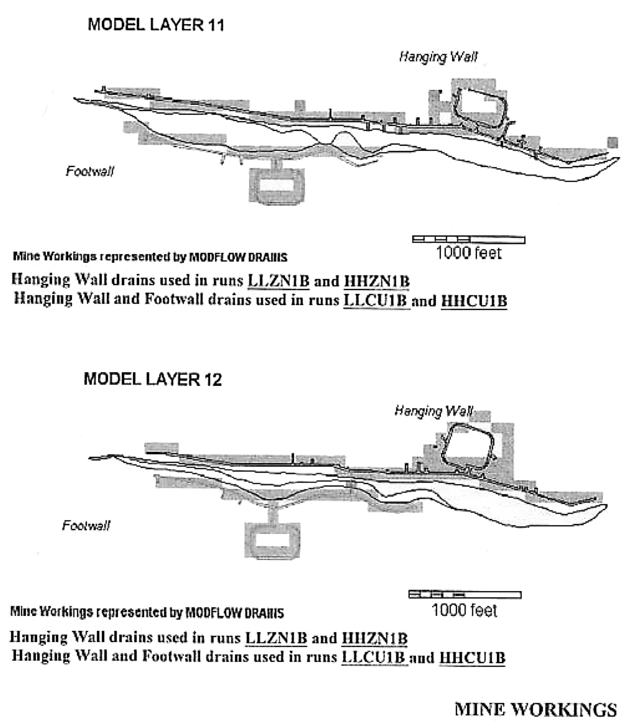


Figure AI-4-7.

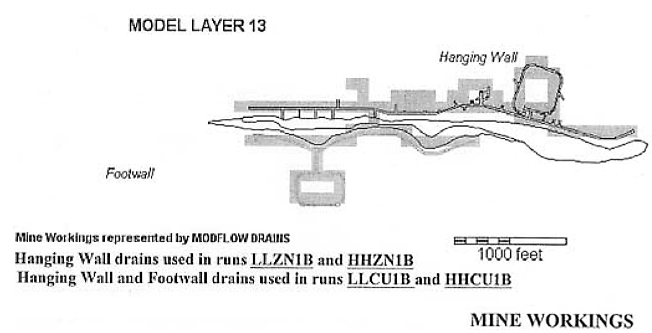


Figure AI-4-8.

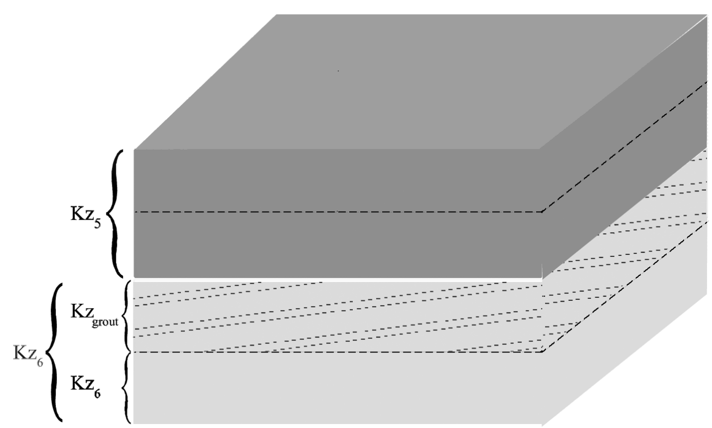
Appendix I-5

Calculation of Leakance for Grout Ceiling

The grout ceiling represents the grouted portion of the crown pillar over the proposed mine. The grout is designed to reduce downward movement of groundwater from the glacial deposits through the crown pillar to the stopes and mine workings. The extent and vertical hydraulic conductivity (K_z) of the grout ceiling differ in Versions 1 and 2 of the model. However, in both versions the grout ceiling at any location is assumed to be a horizontal slab 25 ft thick. Because Layer 6 of the model (corresponding to the bottom part of the crown pillar) is always 50 ft thick, the grout ceiling is inserted in the model by assuming a hydraulic conductivity reduction in the upper half of layer 6.

MODFLOW controls vertical flow between model layers through a leakance term called VCONT. This term is the inverse of the sum of the resistance over the bottom half of one layer and the upper half of the underlying layer, where resistance is the ratio of thickness to K_z. The greater is the thickness of each half layer, the greater is the vertical resistance across the layers and the smaller is the VCONT term. The greater the K_z of each layer, the greater is the VCONT term. The attached sheet shows the formula for VCONT in terms of model layers 5 and 6.

SCHEMATIC MODEL CELLS (not to scale):



FORMULAS

$$VCONT_{5,6} = \frac{1}{\frac{THK_5/2}{Kz_5} + \frac{THK_6/2}{Kz_6}}$$

Whenever $Kz_6 > Kz_{grout}$, then,

$$VCONT'_{5,6} = \frac{1}{\frac{THK_5/2}{Kz_5} + \frac{THK_6/2}{Kz_{grout}}}$$

$$Kz'_6 = ½\,(Kz_{grout} + Kz_6)$$

Where:

THK = thickness of model layer
Kz_5 = vertical hydraulic conductivity of model layer 5
Kz_6 = vertical hydraulic conductivity of model layer 6
Kz_{grout} = vertical hydraulic conductivity of grout
Kz'_6 = updated Kz for model layer 6
$VCONT_{5,6}$ = leakance between model layers 5 and 6
$VCONT'_{5,6}$ = updated leakance between model layers 5 and 6.

EXAMPLE

THK_5 = 100ft THK_6 = 50ft
Kz_5 = 0.5ft/d Kz_6 = 0.1ft/d
Kz_{grout} = 0.028ft/d (1e-5cm/s)

$$VCONT_{5,6} = \frac{1}{\frac{50}{0.5} + \frac{25}{0.1}} = 3.8e\text{-}3ft/d$$

$$VCONT'_{5,6} = \frac{1}{\frac{50}{0.5} + \frac{25}{0.028}} = 7.2e\text{-}4ft/d$$

$$Kz'_6 = ½\,(0.1 + 0.028) = 0.064$$

The grout is designed to lower the vertical conductivity of the crown pillar. At any cell location targeted for grout, a change is made to model input only if the K_z of the crown pillar in layer 6 is greater than the assumed K_z of the grout. The attached sheet shows an example substitution assuming a grout hydraulic conductivity of 1e-5 cm/sec corresponding to Version 1 of the model and for a grout conductivity of 1e-6 cm/sec corresponding to Version 2 of the model.

The algorithm for calculating the leakance across the grouted portion of the crown pillar was developed by the consultants for NMC.

The change n the vertical hydraulic conductivity in the upper half of Layer 6 owing to the grout requires that the vertical hydraulic conductivity value assumed for the cell as a whole be updated. We update it by averaging the original K_z and the grout K_z (see example calculation).

Appendix I-6

Location of Grout Ceiling

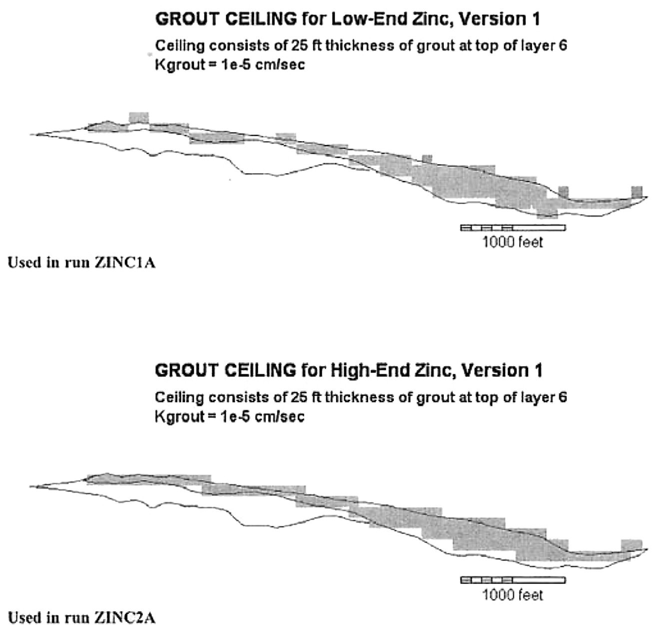
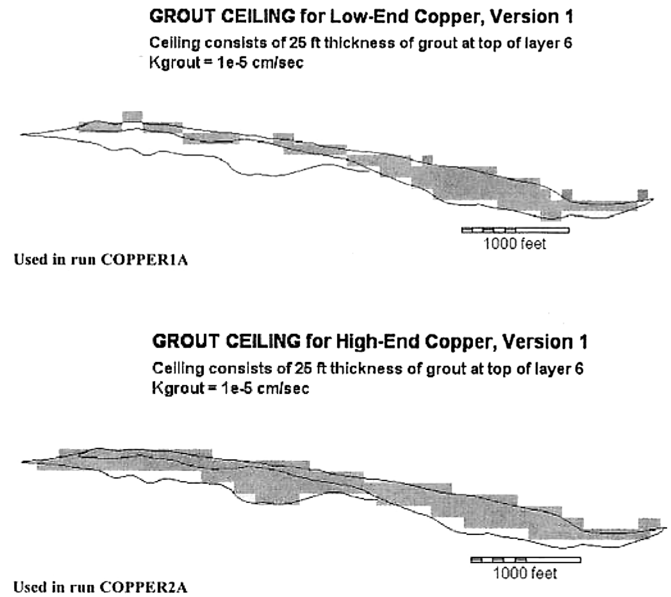


Figure AI-6-1.



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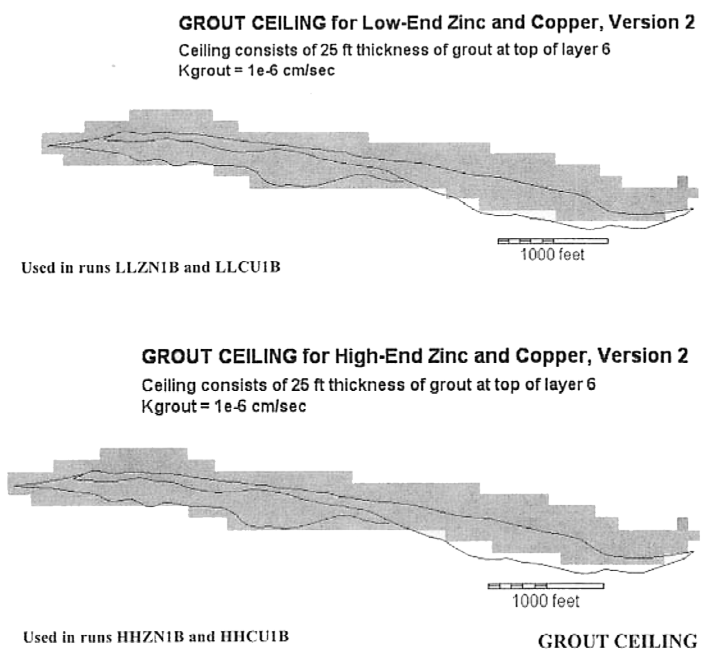


Figure AI-6-3.

Appendix I-7

Calculation of Horizontal Flow Barrier for Grout Curtain

Version 2 of the MODFLOW model incorporates a vertical grout curtain that is designed to control the flow of water laterally into the mine workings as well as into the stopes. The curtain is assumed to surround stopes and drifts along the hanging wall side to the north of the ore body and along the footwall side to the south of the ore body. Vertically, it is assumed to extend from the bottom of the crown pillar across the upper part of the mine. The assumed vertical length of the curtain is on the order of 260 ft; it corresponds to the combined thickness of MODFLOW model layers 6, 7 and 8. Appendix I-8 contains figures showing the location of the curtain in plan view and section.

The curtain design calls for a grout wall that follows the outline of access drifts that surround the ore body. For simplicity, the model represents the curtain as simple vertical walls to the north and south of the ore body that encapsulate the drifts but do not follow their exact contours. In the hanging wall the curtain is “keyed” to the northernmost extension of the drifts in layer 8 of the model. Because the mine dips to the north, a wall keyed to the northernmost extension of the drifts in layer 8 is sure to encapsulate the hanging wall drifts in layer 7. Conversely, in the footwall the curtain is “keyed” to the southernmost drifts in layer 7 so that it automatically encapsulates the drifts in layer 8.

The curtain is input to the MODFLOW as an added resistance element through the Horizontal Flow Barrier Package. This package assumes that flow barrier, or curtain, has a designated thickness and a designated hydraulic conductivity. The flow barrier must be located at the vertical face between two model cells. The resistance of the flow barrier is added to the resistance owing to the aquifer material occupying half of each cell that shares the vertical face. A schematic representation from the MODFLOW documentations shows in planview the arrangement for a vertical barrier oriented either north to south or east to west.

The grout curtain present in Version 2 of the model is assumed to be 25 ft and its hydraulic conductivity is assumed to be 1e-6 cm/sec or 0.0028 ft/day. Suppose each cell sharing the face has a hydraulic conductivity of .05 ft/day and a total width of 100 ft perpendicular to the orientation of the face. Given that the resistance of any element is equal to thickness divided by hydraulic conductivity, the combined resistance is of the cell material plus the curtain is:

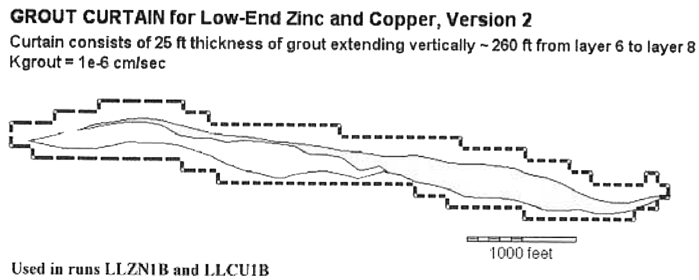
(100/2)/ .05 + 25/0.0028 + (100/2)/.05 =10,928 days.
Half Cell   Curtain   Half Cell

Note that the curtain increases the “natural” resistance by about 5.5 times from 2000 days to 10,928 days for the assumed values. The increased resistance serves to diminish groundwater flow into the mine complex.

Refer to the main text for tables that demonstrate the sensitivity of simulated mine inflow to the assumed grout hydraulic conductivity of the curtain and to its vertical extent.

Appendix I-8

Location of Grout Curtain



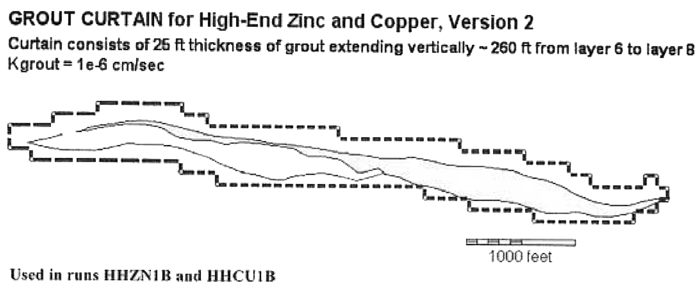


Figure AI-8-1.

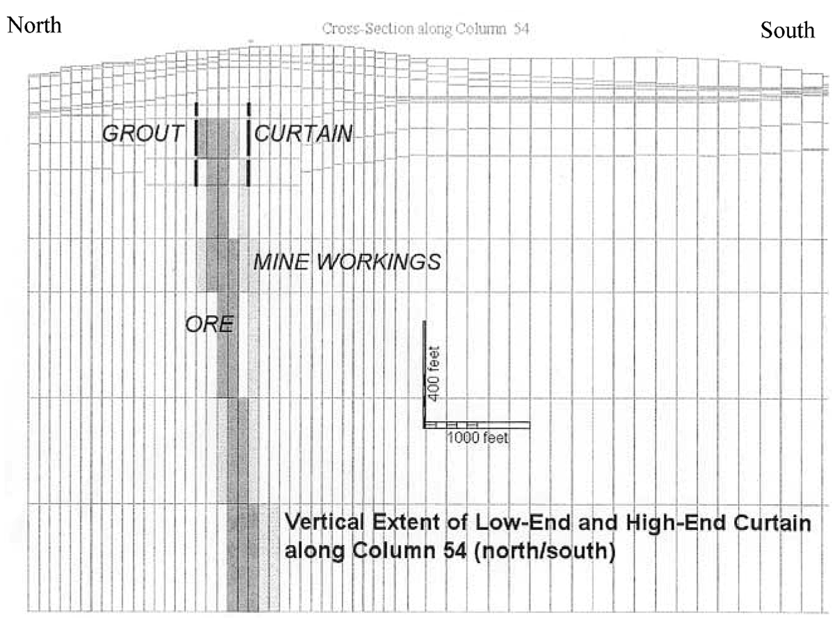


Figure AI-8-2.

Appendix I-9

Added Recharge to Account for Soil Absorption System

The Soil Absorption System (SAS) is designed to infiltrate water derived from the operation of the proposed mine. The approximate area devoted to the SAS is shown in Figure A9-1. It consists of 72.3 acres. The relation of the SAS area to the MODFLOW grid is shown in Figure A9-2.

It is proposed to apply the water from the mine to distinct sectors within the SAS area at nonuniform rates. The following tables show the relation of the sectors to the MODFLOW grid and the percent of water applied to each sector:

Sector	Row	Column	Percent infiltration
A	11	113	11.8
B	11	113	13.6
C	11	113	16.4
D	12	114	10.9
E	12	112	11.7
E	12	113	11.7
F	12	110	11.95
F	12	111	11.95
Total			**100.00**

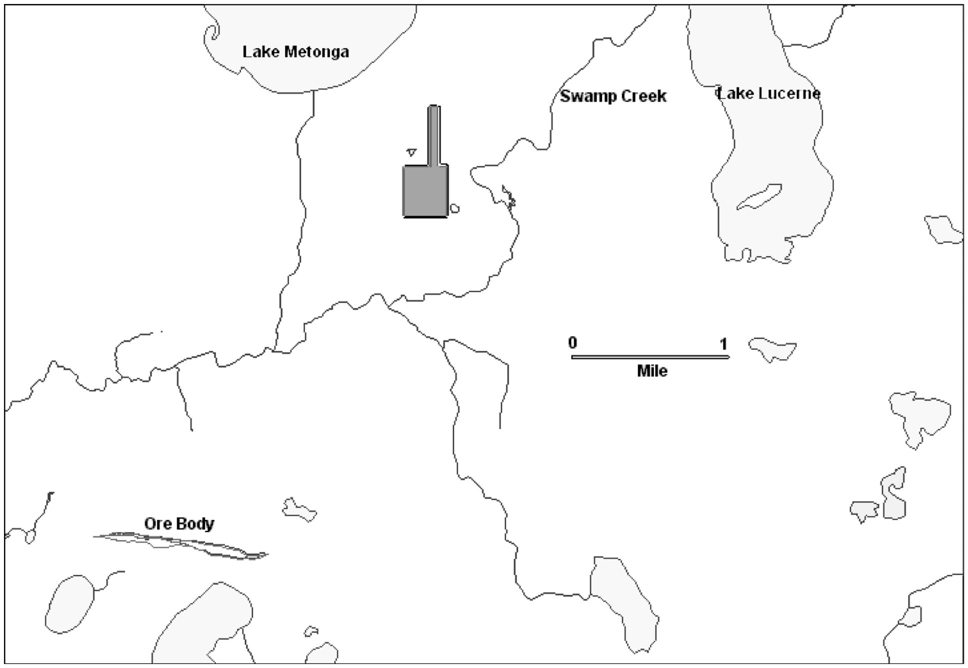
Because the sectors can fall into more than one model cell or less than a full model cell, the percent of the water applied to each cell is uneven. The following table shows the percent distribution by cell:

Layer	Row	Column	Area ft^2	Percent infiltration
1	11	113	600,000	41.8
1	12	110	510,000	11.95
1	12	111	510,000	11.95
1	12	112	510,000	11.7
1	12	113	510,000	11.7
1	12	114	510,000	10.9
Total			**3,150,000**	**100.00**
			= 72.3 acres	

The percent application to each cell is multiplied by the total SAS infiltration to calculate the amount of water applied to each cell. This amount is divided by the cell area to determine a rate. The rate is *added* to the prescribed recharge rate for the cell to calculate the total recharge rate. For example, if a cell ordinarily receives 10 inch/yr of recharge, or 0.0023 ft/day, and if the added SAS infiltration rate for the cell equals 400 inch/yr, or 0.092 ft/day, then the total rate to the cell is 410 inch/yr, or 0.0943.
The following table shows an example calculation of the added recharge rate by SAS sector and by model cell. The assumed total SAS application rate is The following table shows an example calculation of the added recharge rate by SAS sector and by model cell. The assumed total SAS application rate is ***1500 gpm.***

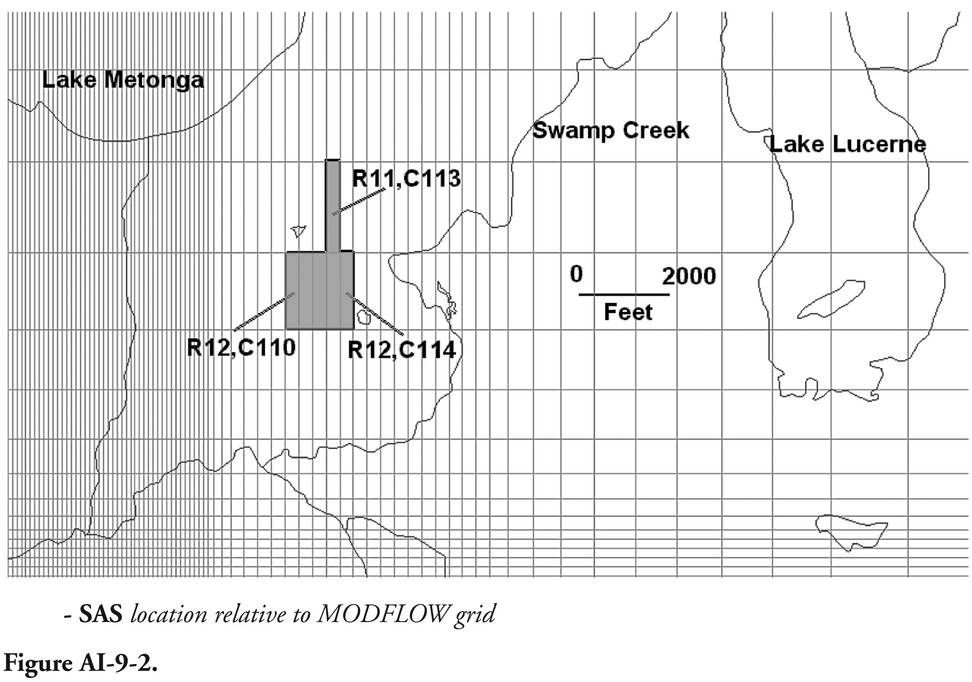
Sector	gpm	ft/day	Row	Column
A	176.5	33,976	11	113
B	203.8	39,234	11	113
C	245.8	47,323	11	113
D	163.9	31,549	12	114
E	175.4+175.4	33,773+33,773	12	112+113
F	179.6+179.6	34,582+34,582	12	110+111
Total	**1500**	**288,792**		

Sector	Row	Column	Area ft^2	Added recharge rate ft/day	inch/yr
A+B+C	11	113	600,000	0.200	880
D	12	114	510,000	0.0619	271
0.5*E	12	112	510,000	0.0662	273
0.5*E	12	113	510,000	0.0662	273
0.5*F	12	110	510,000	0.0678	297
0.5*F	12	111	510,000	0.0678	297
Average				**0.0917**	**402**



- **SAS** *location*

Figure AI-9-1.

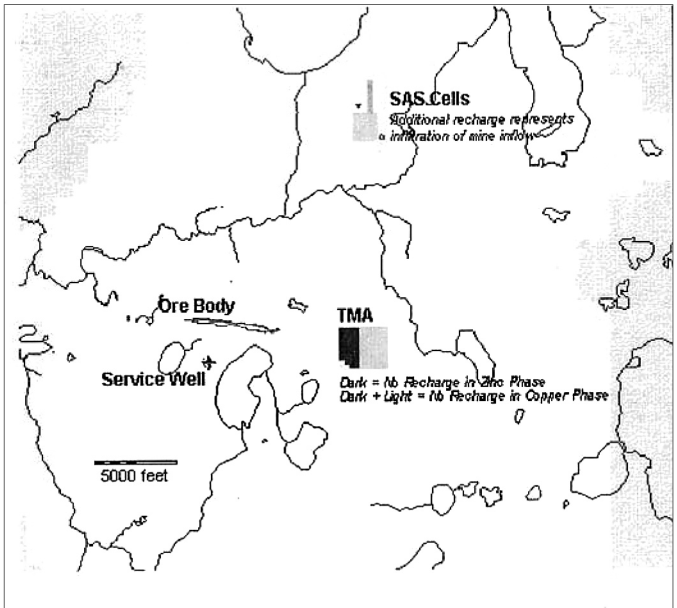


- **SAS** *location relative to MODFLOW grid*

Figure AI-9-2.

Appendix I-10

Location of SAS, TMA and Service Well



Location of SAS, TMA, and Service Well.

Figure AI-10-1.

Appendix I-11

Location of Post Mining Vertical Shafts

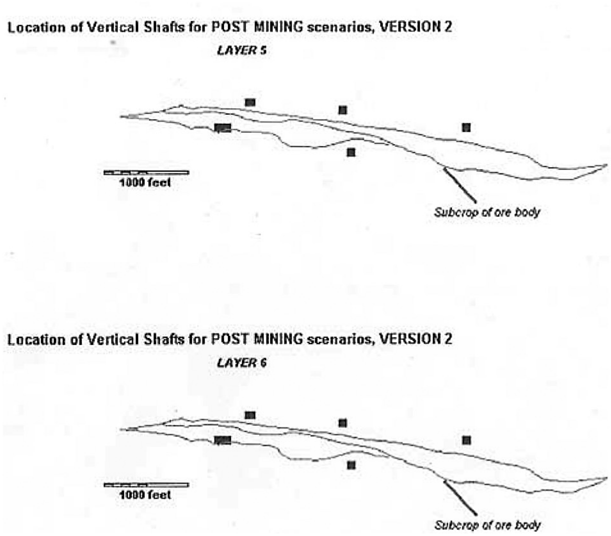


Figure AI-11-1.

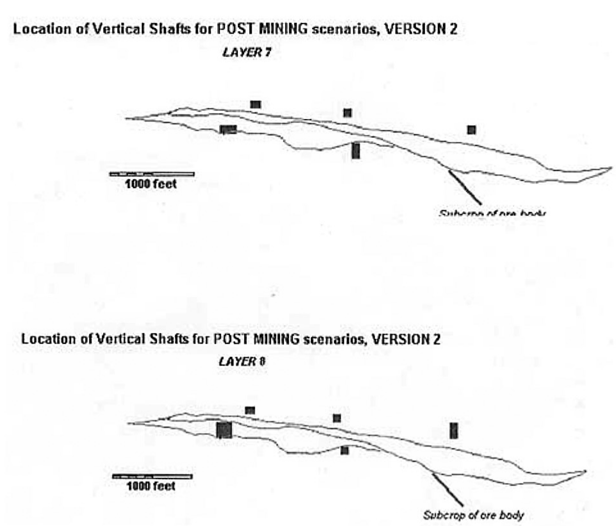


Figure AI-11-2.

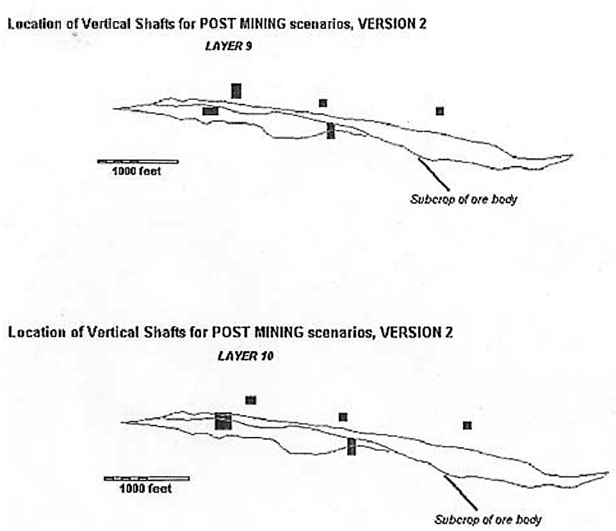


Figure AI-11-3.

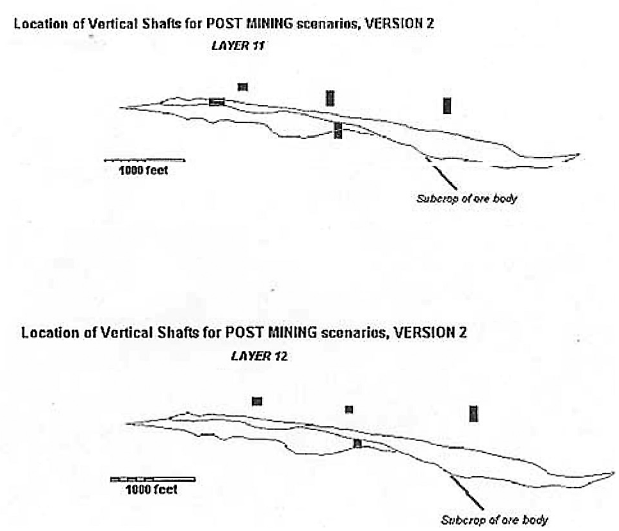


Figure AI-11-4.

Appendix II

High End and Low End Behavior

The High End and Low End simulations in this study are designed to encompass a reasonable range of responses of the groundwater flow system at the Crandon site to proposed mining activities. For that reason it is important to understand both *how* the two representations differ with respect to the simulated responses and *why* they differ. This appendix has three parts. In the first a series of plots show the flux conditions corresponding to High End and Low End simulations in plan view and in section. In the second the results for a series of simulations are reported that shed light on the controls that distinguish High End from Low End behavior. The third discusses how the treatment of unsaturated flow in the model solution affects simulated mine inflow for the High End and Low End cases.

Part I.

Comparison of High End and Low End simulations by means of vertical flux maps

Fluxes are shown in plan view and section:

a) One set of shaded gray-scale plots shows areas of concentrated downward flux in plan view at different elevations.

The elevations correspond to the contact between:

- Outwash and Early Wisconsin Till
- Early Wisconsin Till and Crown Pillar
- Crown Pillar and Upper Stopes of Ore Body

Model cells over most of the plots are 100 ft x 100 ft in area.

On the gray scale:

- 3.162e-3 ft^3/day is equivalent to 0.16 gpm/model cell
- 1e-2 ft^3/day is equivalent to 0.5 gpm/model cell
- 3.162e-2 ft^3/day is equivalent to 1.6 gpm/model cell
- 1e-1 ft^3/day is equivalent to 5 gpm/model cell
- 0.3162 ft^3/day is equivalent to 16 gpm/model cell
- 1 ft^3/day is equivalent to 50 gpm/model cell

In the plan view plots the stippled zones show areas where downward flux occurs across an unsaturated zone.

MODFLOW allows vertical flow in the case of stacked water tables as long as there are no inactive or dry nodes between the two saturated zones. The amount of vertical flow is proportional to the driving head above the unsaturated zone, which is equivalent to the saturated thickness of the upper saturated zone.

b) Shaded gray-scale plots show areas of concentrated downward flux along east-west and north-south sections.

The relative positions of the Uppermost Water Table, Outwash, Early Wisconsin Till, Crown Pillar and Upper Stopes of the Ore Body are indicated on the sections.

The cross section traces correspond to Row 63 and Column 63 of the model.

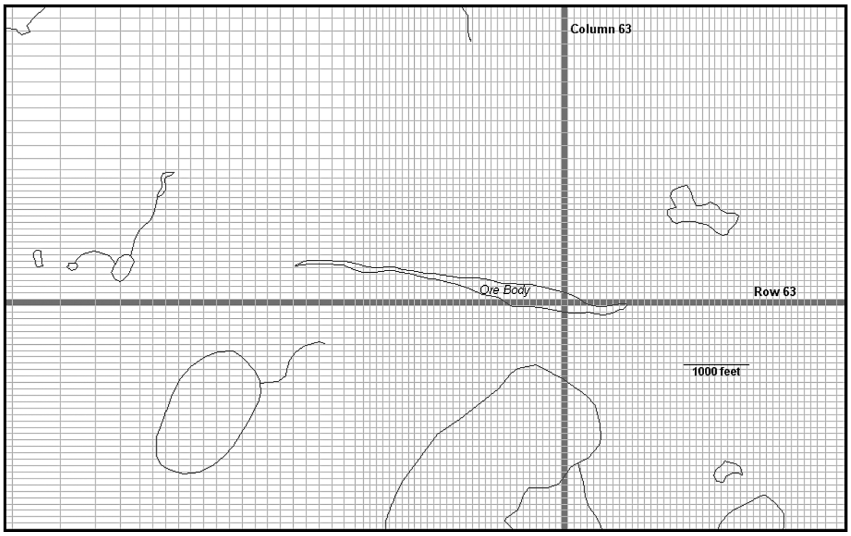


Figure AII-1. *Map view of the model grid in the ore body area. Locations of row G3 and Column 63 are shown.*

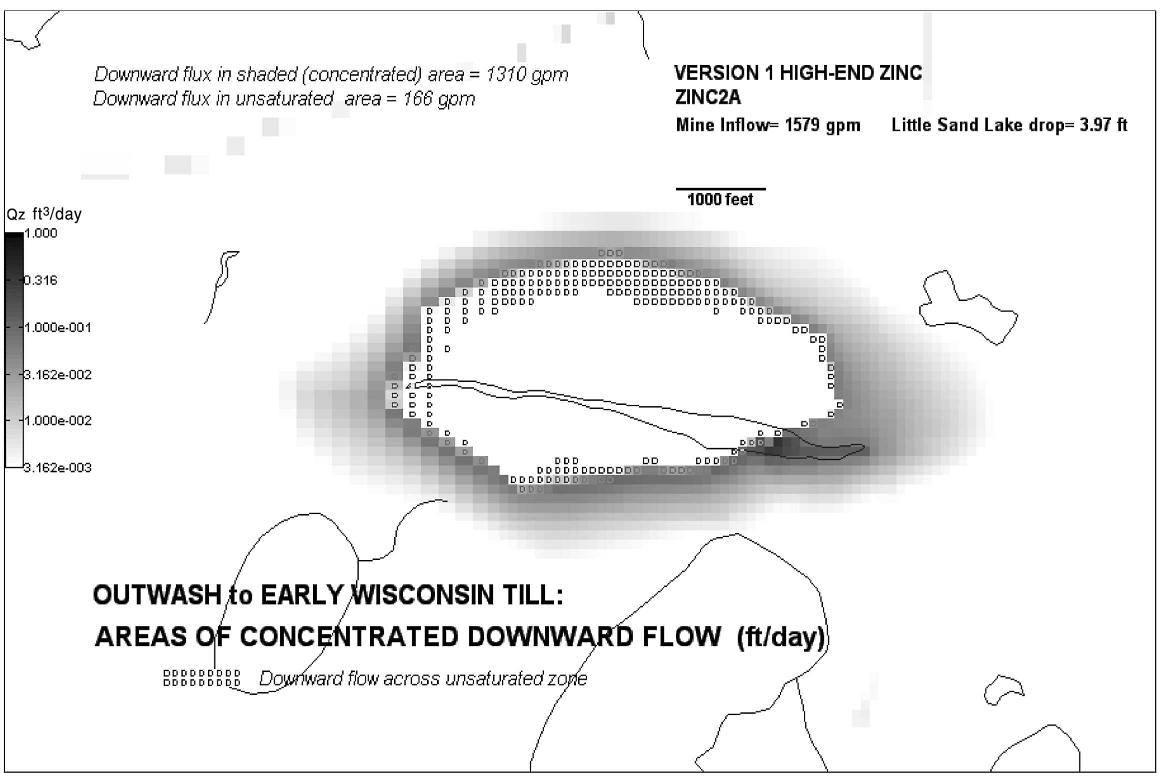


Figure AII-2. *High-end simulation (ZINC2A). Simulated downward flow between model layers 3 and 4.*

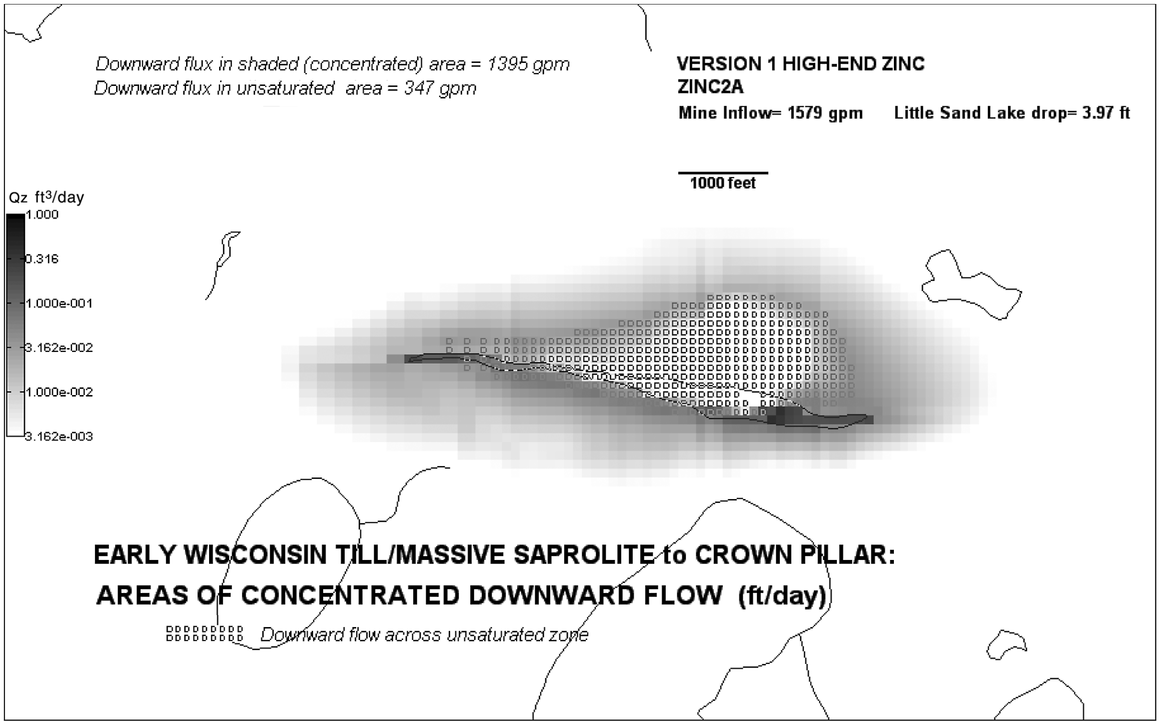


Figure AII-3. *High-end simulation (ZINC2A). Simulated downward flow between model layers 4 and 5.*

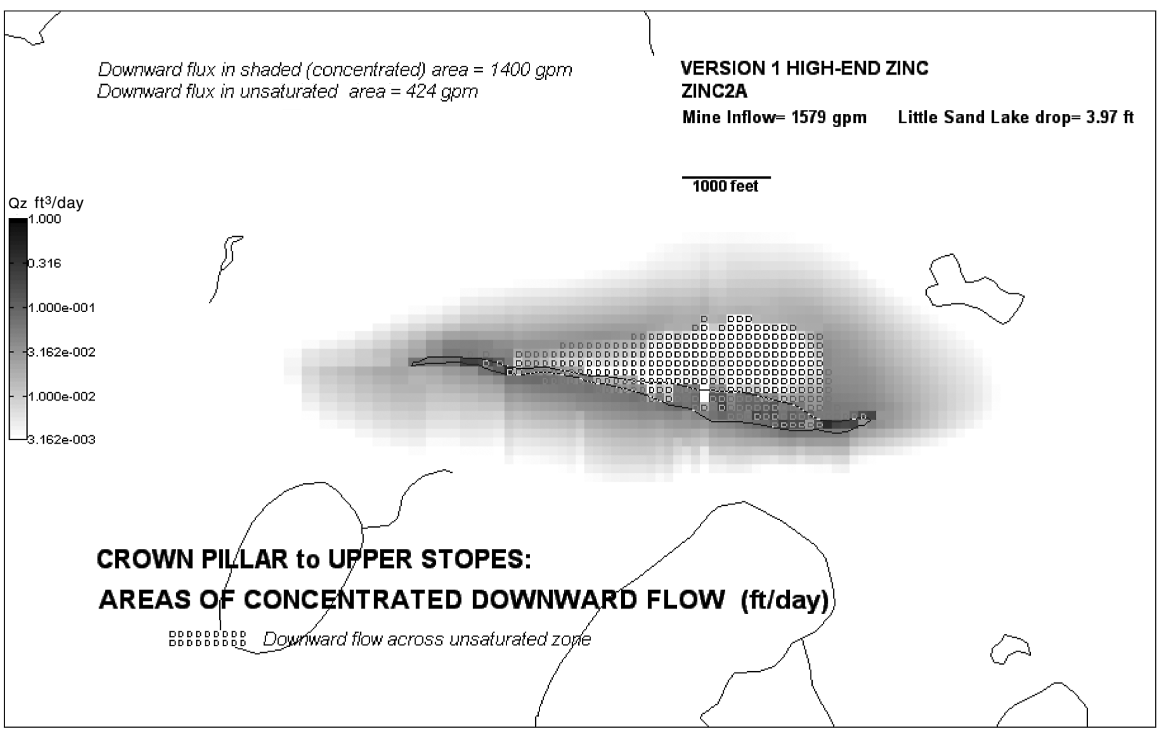


Figure AII-4. *High-end simulation (ZINC2A). Simulated downward flow between model layers 6 and 7.*

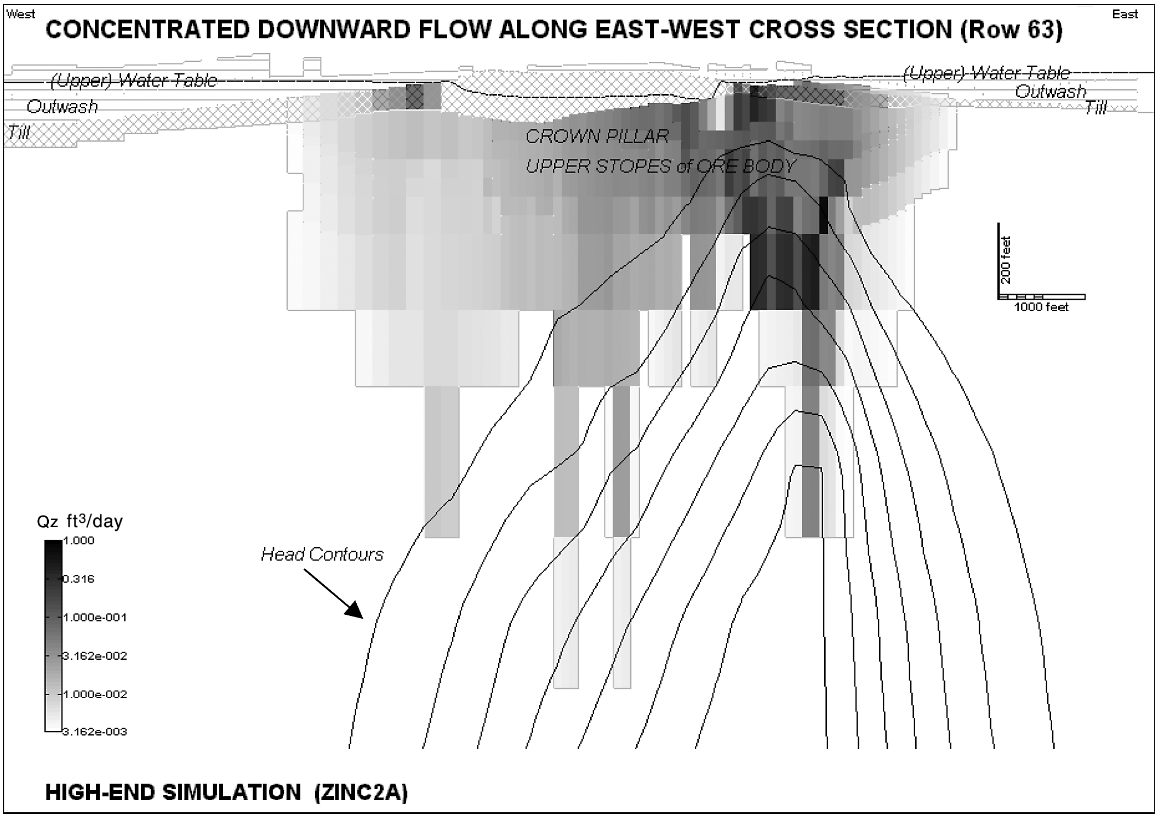


Figure AII-5. *High-end simulation (ZINC2A). East–west cross section along model Row 6*

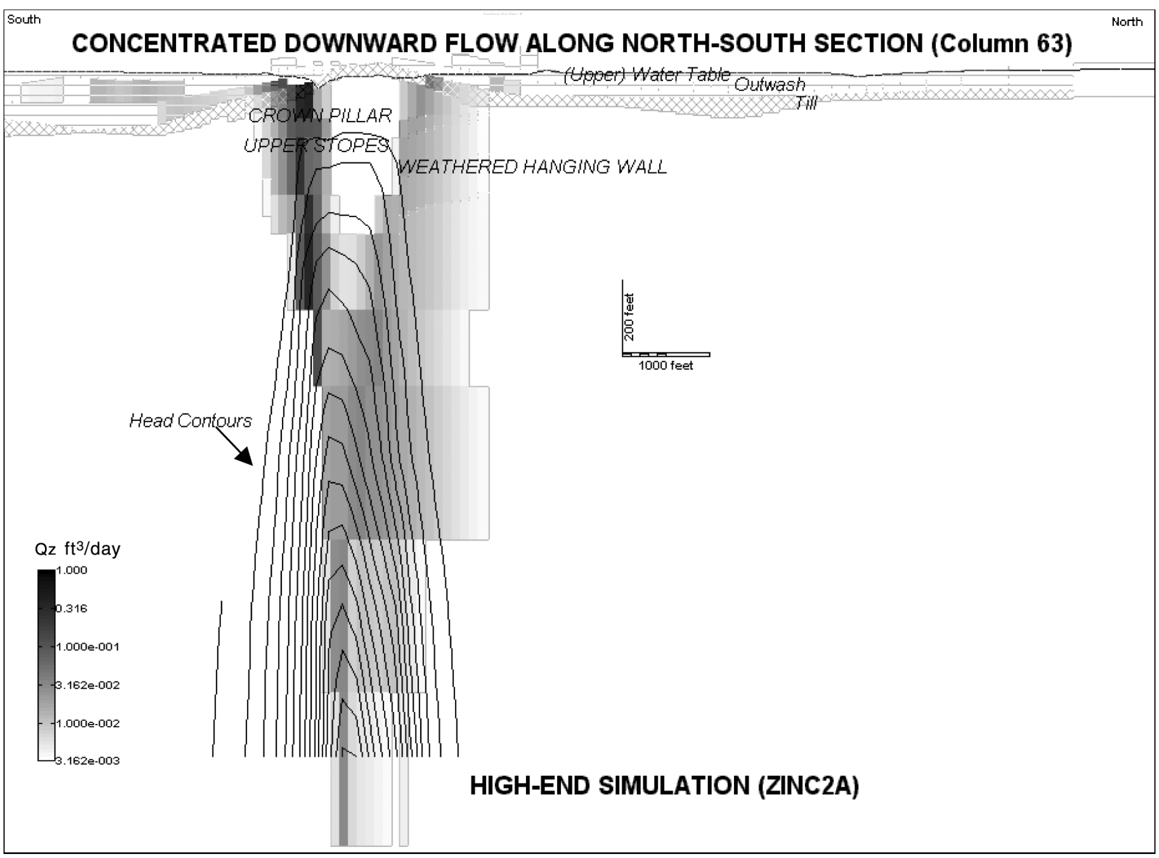


Figure AII-6. *High-end simulation (ZINC2A). North–south cross section along model Column 63.*

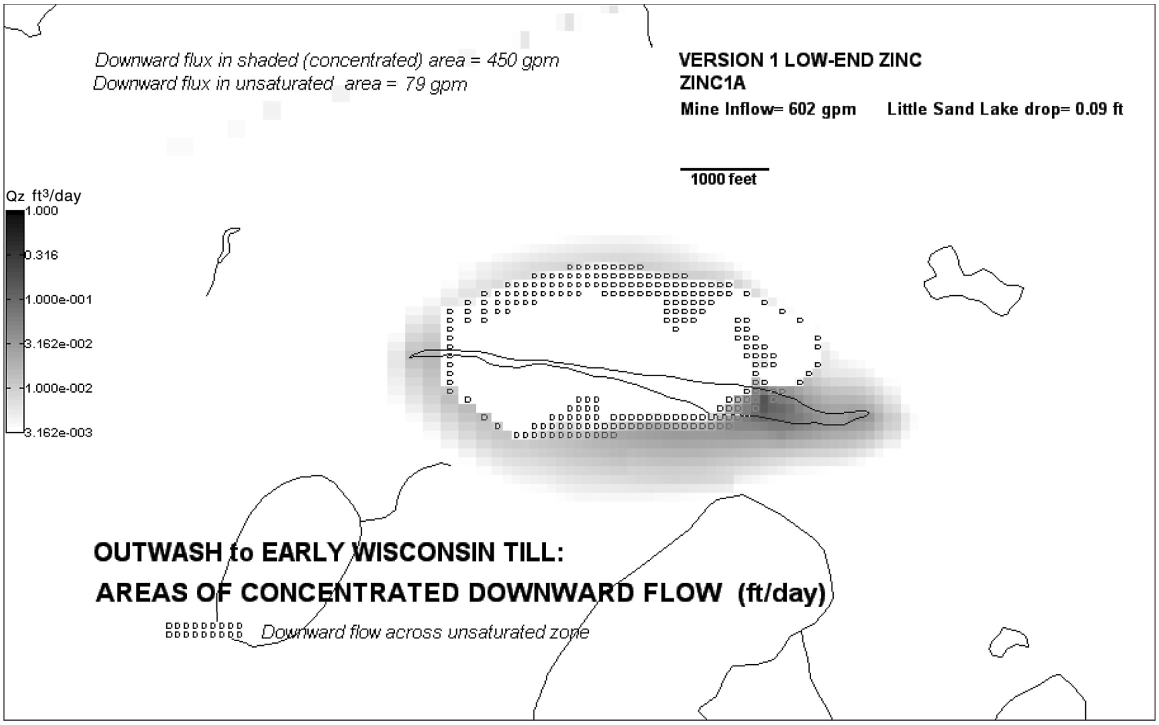


Figure AII-7 *Low-end simulation (ZINC1A). Simulated downward flow between model layers 3 and 4.*

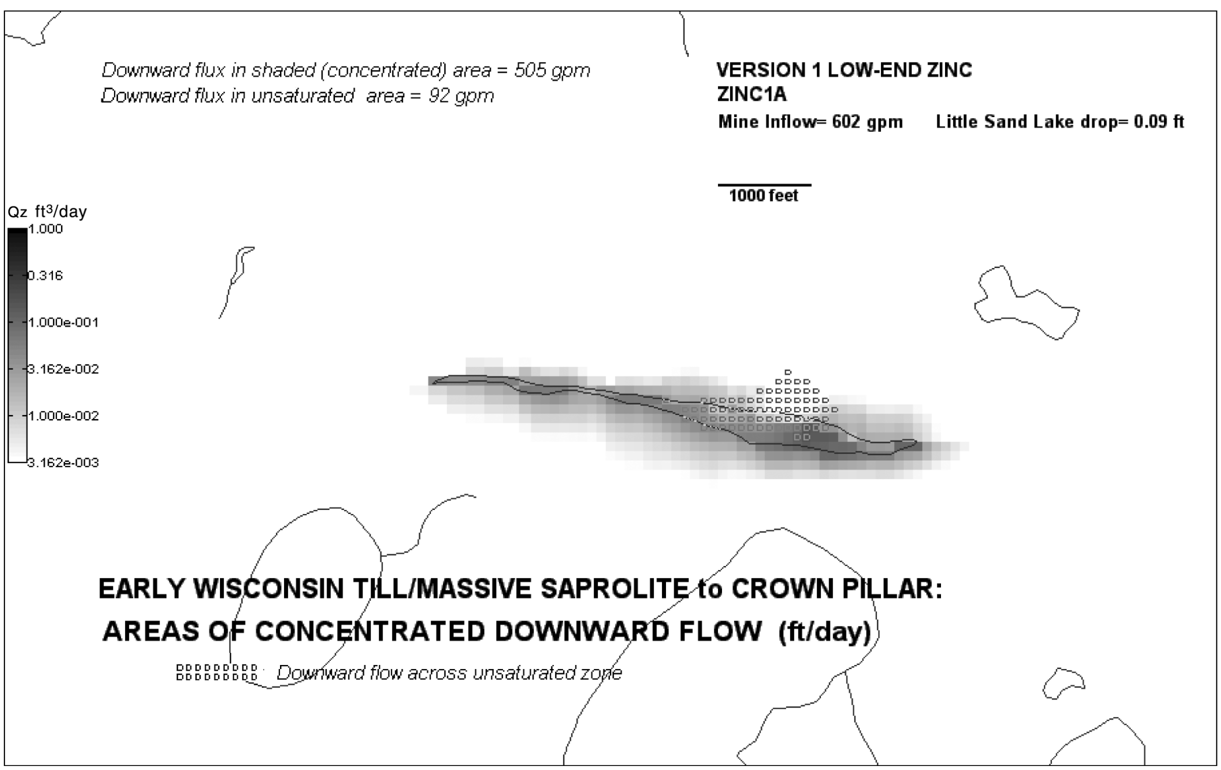


Figure AII-8. *Low-end simulation (ZINC1A). Simulated downward flow between model layers 4 and 5.*

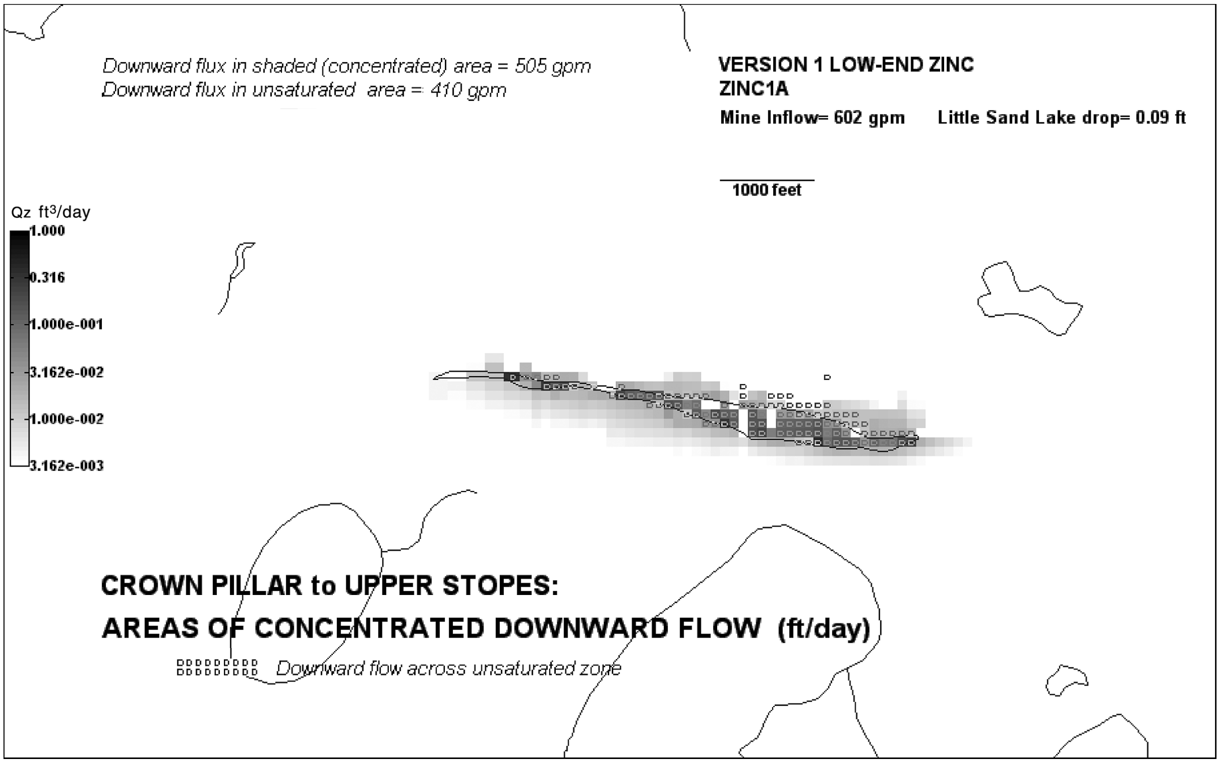


Figure AII-9. *Low-end simulation (ZINC1A). Simulated downward flow between model layers 6 and 7.*

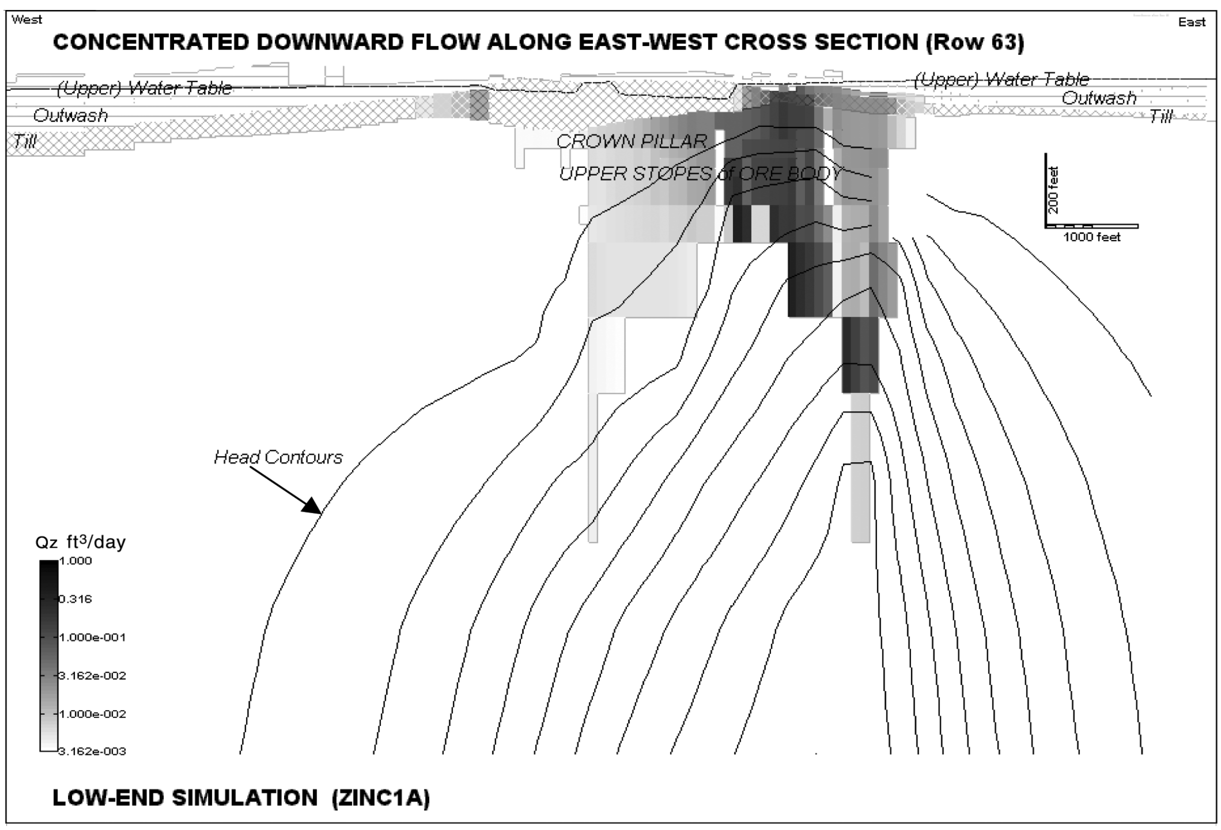


Figure AII-10a. *Low-end simulation (ZINC1A). East–west cross section along model Row 63.*

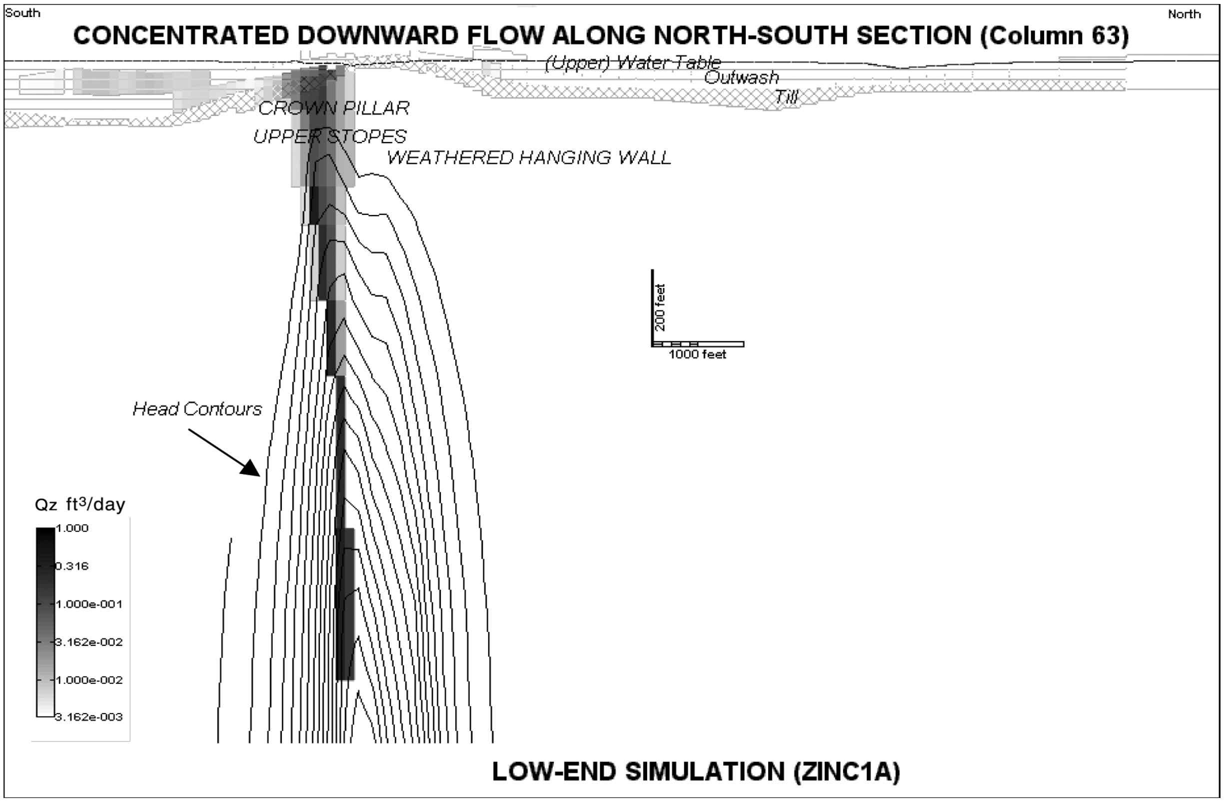


Figure AII-10b *Low-end simulation (ZINC1A). North–south cross section along model Column 63.*

Comments

For zinc-mine simulations:

1) Groundwater does not flow directly downward from the outwash through the till to the bedrock over much of the ore body because the outwash is either absent or unsaturated. Instead, for both High End and Low End simulations, water flows downward from the unconsolidated layers through a doughnut-shaped area. Lower in the system, the groundwater flow funnels into a narrower cone of downward flow.

2) In the case of flow from the outwash to the till, a relatively small amount of water moves between stacked water tables across an unsaturated zone along the inner edge of the "flux doughnut." A more significant proportion of the mine inflow crosses an unsaturated zone between the crown pillar and the upper stopes of the mine immediately above the mined area. For both the High End and Low End cases, about 400 gpm flows directly downward into the mine across unsaturated material.

3) The thickness of the layer representing the Early Wisconsin Till (and massive saprolite) has significant control on where downward flow to the mine occurs. The downward flow is greatest where the water table is in the overlying outwash and the till is thin. This effect is particular strong for the High End simulations where the vertical hydraulic conductivity of the Early Wisconsin till is 8 times higher than it is for the Low End simulations.

4) The High End runs are able to draw water downward from the outwash to the weathered hanging wall bedrock and then horizontally into the mine. This High End effect is owing not only to the higher vertical hydraulic conductivity of the till, but also to the higher horizontal and vertical hydraulic conductivity of the hanging wall itself.

Part II.

What are the controls that determine HIGH END as opposed to LOW END behavior?

In order to investigate this question, we constructed Version 1 zinc mine simulations that consisted just of the mine stopes and excluded any mine workings, ceiling grout, curtain grout, or SAS infiltration. The Low End simulation (SB16) yielded 714 gpm of mine inflow. The High End simulation (SA16) yielded 1614 gpm of mine inflow. The difference is 900 gpm.

We then constructed simulations that modified *single* elements in the Low End simulation, SA16, so that they matched the corresponding settings in the High End simulation, SA16:

Element modified	Key Change
1. Early Wisconsin Till	Vertical hydraulic conductivity: 0.075 ft/day→0.6 ft/day
2. Weathered Bedrock	Weakly weathered hanging wall hydraulic conductivity: 0.00094 ft/day→0.05 ft/day
3. Unweathered Bedrock	Hydraulic conductivity: 0.00094 ft/day→0.005 ft/day
4. Ore Body configuration	Increased volume and continuity

The following table shows the results in terms of simulated mine inflow

Run	Vertical Hyd Cond of Early Wisconsin Till	Hyd Cond of Weathered Bedrock	Hyd Cond of Unweathered Bedrock	Ore Body Configuration	MINE INFLOW gpm
LH1	HIGH	LOW	LOW	LOW	1096
LH2	LOW	HIGH	LOW	LOW	1005
LH3	LOW	LOW	HIGH	LOW	853
LH4	LOW	LOW	LOW	HIGH	823

Each run increased the mine inflow with respect to the Low End base case, but none approached the full 900-gpm difference between the Low End and High End simulations.

The results can be recast in terms of the percent of the low/high difference achieved by each simulation:

Run	Vertical Hyd Cond of Early Wisconsin Till	Hyd Cond of Weathered Bedrock	Hyd Cond of Unweathered Bedrock	Ore Body Configuration	PERCENT OF LOW/HIGH DIFFERENCE
LH1	HIGH	LOW	LOW	LOW	42%
LH2	LOW	HIGH	LOW	LOW	32%
LH3	LOW	LOW	HIGH	LOW	15%
LH4	LOW	LOW	LOW	HIGH	12%

Comments:

The till (and massive saprolite) layer overlying the ore body represent the largest control on mine inflow when Low End and High End runs are compared. However, other elements of the model (weathered bedrock, unweathered bedrock, ore body configuration) also represent significant controls on the stressed system.

Part III.

How does the treatment of vertical flow through UNSATURATED zones affect the results for High End and Low End simulations?

The strong vertical stress posed by the simulated mining can cause such steep vertical gradients in the model that the saturated zone splits. At certain locations over the mine, multiple water tables tend to form with unsaturated zones in between. In the course of solving the groundwater flow equation, the MODFLOW code can handle the emergence of unsaturated zones in three ways:

1) The standard code contains a "vertical flow correction" that moves water downward whenever water tables appear in cells with the same row, column indices but in adjacent layers. The vertical flux is a product of the driving head above the unsaturated zone between the two water tables (that is, the saturated thickness in the cell in the overlying layer), the horizontal area of the cells, and the vertical conductance between the cells. This correction is only invoked when the underlying cell is unconfined, but still active. It is not invoked when the underlying cell is dewatered and the deeper water table drops to a lower layer. That is, there is no "dry-cell bypass."
2) It is possible to change the MODFLOW code so that it does move water downward even if the solution yields dry cells between water table cells on the hypothesis that the water will find some pathway such as fractures. Greg Council of GeoTrans, consultants for the NMC mining company, modified the MODFLOW code to allow a dry-cell bypass. This version permits the maximum mine inflow for a given head solution.
3) It is also possible to change the MODFLOW code to eliminate the "vertical flow correction" and allow no downward movement between water tables based on the hypothesis that any unsaturated zones that develop will be virtually impermeable to vertical flow. This version permits the minimum mine inflow for a given head solution.

For Version 1 of the Crandon model, runs ZINC2A and ZINC1A simulate mine inflow with the "vertical flow correction" active under High End and Low End conditions, respectively. The following runs change the way the unsaturated zone is treated:

High End:

ZINC2B Vertical flow allowed across multilayer unsaturated zones (dry cell bypass active)
Sensitivity on ZINC2A (USGS bedrock with Mine Workings)
Use UD-78 as initial condition

Z2A-NOV No vertical flow allowed across single-layer unsaturated zone (no vertical flow correction)
Sensitivity on ZINC2A (USGS bedrock with Mine Workings)
New background runs needed (UC78-NOV and UD78-NOV)

Low End:

ZINC1B Vertical flow allowed across multilayer unsaturated zones (dry cell bypass active)
Sensitivity on ZINC1A (USGS bedrock with Mine Workings)
Use UD-8 as initial condition

Z1A-NOV No vertical flow allowed across single-layer unsaturated zone (no vertical flow correction)
Sensitivity on ZINC1A (USGS bedrock with Mine Workings)
New background runs needed (UC8-NOV and UD8-NOV)

This table compares the results with respect to mine inflow:

High End:		Low End:	
ZINC2A	1579 gpm	ZINC1A	602 gpm
ZINC2B	1579 gpm	ZINC1B	619 gpm
Z2A-NOV	1432 gpm	Z1A-NOV	211 gpm

Comments:

The High End runs are not greatly affected by the treatment of the unsaturated zone. The Low End runs are more influenced by the form of the solution. In particular, elimination of the vertical flow correction reduces mine inflow to a very low value. This occurs because almost all the mine downward flow from the crown pillar to the upper stopes in the Low End case occurs over a restricted area where the strong downward pull of the mine has produced stacked water tables.

Appendix III-1

Sensitivity Simulations

Table AIII-1-1. Summary of the mass balance from the Version 1 and 2, Zinc and Copper Phase, High End and Low End Case Base Runs

ZINC1A: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 525 + 161 + -33 = 653 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -602 + -25 + -33 = -660 gpm [DIFFERENCE = MASS BALANCE ERROR (1 GPM) + STORAGE RELEASE (1 GPM) + INCREASED FLOW FROM BOUNDARY (5 GPM) = 7 GPM]
ZINC2A: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 1500 + 185 + -70 = 1615 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -1579 + -25 + -33 = -1637 gpm [DIFFERENCE = MASS BALANCE ERROR (8 GPM) + STORAGE RELEASE (2 GPM) + INCREASED FLOW FROM BOUNDARY (12 GPM) = 22 GPM]
COPPER1A: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 275 + 93 + 109 = 477 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -349 + -25 + -86 = -460 gpm [DIFFERENCE = MASS BALANCE ERROR (-4 GPM) + STORAGE RELEASE (-19 GPM) + INCREASED FLOW FROM BOUNDARY (4 GPM) = -17 GPM]
COPPER2A: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 1300 + 181 + 22 = 1503 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -1392 + -25 + -86 = -1503 gpm [DIFFERENCE = MASS BALANCE ERROR (-4 GPM) + STORAGE RELEASE (-7 GPM) + INCREASED FLOW FROM BOUNDARY (11 GPM) = 0 GPM]
LLZN1B: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 200 + 75 + 63 = 338 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -285 + -25 + -33 = -343 gpm [DIFFERENCE = MASS BALANCE ERROR (-1 GPM) + STORAGE RELEASE (4 GPM) + INCREASED FLOW FROM BOUNDARY (2 GPM) = 5 GPM]
HHZN1B: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 1100 + 180 + -60 = 1220 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -1176 + -25 + -33 = -1234 gpm [DIFFERENCE = MASS BALANCE ERROR (4 GPM) + STORAGE RELEASE (1 GPM) + INCREASED FLOW FROM BOUNDARY (9 GPM) = 14 GPM]
LLCU1B: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 150 + 81 + 181 = 412 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -290 + -25 + -86 = -401 gpm [DIFFERENCE = MASS BALANCE ERROR (-2 GPM) + STORAGE RELEASE (-12 GPM) + INCREASED FLOW FROM BOUNDARY (3 GPM) = -11 GPM]
HHCU1B: TOTAL IN = SAS RECHARGE + LAKE SEEPAGE INCREASE + NET BASE FLOW REDUCTION = 1100 + 181 + 76 = 1357 gpm TOTAL OUT = MINE INFLOW + SERVICE WELL + REDUCED TMA RECHARGE = -1250 + -25 + -86 = -1361 gpm [DIFFERENCE = MASS BALANCE ERROR (-2 GPM) + STORAGE RELEASE (-5 GPM) + INCREASED FLOW FROM BOUNDARY (10 GPM) = 3 GPM]

Table AIII-1-2. Sensitivity simulations on parameters that control groundwater-surface water interaction using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A). [abbreviations: K, hydraulic conductivity; ft/day, feet per day; cfs, cubic feet per second; gpm, gallons per minute]

Simulation	Details of Sensitivity Test
SA0	Internal lakebed vertical K's lowered by one-half Deep Hole Lakebed K: changed from 0.003 ft/day to 0.0015 ft/day Duck Lakebed K: changed from 0.003 ft/day to 0.0015 ft/day Little Sand Lakebed K: changed from 0.0095 ft/day to 0.00475 ft/day Skunk Lakebed K: changed from average of 0.00475 ft/day to 0.002375 ft/day Runoff/Precipitation fraction changes from about 0.15 to about 0.10 New steady-state calibration and background simulations needed (runs S0C-78, S0D-78)
SA1	Internal lakebed vertical K's raised by one-half Deep Hole Lakebed K: changed from 0.003 ft/day to 0.0045 ft/day Duck Lakebed K: changed from 0.003 ft/day to 0.0045 ft/day Little Sand Lakebed K: changed from 0.0095 ft/day to 0.014 ft/day Skunk Lakebed K: changed from average of 0.00475 ft/day to 0.007 ft/day Runoff/Precipitation fraction changes from about 0.15 to about 0.20 New steady-state calibration and background simulations needed (runs S1C-78, S1D-78)
SA28	Increase Duck Lakebed vertical K from that of Deep Hole Lake to that of Little Sand Lake and eliminate Duck Lake outlet flow Duck Lakebed K: changed from 0.003 ft/day to 0.0095 ft/day Duck Lake outflow reduced from 0.1 cfs to 0.0 cfs New steady-state calibration and background simulations needed (runs S30C-78, S30D-78)
SA30	Decrease internal lake outlet flow Duck Lake outflow reduced from 0.1 cfs to 0.0 cfs Little Sand Lake outflow reduced from 0.4 cfs to 0.2 cfs Deep Hole Lake outflow reduced from 0.2 cfs to 0.1 cfs New steady-state calibration and background simulations needed (runs S30C-78, S30D-78)
SA6	Replace fixed internal lake outflow with NMC rating equations New steady-state calibration and background simulations needed (runs S6C-78, S6D-78)
SA11	Eliminate Little Sand Lake outlet structure during mining Little Sand Lake outflow remains fixed as in base background simulation (run UC-78)
SA7	Conductance of beds of all streams and external lakes lowered to one-fifth of base value New steady-state calibration and background simulations needed (runs S7C-78, S7D-78)
SA8	Conductance of beds of all streams and external lakes raised to five times the base value New steady-state calibration and background simulations needed (runs S8C-78, S8D-78)
SA12	Soil Absorption Site infiltration reduced Infiltration changed from 1500 gpm to 714 gpm
SB12	Soil Absorption Site infiltration eliminated Infiltration changed from 1500 gpm to 0 gpm
SA18	Eliminate TWG Pinchout Zone New steady-state calibration and background simulations needed (runs S18C-78, S18D-78)
SB18	Eliminate TWG Pinchout Zone and Soil Absorption Site infiltration Infiltration changed from 1500 gpm to 0 gpm Steady-state calibration and background simulations from SA18 used (runs S18C-78, S18D-78)

Table AIII-1-3. Sensitivity simulations on parameters that control mine configuration using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: gpm, gallons per minute; K, hydraulic conductivity; ft, feet; ft/day, feet per day]

Simulation	Details of Sensitivity Test
SC3	NMC's 1st stage zinc open with limited mine workings - Stope drains changed from 309 to 72 - Mine workings drains changed from 366 to 287 - Soil Absorption Site infiltration changed from 1500 gpm to 1300 gpm
S3	NMC's 1st stage zinc open with no mine workings - Stope drains changed from 309 to 72 - Mine workings drains changed from 366 to 0 - Soil Absorption Site infiltration changed from 1500 gpm to 1300 gpm
ZINC2	Full zinc mine open with no mine workings - Mine workings drains changed from 366 to 0
SA2	Full zinc mine open with no grout ceiling
ZN-NOGR1	Full zinc mine open with no grout ceiling and ungrouted mine workings
CU-NOGR1	Full zinc mine open with no grout ceiling and ungrouted mine workings using the Version 1, Copper Phase, High End Case Base Run (COPPER2A) - The output from simulation ZN-NOGR1 used as the initial condition
SA5	Zinc stope backfill K raised by two orders of magnitude using the Version 1, Copper Phase, High End Case Base Run (COPPER2A) - Backfill K changed from 10^{-4} ft/day to 10^{-2} ft/day - The output from simulation ZINC2A used as the initial condition
SA16	Full zinc mine open with no grout ceiling, no mine workings and Soil Absorption Site infiltration eliminated - Mine workings drains changed from 366 to 0 - SAS infiltration changed from 1500 gpm to 0 gpm
SC16	Full zinc mine open with no grout ceiling and Soil Absorption Site infiltration eliminated - SAS infiltration changed from 1500 gpm to 0 gpm
SA19	Full zinc mine open with no grout ceiling - Infiltration changed from 1500 gpm to 0 gpm
SA17	Full zinc mine open with no grout ceiling, no mine workings and Soil Absorption Site infiltration eliminated - Sensitivity on the Version 1, Zinc Phase, Low End Case model (run ZINC1A)
ZINC2AEL	The elevation of the drains representing the stopes and workings lowered - Drain elevation changed from the model layer midpoint to 1 ft above the layer bottom

Table AIII-1-4. Sensitivity simulations on parameters to approximate drought using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: K, hydraulic conductivity; ft/day, feet per day]

Simulation	Details of Sensitivity Test
PRE-SA4	Recharge reduced for three years (drought) on background conditions using the Version 1, Zinc Phase, High End Case Background Run (UD-78) - Model global recharge rate changed from 9.8 inches/year to 6.5 inches/year
PRE-SC4	Recharge reduced for three years (drought) and Little Sand Lake outlet structure eliminated during mining using the Version 1, Zinc Phase, High End Case Background Run (UD-78) - Model global recharge rate changed from 9.8 inches/year to 6.5 inches/year - Little Sand Lake outflow remains fixed as in base calibration simulation (run UC-78)
SA4	Recharge reduced for three years (drought) on mining conditions - Model global recharge rate changed from 9.8 inches/year to 6.5 inches/year - The output from simulation ZINC2A used as the initial condition
SA9	Recharge reduced for three years (drought) on mining conditions and internal lakebed vertical K's lowered by one-half - Model global recharge rate changed from 9.8 inches/year to 6.5 inches/year - Deep Hole Lakebed K: changed from 0.003 ft/day to 0.0015 ft/day - Duck Lakebed K: changed from 0.003 ft/day to 0.0015 ft/day - Little Sand Lakebed K: changed from 0.0095 ft/day to 0.00475 ft/day - Skunk Lakebed K: changed from average of 0.00475 ft/day to 0.002375 ft/day - Runoff/Precipitation fraction changes from about 0.15 to about 0.10 - The output from simulation SA0 used as the initial condition
SA10	Recharge reduced for three years (drought) on mining conditions and internal lakebed vertical K's raised by one-half - Model global recharge rate changed from 9.8 inches/year to 6.5 inches/year - Deep Hole Lakebed K: changed from 0.003 ft/day to 0.0045 ft/day - Duck Lakebed K: changed from 0.003 ft/day to 0.0045 ft/day - Little Sand Lakebed K: changed from 0.0095 ft/day to 0.014 ft/day - Skunk Lakebed K: changed from average of 0.00475 ft/day to 0.007 ft/day - Runoff/Precipitation fraction changes from about 0.15 to about 0.20 - The output from simulation SA1 used as the initial condition

Table AIII-1-5. Sensitivity simulations on bedrock representation using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: K, hydraulic conductivity; ft/day, feet per day; gpm, gallons per minute]

Simulation	Details of Sensitivity Test
SA13	**Increase unweathered bedrock vertical K** - Vertical K of the unweathered bedrock changed from 0.005 ft/day to 0.01 ft/day - New steady-state calibration and background simulations needed (runs S13C-78, S13D-78)
SA15	**Apply the applicant's bedrock configuration and the TWG bedrock parameters** - The bedrock configuration changed from High End to Low End - Resulting model recalibrated using UCODE in a manner consistent with that reported in text - New steady-state calibration and background simulations needed (runs UC-81, UD-81)
S15	**Apply the applicant's bedrock configuration and the TWG bedrock parameters with no mine workings** - The bedrock configuration changed from High End to Low End - Mine workings drains changed from 366 to 0 - Soil Absorption Site discharge reduced from 1500 gpm to 1300 gpm - Resulting model recalibrated using UCODE in a manner consistent with that reported in text - Steady-state calibration and background simulations from SA15 used (runs UC-81, UD-81)
GAB2-ZN	**Implement an approximation of the mapped gabbro dike in the area of the ore body** - The gabbro dike represented in the model as a coherent vertical feature of limited width, with a vertical K of 0.0001 ft/day, located approximately in accordance with submitted drawings - New steady-state calibration and background simulations needed (runs GAB1SSUC, GAB1SSUD)
GAB2-CU	**Apply an approximation of the mapped gabbro dike in the area of the ore body using the Version 1, Copper Phase, High End Case Base Run (COPPER2A)** - The gabbro dike represented in the model as a coherent vertical feature of limited width, with a vertical K of 0.0001 ft/day, located approximately in accordance with submitted drawings - The output from simulation GAB2-ZN used as the initial condition

Table AIII-1-6. Sensitivity simulations on the applicant's submitted dry cell bypass routine using the Version 1, Zinc Phase, High End and Low End Base Runs (ZINC2A and ZINC1A).

Simulation	Details of Sensitivity Test
ZINC2B	Activate the dry cell bypass routine using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A)
Z2A-NOV	Disable the dry cell bypass routine using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A)
ZINC1B	Activate the dry cell bypass routine using the Version 1, Zinc Phase, Low End Case Base Run (ZINC1A)

Table AIII-1-7. Sensitivity simulations on the representation of the "pinchout zone" using the Version 1, Zinc Phase, High End Case Base Run (ZINC2A), except as noted. [abbreviations: K, hydraulic conductivity; ft/day, feet per day]

Simulation	Details of Sensitivity Test
SA18	**Eliminate pinchout zone** - New steady-state calibration and background simulations needed (runs S18C-78, S18D-78)
SB18	**Eliminate pinchout zone and eliminate Soil Absorption Site infiltration** - Infiltration changed from 1500 gpm to 0 gpm - Steady-state calibration and background simulations from SA18 used (runs S18C-78, S18D-78)
10PINC2A	**Introduction of gaps throughout the pinchout zone, realization 1** - Ten percent of the length of the pinchout zone eliminated at random locations - New steady-state calibration and background simulations needed (runs UC10P-78, UD10P-78)
11PINC2A	**Introduction of gaps throughout the pinchout zone, realization 2** - Ten percent of the length of the pinchout zone eliminated at random locations - New steady-state calibration and background simulations needed (runs UC11P-78, UD11P-78)
KINC2A	**Reduced width of the pinchout zone along Hemlock Creek and reduced punchout zone Kh by 50%** - North-south portion of the pinchout zone (along Hemlock Creek) thinned to more realistically match geologic conceptualization - Pinchout zone Kh changed from 6 ft/day to 3 ft/day - New steady-state calibration and background simulations needed (runs UCK-78, UDK-78)
KINC1A	**Reduced width of the pinchout zone along Hemlock Creek and reduced punchout zone Kh by 50% using the Version 1 Low End Case Base Run (ZINC1A)** - North-south portion of the pinchout zone (along Hemlock Creek) thinned to more realistically match geologic conceptualization - Pinchout zone Kh changed from 6 ft/day to 3 ft/day - New steady-state calibration and background simulations needed (runs UCK-8, UDK-8)

Appendix III-2

Skunk Lake Behavior

For any time step, the output from the LAK package implies a mass balance. For Skunk Lake the mass balance terms are:

IN	=	NET PPT + RUNOFF FROM BASIN	= 1.86 gpm + 17.95 gpm for the high-end *base* model
OUT	=	GROUNDWATER SEEPAGE	= 19.81 gpm for the high-end *base* model

Note that IN and OUT are in balance for the *base* run.

When these IN and OUT terms are averaged over the last year of the 40-year *stressed* runs, a good mass balance also results. On closer inspection, we find that each term in the mass balance fluctuates from time step to time step between two levels that depend on the *area* of Skunk Lake. That is, several "high area" results are followed by a "low area" result in a repeating cycle. That in itself is not a problem—we see the same behavior for Deep Hole Lake and Duck Lake, owing in those cases to the presence of a surface outlet. However, for Skunk Lake alone we must reject the "average" values for lake area because they give us a nonsensical result: for scenarios with higher stresses, the LAK package predicts smaller reduction in areas when results are averaged.

It is also a problem to replace the average results for a given scenario with either the "low area" or "high area" results. Each of these fluctuating solutions suffers from mass balance error. For example, in the case of VERSION 2 for the HIGH-END COPPER scenario, we find:

Run	Case	IN (gpm) =PPT+RO	OUT (gpm) =GW SEEPAGE	% ERROR = (IN-OUT)/IN
HHCU1B	"Low-Area" iteration	19.43	17.33	+10.8%
HHCU1B	"High-Area" iteration	19.73	20.35	-3.1%

Note the 2.1 gpm difference between IN and OUT for the "low-area" iteration.

The groundwater seepage change for the "low-area" case is about -2.5 gpm (from 19.8 gpm to 17.3 gpm). The groundwater seepage should hardly decline because the PPT changes little (reduction due to drop in area is equal to 0.4 gpm) and the RO is constant. The 2.1 gpm difference between IN and OUT is due to the model calculating such a large reduction in the groundwater seepage. It results in the mass balance error. Under perfect mass balance, the change in groundwater seepage would be -0.4 gpm, not -2.5 gpm.

Note that the "high-area" case predicts an increase in groundwater seepage. The other internal lakes also have increases in groundwater seepage to balance the reduction in stream outflow. SKL has no stream outflow, so again the increase in groundwater seepage is largely a mass balance error term.

We have reported in tables "low-area" results with respect to stage and area, but have omitted the groundwater flux term because it clearly is dominated by mass balance error.

For all four runs in the files above, the reduction area for the "low-area" case is about 21%. The high-K lakebed (=0.006 ft/day) underlies 75% of the lake area, and the low-K lakebed (=0.001 ft/day) underlies 25% of the lake area; there is no relation between the loss in area and the high-K expanse.

Appendix III-3

Ground Hemlock Sensitivity

nb: GHL = Ground Hemlock
Base flow target for GHL is 2.4 cfs

Runs

UC-78 canonical HIGH END base run optimized with UCODE
62/75 GHL conductances are 10x NMC's, 13/75 are identical to NMC's

GHL1 first sensitivity run
75/75 GHL conductances are 10x NMC's

GHL2 second sensitivity run
computed ratio of summed GHL conductances for UC-78 to NMC run = 8.58
➔ 75/75 GHL conductances are 8.58x NMC's

Run	GHL Net Baseflow (cfs)	Hemlock Ck. Net Baseflow (cfs)	Swamp Ck. Net Baseflow (cfs)	Total Net Baseflow (cfs)	Internal Lakes Discharge to GW (cfs)
UC-78	2.44888	3.41889	13.80536	48.26238	1.28794
GHL1	2.65623	3.2877	13.776	48.26783	1.29148
GHL1 minus					
0.20735	-0.13119	-0.02936	0.00545	0.00354	
Percent Change	**8.47**	**-3.84**	**-0.21**	**0.01**	**0.27**
UC-78	2.44888	3.41889	13.80536	48.26238	1.28794
GHL2	2.51568	3.36438	13.79323	48.26162	1.28777
GHL2 minus					
UC-78	0.06680	-0.05451	-0.01213	-0.00076	-0.00017
Percent Change	**2.73**	**-1.59**	**-0.09**	**0.00**	**-0.01**

Run	Mean Error (ft)	Mean Absolute Error (ft)	Root Mean Square Error (ft)
UC-78	-0.078	1.881	2.642
GHL1	-0.014	1.856	2.609
GHL2	-0.071	1.878	2.634

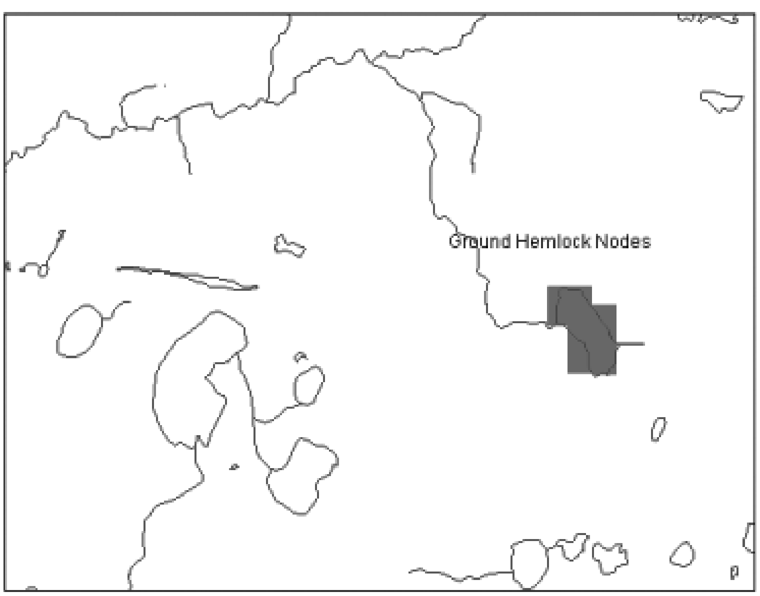


Figure AIII-3-1. *Ground Hemlock node locations*

Appendix IV

Effect of Grout on Mine Inflow

Why does UNGROUTED High End zinc yield a higher mine inflow than UNGROUTED High End copper, when GROUTED High End zinc produces a lower mine inflow than GROUTED High End copper?

Runs (Version 2):

HHZN1B	=	grouted High End zinc:	mine inflow = 1176 gpm
ZN-NOGR2	=	ungrouted High End zinc:	mine inflow = 1757 gpm
HHCU1B	=	grouted High End copper:	mine inflow = 1250 gpm
CU-NOGR2	=	ungrouted High End copper:	mine inflow = 1638 gpm

Possible Answer:

Consider:

1) For the zinc runs, zinc stope drains are active, no copper stope drains are present.

2) For the copper runs, zinc stope cells are backfilled, copper stope drains are active.

3) For the grouted runs, the grout curtain extends across layers 7 and 8, but not deeper.

4) For the grouted runs, the grout ceiling extends over 59 acres.

5) For the ungrouted runs, there is no curtain or ceiling. Moreover, the mineworkings are ungrouted.

Also:

1) In layer 7 there are many more zinc stope drains (47) than copper stope drains (18).

2) A similar condition holds in layer 8 (zinc = 50, copper= 26).

It appears:

The effect of REMOVING the grout ceiling and curtain is much larger for the zinc simulation than for the copper. In particular, the effect on layer 7 mine inflow is much more pronounced for the zinc case:

HHZN1B	=	grouted High End zinc:	layer 7 stope inflow = 0 gpm
ZN-NOGR2	=	ungrouted High End zinc:	layer 7 stope inflow = 268 gpm
HHCU1B	=	grouted High End copper:	layer 7 stope inflow = 5 gpm
CU-NOGR2	=	ungrouted High End copper:	layer 7 stope inflow = 24 gpm

Similar (although not as pronounced) trends hold for layer 8. Because the shallow zinc drains are so efficient in capturing water under ungrouted conditions, the total zinc mine inflow outpaces the copper.

Appendix V

Effect of Pinchout Zone Representation on Base Model Calibration and Flow System Response to Mining

We dedicated a number of sensitivity runs to the pinchout zone. It is present in areas north and east of the proposed mine site roughly along a sloping corridor where the upland terrain meets the lowlands. The pinchout zone imposes low-hydraulic-conductivity material in the unconsolidated layers of the model to simulate the absence of outwash in a setting that over glacial time remained unfavorable for deposition of coarse material from meltwater running off retreating glaciers. Figure AV-1 shows its location in plan view. This configuration was adopted for all Version 1 and Version 2 runs, both High End and Low End.

The sensitivity analysis for the pinchout zone consists of 3 sets of runs for both Pre-Mine and Zinc Phase conditions:

1. No pinchout zone
2. Gaps in the pinchout zone
3. A thinned pinchout zone east of the mine.

These changes are superimposed on Version 1 of the model with High End parameters.

For each set of sensitivity runs we examined

1. the calibration statistics for the Pre-Mine run (for all targets and for targets in TMA area)
2. the regional response of the system to the Zinc Phase of mining, and
3. the drawdown response to the zinc mine at the water table below 15 wetland locations (see figure AV-1).

For the three sets of output the sensitivity results are compared to the corresponding results for Version 1, High End Pre-Mine (run UC-78) or Version 1, High End, Zinc Phase (run ZINC2A).

No Pinchout Zone

In the case where the pinchout zone is absent, the calibration statistics degrade significantly, especially in the area of the TMA (table AV-1a). Consequently, the predictive results for this run should not be considered realistic.

Predicted mine inflow increases significantly in the absence of the pinchout zone (table AV-1b). The drawdown also increases significantly at some wetland locations (table AV-1c). The largest *increase* is 0.64 ft (from 2.84 ft to 3.48 ft) and occurs directly north of the mine. This run can be considered as a kind of “worst case” for the assumed set of parameters, but it is also a very unlikely scenario for geologic/geomorphologic reasons as well as its effect on model fit.

Gaps in Pinchout Zone

In order to test the sensitivity of the solution to possible discontinuities in the low-hydraulic-conductivity material of the pinchout zone, we inserted gaps through its entire north to south or east to west thickness. These gaps are added to the large gap north of Skunk Lake that is present in all versions of the pinchout zone. We experimented with random placement of the gaps at a frequency of 5%, 10%, and 15% (see figures AV-2 through AV-4). Reference to table AV-2a shows that the greater the frequency, the greater is the degrading effect on calibration statistics, particularly in the area of the TMA where the pinchout zone is thickest. We judged the 10% gap frequency to represent the maximum tolerable degradation.

The regional response to mining for two random realizations at the 10% gap frequency is similar to the reference zinc simulation with respect to mine inflow, Little Sand Lake contraction, and baseflow reduction to Pickerel Creek basin water bodies (table AV-2b). The effect on drawdown at selected wetland locations (listed in table AV-2c) depends on the proximity of the gaps to the wetlands, but the maximum *increase* in drawdown across the two realizations is only 0.27 ft. It is interesting to note that the maximum *decrease* in drawdown occurs in the vicinity of the large gap north of Skunk Lake. That is because the drawdown stress is focused in this area most strongly when the pinchout zone is continuous, but weakens when the pressure wave associated with the mine can find other breaches in the low-conductivity material.

Thinned Pinchout Zone East of Mine

The pinchout zone is most important in maintaining good calibration in the TMA area. However, it is also much wider here than elsewhere. We reduced its width as part of the sensitivity analysis so that the zone corresponds better to the dimensions of the sloping corridor between the upland and the adjacent lowland marked by the course of Hemlock Creek (see figure AV-5). Several runs were performed to produce a revised version of the unstressed model that preserves good calibration statistics despite the change.

Table AV-3a shows that by reducing the hydraulic conductivity of the pinchout zone everywhere from 6 ft/day to 3 ft/day we are able to closely reproduce the original calibration statistics. Further reduction in the hydraulic conductivity of the pinchout zone did not improve calibration.

Tables AV-3b and AII-3c show the effect on system response for the Zinc Phase of mining caused by a thinned pinchout zone with decreased hydraulic conductivity to preserve calibration. As in the case of the random gaps, the changes in terms of mine inflow, Little Sand Lake contraction, and basin baseflow reduction is very small relative to the reference zinc simulation. The maximum increase in drawdown relative to the reference run at any of the 15 selected wetland locations is only 0.17 ft.

Table AV-1a. Calibration Statistics (No Pinchout Zone).

ME = Mean Error
MAE = Mean Absolute Error
Degradation = Percent increase in error

		Overall (212 targets)		
Run		**ME**	**MAE**	**Degradation**
UC-78	Pre-Mine High End	-0.078	1.881	—
SA18	No Pinchout Zone	+2.385	3.464	84%
		TMA (26 targets)		
Run		**ME**	**MAE**	**Degradation**
UC-78	Pre-Mine High End	+0.279	1.546	—
SA18	No Pinchout Zone	+3.101	4.585	196%

Table AV-1b. Regional Response (No Pinchout Zone)

Run		Mine Inflow (gpm)	Percent Change in Area of Little Sand Lake Rel. to Pre-Stress	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress	
				Pickerel Basin	Swamp Basin
ZINC2A	High End Zinc, Version 1	1579	-17.1%	-10.6%	+5.3%
SA18	No Pinchout Zone	1658	-15.0%	-9.4%	+3.1%

* *The predicted base flow to the Swamp Creek basin increases for runs owing to the effect of infiltration to the SAS located just north of Swamp Creek. The assumed infiltration rate to the SAS for these runs is 1500 gpm.*

Table AV-1c. Drawdown (ft) at Selected Locations

North of Ore, North of Pinchout Zone (from west to east)

Run	P1	P2	P3	N1	N2	NN	P4
ZINC2A	1.05	0.75	2.84	0.62	7.66	-0.63	0.30
SA18	1.38	0.87	3.48	0.60	6.35	-0.63	0.17

East of Ore, East of Pinchout Zone

Run	P5	P6	P7	P8	EE
ZINC2A	0.22	0.15	0.38	0.38	0.48
SA18	0.13	0.16	0.90	0.69	0.68

South and West of Ore

Run	SS	WW1	WW2
ZINC2A	0.63	1.88	0.06
SA18	0.56	1.46	0.05

Table AV-2a. Calibration Statistics (Gaps in Pinchout Zone).

ME = Mean Error
MAE = Mean Absolute Error
Degradation = Percent increase in MAE error

Run		Overall (212 targets) ME	Overall (212 targets) MAE	Degradation
UC-78	Pre-Mine High End	-0.078	1.881	—
UC5P-78	5% Gap Frequency	+0.105	1.930	3%
UC10P-78	10% Gap Frequency #1	+0.456	2.095	11%
UC11P-78	10% Gap Frequency #2	+0.324	2.01	7%
UC15P-78	15% Gap Frequency	+0.694	2.224	15%

Run		TMA (26 targets) ME	TMA (26 targets) MAE	Degradation
UC-78	Pre-Mine High End	+0.279	1.546	—

UC5P-78	5% Gap Frequency	+0.442	1.759	14%
UC10P-78	10% Gap Frequency #1	+0.887	2.166	40%
UC11P-78	10% Gap Frequency #2	+0.771	2.045	32%
UC15P-78	15% Gap Frequency	+1.182	2.475	60%

Table AV-2b. Regional Response (No Pinchout Zone)

Run		Mine Inflow (gpm)	Percent Change in Area of Little Sand Lake Rel. to Pre-Stress	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress	
				Pickerel Basin	Swamp Basin
ZINC2A	High End Zinc, Version 1	1579	-17.1%	-10.6%	+5.3%
10PINC2A	10% Gap Frequency #1	1574	-16.0%	-10.1%	+4.9%
11PINC2A	10% Gap Frequency #2	1574	-16.0%	-10.1%	+4.9%

* *The predicted base flow to the Swamp Creek basin increases for runs owing to the effect of infiltration to the SAS located just north of Swamp Creek. The assumed infiltration rate to the SAS for these runs is 1500 gpm.*

Table AV-2c. Drawdown (ft) at Selected Locations

North of Ore, North of Pinchout Zone (from west to east)

Run	P1	P2	P3	N1	N2	NN	P4
ZINC2A	1.05	0.75	2.84	0.62	7.66	-0.63	0.30
10PINC2A	1.00	0.82	3.06	0.60	7.21	-0.63	0.26
11PINC2A	1.02	0.77	3.00	0.65	7.31	-0.63	0.28

East of Ore, East of Pinchout Zone

Run	P5	P6	P7	P8	EE
ZINC2A	0.22	0.15	0.38	0.38	0.48
10PINC2A	0.18	0.13	0.42	0.37	0.51
11PINC2A	0.23	0.14	0.38	0.65	0.60

South and West of Ore

Run	SS	WW1	WW2
ZINC2A	0.63	1.88	0.06
10PINC2A	0.61	1.77	0.06
11PINC2A	0.61	1.81	0.06

Table AV-3a. Calibration Statistics (Thinned Pinchout Zone).

ME = Mean Error
MAE = Mean Absolute Error
Degradation = Percent increase in MAE error

Run		Overall (212 targets) ME	Overall (212 targets) MAE	Degradation
UC-78	Pre-Mine High End	-0.078	1.881	—
UCT-78	Thinned, Kpinchout=6 ft/day	+0.608	2.183	16%
UCF-78	Thinned, Kpinchout=4 ft/day	+0.132	2.043	9%
UCD-78	Thinned, Kpinchout=3.5 ft/day	-0.026	2.024	8%
UCK-78	Thinned, Kpinchout=3 ft/day	-0.201	2.023	8%

Run		TMA (26 targets) ME	TMA (26 targets) MAE	Degradation
UC-78	Pre-Mine High End, Version 1	+0.279	1.546	—
UCT-78	Thinned, Kpinchout=6 ft/day	+1.427	2.771	79%
UCF-78	Thinned, Kpinchout=4 ft/day	+0.976	2.272	47%
UCD-78	Thinned, Kpinchout=3.5 ft/day	+0.829	2.108	36%
UCK-78	Thinned, Kpinchout=3 ft/day	+0.662	1.921	24%

Table AV-3b. Regional Response (No Pinchout Zone)

Run		Mine Inflow (gpm)	Percent Change in Area of Little Sand Lake Rel. to Pre-Stress	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress	
				Pickerel Basin	Swamp Basin
ZINC2A	High End Zinc	1579	-17.1%	-10.6%	+5.3%
KINC2A	Thinned, Kpinchout=3 ft/day	1592	-17.3%	-11.0%	+5.3%

* *The predicted base flow to the Swamp Creek basin increases for runs owing to the effect of infiltration to the SAS located just north of Swamp Creek. The assumed infiltration rate to the SAS for these runs is 1500 gpm.*

Table AV-3c. Drawdown (ft) at Selected Locations

North of Ore, North of Pinchout Zone (from west to east)

Run	P1	P2	P3	N1	N2	NN	P4
ZINC2A	1.05	0.75	2.84	0.62	7.66	-0.63	0.30
KINC2A	0.88	0.63	2.36	0.58	7.36	-0.63	0.29

East of Ore, East of Pinchout Zone

Run	P5	P6	P7	P8	EE
ZINC2A	0.22	0.15	0.38	0.38	0.48

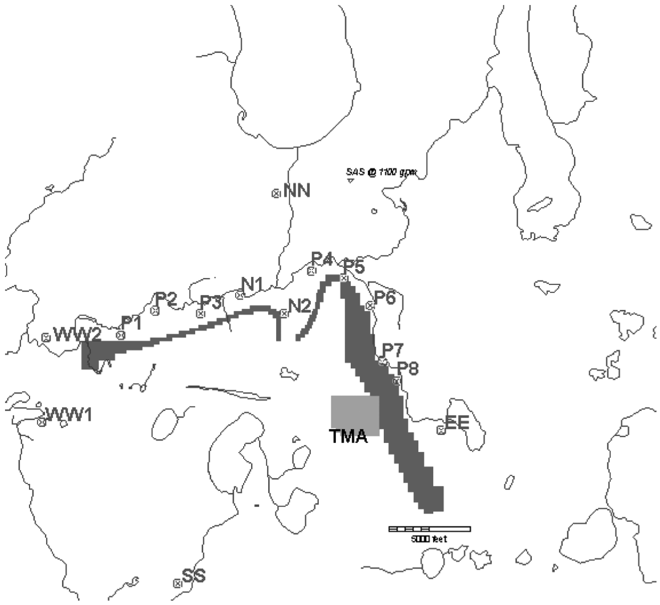


Figure AV-1. *Modified pinchout zone with gap north of Skunk Lake and truncated western portion*

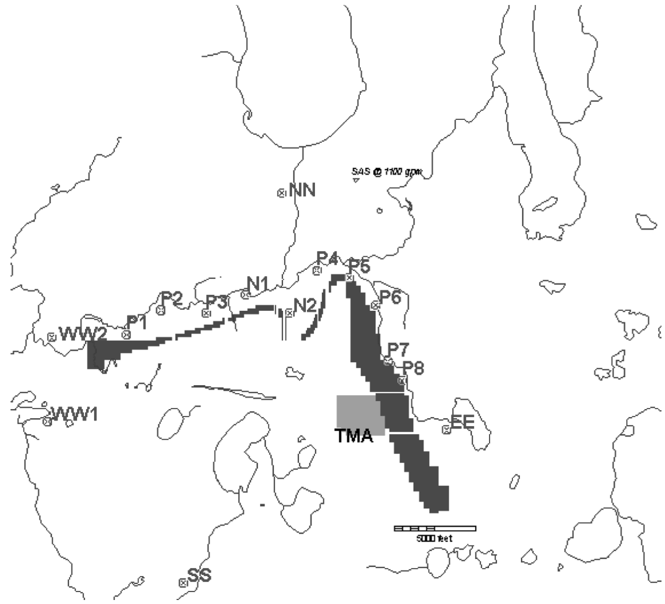


Figure AV-2. *Pinchout zone with approximately 5 percent gaps (UC5P-78).*

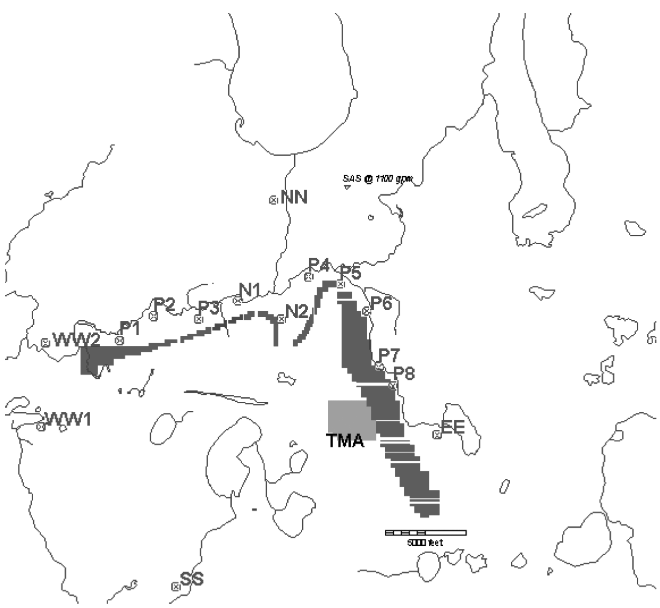


Figure AV-3. *Pinchout zone with approximately 10 percent gaps, second realization (UC11P-78)*

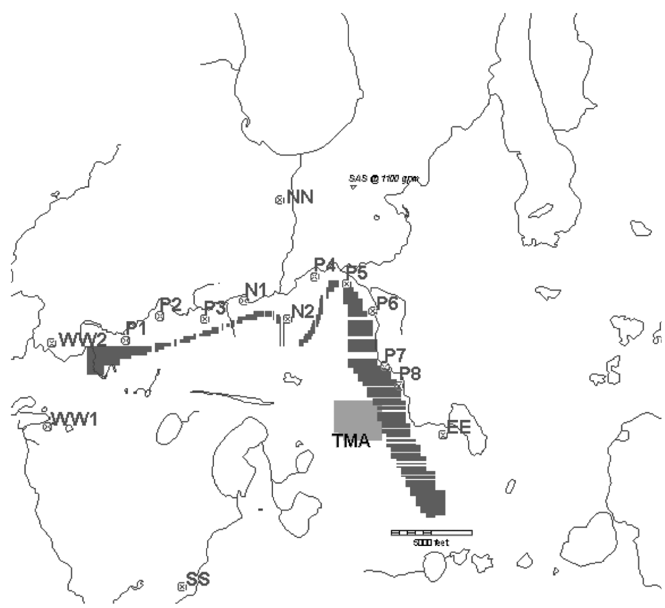


Figure AV-4. *Pinchout zone with approximately 15 percent gaps, second realization (UC15P-78)*

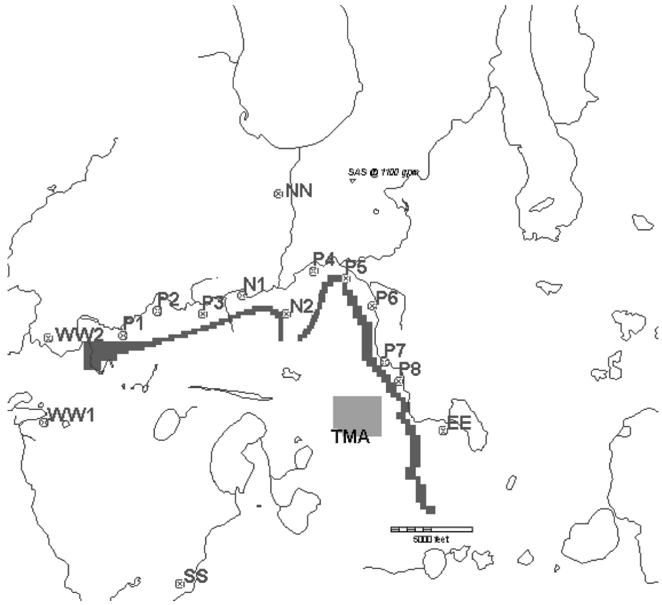


Figure AV-5. *Revised modified configuration with Kpinch = 3 ft/d and thinned TMA segment.*

Appendix VI

Anisotropy in Bedrock

One part of the conceptual model underlying the construction of the regional flow model involves the assumed large-scale anisotropy of the bedrock with respect to planes of weakness, and, by extension, with respect to hydraulic conductivity. In this report we describe the reason for assuming that the direction of maximum hydraulic conductivity in the bedrock lies along the east-west axis in the XZ plane occupied by up-ended bedding planes, an interpretation which is supported by the available oriented-core data. This same plane of weakness is expected to enhance to a lesser degree the hydraulic conductivity in the vertical direction, but not to enhance ease of flow along the north-south axis. As a result, it is assumed that Kx>Kz>Ky. In the model Kz=0.3162*Kx and Ky=0.1*Kx.

While the conceptual model is plausible on geological grounds and supported by the core data, the available aquifer tests do not allow us to precisely quantify the degree of bedrock anisotropy. The pumping test that stressed the massive saprolite (using the PWAR well) was not of a sufficient scale to produce much drawdown in deeper rocks. As a result, it is not surprising that the analysis of the test was not sensitive to the assumed degree of bedrock anisotropy (Foth and Van Dyke, 1995). The 213 test produced a bigger and deeper stress, but because almost all the observation wells measured during pumping were aligned along the east-west axis of the ore body, the test did not yield a clear result with respect to anisotropy. The results presented in the memo that describes the calibration of the regional model to the 213 test show that given Low-End inputs, the pumping test model results were largely indifferent to an assumed Kx:Ky anisotropy of 10:1 or 1:1 (in the latter case Ky is increased by 10 times so that it equals Kx) (Feinstein, 1999).

For the purposes of this appendix, the analysis of the influence of anisotropy on the calibration of the 213 pumping test was extended to Version1, Zinc Phase, High-End inputs. The original calibration reported in the 1999 memo was, in fact, achieved for High-End inputs with Kx:Ky=10 for all bedrock units except the strongly-weathered material in layer 5 of the regional flow model. That is, the Kx value is always 10 times the Ky value for the moderately, weakly and unweathered hydraulic conductivity zones of the ore body, hanging wall, and footwall. The Kz value is intermediate between Kx and Ky, taken as the square root of Kx*Ky.

To test the influence of the assumed anisotropy ratios, we reran the 213 pumping simulations for four scenarios. In the first two scenarios, the bulk horizontal hydraulic conductivity is increased by increasing the value of Ky in all bedrock units below model layer 5 while Kx is held constant. In one case the Ky is multiplied by 10 times (so that it equals Kx), in the second case Ky is multiplied by 3.162 times (so that it equals Kz). One measure of bulk horizontal conductivity is the square root of Kx*Ky. Using this formula, it follows that the bulk horizontal hydraulic conductivity of the bedrock system below layer 5 increases by 3.162 times in the first case and by 1.778 times in the second case.

In the second pair of scenarios, anisotropy ratios are altered, but the bulk horizontal hydraulic conductivity, as defined above, is maintained constant. In one case Ky is increased by 3.162 times and Kx is decreased by 3.162 times, with Kz held constant. Under these circumstances the anisotropy of Kx:Ky is reduced from 10:1 to 1:1 and the entire bedrock is assumed to be isotropic along all three directions. In the second case Ky is increased by 1.778 times and Kx is decreased by 1.778 times with Kz held constant.

* *The calibration of the regional flow model to unstressed long-term average conditions is almost completely insensitive to bedrock anisotropy. The scenarios produced nearly identical calibration statistics for the October 1984 water levels that were taken as representative of long-term unstressed conditions. In contrast, the tables in this appendix indicate that the pumping test calibration results* are *moderately sensitive to bedrock anisotropy.*

Under these circumstances, the anisotropy ratio of Kx:Ky is 0.562:0.178 (or 3.16:1), and the anisotropy ratio of Kx:Kz is 0.562:0.316 (or 1.78:1). This last scenario preserves anisotropy in the bedrock but makes it less pronounced than in the original calibration.* All of bulk the conductivity values examined in this appendix fall into the range of values thought to be reasonable in Bradbury (2002).

The following table summarizes the input to the original calibration run and the four sensitivity runs applied to the 213 pumping test analysis using Version 1, High-End Zinc inputs:

Input to 213 Pumping Test Calibration Runs:

Run	Description	Change to PTW-78P	Kx : Kz : Ky
PTW-78P	Original Calibration	None	1.000 : 0.316 : 0.100
PTW-79P	No horizontal bedrock anisotropy, Bulk bedrock K increased greatly	Ky multiplied by 10	1.000 : 0.316 : 1.000
PTW-91P	Small horizontal bedrock anisotropy, Bulk bedrock K increased moderately	Ky multiplied by 3.162	1.000 : 0.316 : 0.316
PTW-92P	Isotropic bedrock Bulk bedrock K unchanged	Ky multiplied by 3.162 Kx divided by 3.162	0.316 : 0.316 : 0.316
PTW-93P	Small horizontal bedrock anisotropy Bulk bedrock K unchanged	Ky multiplied by 1.778 Ky divided by 1.77	0.562 : 0.316 : 0.178

The 213 pumping test was analyzed by computing ratio-based calibration statistics and by examining the relationship between measured and simulated drawdown at observation wells. To assess the effects that horizontal anisotropy assumptions have on calibration, we recomputed the calibration statistics for a group of 37 observation wells and examined the match at selected wells located on the east side (PW213), center (OW216) and west side (OW211) of the ore body. We also examined the match at the four observation wells located north of the ore body in the hanging wall. The hanging wall wells are important because they yield the most direct evidence on how the stress from the ore body propagates along the north-south axis. Note that no observation wells were available for measurement in the footwall, south of the ore body.

Calibration Statistics:

	Ratio Based Statistics	
Run	Mean Error (Optimal value=1)	Mean Absolute Error (Optimal value=1)
PTW-78P	0.91	1.81
PTW-79P	1.20	1.91
PTW-91P	1.02	1.83
PTW-92P	1.45	2.25
PTW-93P	1.01	1.76

Observed vs Simulated Drawdown:

	Representative Observation Wells			Hanging Wall Wells			
Observed	PW213	OW216	OW211	DMI-2L	195E	OW155	OW214
Drawdown	221.78	28.72	3.88	9.63	33.79	3.47	23.44
Run:							
PTW-78P	191.80	46.52	5.61	6.66	41.29	7.10	14.03
PTW-79P	128.45	33.76	3.75	6.98	23.59	24.41	32.32
PTW-91P	153.17	40.81	4.84	9.33	30.46	15.85	28.17
PTW-92P	224.86	28.31	1.22	9.31	28.46	20.72	33.54
PTW-93P	227.21	42.79	3.39	7.70	41.60	8.39	16.93

Examination of the tabulated results indicates that two of the scenarios, PTW-79P (Ky increased by 10 times) and PTW-92P (Ky increased by 3.162 times, Kx decreased by 3.162 times) do not perform well relative to the original calibration. On the other hand, the PTW-91P run (Ky increased by 3.162 times) yields results that are almost as good as the original calibration, and the PTW-93P run (Ky increased by 1.778 times and Kx decreased by 1.778 times) yields results that are slightly better than the original calibration.

Carrying the two well-calibrated runs forward, the next step is to estimate what effect modified bedrock anisotropy has on the response of the natural system to the mine. We evaluate the implications of the changes by comparing the Version 1, High-End, Zinc Phase run (ZINC2A) with new runs that are identical except for modified bedrock anisotropy. One sensitivity run (SA31) increases Ky by 3.162 times, the second (SA32) increases Ky by 1.778 times and decreases Kx by 1.778 times.

The table below provides key output for the original and two sensitivity runs. Note that the SAS infiltration assumed for each run is also given. The amount of infiltration is set to be approximately 100 gpm less than total pumping up to a maximum rate of 1500 gpm. The SAS is located north of Swamp Creek on the eastern side of the basin. The addition of water to the SAS causes the overall baseflow change in the Swamp Creek basin to be positive despite the stress of the mine. In order to show the effect of the mine in the Swamp Creek basin in areas where SAS infiltration has less influence on shallow flow, the table also provides the baseflow response of part of Swamp Creek itself along the stretch downstream (to the west of) Outlet Creek.

The increase in bedrock bulk hydraulic conductivity in the SA31 sensitivity run causes mine inflow to increase by 27% relative to the base case with corresponding increases in other measures of the effect of the mine on the groundwater and surface-water systems. For the SA32 sensitivity run which maintains the original bedrock bulk hydraulic conductivity, the mine inflow decreases by 7% relative to the base case. However, not all the measures of mine impact decrease with reduced mine inflow. For example, the water-table drawdown near Skunk Lake north of the ore body increases in SA32 relative to ZINC2A, presumably because there is less resistance to flow through the hanging-wall bedrock along the north-south axis.

Version 1, High-End, Zinc Phase Simulation	ZINC2A	SA31	SA32
Assumed infiltration at SAS north of Swamp Creek (gpm)	1500	1500	1500
Mine Inflow (gpm)	1579	2004	1474
Water-Table Drawdown south of Swamp Creek at location N2 (ft)	7.66	10.16	8.52
Percent Baseflow Change			
Swamp Creek Basin	+5.1%	+3.3%	+5.5%
Pickerel Creek Basin	-8.1%	-10.7%	-7.6%
Lily Creek Basin	-2.5%	-3.2%	-2.3%
Swamp Creek west of Outlet Creek	-12.2%	-15.8%	-11.4%
Change in Little Sand Lake Stage (ft)	-3.97	-4.98	-3.63
Percent Change in Little Sand Lake Area	-17.1%	-28.7%	-15.8%

These sensitivity runs provide some idea of the range in predictive model results that arises from uncertainty about anisotropy in the bedrock.

Appendix VII

Effect of Mine Workings on Mine Inflow

Question: What is the effect of removing mineworkings (and grout curtain if present) on mine inflow?

Compare runs.

Run	"end"	Version of Model	Mineworkings?	Curtain?	Mine Inflow	Works Inflow
ZINC2A	High	1	Yes	No	1579 gpm	433 gpm
ZINC2	High	1	No	No	1482 gpm	—
COPPER2A	High	1	Yes	No	1392 gpm	620 gpm
COPPER2	High	1	No	No	773 gpm	—
ZINC1A	Low	1	Yes	No	602 gpm	87 gpm
ZINC1	Low	1	No	No	515 gpm	—
COPPER1A	Low	1	Yes	No	349 gpm	40 gpm
COPPER1	Low	1	No	No	297 gpm	—
HHZN1B	High	2	Yes	Yes	1176 gpm	435 gpm
HHZN1	High	2	No	No	1305 gpm	—
HHCU1B	High	2	Yes	Yes	1250 gpm	866 gpm
HHCU1	High	2	No	No	814 gpm	—

(We have not performed the Version 2 Low End runs without mine workings and curtain).

Results:

For the VERSION 1 runs, removing the mine workings always causes the mine inflow to decrease. The size of the decrease is only large in the case of High End copper. In the other runs, most of the flow to the mine workings is redistributed to the stopes when the workings are removed.

The most interesting results are for the VERSION 2 HIGH-END runs that contain mine workings and the grout curtain. If both these features are removed, the mine inflow actually increases in the case of High End zinc, suggesting that the curtain is more important in decreasing flow than the mine workings are in increasing flow. However, for the High End copper case, the reverse is true. The large decrease owing to removal of mine workings seen in the VERSION 1 High End copper run is also seen in the VERSION 2 run.

Appendix VIII

Transient Response to Pumping

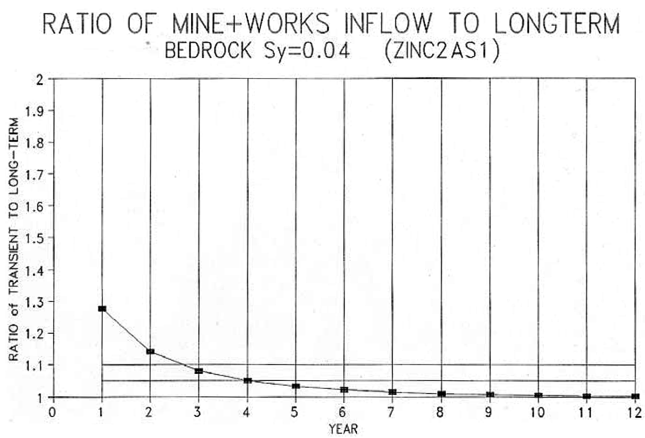


Figure AVIII-1.

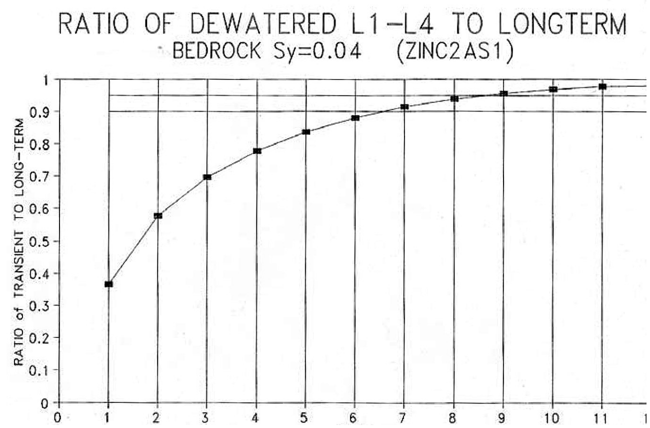


Figure AVIII-2.

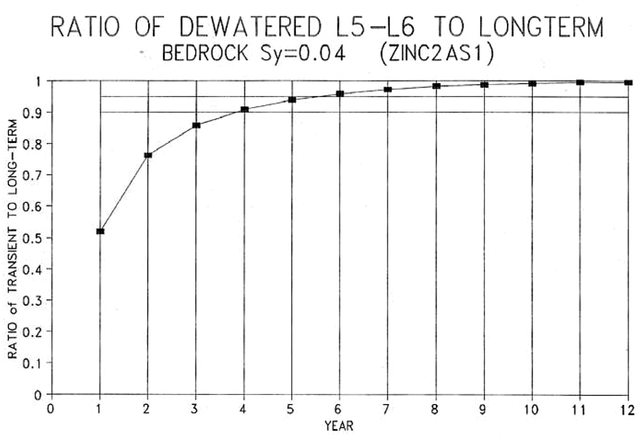


Figure AVIII-3.

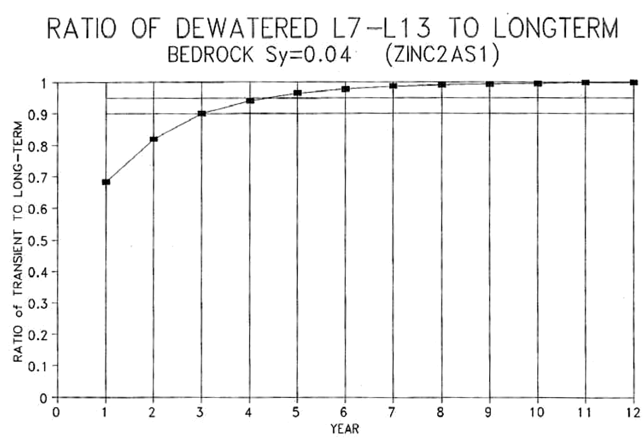


Figure AVIII-4.

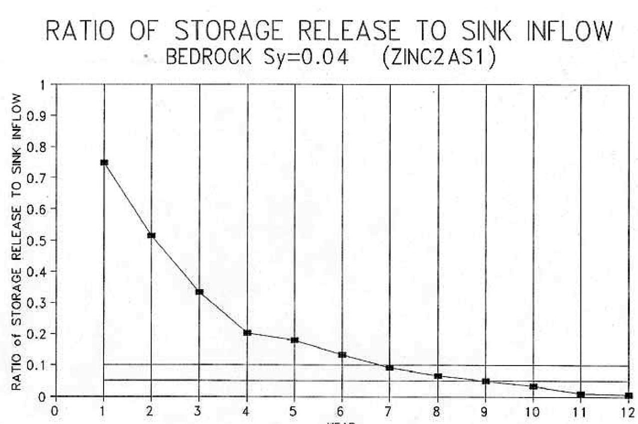


Figure AVIII-5.

Appendix IX-1

Internal Lake Mitigation

The Crandon groundwater model can be used to estimate the mitigation flux necessary to restore an internal lake to a specified level. The mitigation flux applied to the lake can be added to the natural inflow as part of the lake runoff term in the model LAK package and the effects evaluated using model results.

The needed mitigation flux under a mining scenario for an internal lake (Duck, Skunk, Deep Hole, or Little Sand lakes) was calculated by running the model multiple times until the ending lake level matched the target level. For non-drought runs, this target level is the Metallic Mining Minimum Stage (MMMS), established by the WDNR. For drought runs, the target level is not set to the MMMS, but represents instead, a target corresponding to the simulated lake level under 3 years of drought without mining in which recharge and natural runoff to the lakes are only two-thirds normal rates.

In this appendix, results for Little Sand Lake are highlighted. Five cases requiring lake mitigation are considered:

1) Version 1, High End, Zinc Phase with no drought.
2) Version 2, High End, Copper Phase with no drought
3) Version 1, High End, Zinc Phase with drought
4) Version 2, High End, Copper Phase with drought
5) Version 1, Low End, Zinc Phase with drought.

There is no non-drought case corresponding to Case 5 because no lake mitigation would be necessary under Version 1, Low End, Zinc Phase conditions unless a drought is present.

In the non-drought cases, a lake is defined to need mitigation during mining if its level falls below the established Metallic Mining Mitigation Stage (MMMS). The MMMS levels are:[1]

	Deep Hole	Duck	Little Sand	Skunk
Metallic Mining Minimum Stage	1605.25	1610.59	1591.41	1597.01

For all of the non-drought simulations, only Little Sand Lake stage falls below the MMMS and requires mitigation. Deep Hole and Duck Lake stages never fall below the surface water outlet elevations, and the Skunk Lake stage is maintained above the MMMS by low permeability sediments over part of the bed.

In drought cases, a lake is projected to need mitigation during mining if its level falls below the simulated drought level in the absence of mining. For each drought scenario tested, a pre-mine simulation is performed to determine lake levels after 3 years of drought at two-thirds normal recharge rates. Model simulations show that both Deep Hole and Little Sand Lake fall below pre-mine drought levels during mining and both lakes require mitigation.

In all simulations with mitigation, the infiltration applied to the Soil Absorption Site (SAS) without mitigation is reduced by an amount approximately equal to the lake mitigation. This change is made because the water for lake mitigation will be come from treated water otherwise proposed to be routed to the SAS for disposal.

[1] *Deep Hole and Little Sand Lakes have seasonal MMMS levels. For the purposes of this analysis, the highest stage is adopted.*

Table AIX-1-1. Selected results* from simulations assessing internal lake mitigation using Version 1 and 2 Base Runs. [abbreviations: SAS, Soil Absorption Site; gpm, gallons per minute; ft, feet; MSL, mean sea level; %, percentage]

						Change in Base Flow[b]		Mitigation		
Simulation	**Description of the Simulation**	**Model Convergence**	**Quality of Mass Balance[a]**	**Mine Inflow (gpm)**	**SAS Flow (gpm)**	**Pickerel Creek Basin**	**Swamp Creek Basin**	**Internal Lake**	**Goal Stage (ft MSL)**	**Flow (gpm)**
Version 1:										
ZINC2A	High End Zinc Base Run	Yes	Good	1579	1500	-10.6%	5.3%	—	—	—
ZINC2AM4	ZINC2A with Internal Lake Mitigation	No	Good	1610	1318	-9.0%	4.1%	Little Sand	1591.41	175
PRE-SA4	High End, Pre-mine Background Run with Drought	Yes	error= -6.9%	—	—	-21.7%	-22.4%	—	—	—
SA4	PRE-SA4 with Drought (extention of ZINC2A)	Yes	error= -1.0%	1463	1500	-34.2%	-18.8%	—	—	—
SA4M6	SA4 with Internal Lake Mitigation	No	Good	1516	1000	-31.7%	-22.6%	Little Sand	1590.92	380
PRE-SLA4	Low End, Pre-mine Background Run with Drought	No	Good	—	—	-23.1%	-23.7%	—	—	—
SLA4	PRE-SLA4 with Drought (extention of ZINC1A)	Yes	Good	570	525	-27.9%	-22.5%	—	—	—
SLA4M4	SLA4 with Internal Lake Mitigation	No	Good	574	375	-27.3%	-23.7%	Little Sand	1588.20	188
Version 2:										
HHCU1B	High End Copper Base Run	Yes	Good	1250	1100	-8.4%	3.0%	—	—	—
HHCU1BM4	HHCU1B with Internal Lake Mitigation	Yes	Good	1256	1000	-7.4%	2.4%	Little Sand	1591.41	90
CA4	High End Copper Phase Run with Drought (extension of HHCU1B)	Yes	error= -0.2%	1218	1100	-32.3%	-21.1%	—	—	—
CA4M2	CA4 with Internal Lake Mitigation	Yes	error= -0.2%	1228	800	-30.0%	-23.1%	Little Sand	1590.92	293

[a] *The quality of the mass balance was deemed to be good if the error was less that 0.1% for the entire simulation and less than 0.1% for the internal lakes*

[b] *Changes in base flow as compared to the applicable background simulation. Values for the Swamp Creek Basin are positive due to infiltration at the SAS. These results do not account for any other potential surface water mitigation within the basin.*

**Only results associated with runs that result in lake mitigation are included; the remaining Base Runs under normal or drought conditions resulted in no lake mitigation.*

Case 1: Lake Mitigation Without Drought
Version 1, High End, Zinc Phase

Consider two runs simulating zinc mining:

ZINC2A:	Version 1, High End, Zinc Phase, No Mitigation.
ZIN2AM4:	Version 1, High End, Zinc Phase, Lake Mitigation to MMMS levels. Mitigation Flux = 175 gpm to Little Sand Lake The SAS inflow is reduced from 1500 gpm to 1318 gpm

Now consider results pertaining to Little Sand Lake for two conditions (table AIX-1-1):

- pre-mine (UD-78), and
- zinc mine with mitigation (ZINC2AM4).

In the second run the lake is mitigated at a rate of 175 gpm to attain the MMMS level (1591.41 ft)

a) Little Sand Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=UD-78	1591.61 ft	—	230.5 acres	—
ZINC2AM4	1591.41 ft	-0.20 ft	227.2 acres	-2.3 acres (-1.4%)

b) Mass Balance (gpm)

	IN = PPT+ RO (+ MIT)				OUT = SW + GW		
	PPT +	RO +	MIT =	IN	SW +	GW =	OUT
Background=UD-78	67.8	472.4	0.0	540.2	201.5	338.7	540.2
ZINC2AM4	66.8	429.9	175.4	672.1	0.0	672.2	672.2

PPT = precipitation flux into lake
RO = runoff flux into lake
MIT = mitigation flux added to lake
SW = surface water flux out of lake
GW = groundwater flux out of lake

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=UD-78	0.0%	12.6%
ZINC2AM4	26.1%	36.0%

d) Residence time for lake water

Time (years) = LAKE_VOLUME / (PPT+RO), or LAKE_VOLUME / (PPT+RO+MIT)

	Lake Volume	Time
Background=UD-78	0.732e8 ft^3	1.93 yr
ZINC2AM4	0.712e8 ft^3	1.51 yr

Finally, consider the simulated groundwater flux out of Little Sand Lake for pertinent simulations:

		Groundwater Flux
UD-78	(pre-mine)	338.7 gpm
ZINC2A	(zinc mine)	486.4 gpm
ZINC2AM4	(zinc mine, Little Sand Lake mitigated)	672.2 gpm

Case 2: Lake Mitigation Without Drought
Version 2, High End, Copper Phase

Consider two runs simulating copper mining:

HHCU1B:	Version 2, High End, Copper Phase, No Mitigation.
HHCU1BM4:	Version 1, High End, Copper Phase, Lake Mitigation to MMMS levels. Mitigation Flux = **90 gpm** to Little Sand Lake The SAS inflow is reduced from 1100 gpm to 1000 gpm

Now consider results pertaining to Little Sand Lake for two conditions (table AIX-1-1):

pre-mine (UD-78), and
copper mine with mitigation (HHCU1BM4).

In the second run the lake is mitigated at a rate of 90 gpm to attain the MMMS level (1591.41 ft)

a) Little Sand Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=UD-78	1591.61 ft	—	230.5 acres	—
HHCU1BM4	1591.42 ft	-0.19 ft	227.2 acres	-2.3 acres (-1.4%)

b) Mass Balance (gpm)

	IN = PPT+ RO (+ MIT)				OUT = SW + GW		
	PPT +	RO +	MIT =	IN	SW +	GW =	OUT
Background=UD-78	67.8	472.4	0.0	540.2	201.5	338.7	540.2
HHCU1BM4	66.8	429.9	90.0	586.7	0.0	586.5	586.5

PPT = precipitation flux into lake
RO = runoff flux into lake
MIT = mitigation flux added to lake
SW = surface water flux out of lake
GW = groundwater flux out of lake

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=UD-78	0.0%	12.6%
HHCU1BM4	15.3%	26.7%

d) Residence time for lake water

Time (years) = LAKE_VOLUME / (PPT+RO), or LAKE_VOLUME / (PPT+RO+MIT)

	Lake_Volume	Time
Background=UD-78	0.732e8 ft^3	1.93 yr
HHCU1BM4	0.713e8 ft^3	1.73 yr

Finally, consider the simulated groundwater flux out of Little Sand Lake for pertinent simulations:

		Groundwater Flux
UD-78	(pre-mine)	338.7 gpm
HHCU1B	(copper mine)	490.7
HHCU1BM4	(copper mine, Little Sand Lake mitigated)	586.5

Case 3: Lake Mitigation With Drought
Version 1, High End, Zinc Phase

For the drought scenario, the following transient runs were performed:

PRE-SA4 = High End, Pre-mine with 3-year drought
Initial condition is UD-78 (steady-state pre-mine without drought)

SA4 = Version 1, High End, Zinc Phase with 3-year drought
Initial condition is ZINC2A (steady-state zinc mine without drought)

SA4M6 = Version 1, High End, Zinc Phase with 3-year drought and mitigation
Initial condition is ZINC2AM4 (steady-state zinc mine without drought but with mitigation to MMMS)

The new stages from PRE-SA4 determine the *drought mitigation levels*. They are

Deep Hole Lake = 1605.12
Duck Lake = 1611.60
Little Sand Lake = 1590.92
Skunk Lake = 1596.81

The run SA4 (3 years of zinc mine with two-thirds normal recharge) indicated that some lakes would fall below drought mitigation levels due to mining. **The drought mining levels without mitigation** are:

Deep Hole=1604.25, Duck= 1611.60, Little Sand=1584.87, Skunk= 1596.80.

Note that Deep Hole and Little Sand Lakes require mitigation. According to the simulation the Duck Lake stage does not fall below its outlet elevation even in the presence of drought and mining. Also, the Skunk Lake stage is hardly changed by the mine and, therefore, Skunk Lake is not mitigated in the subsequent run.

The mitigation run, SA4M6, restores the lakes to pre-mine drought levels. The SAS inflow is reduced from 1500 to 1000 gpm. For Deep Hole and Little Sand Lake the drought mitigation fluxes are 24 and 379.5 gpm, respectively.

Note: All drought runs are transient, so mass balance includes storage released by daily rate of lake drop. This storage release is a "source" only from the viewpoint of mass balance. In other terms, it is the rate at which the lake is losing water at the end of the 3-yr drought.

Consider one run simulating pre-mine conditions and two runs simulating copper mining:

PRE-SA4: High End, Pre-Mine, Drought
SA4: Version 1, High End, Zinc Phase, Drought, No Mitigation.
SA4M6: Version 1, High End, Zinc Phase, Drought, Lake Mitigation to Pre-Mine Drought levels.
Mitigation Flux = **379.5 gpm** to Little Sand Lake
The SAS inflow is reduced from 1100 gpm to 1000 gpm

Now consider results pertaining to Little Sand Lake for two conditions (table AIX-1-1):

pre-mine with drought (PRE-SA4), and
zinc mine under drought with mitigation (SA4M6).

In the second run the lake is mitigated at a rate of 379.5 gpm to attain pre-mine drought levels (1590.92 ft).

a) Little Sand Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=PRE-SA4	1590.92 ft	—	223.0 acres	—
SA4M6	1590.92 ft	0.00 ft	223.0 acres	0.0 acre (0%)

b) Mass Balance (gpm)

	IN = PPT+ RO + STOR (+ MIT)					OUT = SW + GW		
	PPT	RO	STOR	MIT	IN	SW	GW	OUT
Background=PRE-SA4	43.7	314.6	46.9	0.0	405.2	0.0	405.4	405.4
SA4M6	43.7	286.3	42.6	379.5	752.1	0.0	752.8	752.8

PPT = precipitation flux into lake
RO = runoff flux into lake
MIT = mitigation flux added to lake
SW = surface water flux out of lake
GW = groundwater flux out of lake

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=PRE-SA4	0%	12.2%
SA4M6	53.5%	59.6%

d) Residence time for lake water

Time (years) = LAKE_VOLUME / (PPT+RO), or LAKE_VOLUME / (PPT+RO+MIT)

	Lake Volume	Time
Background=PRE-SA4	0.665e8 ft^3	2.64 yr
SA4M6	0.665e8 ft^3	1.33 yr

Finally, consider the groundwater flux out of Little Sand Lake and its volumetric loss rate for the non-drought and drought cases:

		Groundwater Flux (gpm)	Volumetric Storage Release (gpm)
UD-78	(pre-mine, no drought)	338.7	0
PRE-SA4	(pre-mine, 3 yr drought)	405.4	46.9
ZINC2A	(zinc mine, no drought, no mitigation)	486.4	0
ZINC2AM4	(zinc mine, no drought, mitigated)	672.2	0
SA4	(zinc mine, 3 yr drought, no mitigation)	350.4	39.5
SA4M6	(zinc mine, 3 yr drought, Deep Hole and Little Sand Lake mitigated)	752.8	42.6

Case 4: Lake Mitigation With Drought
Version 2, High End, Copper Phase

For the drought scenario, the following transient runs were performed:

PRE-SA4 = High End, Pre-mine with 3-year drought
Initial condition is UD-78 (steady-state pre-mine without drought)

CA4 = Version 2, High End, Copper Phase with 3-year drought
Initial condition is HHCU1B (steady-state copper mine without drought)

CA4M2 = Version 2, High End, Copper Phase with 3-year drought and mitigation
Initial condition is HHCU1BM4 (steady-state copper mine without drought, with mitigation to MMMS)

The new stages from PRE-SA4 determine the *drought mitigation levels.* They are

Deep Hole Lake = 1605.12
Duck Lake = 1611.60
Little Sand Lake = 1590.92
Skunk Lake = 1596.81

The run CA4 (3 years of copper mine with two-thirds normal recharge) indicated that some lakes would fall below drought mitigation levels due to mining. The **drought mining levels without mitigation** are:

Deep Hole=1604.38, Duck= 1611.60, Little Sand=1586.14, Skunk= 1596.80.

Note that Deep Hole and Little Sand Lakes require mitigation. According to the simulation the Duck Lake stage does not fall below its outlet elevation even in the presence of drought and mining. Also, the Skunk Lake stage is hardly changed by the mine and, therefore, Skunk Lake is not mitigated in the subsequent run.

The mitigation run, CA4M2, restores the lakes to pre-mine drought levels. The SAS inflow is reduced from 1300 to 1100 gpm. For Deep Hole and Little Sand Lake the drought mitigation fluxes are **20.3** and **292.5** gpm, respectively.

Note: All drought runs are transient, so mass balance includes storage released by daily rate of lake drop. This storage release is a "source" only from the viewpoint of mass balance. In other terms, it is the rate at which the lake is losing water at the end of the 3-yr drought.

Consider one run simulating pre-mine conditions and two runs simulating copper mining:

PRE-SA4: High End, Pre-Mine, Drought
CA4: Version 2, High End, Copper Phase, Drought, No Mitigation.
CA4M2: Version 2, High End, Copper Phase, Drought, Lake Mitigation to Pre-Mine Drought levels.
Mitigation Flux = 292.5 gpm to Little Sand Lake
The SAS inflow is reduced from 1100 gpm to 1000 gpm

Now consider results pertaining to Little Sand Lake for two conditions (table AIX-1-1):

pre-mine with drought (PRE-SA4), and
copper mine under drought with mitigation (CA4M2).

In the second run the lake is mitigated at a rate of 292.5 gpm to attain pre-mine drought levels (1590.93 ft)

a) Little Sand Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=PRE-SA4	1590.92 ft	—	223.0 acres	—
CA4M2	1590.92 ft	0.00 ft	223.0 acres	0.00 ft (0%)

b) Mass Balance (gpm)

	IN = PPT+ RO (+ MIT)					OUT = SW + GW		
	PPT +	RO +	STOR +	MIT =	IN	SW +	GW =	OUT
Background=PRE-SA4	43.7	314.6	46.9	0.0	405.2	0.0	405.4	405.4
CA4M2	43.7	286.3	47.6	292.5	670.1	0.0	671.1	671.1

PPT = precipitation flux into lake
RO = runoff flux into lake
MIT = mitigation flux added to lake
SW = surface water flux out of lake
GW = groundwater flux out of lake

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=PRE-SA4	0%	12.2%
CA4M2	43.6%	50.2%

d) Residence time for lake water

Time (years) = LAKE_VOLUME / (PPT+RO), or LAKE_VOLUME / (PPT+RO+MIT)

	Lake Volume	Time
Background=PRE-SA4	0.665e8 ft^3	2.64 yr
CA4M2	0.665e8 ft^3	1.52 yr

Finally, consider the simulated groundwater flux out of Little Sand Lake for pertinent simulations:

		Groundwater Flux (gpm)	Volumetric Storage Release (gpm
UD-78	(pre-mine, no drought)	338.7	0
PRE-SA4	(pre-mine, 3 yr drought)	405.4	46.9
HHCU1B	(copper mine, no drought, no mitigation)	490.7	0
HHCU1BM4	(copper mine, no drought, mitigated)	586.5	0
CA4	(copper mine, 3 yr drought, no mitigation)	392.0	74.9
CA4M2	(copper mine, 3 yr drought, Deep Hole and Little Sand Lake mitigated)	671.1	47.6

Case 5: Lake Mitigation With Drought
Version 1, Low End, Zinc Phase

The final analysis was performed as a sensitivity on the scenario that yields about 600 gpm of mine inflow (ZINC1A). Under non-drought conditions none of the lakes require mitigation. For the drought scenario, the following transient runs were performed:

PRE-SA4 = Low End, Pre-mine with 3-year drought
Initial condition is UD-8 (steady-state pre-mine without drought)

SLA4 = Version 1, Low End, Zinc Phase with 3-year drought
Initial condition is ZINC1A (steady-state zinc mine without drought)

SLA4M4 = Version 1, Low End, Zinc Phase with 3-year drought and mitigation
Initial condition is ZINC1A (steady-state zinc mine without drought, no mitigation needed)

The new stages from PRE-SLA4 determine the *drought mitigation levels*. They are

Deep Hole=1605.06, Duck=1611.60, Little Sand=1590.75, Skunk=1596.68.

The run CA4 (3 years of copper mine with two-thirds normal recharge) indicated that some lakes would fall below drought mitigation levels due to mining. The drought mining levels without mitigation are:

Deep Hole=1604.59, Duck= 1611.59, Little Sand=1588.20, Skunk= 1596.66

Note that Deep Hole and Little Sand Lakes require mitigation. According to the simulation the stages of Duck Lake and Skunk Lake are hardly changed by the mine and, therefore, they are not mitigated in the subsequent run.

The mitigation run, SLA4M4, restores the lakes to pre-mine drought levels. The SAS inflow is reduced from 525 to 375 gpm. For Deep Hole and Little Sand Lake the drought mitigation fluxes are **14** and **188** gpm, respectively.

Note: All drought runs are transient, so mass balance includes storage released by daily rate of lake drop. This storage release is a "source" only from the viewpoint of mass balance. In other terms, it is the rate at which the lake is losing water at the end of the 3-yr drought.

Consider one run simulating pre-mine conditions and two runs simulating copper mining:

PRE-SLA4:	Low End, Pre-Mine, Drought
SLA4:	Version 1, Low End, Zinc Phase, Drought, No Mitigation.
CA4M2:	Version 1, Low End, Zinc Phase, Drought, Lake Mitigation to Pre-Mine Drought levels.
	Mitigation Flux = **188 gpm** to Little Sand Lake
	The SAS inflow is reduced from 525 gpm to 375 gpm

Now consider results pertaining to Little Sand Lake for two conditions (table AIX-1-1):

pre-mine with drought (PRE-SLA4), and
zinc mine under drought with mitigation (SLA4M4).

In the second run the lake is mitigated at a rate of 188 gpm to attain pre-mine drought levels (1590.75 ft)

a) Little Sand Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=PRE-SLA4	1590.75 ft	—	220.9 acres	—
SLA4M4	1590.75 ft	0.00 ft	220.3 acres	-0.6 acre (-4.4%)

b) Mass Balance (gpm)

	IN = PPT + RO + STOR (+ MIT)					OUT = SW + GW		
	PPT +	RO +	STOR +	MIT =	IN	SW +	GW =	OUT
Background=PRE-SLA	443.3	319.2	65.6	0.0	428.1	0.0	428.3	428.3
SLA4M4	43.1	290.4	57.7	188.0	579.2	0.0	577.3	577.3

PPT =	precipitation flux into lake	SW =	surface water flux out of lake
RO =	runoff flux into lake	GW =	groundwater flux out of lake
MIT =	mitigation flux added to lake		

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=PRE-SLA4	0%	11.9%
SLA4M4	36.0%	44.3%

d) Residence time for lake water

Time (years) = LAKE_VOLUME / (PPT+RO), or LAKE_VOLUME / (PPT+RO+MIT)

	Lake Volume	Time
Background=PRE-SLA4	0.648e8 ft^3	2.54 yr
SLA4M4	0.648e8 ft^3	1.77 yr

Finally, consider the groundwater flux out of Little Sand Lake and its volumetric loss rate for the non-drought and drought cases:

		Groundwater Flux (gpm)	Volumetric Storage Release (gpm
UD-8	(pre-mine, no drought)	345.2	0
PRE-SLA4	(pre-mine, 3 yr drought)	428.3	65.6
ZINC1A	(zinc mine, no drought, no mitigation)	491.6	0
SLA4	(zinc mine, 3 yr drought, no mitigation)	452.8	124.8
SLA4M4	(zinc mine, 3 yr drought, Deep Hole and Little Sand Lake mitigated)	579.3	57.7

Appendix IX-2

Stream Mitigation

Some mitigation may be needed to protect streams in the presence of mining so that under baseflow conditions the stream flow does not fall below a regulatory-defined threshold level, called the Metallic Mining Minimum Flow (MMMF). The value of the MMMF and the amount of mitigation needed to preserve the MMMF are a function of what reduction in stream baseflow below average conditions is deemed tolerable.

Average baseflow conditions are assumed to correspond to the Q50 stream flow (i.e., the flow at a stream that is exceeded 50% of the time). For example, the Q50 for Swamp Creek and its tributaries as measured at Highway 55 is 28.2 cfs. Recharge and other inputs to the flow model were calibrated in order to reproduce the assumed average baseflow for Swamp Creek as well as for other streams in the Swamp Creek, Pickerel Creek and Lily Creek Basins.

The flow duration curve for Swamp Creek at Highway 55 can be used to correlate a given percent reduction in average stream baseflow to a flow duration value. A 10% reduction in stream baseflow corresponds approximately to a flow duration value of Q60 (i.e., the flow that is exceeded 60% of the time). A 25% reduction corresponds approximately to a value of Q75, which NMC in the Surface Water Mitigation Plan suggests approximately correspond to the WDNR MMMF where sufficient data exist. A 35% reduction corresponds approximately to a value of Q85.

The baseflow mitigation analysis is predicated on an assumption that baseflow in no stream would be allowed to drop more than a percentage below its average (Q50) level, the mitigation threshold. If the model simulates a drop in excess of the threshold percent, then the mitigation flux equals the amount of water needed to bring it back to the threshold. The same analysis can be used for drought conditions, but instead of comparing baseflow under mining to flows under average pre-mine conditions, baseflow is compared to flows under drought pre-mine conditions.

For each MMMF threshold, it is possible to use model output under different mining scenarios to determine: whether or not a given stream requires mitigation to maintain baseflow at the MMMF threshold; if a stream does require mitigation how much is needed to increase stream flow to the MMMF threshold; the total mitigation required across all streams at the threshold level.

This analysis has been performed for the eight base mining scenarios as well as for selected base mining scenarios with lake mitigation included. In addition it has been performed for two sensitivity runs in which the SAS infiltration is reduced. Finally, the analysis was carried out for drought runs (with lake mitigation included). Appendix IX-3 lists the output by mitigated stream at the three MMMF thresholds for each of these runs. The tabulations show that the streams most commonly in need of mitigation are Creek 33-8, Creek 19-14 and Hoffman Springs/Creek in Swamp Creek Basin and Upper Pickerel Creek, Martin Springs/Creek 11-4 and Creek 12-2 in Pickerel Creek Basin.

Summary results are presented in table AIX-2-1. It compares the total baseflow mitigation flux required to three other fluxes: mine inflow, lake mitigation (if considered), and SAS inflow.

The results indicate:

- The range of simulated baseflow mitigation for base mine scenario runs is 4 to 204 gpm for the 10% reduction threshold, 0 to 28 gpm for the 25% reduction threshold, and 0 to 14 gpm for the 35% reduction threshold.

Table AIX-2-1. Baseflow mitigation.

Version 1 Cases	Mining Simulation	Mine Inflow, gpm	Estimated Mitigation to Internal Lakes, gpm	Estimated SAS Flux to Swamp Creek Basin[1] gpm	Total Stream Mitigation Needed to Limit Baseflow Reduction to Selected Threshold[2]: 10%, gpm	25%, gpm	35%, gpm
High End, Zinc	ZINC2A	1579	0[3]	1429	204	28	14
with lake mitigation	ZINC2A=>ZINC2AM4	1610	175	1285	158	19	14
High End, Copper	COPPER2A	1392	0[3]	1242	179	16	13
Low End, Zinc	ZINC1A	602	0[4]	452	14	4	1
Low End, Copper	COPPER1A	349	0[4]	199	5	1	0

Version 2 Cases	Mining Simulation	Mine Inflow, gpm	Estimated Mitigation to Internal Lakes, gpm	Estimated SAS Flux to Swamp Creek Basin[1] gpm	Total Stream Mitigation Needed to Limit Baseflow Reduction to Selected Threshold[2]: 10%, gpm	25%, gpm	35%, gpm
High End, Zinc	HHZN1B	1176	0[3]	1026	93	13	11
High End, Copper	HHCU1B	1250	0[3]	1100	140	14	11
with lake mitigation	HHCU1B=>HHCU1BM4	1256	90	1016	111	13	11
Low End, Zinc	LLZN1B	285	0[4]	135	4	0	0
Low End, Copper	LLCU1B	290	0[4]	140	4	0.2	0

Fixed SAS Infiltration	Mining Simulation	Mine Inflow, gpm	Estimated Mitigation to Internal Lakes, gpm	Estimated SAS Flux to Swamp Creek Basin gpm	Total Stream Mitigation Needed to Limit Baseflow Reduction to Selected Threshold[1]: 10%, gpm	25%, gpm	35%, gpm
Version 1, High End, Zinc	ZINC2A=>SA12	1579	0[2]	714	215	28	14
Version 1, High End, Zinc	ZINC2A=>SB12	1579	0[2]	0	228	29	14

Drought Cases[3]	Mining Simulation	Mine Inflow, gpm	Estimated Mitigation to Internal Lakes, gpm	Estimated SAS Flux to Swamp Creek Basin[4] gpm	Total Stream Mitigation Needed to Limit Baseflow Reduction to Selected Threshold[1]: 10%, gpm	25%, gpm	35%, gpm
Version 1, High End, Zinc	ZINC2A=>SA4	1463	0[2]	1313	414	61	20
with lake mitigation	SA4=>SA4M6	1513	404	959	286	29	8
Version 2, High End, Copper	HHCU1B=>CA4	1218	0[2]	1068	278	34	8
with lake mitigation	CA4=>CA4M2	1228	310	749	174	15	8
Version 1, Low End, Zinc	ZINC1A=>SLA4	570	0[2]	420	28	4	3
with lake mitigation	SLA4=>SLA4M4	574	202	222	19	4	2

[1] *SAS infiltration estimated as mine inflow less 150 gpm for mine operations less any lake mitigation flux.*
[2] *Mitigation fluxes summed across streams in Pickerel and Swamp Creek Basins.*
[3] *Lake mitigation not considered.*
[4] *Lake mitigation not needed.*

- When lake mitigation is added to a simulation, that change alone means that less water is required for baseflow mitigation because part of the water added to lakes discharges to streams and, therefore, buffers the effect of the mine (compare run ZINC2AM4 to ZINC2A and run HHCU1BM2 to HHCU1B).
- Elimination of the SAS infiltration has only a small effect on required baseflow mitigation flux for the non-drought Version 1, High End, Zinc phase simulation.
- Under drought conditions more water is needed to restore baseflow to MMMF levels than under non-drought conditions. For example, the 10% threshold value is 286 gpm for Version 1, High End, Zinc Phase with lake mitigation. Under non-drought conditions with lake mitigation the corresponding value is 158 gpm.

According to the mining plan, the source of water for any baseflow mitigation will be groundwater pumped from a well open to the glacial material in the Swamp Creek Basin located about 1.5 miles west of Outlet Creek and 0.75 miles north of Swamp Creek. This approach assumes that the reduction in baseflow occasioned by the pumping does not add to mitigation requirements imposed by the mine. Scoping simulations show that virtually all the water pumped from a mitigation well at the selected location will derive from groundwater that would otherwise discharge to Swamp Creek or its tributaries. However, it is also true that infiltration of mine inflow to the SAS increases baseflow to these water bodies over and above what would occur under natural conditions.

The model simulations presented so far do not include the action of the mitigation well. To determine what effect the mitigation well has on the flux needed for baseflow mitigation, we repeated two simulations with the mitigation well pumping at summed baseflow mitigation corresponding to the 10% MMMF threshold. The first is the Version 1, High End, Zinc simulation that includes the effect of lake mitigation (ZINC2A=>ZINC2AM4) with the mitigation well pumping 158.3 gpm (ZINC2AM4=>ZINC2AMM). The second is the drought scenario for Version 1, High End Zinc (ZINC2A=>SA4),, including lake mitigation (SA4=>SA4M6) with the mitigation well pumping 286.4 gpm (SA4M6=>SA4MM). The question to be answered – does the mitigation well itself increase the required baseflow mitigation flux?

For the non-drought case with a mitigation well simulated (ZINC2AMM), the baseflow mitigation required for the 10% MMMF threshold is 158 gpm, unchanged from the mitigation required with no mitigation well simulated (ZINC2AM4). The reason that the mitigation well has no effect on the analysis is that Swamp Creek and its tributaries have more, rather than less, baseflow under mining owing to the SAS infiltration. The surplus provided by the SAS in the basin is more than enough to offset the action of the well.

For the drought case with a mitigation well simulated (SA4MM), the baseflow mitigation required for the 10% MMMF threshold is 284 gpm, virtually identical to the mitigation required with no mitigation well simulated (SA4M6). Again, the routing of water from the SAS to baseflow within the Swamp Creek Basin means that groundwater can be removed by pumping from the basin without increasing the need for mitigation of Swamp Creek Basin streams.

Detailed Results

Baseflow mitigation is keyed to not allowing baseflow in any stream to fall more than a threshold percentage below its Pre-mine average level (approximately the Q50 flow duration) or below a simulated Pre-mine drought level. If the model simulates a fall in excess of the threshold percent, then the mitigation flux equals the amount of water needed to bring it back to the threshold.

Mitigation rates are calculated by stream for three mitigation thresholds:

- 10% reduction (roughly equivalent to the Q60 flow duration)
- 25% reduction (roughly equivalent to the Q75 flow duration)
- 35% reduction (roughly equivalent to the Q85 flow duration)

This appendix contains the estimated amount of mitigation needed under each of the three thresholds for individual streams.

The following simulations are considered:

High End Base Case simulations:

ZINC2A	Version 1, High End, Zinc Phase
COPPER2A	Version 1, High End, Copper Phase
HHZN1B	Version 2, High End, Zinc Phase
HHCU1B	Version 2, High End, Copper Phase

Low End Base Case simulations:

ZINC1A	Version 1, Low End, Zinc Phase
COPPER1A	Version 1, Low End, Copper Phase
LLZN1B	Version 2, Low End, Zinc Phase
LLCU1B	Version 2, Low End, Copper Phase

Simulations including lake mitigation:

ZINC2AM4	Version 1, High End, Zinc Phase
HHCU1BM4	Version 2, High End, Copper Phase

Simulations including drought:

SA4	Version 1, High End, Zinc Phase
CA4	Version 2, High End, Copper Phase
SLA4	Version 1, Low End, Zinc Phase

Simulations including lake mitigation and drought:

SA4M6	Version 1, High End, Zinc Phase
CA4M2	Version 2, High End, Copper Phase
SLA4M4	Version 1, Low End, Zinc Phase

Simulations with reduced SAS infiltration:

SA12	Version 1, High End, Zinc Phase; SAS infiltration = 714 gpm
SB12	Version 1, High End, Zinc Phase; SAS infiltration = 0 gpm

Appendix IX-3

Results of Stream Mitigation Runs

Version 1, High End, Zinc Phase (ZINC2A)

****

Mitigation level = **10% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
UPPER PICKEREL CREEK	1280.0	200.5	15.7%	72.5
MARTIN SPRINGS/CR 11-4	301.0	43.2	14.4%	13.1
CREEK 12-2	301.4	86.8	28.8%	56.7
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 33-8	37.8	4.1	10.8%	0.3
CREEK 19-14	25.1	23.2	92.7%	20.7
HOFFMAN SPRINGS/CREEK	270.7	67.3	24.9%	40.2

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.4537	203.6

****

Mitigation level = **25% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
CREEK 12-2	301.4	86.8	28.8%	11.5
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.2	92.7%	17.0

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0634	28.5

****

Mitigation level = **35% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.2	92.7%	14.5

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0322	14.5

Version 1, High End, Copper Phase (COPPER2A)

```
*************************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS      PCT     MITIGATION
                           BASEFLOW     gpm       LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   UPPER PICKEREL CREEK     1280.0      191.9    15.0%       63.9
   MARTIN SPRINGS/CR 11-4    301.0       39.4    13.1%        9.3
   CREEK 12-2                301.4       76.1    25.2%       45.9
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       21.4    85.2%       18.8
   HOFFMAN SPRINGS/CREEK     270.7       67.9    25.1%       40.9

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .3985         178.8

 *************************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS      PCT     MITIGATION
                           BASEFLOW     gpm       LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   CREEK 12-2                301.4       76.1    25.2%        0.7
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       21.4    85.2%       15.1
   HOFFMAN SPRINGS/CREEK     270.7       67.9    25.1%        0.3

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0358          16.1

 *************************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS      PCT     MITIGATION
                           BASEFLOW     gpm       LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       21.4    85.2%       12.6

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0280          12.6
```

Version 2, High End, Zinc Phase (HHZN1B)

```
**********************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY                PRE-MINE     LOSS     PCT     MITIGATION
                             BASEFLOW     gpm      LOSS       gpm
                                gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   UPPER PICKEREL CREEK       1280.0      144.7    11.3%       16.7
   MARTIN SPRINGS/CR 11-4      301.0       30.4    10.1%        0.2
   CREEK 12-2                  301.4       65.9    21.8%       35.7
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                  25.1       19.7    78.4%       17.2
   HOFFMAN SPRINGS/CREEK       270.7       50.0    18.5%       22.9

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .2065          92.7

**********************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY                PRE-MINE     LOSS     PCT     MITIGATION
                             BASEFLOW     gpm      LOSS       gpm
                                gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                  25.1       19.7    78.4%       13.4

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0299          13.4

**********************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY                PRE-MINE     LOSS     PCT     MITIGATION
                             BASEFLOW     gpm      LOSS       gpm
                                gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                  25.1       19.7    78.4%       10.9

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0243          10.9
```

Version 2, High End, Copper Phase (HHCU1B)

****

Mitigation level = **10% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
UPPER PICKEREL CREEK	1280.0	170.1	13.3%	42.1
MARTIN SPRINGS/CR 11-4	301.0	34.8	11.6%	4.7
CREEK 12-2	301.4	73.3	24.3%	43.1
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	20.0	79.9%	17.5
HOFFMAN SPRINGS/CREEK	270.7	59.8	22.1%	32.7

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.3123	140.1

****

Mitigation level = **25% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	20.0	79.9%	13.8

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0307	13.8

****

Mitigation level = **35% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	20.0	79.9%	11.3

Summed baseflow mitigation fo
r 35% threshold:

CFS	GPM
.0251	11.3

Version 1, Low End, Zinc Phase (ZINC1A)

```
*************************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY             PRE-MINE     LOSS     PCT     MITIGATION
                          BASEFLOW     gpm      LOSS       gpm
                             gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]
   CREEK 12-2               303.8       36.7    12.1%        6.3
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14               26.8       10.6    39.4%        7.9

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .0315          14.2

*************************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY             PRE-MINE     LOSS     PCT     MITIGATION
                          BASEFLOW     gpm      LOSS       gpm
                             gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14               26.8       10.6    39.4%        3.9

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0086           3.9

*************************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY             PRE-MINE     LOSS     PCT     MITIGATION
                          BASEFLOW     gpm      LOSS       gpm
                             gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14               26.8       10.6    39.4%        1.2

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0026           1.2
```

Version 1, Low End, Copper Phase (COPPER1A)

```
************************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                            BASEFLOW     gpm      LOSS       gpm
                               gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14                 26.8        7.6    28.4%        4.9

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .0110           4.9

************************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                            BASEFLOW     gpm      LOSS       gpm
                               gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14                 26.8        7.6    28.4%        0.9

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0020            .9

************************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                            BASEFLOW     gpm      LOSS       gpm
                               gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0000            .0
```

Version 2, Low End, Zinc Phase (LLZN1B)

```
***********************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14                26.8        6.3    23.6%        3.7

  Summed baseflow mitigation for 10% threshold:
     CFS             GPM
     .0081          3.7

***********************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]

  Summed baseflow mitigation for 25% threshold:
      CFS          GPM
     .0000           .0

***********************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]

  Summed baseflow mitigation for 35% threshold:
      CFS          GPM
     .0000           .0
```

Version 2, Low End, Copper Phase (LLCU1B)

```
**********************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14                26.8        6.9    25.7%        4.2

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .0094           4.2

**********************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]
   CREEK 19-14                26.8        6.9    25.7%        0.2

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0004            .2

**********************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6728 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13190 gpm]

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0000            .0
```

Version 1, High End, Zinc Phase with Lake Mitigation (ZINC2AM4)

```
**********************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   UPPER PICKEREL CREEK     1280.0      177.2    13.8%       49.2
   MARTIN SPRINGS/CR 11-4    301.0       36.6    12.2%        6.5
   CREEK 12-2                301.4       77.7    25.8%       47.5
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       22.6    90.1%       20.1
   HOFFMAN SPRINGS/CREEK     270.7       62.1    23.0%       35.1

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .3528         158.3

**********************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   CREEK 12-2                301.4       77.7    25.8%        2.3
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       22.6    90.1%       16.3

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0416          18.7

**********************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       22.6    90.1%       13.8

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0308          13.8
```

Version 2, High End, Copper Phase with Lake Mitigation (HHCU1BM4)

```
**********************************************************************
  Mitigation level = 10% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
   UPPER PICKEREL CREEK     1280.0      156.1    12.2%       28.1
   MARTIN SPRINGS/CR 11-4    301.0       31.4    10.4%        1.3
   CREEK 12-2                301.4       64.9    21.5%       34.8
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       19.6    78.1%       17.1
   HOFFMAN SPRINGS/CREEK     270.7       56.6    20.9%       29.5

  Summed baseflow mitigation for 10% threshold:
     CFS              GPM
     .2469         110.8

**********************************************************************
  Mitigation level = 25% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]
  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       19.6    78.1%       13.3

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0297          13.3

**********************************************************************
  Mitigation level = 35% reduction relative to Q50 (average conditions)
  Only streams requiring mitigation are listed.

   WATER BODY              PRE-MINE     LOSS     PCT     MITIGATION
                           BASEFLOW     gpm      LOSS       gpm
                              gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]
   CREEK 19-14                25.1       19.6    78.1%       10.8

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0241          10.8
```

Version 1, High End, Zinc Phase with Drought (SA4)

****

Mitigation level = **10% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW,gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
UPPER PICKEREL CREEK	907.4	179.6	19.8%	88.9
MARTIN SPRINGS/CR 11-4	231.2	49.6	21.5%	26.5
CREEK 12-2	206.1	84.3	40.9%	63.7
CREEK 12-9	1215.6	220.2	18.1%	98.7
CREEK 20-3	512.1	54.4	10.6%	3.2
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 33-8	27.7	5.3	19.3%	2.6
CREEK 19-14	12.6	12.6	100.0%	11.3
HOFFMAN SPRINGS/CREEK	225.4	75.0	33.3%	52.4
(Hemlock Creek and tributaries......)				
HEMLOCK CREEK SYSTEM	2143.8	271.4	12.7%	57.0

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.9222	413.8

****

Mitigation level = **25% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW,gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
CREEK 12-2	206.1	84.3	40.9%	32.8
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	9.4
HOFFMAN SPRINGS/CREEK	225.4	75.0	33.3%	18.6

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.1356	60.8

****

Mitigation level = **35% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW,gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
CREEK 12-2	206.1	84.3	40.9%	12.2
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	8.2

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0453	20.3

Version 2, High End, Copper Phase with Drought (CA4)

****

Mitigation level = **10% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW, gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
UPPER PICKEREL CREEK	907.4	154.7	17.0%	63.9
MARTIN SPRINGS/CR 11-4	231.2	42.1	18.2%	19.0
CREEK 12-2	206.1	64.6	31.4%	44.0
CREEK 12-9	1215.6	175.8	14.5%	54.3
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 33-8	27.7	4.5	16.4%	1.8
CREEK 19-14	12.6	12.6	100.0%	11.3
HOFFMAN SPRINGS/CREEK	225.4	67.4	29.9%	44.9
(Hemlock Creek and tributaries......)				
HEMLOCK CREEK SYSTEM	2143.8	233.5	10.9%	19.1

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.6188	277.7

****

Mitigation level = **25% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
CREEK 12-2	206.1	64.6	31.4%	13.1
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	9.4
HOFFMAN SPRINGS/CREEK	225.4	67.4	29.9%	11.0

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0749	33.6

****

Mitigation level = **35% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	8.2

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0182	8.2

Version 1, Low End, Zinc Phase with Drought (SLA4)

****

Mitigation level = **10% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
CREEK 12-2	203.3	37.3	18.3%	17.0
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	7.0	55.6%	5.7
HOFFMAN SPRINGS/CREEK	218.6	27.0	12.3%	5.1

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.0619	27.8

****

Mitigation level = **25% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	7.0	55.6%	3.8

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0086	3.8

****

Mitigation level = **35% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	7.0	55.6%	2.6

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0058	2.6

Version 1, High End, Zinc Phase with Lake Mitigation and Drought (SA4M6)

****

Mitigation level = **10% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW, gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
UPPER PICKEREL CREEK	907.4	154.0	17.0%	63.3
MARTIN SPRINGS/CR 11-4	231.2	40.7	17.6%	17.6
CREEK 12-2	206.1	60.5	29.4%	39.9
CREEK 12-9	1215.6	169.3	13.9%	47.7
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 33-8	27.7	4.9	17.5%	2.1
CREEK 19-14	12.6	12.6	100.0%	11.3
HOFFMAN SPRINGS/CREEK	225.4	66.9	29.7%	44.4
(Hemlock Creek and tributaries......)				
HEMLOCK CREEK SYSTEM	2143.8	260.4	12.1%	46.0

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.6383	286.4

****

Mitigation level = **25% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
CREEK 12-2	206.1	60.5	29.4%	9.0
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	9.4
HOFFMAN SPRINGS/CREEK	225.4	66.9	29.7%	10.6

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0647	29.1

****

Mitigation level = **35% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]				
CREEK 19-14	12.6	12.6	100.0%	8.2

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0182	8.2

Version 2, High End, Copper Phase with Lake Mitigation and Drought (CA4M2)

```
*************************************************************************
  Mitigation level = 10% reduction relative to Drought (3 yrs @ 2/3 normal
  precipitation). Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                         BASEFLOW, gpm   gpm      LOSS       gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]
   UPPER PICKEREL CREEK       907.4      126.9    14.0%       36.1
   MARTIN SPRINGS/CR 11-4     231.2       34.3    14.8%       11.2
   CREEK 12-2                 206.1       52.3    25.4%       31.7
   CREEK 12-9                1215.6      136.5    11.2%       14.9
  [Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]
   CREEK 33-8                  27.7        4.1    14.7%        1.3
   CREEK 19-14                 12.6       12.6   100.0%       11.3
   HOFFMAN SPRINGS/CREEK      225.4       61.2    27.2%       38.7
    (Hemlock Creek and tributaries......)
   HEMLOCK CREEK SYSTEM      2143.8      216.2    10.1%        1.8

  Summed baseflow mitigation for 10% threshold:
     CFS            GPM
     .3878         174.0
*************************************************************************
  Mitigation level = 25% reduction relative to Drought (3 yrs @ 2/3 normal
  precipitation). Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                            BASEFLOW     gpm      LOSS       gpm
                               gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]
   CREEK 12-2                 206.1       52.3    25.4%        0.8
  [Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]
   CREEK 19-14                 12.6       12.6   100.0%        9.4
   HOFFMAN SPRINGS/CREEK      225.4       61.2    27.2%        4.9

  Summed baseflow mitigation for 25% threshold:
      CFS           GPM
     .0337          15.1
*************************************************************************
  Mitigation level = 35% reduction relative to Drought (3 yrs @ 2/3 normal
  precipitation). Only streams requiring mitigation are listed.

   WATER BODY               PRE-MINE     LOSS     PCT     MITIGATION
                         BASEFLOW, gpm   gpm      LOSS       gpm
  [Pickerel Creek Basin: Total Pre-mine Baseflow = 5205 gpm]

  [Swamp Creek Basin: Total Pre-mine Baseflow = 10207 gpm]
   CREEK 19-14                 12.6       12.6   100.0%        8.2

  Summed baseflow mitigation for 35% threshold:
      CFS           GPM
     .0182           8.2
```

Version 1, Low End, Zinc Phase with Lake Mitigation and Drought (SLA4M4)

****

Mitigation level = **10% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
CREEK 12-2	203.3	30.9	15.2%	10.6
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	6.8	54.5%	5.6
HOFFMAN SPRINGS/CREEK	218.6	25.0	11.4%	3.1

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.0431	19.3

****

Mitigation level = **25% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	6.8	54.5%	3.7

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0083	3.7

****

Mitigation level = **35% reduction** relative to Drought (3 yrs @ 2/3 normal precipitation). Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 5139 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 9988 gpm]				
CREEK 19-14	12.6	6.8	54.5%	2.5

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0055	2.5

Version 1, High End, Zinc Phase; SAS infiltration = 714 gpm (SA12)

****

Mitigation level = **10% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
UPPER PICKEREL CREEK	1280.0	200.3	15.6%	72.3
MARTIN SPRINGS/CR 11-4	301.0	43.1	14.3%	13.0
CREEK 12-2	301.4	86.8	28.8%	56.6
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 33-8	37.8	4.1	10.8%	0.3
CREEK 19-14	25.1	23.2	92.7%	20.7
HOFFMAN SPRINGS/CREEK	270.7	67.3	24.9%	40.2

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.4792	215.0

****

Mitigation level = **25% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
CREEK 12-2	301.4	86.8	28.8%	11.4
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.2	92.7%	17.0

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0633	28.4

****

Mitigation level = **35% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.2	92.7%	14.5

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0322	14.5

Version 1, High End, Zinc Phase; SAS infiltration = 0 gpm (SB12)

****

Mitigation level = **10% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
UPPER PICKEREL CREEK	1280.0	200.9	15.7%	72.9
MARTIN SPRINGS/CR 11-4	301.0	43.3	14.4%	13.2
CREEK 12-2	301.4	87.1	28.9%	57.0
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 33-8	37.8	4.1	10.9%	0.4
CREEK 19-14	25.1	23.3	92.9%	20.8
HOFFMAN SPRINGS/CREEK	270.7	67.4	24.9%	40.3

Summed baseflow mitigation for 10% threshold:

CFS	GPM
.5089	228.4

****

Mitigation level = **25% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
CREEK 12-2	301.4	87.1	28.9%	11.8
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.3	92.9%	17.0

Summed baseflow mitigation for 25% threshold:

CFS	GPM
.0642	28.8

****

Mitigation level = **35% reduction** relative to Q50 (average conditions)
Only streams requiring mitigation are listed.

WATER BODY	PRE-MINE BASEFLOW gpm	LOSS gpm	PCT LOSS	MITIGATION gpm
[Pickerel Creek Basin: Total Pre-mine Baseflow = 6699 gpm]				
[Swamp Creek Basin: Total Pre-mine Baseflow = 13211 gpm]				
CREEK 19-14	25.1	23.3	92.9%	14.5

Summed baseflow mitigation for 35% threshold:

CFS	GPM
.0323	14.5

Appendix X-1

Replacement of Creeks 12-12a and 12-12d by Creek 12-2

During the initial stages of model development, the applicant used the USGS Mole Lake, WI, quad map to digitize the perennial streams into the MODFLOW model. As indicated on the quad map, this resulted in the inclusion of Creek 12-12a and Creek 12-12d as tributaries to Creek 12-9. However, through project-site field work by personnel from the Wisconsin DNR, it was recognized several years into the groundwater modeling process that Creeks 12-12a and 12-12d on the USGS Mole Lake, WI, quad map were not an accurate representation of the surface water flow conditions in that area on the west side of Creek 12-9. Rather, the only perennial flow in that area occurred in a different channel system, Creek 12-2. What had been called Creeks 12-12a and 12-12d appear to correspond to a single ephemeral tributary to Creek 12-2 just upstream of its confluence with Creek 12-9.

By the time the discrepancy between the model representation and the field was recognized, model calibration was complete and it was not possible to change it for the Base Runs. The distance of this area along Creek 12-9 from the ore body and the size of the features involved indicate that making such an adjustment would not have a substantial effect on the overall predictions from the regional flow model. In addition, the changes between the Creeks 12-12a and 12-12d representation and a reasonable Creek 12-2 representation are relatively small. Therefore, the results from the combined Creeks 12-12a and 12-12d have been reported as Creek 12-2. However, due to the proximity of these changes to a State Wildlife Area, Martin Springs, a sensitivity analysis was completed in which the model representation of Creeks 12-12a and 12-12d were removed from the STR package and an estimate of the location of Creek 12-2 based upon field visits, aerial photographs, and the Mole Lake quad map was incorporated into the STR package. The alternate model representations are shown in Figure AX-1-1. The limited effect on the large-scale model results can be seen in the Table AX-1-1.

The new STR file (49A-12-2) replaces the old streams 12-12a and 12-12d with 12-2, and updates the routing. The old 9-segment network is reduced to 7. The stage of Creek 12-2 is estimated by assuming a gradient of 0.00665 and a stage of 1545.10 at its most downgradient node just above the confluence with Creek 12-9 (these values are based on existing information from the pre-existing STR file). This calculation yields a headwater stage for 12-2 of 1558.81 ft, consistent with the land surface contours.

The number of reaches in the old segments 12-12a + 12-12d was equal to 50 + 9 = 59. The number of reaches in the single segment for 12-2 is equal to 8. It also follows a different course than the old 12-12a and 12-12d, except near the confluence with 12-9.

Other assumptions:

Kbed=1 ft/day

Width=2 ft

Bed thickness = 1 ft

Stream freeboard (water depth) = 1 ft

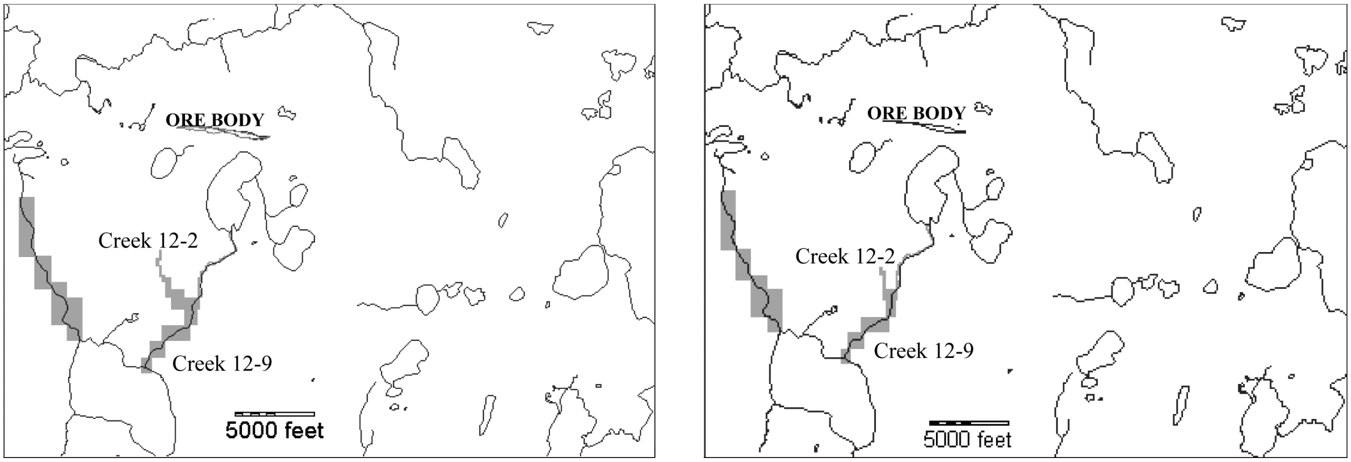


Figure AX-1-1. *Alternate depictions of Creek 12-2 in the STR package of MODFLOW. a) Original representation of Creek 12-2 (as Creeks 12-12a and 12-12d) and Creek 12-9 (UC-78➔UD-78➔ZINC2A). b) Alternative representation of Creek 12-2 and Creek 12-9 (MC-78➔MD-78➔MZINC2A). Note that the stream nodes representing upper Pickerel Creek are also shown.*

Table AX-1-1. Select results from sensitivity simulations adjusting the representation of Creek 12-2.

Run	Run Name	Converged? Mass Balance?	Mine Inflow (gpm)	Percent Change in Area of Little Sand Lake Rel. to Pre-Stress (stage change)	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress		
					Pickerel Basin	*Swamp Basin*	*Lily Basin*
Base Predictive Zinc Mine with USGS Bedrock and Mine Workings	**ZINC2A**	Yes Good	1579	-17.1% (-3.97 ft)	-8.1%	+5.1%	-2.5%
(Calibration Run=UC-78)	Calibration Mean Error= -0.078						
(Pre-Mine Run=UD-78)	Calibration Mean Absolute Error=1.881						
Alternative Representation of Creeks 12-9 and 12-2	**MZINC2A**	Yes Good	1580	-17.1% (-4.02 ft)	-8.1%	+5.0%	-2.5%
(Calibration Run=MC-78)	Calibration Mean Error= -0.151						
(Pre-Mine Run= MD-78)	Calibration Mean Absolute Error= 1.877						

NB: Mass balance is "good" if the error is less than ±0.1% for simulation as a whole and less than ±1% for internal lakes.

* *The predicted base flow to the Swamp Creek basin increases for both runs owing to the effect of infiltration to the SAS located just north of Swamp Creek. The assumed infiltration rate to the SAS is 1500 gpm .for both runs.*

Table AX-1-2. Select streamflow results from sensitivity simulations adjusting the representation of Creek 12-2 using the Version 1, Zinc Phase, High End Case model.

Original representation of Creeks 12-9 and 12-2

Run	Martin Springs/Creek 11-4		Creek 12-2 (as Creeks 12-12a/12-12d)		Creek 12-9	
	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)
Pre-mine Background (UD-78)	0.671	301	0.672	301.4	3.130	1404.5
Base Run (ZINC2A)	0.574	257.8	0.478	214.6	2.836	1272.9
Difference	-0.096	-43.2	-0.194	-86.8	-0.293	-131.6
Difference (percent)	-14.4%		-28.8%		-9.4%	

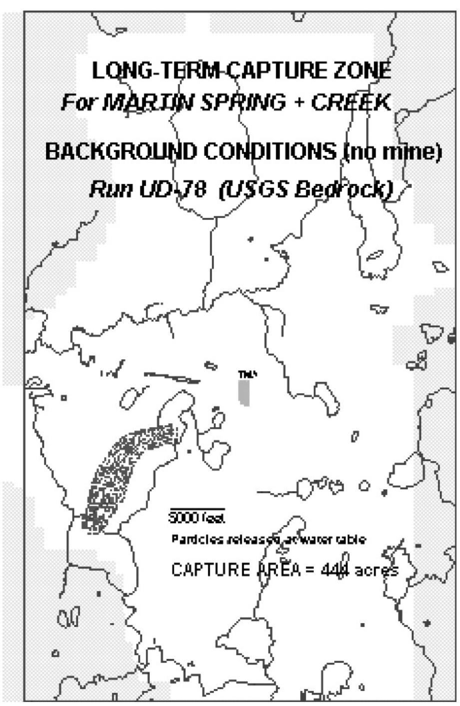
Alternative representation of Creeks 12-9 and 12-2

Run	Martin Springs/Creek 11-4		Creek 12-2		Creek 12-9	
	(cfs)	(gpm)	(cfs)	(gpm)	(cfs)	(gpm)
Pre-mine Background (MD-78)	0.702	315	0.229	102.9	3.467	1556
Base Run (MZINC2A)	0.596	267.6	0.153	68.4	3.084	1384
Difference	-0.106	-47.4	-0.077	-34.5	-0.383	-172
Difference (percent)	-15.0%		-33.4%		-11.0%	

Original Representation *of Creek 12-2 (as Creeks 12-12a and 12-12d):*

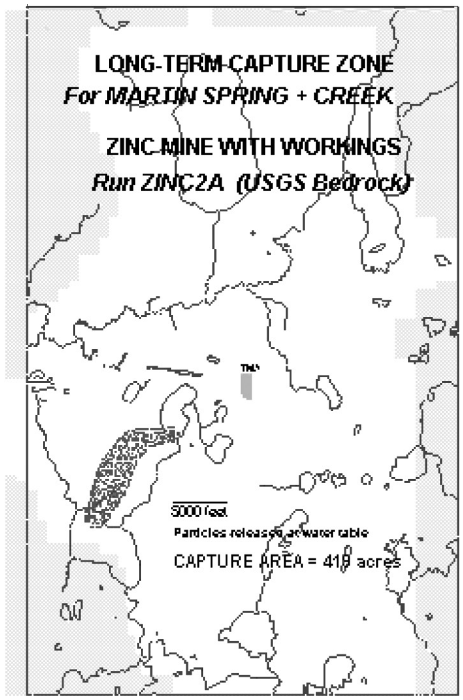
PREDICTED CAPTURE ZONE for MARTIN SPRINGS
+ CREEK 11-4

Pre-Mine Conditions (Version 1, High End



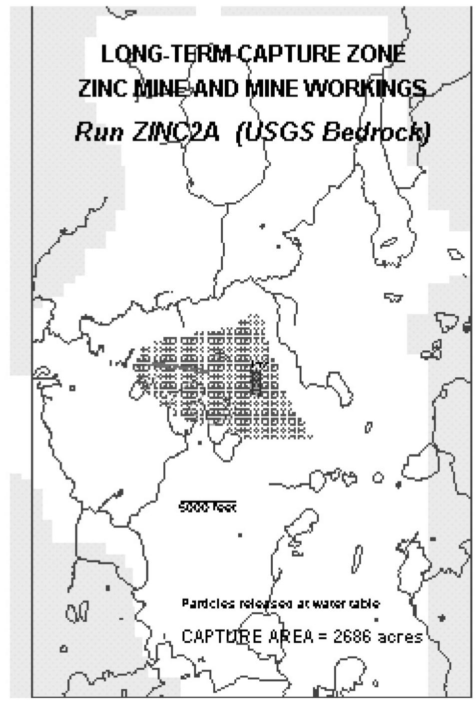
PREDICTED CAPTURE ZONE for MARTIN SPRINGS + CREEK 11-4

Mining Conditions (Version 1, High End, Zinc)



PREDICTED CAPTURE ZONE for ZINC MINE + WORKINGS

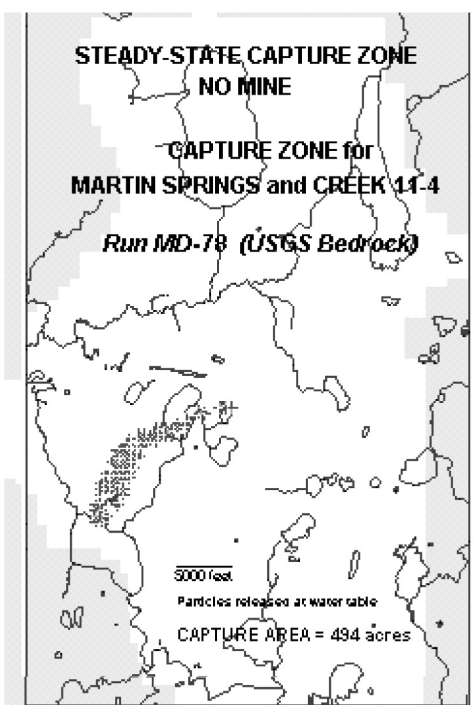
Mining Conditions (Version 1, High End, Zinc)



Revised Representation *of Creek 12-2 (as Creeks 12-12a and 12-12d):*

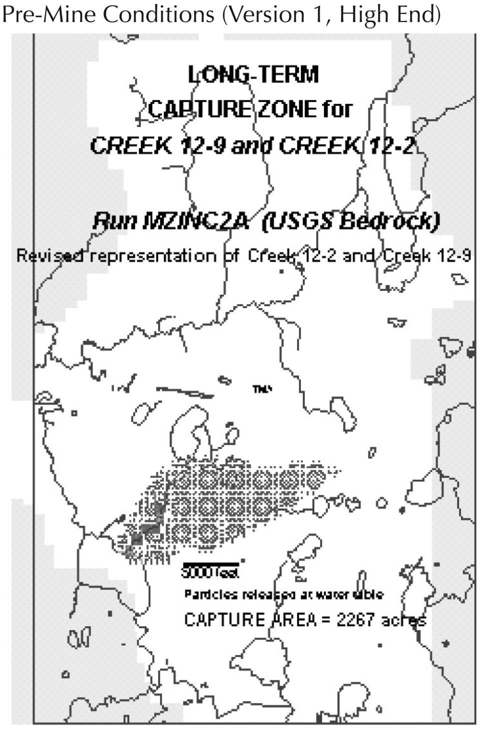
PREDICTED CAPTURE ZONE for MARTIN SPRINGS AND CREEK 11-4

Pre-Mine Conditions (Version 1, High End)



PREDICTED CAPTURE ZONE for CREEK 12-9 and CREEK 12-2

Pre-Mine Conditions (Version 1, High End)

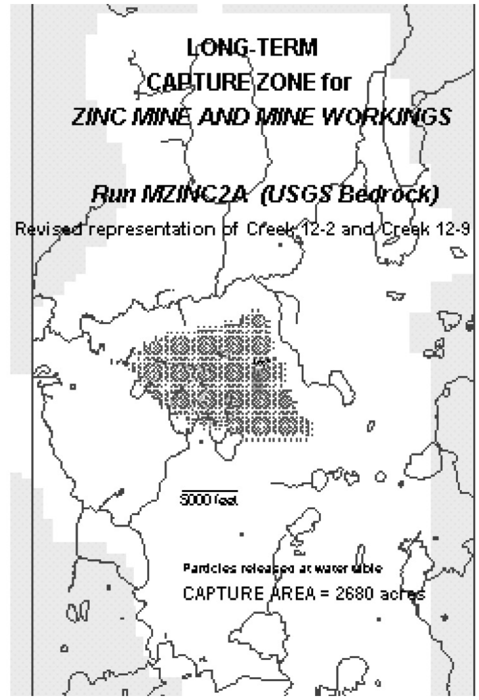


PREDICTED CAPTURE ZONE for MARTIN SPRINGS AND CREEK 11-4

Mining Conditions (Version 1, High End, Zinc)

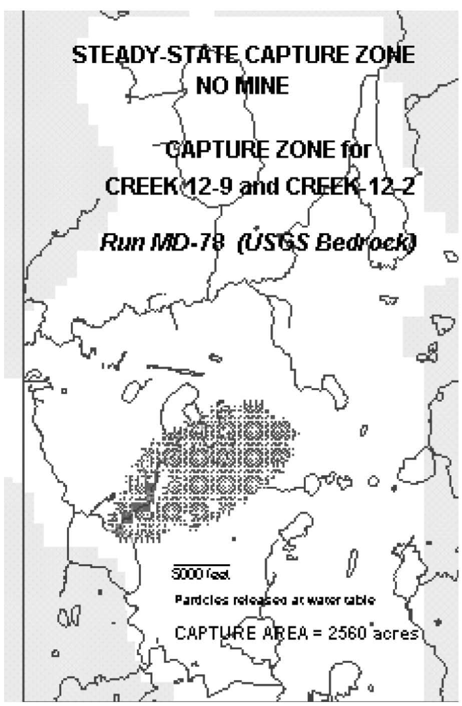
PREDICTED CAPTURE ZONE for ZINC MINE and WORKINGS

Mining Conditions (Version 1, High End, Zinc)



PREDICTED CAPTURE ZONE for CREEK 12-9 and CREEK 12-2)

Mining Conditions (Version 1, High End, Zinc)



Appendix X-2

The Effect of Outlet Uncertainty on the Response of Internal Lakes to Mining

The interaction of the lakes with their basin is tied to the expected ratio of long-term average overland runoff received by the lakes (RO) to the long-term average precipitation on their dryland basins (PPT). Studies suggest that this ratio should be on the order of 0.15 for the lakes under investigation (Dames and Moore, 1985; Krohelski et al., 1999). However, this value like many others in the modeling is uncertain. Given uncertainty in the correct RO/PPT ratio, there is uncertainty about the correct surface (stream) outflow for LSL, DHL and DKL since the two quantities are linked in the lake water budgets. The lower the assumed ratio of overland runoff to dryland precipitation, the lower the surface outflow needed to keep the lakes in balance under natural conditions.

For the Crandon study the RO/PPT ratio is an output of the pre-mine regional model. The assumed stream outflow, on the other hand, is a key input to the model with important implications for the lake water balances. In the WDNR simulations, the estimate for the surface outflow of LSL, DHL and DKL is set to a fixed rate for each lake as long as the lake level is above the lake cutoff elevation. Under natural conditions, the long-term average stage for LSL, DHL and DKL is always above the cutoff, and, therefore, the surface-water outflow is active at the assumed rate. By reducing that assumed outflow, we lower the amount of water needed by the lake to maintain its long-term average stage, and therefore, we lower the amount of overland runoff to the lakes needed to keep the model in balance.

If we relax the RO/PPT=0.15 constraint, then we are free to solve the model for a lower overland runoff by reducing the surface outflow. Given that PPT is a relatively well-known parameter, the decreased RO in these new simulations implies a value of RO/PPT of less than 0.15.

For the Base Runs under mining (e.g., ZINC2A, ZINC1A, HHCU1B), the stream outflow values are 0.4 cfs for LSL, 0.2 cfs for DHL, and 0.1 cfs for DKL. For both high-end and low-end pre-mine simulations, these rates imply RO/PPT ratios in the range of 0.14 to 0.16. Suppose we decrease these values and accept lower RO/PPT ratios. Because decreased surface outflow means that less water is moving through the lakes, this alternative causes the effect of the mine on lake levels to be greater than when the model is constrained by a RO/PPT ratio close to 0.15.

From a field data viewpoint, although the outflow values of 0.4, 0.2 and 0.1 cfs do not conflict with the little data that are available, it is possible that the average long-term stream outflow from these lakes are smaller than assumed in the Base Runs. Observation suggests that the long-term average outflow from DKL might be close to zero, while it is possible that the outflow for LSL and DHL, while not zero, is significantly smaller than what has been assumed in the Base Runs (say 1/2).

[Note: The hydraulic conductivity assigned the lakebed also can affect the lake water balances and the implied RO/PPT ratios. For example, raising the K will cause groundwater outflow from these seepage lakes to increase and, thus, tend to raise the RO/PPT ratio to insure balance, thus counteracting the tendency to lower the RO/PPT ratio imposed by reducing the stream outflow. We exploited this relation in the study focused on an alternative treatment of Duck Lake. But for this set of sensitivity runs they have been left equal to the values in the Base Runs.]

For the following set of sensitivity runs, the only fundamental change to the input is the prescribed stream outflow for the internal lakes:

LSL: 0.4=>0.2, DHL: 0.2=>0.1, DKL: 0.1=>0.

This change directly implies a change in overland runoff to the lakes and, therefore, a change in the amount of water circulating through the lakes.

- The High End Case alternative calibration run is called S30C-78 (corresponding to UC-78).
- The High End Case alternative background run is called S30D-78 (corresponding to UD-78).
- The Version 1, Zinc Phase, High End Case alternative run is called SA30 (corresponding to ZINC2A).
- The Version 2, Zinc Phase, High End Case alternative run is called HHZ30 (corresponding to HHZN1B).
- The Version 2, Copper Phase, High End Case alternative run is called HHC30 (corresponding to HHCU1B).
- The Low End Case alternative calibration run is called S30C-8 (corresponding to UC-8).
- The Low End Case alternative background run is called S30D-8 (corresponding to UD-8).
- The Version 1, Zinc Phase, Low End Case alternative run is called SB30 (corresponding to ZINC1A).

Results

Table AX-2-1 presents the RO/PPT, mine inflow, lake stage change and lake area change are listed for the canonical simulations and the alternative simulations.

The comparisons show that a reduction of assumed surface-water outflow in the case of DHL (from 0.2 cfs to 0.1 cfs) implies only a small reduction in the RO/PPT ratio under natural conditions and has virtually no effect on the simulated impact of mining. Even with the change in surface outflow, the model simulates that the lake stage does not fall below DHL's cutoff elevation. The reduction of assumed surface-water outflow in the case of LSL (from 0.4 cfs to 0.2 cfs) also implies only a small reduction in the RO/PPT ratio, but it entails an increased effect of mining on the lake level, dropping it even further below the cutoff elevation. In the case of DKL, the assumed surface water outflow reduction (form 0.1 cfs to 0.0 cfs) yields a very low RO/PPT ratio, causes the lake level to fall below the cutoff elevation with mining, and has strong implications for the simulated effect of the mine on the size of the lake. It is worth noting that for DKL the low RO/PPT ratio can be restored to a value of 0.15 by assuming that the lakebed K is closer in value to that of LSL than DHL. The implications of changes to both outlet rate and lakebed K are discussed in the separate analysis in report sections titled "Internal lake-Surface Outlet Flow" and "Alternative Duck Lake Representation" and Appendixes X-3a and b.

Table AX-2-1. Change in lake stage for internal lakes under an alternate outlet discharge condition for select Version 1 and 2, Zinc and Copper Phase, Low End and High End Case simulations.

			Deep Hole			Little Sand			Duck		
Simulation	**Type**	**Mine Inflow**	**Premine RO/PPT**	**Stage Change**	**Area Change**	**Premine RO/PPT**	**Stage Change**	**Area Change**	**Premine RO/PPT**	**Stage Change**	**Area Change**
		gpm		*ft*	*percent*		*ft*	*percent*		*ft*	*percent*
Version 1											
Zinc Phase:											
Low End Case											
ZINC1A	Base Run	602	0.16	-0.23	-0.1%	0.16	-0.09	-0.8%	0.14	-0.20	-0.0%
SB30	Alternative	598	0.13	-0.23	-0.2%	0.13	-1.74	-8.6%	0.05	-1.06	-6.0%
High End Case											
ZINC2A	Base Run	1579	0.16	-0.24	-0.2%	0.16	-3.97	-17.1%	0.14	-0.20	-0.0%
SA30	Alternative	1562	0.13	-0.24	-0.2%	0.13	-5.11	-30.7%	0.05	-2.18	-16.9%
Version 1											
Copper Phase:											
High End Case											
HHCU1B	Base Run	1250	0.16	-0.24	-0.1%	0.16	-2.16	-10.4%	0.14	-0.20	-0.0%
HHC30	Alternative	1245	0.13	-0.24	-0.2%	0.13	-4.31	-18.4%	0.05	-1.70	-12.2%

Appendix X-3A

Alternative Representation of Duck Lake

The alternative representation of Duck Lake consists of two changes to the model inputs:

- The assumed lakebed hydraulic conductivity is increased from 0.003 ft/day (the value for Deep Hole Lake) to 0.0095 ft/day (the value for Little Sand Lake); and

- the assumed surface outlet flow is reduced from 0.1 cfs to 0.0 cfs.

Both of these inputs are uncertain. Visual evidence suggests that surface outlet flow from Duck Lake has been highly variable through time; beaver have controlled the outlet elevation and discharge at times, and when beaver are not a factor, the outlet often has no flow in the summer and fall. Since a detailed analysis of the available Duck Lake hydrological data was not made as a part of this work, the highest value for the Pickerel Creek basin internal lakes was used to assess effects. It is possible that the available field data for Duck Lake would suggest that a realistic upper-end lakebed hydraulic conductivity would be less than 0.0095 ft/day.

These changes affect the water budget for the lake. Additional model inputs consist of overland flow into the lake and net precipitation. Outputs consist of seepage to groundwater and surface outflow. The values for overland flow and groundwater seepage are not assumed values, but are part of the model solution. For Duck Lake, both solved terms are very sensitive to the assumed values for lakebed hydraulic conductivity and surface outflow. Mass balance dictates that the new assumed values in the alternative representation imply a higher rate of overland flow and a higher rate of groundwater seepage than for the original representation. The changes also affect the ratio of overland flow (runoff) to net precipitation simulated by the model. The new ratio values are somewhat different than the original output (increasing from 0.14 to 0.16), but still close to the expected value of 0.15.

In the following tables, base case inputs and outputs are compared to the same values for the alternative Duck Lake representation for selected pre-mine and mining simulations. The outputs indicate that the changes to Duck Lake have negligible influence on the regional effects of mining (as measured by mine inflow and baseflow reductions), and little effect on the other lakes. However, the alternative representation does imply a much greater effect of mining on Duck Lake than does the original representation. The increased effect occurs for both Version 1 and Version 2 scenarios.

Table AX-3a-1. Key Inputs for Base and Alternative Simulations

Run			
Version 1, Zinc Phase, Low End Case			
Base:	UC-8 → UD-8 → ZINC1A	0.1 cfs	0.003 ft/day
Alternative:	S28C-8 → S28D-8 → SL28	NONE	0.0095 ft/day
Version 1, Zinc Phase, High End Case			
Base:	UC-78 → UD-78 → ZINC2A	0.1 cfs	0.003 ft/day
Alternative:	S28C-78 → S28D-78 → SA28	NONE	0.0095 ft/day
Version 2, Copper Phase High End Case			
Base:	**UC-78 → UD-78 →** HHCU1B	0.1 cfs	0.003 ft/day
Alternative:	S28C-78 → S28D-78 → HC28	NONE	0.0095 ft/day

Table AX-3a-2. Calibration runs - implied runoff and ratio of runoff to precipitation

Version 1, Low End Case

	Runoff (ft^3/day)		Runoff to Precipitation Ratio	
	UC-8	**S28C-8**	**UC-8**	**S28C-8**
	Base	***Alternative***	***Base***	***Alternative***
Deep Hole	44,266	43,705	0.163	0.161
Duck	**12,978**	**15,240**	**0.138**	**0.162**
Little Sand	92,267	90,026	0.161	0.157
Skunk	3,367	3,235	0.150	0.144

Versions 1 and 2, High End Case

	Runoff (ft^3/day)		Runoff to Precipitation Ratio	
	UC-78	**S28C-78**	**UC-78**	**S28C-78**
	Base	***Alternative***	***Base***	***Alternative***
Deep Hole	43,827	43,250	0.161	0.159
Duck	**12,930**	**15,056**	**0.138**	**0.160**
Little Sand	90,957	88,745	0.159	0.155
Skunk	3,456	3,331	0.154	0.148

Table AX-3a-3. Calibration runs – rate of groundwater seepage from lakes (in/yr)

Version 1, Low End Case

	UC-8	**S28C-8**
	Base	***Alternative***
Deep Hole	33.8	33.2
Duck	**23.8**	**69.2**
Little Sand	30.3	29.3
Skunk	59.2	57.1

Versions 1 and 2, High End Case

	UC-78	**S28C-78**
	Base	***Alternative***
Deep Hole	33.3	32.7
Duck	**23.6**	**68.4**
Little Sand	29.7	28.8
Skunk	60.6	58.6

Table AX-3a-4. Background Runs – Pre-Mine Lake Levels with Little Sand Lake Structure (ft MSL)

Version 1, Low End Case

	UC-8	**S28C-8**
	Base	***Alternative***
Deep Hole	1605.63	1605.63
Duck	**1611.82**	**1611.82**
Little Sand	1591.61	1591.61
Skunk	1597.52	1597.50

Versions 1 and 2, High End Case

	UC-78	**S28C-78**
	Base	***Alternative***
Deep Hole	1605.63	1605.62
Duck	**1611.82**	**1611.82**
Little Sand	1591.61	1591.61
Skunk	1597.52	1597.51

Table AX-3a-5. Mining runs – mine inflow (gpm)

Version 1, Zinc Phase Low End Case		Version 1, Zinc Phase High End Case		Version 2, Copper Phase High End Case	
ZINC1A	SL28	ZINC2A	SA28	HHCU1B	HC28
Base	*Alternative*	*Base*	*Alternative*	*Base*	*Alternative*
602	612	1579	1582	1250	1252

Table AX-3a-6. Mining runs – change in Pickerel Creek baseflow (%)

Version 1, Zinc Phase Low End Case		Version 1, Zinc Phase High End Case		Version 2, Copper Phase High End Case	
ZINC1A	SL28	ZINC2A	SA28	HHCU1B	HC28
Base	*Alternative*	*Base*	*Alternative*	*Base*	*Alternative*
-3.7%	-3.7%	-10.6%	-10.8%	-8.4%	-8.4%

Table AX-3a-7. Mining runs – reduction in lake area and lake stage

Version 1, Zinc Phase, Low End Case

	Lake Area Reduction (%)		Lake Stage Reduction (ft)	
	ZINC1A	SL28	ZINC1A	SL28
	Base	*Alternative*	*Base*	*Alternative*
Deep Hole	-0.1%	-0.1%	-0.23	-0.23
Duck	-0.0%	-4.9%	-0.20	-1.03
Little Sand	-0.8%	-0.8%	-0.09	-0.10
Skunk	-10.7%	-14.5%	-0.44	-0.42

Version 1, Zinc Phase, High End Case

	Lake Area Reduction (%)		Lake Stage Reduction (ft)	
	ZINC2A	SA28	ZINC2A	SA28
	Base	*Alternative*	*Base*	*Alternative*
Deep Hole	-0.1%	-0.1%	-0.24	-0.23
Duck	**-0.0%**	**-15.7%**	**-0.20**	**-2.16**
Little Sand	-17.1%	-17.3%	-3.97	-4.09
Skunk	-8.0%	-11.8%	-0.44	-0.43

Version 2, Copper Phase, High End Case

	Lake Area Reduction (%)		Lake Stage Reduction (ft)	
	HHCU1B	HC28	HHCU1B	HC28
	Base	*Alternative*	*Base*	*Alternative*
Deep Hole	-0.1%	-0.1%	-0.24	-0.23
Duck	**-0.0%**	**-11.0%**	**-0.20**	**-1.70**
Little Sand	-10.4%	-10.6%	-2.16	-2.18
Skunk	-8.3%	-11.6%	-0.44	-0.43

Appendix X-3B

Alternative Duck Lake Representation with Mitigation

The alternative representation of Duck Lake consists of a higher lakebed hydraulic conductivity (0.0095 ft/day instead of 0.003 ft/day) and the removal of the surface-water outlet (0 cfs outflow instead of 0.1 cfs outflow).

In this appendix, results for Duck Lake are presented under mitigation. Two cases are considered:

1) Mitigation for Version 1, Zinc Phase, High End Case; and

2) Mitigation for Version 1, Zinc Phase, High End Case under drought conditions.

In the first case, Duck Lake and Little Sand Lake require mitigation to restore lake levels to the Minimum Metallic Mining Stage (MMMS). The MMMS for Duck Lake is 1610.59 ft. The MMMS for Little Sand Lake is 1591.41 ft. The mitigation fluxes necessary to achieve these levels are 8.9 gpm for Duck Lake and 175.1 gpm for Little Sand Lake.

In the second case, Deep Hole Lake, Duck Lake, and Little Sand Lake require mitigation to restore lake levels to drought levels in the absence of mining. Drought is simulated as a three-year period in which recharge and runoff to the lakes are two-thirds normal rates. The drought levels are 1605.08, 1609.03, and 1590.88 ft for Deep Hole, Duck and Little Sand Lake, respectively.

Case 1: Lake Mitigation Without Drought
Version 1, High End, Zinc Phase

Consider three runs simulating zinc mining:

ZINC2A: Original representation of Duck Lake, Version 1, High End, Zinc Phase, No Mitigation.
SA28: Alternative representation of Duck Lake, Version 1, High End, Zinc Phase, No Mitigation
SA28M2: Alternative representation of Duck Lake, Version 1, High End, Zinc Phase, Lake Mitigation to MMMS levels.

The following table shows general output for these runs and results for Duck Lake:

Run	Run Name	Converged? Mass Balance?	Mine Inflow (gpm)	Percent Change in Area of Duck Lake Rel. to Pre-Stress	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress	
					Pickerel Basin	*Swamp Basin**
Base Predictive Zinc Mine with USGS Bedrock and Mine Workings SAS = 1500 gpm Original representation of Duck Lake	**ZINC2A**	Yes Good	1579	-0.0%	-10.6%	+5.3%
Base Predictive Zinc Mine with USGS Bedrock and Mine Workings SAS = 1500 gpm Alternative representation of Duck Lake	**SA28**	Yes Good	1582	-15.7%	-10.8%	+5.2%
Mitigated Version of SA28 Mitigated to MMMS Stage=1610.59 ft Mitigation Flux = 8.9 gpm, 175.1 gpm to DKL, LSL SAS = 1318 gpm Alternative representation of Duck Lake	**SA28M2**	Yes Good	1617	-8.1%	-8.9%	+4.1%

** These runs do not take account of any baseflow mitigation to streams.*
The baseflow in the Swamp Creek basin increases owing to the inflow of water from the SAS.

Now consider results pertaining to Duck Lake for two conditions:

- pre-mine (S28D-78), and
- zinc mine with mitigation (SA28M2).

Both runs apply the alternative representation of Duck Lake. In the second run the lake is mitigated at a rate of 8.9 gpm to attain the Metallic Minimum Mining Stage (1610.59 ft)

a) Duck Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=S28D-78	1611.82 ft	—	24.0 acres	—
SA28M2	1610.59 ft	-1.23 ft	22.1 acres	-1.9 acres

b) Mass Balance (gpm)

PPT = precipitation flux into lake
RO = runoff flux into lake
MIT = mitigation flux added to lake
SW = surface water flux out of lake
GW = groundwater flux out of lake

	IN = PPT+ RO (+ MIT)			OUT = SW + GW	
	PPT	RO	MIT	SW	GW
Background=S28D-78	7.1	78.2	0.0	0.0	84.7
SA28M2	6.5	78.6	8.9	0.0	94.0

	IN	OUT
Background=S28D-78	85.3	84.7
SA28M2	94.0	94.0

c) Mitigation contribution

	Percent Mitigated Water = 100* [MIT / (PPT+RO+MIT)]	Percent Dilute Water = 100* [(PPT+MIT)/ (PPT+RO+MIT)]
Background=S28D-78	0.0%	8.3%
SA28M2	9.5%	16.4%

d) Residence time (years) = LAKE_VOLUME / (PPT+RO) or LAKE_VOLUME / (PPT+RO+MIT)

	Lake Volume	Time
Background=S28D-78	0.540e7 ft^3	0.97 yr
SA28M2	0.414e7 ft^3	0.63 yr

Finally, consider the simulated groundwater flux out of Duck Lake for:

UD-78	(pre-mine, original Duck Lake representation)	29.2 gpm
ZINC2A	(zinc mine, original Duck Lake representation, no mitigation)	38.2 gpm
S28D-78	(pre-mine, alternative Duck Lake representation)	84.7 gpm
SA28A	(zinc mine, alternative Duck Lake representation)	84.6 gpm
SA28M2	(zinc mine with mitigation, alternative Duck Lake representation)	94.0 gpm

Case 2: Lake Mitigation With Drought
Version 1, High End, Zinc Phase

For the alternative Duck Lake representation, the following transient runs were performed:

- PRE-SA29 = Version 1, High End, Pre-mine with 3-year drought
  Initial condition is S28D-78 (steady-state pre-mine without drought)
- SA29 = Version 1, High End, Zinc Phase with 3-year drought
  Initial condition is SA28 (steady-state zinc mine without drought)
- SA29M4 = Version 1, High End, Zinc Phase with 3-year drought and mitigation
  Inititial conditon is SA28M2 (steady-state zinc mine without drought but with mitigation to MMMS)

The new stages from PRE-SA29 determine the *drought mitigation levels*. They are

Deep Hole= 1605.08, Duck= 1609.03, Little Sand= 1590.88, Skunk= 1596.62.

The run SA29 (3 years of zinc mine with two-thirds normal recharge) indicated that the lakes would fall below drought mitigation levels due to mining. The drought mining levels without mitigation are:

Deep Hole=1604.20, Duck= 1606.47, Little Sand=1584.80, Skunk= 1596.60.

Note that Deep Hole, Duck and Little Sand Lakes require mitigation. According to the simulation Skunk Lake is hardly changed by the mine and, therefore, is not mitigated.

The mitigation run, SA29M4, restores the lakes to pre-mine drought levels. The SAS inflow is reduced from 1500 to 1000 gpm**.** For Deep Hole, Duck and Little Sand Lake the drought mitigation fluxes are **24, 23.3 and 374** gpm, respectively.

Case 2: Lake Mitigation With Drought
Version 1, High End, Zinc Phase

Consider one run simulating pre-mine conditions and two runs simulating zinc mining:

PRE-SA29:	Drought with alternative representation of Duck Lake, Version 1, Pre-mine.
SA29:	Drought with alternative representation of Duck Lake, Version 1, High End Zinc Phase, No Mitigation
SA28M2:	Drought with alternative representation of Duck Lake, Version 1, High End Zinc Phase, Lake Mitigation to pre-mine drought levels.

The following table shows general output for these runs and results for Duck Lake:

Run	Run Name	Converged? **Mass Balance Error** Entire Model Duck Lake	Mine Inflow (gpm)	Percent Change in Area of Duck Lake Rel. to Pre-Stress and Pre-drought	Percent Change in Base Flow to Surface Water Rel. to Pre-Stress and Pre-drought	
					Pickerel*	***Swamp****
3 Year Drought						
in absence of mine	PRE-SA29	Yes	—	-22.9%	-21.8%	-22.5%
(extension of background run S28D-78)		Error=-1.2%,				
		Duck Lake error= 1.0%				
in presence of mine	SA29	Yes	1465	-42.7%	-34.3%	-18.9%
(extension of stressed run SA28)		Error=-1.2%				
SAS=1500 gpm		Duck Lake error= -0.0%				
3 Year Drought,						
Mine and Lake Mitigation	SA29M4	Yes	1516	-21.9%	-31.8%	-22.6%
(extension of stressed run SA28M2)		Error=-1.0%				
Mitigation Flux = 24, 23.3, 374 gpm to DHL, DKL, LSL		Duck Lake error=-0.0%				
SAS = 1000 gpm						

** These runs do not take account of any baseflow mitigation to streams.*
The baseflow in the Swamp Creek basin for mining conditions decreases less than Pickerel Creek basin owing to the inflow of water from the SAS.

Now consider results pertaining to Duck Lake for two conditions:

- pre-mine with drought (PRE-SA29), and
- zinc mine under drought with mitigation (SA29M4).

Both runs apply the alternative representation of Duck Lake. In the second run the lake is mitigated at a rate of 23.3 gpm to attain pre-mine drought levels (1609.03 ft)

Note: All drought runs are transient, so mass balance includes storage released by daily rate of lake drop.
This storage release is a "source" only from the viewpoint of mass balance. In other terms, it is the rate the lake is losing water at the end of the 3-yr drought.

a) Duck Lake stage and area

	Stage	Stage Change	Area	Area Change
Background=PRE-SA29	1609.03 ft	—	18.5 acres	—
SA29M4	1609.03 ft	0.00 ft	18.8 acres	+0.3 acre

b) Mass Balance (gpm)

PPT = precipitation flux into lake SW =surface water flux out of lake MIT =mitigation flux added to lake
RO = runoff flux into lake GW =groundwater flux out of lake

	IN = PPT+ RO + STOR (+ MIT)				OUT = SW + GW	
	PPT	**RO**	**STOR**	**MIT**	**SW**	**GW**
Background=PRE-SA29	3.6	52.1	3.6	0.0	0.0	58.7
SA29M46	3.7	52.3	1.9	23.3	0.0	81.3

	IN	OUT
Background=PRE-SA29	59.3	58.7
SA29M4	81.2	81.3

c) Mitigation contribution

	Percent Mitigated Water = **100* [MIT / (PPT+RO+MIT)]**	**Percent Dilute Water =** **100* [(PPT+MIT)/ (PPT+RO+MIT)]**
Background=PRE-SA29	0%	6.1%
SA29M4	28.7%	33.2%

d) Residence time (years) = LAKE_VOUMEL / (PPT+RO) or LAKE_VOLUME / (PPT+RO+MIT)

	Lake_Volume	**Time**
Background=PRE-SA29	0.274e7 ft^3	0.70 yr
SA29M4	0.275e7 ft^3	0.49 yr

Finally, consider the groundwater flux out of Duck Lake and its volumetric loss rate for the non-drought and drought cases under the alternative Duck Lake representation:

		GW Flux (gpm)	**Volumetric Storage Release (gpm)**
S28D-78	(pre-mine, no drought)	85.6	0
PRE-SA29	(pre-mine, 3 yr drought)	58.7	3.6
SA28	(zinc mine, no drought, no mitigation)	84.6	0
SA28M2	(zinc mine, no drought, mitigated to MMMS)	94.0	0
SA29	(zinc mine, 3 yr drought, no mitigation)	57.6	2.6
SA29M2	(zinc mine, 3 yr drought, mitigated to pre-mine drought level)	81.3	1.9

Cover photograph: Skunk Lake, a 6.5-acre water body approximately 0.25 mi from the Crandon ore body. (Photograph courtesy of John Coleman, Great Lakes Indian Fish and Wildlife Commission.) Front cover illustration: Groundwater flow model grid, layer 4 active cell boundary and 1984 water table.