Appendix C

Numerical Groundwater Flow Model

Umetco Gas Hills Site

Fremont and Natrona Counties, Wyoming

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1.0 INTRODUCTION

Umetco Minerals Corporation (Umetco) has developed a numerical groundwater flow and transport model for the former uranium mill site in Gas Hills, Wyoming. The model is intended to support the Alternate Concentration Limits (ACLs) Application to the U.S. Nuclear Regulatory Commission (NRC). Umetco is conducting a groundwater Corrective Action Program (CAP) to comply with Source Materials License SUA-648, Docket No. 40-0299, Condition 35, (NRC 1998). The CAP is designed to abate milling-related impacts to groundwater by reducing constituent concentrations at point of compliance (POC) wells to groundwater quality standards set forth in the license. Umetco seeks to replace the current licensed groundwater protection standards with ACLs that are equally protective of human health and the environment.

The numerical model is based on the site conceptual model. The groundwater flow and transport model is calibrated to site-specific hydrologic conditions. This report documents the development and results of the numerical groundwater flow and transport model.

The groundwater flow and transport model is used to address several key issues related to the ACL application, including the following:

- estimating groundwater flowpaths and velocities,
- evaluating mining impacts on the groundwater flow system,
- evaluating the effectiveness of the CAP,
- simulating alternative corrective action options for the site, and
- analyzing fate and transport of non-reactive, conservative constituents (chloride and sulfate).

Groundwater velocities and distances to the Point of Exposure (POE) derived from the groundwater flow model were used to develop a geochemical speciation model (PHREEQC). The geochemical model evaluated attenuation of milling-derived constituents along the flowpaths as described in Appendix B.

Extensive mining of uranium ore bodies and subsequent reclaiming of those mines has occurred upgradient and downgradient of the site. The groundwater flow model is used to assess the potential impacts of mining activities, including mine reclamation, on the groundwater flow regime with respect to flow direction, velocity, and water quality.

Umetco has conducted a groundwater CAP at the site since 1983. The CAP has undergone numerous revisions since startup, but is essentially a pump and evaporate remedial system. The groundwater flow model is used to evaluate the effectiveness of the CAP as required under the Corrective Action Assessment (Section 3) of the ACL Application. Additionally, the flow model is used to evaluate alternative corrective actions for the site as part of the As Low As Reasonably Achievable (ALARA) analysis.

The groundwater flow and transport model is also used to estimate the degree of attenuation that will occur to non-reactive constituents such as chloride and sulfate migrating from the site. The flow and transport model only addresses attenuation that occurs because of advective processes. Attenuation of other more reactive and redox-sensitive parameters is evaluated using results of the geochemical speciation model previously mentioned (Appendix B).

2.0 CONCEPTUAL MODEL

Regional and site-specific data were reviewed to develop a general understanding of geologic, hydrogeologic, and geochemical conditions at Gas Hills. Site conditions are described in Sections 1 and 2 of the ACL Application. This information was used to develop the conceptual model presented in the following section.

2.1 Site Description

Gas Hills is in Fremont and Natrona Counties, approximately 60 miles east of Riverton in central Wyoming. The site is within the Gas Hills Uranium District of the Wind River Basin. Uranium reserves mining occurred throughout the area from the late 1950s until 1984. The mill operated at the facility from 1958 through 1984 but is now decommissioned as the site is being reclaimed. Key features of the former mill site include the reclaimed Above Grade Tailings Impoundment (AGTI), the A-9 Repository, the reclaimed heap leach area, inactive evaporation ponds, and one active synthetic-membrane lined evaporation pond (Figure C-1).

From 1960 through 1979, waste by-products from mill (predominately tailings) were placed in the AGTI. From 1979 through 1984, tailings were placed in the A-9 Repository and excess water was pumped into the clay lined evaporation ponds.

Umetco initiated Gas Hills groundwater remediation in 1983 by installing extraction wells in the Wind River aquifer downgradient of the A-9 Repository. Groundwater extraction downgradient of the AGTI began in 1990 and was discharged into clay-lined ponds until 1991. The clay-lined evaporation ponds were decommissioned and replaced by synthetic-lined ponds GHP1 and GHP2 (constructed in 1991 and 1996, respectively). GHP1 was decommissioned in the third quarter of 2000.

In 1990, Umetco began using ion exchange (IX) and reverse osmosis (RO) to treat groundwater. Treated water was injected into a series of wells upgradient and downgradient of the AGTI and A-9 Repository to increase the groundwater flux within the aquifer and enhance groundwater remediation. The IX/RO system and injection components of the CAP were decommissioned in 1996 because of demonstrated ineffectiveness (NRC 1997b). Currently the CAP consists of extracting groundwater downgradient of the AGTI and A-9 Repository and discharging the recovered groundwater into GHP2 for evaporation.

Open-pit mining disturbed 35 percent of the area within the Restricted Area (RA) of the site. Other companies (Figure C-2) developed additional open-pit mines east, west, and south of the RA. Acid mine drainage associated with these pits has degraded water quality in the area. Former mine pits located south and east of the Umetco site have been reclaimed by the Wyoming Abandoned Mine Lands (AML) Program. Reclaiming these pits has impacted groundwater quality both upgradient and downgradient of the former mill site.

2.2 Hydrologic Setting

The Eocene Wind River Formation contains the aquifer of interest with respect to uranium mineralization and potential impacts from associated mining and milling activities.

Groundwater is present in the Wind River Formation beneath Gas Hills under confined, unconfined, and perched hydrostatic conditions. Although the Wind River Formation contains a regionally extensive aquifer system, the aquifer is locally discontinuous.

West of the site, truncation of the Wind River Formation against Cretaceous rocks results in discharging groundwater to seeps and springs. East of the site, the Wind River Formation pinches out against the Rattlesnake Hills. The Pre-Paleozoic Granite Mountains south of the Beaver Divide delineate the southern extent of the Wind River Formation. These southern and eastern limits mark the upgradient extent of the Wind River aquifer.

Recharge to the Wind River aquifer is derived from several sources, including infiltration of precipitation, infiltration from streams and surface drainages, discharge from pre-Wind River deposits, infiltration of impounded waters associated with mining, milling and reclamation activities and, historically, injection of treated water from the CAP.

2.3 Hydraulic Properties

The transmissivity, hydraulic conductivity, and storativity values of the Wind River aquifer are estimated from numerous single-well and multi-well pumping tests. Transmissivity is a quantitative definition of the ability of an aquifer to transmit water. Hydraulic conductivity is a quantitative measure of the ability of an aquifer to transmit water per unit of saturated thickness. Hydraulic conductivity values are determined by dividing the transmissivity calculated for a specific well by the saturated thickness in the well. Storativity defines the volume of water released by a confined aquifer from storage per unit surface area per unit decline in the potentiometric surface (Freeze 1979). For an unconfined aquifer, the storage term is the specific yield. Specific yield is a measure of the fraction of water that will drain from a given volume of the aquifer material.

Aquifer properties are determined from numerous pumping tests conducted in the vicinity of the AGTI and A-9 Repository and are summarized in Table C-1 (Dames & Moore 1979a and 1979b; Hydro-Engineering 1980a, 1980b, 1982, and 1990; Lidstone & Anderson 1989; and U.S. Environmental Services 1990 and 1997). The range of transmissivity is from 0.5 to 960 feet^2 per day (ft^2/d) or 4 to 7,200 gallons per day per foot (gpd/ft). Hydraulic conductivity values range from 6.0E-04 to 8.1 feet per day (ft/d) with a mean value of approximately 1.5 and a median of 0.94. Permeability measurements for the mudstone unit indicate a range from 1.6E-03 to 1.3E-01 ft/d. The range of specific yields or storage coefficients measured in Gas Hills wells is from 7.0E-06 to 0.27.

2.4 Groundwater Flow Direction

In the northern portion of the site, groundwater flow is to the west, whereas in the southern portion, flow is to the southwest. Groundwater flowing west discharges in seeps and springs because of the pinchout of the Wind River Formation (Figure 1.16 of the ACL Application). Groundwater flowing southwest continues until reaching the area of the Lucky Mc mill (approximately 5 miles away).

A low permeability mudstone unit delineates the shift in groundwater flow direction from west to southwest. The mudstone unit dips to the south-southwest and outcrops at the northern extent of the AGTI. Groundwater beneath the mudstone unit generally flows to the west following the regional hydrologic trend toward the Wind River. Groundwater flow above the mudstone in the vicinity of the site flows to the southwest. Perched groundwater is present above the mudstone unit beneath the southern portion of the AGTI. The perched groundwater is primarily the result of tailings seepage and re-injected water that is impeded vertically by the mudstone unit.

2.5 Sources and Sinks

A conceptual water budget was developed to evaluate potential sources and sinks to the groundwater flow system. Groundwater sources entering the aquifer within the area of study include precipitation infiltration, subsurface groundwater flow from adjacent areas, vertical flow between aquifers, seepage from the AGTI and A-9 Repository, and injection of water that was recovered and treated under the CAP. Groundwater sources flowing out include losses through evapotranspiration, subsurface flow to adjacent areas (horizontal and vertical), discharge to seeps and springs, and extraction from pumping wells.

Net infiltration was estimated to be relatively small compared to the net precipitation rates of approximately 10 inches per year because of high evaporation rates (greater than 40 inches per year). A net infiltration rate of 1 to 2 inches per year was assumed for the conceptual model.

Based on monitor well water level elevations, subsurface groundwater flow enters the study area from the east and the southeast. Under non-pumping conditions, most of the subsurface groundwater flow that enters the study area eventually discharges to seeps and springs west and southwest of the site.

Vertical groundwater flow between the hydrostratigraphic units of the Wind River aquifer above and below the mudstone unit was based on the vertical hydraulic gradients evident from water level measurements and largely constrained by the low hydraulic conductivity of the mudstone unit. Vertical groundwater flow between the Wind River Formation and older rocks was not considered in the conceptual model because there were no data to adequately estimate vertical hydraulic gradients. Confined conditions are known to exist within the pre-Cretaceous units.

Previous investigations indicate that a recharge mound formed beneath the AGTI because of seepage from tailings placement from 1960 to 1979 (Dames & Moore 1979, Hydro Engineering 1983). A water balance performed by Dames & Moore indicates that seepage rates exceeded 100 gpm at the time that the tailings impoundment was removed from service in 1979. Those rates have diminished as a result of removing the impoundment from service, evident from dissipation of the recharge mound (Figure 1.17 of the ACL Application). Current seepage rates from the AGTI are estimated between 20 and 30 gpm, based on seepage flow model results (Shepard Miller, Inc. 1997). The model results indicate continuous decline in seepage rates to less than 1 gpm within the next 10 to 20 years.

Seepage rates from the A-9 Repository were initially much lower than for the AGTI because a liner and leachate collection system was implemented and smaller volumes were placed in the impoundment. An estimated 20 to 30 gpm were put in during early period usage. Current rates are much lower, based on the absence of a recharge mound and discontinued disposal in the repository. A-9 Repository seepage modeling indicates current rates of less than 10 gpm and an eventual steady state seepage rate of approximately 3 gpm (due largely to incidental infiltration) (Shepard Miller, Inc. 1998).

Evapotranspiration losses from the aquifer are considered minimal because the depth to groundwater generally exceeds root depth of the native vegetation. There are no seeps and springs or natural surface water bodies within the RA.

Extraction rates for the CAP have varied as the program has evolved. The average combined pumping rate from June 1999 through June 2000 for the eight A-9 Repository extraction wells was approximately 9.5 gpm. The average combined pumping rate for the three AGTI extraction wells was 3.3 gpm from June 1999 through June 2000 (Table C-2).

3.0 NUMERICAL MODEL DESIGN

A numerical model includes computer codes (software) and an input data set. Computer codes are selected for a modeling effort based on the suitability of the code to simulate desired conditions and stresses in the aquifer and on the scientific acceptance of the code. Input data are selected on the basis of representativeness of the aquifer system to be modeled. Input data selection for the numerical model is largely based on the data review results and development of the conceptual model.

3.1 Code Selection

Three-dimensional groundwater flow in the Wind River aquifer system was analyzed with the finite difference groundwater flow model (MODFLOW) developed by the USGS (McDonald 1988). MODFLOW was selected for simulating groundwater flow at the Gas Hills site because it is capable of a wide array of boundary conditions, in addition to being a public domain code that is well accepted in the scientific community. MODFLOW can be used to simulate transient or steady-state saturated groundwater flow in one, two, or three dimensions. MODFLOW is capable of simulating areal recharge, injection or extraction wells, evapotranspiration, drains and streams or rivers. The code simulates groundwater flow using a block-centered, finite-difference approach. Modeled aquifers can be simulated as unconfined, confined, or a combination of confined and unconfined. MODFLOW also supports variable thickness layers (i.e., variable aquifer bottoms and tops).

Advective transport in the Wind River aquifer system was evaluated using MODPATH, developed by the USGS (Pollock 1989 and 1994), and MT3D, developed by the U.S. Environmental Protection Agency (Zheng 1990). MODPATH was selected because it is compatible with MODFLOW outputs, is suitable for capture zone analysis of steady state or transient simulations, and is a public domain code that is well accepted in the scientific community. MODPATH is used for computing three dimensional path lines based on output from steady-state simulations obtained with MODFLOW.

MT3D was selected to model the transport of the non-reactive chloride and sulfate constituents. The MT3D code was selected because it is compatible with MODFLOW outputs and is suitable for simulating advection, dispersion, and chemical reactions in groundwater systems. Conservatively, only the advection module was used to evaluate the chloride and sulfate constituents, and no sorption was assumed. Redox sensitive constituents were modeled using the PHREEQC speciation code as described in Appendix B. MT3D is also a public domain code widely accepted in the scientific community.

In addition to the computer codes MODFLOW, MODPATH, and MT3D, a pre-processor assisted with data input and a post-processor was used for contouring the modeling results and providing graphical outputs. The pre-processor used in the modeling effort was Groundwater Vistas, Version 2.0 (Environmental Solutions, 1998). The post-processor was Surfer for Windows, Version 7.0 (Golden Software, 1999).

3.2 Model Discretization

The finite-difference technique requires the aquifer system being studied be divided into a set of discrete cells. These cells form the model grid and the process is termed discretization. Model parameters (such as water levels) are computed for a cell and represent average conditions over the volume of the cell. Thus, adequate discretization is required to resolve features that may impact the area of interest. Of secondary concern is avoiding discretization that is computationally burdensome. An algebraic equation that describes groundwater flow is developed for each cell in terms of the surrounding cell and the complete set of linear equations is iteratively solved until the change in head between iterations meets a set criterion.

The model grid encompasses approximately three square miles with a north-south dimension of 11,720 feet and an east-west dimension of 12,500 feet. The model grid is centered over the Gas Hills Restricted Area (Figure C-3). The model consists of 242 rows by 232 columns in 3 layers for a total of 168,432 finite difference cells.

The empirical "50 percent rule" was followed in the developing the model grid. This rule holds that no cell size changes more than 50 percent relative to adjacent cells. The rule is intended to control numerical truncation and preserve fluid mass balances. The finite difference method represents water levels and aquifer properties as uniform within a grid cell. The Gas Hills model cell dimensions range from 150 feet by 200 feet at the edges of the grid to 30 feet by 30 feet in the central portion of the model (the area of primary interest). Boundary conditions are positioned at a sufficient distance so that the solution in the area of interest is not impacted.

The discretization process includes determining both the lateral and vertical extent of the aquifer system being modeled. The lateral and vertical extent of the Wind River aquifer at Gas Hills was evaluated by examining the hydrogeologic maps and cross sections, reviewing well logs, and interpolating existing data. Variability in hydrostatic conditions (perched, unconfined, and confined) and variability in the direction of groundwater flow within the Wind River aquifer system were addressed by using the three dimensional functionality of the model. The Wind River was subdivided into three hydrostratigraphic intervals, each represented by a separate layer in the model. The upper layer of the model (Layer 1) represents the shallower portion of the Wind River aquifer that is characterized by south-southwesterly flow direction, perched conditions north of the A-9 Repository, and unconfined conditions in the southern portion of the site. The lower layer of the model (Layer 3) represents the deeper portion of the Wind River characterized by flow to the west, unconfined conditions in the north portion of the site, and confined conditions in the south portion of the site. The middle layer of the model (Layer 2) represents the mudstone unit.

Variability in the saturated thickness of the shallow portion of the aquifer (Layer 1) was addressed by estimating the elevation of the top of the mudstone unit (Layer 2) and using that surface as input data for the bottom elevation of Layer 1. The saturated thickness of Layer 1 varies from 0 feet in the north and northwest portions of the model domain to approximately 100 feet in the southwest portion of the model except for an area directly south of the A-9

Repository. A downthrown fault block (the Thunderbird Graben) significantly lowers the elevation of the top of mudstone unit in that area and increases the saturated thickness of Layer 1 to over 300 feet. Layer 1 was designated as unconfined in the model. Layer 2 was assigned a uniform thickness of 25 feet across the model domain. Variability in the saturated thickness of the deeper portion of the aquifer (Layer 3) was based on the bottom elevation of the mudstone unit and the contact surface between the Wind River aquifer and the underlying pre-Tertiary rocks. The thickness of Layer 3 varies from approximately 220 to 350 feet. Layers 2 and 3 of the model were treated as unconfined aquifers with variable transmissivity, meaning that if upper layers of the model dewatered, these layers became unconfined. This technique allows the model to more accurately estimate transmissivity (the product of the hydraulic conductivity and the saturated thickness) at each model cell. The basal contact of the Wind River aquifer is modeled as no flow boundary. Areas outside of the model domain or beyond controlling boundaries are not included in the model.

3.3 Boundary Conditions

Boundary conditions imposed on a numerical model define the external geometry of the groundwater flow system. The three types of boundary conditions are specified-head, specified-flux, and head-dependent flux boundaries. Boundary conditions assigned in the model were determined from observed conditions.

The specified-head boundary condition in MODFLOW is implemented as a constant-head or constant water-elevation boundary. The head at a constant-head boundary is specified independently of the simulation results, and is fixed at the specified value throughout the simulation. Constant head boundaries should be included in any model to ensure non-zero matrix eigenvalues and solution convergence (Kipp 1987). The constant head boundary condition was used in the Gas Hills model.

The specified-flux boundary condition is implemented in MODFLOW as recharge, well injection/extraction, and the no-flow (flux equals zero) boundary condition. The recharge package allows specification of flow rates per unit area for each cell in the model grid, and is used to simulate groundwater recharge from precipitation and infiltration. The well package requires input of a discharge or injection rate. The no-flow boundary condition allows specification of those areas that are outside the model domain and do not contribute flow. The recharge and well packages and the no-flow boundary condition were used in the Gas Hills model.

The head-dependent flux boundary condition may be implemented in MODFLOW in several ways including general-head boundaries, drains, rivers, and evapotranspiration. The head dependent flux boundary is typically used when flux entering or exiting the groundwater flow model is dependent upon the head difference between the model and a source of water maintained at a constant level outside the model. The source/sink is connected to the model through a conduit aquifer material. The conductance of the aquifer material may be estimated as (McDonald and Harbaugh 1988):

$$C = K A / b$$

where:

K is hydraulic conductivity,
A is the area across which flow occurs, and
b is a representative distance.

McDonald and Harbaugh further describe the implementation of the head-dependent flux packages. The general-head boundary and drain packages were used in the Gas Hills model.

The model grid and the location of constant-head, general-head, and no-flow boundaries within the model are illustrated in Figures C-3 (Layer 1) and C-4 (Layer 3). Discussion of the placement and values for these boundary conditions is provided below. Extraction wells are located in various positions for different simulations and are discussed in later sections.

The no-flow boundary is used in the Gas Hills model to represent areas where the upper portion of the Wind River Formation is absent or not saturated. This is the case in the area west of the AGTI and the A-9 Repository and beneath most of the AGTI. Data from wells and borings confirmed the absence of saturated conditions in the Wind River above the mudstone in those areas.

Based on data from the shallower portion of the Wind River aquifer, constant-head values ranging from 6,925 to 7,015 feet were assigned along the east limits of Layer 1. The constant-head boundaries represent groundwater that is flowing toward the Gas Hills site from upgradient areas. The eastern boundary of the model is located far enough from the area of interest (the RA) that stresses imposed in the model simulations do not impact the heads along that boundary. Constant-head values were assigned along the north and south model boundaries of Layer 3 based on water-level data for the deeper portion of the Wind River. These constant-head boundaries represent the more regional westward component of flow within the Wind River aquifer. Values along the north boundary range from 6,650 to 6,827 feet, decreasing from east to west. Constant heads along the north model boundary represent unconfined conditions because water levels exist at depths below the bottom of the mudstone unit. Values along the south boundary range from 6,650 to 6,860 feet, also decreasing from east to west. The constant heads along the south model boundary represent confined conditions because water levels in the deeper portion of the Wind River are above the bottom of the mudstone unit but below the water levels in the shallower portion of the Wind River aquifer.

The general-head boundary is used in the Gas Hills model to account for inflow and outflow from the model domain. General-head boundaries are assigned along model boundaries where water-level data indicate the Wind River aquifer is being recharged from, or discharging to, a source external to the model domain. General-head boundaries are used because the groundwater elevation at those boundaries can change in response to simulated stresses. In the Gas Hills model, general-head boundaries were assigned to the south and west boundaries of Layer 1, and the east and west boundaries of Layer 3. These boundaries are relatively distal from the principal area of interest. The general-head boundary

conductance terms were calculated using the equation previously described and then modified during calibration. The values assigned to the general-head boundary along the south boundary of Layer 1 ranged from 6,685 to 7,030 feet, with a range for the conductance from 300 to 1,250 ft^2/d. A general-head boundary was only applied along the southwestern portion of the west boundary of Layer 1 because the upper portion of the Wind River above the mudstone is unsaturated north of this area. The head assigned along the west boundary of Layer 1 ranged from 6,685 to 6,750 feet decreasing to the south. The values of head assigned to the general-head boundary along the east side of Layer 3 ranged from 6,835 to 6,845 feet, with a range for the conductance from 300 to 1,000 ft^2/d. The general-head boundary along the west side of the model had a constant value of 6,650 feet and 150 ft^2/d for the conductance term.

The drain package was used to simulate groundwater exiting from the upper portion of the Wind River aquifer along the south face of East Canyon Creek, east of the AGTI. The values of head assigned to the drain cells of Layer 1 along East Canyon Creek ranged from 6,880 to 6,900 feet, decreasing to the west. The conductance for the drain cells ranged from 80 to 125 ft^2/d.

The recharge package was used to simulate an annual net recharge via precipitation to the Wind River aquifer system and seepage from surface impoundments. The selection of recharge zones is described in the following section.

3.4 Parameter Zonation

Parameters entered into MODFLOW for the Gas Hills model included hydraulic conductivity, bottom elevations, and storage coefficients of the Wind River aquifer system as well as recharge.

Elevation data derived from boring logs were contoured using SURFER to develop bottom elevation maps for the upper, middle (mudstone), and lower portions of the Wind River aquifer system (Layers 1, 2 and 3 respectively). The output grid file from SURFER was imported into the pre-processor. One hundred fifty bottom elevation zones were differentiated in the pre-processor, ranging from 6,000 to 6,955 feet. The pre-processor was then used to read the grid file, identify all cells within the area covered by the SURFER grid file, and interpolate a zone value for each cell. The bottom elevation parameter zonation is presented in Figures C-5 and C-6 for Layers 1 and 3 respectively.

Interpolation techniques are often inadequate for assigning hydraulic conductivity values to model cells because of the tremendous variability (both laterally and vertically) that may exist. Instead of interpolation, the concept of parameter zonation is often used to define parameter values in heterogeneous aquifers (Peck 1988). This method requires definition of zones within which a constant value of the parameter is assigned. Zones should be chosen based on hydrogeologic information such as the characteristics and thickness of the formation.

Initial values and areal extent of hydraulic conductivity zones used in the Gas Hills model for the Wind River aquifer were based on results of pumping tests and geologic description of

aquifer materials (Table C-1). During calibration, the hydraulic conductivity zonation and zone values were modified to obtain a reasonable match between observed and simulated water-level elevations. Hydraulic conductivity zones used in Layers 1 and 3 ranged from 0.2 to 2.32 ft/d. The range is consistent with observed values determined from pumping tests. Hydraulic conductivity zones used in Layer 2 ranged from 2.0E-03 to 9.2E-03 ft/d. These values are within the range reported for the mudstone unit (Table C-1). The resulting values and distribution of hydraulic conductivity zones (determined during calibration) for Layers 1 and 3 are shown in Figures C-7 and C-8, respectively. A uniform value of 0.15 was used for the specific yield that corresponds to an effective porosity of 15 percent. A uniform value of 1.0E-4 was used for the storage coefficient. This value is within the range for a confined aquifer system (Driscoll 1986).

Recharge zones were used to simulate an annual net recharge via precipitation to the Wind River aquifer system and seepage from impoundments. A value of 3.85E-04 ft/d (1.6 inches per year) was used for Layer 1 except in areas where seepage from impoundments was simulated. In the area of the AGTI, a recharge zone was applied to simulate seepage from beneath the impoundment at a rate equivalent to approximately 21 gpm. The recharge option used in the model is for recharge to be applied only to the uppermost active layer in the model. In areas where Layer 1 is not saturated, recharge for Layers 2 and 3 was simulated at a rate of 2.3E-04 ft/d (1 inch per year).

4.0 NUMERICAL MODEL CALIBRATION

Calibrating a numerical groundwater flow model involves adjusting model parameters to obtain an acceptable correlation between field measured values and model predicted values of heads and fluxes (Woessner 1992). The calibration procedure is generally executed by varying estimates of model parameters (hydraulic properties) and/or boundary condition values from a set of initial values until an acceptable match of calculated and observed water levels and/or flux is achieved. This process is known as inverse modeling and can be accomplished using manual trial and error methods or with automated calibration techniques. In addition to observed water levels and flux, groundwater velocity and flow direction is also considered in model calibration (Duffield 1990). Successful calibration of a flow model to observed water levels, velocities, and flow directions enables the model to be used in the predicted travel times and transport of dissolved constituents.

Adequacy of model calibration is judged by examining model residuals. A residual (as defined for use in this report) is the difference between the observed groundwater elevation and the groundwater elevation predicted by the model. Model convergence should be accompanied by minimizing the residual mean, residual standard deviation, and residual sum of squares (RSS) (Duffield 1990). The residual mean is the arithmetic average of all the differences between observed and computed water levels. A positive sign indicates that the model has under-predicted the observed water level, a negative sign indicates overprediction. The residual standard deviation quantifies the spread of the differences between observed and predicted water levels around the mean residual. The ratio of residual standard deviation to the total head change across the model domain should be small, indicating the residual errors are only a small part of the overall model response (Anderson 1992). The RSS is computed by adding the square of each residual and is a measure of overall variability. For a statistically accurate model calibration, the residuals and the statistics based on the residual should approach zero.

4.1 Calibration Targets

Calibration targets are a set of field measured values, typically groundwater elevations and flux measurements, to which model predicted values are compared. The Gas Hills model was calibrated to water-level data that are considered representative of current hydrologic conditions in the Wind River aquifer. These data were collected while the groundwater CAP was operational. However, the selection of representative calibration targets was not straightforward because of the large variability in water level elevations for specific wells in the monitoring network.

Groundwater conditions respond to changes that are transitory and, in some cases, localized. For example, as tailings seepage rates have decreased from the AGTI, water levels in surrounding monitor wells have shown significant declines. Wells located east and upgradient of the A-9 Repository show increasing water levels in response to reclamation and backfilling of former dewatered mine pits that has resulted in a hydrostatic rebound of the water table. Onsite injection resulted in recharge mounds in various areas of the site, particularly at the upgradient edge of the A-9 Repository near monitor well MW7. These

trends are illustrated in Figure C-9. The recharge mounds have generally subsided in response to cessation of injection in 1996. A visual analysis of hydrographs for all wells indicated that, despite these transitory and localized impacts to the hydrologic system, water-levels have been relatively consistent for more recent measurements. Water-levels measured since April 1998 for the deeper portion of the Wind River and since October 1998 for the upper portion of the Wind River appear relatively stable.

Calibration targets were selected as the mean water-level elevation for wells completed in the deeper portion of the Wind River aquifer for measurements from April 1998 through March 2000 and for wells screened in the upper portion of the Wind River aquifer for measurements from October 1998 through March 2000. No extraction wells were included as calibration targets because water levels measured in extraction wells reflect well efficiency in addition to aquifer characteristics. Furthermore, only wells exclusively screened within the Wind River above the mudstone unit were included as targets for Layer 1 in the model and only wells exclusively screened below the mudstone were included as calibration targets for Layer 3 of the model.

Twenty-three monitoring wells were used as calibration targets for Layer 1 (the Wind River aquifer above the mudstone unit) and twenty-two monitoring wells were used as calibration targets for Layer 3 (the Wind River aquifer below the mudstone) (Table C-3).

No calibration targets were established for Layer 2 because the mudstone unit acts as an aquitard and there are no wells completed exclusively within that unit.

4.2 Calibration Results

Calibration was achieved using a combination of manual trial and error and automated calibration techniques. Hydraulic conductivity zones, recharge values, constant-head, and general-head boundaries were varied during the process. The calibration simulation used average well extraction rates for the period from June 1999 to June 2000, as provided in Table C-2. The calibration simulation is run as a steady state-simulation.

The mean residual and standard deviation for the final calibration simulation of the steady-state Gas Hills groundwater flow model are 0.13 ft and 3.99 ft, respectively (Table C-4). For Layer 1, the mean residual and standard deviation values are 0.12 ft and 5.34 ft, respectively. The Layer 3 values are 0.14 ft and 1.67 ft. Note that the mean residuals are close to zero for both layers indicating no significant bias to either overprediction (negative) or underprediction (positive) of water levels. The standard deviation for the model represents less than five percent of the total head change across the model domain, indicating that the residual errors are only a small part of the overall model response. A summary of calibration targets, predicted water levels, and residuals are presented in Table C-3. Table C-4 presents a summary of the calibration statistics.

The calibration target water elevations are plotted versus model simulated water elevations in Figure C-10. The tight clustering and even distribution of points around the line indicate that the model was accurate in reproducing the calibration targets without consistently overpredicting or underpredicting the observed values. If the observed and predicted water

levels matched exactly they would fall on a straight line at forty-five degrees with the intercept at equal values of simulated and observed groundwater elevations.

The spatial distribution of residuals and the model simulated groundwater elevations for Layer 1 and Layer 3 are shown in Figures C-11 and C-12, respectively. The largest residuals are at PW6 (11.18 ft) and GW6 (-11.97 ft). These target locations are relatively close together, east of the RA. The fact that both the maximum negative and positive residuals occur in the same vicinity indicates that the model does not adequately simulate the steep hydraulic gradient in that area. Attempts at reducing the residuals in this area of the model were unsuccessful. Water-level data from this area indicate that the water level is rebounding in response to reclamation of mine pits. Therefore, conditions immediately east of the site are not well represented by steady state simulation. Also, the model simulations de-saturated the area north of the A-9 Repository in Layer 1. However, the model prediction is consistent with observed data because the saturated thickness in that area is thin. As recharge from tailings continues to decline, portions of the Wind River aquifer above the mudstone in the area north of the A-9 Repository will dewater. Overall, the model adequately reproduced the observed values in the Wind River aquifer, particularly in the areas of interest at the south end of the A-9 Repository in Layer 1 and beneath the AGTI in Layer 3.

4.3 Water Budget

The water budget for the entire model domain was used to verify the overall acceptability of the solution. The combined use of observed groundwater elevations and water budget for model calibration increased the likelihood of obtaining a unique calibration (Woessner 1992). The water budget or "mass balance" percent error was used throughout calibration as an independent check of the numerical accuracy of the solution procedure. The percent error in the mass balance of the model is calculated as the difference between the total inflow and outflow of the model divided by the average of the total inflow and outflow. The percent error for the mass balance of the Gas Hills calibration simulation is 0.006 (Table C-5), indicating adequate model convergence (Konikow 1978). Mass balance percent errors of less than one are considered acceptable (Spitz 1996).

Total inflow into the calibrated model is 82,677 ft^3/d, with approximately 68 percent of the flow coming from infiltration recharge (Table C-5). Approximately 32 percent of the inflow comes from the general-head and constant-head boundaries around the perimeter of the model domain. This inflow represents recharge to the aquifer from areas outside of the model domain. Total outflow from the model is 82,671 ft^3/d, with the majority of the outflow accounted for through the constant-head and general-head boundaries and minor amounts through the well and drain boundaries.

4.4 Sensitivity Analysis

A sensitivity analysis was used for hydraulic conductivity and recharge to evaluate the uncertainty in the calibrated model caused by estimates of these model parameters. Evaluating the influence of each zone on the model response helps determine which zone values should be defined or estimated more accurately, and which zone values are already adequate or require only minimal definition (Konikow 1978). Individual zones of hydraulic

conductivity were systematically changed while holding other parameters fixed at the calibrated values to observe the model response. The same exercise was used on recharge zones. The magnitude of change in heads from the calibrated solution is a measure of the sensitivity of the solution to that particular parameter (Anderson, 1992). The sensitivity analysis results are reported as the normalized RSS, which indicates the sensitivity of the solution to a parameter relative to the calibrated RSS.

All zones of hydraulic conductivity in the model were increased and decreased by 10 and 25 percent. The sensitivity analysis results for hydraulic conductivity are shown in Figure C-13. Hydraulic conductivity Zones 5 and 9 were the most sensitive to parameter value changes, indicating the need for accurate definition of these zone values. Hydraulic conductivity Zones 5 and 9 cover most of Layers 1 and 3, respectively. As previously stated, the values used in the model are supported by pumping test data from numerous site monitor and extraction wells (Table C-1).

The recharge values in the model were also increased and decreased by 10 and 25 percent. The sensitivity analysis results for recharge are shown in Figure C-14. The analysis indicates that the model is most sensitive to recharge Zone 2, which covers most of Layer 2. Recharge Zone 2 is equally sensitive to decreasing or increasing the recharge value relative to the calibrated value. This would indicate the calibrated value for recharge Zone 2 is a reasonable representation of site conditions.

Results of the sensitivity analysis indicate that the hydraulic conductivity and recharge values used in the final calibrated model provide a reasonable match to site hydrologic conditions. Changes to the calibrated values do not decrease the RSS and in some cases significantly increase the RSS, indicating a poorer calibration.

5.0 NUMERICAL MODEL ANALYSES

The Gas Hills groundwater flow model was developed and calibrated to represent current hydrologic conditions. Additional simulations were run using a stochastic approach to address the uncertainty in the values assigned to the hydraulic conductivity zones. Results of the stochastic modeling effort were used to bracket the range of probable flowpaths and groundwater velocities and were incorporated into the geochemical speciation model (Appendix B). The model was also used to evaluate potential impacts of mining activities and to assess the migration and attenuation of non-reactive milling-related constituents. The calibrated flow model was used to evaluate the effectiveness of the groundwater CAP. Discussion of each of the model applications is presented in the following sections.

5.1 Calibration Simulation

The Gas Hills groundwater flow model was calibrated to water-level data that are representative of current hydrologic conditions. The calibration simulation provides a baseline to which other scenarios can be compared and also provides a check as to the adequacy of the model in representing site hydrologic conditions. As previously discussed, the site has undergone significant hydrologic stresses since mining began in the area. Each of these stresses has impacted different areas within the model domain and at different times. Reviewing the hydrographs indicates that water-level data have been consistent for the past two years. Therefore, the model was calibrated to recent hydrologic conditions, recognizing that there are residual impacts from some of the historic stresses. The targets used for calibrating the model represent average conditions for a period of approximately two years. The model was calibrated to water-level elevations measured in monitoring wells from April 1998 through March 2000 (Table C-3). Pumping rates used for the extraction wells in the calibration simulation are the average rates reported for the period from June 1999 through June 2000 (Table C-2).

The potentiometric surfaces of the steady-state calibration simulation for Layers 1 and 3 are presented in Figures C-15 and C-16, respectively. The predominant direction of groundwater flow in the shallow portion of the Wind River aquifer beneath the site is to the southwest based on the modeled potentiometric surface (Figure C-15). The modeled potentiometric surface for the deeper portion of the Wind River aquifer indicates groundwater flow is to the west (Figure C-16). Comparing the modeled potentiometric surfaces and the March 2000 water-level elevation map (Figure C-17) shows agreement between the figures with respect to groundwater flow direction and the elevation of the potentiometric surface.

The ACL Application discusses the fate and transport of contaminants from the site without active remediation. Therefore, the calibrated groundwater flow model was also run to simulate conditions with no pumping occurring. All pumping wells were turned off for this simulation. The potentiometric surfaces for the non-pumping simulation are illustrated in Figures C-18 and C-19. Advective transport was simulated to identify groundwater flow paths under the non-pumping scenario. Simulation of advective transport was accomplished through the computation of path-lines and the position of particles at specified points in time as well as the discharge point coordinates and total travel time for each particle. This

technique is termed particle tracking. Particle tracking was implemented for this model simulation with lines of particles located along the downgradient edge of the AGTI and the A-9 Repository. The particle tracks are also shown on the figures.

5.2 Stochastic Model Simulations

There is a degree of uncertainty associated with parameter values used in the model. One of the more sensitive parameters that varies during the calibration process is hydraulic conductivity. A stochastic approach was used to address the uncertainty associated with model values assigned to hydraulic conductivity zones.

For the stochastic model, values of hydraulic conductivity for zones in Layers 1 and 3 were randomly varied within a range of 0.01 to 5 ft/d. Of the 102 pumping test analyses included in Table C-1, only seven hydraulic conductivity values fall outside of this range (three below and four above). In other words, over ninety percent of the hydraulic conductivity values determined from pumping test data fall within the range of 0.1 to 5 ft/d.

The stochastic model was used for 100 simulations. The RSS calibration statistic was calculated for each of the simulations to provide an indication of "goodness of fit" of the model results (i.e., the lower the RSS, the better the calibration). In many of the simulations, the RSS calibration statistics increased significantly, indicating the model results were moving away from an acceptable calibration. Figure C-20 shows the RSS values for each of the 100 simulations. In an effort to evaluate model simulations that were representative of the site hydrologic system, only the twenty simulations with the lowest RSS calibration statistics were selected for further analysis.

Particle tracking was used on the twenty simulations with the lowest RSS. Results of the particle tracking simulations are illustrated on Figure C-21. The intersection of the range of all flowpaths (particle tracks) from each of the twenty stochastic simulations for both the Western and Southwestern Flow Regimes at the Long Term Care Boundary (LTCB) are indicated by colored bars (red for the Western Flow Regime and blue for the Southwestern Flow Regime). All flowpaths terminate along the western edge of the LTCB with no excursions to the north or south.

The average and maximum groundwater velocities for flowpaths in each of the twenty simulations for each flow regime were calculated. The maximum velocity calculated for the Western Flow Regime was 0.33 ft/d and the average of the twenty simulations was 0.15 ft/d (Figure C-22). The maximum velocity calculated for the Southwestern Flow Regime was 0.28 ft/d and the average was 0.1 ft/d (Figure C-23).

The average and minimum travel time to reach the LTCB from the downgradient edge of the AGTI and A-9 Repository for each simulation and each flow regime were also calculated. The minimum and average travel times for the Western Flow Regime were 30 and 101 years, respectively (Figure C-24). The minimum travel time for the Southwestern Flow Regime was 40 years and the average of all simulations was 139 years (Figure C-25).

The maximum velocity of 0.33 ft/d was used as an upper limit for the geochemical speciation model for the Western Flow Regime. The upper limit used for the Southwestern Flow Regime was 0.28 ft/d. Geochemical model simulations were also run for both flow regimes using a more typical and representative groundwater velocity of 0.167 ft/d.

As illustrated in the plot of particle tracks from the twenty model simulations (Figure C-21), variation of the hydraulic conductivity values assigned in the model did not substantially alter the flowpath of groundwater migrating from the site. All groundwater migrating from the downgradient edge of both tailings impoundments intercepts the western edge of the LTCB with first arrivals occurring in 40 years or less.

5.3 Mining Impact Simulations

Extensive mining has occurred east, west, and south of the RA. Most of the mines targeted ore zones within the upper portion of the Wind River Formation (above the mudstone). The majority of the mined areas are reclaimed. The most common reclamation method was backfilling with mine spoils or overburden materials (Lidstone and Anderson 1989). Backfilling former mine pits may have altered hydraulic properties of the aquifer matrix. Points of concern regarding mining impacts to the hydrologic system are whether or not the mine pits penetrated the water table, and what changes to the hydrologic properties of the aquifer matrix resulted from reclamation.

Review of aerial photographs and other records indicates that there were only two penetrations of the water table in the upper portion of the Wind River west and south of the RA. Groundwater was encountered during mining of the PC Pit located approximately 6,000 feet west-southwest of the A-9 Repository. This mine pit has not been backfilled and is currently a reservoir. Groundwater was also encountered during mining of the Veca Pit, located 3,000 south of the A-9 Repository. The Rim Pits located approximately 5,000 feet to the west of the AGTI also penetrated groundwater but in the lower portion of the Wind River Formation, beneath the mudstone unit. The lack of groundwater encountered during mining west of the RA is generally attributed to the pinch out of the water table in the upper portion of the Wind River Formation. The mine pits west of the RA are located outside of LTCB and near the west edge of the model domain. The Veca Pit is not within the flowpath of groundwater migrating from the Gas Hills site. Changes in hydraulic properties in these areas will not significantly impact either groundwater flow direction or velocity between the POC and POE. Therefore, areas west and south of the RA were not considered for further evaluation of mining impacts.

East of the RA, several mine pits intercepted groundwater above the mudstone unit, including A-8, B-2, B-3 and the Tee Pit (Figure C-2). Other mines provided backfill materials that may have different hydraulic properties than the native materials that existed prior to mining (Table C-1). A pump test was done in a well completed with the backfill material (LA-3) (Lidstone & Anderson 1989). That pumping test indicated the lowest hydraulic conductivity value measured in the area at 0.0006 ft/d.

Because of the uncertainty associated with the hydraulic conductivity of the backfill materials, evaluation of the potential impacts of mine reclamation on groundwater flow was

used as a sensitivity analysis. Specifically, discrete hydraulic conductivity zones were superimposed on the areal extent of reclaimed pits A-8, B-2, B-3, and the Tee Pit (Figure C-26). Simulations used values assigned to the hydraulic conductivity zone representing the reclaimed mine pits of 0.002, 0.02, 2 and 5 ft/d. The value of the hydraulic conductivity zone for this area in the calibrated model simulation was 0.25 ft/d.

The primary concern regarding altering the hydraulic properties of the reclaimed pit is the potential for changes in flowpaths and or groundwater velocity. Particle tracking was used to evaluate those potential changes. The flowpaths resulting from the mining impact simulations are shown in Figure C-27. The bars representing the range of flowpaths intersecting the LTCB from the previous stochastic modeling are also shown on the figure for comparison. The flowpaths resulting from altering the hydraulic conductivity of the reclaimed mine pits intersect the LTCB within the range previously modeled. The maximum and average velocities (Figures C-28 and C-29), as well as the minimum and average travel times (Figures C-30 and C-31) fall within the range determined from the stochastic model. Therefore, no further consideration was given to impacts from reclamation of former mine pits upgradient of the RA with respect to flow direction or velocity.

5.4 Corrective Action Program Evaluation

The calibration simulation was run using pumping rates representative of the CAP. The pumping rates for the AGTI and A-9 Repository extraction systems used in the simulation are provided in Table C-2. Particle tracking used MODPATH to evaluate the degree of hydraulic capture that occurs under the current CAP.

The CAP pumping configuration results in total hydraulic capture of groundwater passing beneath the A-9 Repository (Figure C-32). A significant portion of groundwater derived from offsite sources to the southeast is also captured by the extraction wells. The particle flowpaths indicate that groundwater from areas east of the A-9 Repository migrates through the compliance wells and then to the extraction wells. Groundwater quality resulting from mining and reclamation activities east of the A-9 Repository exceeds many of the license standards for Gas Hills (reference here). Groundwater quality measured at compliance wells GW7 and GW8 can be at least partially attributable to impacts from mining, reclamation activities, and naturally-occurring mineralization east of the site.

The hydraulic effects of the CAP for the AGTI are illustrated in Figure C-33. Under this pumping configuration, there is minimal capture in the vicinity of the AGTI. As illustrated with the particle tracking, groundwater travel times from the east side of the AGTI to the west side of the impoundment exceed 100 years. Previous pumping rates for the AGTI were much higher than current rates. A simulation used the former pumping rates for purposes of comparison. As illustrated in Figure C-34, the increased pumping rates also did not achieve full hydraulic capture along the downgradient edge of the AGTI.

5.5 Simulating Non-Reactive Constituent Migration

Migration and attenuation of the licensed constituents (As, Be, Se, Ni, Pb-210, Ra-226+228, Th-230, and natural U) are strongly influenced and controlled by redox conditions and the

neutralization capacity of the aquifer matrix. A geochemical speciation model (PHREEQC) was used to predict changes in solution speciation and mineralogical controls on dissolved constituent concentrations as mill-affected water moves through the aquifer (revised Appendix B). However, some constituents commonly (but not exclusively) derived from the milling process are not significantly attenuated through interaction with the aquifer matrix. The geochemical model does not adequately address attenuation of these constituents that are predominately affected by advective (mixing) processes because it is a one-dimensional model. Groundwater migrating from the site mixes with surrounding groundwater, both laterally and vertically. The further from the site the initial groundwater migrates, the greater the degree of mixing with background waters. This has the net effect of equalizing the concentration of site-derived groundwater and background water.

A groundwater flow and transport model evaluated the reduction in concentrations of sulfate and chloride that occur between the POC and POE as a result of advective processes. The flow component of the model used to simulate migration of chloride and sulfate was the MODFLOW calibration simulation with the pumping wells turned off. The transport component of the model used MT3D. Isoconcentration maps were developed for the west and Southwestern Flow Regimes for chloride and sulfate using water quality data collected from the first quarter of 2000. The isoconcentration maps were imported into the model as initial conditions for the model simulations. The maps are presented in Figures C-35 through C-38.

An important conservative assumption built into the transport model is that the isoconcentration maps represent constituent distribution throughout the entire saturated interval (vertical thickness) of the respective layers of the model. The chloride and sulfate isoconcentration maps for the Southwestern Flow Regimes are used to represent a uniform vertical distribution of constituents in Layer 1 of the model. The chloride and sulfate isoconcentration maps for the Western Flow Regime are used to represent a uniform vertical distribution of constituents in Layer 3 of the model. For the Southwestern Flow Regime, this assumption is probably valid, given the thin saturated thickness that exists in the vicinity of the A-9 Repository. However, as previously described in Section 2 of the ACL Application, groundwater concentrations of milling-related constituents decline rapidly with depth and are restricted to the upper 50 to 100 feet of the aquifer beneath the AGTI. The thickness of the aquifer beneath the AGTI is based on well data and is represented in the model as ranging from 150 to 200 feet thick. By assuming that the isoconcentration maps generated from the 2000 water quality data represent a uniform vertical concentration profile, the total mass of a specific constituent is overestimated in the model by a factor of 1.5 to 4. For example, if the actual thickness of the aquifer is 200 feet and only the upper 50 feet of the aquifer is actually contaminated then using the isoconcentration map to represent the initial vertical distribution of constituents will overpredict the initial constituent mass by a factor of 4.

Chloride isoconcentration maps are presented for 100 and 200 years after the start of the simulation for the Western Flow Regime (Figure C-39). A chloride trend versus time plot for the Western Flow Regime POC and POE is provided in Figure C-40. In the Western Flow Regime the chloride concentration at the POE peaks at 130 mg/l at approximately 78 years after the start of the simulation and then rapidly declines to 3.1 mg/l at 400 years.

Chloride isoconcentration maps for 100 and 200 years after the start of the simulation are also presented for the Southwestern Flow Regime (Figure C-41). The maximum chloride concentration at the POE for the Southwestern Flow Regime occurs approximately 114 years after startup at a value of 77 mg/l as shown on the chloride trend plot for the Southwestern Flow Regime POE, and decreases to less that 10 mg/l by 160 years (Figure C-42).

Sulfate isoconcentration maps are presented for 100 and 200 years after the start of the simulation for the Western Flow Regime (Figure C-43). A sulfate trend versus time plot for the Western Flow Regime POC and POE is provided in Figure C-44. In the Western Flow Regime, the sulfate concentration at the POE reaches a maximum slightly above 3,000 mg/l from 70 to 80 years after the start of the simulation and declines to less that 6 mg/l after approximately 300 years.

Sulfate isoconcentration maps for 100 and 200 years after the start of the simulation are presented for the Southwestern Flow Regime (Figure C-45). The sulfate concentration at the POE for the Southwestern Flow Regime peaks at approximately 1,400 mg/l at 105 years after startup and then declines to less than 200 mg/l within another 60 years as shown on the sulfate trend plot for the Southwestern Flow Regime POE (Figure C-46). At 400 years, the sulfate concentration is predicted as 51 mg/l.

In summary, the modeled chloride concentration never exceeds the Wyoming Department of Environmental Quality (WDEQ) Class I groundwater standard (250 mg/l) at the POE for either the Western or Southwestern Flow Regime. For sulfate, the Class III standard (3,000 mg/l) is not exceeded at the POE for the Southwestern Flow Regime at any time in the model simulation. Modeled sulfate concentrations exceed the Class III standard at the POE for a 10-year period from 70 to 80 years after simulation startup. However, as previously stated, the initial mass of sulfate for the Western Flow Regime was probably overestimated by a factor of 1.5 to 4. Therefore, sulfate concentration trend plot for the Western Flow Regime POE reflects a similar overestimate and the actual concentrations will be on the order of half (or less) of the values represented in the plot. Linear correction of the modeled data by a factor of 1.5 would reduce the maximum sulfate concentration to levels below the WDEQ Class III standard.

6.0 MODEL LIMITATIONS

Numerical groundwater flow models are among the best tools available for simulating complex groundwater flow systems. Conceptual models are first developed based upon the available data. The numerical model is then based upon the conceptual model and is only as good or reliable as the available data. The available data typically do not provide comprehensive coverage of the study area. Therefore, estimates of initial and boundary conditions in areas lacking data are made using either interpolation or extrapolation techniques or knowledge and experience of groundwater flow systems in similar hydrogeologic settings. Obviously, the greatest uncertainty exists in the Gas Hills groundwater flow model in areas containing limited data.

The areas of greatest uncertainty in the Gas Hills groundwater flow model include:

- Hydraulic interaction between the Wind River Formation and underlying rocks,
- Vertical conductivity of the mudstone unit,
- Vertical distribution of constituent concentration.

The Gas Hills groundwater flow model was successfully calibrated to groundwater elevations assumed to be representative of current hydrologic conditions in the Wind River aquifer system. Groundwater conditions in the area have undergone and continue to respond to significant transitory changes. However, the groundwater elevations used as calibration targets reflect the changes taking place in the groundwater flow system in recent years, the most significant of which are the declining seepage rates from the AGTI and discontinuing injection as a remedial measure.

7.0 SUMMARY AND CONCLUSIONS

A groundwater flow model was developed for the former uranium mill site at Gas Hills, Wyoming to support the ACL Application for revised groundwater protection standards. The groundwater flow and transport model is used to address several issues related to the ACL application, including the following:

- estimating groundwater flowpaths and velocities,
- evaluating mining impacts on the groundwater flow system,
- evaluating the effectiveness of the CAP,
- simulating alternative corrective action options for the site, and
- analyzing the fate and transport of non-reactive, conservative constituents (chloride and sulfate).

A three-dimensional numerical model of the Wind River aquifer was developed using the MODFLOW code. Groundwater flow was calibrated by matching simulated water levels with reported water levels representative of current hydrologic, conditions. Calibration statistics show an adequate match.

Stochastic modeling provided a range of groundwater velocity and flowpaths to be used in the geochemical speciation model. Groundwater velocity and flowpaths to the proposed LTCB were evaluated using particle tracking. The maximum and average groundwater velocities for the upper portion of the Wind River aquifer system (above the mudstone) are 0.28 and 0.1 ft/d, respectively. For the deeper portion of the aquifer (below the mudstone), the maximum and average groundwater velocities are 0.33 and 0.15 ft/d. First arrival of particles migrating from the site arrived at the POEs within 40 years for both flow regimes.

Mining impacts were simulated using the groundwater flow model. Areas upgradient (east) of the site were considered in the evaluation. Data indicate that groundwater was not encountered in mines in the upper portion of the Wind River Formation in areas downgradient of the site within the LTCB. Mining impacts were evaluated by varying hydraulic conductivity values where mines had intercepted groundwater and were subsequently reclaimed by backfilling with mine spoils and overburden materials. Simulations indicate negligible impacts to groundwater velocity and flowpaths between the POC and POE.

Effectiveness evaluation simulations indicate that the current groundwater extraction program (i.e. well locations and pumping rates) provides total hydraulic capture at the south edge of the A9 Repository, but not in the vicinity of the AGTI.

Attenuation of non-reactive sulfate and chloride constituents was evaluated using a groundwater flow and transport model (MODFLOW and MT3D). Modeling showed chloride concentration never exceeds the WDEQ Class I groundwater standard at the POE for either the Western or Southwestern Flow Regime. The Class III standard for sulfate is not

exceeded at the POE for the Southwestern Flow Regime. Modeled sulfate concentrations exceed the Class III standard at the POE for a period of 10 years. However, conservative assumptions used in the model overestimate the initial mass of sulfate for the Western Flow Regime. Thus the modeled concentrations are over-predicted by a factor of 1.5 to 4. Decreasing the modeled concentrations by a factor of 1.5 would reduce the maximum concentration to below the Class III groundwater standard.

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Table C-1 Summary of Pumping Test Results, Gas Hills Site, Umetco Minerals Corporation, Grand Junction, Colorado

Well Identification	Reference	Method of Analysis	Hydraulic Conductivity (feet/day)	Transmissivity ($feet^2$/day)	Saturated Thickness (feet)	Specific Yield or Storativity	Aquifer Tested
A-9 Pit Pz-9	D&M[1]	Boulton	0.87	8.7	10		UWR
A-9 Pit Obs 9B	D&M[1]	Boulton	0.84	12	14.1	0.005	UWR
A-9 Pit Obs 9B	D&M[1]	Boulton	1.4	20	14.1	0.0015	UWR
A-9 Pit Pz-A-9-5	D&M[1]	Boulton	0.02	0.47	20.5		UWR
A-9 Pit Pz-A-9-5	D&M[1]	Theis	0.25	5.3	20.5		UWR
A-9 Pit Pz-A-9-4	D&M[1]	Boulton	0.74	19.4	26.2	0.025	UWR
A-9 Pit Pz-A-9-4	D&M[1]	Theis	0.5	13.4	26.2	0.08	UWR
Mudstone	D&M[1]	USBR & Air permeability	1.6e-03 to 1.3e-01				Mudstone
MW2	D&M[2]	Boulton	0.62	168	273		LWR
MW2	D&M[2]	Theis (Recovery)	0.67	183	273		LWR
MW3	D&M[2]	Boulton	0.01	1.34	122		LWR
MW3	D&M[2]	Theis (Recovery)	0.09	10.7	122		LWR
MW16	D&M[2]	Boulton	0.18	3.3	18		LWR
MW16	D&M[2]	Theis (Recovery)	0.27	5.3	18		LWR
MW18	D&M[2]	Boulton	2.54	241	95		LWR
MW18	D&M[2]	Theis (Recovery)	2.54	241	95		LWR
OW18	D&M[2]	Boulton	4.11	390	95		LWR
OW18	D&M[2]	Theis (Recovery)	8.05	766	95	0.01	LWR
MW19	D&M[2]	Boulton	0.66	50	76		LWR
MW19	D&M[2]	Theis (Recovery)	0.68	51	76		LWR
MW20-1st test	D&M[2]	Boulton	0.79	67	86		LWR
MW20-1st test	D&M[2]	Theis (Recovery)	0.82	71	86		LWR
MW20-2nd test	D&M[2]	Boulton	0.93	80	86		LWR
MW20-2nd test	D&M[2]	Theis (Recovery)	0.9	76	86		LWR
OW20-1st test	D&M[2]	Boulton	0.19	160	86		LWR
OW20-1st test	D&M[2]	Theis (Recovery)	2.73	241	86	0.3	LWR
OW20-2nd test	D&M[2]	Boulton	3.83	321	86		LWR
OW20-2nd test	D&M[2]	Theis (Recovery)	5.37	455	86	0.02	LWR

Table C-1 Summary of Pumping Test Results, Gas Hills Site, Umetco Minerals Corporation, Grand Junction, Colorado

Well Identification	Reference	Method of Analysis	Hydraulic Conductivity (feet/day)	Transmissivity ($feet^2$/day)	Saturated Thickness (feet)	Specific Yield or Storativity	Aquifer Tested
DW2	HydEng[1]	Jacob	1.89	200	106		LWR
DW1 (MW22)	HydEng[1]	Theis	1.56	370	239	4.90E-04	LWR
DW1 (MW22)	HydEng[1]	Jacob	1.72	410	239		LWR
RMW1	HydEng[2]	Theis (Recovery)	5.1	572	113		LWR
RMW1-1	HydEng[2]	Dagan	1.5	175	113	0.03	LWR
RMW1-2	HydEng[2]	Dagan	4	455	113	0.025	LWR
RMW1-3	HydEng[2]	Dagan	2.7	307	113	0.0035	LWR
RMW2	HydEng[2]	Theis (Recovery)	4.4	807	183		LWR
RMW2-1	HydEng[2]	Dagan	1	187	183	0.034	LWR
RMW-3	HydEng[2]	Theis (Recovery)	7.86	582	74		LWR
RW3-1	HydEng[2]	Dagan	4	428	74	0.032	LWR
GW1	HydEng[3]	Jacob	0.45	13.4	30		UWR
GW3	HydEng[3]	Jacob	0.92	41.4	45		UWR
GW3	HydEng[3]	Neuman	0.65	29.4	45	0.025	UWR
GW4	HydEng[3]	Jacob	0.89	8	9		UWR
GW5	HydEng[3]	Jacob	0.28	14.7	53		UWR
PW1	HydEng[3]	Jacob	0.06	1.2	20		UWR
PW3	HydEng[3]	Jacob	0.58	22.7	39		UWR
PW4	HydEng[3]	Jacob	0.99	160.4	40		UWR
PW6	HydEng[3]	Jacob	0.54	21.4	39		UWR
MW9	HydEng[3]	Neuman	1.15	52	40	0.11	UWR
MW9	HydEng[3]	Jacob	0.9	36	40	0.27	UWR
MW7A	HydEng[3]	Jacob	0.18	9.4	52		UWR
EPW1	HydEng[3]	Jacob	0.31	2.4	8		UWR/LWR
EPW2	HydEng[3]	Jacob	0.43	4.3	10		UWR/LWR
EPW3	HydEng[3]	Jacob	3.1	82.9	27		UWR
MW30 (30026)	HydEng[3]	Jacob	0.014	0.82	57		LWR

Table C-1 Summary of Pumping Test Results, Gas Hills Site, Umetco Minerals Corporation, Grand Junction, Colorado

Well Identification	Reference	Method of Analysis	Hydraulic Conductivity (feet/day)	Transmissivity ($feet^2$/day)	Saturated Thickness (feet)	Specific Yield or Storativity	Aquifer Tested
MW21A	HydEng[4]	Jacob	1.13	270	240		LWR
MWC33	HydEng[4]	Jacob	0.22	53	240		LWR
MWC34	HydEng[4]	Jacob	0.28	67	240		LWR
MWC35	HydEng[4]	Jacob	0.78	187	240		LWR
MWC36	HydEng[4]	Jacob	1.23	341	240		LWR
MWI37	HydEng[4]	Jacob	1.13	271	240		LWR
MWI39	HydEng[4]	Jacob	4.02	960	240		LWR
MWC42	HydEng[4]	Jacob	0.6	165	240		LWR
MWO40	HydEng[4]	Jacob	0.7	167	240	0.1	LWR
MWO41	HydEng[4]	Jacob	0.9	219	240		LWR
LA-1	L&A[1]	Thompson	0.04				UWR
LA-2	L&A[1]	Thompson	0.3				UWR
LA-3	L&A[1]	Thompson	0.0006				UWR
LA-4	L&A[1]	Thompson	0.003				UWR
LA-5	L&A[1]	Thompson	0.1				UWR
LA-6	L&A[1]	Thompson	0.4				UWR
LA-7	L&A[1]	Thompson	0.003				UWR
MW70B	USES[1]	Theis	0.95	95	60	0.016	LWR
MW70B	USES[1]	Jacob	0.9	90	60	0.02	LWR
MW71B	USES[1]	Theis	1.15	117	102	0.019	LWR
MW71B	USES[1]	Jacob	1.15	117	102	0.019	LWR
MW72	USES[1]	Theis	2.1	62.2	30	0.0004	UWR
MW72	USES[1]	Jacob	2.2	65	30	0.0003	UWR
MW73	USES[1]	Jacob	0.11	5.6	50	0.0015	UWR
MW74	USES[1]	Bouwer	0.04	0.5	12	NA	UWR
MW79	USES[1]	Theis	1.6	47.6	30	0.0001	UWR
MW79	USES[1]	Jacob	2	58.4	30	0.000007	UWR
MW81	USES[1]	Theis	1.9	113	60	0.016	LWR
MW81	USES[1]	Jacob	2	119	60	0.01	LWR

Table C-1 Summary of Pumping Test Results, Gas Hills Site, Umetco Minerals Corporation, Grand Junction, Colorado

Well Identification	Reference	Method of Analysis	Hydraulic Conductivity (feet/day)	Transmissivity ($feet^2$/day)	Saturated Thickness (feet)	Specific Yield or Storativity	Aquifer Tested
MWC33	USES[2]	Theis	0.23	22.7	100		LWR
MWC33	USES[2]	Jacob	0.45	45.1	100		LWR
MWC35	USES[2]	Theis	0.12	12	100		LWR
MWC36	USES[2]	Theis	2.1	105	50		LWR
MWC36	USES[2]	Jacob	3.3	163	50		LWR
MWC37	USES[2]	Theis	2.7	53.5	20		LWR
MWC37	USES[2]	Jacob	2	40.8	20		LWR
MWC42	USES[2]	Theis	1	90	90		LWR
MWC42	USES[2]	Jacob	3.34	301	90		LWR
MWC56	USES[2]	Theis	0.95	95	100		LWR
MWC56	USES[2]	Jacob	0.95	94.9	100		LWR
MWC57	USES[2]	Theis	3.25	325	100		LWR
MWC57	USES[2]	Jacob	3.26	326	100		LWR
MWC58	USES[2]	Theis	4.05	405	100		LWR
MWC58	USES[2]	Jacob	4.05	405	100		LWR
MWC59	USES[2]	Theis	2.52	278	110		LWR
MWC59	USES[2]	Jacob	2.65	292	110		LWR
MWC62	USES[2]	Theis	1.08	70	65		LWR
MWC62	USES[2]	Jacob	1.06	69	65		LWR

UWR-Upper Wind River
LWR-Lower Wind River

D&M[1] Dames & Moore, 1979. Environmental Assessment of Below Grade Uranium Tailings Disposal in the A-9 Open Pit, East Gas Hills Uranium Mine and Mill, Wyoming, prepared for Union Carbide Corporation, Feburary 1979

D&M[2] Evaluation of groundwater contamination, Exisiting Tailings Impoundment, East Gas Hills, Wyoming, prepared for Union Carbide Corporation, June 1979.

Hyd Eng[1] HydroEngineering, 1980, A-9 Leaky Aquifer Test, prepared for Union Carbide Corporation, 1980.

HydEng[2] HydroEngineering, 1980, Rim Pit Hydrology, prepared for Union Carbide Corporation, September 1980.

HydEng[3] HydroEngineering, 1982, Groundwater Hydrology Near the A-9 Pit Below Grade Tailings, prepared for Union Carbide Corporation, September 1982.

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L&A[1] Lidstone and Anderson, Groundwater Investigation of the East Gas Hills AML 16-E, Prepared for Worthington, Lenhart & Carpenter, December 1989.

USES[1] U.S Environmental Services-Drilling and Construction and Testing of Monitoring Wells MW70A, MW70B, MW71A, MW71B, MW72, MW73, MW74 and Extraction Wells MW78, MW79, MW80 and MW81, East Gas Hills, Wyoming, prepared for Umetco Minerals Corporation, September 1997.

USES[2] U.S Environmental Services-unpublished data

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U.S Bureau of Reclamation. 1974- Standard permeability procedure E-18

Table C-2 Extraction Rates for the Gas Hills Groundwater Corrective Action Program, June 1999-June 2000
Umetco Minerals Corporation

1999

	6/1-6/28	6/28-7/26	7/26-8/30	8/30-9/27	9/27-10/25	10/25-11/29	11/29/99-1/4/00
A-9 Repository Extraction Wells							
MW24	0.6	0.3	0.4	0.4	0.5	0.5	0.6
MW32	0.3	0.2	0.2	0.3	0.6	0.4	0.1
MWC60	2.3	2.0	1.4	1.3	1.3	1.3	1.3
MWC61	0.5	0.2	0.7	0.8	0.8	0.6	0.4
MWC62	1.6	0.8	1.0	0.9	0.8	0.4	0.4
MW78	2.6	1.5	3.2	3.6	3.5	2.4	2.6
MW79	2.4	1.4	2.2	1.9	1.2	2.2	0.7
MW80	1.9	1.3	1.8	1.8	1.8	1.7	1.7
Total (A-9)	12.1	7.6	10.8	11.0	10.6	9.6	7.7
AGTI Extraction Wells							
MWI 64	3.2	2.1	1.6	1.2	0.7	0.5	0.0
MWI 43	3.7	2.4	0.9	0.8	1.0	1.0	0.0
Total (AGTI)	6.9	4.5	2.5	2.0	1.6	1.5	0.0
Total (All Wells)	19.0	12.2	13.4	13.0	12.3	11.1	7.7

2000

	1/4-1/31	1/31-2/28	2/28-4/3	4/3-5/1	5/1-5/31	6/1-6/30	Average Extraction Rate 6/99 through 6/00
A-9 Repository Extraction Wells							
MW24	0.5	0.3	0.3	0.4	0.9	0.9	0.5
MW32	0.2	0.4	0.3	0.5	0.2	0.2	0.3
MWC60	1.3	1.5	2.4	2.2	2.0	1.5	1.7
MWC61	0.7	0.5	1.0	1.4	1.2	1.2	0.8
MWC62	0.5	1.2	1.6	0.9	0.7	0.6	0.9
MW78	2.2	2.3	1.4	0.4	1.9	1.8	2.2
MW79	1.4	0.5	2.4	1.6	1.2	1.3	1.6
MW80	1.8	1.4	1.7	1.3	1.3	1.2	1.6
Total (A-9)	8.5	8.1	11.1	8.5	9.5	8.7	9.5
AGTI Extraction Wells							
MWI 64	0.0	0.0	4.5	0.3	2.4	1.9	1.4
MWI 43	0.0	0.0	5.1	4.9	3.5	1.8	1.9
Total (AGTI)	0.0	0.0	9.5	5.1	5.9	3.8	3.3
Total (All Wells)	8.5	8.1	20.6	13.6	15.4	12.4	12.9

Table C-3. Calibration Targets for the Gas Hills Groundwater Flow Model, Umetco Minerals Corporation

Target Identification	Model Layer	Observed Water Level Elevation	Computed Water Level Elevation	Residual (Observed-Computed)
DW3	3	6770.40	6773.77	-3.37
MW17	3	6803.90	6802.56	1.34
MW18	3	6815.20	6815.44	-0.24
MW19	3	6822.90	6824.19	-1.29
MW2	3	6790.70	6789.12	1.58
MW20	3	6826.00	6827.11	-1.11
MW21A	3	6788.30	6789.80	-1.50
MW23	3	6810.20	6808.87	1.33
MW25	3	6743.80	6743.54	0.26
MW26	3	6802.70	6802.27	0.43
MW27	3	6828.30	6828.16	0.14
MW28	3	6737.50	6734.93	2.57
MW4	3	6813.30	6812.75	0.55
MW70B	3	6764.30	6763.77	0.53
MW71B	3	6732.40	6734.62	-2.22
MW81	3	6794.30	6794.33	-0.03
MW30	3	6767.50	6766.36	1.14
MW77	3	6711.20	6709.66	1.54
MW6D	3	6808.40	6810.53	-2.13
MW7D	3	6797.50	6797.55	-0.05
MW10D	3	6815.40	6811.14	4.26
MW24D	3	6787.80	6788.45	-0.65
EPW2	1	6797.65	6800.20	-2.55
EPW3	1	6798.59	6792.10	6.49
GW1	1	6806.49	6799.48	7.00
GW2	1	6794.96	6794.04	0.93
GW3	1	6785.62	6792.27	-6.65
GW4	1	6790.88	6797.28	-6.39
GW5	1	6808.73	6811.36	-2.62
GW6	1	6806.08	6818.05	-11.97
MW7	1	6821.48	6824.90	-3.42
PW1	1	6818.44	6818.46	-0.02
PW2	1	6801.63	6801.70	-0.07
PW3	1	6793.51	6792.33	1.18
PW4	1	6791.00	6792.52	-1.53
PW5	1	6789.40	6795.22	-5.82
PW6	1	6831.54	6820.35	11.18
PW7	1	6839.40	6839.14	0.26
RW2	1	6795.53	6791.57	3.96
MW73	1	6812.61	6807.88	4.73

Table C-3. Calibration Targets for the Gas Hills Groundwater Flow Model, Umetco Minerals Corporation

Target Identification	Model Layer	Observed Water Level Elevation	Computed Water Level Elevation	Residual (Observed-Computed)
MW72	1	6798.17	6790.16	8.01
MW74	1	6789.25	6790.85	-1.60
LA-1	1	6929.05	6923.26	5.79
LA2	1	6915.73	6916.86	-1.12
LA-6	1	6893.08	6895.99	-2.92

Note: A negative residual indicates the model simulation overpredicted the head at the calibration target.

Table C-4. Summary of Calibration Statistics, Gas Hills Groundwater Flow Model Umetco Minerals Corporation.

Model Summary	
Residual Mean	0.13
Residual Standard Deviation	3.99
Residual Sum of Squares	718
Absolute Residual Mean	2.77
Minimum Residual	-11.97
Maximum Residual	11.18
Observed Range in Head	217.85
Residual Standard Deviation/Observed Range in Head	0.018
Layer 1	
Residual Mean	0.12
Residual Standard Deviation	5.34
Residual Sum of Squares	656
Absolute Residual Mean	4.18
Minimum Residual	-11.97
Maximum Residual	11.18
Observed Range in Head	143.43
Residual Standard Deviation/Observed Range in Head	0.037
Layer 3	
Residual Mean	0.14
Residual Standard Deviation	1.67
Residual Sum of Squares	61.8
Absolute Residual Mean	1.28
Minimum Residual	-3.37
Maximum Residual	4.26
Observed Range in Head	117.10
Residual Standard Deviation/Observed Range in Head	0.014

Note: There were no calibration targets in Layer 2

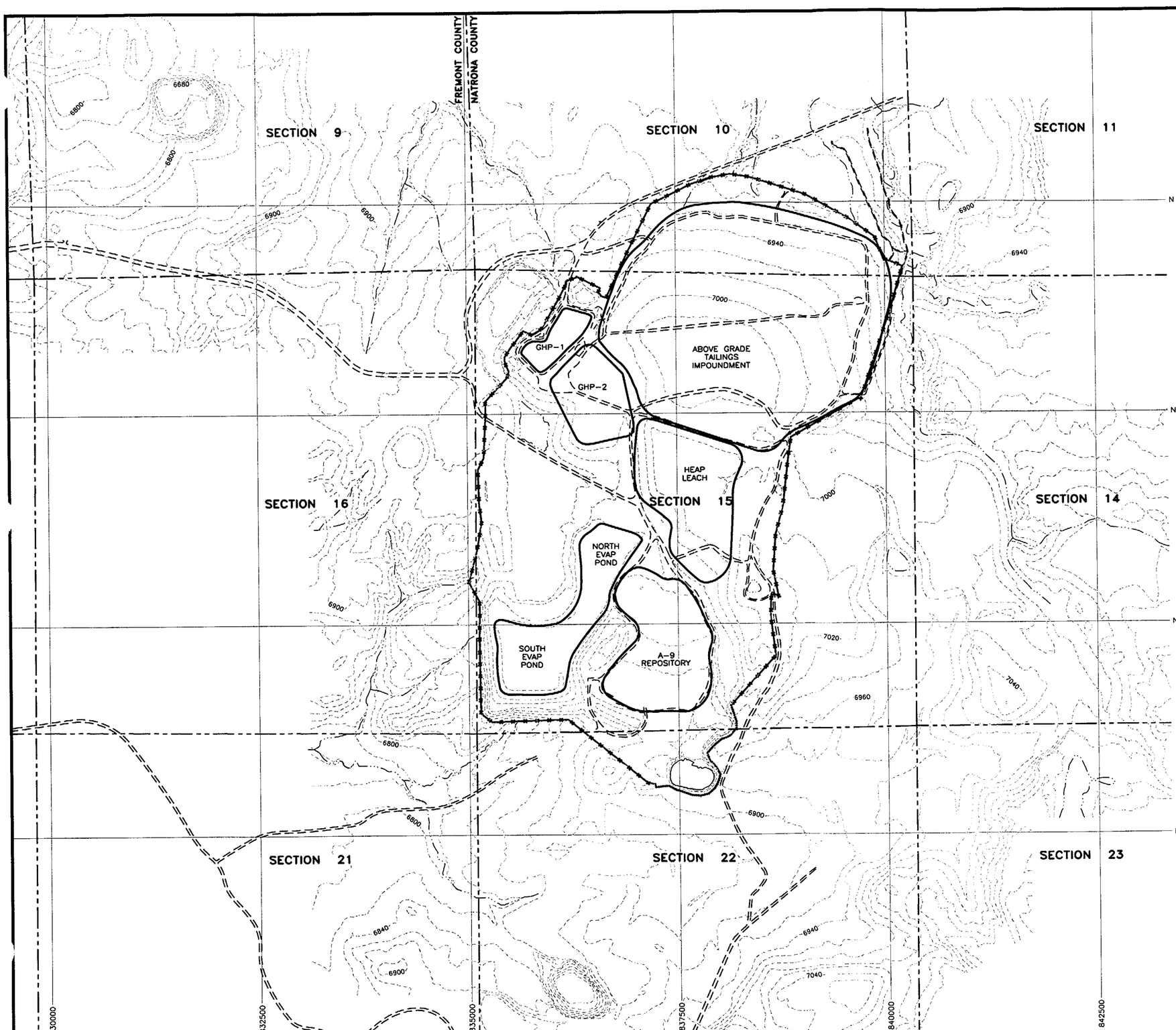
Calibration Statistics derived from the following MODFLOW files:

MODFLOW BCF File Name: ghpmpcal.bcf
MODFLOW BAS File Name: ghpmpcal.bas
Target Information in: ghpmpcal.trg
Model-Computed Heads in: ghcalpmp.hds

Table C-5. Volumetric Budget for Gas Hills Groundwater Flow Model Calibration Simulation Umetco Minerals Corporation.

	Inflow				Outflow					
	Constant Head & Head Dependent	Recharge	Top	Total In	Well	Drain	Constant Head & Head Dependent	Bottom	Total Out	Mass Balance Error
All Layers	27,055	56,109	0	83,164	2,476	873	79,809	0	83,158	0.007
Layer 1	20,768	30,737	0	51,505	1,832	873	12,086	36,629	51,420	0.165
Layer 2	0	180	36,629	36,809	0	0	0	36,809	36,809	0.001
Layer 3	6,286	25,192	36,809	68,287	644	0	67,723	0	68,367	-0.116

Mass balance error reported as percentage of total inflow. All other values reported in cubic feet per day, rounded to nearest whole number



N

SCALE: 1" = 1200'

LEGEND:

- RESTRICTED AREA BOUNDARY (FENCE)
- SECTION LINE
- N 787500 — UMETCO SITE 2500' GRID SYSTEM
- 7000 — SURFACE CONTOUR LINE
- UNPAVED ROAD
- SURFACE WATER

NOTES:

1). SURFACE CONTOURS FROM 1997 AERIAL MAPPING BY DATA MAPPING.

2). SECTIONS SHOWN ALL FROM TOWNSHIP 33 NORTH, RANGE 89 WEST OF THE SIXTH PRINCIPAL MERIDIAN.

UMETCO MINERALS CORPORATION

SITE MAP

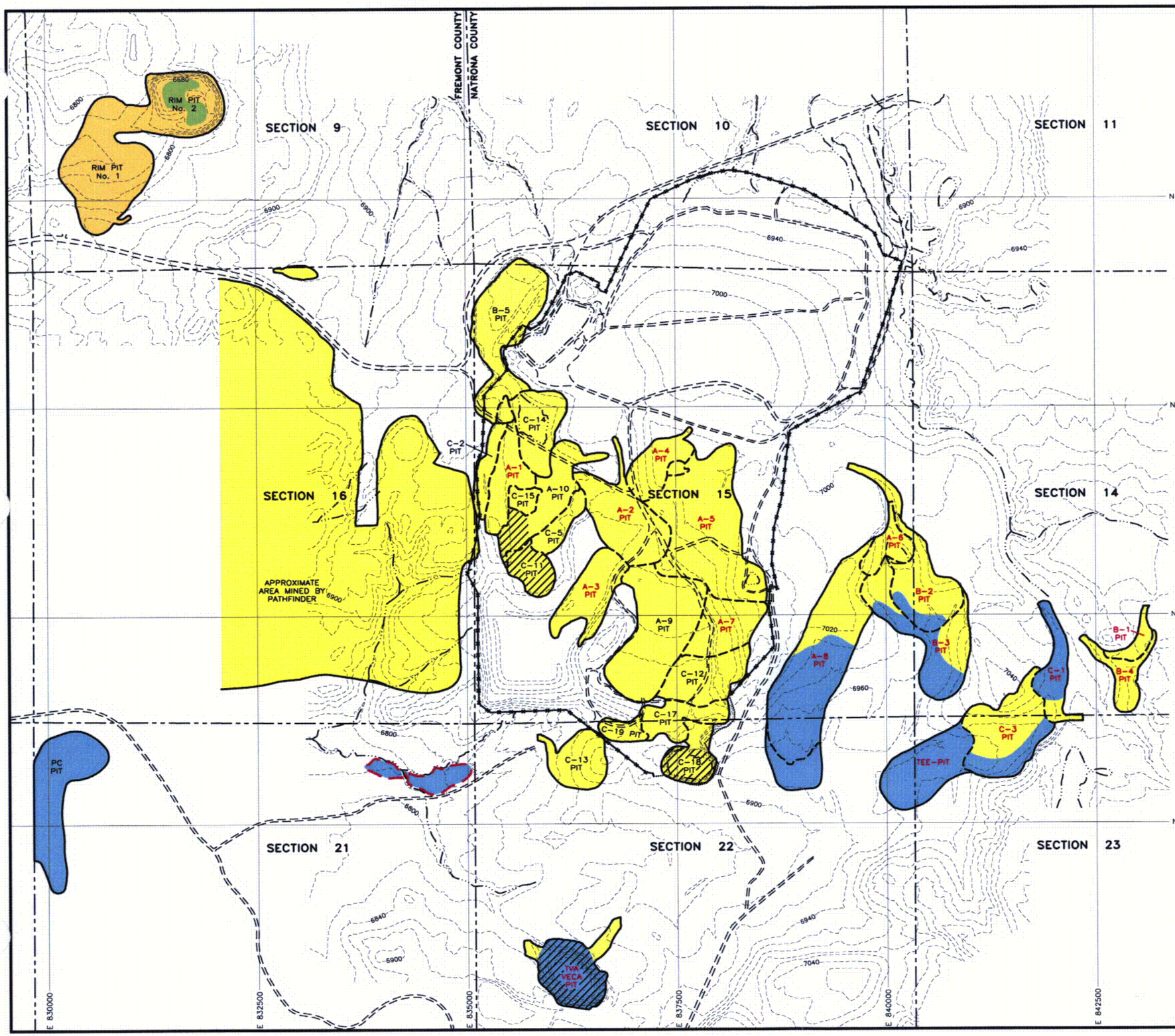
EAST GAS HILLS AREA

GAS HILLS SITE

DECEMBER 2000

FIGURE C-1

FIGURE-C1.DWG



N

SCALE: 1" = 1200'

LEGEND:

- CURRENT AND HISTORIC SURFACE WATER IMPOUNDMENT
- GROUNDWATER ENCOUNTERED LOWER WIND RIVER
- NO GROUNDWATER ENCOUNTERED LOWER WIND RIVER
- GROUNDWATER ENCOUNTERED UPPER WIND RIVER
- NO GROUNDWATER ENCOUNTERED UPPER WIND RIVER
- C-1 PIT – PIT DESIGNATION (INDICATES MINING ACTIVITIES WERE PRE-LAW AND/OR WERE RECLAIMED BY AML PROGRAM)
- C-18 PIT – PIT DESIGNATION (POST-LAW)
- MINE OUTLINE (ABOVE GROUND PIT)
- UNDERGROUND MINE OUTLINE
- RESTRICTED AREA BOUNDARY (FENCE)
- SECTION LINE
- N 787500 UMETCO SITE 2500' GRID SYSTEM
- 7000 SURFACE CONTOUR LINE
- UNPAVED ROAD
- SURFACE WATER

NOTES:

1). SURFACE CONTOURS FROM 1997 AERIAL MAPPING BY DATA MAPPING.

2). SECTIONS SHOWN ALL FROM TOWNSHIP 33 NORTH, RANGE 89 WEST OF THE SIXTH PRINCIPAL MERIDIAN.

UMETCO MINERALS CORPORATION

URANIUM MINES

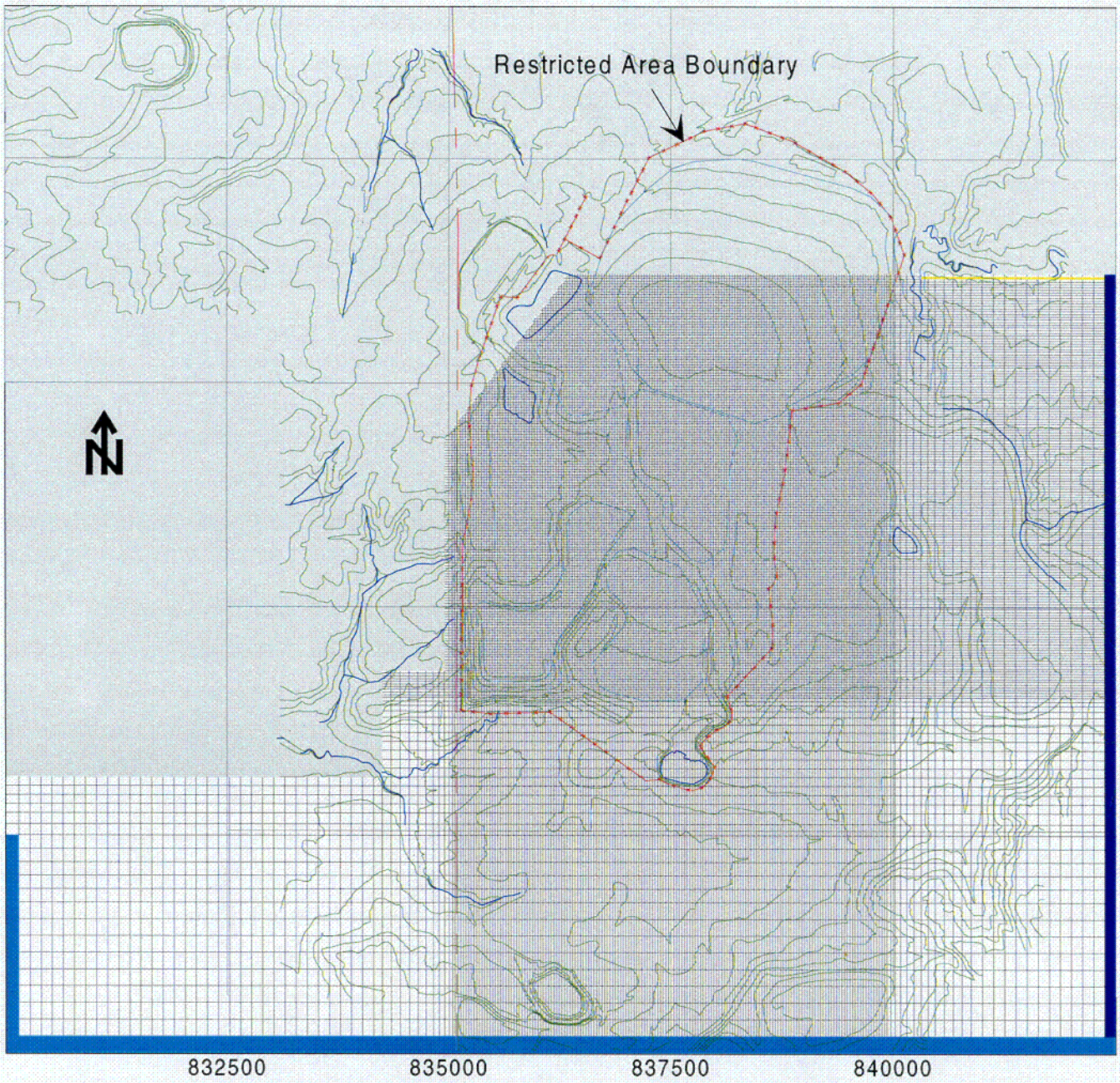
EAST GAS HILLS AREA

GAS HILLS SITE

DECEMBER 2000 FIGURE C-2

FIGURE-C2.DWG

C-1



Boundary Condtions

- Constant Head
- General Head
- Drain
- No-Flow

Topographic Contours (20 foot intervals)

UMETCO MINERALS CORPORATION

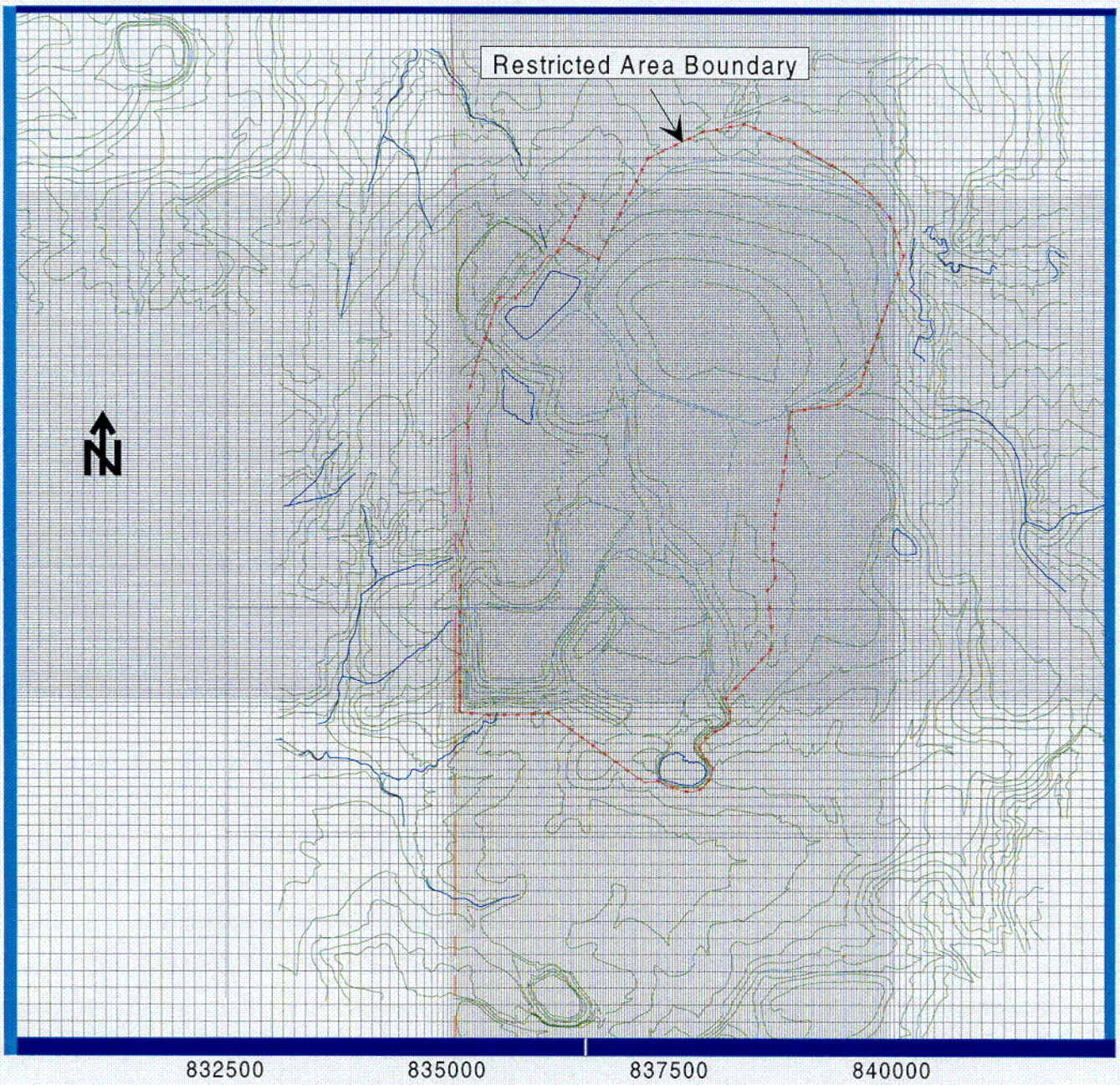
MODEL GRID AND
BOUNDARY CONDITIONS
LAYER 1

GAS HILLS SITE

JANUARY 1999 FIGURE C-3

FIGC1.SRF

C-2



Boundary Condtions

- Constant Head
- General Head

Topographic Contours (20 foot intervals)

UMETCO MINERALS CORPORATION

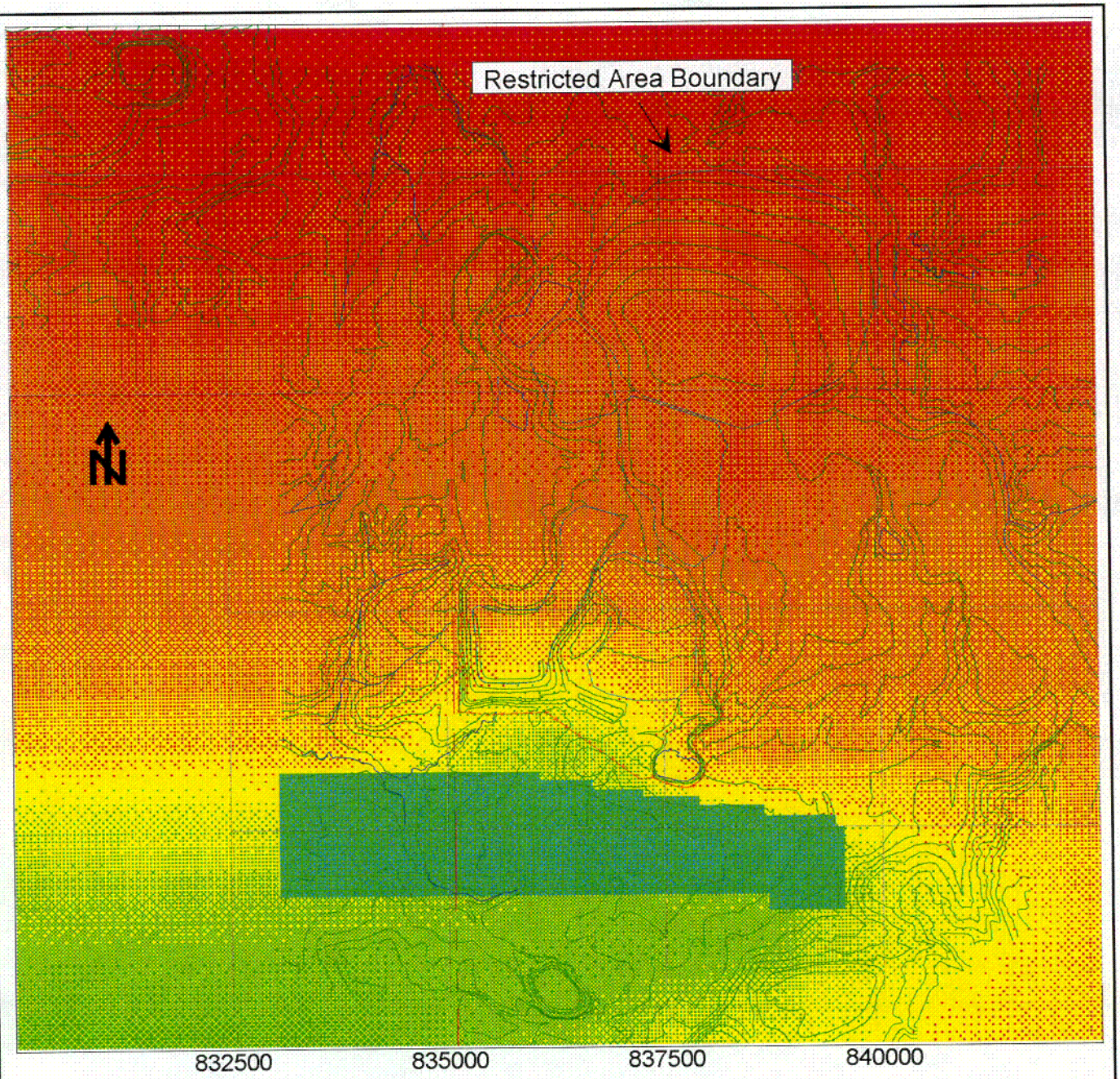
MODEL GRID AND
BOUNDARY CONDITIONS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-4

FIGC1.SRF



Bottom Elevations

Zone	Elevation (feet)
59	6500
89	6650
107	6740
125	6830
142	6920

Note: Only a representative sampling of bottom elevation zones are included in the legend

Topographic Contours (20 foot intervals)

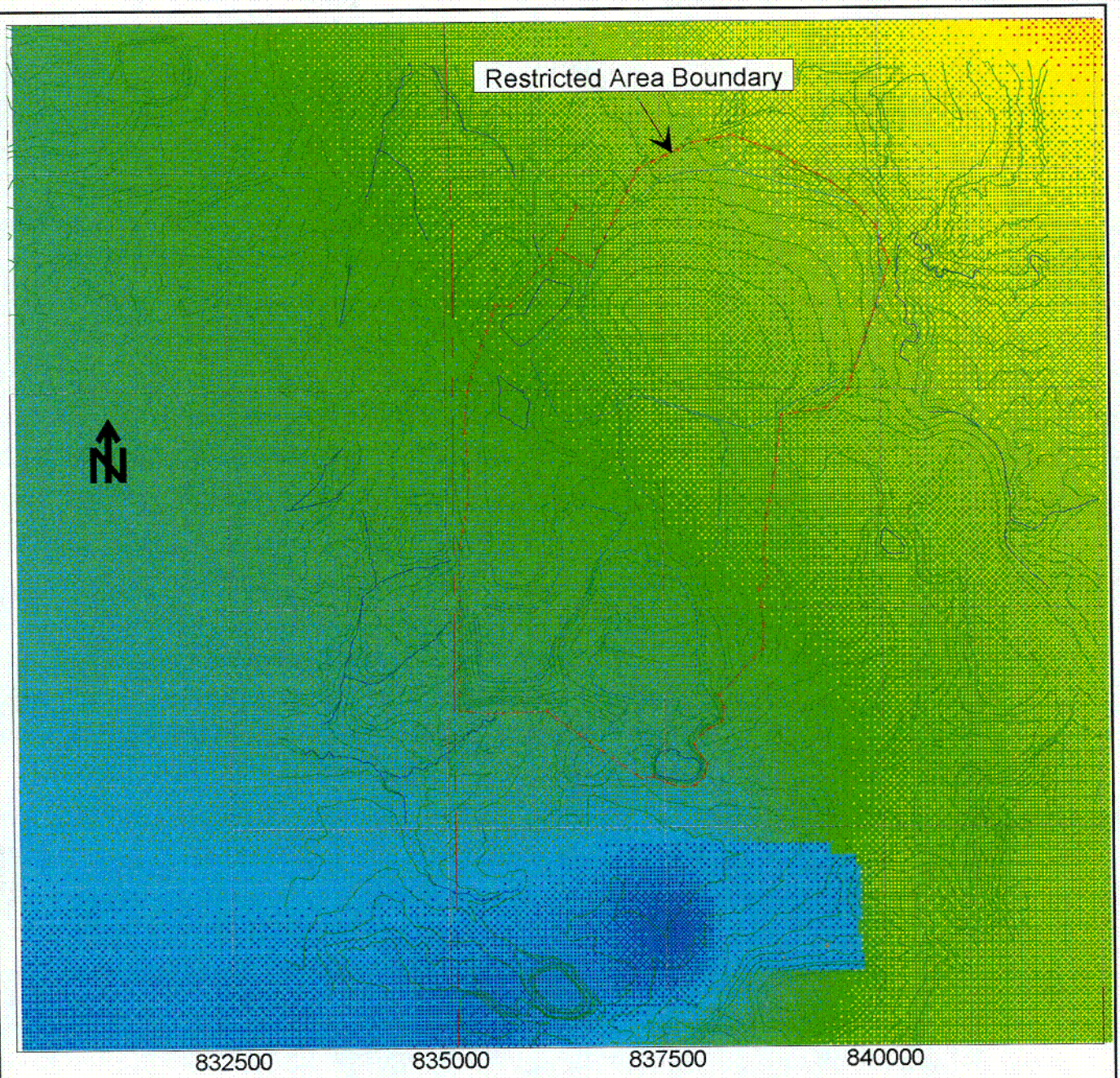
UMETCO MINERALS CORPORATION

MODEL ZONATION
BOTTOM ELEVATION
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-5



Bottom Elevations

Zone	Elevation (feet)
17	6300
37	6400
61	6500
89	6650
111	6760

Note: Only a representative sampling of bottom elevation zones are included in the legend

Topographic Contours (20 foot intervals)

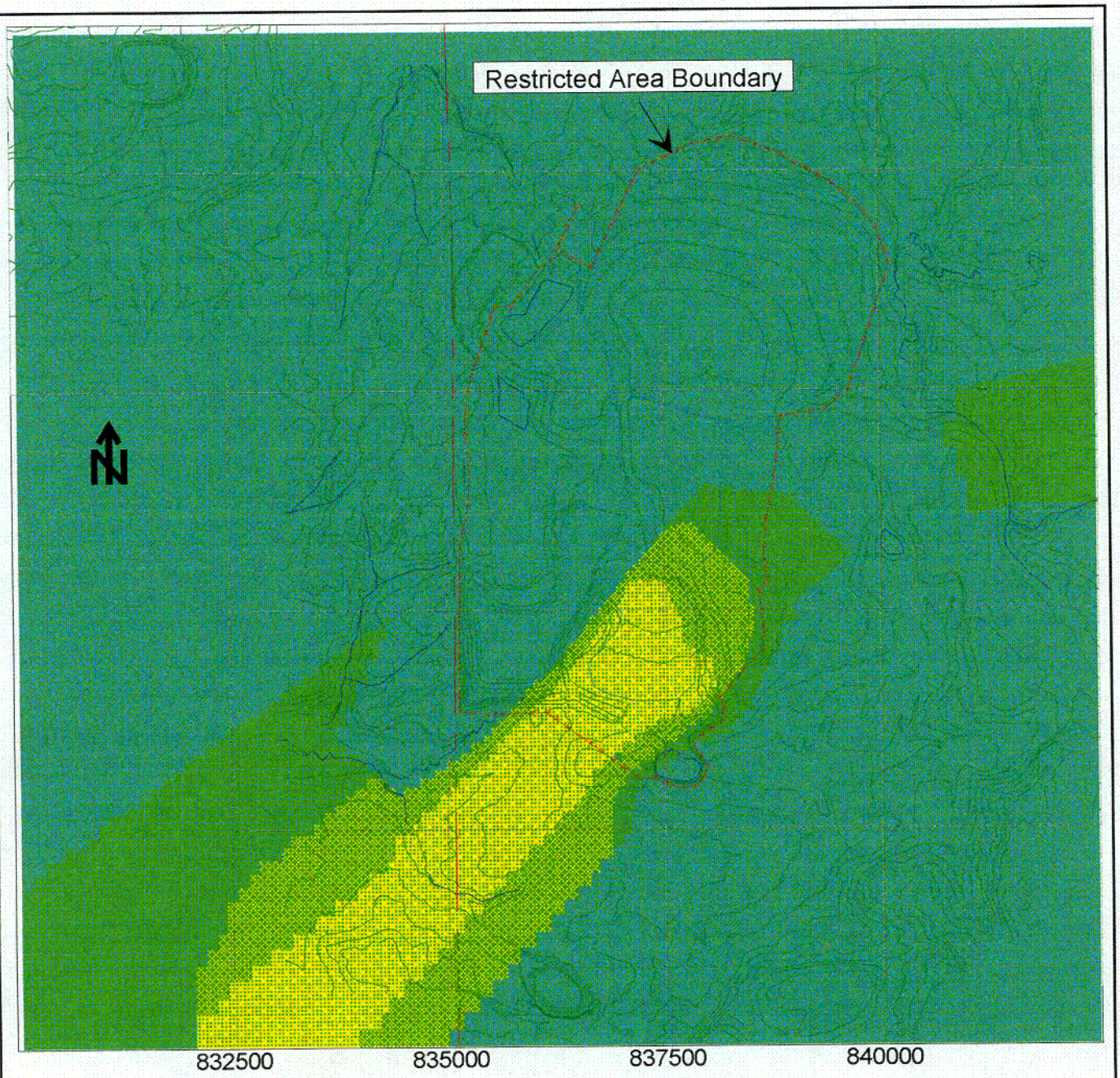
UMETCO MINERALS CORPORATION

MODEL ZONATION
BOTTOM ELEVATION
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-6



Hydraulic Conductivity

Zone	Value (feet/day)
5	0.20
7	0.66
8	0.46
11	2.32

Topographic Contours (20 foot intervals)

UMETCO MINERALS CORPORATION

MODEL ZONATION
HYDRAULIC CONDUCTIVITY
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-7

Hydraulic Conductivity

Zone	Value (feet/day)
6	0.27
9	0.69
10	1.37

Topographic Contours (20 foot intervals)

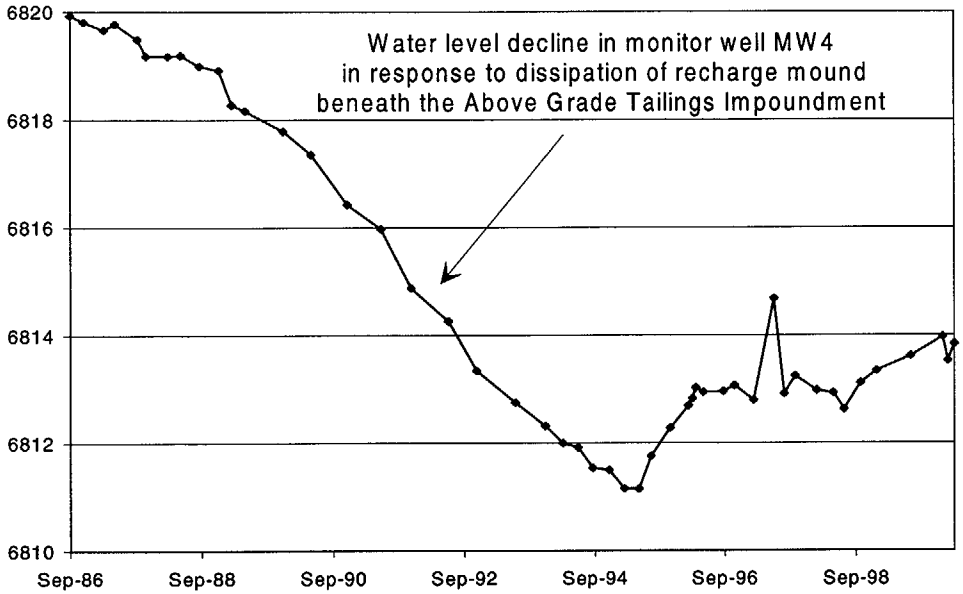
UMETCO MINERALS CORPORATION

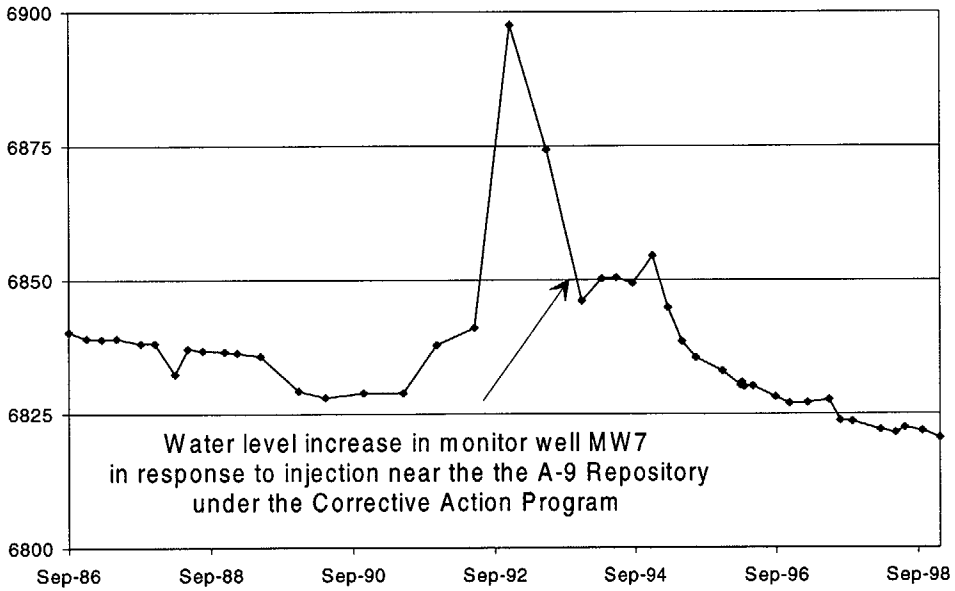
MODEL ZONATION
HYDRAULIC CONDUCTIVITY
LAYER 3

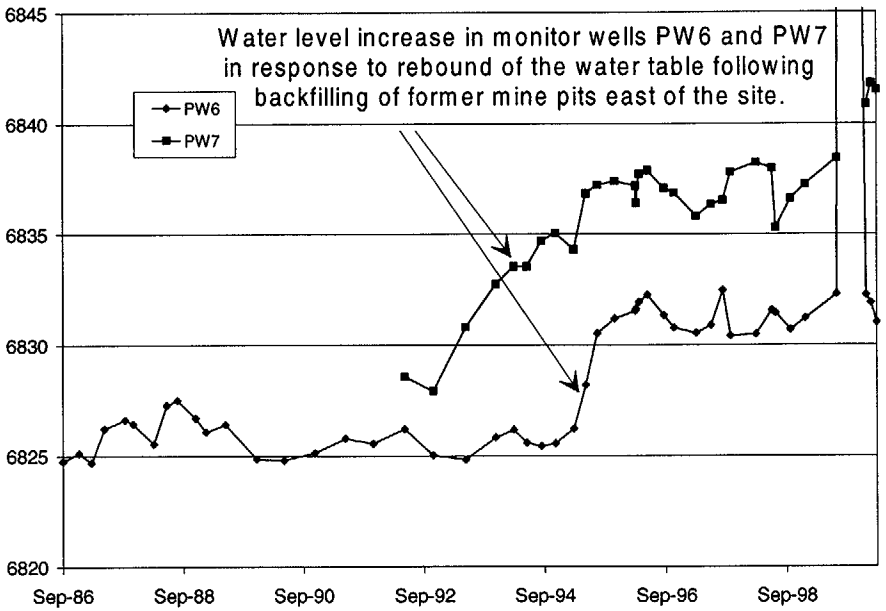
GAS HILLS SITE

NOVEMBER 2000

FIGURE C-8







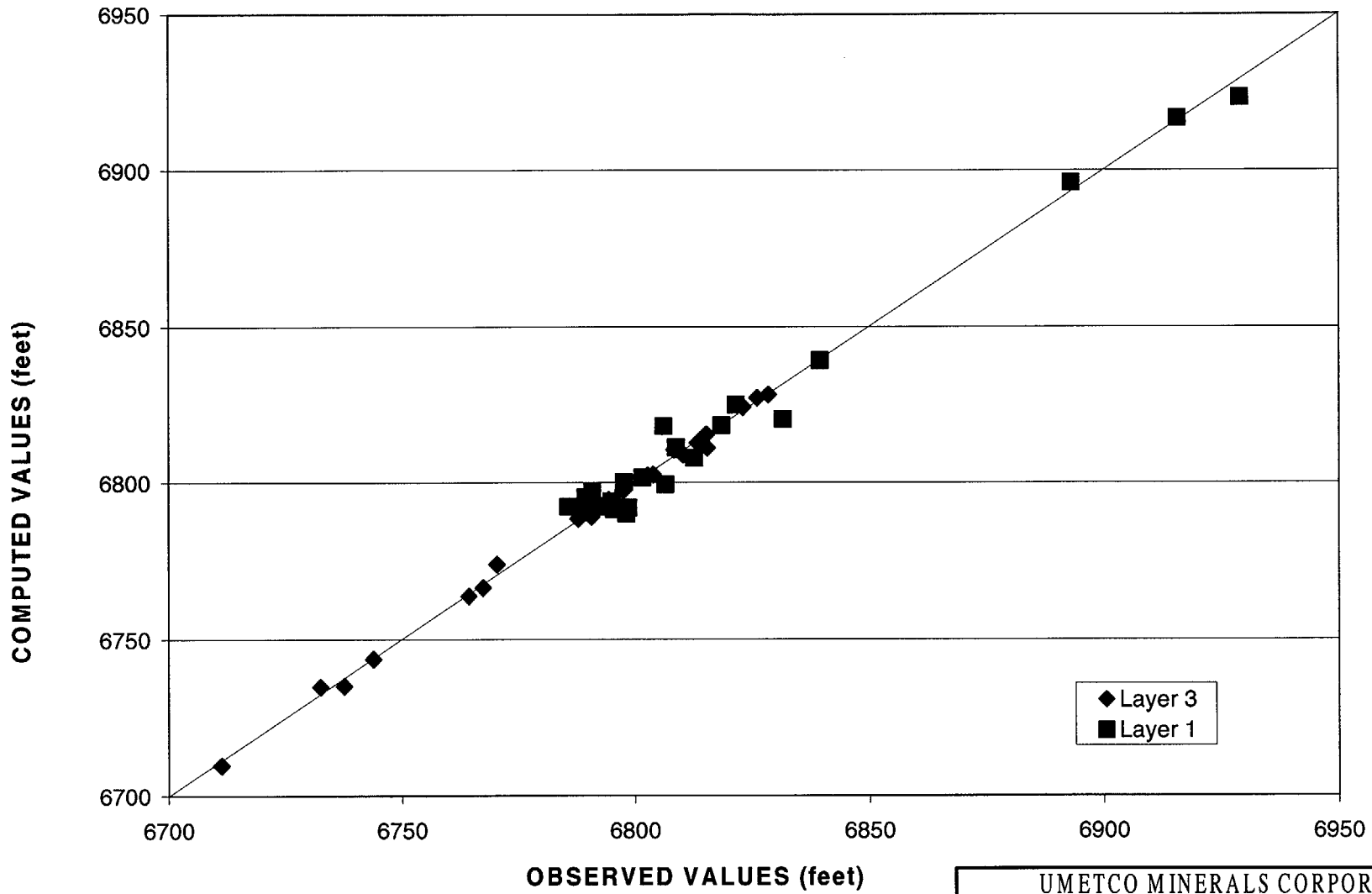
UMETCO MINERALS CORPORATION

HYDROGRAPHS INDICATING
HYDROLOGIC STRESSES TO THE
WIND RIVER AQUIFER

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-9



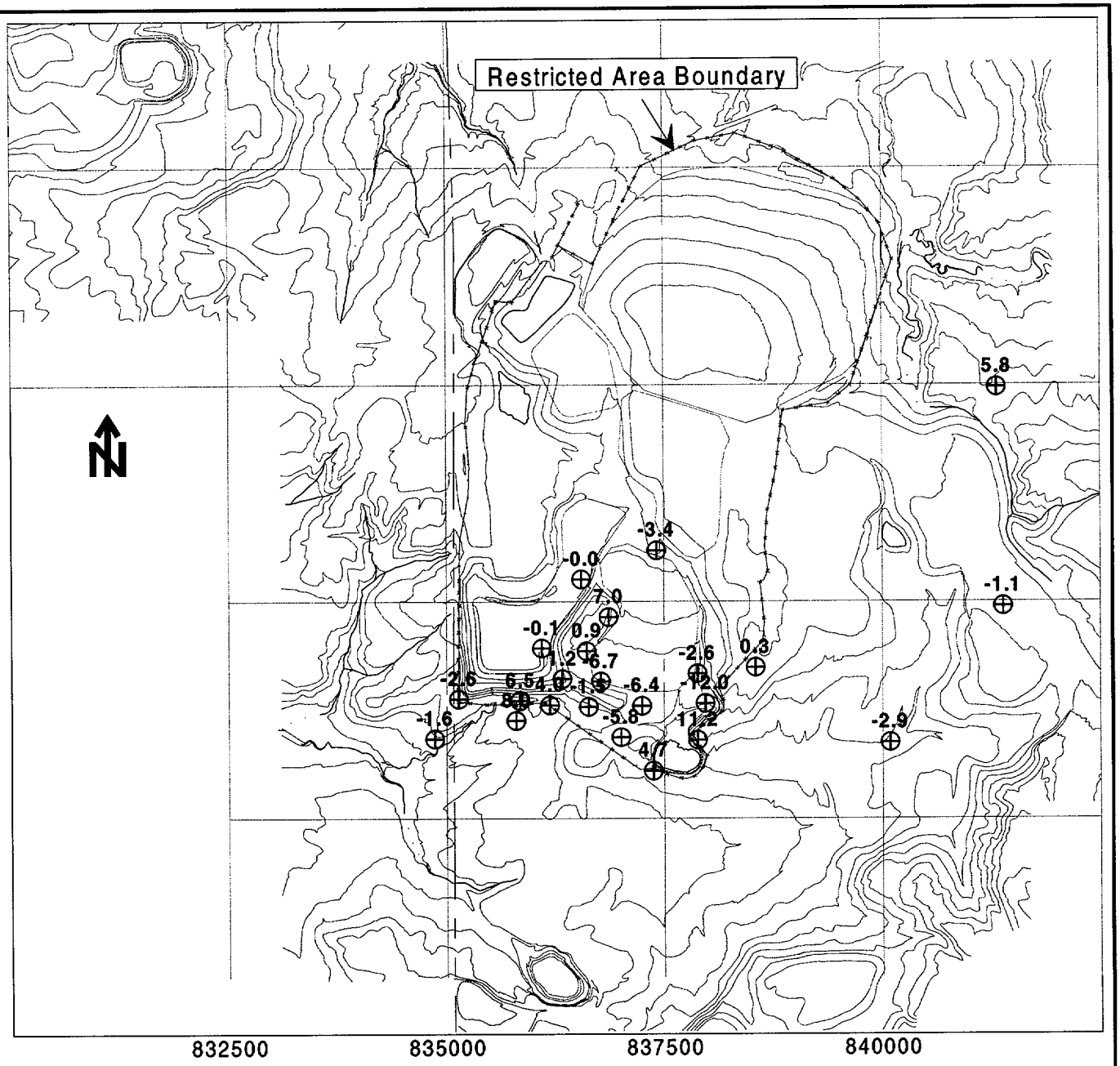
UMETCO MINERALS CORPORATION

OBSERVED VERSUS SIMULATED GROUNDWATER ELEVATIONS

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-10



-1.1
⊕ Calibration Target - posted value is the residual (observed - simulated)

Topographic Contours (20 foot intervals)

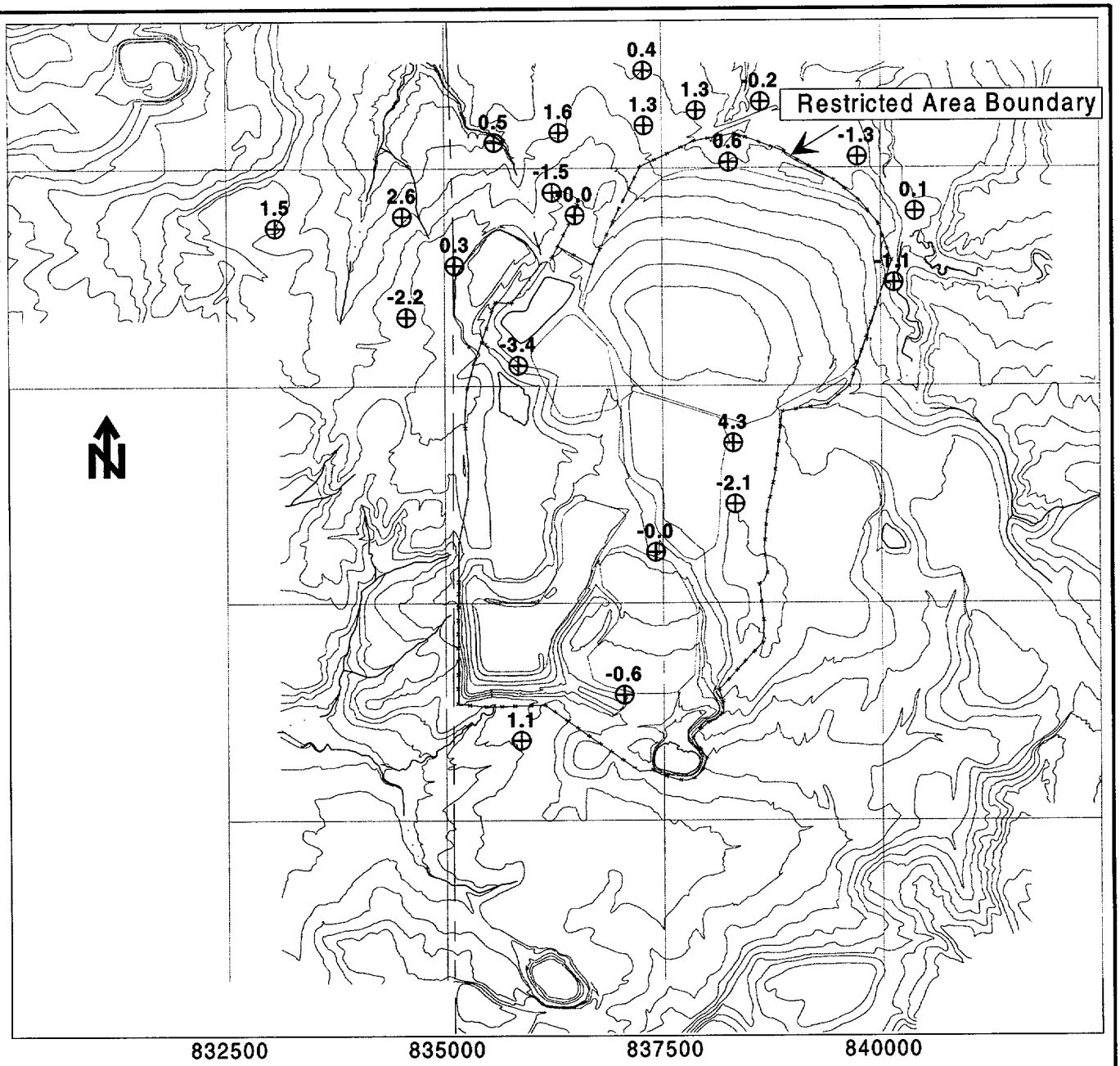
UMETCO MINERALS CORPORATION

SPATIAL DISTRIBUTION OF MODEL RESIDUALS
LAYER 1

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-11

FIGC1.SRF



-1.1
⊕ Calibration Target - posted value is the residual (observed - simulated)

Topographic Contours (20 foot intervals)

UMETCO MINERALS CORPORATION

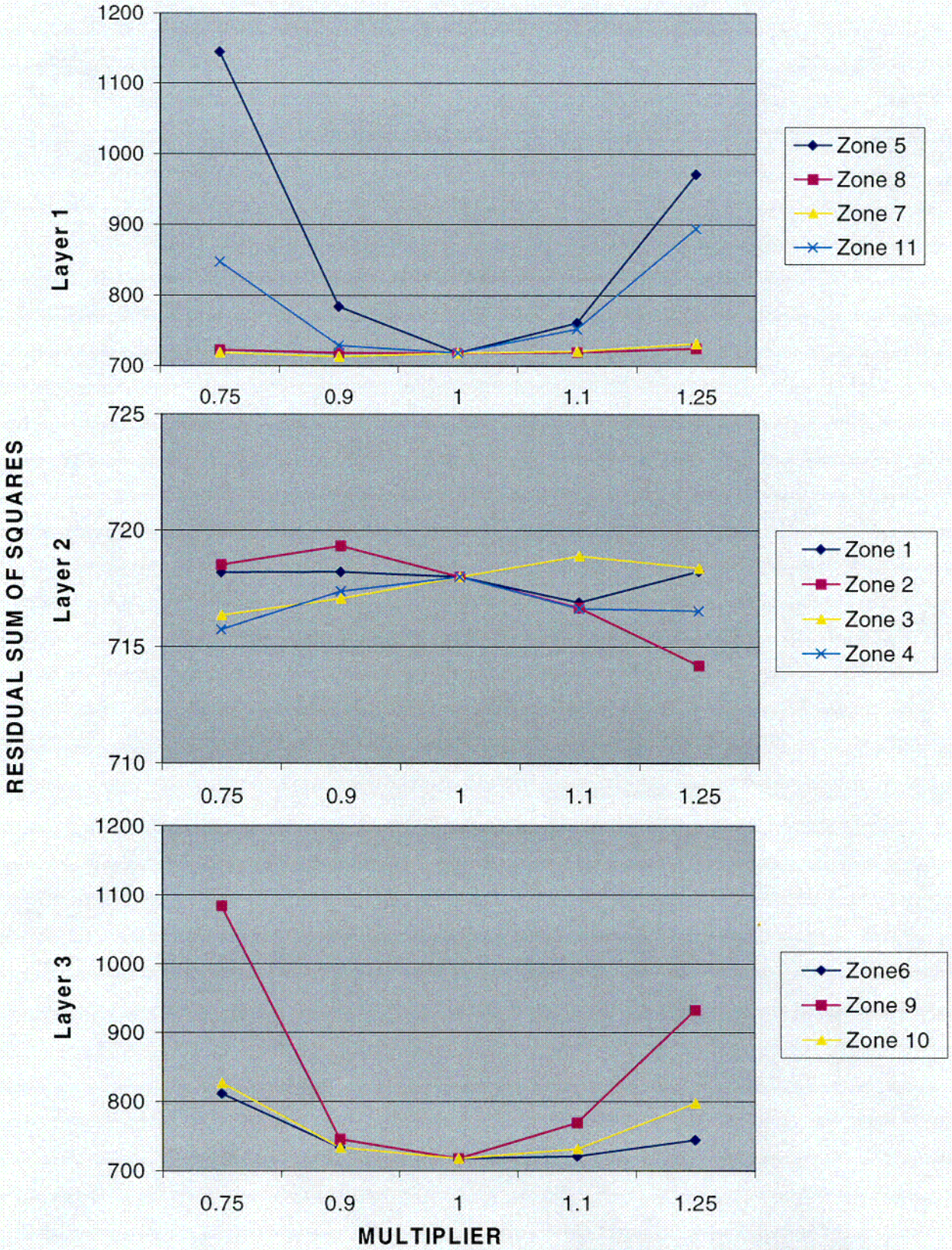
SPATIAL DISTRIBUTION OF MODEL RESIDUALS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-12

FIGC1.SRF



UMETCO MINERALS CORPORATION

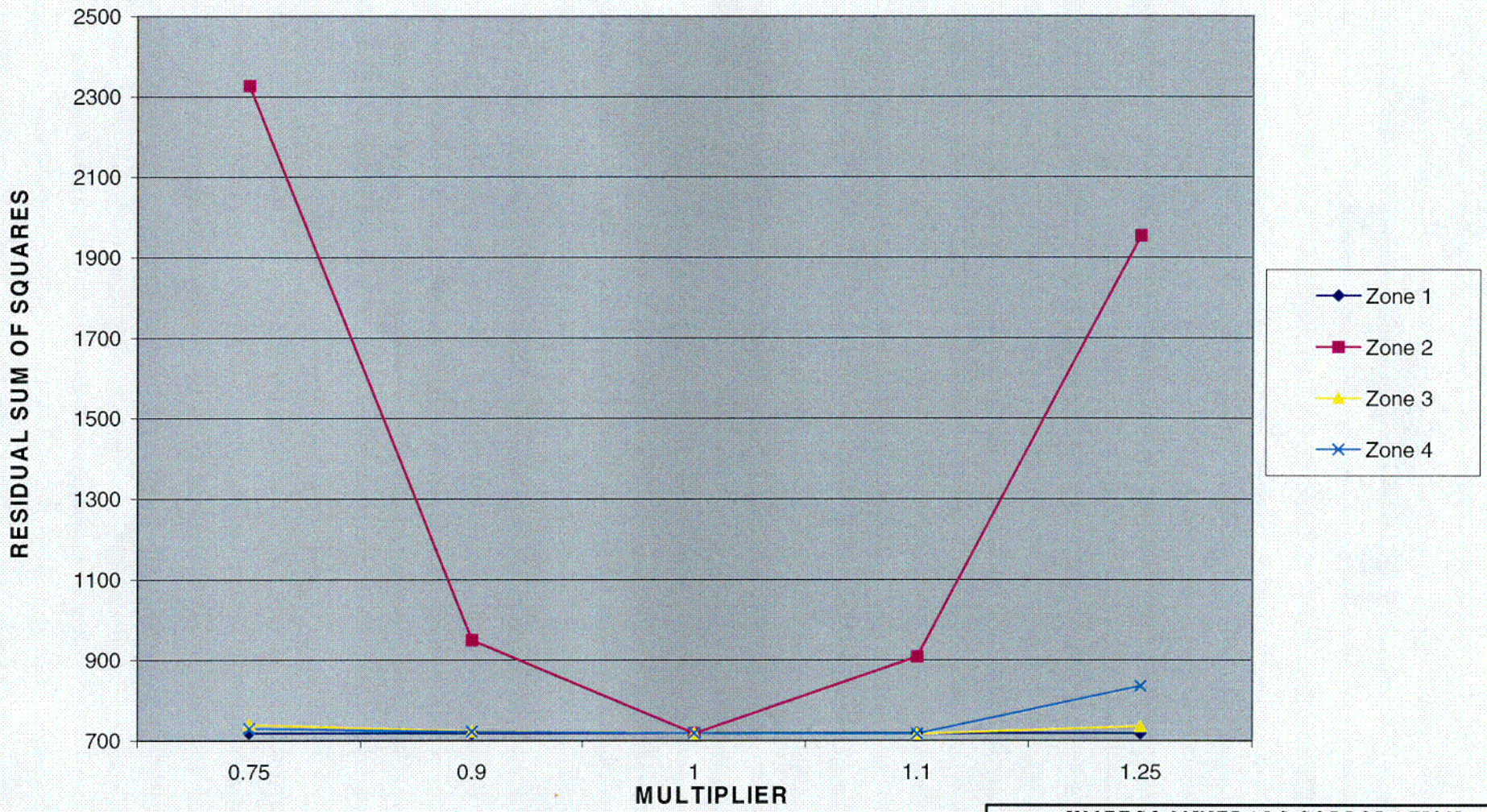
SENSITIVITY ANALYSIS
HYDRAULIC CONDUCTIVITY ZONES

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-13

FIGCT.SHF

C-8



UMETCO MINERALS CORPORATION

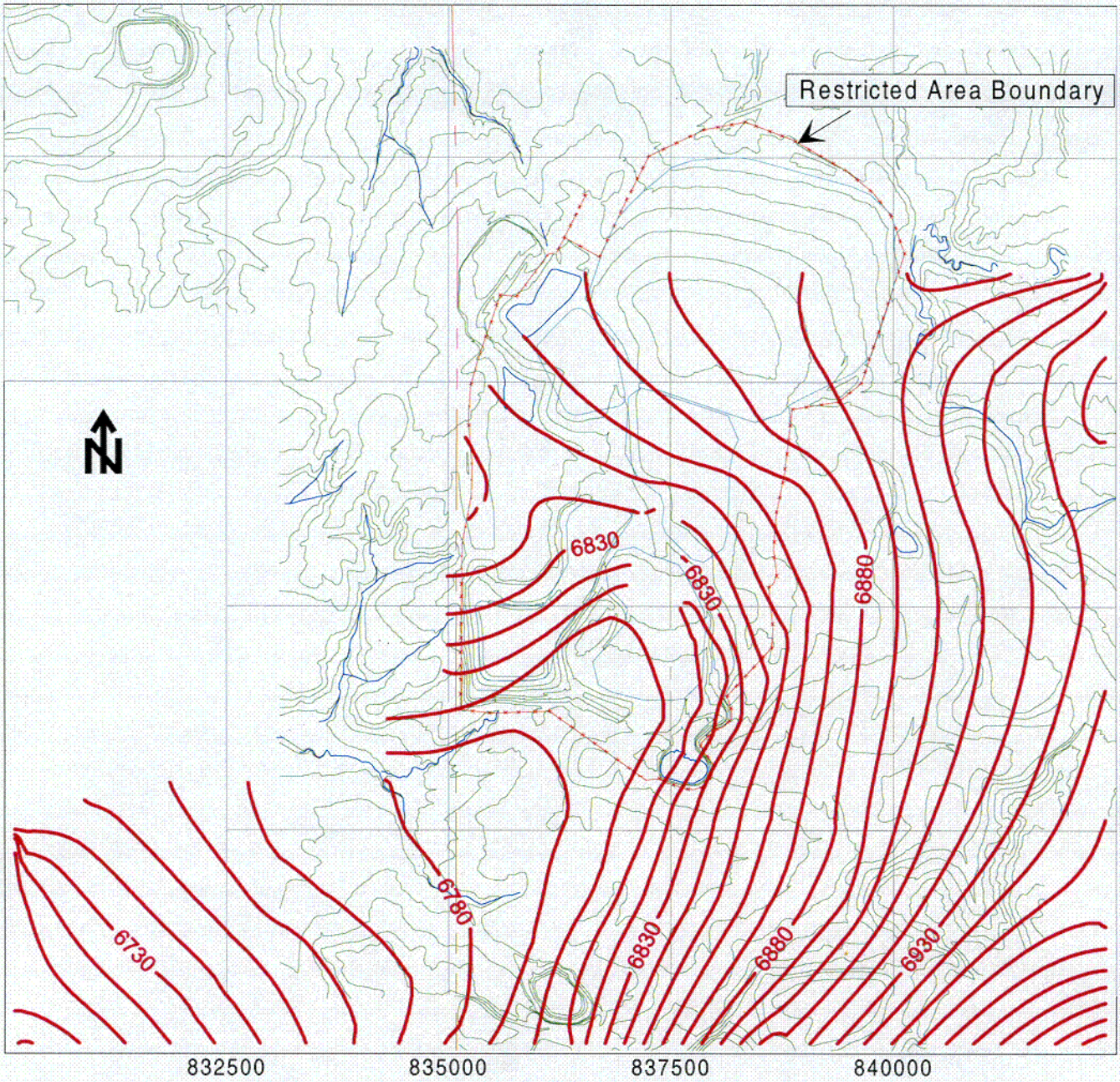
SENSITIVITY ANALYSIS-RECHARGE ZONES

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-14

C-9



Potentiometric Surface (10 foot contour intervals)

Topographic Contours (20 foot intervals)

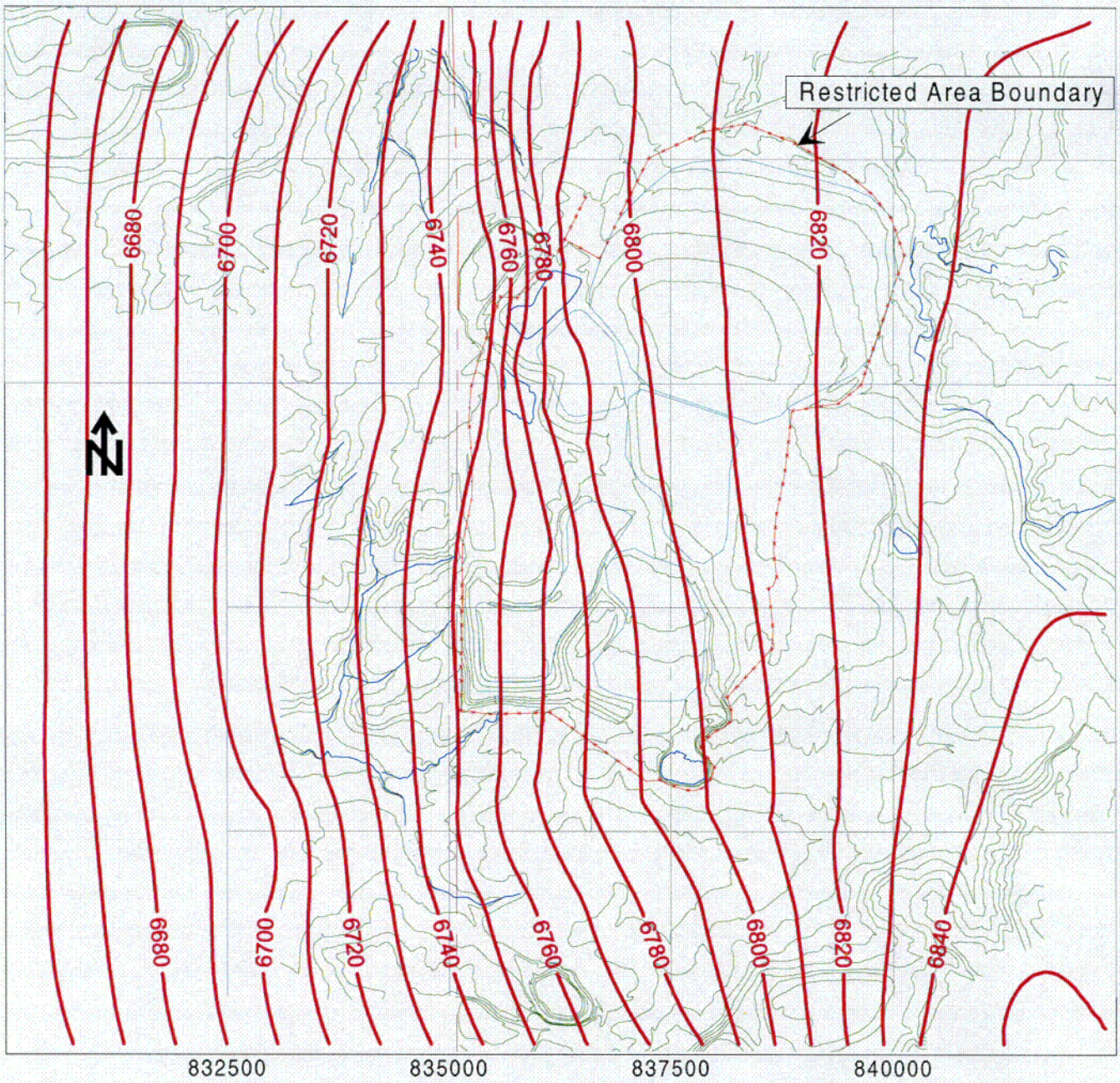
UMETCO MINERALS CORPORATION

POTENTIOMETRIC SURFACE FOR
THE CALIBRATION SIMULATION
LAYER 1

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-15

FIGC1.SRF



Potentiometric Surface (10 foot contour intervals)

Topographic Contours (20 foot intervals)

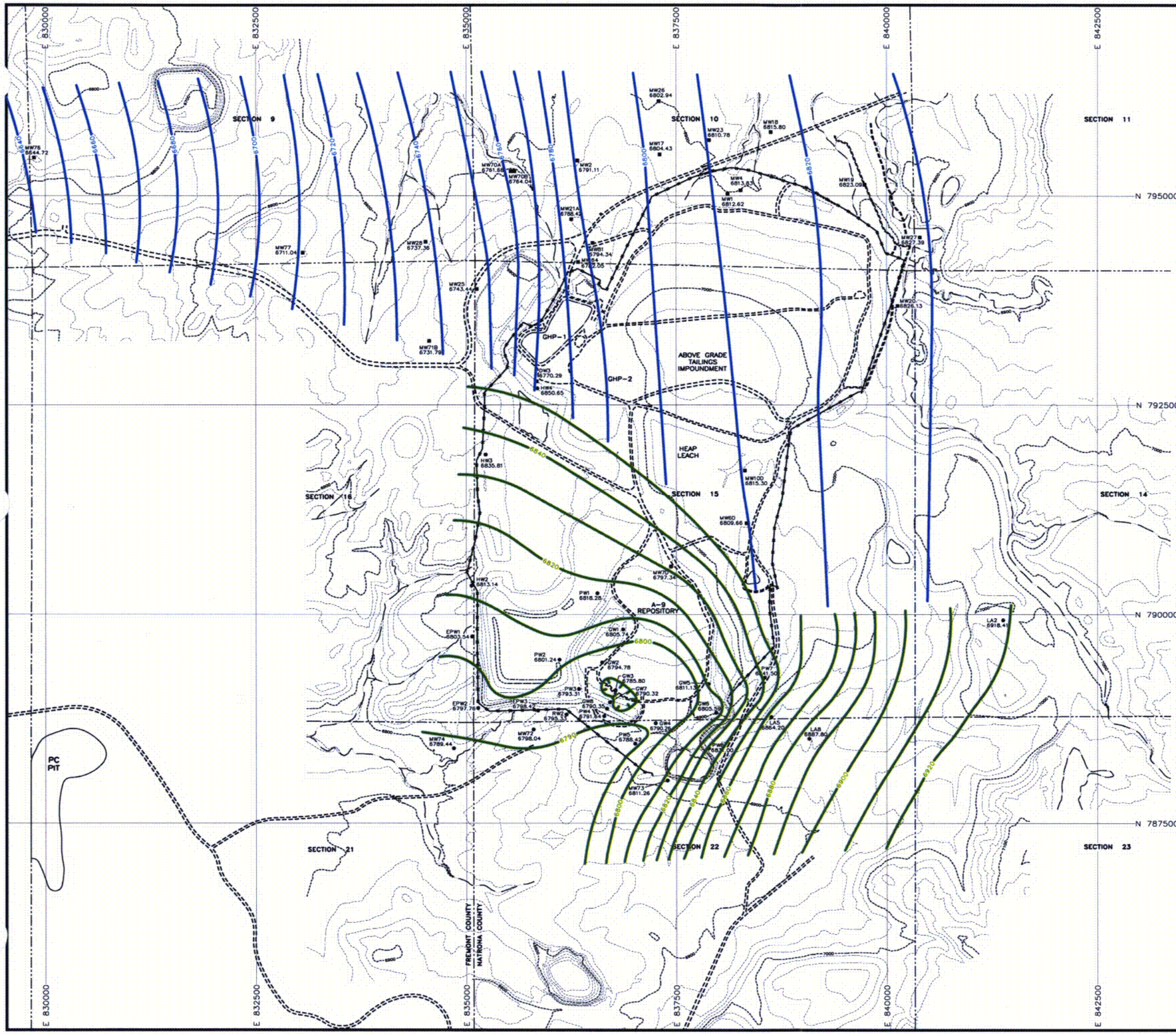
UMETCO MINERALS CORPORATION

POTENTIOMETRIC SURFACE FOR
THE CALIBRATION SIMULATION
LAYER 3

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-16

FIGC1.SRF



N

SCALE: 1" = 1200'
SURFACE CONTOUR INTERVAL: 20'
POTENTIOMETRIC CONTOUR INTERVAL: 10'

LEGEND:

- MW25 6753.91 ■ – MONITOR WELL IN THE WESTERN FLOW REGIME OF THE WIND RIVER AQUIFER. (WITH WATER LEVEL ELEVATION)
- GW2 6794.83 ● – MONITOR WELL IN THE SOUTHWESTERN FLOW REGIME OF THE WIND RIVER AQUIFER. (WITH WATER LEVEL ELEVATION)
- RESTRICTED AREA BOUNDARY (FENCE)
- SECTION LINE
- N 787500 — UMETCO SITE 2500' GRID SYSTEM
- 7000 — SURFACE CONTOUR LINE
- UNPAVED ROAD
- WATER FLOW/WATER SURFACE LINE
- POTENTIOMETRIC SURFACE OF THE WESTERN FLOW REGIME OF THE WIND RIVER AQUIFER
- POTENTIOMETRIC SURFACE OF THE SOUTHWESTERN FLOW REGIME OF THE WIND RIVER AQUIFER

NOTES:

1). SURFACE CONTOURS FROM 1997 AERIAL MAPPING BY DATA MAPPING.

2). SECTIONS SHOWN ALL FROM TOWNSHIP 33 NORTH, RANGE 89 WEST OF THE SIXTH PRINCIPAL MERIDIAN.

3). WATER-LEVEL ELEVATION DATA COLLECTED ON 3-13-00 AND 3-14-00.

C-12

UMETCO MINERALS CORPORATION

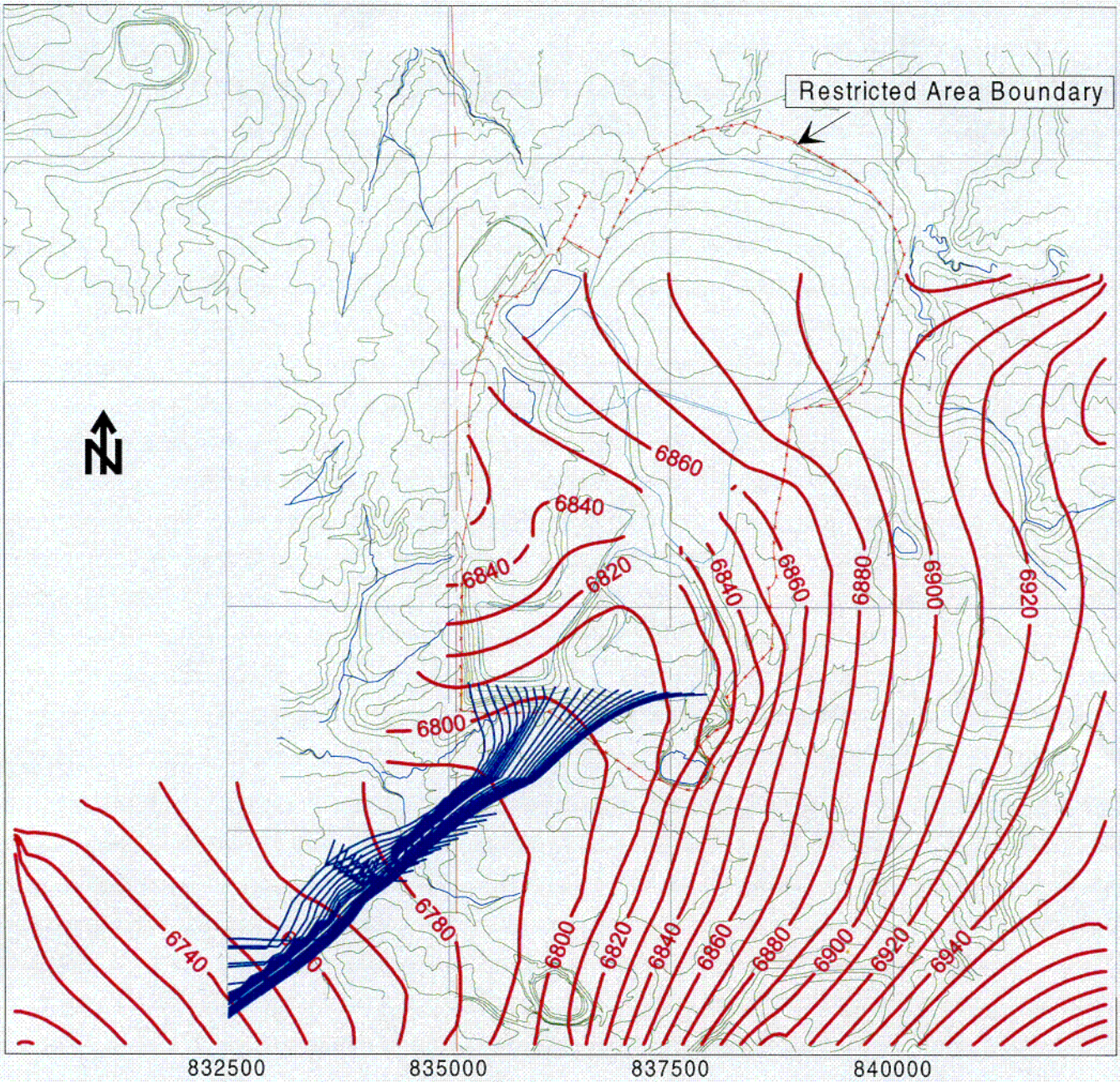
POTENTIOMETRIC SURFACE

MARCH 2000

GAS HILLS SITE

DECEMBER 2000 FIGURE C-17

FIGURE-C17.DWG



Particle track (groundwater flowpath)

Potentiometric Surface (10 foot contour intervals)

Topographic Contours (20 foot intervals)

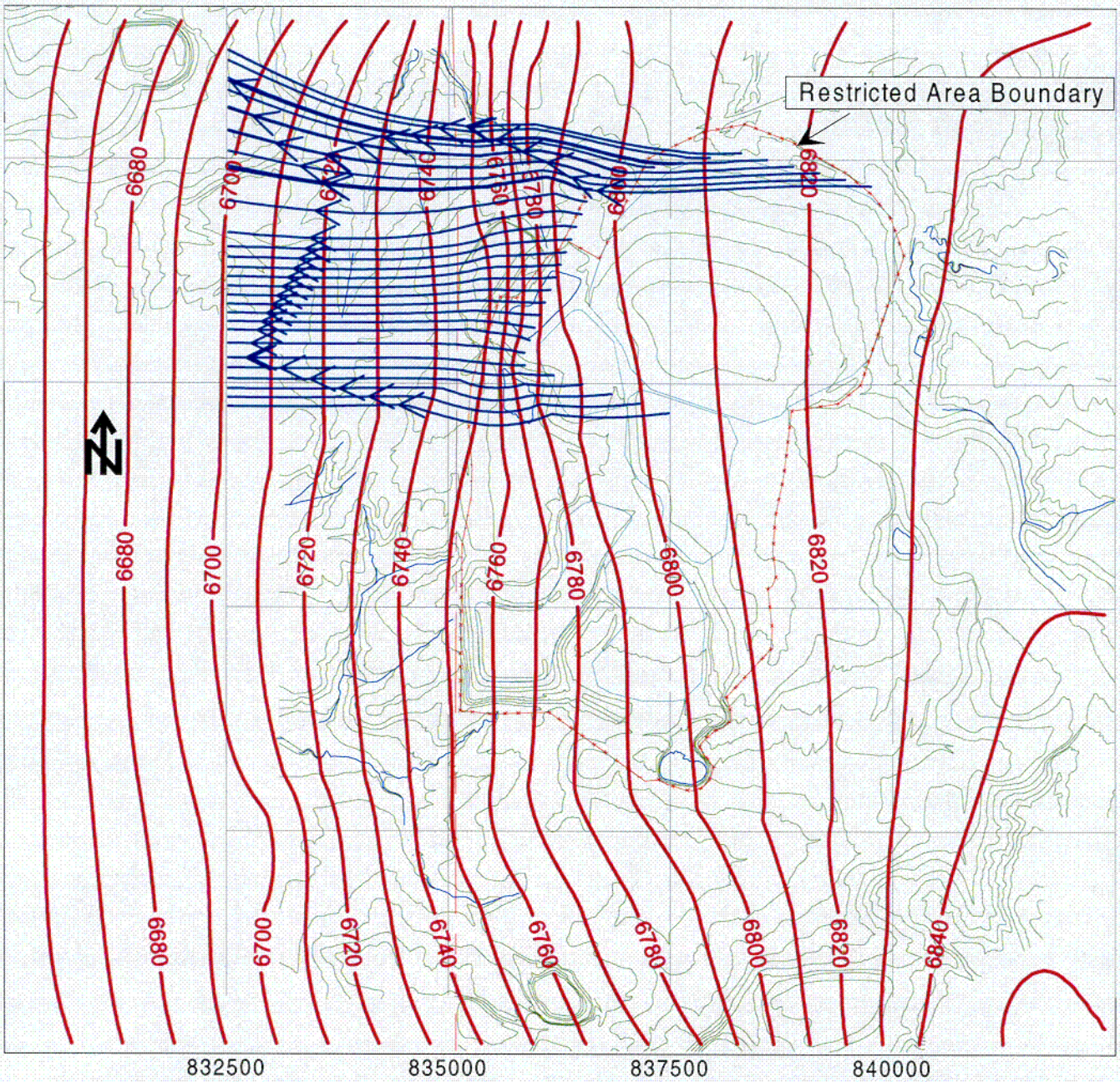
UMETCO MINERALS CORPORATION

POTENTIOMETRIC SURFACE FOR
THE CALIBRATION SIMULATION
WITHOUT PUMPING
LAYER 1
GAS HILLS SITE

NOVEMBER 2000 FIGURE C-18

FIGC1.SRF

C-13



Particle track (groundwater flowpath)

Potentiometric Surface (10 foot contour intervals)

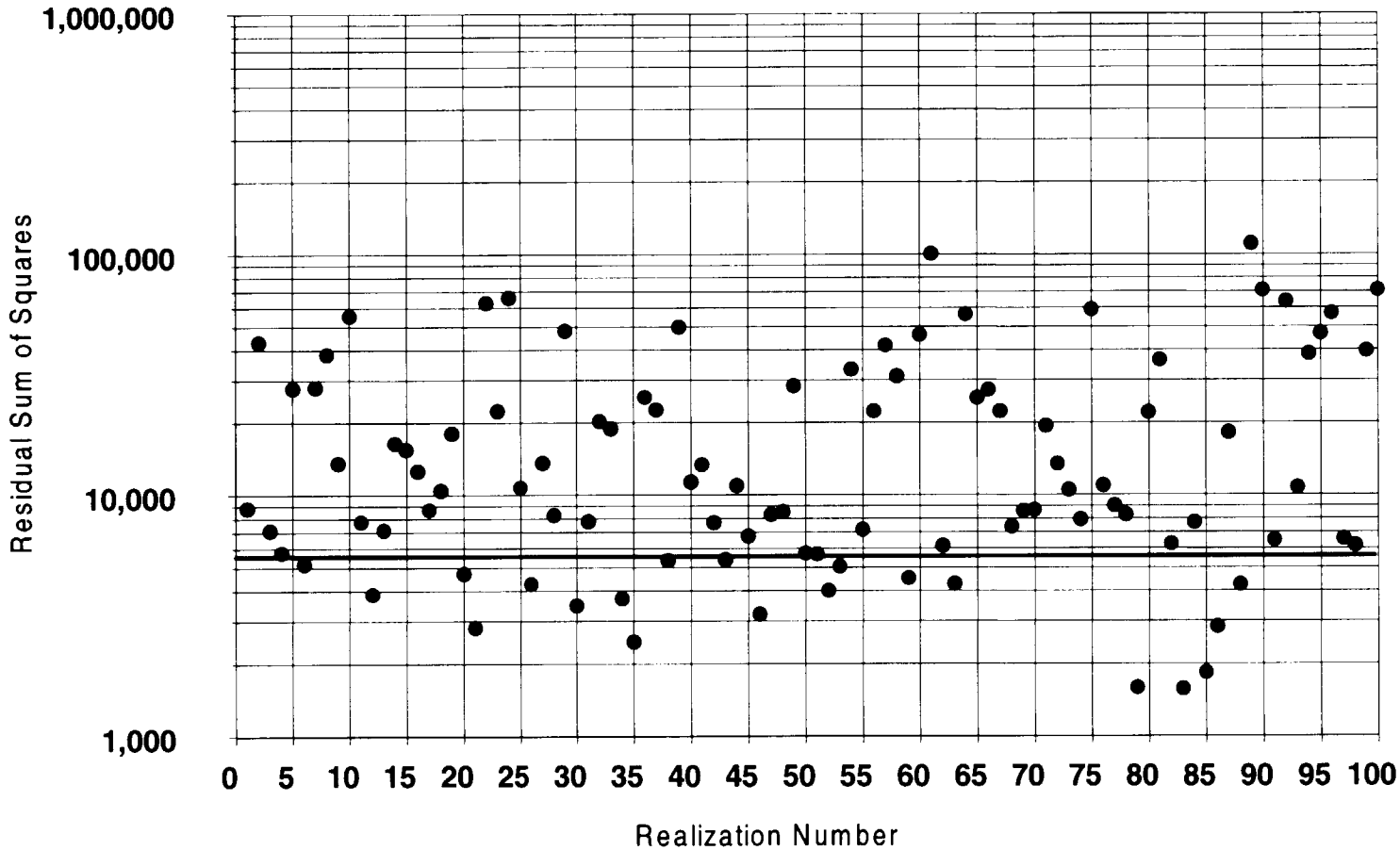
Topographic Contours (20 foot intervals)

UMETCO MINERALS CORPORATION

POTENTIOMETRIC SURFACE FOR
THE CALIBRATION SIMULATION
WITHOUT PUMPING
LAYER 3
GAS HILLS SITE

NOVEMBER 2000 FIGURE C-19

FIGC1.SRF



Note: only realizations with values below the red line (an RSS of approximately 5,800) were included for additional analysis

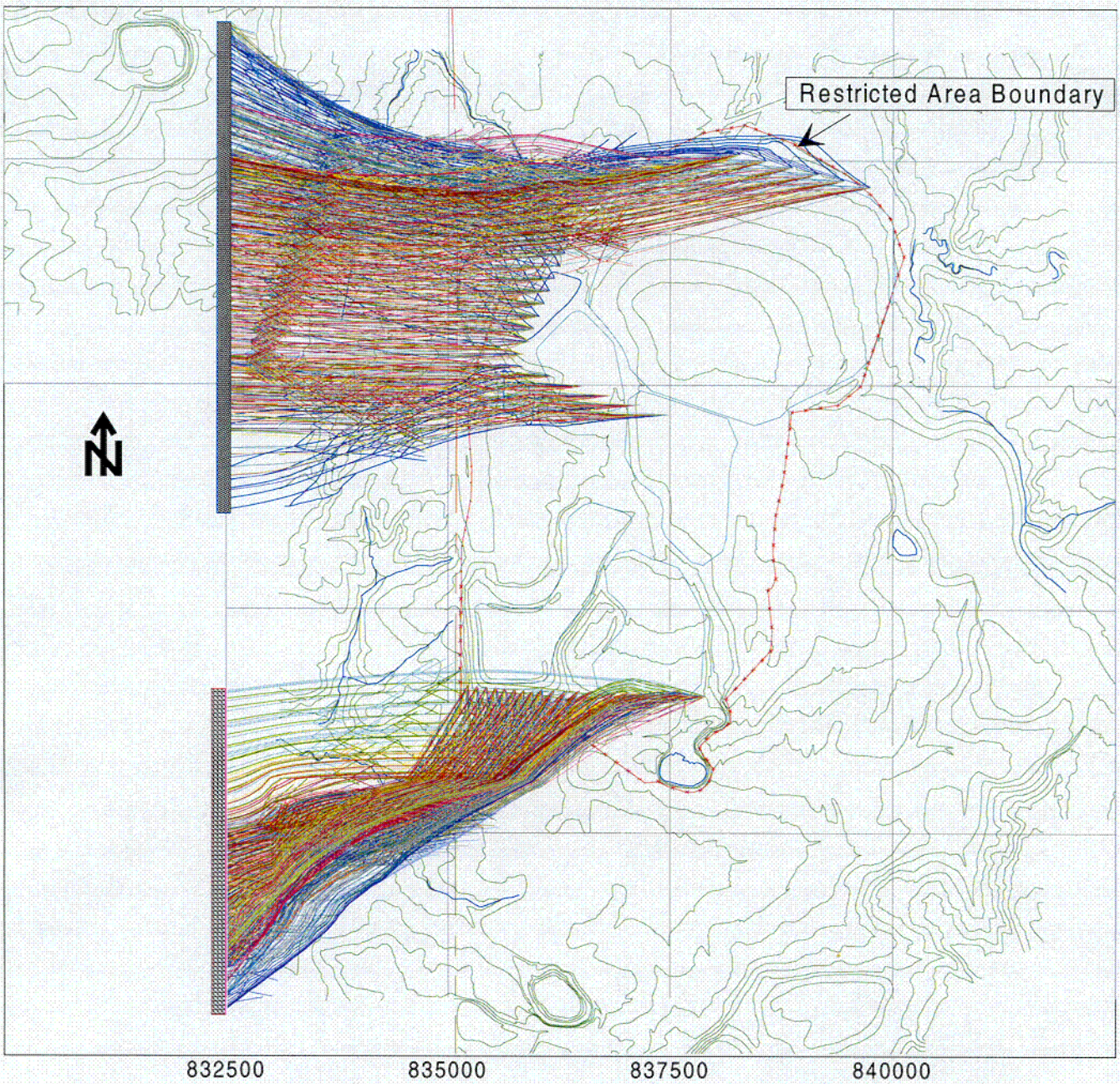
UMETCO MINERALS CORPORATION

RESIDUAL SUM OF SQUARES VALUES FOR STOCHASTIC MODEL SIMULATIONS

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-20



Groundwater flowpath-each distinct color represents flowpaths for a separate stochastic simulation

Indicates the range of flowpath intersections with the proposed land transfer boundary for Layer 1

Indicates the range of flowpath intersections with the proposed land transfer boundary for Layer 3

Topographic Contours (20 foot intervals)

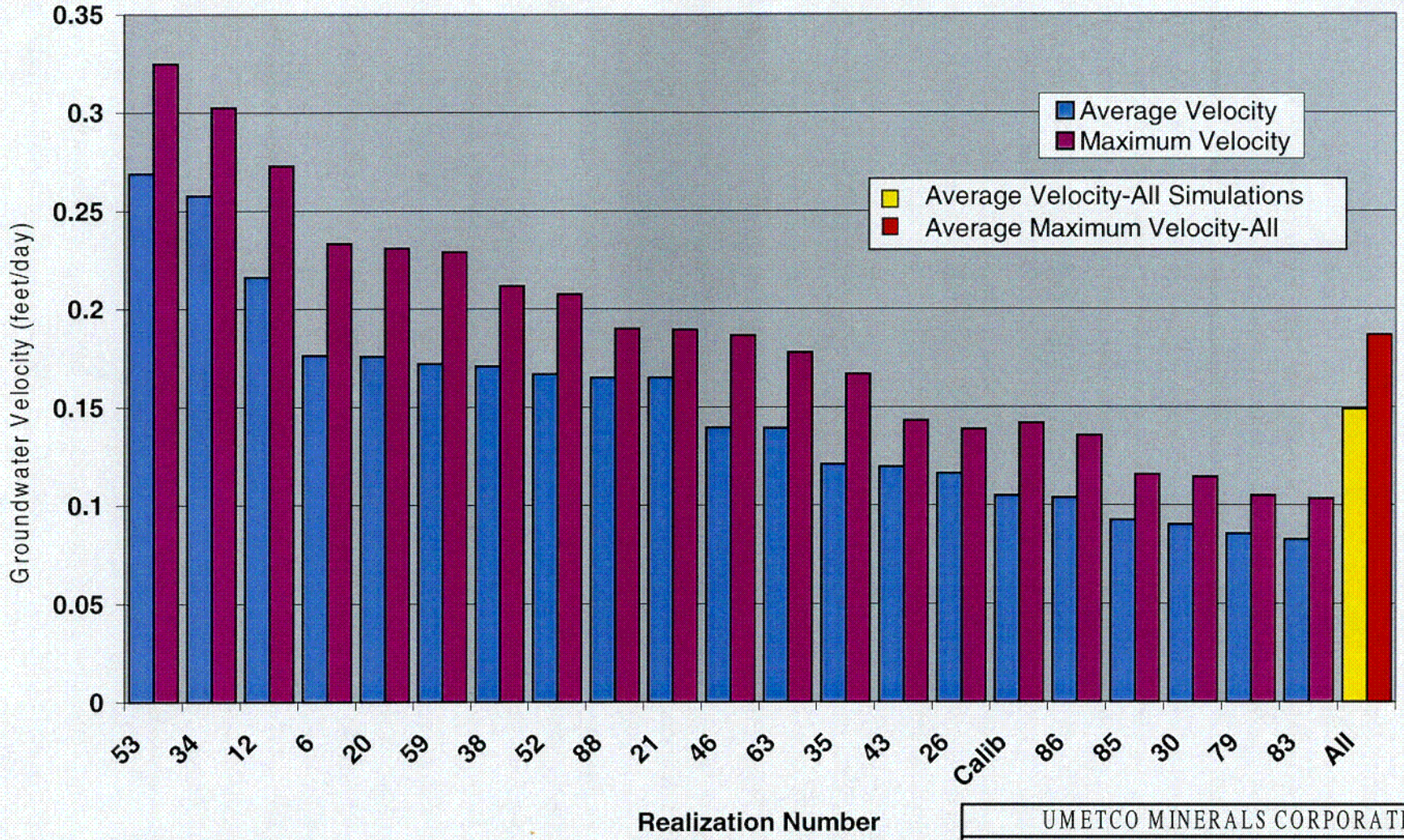
UMETCO MINERALS CORPORATION

FLOWPATHS FOR
STOCHASTIC MODEL SIMULATIONS

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-21

FIGC1.SRF



UMETCO MINERALS CORPORATION

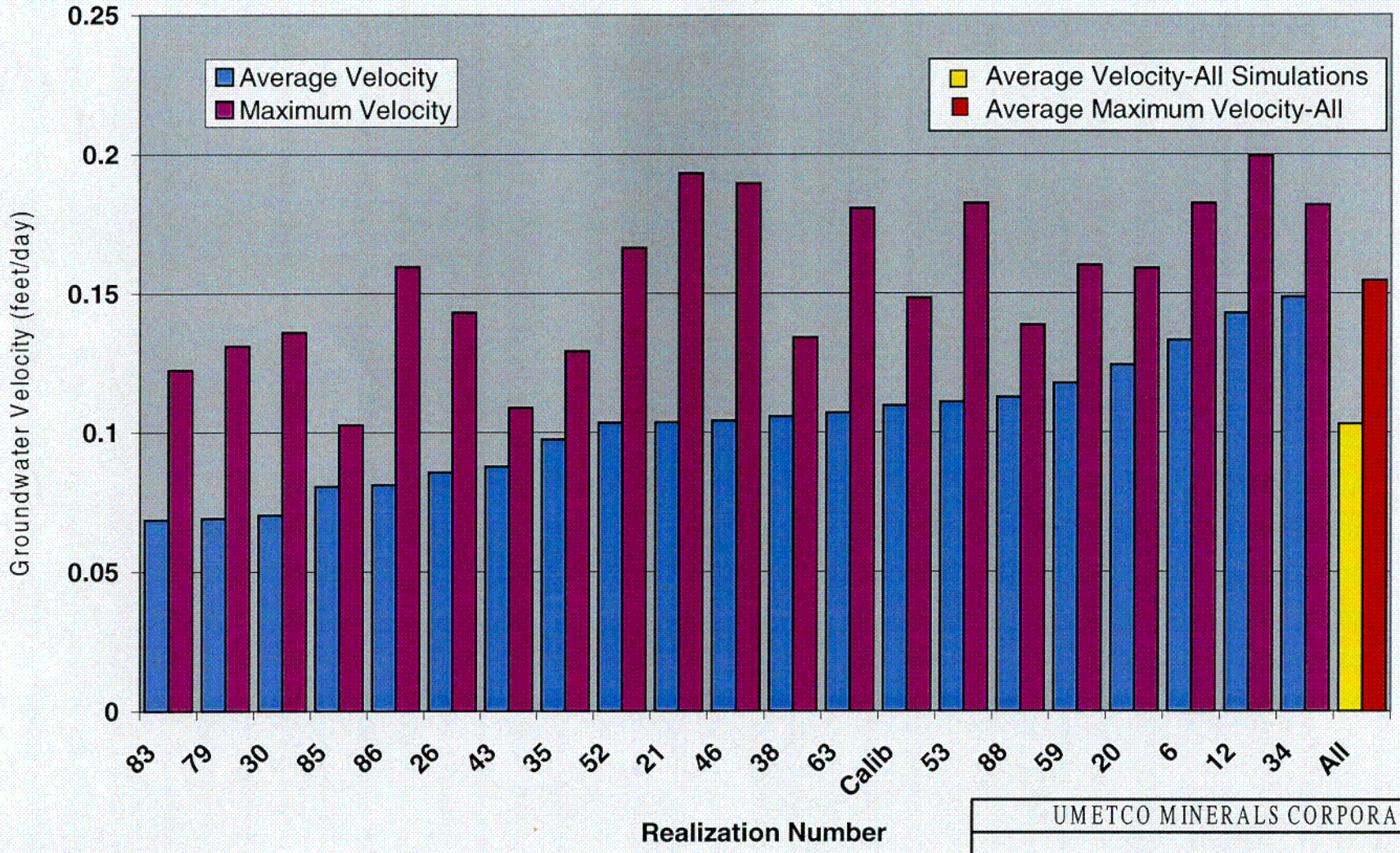
GROUNDWATER VELOCITY
STOCHASTIC MODEL SIMULATIONS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-22

C-16



UMETCO MINERALS CORPORATION

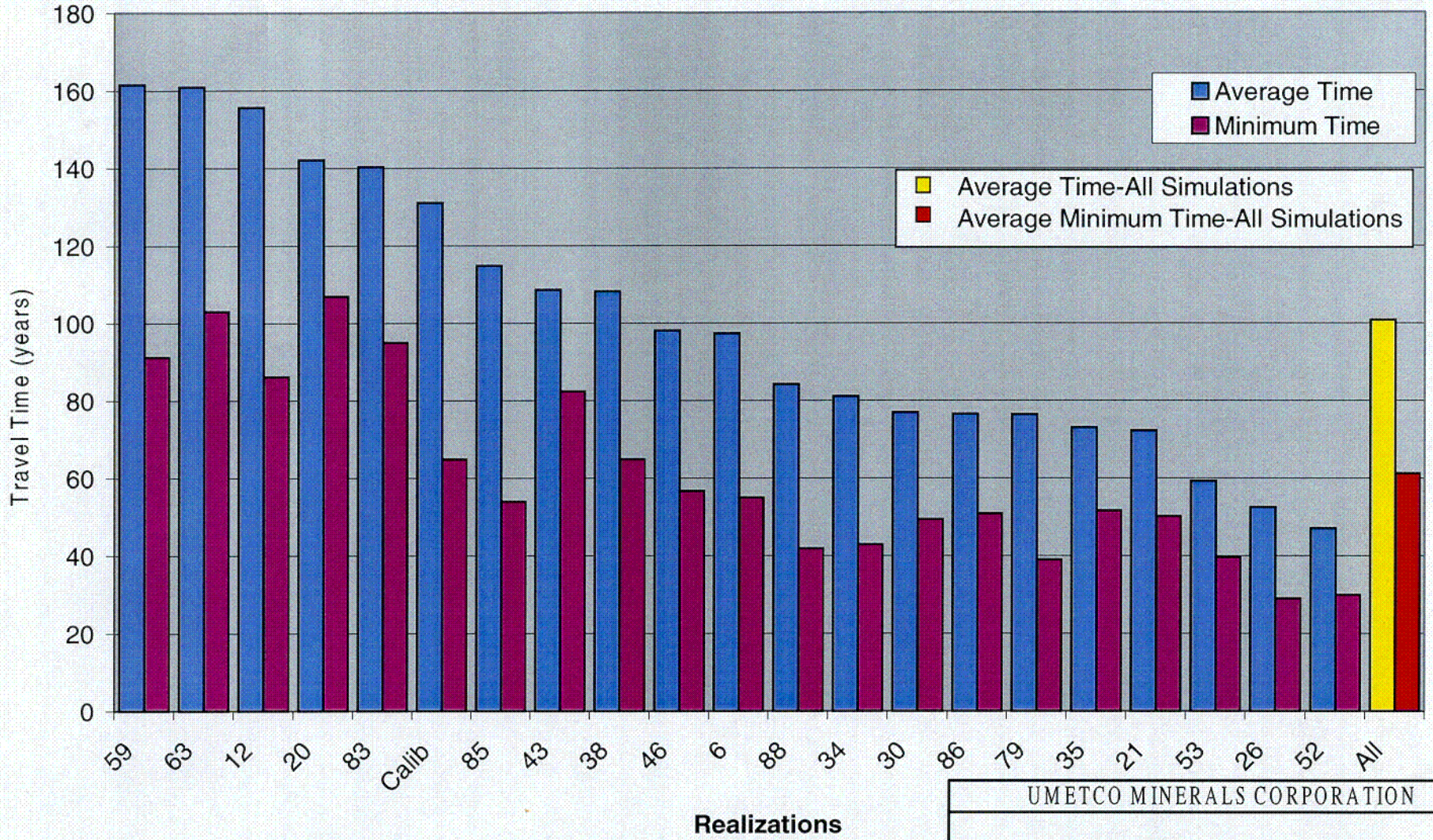
GROUNDWATER VELOCITY
STOCHASTIC MODEL SIMULATIONS
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-23

C-17



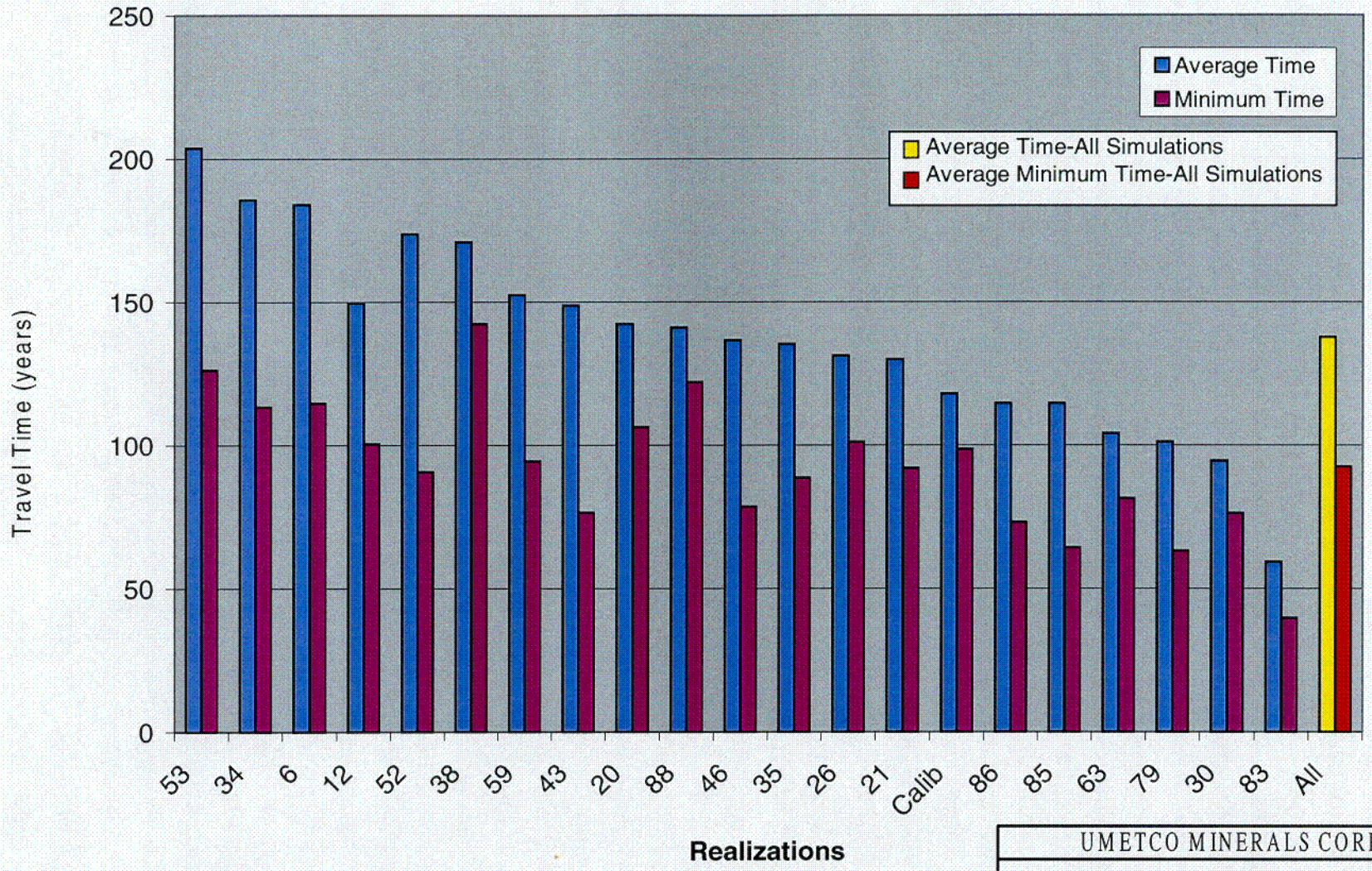
UMETCO MINERALS CORPORATION

GROUNDWATER TRAVEL TIMES
STOCHASTIC MODEL SIMULATIONS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-24



UMETCO MINERALS CORPORATION

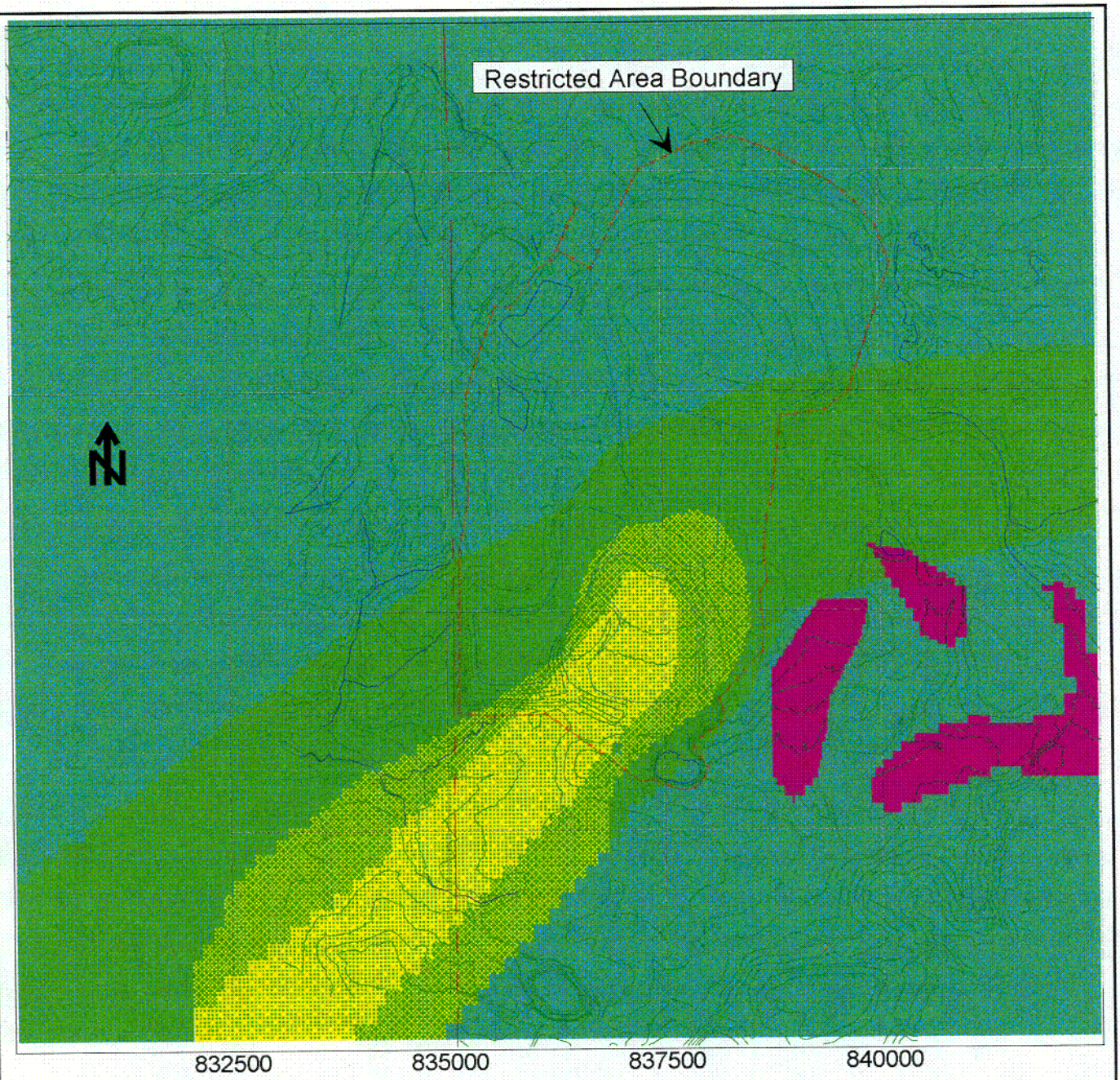
GROUNDWATER TRAVEL TIMES
STOCHASTIC MODEL SIMULATIONS
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-25

C-19



Hydraulic Conductivity

Zone	Value (feet/day)
5	0.20
7	0.66
8	0.46
11	2.32
12	*Ranged from 0.002 to 5

* Zone 12 represents hydraulic conductivity in reclaimed mine pits that penetrated the water table above the mudstone. (See text for description of different simulations)

Topographic Contours (20 foot intervals)

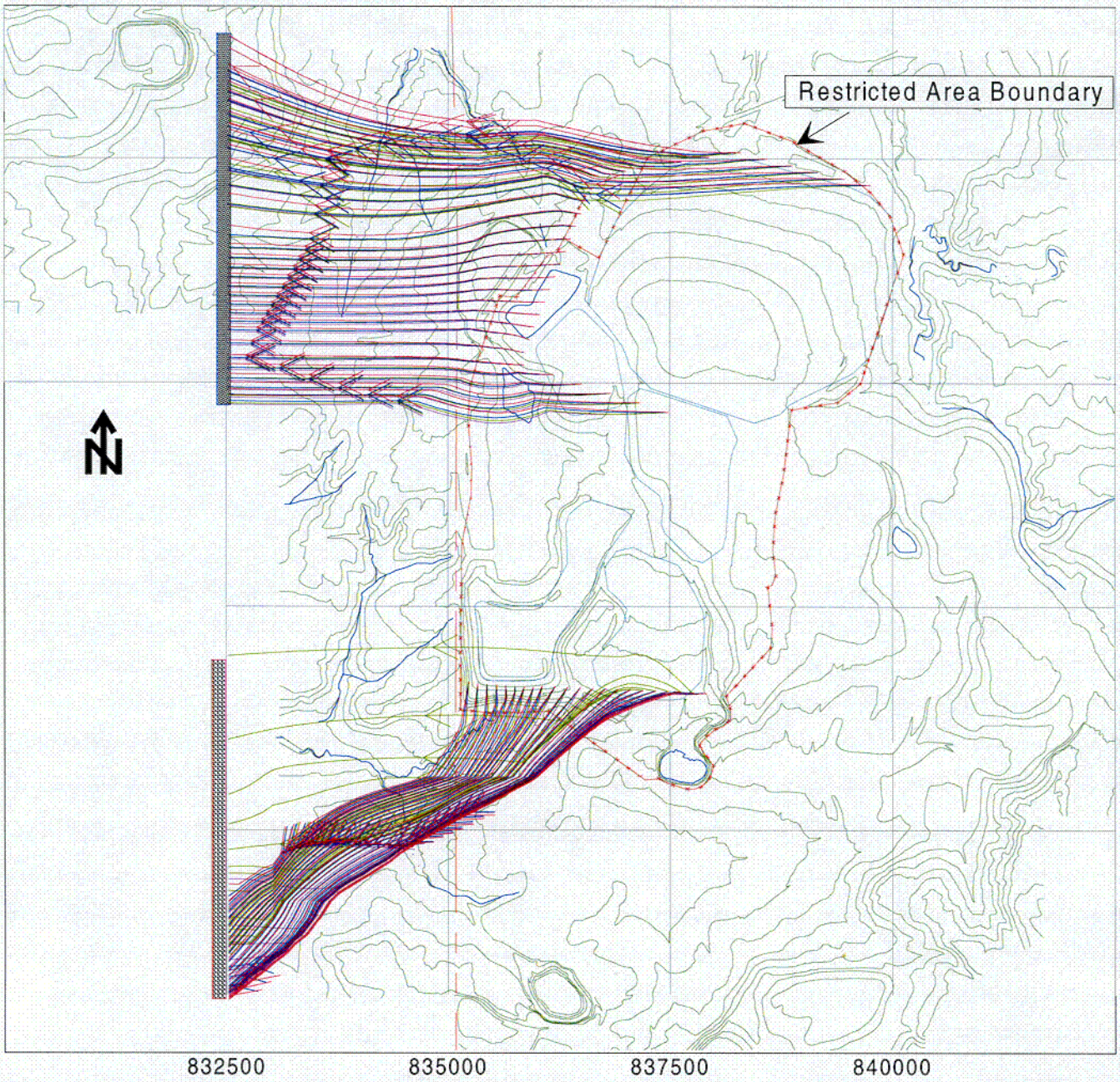
UMETCO MINERALS CORPORATION

HYDRAULIC CONDUCTIVITY ZONATION
MINING IMPACT SIMULATIONS

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-26



Groundwater flowpath-each distinct color represents flowpaths for a separate mining impactsimulation

Indicates the range of flowpath intersections with the proposed land transfer boundary for Layer 1

Indicates the range of flowpath intersections with the proposed land transfer boundary for Layer 3

Topographic Contours (20 foot intervals)

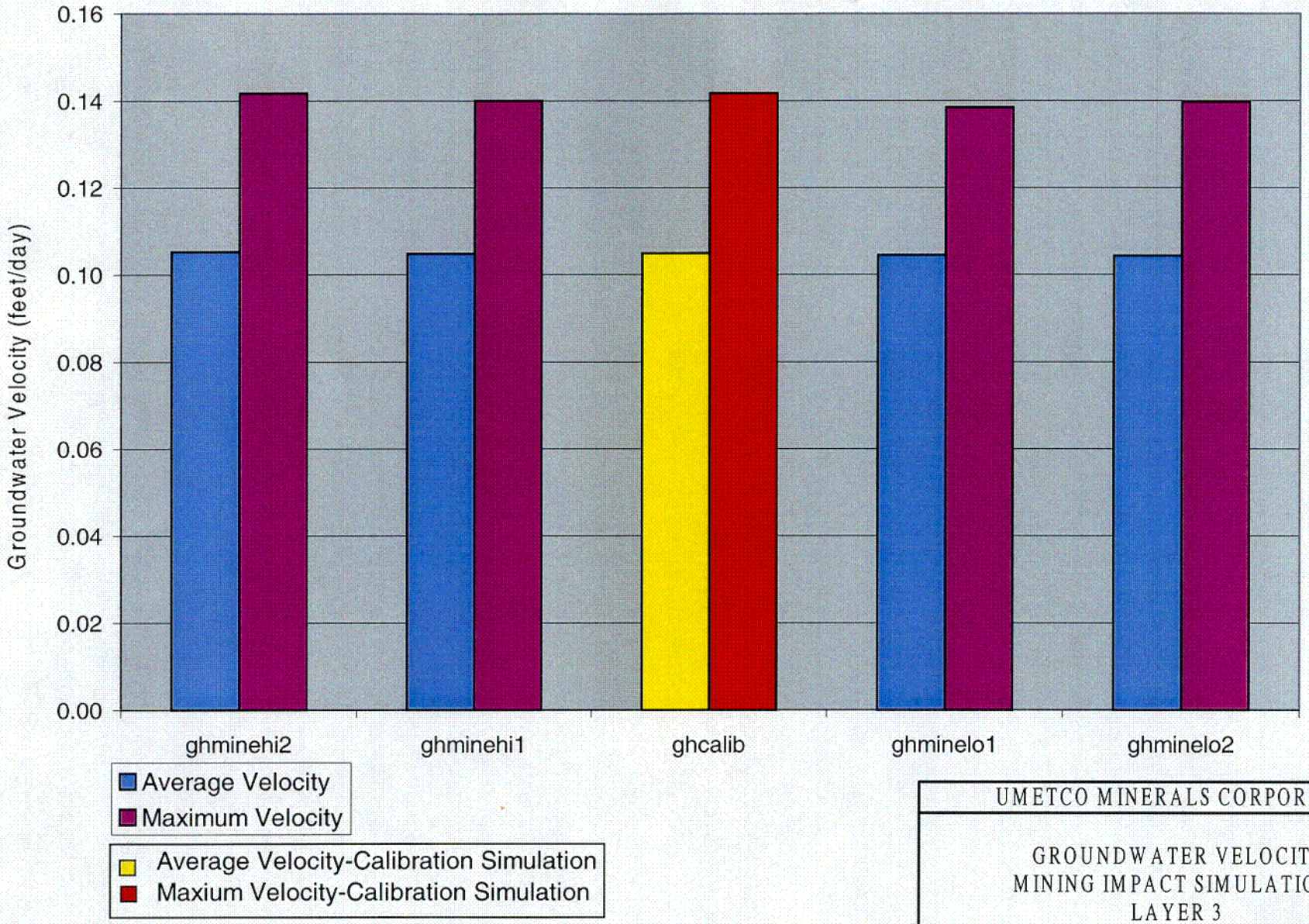
UMETCO MINERALS CORPORATION

FLOWPATHS FOR
MINING IMPACT SIMULATIONS

GAS HILLS SITE

NOVEMBER 2000 FIGURE C-27

FIGC1.SRF



UMETCO MINERALS CORPORATION

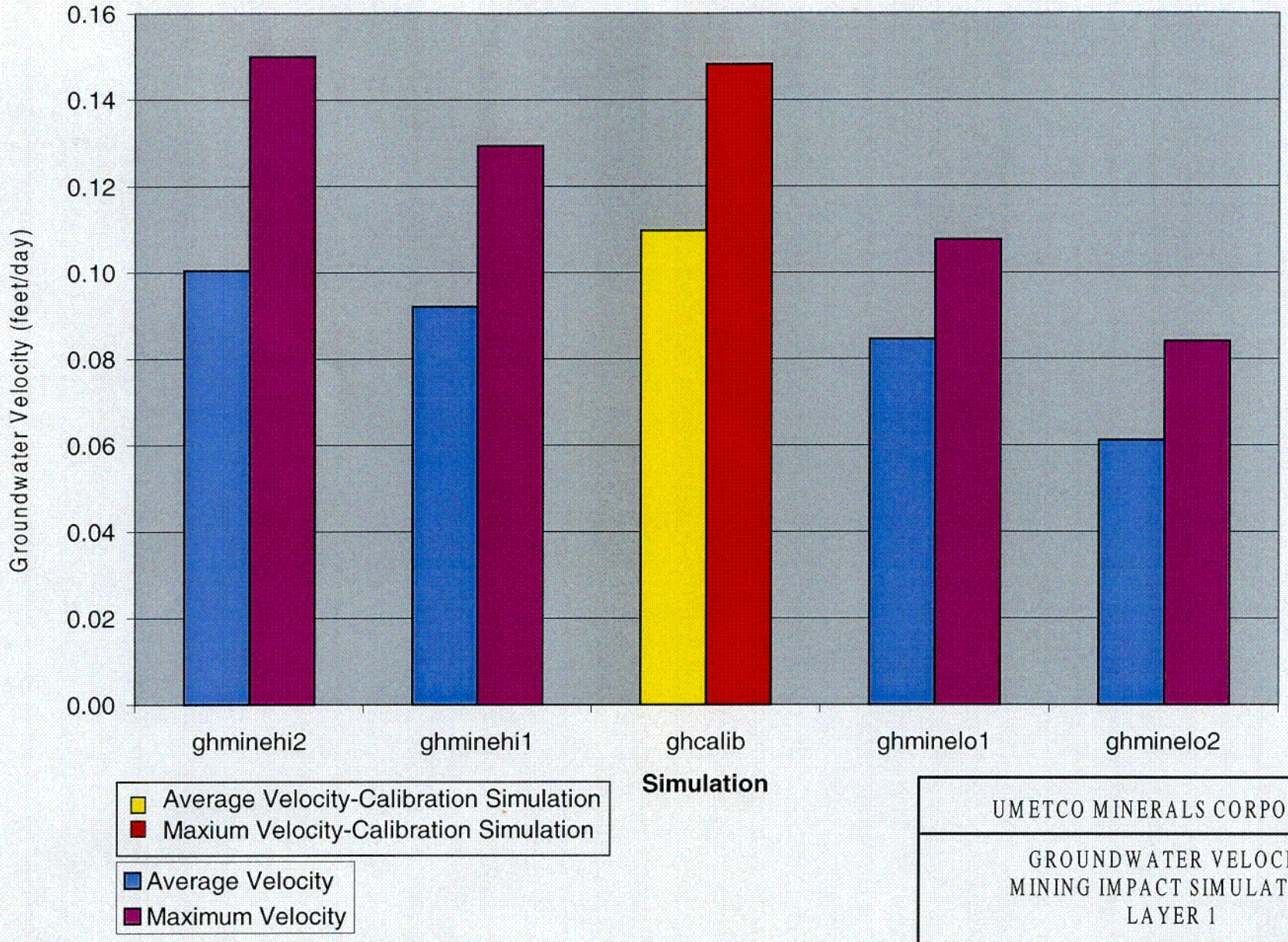
GROUNDWATER VELOCITY
MINING IMPACT SIMULATIONS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-28

C-22



UMETCO MINERALS CORPORATION

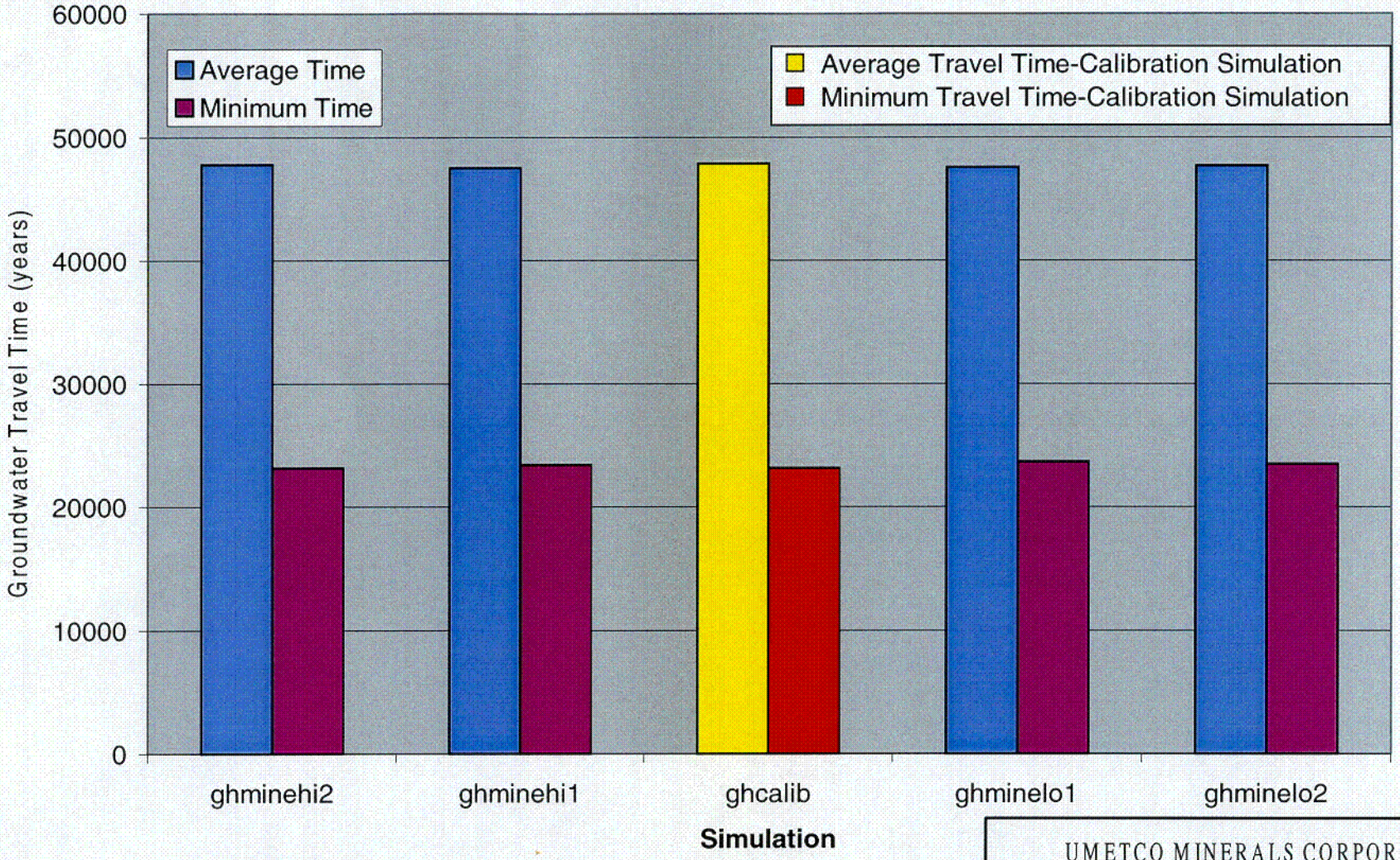
GROUNDWATER VELOCITY
MINING IMPACT SIMULATIONS
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-29

C-23



UMETCO MINERALS CORPORATION

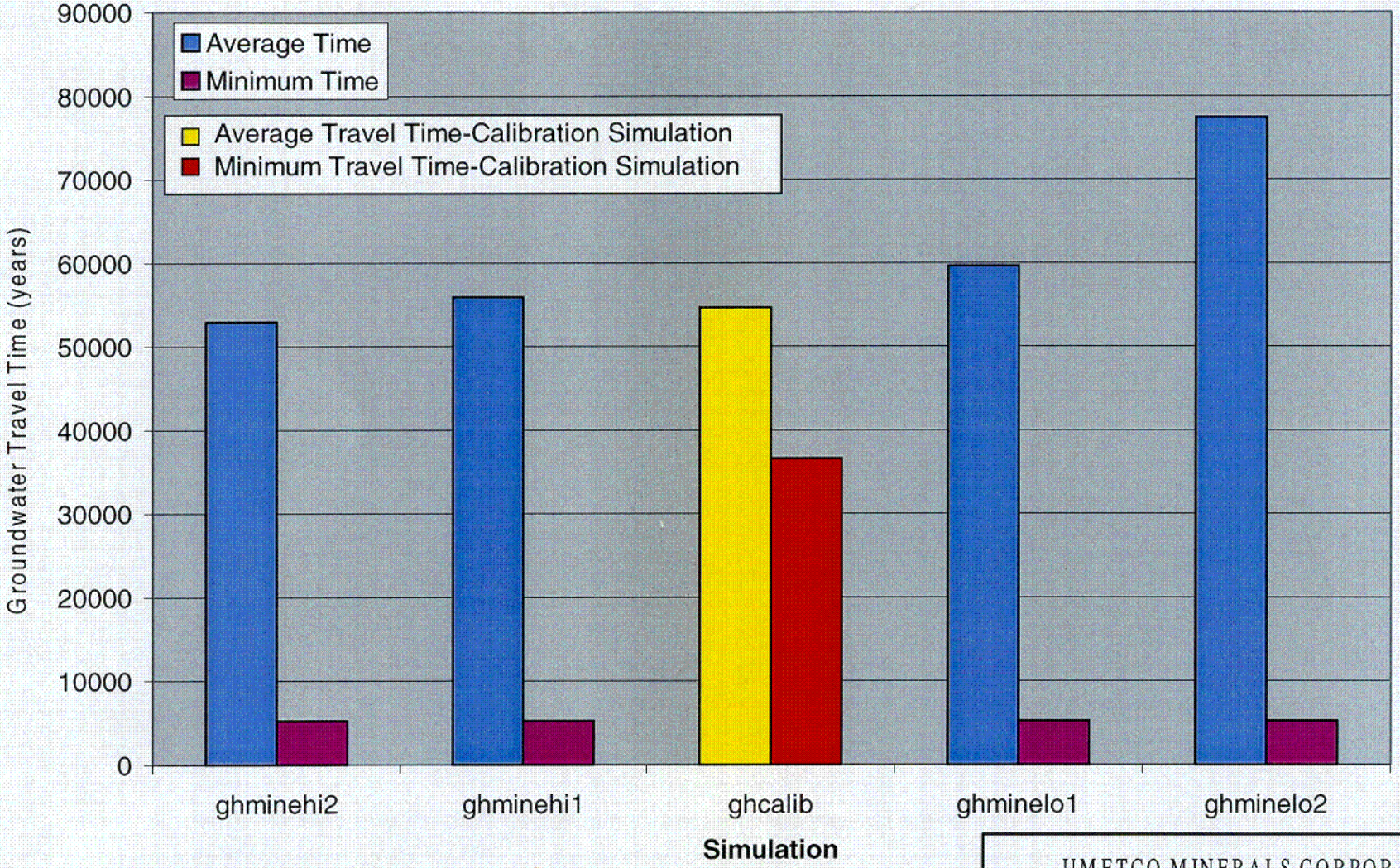
GROUNDWATER TRAVEL TIME
MINING IMPACT SIMULATIONS
LAYER 3

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-30

C-29



UMETCO MINERALS CORPORATION

GROUNDWATER TRAVEL TIME
MINING IMPACT SIMULATIONS
LAYER 1

GAS HILLS SITE

NOVEMBER 2000

FIGURE C-31

C-25