# Chapter 8

NATURAL RESOURCE TECHNOLOGY

# TECHNICAL MEMORANDUM

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**Date:** April 3, 2009

**Subject:** Groundwater Modeling of Hutsonville Pond D

**From:** Bruce Hensel

## Introduction

This technical memorandum describes results of modeling performed to evaluate fate and transport in the upper migration zone at the Hutsonville Power Station. The power station is located in Crawford County Illinois, north of the City of Hutsonville (Figure 1). Modeling was performed in 2000 and 2005; however, the results were reported separately and, as a result, were difficult to follow and comprehend. This technical memorandum is a stand-alone document that fully describes model development and reports on results that are relevant to current conditions and closure of Pond D. Specifically, the model was used to provide the following information:

- The southward extent to which off-site concentrations exceeded Illinois Class I Groundwater Quality Standards;
- The reduction in boron loading to the Wabash River as a result of dewatering and closure of Pond D;
- The effectiveness of the proposed remedial strategy for Pond D (consisting of a synthetic cap coupled and a groundwater collection trench along the south property boundary); and
- The volume of groundwater that will discharge to the groundwater collection trench.

Transport of boron was modeled because it is an indicator parameter for coal ash leachate, it is mobile in groundwater, and its concentration in downgradient monitoring wells is nearly an order of magnitude higher than its Class I groundwater quality standard.

Three model codes were used to simulate groundwater flow and contaminant transport:

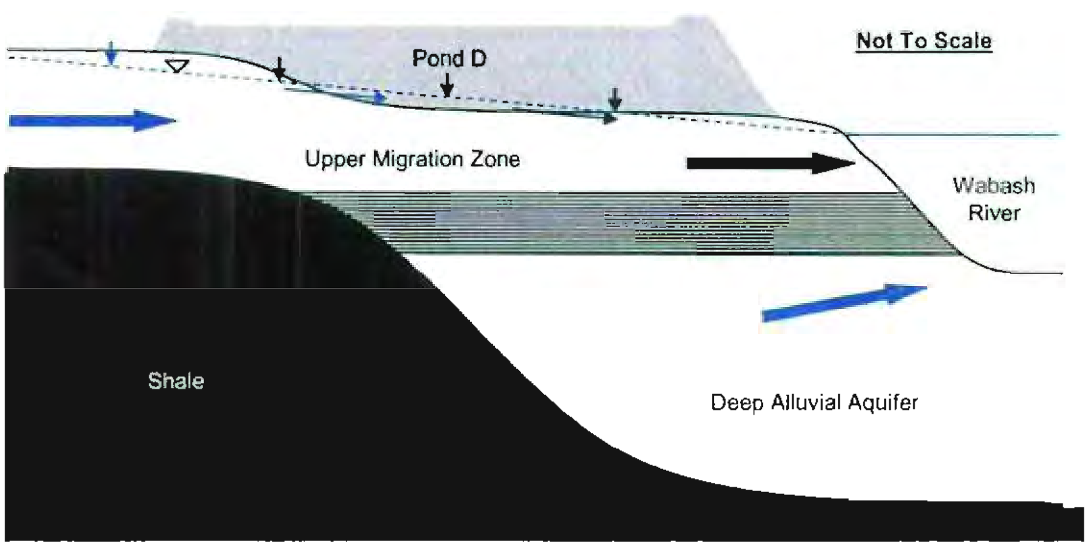
- Leachate percolation after pond closure was modeled using the Hydrologic Evaluation of Landfill Performance (HELP) model;

- Groundwater flow was modeled in three dimensions using MODFLOW (The HELP model provided post-closure leachate percolation rates for input to MODFLOW); and
- Contaminant transport was modeled in three dimensions using MT3DMS (MODFLOW calculated the flow field that MT3DMS used in the contaminant transport calculations).

## Conceptual Model

Hydrostratigraphy, developed from site boring logs, indicates that the upland area near Pond D consists of sand and gravel of varying thickness, typically 10 to 20 feet, underlain by 15 to more than 30 feet of sandstone--this is referred to as the upper migration zone (Figure 2, Cross Section A-A'). The upper sand appears to grade to a fine-grained silty clay toward the northern portion of the site (Figure 2, Cross Section C-C'). A thick shale unit underlies the sandstone at an approximate elevation of about 415 to 420 feet. The Wabash River valley contains a relatively fine-grained alluvium from land surface to an elevation of about 410 to 415 feet, underlain by sand and gravel to an elevation of about 350 feet—the sand and gravel at depth in the Wabash river valley is referred to as the deep alluvial aquifer.

The conceptual model for this site is schematically illustrated below and as follows: There are three sources of water: natural recharge within the model domain, percolation water from Pond D, and groundwater flow from the west. Groundwater in the upper migration zone flows horizontally east, discharging into the Wabash River, a regional groundwater sink. Where coal ash is encountered within the upper migration zone, groundwater flows horizontally through the ash. Percolation through the coal ash and groundwater flow through ash at elevations below the water table are the sources of solute mass to the model, and the sink for solute mass is the Wabash River.






TSD 000495

# HELP Modeling

The Hydrologic Evaluation of Landfill Performance (HELP) code was developed by the U.S. Environmental Protection Agency and is used extensively in waste facility assessments. HELP predicts one-dimensional vertical percolation from a landfill or soil column based on precipitation, evapotranspiration, runoff, and the geometry and hydrogeologic properties of a layered soil and waste profile.

HELP (Version 3.07; Schroeder et. al, 1994) was used to estimate percolation from Pond D during dewatering and after construction of the synthetic cap. The hydrologic data required by and entered into HELP are listed in Table 1 and described in the following paragraphs.

## Help Model Approach

The time line for the HELP modeling is as follows: Dewatering was simulated for a three year period, then the cap was simulated for 22 years. The 22-year cap simulation period was sufficient for the system to reach equilibrium.

## Input Data

Climatic input variables were synthetically generated by the model using modified default values for Evansville, Indiana, and a latitude of 39.13° N for the Hutsonville Power Station. Rainfall frequency and temperature patterns for more than 100 cities are programmed into HELP. Evansville was selected as the closest city to Hutsonville. The model used Evansville's precipitation and temperature patterns with average monthly precipitation data recorded at the two closest monitoring stations with long-term records[1] to generate daily precipitation and temperature data. Modeling was performed assuming fair vegetation, which generally results in greater infiltration than good vegetation and is therefore conservative.

Physical input data were based on a combination of measured and assumed soil properties. The ash was subdivided into three 60-inch thick sublayers. This subdivision resulted in more rapid percolation responses to surface changes, such as dewatering, than two 90-inch layers, yet provided the same results as six 30-inch thick layers. The 15-foot combined thickness of the ash layers represented the estimated thickness of ash above the water table after dewatering.

Hydrogeologic properties for the ash and cap soils were selected from the HELP database. Initial moisture content was set equal to its porosity, representing ponded conditions immediately prior to dewatering. The cap scenario was simulated with initial moisture content of the ash layers equal to the moisture content calculated by HELP at the end of the dewatering period. Initial moisture content of the cap materials used in the closure scenarios was set equal to their field capacity.

The HELP modeling assumed that sluice water discharge to Pond D ceased immediately before the simulation began, the cap was instantaneously placed after the dewatering period, the cap materials and ash had uniform texture and hydraulic properties, there was no lateral groundwater flow into or out of the impoundment, and all leakage to groundwater was vertical. Other assumptions inherent in the model are listed in Schroeder et al. (1994).

### Help Model Results

Help model results are discussed below in the recharge subsection. A disk containing model files is attached to the back of the report.

## MODFLOW / MT3DMS Modeling

### Model Description

MODFLOW uses a finite difference approximation to solve a three-dimensional head distribution in a transient, multi-layer, heterogeneous, anisotropic, variable-gradient, variable-thickness, confined or unconfined flow system—given user-supplied inputs of hydraulic conductivity, aquifer/layer thickness, recharge, wells, and boundary conditions. The program also calculates water balance at wells, rivers, and drains.

MODFLOW was developed by the United States Geological Survey (McDonald and Harbaugh, 1988), has been extensively tested for accuracy (van der Heijde and Elnawawy, 1993), and is the most widely used code for groundwater model applications (Rumbaugh and Ruskauff, 1993). Major assumptions of the code are: 1) groundwater flow is governed by Darcy's law; 2) the formation behaves as a continuous porous medium; 3) flow is not affected by chemical, temperature, or density gradients; and 4) hydraulic

[1] Precipitation recorded at the Hutsonville power station and average temperature data recorded at Palestine, Illinois.

properties are constant within a grid cell. Other assumptions concerning the finite difference equation can be found in McDonald and Harbaugh (1988).

MT3DMS (Zheng and Wang, 1998) is an update of MT3D. It calculates concentration distribution for a single dissolved solute as a function of time and space. Concentration is distributed over a three-dimensional, non-uniform, transient flow field. Solute mass may be input at discrete points (wells, drains, river nodes, constant head cells), or areally distributed evenly or unevenly over the land surface (recharge).

MT3DMS accounts for advection, dispersion, diffusion, first-order decay, and sorption. Sorption can be calculated using linear, Freundlich, or Langmuir isotherms. First-order decay terms may be differentiated for the adsorbed and dissolved phases.

The program uses a finite difference solution, third-order total-variation-diminishing (TVD) solution, or one of three Method of Characteristics (MOC) solutions. The finite difference solution can be prone to numerical dispersion for low-dispersivity transport scenarios, and the MOC solutions sometimes fail to conserve mass. The TVD solution is not subject to numerical dispersion and conserves mass well, but is computationally intensive.

For this modeling, the TVD solution was attempted first; however, results outside the area of interest were anomalous (e.g., in the thousands and negative thousands). Therefore, the finite difference solution was used, resulting in similar concentrations as the TVD solution within the area of interest and concentrations near zero outside the area of interest. Zheng and Wang (1998) indicated that the effects of numerical dispersion are minimal when grid Peclet[2] numbers are smaller than 4.0. Since a Peclet number of 3.3 was maintained for this analysis[3], the finite difference solution is acceptable.

MT3D has been tested and verified, and is widely used (van der Heijde and Elnawawy, 1993). Major assumptions are: 1) changes in the concentration field do not affect the flow field; 2) changes in the concentration of one solute do not affect the concentration of another solute; 3) chemical and hydraulic properties are constant within a grid cell; and 4) sorption is instantaneous and fully reversible, and decay is not reversible.

[2] Peclet number (Pe) = Grid spacing divided by longitudinal dispersivity.

[3] $Pe = 100 \div 30 = 3.3$

## Model Approach

MODFLOW was calibrated to in-service conditions (e.g., active use of Pond D as a disposal area) as represented by heads measured in November 1998. This measurement event was selected because all wells installed for the 1999 hydrogeologic assessment were measured at that time, and because river elevation and groundwater elevation (head) values at older wells were near long-term median values. Next, MT3DMS was run, and model-predicted concentrations were calibrated to observed boron concentration values. These calibration runs were performed assuming steady-state flow. Multiple iterations of MODFLOW and MT3DMS calibration were performed to achieve an acceptable match to observed data. Sensitivity analyses were then performed to test the effect of selected parameters on model results. Because the Wabash River cuts across, and is on the west side of its bedrock valley at north part of the model domain (near the power plant), and no calibration data were available east of the river, the deep alluvial aquifer was not fully represented in the model. Therefore, this layer in the model does not accurately portray groundwater conditions in this aquifer.

The calibrated model was then modified for simulation of Pond D closure. The following changes were made for the closure simulation:

- The model was run in transient mode to simulate decreasing recharge as Pond D dewatered.
- Recharge and source concentration nodes representing the ash laydown area, which was present at the time of calibration, were replaced with recharge and source concentration nodes representing Ponds B and C, which were constructed in 2001. Inputs for Ponds B and C were the same as developed for Pond A during calibration.
- Recharge rates for Pond D were decreased based on HELP modeling to simulate dewatering followed by application of the geomembrane cap.
- A drain was added along the south property boundary to represent a groundwater collection trench.

## Model Setup

### *Grid and Boundaries*

A four layer, 56 by 60 node grid was established with variable grid spacing ranging from 100 feet to 500 feet in length parallel to the primary flow direction and 100 feet to 500 feet perpendicular to the primary flow direction (Figure 3). The largest node spacings were near the upgradient and lateral model boundaries, and the finest node spacings were along the river and near Pond D.

Flow and transport boundaries were the same for all scenarios (Figures 3 through 6). The upgradient edge of the model was a constant head (Dirichlet) boundary. The lower and lateral boundaries were no-flow (Neumann) boundaries. The downgradient boundaries were either MODFLOW river (Mixed) boundaries (layers 2-4) or no flow (layer 1). The upper boundary was a time-dependent specified flux (Neumann) boundary, with specified flux rates equal to the recharge rate or the rate of percolation from Pond D.

Two types of transport boundaries were used. Specified mass flux (Cauchy condition) boundaries were used to simulate downward percolation of solute mass in areas where ash is above the water table, and constant concentration (Dirichlet condition) boundaries were used in areas where ash is below the water table. The former boundary condition assigns a specified concentration to recharge water entering the cell, and in this application the resulting concentration in the cell is a function of the relative rate and concentration of water percolating from the ash compared to the rate and concentration of groundwater flow. The latter boundary type assigns the specified concentration to all water passing through the cell.

### MODFLOW Input Values and Sensitivity

MODFLOW input values are listed in Table 2 and described below.

### *Aquifer Top/Bottom*

Groundwater in the upper migration zone is unconfined; therefore, the top of the aquifer was the water table and the elevation of the top model layer (layer 1) was set at 460 feet, a value higher than the observed water table elevation of 427 to 450 feet. The top of layers 2-4 was the base of the overlying layer.

The base of the upper sand unit was determined by contouring bedrock elevation and importing the contour data into MODFLOW. The corresponding base elevations for layer 1 were between 424 and 450 feet. The base of the second layer corresponded to the base of the sandstone, 418 feet. The base of the third layer corresponded to the top of the Wabash River valley sand unit, 412 feet. The base of the bottom layer (deep alluvial aquifer) corresponded to the base of the Wabash River valley sand unit (350 feet).

Layer 1 of the model included a zone with hydraulic conductivity representing ash. This zone was also used as a source area, representing saturated ash, during transport modeling. The base elevation of this zone was determined from contouring, as was the rest of model layer 1. Base elevations of the coal ash were contoured from 424 to 444 feet.

### *Hydraulic Conductivity*

Hydraulic conductivity values (Figures 7 through 10) were initially derived from field measured values, then adjusted during calibration.

Vertical anisotropy ratios were set at 2.0 everywhere except layer 4, where a ratio of 10 was the lowest possible without the affecting the single calibration point in that layer. The larger $K_x/K_z$ ratio represented anticipated stratification within the deep alluvial aquifer.

The shale bedrock underlying the sandstone was not discretely modeled. Rather, cells representing shale, all in layers 3 and 4, were set with no-flow boundary conditions. This setting inherently assumed that groundwater flow in the shale is negligible.

Model sensitivity to hydraulic conductivity ranged from negligible to high. The model was most sensitive to the layer 1 sand unit and the layer 2 sandstone, and was generally not sensitive to vertical hydraulic conductivity.

### *Storage*

No field data defining these terms were available, so representative values for similar materials were obtained from Smith and Wheatcraft (1993). The storage term had no effect on model calibration because it was calibrated at steady state, however it did slightly affect the rate at which groundwater elevation decreased as percolation rates decreased (representing dewatering of Pond D) during the Pond D closure simulation. This effect on groundwater elevation had a corresponding slight effect on predicted concentrations as Pond D dewatered, but no effect on long term concentrations. Therefore, the model is insensitive to this parameter.

### *Recharge*

Recharge rates were established during calibration (Figure 11). Two recharge zones were established for the Pond D area during calibration, one representing the ponded, southern portion and one representing the dry, northern portion of the pond at the time of the calibration dataset, just prior to dewatering.

During Pond D closure modeling, recharge rates for the ponded portion of Pond D were reduced from the calibrated values based on results of HELP modeling (i.e., percolation). Recharge for the dry portion of the pond was decreased by about half from the calibration value, and held constant until the cap was simulated, at which time the same recharge rate was used for the entire Pond D area (Table 4). For simplicity, HELP percolation rates were averaged for periods where there was little change in predicted percolation rate (Figure 12).

### *River Parameters*

The Wabash River and tributaries were represented by head-dependent flux nodes that required inputs for river stage, width, bed thickness, and bed hydraulic conductivity. The latter three parameters were used to calculate a conductance term for the boundary node. This conductance term was determined by adjusting hydraulic conductivity during model calibration, while bed thickness was set at 1 (i.e., bed hydraulic conductivity represented conductance normalized for river width and bed thickness). River stage for the Wabash River was set near mean stage, and adjusted slightly during calibration. River stage for the tributaries was determined from USGS topographic maps.

Sensitivity analysis showed that the model was highly sensitive to the presence of the rivers and tributaries, but not very sensitive to the conductance term used.

### *Drain Parameters*

A MODFLOW drain boundary was added to the Pond D closure model to evaluate the effect of a groundwater collection trench on migration south of Pond D. Drain parameters are listed in Table 5.

### *MT3DMS Input Values and Sensitivity*

MT3DMS input values are listed in Table 3 and described below.

### *Initial Concentration*

Initial groundwater concentration for the calibration run was set at zero. Initial groundwater concentration for the Pond D closure simulations was the final calibration concentration.

### *Source Concentration*

Two primary sources were simulated. For calibration runs, which simulated in-service conditions, and for the initial portion of the Pond D dewatering simulation (stress periods 1 through 3) the primary source was percolating water from Pond D. The dominant source following dewatering of Pond D is leaching of ash that remains below the water table. Therefore, a second primary source term, representing the saturated ash, was added for the Pond D closure simulation, beginning with model stress period 4 (after one year of dewatering). This source boundary assumes that mass loading at that time will primarily be from leaching of ash below the water table, rather than percolation.

Concentration values for the ash cells were held constant during calibration and the dewatering period of the Pond D closure simulation, and then increased to 20 mg/L after the cap was applied. This change assumes that constituent concentrations in leachate will increase after surface water accumulation is eliminated, and the cap is applied, due to increased contact time with the ash.

Secondary sources were Pond A and the coal pile. Concentrations for these two sources were set at 20 and 2 mg/L, respectively, based on concentrations in leachate samples obtained during the 1999 hydrogeologic assessment.

Concentrations at several wells were sensitive to the concentration of the percolation source term. Only well MW8 was sensitive to the concentration of the saturated ash source term.

### *Effective Porosity*

Effective porosity values were based on ranges provided by Mercer and Waddel (1993). Predicted concentrations were not sensitive to this term, so it was not adjusted during calibration.

### *Dispersivity*

One well (MW3) was highly sensitive to dispersivity values, and the value of 30 feet was selected during calibration based on predicted concentration at that well. Transverse and vertical dispersion were estimated according to ratios developed by Gelhar et al. (1985).

### *Retardation*

Retardation was calculated by the model based on the distribution coefficient ($K_d$). The $K_d$ value used for the sandy materials in this model (0.17 milliliters per gram, or mL/g) was based on testing performed by

NRT for similar materials in another state. The $K_d$ value for the silt materials (0.85 mL/g) was assumed a factor of five higher than that for sand. These $K_d$ values were slightly lower than published values for similar materials and boron concentrations (0.44 L/kg in sand; 1.07 L/kg in silt for boron at 5 mg/L; EPRI, 2005). While concentrations at several wells varied with $K_d$, no concentrations varied by more than 10 percent, so this number was not adjusted during calibration.

### *Input Data Assumptions*

Simplifying assumptions were made while developing this model, including:

- Leachate is assumed to instantaneously reach groundwater (e.g., migrate through the unsaturated zone);
- River stage and natural recharge are assumed constant over time; and
- Leachate concentrations are assumed to remain constant over time (except as noted above).

# Modeling Results

Results of the MODFLOW/MT3DMS modeling are presented below. A disk containing model files is attached to the back of the report. Model file folder names are listed in Table 7.

## Calibration

The model was calibrated to reproduce conditions while Pond D was active, prior to 2000. The model was first calibrated to observed groundwater head data collected in November 1998, and then to observed concentration data mostly collected from November 1998 through May 1998. An exception to the concentration date range was made for wells MW2 and MW3. Boron concentrations at these wells were affected by a leaking pipe that was not simulated in the model because the volume of the pipe leak was unknown, the leak was temporary (i.e., transient), and the calibration was performed for steady-state conditions. Therefore, these wells were calibrated to the concentration range recorded prior to the pipe leak.

Head calibration results were generally good, with modeled heads mostly within 1 foot of target heads (Figures 13a and 14a), particularly between and downgradient of Ponds A and D. The areas of largest discrepancy were near MW6, MW9, and MW11. The discrepancy at MW9 is acceptable given its distance from Ponds A and D and the sparse geologic data in that area. The discrepancies at MW6 and

MW11 are likely due to the close proximity of these wells to Pond D, where heads change rapidly over a short distance. Given this observation, and considering that the concentration match for these two wells was acceptable, the head discrepancy is also considered acceptable.

Concentration calibration was within the range of observed concentrations at most monitoring wells (Figure 13b and 14b). The model calculated elevated boron concentrations at wells with observed boron concentrations greater than Class I standards, and generally did not show elevated boron concentrations for wells with low boron concentrations. The two notable exceptions, for wells MW7D and MW12, were both cases where the model calculated higher concentrations than observed. The low observed concentration at MW7D could not be replicated without using unrealistically low hydraulic conductivities, and would have probably required several additional model layers to simulate. The high concentration at MW12 is likely due to model discretization. Concentration match may have improved with a finer grid spacing; however, this result was conservatively high, and such a grid spacing was considered unwarranted. Slightly low concentrations were predicted for MW6 and MW13. The concentration discrepancy at MW6 was likely due to model discretization, similar to MW12. The discrepancy at MW13, where observed boron concentration was higher than any other monitoring well on site, is likely related to the leak that was not simulated.

### *Extent of Southward Migration*

The extent of migration south of Pond D was determined based on the results of the calibration scenario, when southward extent was greatest due to mounding caused by the large recharge flux modeled from the pond. This distance is approximately 500 feet south of the south property line (Figure 15), and represents a conservative approach to calculating this value since the impoundment has not been ponded since 2000. This estimate is also conservative because the model-predicted southward extent of boron, as defined by concentrations higher than Class I standards, will be greater than for the other ash indicator constituent, sulfate. This is because the source boron concentration of 20 mg/L is an order of magnitude higher than its Class I standard, while the highest sulfate concentrations observed in leachate samples from the ash ponds (1,326 mg/L) and in Pond D monitoring wells (960 mg/L) are only a factor of three to four higher than its Class I standard.

## Pond D Closure Simulation

Two scenarios were performed for Pond D closure, one with a groundwater collection trench and one without a groundwater collection trench. Without the trench, boron concentrations south of the property boundary were predicted to be below Class I standards after 17 years. With the trench, boron concentrations were predicted to be below Class I standards after 10 years (Figure 16). The site-wide decrease in plume extent over time is shown in Figure 17. The model-predicted rate of groundwater collection in the trench was 62 gpm (Table 6).

### *Boron Loading to the Wabash River*

The model was used to calculate boron loading rate in groundwater discharge to the Wabash River and tributaries. The results of this analysis indicated an 84 percent decrease in loading rate after 3 years of dewatering, and 97 percent decrease relative the calibrated rate of boron loading one year after the cap was simulated (Figure 18).

## References

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**Table 1**
**HELP Input Parameters**
**Hutsonville Power Station**
**Ameren Services**

| | | | |
|---|---|---|---|
| **Input Parameter** | **Dewatering** | **Cap** | **Notes** |
| **Climate-General** | | | |
| City | Evansville | Evansville | |
| Latitude | 39.13 | 39.13 | Plant |
| Evap Zone | 9 | 21 | bare (9), fair (21) |
| Leaf Index | 1 | 2 | bare (1), fair (2) |
| All Others | | | Defaults for Evansville, IN |
| **Climate-precip/temp/ET** | | | |
| All | see note | see note | Synthetically generated using Evansville defaults, plant 30-year avg precip, and avg temp in Palestine, IL |
| **Soils-General** | | | |
| Area | 1 | 1 | unit area |
| % where runoff possible | 0 | 100 | |
| Specify Initial MC | Y | Y | |
| Surface Water/Snow | 60* | 0 | *represents ponded condition |
| **Soils-Layers** | | | |
| 1 | ash | native | |
| 2 | ash | synthetic | |
| 3 | ash | ash | |
| 4 | | ash | |
| 5 | | ash | |
| **Soil Parameters--native** | | | |
| Type | | 1 | vertical percolation layer |
| Thickness (in) | | 36 | |
| Texture | | 8 | loam, default parameters used |
| Moisture Content | | 0.232 | set equal to field capacity |
| **Soil Parameters--synthetic** | | | |
| Type | | 4 | geomembrane |
| Thickness (in) | | 0.03 | |
| Texture | | 37 | default for PVC |
| K (cm/s) | | 2.00E-11 | |
| Pinhole density | | 1 | |
| Installation Defects | | 4 | |
| Placement Quality | | 3 | good placement quality |

**Table 1**
**HELP Input Parameters**
**Hutsonville Power Station**
**Ameren Services**

| | | | |
|---|---|---|---|
| **Input Parameter** | **Dewatering** | **Cap** | **Notes** |
| **Soil Parameters--ash layers** | | | |
| Type | 1 | 1 | |
| Thickness (in) | 60 | 60 | |
| Texture | 30 | 30 | |
| Porosity | 0.541 | 0.541 | |
| Field Capacity | 0.187 | 0.187 | |
| Wilting point | 0.047 | 0.047 | |
| Moisture Content - L1 | 0.541 | 0.2504 | Dewatering-moisture content for saturated (ponded) conditions. Cap MC values equal to MC at end of Dewatering simulation. |
| Moisture Content - L2 | 0.541 | 0.2883 | |
| Moisture Content - L3 | 0.541 | 0.3212 | |
| K (cm/s) | 5.00E-05 | 5.00E-05 | |
| **Soils--Runoff** | | | |
| Equation | n/a | HELP CN | |
| Slope | n/a | 2% | |
| Length (ft) | n/a | 500 | |
| Texture | n/a | 8 | |
| Vegetation | n/a | fair | |
| **Execution Parameters** | | | |
| Years | 1-3 | 4-25 | |
| Report Daily | n | n | |
| Report Monthly | y | y | |
| Report Annual | y | y | |
| | | | |
| **Output Filename (*.out)** | Base | CO-2 | |
| **Precip File (*.D4)** | hutx | hutx4_23 | |
| **Temp File (*.D7)** | hutx | hutx4_23 | |
| **SR (*.D13)** | hutbase | hutco | |
| **ET/general (*.D11)** | hutbase | hutco | |
| **Soil File (*.D10)** | Base | CO-2 | |

## Table 2
## MODFLOW Input Parameters
## Hutsonville Power Station
## Ameren Services

| Horizontal Hydraulic Conductivity | | ft/d | cm/s | Sensitivity[1] |
|---|---|---|---|---|
| Layer 1 ash | | 0.14 | 5.0E-05 | negligible |
| Layer 1 silt unit | | 0.10 | 3.5E-05 | low |
| Layer 1 sand unit | | 80 | 2.8E-02 | high |
| Layer 1, 2, 3 alluvium | | 30 | 1.1E-02 | moderate |
| Layer 2 sandstone | | 4.0 | 1.4E-03 | high |
| Layer 4 valley fill sand and gravel | | 136 | 4.8E-02 | moderate |
| **Vertical Hydraulic Conductivity** | | **ft/d** | **Kh/Kv** | **Sensitivity** |
| Layer 1 ash | | 0.07 | 2.0 | negligible |
| Layer 1 silt unit | | 0.05 | 2.0 | negligible |
| Layer 1 sand unit | | 40 | 2.0 | negligible |
| Layer 1, 2, 3 alluvium | | 3.0 | 10.0 | low |
| Layer 2 sandstone | | 2.0 | 2.0 | low |
| Layer 4 valley fill sand and gravel | | 68 | 2.0 | negligible |
| **Recharge** | | **ft/d** | **in/yr** | **Sensitivity** |
| General | | 0.001 | 4.4 | high |
| Pond D - ponded* | | 0.0822 | 360 | high |
| Pond D - not ponded* | | 0.0027 | 11.8 | low |
| Ponds A, B, C | | 2.30E-05 | 0.10 | negligible |
| Ash laydown area | | 0.0027 | 11.8 | low |
| Coal pile | | 0.0027 | 11.8 | negligible |
| Area between impoundments | | 0.0027 | 11.8 | low |
| Lowlands | | 0 | 0.0 | high |
| **Storage/Porosity** | | **$S_S$** | **$S_Y$** | **Sensitivity** |
| Layer 1 ash | | 1.00E-03 | 0.10 | negligible |
| Layer 1 silt unit | | 1.00E-03 | 0.10 | negligible |
| Layer 1 sand unit | | 1.00E-05 | 0.20 | negligible |
| Layer 1, 2, 3 alluvium | | 1.00E-03 | 0.10 | negligible |
| Layer 2 sandstone | | 1.00E-06 | 0.15 | negligible |
| Layer 4 valley fill sand and gravel | | 1.00E-05 | 0.20 | negligible |
| **River Parameters** | **Wabash** | **Trib west** | **Trib east** | **Sensitivity** |
| Bed Thickness (ft) | 1 | 1 | 1 | not tested |
| Hydraulic Conductivity (ft/d) | 0.7 - 136 | 0.1 | 0.01 | not tested |
| Conductance ($ft^2$/d, normalized per $ft^2$ area) | 0.7 - 136 | 0.1 | 0.01 | low |
| River Width (ft) | variable | 5 | 5 | not tested |
| River Cell Length (ft) | variable | variable | variable | not tested |
| **Constant Head Boundary Parameters** | | **Layer 1 (west)** | | **Sensitivity** |
| Head (ft) | | 451 | | moderate |

1. Sensitivity Explanation
Negligible - had little effect on overall model residuals
Low - effect on residuals insufficient to nullify calibration
Moderate - extreme values changed residuals sufficiently to nullify calibration
High - all tested values changed residuals sufficiently to nullify calibration

* Pond D recharge values are for calibration. See Table 4 for values used during Pond D closure simulation

**Table 3**
**MT3DMS Input Parameters**
**Hutsonville Power Station**
**Ameren Services**

| Initial Concentration (mg/L) | Value | Alternatives | Sensitivity[1] |
|---|---|---|---|
| Entire Domain (calibration) | 0.0 | not tested | |
| Entire Domain (Pond D Closure) | final calibration values | not tested | |
| **Source Concentration - Recharge (mg/L)** | **Value** | **Alternatives** | **Sensitivity** |
| Pond D (ponded) | 5 / 20* | not tested | high[2] |
| Pond D (not ponded) | 20 | not tested | high[2] |
| Ash Laydown Area | 30 | not tested | high[2] |
| Ponds A, B, C | 20 | not tested | high[2] |
| Coal Pile | 2 | not tested | high[2] |
| **Source Concentration - Constant (mg/L)** | **Value** | **Alternatives** | **Sensitivity** |
| Saturated Ash Nodes | 20* | 10, 30 | high |
| **Effective Porosity** | **Value** | **Alternatives** | |
| Layer 1 ash | 0.10 | 0.05, 0.15 | low |
| Layer 1 silt unit | 0.10 | 0.05, 0.15 | low |
| Layer 1 sand unit | 0.20 | 0.15, 0.25 | low |
| Layer 1-3 alluvium | 0.10 | 0.05, 0.15 | low |
| Layer 2 sandstone | 0.15 | 0.10, 0.20 | low |
| Layer 4 valley fill sand and gravel | 0.20 | 0.15, 0.25 | low |
| **Dispersivity (ft)** | **Value** | **Alternatives** | **Sensitivity** |
| Longitudinal | 30 | 10, 50 | high |
| Transverse | 3.75 | 2, 5 | high |
| Vertical | 0.188 | 0.10, 0.30 | high |
| **Retardation** | **Value** | **Alternatives** | **Sensitivity** |
| Bulk Density (g/cm$^3$) | 1.6 | not tested | |
| Distribution Coefficient - sand (mL/g) | 0.17 | 0, 0.25 | moderate |
| Distribution Coefficient - silt (mL/g) | 0.85 | 0, 0.5, 1.2 | moderate |

1. Sensitivity Explanation
   Negligible - little effect on concentrations
   Low - concentrations at one or two wells changed by 2 to 10 percent
   Moderate - concentrations at one or two wells changed by 10 to 20 percent
   High - concentration at one or two wells changed by more than 20 percent or concentration at more than two wells changed by 2 to 10 percent
2. Determined to be highly sensitive during transport model calibration
* See text for explanation

**Table 4**
**Pond D Recharge Rates used in MODFLOW**
**Hutsonville Power Station**
**Ameren Services**

| Model Year | Stress Period | Period Length (days) | Recharge Rates Used in MODFLOW (feet/day) | | |
|---|---|---|---|---|---|
| | | | Dry | Wet | Notes |
| 2001 | 1 | 120 | 0.0015 | 0.0670 | Dewatering, no cap or groundwater collection system modeled |
| 2001 | 2 | 123 | 0.0015 | 0.0103 | |
| 2001 | 3 | 122 | 0.0015 | 0.0032 | |
| 2002 | 4 | 120 | 0.0015 | 0.0036 | |
| 2002 | 5 | 123 | 0.0015 | 0.0085 | |
| 2002 | 6 | 122 | 0.0015 | 0.0045 | |
| 2003 | 7 | 365 | 0.0015 | 0.0042 | |
| 2004 | 8 | 365 | 0.0018 | 0.0018 | Cap (and groundwater collection trench) modeled during these two stress periods |
| 2005-2025 | 9 | 7665 | 0.0004 | 0.0004 | |

## Table 5
## MODFLOW Drain Construction
## Hutsonville Power Station
## Ameren Services

| Drain | 1a |
|---|---|
| Drain Length (feet) | 1000 |
| Drain Pipe Diameter (feet) | 3 |
| Drain Bed Thickness (feet) | 1 |
| Drain Bed Hydraulic Conductivity (cm/s) | 0.10 |
| Drain Bed Hydraulic Conductivity (ft/day) | 283 |
| East Drain Base Elevation | 440 |
| West Drain Base Elevation | 423 |
| MODFLOW Layer Number | 2 |
| MODFLOW Drain Reach | 1 |

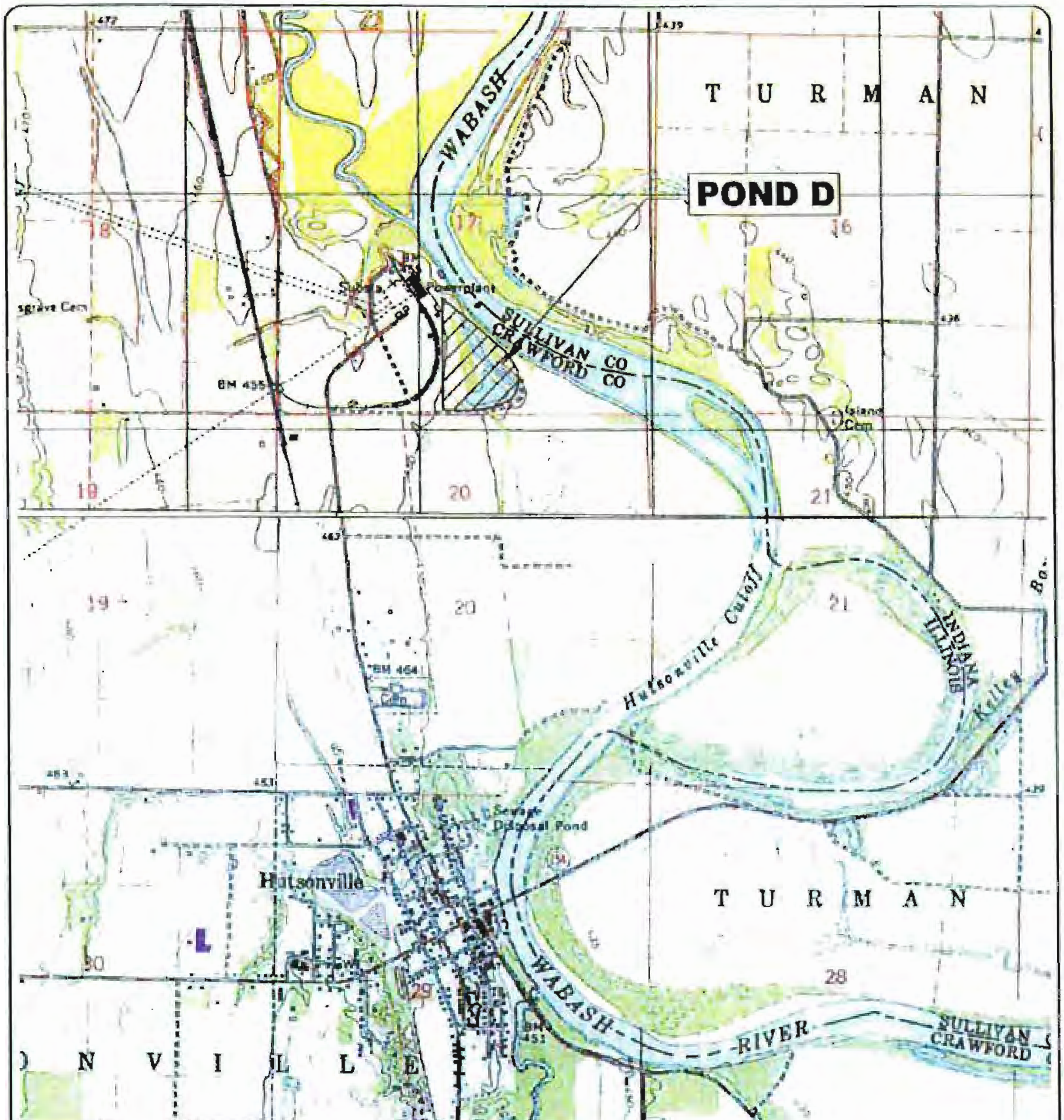
**Table 6**
**Estimated Drain Discharge Volumes (MODFLOW Data)**
**Hutsonville Power Station**
**Ameren Services**

| Stress | | Drain | |
|---|---|---|---|
| Period | Step | $ft^3$/day | gpm |
| 8 | 1 | 14,191 | 74 |
| | 2 | 12,791 | 66 |
| | 3 | 12,517 | 65 |
| | 4 | 12,361 | 64 |
| | 5 | 12,234 | 64 |
| | 6 | 12,152 | 63 |
| 9 | 1 | 12,017 | 62 |
| | 2 | 11,934 | 62 |
| | 3 | 11,859 | 62 |
| | 4 | 11,797 | 61 |
| | 5 | 11,729 | 61 |
| | 6 | 11,685 | 61 |
| | 7 | 11,662 | 61 |
| | 8 | 11,628 | 60 |
| | 9 | 11,605 | 60 |
| | 10 | 11,594 | 60 |
| | 11 | 11,579 | 60 |
| | 12 | 11,576 | 60 |
| | 13 | 11,576 | 60 |
| | 14 | 11,576 | 60 |
| | 15 | 11,574 | 60 |
| | 16 | 11,574 | 60 |
| | 17 | 11,574 | 60 |
| | 18 | 11,574 | 60 |
| | **Average** | 11,932 | 62 |

**Table 7**
**Model Files**
**Hutsonville Power Station**
**Ameren Services**

**The disk attached to this report contains the ASCII input files and output files used and generated by HELP, MODFLOW, and MT3DMS for each scenario. The files are named as follows:**

| Folder / Subfolder 1 / Subfolder 2 | Description |
|---|---|
| MODFLOW_MT3DMS / | |
| hut5 | Calibration model files |
| CO-2 & LEOa-3 | Pond D closure simulation with groundwater collection trench |
| CO-2 | Pond D closure simulation without groundwater collection trench |
| Sensitivity Analysis/ | Steady state flow parameters tested using GroundwaterVistas autosensitivity tool (see autosens.out in hut5 folder) |
| hut5aS1 | Ss=0.5 x Base, Sy=Base - 0.05 |
| hut5aS2 | Ss=2 x Base, Sy=Base + 0.05 |
| hut5t01 | Constant Concentration Boundary = 10 mg/L |
| hut5t02 | Constant Concentration Boundary = 30 mg/L |
| hut5t03 | Ne = base - 0.05 |
| hut5t04 | Ne = base + 0.05 |
| hut5t05 | Dispersivity = 10, 1.25, 0.0625 |
| hut5t06 | Dispersivity = 50, 6.25, 0.3125 |
| hut5t07 | Kd sand = 0 |
| hut5t08 | Kd sand = 0.25 |
| hut5t09 | Kd silt = 0.17 |
| hut5t10 | Kd silt = 0.5 |
| hut5t11 | Kd silt = 1.2 |
| | |
| Help Files / | |
| Dewatering | HELP files for the dewatering period (years 1-3) |
| Geomembrane Cap | HELP files for the cap period (years 4-25) |




SOURCE: DIGITAL DOWNLOAD FROM
http://STORE.USGS.GOV
USGS 7.5 MINUTE QUADRANGLE,
WEST UNION IL, IN., HUTSONVILLE, IL.
DATED: 1998, 2002


N

0 2000 4000

SCALE IN FEET

CONTOUR INTERVAL 10 FEET

# SITE LOCATION MAP

HUTSONVILLE POWER STATION
AMEREN ENERGY GENERATING
HUTSONVILLE, ILLINOIS

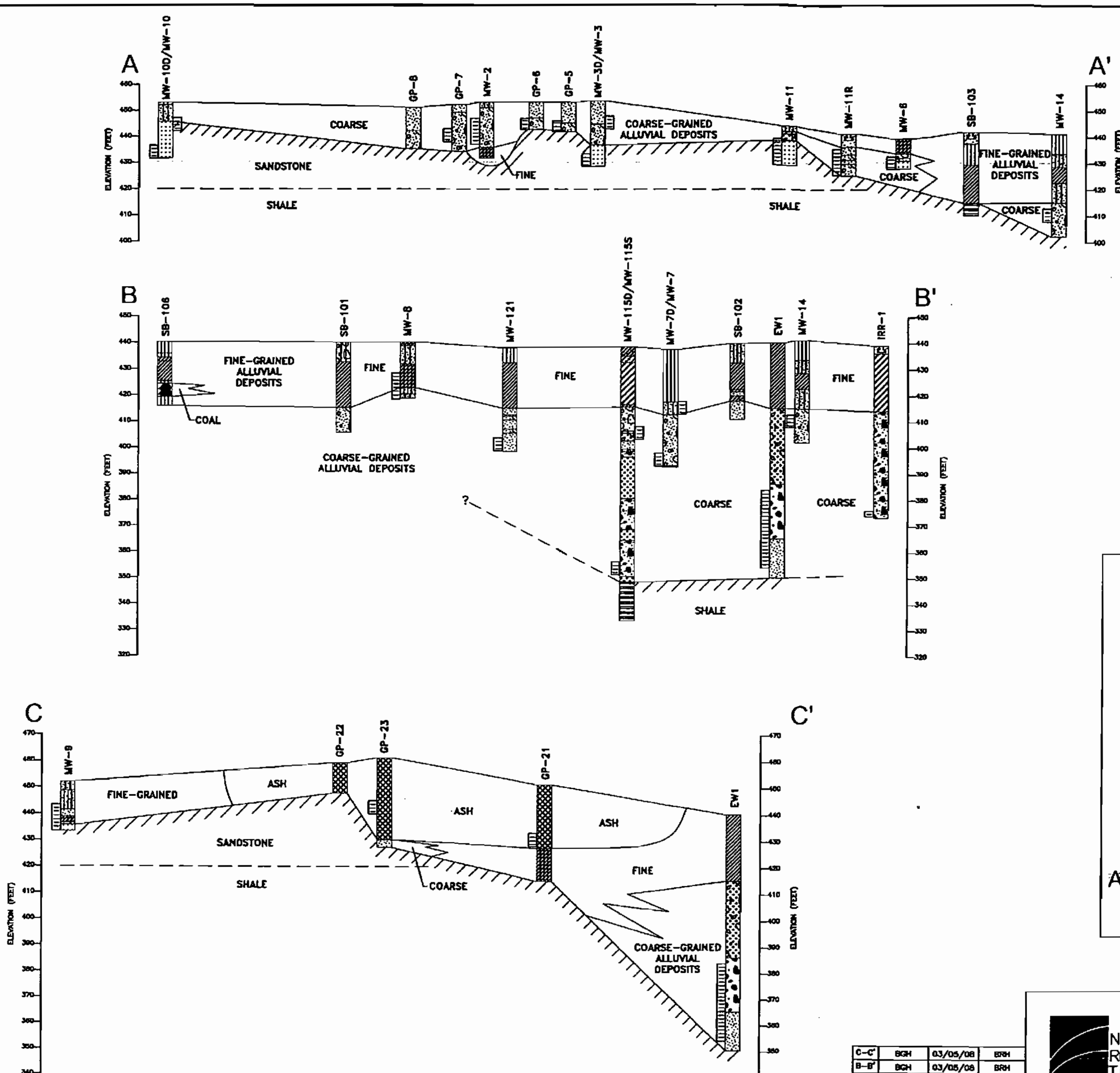
NATURAL RESOURCE TECHNOLOGY

DRAWN BY: BJK 03/10/08 APP'D BY: BRH DATE: 03/10/08

PROJECT NO 1375

DRAWING NO 1375-A06

FIGURE NO 1-1

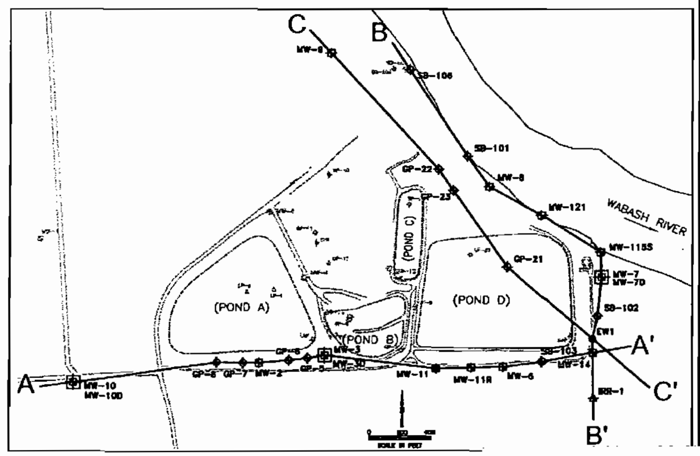



## LEGEND

- TOPSOIL
- SILT
- SILTY LEAN CLAY
- SANDY SILT
- SILTY SAND
- LEAN CLAY
- FAT CLAY
- GRAVELLY SILT
- SANDSTONE
- SHALE
- COAL
- WELL GRADED SAND
- WELL GRADED GRAVEL WITH SAND
- WELL GRADED SAND WITH GRAVEL
- POORLY GRADED SAND
- POORLY GRADED SAND WITH GRAVEL
- SANDY LEAN CLAY
- ASH
- WELL GRADED GRAVEL
- SCREENED INTERVAL

NOTES:
1. IRR-1 IS THE WAMPLER IRRIGATION WELL (ISGS WELL #12-033-36667-00).
2. EW1 IS BASED ON ISGS WELL, PERMIT #47367.
3. SURFACE ELEVATION FOR SB-106 WAS ESTIMATED FROM NEIGHBORING BORING ELEVATIONS.
4. C-C' SHALE/SANDSTONE CONTACT EXTRAPOLATED FROM A-A'.

VERTICAL SCALE IN FEET 20
HORIZONTAL SCALE IN FEET 200




TSD 000517

| ID | CHK'D BY: | DATE: | APP'D BY: |
|---|---|---|---|
| C-C' | BGH | 03/05/08 | BRH |
| B-B' | BGH | 03/05/08 | BRH |
| A-A' | BGH | 03/05/08 | BRH |

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1375/6.2
DRAWN BY: BJK 02/27/08
CHECKED BY: BGH 03/05/08
APPROVED BY: BRH 03/05/08

# GEOLOGIC CROSS SECTIONS

EXHIBIT 13 MONITORING PLAN
HUTSONVILLE POWER STATION
AMEREN
HUTSONVILLE, ILLINOIS

DRAWING NO: 1375-62-B03
REFERENCE: -
FIGURE NO. 2

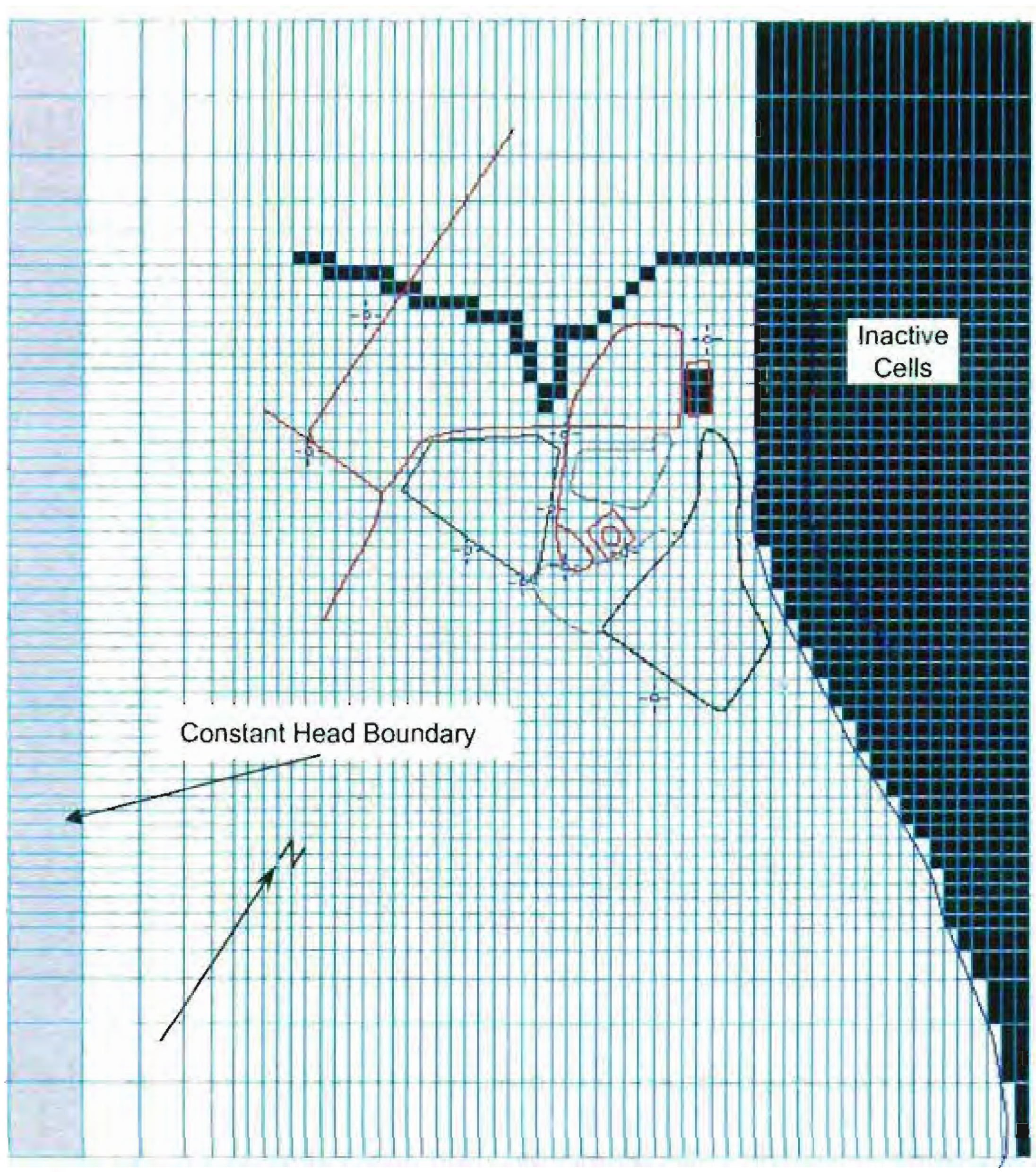



Figure 3. MODEL grid - Layer 1 - showing boundary conditions.

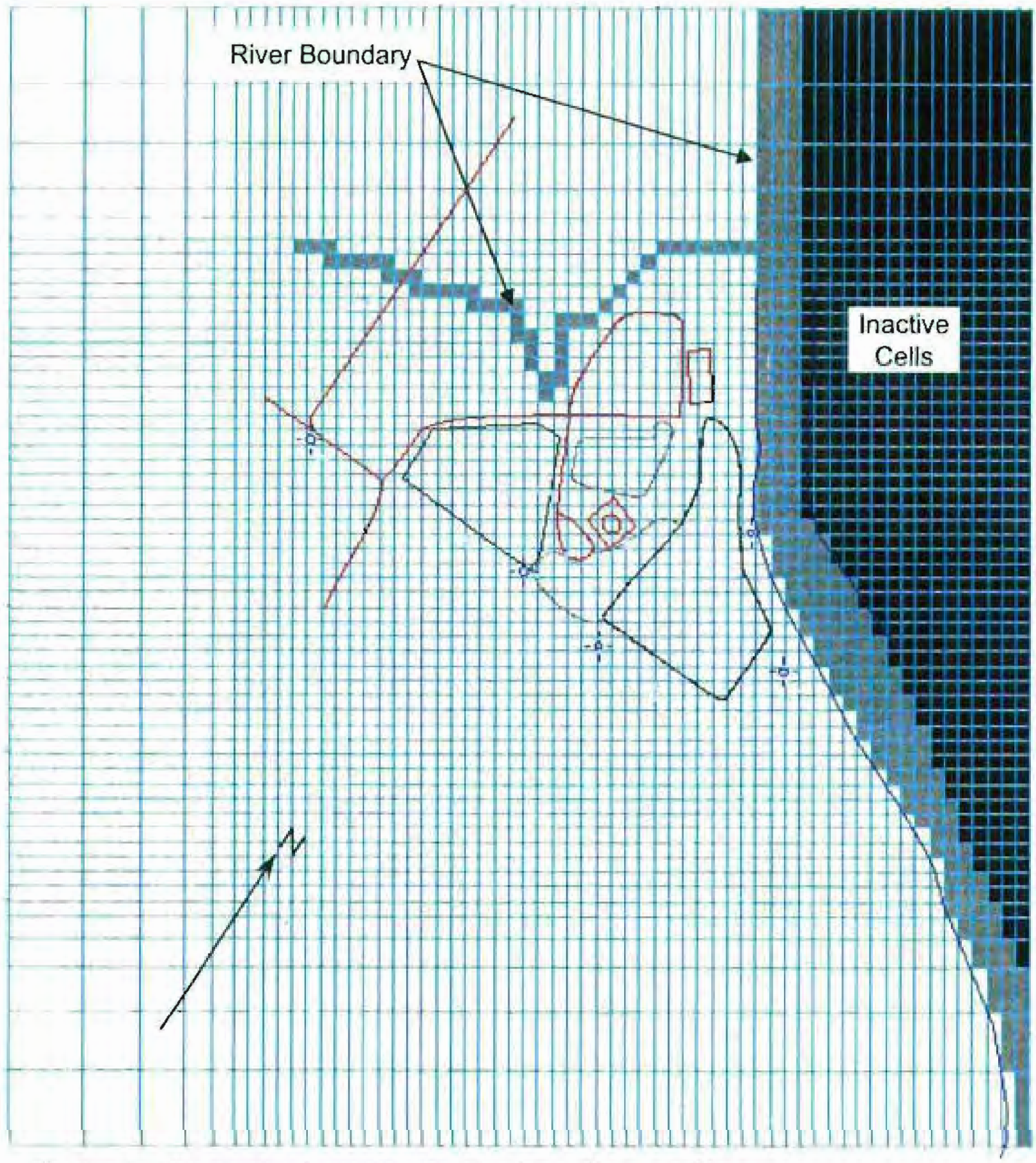



Figure 4. Model grid - Layer 2 - showing boundary conditions.

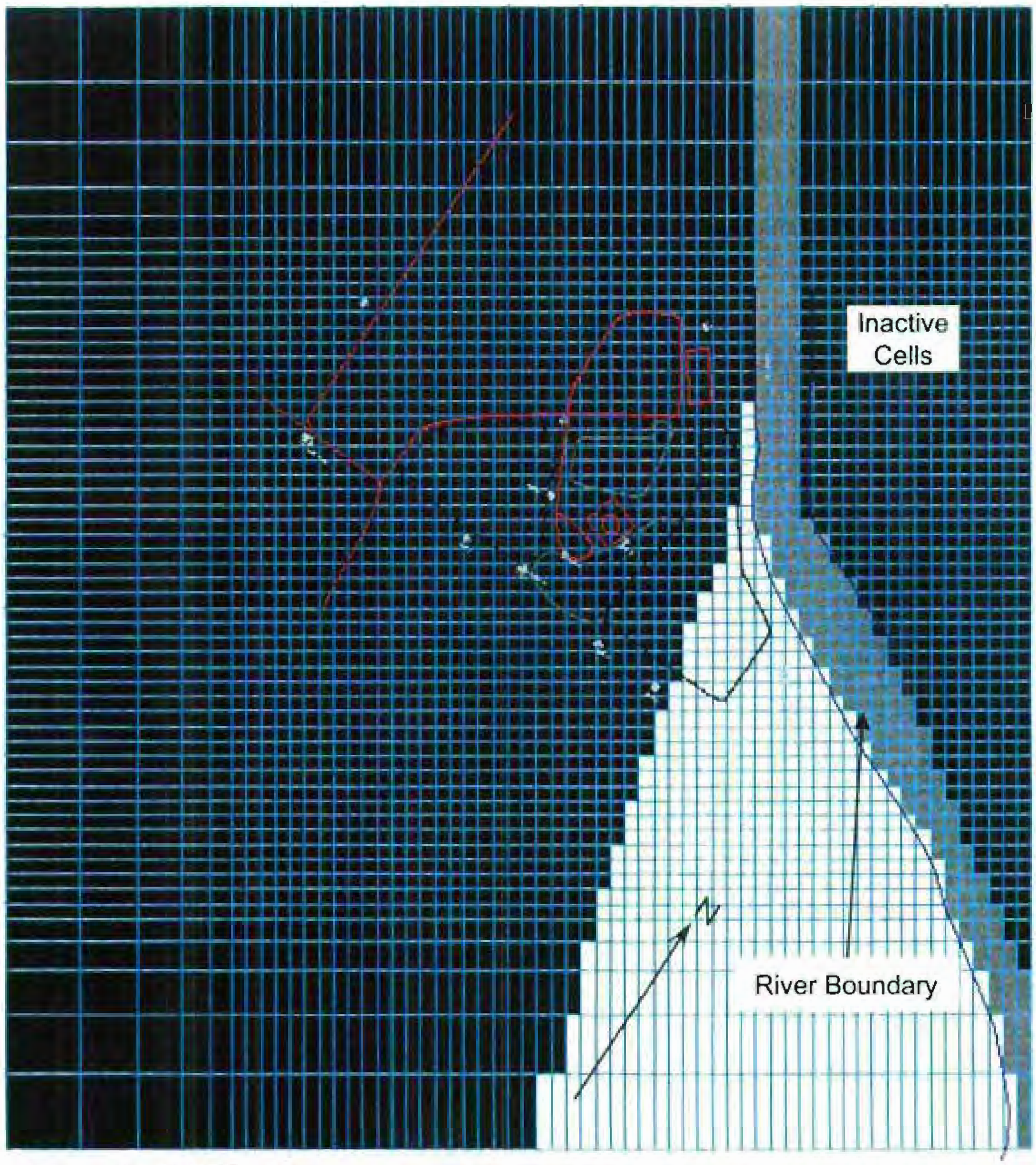



Figure 5. MODEL grid - Layer 3 - showing boundary conditions.

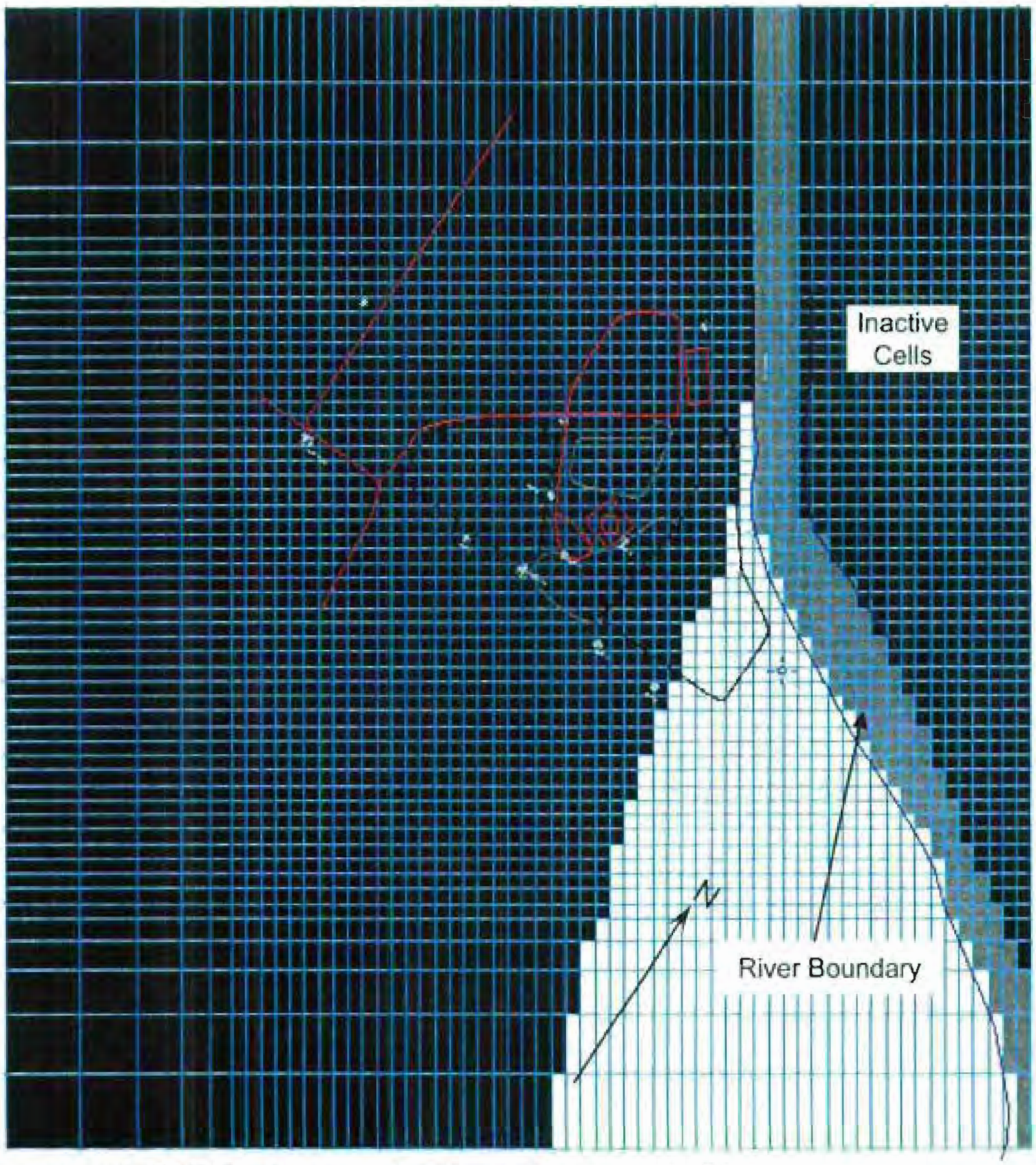



Figure 6. MODEL grid - Layer 4 - showing boundary conditions.

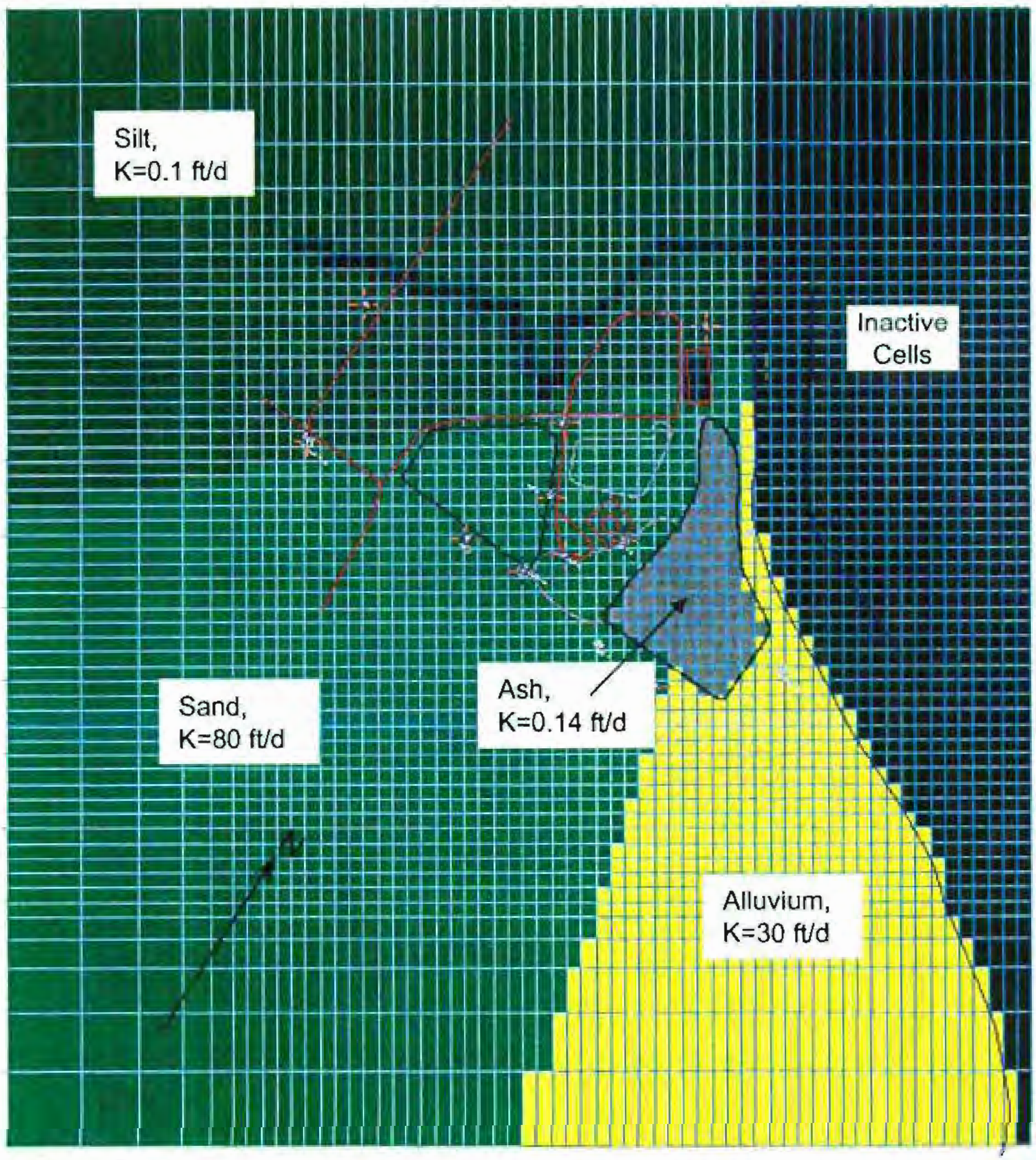


Figure 7. Hydraulic conductivity array - Layer 1.

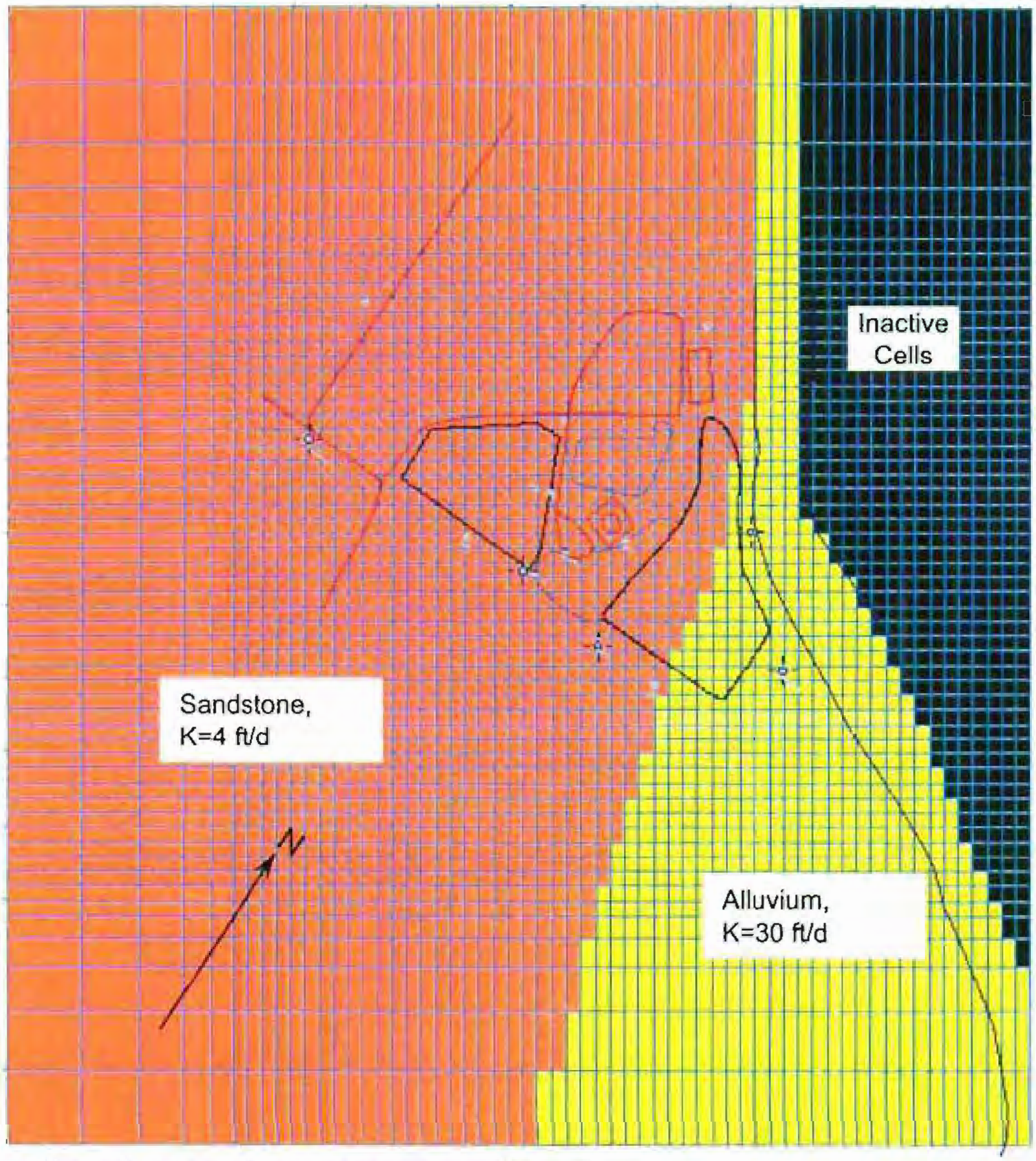



Figure 8. Hydraulic conductivity array - Layer 2.

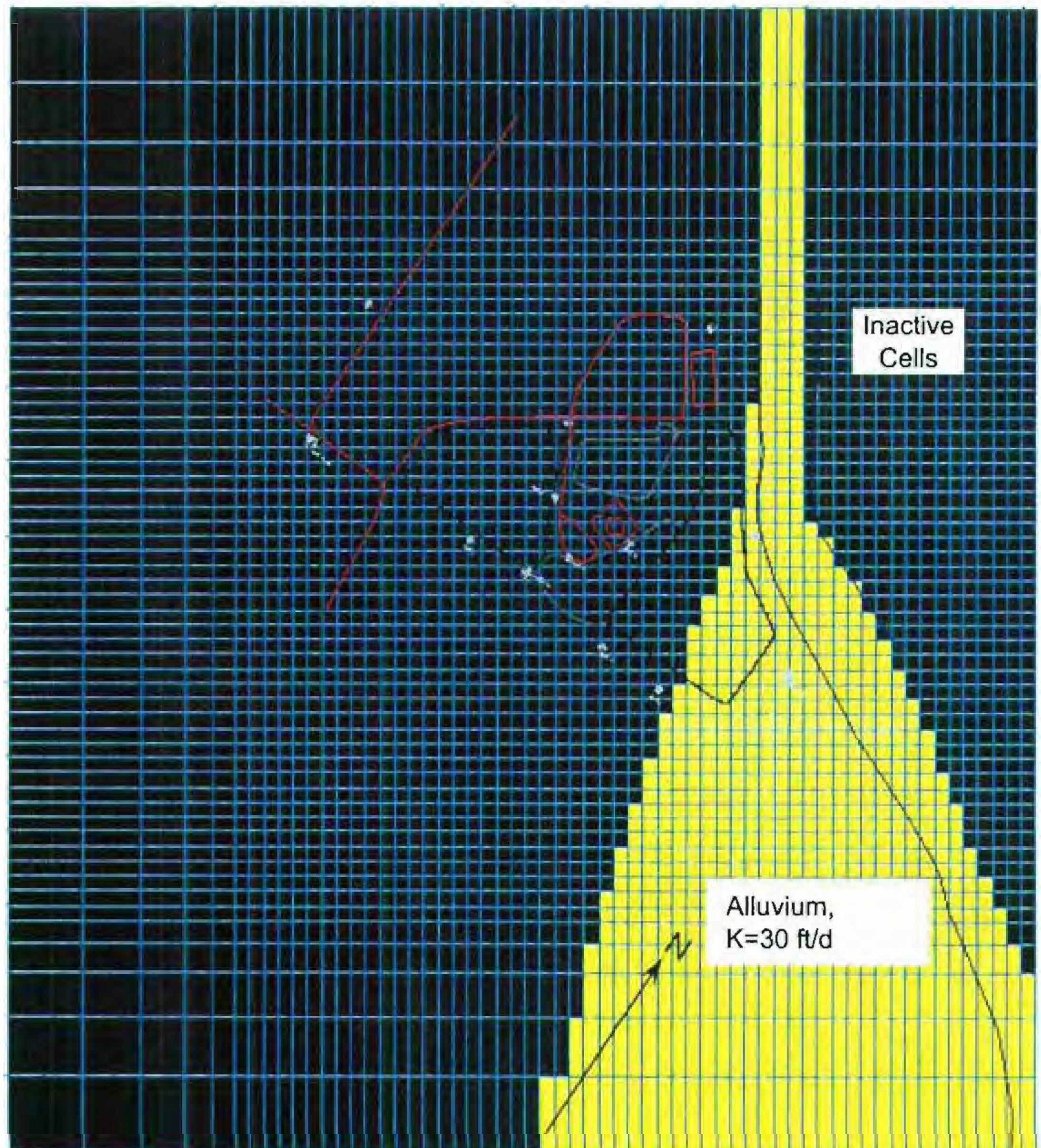



Figure 9. Hydraulic conductivity array - Layer 3.

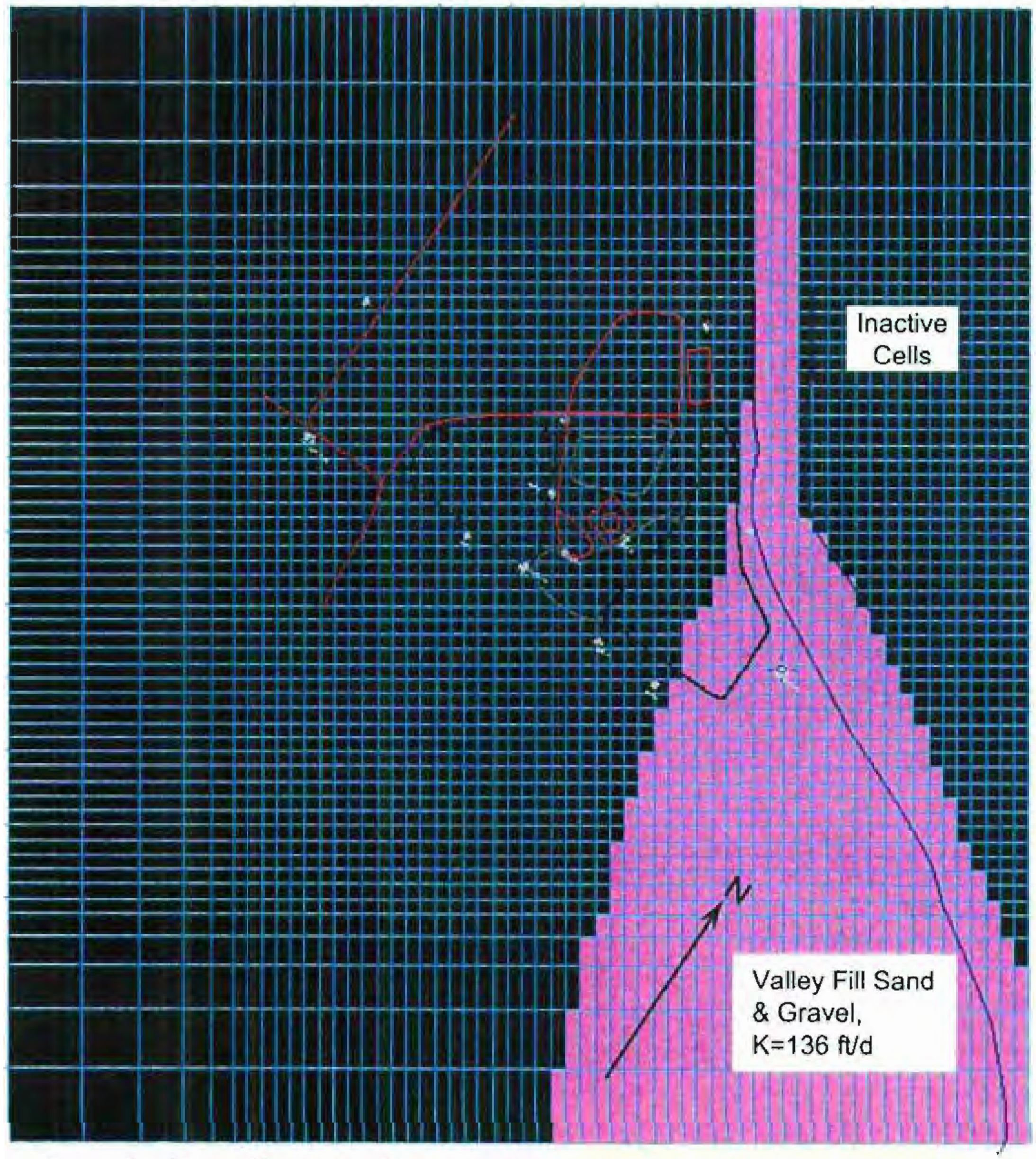



Figure 10. Hydraulic conductivity array - Layer 4.

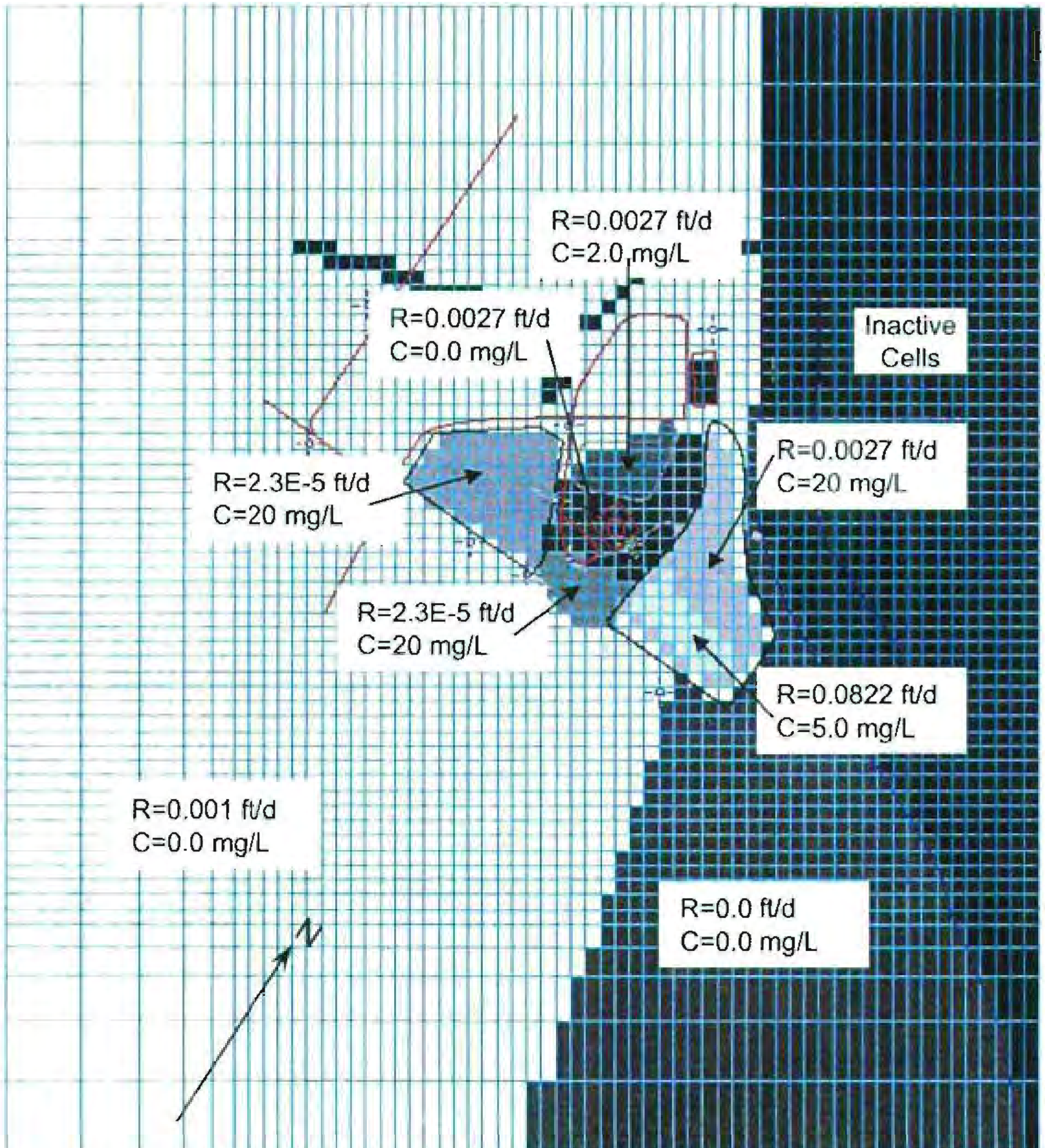



Figure 11. MODFLOW recharge and MT3DMS recharge concentration array (calibration values).

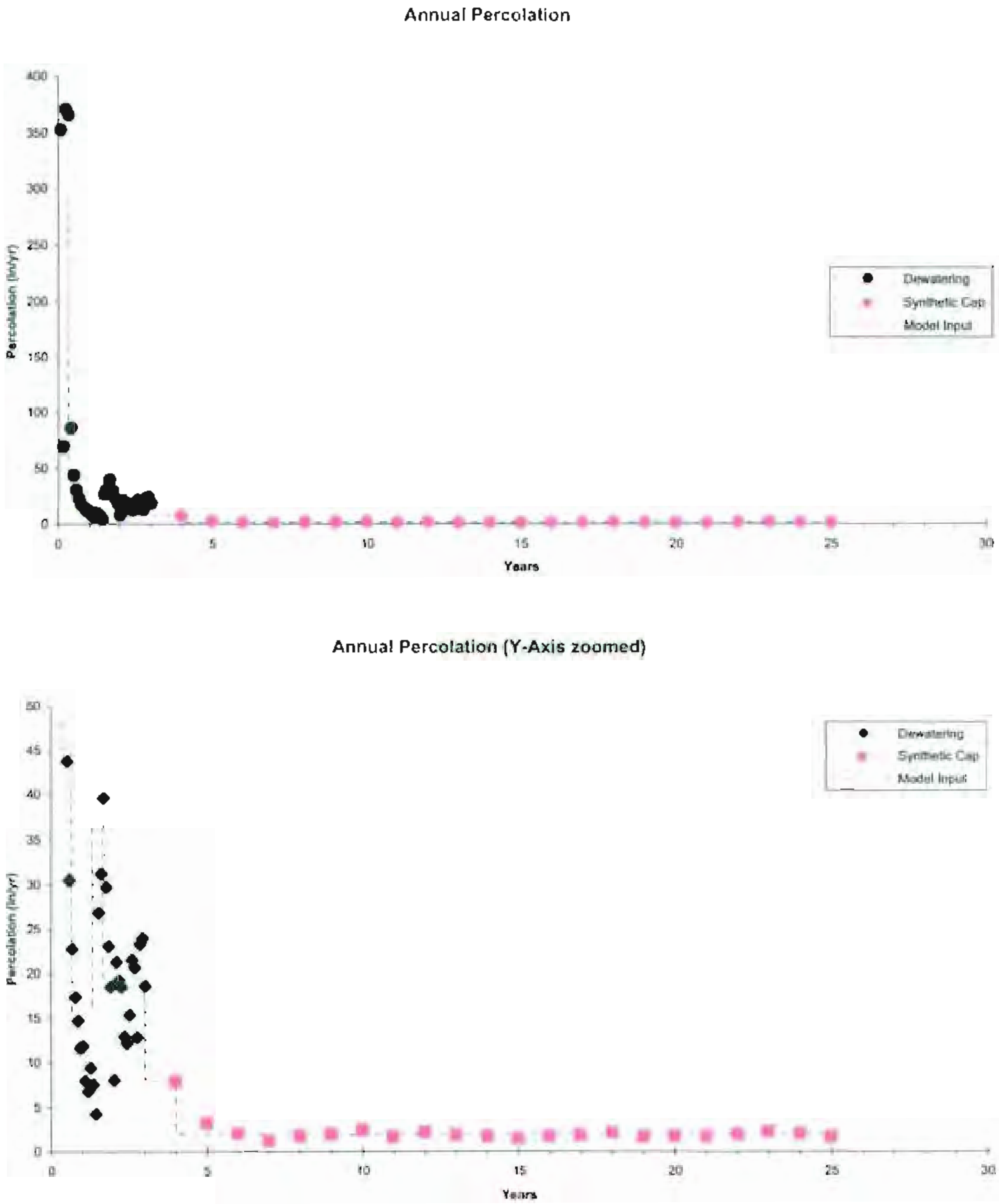



Figure 12. HELP percolation rates (monthly rates during dewatering are annualized).

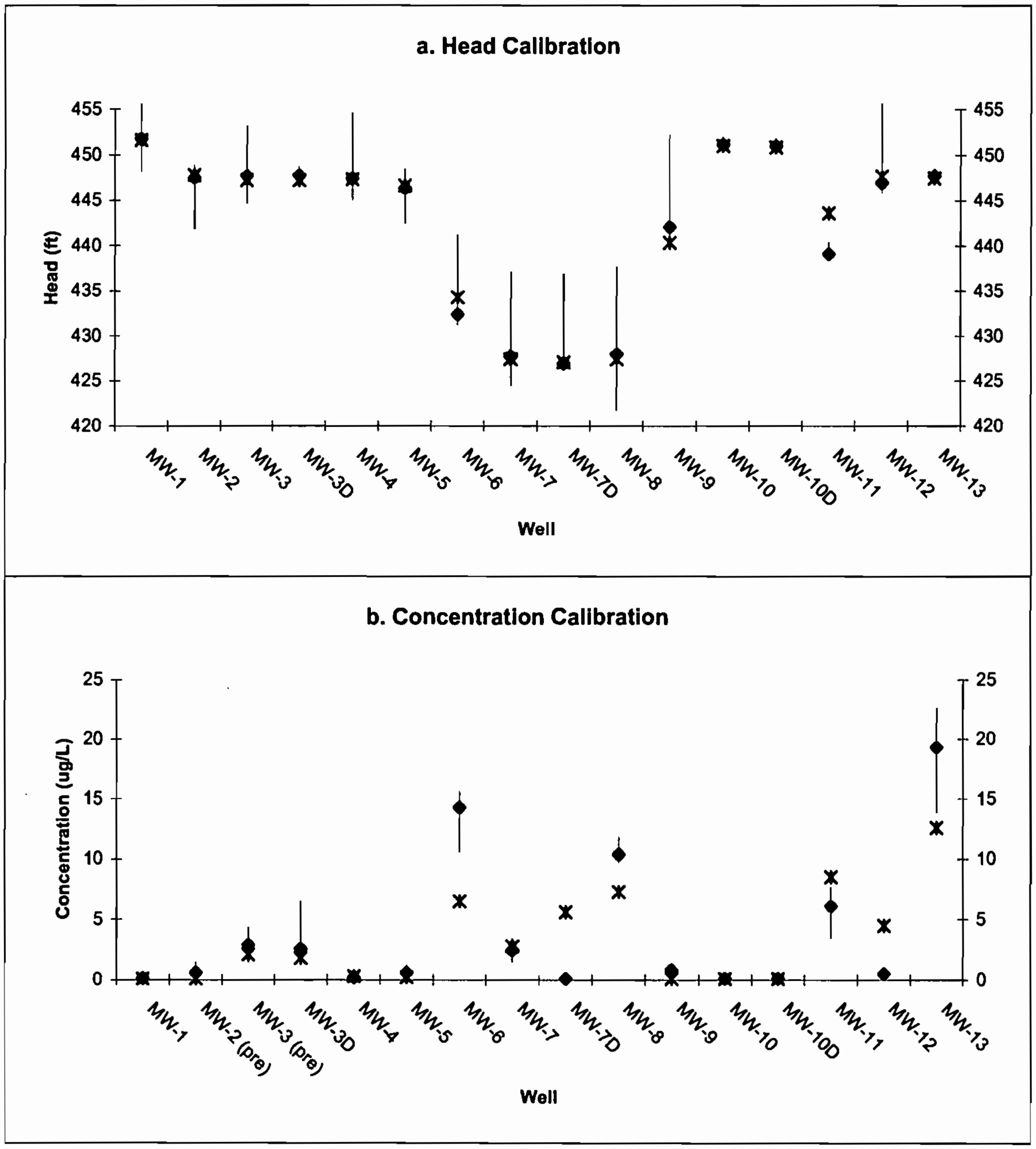



Figure 13. Calibration Results. The vertical bar represents the range of observed values, the diamond symbol represents the calibration target (head in November 1998 or median concentration), and the * symbol is the calibration result.

Fig 13 CALIBRAT.xls
Chart


Figure 14. Calibrated head and concentration distribution for Layer 1.

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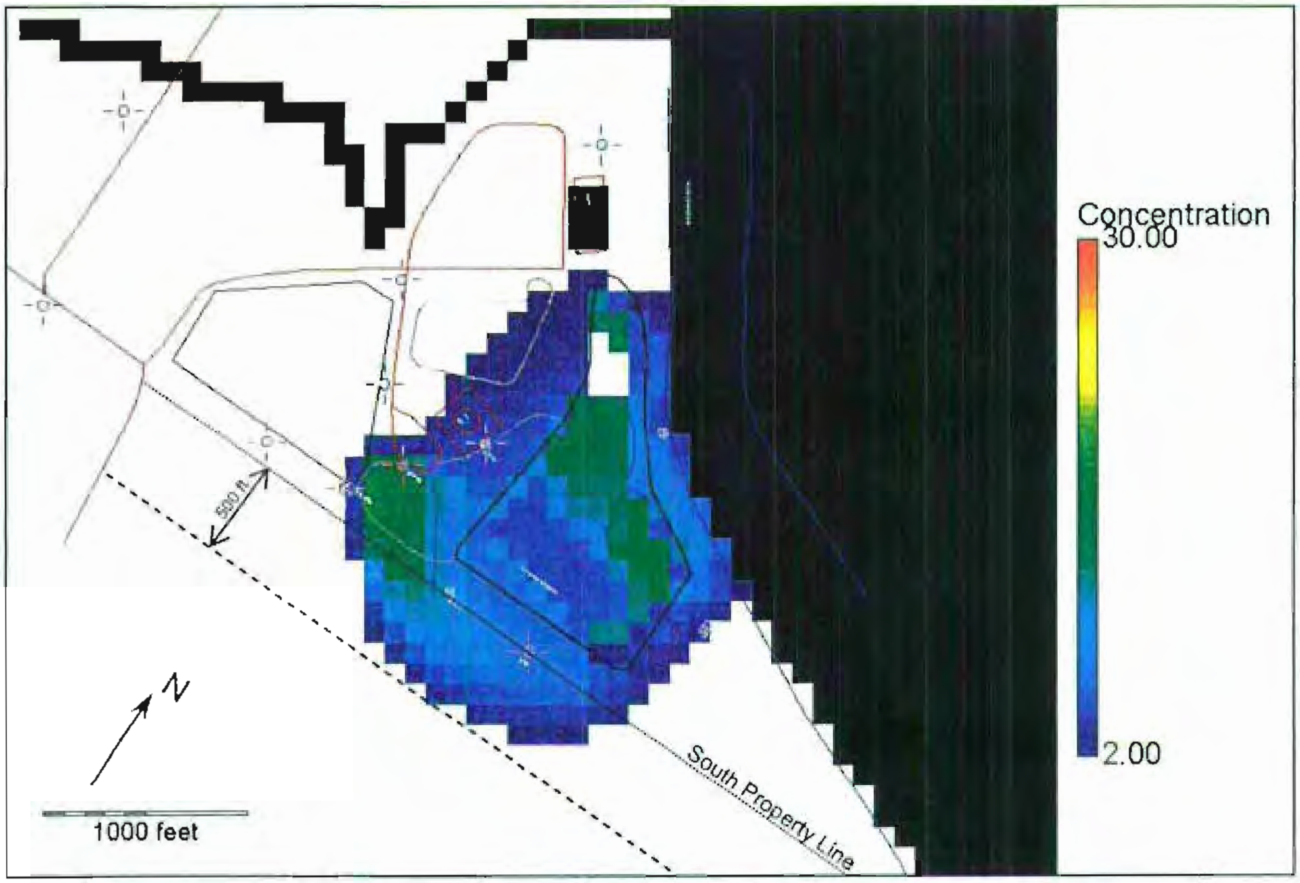


Figure 15. Calibrated model--extent of concentration greater than 2 mg/L.

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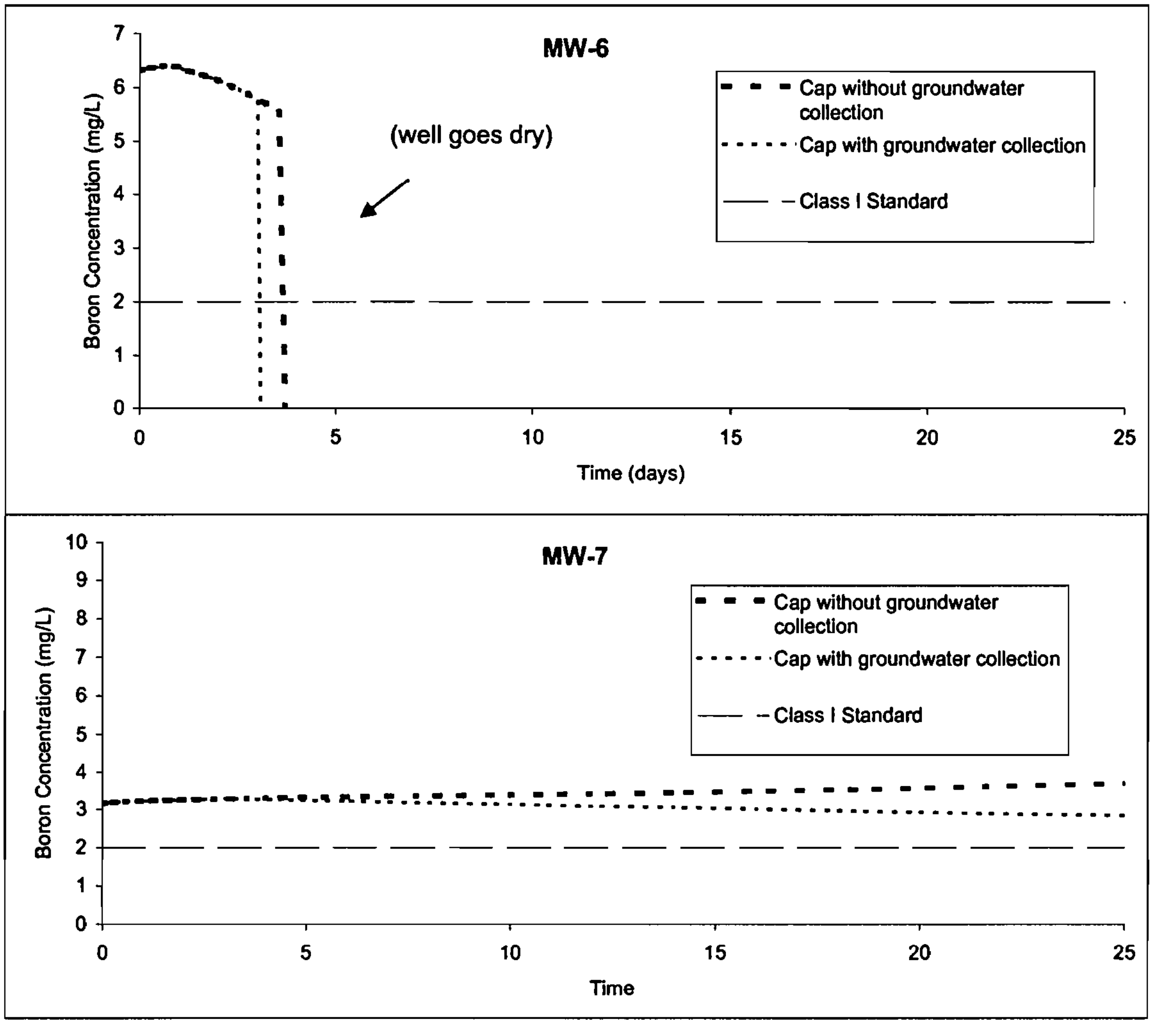



**Figure 16a. Predicted concentrations for the groundwater collection scenarios.**

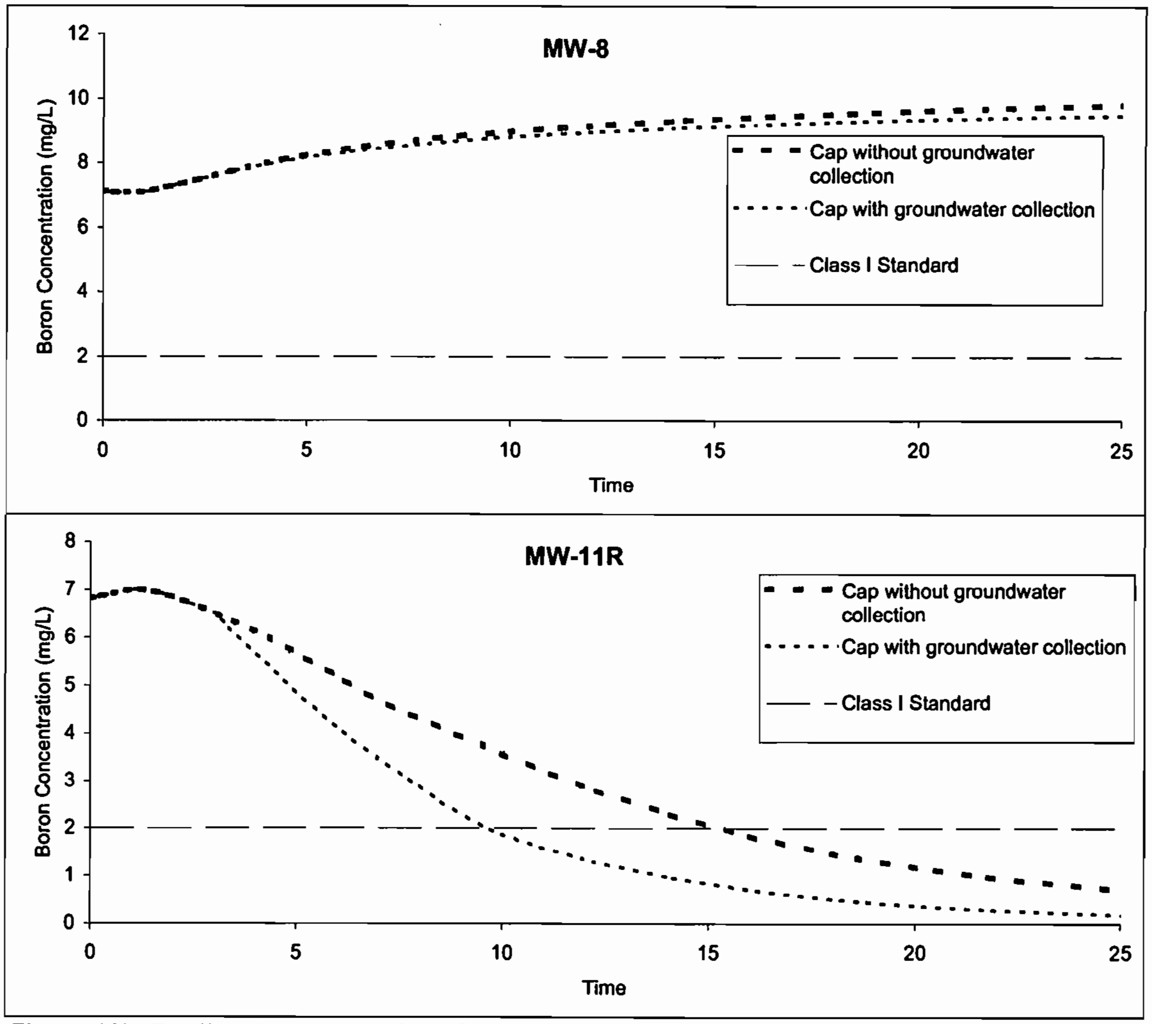
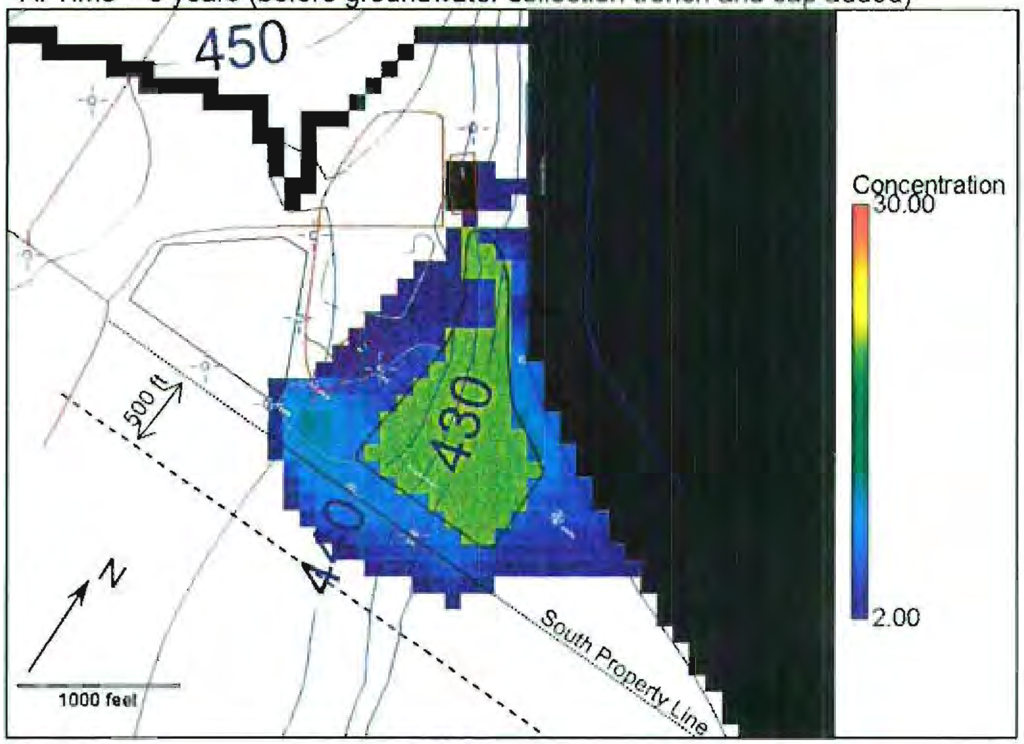



**Figure 16b. Predicted concentrations for the groundwater collection scenarios.**

A. Time = 3 years (before groundwater collection trench and cap added)




B. Time = 6 years

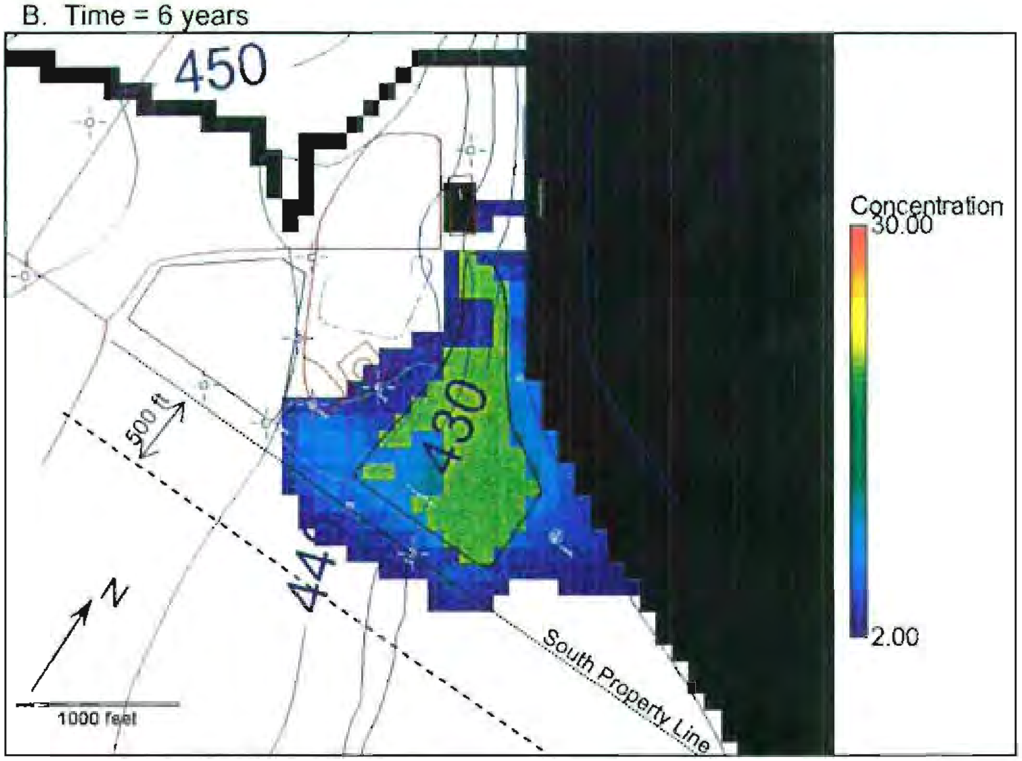



Figure 17A-B. Pond D Closure Scenario Model Head and Concentration Results

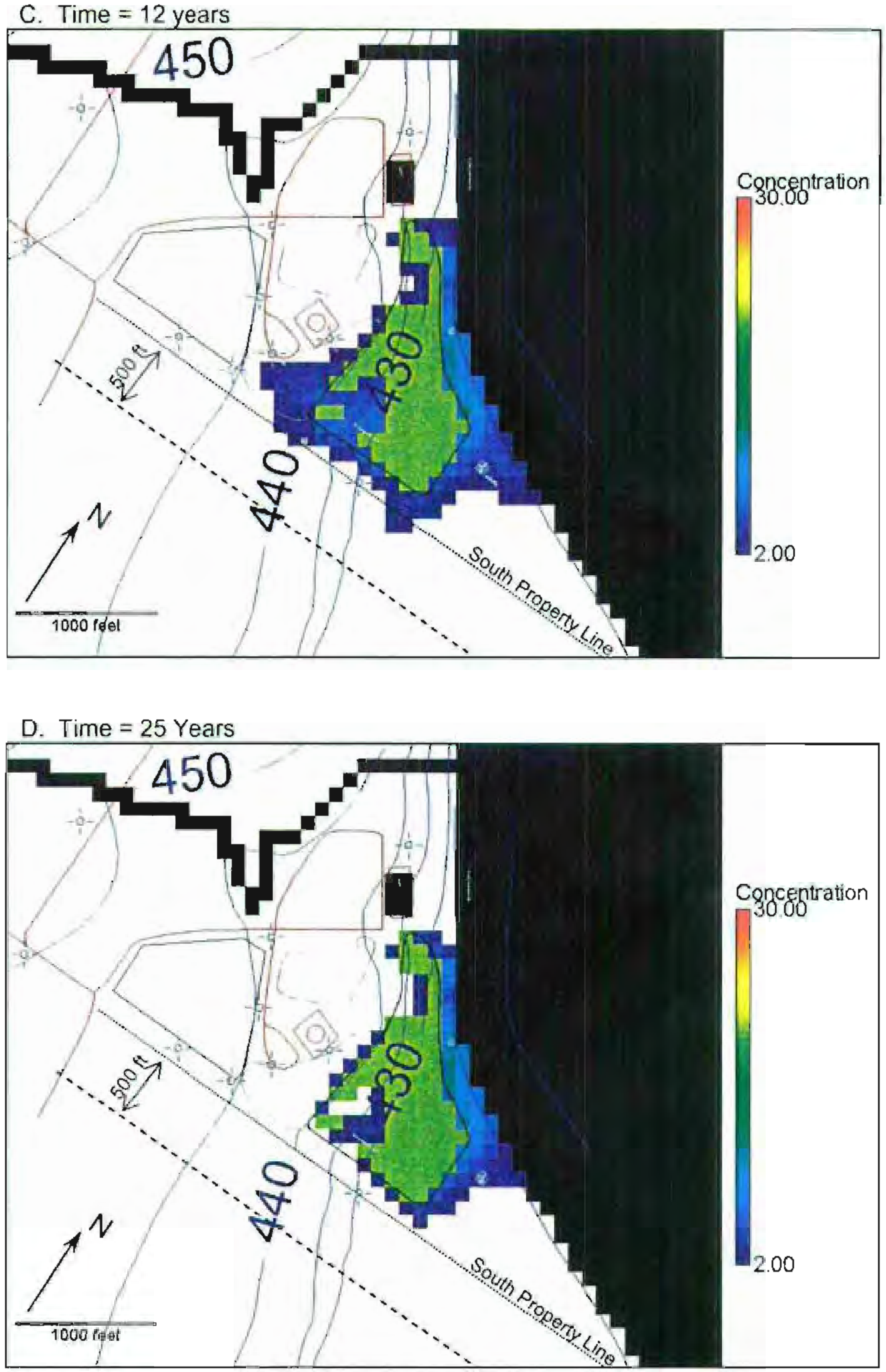



Figure 17C-D. Pond D Closure Scenario Model Head and Concentration Results

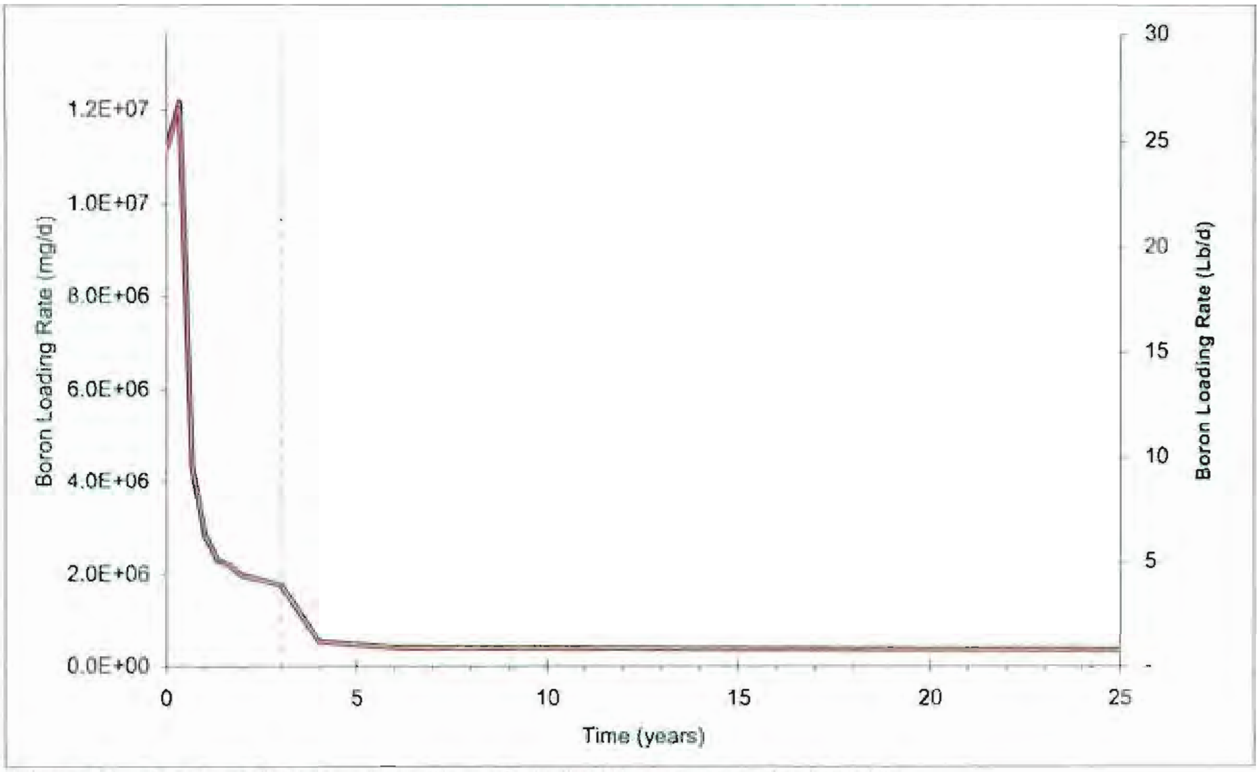



Figure 18. Model-predicted boron loading rate to the Wabash River & tributaries.
Years 0 to 3 represent dewatering, the cap and groundwater collection were simulated beginning in year 3,


Groundwater Modeling of
Huttsonville Pond D
April 13, 2009
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Model Files