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GREDELL Engineering Resources, Inc.

Ameren Missouri
Labadie Energy Center
Bottom Ash Pond
Groundwater Model Report

Prepared for:

Ameren Missouri
Power Operation Services
11149 Lindbergh Business Court
St. Louis, Missouri 63123

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1.0 INTRODUCTION

This report has been prepared on behalf of Ameren Missouri by GREDELL Engineering Resources, Inc. (Gredell Engineering) to provide a predictive analysis of groundwater flow subsequent to final capping and closure of the fly ash pond (FAP) and bottom ash pond (BAP) located at the Ameren Missouri – Labadie Energy Center in Franklin County, Missouri. The report describes the subsurface, hydrogeologic conditions, which are used to develop the numerical groundwater flow and chemical transport models for the BAP and surrounding area. The objective of the modeling is to assess the dissipation of the of excess hydraulic head in the BAP, the influence it has on groundwater flow, and to predict changes in the transport of Boron, Molybdenum, and Arsenic in the deeper parts of the alluvial aquifer following the completion of capping and closure scenarios.

This report is prepared exclusively for confidential use by Ameren and their designated representatives. It is subject to attorney-client privilege and is not intended for general distribution to regulatory entities or other interested parties.

1.1 Background

The Labadie Energy Center is located in northeastern Franklin County, approximately 10 miles east of the City of Washington. The facility resides within approximately 2,400 acres of largely agricultural bottomland owned by Ameren Missouri (Figure 1). The property is bounded to the north by the Missouri River, to the south by a railroad line and rock bluffs, and to the west by Labadie Creek. The eastern boundary is marked by additional agricultural bottomland. Other industrial facilities are not present near the Labadie Energy Center. Residential properties are located at higher elevation on the river bluffs south of the site but are not present within adjoining bottomland tracts east and west of the site. The National Geodetic Survey indicates that the ash pond site lies within the northwestern part of Township 44 North, Range 2 East, within portions of Sections 17, 18, and 19.

According to Missouri State Operating Permit MO-0004812, re-issued September 1, 2018, the ash pond site includes an unlined BAP that began operation in 1970 and an adjacent lined FAP that was constructed in 1993. Both ponds are located south and east of the Labadie Energy Center (Figure 1).

The BAP was created as a result of borrow activities for construction of the Labadie Energy Center. A berm with a crest elevation of 482 feet was constructed around the bottom ash pond (Bechtel, 1966) and later raised to approximately 494 feet following a geotechnical assessment by Reitz & Jens, Inc. (1988). The base of the BAP at its deepest point is at an elevation of approximately 407.5 feet (Gredell Engineering, 2015).

1.2 Site Hydrogeology

The ash pond site is located within the alluvial plain of the Missouri River and is within an area colloquially called the “Labadie Bottoms”. This area essentially has the configuration of a large point bar deposit that has accreted along the south side of the river valley as the main channel of the Missouri River progressively migrated northward away from the site.

The primary groundwater resource underlying the ash pond site and surrounding area is Holocene-age alluvium. The alluvial aquifer system is underlain by less permeable Ordovician-age bedrock, which also forms the bluffs that mark the southern limits of Labadie Bottoms. The alluvial aquifer is characterized by a shallow (<20 feet) water table and retains unconfined hydraulic properties. Yields ranging from 1,000 to 2,000 gallons per minute (gpm) from this aquifer have been reported (Gredell Engineering et al., 2011). However, residential water usage is from bedrock water wells (WIMS, 2019, GeoSTRAT, 2019) drilled on the bluffs south of the site. Wells drilled on the bluffs produce water from multiple Ordovician-age bedrock units (i.e., St. Peter Sandstone, Powell Dolomite, Jefferson City-Cotter Dolomite, Roubidoux Formation) that are collectively referred to as the “Ozark Aquifer”. These rock units typically possess weakly developed, intercrystalline pore networks and exhibit low formation permeability (Gredell Engineering et al., 2011). Yields reported for the wells are typically less than 30 gpm (WIMS, 2019).

As reported by Ferrara (2016), groundwater flow direction in the bedrock aquifer south of the Labadie Energy Center is consistently northward toward the Missouri River. Moreover, numerical groundwater modeling conducted by Golder Associates (Golder) demonstrated that even in an extreme worst case flood event, the northward flow of groundwater in the bedrock aquifer persisted (Golder, 2015). Ferrara (2016) also concluded that there was no potential for groundwater within the bedrock underlying the Labadie Bottoms to move up into the bedrock aquifer in the bluffs south of the site.

The hydraulic characteristics of the alluvial aquifer have been the focus of multiple investigations (Gredell Engineering et al., 2011; Gredell Engineering, 2017a, b; Golder, 2017a, b, & c). The hydrogeologic findings of these investigations generally corroborate one another and the reported groundwater flow direction, hydraulic gradient, and hydraulic conductivity are similar.

Groundwater flow direction in the alluvial aquifer is generally toward the Missouri River under normal river stage conditions. However, during periods of increased river levels, the river recharges the local aquifer and the primary direction of groundwater flow shifts to an easterly direction. Hydraulic gradients in the alluvial aquifer have been shown to consistently range from 1×10^{-4} to 9×10^{-4} feet per foot (ft/ft). Hydraulic conductivity values in the shallower part of the alluvial aquifer range between 1×10^{-2} and 5.5×10^{-2} centimeters per second (cm/s) and range from 4.7×10^{-2} to 1.8×10^{-1} cm/s in the deeper part of the alluvial aquifer.

Unified Guidance (USEPA, 2009) indicates that an effective porosity value of 20 percent is appropriate for the sandy/gravelly materials underlying the site. Additionally, Gelhar et al., (1992) reported a review of tracer test studies and found 20 percent effective porosity for clay, silt, sand, and gravel alluvial aquifers. Based on this porosity value and the hydraulic conductivity values summarized above, groundwater velocity values were derived during the Site Characterization (Gredell Engineering, 2017b) using the average hydraulic gradient representative of prevailing groundwater movement at the site. These velocity values range between 24 and 344 feet per year (ft/yr), dependent on the hydraulic conductivity value of the alluvial materials.

1.3 Groundwater Quality

Groundwater quality in the alluvial aquifer has been evaluated since April 2013. Initially, water quality testing was conducted in the monitoring system bordering the utility waste landfill (UWL). However, since that time, several additional groundwater monitoring systems have been installed around the ash pond site, and there currently are 95 monitoring wells that are subject to sampling and chemical analysis at Labadie Energy Center.

1.4 Ash Pond Pore Water Quality

Sampling of pore water within the BAP from temporary piezometers was conducted by Golder in 2018 (Golder, 2018c). As reported by Golder (2018c), the average concentrations of dissolved Boron, Molybdenum, and Arsenic in the pore water samples were approximately 10 mg/L, 415 μg/L, and 39 μg/L, respectively. These parameters were chosen for analysis because, due to their mobility, they function as a surrogate for other metals or to address public interest in groundwater quality in the Labadie Bottoms area. Accordingly, they are generally referred to as parameters of interest (POI) in this report.

1.5 Implementation of Proposed Capping and Closure Actions

Pursuant to 40 CFR §257.102, a surface impoundment (ash pond) can be closed by leaving the coal combustion residual (CCR) material in place and installing a final cover system. Ash ponds at the Labadie Energy Center will be closed by capping and leaving the CCR materials in place. To preclude the probability of future impoundment of water, conveyance systems and piping will be rerouted to prevent future discharge of plant service water systems or other drainage into the closed ash pond.

1.6 Timeline of Ash Pond Actions

The BAP capping and closure is planned to begin in 2020. At that time, the excess hydraulic head in the BAP will begin to dissipate due to the termination of inflow from plant processing systems.

2.0 GROUNDWATER MODEL APPROACH

The following sections present the conceptual groundwater flow model and the overall modeling methodology. The models are developed to predict the effect of the proposed capping and closure activities for the ash ponds on groundwater quality at the site and surrounding area. Groundwater flow in the alluvial aquifer is locally influenced by operation of the BAP (Golder, 2017b). Additionally, Golder demonstrated that the statistically significant increases identified during the detection monitoring event for the FAP were the result of impacts from the BAP (Golder, 2018c). Therefore, the BAP is the focus of this groundwater model report.

The objectives of the groundwater model are to:

- Incorporate recent and pertinent data into integrated conceptual and numerical models for use in evaluating remedial strategies (scenarios) at the ash pond site.
- Use the groundwater flow models to predict and compare various cap alternatives for the ash ponds as related to the dissipation of excess hydraulic head (dewatering) of the BAP.
- Use the models to predict and compare the effectiveness of capping and closure and other remedial alternatives.

2.1 Conceptual Model

The conceptual model for the ash pond site is schematically illustrated on Figure 2. Two sources for groundwater are present: Recharge within the model domain resulting from precipitation, and percolation water resulting from precipitation and process water discharged to the surface of the BAP. Groundwater flow in the alluvial aquifer flows toward the Missouri River, a regional groundwater sink, to the north of the ash pond site with an easterly component resulting from the influence of the BAP percolation. Excess hydraulic head in the BAP causes vertical (downward) percolation to the lower extents of the pond. Water enters the deeper portions of the alluvial aquifer where it then generally flows horizontally toward the river. Groundwater upgradient of the BAP generally flows under or around the BAP as a result of the hydraulic gradient in the pond and the permeability differential between the (lower permeability) ash and the (higher permeability) alluvium.

Boron, Molybdenum, and Arsenic are modeled to simulate migration of POIs. The conceptual model for transport assumes that these POIs migrate in pore water and groundwater as it moves through the BAP and aquifer, respectively. Therefore, the model uses the conservative assumption that chemicals instantaneously dissolve into the water passing through the ash as it percolates vertically or flows horizontally through the BAP below the water table. In reality, it is unlikely that mass transference occurs on an instantaneous basis.

Mass is discharged at the models' representation of the Missouri River. The conceptual transport model uses the conservative assumption that POIs are not removed via reaction, degradation, or irreversible sorption in the alluvial aquifer. The conceptual transport model also assumes that the Boron, Molybdenum, and Arsenic concentrations in the pore water do not vary as a function of time. However, the amount and rate of flow decreases over time as a result of: (1) cessation of plant discharge into the BAP; (2) reduction of precipitation recharge resulting from capping of the ash pond site, and; (3) pond dewatering.

2.2 Model Approach

Three model codes (programs) are used to simulate groundwater flow and Boron, Molybdenum, and Arsenic transport:

- Precipitation percolation through the cap after capping and closure of the ash ponds is modeled using the Hydrologic Evaluation of Landfill Performance (H.E.L.P.) model and the rates of percolation are uniformly applied in MODFLOW to simulate recharge through the cap and into the underlying waste mass.
- Three-dimensional groundwater flow through the BAP and alluvial aquifer is modeled using MODFLOW.
    - Three stress periods (or simulated time periods during which model input parameters can be changed), summarized in Table 1, are used to represent flow and transport conditions from the construction of the BAP to present (50 years from 1970 to 2020), and to simulate proposed capping and closure activities and predict changes in groundwater flow and quality over a period of 100 years.
- Three-dimensional Boron, Molybdenum, and Arsenic transport are modeled using MT3DMS after MODFLOW calculates the flow field.

Data Sources

The primary data sources used are:

- United States Geological Survey (USGS): River gauge data.
- Haley & Aldrich (2018): General site hydrology and Missouri River gradient.
- Gredell Engineering (2014, 2016, & 2017b): Ash pond capping and closure options, general hydrogeology, geology, aquifer (slug) test results, groundwater elevations, and potentiometric maps.
- Gredell Engineering et al. (2011): General hydrogeology, geology, aquifer (slug) test results, groundwater elevations, and potentiometric maps.
- Golder (2017b, c, d, 2018c, & d): General hydrogeology, geology, aquifer (slug) test results, groundwater elevations, potentiometric maps, and water quality data.

- Reitz & Jens et al. (2013b, c, d, e, g, 2014, & 2016): Geology, groundwater elevations, potentiometric maps, and water quality data.

A summary of the model input data derived from these and other sources is provided in Tables 2 and 3. Numerous additional references are listed in Section 8.0, some of which serve as secondary data sources utilized for development of the conceptual and numerical models.

The groundwater flow and transport models are calibrated to the monitoring data presented in Golder (2018d). The flow and transport results are also compared to data sets stemming from numerous investigations over smaller lateral extents within the model domain including. These include, but are not limited to, the Detailed Site Investigation (Gredell Engineering et al., 2011) for the UWL east of the ash pond site, which monitored water levels in the alluvial aquifer with 100 piezometers during 12 monthly events from December 2009 through November 2010.

The approach used to calibrate the groundwater flow model and transport model is:

- The flow model is calibrated to the prevailing flow direction based on recorded monitoring well measurements made from 2009 to 2018.
- The flow model is further calibrated to head observations measured during four representative monitoring events conducted by Golder from June to September 2018 (Golder, 2018d).
- The transport model is calibrated to the general distribution and average concentration of Boron, Molybdenum, and Arsenic as presented by Golder (2018d).

Calibration of MODFLOW and MT3DMS simulations is an iterative process. Multiple simulations were performed to achieve an acceptable match to the observed data. In order to provide a reliable set of input parameters, all available monitoring well data were considered for the calibration. The transport model calibration process required multiple iterations of, adjustments to, and recalibration of the groundwater flow model. The results provide a reasonable simulation of groundwater flow and transport at the ash pond site and surrounding area.

The calibrated models are run forward for an initial stress period of 50 years (1970-2020) assuming present-day lateral and vertical extent of ash pond contents. This is accomplished by calibrating the groundwater flow model and inputting the MODFLOW calculated flow field into MT3DMS to simulate the downgradient concentration configurations of Boron, Molybdenum, and Arsenic for the same time period.

A second stress period of 30 years (2020-2050) is used to simulate and predict groundwater flow and groundwater quality changes following capping and closure. This second stress period simulates transient changes in the flow system resulting from ash pond site capping and closure options/remedial scenarios. The transient MODFLOW simulation is used to assess the dissipation of excess hydraulic head (pond dewatering time) in the BAP following capping and closure. The flow field calculated by MODFLOW is used by MT3DMS to predict groundwater quality changes in the alluvial aquifer following capping and closure.

A third, 70-year stress period (2050-2120) extends the predictions for groundwater flow and groundwater quality changes following capping and closure to 100 years. As above, the flow field calculated by MODFLOW is used by MT3DMS to predict groundwater quality changes in the alluvial aquifer during this time period.

3.0 INFILTRATION MODELING

3.1 H.E.L.P. Model Description

The Hydrologic Evaluation of Landfill Performance (H.E.L.P.) code is a quasi-two-dimensional model developed by the U.S. Army Corps of Engineers for the U.S. Environmental Protection Agency. H.E.L.P. calculates vertical percolation through containment facilities based on a representative column of layers. The model accepts weather, soil, and design data of a layered soil column to generate hydrologic predictions over time.

H.E.L.P. version 3.07 (Schroeder et al. 1994) is the most recent iteration of the model and is utilized to estimate cap performance discussed in this report. The hydrologic data required by and entered into H.E.L.P. are listed in Table 4 and described in the following paragraphs.

3.2 H.E.L.P. Model Setup

The H.E.L.P. modeling considered the BAP cap configuration. The specific cap configuration evaluated includes a minimum of six inches thick vegetative soil cover over a minimum eighteen inches thick compacted clay soil layer. Further information on specific H.E.L.P. input parameters are described in Appendix 1.

3.3 H.E.L.P. Model Approach

The H.E.L.P. model is used to generate output values for average annual data including precipitation, evapotranspiration, and runoff as percolation with varied input parameters such as permeability, slope, layer type, or drainage length. Further information regarding the sensitivity of H.E.L.P. input parameters are described in Appendix 1.

3.4 H.E.L.P. Model Results

A summary of H.E.L.P. model results, including the impact of variations in hydraulic conductivity on average annual percolation, are shown in Appendix 1, Table 3. The model is run for multiple scenarios to evaluate the impact of cap design, slope, or hydraulic conductivity on the estimated average annual percolation. The H.E.L.P. output value for average annual percolation is 9.5 inches per year for the minimum required cap permeability of 1×10^{-5} cm/s. By decreasing the modeled hydraulic conductivity values to 1×10^{-6} cm/s and 1×10^{-7} cm/s, the average annual percolation is predicted to decrease to 5.4 and 0.9 inches, respectively. Therefore, the hydraulic conductivity of 1×10^{-7} cm/s modeled at 30 years with an annual percolation of 0.9 inches per year is chosen for the cap design and is a more conservative choice than the minimum cap requirement. This value is applied in the MODFLOW and MT3DMS models.

4.0 FLOW AND TRANSPORT MODEL SETUP AND CALIBRATION

Two groundwater modeling programs are used. MODFLOW simulates groundwater flow and calculates a flow field. The outputs from MODFLOW are input into MT3DMS, which simulates chemical transport in the groundwater flow field.

4.1 MODFLOW Model Overview

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

MODFLOW was developed by the United State Geological Survey (McDonald and Harbaugh, 1988). 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 properties are constant within a grid cell. Other assumptions concerning the finite difference equation can be found in McDonald and Harbaugh (1988). The 2000 version of MODFLOW (Harbaugh et al., 1996, 2000) is used to execute the simulations with the graphical user interface Visual MODFLOW, (Waterloo Hydrogeologic, 2018).

4.2 MT3DMS Model Overview

MT3DMS (Zheng and Wang, 1999) simulates chemical transport. It is a modular, three-dimensional multispecies transport modeling program that simulates advection, dispersion, and chemical reactions of constituents of interest in groundwater systems. It calculates the concentration distribution for a dissolved chemical constituent 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 (point source, or constant concentration cells), or distributed, evenly or unevenly, over the land surface (recharge source).

MT3DMS accounts for advection, dispersion, diffusion, first-order decay, and sorption. First-order decay terms may be differentiated for the absorbed and dissolved phases. The first-order Eulerian particle-tracking method is used for chemical transport modeling presented in this report. Sorption can be calculated using linear, Freundlich, or Langmuir isotherms.

Assumptions of MT3DMS are: (1) changes in the concentration field do not affect the flow field; (2) changes in concentration of one solute do not affect the concentration of another solute; (3) chemical and hydraulic/hydrologic properties are constant within a grid cell and; (4) sorption is instantaneous and reversible, while first-order decay is not reversible.

4.3 Base Model Descriptions

The groundwater flow and transport model's parameters are summarized on Figures 3 through 10. The model domain is a subset of a six-layer, 97 by 141 node grid with spacing ranging from 75.7 ft x 56.5 ft to 302.7 ft x 225.8 ft (Figures 3 and 4). The grid is rotated approximately 36 degrees clockwise to align the model's primary axis with the aquifer's predominant boundary conditions (Figure 3). The smallest node spacing is in the area of the BAP, where hydraulic gradients are highest due to the large hydraulic conductivity contrast between the ash and berms and the surrounding alluvium. The largest node spacing is in areas removed from the ash pond area. Refined (reduced) node spacing in areas of interest provides better resolution and representation of groundwater flow and transport.

Three stress periods (simulated time periods) are used (Table 1) for simulation of conditions associated with: (1) 50 years of BAP operation; (2) 30 years following capping and closure of the BAP, and; (3) an additional 70 years following the 30-year post-closure period.

4.4 Base Flow and Transport Model Setup

Flow and transport model boundary conditions are graphically summarized on Figure 5. The Missouri River is denoted by blue cells. The river parameters are summarized in Table 2. The river is the only groundwater and transport sink in the base model domain. Inactive model cells and domain limits serve as no-flow boundaries surrounding the remainder of the modeled domain. Inactive cells are indicated in gray on Figures 6, 7, and 8. Recharge areas are summarized on Figure 9. Recharge is varied spatially as indicated on Figure 9 and temporally as summarized in Table 2 to simulate hydrologic processes and changes associated with capping and closure of the ash ponds, respectively.

Hydraulic conductivity arrays for the model layers are summarized on Figures 6, 7, and 8. The hydraulic conductivity values within the layers are also summarized in Table 2, along with storage and porosity values.

4.5 Base Flow and Transport Model Assumptions

The following describes groundwater flow model assumptions:

- Alluvial Aquifer:
  - Can be represented as multiple flat layers of uniform thickness
    - Each layer is comprised of zones with uniform (homogeneous) hydraulic conductivity.
  - Is water-saturated; therefore, the terms "hydraulic conductivity" and "permeability" are synonymous in this report.
  - Is vertically anisotropic (horizontal permeability (hydraulic conductivity) is greater than vertical permeability (hydraulic conductivity)).
  - Has equivalent and uniform total porosity, effective porosity, and Specific Yield throughout the model domain.
- BAP CCR Mass:
  - Is homogeneous and isotropic.
  - Retains the same dimensions throughout the modeled stress periods.
  - Has permeability values consistent with data provided in Reitz & Jens (2017).
  - Is bounded on all sides by berms consisting of materials having less permeability than underlying alluvial materials (1.0×10^{-6} cm/s).
- Natural groundwater flow is affected by the excess hydraulic head in the BAP.
- There is a significant permeability contrast between the BAP CCR mass and natural alluvial materials.
- Natural recharge (precipitation) is constant over the model simulated periods.
- Temporal data involving stresses to the BAP do not exist for transient calibration of recharge estimate.
- Placement of the closure cap over the ponds occurs instantaneously.
- The groundwater model in this report is assumed to adequately estimate groundwater flow, velocities, and hydraulic head.

The following describes chemical transport model assumptions:

- The groundwater flow fields simulated with the groundwater model are valid inputs for transport modeling.
- The POI distributions presented in Golder (2018d) represent the current conditions in the alluvial aquifer.
- The BAP is the source for the POIs (Boron, Molybdenum, and Arsenic).
- The BAP retains the same dimensions throughout the modeled stress periods.
- Groundwater flow and POIs are preferentially transported in zones of higher permeability.

- Transport mechanisms:
  - POIs migrate through advection.
  - Natural attenuation is not considered.
  - POIs within the alluvial aquifer are not significantly changing with time prior to pond capping and closure (i.e., the concentration distributions are at or near equilibrium).
- Source concentrations within the BAP remain constant over time.
- POIs instantly dissolve into pore water.
- Chemical sinks are modeled the same as groundwater sinks.

4.6 Base Flow and Transport Model Calibration Results

The base model simulates the general groundwater flow direction and hydraulic gradients documented in previous investigations and sampling events. Groundwater flow model calibration results are summarized on Figures 11A/B through 14A/B. The flow model is calibrated to the prevailing groundwater flow direction based on recorded observation data from 2009 to 2018. Values of hydraulic conductivity were varied within a reasonable range based on available aquifer (slug) test data to improve model fit to calibration targets. The flow model is also calibrated to head observations measured during four consecutive monitoring events conducted in June, July, August, and September 2018 (Golder, 2018d). The simulated Missouri River elevation is the only model input parameter altered between simulations for each of the four monitoring events. Figures 11A, 12A, 13A, and 14A are residual correlation plots for groundwater elevations (simulated vs. observed) for the four monitoring events, with model fit statistics summarized. Figures 11B, 12B, 13B, and 14B compare the simulated potentiometric surface to the interpreted groundwater surface based on observations during each monitoring event.

The transport model is developed by assigning a constant source concentration to the entire BAP mass. The simulated constant source concentrations for Boron, Molybdenum, and Arsenic were initially assigned the average concentration of the pore water samples collected from the BAP (Golder, 2018c). The average concentrations are 10.345 mg/L (Boron), 0.410 mg/L (Molybdenum), and 0.039 mg/L (Arsenic). The model outputs were then compared to the distribution pattern of each POI presented by Golder (2018d). Horizontal hydraulic conductivity was manually adjusted to simultaneously optimize the fit between the simulated heads in the flow model and the simulated concentrations in the transport model to the observed heads and interpreted distribution pattern of each POI presented by Golder (2018d).

Once the model was sufficiently calibrated to simulate the observed heads and distribution patterns, the simulated constant source concentration of each POI was manually adjusted to reduce the mean residual concentration at the observation locations (Golder, 2018d) in order to minimize the average difference between observed and simulated concentrations in the monitoring wells. The resulting constant source concentrations simulated for Boron, Molybdenum, and Arsenic are 9.5 mg/L, 0.350 mg/L, and 0.020 mg/L, respectively (Table 3). Transport model calibration results for Boron are summarized on Figure 15 and concentration distributions are illustrated in Appendix 3. Transport model calibration results for Molybdenum are summarized on Figure 16 and concentration distributions are illustrated in Appendix 4. Transport model calibration results for Arsenic are summarized on Figure 17 and concentration distributions are illustrated in Appendix 5.

5.0 SIMULATION OF CAPPING AND CLOSURE ACTIVITIES

5.1 Overview

Groundwater flow and chemical transport modeling are conducted to simulate the effects of terminating plant process discharge into and capping and closure of the BAP. Initially, the dissipation rate of excess hydraulic head in the BAP is simulated to estimate dewatering times. Then a transport model simulates the change in distribution of POIs in the alluvial aquifer over a 30-year period following capping and closure of the BAP. Capping and closure activities are simulated by the second model stress period. This stress period is transient and recharge rates over the BAP and berms were decreased to simulate the emplacement of the low permeability cap options.

Predictive time series plots developed with outputs from the second and third stress periods illustrate the predicted changes in POI concentrations at three depth intervals using seven observation locations within the model domain. The third stress period was added to the base model to extend the prediction interval to 100 years following capping and closure. The second and third stress periods have the identical input parameters. The time series plots presented in Appendices 3, 4, and 5 are based on the use of a 1 x 10^{-7} cm/s closure cap.

Flow path tracing is used to assess flow following cessation of process water discharge to the BAP. Multiple hydraulic control scenarios are assessed, both without and with installation of a low permeability (1 x 10^{-7} cm/s) cap (Appendices 6A and 6B). These scenarios trace particles introduced at discrete points along the inner edges of the BAP sides and floor and allowed to track forward from the start of the second MODFLOW (transient) stress period. The particle introduction time is therefore modeled simultaneously with cessation of process water discharge into the BAP. The following eight scenarios are assessed and adjustments made to MODFLOW input parameters are summarized on Table 5.

1 No hydraulic control and no cap.
2 Hydraulic control via an array of pumping wells and no cap.
3 Hydraulic control via an array of pumping wells and a barrier wall installed from ground surface to the depth of ash in the BAP and no cap.
4 Hydraulic control via an array of pumping wells and a barrier wall installed from ground surface to the bedrock at the base of the alluvial aquifer and no cap.
5 No hydraulic control and installation of a low-permeability (1 x 10^{-7} cm/s) cap.
6 Hydraulic control via an array of pumping wells, and installation of a low-permeability (1 x 10^{-7} cm/s) cap.

7 Hydraulic control via an array of pumping wells, a barrier wall installed from ground surface to the depth of ash in the BAP, and installation of a low-permeability (1 x 10^{-7} cm/s) cap.
8 Hydraulic control via an array of pumping wells, a barrier wall installed from ground surface to the bedrock at the base of the alluvial aquifer, and installation of a low-permeability (1 x 10^{-7} cm/s) cap.

5.2 Predicted Dissipation of Hydraulic Head in BAP

The results of the BAP dewatering predictive simulations are summarized graphically in Appendix 2. The hydraulic head is plotted on the Y-axis in feet. The length of time following capping and closure of the pond is presented on the X-axis in years. This plot presents the model outputs of three cap permeability scenarios (1 x 10^{-5}, 1 x 10^{-6} and 1 x 10^{-7} cm/s).

The plot in Appendix 2 displays the lowering of excess hydraulic head in the BAP as a function of time after capping. In all three capping scenarios, the excess hydraulic head dissipates at similar rates with stabilization occurring at about five to six years after capping and closure. However, a lower permeability cap permits less seepage and results in a lower final excess hydraulic head in the BAP. A reduced hydraulic head in the BAP relative to the underlying aquifer will induce less loading into the groundwater. Therefore, the predictive simulations described in Sections 5.3 through 5.5 are based on a closure cap with 1 x 10^{-7} cm/s permeability.

5.3 Predicted Boron Distribution

The results of the predictive simulations for Boron distribution are illustrated in Appendix 3. Each map depicts simulated Boron distribution using iso-concentration contours of 2, 4, and 8 mg/L in model layers 2, 5, and 6. The concentration distributions simulated for 0 and 30 years following capping and closure of the ash ponds are presented at the beginning of Appendix 3, with 0 years representing the moment capping and closure are completed. Model outputs for layers 2, 5, and 6 are presented because most of the observation data used to calibrate the model coincide with these three layers. In addition, the elevations of layers 2, 5, and 6 generally coincide with the concentration distributions presented by Golder (2018d).

The time series plots presented at the end of Appendix 3 for the second and third stress periods (0 to 100-years post-closure) are preceded by a map showing the location of the seven observation locations. The map depicts four simulated observation locations along the BAP berm (indicated with small blue circles) and three simulated observation locations downgradient of the BAP (indicated with larger green circles). The berm observation locations are identified in a clockwise manner as OBS-BERM-1 through 4. The downgradient locations are identified, from west to east, as DG-OBS-1 through 3. Predicted concentration changes for model layers 2, 5, and 6 are presented for each observation location for the 100-year period following closure.

The Boron time series plots indicate that model layer 2, 5, and 6 observations at OBS-BERM-1 and layer 6 observations at OBS-BERM-2, 3, and 4 are predicted to be at or below 2 mg/L in less than 30 years after capping and closure. The Boron time series plots indicate that layers 2, 5, and 6 at the downgradient observation locations are predicted to be below 2 mg/L in approximately 34 years or less following capping and closure.

5.4 Predicted Molybdenum Distribution

The results of the predictive simulations for future Molybdenum distribution are illustrated in Appendix 4. Each map depicts simulated Molybdenum distribution using an iso-concentration contour of 0.100 mg/L in model layers 2, 5, and 6. The concentration distributions simulated for 0 and 30 years following capping and closure of the ash ponds are presented at the beginning of Appendix 4, with 0 years representing the instant in time capping and closure are completed. Model outputs for layers 2, 5, and 6 are presented because most of the observation data used to calibrate the model coincide with these three layers. In addition, the elevations of layers 2, 5, and 6 generally coincide with the concentration distributions presented by Golder (2018d).

The time series plots presented at the end of Appendix 4 for the second and third stress periods (0 to 100-years post-closure) are preceded by a map showing the same seven observation locations as used for Boron. Four are located along the BAP berm (indicated with small blue circles) and three are located downgradient of the BAP (indicated with larger green circles). The berm and downgradient observation locations are also identified in the same manner as presented for Boron. Predicted concentration changes for model layers 2, 5, and 6 are presented for each observation location for the 100-year period following closure.

The Molybdenum time series plots indicate that model layer 2, 5, and 6 observations at OBS-BERM-1 and the layer 6 observations at OBS-BERM-2, 3, and 4 are predicted to be at or below 0.100 mg/L in less than 30 years after capping and closure. The Molybdenum time series plots indicate that layers 2, 5, and 6 at the downgradient observation locations are predicted to be below 0.100 mg/L in less than 34 years following capping and closure.

5.5 Predicted Arsenic Distribution

The results of the predictive simulations for future Arsenic distribution are illustrated in Appendix 5. Each map depicts simulated Arsenic distribution using an iso-concentration contour of 0.010 mg/L in model layers 2, 5, and 6. The concentration distributions simulated for 0 and 30 years following capping and closure of the ash ponds are presented at the beginning of Appendix 5, with 0 years representing the moment capping and closure are completed. Model outputs for layers 2, 5, and 6 are presented because most of the observation data used to calibrate the model coincide with these three layers. In addition, the elevations of layers 2, 5, and 6 generally coincide with the concentration distributions as presented by Golder (2018d).

The time series plots presented at the end of Appendix 5 for the second and third stress periods (0 to 100-years post-closure) are preceded by a map showing the same seven observation locations as used for Boron and Molybdenum. Four simulated observation locations are located along the BAP berm (indicated with small blue circles) and three simulated observation locations are located downgradient of the BAP (indicated with larger green circles). The berm and downgradient observation locations are also identified in the same manner as presented for Boron and Arsenic. Predicted concentration changes for model layers 2, 5, and 6 are presented for each observation location for the 100-year period following closure.

The Arsenic time series plots indicate that model layer 2, 5, and 6 observations at OBS-BERM-1 and 2, and the layer 5 and 6 observations at OBS-BERM-3 and 4 are predicted to be at or below 0.01 mg/L in less than 30 years after capping and closure. The Arsenic time series plots indicate that layers 2, 5, and 6 at the downgradient locations are predicted to be below 0.01 mg/L in less than 30 years following capping and closure.

5.6 Flow Path Tracing from Bottom Ash Pond

The results of eight closure scenario simulations are presented in Appendices 6A and 6B and summarized on Table 5. The scenarios range from no hydraulic control and no cap over the BAP to installation of pumping wells, construction of a barrier wall to the top of bedrock, and use of a low permeability (1 x 10^{-7} cm/s) cap over the BAP.

The no hydraulic control and no cap scenario (Scenario 1) is assessed with particle tracing based on a MODFLOW output flow field. This flow field is simulated after adjusting the recharge values for the BAP and BAP berms (Figure 9) in the base MODFLOW model (Section 4) to 11.4 inches per year during the post-closure stress period. The model-predicted flow paths from the BAP without a low-permeability cap or other hydraulic controls are projected on Figure 6A-1 of Appendix 6A.

Hydraulic control via an array of pumping wells without use of a cap over the BAP (Scenario 2) is simulated by adding eight pumping wells to Scenario 1. The eight wells are positioned along the northern and eastern (downgradient) margin of the BAP as depicted on Figure 6A-2 of Appendix 6A. Hydraulic control is demonstrated for the 30 year post-closure period with this array of pumping wells. Pumping rates for each well range from 10 to 45 gpm (Table 5). The total extraction rate of the pumping array is 215 gpm.

Hydraulic control via an array of pumping wells and use of a barrier wall extending from ground surface to the base of ash in the BAP without use of a cap (Scenario 3) is simulated by adding a wall boundary condition to Scenario 2 and adjusting the pumping rates. Seven of the eight wells shown for Scenario 2 are simulated with pumping rates ranging from 15 to 40 gpm, as depicted on Figure 6A-3 of Appendix 6A. The well pumping rates and barrier wall parameters are summarized on Table 5. The total extraction rate of the seven well pumping array is 195 gpm.

Hydraulic control via an array of pumping wells and use of a barrier wall extending from ground surface to the top of bedrock without use of a cap (Scenario 4) is simulated by extending the wall boundary condition in Scenario 3 vertically and adjusting the well pumping rates. Five of the eight wells shown for Scenario 2 are simulated with pumping rates ranging from 15 to 70 gpm, as depicted on Figure 6A-4 of Appendix 6A. The well pumping rates and barrier wall parameters are summarized on Table 5. The total extraction rate of the five well pumping array is 205 gpm.

The low permeability (1 x 10^{-7} cm/s) cap scenario (Scenario 5) is simulated with particle tracing with the base groundwater model setup described in Section 4 unchanged. This flow field is simulated with the MODFLOW inputs summarized in Table 2. Model-predicted post-closure flow paths from the BAP with a low-permeability cap and no other hydraulic controls are projected on Figure 6B-1 of Appendix 6B.

Hydraulic control via an array of pumping wells and a low-permeability cap (Scenario 6) is simulated by adding seven pumping wells to Scenario 5. The seven wells are positioned along the northern and eastern (downgradient) margin of the BAP as depicted on Figure 6B-2 of Appendix 6B. Hydraulic control is demonstrated for the 30 year post-closure period with this array of pumping wells. Pumping rates for each well range from 15 to 25 gpm (Table 5). The total extraction rate of the pumping array is 145 gpm.

Hydraulic control via an array of pumping wells, a barrier wall extending from ground surface to the base of ash in the BAP, and a low-permeability cap (Scenario 7) is simulated by adding a wall boundary condition to Scenario 6 and adjusting the pumping rates of the seven-well array. As depicted on Figure 6B-3 of Appendix 6B, hydraulic control is demonstrated by the same array as depicted for Scenario 6, but with a lesser extraction rate of 100 gpm (total). The well pumping rates and barrier wall parameters are summarized on Table 5.

Hydraulic control via an array of pumping wells, a barrier wall extending from ground surface to the top of bedrock, and a low-permeability cap (Scenario 8) is simulated by extending the wall boundary condition in Scenario 7 vertically and adjusting the well pumping rates. Four of the seven wells shown for Scenario 7 are simulated with rates ranging from 5 to 50 gpm, as depicted on Figure 6B-4 of Appendix 6B. The well pumping rates and barrier wall parameters are summarized on Table 5. The total extraction rate of the four-well pumping array is 115 gpm.

5.7 Prediction Summary

Predictive model simulations are used to assess the potential long-term effects of ash pond caps constructed with permeabilities of 1 x 10^{-5}, 1 x 10^{-6} and 1 x 10^{-7} cm/s (Appendix 2). The simulations indicate that a cap system with 1 x 10^{-7} cm/s permeability will result in the lowest amount of percolation into the BAP and the lowest amount of leakage from the BAP into the alluvial aquifer. Chemical transport from the BAP is also simulated to predict the long-term effects of the three cap permeability options. The results demonstrate that a 1 x 10^{-7} cm/s permeability cap system will reduce concentrations of POIs in the alluvial aquifer the most (Appendices 3, 4, and 5).

The simulated concentrations at 0 years for Boron, Molybdenum, and Arsenic are intended to show the POI distribution at the time of pond capping and closure (Appendices 3, 4, and 5, respectively). These distributions are based on the conservative assumption that the BAP has been filled to capacity for 50 years and that concentrations of each POI have been entering the alluvial aquifer at a constant rate for the duration of the (pre-closure) modeled period. These are intended for juxtaposition with the predicted POI distributions simulated for 30-years post-closure with a 1 x 10^{-7} cm/s cap (Appendices 3, 4, and 5).

The predicted Boron, Molybdenum, and Arsenic 100-year time series plots provided in Appendices 3, 4, and 5, respectively display the projected POI concentrations from 2020 to 2120 at 21 points of interest (3 depths at 7 locations). These outputs predict Boron, Molybdenum, and Arsenic concentrations less than 2.00, 0.100, and 0.010 mg/L, respectively at the downgradient observation locations within 34 years of closure with a 1 x 10^{-7} cm/s cap.

Groundwater flow path tracing is used to assess flow directions following cessation of process water discharge to the BAP. Multiple hydraulic control scenarios are assessed, both without and with installation of a low permeability (1 x 10^{-7} cm/s) cap (Appendices 6A and 6B). Six scenarios demonstrate hydraulic control of particles introduced near the BAP inner margins for the 30-year period following cessation of process water discharge into the BAP. The six scenarios involve a barrier wall and/or pumping wells (Table 5). The lowest total pumping rate necessary to maintain hydraulic control is 100 gpm and is simulated with Scenario 7 which utilizes seven pumping wells and a barrier wall extending to the base of the BAP. Fewer pumping wells may achieve control, but a higher cumulative pumping rate may be necessary.

6.0 CONCLUSIONS

Extensive hydrogeologic and chemical data were reviewed and used to develop numerical models to assess percolation rates through three different closure cap options for the Labadie Energy Center ash pond site and to assess predicted changes in groundwater flow and chemical transport for the BAP and surrounding area resulting from the three cap permeability options.

Model simulations provide insight for estimating dissipation rates of the excess hydraulic head in the BAP using the three closure cap options. The model simulation outputs in this report demonstrate that a closure cap with 1 x 10^{-7} cm/s permeability will result in the least amount of percolation and the greatest reduction in POI concentrations in the alluvial aquifer.

The numerical models are also used for predicting changes in flow and the predicted temporal concentration and distribution of Boron, Molybdenum, and Arsenic in the alluvial aquifer resulting from various capping and closure scenarios. Model simulations based on eight closure scenarios ranging in complexity from no action to hydraulic control using a barrier wall and/or an array of pumping wells provide insights into the feasibility of each scenario.

7.0 LIMITATIONS

Numerical models discussed in this report provide mathematical solutions for groundwater flow and chemical transport. However, as noted by Anderson et al., (2015), a model is a simplified representation of the complex natural world. With MODFLOW, a multi-cell grid is defined to depict a simplified three-dimensional discretization of the natural aquifer system using the laws of science and mathematics to describe that system. As such, a model is a computer generated representation of the hydrologic system based on available information. Consequently, although a computer model lacks the almost limitless complexity and detail that can exist in the natural world, a calibrated model reasonably approximates the processes in the area for which it was calibrated. For these reasons, each model is a simplification of real-world processes. Models are subject to the limitations of available data, the degree of complexity of the system being evaluated, and the degree of accuracy involved in previous data collection.

This model uses inputs based on site-specific data, published data for similar hydrogeologic settings, and/or estimates of hydraulic and chemical data based on available information. Thus, because a model is limited to these inputs, predictions generated from model outputs are also limited in similar fashion.

Hydrogeologic evaluations and groundwater modeling are based on generally accepted, scientifically based best practices that result in non-unique solutions for properties used to describe complex subsurface environments. Scientific best practices constantly evolve, along with the ability to produce more refined estimates of hydrologic properties. In some cases, these properties, or our ability to characterize them, may change with time. Heterogeneities exist at infinite scales, but data are finite and limited to available information. For these reasons, these systems are complex beyond science's ability to precisely predict. In this regard, models must be viewed as constantly evolving predictive tools that are subject to update and refinement as additional data become available. MODFLOW and MT3DMS are predictive tools that evaluate a natural groundwater system of specified hydrogeologic stresses under various model scenarios. Consequently, the accuracy inherent in the model outputs are bound to the uncertainty normally associated with groundwater modeling and no warranty, express or implied, is made as to the accuracy of the results.

Gredell Engineering conducted the groundwater and chemical transport modeling described in this report in a manner consistent with the level of professional care normally exercised by other members of scientific and engineering communities conducting similar hydrologic investigations and model analysis. As previously noted, model predictions are not only predicated on the availability and quality of data, they are constrained by time considerations and financial limitations applicable to the services being provided. Unless otherwise specified, the results of previous investigations developed by sources other than Gredell Engineering and used herein are considered to have been obtained in accordance with generally recognized and accepted professional protocols and practices.

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TABLES

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Table 1
Model Stress Periods[1]

Modeled Time (year A.D.)	Stress Period[1]	Category	Flow Model State	Length (days / years)	Description
1970 to 2020	1	Calibration	Multiple/ Steady[2]	18250 / 50	Pond Operation with Process Water Application to Bottom Ash Pond
2020 to 2050	2	Prediction	Transient[3]	10950 / 30	Post Capping of Bottom Ash Pond Discontinue Application of Process Water release to Bottom Ash Pond
2050 to 2120	3	Prediction	Transient[3]	25550 / 70	Continuation of Stress Period 2

NOTES:

1. Stress Period is a modeled time period with specific input parameters. Parameters such as recharge rate may be assigned differently in successive stress periods.
2. Multiple steady state (hydraulic head not changing with time) simulations were used to calibrate to multiple data sets.
3. Transient simulations allow the magnitude and direction of flow to change as hydraulic head changes.
4. Stress period 2 was extended via addition of a third stress period with identical inputs.

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Checked by: CMW

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Table 2
MODFLOW Input Parameters

Parameter		Model Values			Reported Range	Data Source(s)
		Horizontal (cm/s)		Vertical (cm/s)		
Hydraulic Conductivity	**Stress Periods**	K_x	K_y	K_z	**cm/s**	
Layer 1 Compacted Berms	1-3	10^{-6}	10^{-6}	10^{-6}	10^{-6}	Reitz & Jens, 1988
Layers 1-4 Ash (Fly and Bottom Mixed)		$3x10^{-5}$	$3x10^{-5}$	$3x10^{-5}$	non-ponded fly ash= $8.3x10^{-6}$ cm/s ponded fly ash = $4.5x10^{-5}$ cm/s, bottom ash = 0.73 to 0.5 cm/s	Reitz & Jens et al, 2017
Layer 1 Shallow Alluvium (F/L)		0.01	0.01	0.001	$3x10^{-2}$ to $1x10^{-2}$ cm/s	Gredell et al, 2011, Golder, 2017b, c, &d, Gredell, 2017b, Fetter, 1988
Layers 2-4 Intermediate Alluvium (CM)		0.15	0.15	0.005	$1.1x10^{-2}$ to $5x10^{-2}$ cm/s	Gredell et al, 2011, Golder, 2017b, c, &d, Gredell, 2017b, Fetter, 1988
Layers 5-6 Deep Alluvium (CH)		0.45	0.45	0.015	$1.3x10^{-2}$ to $1.5x10^{-1}$ cm/s	Gredell et al, 2011, Golder, 2017b, c, &d, Gredell, 2017b, Fetter, 1988
Recharge	**Stress Periods**	**(in/yr)**			**in/yr**	
General	1-3	11.4			11.4	HELP Model Database
Bottom Ash Pond (In Service)	1	120			Estimated	Estimated
Bottom Ash Pond (Closed)	2-3	0.9			0.9	HELP Model, Appendix 1
Bottom Ash Pond Berms (In Service)	1	11.4			11.4	HELP Model Database
Bottom Ash Pond Berms (Closed)	2-3	0.9			0.9	HELP Model, Appendix 1
Fly Ash Pond (Lined)	1-3	11.4			11.4	HELP Model Database
Utility Waste Landfill (Lined)	1-3	11.4			11.4	HELP Model Database
Storage/Porosity	**Stress Periods**	**S_S (1/ft)**	**S_Y**	**Effective Porosity**	**Effective Porosity**	
Layer 1 Shallow Alluvium (F/L)	1-3	$2.3x10^{-4}$	0.2	0.2	0.2	Gredell, 2017b, Gelhar et al, 1992, USEPA, 2009
Layer 1 Compacted Berms		$2.3x10^{-4}$	0.2	0.2	Estimated	NA
Layers 1-4 Ash (Fly and Bottom Mixed)		$2.3x10^{-4}$	0.2	0.2	Estimated	NA
Layers 2-4 Intermediate Alluvium (CM)		$2.3x10^{-4}$	0.2	0.2	0.2	Gredell, 2017b, Gelhar et al, 1992, USEPA, 2009
Layers 5-6 Deep Alluvium (CH)		$2.3x10^{-4}$	0.2	0.2	0.2	Gredell, 2017b, Gelhar et al, 1992, USEPA, 2009
River Parameters	**Stress Periods**	**Missouri River**				
River Stage Elevation (at gauge)	1-3	457.12 ft, 457.70 ft, 456.32 ft, 457.52 ft			Min = 447.99 ft, Max = 478.33 ft, Avg = 456.97 ft (Available History)	USGS, 2018
River Gradient		0.95 ft/mile			0.95 ft/mile	Haley & Aldrich, 2018
Bed Thickness		1			Estimated	NA
River Bed K_z (cm/s)		$1.5x10^{-2}$			Estimated	NA
River Bed Conductance (ft^2/d)		normalized by cell dimensions			normalized by cell dimensions	NA
River Width (ft)		1,500 ft			1,500 ft	Google Earth, 2019
Cell Length (ft)		variable			variable	NA

NOTES:

1. NA = not applicable.

Prepared by: KAE

Checked by: CMW

Prepared by: GREDELL Engineering Resources, Inc.

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Bottom Ash Pond Groundwater Model Report

Table 3
MT3DMS Input Parameters

Parameter	Stress Periods	Modeled Values	Reported Range	Data Source
Initial Concentrations (all constituents) (mg/L)	1	0.000	NA	NA
Source Concentration - Boron (mg/L)	1-3	9.5	3.26 - 21.7	Golder, 2018c
Source Concentration - Molybdenum (mg/L)	1-3	0.350	0.0797 - 1.460	Golder, 2018c
Source Concentration - Arsenic (mg/L)	1-3	0.020	0.0092 - 0.0739	Golder, 2018c
Effective Porosity	1-3	0.20	0.20	Gredell, 2017b, Gelhar et al., 1992, USEPA, 2009
Dispersivity (Longitudinal)	1-3	30 ft	Estimated	Gelhar et al., 1992
Dispersivity (Transverse)	1-3	3 ft	Estimated	Gelhar et al., 1992
Dispersivity (Vertical)	1-3	0.3 ft	Estimated	Gelhar et al., 1992

NOTES:

1. NA = Data not considered for initial concentration assumption.

Prepared by: KAE
Checked by: CMW

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Table 4
H.E.L.P. Input Parameters

	Parameter	Description
Climate (general)		
City	St. Louis, MO	nearby city in H.E.L.P. database
Latitude	38.45	Labadie Energy Center Location
Evap. Zone Depth	6	inches
Leaf Index	3.5	1 - 5; poor - excellent grass
All Other Options	-	defaults for St. Louis, MO
Precipitation/Temperature Evapotranspiration		
Soils		
Area	165	acres (approximate)
Initial Moisture Content	-	Calculated by the H.E.L.P. model
Surface Water/Snow	0	No surface water
Soil Layers (cap design)		
1	vegetative soil	6" thick
2	barrier clay	18" thick
Layer Parameters		
Layer 1		
Type	1	H.E.L.P. Code : vertical percolation layer
Thickness	6	inches
Texture	8	H.E.L.P. Soil Code
Porosity	0.463	vol/vol; default for selected Soil Code
Field Capacity	0.232	vol/vol; default for selected Soil Code
Wilting Point	0.116	vol/vol; default for selected Soil Code
Hydraulic Conductivity	0.369×10^{-3}	cm/s; default for selected Soil Code
Layer 2		
Type	3	H.E.L.P. Code : barrier soil layer
Thickness	18	inches
Texture	0	H.E.L.P. Soil Code
Porosity	0.427	vol/vol; default for selected Soil Code
Field Capacity	0.418	vol/vol; default for selected Soil Code
Wilting Point	0.367	vol/vol; default for selected Soil Code
Hydraulic Conductivity	1×10^{-7}	cm/s (minimum required)
Soil Runoff		
Slope	3	percent (per closure design)
Length	2000	feet (per closure design)
Texture	8	H.E.L.P. Soil Code

Prepared by: CMW

Checked by: JB

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Table 5
Closure Scenario Simulations
MODFLOW Input Parameters

				Pumping Wells								▨	Barrier Wall			
Scenario		BAP Recharge (in/yr)	BAP Berms Recharge (in/yr)	PW-1 rate (GPM)	PW-1(2) rate (GPM)	PW-1(3) rate (GPM)	PW-1(4) rate (GPM)	PW-1(5) rate (GPM)	PW-1(6) rate (GPM)	PW-1(7) rate (GPM)	PW-1(8) rate (GPM)	Sum of pumping rates (GPM)	Hydraulic Conductivity (cm/s)	Thickness (ft)	Continuous from Ground Surface to Elevation Indicated (ft)	Hydraulic Control Demonstrated? (Yes / No)
1	No Hydraulic Control and No Cap	11.4	11.4	0	0	0	0	0	0	0	0	0	N/A	N/A	N/A	No
2	Pumping Wells	11.4	11.4	20	10	35	35	45	35	20	15	215	N/A	N/A	N/A	Yes
3	Pumping Wells and Barrier Wall to Base of Ash	11.4	11.4	15	0	25	25	35	40	25	30	195	10^{-6}	2	407.5	Yes
4	Pumping Wells and Barrier Wall to Bedrock	11.4	11.4	60	15	0	0	40	70	20	0	205	10^{-6}	2	350	Yes
5	10^{-7} cm/s Cap	0.9	0.9	0	0	0	0	0	0	0	0	0	N/A	N/A	N/A	No
6	Pumping Wells and 10^{-7} cm/s Cap	0.9	0.9	25	0	25	20	20	25	15	15	145	N/A	N/A	N/A	Yes
7	Pumping Wells, Barrier Wall to Base of Ash, and 10^{-7} cm/s Cap	0.9	0.9	20	0	10	10	15	20	15	10	100	10^{-6}	2	407.5	Yes
8	Pumping Wells, Barrier Wall to Bedrock, and 10^{-7} cm/s Cap	0.9	0.9	40	0	0	0	20	50	5	0	115	10^{-6}	2	350	Yes

NOTES:

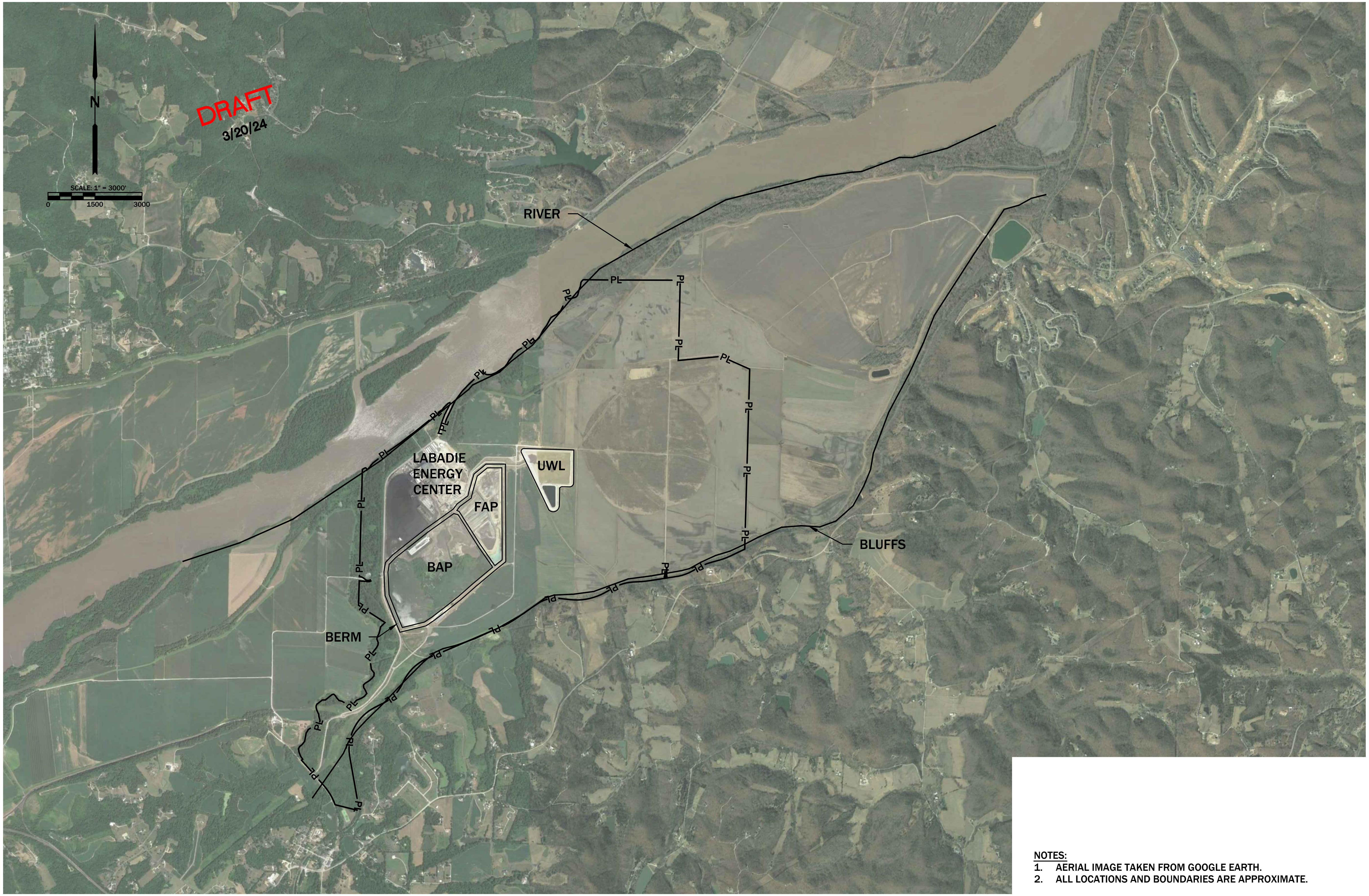
1. MODFLOW inputs changed for closure scenario simulation are shown.
2. GPM - Gallons per Minute.
3. N/A indicates Barrier Wall not simulated for the scenario.
4. Scenarios 1-4 simulate no designed pond cap installation. Scenarios 5-8 simulate pond cap with 10^{-7} cm/s hydraulic conductivity.

Prepared by: KAE
Checked by: MCC

Prepared by: GREDELL Engineering Resources, Inc.

FIGURES

O:\CADDFILES-INACTIVE\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 1.dwg, FIGURE 1, 3/20/2024 11:40:23 AM



NOTES:
1. AERIAL IMAGE TAKEN FROM GOOGLE EARTH.
2. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.

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FIGURE 1
SITE LOCATION MAP

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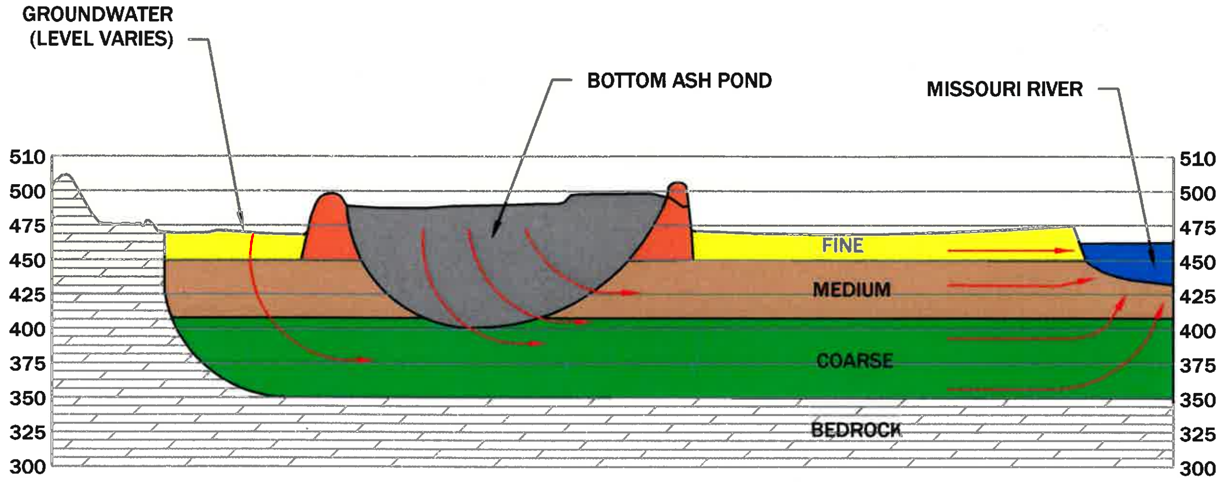

LEGEND

FLOW DIRECTION	→
ASH	■
ASH POND BERM MATERIAL	🟥
FINE GRAINED ALLUVIAL MATERIAL	🟨
MEDIUM GRAINED ALLUVIAL MATERIAL	🟫
COARSE GRAINED ALLUVIAL MATERIAL	🟩
BEDROCK	▤

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. CROSS-SECTION IS NOT TO SCALE AND IS ONLY A CONCEPTUAL REPRESENTATION OF THE SUBSURFACE GEOLOGY AND FEATURES.

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2/22/19

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FIGURE 2
CONCEPTUAL MODEL SCHEMATIC

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CP	MCC	FIGURE 2	1 OF 1

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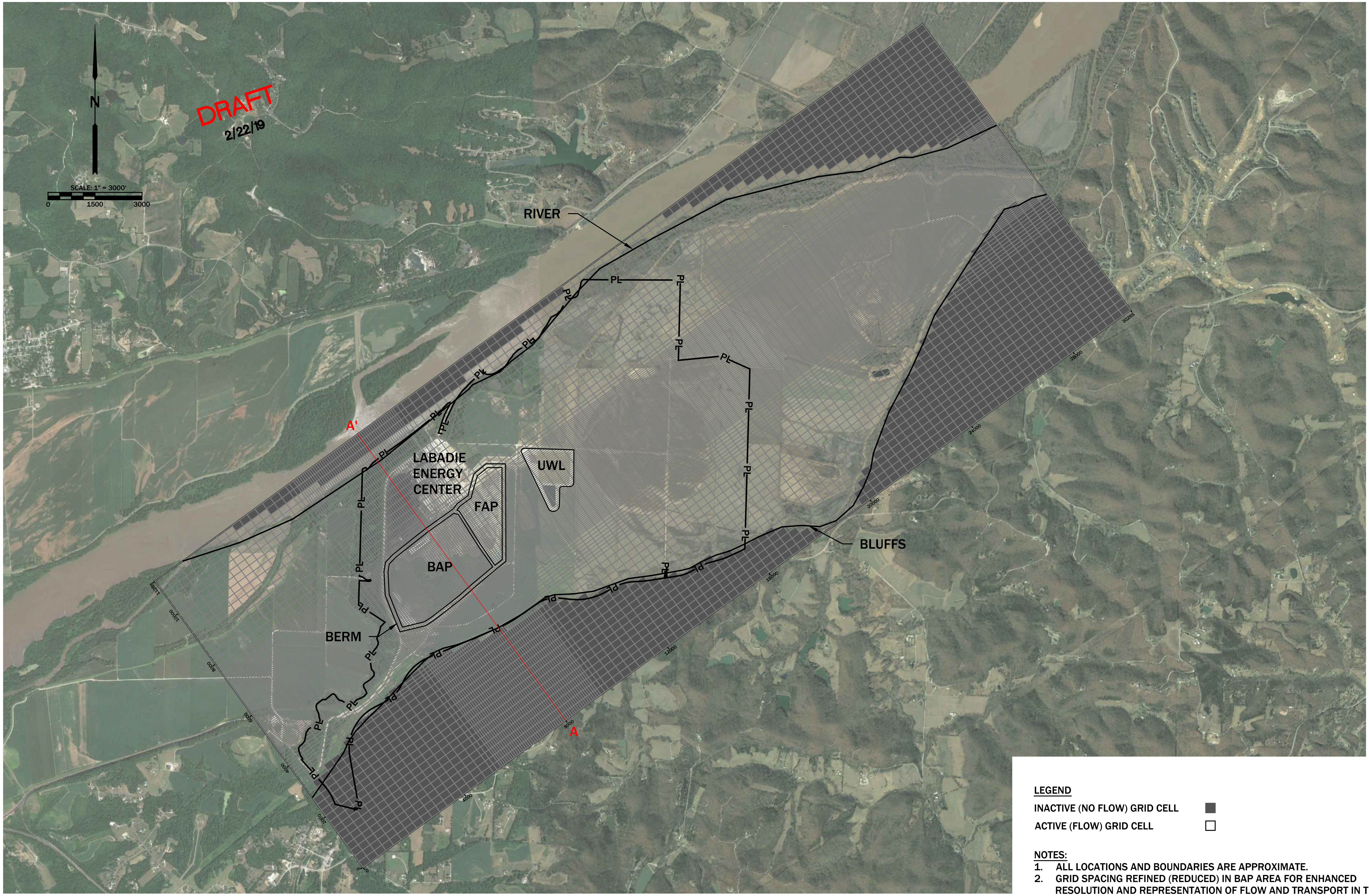

LEGEND

INACTIVE (NO FLOW) GRID CELL	■
ACTIVE (FLOW) GRID CELL	☐

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

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FIGURE 3
MODFLOW AND MT3DMS GRID AND MODEL DOMAIN

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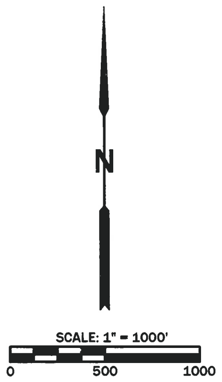

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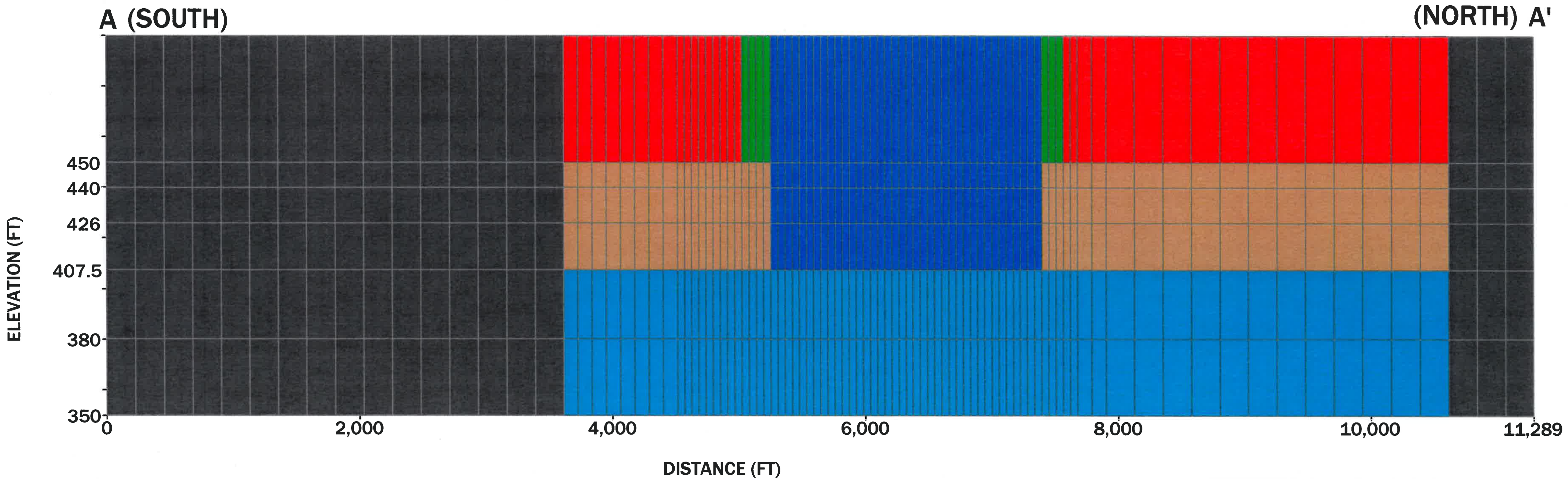

HYDRAULIC CONDUCTIVITY	Kx (cm/s)	Ky (cm/s)	Kz (cm/s)
COMPACTED BERMS	10^{-6}	10^{-6}	10^{-6}
ASH (FLY AND BOTTOM MIXED)	$3X10^{-5}$	$3X10^{-5}$	$3X10^{-5}$
SHALLOW ALLUVIUM (F/L)	0.01	0.01	0.001
INTERMEDIATE ALLUVIUM (CM)	0.15	0.15	0.005
DEEP ALLUVIUM (CH)	0.45	0.45	0.015

LEGEND

COMPACTED BERMS	🟩
ASH (FLY AND BOTTOM MIXED)	🟦
SHALLOW ALLUVIUM (F/L)	🟥
INTERMEDIATE ALLUVIUM (CM)	🟫
DEEP ALLUVIUM (CH)	🟦

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. SEE TABLE 2 FOR PARAMETER VALUES.
3. SEE FIGURE 3 FOR CROSS SECTION LOCATION.
4. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

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FIGURE 4
MODFLOW and MT3DMS GRID
CROSS SECTION A-A'

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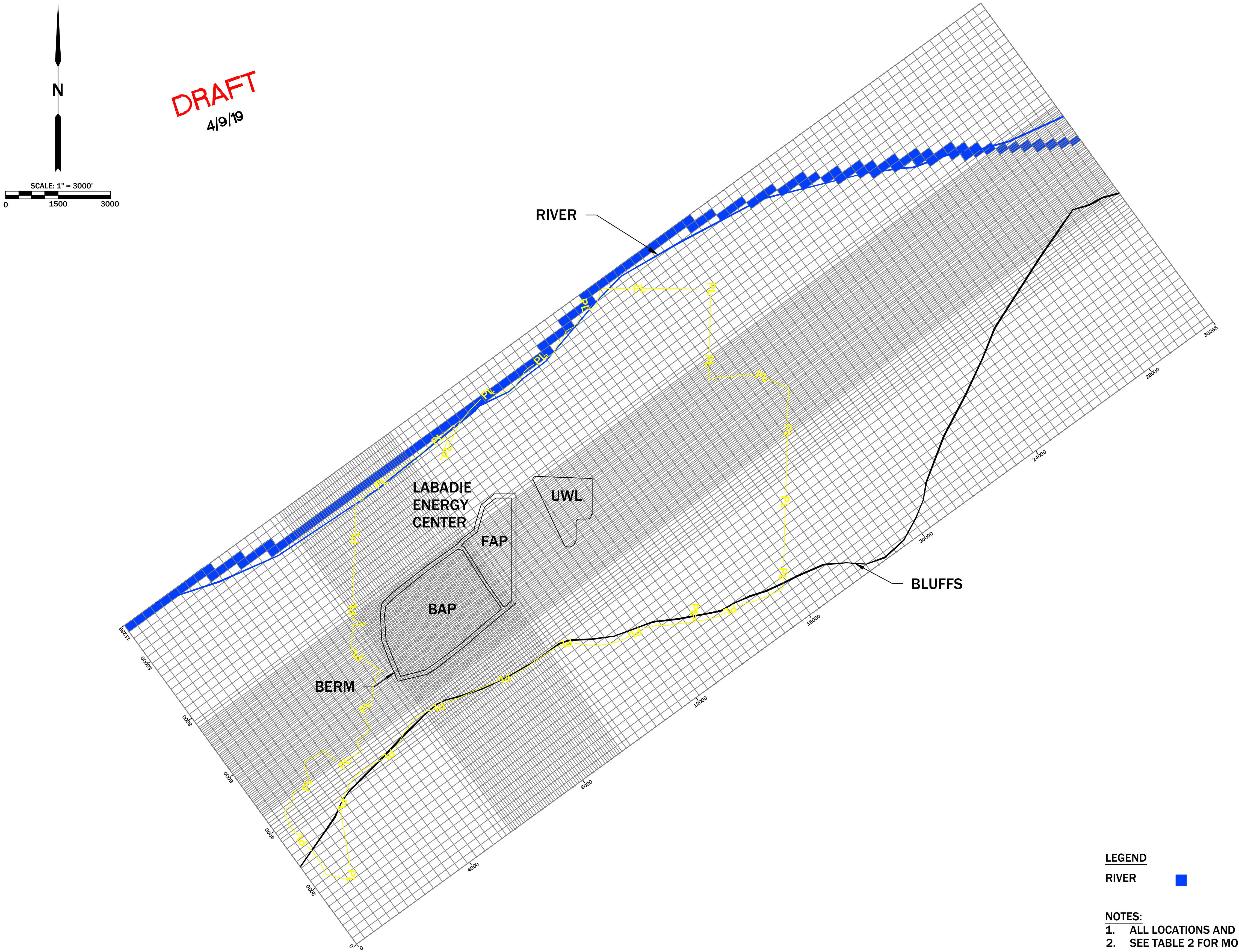

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LEGEND

RIVER	🟦

NOTES:
1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. SEE TABLE 2 FOR MODFLOW INPUT PARAMETER VALUES.
3. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

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FIGURE 5
MODFLOW AND MT3DMS
BOUNDARY CONDITIONS

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NA	KE	CP	CW	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 5	1 OF 1

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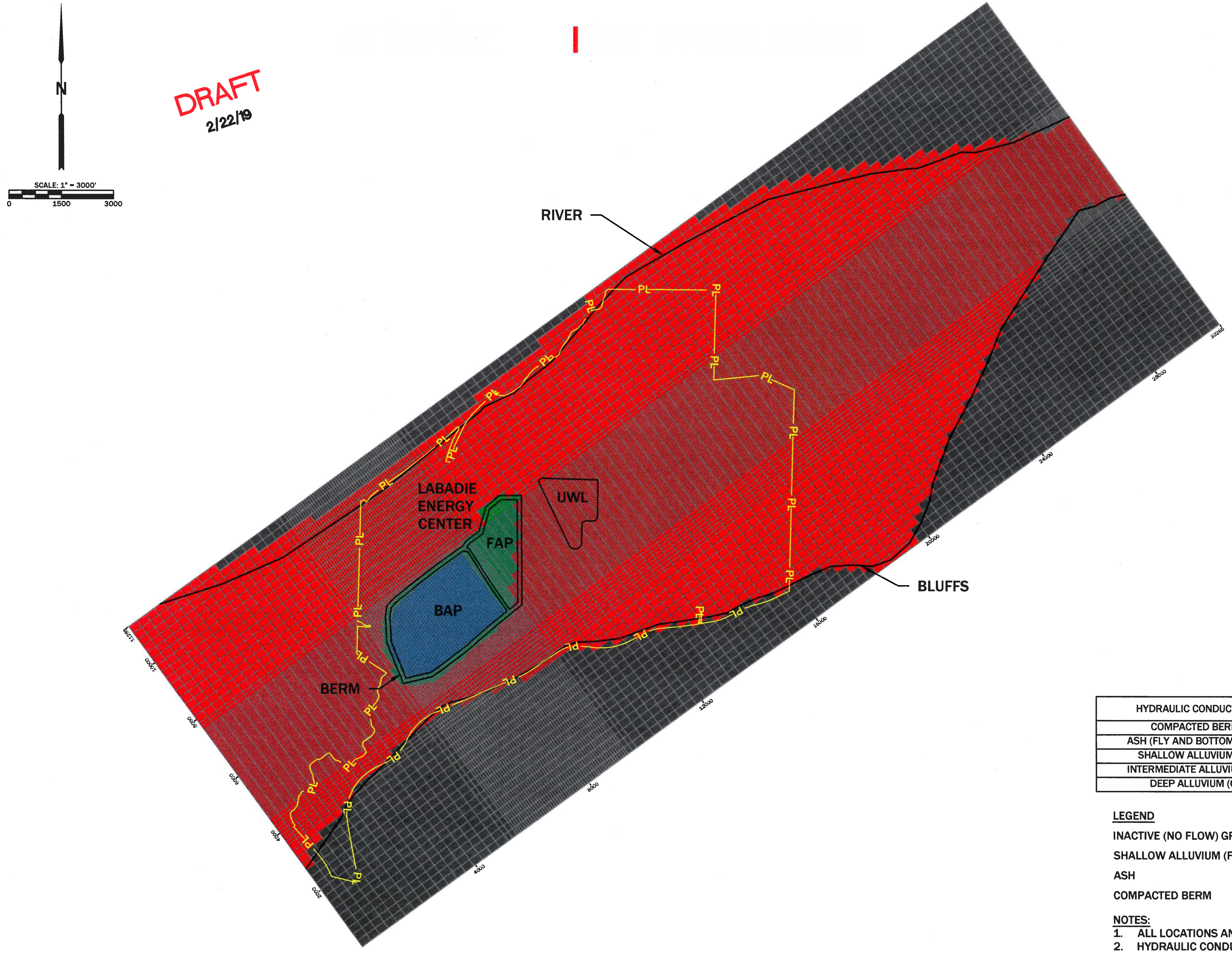

HYDRAULIC CONDUCTIVITY	Kx (cm/s)	Ky (cm/s)	Kz (cm/s)
COMPACTED BERMS	10^{-6}	10^{-6}	10^{-6}
ASH (FLY AND BOTTOM MIXED)	$3X10^{-5}$	$3X10^{-5}$	$3X10^{-5}$
SHALLOW ALLUVIUM (F/L)	0.01	0.01	0.001
INTERMEDIATE ALLUVIUM (CM)	0.15	0.15	0.005
DEEP ALLUVIUM (CH)	0.45	0.45	0.015

LEGEND

INACTIVE (NO FLOW) GRID CELL	⬛
SHALLOW ALLUVIUM (F/L)	🟥
ASH	🟦
COMPACTED BERM	🟩

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. HYDRAULIC CONDUCTIVITY FOR EACH LAYER IS DESCRIBED IN TABLE 2.
3. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

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FIGURE 6
HYDRAULIC CONDUCTIVITY ARRAY
(LAYER 1)

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NA	KE	CP	CW	MCC	2/2019	AS NOTED	LABADIE GW MODEL	FIGURE 6	1 OF 1

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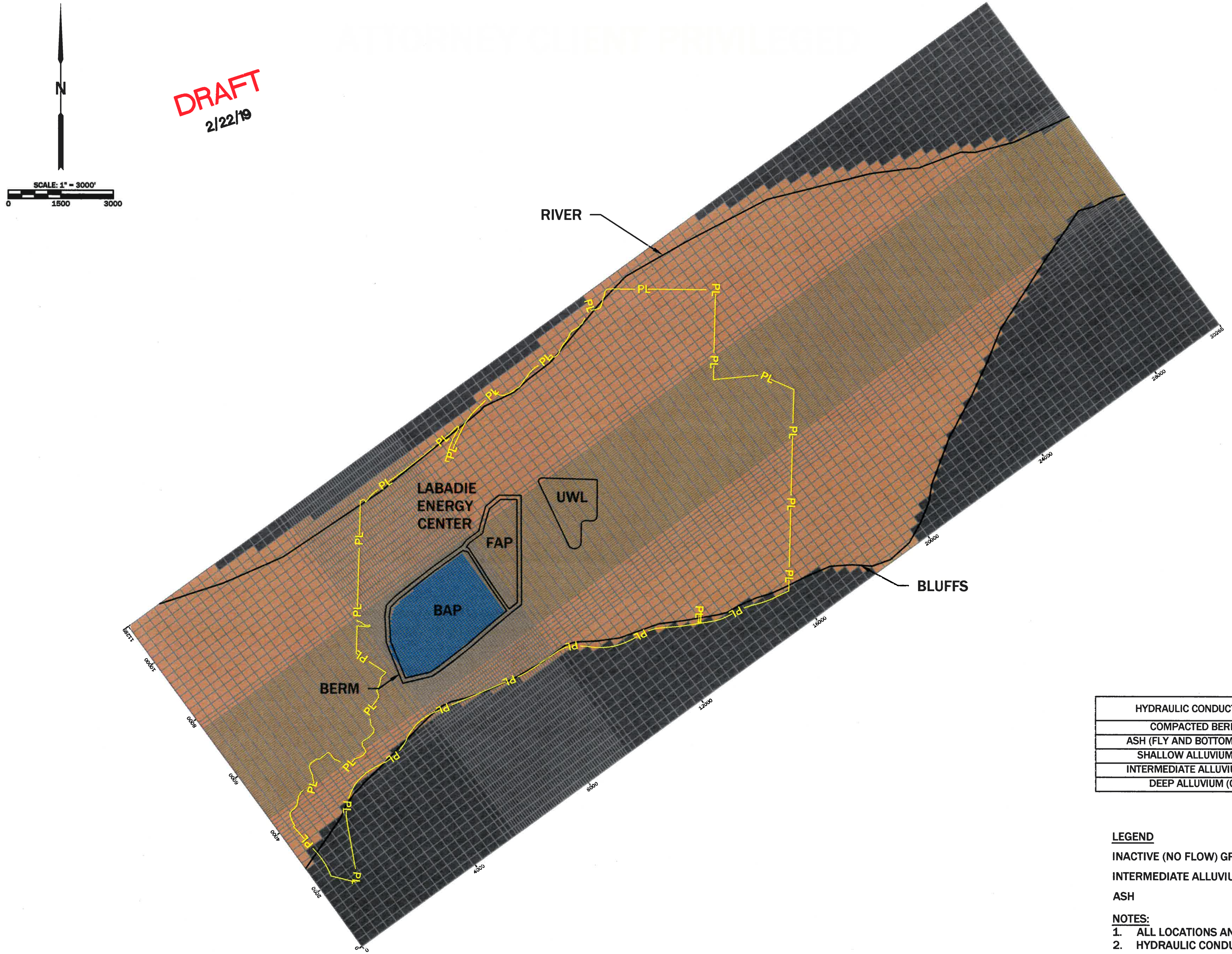

HYDRAULIC CONDUCTIVITY	Kx (cm/s)	Ky (cm/s)	Kz (cm/s)
COMPACTED BERMS	10^{-6}	10^{-6}	10^{-6}
ASH (FLY AND BOTTOM MIXED)	$3X10^{-5}$	$3X10^{-5}$	$3X10^{-5}$
SHALLOW ALLUVIUM (F/L)	0.01	0.01	0.001
INTERMEDIATE ALLUVIUM (CM)	0.15	0.15	0.005
DEEP ALLUVIUM (CH)	0.45	0.45	0.015

LEGEND

INACTIVE (NO FLOW) GRID CELL	■
INTERMEDIATE ALLUVIUM (CH)	■
ASH	■

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. HYDRAULIC CONDUCTIVITY FOR EACH LAYER IS DESCRIBED IN TABLE 2.
3. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

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FIGURE 7
HYDRAULIC CONDUCTIVITY ARRAY
(LAYERS 2, 3, & 4)

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	CP	CW	MCC	2/2019	AS NOTED	LABADIE GW MODEL	FIGURE 7	1 OF 1

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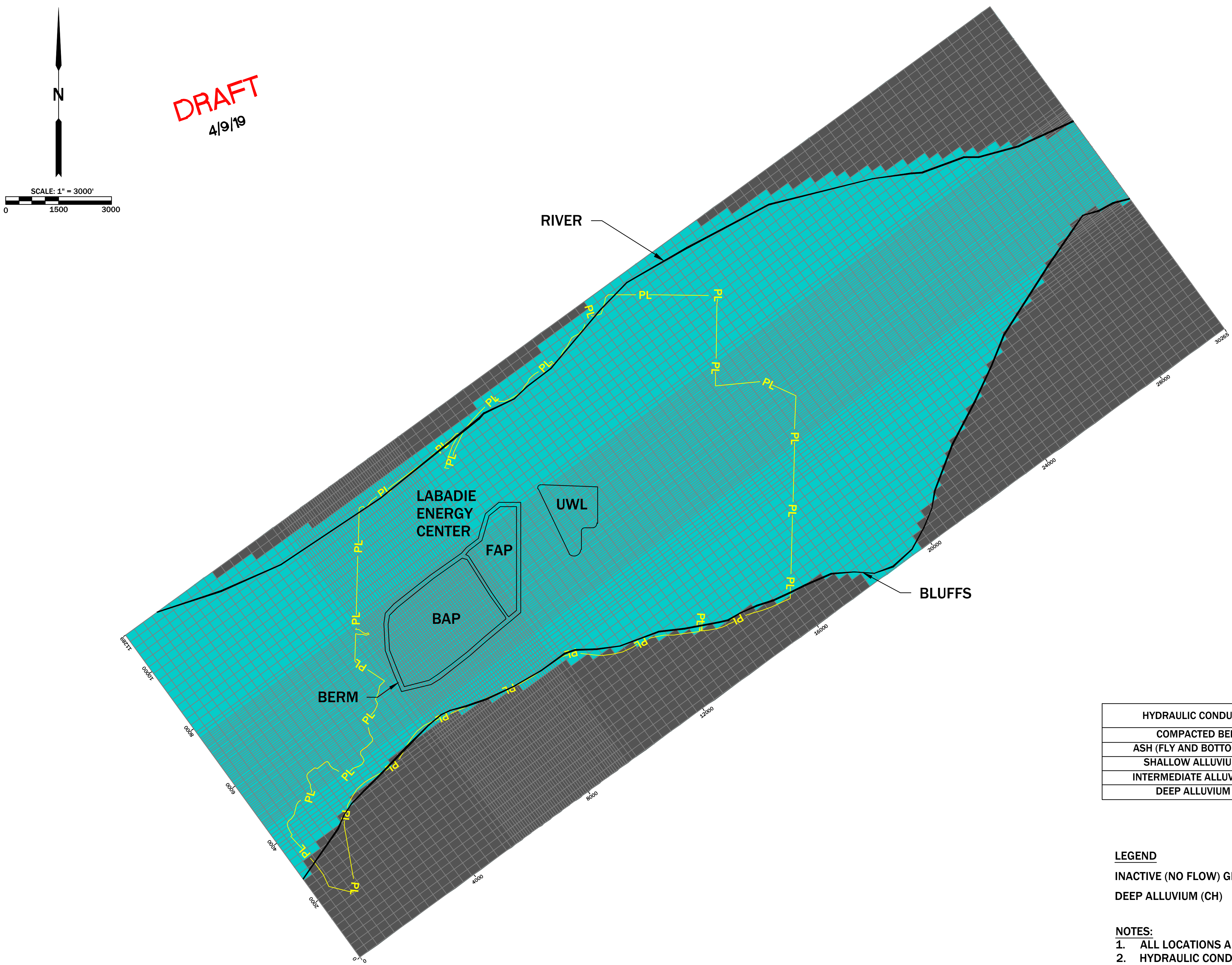

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HYDRAULIC CONDUCTIVITY	Kx (cm/s)	Ky (cm/s)	Kz (cm/s)
COMPACTED BERMS	10^{-6}	10^{-6}	10^{-6}
ASH (FLY AND BOTTOM MIXED)	$3X10^{-5}$	$3X10^{-5}$	$3X10^{-5}$
SHALLOW ALLUVIUM (F/L)	0.01	0.01	0.001
INTERMEDIATE ALLUVIUM (CM)	0.15	0.15	0.005
DEEP ALLUVIUM (CH)	0.45	0.45	0.015

LEGEND

INACTIVE (NO FLOW) GRID CELL	■
DEEP ALLUVIUM (CH)	🟦

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. HYDRAULIC CONDUCTIVITY FOR EACH LAYER IS DESCRIBED IN TABLE 2.
3. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

#	DATE	REVISION DESCRIPTION	BY

FIGURE 8
HYDRAULIC CONDUCTIVITY ARRAY
(LAYERS 5 & 6)

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GROUNDWATER MODEL REPORT

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NA	KE	CP	CW	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 8	1 OF 1

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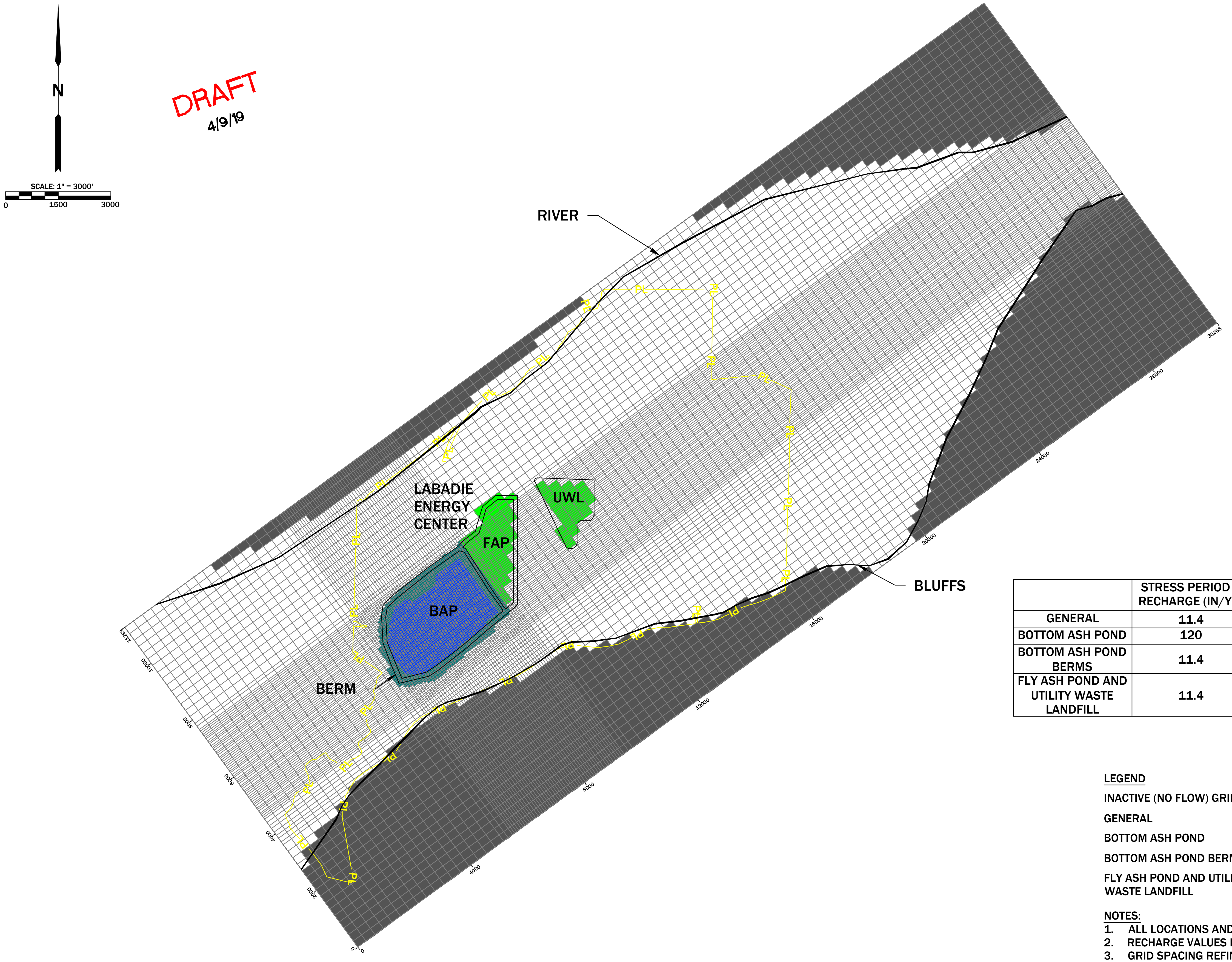

	STRESS PERIOD 1 RECHARGE (IN/YR)	STRESS PERIOD 2 RECHARGE (IN/YR)	STRESS PERIOD 3 RECHARGE (IN/YR)
GENERAL	11.4	11.4	11.4
BOTTOM ASH POND	120	0.9	0.9
BOTTOM ASH POND BERMS	11.4	0.9	0.9
FLY ASH POND AND UTILITY WASTE LANDFILL	11.4	11.4	11.4

LEGEND

INACTIVE (NO FLOW) GRID CELL	■
GENERAL	□
BOTTOM ASH POND	🟦
BOTTOM ASH POND BERMS	■
FLY ASH POND AND UTILITY WASTE LANDFILL	🟩

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. RECHARGE VALUES FOR EACH ZONE DESCRIBED IN TABLE 2.
3. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.

#	DATE	REVISION DESCRIPTION	BY

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Jefferson City, Missouri Facsimile: (573) 659-9079
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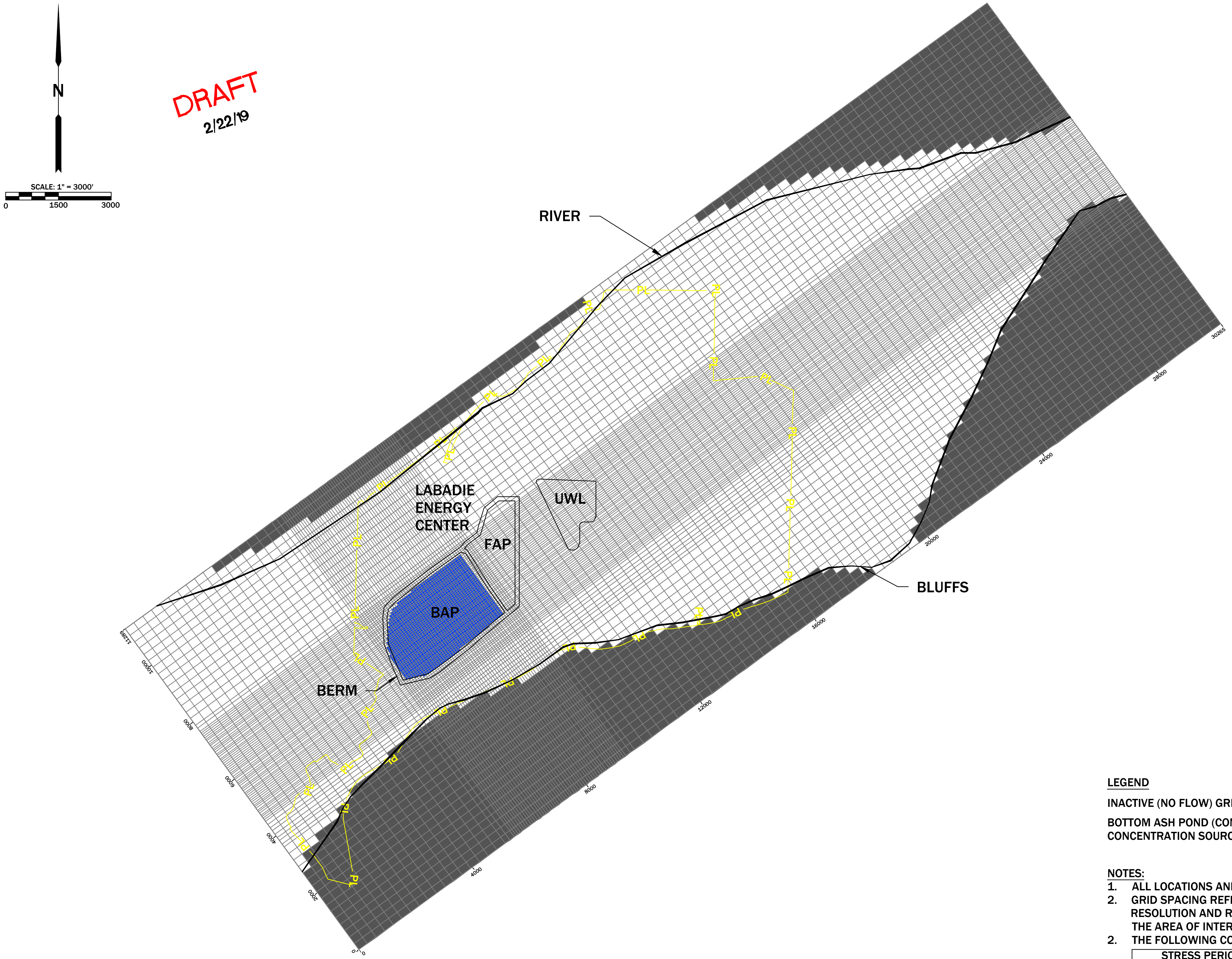
BOTTOM ASH POND
GROUNDWATER MODEL REPORT

FIGURE 9
RECHARGE ARRAY

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	CP	CW	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 9	1 OF 1

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 9.dwg, FIGURE 9, 4/9/2019 7:16:12 AM

DRAFT
2/22/19



LEGEND

INACTIVE (NO FLOW) GRID CELL	■
BOTTOM ASH POND (CONSTANT CONCENTRATION SOURCE AREA)	🟦

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. GRID SPACING REFINED (REDUCED) IN BAP AREA FOR ENHANCED RESOLUTION AND REPRESENTATION OF FLOW AND TRANSPORT IN THE AREA OF INTEREST.
2. THE FOLLOWING CONCENTRATIONS WERE MODELED:

STRESS PERIOD 1, 2 & 3		
B	Mo	As
9.5 mg/L	0.350 mg/L	0.020 mg/L

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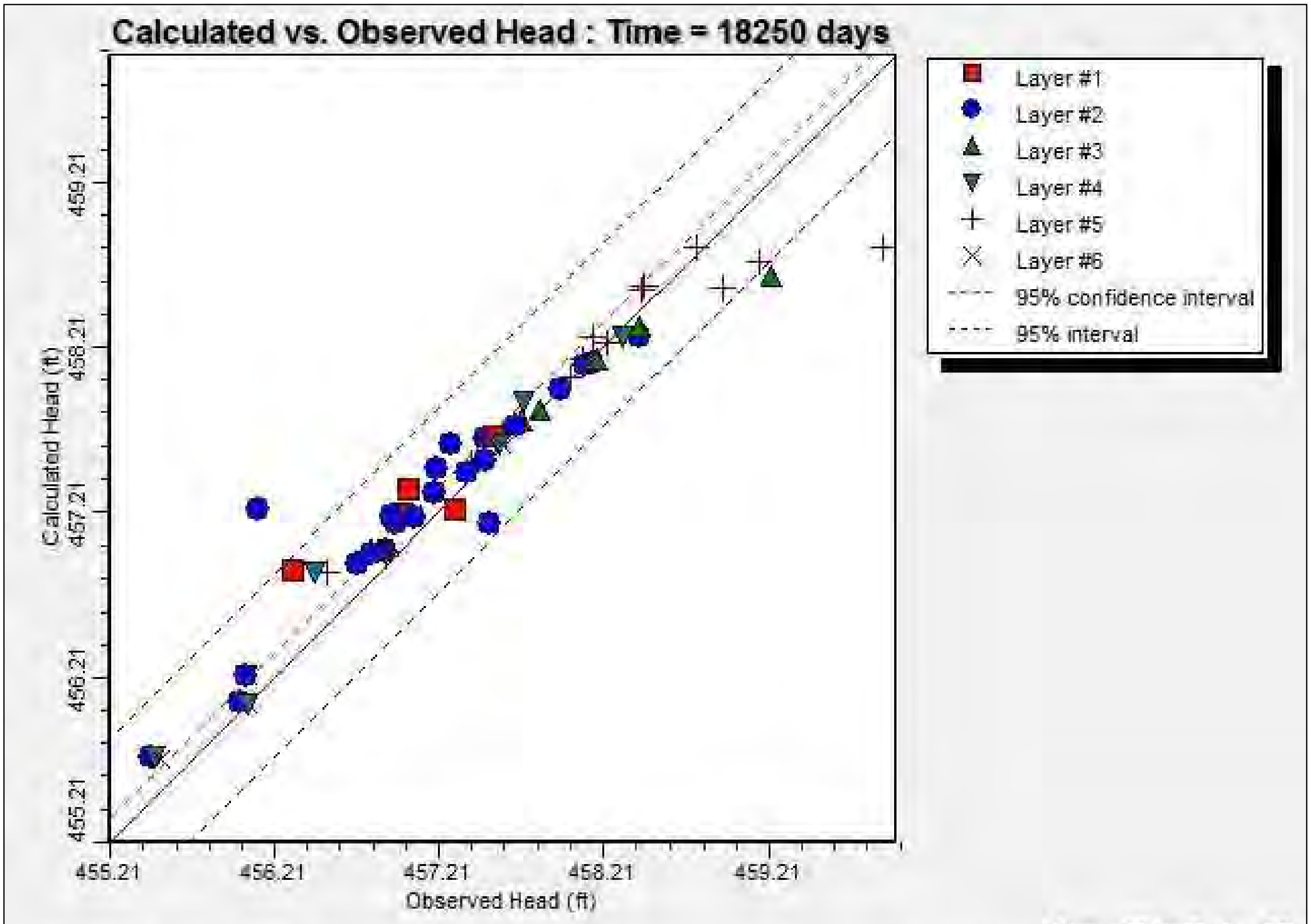
FIGURE 10
CONSTANT SOURCE
CONCENTRATION ARRAY
(LAYERS 1, 2, 3, & 4)

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	CP	CW	MCC	2/2019	AS NOTED	LABADIE GW MODEL	FIGURE 10	1 OF 1

#	DATE	REVISION DESCRIPTION	BY

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 10.dwg, FIGURE 10, 4/10/2019 9:42:28 AM



Num. of Data Points : 60
Standard Error of the Estimate : 0.036 (ft)
Root Mean Squared : 0.285 (ft)
Normalized RMS : 6.424 (%)
Correlation Coefficient : 0.968

Max. Residual: 1.116 (ft) at TMW-3/A
Min. Residual: -0.001 (ft) at UMW-6D/A
Residual Mean : 0.075 (ft)
Abs. Residual Mean : 0.187 (ft)

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M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 11A.dwg, FIGURE 11 - JUNE 25 2018 GROUNDWATER ELEVATION OBSERVATIONS, 4/9/2019 7:32:47 AM

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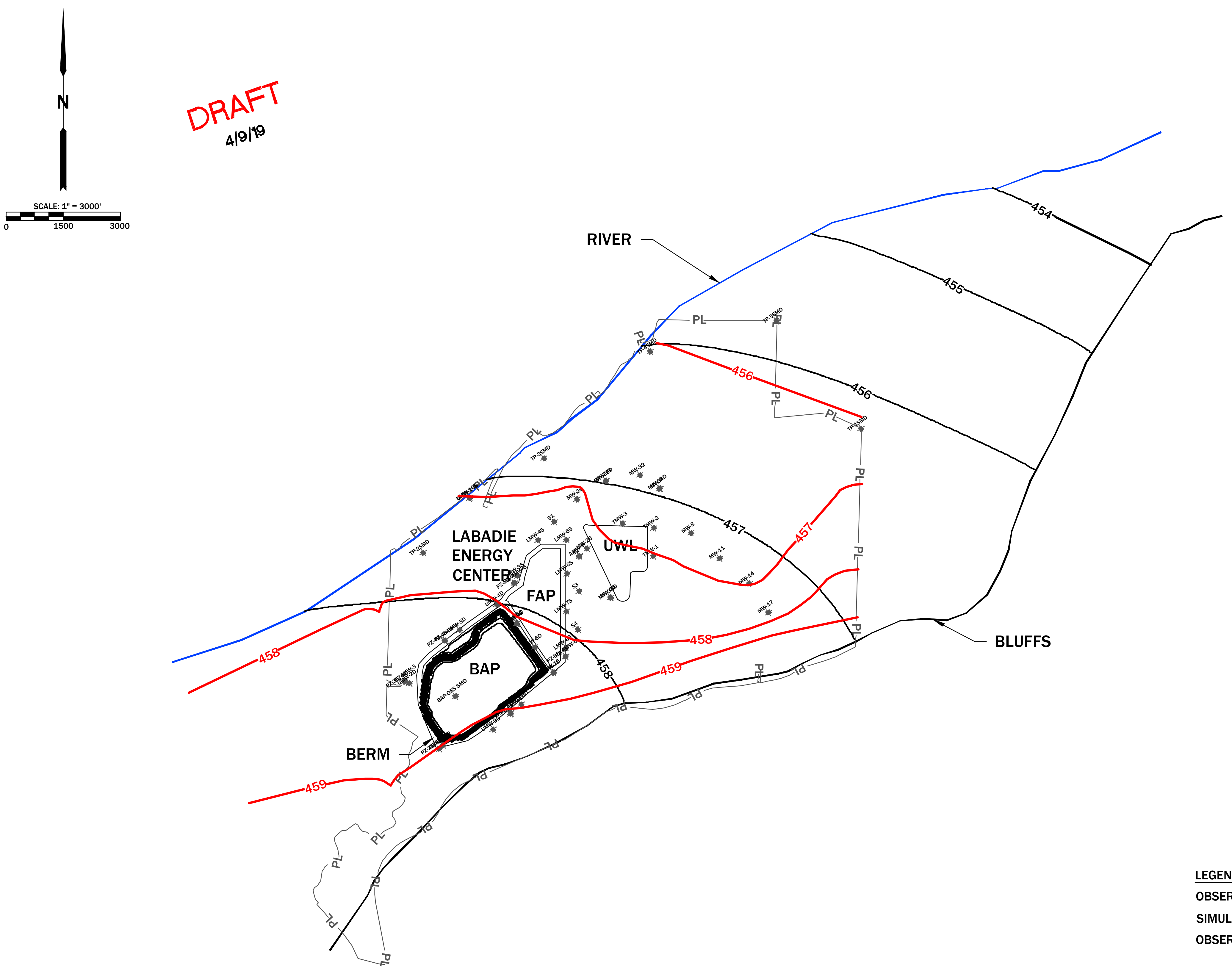
FIGURE 11A - GROUNDWATER MODEL QUANTITATIVE CALIBRATION RESULTS - JUNE 25, 2018 STATISTICS

DATE	SCALE	PROJECT NAME	REVISION
4/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 11A	1 OF 1



LEGEND

OBSERVATION WELL	MW-17 ✱
SIMULATED POTENTIOMETRIC CONTOURS	—457—
OBSERVED POTENTIOMETRIC CONTOURS	—457—

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. CONTOUR INTERVAL = 1 FOOT.
3. OBSERVED POTENTIOMETRIC CONTOURS REPRODUCED FROM GOLDER, 2018D.

#	DATE	REVISION DESCRIPTION	BY

FIGURE 11B
GROUNDWATER MODEL QUALITATIVE CALIBRATION RESULTS - JUNE 25, 2018

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BOTTOM ASH POND
GROUNDWATER MODEL REPORT

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	BR	KE	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 11B	1 OF 1

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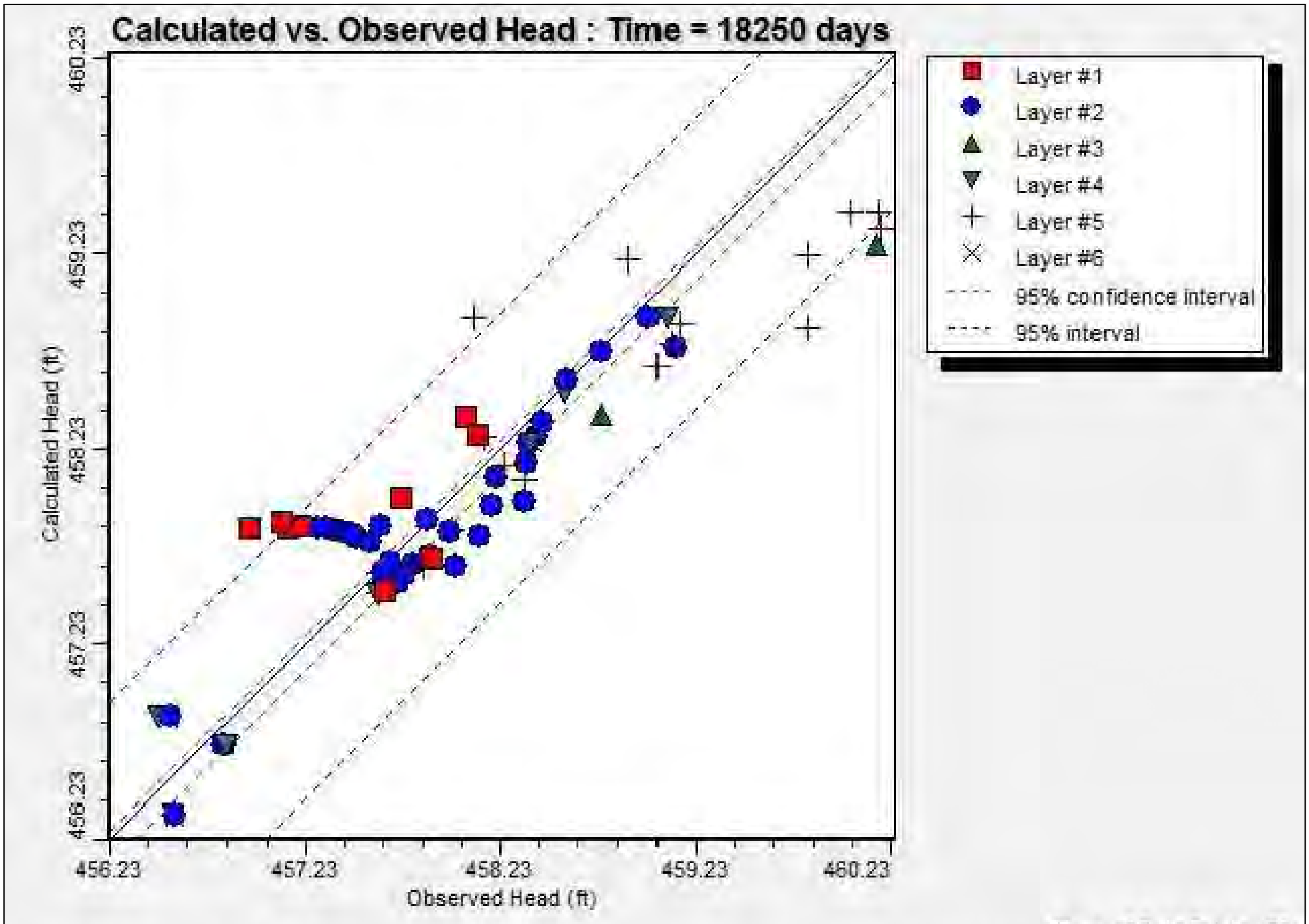
M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 11B.dwg, 11B FIGURE 11B1, 4/9/2019 8:08:32 AM

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 12A.dwg, FIGURE 12 - JULY 24 2018 GROUNDWATER ELEVATION OBSERVATIONS, 4/9/2019 7:23:14 AM



Max. Residual: -0.942 (ft) at AMW-7/A
Min. Residual: 0.009 (ft) at TMW-3/A
Residual Mean : -0.045 (ft)
Abs. Residual Mean : 0.29 (ft)

Num. of Data Points : 73
Standard Error of the Estimate : 0.043 (ft)
Root Mean Squared : 0.371 (ft)
Normalized RMS : 10.039 (%)
Correlation Coefficient : 0.922

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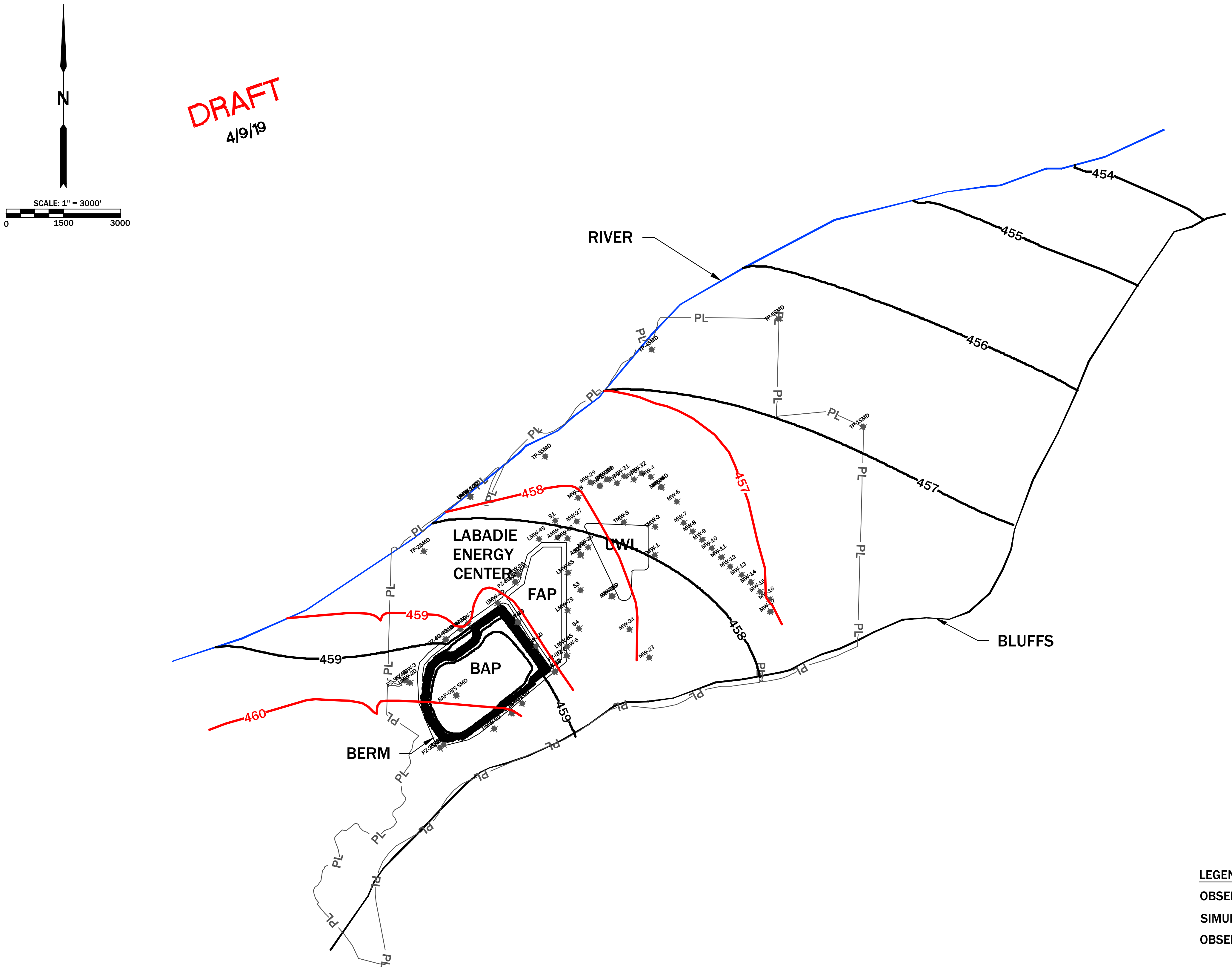
FIGURE 12A - GROUNDWATER MODEL QUANTITATIVE CALIBRATION RESULTS - JULY 24, 2018 STATISTICS

DATE	SCALE	PROJECT NAME	REVISION
4/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 12A	1 OF 1



LEGEND

OBSERVATION WELL MW-17 ✱

SIMULATED POTENTIOMETRIC CONTOURS —457—

OBSERVED POTENTIOMETRIC CONTOURS —457—

NOTES:
1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. CONTOUR INTERVAL = 1 FOOT.
3. OBSERVED POTENTIOMETRIC CONTOURS REPRODUCED FROM GOLDER, 2018D.

#	DATE	REVISION DESCRIPTION	BY

FIGURE 12B
GROUNDWATER MODEL
QUALITATIVE CALIBRATION
RESULTS - JULY 24, 2018

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BOTTOM ASH POND
GROUNDWATER MODEL REPORT

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	BR	KE	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 12B	1 OF 1

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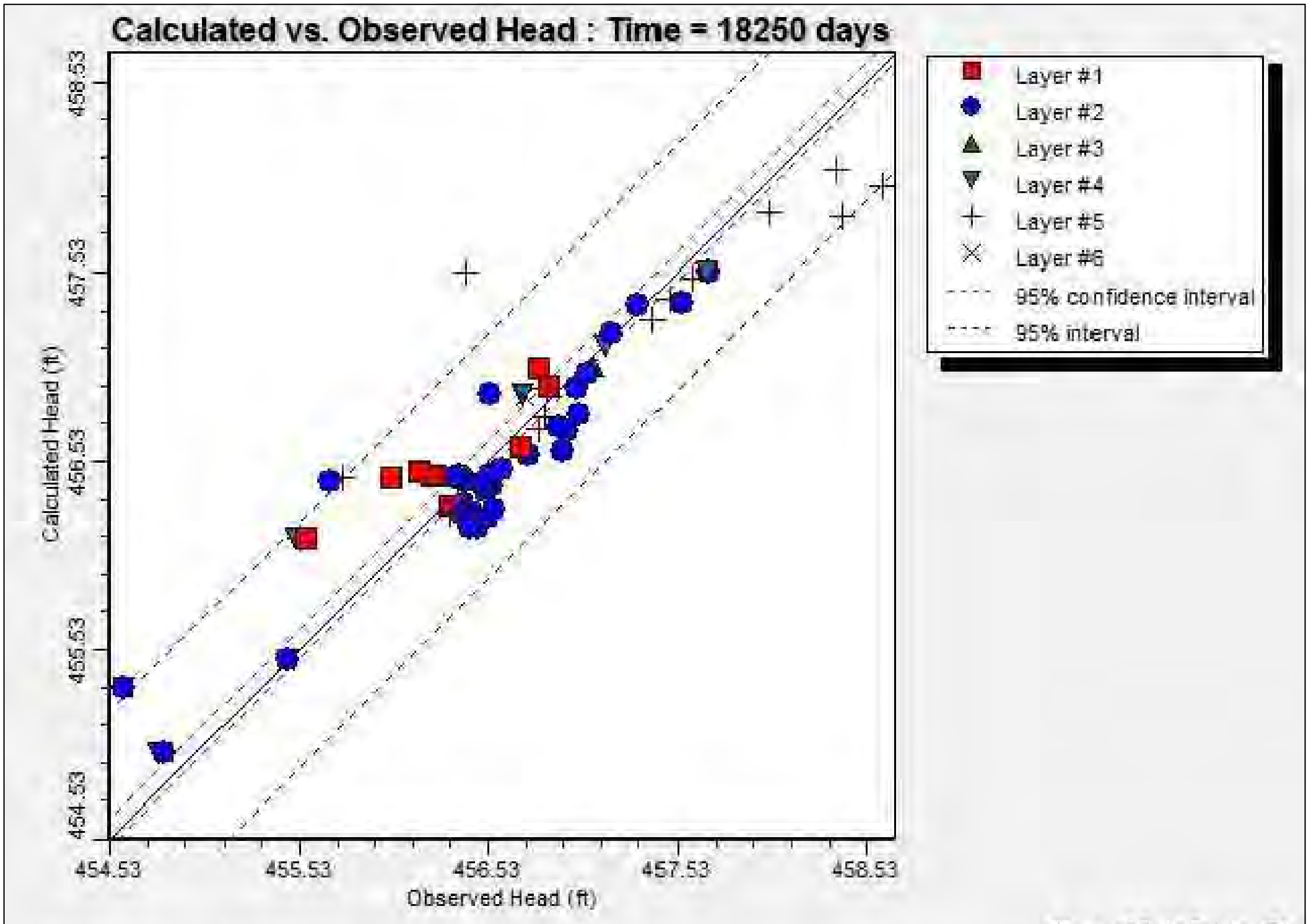

Max. Residual: 1.121 (ft) at UMW-3D/A
Min. Residual: 0.006 (ft) at TP-1SMD/S
Residual Mean : 0.032 (ft)
Abs. Residual Mean : 0.235 (ft)

Num. of Data Points : 71
Standard Error of the Estimate : 0.039 (ft)
Root Mean Squared : 0.325 (ft)
Normalized RMS : 8.127 (%)
Correlation Coefficient : 0.935

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4/9/19

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 13A.dwg, FIGURE 13 - AUGUST 22 2018 GROUNDWATER ELEVATION OBSERVATIONS, 4/9/2019 7:26:56 AM

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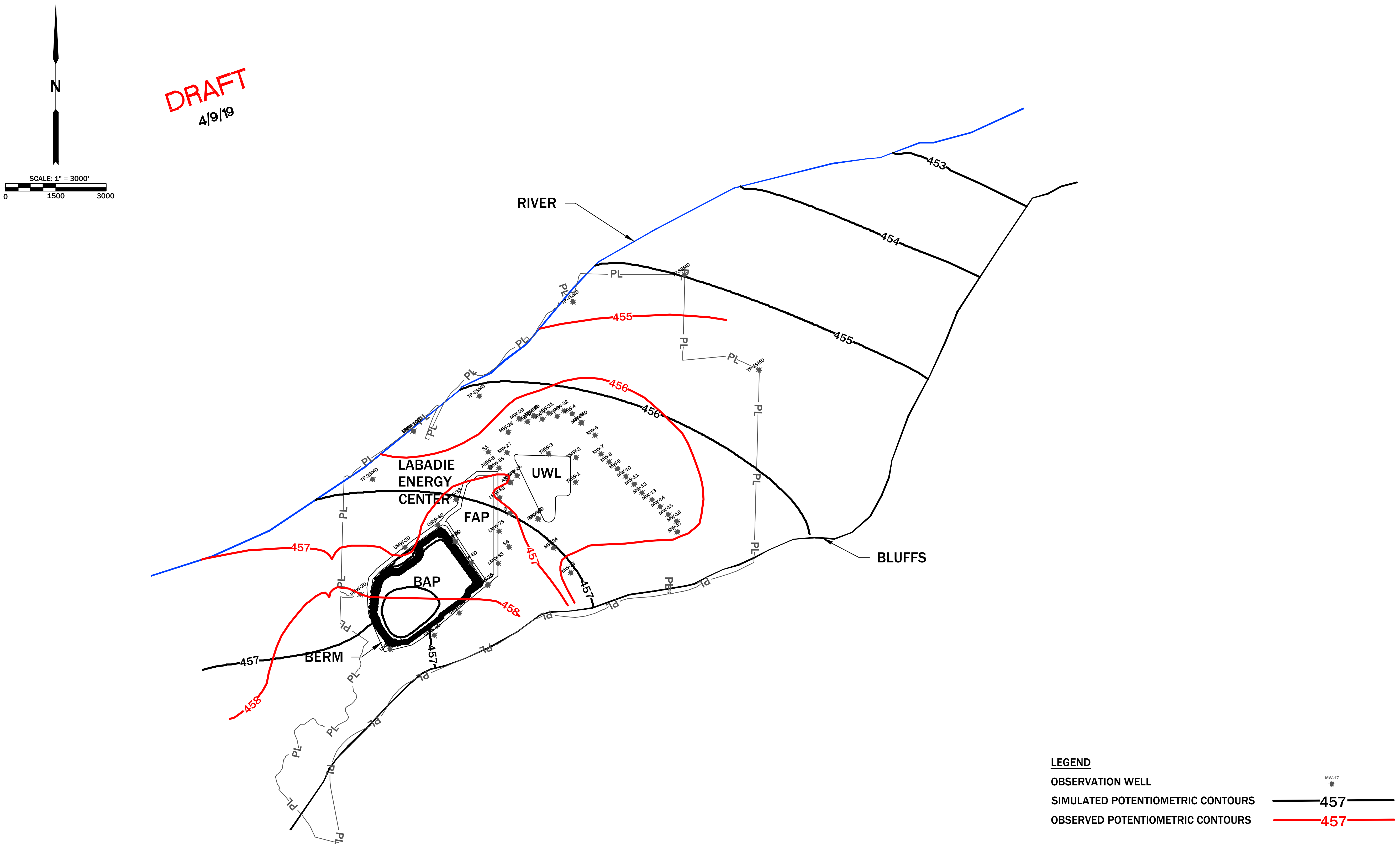
FIGURE 13A - GROUNDWATER MODEL
QUANTITATIVE CALIBRATION RESULTS -
AUGUST 22, 2018 STATISTICS

DATE	SCALE	PROJECT NAME	REVISION
4/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 13A	1 OF 1



LEGEND

OBSERVATION WELL

SIMULATED POTENTIOMETRIC CONTOURS —457—

OBSERVED POTENTIOMETRIC CONTOURS —457—

NOTES:

1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. CONTOUR INTERVAL = 1 FOOT.
3. OBSERVED POTENTIOMETRIC CONTOURS REPRODUCED FROM GOLDER, 2018D.

#	DATE	REVISION DESCRIPTION	BY

FIGURE 13B
GROUNDWATER MODEL QUALITATIVE CALIBRATION RESULTS - AUGUST 22, 2018

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BOTTOM ASH POND
GROUNDWATER MODEL REPORT

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	BR	KE	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 13B	1 OF 1

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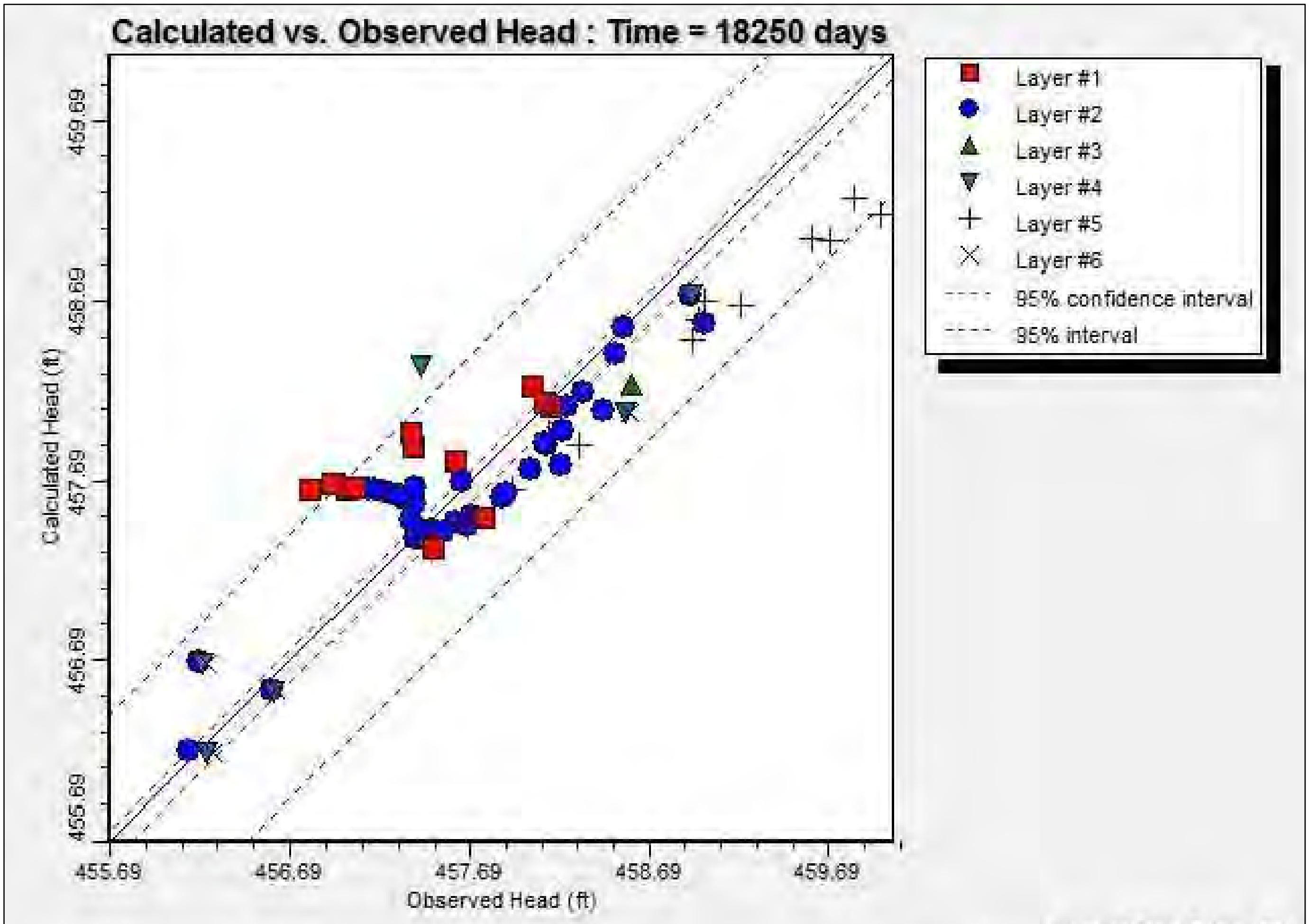
M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 13B.dwg, 20 FIGURE 13B, 4/9/2019 7:37:58 AM



Max. Residual: 0.926 (ft) at LMW-7S/448.6
Min. Residual: -0.004 (ft) at MW-34D/A
Residual Mean : -0.035 (ft)
Abs. Residual Mean : 0.297 (ft)

Num. of Data Points : 74
Standard Error of the Estimate : 0.043 (ft)
Root Mean Squared : 0.369 (ft)
Normalized RMS : 9.594 (%)
Correlation Coefficient : 0.923

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4/9/19

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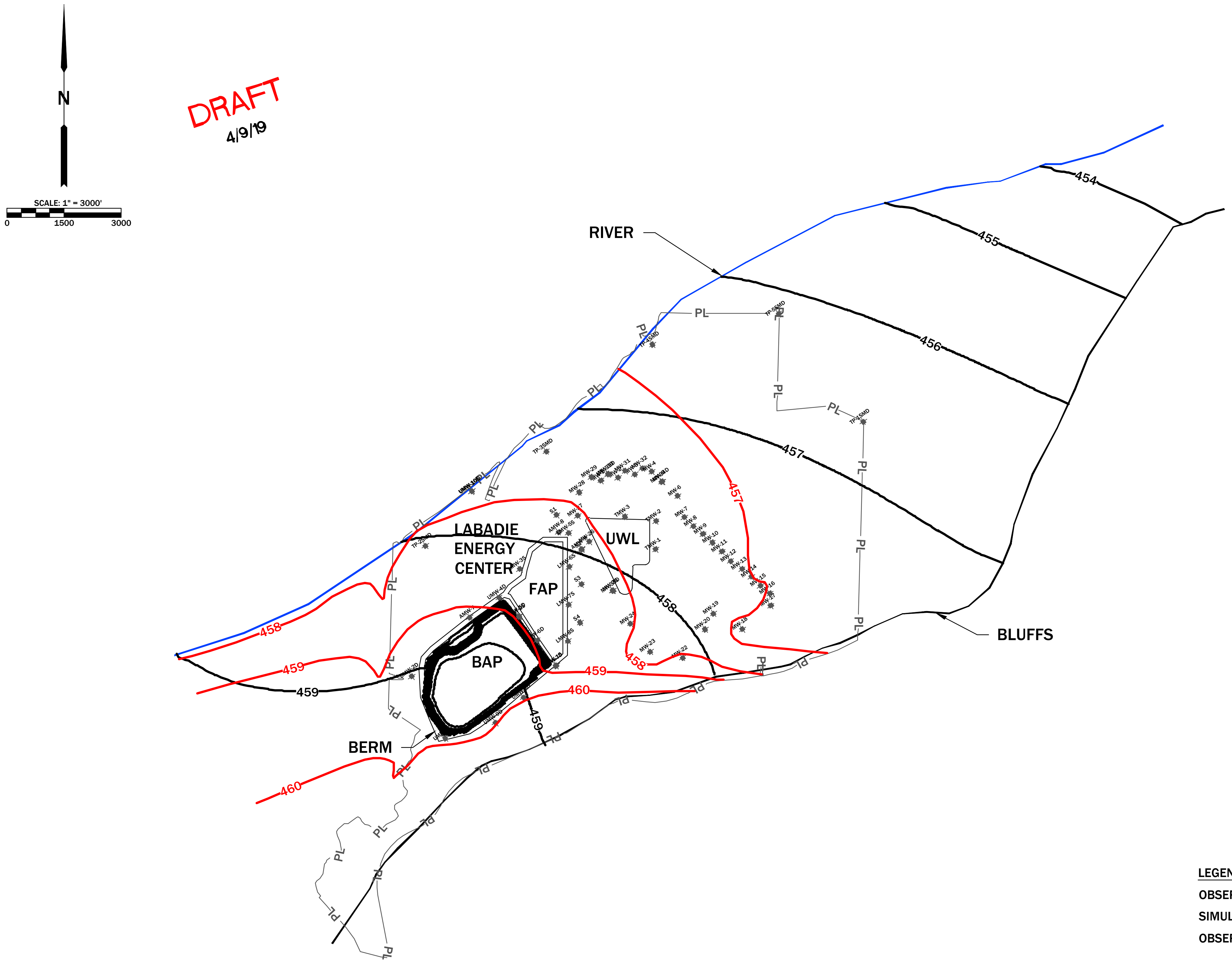
FIGURE 14A - GROUNDWATER MODEL
QUANTITATIVE CALIBRATION RESULTS -
SEPTEMBER 27, 2018 STATISTICS

DATE	SCALE	PROJECT NAME	REVISION
4/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 14A	1 OF 1

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 14A.dwg, FIGURE 14 - SEPTEMBER 27 2018 GROUNDWATER ELEVATION OBSERVATIONS, 4/9/2019 7:30:38 AM



LEGEND

OBSERVATION WELL ✱

SIMULATED POTENTIOMETRIC CONTOURS —457—

OBSERVED POTENTIOMETRIC CONTOURS —457—

NOTES:
1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.
2. CONTOUR INTERVAL = 1 FOOT.
3. OBSERVED POTENTIOMETRIC CONTOURS REPRODUCED FROM GOLDER, 2018D.

#	DATE	REVISION DESCRIPTION	BY

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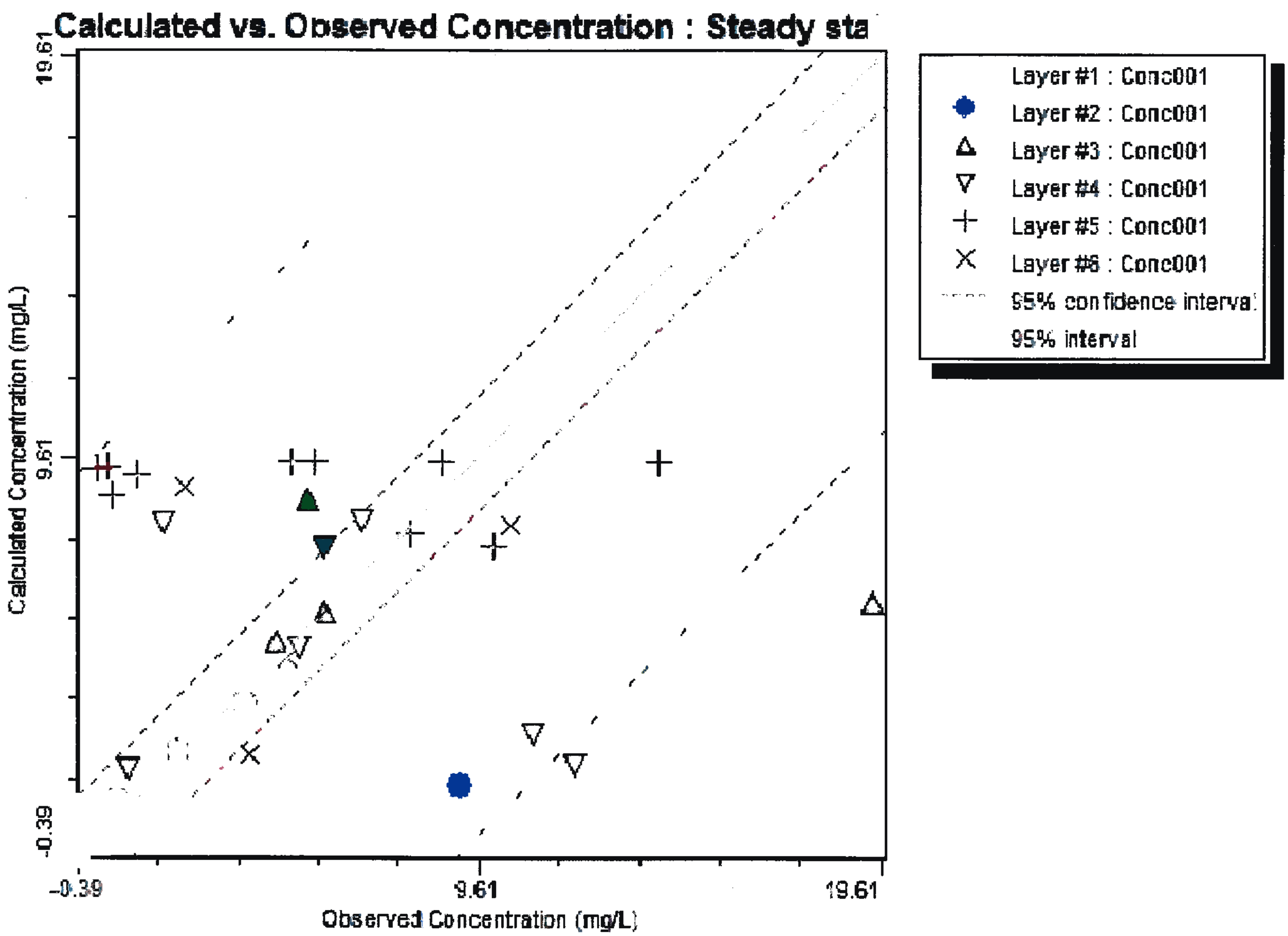
GROUNDWATER MODEL REPORT

FIGURE 14B
GROUNDWATER MODEL
QUALITATIVE CALIBRATION
RESULTS - SEPT. 27, 2018

SURVEYED	DESIGNED	DRAWN	CHECKED	APPROVED	DATE	SCALE	PROJECT NAME	FILE NAME	SHEET #
NA	KE	BR	KE	MCC	4/2019	AS NOTED	LABADIE GW MODEL	FIGURE 14B	1 OF 1

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 14B.dwg, FIGURE 14B, 4/9/2019 7:31:51 AM



Max. Residual: -13.401 (mg/L) at PZ-1S/A
Min. Residual: -0.028 (mg/L) at PZ-5S/A
Residual Mean : 0.133 (mg/L)
Abs. Residual Mean : 3.12 (mg/L)

Num. of Data Points : 43
Standard Error of the Estimate : 0.718 (mg/L)
Root Mean Squared : 4.655 (mg/L)
Normalized RMS : 24.069 (%)
Correlation Coefficient : 0.327

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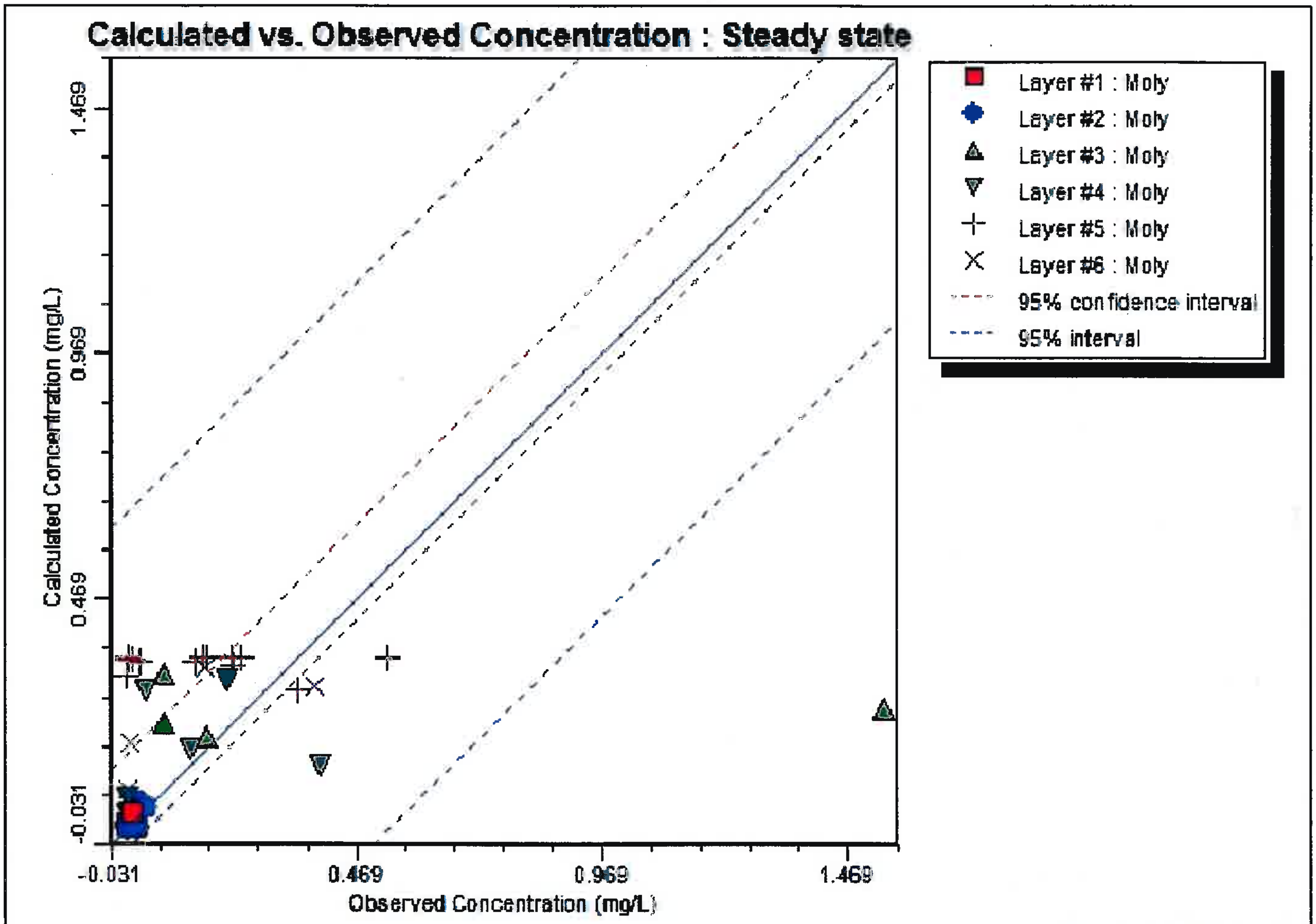
FIGURE 15 - TRANSPORT MODEL CALIBRATION RESULTS - BORON OBSERVATIONS

DATE	SCALE	PROJECT NAME	REVISION
2/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 15	1 OF 1

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 15.dwg, FIGURE 15 - BORON CONCENTRATION OBSERVATIONS, 2/22/2019 8:18:17 AM



Max. Residual: -1.293 (mg/L) at PZ-1S/A
Min. Residual: -0.001 (mg/L) at PZ-2S/A
Residual Mean : 0.056 (mg/L)
Abs. Residual Mean : 0.157 (mg/L)

Num. of Data Points : 38
Standard Error of the Estimate : 0.043 (mg/L)
Root Mean Squared : 0.268 (mg/L)
Normalized RMS : 17.372 (%)
Correlation Coefficient : 0.285

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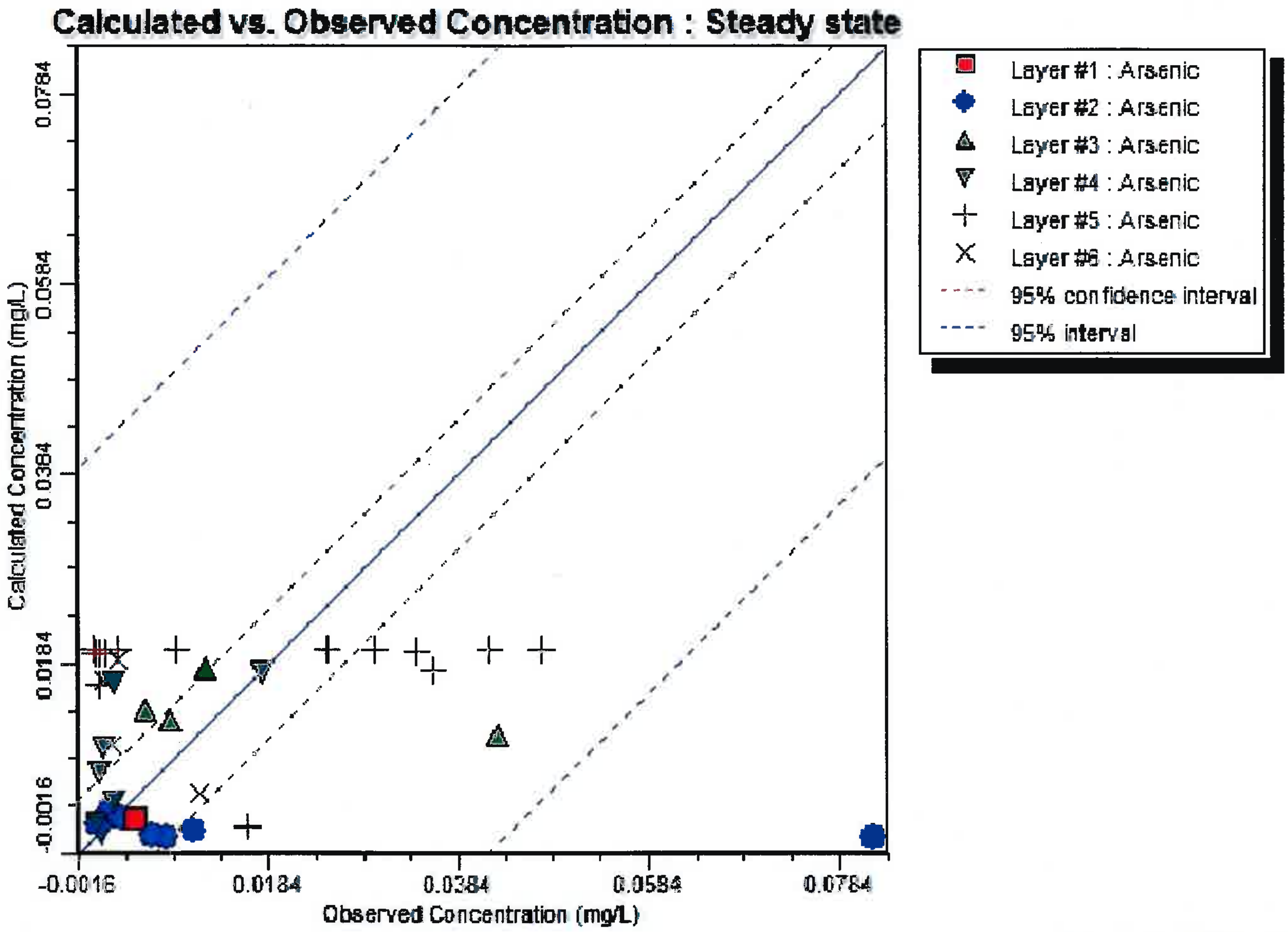
FIGURE 16 - TRANSPORT MODEL CALIBRATION RESULTS - MOLYBDENUM OBSERVATIONS

DATE	SCALE	PROJECT NAME	REVISION
2/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	APPROVED	FILE NAME	SHEET #
CP	MCC	FIGURE 16	1 OF 1

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 16.dwg, FIGURE 16 - MOLYBDENUM CONCENTRATION OBSERVATIONS, 2/22/2019 8:18:22 AM



Num. of Data Points : 38

Max. Residual: -0.082 (mg/L) at PZ-2S/A
Min. Residual: 0 (mg/L) at TP-1SMD/M
Residual Mean : -0.001 (mg/L)
Abs. Residual Mean : 0.012 (mg/L)

Standard Error of the Estimate : 0.003 (mg/L)
Root Mean Squared : 0.019 (mg/L)
Normalized RMS : 22.726 (%)
Correlation Coefficient : 0.111

DRAFT
2/22/19

M:\Share\CADDFiles\CONFIDENTIAL\SCHIFF-HARDIN 2014\ASH POND NPDES\GW MODELING 2018\FIGURE 17.dwg, FIGURE 17 - ARSENIC CONCENTRATION OBSERVATIONS, 2/22/2019 8:18:27 AM

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FIGURE 17 - TRANSPORT MODEL CALIBRATION RESULTS - ARSENIC OBSERVATIONS

DATE	SCALE	PROJECT NAME	REVISION
2/2019	AS NOTED	LABADIE GW MODEL	
DRAWN	**APPROVED**	**FILE NAME**	**SHEET #**
CP	MCC	FIGURE 17	1 OF 1

APPENDICES

Appendix 1

H.E.L.P. Model Analysis Technical Memorandum

9718 Rosehill Road
Lenexa, KS
Telephone No. (913) 808-5004
Fax No. (913) 3037-2028

GREDELL Engineering Resources, Inc.

Memo

To: Mikel C. Carlson, R.G.

From: Connie Walden, Ph.D., E.I.

CC: Thomas R. Gredell, P.E., Ken Ewers, R.G.

Date: 04/09/2019

Re: Ameren Labadie Energy Center CCR Bottom Ash Pond (BAP) Closure – H.E.L.P. Model Summary Technical Memorandum

---

The following memorandum summarizes the results of the H.E.L.P. model analysis used to predict the annual precipitation infiltration (as inches per year) through closure cap design alternatives for the Ameren Labadie Energy Center Bottom Ash Pond (BAP). The annual infiltration values will be used as input values to assess the impact of contaminant movement from the BAP during the 30-year post-closure period.

Background

GREDELL Engineering Resources, Inc. (Gredell Engineering) performed an evaluation of the closure cap design alternatives for the Labadie Energy Center BAP using the Hydraulic Evaluation of Landfill Performance model (H.E.L.P.). The H.E.L.P. model was developed by the United States Environmental Protection Agency (EPA) and United States Army Corps of Engineers (Corps) as a tool that could be used to simulate the impact of rainfall and the hydrologic cycle for various closure caps and liner configurations associated with solid waste storage and disposal facilities (i.e., landfills). H.E.L.P. version 3.07 (Schroeder et al. 1994) is the most recent iteration of the model and the version utilized to estimate cap performance discussed in this memorandum. In this situation, the H.E.L.P. model is used to evaluate CCR surface impoundment closure caps estimate percolation rates through various closure cap alternatives at the Labadie Energy Center BAP.

Inputs to the quasi-two-dimensional H.E.L.P. model can include weather data, vegetative cover, physical properties of soils, geonet material (drainage layers), geocomposite material (drainage and impermeable layers), various synthetic liner materials (impermeable layers), and certain wastes. Percolation is defined in the H.E.L.P. model as the amount of precipitation that flows through a vegetative or drainage layer (such as one designed to support vegetation and evaporation), and a barrier layer (such as compacted clay), into the stored materials. Variables related to percolation can include precipitation, type of vegetation, drainage material (when present), nature or type of barrier material, and cover slope and length.

Analysis

For the purpose of evaluating percolation into the Labadie Energy Center BAP, only the cap configuration was considered. The primary cap configuration evaluated consists of a minimum six-inch thick vegetative soil cover (percolation layer) over a minimum eighteen-inch thick compacted clay soil layer (barrier layer). The compacted clay layer was initially evaluated using a minimum hydraulic conductivity that is 1 x 10^{-5} centimeters per second (cm/s) or less. Table 1 presents values used by the H.E.L.P. model for each material present in the BAP cap configuration.

Table 1
Material Properties used in H.E.L.P. Model Cap Evaluation

	H.E.L.P. Material ID #	Layer Thickness inches	Total Porosity vol/vol	Field Capacity vol/vol	Wilting Point vol/vol	Hydraulic Conductivity cm/sec
Vegetative Soil	8	6	0.463	0.232	0.116	3.7x10^{-3}
Compacted Clay	16	18	0.427	0.418	0.367	1.0 x 10^{-5} – 1.0 x 10^{-7}

H.E.L.P. model default probability values from historic precipitation in St. Louis, Missouri (1951–1970) are used to synthesize 30 years of future weather data. The final cap surface is assumed to have a good grass cover growing on a 1.5 or 3.0 percent (%) slope extending 2,000 feet before discharge to a surface water outlet (Design slopes for the closure cap are described in Labadie Energy Center Closure Plan).

A sensitivity analysis was performed to test the impact of changing the barrier layer of the cap and barrier layer model input values on percolation rates through the closure cap. The analysis initially used the minimum hydraulic conductivity of 1 x 10^{-5} cm/s as presented in Table 2. Average annual approximations for evapotranspiration ranged from 21.6–23.7 inches for the five sensitivity model runs. The total average annual precipitation for 30 years was estimated to be 33.2 inches. Table 2 presents H.E.L.P. pertinent output values for average annual data, including precipitation, evapotranspiration, runoff, and percolation. All units are in 'inches'.

Evapotranspiration, runoff, and precipitation showed less variation as the number of years modeled increased. At 20 and 30 years, the average annual values show minimal change. As these values show low sensitivity for longer durations. Therefore, subsequent sensitivity analysis for additional barrier layer variations focused on at the full post-closure period (or 30 years).

Table 2
H.E.L.P. Model Sensitivity Analysis Over Time (Average Annual Values)
Based on 1 x 10^{-5} cm/s compacted clay cap

Source Filename	Time (Years)	Precipitation (inches)	Evapotranspiration (inches)	Runoff (inches)	Percolation (inches)
BAP1YR	1	30.7	23.7	0.0	7.0
BAP5YR	5	34.7	23.4	1.3	10.1
BAP10YR	10	34.3	22.5	1.7	9.9
BAP20YR	20	33.0	21.6	1.9	9.5
BAP30R2	30	33.2	21.9	1.9	9.5

Note: Filenames are as follows:
a. The first three letters, BAP, represent Bottom Ash Pond.
b. The next four spaces represent the number of years modeled.
c. If a run was re-calculated, the 'YR' was changed to a run number as RX.

Continuing the sensitivity analysis, hydraulic conductivities of 1 x 10^{-6} and 1 x 10^{-7} cm/s, slopes of 1.5% and 3.0%, and other variations in design criteria were tested and are presented in Table 3.

H.E.L.P. model average annual output values for percolation through the cap with varied input parameters show the changes in percolation with different design values. Table 3 demonstrates that runoff and percolation values exhibit negligible sensitivity to differing slope conditions. In the model, percolation is most sensitive to cap layer thickness and/or hydraulic conductivity.

Table 3
H.E.L.P. Model Sensitivity Analysis for Select Parameters (Average Annual Values)

H.E.L.P. Run Reference Number	Time (Years)	Drainage Length (feet)	Cap Layering	Hydraulic Conductivity (cm/s)	Slope (percent)	Runoff (inches)	Percolation (inches)	Precipitation (inches)
1	30	2000	6-inches barrier soil 18-inches barrier clay	1×10^{-5}	1.5	1.9	9.5	33.2
2	30	**2200**	6-inches barrier soil 18-inches barrier clay	1×10^{-5}	1.5	1.9	9.5	33.2
3	30	2000	6-inches barrier soil 18-inches barrier clay	1×10^{-5}	**3.0**[1]	1.9	9.5	33.2
4	30	2000	6-inches barrier soil **60 mil HDPE geomembrane**[1]	1×10^{-5}	3.0	1.8	0.9	33.2
5	30	2000	6-inches barrier soil **24-inches barrier clay**[1]	1×10^{-5}	3.0	1.9	9.4	33.2
6	30	2000	**24-inches barrier soil** **12-inches barrier clay**[1]	1×10^{-5}	3.0	1.0	5.5	33.2
7	30	2000	6-inches barrier soil 18-inches barrier clay	**1×10^{-6}**	3.0	3.3	5.4	33.2
8	30	2000	6-inches barrier soil 18-inches barrier clay	**1×10^{-7}**	3.0	6.1	0.9	33.2

Note: Bold font indicates the parameter changed for each model run.

Model Assumptions and Limitations

The H.E.L.P. model is based on several simplifying assumptions. Generally, these assumptions are reasonable and consistent with the objectives of the software when applied to typical solid waste storage designs. The H.E.L.P. model is the current industry standard for hydrologic evaluation of waste storage designs and design alternatives. The major assumptions and limitations of the model are summarized below:

- The model assumes Darcian flow by gravity through homogenous materials.
- Runoff is computed using the SCS Curve Method based on daily rainfall and snowmelt.
- The model does not consider stormwater runon.
- The time distribution of rainfall intensity is not considered; however because the SCS rainfall-runoff calculation is based on extensive daily field data, long-term estimates of runoff are reasonable.
- The model contains the option to apply default values of soil coefficients, which are described in the documentation for H.E.L.P. Version 3.07.
- Synthetically generated temperature and solar radiation are assumed to be representative of the climate at the site.

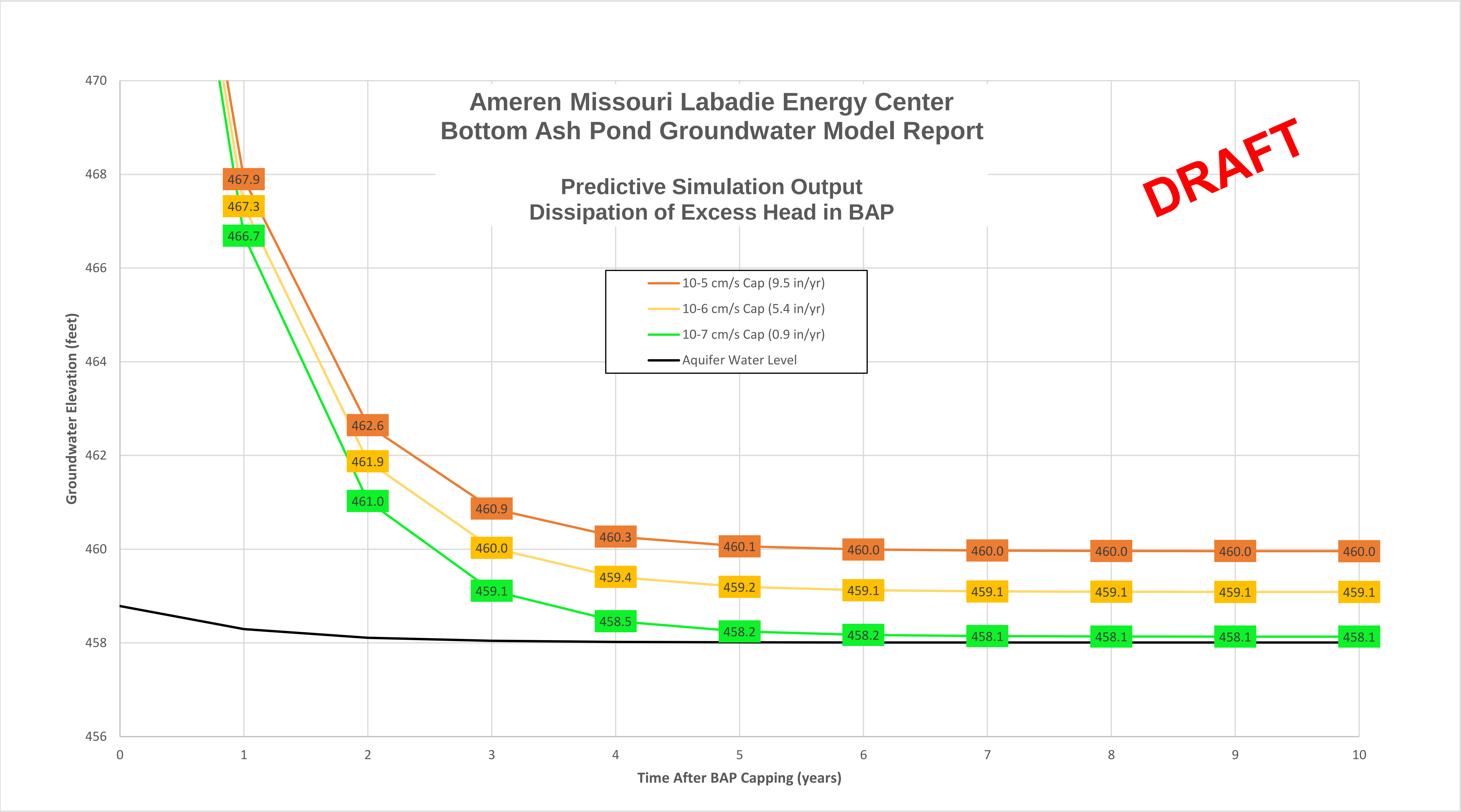
Summary

Based on this sensitivity analysis, the H.E.L.P. model shows percolation through the closure cap design alternatives is most sensitive to changes in layer thicknesses and soil hydraulic conductivity. Evapotranspiration shows variability dependent on the number of years modeled and is dependent on the synthetically generated weather events chosen for use in this analysis.

The H.E.L.P. model also shows that the closure cap design of 6-inches of vegetative soil over 18-inches of barrier clay with a hydraulic conductivity of 1×10^{-7} cm/s results in the least annual amount of percolation through the closure cap (approximately 0.9 inches/year) for the BAP at the Labadie Energy Center. This annual percolation is very comparable to the percolation rate used for a geomembrane liner.

Appendix 2

Predictive Simulation Output – Dissipation of Excess Head in BAP


Ameren Missouri Labadie Energy Center
Bottom Ash Pond Groundwater Model Report

Predictive Simulation Output
Dissipation of Excess Head in BAP

Prepared by: GREDELL Engineering Resources, Inc.

Prepared by: KAE
Checked by: MCC

Appendix 3

Predictive Simulation Output – Future Boron Concentration

- Shallow (Layer 2) Boron Distribution at 0 years Post-Closure
- Shallow (Layer 2) Boron Distribution at 30 years Post-Closure
- Medium (Layer 5) Boron Distribution at 0 years Post-Closure
- Medium (Layer 5) Boron Distribution at 30 years Post-Closure
- Deep (Layer 6) Boron Distribution at 0 years Post-Closure
- Deep (Layer 6) Boron Distribution at 30 years Post-Closure
- Predicted Boron Concentration Time Series – Observation Locations
- Predicted Boron Concentration Time Series – Berm Observation Locations
- Predicted Boron Concentration Time Series – Down Gradient Observation Locations

Ameren Missouri - Labadie Energy Center
Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution

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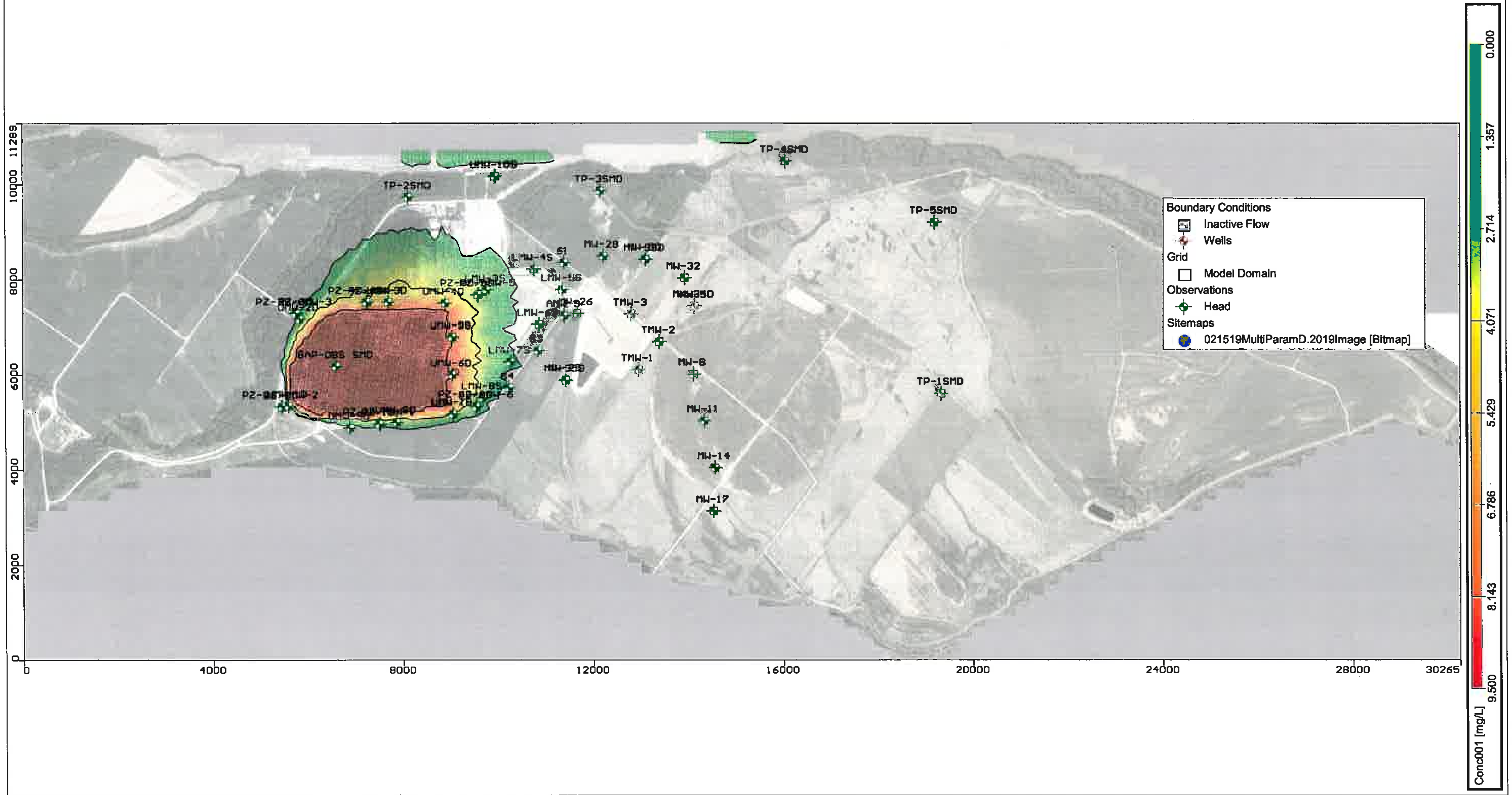

Boron Iso-Concentrations (2, 4, & 8 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 9.50 mg/L
Time = 0 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution

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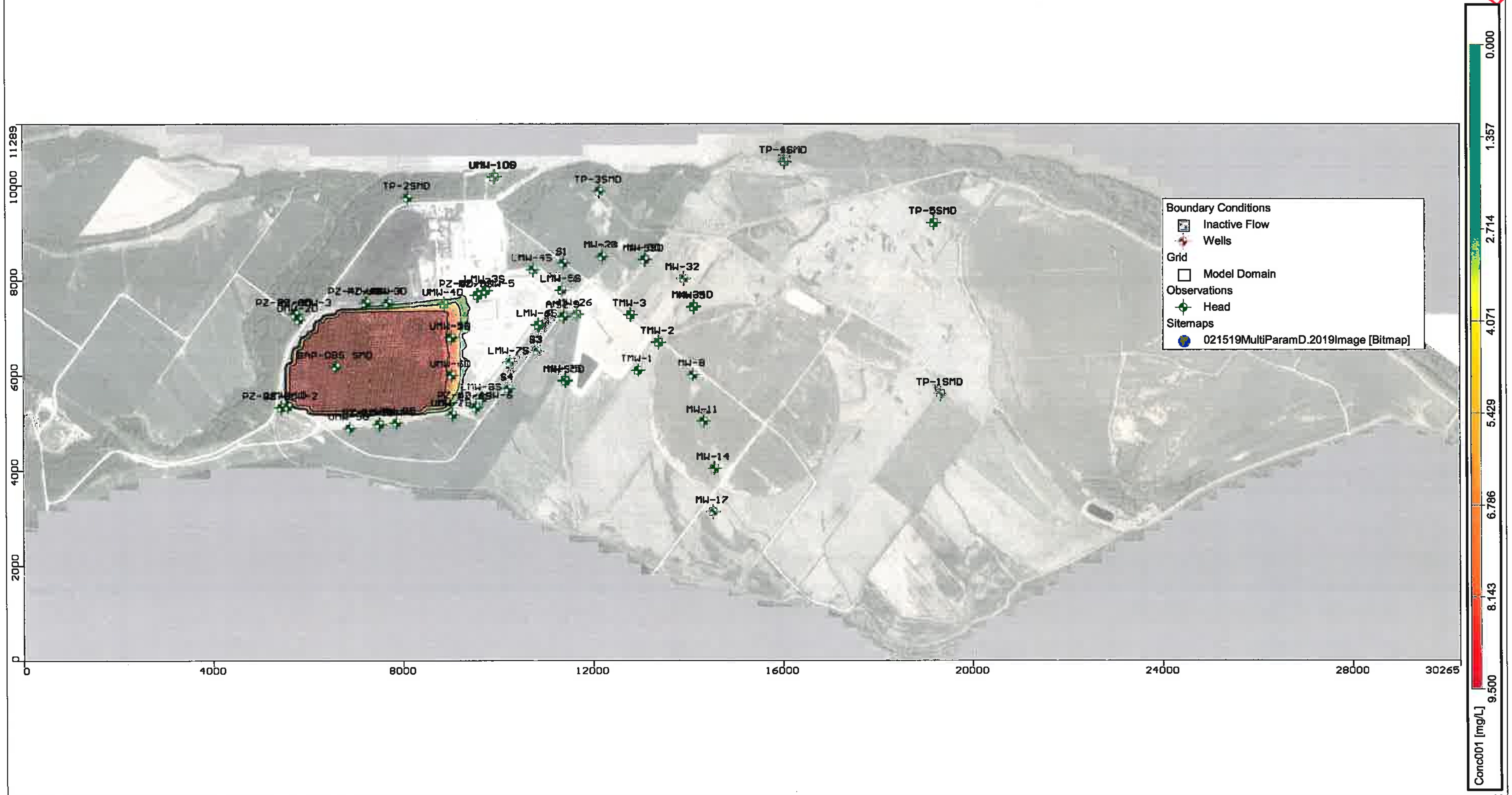

Boron Iso-Concentrations (2, 4, & 8 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 9.50 mg/L
Time = 30 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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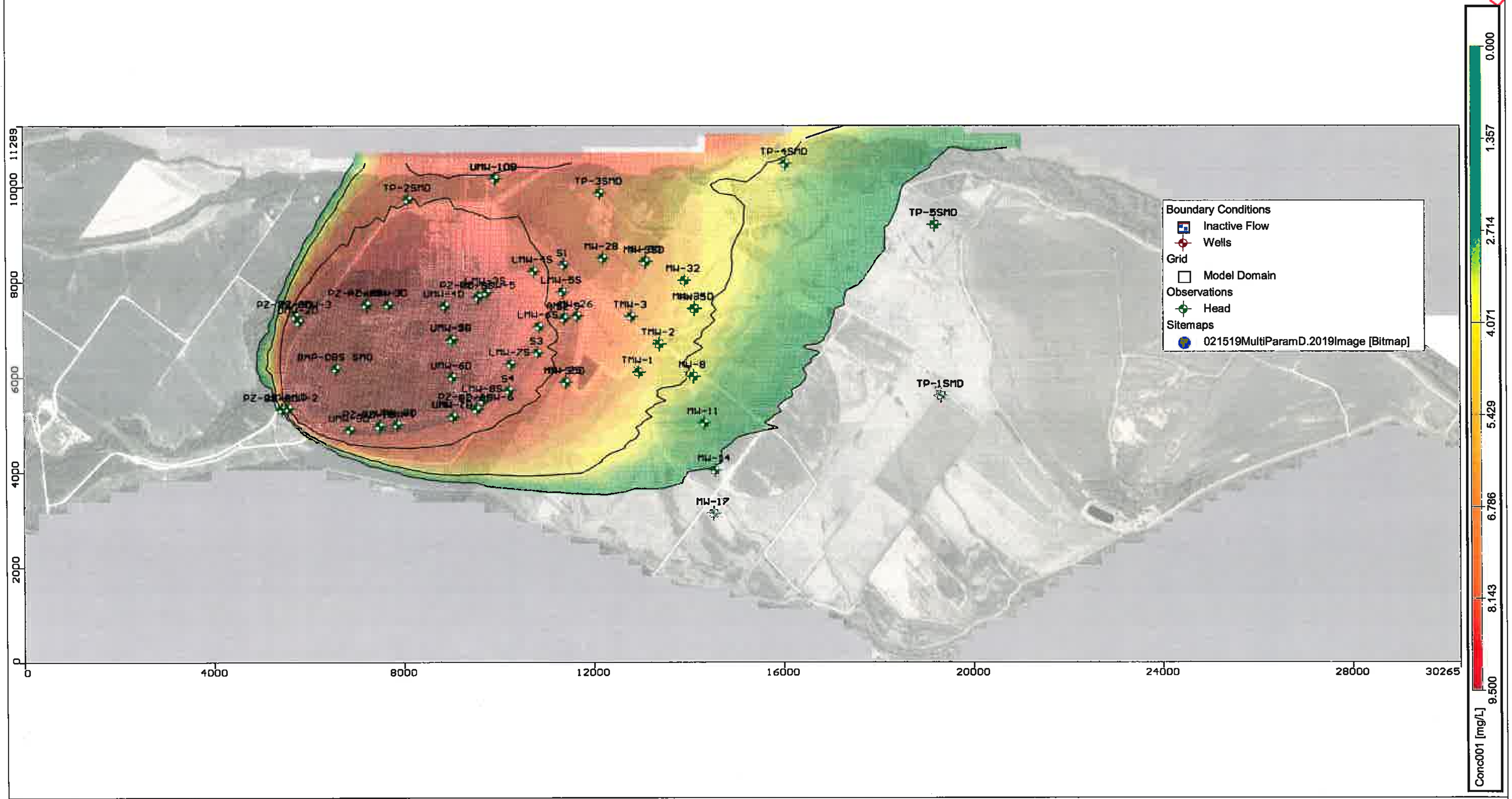
Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution



Boron Iso-Concentrations (2, 4, & 8 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 9.50 mg/L
Time = 0 Years Post-Closure

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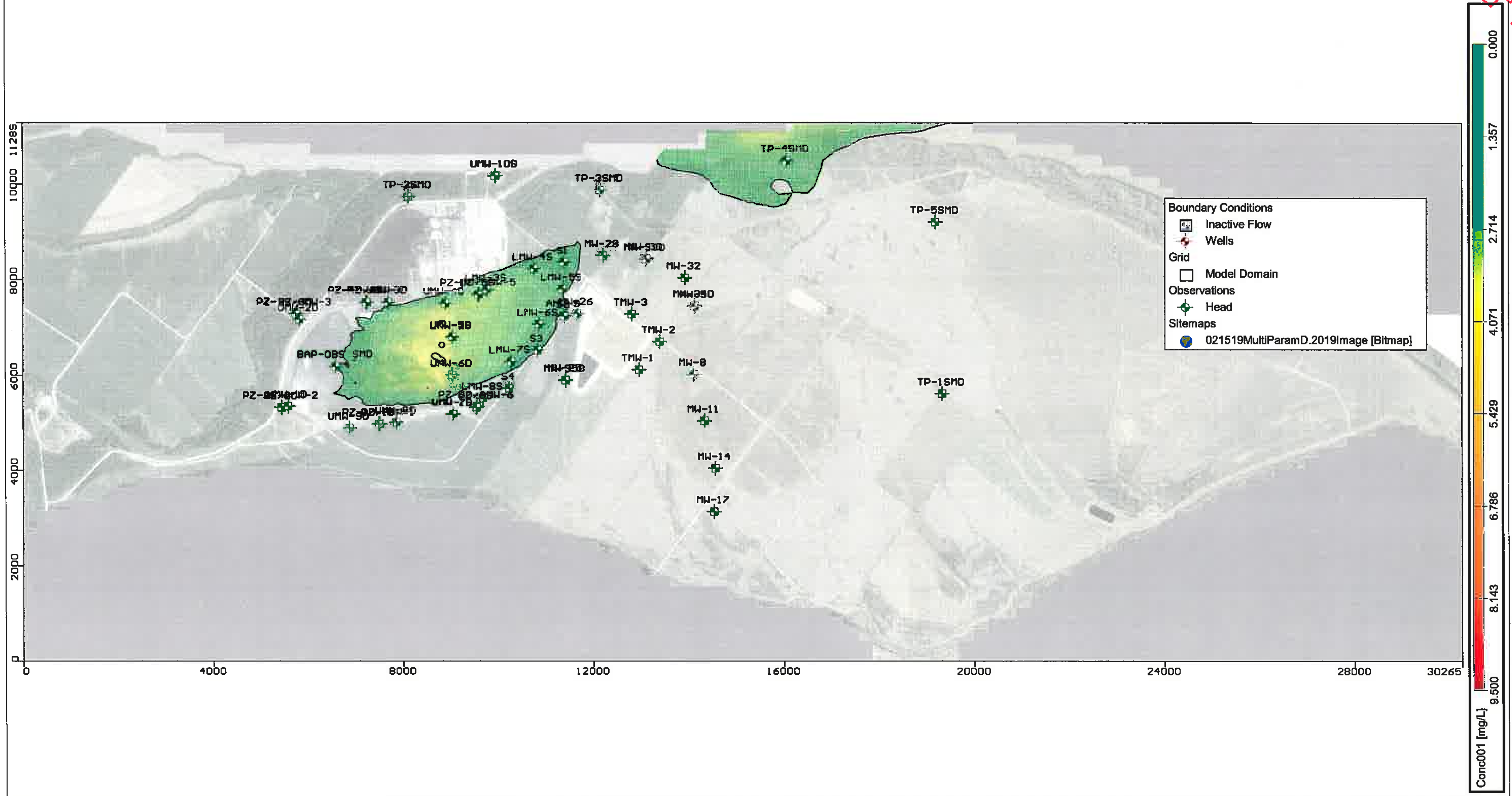
Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution



Boron Iso-Concentrations (2, 4, & 8 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 9.50 mg/L
Time = 30 Years Post-Closure

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Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution

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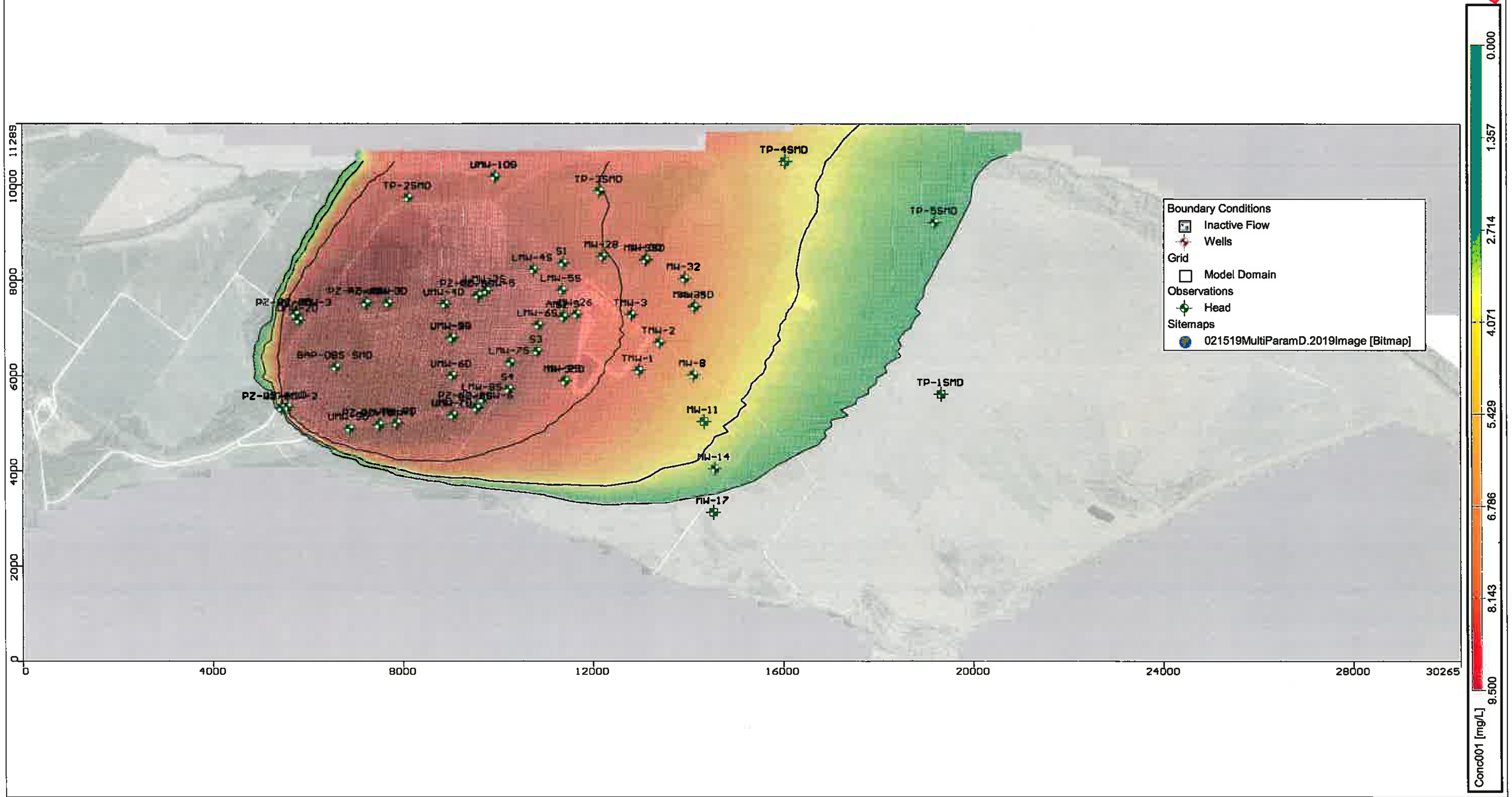

Boron Iso-Concentrations (2, 4, & 8 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 9.50 mg/L
Time = 0 Years Post-Closure

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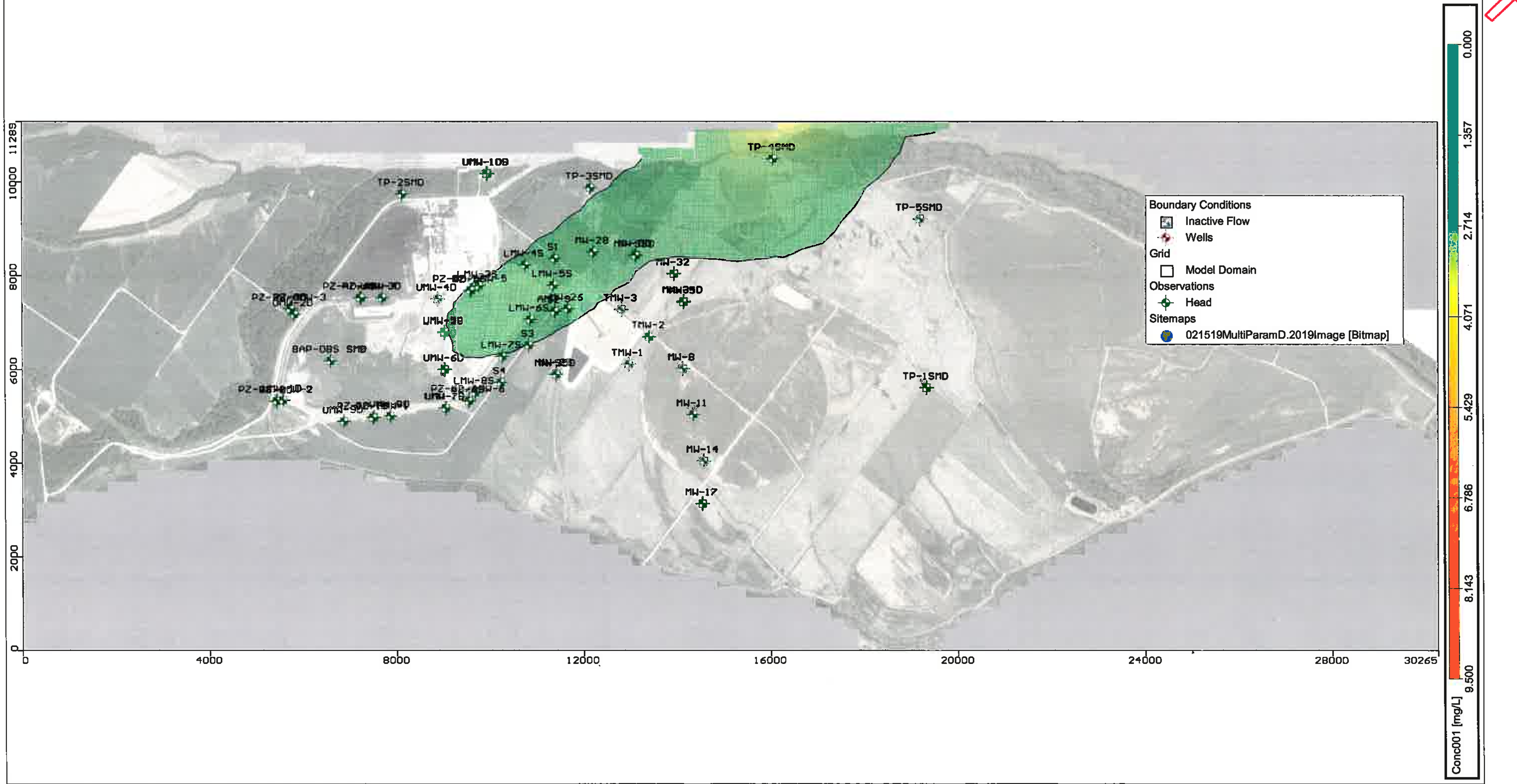
Bottom Ash Pond Closure Groundwater Model Report
Boron Distribution



Boron Iso-Concentrations (2, 4, & 8 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 9.50 mg/L
Time = 30 Years Post-Closure

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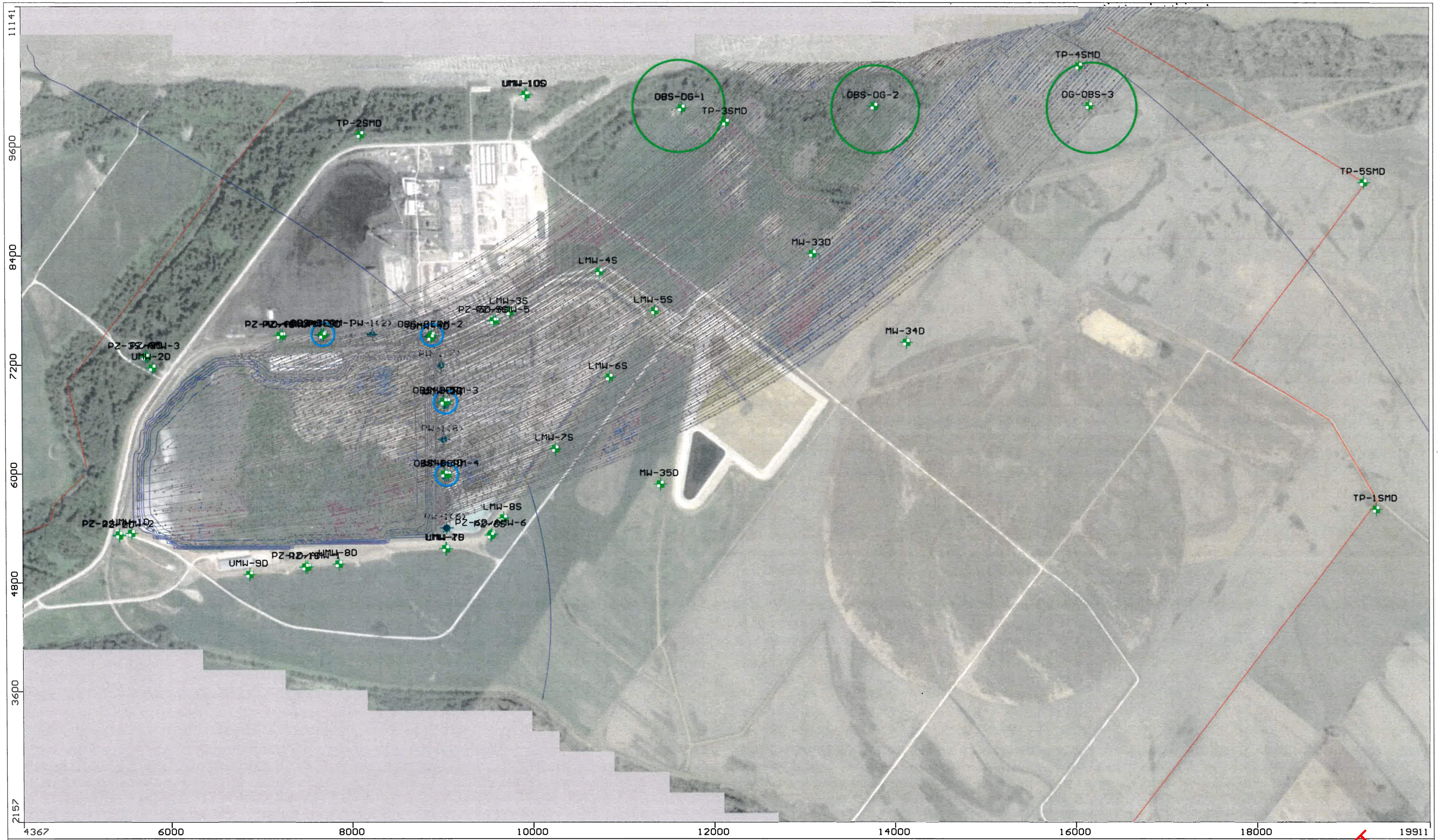
AMLEC BAP Groundwater Model
File Name: 021519MultiParamD



Appendix 3: Predicted Boron Concentration Time Series - Observation Locations
Simulated Source Concentration = 9.5 mg/L
10-7 Cap, No Hydraulic Controls
Blue = Berm Wells   Green - Down Gradient Wells   Gray = Flow Path Traces

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AMLEC BAP Groundwater Model
File Name: 031819Obs100

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Appendix 3: Predicted Boron Concentration Time Series - Berm Observation Locations
Simulated Source Concentration = 9.5 mg/L
10-7 Cap, No Hydraulic Controls

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AMLEC BAP Groundwater Model
File Name: 031819Obs100

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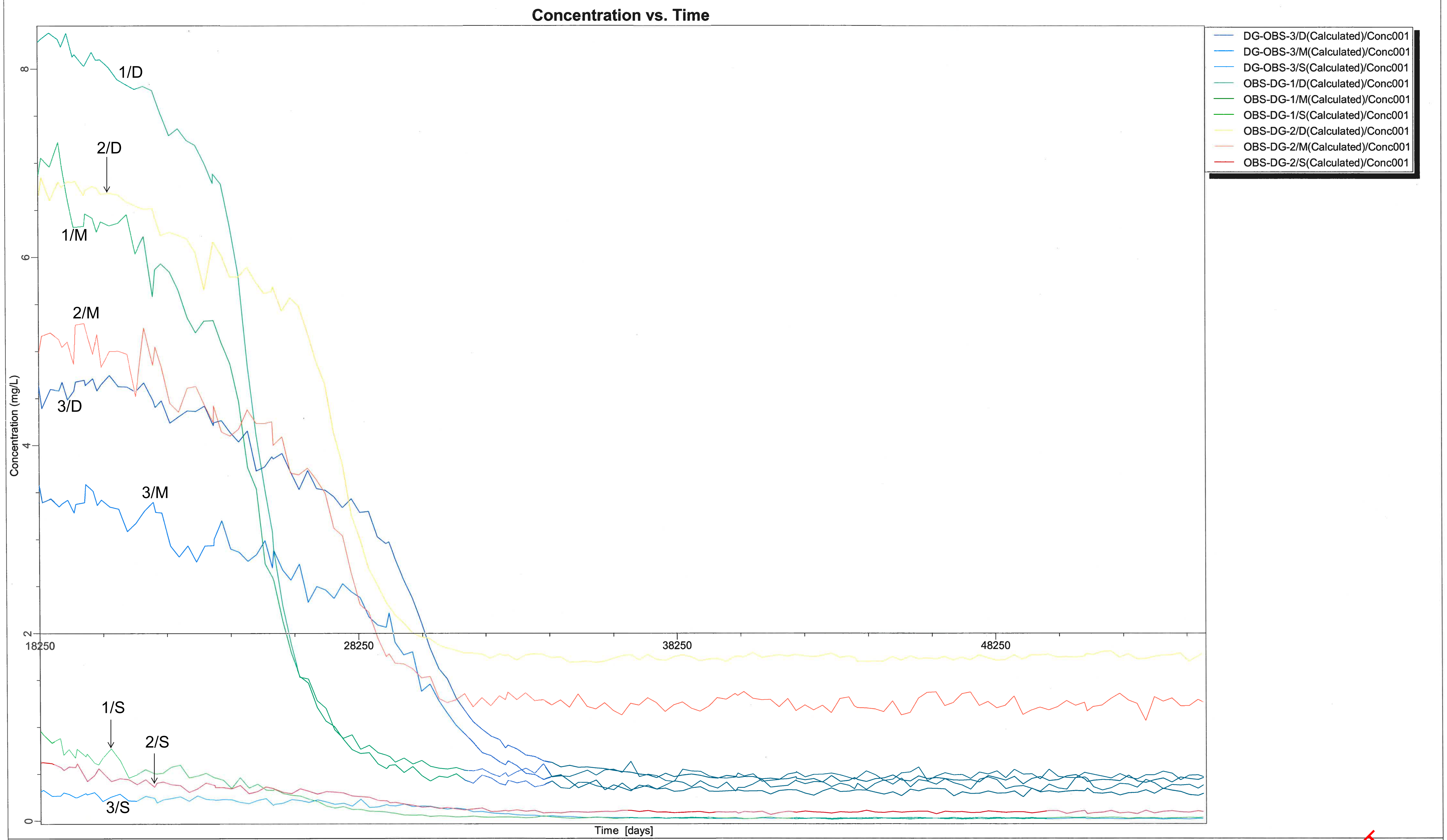

Appendix 3: Predicted Boron Concentration Time Series - Down Gradient Observation Locations
Simulated Source Concentration = 9.5 mg/L
10-7 Cap, No Hydraulic Controls

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AMLEC BAP Groundwater Model
File Name: 031819Obs100

Appendix 4

Predictive Simulation Output – Future Molybdenum Concentration

- Shallow (Layer 2) Molybdenum Distribution at 0 years Post-Closure
- Shallow (Layer 2) Molybdenum Distribution at 30 years Post-Closure
- Medium (Layer 5) Molybdenum Distribution at 0 years Post-Closure
- Medium (Layer 5) Molybdenum Distribution at 30 years Post-Closure
- Deep (Layer 6) Molybdenum Distribution at 0 years Post-Closure
- Deep (Layer 6) Molybdenum Distribution at 30 years Post-Closure
- Predicted Molybdenum Concentration Time Series – Observation Locations
- Predicted Molybdenum Concentration Time Series – Berm Observation Locations
- Predicted Molybdenum Concentration Time Series – Down Gradient Observation Locations

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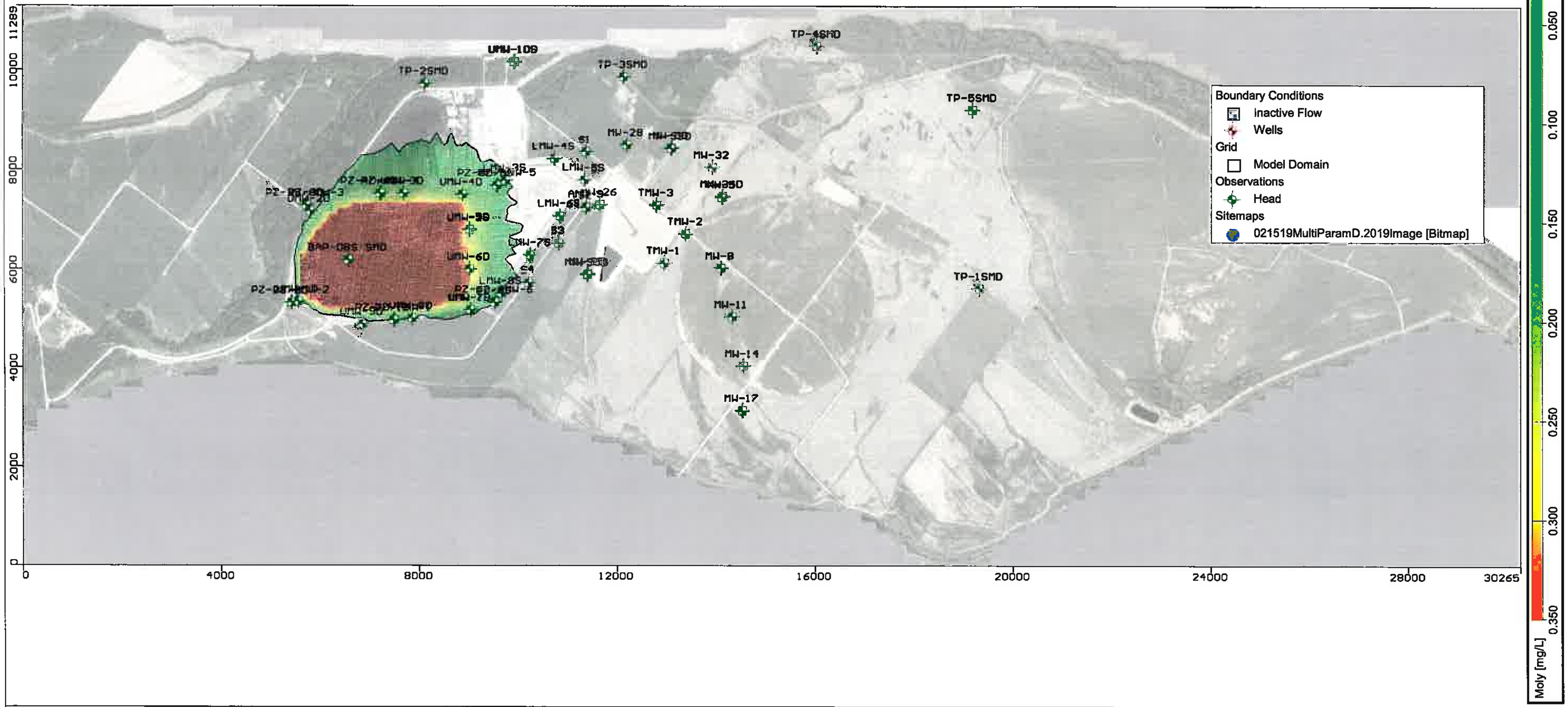
Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution



Molybdenum Iso-Concentration (0.100 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 0.350 mg/L
Time = 0 Years Post-Closure

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File Name: 021519MultiParamD

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Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution

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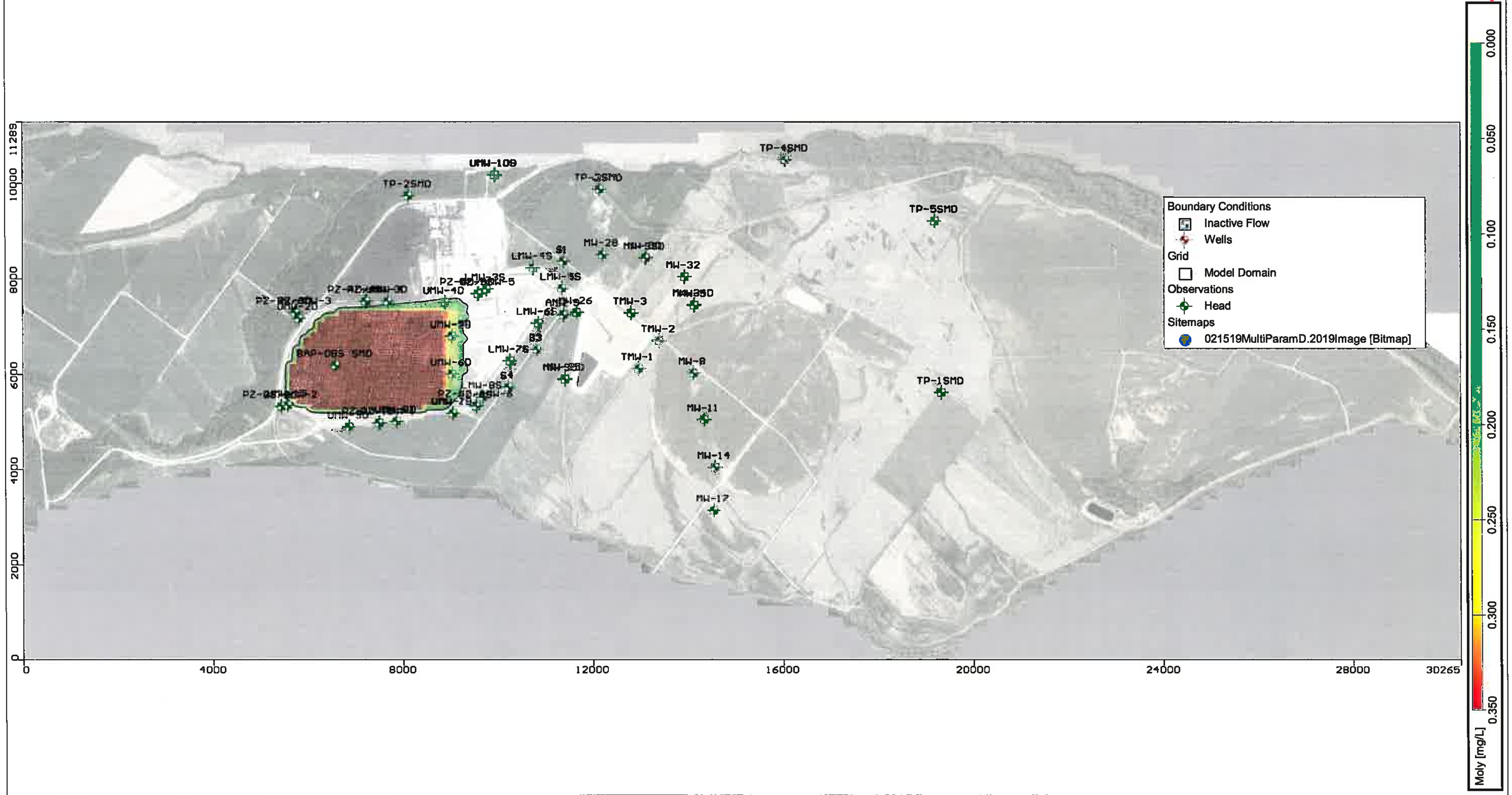

Molybdenum Iso-Concentration (0.100 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 0.350 mg/L
Time = 30 Years Post-Closure

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Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution

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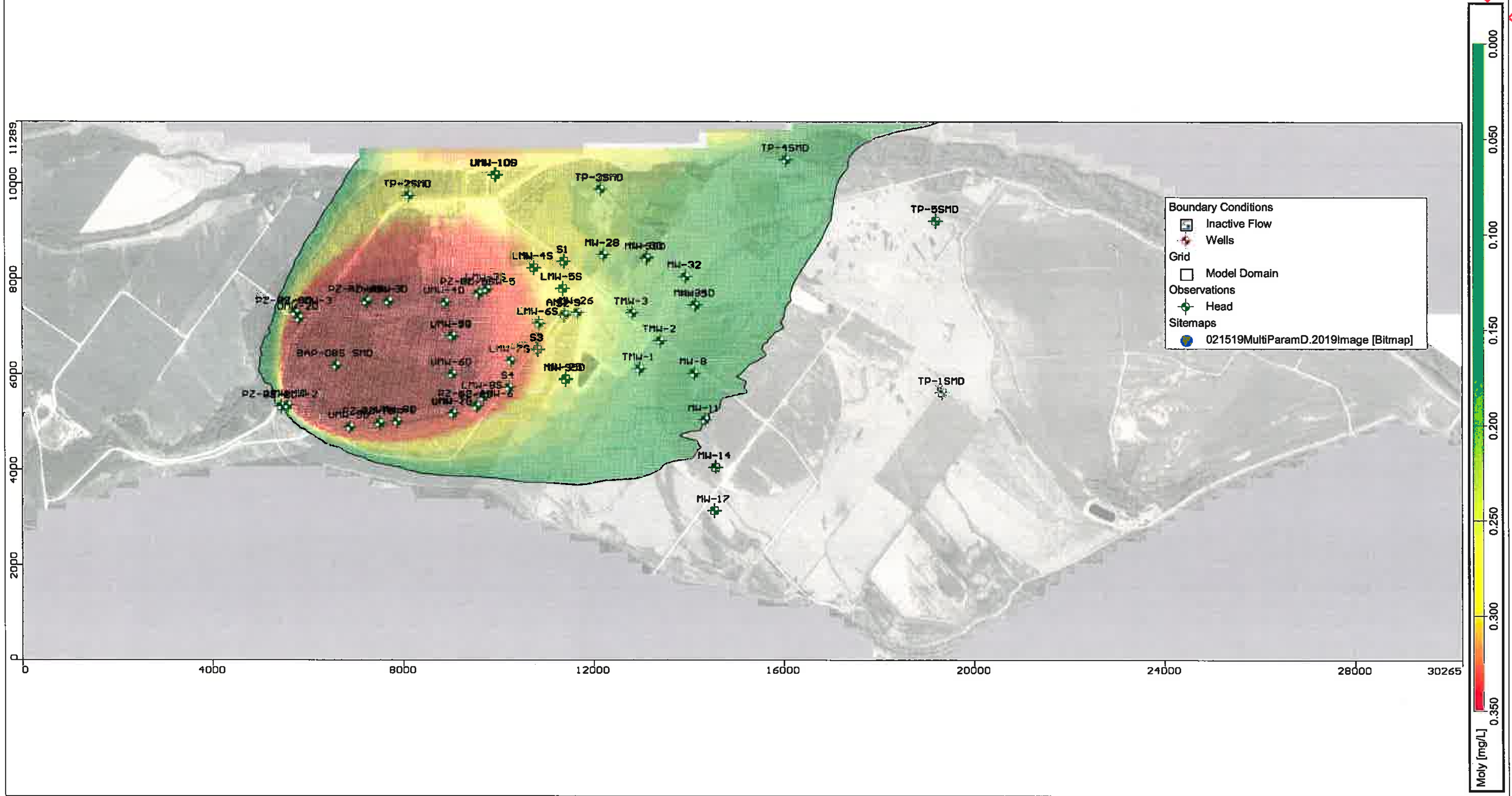

Molybdenum Iso-Concentration (0.100 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 0.350 mg/L
Time = 0 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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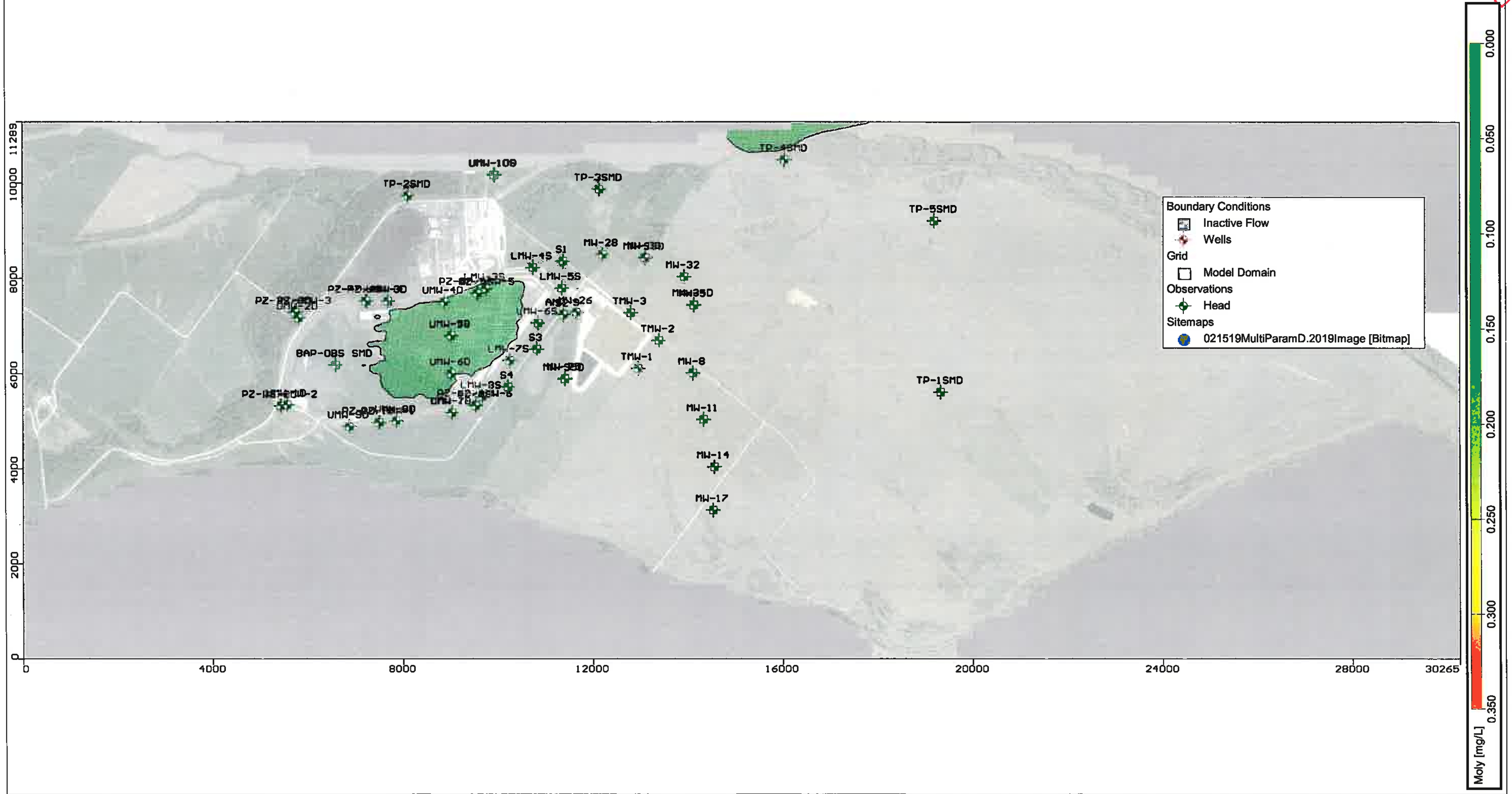
Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution



Molybdenum Iso-Concentration (0.100 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 0.350 mg/L
Time = 30 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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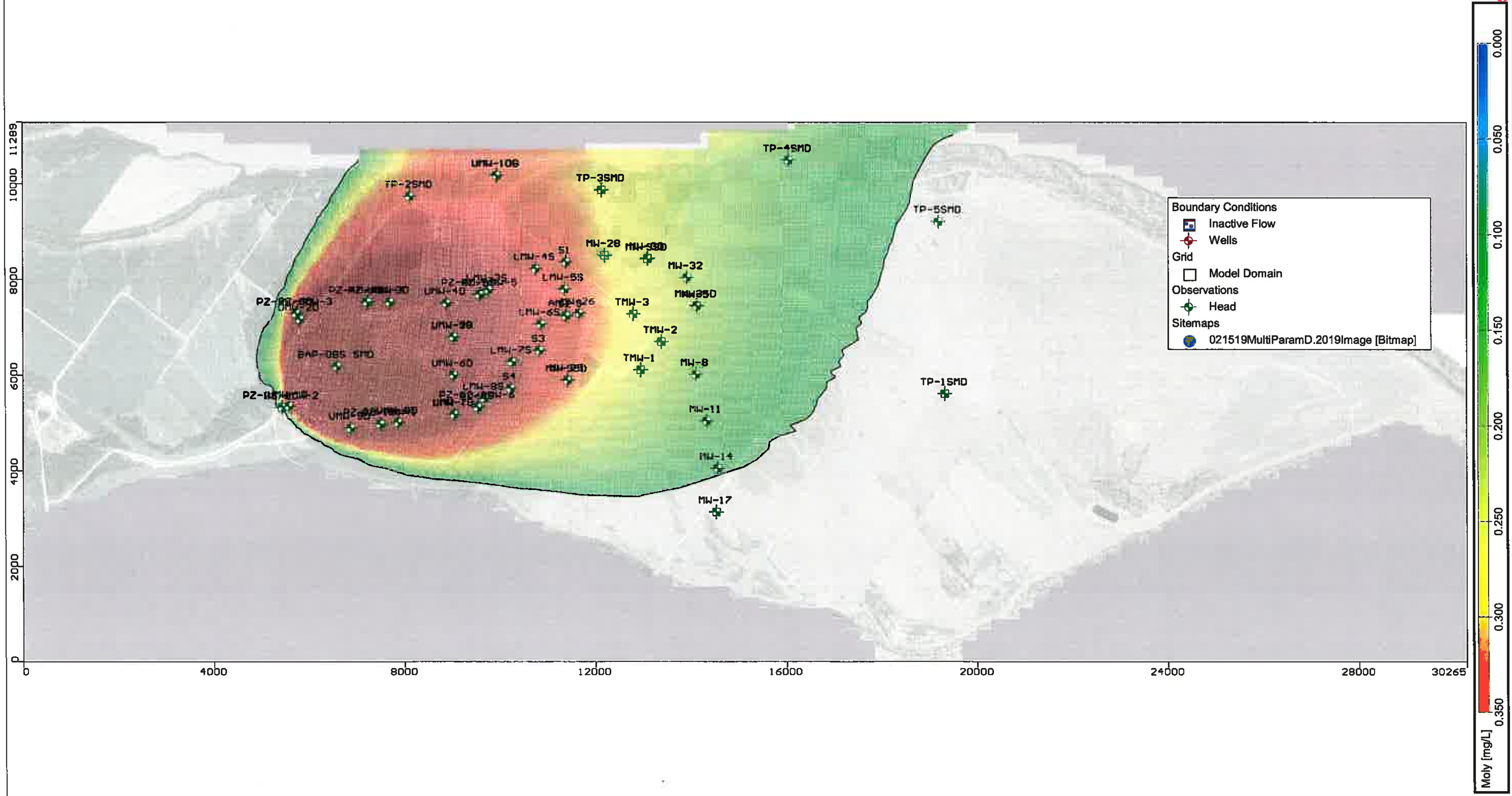
Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution



Molybdenum Iso-Concentration (0.100 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 0.350 mg/L
Time = 0 Years Post-Closure

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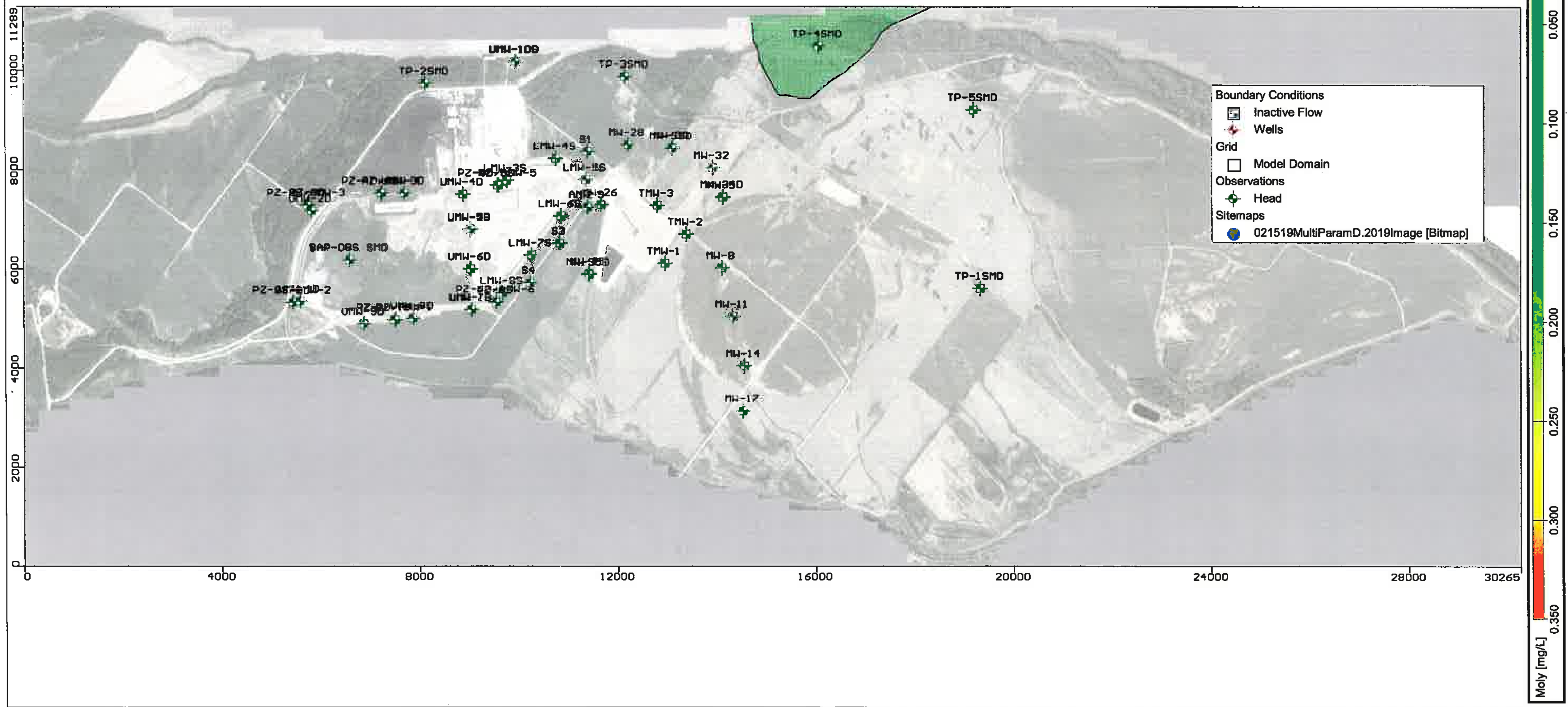
Bottom Ash Pond Closure Groundwater Model Report
Molybdenum Distribution



Molybdenum Iso-Concentration (0.100 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 0.350 mg/L
Time = 30 Years Post-Closure

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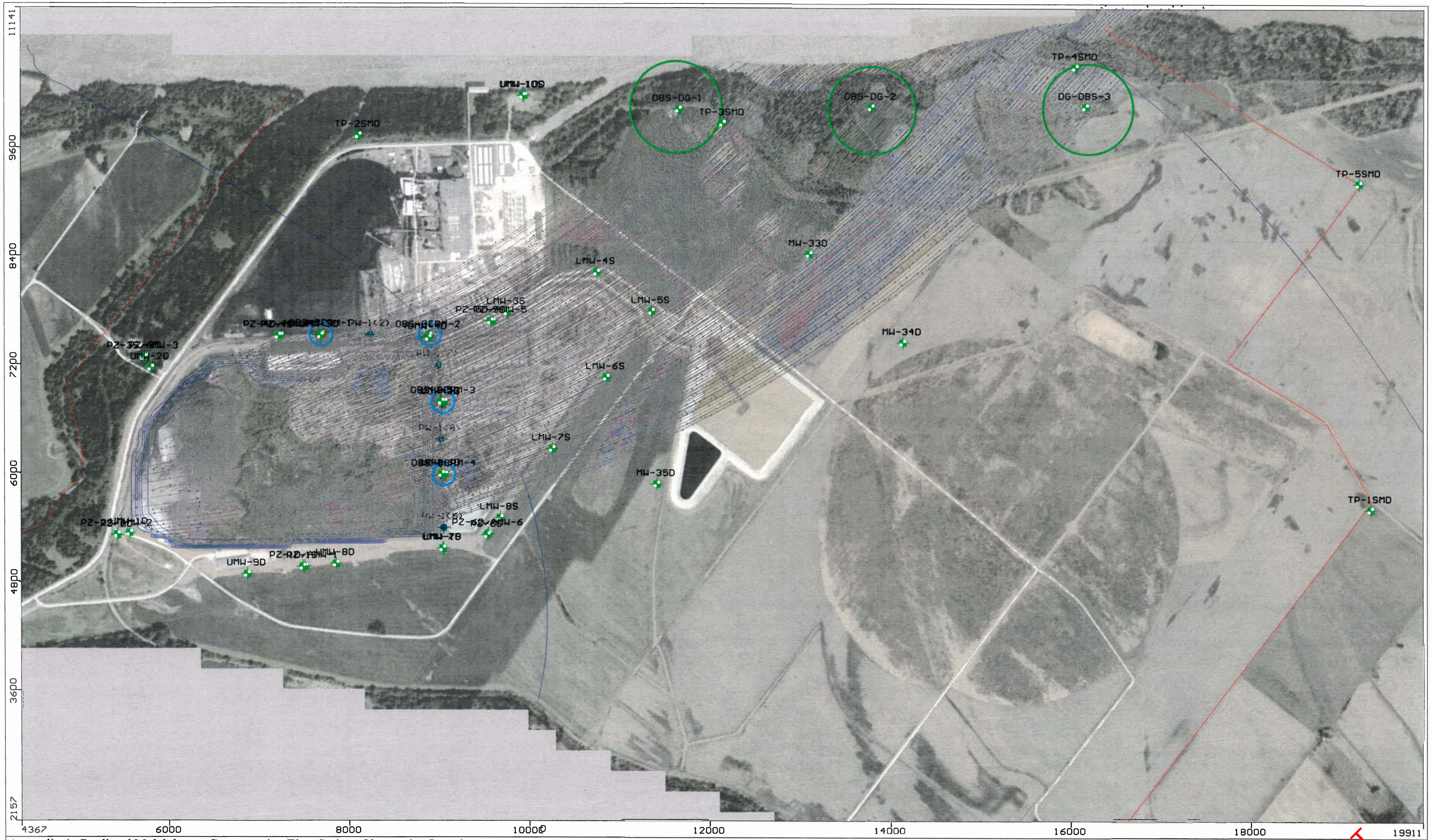
AMLEC BAP Groundwater Model
File Name: 021519MultiParamD



Appendix 4: Predicted Molybdenum Concentration Time Series - Observation Locations
Simulated Source Concentration = 0.350 mg/L
10-7 Cap, No Hydraulic Controls
Blue = Berm Wells Green - Down Gradient Wells Gray = Flow Path Traces

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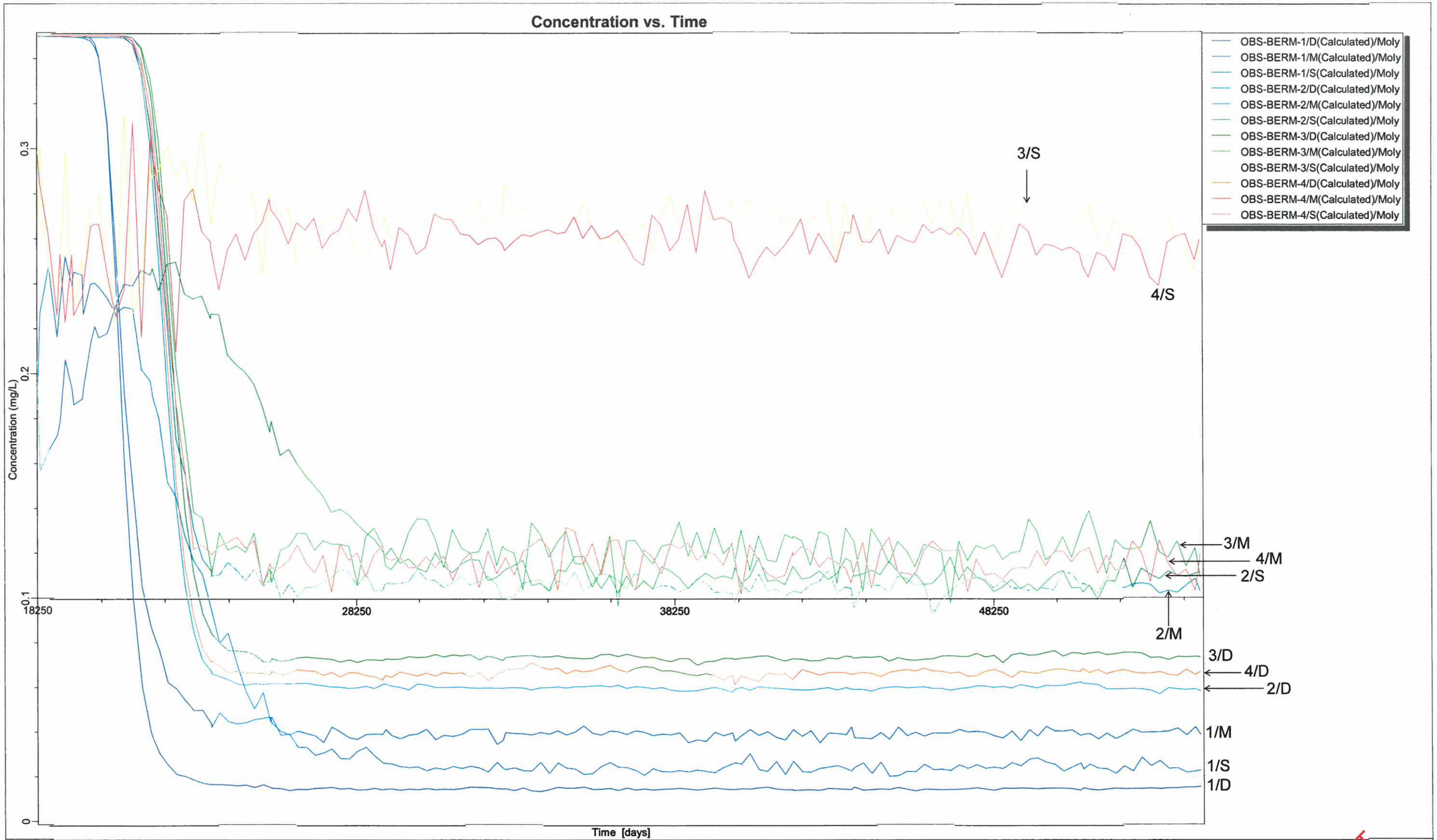
AMLEC BAP Groundwater Model
File Name: 031819Obs100



Appendix 4: Predicted Molybdenum Concentration Time Series - Berm Observation Locations
Simulated Source Concentration = 0.350 mg/L
10-7 Cap, No Hydraulic Controls

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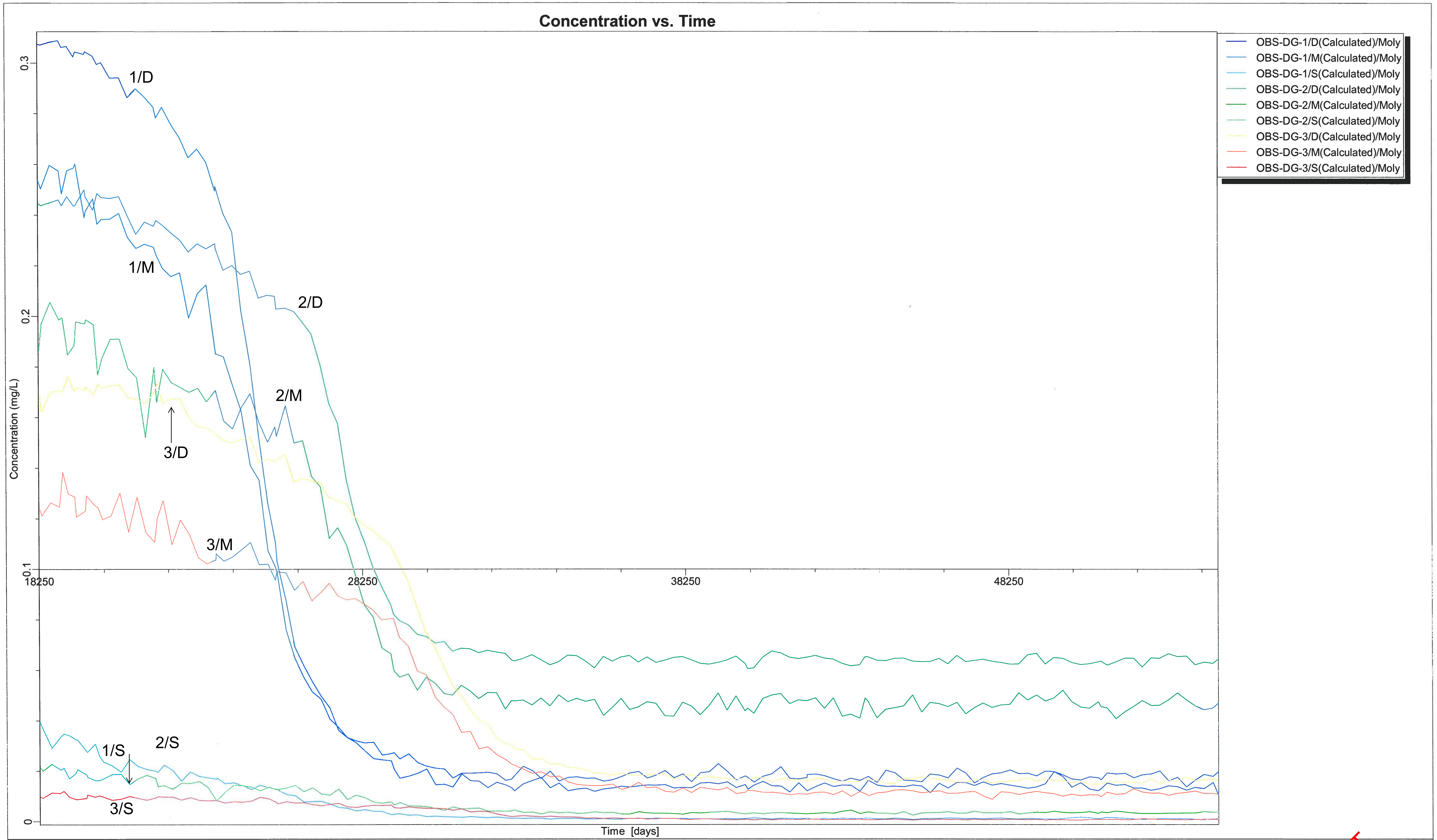
File Name: 031819Obs100



Appendix 4: Predicted Molybdenum Concentration Time Series - Down Gradient Observation Locations
Simulated Source Concentration = 0.350 mg/L
10-7 Cap, No Hydraulic Controls

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AMLEC BAP Groundwater Model
File Name: 031819Obs100

Appendix 5

Predictive Simulation Output – Future Arsenic Concentration

- Shallow (Layer 2) Arsenic Distribution at 0 years Post-Closure
- Shallow (Layer 2) Arsenic Distribution at 30 years Post-Closure
- Medium (Layer 5) Arsenic Distribution at 30 years Post-Closure
- Medium (Layer 5) Arsenic Distribution at 0 years Post-Closure
- Deep (Layer 6) Arsenic Distribution at 0 years Post-Closure
- Deep (Layer 6) Arsenic Distribution at 30 years Post-Closure
- Predicted Arsenic Concentration Time Series – Observation Locations
- Predicted Arsenic Concentration Time Series – Berm Observation Locations
- Predicted Arsenic Concentration Time Series – Down Gradient Observation Locations

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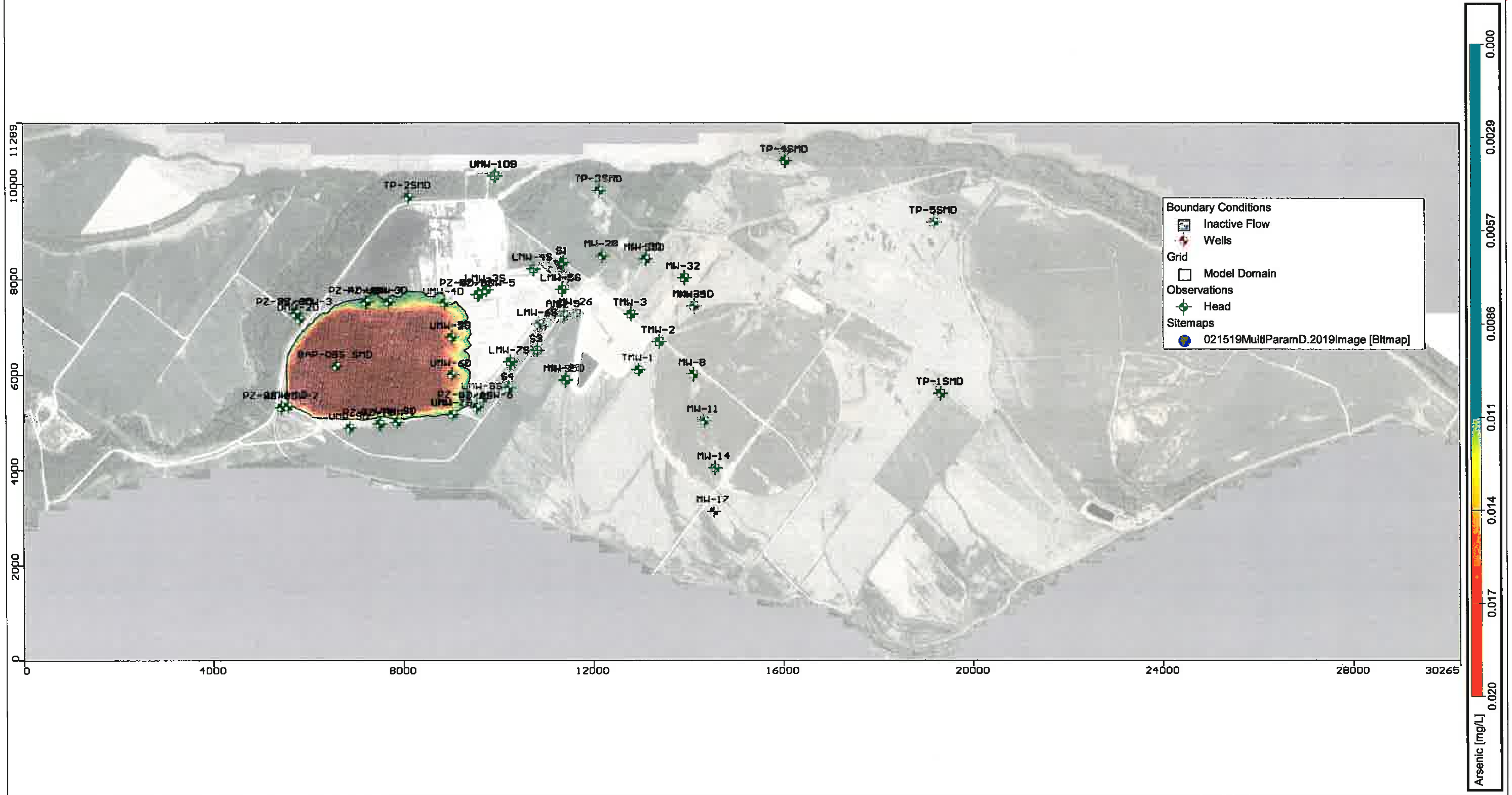
Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution



Arsenic Iso-Concentration (0.010 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 0.020 mg/L
Time = 0 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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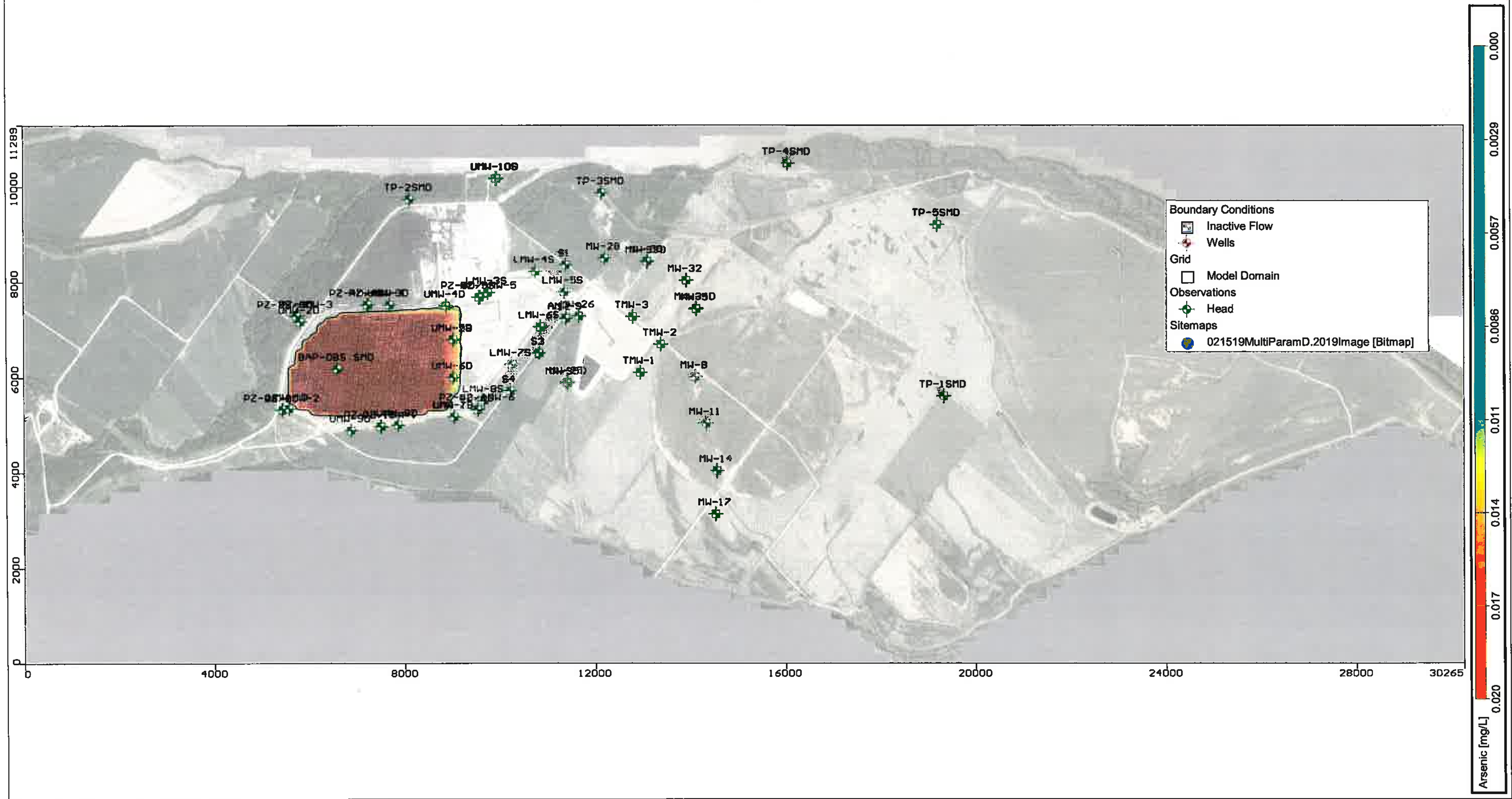
Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution



Arsenic Iso-Concentration (0.010 mg/L)
Shallow (Layer 2)
Simulated Source Concentration = 0.020 mg/L
Time = 30 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

Ameren Missouri - Labadie Energy Center
Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution

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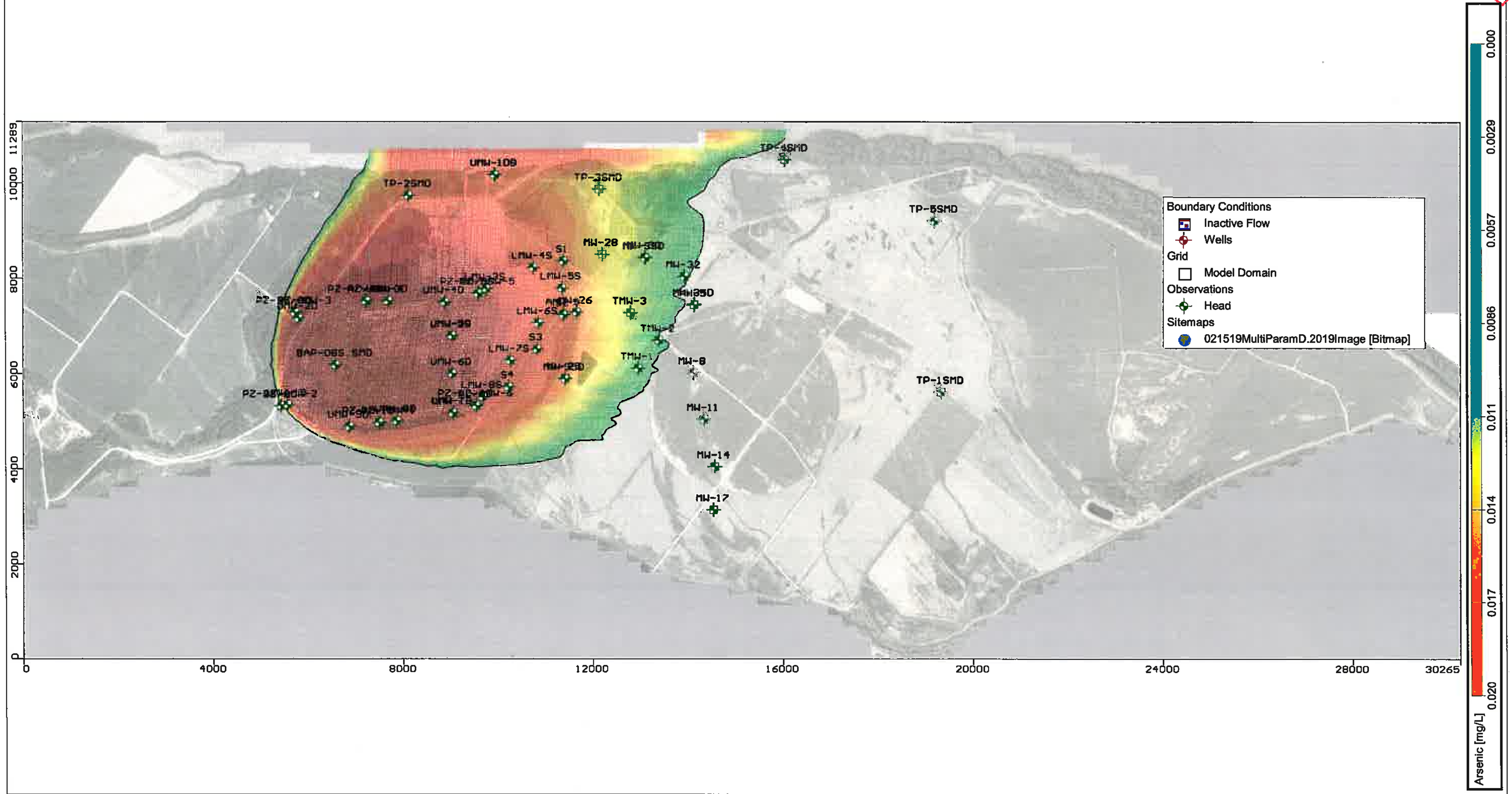

Arsenic Iso-Concentration (0.010 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 0.020 mg/L
Time = 0 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution

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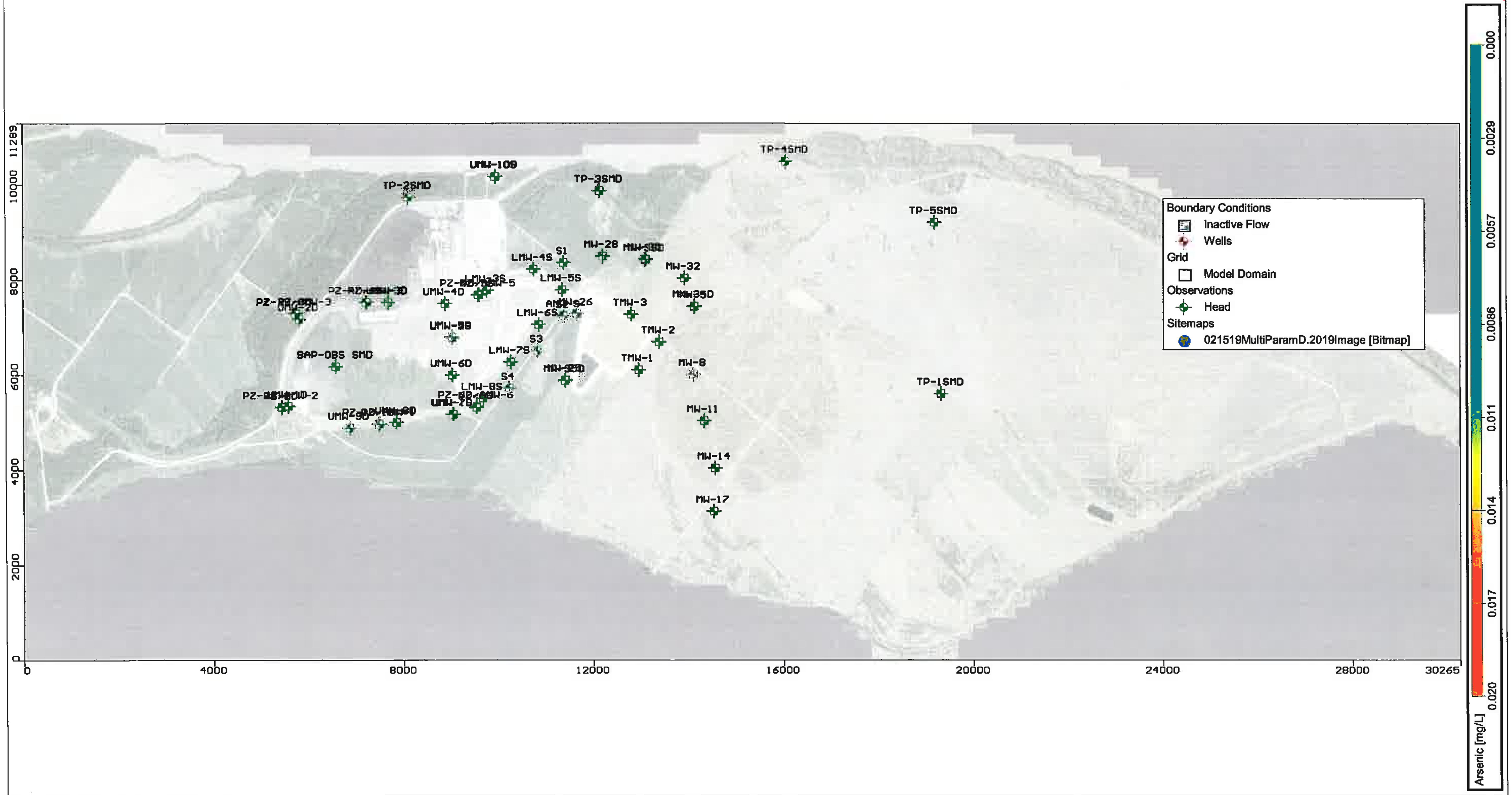

Arsenic Iso-Concentration (0.010 mg/L)
Medium (Layer 5)
Simulated Source Concentration = 0.020 mg/L
Time = 30 Years Post-Closure

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AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

Ameren Missouri - Labadie Energy Center
Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution

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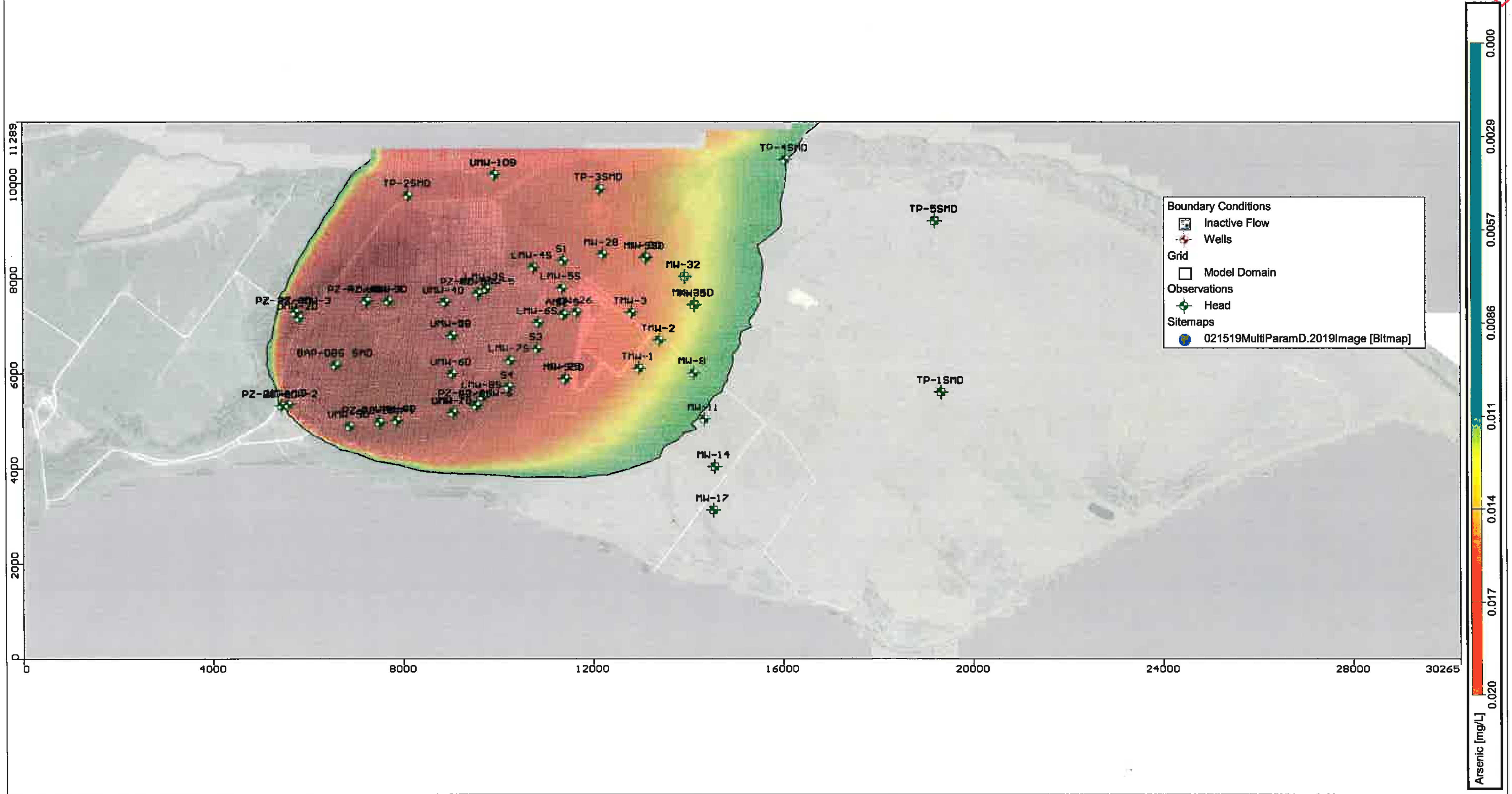

Arsenic Iso-Concentration (0.010 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 0.020 mg/L
Time = 0 Years Post-Closure

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 021519MultiParamD

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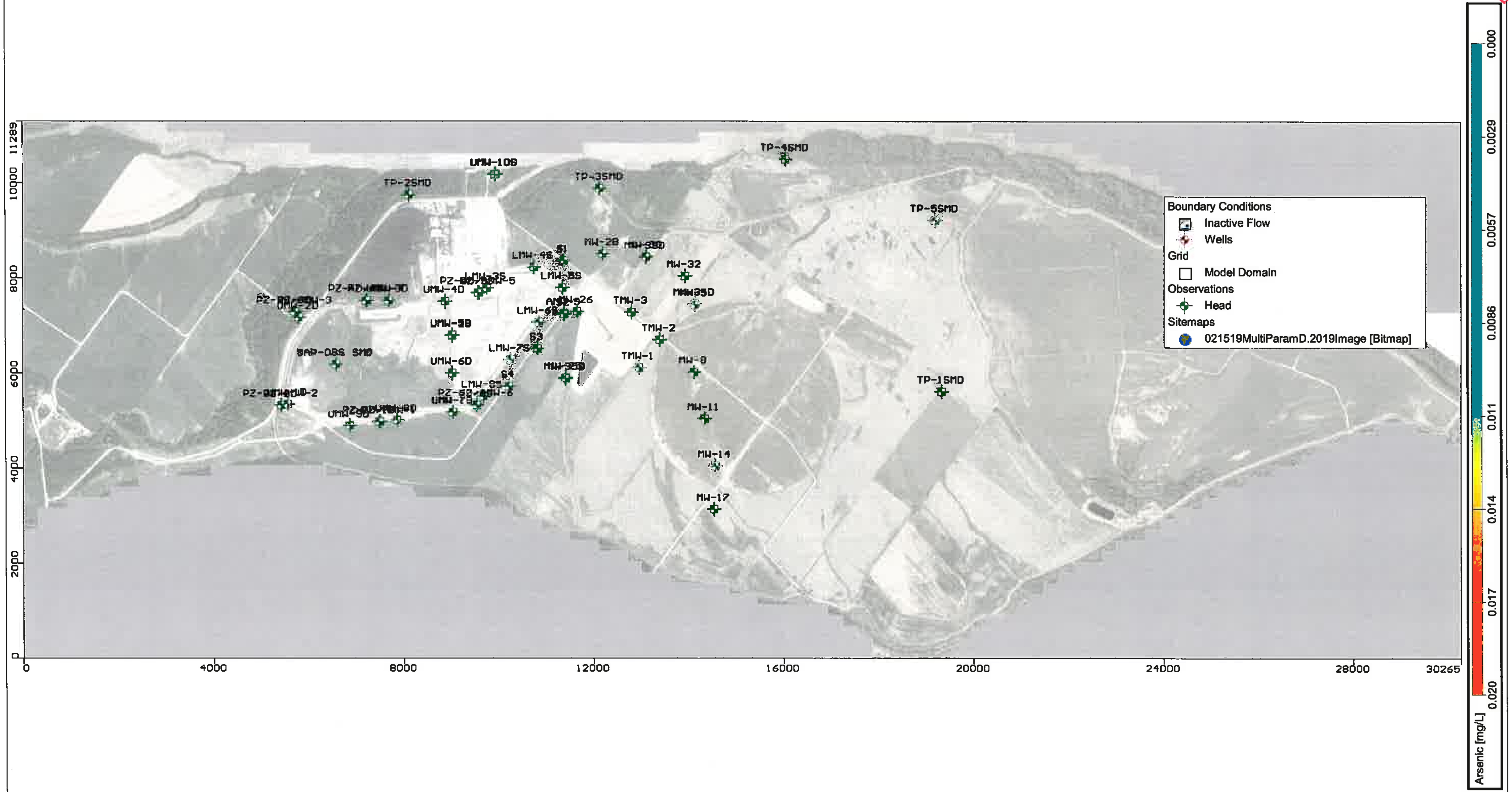
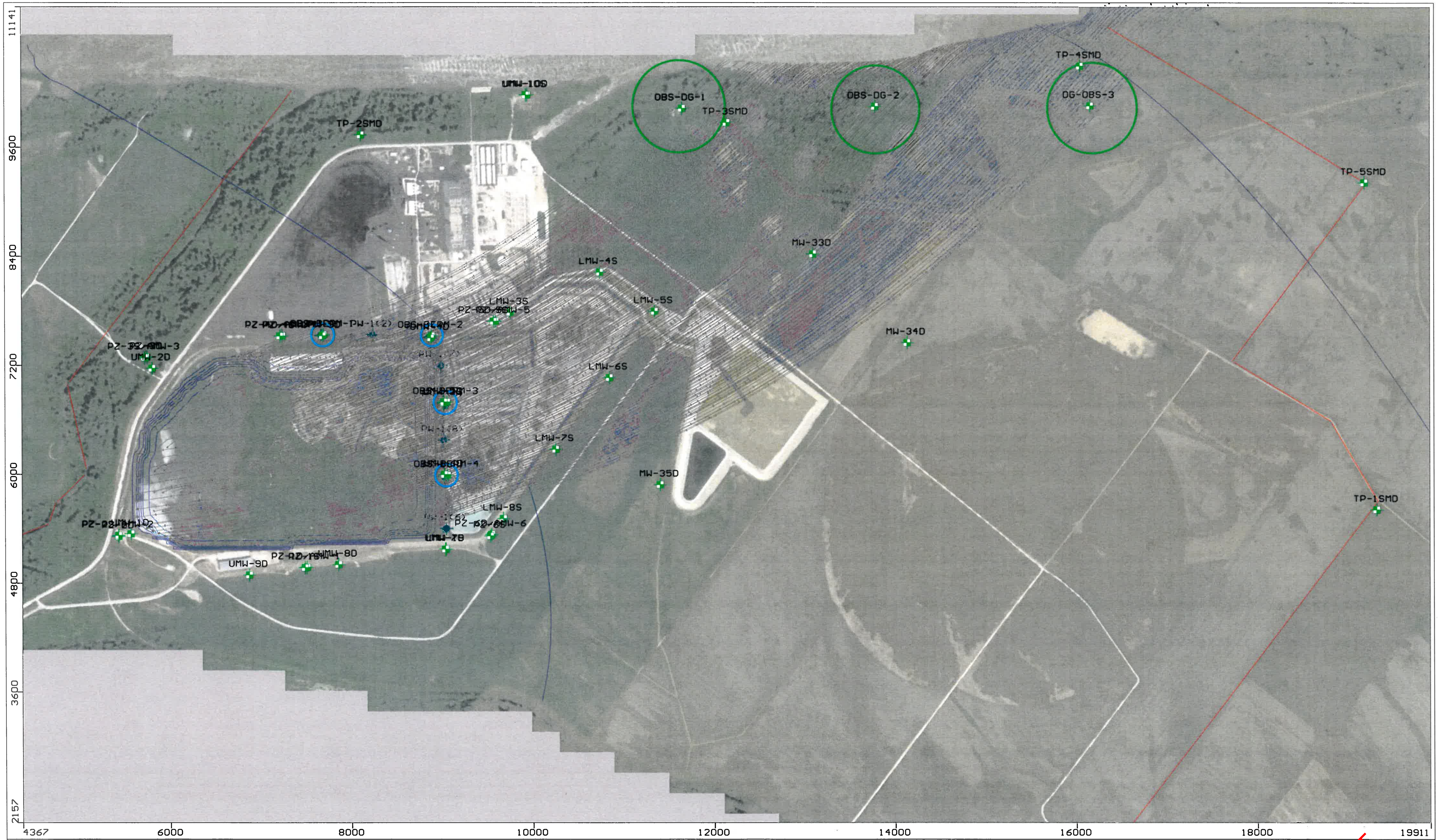
Ameren Missouri - Labadie Energy Center
Bottom Ash Pond Closure Groundwater Model Report
Arsenic Distribution



Arsenic Iso-Concentration (0.010 mg/L)
Deep (Layer 6)
Simulated Source Concentration = 0.020 mg/L
Time = 30 Years Post-Closure

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 021519MultiParamD



Appendix 5: Predicted Arsenic Concentration Time Series - Observation Locations
Simulated Source Concentration = 0.020 mg/L
10-7 Cap, No Hydraulic Controls
Blue = Berm Wells   Green - Down Gradient Wells   Gray = Flow Path Traces

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AMLEC BAP Groundwater Model
File Name: 031819Obs100

Appendix 5: Predicted Arsenic Concentration Time Series - Berm Observation Locations
Simulated Source Concentration = 0.020 mg/L
10-7 Cap, No Hydraulic Controls

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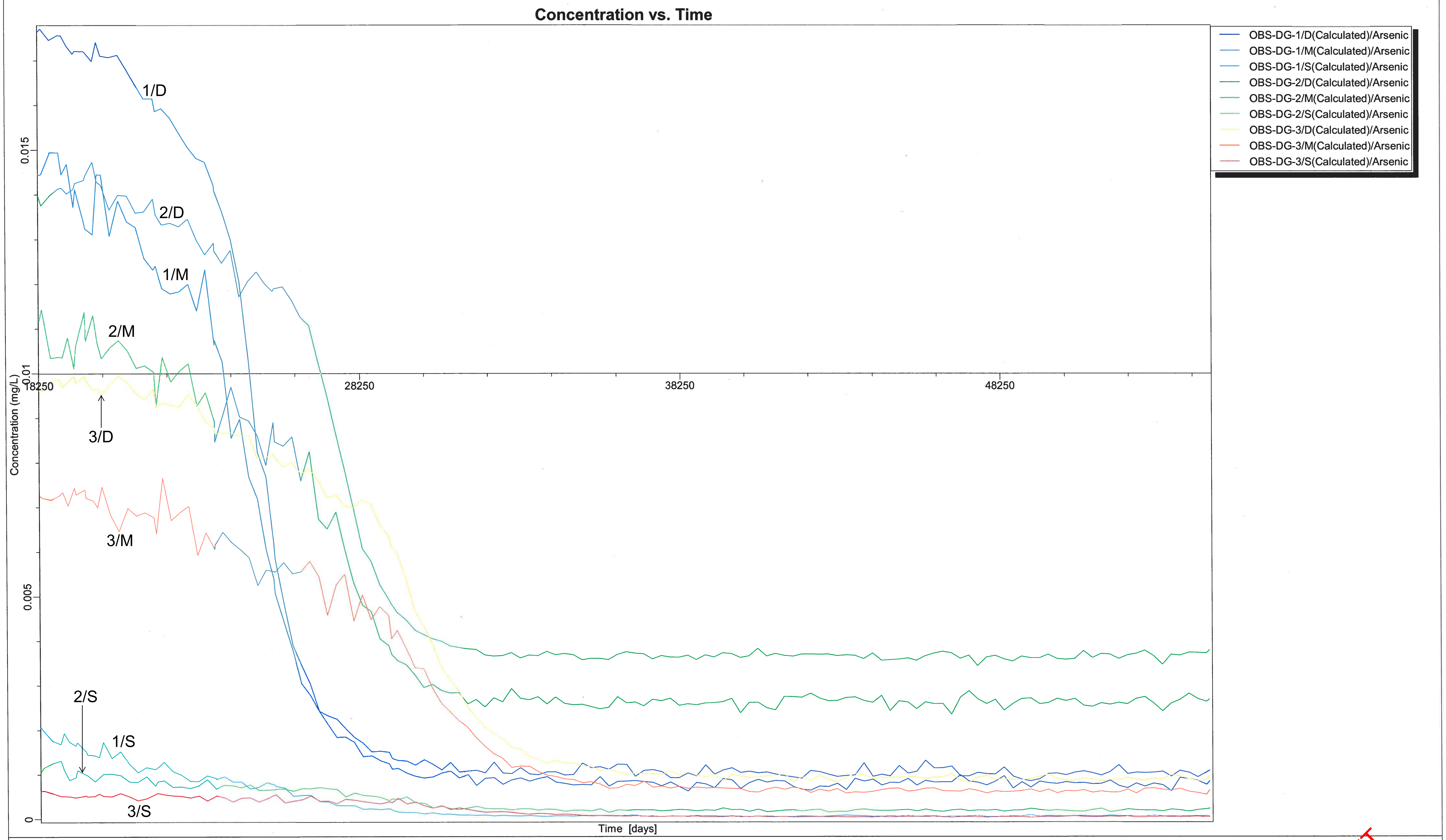
AMLEC BAP Groundwater Model
File Name: 031819Obs100



Appendix 5: Predicted Arsenic Concentration Time Series - Down Gradient Observation Locations
Simulated Source Concentration = 0.020 mg/L
10-7 Cap, No Hydraulic Controls

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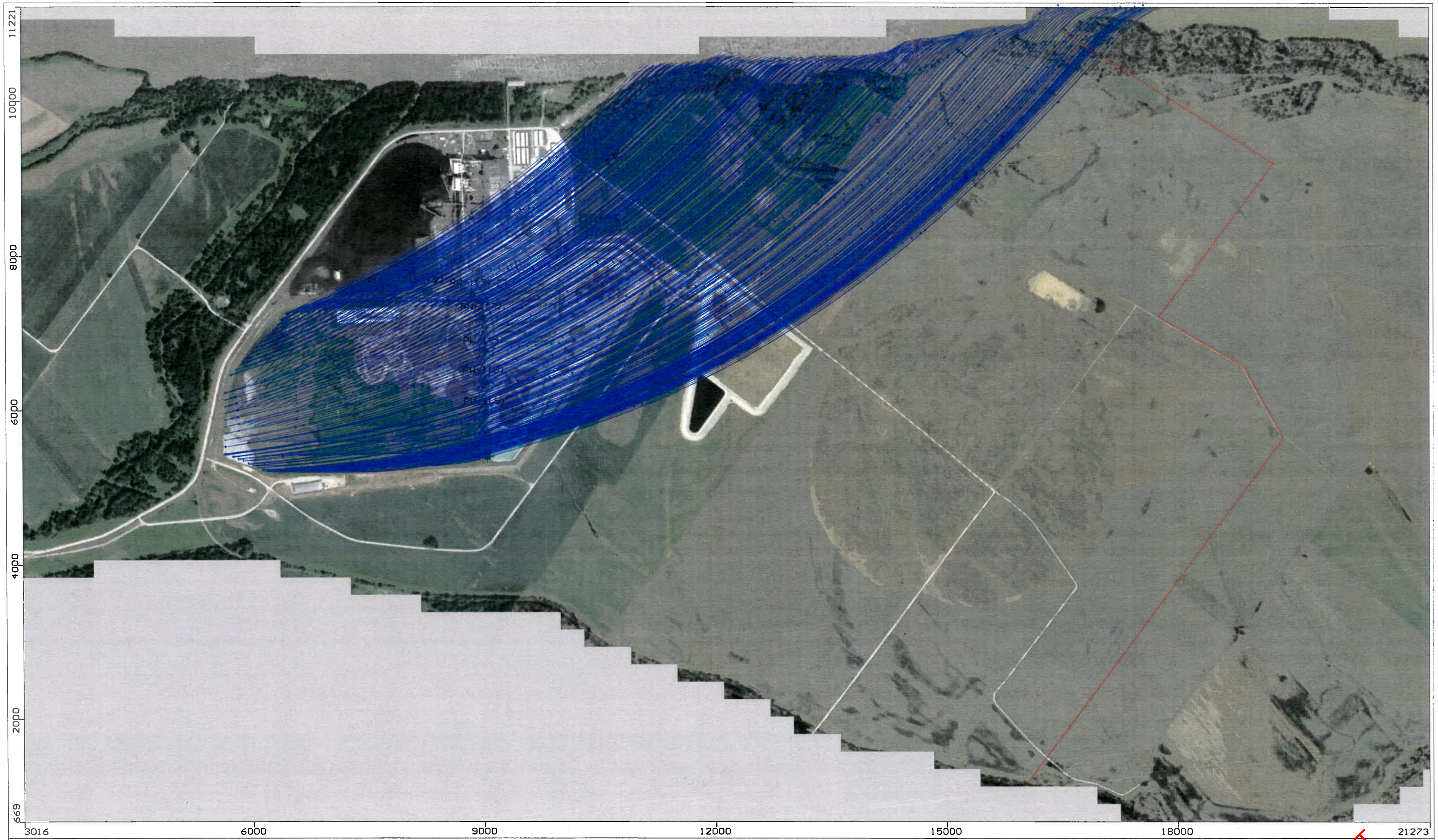
AMLEC BAP Groundwater Model
File Name: 031819Obs100

Appendix 6A

Flow Path Tracing from Bottom Ash Pond – Various Scenarios with No Cap



Appendix 6A-1: Flow Path Tracing from Bottom Ash Pond
No Hydraulic Control and No Cap

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AMLEC BAP Groundwater Model
File Name: 031519Base

Appendix 6A-2: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells and No Cap

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AMLEC BAP Groundwater Model
File Name: 031519PW

Appendix 6A-3: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells, Barrier Wall to 407.5 feet elevation, and No Cap
Wells Pumping at 15, 0, 25, 25, 35, 40, 25, and 30 GPM (Total Q = 195 GPM)

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AMLEC BAP Groundwater Model
File Name: 031819WallSPW

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Appendix 6A-4: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells, Barrier Wall to Bedrock, and No Cap
Wells Pumping at 60, 15, 0, 0, 40, 70, 20, and 0 GPM (Total Q = 205 GPM)

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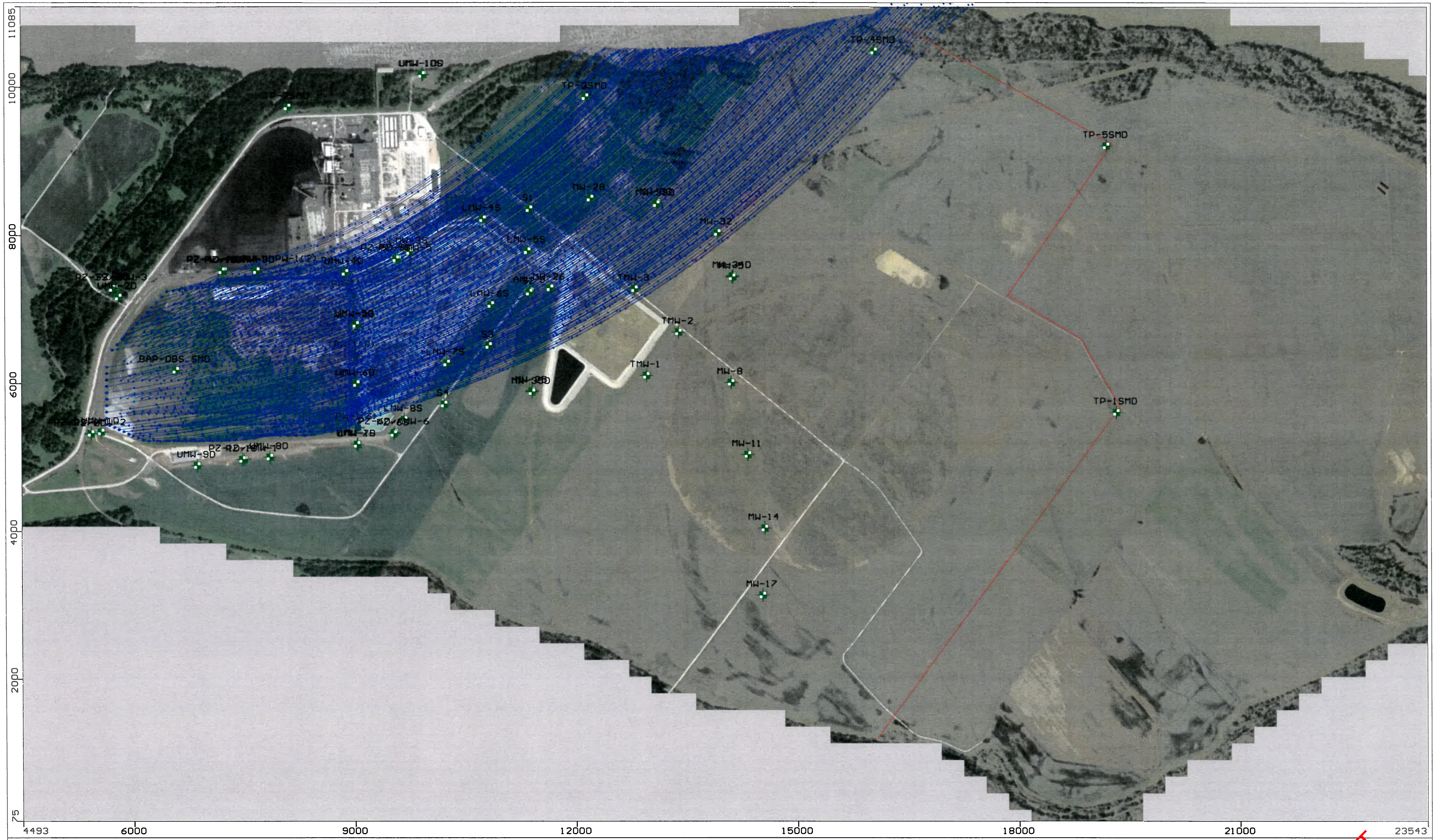
GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 031819WallBRPW

Appendix 6B

Flow Path Tracing from Bottom Ash Pond – Various Scenarios with Cap



Appendix 6B-1: Flow Path Tracing from Bottom Ash Pond
No Hydraulic Control with 10-7 Cap

DRAFT

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 031519CapBase

Appendix 6B-2: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells, and 10-7 Cap
Wells Pumping at 25, 0, 25, 20, 20, 25, 15, and 15 GPM (Total Q = 145 GPM)

DRAFT

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 031519PWCap

Appendix 6B-3: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells, Barrier Wall to 407.5 feet elevation, and 10-7 Cap
Wells Pumping at 20, 0, 10, 10, 15, 20, 15, and 10 GPM (Total Q = 100 GPM)

DRAFT

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 031819WallSPWCap

Appendix 6B-4: Flow Path Tracing from Bottom Ash Pond
Hydraulic Control Via Pumping Wells, Barrier Wall to Bedrock, and 10-7 Cap
Wells Pumping at 40, 0, 0, 0, 20, 50, 5, and 0 GPM (Total Q = 115 GPM)

GREDELL Engineering Resources Inc.
AMLEC BAP Groundwater Model
File Name: 031819WallBRPWCap

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