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APR 03 2017

PPPO-02-4106868-17

Mr. Brian Begley
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Ms. Julie Corkran
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61 Forsyth Street
Atlanta, Georgia 30303

Dear Mr. Begley and Ms. Corkran:

2016 UPDATE OF THE PADUCAH GASEOUS DIFFUSION PLANT SITEWIDE GROUNDWATER FLOW MODEL, DOE/LX/07-2415&D1

Please find enclosed the *2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model*, DOE/LX/07-2415&D1, for your review and comment. This update is a product of the Paducah Site's Groundwater Modeling Working Group, which is composed of members from the U.S. Department of Energy, the Kentucky Division of Waste Management, the U.S. Environmental Protection Agency and the Kentucky Research Consortium for Energy and the Environment.

This document is not defined as a primary or a secondary document by the Federal Facility Agreement. As discussed within Modeling Working Group meetings, we request that comments be provided 30 days from transmittal date.

If additional information is required, please contact Rich Bonczek at (859) 219-4051.

Sincerely,

Tracey Duncan
Federal Facility Agreement Manager
Portsmouth/Paducah Project Office

Enclosure:
2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model

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DOE/LX/07-2415&D1

2016 Update
of the Paducah Gaseous Diffusion Plant
Sitewide Groundwater Flow Model

A Product of the Paducah Gaseous Diffusion Plant
Site Groundwater Modeling Working Group

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DOE/LX/07-2415&D1

2016 Update
of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model

A Product of the Paducah Gaseous Diffusion Plant Site Groundwater Modeling Working Group

Date Issued—March 2017

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FLUOR FEDERAL SERVICES, INC.
Paducah Deactivation Project
managing the
Deactivation Project at the
Paducah Gaseous Diffusion Plant
under Task Order DE-DT0007774

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ACRONYMS

amsl	above mean sea level
AOC	area of concern
BC	Bayou Creek
bgs	below ground surface
CAER	Center for Applied Energy Research
CSM	conceptual site model
DNAPL	dense nonaqueous-phase liquid
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESI	Environmental Simulations, Inc.
EW	extraction well
Geosyntec	Geosyntec Consultants, Inc.
GW	groundwater
HPFW	High Pressure Fire Water
HU	hydrostratigraphic unit
KDEP	Kentucky Department for Environmental Protection
KRCEE	Kentucky Research Consortium for Energy and Environment
LBC	Little Bayou Creek
LIDAR	Light Detection and Ranging
MWG	Modeling Working Group
PGDP	Paducah Gaseous Diffusion Plant
RGA	Regional Gravel Aquifer
SP1	Stress Period 1
SP2	Stress Period 2
SVD	singular value decomposition
SWMU	solid waste management unit
TVA	Tennessee Valley Authority
UCRS	Upper Continental Recharge System
USGS	United States Geological Survey
WHAT	Web-based Hydrograph Analysis Tool
WKWMA	West Kentucky Wildlife Management Area

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1. INTRODUCTION

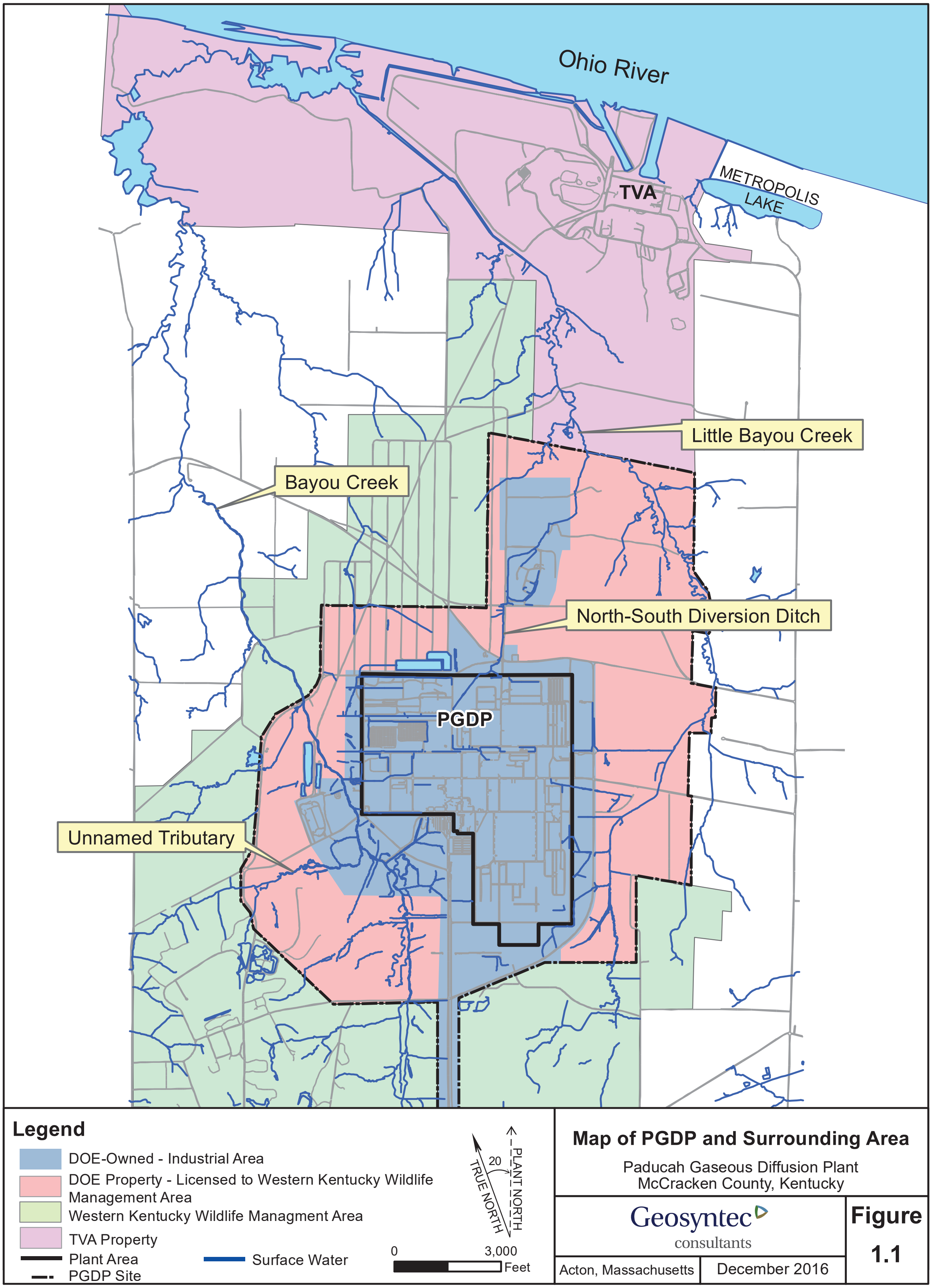
The Paducah Gaseous Diffusion Plant (PGDP) Sitewide Groundwater Flow Model described herein is an update to the current model most recently updated in 2012. The original model, constructed in 1990, has undergone numerous revisions; these are described briefly in Section 1.3 of this report. The 2016 model revisions described herein were developed through consensus of the PGDP Modeling Working Group (MWG), which includes representatives from the U.S. Environmental Protection Agency (EPA), the Kentucky Department for Environmental Protection (KDEP), Kentucky Research Consortium for Energy and Environment (KRCEE), and the U.S. Department of Energy (DOE) and their technical consultants. Reference in this report to the PGDP Site generally means the property and facilities at or near PGDP for which DOE has ultimate responsibility, and references to the plant area are defined as the industrialized area of the PGDP Site (see Figure 1.1).

1.1 MODELING OBJECTIVE

The objective of the ongoing sitewide groundwater modeling effort is to develop a tool that can be relied on to assist in determining additional data needs, evaluating potential remedies (e.g., evaluation of extraction well capture zones), developing cleanup criteria in decision documents (e.g., refinement of soil cleanup levels to protect groundwater and setting of monitoring goals), and providing inputs needed for remedy design. Sitewide groundwater modeling efforts began in 1990, with the most recent model revisions developed in 2008 (DOE 2010) and updated in 2012 (A. D. Laase Hydrologic Consulting 2014). The objective of the 2016 model revisions documented in this report is to update the 2012 model to include more recent PGDP Site data collected from the period 2012 to 2016 and to refine model boundary conditions. Summaries of the 2008 model and subsequent 2012 model update, as well as the revisions implemented in 2016, are provided in the following sections.

1.2 GEOLOGIC AND HYDROGEOLOGIC SETTING

PGDP is located in the Jackson Purchase region of western Kentucky, approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River. At depth beneath PGDP, Cretaceous marine sediments of the Mississippian Embayment, comprising the McNairy Formation, unconformably overlie Mississippian-age carbonate bedrock. Buried Pleistocene fluvial deposits of the ancestral Tennessee River, in turn, unconformably overlie the Cretaceous marine sediments directly beneath and north of PGDP. The Pleistocene fluvial deposits in contact with the marine sediments included in the McNairy Formation consist of a gravel unit that ranges in thickness from 30 ft to 50 ft, with the top of the unit encountered at a general depth of 60 ft below ground surface (bgs) at the plant area. This gravel unit is the primary member of the uppermost aquifer, the Regional Gravel Aquifer (RGA), beneath the plant area and north to the Ohio River. The RGA pinches out to the south, southeast, and southwest along the buried slope of the Porters Creek Clay Terrace, which is overlain to the south by the Terrace Gravel flow system. The Upper Continental Recharge System (UCRS) overlies the RGA and Terrace Gravel. The RGA is the main conduit for groundwater flow to the north, where groundwater discharges to the Ohio River, and the main pathway for off-site contaminant plume migration. Figure 1.2 presents a general cross section of the geology across the region, while Figures 1.3 and 1.4 illustrate the main features of the geology and groundwater flow systems near the PGDP Site (PRS 2009).



Source: Fluor GIS database, 2016

Figure 1.1. PGDP Site Map

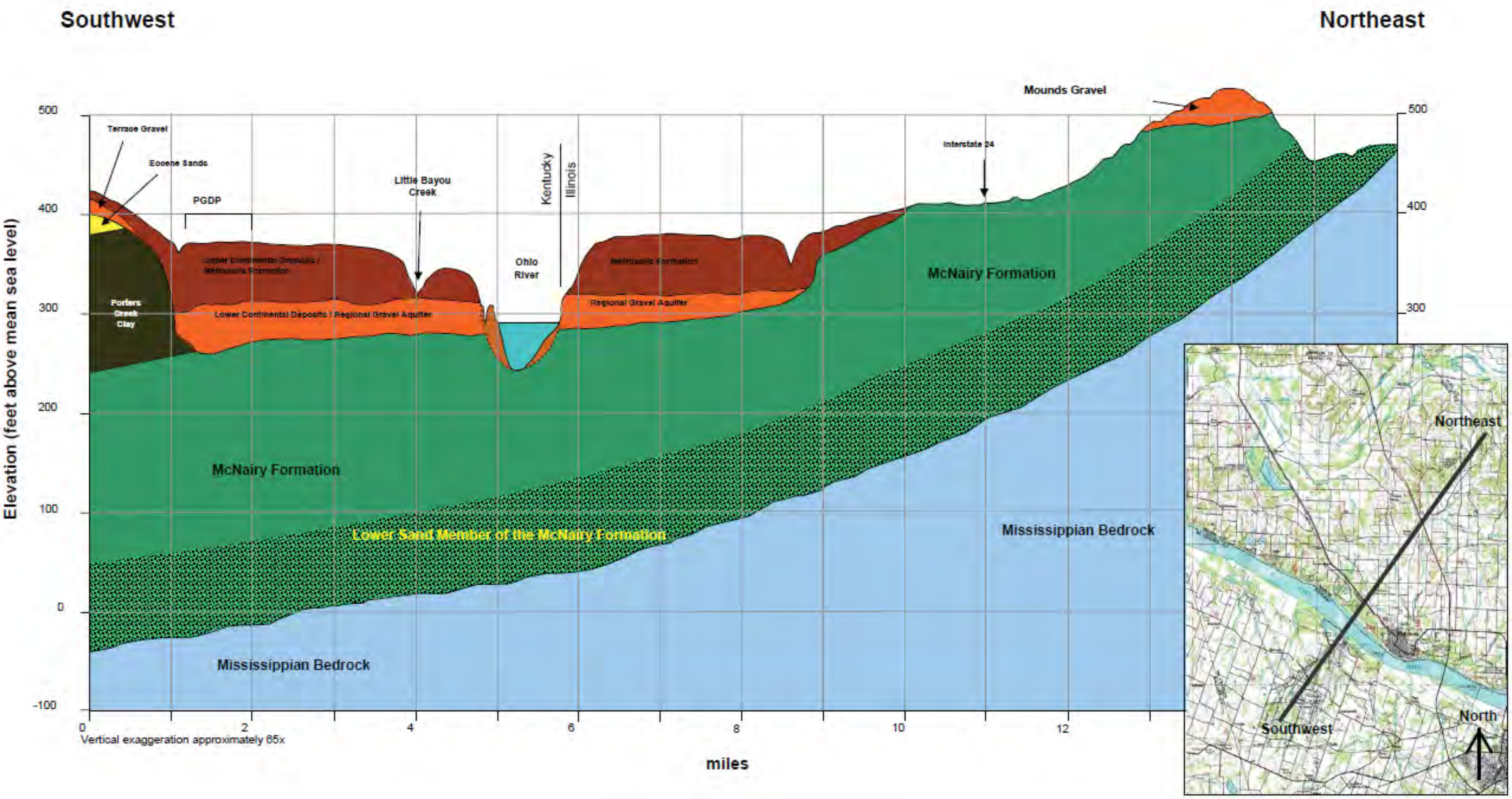


Figure 1.2. PGDP Regional Stratigraphy

PGDP Regional Stratigraphy

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

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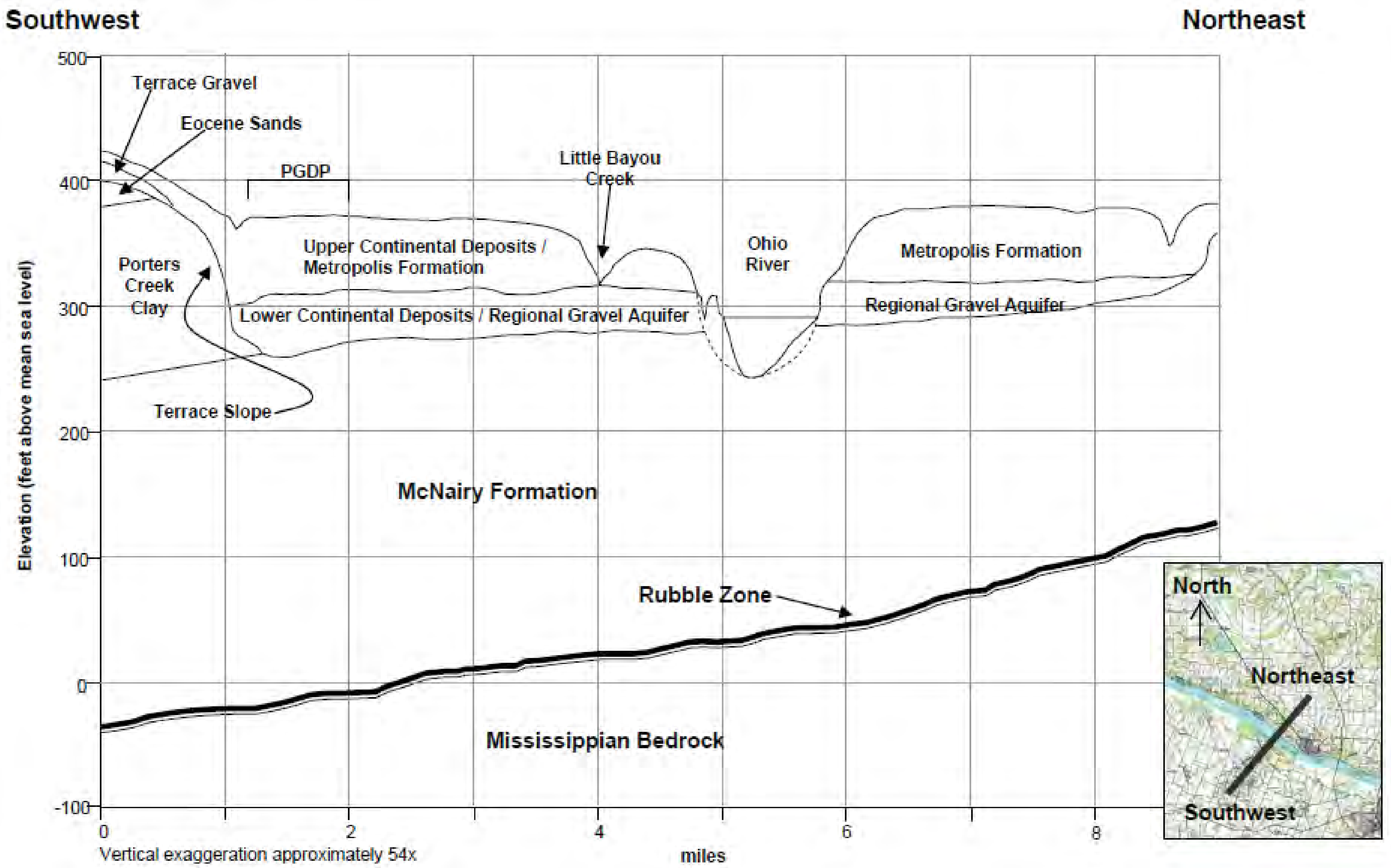
FIGURE 1.2

Source: Adapted from Paducah Remediation Services, 2009; Figure 1

Figure 1.3. PGDP Local Stratigraphy



PGDP Local Stratigraphy

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

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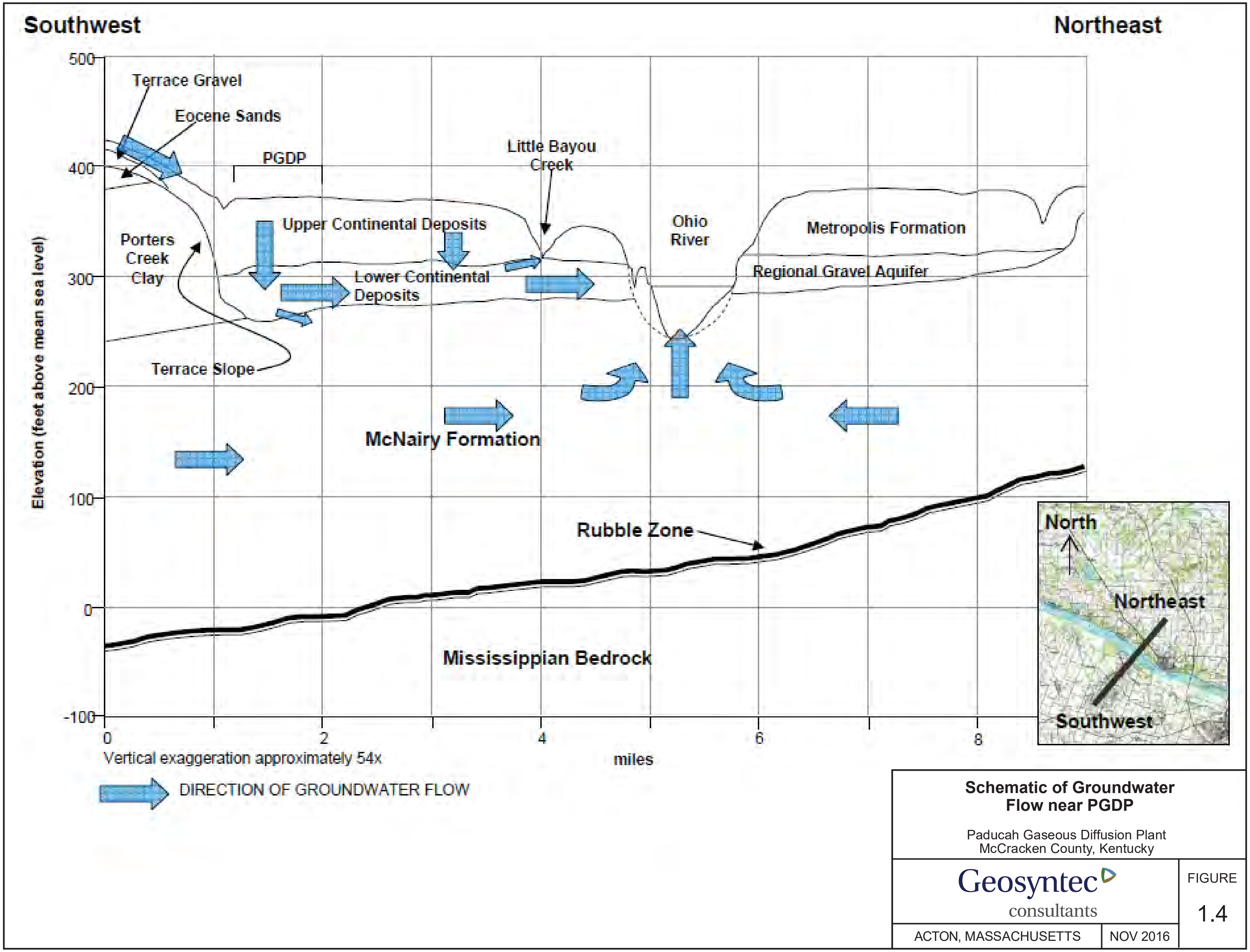
FIGURE 1.3

Source: Adapted from Paducah Remediation Services, 2009; Figure 2

Figure 1.4. Schematic of Groundwater Flow near PGDP



Schematic of Groundwater Flow near PGDP

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec consultants

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FIGURE 1.4

Source: Adapted from Paducah Remediation Services, 2009; Figure 3

1.3 EVOLUTION OF THE SITEWIDE GROUNDWATER MODEL

Numerous numerical modeling configuration and calibration efforts have been conducted for the PGDP sitewide groundwater model. The first groundwater flow model was developed in 1990 followed by several revisions through 1997 and the development of a transport model in 1998 and 1999. The next substantial revision was conducted in 2008. The details of the 2008 revisions, as well as a more detailed summary of the earlier groundwater and transport models, are documented in the 2008 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow and Transport Model (DOE 2010).

1.3.1 2008 Sitewide Groundwater Model

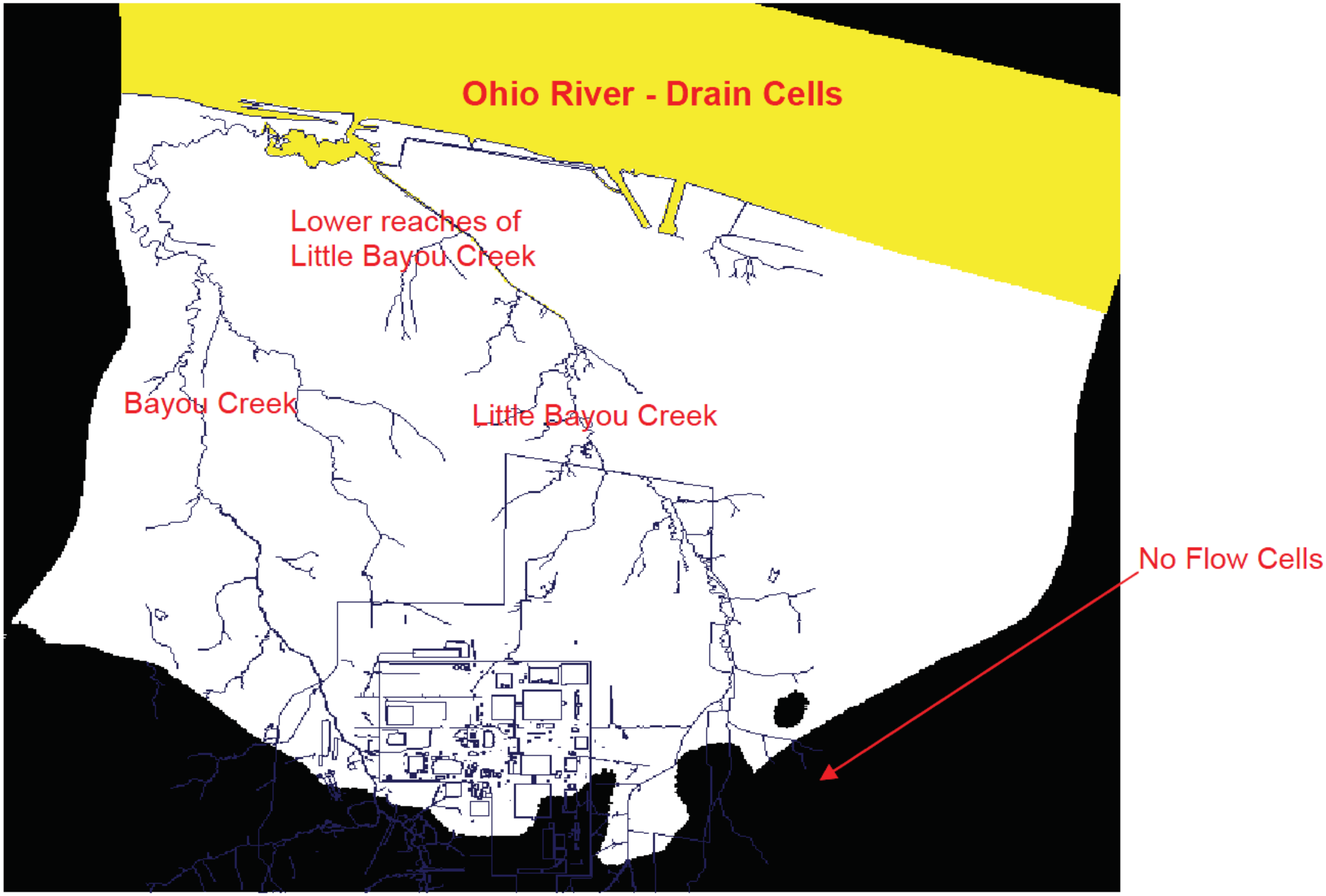
The 2008 model was developed collaboratively to complete the modeling tasks described in the Paducah Risk Methods Document (DOE 2008a). These modeling tasks were developed to assist in determining additional data needs, evaluating potential remedies, calculating cleanup criteria in decision documents (e.g., refinement of soil cleanup levels to protect groundwater and setting of monitoring goals), and developing inputs to design selected remedies.

The 2008 model simulated flow in the RGA and excluded flow in the UCRS and McNairy from the modeling domain. The UCRS and McNairy were represented by recharge and no flow boundary conditions, respectively. The rationale for representing the UCRS by recharge boundary conditions is that groundwater flow within the UCRS is primarily vertical; the unit is, for all practical purposes, only a conduit for recharge to the underlying RGA; and the McNairy is represented by a no flow boundary condition because the volume of groundwater flowing through the McNairy is much less than the volume of water flowing through the RGA. The numerical model was discretized into 582 rows and 627 columns with a constant computation cell width of 50 ft. The top elevation of model layer 1 corresponded to the top of the RGA (i.e., the contact of the RGA and the UCRS), and the bottom of model layer 3 represented the top of the McNairy (i.e., the base of the RGA). The RGA was divided numerically into three layers of equal thickness to allow a future, appended transport model to simulate more accurately the observed vertical movement of dissolved contamination within the RGA. The east, south, and west boundaries were specified as no-flow, and the northern boundary corresponded to the Ohio River. The Ohio River and lower reaches of Bayou Creek (BC) and Little Bayou Creek (LBC) were simulated as drain cells in layer 1. The model was calibrated to a single water level dataset measured in February 1995, prior to the start of pump-and-treat operations. Figure 1.5 depicts the 2008 model domain and boundary conditions as presented by DOE 2010.

1.3.2 2012 Sitewide Groundwater Model Update

The objective of the 2012 model revision was to evaluate how potential variability in anthropogenic recharge rates can influence extraction well capture performance. Details of the 2012 model revisions were not documented in a formal report, but were described in a 2014 presentation to the MWG on January 29 and 30, 2014, in Lexington, Kentucky (A.D. Laase Hydrologic Consulting 2014). The 2012 model was based on the 2008 model that simulated groundwater flow within the RGA using a single steady-state stress period. The 2012 groundwater flow model was configured using seven steady-state stress periods and one transient stress period with each of the seven steady-state stress periods having unique calibrated anthropogenic and ambient recharge rates. Particle tracking capture zone analysis was performed using the seven calibrated recharge regimes. The 2012 model update included updating the bottom and top RGA elevations based on an in-depth review of KRCEE data and calibrating the model to seven synoptic water-level measurement dates and the ten-day Northwest Plume extraction system performance test. The

Figure 1.5. 2008 Model Domain and Boundaries



2008 Model Domain and Boundaries

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

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FIGURE 1.5

Source: DOE, 2010; Figure 6.1

concept behind including multiple sets of water-level data in the calibration was to capture better the potential anthropogenic recharge variability at PGDP. While the long-term trajectories of the Northeast and Northwest Plumes suggest that the anthropogenic recharge variability does not impact contaminant migration significantly, it was included in the model to evaluate the influence of anthropogenic recharge variability on capture performance of the two Northwest Plume extraction wells (referred to as EW232 and EW233). Specifically, the single 1995 steady-state stress period from the 2008 model was expanded to include five more steady-state stress periods from third quarter 2005 to October 2011. Ten one-day transient stress periods were added to simulate the October 2010 pumping test in EW232 and EW233 in the Northwest Plume. Calibration targets included heads in monitoring wells, trajectory targets along the Northwest and Northeast Plumes, flux targets in LBC and the Ohio River, and drawdown targets during the 2010 transient pumping test.

1.3.3 2016 Model Revisions

The 2016 PGDP Sitewide Groundwater (GW) Model is based on the 2012 configuration that simulated groundwater flow within the RGA. The model was revised to include revisions identified by the MWG from review of site data and technical discussions that took place from March to October 2016. Minutes of the MWG meetings are included in Appendix A. The following are the primary model revisions implemented in 2016 and documented in this report:

- Optimizing calibration periods, building on calibrations performed prior to 2016;

- Converting the lower reaches of BC, LBC, and the Ohio River from drain to river boundary conditions;

- Including groundwater flow originating upgradient of the model from the Terrace Gravel;

- Revising the southern model boundary at the limit of the RGA;

- Updating anthropogenic recharge zonation in the plant area; and

- Supporting data analyses and detailed descriptions of the revisions are provided in subsequent sections.

1.4 REPORT ORGANIZATION

The following are the contents of the report.

Section 2, Technical Approach, discusses the technical approach used for the groundwater flow model development and calibration.

Section 3, Data Analysis, describes data evaluation and analysis performed as part of the updated flow modeling exercise.

Section 4, Conceptual Site Model, presents the site hydrogeologic conceptual site model (CSM) as a summary of the volumetric inflows and outflows of the system and the factors influencing groundwater movement.

Section 5, Model Configuration, describes the groundwater flow model configuration, which is the process by which the site hydrogeologic CSM is translated into a numerical model.

Section 6, Model Calibration, discusses groundwater flow model calibration, sensitivity analysis, and model validation.

Section 7, Calibration Summary, provides an evaluation of the revised and calibrated groundwater flow model and summarizes model assumptions and limitations.

Section 8, Conclusions and Recommendations, assesses whether the modeling objectives are satisfied and provides recommendations regarding the updated groundwater flow.

Section 9, References, includes a list of references cited in the text.

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2. TECHNICAL APPROACH

The 2016 groundwater flow model update is based on the existing 2012 MODFLOW model described previously in Section 1.3.2. Model revisions were developed by the MWG consisting of personnel from DOE, EPA, KDEP, KRCEE, and contractors to these organizations. Subcontractors, Drummond Carpenter, Navarro Research and Engineering (Navarro), Environmental Simulations, Inc., (ESI), and Geosyntec Consultants (Geosyntec), performed the modeling. Navarro and Geosyntec chaired the discussion group.

The MWG agreed on the following revisions to incorporate more recent site data and improve upon the existing model. The following are the primary model revisions:

- Revising RGA top and bottom elevations based on digital lithologic, stratigraphic, hydrostratigraphic, and subsurface material interval information for PGDP compiled in the KRCEE database (Revision 8) (CAER KRCEE 2016);

- Converting drain cells representing the Ohio River and lower reaches of BC and LBC to river cells, accounting for river/creek bathymetry and observed creek river stages;

- Adding recharge zones along the southern model boundary to represent groundwater flow off the Terrace from the East and West Terrace Basins;

- Revising recharge zonation to represent anthropogenic recharge in the plant area that is reflective of plant use and UCRS lithology; and

- Simulating two steady-state stress periods representing unique periods of operation and annual precipitation conditions with associated water-level elevation targets derived from synoptic water level collection across the model domain to optimize runtime and model representativeness.

Modeling was initiated by evaluating and analyzing recent site data, including groundwater and surface water levels, subsurface hydraulic properties, ambient and anthropogenic recharge potentials, well construction details, and plume geometries. These data serve to constrain the model regarding expected parameter distributions and typical groundwater flow patterns and discharge volumes. Details regarding the data evaluation effort are presented in Section 3 of this report.

Groundwater flow modeling was performed using MODFLOW 2005 (Version 1.1.00), a widely-used and accepted finite-difference code developed by the U.S. Geological Survey (USGS) (Harbaugh 2005). Pre- and post-processing of model data were accomplished using the industry standard graphical user interface Groundwater Vistas (Version 6.89, build 23) developed by ESI (ESI 2011). Model calibration was conducted using PEST (Version 13.6) and PEST-SVD Assist coupled with pilot points (Doherty 2015; Doherty 2016). PEST is a parameter estimation code used to determine parameter values for model calibration. PEST-SVD Assist is an updated version of PEST that facilitates faster execution times. Parameters are model input values that are adjusted during model calibration. Common examples are recharge and river cell conductance. Pilot points take parameter estimation a step further and determine parameter distributions for model calibration, given specific boundary configurations and target values. For this application, pilot points were used to determine hydraulic conductivity distributions for the calibrated model. A detailed description of parameter estimation, pilot points, and model calibration methodology is presented in Section 6.

After completing the model calibration, a sensitivity analysis (Section 6.7) was performed to determine which input parameters have the greatest influence on the resulting calibrated flow model. Typically, a sensitivity analysis is conducted by individually adjusting input parameters and evaluating related changes to the water level calibration statistics. While the water level statistics provide an assessment of how input parameter adjustment influences predicted water levels, this sensitivity analysis does not evaluate how parameter changes influence predicted plume trajectories, which is ultimately more important regarding the potential to simulate the influence of remedial action on contaminant plume behavior in groundwater. For this model, the sensitivity analysis evaluated how individual parameter adjustment (one at a time) affects simulated plume trajectories.

3. DATA ANALYSIS

A thorough analysis of site data previously was conducted in 2008 to develop a representative site conceptual model to support the configuration of the 2008 groundwater model (DOE 2010). Additional data analysis regarding RGA elevations and lithology using the KRCEE database was conducted for the 2012 model revision. For the 2016 model, revisions relied on LIDAR (Light Detection and Ranging) data updated in 2013, an updated KRCEE Database (Revision 8), additional monitoring well data, maps of plant facilities, site reconnaissance, and information regarding historical operations provided by the site facilities manager.

3.1 RGA EXTENT

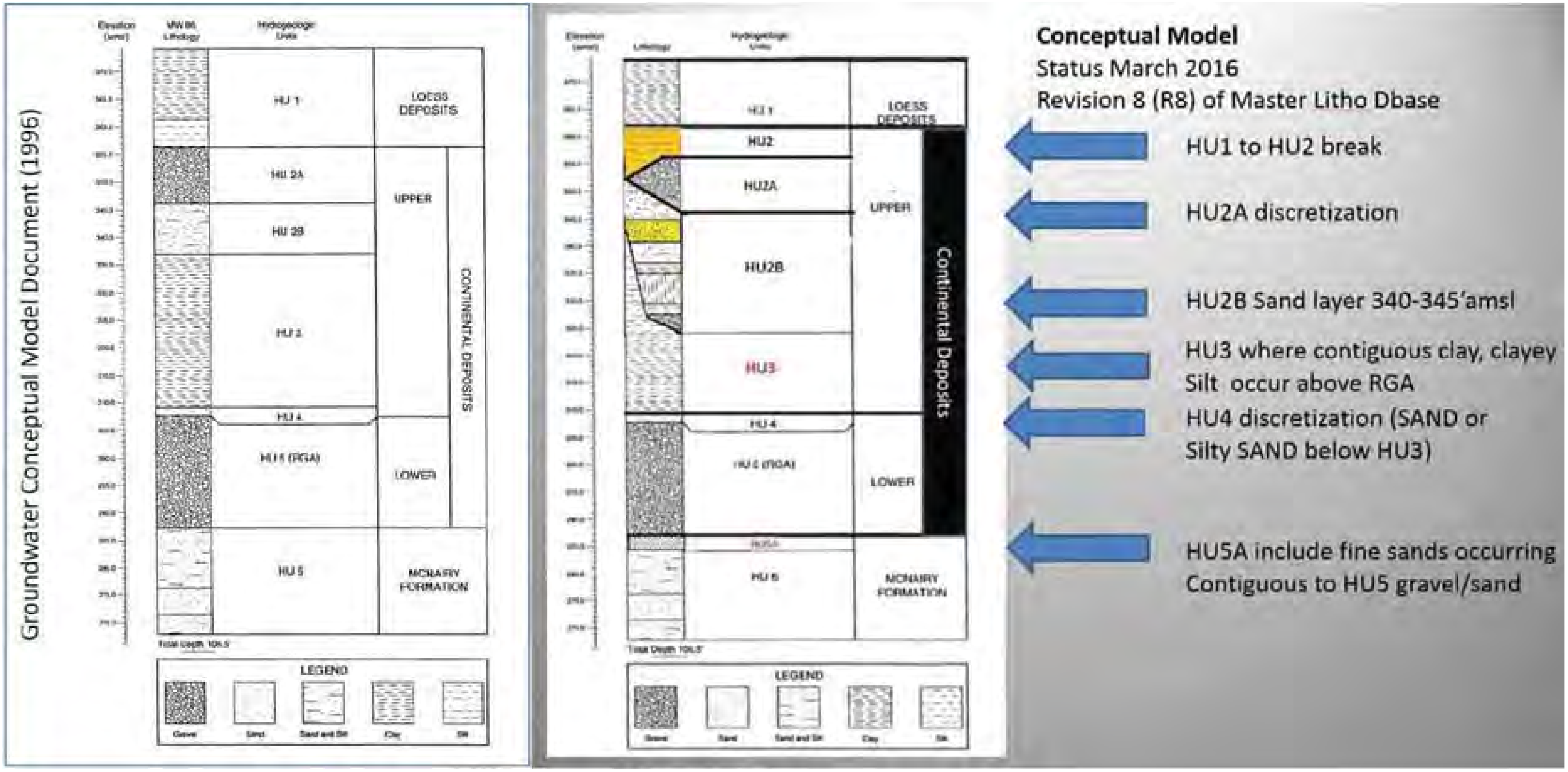
3.1.1 RGA Elevation and Thickness

The top of model layer 1 (top of RGA, bottom of UCRS) and the bottom of model layer 3 (bottom of RGA, top of McNairy) were revised to incorporate the most recent and comprehensive evaluation and compilation of digital lithologic, stratigraphic, hydrostratigraphic, and subsurface material interval information for PGDP and its environs by KRCEE referred to as Revision 8 (CAER KRCEE 2016). The 1996 Hydrostratigraphic Unit (HU) Conceptual Model and the Update to that Conceptual Model, used as a basis for the development of Revision 8 of the Lithologic Database, are illustrated in Figure 3.1. For this model revision, the top of the RGA (bottom of UCRS) was identified as either the top of HU5 characterized as RGA sand and gravel or, when present, the top of HU4 characterized as sand or silty sand beneath HU3. The bottom of the RGA (top of McNairy) was identified by KRCEE as either the bottom of HU5 or, when present, the bottom of HU5A characterized as fine sands occurring contiguous to HU5.

The top of RGA dataset included 810 data points, 376 of which were within the plant area. The bottom of RGA (top of McNairy) dataset included 549 data points, 166 of which were within the plant area (Figures 3.2 and 3.3). Top and bottom surfaces for the RGA were generated by performing an inverse distance weighted interpolation (with an additional spline interpolation step for smoothing) on the datasets. In limited portions of the model, particularly near the Terrace slope and the Tennessee Valley Authority (TVA) discharge pond, the interpolated surfaces showed thin sections of the RGA with thicknesses less than 10 ft. The model thickness in these sections was constrained to a minimum of 10 ft to promote numerical stability. The bottom elevation of model layers 1 and 2 were adjusted to maintain three model layers of equal thickness. The revised model RGA top and bottom elevations are illustrated in Figures 3.2 and 3.3, respectively, and the model thicknesses across the domain are shown in Figure 3.4.

3.1.2 Revised Model Boundary

The southern model boundary was revised to represent more accurately the southern extent of the RGA. For the southwestern model boundary, this was accomplished by adjusting the boundary to coincide with the overlap of the interpolated top and bottom RGA surfaces, which corresponds to the limit of the RGA along the Terrace slope. Along the southeastern model boundary, an upper RGA elevation of 320 ft to 325 ft above mean sea level (amsl) was used to distinguish the RGA from Terrace Gravel. The base of gravel in soil borings P2-S9, P3-S25, and P4-H1 is at 333 ft to 339 ft amsl, which places these borings south of the RGA. Borings MW151, P3-S17, and AH-209 appear to be at the southern margin with a very thin to thin RGA layer thickness, and P2-S8, P4-G7, and P4-H6 have RGA presence. The southeastern model boundary was adjusted to be consistent with this interpretation. The layer overlap used to define the



Conceptual Model
Status March 2016
Revision 8 (R8) of Master Litho Dbase

- HU1 to HU2 break
- HU2A discretization
- HU2B Sand layer 340-345'amsl
- HU3 where contiguous clay, clayey Silt occur above RGA
- HU4 discretization (SAND or Silty SAND below HU3)
- HU5A include fine sands occurring Contiguous to HU5 gravel/sand

Schematic of Lithologic Units

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FIGURE
3.1

Source: CAER KRCEE 2016; Figure 3

Figure 3.1. Hydrostratigraphic Unit Conceptual Site Model

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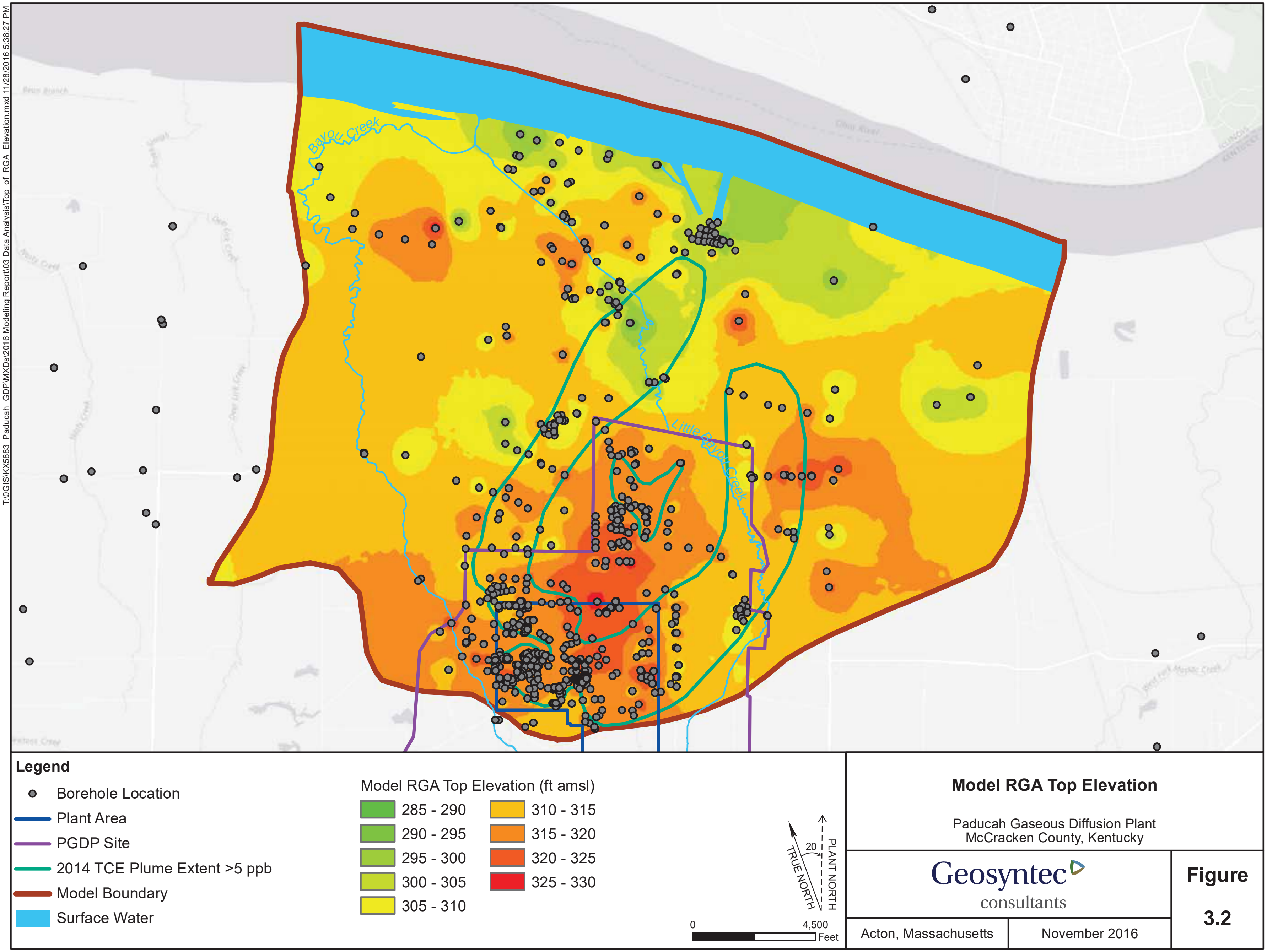
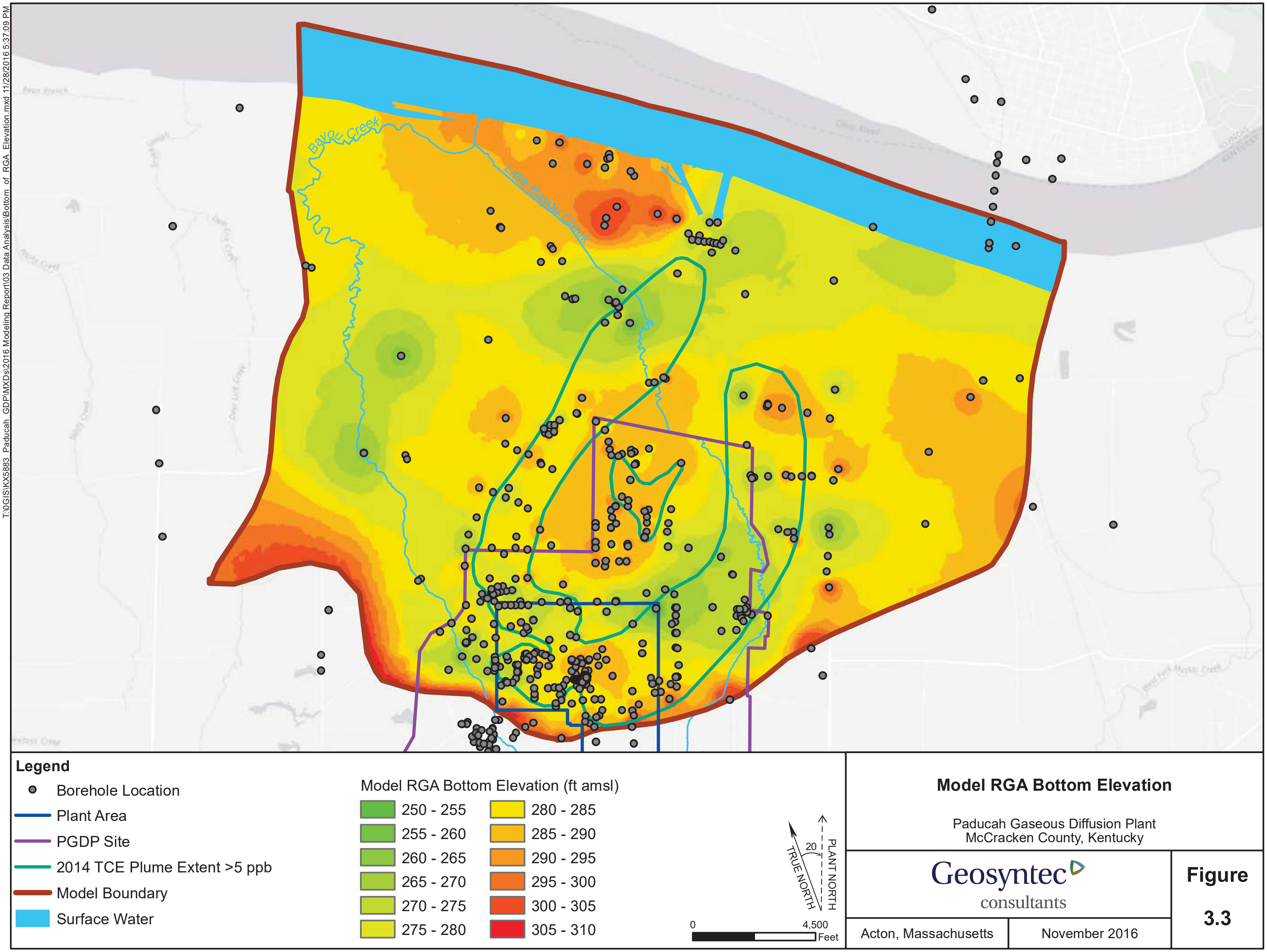


Elevation Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 3.2. Model RGA Top Elevation



Elevation Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 3.3. Model RGA Bottom Elevation

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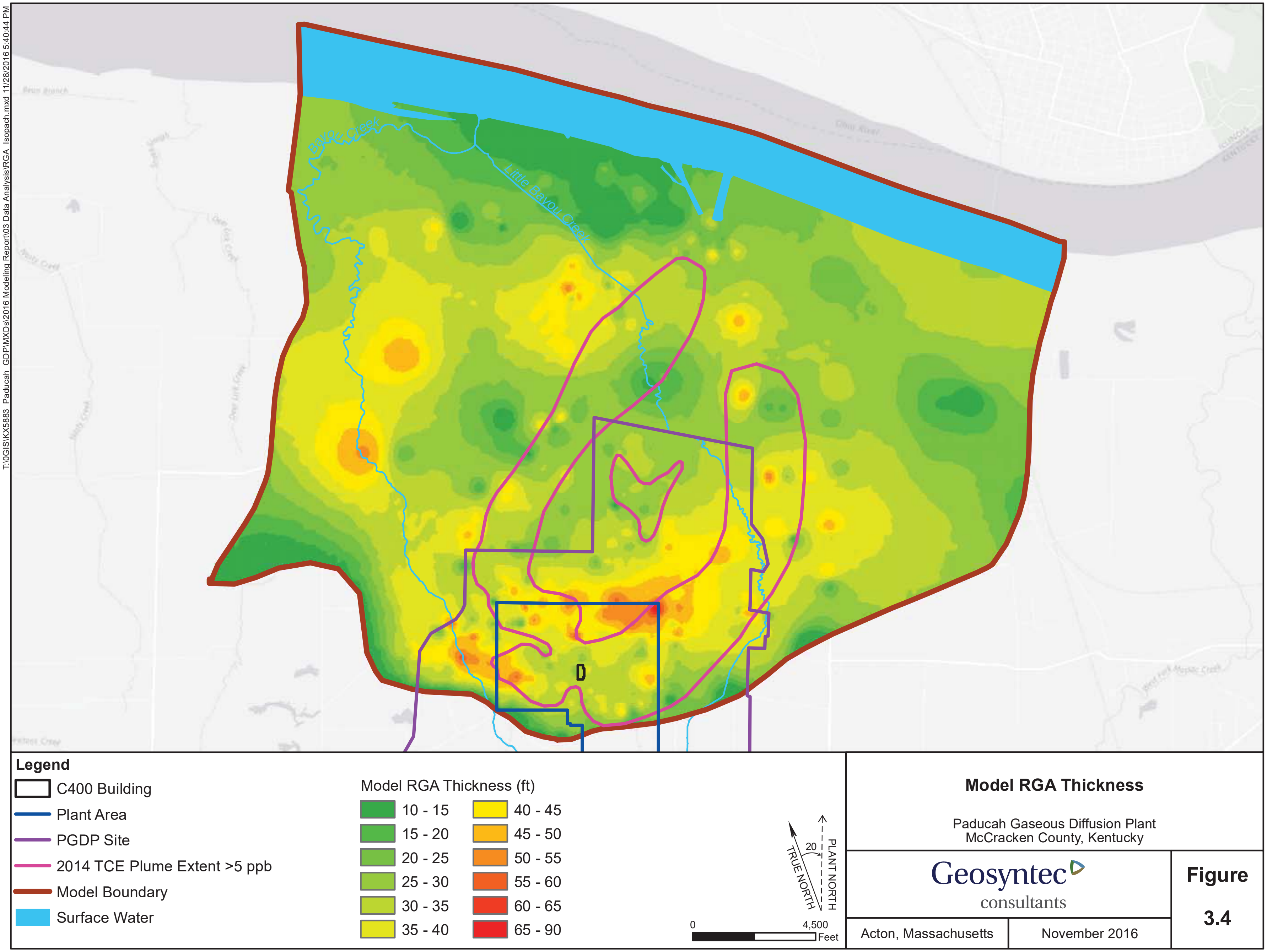


Elevation Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 3.4. Model RGA Thickness

southwestern model boundary and the borings used to define the southeastern model boundary are illustrated in Figure 3.5.

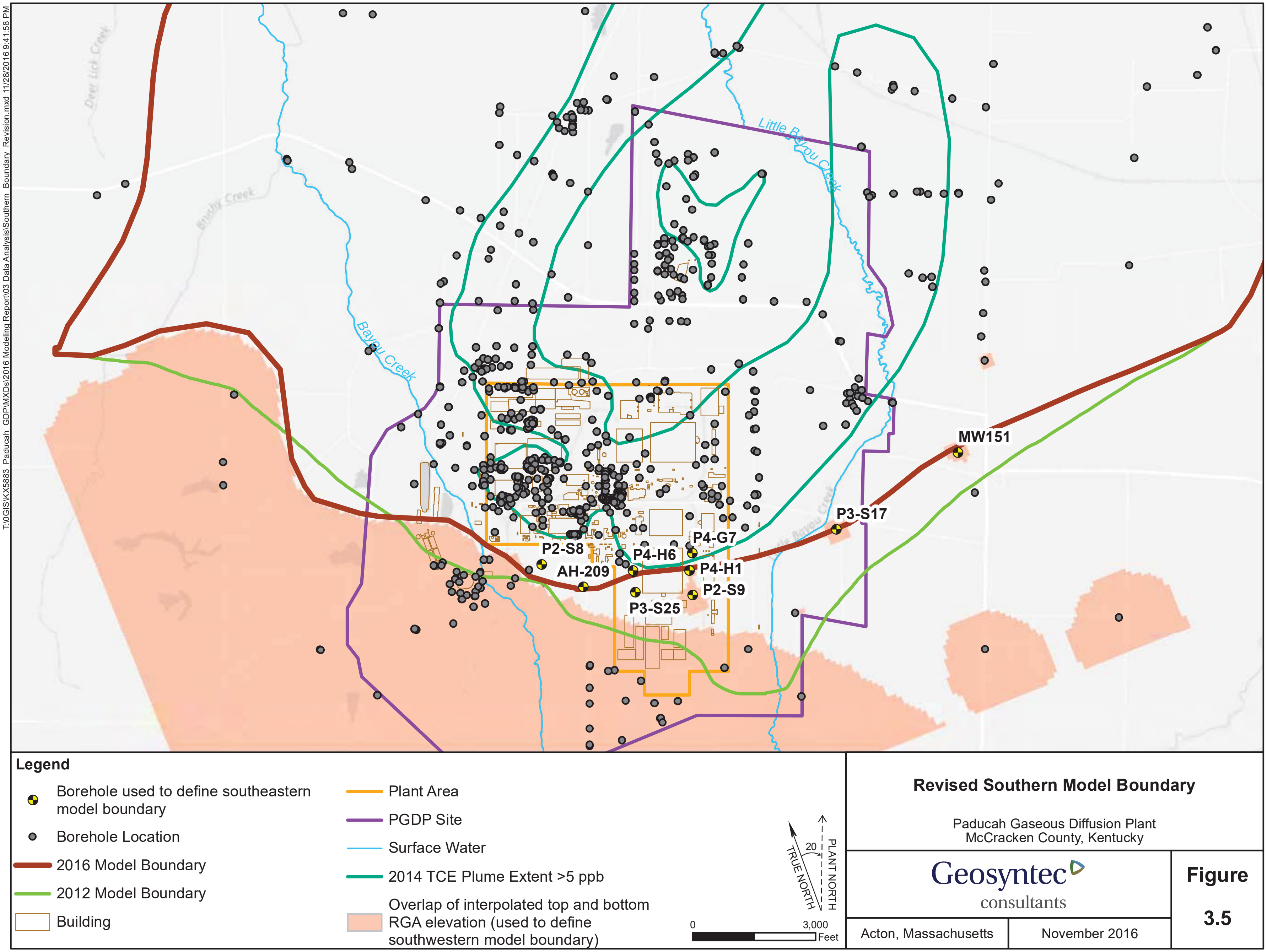
3.2 TERRACE RECHARGE

Underflow across the Terrace slope recharges the RGA along its southern boundary; however, recharge from Terrace underflow was not included in the 2008 and 2012 model revisions. Outcrops of Porters Creek Clay located immediately south of the Terrace slope force groundwater flow to discharge to BC; thus, Terrace underflow in the upper BC drainage basin is expected to be negligible, but significant underflow is expected in Terrace drainage basins to the west and east of the upper BC basin (DOE 1997). A delineation of these three drainage basins based on LIDAR data from spring 2013, along with measurements of the area of each basin (upper BC, west and east), is illustrated in Figure 3.6.

To estimate the recharge to the RGA from Terrace underflow, stream flow data for BC were evaluated at two USGS gauging stations, Station 45 and USGS 03611800 (Figure 3.6). The baseflow in BC is assumed to be representative of groundwater flow in the upstream BC basin. Division of baseflow volume by drainage area provides an estimate of the recharge rate across the Terrace. Assuming the recharge rate is uniform across the Terrace, the estimated recharge rate for the BC basin can be used to determine the underflow from the East and West Terrace Basins across the Terrace slope.

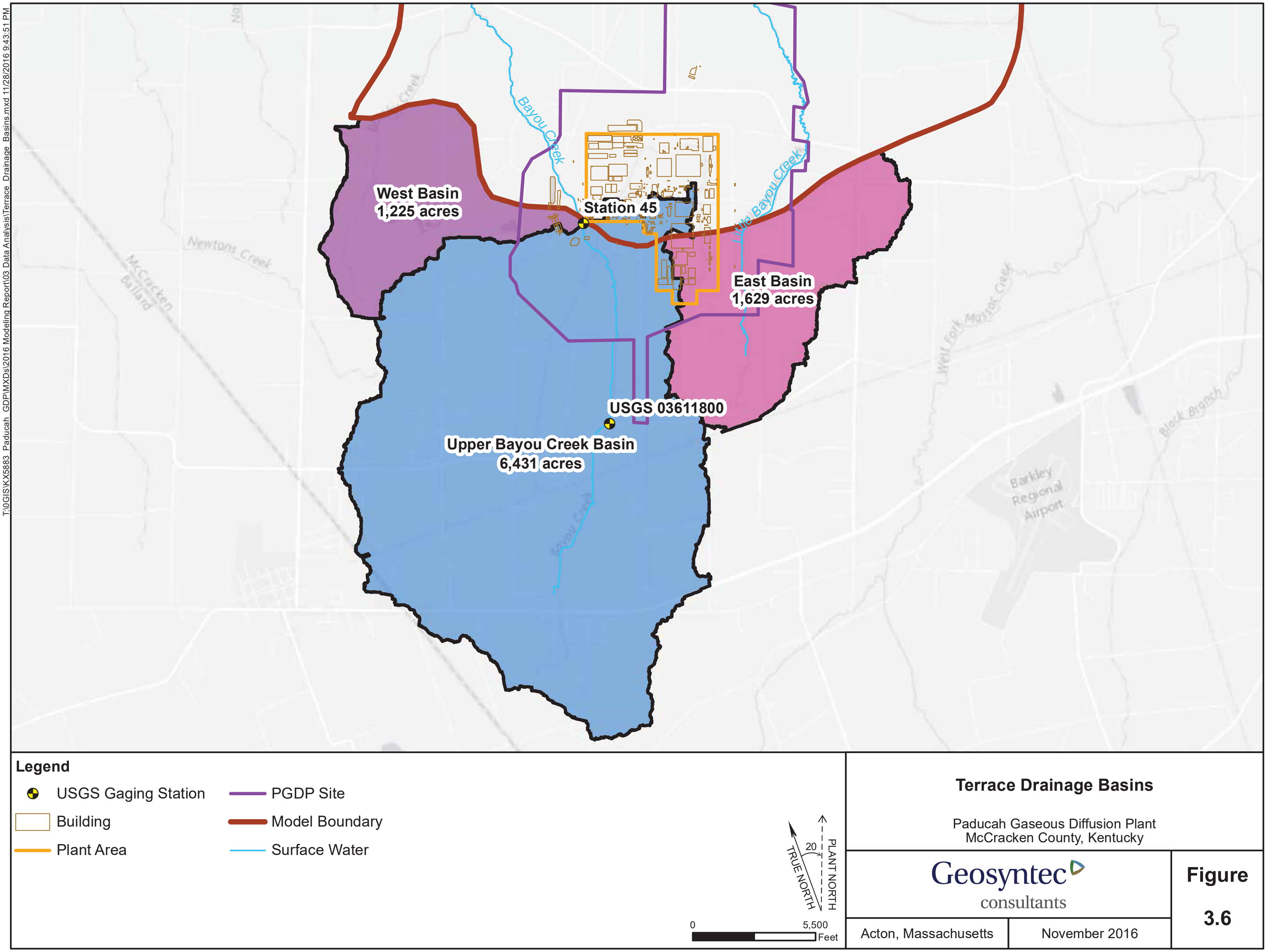
USGS Station 03611800 at BC near Heath, Kentucky, has stream flow data available from 1990 through 2010. The Web-based Hydrograph Analysis Tool (WHAT) was used to estimate baseflow at this gauging station (Lim et al. 2005). WHAT has three different baseflow separation techniques available: the local minimum method, a one parameter digital filter (the "BFLOW" filter), and a recursive digital filter (the "Eckhardt" filter). Each separation method was used to determine the annual average baseflow and the September baseflow for each year with available data, and the results are presented in Table 3.1. The September baseflow was included in the analysis to understand dry season conditions. The average of the three separation techniques was calculated; from that, an average annual recharge rate and average September recharge rate were calculated for the Terrace. The recharge rate was determined from estimated baseflow divided by the USGS reported drainage area for the gauging station (6.55 square miles or 4,192 acres). The median of the estimated average annual recharge rates is 2.6 inches/year, with minimum and maximum estimates of 1.4 inches/year and 4.6 inches/year, respectively. The median of the estimated average September recharge rates is 0.45 inches/year, with minimum and maximum estimates of 0.28 inches/year and 3.68 inches/year, respectively.

Station 45 is located at the edge of the Terrace. The location of this station makes it ideal for estimating Terrace recharge, but it cannot be used to assess temporal variability because stream measurements are available only for a single date. Streamflow data were collected by the USGS at Station 45 in August 1989 during baseflow conditions (Evaldi and McClain 1989). The measured baseflow was 0.3 ft^3/second [135 gal per minute (gpm)]. Based on the drainage area of the upper BC basin upstream of Station 45 (6,431 acres, Figure 3.6), this flow rate translates to a recharge rate of 0.41 inches/year for the Terrace. This value is consistent with the estimated Terrace recharge rates for the dry season based on the September baseflow data at USGS 03611800. Note that the dry season values are an order of magnitude lower than the annual average recharge values presented in Table 3.1. The baseflow separation analysis performed for the full period of record at USGS Station 03611800 indicates that baseflow in upper BC is lowest in August and September. The recharge values estimated for USGS Station 03611800 for the month of August from 1990 to 2010 range from 0.25 inches/year to 2.72 inches/year with a median value of 0.55 inches/year, which is also consistent with the recharge estimated from Station 45. This check helps validate the use of the baseflow separation technique at USGS Station 03611800 for



Elevation Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 3.5. Revised Southern Model Boundary



Elevation Data Source for Basin Delineation: Kentucky, 2013; http://kygeonet.ky.gov/kyfromabove/

Figure 3.6. Terrace Drainage Basins

Table 3.1. Estimated Baseflow at USGS Station 03611800 Bayou Creek near Heath, Kentucky

Year	Annual Average Base Flow (gal/minute)				Estimated Average Annual Terrace Recharge Rate (inches/year)	September Base Flow (gal/minute)				Estimated Average September Terrace Recharge Rate (inches/year)
	Recursive Filter	Local Minimum	One-Parameter Filter	Average		Recursive Filter	Local Minimum	One-Parameter Filter	Average	
1990~1991	763	314	673	583	2.69	63	81	67	70	0.32
1993~1994	673	583	628	628	2.90	76	99	76	84	0.39
1994~1995	494	269	449	404	1.87	85	108	94	96	0.44
1995~1996	404	180	359	314	1.45	162	112	148	141	0.65
1996~1997	1,122	853	1,032	1,002	4.63	63	67	67	66	0.30
1997~1998	539	224	449	404	1.87	58	63	58	60	0.28
1998~1999	673	359	583	539	2.49	72	81	81	78	0.36
1999~2000	404	180	359	314	1.45	112	94	112	106	0.49
2000~2001	449	449	404	434	2.00	193	108	175	159	0.73
2001~2002	1,122	494	987	868	4.01	166	63	126	118	0.55
2002~2003	987	673	942	868	4.01	139	112	135	129	0.59
2003~2004	359	314	359	344	1.59	72	72	76	73	0.34
2004~2005	673	539	628	613	2.83	148	130	148	142	0.66
2005~2006	673	314	628	539	2.49	1,019	81	763	621	2.87
2006~2007	763	449	718	643	2.97	99	117	103	106	0.49
2007~2008	942	539	808	763	3.52	67	76	72	72	0.33
2008~2009	853	539	763	718	3.32	597	606	588	597	2.76
2009~2010	673	404	583	554	2.56	108	72	90	90	0.41
Minimum	359	180	359	299	1.38	58	63	58	60	0.28
Median	673	426	628	576	2.66	103	88	99	96	0.45
Maximum	1,122	853	1,032	1,002	4.63	1,019	606	763	796	3.68

Note: Years 1991 to 1993 were excluded from the analysis because of missing data.

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determining Terrace recharge. This analysis also demonstrates the importance of seasonal variability in Terrace recharge estimates. Because most of the sitewide groundwater monitoring events at PGDP occur during the dry season (see Section 3.4), the modeled Terrace recharge reflects seasonal steady-state conditions that are representative of the dry season rather than the annual average conditions.

The volumetric flow rate calculated from Terrace recharge is the flow available to recharge the RGA via underflow across the Terrace slope. The volumetric Terrace flow rate from the West and East Terrace Basins was determined by multiplying the estimated Terrace recharge rates by the respective East and West Terrace Basin areas south of the model boundary. The estimated drainage areas for the West and East Terrace Basins are 1,225 acres and 1,629 acres, respectively (Figure 3.6). The median annual average volumetric flow value for the West and East Terrace Basins is 168 and 224 gpm, respectively, and the median September volumetric flow value for the West and East Terrace Basins is 30 and 39 gpm, respectively. The estimated range of underflow from each basin is presented in Table 3.2.

In the model, the area specified for Terrace recharge to the RGA was calculated by multiplying the number of model cells adjacent to the boundary of the West and East Terrace Basins by the area of each cell. There are 252 model cells along this boundary for the West basin and 172 cells for the East Terrace Basin. Because each cell is 50 ft by 50 ft, the total area of recharge to the RGA from the West and East Terrace Basins is 14.5 acres and 9.9 acres, respectively. The model simulates underflow from the Terrace as additional recharge applied to the model cells along the West and East Terrace Basins boundaries. The recharge rate for these model cells is calculated by dividing the volumetric flow rate by the total area of the cells along each basin (14.5 acres and 9.9 acres for the West and East Terrace Basins, respectively). The results are presented in Table 3.2. The median annual average recharge rate applied to each model cell along the boundary for the West and East Terrace Basins is 225 inches/year and 439 inches/year, respectively. The median recharge rates are used as initial calibration recharge rates. The maximum annual average recharge rates are used as maximum calibration constraints (392 and 764 inches/year for the West and East Terrace Basins, respectively). Instead of using the minimum annual average recharge rates, the minimum average recharge rates for September are used as minimum recharge constraints (23 inches/yearand 46 inches/year for the West and East Terrace Basins, respectively) so that a dry season steady-state condition can be represented in the model (see Section 3.4 for discussion of available water level datasets).

3.3 ANTHROPOGENIC RECHARGE

Various sources of anthropogenic recharge (i.e., recharge that is caused or produced by human activity) are present in the plant area, such as leaking water lines, infiltration from drainage ditches, leakage from lagoons, and runoff from compromised roof drains. Estimated average recharge rates over the PGDP area range from 4.1 inches/year to 48 inches/year (DOE 2010). The wide range of estimates illustrates the variability in potential anthropogenic recharge rates. The recharge contributed to the groundwater system by anthropogenic sources depends on the quantity of water released from the source and the underlying lithology. For example, if the hydraulic conductivity of the formation beneath a drainage ditch is low, then water in the ditch would tend to be lost to evapotranspiration or runoff rather than percolating to the water table. The following subsections consider the effects of both lithology and land use on anthropogenic recharge potential. These considerations serve as the basis for assignment of maximum calibration constraints to anthropogenic recharge zones and revision of anthropogenic recharge zonation in the plant area.

Table 3.2. Potential Range of Recharge to RGA[1] off the Terrace

Basis of Estimate	Basin	Statistic	Volumetric Flow (gal/minute)	Recharge[2] (inches/year)
Average Annual Recharge	**West Basin**	**Minimum**	87	117
		Median	168	225
		Maximum	293	392
	East Basin	**Minimum**	116	228
		Median	224	439
		Maximum	389	764
Average September Recharge	**West Basin**	**Minimum**	17	23
		Median	30	39
		Maximum	181	243
	East Basin	**Minimum**	23	46
		Median	39	77
		Maximum	241	473

[1] RGA indicates Regional Gravel Aquifer.

[2] Recharge rate applied to model cells along each basin's Terrace boundary to simulate Terrace underflow.

3.3.1 Lithologic Based Recharge Potential

UCRS lithology can be used to constrain anthropogenic recharge estimates. To do so requires correlating lithology to hydraulic conductivity. Groundwater flow in the UCRS is primarily vertical and, as such, is controlled by vertical hydraulic conductivity. Under unity hydraulic gradient (i.e., 1 ft/ft, the commonly observed UCRS vertical gradient), the maximum possible gradient for gravity drainage, the maximum potential recharge rate is equivalent to the effective bulk vertical hydraulic conductivity. Harmonic averaging yields the bulk hydraulic conductivity for systems with groundwater flow perpendicular to lithologic layering. Hydraulic conductivity, percent silt/clay, and percent sand/gravel are used as input to the harmonic average equation to determine the effective bulk vertical hydraulic conductivity, as shown in Equation 3.1.

$$K_v = \frac{b_T}{\frac{b_{cs}}{K_{cs}} + \frac{b_{sg}}{K_{sg}}} \qquad (3.1)$$

where:

K_v is the effective bulk vertical hydraulic conductivity

b_T is the total thickness (100%)

b_{cs} is the thickness of clay/silt as a percentage of the total thickness

b_{sg} is the thickness of sand/gravel as a percentage of the total thickness

K_{cs} is the vertical hydraulic conductivity of clay/silt

K_{sg} is the vertical hydraulic conductivity of sand/gravel

Several slug tests have been performed in the UCRS in previous investigations. To avoid bias, only wells with screen intervals spanning a single lithology were used for determination of K_{cs} and K_{sg}. Vertical hydraulic conductivity was assumed to be one-tenth of horizontal hydraulic conductivity. The slug test results used for this evaluation are given in Table 3.3, and a statistical summary of the results is presented in Table 3.4. The locations of the wells included in the analysis are shown on Figure 3.7. As shown in Table 3.3, some wells have duplicate slug test results, whereas a single slug test was performed on other wells. To avoid giving additional weight to wells with duplicate slug tests, the geometric mean of duplicate slug tests was used in the statistical analysis so that each well would have only one associated hydraulic conductivity value.

Results from Table 3.4 were used as input to Equation 3.1 for various soil compositions, and the results are provided in Table 3.5. Based on lithologic interpretation of percent clay/silt provided in the KRCEE database (Revision 8), the spatial variation of clay/silt in the UCRS was interpolated across the Plant area (Figure 3.8). The distribution was used to constrain the upper allowable recharge value used in the calibration for plant area recharge zones. For example, the minimum percent clay shown on Figure 3.8 is 30% to 35%. Based on this lithology, the maximum possible recharge rate specified in the model in an area where clay/silt comprise 30% of the vertical section would be 29 inches/year using the geometric mean of values (83 inches/year using the median). It should be noted that in this example 29 inches/year represents the maximum possible recharge rate based on lithology; therefore, the actual recharge rate at this location could be less than 29 inches/year depending on available water.

Table 3.3. Slug Test Results for UCRS[1] Monitoring Wells Screened in a Single Lithologic Interval

Well ID	Reference Well[2]	Easting[3] (ft)	Northing[3] (ft)	Lithology	Hydraulic Conductivity (ft/day)	Reference
MW127	MW121	-5,664.1	6,161.2	Clay/Silt	5.98E-04	Phase I Site Investigation
MW157	MW155	-4,025.7	-1,688.6	Clay/Silt	7.00E-02	Phase II Site Investigation
MW160	MW158	-6,945.9	-971.9	Clay/Silt	1.53E-02	Phase II Site Investigation
					2.40E-01	Phase II Site Investigation
MW170[4]	MW169	-5,557.6	-175.8	Clay/Silt	4.62E-04	Phase II Site Investigation
					2.81E-01	Phase II Site Investigation
MW177	MW178	-4,073.8	-1,227.5	Clay/Silt	7.97E-01	Phase II Site Investigation
MW189	MW188	-6,997.6	-2,057.3	Clay/Silt	1.21E-01	Phase II Site Investigation
					1.21E-01	Phase II Site Investigation
MW128	MW122	1,883.1	746.2	Transitional	2.05E-03	Phase I Site Investigation
MW164	MW163	-2,034.2	-1,415.6	Sand/Gravel	1.85E+00	Phase II Site Investigation
MW167	MW168	-4,822.5	-908.7	Sand/Gravel	1.03E-01	Phase II Site Investigation
					1.03E-01	Phase II Site Investigation

[1] UCRS indicates Upper Continental Recharge System.

[2] Independent lithologic logs are not available for the slug test wells. Instead, the lithology of a deeper, adjacent well (the reference well) is reported for each slug test well.

[3] Northing and Easting are referenced to the local Paducah coordinate system.

[4] Duplicate slug test (in grey) excluded from analysis due to limited test duration.

Table 3.4. Statistical Summary of Slug Test Results

Statistic	**Horizontal Hydraulic Conductivity**		**Vertical Hydraulic Conductivity**[1]	
	Silt/Clay	**Sand/Gravel**	**Silt/Clay**	**Sand/Gravel**
Minimum (ft/day)	4.62E-04	1.03E-01	4.62E-05	1.03E-02
Maximum (ft/day)	7.97E-01	1.85E+00	7.97E-02	1.85E-01
Arithmetic Mean (ft/day)	1.75E-01	9.79E-01	1.75E-02	9.79E-02
Median (ft/day)	6.53E-02	9.79E-01	6.53E-03	9.79E-02
Geometric Mean (ft/day)	2.20E-02	4.38E-01	2.20E-03	4.38E-02

[1] Vertical hydraulic conductivity assumed to be 10% of horizontal hydraulic conductivity.

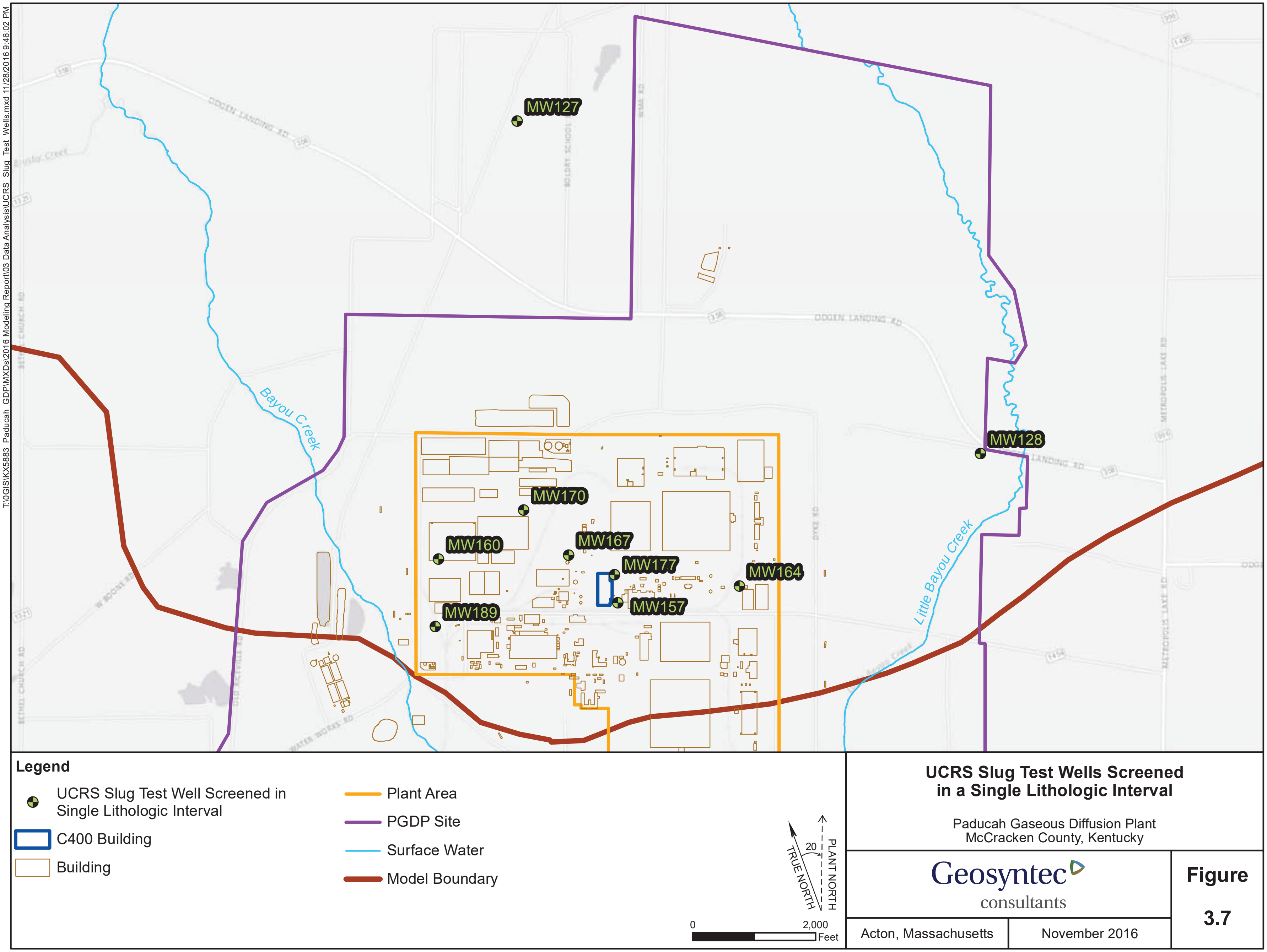


Figure 3.7. UCRS Slug Test Wells Screened in a Single Lithologic Interval

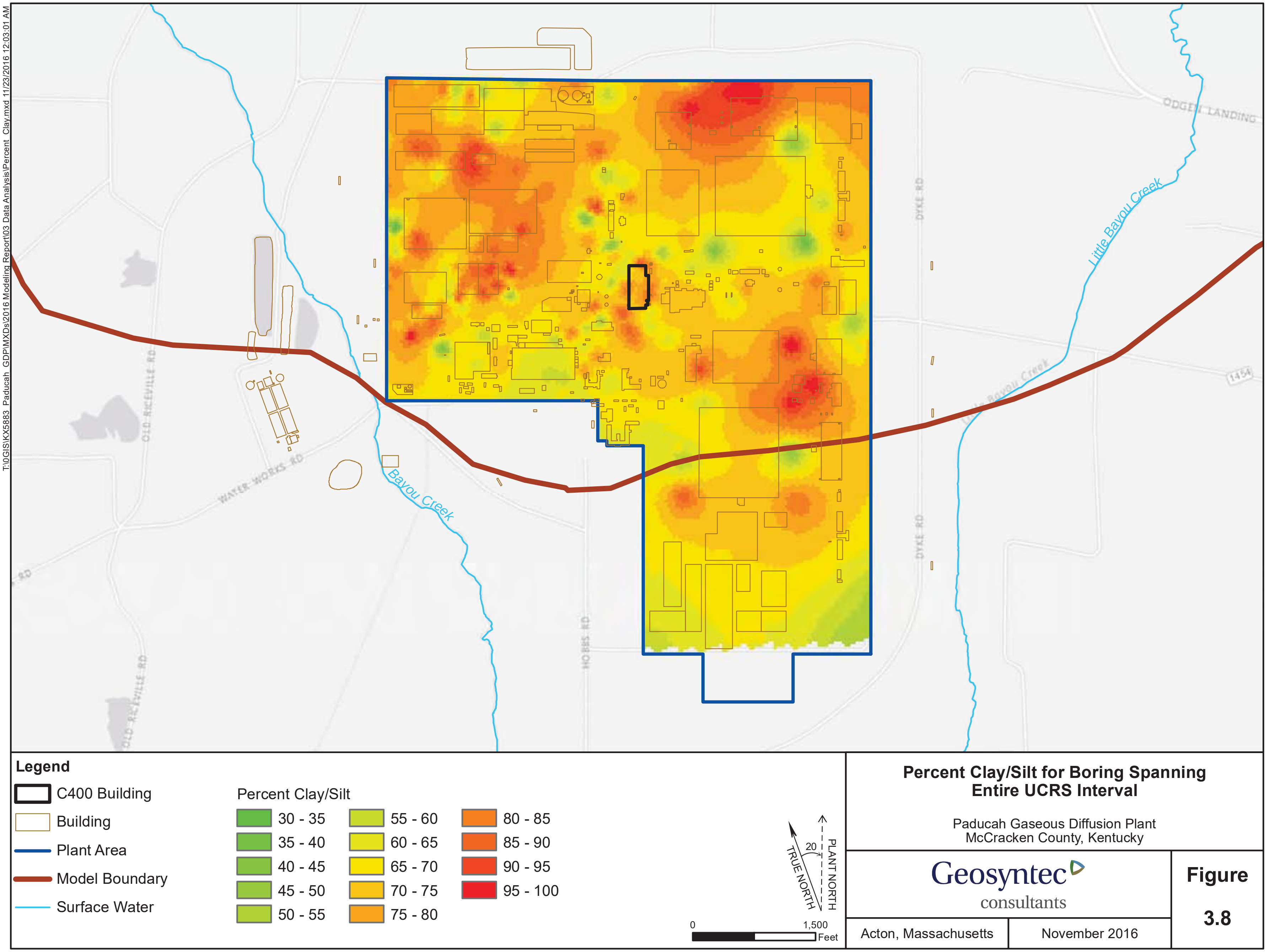
Table 3.5. Maximum Potential Recharge Based on Lithology*

Percent Sand/Gravel	Percent Clay/Silt	Potential Maximum Recharge (inches/year)			
		Maximum Hydraulic Conductivity**	Arithmetic Mean of Hydraulic Conductivity**	Median of Hydraulic Conductivity**	Geometric Mean of Hydraulic Conductivity**
0	100	349	77	29	10
5	95	359	80	30	10
10	90	370	83	32	11
15	85	382	87	33	11
20	80	394	92	35	12
25	75	407	96	37	13
30	70	421	102	40	13
35	65	436	107	42	14
40	60	452	114	46	16
45	55	469	122	49	17
50	50	488	130	54	18
55	45	508	140	59	20
60	40	530	151	65	22
65	35	554	164	73	25
70	30	581	180	83	29
75	25	610	199	95	33
80	20	642	223	113	40
85	15	677	254	138	50
90	10	717	294	179	66
95	5	761	349	252	99
100	0	812	429	429	192

🟩 Typical grain size distribution observed in plant area (see Figure 3.8).

* Potential Maximum Recharge = Vertical Hydraulic Conductivity × 1 ft/ft Gradient × 4,380 inches/year per feet/day. See Section 3.3.1 for basis of recharge calculation

** See Tables 3.3 and 3.4 for basis of hydraulic conductivity statistics.



Lithology Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016

Figure 3.8. Percent Clay/Silt for Boring Spanning the Entire UCRS Interval

Results from permeameter tests, which measure vertical hydraulic conductivity in soil core samples, were used to check the vertical hydraulic conductivity estimates for clay/silt. Permeameter results for UCRS samples with 80% or greater clay content are provided in Table 3.6. The locations of the wells included in the analysis are shown on Figure 3.9. The arithmetic and geometric means of the permeameter results are of the same order of magnitude as the arithmetic and geometric means of the vertical hydraulic conductivity determined from the slug test results. This comparison supports the assumption that vertical hydraulic conductivity is on the order of one-tenth of horizontal hydraulic conductivity in the UCRS. This estimate of vertical anisotropy is consistent with the assumed 10:1 horizontal to vertical anisotropy used for the UCRS in the Treatability Study for Steam Injection (DOE 2016, Figure 13).

3.3.1.1 Clay prevalence at the top of RGA (HU3)

An evaluation of UCRS lithology was conducted to identify intervals with clay as the prevalent primary material within the HU just above the RGA. This unit is described as contiguous clay of HU3 (Figure 3.10). The evaluation relied on the KRCEE database (Revision 8) (CAER KRCEE 2016) to provide a compilation of lithologic material reported in boring logs within the model domain. Review of the data indicates a high degree of variability in the level of detail and lithologic descriptions not uncommon in a compilation of logs collected over an extended period by multiple contractors to meet multiple objectives. In the context of the variability observed in the data, delineation of clay less than 2-ft thick depicted on Figure 3.10 serves as a reasonable representation of areas with increased hydraulic connection between the UCRS and the RGA.

3.3.2 Land Use Based Recharge Potential

PGDP site information from multiple sources was used to assess land use and site operations within the plant area to develop a qualitative characterization of potential anthropogenic recharge. Available information included leaks in the stormwater or High Pressure Fire Water (HPFW) piping systems reported by the facilities manager in 2016, UCRS lithology and delineation of the clay unit contiguous to the RGA (HU3) less than 2-ft thick, land use map characterizing surface water runoff, and the 2014 plume delineation and potentiometric surface. The 2014 plume delineation, which was not performed as part of this modeling effort but was completed previously by DOE contractors, is the most complete evaluation available at the time of the analysis and is representative of current site conditions (DOE 2015). A plume map depicting the general footprint of the trichloroethene (TCE) contamination in the RGA and conveying the general magnitude and distribution of contamination within the plumes is reported in Figure C.2 of the delineation report (DOE 2015). In addition to review of available information, the MWG conducted a site walkover on August 24, 2016, along with the PGDP Facility Manager, Andy Anderson, who has worked at the Site for over 30 years. The site tour was conducted to survey the plant area and gather additional site specific information relative to potential anthropogenic recharge. Figure 3.11 presents an overlay of the information collected.

Two of the main systems of underground piping present in the plant area, the storm water system and the HPFW system, have been identified as contributors to anthropogenic recharge in the plant area. In addition, leakage from the TVA water supply line, which runs through the western portion of the plant area and to the west outside the plant area, has been documented, and leak repair of the line is conducted at the site on a routine basis. In 2016, correspondence with the PGDP facility manager revealed that several leaks were reported (sometimes observed as standing water or flow from the ground surface) in

Table 3.6. Permeameter Results for Samples with 80% or Greater Clay Content

Soil Boring	Hydraulic Conductivity (feet/day)	Sample Description	Reference
026001SA010	1.09E-03	Clay (90%), 10YR5/6 (yellowish brown) to 10YR2/2 (dark brown)	Remedial Investigation Report for WAG 6
400036SA010	7.80E-04	Clay (80%), Silt (20%); 10YR8/2 (very pale brown) to 10YR6/6 (brownish yellow)	Remedial Investigation Report for WAG 6
400038SA010	5.87E-02	Clay (90%), firm, cohesive; Silt (10%); slightly moist, 10YR4/8 (dark yellowish brown) with 10YR7/1 (light gray) and 10YR6/8 (brownish yellow) mottling	Remedial Investigation Report for WAG 6
400038SA045	5.79E-02	Clay (90%), firm, cohesive, slightly moist; Silt (10%); trace Gravel; 10YR6/8 (brownish yellow) with 10YR6/2 (light brownish gray) mottling	Remedial Investigation Report for WAG 6
400208SA010	7.63E-04	Clay with trace Silt, firm, hard, moist, heavily mottled and iron stained, 10YR6/8 (brownish yellow), 10YR6/1 (gray), and 10YR5/6 (brownish yellow), with occasional 10YR3/1 (very dark gray)	Remedial Investigation Report for WAG 6
400210SA045	4.85E-03	Clay, Silt (20%), strong brown	Remedial Investigation Report for WAG 6
400212SA010	4.85E-05	Clay (90%), firm, cohesive, moist; Silt (10%); 10YR6/6 (brownish yellow) with 10YR6/8 (brownish yellow) and 10YR7/1 (light gray) mottling, trace 10YR3/1 (very dark gray) organic stain	Remedial Investigation Report for WAG 6
GB-09S	2.80E-04	Slightly Silty (10%) lean Clay	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-14S	3.37E-02	Lean Clay with Silt (15-20%)	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-21S	4.71E-04	Lean Clay with Silt (20%)	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-25S	6.41E-04	Slightly Silty (10-20%) lean Clay	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GWW-01	9.6E-05	Clay (80%) with Silt (20%), 7.5YR5/6 (strong brown) with 7.5YR7/1 (light gray) mottling and small black specs (1-2 mm) and larger (4 mm) 7.5YR3/4 (dark brown) concretions	Remedial Investigation Report for SWMUs 7 and 30 of WAG 22
SWMU 2-09	2.83E-05	Clay (80%) with Silt (20%), mottled 7.5YR6/1 (gray) and 5YR4/6 (yellowish red)	Data Summary and Interpretation Report for Interim Remedial Design at SWMU 2 of WAG 22
Arithmetic Mean	1.23E-02		
Geometric Mean	1.11E-03		

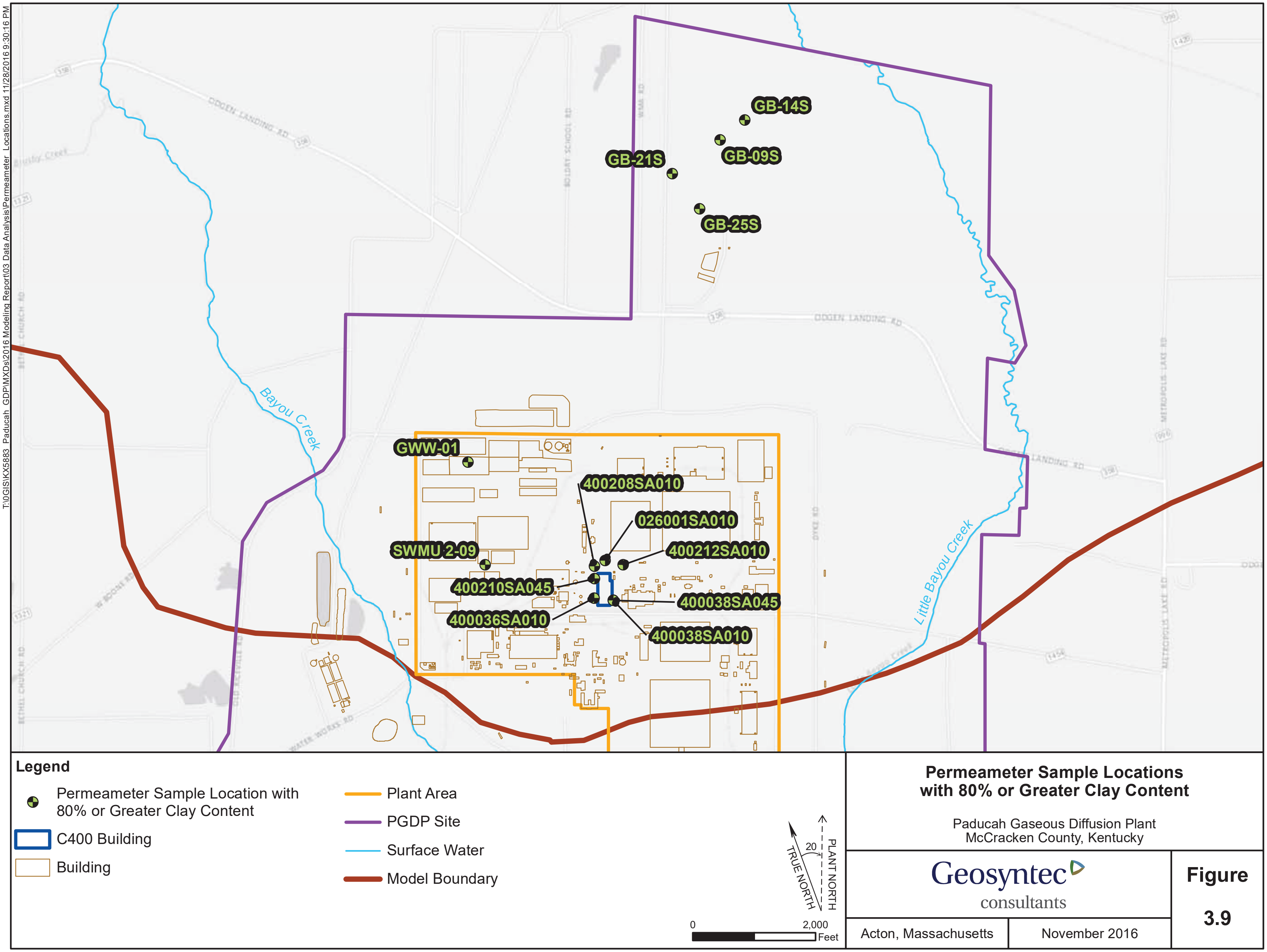


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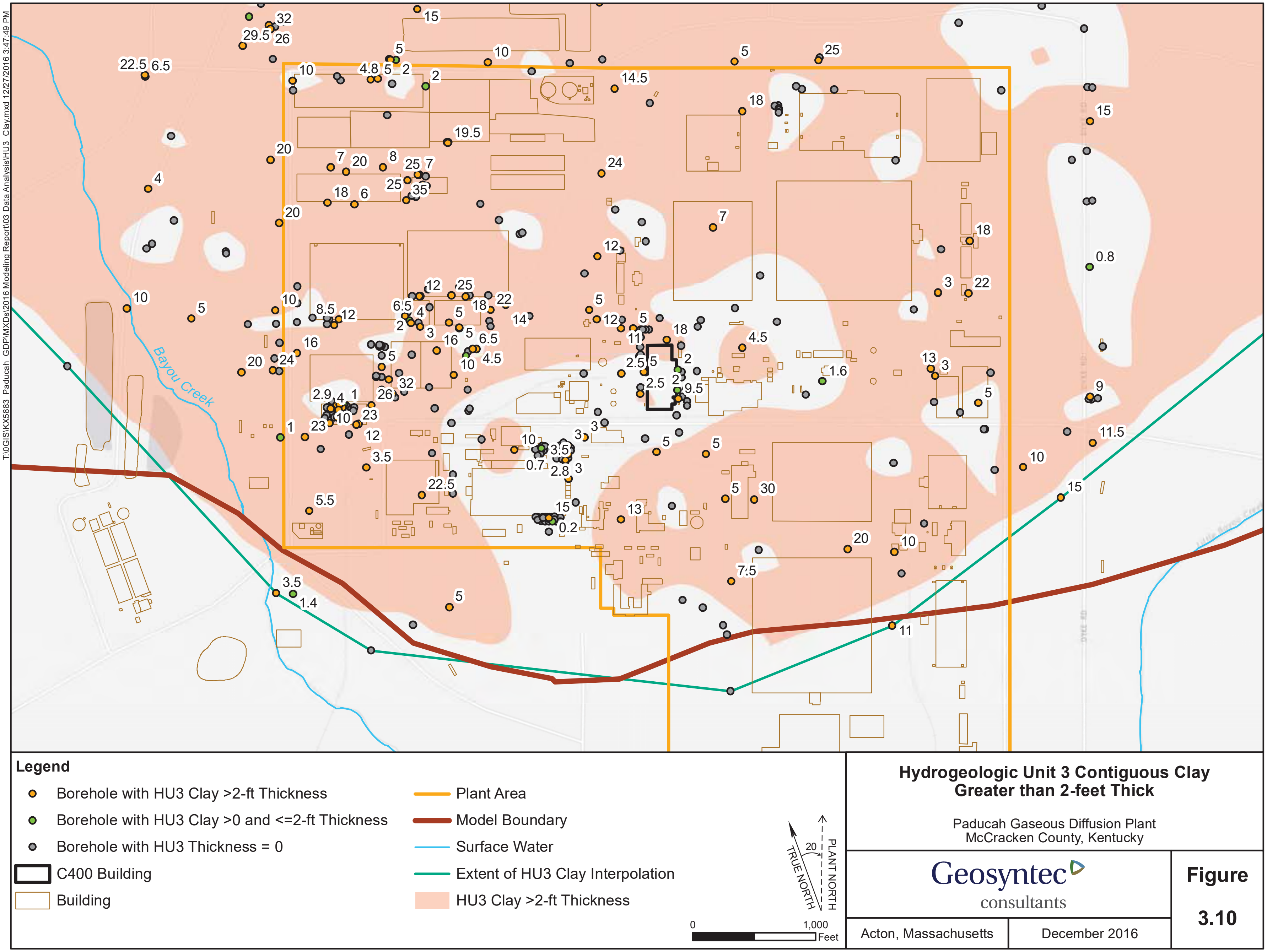
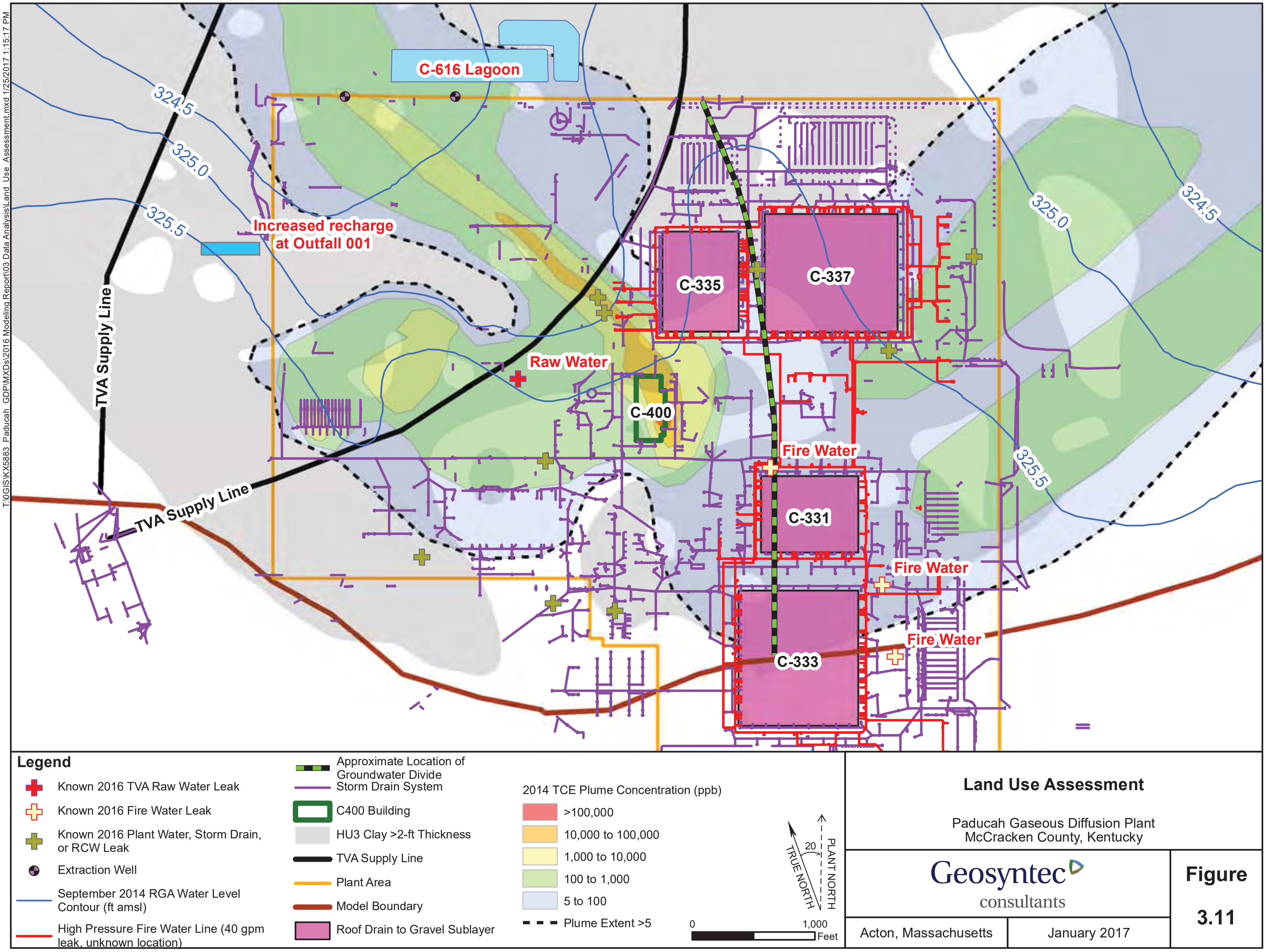
Figure 3.9. Permeameter Sample Locations with 80 Percent or Greater Clay Content



Note: Numbers indicate thickness of contiguous HU3 clay.
Lithology Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016

Figure 3.10. Hydrogeologic Unit Contiguous Clay Greater than 2-ft Thick



Plume Contour Source: DOE, 2015; Figure C.2

Figure 3.11. Land Use Assessment

the storm water and HPFW systems, as well as a leak in the TVA water supply line (see Figure 3.11). Quantifying historical leakage rates is problematic; however, the current leakage from the HPFW system is estimated to be 40 gpm based on the refill rate required to maintain a constant water level in the HPFW supply tower. Moreover, the locations of historical leaks are not well characterized, but it is likely that leaks in the piping system spread horizontally within the piping subbase gravel before migrating vertically to recharge the UCRS. The intersection of the piping system with areas where the HU3 contiguous clay layer is less than 2-ft thick is considered an area of increased anthropogenic recharge.

The main process buildings (C-335, C-337, C-331, and C-333) are constructed with roof drains designed to divert precipitation runoff to the storm drain system; however, water in the basements of the buildings observed during precipitation events indicates that the systems are not operating as designed. Sump pumps located in the basement of the buildings are reported to operate after rain events approximately 10% of the time (September 8, 2016, e-mail correspondence between D. Tripp and A. Anderson). In buildings C-337 and C-333, flow from beneath the slab into the building is observed during precipitation events (December 22, 2016, e-mail correspondence between D. Tripp and A. Anderson). It is likely that leaks in the roof drain system migrate horizontally through the building gravel subbase before recharging the UCRS. The intersection of the building gravel subbase with areas where the HU3 contiguous clay layer is less than 2-ft thick is considered an area of increased anthropogenic recharge.

Two surface water features are also potential locations of increased anthropogenic recharge. Near Outfall 001 at the western boundary of the plant area, an area of pooled surface water behind the oil control dam was observed during site visits in June and August 2016. This area coincides with an area where the HU3 contiguous clay layer is less than 2-ft thick and is considered an area of increased anthropogenic recharge.

The C-616 lagoon is a surface impoundment that receives water from the recirculating cooling water system and the groundwater recovery treatment system before discharging to Outfall 001 through a drainage ditch. It began operation in 1977 and is reported to be constructed without a clay liner because a geological survey indicated that the natural clay soil conditions were sufficient (August 31, 2016, e-mail correspondence with Andy Anderson). The water level in the basin is maintained at a depth of approximately 6 ft. Although reported to be constructed in an area of natural clay, an area just south of the lagoon where the HU3 contiguous clay layer is less than 2 ft was identified through lithologic interpretation reported in the KRCEE database (Revision 8) (CAER KRCEE 2016) and is considered an area of increased anthropogenic recharge.

In summary, sources of anthropogenic recharge to the UCRS identified from a comprehensive review of available information have been attributed to the following:

- HPFW piping system;
- Storm drain piping system;
- TVA water supply piping;
- C-616 Lagoon and drainage ditch;
- Outfall 001 area; and
- Improperly functioning process building roof drains.

These potential recharge source areas were evaluated in the context of observed potentiometric surfaces and TCE plume configurations; the following four zones of potentially enhanced anthropogenic discharge coincident with areas with less than 2 ft of contiguous clay at the base of the UCRS were identified (Figure 3.11).

The area in the vicinity of Outfall 001, where surface water accumulation was observed during site visits in 2016 coincident to areas of contiguous clay less than 2-ft thick in the lower UCRS/HU3 (Figure 3.11), increased recharge and elevated water levels in the area and aligns with the limit of the western extent of the Northwest Plume.

The area near the reported long-term raw water leak along the TVA supply line is coincident with areas of HU3 clay less than 2-ft thick and higher water level elevations in the RGA and aligns with the limit of the western extent of the Northwest Plume.

The area where the C-616 Lagoon is coincident with areas of HU3 clay less than 2-ft thick and higher water level elevations in the RGA and contributes to limiting the eastern extent of the Northwest Plume.

The area near the four buildings (C-335, C-337, C-331, and C-333) that have faulty roof drain systems and are connected to the HPFW system that has been reported in 2016 to leak at a rate of 40 gpm. This area is coincident with areas of HU3 clay less than 2-ft thick and a groundwater divide in the RGA that runs approximately north/south along the eastern portion of the plant and contributes to limiting the eastern extent of the Northwest Plume.[1]

3.4 WATER LEVEL DATA

Water level data from several water level gauging events were evaluated for inclusion in the model calibration and validation. Data is available from water level measurement events conducted from 1995 through 2016. Generally, the events fall into two categories consisting of annual sitewide events and quarterly landfill permit monitoring events. The landfill permit monitoring events include a subset of monitoring wells from the annual sitewide monitoring well network with locations limited to the central area of the model domain (Figure 3.12). Sitewide monitoring events include a more comprehensive set of wells that are distributed more widely across the model domain (Figure 3.13). Additionally, a transient set of water level data is available from the 2010 pump test conducted at Northwest Plume extraction wells, EW232 and EW233. The available datasets are summarized in Table 3.7.

To evaluate data suitability for use in model calibration or validation, measured precipitation and river stages prior to each monitoring event were evaluated to determine if the measured water levels were representative of relatively steady-state conditions. In the context of the PGDP Hydrologic Basin (see Section 4), the evaluation of steady-state conditions is most significant in the area near the Ohio River. If the river is rising or declining, then the river stage and groundwater are not in equilibrium (steady-state). Long periods of relatively constant river stage result in equilibrium between groundwater and the Ohio River (i.e., steady-state condition).

Historical precipitation data were obtained from the National Oceanic and Atmospheric Administration for the Paducah Barkley Regional Airport weather station. Ohio River stage data were obtained from USGS gauging stations located at Paducah, Kentucky (USGS 03611000); Metropolis, Illinois (USGS 03611500); and Olmsted, Illinois (USGS 03612600). The Metropolis station is located adjacent to the model domain and provides the most representative Ohio River stage measurements; however, the period of record is limited to the years 2007 through 2015. For water level datasets collected prior to

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[1] The groundwater divide location is approximate and is assumed to change location due to varying seasonal and anthropogenic recharge conditions.

Figure 3.12. Landfill Permit Monitoring Wells

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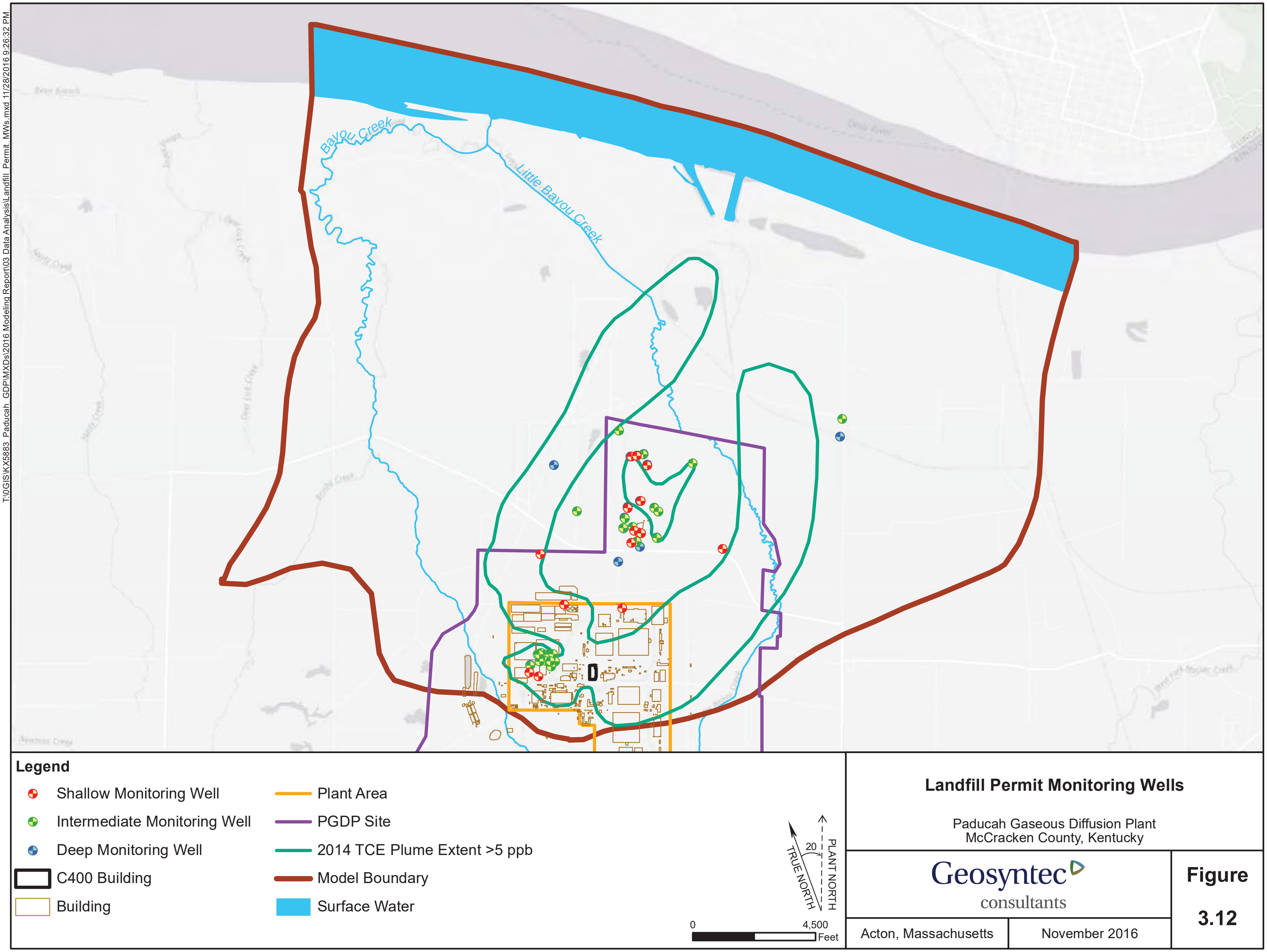
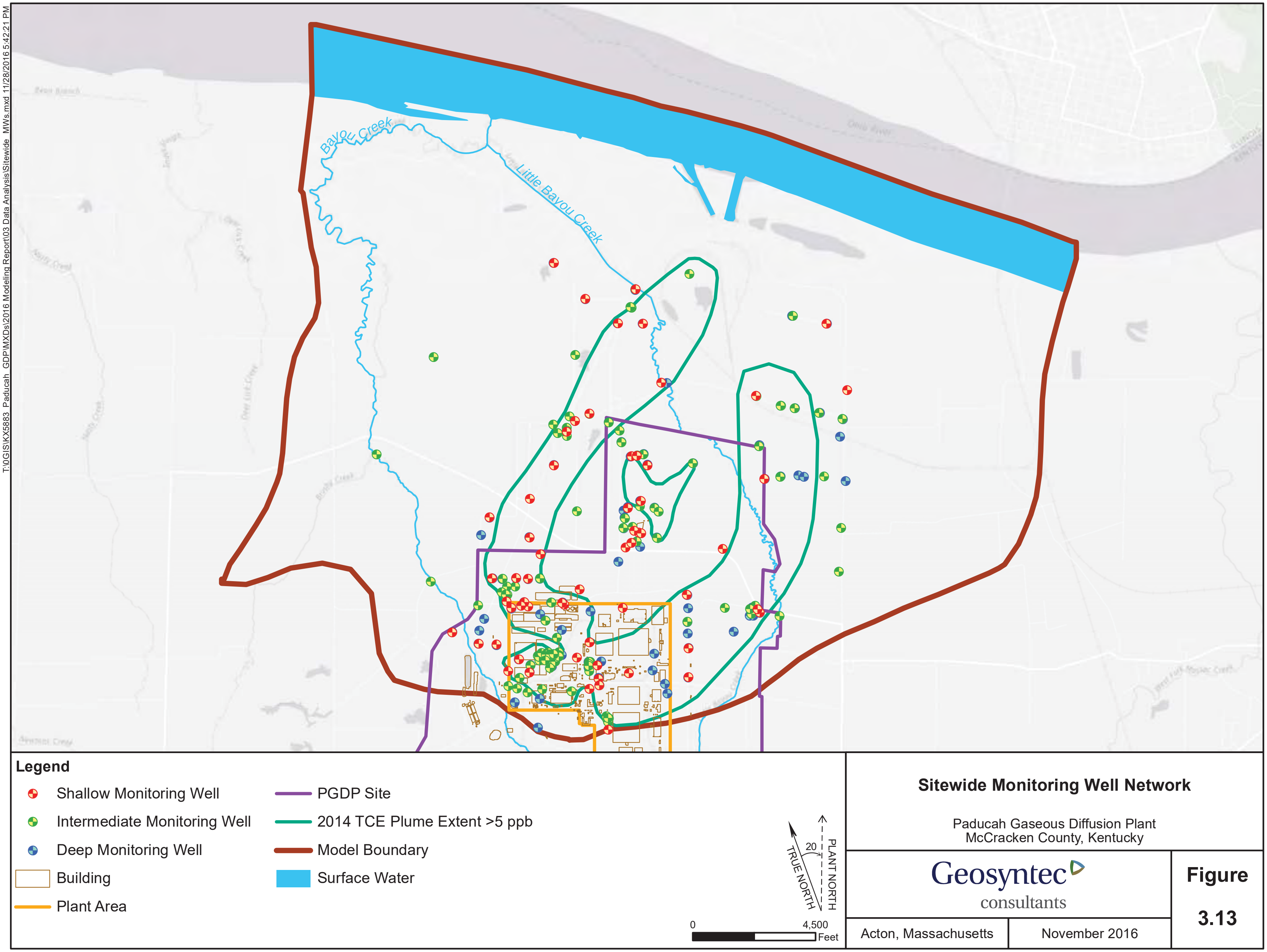


Plume Contour Source: DOE, 2015a; Figure C.2



Plume Contour Source: DOE, 2015a; Figure C.2

Figure 3.13. Sitewide Monitoring Well Network

Table 3.7. Selected Calibration and Validation Stress Periods

Monitoring Period	Steady State Conditions (Y/N)	Number of Head Targets	Ohio River Stage* (ft msl)	Synoptic (Y/N)	Monitoring Event Type	Annual Precipitation (inches/yr)	Rationale
February 1995	N	76	295.2**	N	Sitewide Pre-pumping	38.6	Variability in river stage, system is not in SS condition, but only available pre-pumping data set, relatively low annual rainfall
3rd Q 2005	Y	110	300.0**	N	Sitewide	37.5	Representative of SS conditions, pumping system in operation
1st Q 2007	N	110	311.7	N	Sitewide	43.3	Variability in river stage, system is not in SS conditior
April 2010	N	38	311.1	N	NA	36.7	Variability in river stage, system is not in SS condition, only 38 point
October 11, 2010	Y	13	293.9	Y	Pump test	36.7	Monitoring network limited to area in the vicinity of pumping well, exclude from calibration and use for transient calibration
October 12, 2010	N	13	295.5	Y	Pump test		
October 13, 2010	N	13	295.5	Y	Pump test		
October 14, 2010	N	13	294.9	Y	Pump test		
October 15, 2010	N	13	294.5	Y	Pump test		
October 16, 2010	N	13	294.3	Y	Pump test		
October 17, 2010	N	13	293.8	Y	Pump test		
October 18, 2010	N	13	293.5	Y	Pump test		
October 19, 2010	N	13	293.1	Y	Pump test		
October 20, 2010	N	13	292.8	Y	Pump test		
October 21, 2010	N	13	292.7	Y	Pump test		
April 12, 2011	N	212	327.2	Y	Sitewide	74.8	High relative annual precipitation, flooding conditions not representative of steady state conditions, use for secondary validation of extreme conditions
October 10, 2011	Y	202	295.5	Y	Sitewide	74.8	Full data set, approximate SS conditions one month prior to gauging, high relative annual precipitation
July 17, 2012	Y	184	290.0	Y	Sitewide	27.6	Full data set, approximate SS conditions one month prior to gauging, low relative annual precipitation
January 3, 2013	N	47	TBD	Y	LPM	60.3	Variability in river stage, system is not in SS conditior
April 16, 2013	N	36	TBD	Y	LPM	60.3	Variability in river stage, system is not in SS conditior
August 5, 2013	N	52	TBD	Y	LPM	60.3	Variability in river stage, system is not in SS conditior
September 24, 2013	Y	203	292.5	Y	Sitewide	60.3	Full data set, approximate SS conditions one month prior to gaugin
October 23, 2013	Y	52	TBD	Y	LPM	60.3	Approximate SS conditions, less data points than September 2013 event
January 30, 2014	N	52	TBD	Y	LPM	46.8	Variability in river stage, system is not in SS conditior
April 29, 2014	N	52	TBD	Y	LPM	46.8	Variability in river stage, system is not in SS condition
July 30, 2014	N	52	TBD	Y	LPM	46.8	Variability in river stage, system is not in SS conditior
September 29, 2014	Y	206	295.2	Y	Sitewide	46.8	Full data set, representative of SS conditions, post plant shut dowr
October 28, 2014	N	52	TBD	Y	LPM	46.8	Variability in river stage, system is not in SS conditior
January 28, 2015	N	53	TBD	Y	LPM	59.2	Variability in river stage, system is not in SS conditior
April 29, 2015	N	54	TBD	Y	LPM	59.2	Variability in river stage, system is not in SS conditior
August 4, 2015	N	53	TBD	Y	LPM	59.2	Variability in river stage, system is not in SS conditior
September 1, 2015	N	205	296.7	Y	Sitewide	59.2	Variability in river stage, system is not in SS conditior
October 28, 2015	Y	53	TBD	Y	LPM	59.2	Representative of SS conditions
January 26, 2016	N	53	TBD	Y	LPM	NA	Variability in river stage, system is not in SS conditior
April 28, 2016	N	54	TBD	Y	LPM	NA	Variability in river stage, system is not in SS conditior
July 26, 2016	N	54	TBD	Y	LPM	NA	Variability in river stage, system is not in SS conditior
August 23, 2016	Y	216	298.0**	Y	Sitewide	NA	Full data set, approximate SS conditions one month prior to gaugin

⬜ Use for Calibration
🟪 Use for Validation
🟦 Use for transient calibration
▨ Not used
See Section 3.4 for explanation of data set selection.

Notes: LPM = Landfill Permit Monitorin
TBD = To Be Determined
*Average Ohio River stage at the Metropolis station for 30 days prior to the water level measurement event, except a
noted.
** 30-day average Ohio River stage not used; see text for details (Section 3.4)

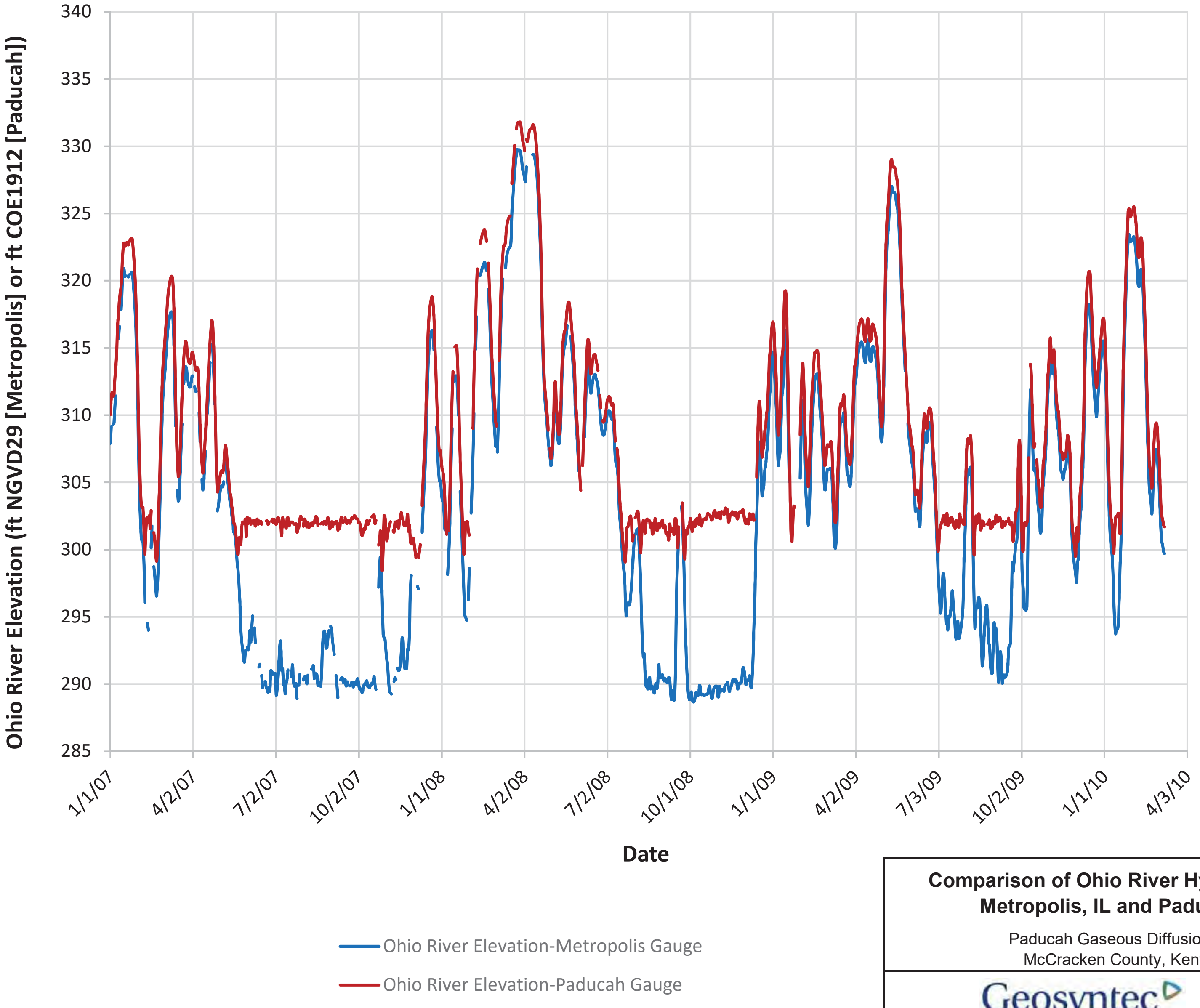
2007, the Ohio River stage was assessed based on data from the Paducah station. For water level datasets collected after 2015, data from both the Paducah and Olmsted stations were used to assess Ohio River stage. The Paducah station is located approximately 9 miles upstream of the Metropolis station, and the Olmsted station is located approximately 20 miles downstream of the Metropolis station.

A comparison of the Ohio River stage measured at the Paducah and Metropolis stations from January 2007 through March 2010 is presented in Figure 3.14. During high flow conditions, the reported river stage for the Metropolis station is on average 1.8 ft lower than the stage reported for the Paducah station. This difference is attributable to the downstream location of the Metropolis station relative to the Paducah station and a different vertical datum used for reporting (i.e., NGVD29 for the Metropolis station and COE1912 for the Paducah station). During low flow conditions, the Ohio River stage measured at the Metropolis station is as much as 13.7 ft lower than the stage measured at the Paducah station. This difference is due to the presence of a low flow wicket located in between the two stations that maintains a navigable depth of water in the Paducah area. Consequently, measurements from the Paducah station are not representative of the Ohio River stage within the model domain whenever the Ohio River falls below approximately 302 ft (COE1912) at the Paducah station, which corresponds to an Ohio River stage less than or equal to approximately 300 ft amsl in the model domain.

For each year in which groundwater level data were available, cumulative precipitation curves along with the cumulative average monthly precipitation of all the years evaluated on the graph are presented in Figure 3.15. Average annual precipitation for the years evaluated is 45.1 inches per year. Figures 3.16 to 3.25 present Ohio River stage and cumulative precipitation by year, for each year groundwater level measurements were available. The criteria for selecting a dataset as suitable for modeling steady-state conditions are relatively steady river stage measurements and a steady trend in cumulative precipitation for approximately one month prior to the water level measurement. Based on these criteria, several gauging events were identified as potentially suitable (Table 3.7). The representative Ohio River stage for each dataset was defined as the average Ohio River stage at the Metropolis station for 30 days prior to the groundwater level measurement event. For datasets where Ohio River stage data were unavailable for the Metropolis station, Ohio River stage was assessed based on available data from the Paducah and/or Olmsted stations. In particular, a representative Ohio River stage was assigned to the February 1995, 3rd Quarter 2005, and August 2016 datasets based on the following considerations.

- February 1995—The exact date of this water level measurement event is unknown and the Ohio River stage was variable. Data from the Paducah station show that whereas the Ohio River stage was as high as 320 ft amsl in January 1995, the stage plunged below 300 ft amsl in mid-February. Because of the low-flow wicket in between the model domain and the Paducah station, the Ohio River stage in the area of interest could have reached a level anywhere between approximately 290 to 300 ft amsl during mid-February 1995. Based on the relatively low groundwater levels measured during the event, it was assumed that the representative, steady-state Ohio River stage would be similar to that of the September 29, 2014, event; therefore, an Ohio River stage of 295.2 ft amsl was assigned to the February 1995 dataset.

- 3rd Quarter 2005—The exact date of this water level measurement event is unknown. The Ohio River stage at the Paducah station was relatively constant at about 302 ft (COE1912) for all of 3rd Quarter 2005. Because of the low flow wicket in between the model domain and the Paducah station, the Ohio River stage in the area of interest could have reached a level anywhere between approximately 290 ft to 300 ft amsl during 3rd Quarter 2005. Based on the relatively high groundwater levels measured during the event, it was assumed that the representative, steady-state Ohio River stage would be higher than that of the September 29, 2014, event; therefore, an Ohio River stage of 300 ft amsl was assigned to the 3rd Quarter 2005 dataset.



Notes:
1) The vertical datum for the Metropolis, IL gauge is NGVD29. The vertical datum for the Paducah, KY gauge is COE1912.
2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

Comparison of Ohio River Hydrographs at Metropolis, IL and Paducah, KY

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Figure

3.14

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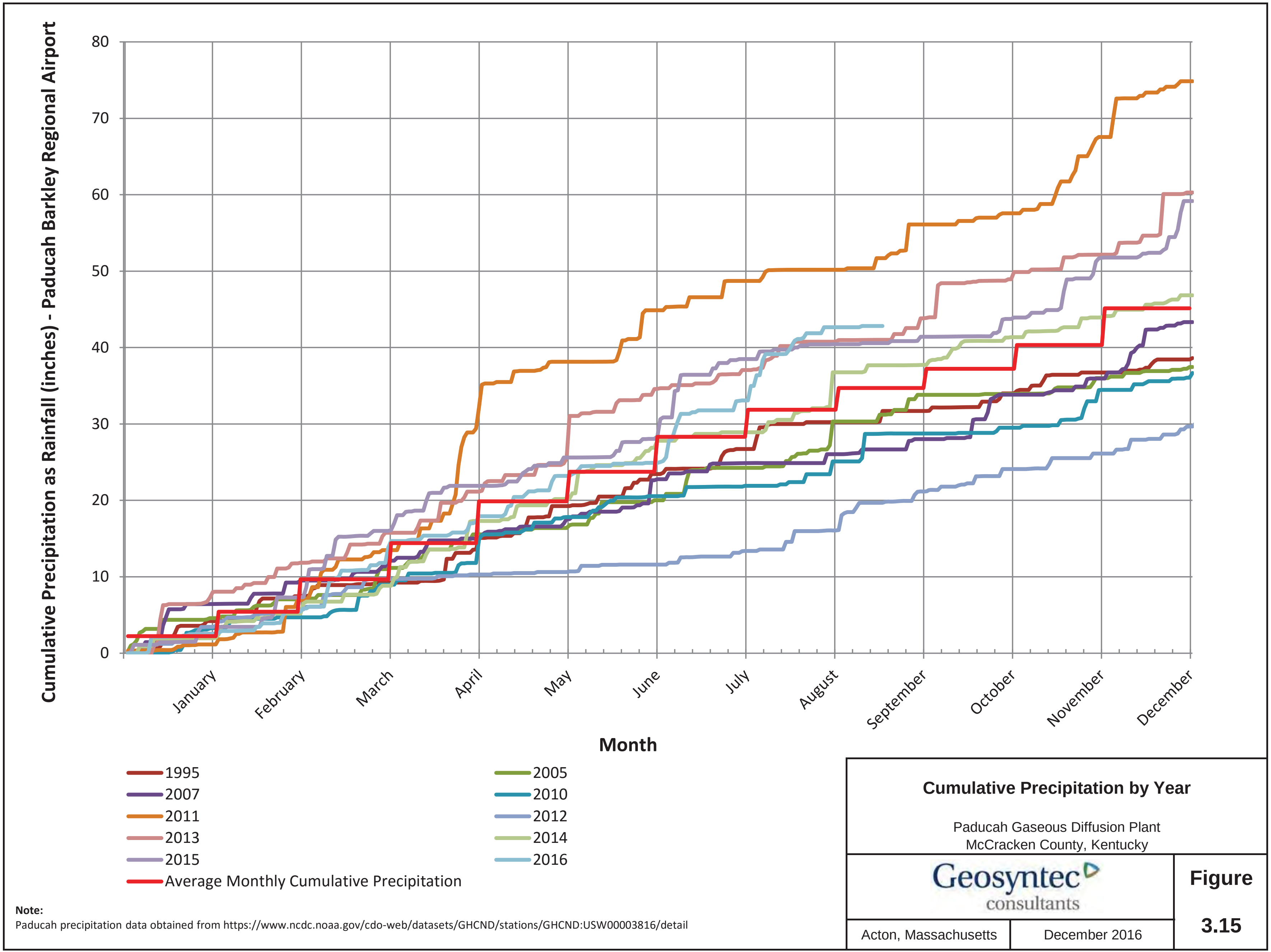
Figure 3.14. Comparison of Ohio River Hydrographs at Metropolis, IL, and Paducah, KY



Note:
Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation by Year

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3.15

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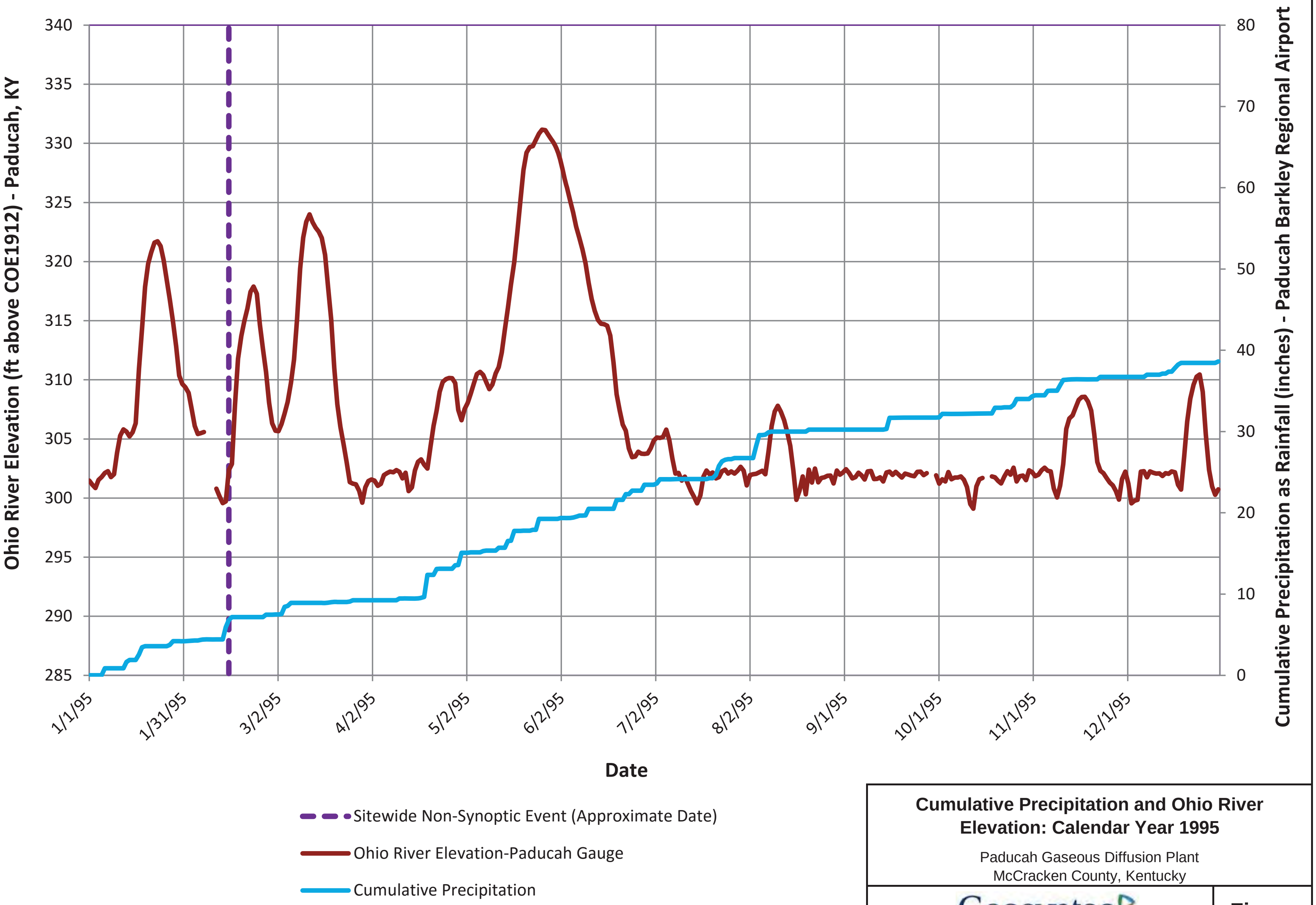
Figure 3.15. Cumulative Precipitation by Year

Figure 3.16. Cumulative Precipitation and Ohio River Elevation: Calendar Year 1995



Notes:
1) The vertical datum for the Paducah, KY gauge is COE1912.
2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis
3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 1995

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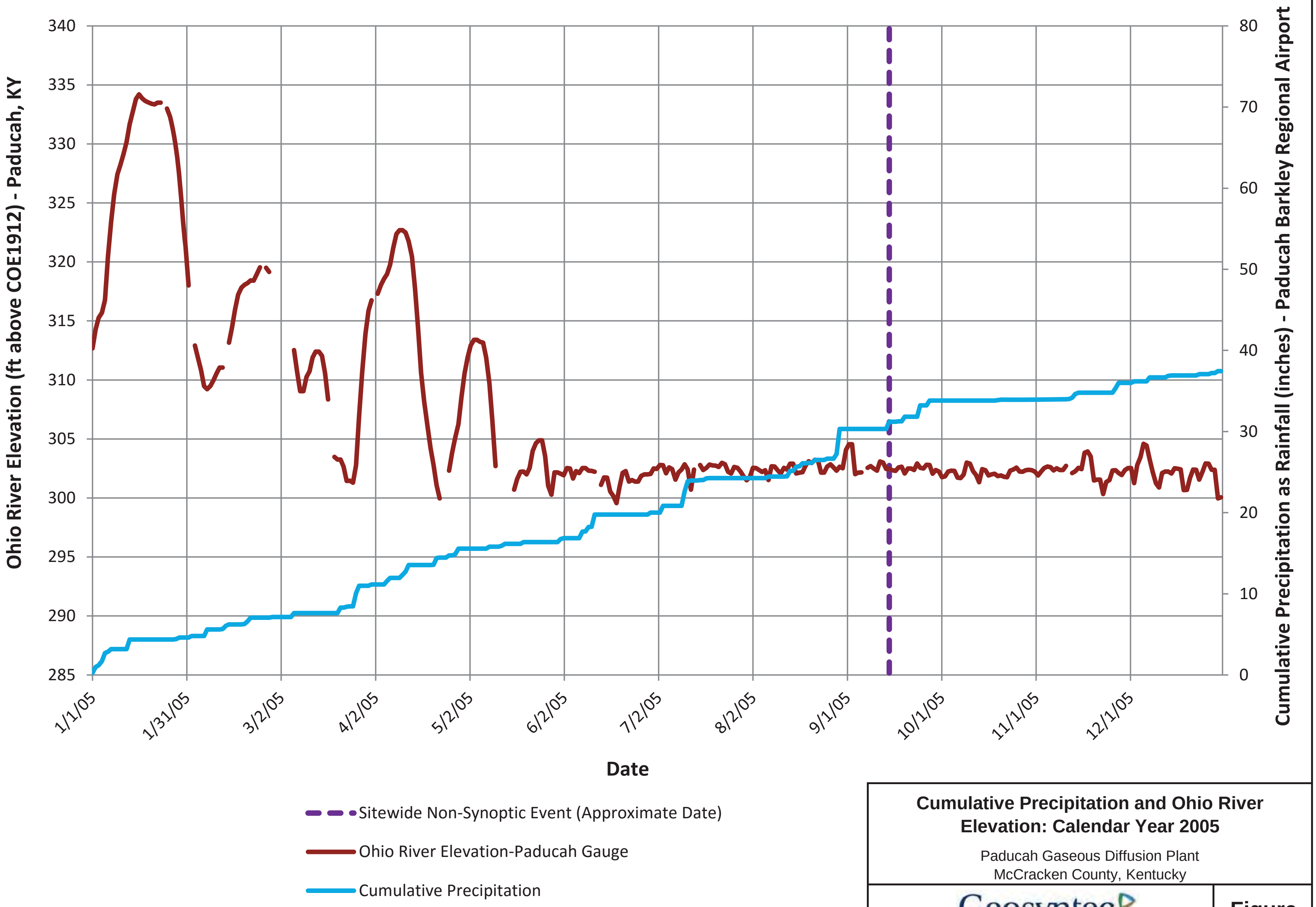
Figure 3.17. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2005



Notes:
1) The vertical datum for the Paducah, KY gauge is COE1912.
2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis
3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2005

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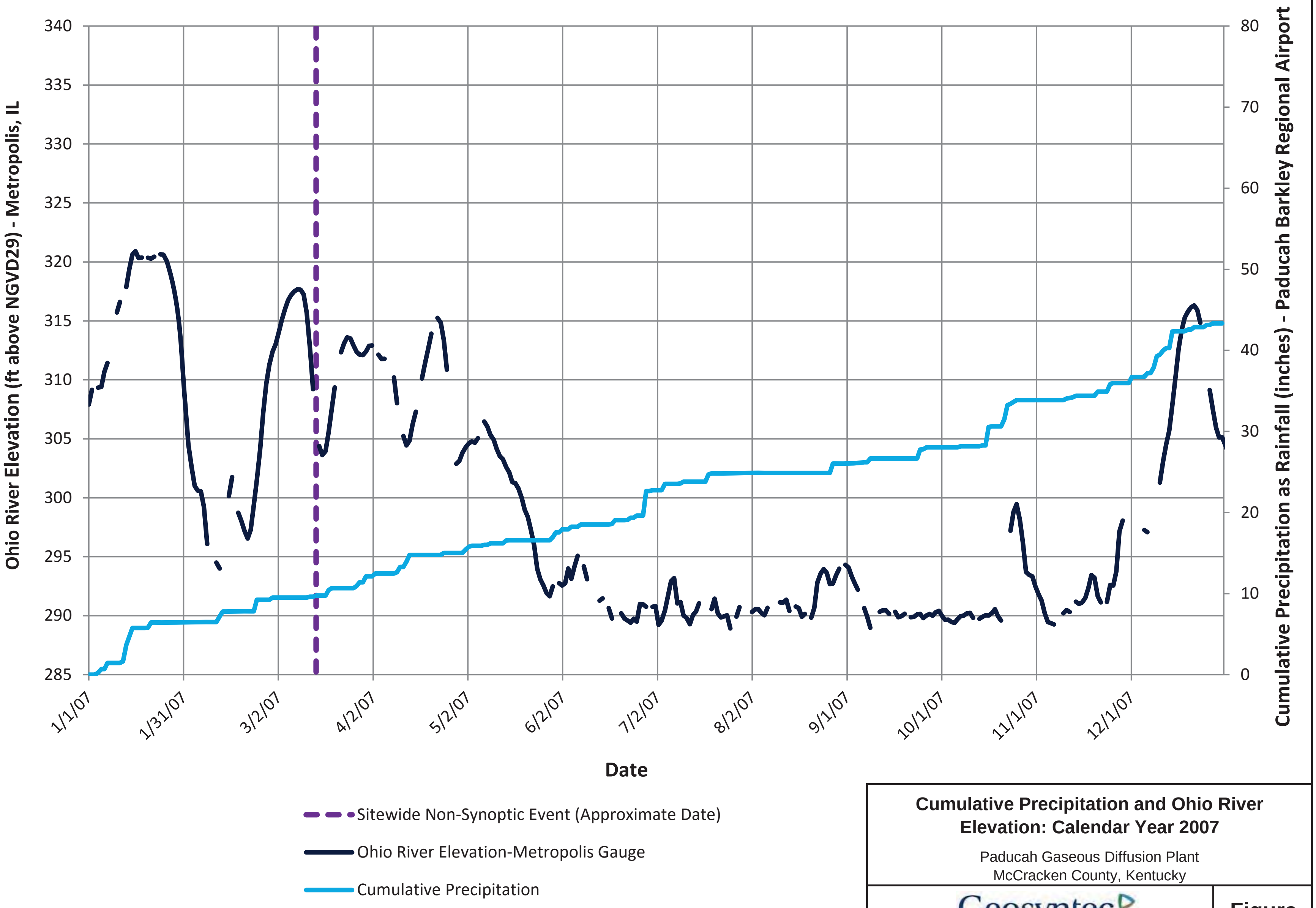
Figure 3.18. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2007



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2007

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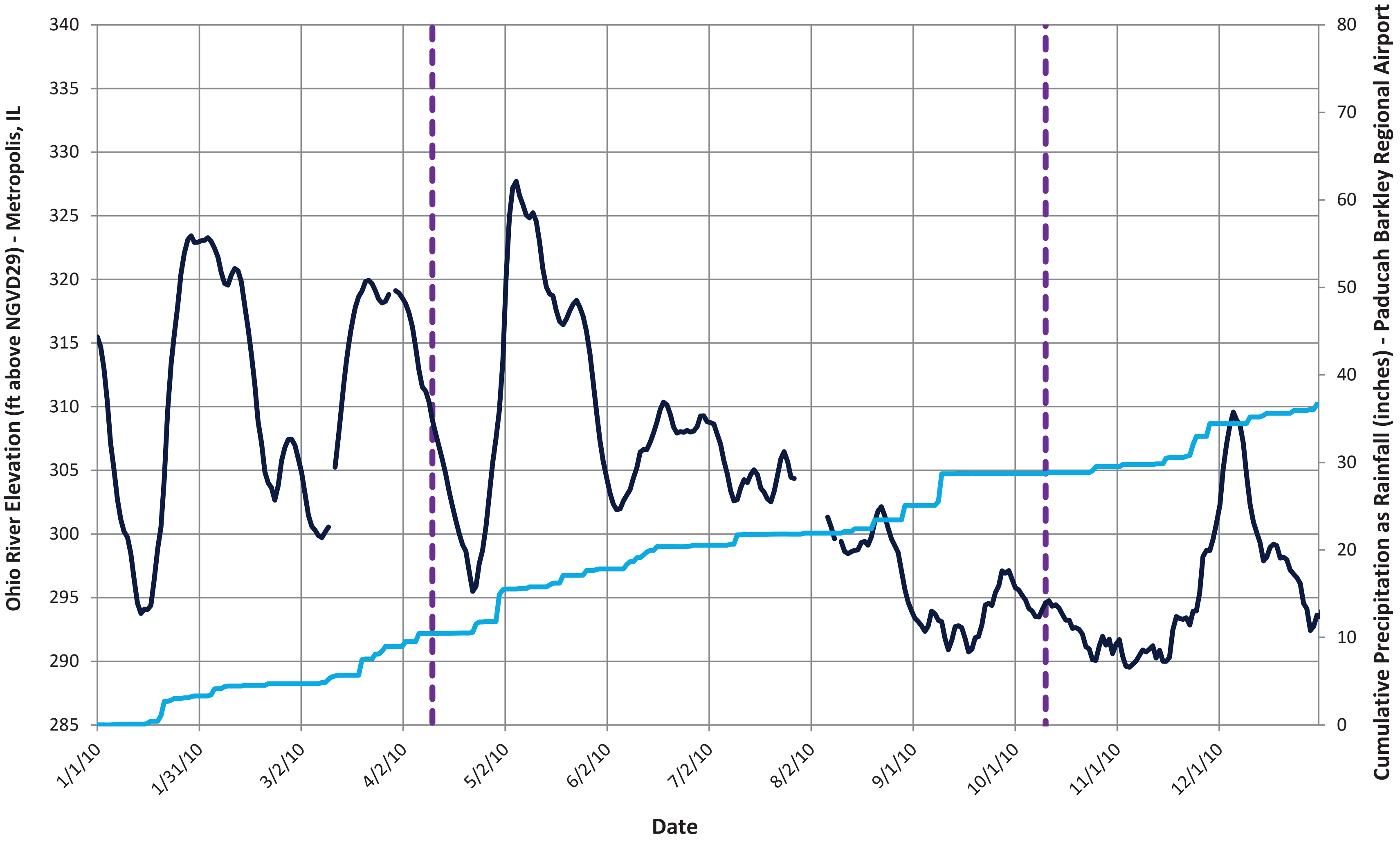
3.18

Figure 3.19. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2010



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2010

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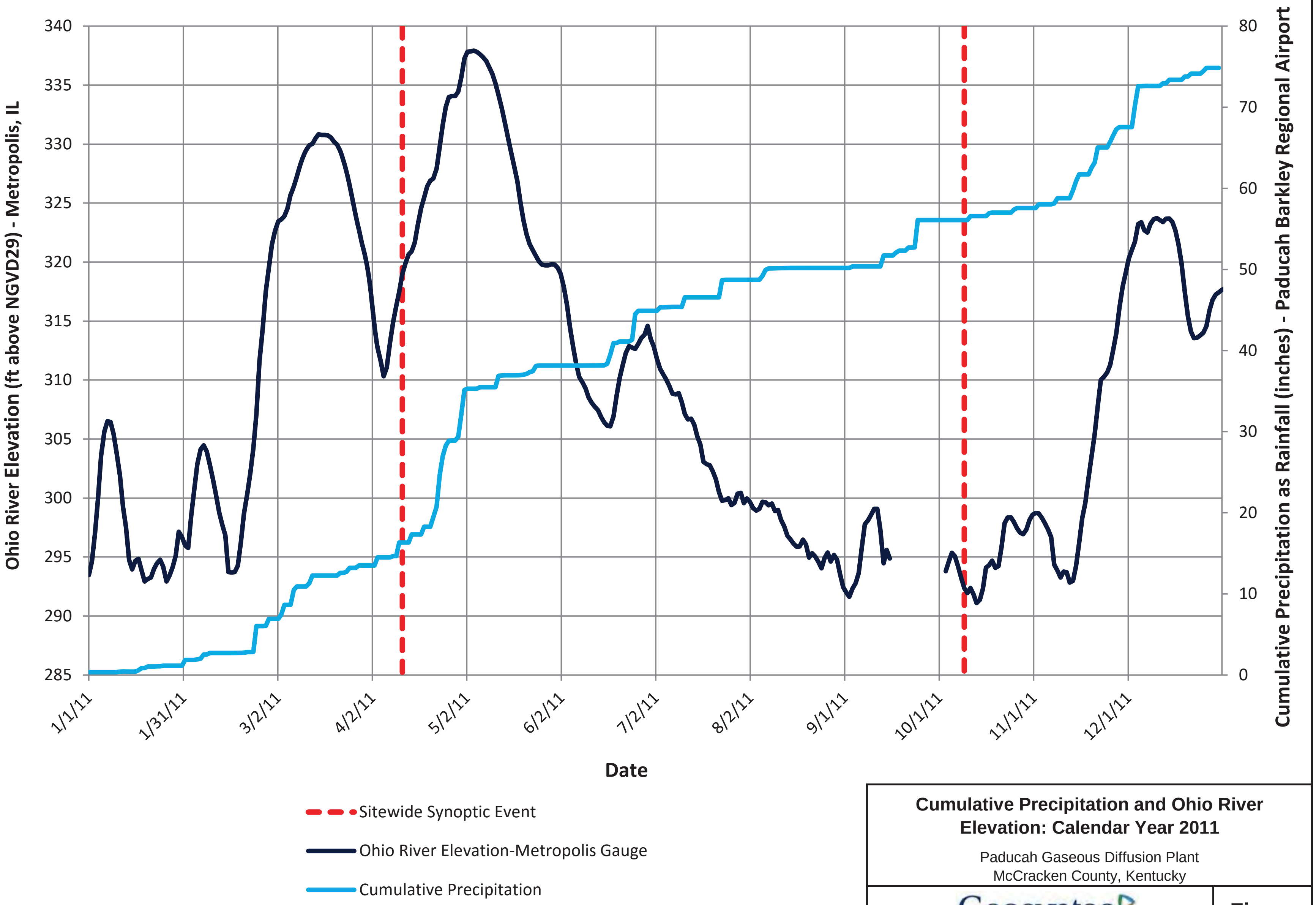
Figure 3.20. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2011



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2011

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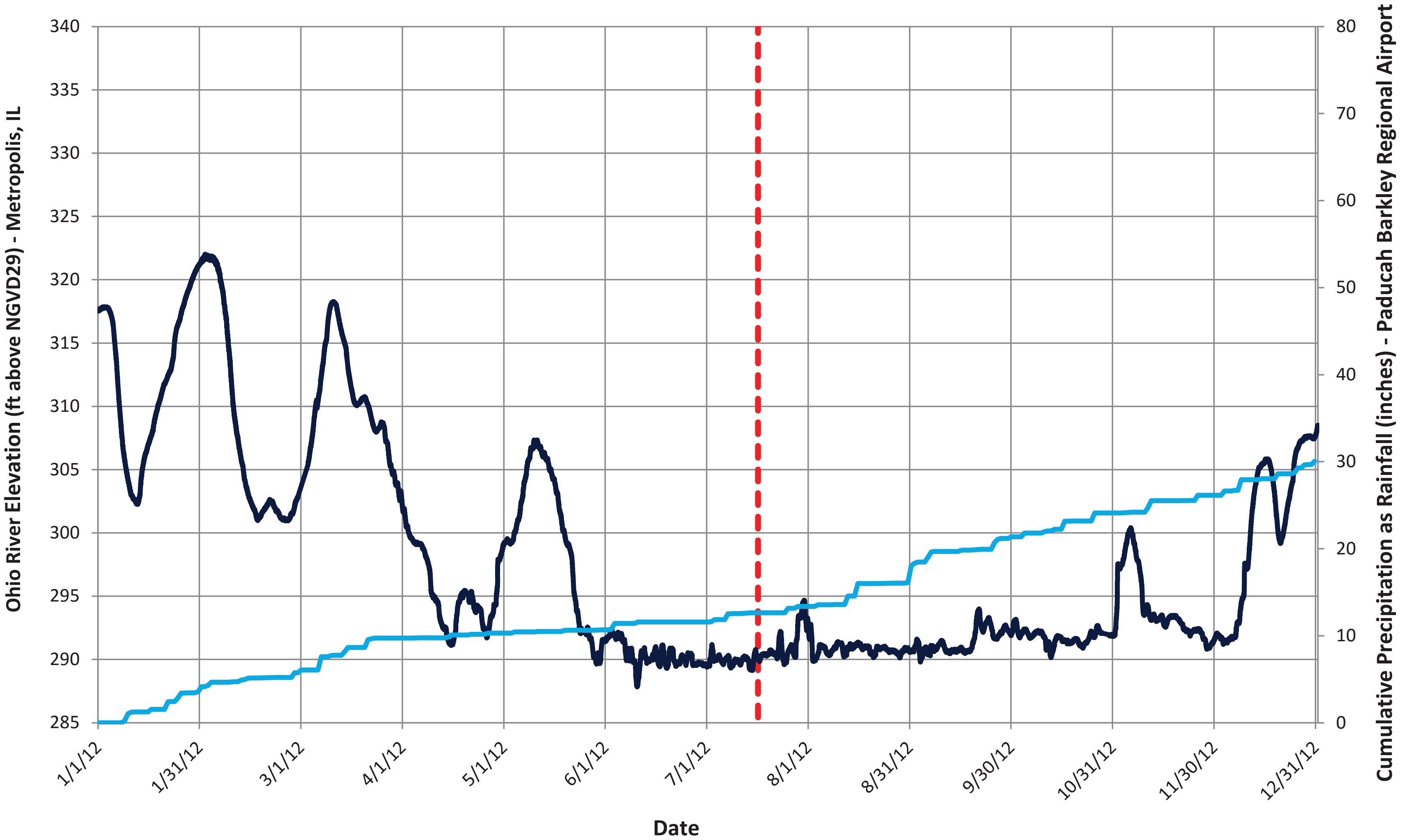
Figure 3.21. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2012



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2012

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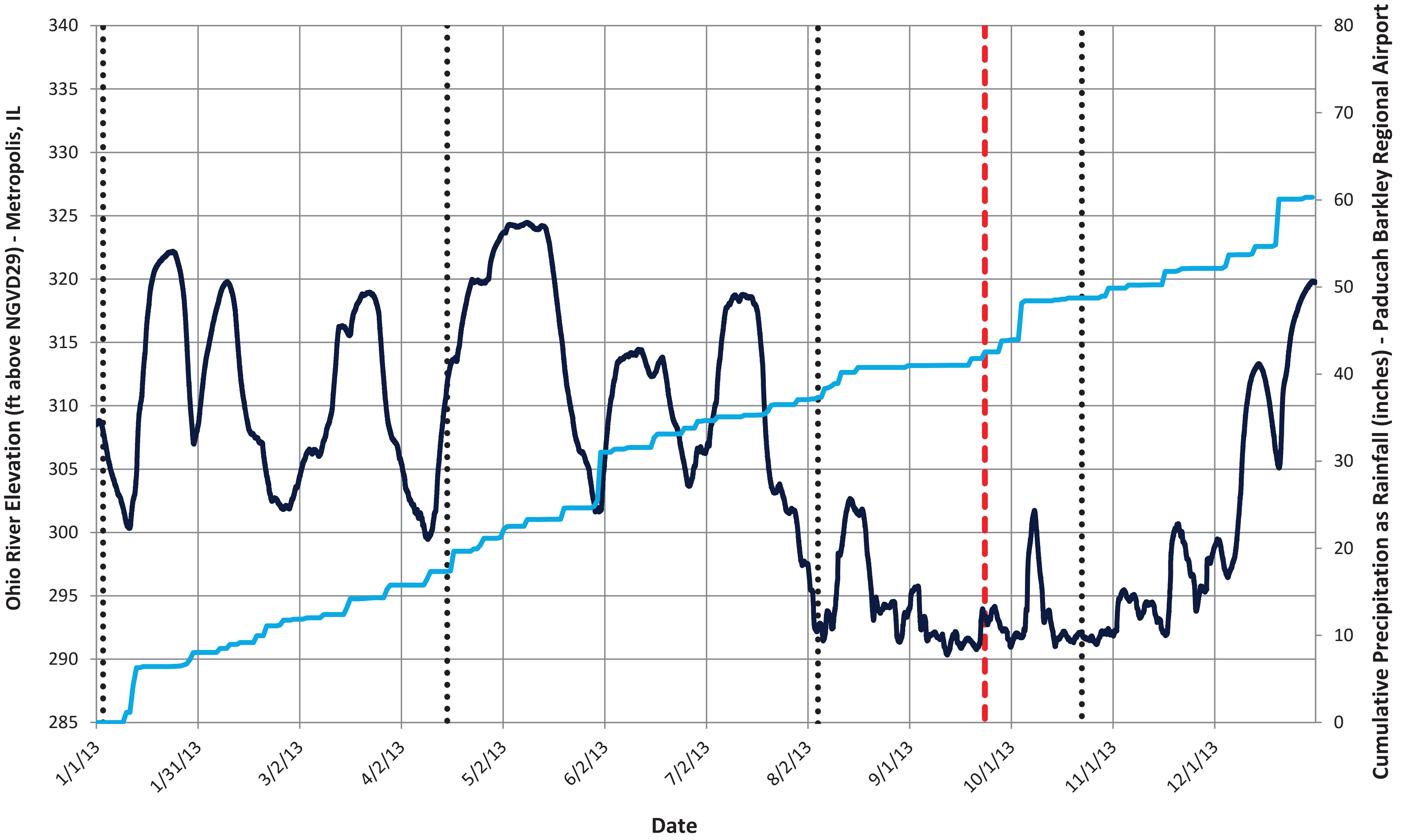
Figure 3.22. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2013



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2013

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3.22

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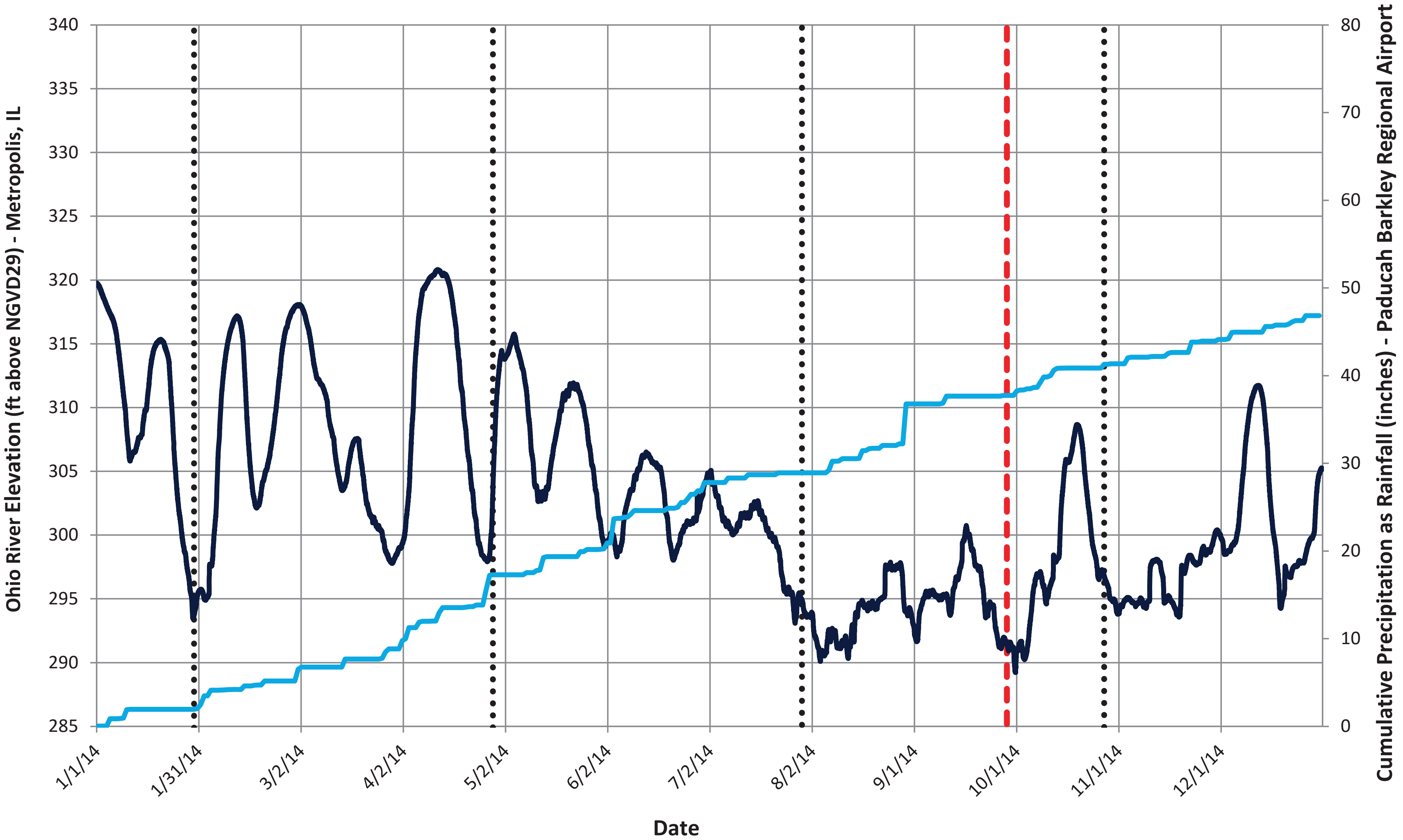
Figure 3.23. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2014



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2014

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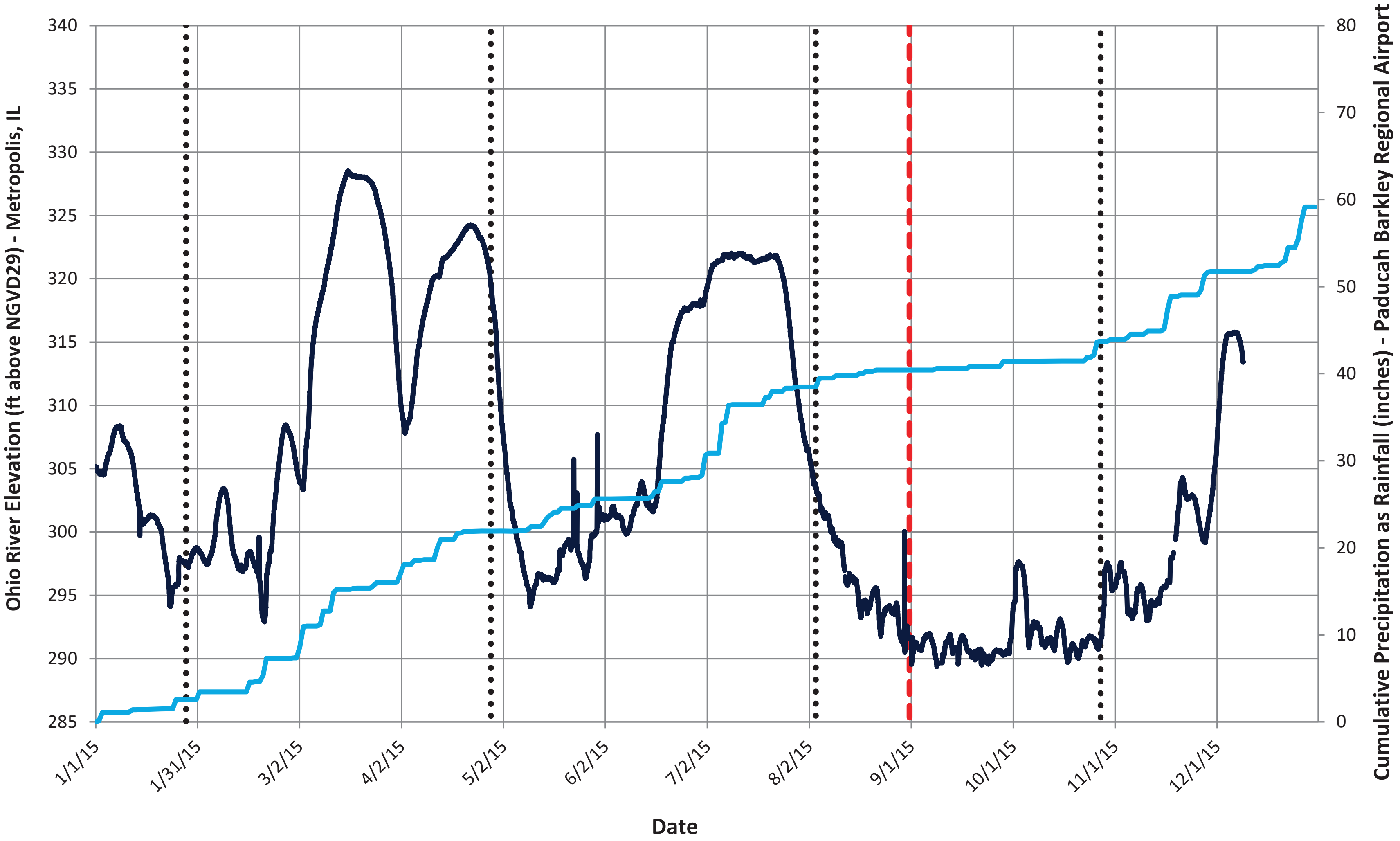
Figure 3.24. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2015



Notes:

1) The vertical datum for the Metropolis, IL gauge is NGVD29.

2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis

3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2015

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3.24

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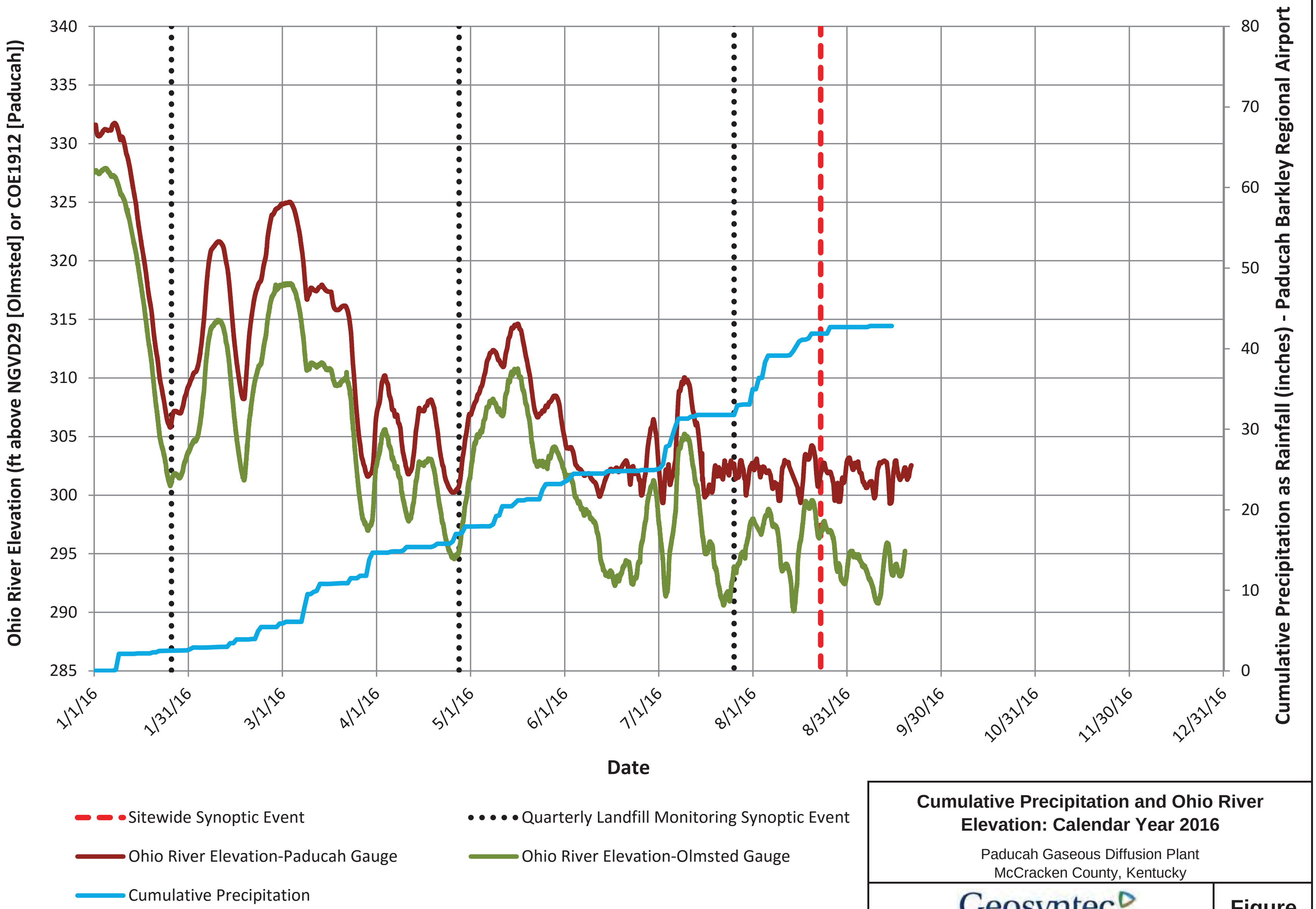
Figure 3.25. Cumulative Precipitation and Ohio River Elevation: Calendar Year 2016



Notes:
1) The vertical datum for the Olmsted, IL gauge is NGVD29. The vertical datum for the Paducah, KY gauge is COE1912.
2) Ohio River elevation data obtained from https://waterdata.usgs.gov/nwis
3) Paducah precipitation data obtained from https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00003816/detail

Cumulative Precipitation and Ohio River Elevation: Calendar Year 2016

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- August 23, 2016—The 30-day average Ohio River stage at the Paducah and Olmsted stations was 302.0 ft (COE1912) and 295.8 ft (NGVD29), respectively. Based on this information, the 30-day average Ohio River stage in the area of interest must be somewhere in between approximately 296 and 300 ft amsl; therefore, an Ohio River stage of 298 ft amsl was assigned to the August 23, 2016, dataset.

For model calibration, a subset of the data representing steady-state conditions was identified to optimize run time while simulating a range of site conditions with respect to annual precipitation and site operations. An additional criterion included wide spread distribution of measurement locations within the model domain. The final list of water level measurement events identified as suitable for use in model calibration is summarized in Table 3.7 and includes the following five operational periods:

- 1995—Pre-pumping;

- 2005—Initial EW system in Northwest and Northeast Plumes;

- 2011—Updated EW system, including EW232 and EW233, with relatively high annual precipitation;

- 2012—Updated EW system, including EW232 and EW233, with relatively low annual precipitation; and

- 2014—Post plant shutdown.

The 1995 data was determined not to be at steady-state conditions, but is included because it is the only dataset that includes water level data collected before the Northwest Plume and Northeast Plume extraction wells were installed and began operating (i.e., the data are representative of pre-pumping conditions).

Of the four remaining candidate datasets (i.e., 2005, 2011, 2012, and 2014), the 2014 data was included in the model calibration. The September 2014 dataset was chosen because it is representative of steady-state conditions and average annual precipitation (i.e., the average annual precipitation in 2014 was approximately the same as the average annual precipitation calculated from 1995 to 2016 for each year for which water level data were available, see Figure 3.15).

For model validation, seven datasets, including the three data sets that were identified as suitable for calibration data sets, but not selected for inclusion in the model calibration, were chosen to evaluate the calibrated model under alternative conditions that include more extreme precipitation and river stage values. In addition, the most recent sitewide synoptic monitoring event was included to evaluate current conditions. The selected datasets are summarized in Table 3.7.

Finally, the transient dataset from the 2010 Northwest Plume pumping test was selected for use in a supplemental transient model calibration.

4. CONCEPTUAL SITE MODEL

A hydrological CSM is a description of how, where, and in what quantities water enters the groundwater flow system and the factors controlling groundwater movement between inflow and outflow locations. The CSM is derived from site-specific data and is intended to force condensation of concepts and ideas about the flow system into a series of statements that will guide model configuration and calibration. The following CSM of the PGDP Site is based on historical data and data analysis presented in the 2010 report of the 2008 GW Model Update and additional data analyses presented in Section 3 of this report. The extent of the hydrogeologic system included in the CSM, herein referred to as the PGDP Hydrologic Basin, is defined from south to north as the northern extent of the Terrace Gravel/Porters Creek Clay to the Ohio River, and from east to west along surface water divides that are assumed to approximate groundwater divides. The PGDP Hydrologic Basin is illustrated in Figure 4.1 (DOE 2010, Figure 4.10).

The PGDP Site groundwater flow system is represented schematically in Figure 4.2 and primary findings are listed below.

- Strong downward vertical hydraulic gradients between the UCRS and RGA indicate that groundwater movement in the UCRS is primarily vertically downward. Simplistically, the UCRS conveys recharge at land surface to the RGA.

- Groundwater flow originating south of the Paducah Site within the Terrace Gravel recharges the RGA through the UCRS.

- Mass balance assessment based on comparable horizontal gradients but a hydraulic conductivity contrast between the RGA and the adjacent McNairy of two to three orders of magnitude indicates that the RGA has a significantly greater horizontal groundwater flow than the McNairy downgradient in the direction of the Ohio River (see Sections 4.4, 4.5, and 4.10 of DOE 2010).

- Vertical hydraulic gradient and mass balance evaluation indicates that there is vertical movement of groundwater between the RGA and McNairy, but the volume of groundwater moving between the two units is much less relative to the volume of groundwater moving horizontally in the RGA (see Section 4.10 of DOE 2010).

In summary, the RGA is the primary conveyor of groundwater from the PGDP Site to the Ohio River.

Below are observations regarding the presence of steady-state or transient groundwater flow conditions.

- A three-point vector analysis of water level data from the period 1993 to 2006, described in detail in the 2010 report on 2008 GW Model Update (DOE 2010, Section 4.3.2), shows that RGA groundwater flow directions between PGDP and the Ohio River remain relatively constant regardless of river stage. This assessment is supported by the temporal consistency of the PGDP plumes (DOE 2010, Section 4.3.2).

- The same three-point analysis indicates that groundwater flow directions beneath the plant area are variable because of differing anthropogenic recharge time constants. Despite flow direction variability, plume orientation at PGDP remains relatively constant, suggesting “average” flow conditions do exist (DOE 2010, Section 4.3.2).

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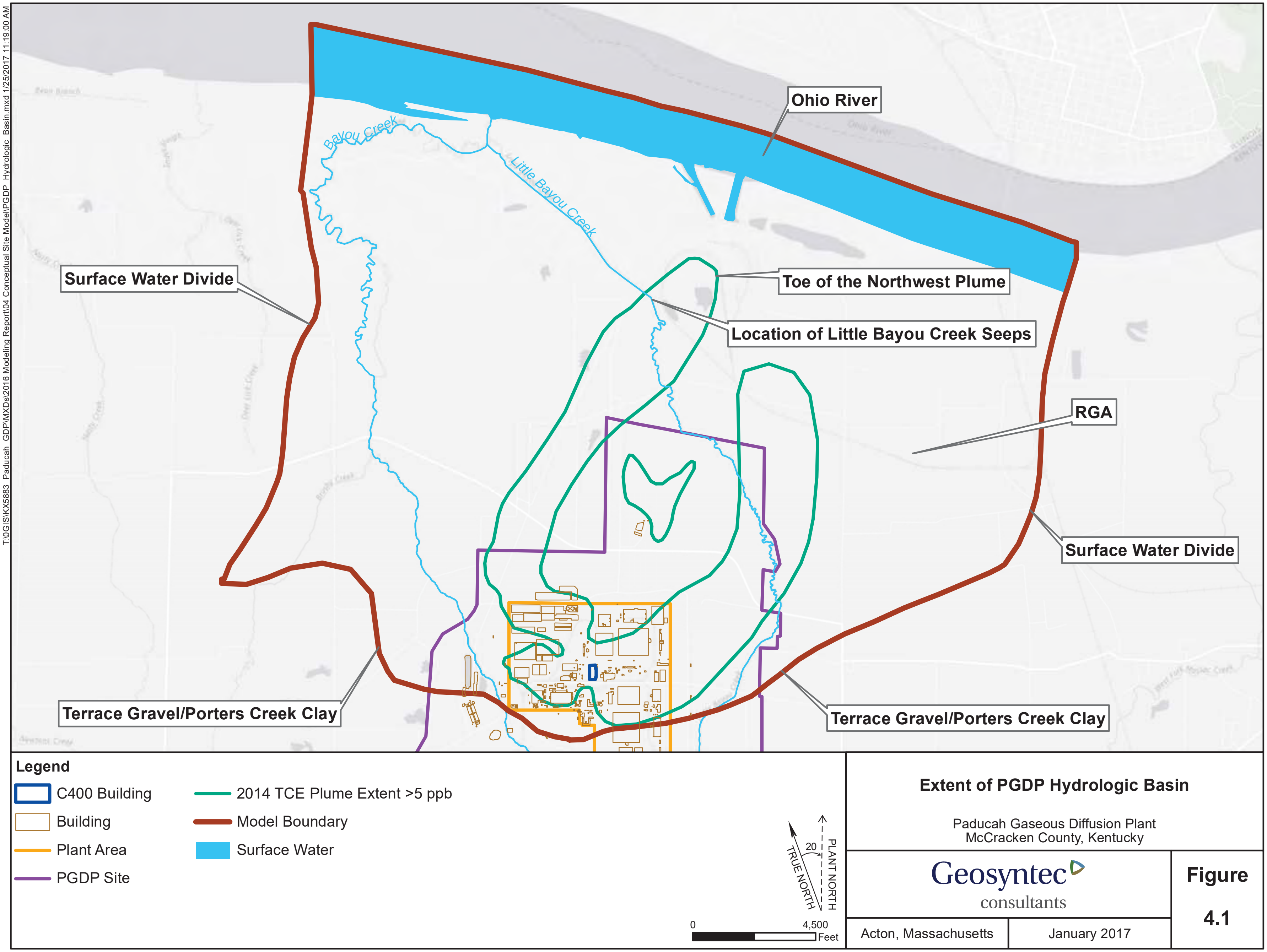
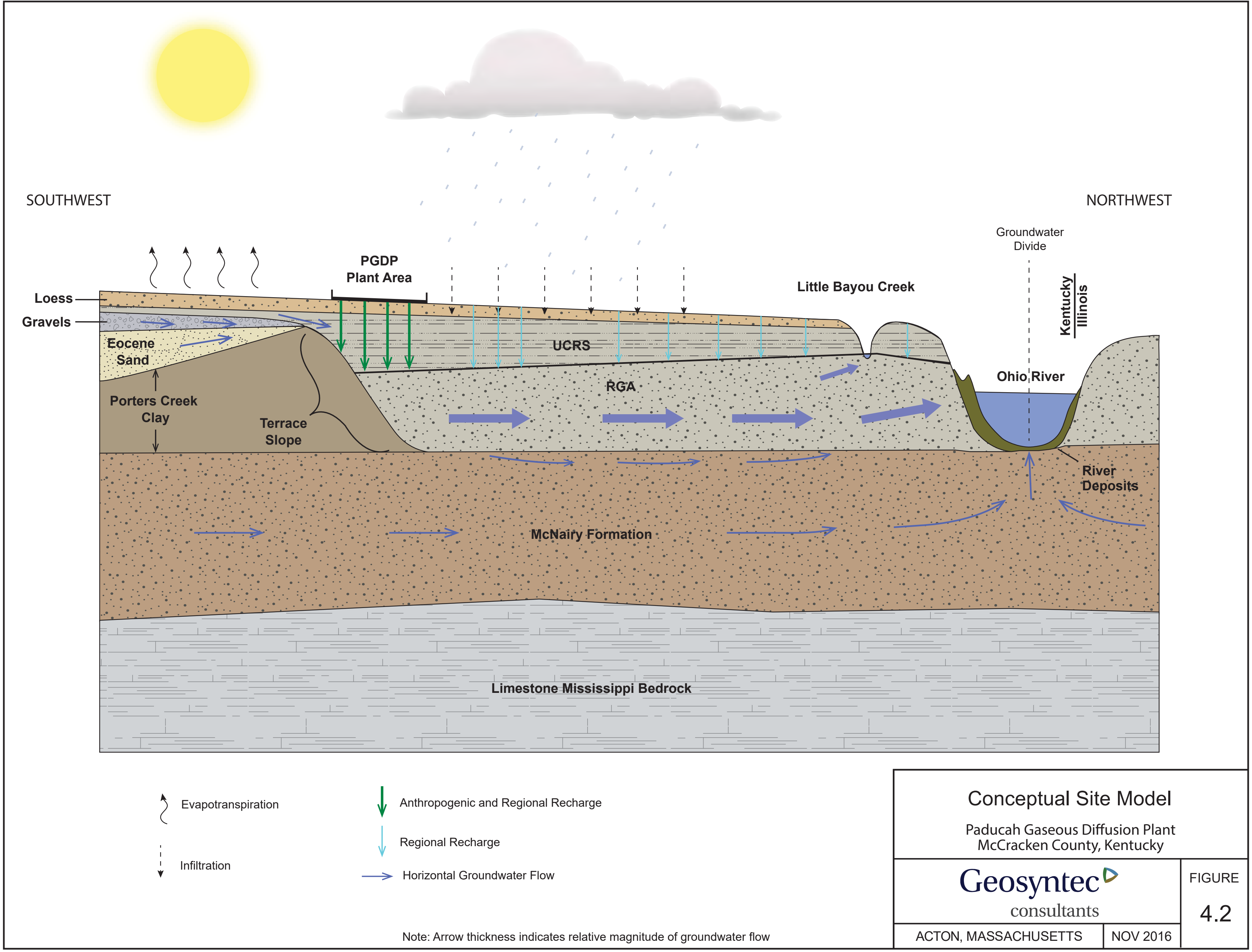


Plume Contour Source: DOE, 2015; Figure C.2

Figure 4.1. Extent of PGDP Hydrologic Basin

Figure 4.2. Conceptual Site Model



Note: Arrow thickness indicates relative magnitude of groundwater flow

Conceptual Site Model

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FIGURE

4.2

- A comprehensive analysis of RGA water level data, UCRS lithology and moisture content, and land use (see Section 3.3) indicates areas of increased recharge in the plant area are associated with roof drains, surface water discharges, and leaks in the TVA supply line (see Figure 3.11). Historical and present groundwater level data indicate the presence of a divide in the eastern portion of the plant area that is coincident with some of these areas of increased anthropogenic recharge.

Post plant shut-down water level monitoring of the RGA in the plant area indicates negligible change in water levels suggesting leaks in subsurface piping and roof drain systems provide a continuing source of anthropogenic recharge.

Steady-state conditions can be assumed for periods where boundary conditions such as the Ohio River stage and precipitation rates are relatively constant. In periods of more extreme and variable boundary conditions more typical of winter and springtime, the groundwater flow system exhibits more transient conditions due to time dependent storage near surface water bodies in response to fluctuating stage elevations.

Recharge within the PGDP Hydrologic Basin is as presented below.

- The most significant source of recharge within the PGDP Hydrologic Basin is precipitation with likely ranges between 2.64 inches/year and 7.64 inches/year over the model area (DOE 2010, Section 4.6.1).

- The portions of LBC and BC starting at the southern extent of the PGDP Hydrologic Basin lose water to the groundwater flow system (i.e., are losing streams). The total volume contributed to the groundwater flow system from LBC and BC is much less than the volume derived from precipitation.

- Anthropogenic recharge from leaking underground water supply lines, runoff from building roofs, infiltration from lagoons, and seepage through ditch and outfalls contribute recharge to groundwater.

- In the short-term, anthropogenic recharge is temporally and spatially variable and is dependent on precipitation, infrastructure integrity, and UCRS lithology.

- In the long-term, anthropogenic recharge appears relatively constant with minimal change following plant closure.

In summary, precipitation is the dominant recharge provider in the PGDP Hydrologic Basin, and characterizing anthropogenic recharge locations and rates is problematic.

Groundwater discharge is as follows:

- Most groundwater within the PGDP Hydrologic Basin discharges to the Ohio River.

- Groundwater also discharges to the lower portions of BC and LBC (i.e., the lower portions are gaining streams).

The following is a summary of hydraulic conductivity for the three PGDP HUs based on measurements via pumping, slug, and laboratory permeameter testing and PGDP Hydrologic Basin bulk hydraulic conductivity estimates (Section 4.5, DOE 2010):

- Pumping tests indicate RGA horizontal hydraulic conductivity values range between 100 ft and 3,600 ft/day.

- The assumption that all recharge enters the RGA indicates the bulk RGA hydraulic conductivity ranges between 713 ft and 2,063 ft/day.

- The average horizontal UCRS hydraulic conductivity derived from slug testing is 0.28 ft/day. Permeameter testing yielded an average UCRS vertical hydraulic conductivity of 0.03 ft/day.

- Slug and permeameter testing yielded average McNairy horizontal and vertical hydraulic conductivities of 0.30 ft and 0.02 ft/day, respectively.

In summary, RGA hydraulic conductivity is much greater relative to either the UCRS or McNairy hydraulic conductivity and serves as a basis for excluding the latter two units from the model domain.
Finally, with respect to the PGDP Hydrologic Basin groundwater mass balance:

- Estimated cumulative groundwater recharge ranges between 3,625 and 9,685 gpm (697,860 ft^3/day and 1,864,492 ft^3/day).

- Estimated cumulative groundwater discharge ranges between 1,161 and 15,434 gpm (223,508 ft^3/day and 2,971,251 ft^3/day) (DOE 2010; Section 4.10).

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5. MODEL CONFIGURATION

5.1 MODEL DISCRETIZATION

The model used for this study simulates groundwater flow in the RGA, the primary conveyor of groundwater from the PGDP site to the Ohio River. The model was discretized into three model layers and consists of 525 rows and 627 columns with a constant width of 50 ft. Constant cell size dimensions were used to ensure that future versions of the model could simulate contaminant transport and be used for remedial design evaluation anywhere within the model domain.

The top elevation of model layer 1 corresponds to the top elevation of the RGA, and the bottom elevation of model layer 3 corresponds to the bottom elevation of the RGA (HU5) or, when present, fine sands contiguous to HU5 (HU5A, see Figure 3.1). Equivalently, the bottom elevation of model layer 3 corresponds to the top elevation of silts and clays of the McNairy. The RGA was divided into three layers of equal thickness to allow future versions of the transport model to simulate more accurately the observed vertical movement of dissolved contamination within the RGA. Water quality results show that dissolved TCE contamination tends to migrate downward toward the bottom of the RGA with distance away from PGDP.

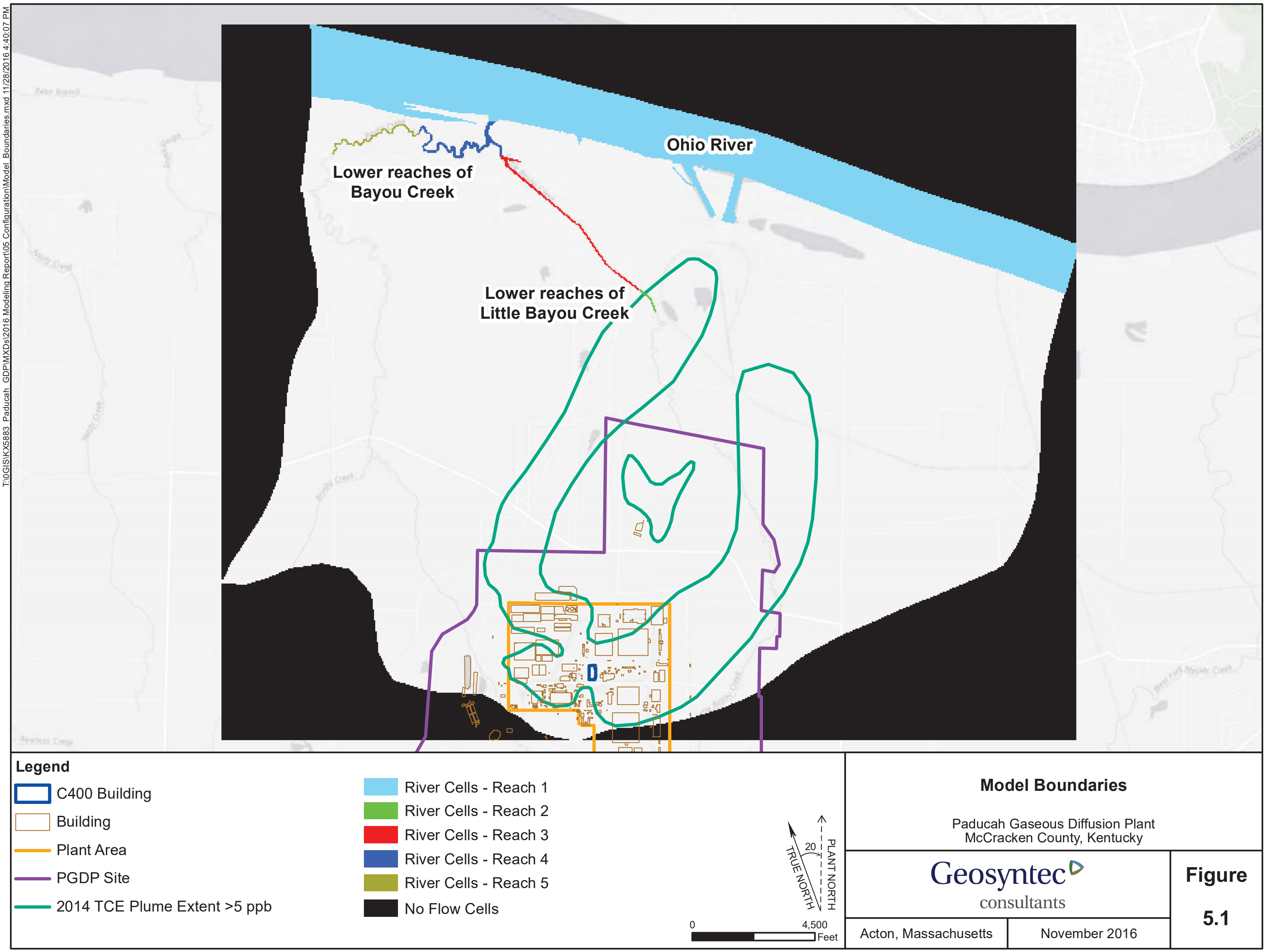
5.2 MODEL BOUNDARY CONDITIONS

Model boundary conditions contribute, remove, or prevent the movement of water within the model domain. Boundary conditions can be further characterized as located along the exterior and within the interior of the model domain. While technically a boundary condition, recharge is typically viewed as a parameter (analogous to hydraulic conductivity) and, as such, will be discussed in Section 5.3.2.

Boundary conditions that define the exterior model boundaries located in model layers 1 through 3 are illustrated in Figure 5.1. The black areas represent no flow cells and define, as the name implies, areas where water does not enter or leave the model. The no flow boundaries along the east and west correspond to flow lines derived from topographic highs (i.e., surface water divides) that are sufficiently distant from the area of interest. The no flow boundary along the southern model boundary is coincident with the pinch out of the RGA at the Terrace slope. Groundwater flow originating in the Terrace Gravel that recharges the RGA through the UCRS along the southern boundary is included in the model through recharge specified in the grid block adjacent to the boundary along the East and West Terrace Basins (Section 5.3.2). And the no flow boundary on the north is coincident with the divide along the Ohio River that results from groundwater flow discharging to the river from the north and the south.

The bottom of model layer 3 is also a no flow boundary and corresponds to the top of the McNairy. It is recognized that groundwater flow does occur in the McNairy; however, the groundwater flow rates are significantly less than those of the RGA. Because of the minimal water transmission capabilities, the McNairy was excluded from the model.

Within the model domain, the Ohio River is configured in layer 1, 2 and 3 using river cells. Simplistically, river boundary cells have head and conductance components that control the amount of water entering or leaving the cell. If the groundwater level in the cell is higher than the specified river stage elevation value, then water discharges from the cell to the river. Conversely, if the groundwater level is lower than the specified river stage elevation value, then water recharges the cell from the river. The river cell conductance, which represents the silt layer at the bottom of river, provides resistance to flow in and out of the river cells. For each steady-state stress period, the Ohio River was assigned a river



Plume Contour Source: DOE, 2015a; Figure C.2

Figure 5.1. Model Boundaries

stage equal to the daily average for the thirty days prior to the date that the water level elevations used for calibration were measured, except as previously noted (see Section 3.4). The "best" conductance value was determined during model calibration.

The lower reaches of BC and LBC that are hydraulically connected to the RGA also were configured in layer 1 using river boundary conditions. The stage of the creeks was derived from available information on the creek bottom slopes, the elevation of the mouth of BC, and typical depths for the creeks. The creek bottom slopes were obtained from a May 1994 floodplain investigation performed by the Army Corps of Engineers (COE 1994). The bottom slopes for BC and LBC used to calculate stage are 0.00085 and 0.0006, respectively. The elevation of the mouth of BC was estimated to be 300 ft from an August 2015 bathymetric survey performed by the Army Corps of Engineers along Miles 947 to 949 of the Ohio River. The depth of LBC is commonly less than 1 to 2 ft, and BC typically is less than 3-ft to 4-ft deep; thus, depths of 1.5 ft and 3 ft were assumed for LBC and BC, respectively. The creek stages derived from this information were overridden by the Ohio River stage in some model simulations (i.e., for one validation dataset and one sensitivity analysis simulation where the derived creek stage for a cell was less than the Ohio River stage, the Ohio River stage was used instead). Conductance values for the creeks were determined during model calibration.

The upper reaches of BC and LBC, which are in hydraulic connection with the UCRS, were simulated using recharge cells, and, while these features are technically boundary conditions, because they were simulated using recharge cells, the creeks will be discussed in Section 5.3.2.

Metropolis Lake was not configured using a surface water boundary condition but rather with a hydraulic conductivity value of 50,000 ft/day assigned to the area corresponding to the lake in model layer 1. Use of a high hydraulic conductivity value results in a near horizontal water table (lake surface) in the feature that can move up and down during the calibration process and remain neutral with respect to the groundwater mass balance.

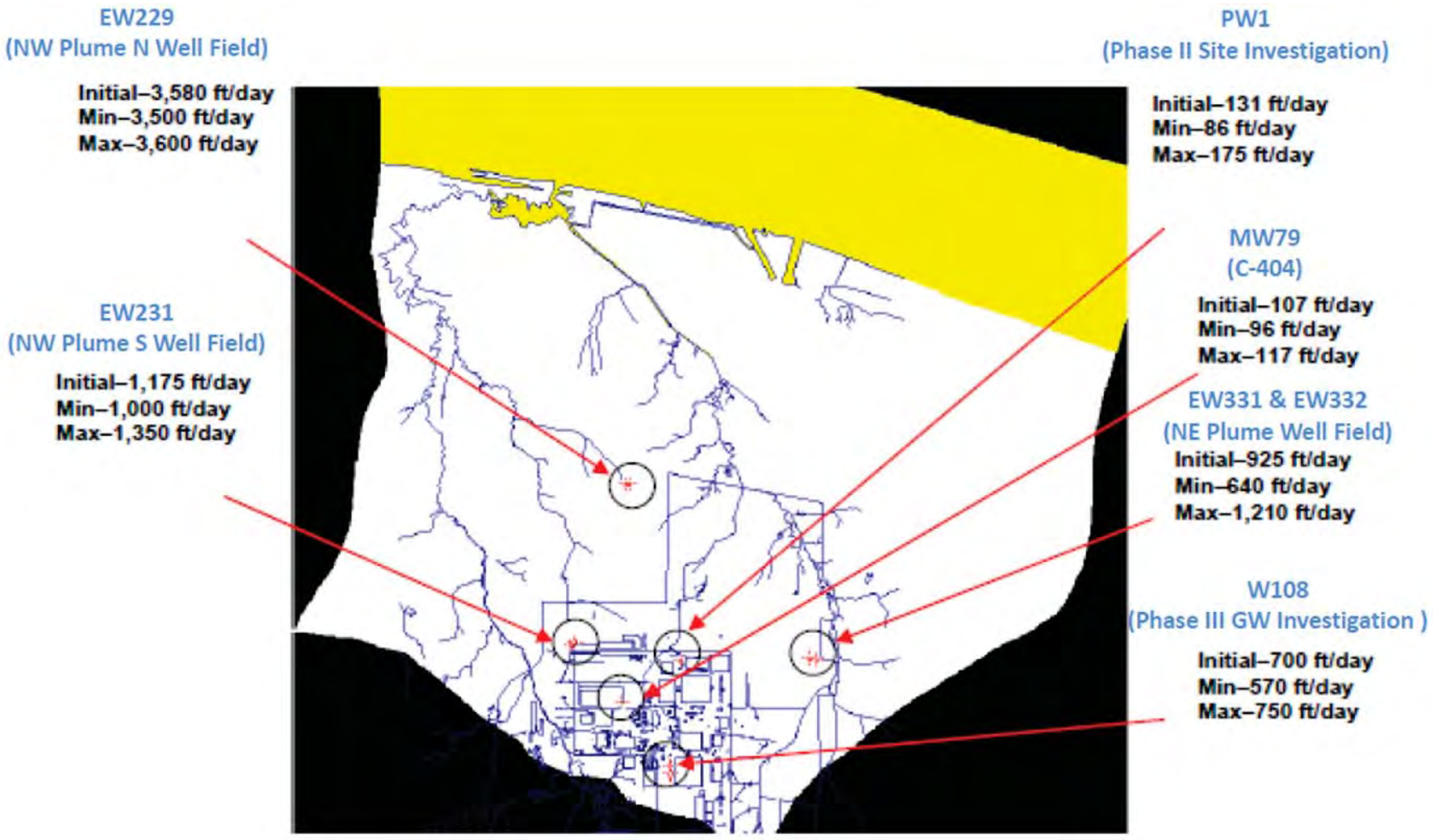
5.3 PARAMETER DISTRIBUTION

5.3.1 Hydraulic Conductivity Zonation

Horizontal and vertical hydraulic conductivity distribution within the model domain was determined using pilot-points (Doherty 2015). To implement the technique, pilot points are located within the model domain and assigned initial, minimum, and maximum hydraulic conductivity values. Automated model calibration adjusts the pilot points between the minimum and maximum hydraulic conductivity values using nonlinear regression techniques. Kriging is used to interpolate hydraulic conductivities between the points for each pilot point modification. The "calibrated" hydraulic conductivity configuration is the continuous hydraulic conductivity field that produces the best match with the calibration targets. For this application, the horizontal to vertical hydraulic conductivity ratio was assumed constant at 10:1.

Pilot points can be assigned locations and initial hydraulic conductivity values corresponding to well location and aquifer test results, respectively. For this application, pilot points were located where pumping tests had been conducted and assigned initial, minimum, and maximum hydraulic conductivity values corresponding to the pumping test results (Figure 5.2).

Pilot points were used to determine hydraulic conductivity distribution in model layers 1 through 3 at locations absent of pumping test results (Figure 5.3). Greater pilot point density was used in the plant area and within the groundwater plumes to allow for more detailed discretization of hydraulic conductivity in



Extraction Well Locations and Pumping Test Results

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec consultants

ACTON, MASSACHUSETTS | NOV 2016

FIGURE 5.2

Source: DOE, 2010; Figure 6.1 (the 2008 model domain is shown)

Figure 5.2. Extraction Well Locations and Pumping Test Results

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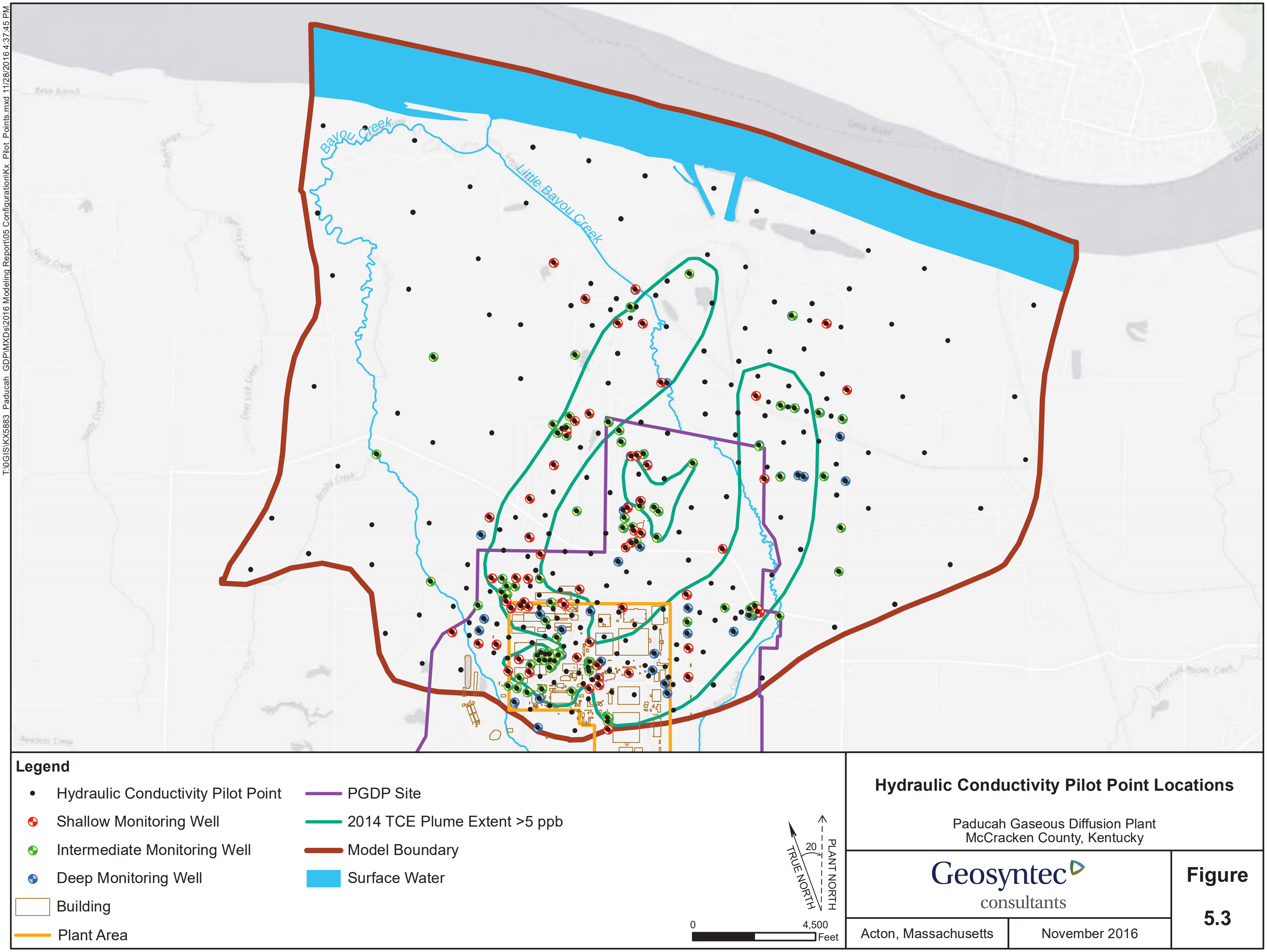
Figure 5.3. Hydraulic Conductivity Pilot Point Locations



Plume Contour Source: DOE, 2015; Figure C.2

these areas. Pilot points were assigned at target locations in accordance with the following guidance described by Doherty (2016):

- Good spread throughout the domain extending to model boundaries;
- Not too close unless in area of disparate field measurements;
- Between boreholes with substantial head differences; and
- Locations at which key model predictions are most sensitive to calibrated value.

These guidelines were applied to layer 1 for the full set of calibration targets regardless of layer. Then the same locations were copied to layers 2 and 3 resulting in a total of 1,041 pilot points. In model layers 1 through 3, pilot points other than those with aquifer test results were assigned initial horizontal hydraulic conductivity values of 300 ft/day and constrained to minimum and maximum values of 100 ft/day and 3,600 ft/day outside the plant area and 100 ft/day to 1,500 ft/day in the plant area. The different constraints inside versus outside the plant area are based on pumping test results that indicate hydraulic conductivities less than 1,500 ft/day at test locations inside and near the plant area and hydraulic conductivities as high as 3,600 ft/day at test locations outside the plant area (Figure 5.2). Initial values are adjusted within the maximum and minimum value during the calibration process. Initial vertical hydraulic conductivities were assumed to be one-tenth of the initial horizontal hydraulic conductivity estimates.

5.3.2 Recharge Zonation

Both recharge from precipitation and anthropogenic recharge are represented in the model. To incorporate inflow from the Terrace, estimated total flow (see Section 3.2) was assigned to cells along the southern model boundary. Additionally, creek recharge in the upper reaches of BC and LBC in the PGDP Hydrologic Basin are represented in the model using recharge cells. The basis for specifying recharge in the upper reaches of the creeks is based on studies indicating the primary source of flow in the upper reaches of the creeks originates as process effluent or surface water runoff from the PGDP Site and minimal exchange occurs between shallow groundwater and adjacent ditches on the PGDP Site (DOE 2008b). Additionally, a study of BC and LBC conducted between 1996 and 1998 concluded that both creeks tend to gain flow where they are incised into the RGA or contiguous strata in the Ohio River flood plain, BC gains flow upstream of PGDP, and the remaining reaches of both creeks tend to lose flow (Fryar et al. 2000). While there are no springs near the PGDP site, seeps are present over a limited stretch of LBC near the Ohio River where the hydraulic potential within the RGA exceeds the elevation of the creek (DOE 2008c). Recharge zonation for the model domain and within the plant area is illustrated on Figures 5.4 and 5.5.

Recharge associated with precipitation (Zone 2) was assigned to all cells except those containing surface water and anthropogenic features. Open areas within the plant area, which also could be considered as ambient recharge, were assigned to Zone 12. The cells representing the Ohio River and lower reaches of BC and LBC were assigned a zero recharge rate (Zone 1). This was done because water falling on the surface water bodies in contact with the RGA does not enter the groundwater flow system. Recharge from precipitation was assigned an initial value of 5.14 inches/year and minimum and maximum allowable values of 2.64 inches/year and 7.64 inches/year.

The creeks were simulated with multiple recharge zones to allow for different recharge rates during calibration. BC was assigned three zones to represent the upper most reach receiving plant discharge (Zone 3), BC (Zone 4), and its tributary (Zone 5). LBC was assigned Zone 6 and its tributary was assigned Zone 7. It was assumed that the recharge from the creeks would not be less than ambient recharge; therefore, the minimum recharge constraint for the creeks was set to 7.64 inches/year. The maximum constraint for creek recharge was set to 40 inches/year, based on the median UCRS hydraulic conductivity presented in Table 3.5 and the assumption of 70% clay/silt as a representative value for the UCRS.

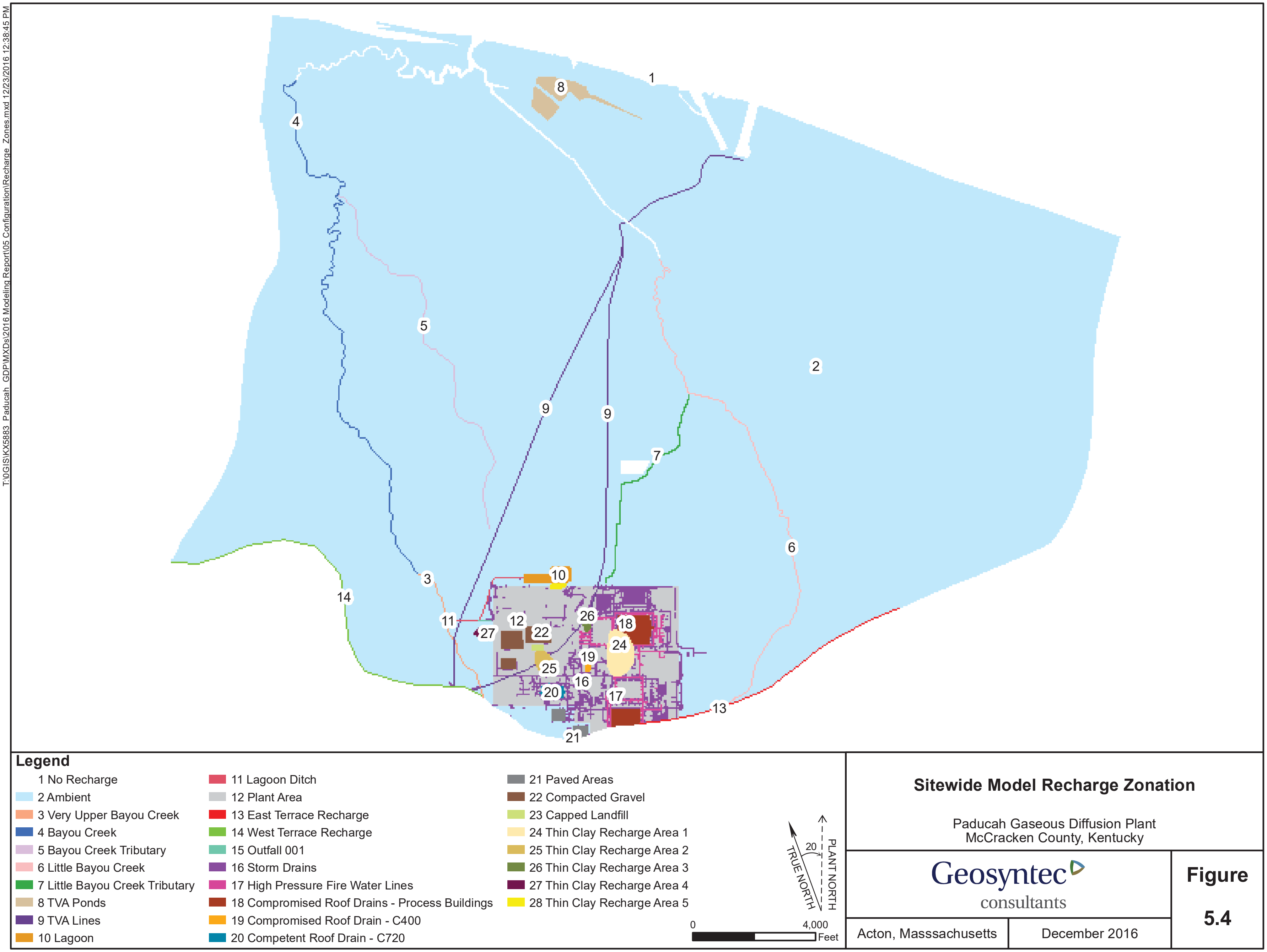


Figure 5.4. Sitewide Model Recharge Zonation

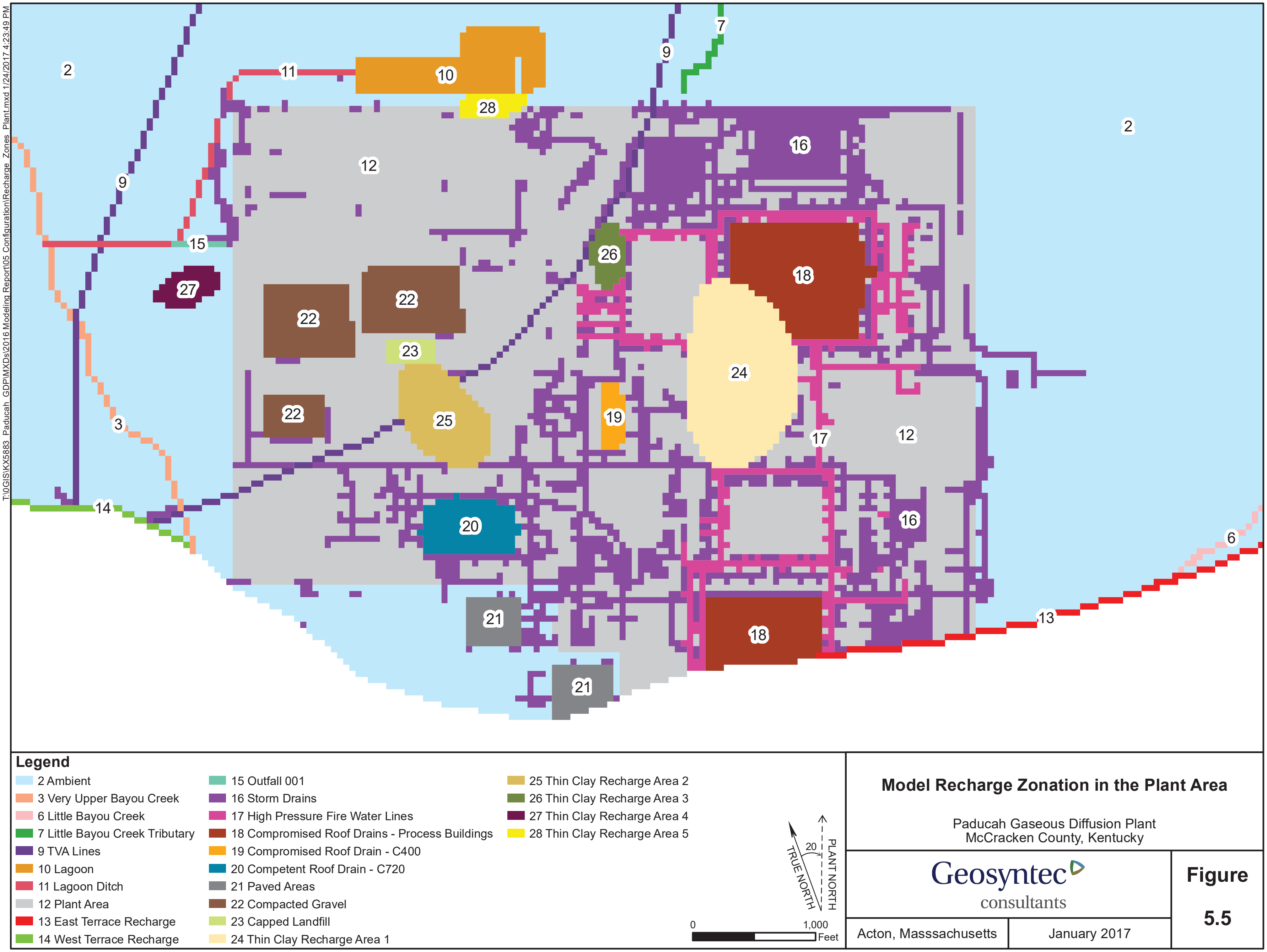


Figure 5.5. Model Recharge Zonation in the Plant Area

Initially, the geometric mean hydraulic conductivity presented in Table 3.5 was used for determination of maximum recharge constraints based on lithology; however, the constraints were adjusted to the median hydraulic conductivity following initial calibration runs in which the majority of recharge zones were estimated to be a value equal to the maximum calibration constraint by PEST.

To simulate anthropogenic recharge, distinct zones were assigned to man-made features based on a review of the following information (summarized in Section 3.3): plant operations, UCRS lithology, potentiometric surface, and plume delineation. Specific man-made features include the TVA ponds (Zone 8), TVA water supply lines (Zone 9), the C-616 lagoon (Zone 10) and drainage ditch (Zone 11), and Outfall 001 (Zone 15). Within the main plant area anthropogenic recharge was simulated with multiple zones corresponding to storm water piping (Zone 16), HPFW piping (Zone 17), roof drains (Zones 18 and 19), the reported leak in the TVA supply line (Zone 9), and areas identified with less than 2 ft of clay at the top of the RGA (HU3) (Zones 24 through 28). The recharge areas for the storm water and HPFW piping zones were based on the location of the piping systems illustrated on Figure 3.11. All the anthropogenic recharge zones were assumed to have recharge values greater than ambient; therefore, the minimum recharge constraint for the anthropogenic recharge zones was set to 7.64 inches/year. The maximum recharge constraint for all anthropogenic recharge zones was based on the evaluation of UCRS lithology. With the exception of the thin clay zones, the maximum recharge constraint for the anthropogenic recharge zones was set to 40 inches/year, as was done for recharge to the creeks. For the thin clay zones, the maximum recharge constraint was set to 83 inches/year, which is based on the median UCRS hydraulic conductivity and the minimum percentage of clay/silt observed in the plant area (Table 3.5).

In addition to the enhanced anthropogenic recharge zones described above, several zones of reduced recharge were assigned to anthropogenic features. Namely, the competent roof drain of the C-720 building (Zone 20), paved areas (Zone 21), compacted gravel (Zone 22), and the C-404 capped landfill (Zone 23). The area of competent roof drains is expected to have minimal recharge due to effective drainage to storm water ditches, and Zones 21 through 22 are expected to have minimal recharge due to their relatively low permeability. The initial recharge value for these four reduced recharge zones was set to 0.001 inch/year, with a minimum constraint of 10-6 inch/year and a maximum constraint of 1 inch/year.

Groundwater flow from the Terrace along the East and West Terrace Basins were assigned to cells along the southern model boundary in Zones 13 and 14, respectively. Based on the estimated maximum annual average underflow presented in Table 3.2, the maximum recharge constraints for the Terrace recharge cells were set to 764 inches/year and 392 inches/year for the East and West Terrace Basins, respectively. The estimated minimum seasonal underflow for September was used as the minimum recharge constraint so that dry season conditions could be better represented by the model. Accordingly, the minimum recharge constraints set for the East and West Terrace basins were 45.6 inches/year and 23.4 inches/year, respectively.

Recharge zone values were determined during calibration. To allow for variation of recharge rates over the model simulation periods, Zones from the first stress period were duplicated in subsequent stress periods and assigned the zonation numbers that increase incrementally by 100 for each stress period.

For example the recharge area assigned to Zone 12 in stress period 1 is assigned to Zone 112 in stress period 2, allowing variable rates to be calibrated for each steady-state stress period.

5.3.3 Storage and Porosity

Specific storage is only specified for the transient calibration (see Section 6.9) and was assigned a value of 0.0002 ft^{-1}. Using an approximate RGA thickness of 30 ft, this translates to a storativity of 0.006. Porosity within the model domain was assigned a uniform value of 30%.

6. MODEL CALIBRATION

Model calibration was performed using PEST and PEST-SVD Assist coupled with pilot points (Doherty 2015; Doherty 2016). PEST, from which PEST-SVD Assist is developed, is a parameter estimation code that automatically determines the best parameter values for a model as configured. Parameters are model input values, such as hydraulic conductivity and recharge, and are adjusted during model calibration. Using pilot points, the PEST auto calibration determines "best fit" parameter distributions for the model given specific boundary configurations and target values. For this application, pilot points were used to assign hydraulic conductivity. The model is configured to simulate steady-state conditions.

While the underlying mathematics comprising parameter estimation and pilot points is complex, the concept behind the parameter estimation algorithm is simple and is identical to the thought process used with traditional trial-and-error calibration, which is, find the combination of parameters that results in the smallest difference between observed and model-predicted water levels, flow directions, and groundwater discharges.

During the calibration process, hydraulic conductivity and recharge parameters were constrained and PEST results were interpreted and parameter constraints were revised to be consistent with the CSM and expected parameter ranges based on analysis of site data as described in Section 3. This process of PEST calibration, followed by parameter adjustment informed by the CSM, was used to iterate to the final calibration.

6.1 CALIBRATION STRESS PERIODS

As described in Section 3.4, a total of five stress periods were identified as suitable for the steady-state model calibration based on available groundwater elevation, precipitation, and Ohio River stage data. For the model described herein, a two-stress period model simulating pre-pumping groundwater conditions in 1995 (Stress Period 1; SP1) and steady-state groundwater conditions in September 2014 (Stress Period 2; SP2) was used for calibration. The inclusion of the 1995 data set is necessary because it includes trajectory targets along the full length of the plume under non-pumping conditions, which is necessary to simulate flow path direction (consistent with previous modeling efforts in 2008 and 2012). The September 2014 data set was chosen because it is representative of steady-state conditions, and precipitation in 2014 was approximately the same as the average annual precipitation calculated from 1995 to 2016 for each year for which water level data were available (see Figure 3.15). This calibration effort builds upon previous efforts of the 2012 model which included the use of up to seven stress periods.

6.2 CALIBRATION TARGETS

Model calibration requires targets as bench marks for evaluating the reliability of the model results. The following calibration targets were derived from site data collected during the model simulation period from 1995 to 2014:

- Monitoring well groundwater elevation targets;
- Flux targets from seepage measurements in LBC;
- Hydraulic conductivity derived from pumping tests; and
- Flow direction or trajectory targets from plume flow paths.

This section describes the calibration targets used in the model and the process undertaken in selecting the targets.

6.2.1 Water Level Elevation Targets

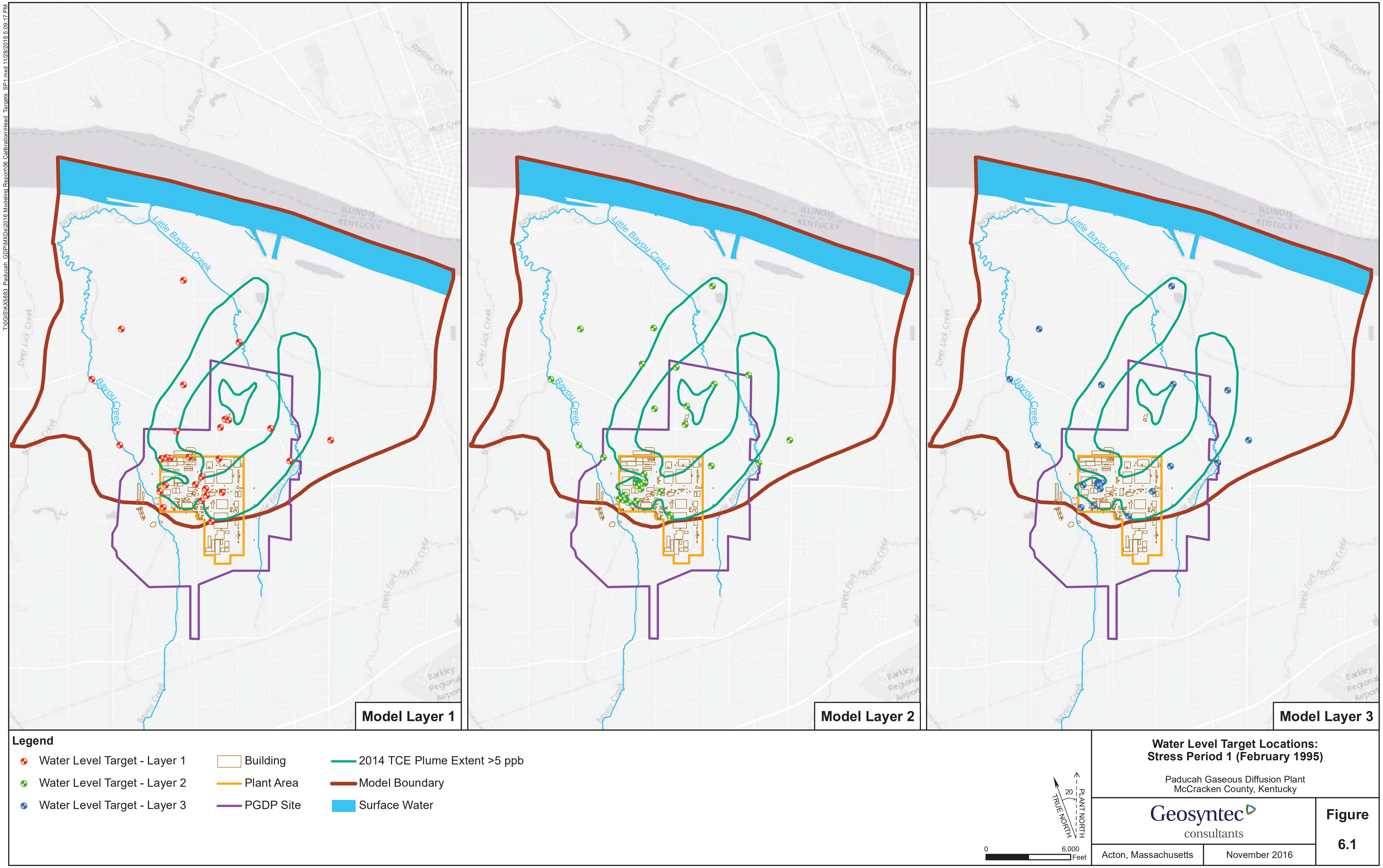
Water level elevations measured during synoptic water level measurement events within both of the steady-state stress periods were used as calibration targets. The 1995 water level dataset was used for SP1 primarily because it occurred prior to initiating pumping of the extraction wells in August 1995 and includes measurements from 76 monitoring wells. As site investigations continued, the number of monitoring wells increased. The September 2014 measurement period was selected for SP2 to represent steady-state conditions with the current extraction systems in operation (i.e., pumping from EW231 and EW232 in the Northwest Plume and from EW331 and EW332 in the Northeast Plume) and includes 206 monitoring wells. The locations of the targets within each model layer are presented in Figures 6.1 and 6.2 for SP1 and SP2, respectively. Target values are listed in Appendix C. Note that in some locations where target density was sparse and monitoring wells were present in a single layer, the target for that well was included in all layers. These wells are annotated in Appendix C [e.g., MW194_(L2toL1)] to indicate that the value was added from another layer.

Water level elevation targets were assigned a weight of one based on their measurement accuracy relative to other target types used in the calibration. The weight is related ideally to the inverse of the measurement error. Hence, a target with a large measurement error would be assigned a small weight relative to a target with a lower measurement error. The use of weights facilitates meaningful comparison of dissimilar target types, such as water level and flux targets.

6.2.2 Flux Targets

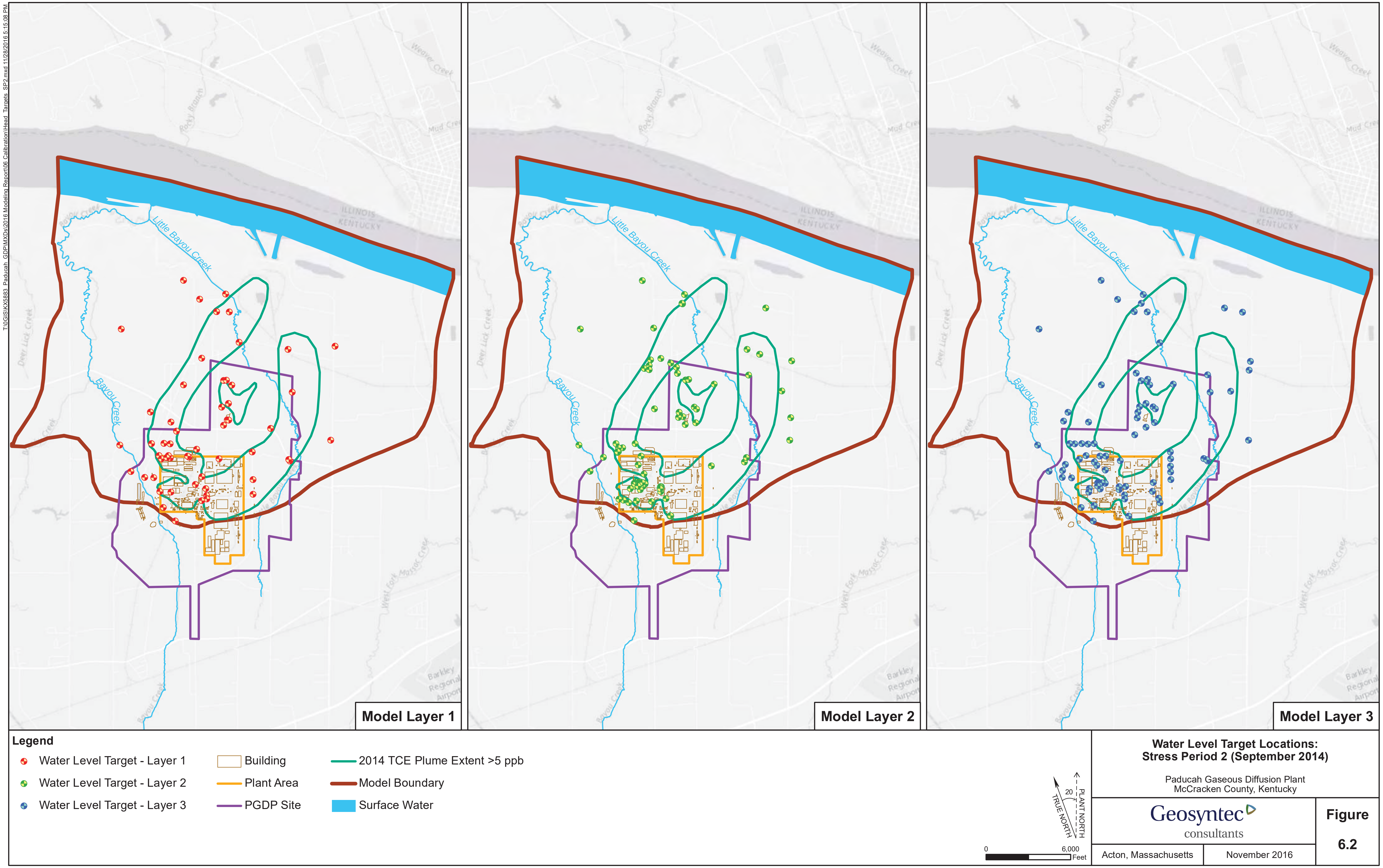
A flux target of 14,850 ft^3/day (77.1 gpm) was assigned to the river cell at the top of river reach 2 in LBC in both stress periods (Figure 6.3). This target value is in line with ranges provided by Tripathi and Fryar (USGS 2013). Flux measurements are at a different scale than water level measurements. For example, a 1-ft difference in water levels represents a different degree of accuracy than a 1 ft^3/day difference in flux. Based on experience, matching the flux target within a value of approximately 50% would be considered a good match. To keep the flux target from dominating the calibration, the target was assigned a weight of 0.003, which, when multiplied by the difference between the predicted and target flux values, produced a weighted target difference of between 45 and 139 (unitless) if the predicted flux value in ft^3/day reaches the extreme calculated values of either the estimated minimum of 0 ft^3/day (0 gpm) or the maximum flux of 61,411 ft^3/day (319 gpm). Selection of the weighted difference is entirely arbitrary and is based on professional judgment. See Section 7.1.2 of the 2010 report on the 2008 GW Model Update for additional discussion about the interpretation of weighted differences (DOE 2010).

The groundwater discharge to the Ohio River was estimated to be in the range of 228 gpm to 8,218 gpm based on Darcy's Law and estimated values for hydraulic conductivity (100 ft/day to 3,600 ft/day), hydraulic gradient (4.4×10^{-4} ft/ft), RGA aquifer thickness (35 ft), and Ohio River length (28,535 ft) (DOE 2010, Section 4.8.1). Initially, a flux target for the Ohio River was included in the calibration process, but due to the wide range of estimated values and uncertainty regarding the estimated target value, a minimal weighting factor was applied such that the target provided minimal contribution to the objective function. Consequently, the Ohio River flux was excluded as a target in subsequent calibration efforts in lieu of evaluating flux to the Ohio River in the post-calibration review of mass balance.



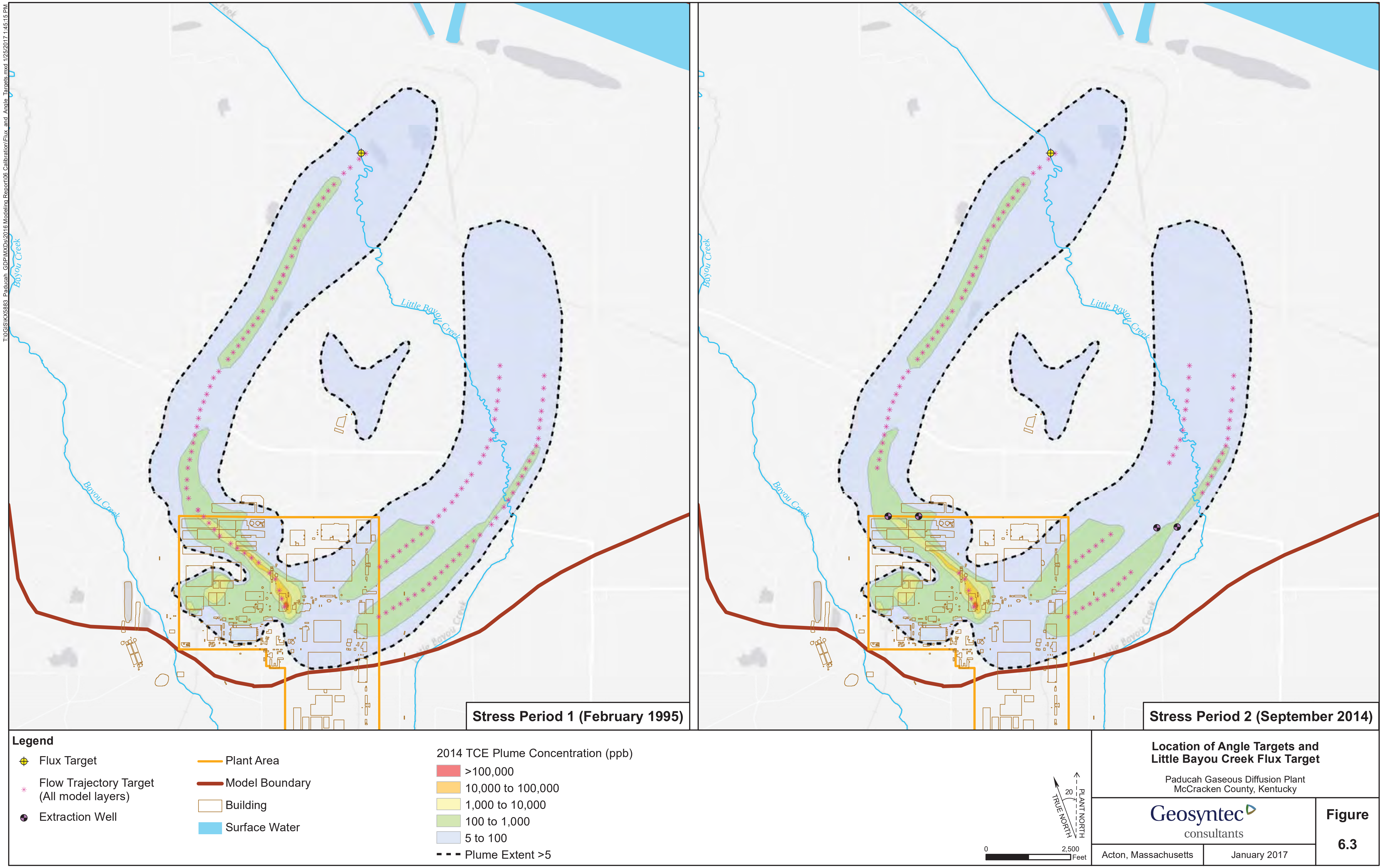
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.1. Water Level Target Locations: Stress Period 1 (February 1995)



Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.2. Water Level Target Locations: Stress Period 2 (September 2014)



Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.3. Location of Angle Targets and Little Bayou Creek Flux Target

6.2.3 Angle (Trajectory) Calibration Targets

Angle targets along the centerline of the Northwest Plume and Northeast Plume cores, delineated by TCE concentrations greater than 100 μ/L (ppb), were assigned in each steady-state stress period. Northwest Plume trajectory targets were located by digitizing along a line coincident with the core of the plume starting at C-400 Building going northward to LBC. Northeast Plume trajectory targets were located by digitizing along the plume cores from the eastern fence line of the plant area and approximately 5,000 ft beyond LBC to capture the change in plume alignment from northeast to a more northerly direction. For the 2014 stress period, trajectory targets were removed near pumping wells. The total number of angle targets assigned in SP1 and SP2 is 357 and 261, respectively. Angle targets were assigned a weight of 0.1 based on preliminary calibration results that indicated that this value provided a satisfactory balance between matching angle targets and water level targets.

6.2.4 Hydraulic Conductivity Pilot Points

Pilot points were assigned to model layers 1 through 3 as described in Section 5.3.1. During the automated calibration process, horizontal hydraulic conductivity was estimated at each pilot point. These values were then spatially interpolated to the model grid using kriging to provide a continuous hydraulic conductivity field. To add stability to the parameter estimation process, PEST was run in preferred value regularization mode. In other words, PEST added the initial pilot point hydraulic conductivity values to the regression analysis as targets such that estimates that stray far from the initial values are penalized in the algorithm. To keep the pilot point residuals from dominating the regression analysis, PEST calculated a pilot point weighting factor such that the contribution to the objective function from the hydraulic conductivity residuals at pilot points is minimized compared to the contribution from observed calibration target residuals. Refer to the PEST User Manual for additional details on the regularization process.

6.3 PEST

6.3.1 Parameter Sensitivities

During calibration using PEST, composite parameter sensitivities were reviewed periodically to determine the relative sensitivity of the parameters being estimated. In general, parameters with sensitivities within two orders of magnitude of the most sensitive parameter can be estimated with reasonable accuracy during the calibration (Hill 1998). It may or may not be possible to estimate accurately the parameter values for parameters having sensitivities within two to three orders of magnitude of the most sensitive parameter. Sensitivities that are more than three orders of magnitude less sensitive than the most sensitive parameter cannot be estimated with reasonable accuracy. Scaled composite sensitivities relative to the most sensitive parameter were reviewed during the calibration process, and final relative composite scaled sensitivities are presented in Section 6.6.

6.3.2 Estimated Hydraulic Conductivity and Transmissivity Values

The estimated horizontal hydraulic conductivity distributions for model layers 1 through 3 are shown in Figure 6.4. Predicted pilot point hydraulic conductivity values range between 86 ft/day and 3,600 ft/day and average 1,201 ft/day. Within the plant area, pilot point hydraulic conductivity values range between 86 ft/day and 1,500 ft/day and average 743 ft/day. Summary statistics are compiled in Table 6.1. The average hydraulic conductivity across the model domain (interpolated at each grid block and excluding Metropolis Lake) is 622 ft/day. In general, higher hydraulic conductivities are predicted east and west of the plant area extending toward the north to the Ohio River with relatively lower hydraulic conductivities

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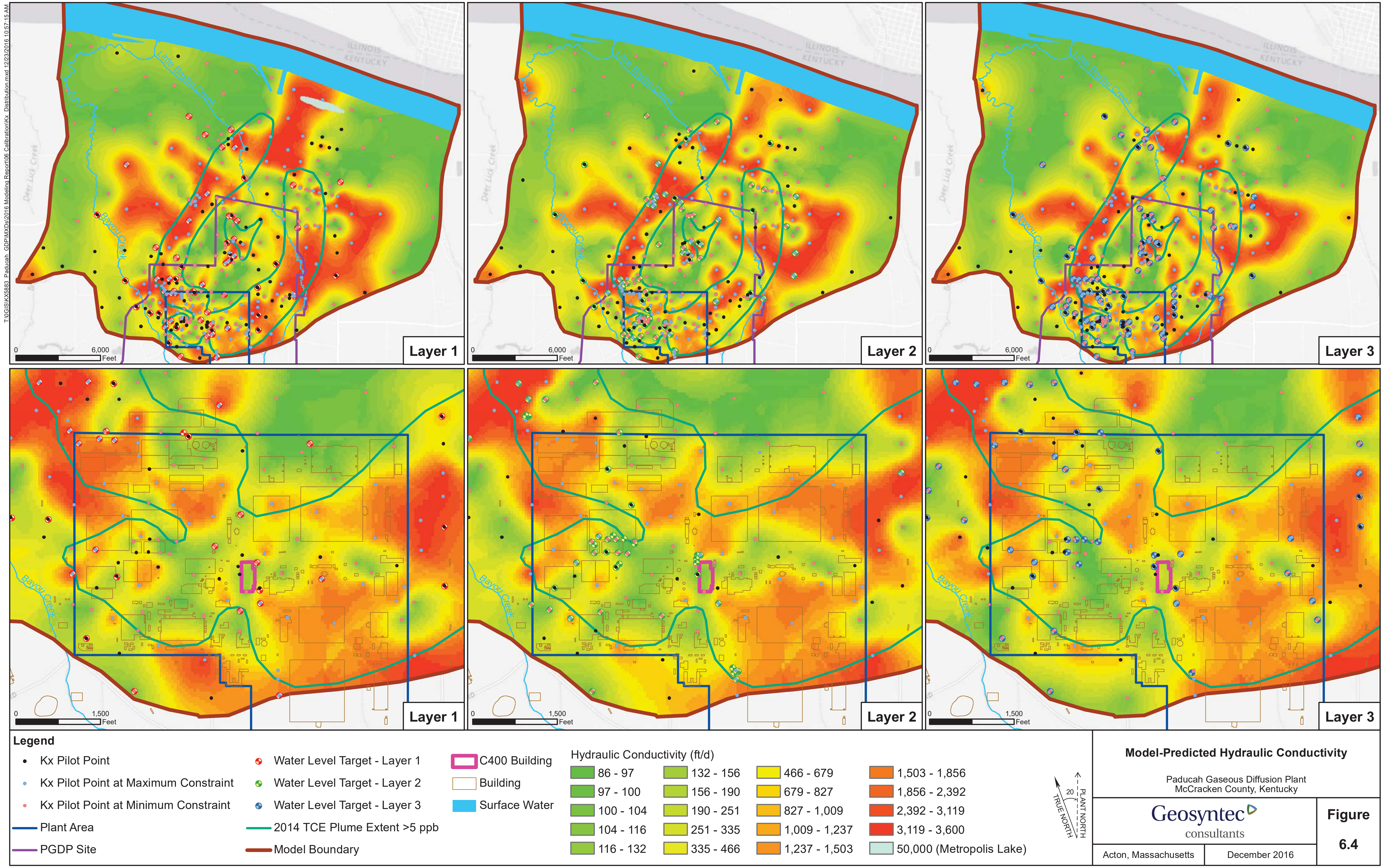

Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.4. Model-Predicted Hydraulic Conductivity

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Table 6.1. Calibrated Hydraulic Conductivity Statistics—Pilot Points and Model Domain

Hydraulic Conductivity (ft/day)	All Layers	Layer 1	Layer 2	Layer 3
All Hydraulic Conductivity Pilot Points				
Average	1,201	1,201	1,196	1,208
Median	311	312	355	232
Geometric Mean	450	453	454	444
Standard Deviation	1,409	1,404	1,403	1,420
Maximum	3,600	3,600	3,600	3,600
Minimum	86	86	96	96
Range	3,514	3,514	3,504	3,504
Number of Pilot Points	1,041	347	347	347
Plant Area Hydraulic Conductivity Pilot Points				
Average	743	739	757	734
Median	467	489	447	447
Geometric Mean	401	400	406	399
Standard Deviation	649	644	658	645
Maximum	1,500	1,500	1,500	1,500
Minimum	86	86	96	96
Range	1,414	1,414	1,404	1,404
Number of Pilot Points	253	84	84	85
Model Domain Hydraulic Conductivity				
Average	622	672	629	566
Median	217	210	237	205
Geometric Mean	312	326	324	287
Standard Deviation	835	903	814	779
Maximum	3,600	3,600	3,600	3,600
Minimum	86	86	86	86
Range	3,514	3,514	3,514	3,514
Number of Domain Model Cells	658,557	219,121	219,718	219,718

Note: Metropolis Lake excluded from model domain statistics.

predicted beneath the plant area. The contrast between relatively higher and lower hydraulic conductivity generally is aligned with the plume trajectories and is a result of the PEST calibration process to minimize calibration target residuals (i.e., flow direction, water level, flux, hydraulic conductivity pilot points). The hydraulic conductivity distribution is consistent with hydraulic conductivity estimated from pumping tests indicating values from 107 ft/day to 1,175 ft/day in the plant area and 925 ft/day to 3,580 ft/day north and east of the plant area (Figure 5.2) and previous modeling efforts indicating similar contrast in hydraulic conductivity necessary to match site conditions as defined by the calibration targets.

Metropolis Lake is a surface water feature that represents the intersection of land surface and the water table. As such, Metropolis Lake is an area of both groundwater recharge and discharge. The recharge (inflow) equals discharge (outflow) so the lake's contribution to the groundwater flow system is neutral. In the model, Metropolis Lake was configured in layer 1 by assigning a hydraulic conductivity value of 50,000 ft/day to the area corresponding to the lake. Use of a high hydraulic conductivity value results in a near horizontal water table (lake surface) in the feature that can move up and down during the calibration process and remain neutral with respect to the groundwater mass balance.

Transmissivity is a term used to describe the permeability of a thickness of sediments. The transmissivity of the PGDP Hydrologic Basin was calculated by multiplying the layer predicted hydraulic conductivity values (Figure 6.4) by the layer thickness (Figure 3.4) and then summing the individual transmissivities of the three layers (Figure 6.5). In general, lower transmissivity areas are located along the Ohio River west of the TVA intake canals and east of Metropolis Lake and north of the plant area between the Northwest and Northeast Plumes. Transmissivity in the plant area is relatively lower compared to the area within the Northeast and Northwest Plumes and the area to the north of the plumes. The contrast of relatively high and low transmissivity aligned with the Northeast and Northwest Plumes is consistent with site data and necessary to match calibration targets, especially flow direction targets.

6.3.3 Estimated Recharge Values

Estimated recharge values for the calibrated model are summarized in Table 6.2 and illustrated on Figures 6.6 and 6.7. The process for calibrating recharge was iterative and relied on knowledge of relative composite sensitivities and intuitive knowledge based on the historical land use, plant operations, and the CSM. Recharge values estimated by PEST were evaluated following the automated calibration process, and limited manual calibration was performed to adjust values that approached their calibration constraints or otherwise seemed inconsistent with expected site conditions. The manual adjustments generally did not appreciably change the simulated flow directions or the calibration to flux and water level targets.

The predicted recharge rates for precipitation recharge estimated for SP1 and SP2 are 3.63 inches/year and 4.29 inches/year, respectively. These values comprise 8.0% and 9.5% of the average annual precipitation rate of 45.1 inches/year estimated in Section 3.4. The higher precipitation recharge value for SP2 relative to SP1 is counterintuitive because the SP1 calibration dataset was collected during the rainy season whereas the SP2 calibration dataset was collected during the dry season. The apparent inconsistency may be attributable to the non-steady-state conditions that prevail in SP1.

The creek recharge zones for LBC and BC tended to calibrate at either the maximum or minimum constraints during initial PEST runs. Manual adjustments were made to favor typical values (i.e., 20 inches/year) for creek recharge zones that had calibrated values at constraint limits. A somewhat higher value of 25 inches/year was assigned to very upper BC to account for the additional inputs expected from the plant area for that stretch of the creek.

Figure 6.5. Model-Predicted Transmissivity

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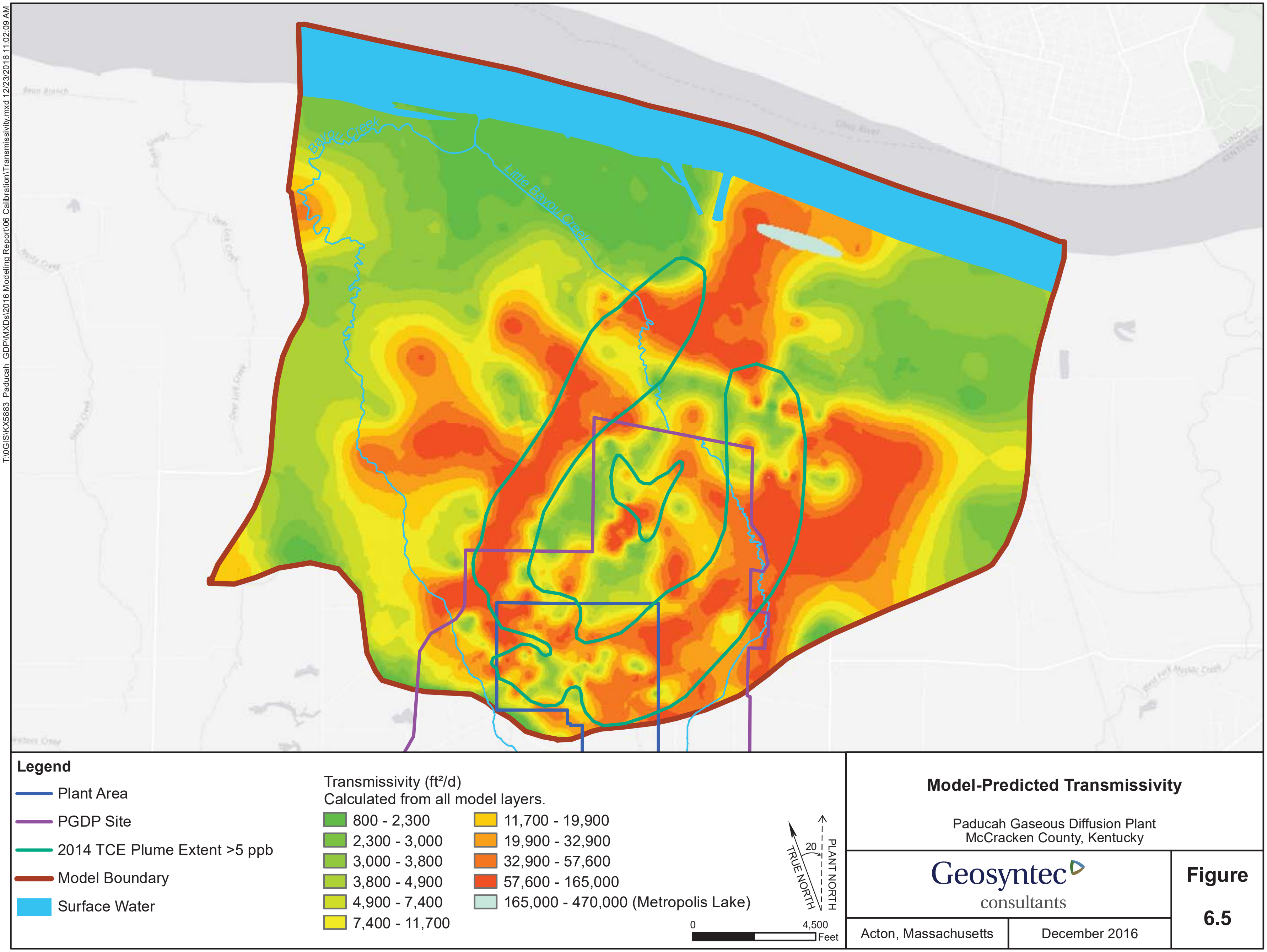

Elevation Data Source: Hydro-Litho-Stratigraphy Database, Revision 8, CAER KCREE 2016
Plume Contour Source: DOE, 2015; Figure C.2

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Table 6.2. Calibrated Recharge Rates

		Units in Ft per Day						Units in Inches per Year					
				Initial Recharge		Calibrated Recharge				Initial Recharge		Calibrated Recharge	
Zone	Model Parameter	Minimum Constraint	Maximum Constraint	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Minimum Constraint	Maximum Constraint	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
2	Ambient	6.00E-04	1.74E-03	8.41E-04	9.92E-04	8.30E-04	9.80E-04	2.6	7.6	3.7	4.3	3.6	4.3
3	Very Upper Bayou Creek	1.74E-03	9.13E-03	5.71E-03	5.71E-03	5.71E-03	5.71E-03	7.6	40.0	25.0	25.0	25.0	25.0
4	Bayou Creek	1.74E-03	9.13E-03	4.57E-03	4.57E-03	4.57E-03	4.57E-03	7.6	40.0	20.0	20.0	20.0	20.0
5	Bayou Creek Tributary	1.74E-03	9.13E-03	4.57E-03	4.57E-03	4.57E-03	4.57E-03	7.6	40.0	20.0	20.0	20.0	20.0
6	Little Bayou Creek	1.74E-03	9.13E-03	4.57E-03	3.97E-03	4.57E-03	3.97E-03	7.6	40.0	20.0	17.4	20.0	17.4
7	Little Bayou Creek Tributary	1.74E-03	9.13E-03	4.57E-03	4.57E-03	4.57E-03	4.57E-03	7.6	40.0	20.0	20.0	20.0	20.0
8	TVA Ponds	1.74E-03	9.13E-03	4.57E-03	4.57E-03	4.57E-03	4.57E-03	7.6	40.0	20.0	20.0	20.0	20.0
9	TVA Lines	1.74E-03	9.13E-03	2.06E-03	2.06E-03	2.06E-03	2.06E-03	7.6	40.0	9.0	9.0	9.0	9.0
10	Lagoon	1.74E-03	9.13E-03	2.74E-03	2.74E-03	2.74E-03	2.74E-03	7.6	40.0	12.0	12.0	12.0	12.0
11	Lagoon Ditch	1.74E-03	9.13E-03	2.28E-03	2.28E-03	2.28E-03	2.28E-03	7.6	40.0	10.0	10.0	10.0	10.0
12	Plant Area	6.00E-04	1.74E-03	8.41E-04	9.92E-04	8.30E-04	9.80E-04	2.6	7.6	3.7	4.3	3.6	4.3
13	East Terrace Recharge	1.04E-02	1.74E-01	1.60E-02	1.37E-02	1.60E-02	1.37E-02	45.6	763.8	70.0	60.0	70.0	60.0
14	West Terrace Recharge	5.34E-03	8.95E-02	8.20E-03	7.03E-03	8.20E-03	7.03E-03	23.4	392.0	35.9	30.8	35.9	30.8
15	Outfall 001	1.74E-03	9.13E-03	3.43E-03	3.43E-03	3.43E-03	3.43E-03	7.6	40.0	15.0	15.0	15.0	15.0
16	Storm Drains	1.74E-03	9.13E-03	3.29E-03	5.02E-03	3.29E-03	5.02E-03	7.6	40.0	14.4	22.0	14.4	22.0
17	High Pressure Fire Water Lines	1.74E-03	9.13E-03	4.29E-03	6.85E-03	4.29E-03	6.85E-03	7.6	40.0	18.8	30.0	18.8	30.0
18	Compromised Roof Drains - Process Buildings	1.74E-03	9.13E-03	6.85E-03	6.85E-03	6.85E-03	6.85E-03	7.6	40.0	30.0	30.0	30.0	30.0
19	Compromised Roof Drains - C400	1.74E-03	9.13E-03	2.28E-03	3.66E-03	2.28E-03	3.66E-03	7.6	40.0	10.0	16.0	10.0	16.0
20	Competent Roof Drain - C720	2.28E-10	2.28E-04	2.28E-07	2.28E-07	2.28E-07	2.28E-07	0.0	1.0	0.0	0.0	0.0	0.0
21	Paved Areas	2.28E-10	2.28E-04	2.28E-07	2.28E-07	2.28E-07	2.28E-07	0.0	1.0	0.0	0.0	0.0	0.0
22	Compacted Gravel	2.28E-10	2.28E-04	2.28E-07	2.28E-07	2.28E-07	2.28E-07	0.0	1.0	0.0	0.0	0.0	0.0
23	Capped Landfill	2.28E-10	2.28E-04	2.28E-07	2.28E-07	2.28E-07	2.28E-07	0.0	1.0	0.0	0.0	0.0	0.0
24	Enhanced Recharge at Thin Clay	1.74E-03	1.89E-02	1.03E-02	1.03E-02	1.03E-02	1.03E-02	7.6	83.0	45.0	45.0	45.0	45.0
25	Enhanced Recharge at Thin Clay	1.74E-03	1.89E-02	3.35E-03	9.13E-03	3.35E-03	9.13E-03	7.6	83.0	14.7	40.0	14.7	40.0
26	Enhanced Recharge at Thin Clay	1.74E-03	1.89E-02	3.43E-03	4.57E-03	3.43E-03	4.57E-03	7.6	83.0	15.0	20.0	15.0	20.0
27	Enhanced Recharge at Thin Clay	1.74E-03	1.89E-02	4.44E-03	9.13E-03	4.44E-03	9.13E-03	7.6	83.0	19.5	40.0	19.5	40.0
28	Enhanced Recharge at Thin Clay	1.74E-03	1.89E-02	6.61E-03	4.66E-03	6.61E-03	4.66E-03	7.6	83.0	28.9	20.4	28.9	20.4

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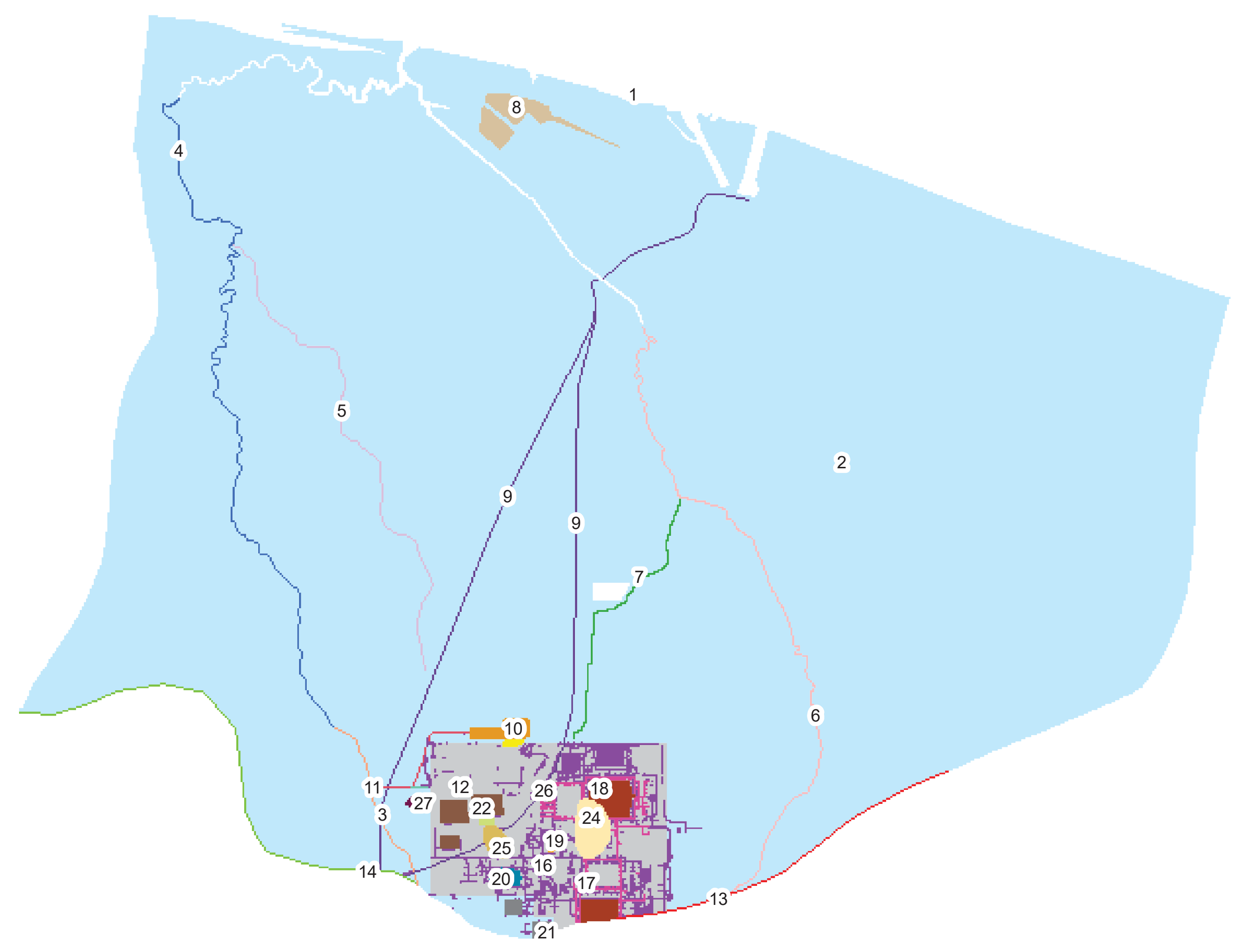

Zone	Calibrated Recharge (inches/year)	
	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
2	3.6	4.3
3	25.0	25.0
4	20.0	20.0
5	20.0	20.0
6	20.0	17.4
7	20.0	20.0
8	20.0	20.0
9	9.0	9.0
10	12.0	12.0
11	10.0	10.0
12	3.6	4.3
13	70.0	60.0
14	35.9	30.8
15	15.0	15.0
16	14.4	22.0
17	18.8	30.0
18	30.0	30.0
19	10.0	16.0
20	0.001	0.001
21	0.001	0.001
22	0.001	0.001
23	0.001	0.001
24	45.0	45.0
25	14.7	40.0
26	15.0	20.0
27	19.5	40.0
28	28.9	20.4

Sitewide Calibrated Recharge

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec
consultants

Acton, Masssachusetts

December 2016

Figure

6.6

Figure 6.6. Sitewide Calibrated Recharge

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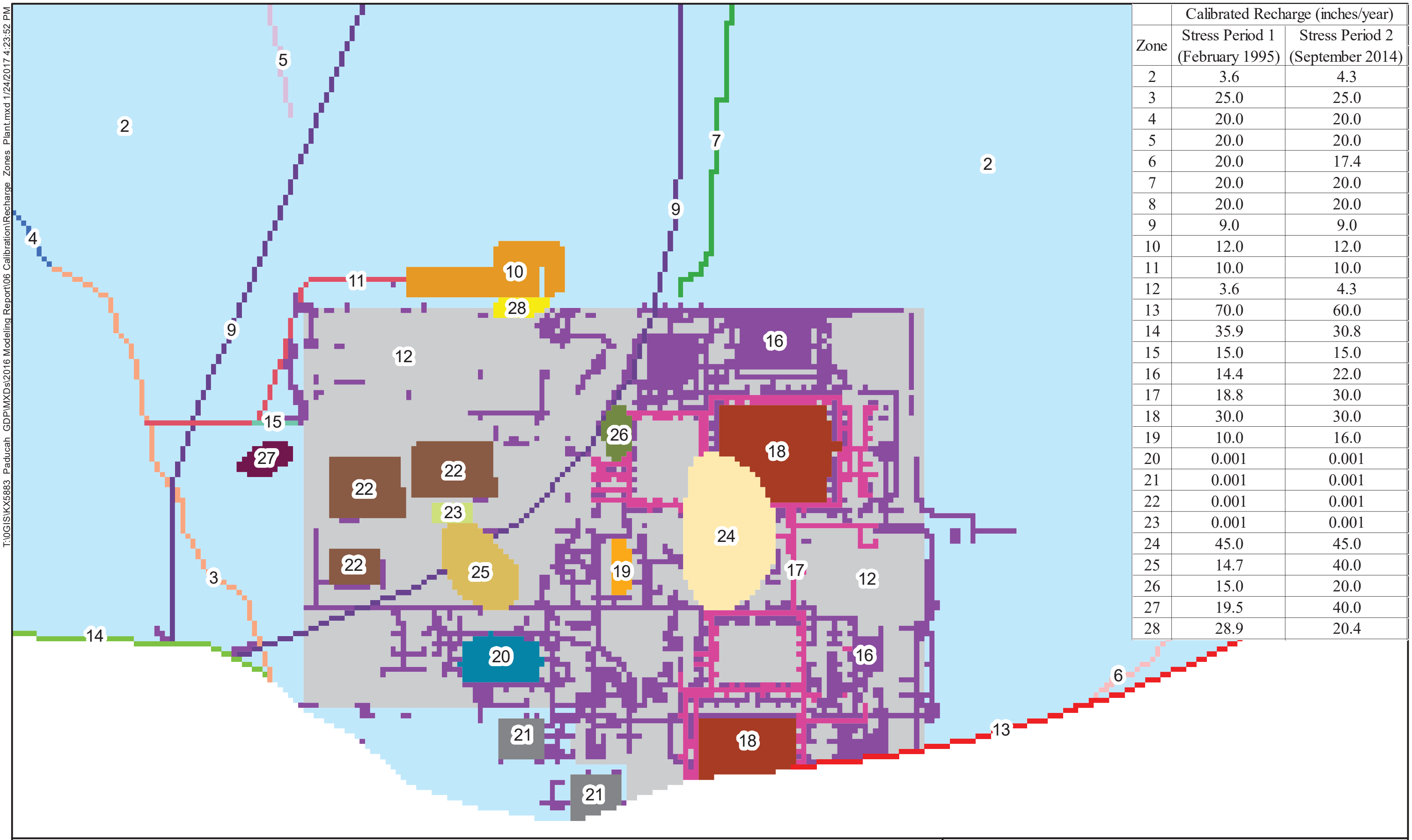


Zone	Calibrated Recharge (inches/year)	
	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
2	3.6	4.3
3	25.0	25.0
4	20.0	20.0
5	20.0	20.0
6	20.0	17.4
7	20.0	20.0
8	20.0	20.0
9	9.0	9.0
10	12.0	12.0
11	10.0	10.0
12	3.6	4.3
13	70.0	60.0
14	35.9	30.8
15	15.0	15.0
16	14.4	22.0
17	18.8	30.0
18	30.0	30.0
19	10.0	16.0
20	0.001	0.001
21	0.001	0.001
22	0.001	0.001
23	0.001	0.001
24	45.0	45.0
25	14.7	40.0
26	15.0	20.0
27	19.5	40.0
28	28.9	20.4

Legend

- 2 Ambient
- 3 Very Upper Bayou Creek
- 4 Bayou Creek
- 5 Bayou Creek Tributary
- 6 Little Bayou Creek
- 7 Little Bayou Creek Tributary
- 9 TVA Lines
- 10 Lagoon
- 11 Lagoon Ditch
- 12 Plant Area
- 13 East Terrace Recharge
- 14 West Terrace Recharge
- 15 Outfall 001
- 16 Storm Drains
- 17 High Pressure Fire Water Lines
- 18 Compromised Roof Drains - Process Buildings
- 19 Compromised Roof Drain - C400
- 20 Competent Roof Drain - C720
- 21 Paved Areas
- 22 Compacted Gravel
- 23 Capped Landfill
- 24 Thin Clay Recharge Area 1
- 25 Thin Clay Recharge Area 2
- 26 Thin Clay Recharge Area 3
- 27 Thin Clay Recharge Area 4
- 28 Thin Clay Recharge Area 5

TRUE NORTH 20 PLANT NORTH

0 1,400 Feet

Plant Area Calibrated Recharge

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec
consultants

Acton, Masssachusetts | January 2017

Figure 6.7

Figure 6.7. Plant Area Calibrated Recharge

The recharge zones representing the West and East Terrace basins were tied together during PEST runs to maintain a constant recharge ratio between the two basins. During manual calibration, Terrace recharge was adjusted so that it would be higher for SP1 than it is for SP2 to account for the expected seasonal difference between the two stress periods. The final estimated recharge rate from the East and West Terrace Basins (applied to the cells along the southern model boundary), is 70.0 inches/year and 35.9 inches/year for SP1 and 60.0 inches/year and 30.8 inches/year for SP2, respectively. In terms of groundwater discharge, flow from the Terrace Gravel along the East and West Terrace basins is estimated to be, respectively, 36 and 27 gpm for SP1 and 31 and 23 gpm for SP2.

Limited temporal variability was assumed for recharge in the TVA ponds and the lagoon because the operating conditions are expected to be constant with time, so recharge in these zones was not allowed to vary by stress period during PEST runs. Estimated recharge from the TVA ponds is 20 inches/year. Estimated recharge from losses along the TVA water supply lines is 9 inches/year. The lagoon and associated drainage ditch at the NW corner of the plant is estimated to contribute 12 and 9 inches/year, respectively. The TVA-associated recharge values have been adjusted for computational cell size, which is the reason why the thin, linear TVA water supply line recharge has a lower magnitude than the lagoon value.

In the plant area, open areas (Zone 12) were tied to the ambient precipitation recharge (Zone 2) because the two zones are expected to have similar recharge. The maximum constraint for anthropogenic recharge was specified at 83 inches/year based on Darcy calculations that use a unity vertical hydraulic gradient and median UCRS vertical hydraulic conductivity (see Section 3.3). The maximum model-estimated anthropogenic recharge rate is 45 inches/year and is associated with thin clay recharge area 1 (Zone 24). Initially the range of recharge values estimated with the geometric mean UCRS vertical hydraulic conductivity was specified as a maximum constraint (10 inches/year to 29 inches/year), but the model as configured required higher recharge values for calibration, as indicated by the majority of recharge zones being assigned a value equal to the maximum calibration constraint by PEST. Consequently, the maximum constraints were increased based on the range calculated with the median UCRS hydraulic conductivity (29 inches/year to 83 inches/year). The decision to use the median over the geometric mean was guided by the calibration. As models are non-unique, the calibrated recharge values could be lower if the model used other reasonable values of lower hydraulic conductivity.

Thin clay recharge area 1 (Zone 24) is coincident with the apparent groundwater divide identified in the plant area. The compromised roof drains for process buildings and HPFW system, which also are co-located with the apparent groundwater divide, similarly have high recharge rates relative to other anthropogenic recharge zones. Anthropogenic recharge rates tended to be higher in SP2 than SP1, consistent with the notion that more leaks would occur as infrastructure ages. The calibration was insensitive in areas with minimal recharge (i.e., paved areas, compacted gravel, capped landfills, and competent roof drains). PEST simulation estimates did not exhibit much variability in the recharge rate for these zones, and ultimately recharge was set at a fixed value of 0.001 inch/year for all low magnitude recharge zones. The calibrated recharge distribution in the plant area is consistent with the qualitative recharge estimates reported in Section 3.3 and Section 4.

6.4 MASS BALANCE

The model-predicted mass balance is summarized for each recharge/discharge feature by stress period and presented in Table 6.3. The greatest source (approximately 81%) of recharge to the PGDP Hydrologic Basin is from precipitation. Anthropogenic recharge contributes approximately 13% to 14% of the total inflow to the hydrologic basin. Approximately 3% of the total basin inflow is contributed by creek

Table 6.3. Calibrated Mass Balance

		Units in ft^3/day		Units in GPM		Percent	
Description	Zone, Reach, Well	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
Cells with No Recharge	1	0	0	0	0	0.0%	0.0%
Ambient	2	376,571	444,620	1,956	2,310	78.9%	79.1%
Very Upper Bayou Creek	3	1,241	1,241	6	6	0.3%	0.2%
Bayou Creek	4	4,669	4,669	24	24	1.0%	0.8%
Bayou Creek Tributary	5	2,922	2,922	15	15	0.6%	0.5%
Little Bayou Creek	6	4,098	3,566	21	19	0.9%	0.6%
Little Bayou Creek Tributary	7	2,066	2,066	11	11	0.4%	0.4%
TVA Ponds	8	7,169	7,169	37	37	1.5%	1.3%
TVA Water Lines	9	3,565	3,565	19	19	0.7%	0.6%
Lagoon	10	1,685	1,685	9	9	0.4%	0.3%
Lagoon Ditch	11	365	365	2	2	0.1%	0.1%
Plant Area	12	11,755	13,879	61	72	2.5%	2.5%
East Terrace Basin	13	6,872	5,891	36	31	1.4%	1.0%
West Terrace Basin	14	5,163	4,426	27	23	1.1%	0.8%
Outfall 001	15	77	77	0.4	0.4	0.0%	0.0%
Storm Drains	16	19,325	29,485	100	153	4.0%	5.2%
High Pressure Fire Water	17	5,322	8,493	28	44	1.1%	1.5%
Compromised Roof Drains—Process Buidlings	18	9,537	9,537	50	50	2.0%	1.7%
Compromised Roof Drain—C-400	19	234	375	1	2	0.0%	0.1%
Competent Roof Drain—C-720	20	0	0	0	0	0.0%	0.0%
Paved Areas	21	0	0	0	0	0.0%	0.0%
Compacted Gravel	22	0	0	0	0	0.0%	0.0%
Capped Landfill	23	0	0	0	0	0.0%	0.0%
Thin Clay Recharge Area 1	24	11,558	11,558	60	60	2.4%	2.1%
Thin Clay Recharge Area 2	25	1,581	4,315	8	22	0.3%	0.8%
Thin Clay Recharge Area 3	26	445	594	2	3	0.1%	0.1%
Thin Clay Recharge Area 4	27	611	1,256	3	7	0.1%	0.2%
Thin Clay Recharge Area 5	28	644	454	3	2	0.1%	0.1%
Extraction Well 232	EX232	0	-21,175	0	-110	0.0%	-3.8%
Extraction Well 233	EX233	0	-21,175	0	-110	0.0%	-3.8%
Extraction Well 331	EX331	0	-16,940	0	-88	0.0%	-3.0%
Extraction Well 332	EX332	0	-19,828	0	-103	0.0%	-3.5%
Ohio River Boundary Condition	Riv1	-368,079	-370,531	-1,912	-1,925	-77.1%	-65.9%
Little Bayou Creek Boundary Condition	Riv2	-14,956	-14,798	-78	-77	-3.1%	-2.6%
Little Bayou Creek Boundary Condition	Riv3	-71,437	-72,209	-371	-375	-15.0%	-12.8%
Bayou Creek Boundary Condition	Riv4	-18,595	-20,057	-97	-104	-3.9%	-3.6%
Bayou Creek Boundary Condition	Riv5	-4,410	-5,497	-23	-29	-0.9%	-1.0%
	Total In	477,477	562,208	2,480	2,920	100.0%	100.0%
	Total Out	-477,477	-562,209	-2,480	-2,920	-100.0%	-100.0%

1. Negative = outflow, positive = inflow

recharge and approximately 2% is contributed by recharge from the Terrace Gravel. During the simulated periods of average to low river stages, most groundwater within the PGDP Hydrologic Basin discharges to the Ohio River (approximately 77 and 65% for SP1 and SP2, respectively), with the remaining groundwater discharging to the lower reaches of BC and LBC and extraction wells (SP2 only).

Model-predicted discharge around the seeps located at the toe of the Northwest Plume, which corresponds to River Reach 2, is 78 and 77 gpm for SP1 and SP2, respectively. This represents approximately 3.1 and 2.6% of the total volume of groundwater (2,480 and 2,920 gpm) flowing through the area for SP1 and SP2, respectively. The combined discharge to the extraction wells (SP2 only) was fixed at 411 gpm to be consistent with reported pumping rates. This rate represents 14.1% of the total volume of groundwater and is comparable to anthropogenic recharge.

6.5 CALIBRATION STATISTICS

6.5.1 Model-Predicted Water Level Elevations

Model calibration assessment includes comparing model-predicted water levels to measured or target water levels. For each steady-state stress period, summary statistics of model-predicted and target water levels, referred to as residuals, are compiled in Table 6.4 and individual calibration target residuals are compiled in Appendix C. The scaled residual standard deviations for SP1 and SP2 are 4 and 3%, respectively. These statistics indicate the differences between simulated and observed data across the model domain and are well within the recommended range of up to 10% for a well calibrated model. For each stress period, a chart of water level residuals versus target water levels is presented in Figure 6.8. In a well calibrated model, the data points will be generally well distributed along the horizontal line corresponding to a residual of zero indicating a good match to water level targets across the model area. For SP1, the data points are generally distributed along the zero-residual line, and the majority of the model-predicted water levels in SP1 are within +/- 1 ft of the target values. For one target located near LBC, the model-predicted water level was under predicted by 2.21 ft. For SP2, the data points are generally distributed along the zero-residual line and most of the model-predicted water levels are within +/- 0.5 ft of the target values with a maximum residual of 1.07 ft at a target located north of the plant area near the river. In general, most predicted water levels are within +/- 1 ft of the target value, with the closer match simulated in SP2. The higher variability exhibited in SP1 may be attributed to the longer measurement period (February 1995) compared to the synoptic measurement event associated with SP2. Although the cause of the variability in SP1 is uncertain, it does appear to be related to measurement errors rather than model deficiencies, which is evident when comparing positive residuals of approximately 0.5 ft to 1.0 ft with adjacent negative residuals of approximately -0.5 ft to -1.0 ft. In general, such drastic fluctuations in water level over such short distances are not expected in the RGA.

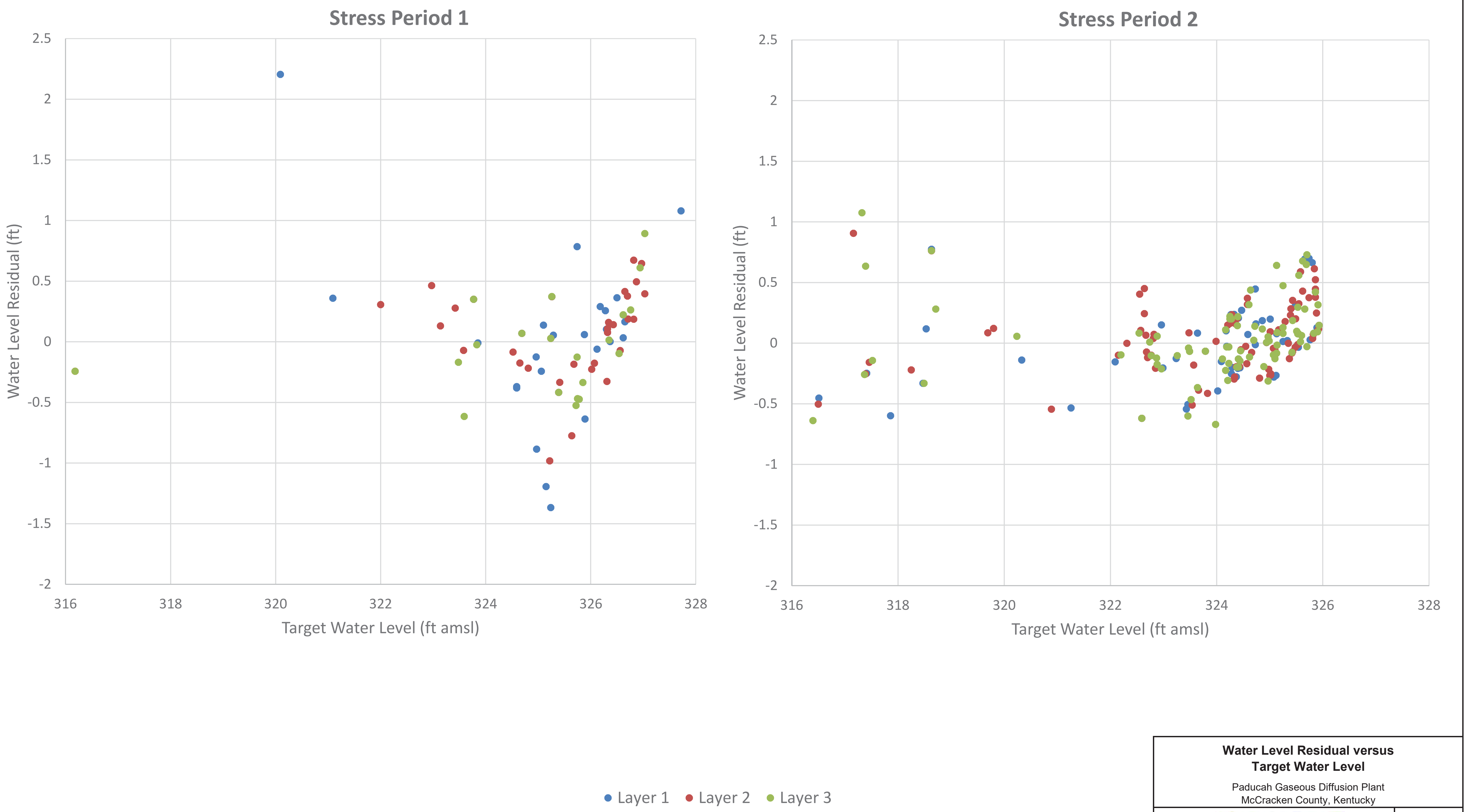
Model-predicted potentiometric surfaces as well as the distribution of the target residuals within the model domain for model layers 1 through 3 are presented in Figures 6.9 and 6.10. The residual circles are color-coded red for overestimate and green for underestimate and scaled (the bigger the residual circle, the larger the target residual). The purple areas shown in layer 1 on Figures 6.9 and 6.10 represent dry cells, which result when the predicted water level elevation drops below the bottom of the model layer. These occur in the area west of the TVA ponds where boring log data indicate a rise in the elevation of the base of the RGA, resulting in a thinning of the RGA. The model cells below these dry cells in model layers 2 and 3 are saturated. All model layers show mounding (i.e., the water level contours bow out resulting in a groundwater divide) at the PGDP resulting from anthropogenic recharge, which is consistent with site data.

Table 6.4. Water Level Target Residual Statistics

Statistic	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
Residual Mean	0.02	0.03
Absolute Residual Mean	0.35	0.24
Residual Std. Deviation	0.49	0.31
Sum of Squares	20.12	21.46
RMS Error	0.49	0.31
Min. Residual	-1.37	-0.67
Max. Residual	2.20	1.08
Number of Observations	84	220
Range in Observations	11.54	9.53
Scaled Residual Std. Deviation	0.04	0.03
Scaled Absolute Residual Mean	0.03	0.02
Scaled RMS Error	0.04	0.03
Scaled Residual Mean	0.002	0.003

Notes:

1. Units are in ft.
2. Negative residuals denote overestimates and positive residuals denote underestimates.



Water Level Residual versus
Target Water Level

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		Figure
Acton, Massachusetts	December 2016	**6.8**

Note:
Negative residuals denote overestimates and positive residuals denote underestimates.

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Figure 6.8. Water Level Residual versus Target Water Level

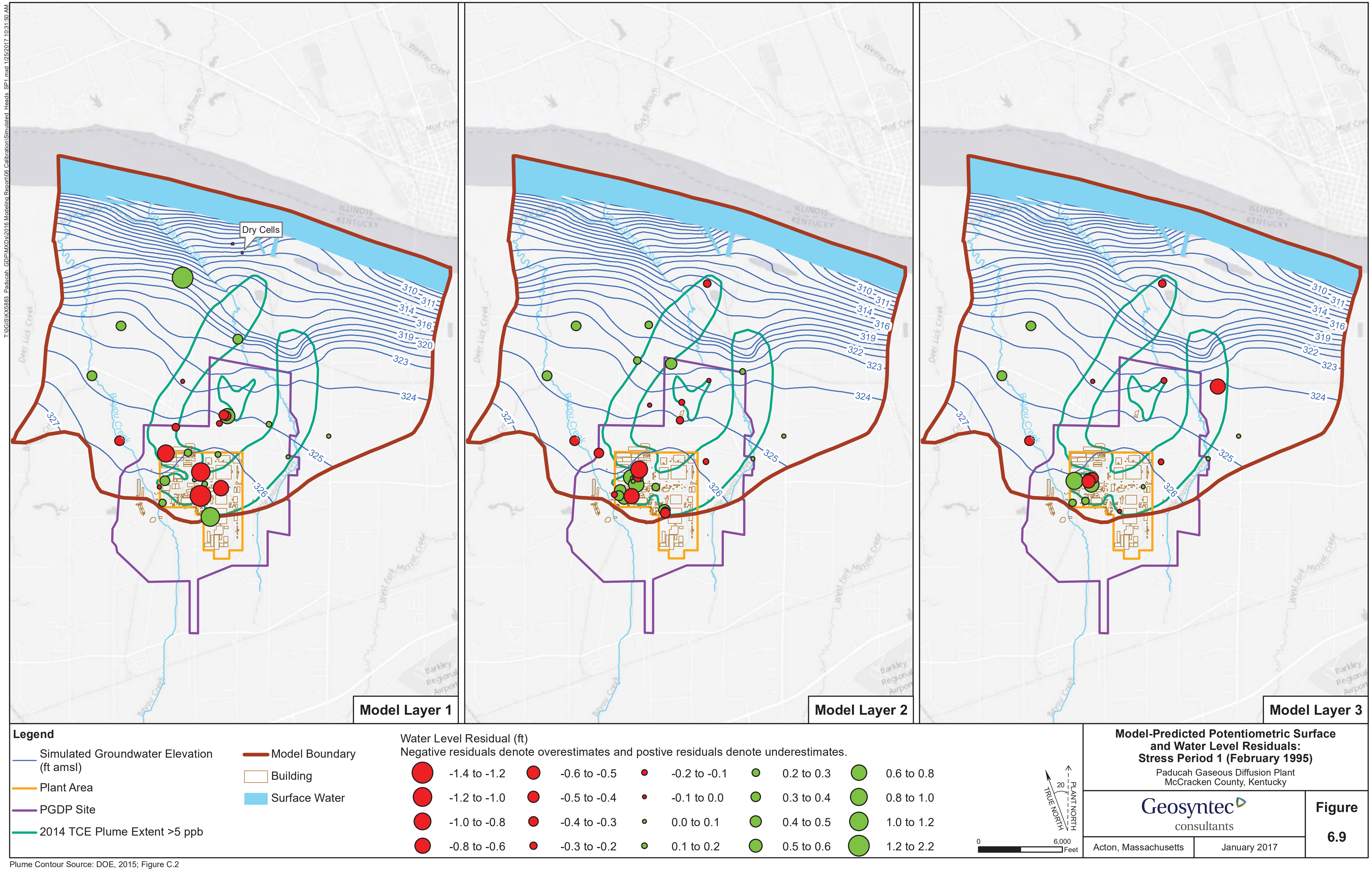
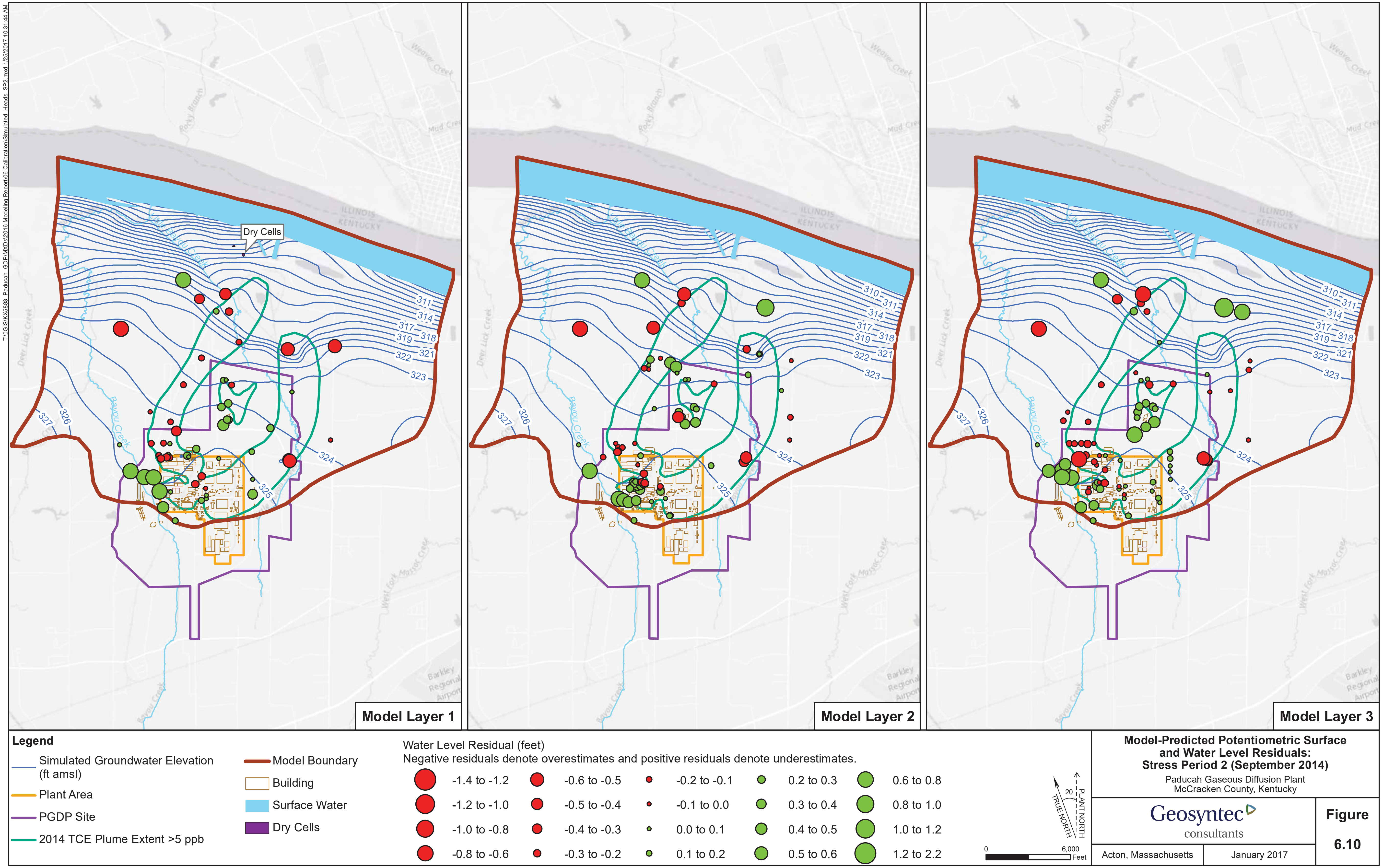


Figure 6.9. Model-Predicted Potentiometric Surface and Water Level Residuals: Stress Period 1 (February 1995)



Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.10. Model-Predicted Potentiometric Surface and Water Level Residuals: Stress Period 2 (September 2014)

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6.5.2 Model-Predicted Flux

The model predicts a groundwater discharge rate to the Ohio River of 1,912 and 1,925 gpm for stress periods SP1 and SP2, respectively. This is within the range of recharge estimated between 228 to 8,218 gpm (Section 6.2.1). The model-predicted discharge at the LBC seep located at the toe of the Northwest Plume is 78 and 77 gpm for stress periods SP1 and SP2, respectively which is a good match to the target discharge rate of 77.1 gpm.

6.5.3 Flow Direction (Trajectory) Targets

Calibration statistics for the flow direction targets are presented in Table 6.5 and Figure 6.11. For each stress period, a chart of flow direction residuals versus observed flow directions is presented in Figure 6.12. The absolute mean error for all angle targets is less than 3.7 degrees. Additionally, the majority (60%) of the predicted angles are within +/- 2 degrees of the target value and more than 90% of the predicted angles are within +/-5 degrees of the target value.

6.5.4 Model-Predicted Plume Trajectory

For each stress period, particles were placed within the model domain in model layers 1 through 3 at locations corresponding to known and possible source areas and allowed to migrate with the predicted groundwater flow fields (Figure 6.13). The ability to replicate the plume flow path is a measure of model calibration, with the closer agreement suggesting a more representative model. The figures show that for both SP1 and SP2 the model reasonably replicates the Northeast and Northwest Plumes flow paths. Particle capture in the Northeast Plume indicates the western-most particle bypasses the western EW (EW331) and is captured by the eastern EW (EW332). This is consistent with the results of the EW pumping tests indicating a larger capture zone for EW332 compared to EW331 (TN & Associates and CDM Federal Programs Corporation 1997).

6.6 FINAL PARAMETER SENSITIVITIES

PEST calculates sensitivities for all estimated parameters for each iteration of the parameter estimation process. Figure 6.14 shows the final relative composite scaled sensitivities of the 52 model parameters. Except for the recharge areas specified with a very low recharge value to simulate minimal infiltration (paved areas, compacted gravel, competent roof drain, and capped landfill), all the parameter sensitivities are within two orders of magnitude of the most sensitive parameter, indicating that these parameters can be estimated with reasonable accuracy. With the exception of the capped landfill recharge, the least sensitive parameters in minimal infiltration areas have sensitivities within two to three orders of magnitude of the most sensitive parameter, indicating that a reasonably accurate estimation of these parameters is uncertain. The relative sensitivity for recharge in the capped landfill areas is less than three orders of magnitude from the most sensitive parameter, indicating that the parameter cannot be estimated. It should be noted that sensitivities are estimated by calculating changes in the objective function related to incremental changes in the calibrated value of each parameter. For relatively low recharge values such as paved areas or capped landfills, incremental changes would represent a small change to the relatively low value and therefore contribute very little to the objective function. For this reason, low composite sensitivities for these parameters are expected.

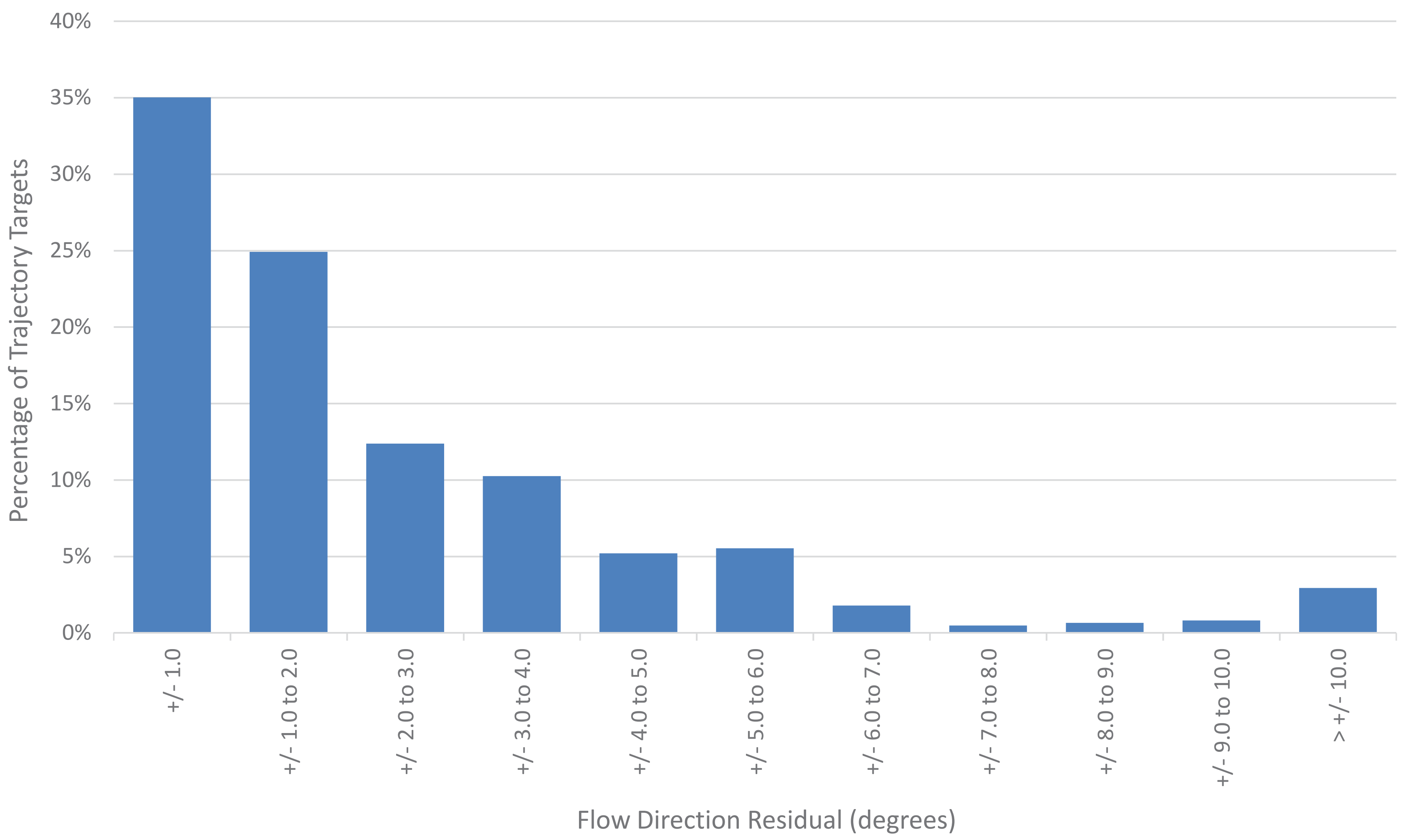
Table 6.5. Trajectory Target Residual Statistics

Statistic	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
Residual Mean	0.21	0.64
Absolute Residual Mean	2.41	2.36
Residual Std. Deviation	3.55	3.53
Sum of Squares	4,505.01	3,354.10
RMS Error	3.55	3.58
Min. Residual	-10.74	-14.09
Max. Residual	16.79	14.73
Number of Observations	357	261
Range in Observations	114.46	105.00
Scaled Residual Std. Deviation	0.03	0.03
Scaled Absolute Residual Mean	0.02	0.02
Scaled RMS Error	0.03	0.03
Scaled Residual Mean	0.00	0.01

Notes:

1. Units are in degrees.
2. Negative residuals denote overestimates and positive residuals denote underestimates.

Figure 6.11. Percentage of Trajectory Targets versus Flow Direction Residual



Percentage of Trajectory Targets versus Flow Direction Residual

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Figure 6.11

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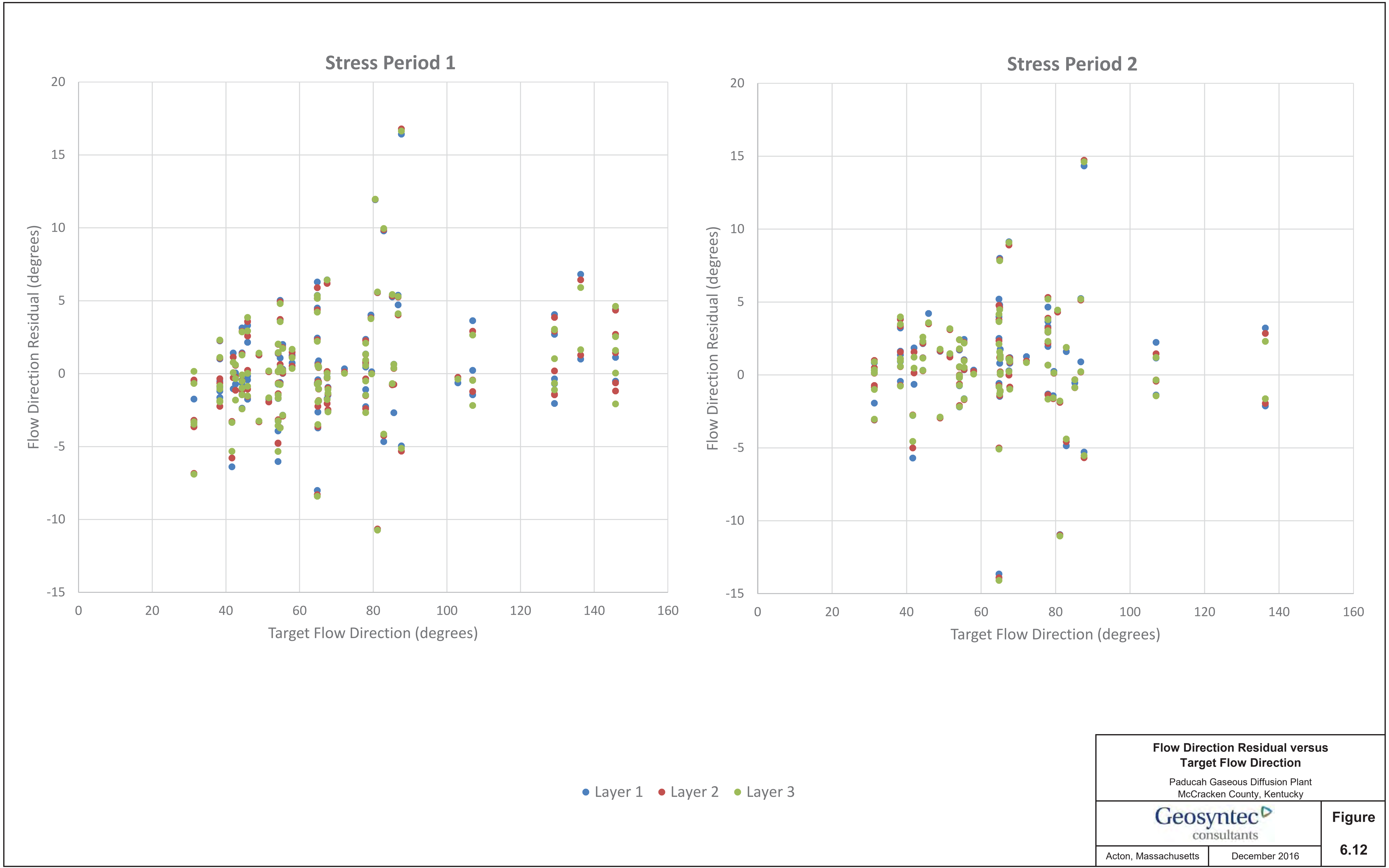
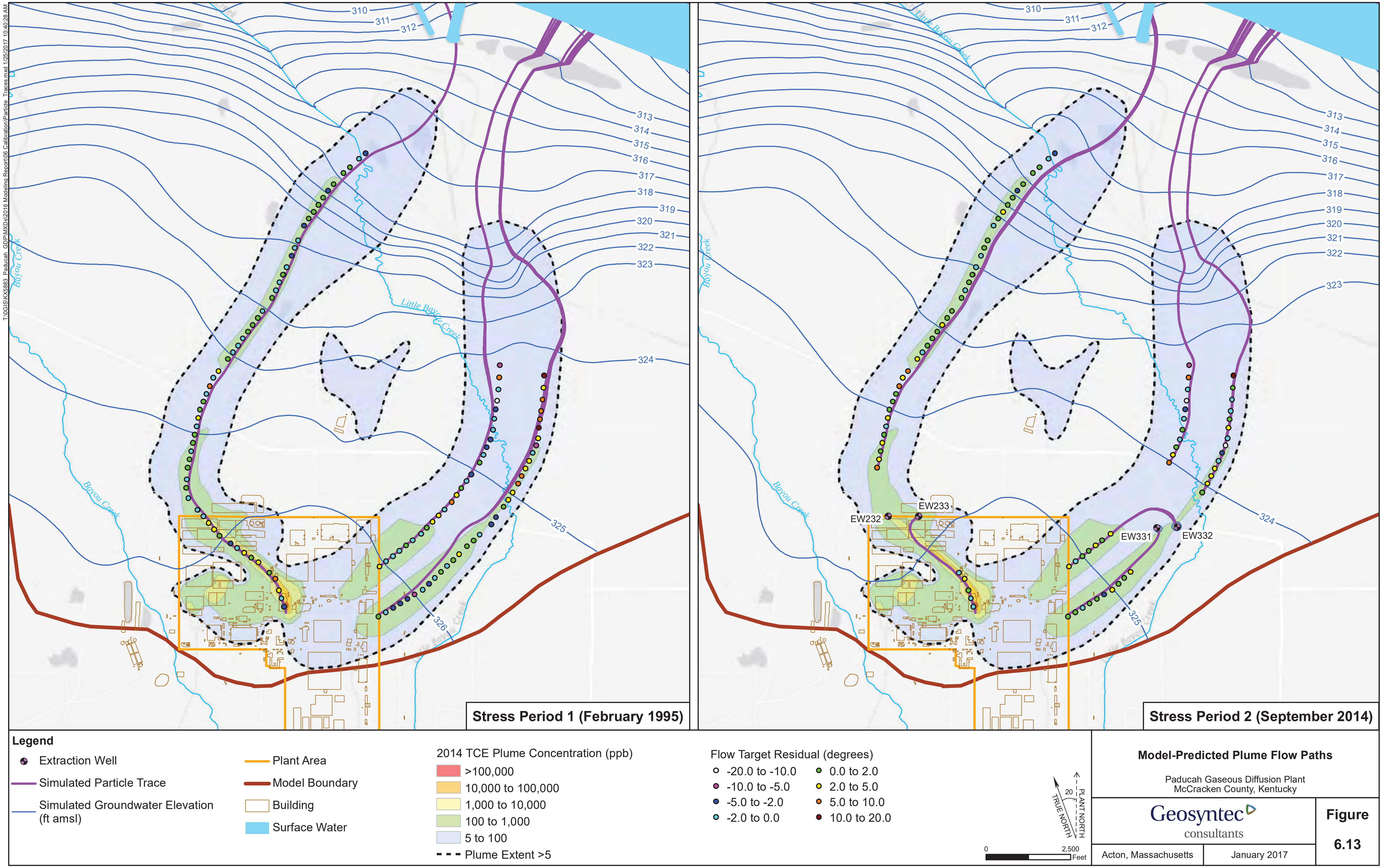
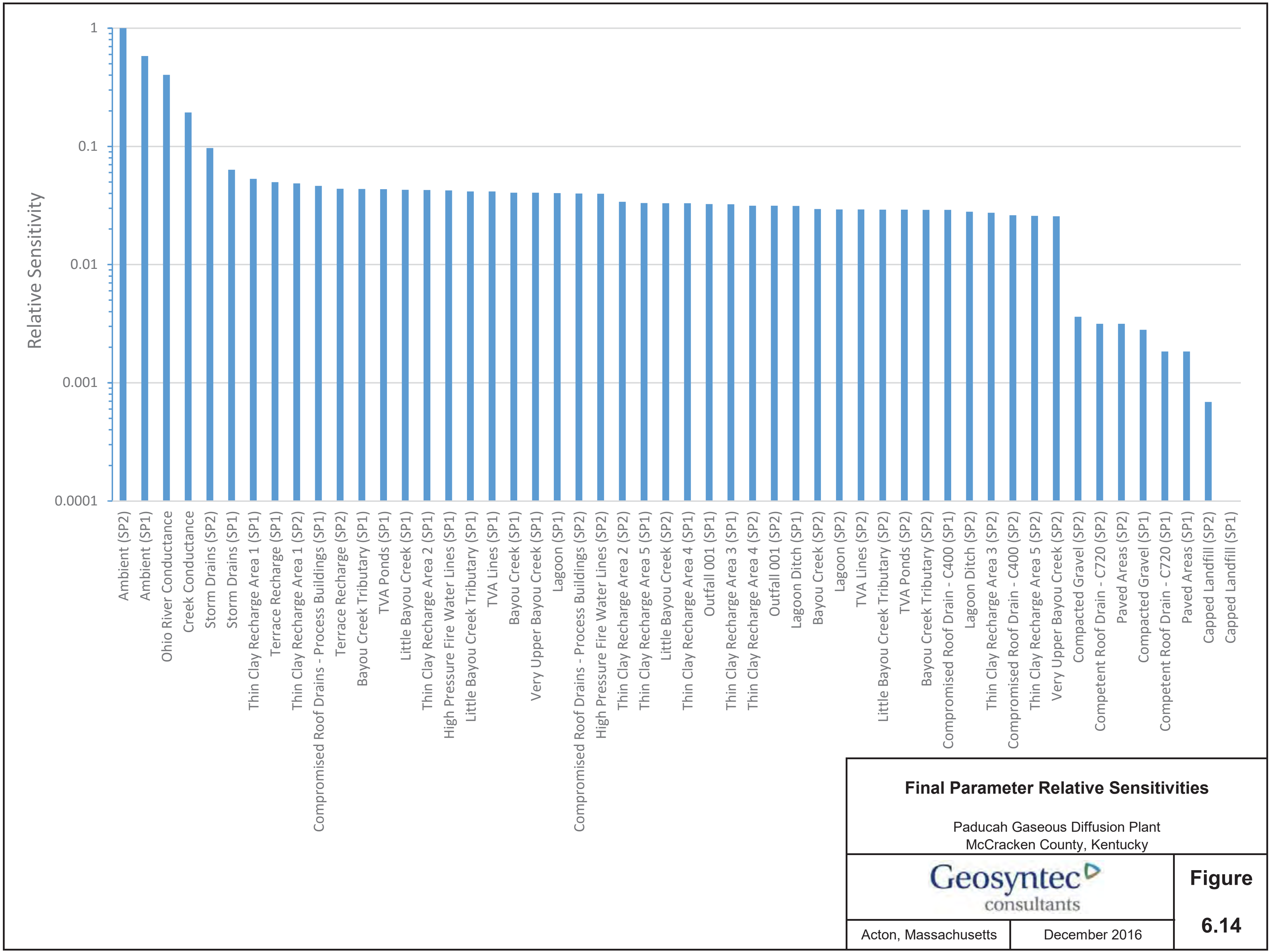


Figure 6.12. Flow Direction Residual versus Target Flow Direction



Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.13. Model-Predicted Plume Flow Paths



Final Parameter Relative Sensitivities

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Figure 6.14

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Figure 6.14. Final Parameter Relative Sensitivities

Final hydraulic conductivity pilot point sensitivities for model layers 1 through 3 relative to the most sensitive parameter are shown in Figure 6.15. With the exception of 13 pilot points out of the total of 1,041 pilot points specified in the model, sensitivities are within two orders of magnitude of the most sensitive parameter, indicating that unique hydraulic conductivities can be estimated for 98.8% of all pilot points in the model.

6.7 PLUME FLOW PATH SENSITIVITY ANALYSIS

A sensitivity analysis was performed to determine how individual 25% increases and decreases in the calibrated values of the most sensitive parameters (based on the final PEST sensitivities, Figure 6.14) influence predicted plume flow paths as defined by resultant changes in predicted particle traces. The +/- 25% sensitivity range was selected to recognize that over the plumes' time scale, parameter fluctuations are not expected to be as extreme as might occur short-term. The following parameters were evaluated as part of the plume flow path sensitivity analysis:

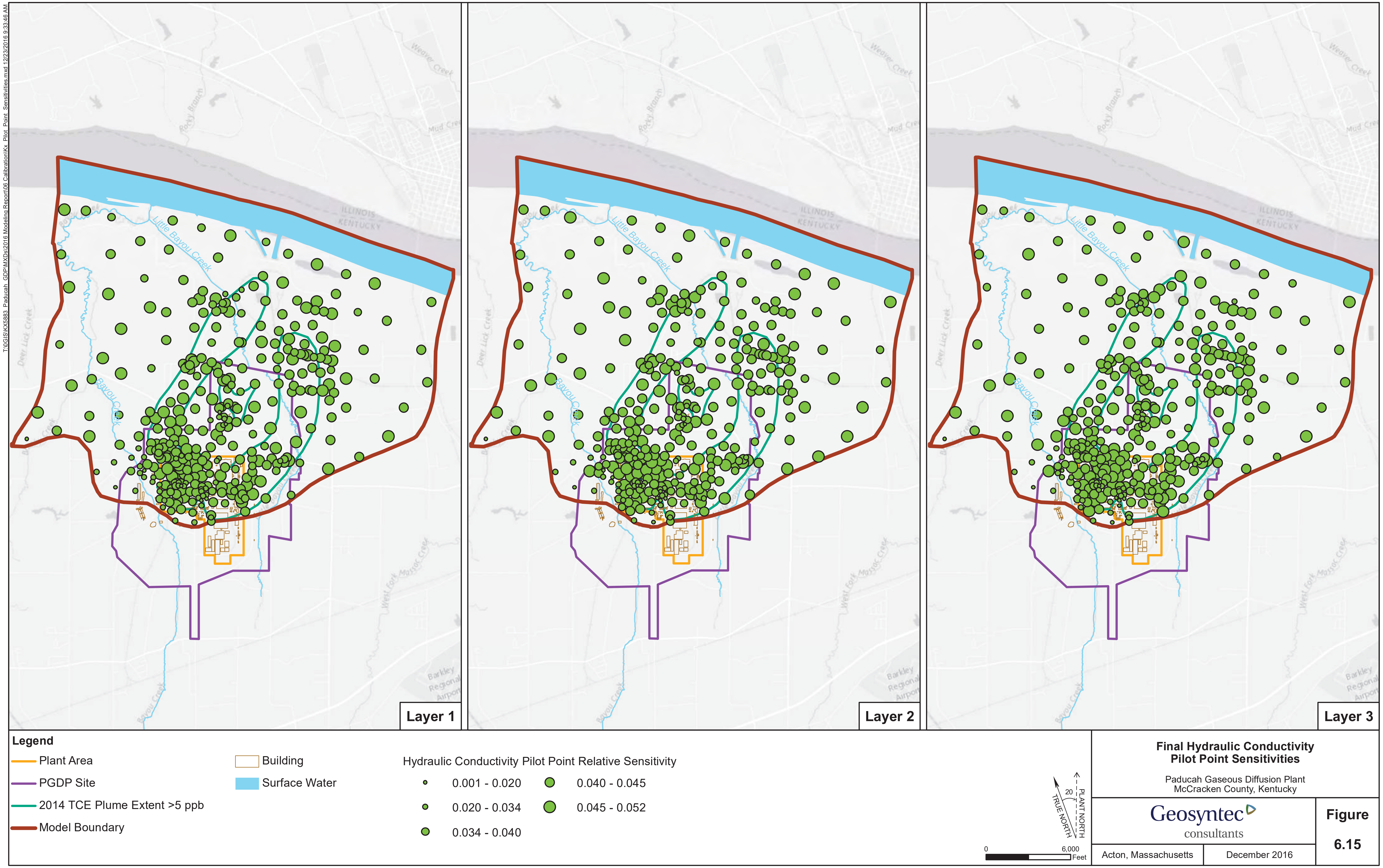
- Ambient recharge;
- Hydraulic conductivity (conductance) of the Ohio River sediments;
- Hydraulic conductivity (conductance) of BC and LBC sediments;
- Storm drain recharge;
- Largest thin clay recharge area;
- Compromised roof drain recharge area;
- HPFW piping system recharge area;
- TVA supply line recharge; and
- Recharge from the Terrace Gravel.

In addition to the parameters listed above, a sensitivity analysis was performed to determine how changes in Ohio River stage influence predicted plume flow paths.

For both SP1 and SP2, simulated increases and decreases in precipitation recharge caused the Northwest and Northeast Plumes to shift minimally east and west relative to the observed plume centroid (Figures 6.16 and 6.17). An increase in precipitation recharge results in a slight westward shift of the particle traces and a decrease results in a slight eastward shift, but overall there is minimal change in predicted plume trajectories.

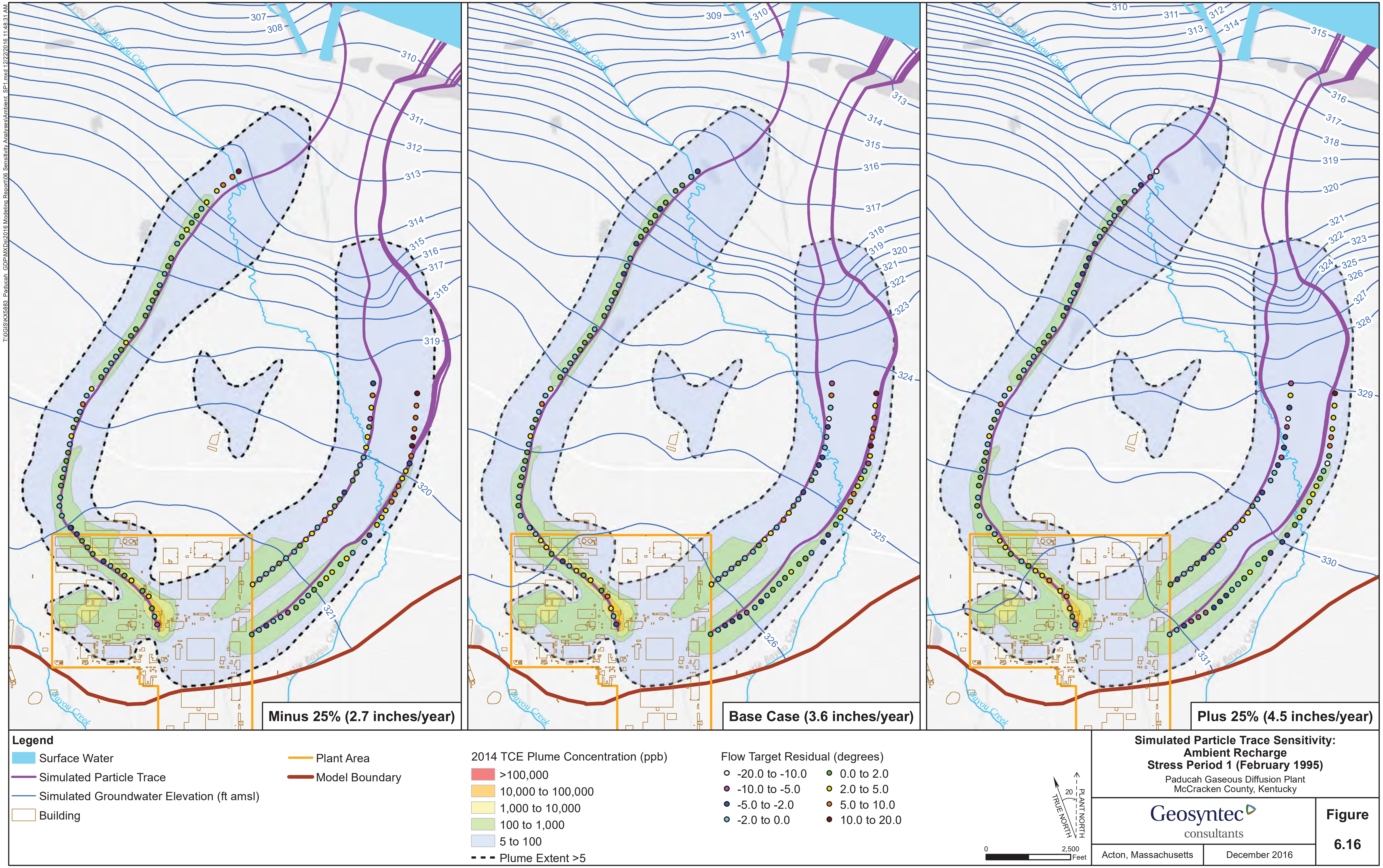
A 25% increase in hydraulic conductivity (conductance) of the Ohio River bottom sediments has minimal influence on the Northeast Plume and Northwest Plumes trajectories in SP1 and SP2 (Figures 6.18 and 6.19). A 25% decrease in the hydraulic conductivity of the river sediments causes the predicted Northwest and Northeast Plumes trajectories to shift westward in both stress periods. A more pronounced effect is observed in the Northwest Plume particle traces in the area between LBC and the Ohio River where the particle traces turn westward and the particles migrate approximately parallel to LBC, rather than northward toward the Ohio River. Review of groundwater elevation contours in this area indicates a significant increase in groundwater elevations and change to the shape of the water table between LBC and the Ohio River. The result is increased predicted discharge to the creeks and decreased discharge to the river due to a shift in groundwater gradients.

For both SP1 and SP2, simulated increases and decreases in hydraulic conductivity (conductance) of BC and LBC cause the predicted Northwest and Northeast Plumes to shift direction minimally and negligibly changes the plume trajectories (Figures 6.20 and 6.21).



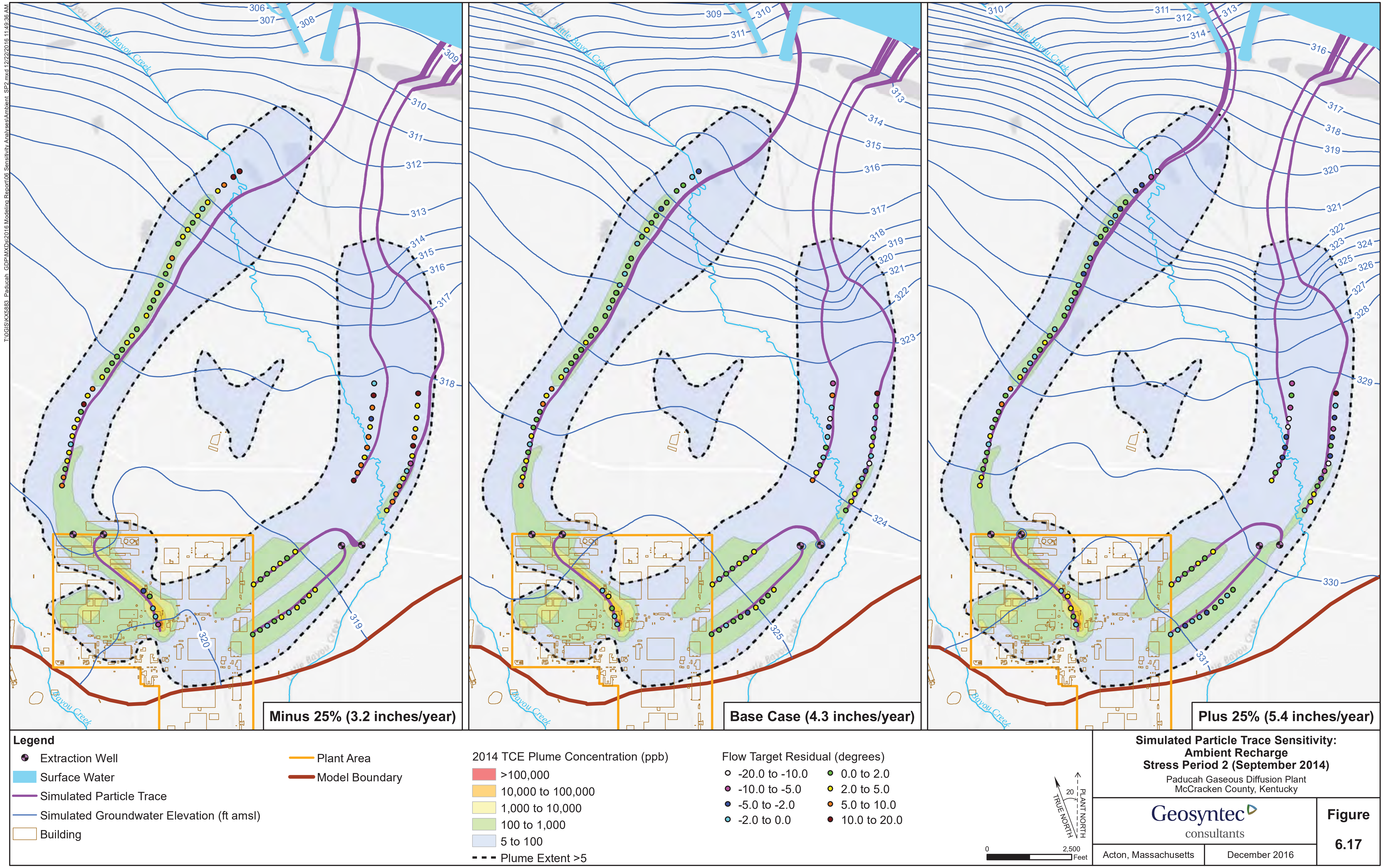
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.15. Final Hydraulic Conductivity Pilot Point Sensitivities



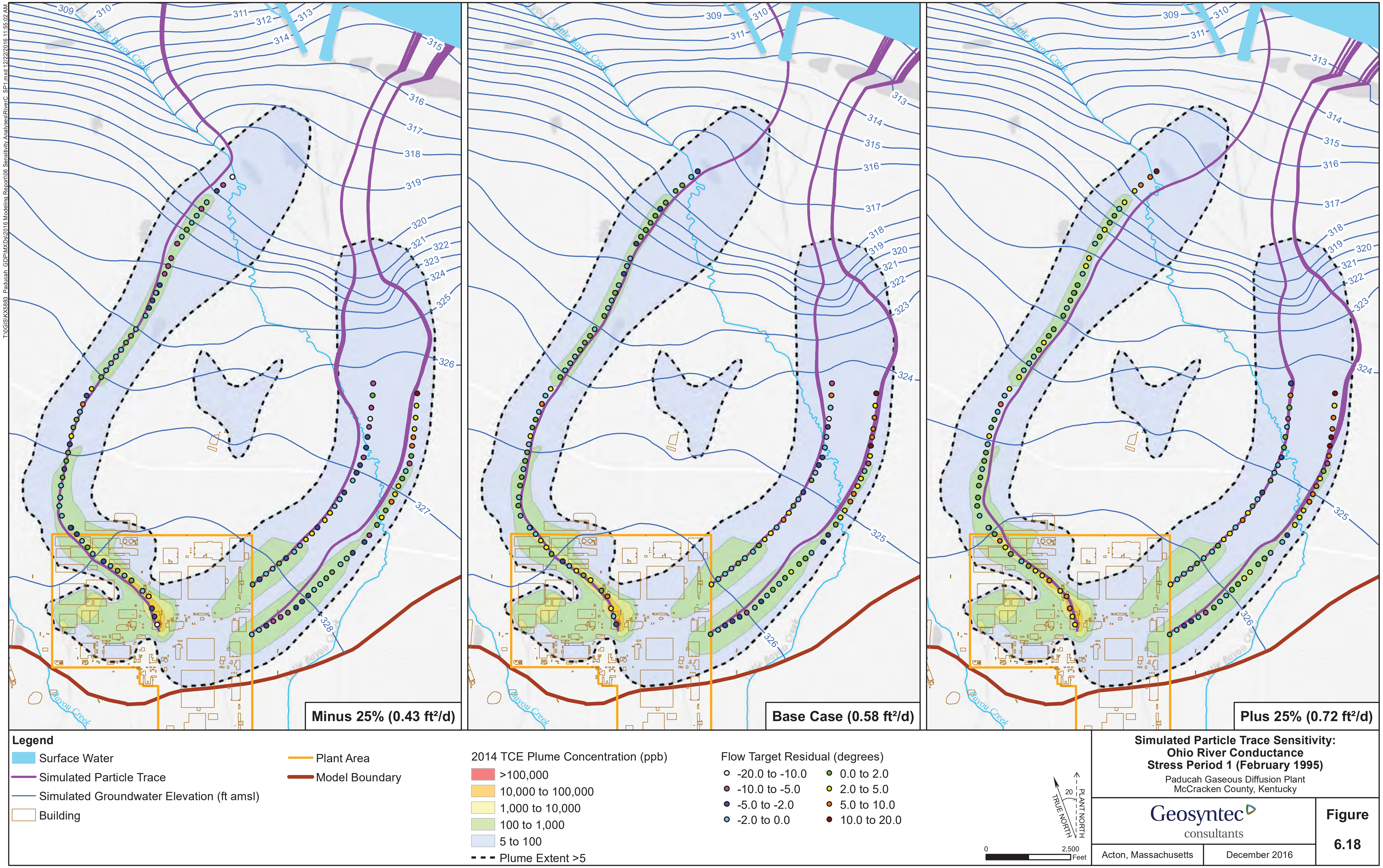
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.16. Simulated Particle Trace Sensitivity: Ambient Recharge, Stress Period 1 (February 1995)



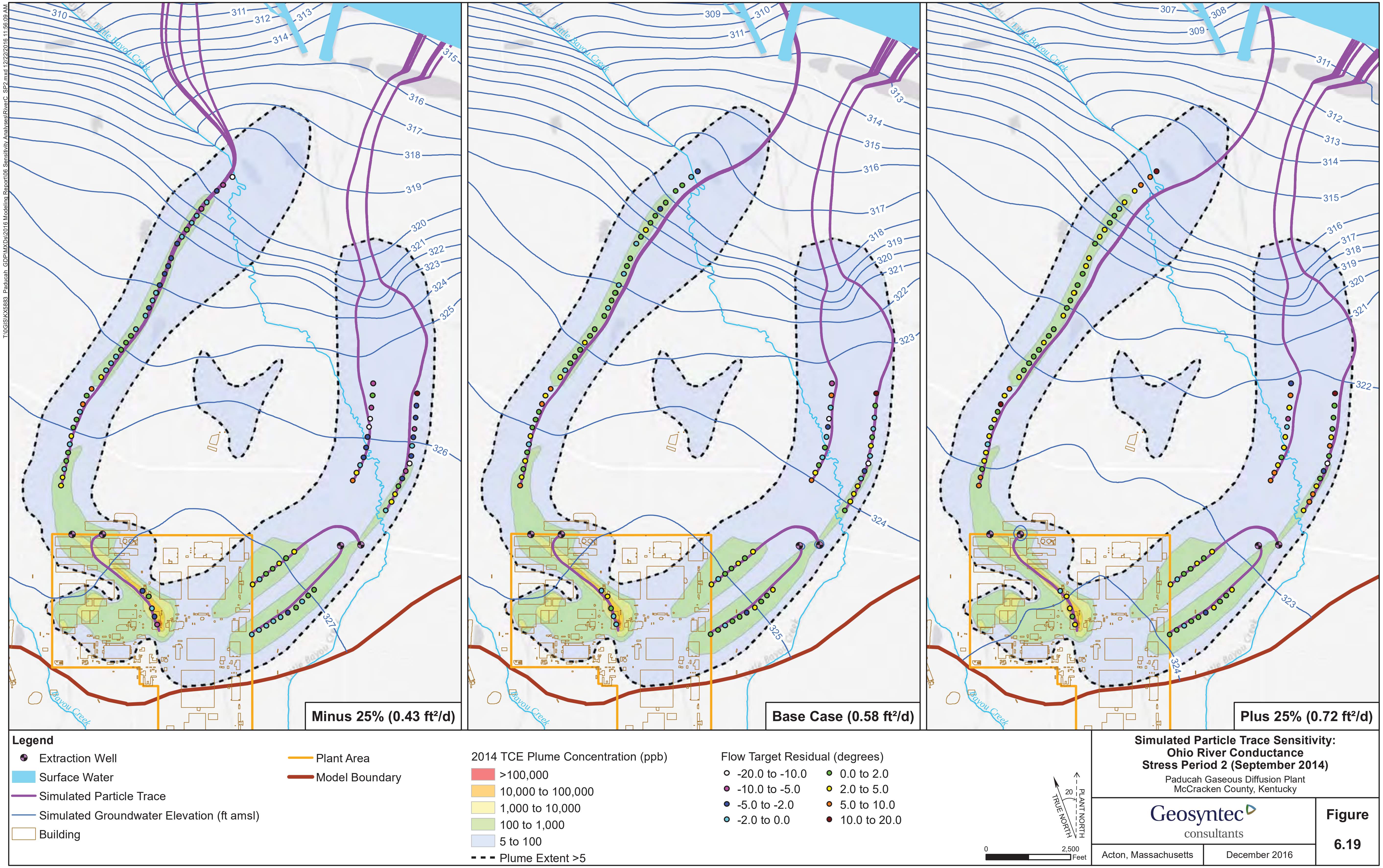
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.17. Simulated Particle Trace Sensitivity: Ambient Recharge, Stress Period 2 (September 2014)



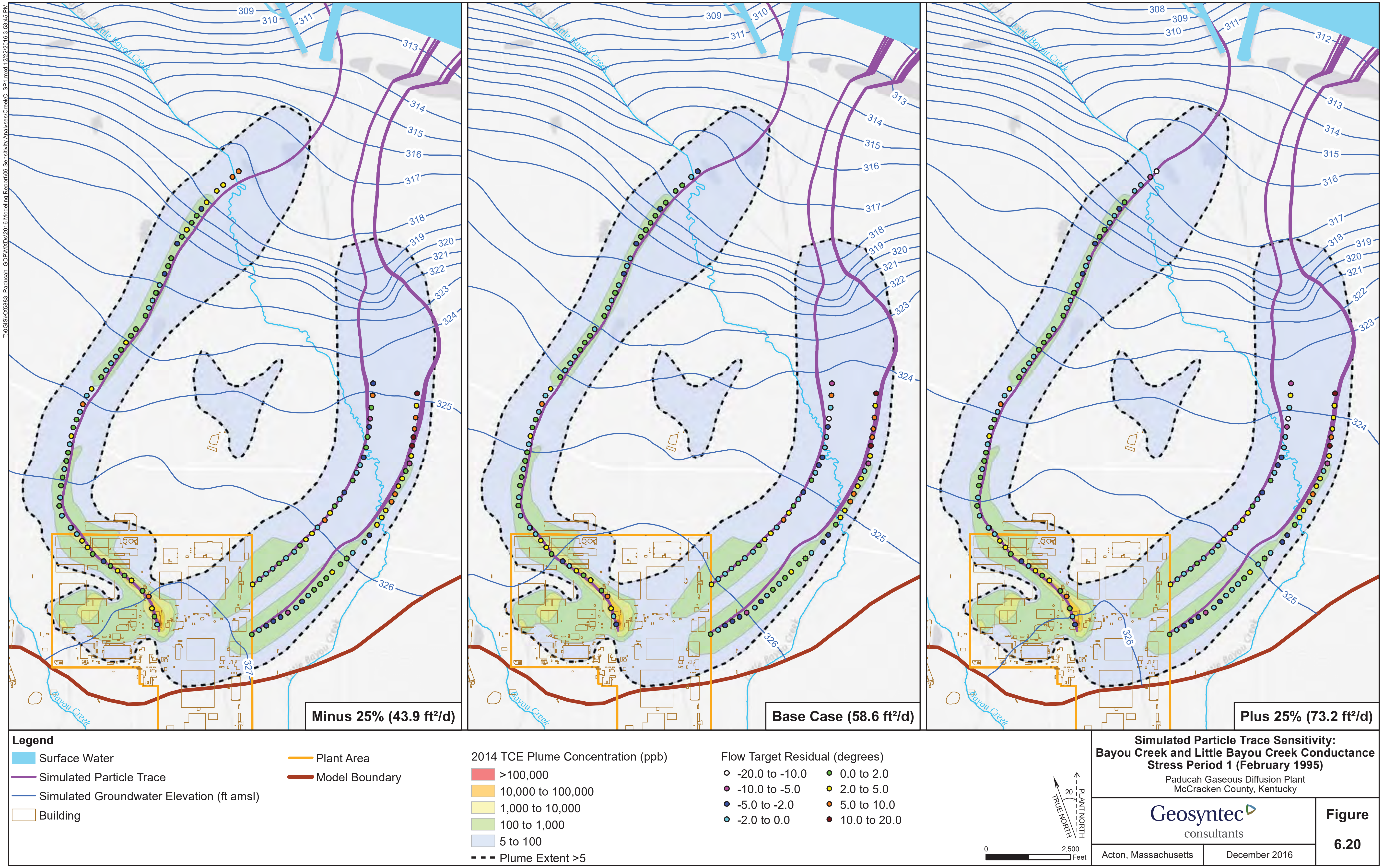
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.18. Simulated Particle Trace Sensitivity: Ohio River Conductance, Stress Period 1 (February 1995)



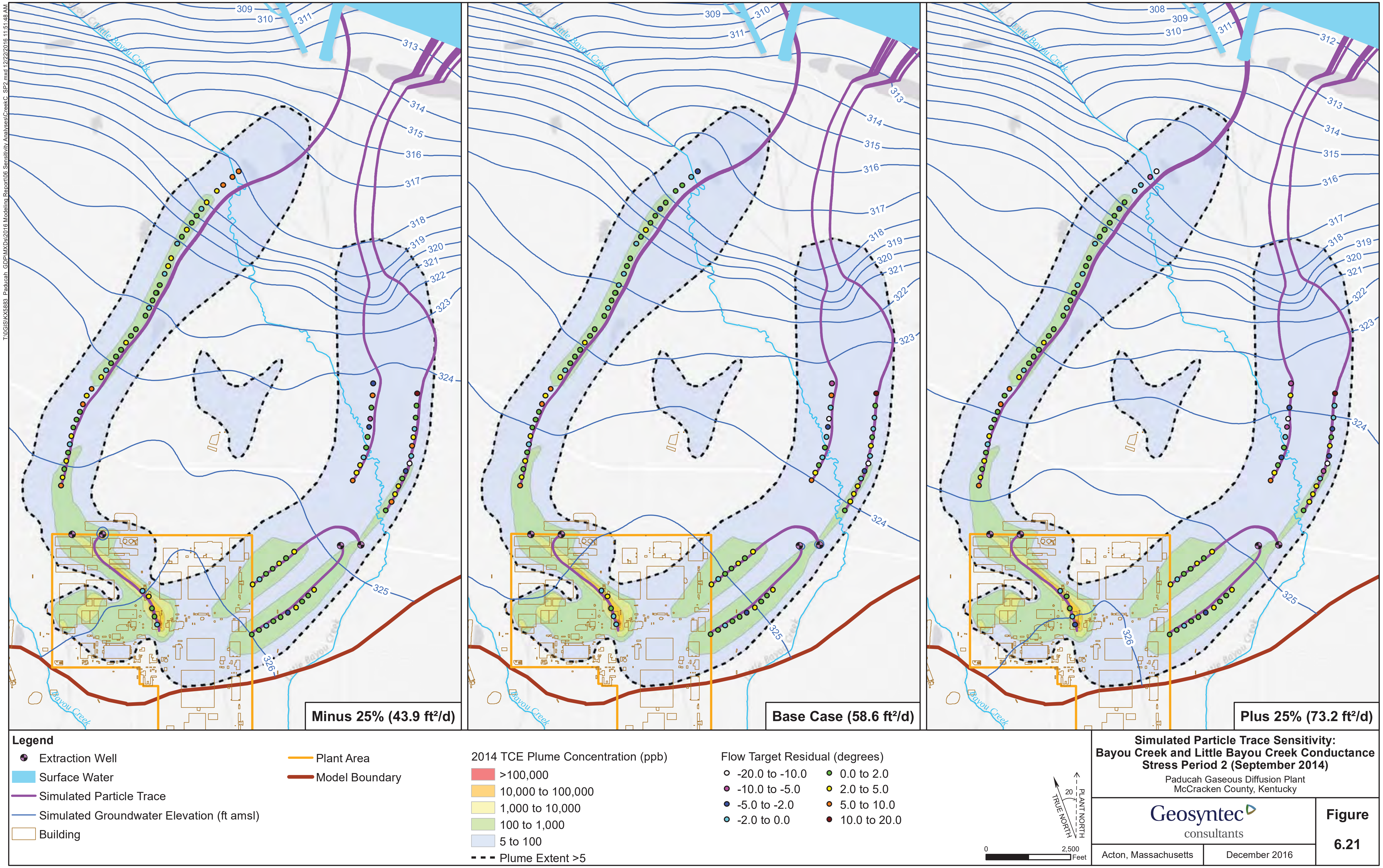
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.19. Simulated Particle Trace Sensitivity: Ohio River Conductance, Stress Period 2 (September 2014)



Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.20. Simulated Particle Trace Sensitivity: Bayou Creek and Little Bayou Creek Conductance, Stress Period 1 (February 1995)



Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.21. Simulated Particle Trace Sensitivity: Bayou Creek and Little Bayou Creek Conductance, Stress Period 2 (September 2014)

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For the relatively more sensitive anthropogenic recharge zones (as identified by PEST). which include storm drain recharge (Figures 6.22 and 6.23), the largest thin clay recharge area (Figures 6.24 and 6.25), the compromised roof drain recharge area (Figures 6.26 and 6.27), and the HPFW piping system recharge area (Figures 6.28 and 6.29), simulated increases and decreases in parameter values result in no discernable difference in particle traces or plume trajectory in either SP1 or SP2.

For both stress periods, SP1 and SP2, simulated increases and decreases in recharge from the Terrace Gravel in the East and West Terrace Basins cause the predicted Northwest Plume and Northeast Plume particle traces to shift minimally (Figures 6.30 and 6.31).

In addition to the aforementioned model parameters, a sensitivity analysis was performed to assess how specified changes in Ohio River stage influences simulated plume trajectories (Figures 6.32 and 6.33). Unlike the other parameters, the minimum and maximum stage values do not correspond to 25% increases and decreases; rather, the minimum and maximum values correspond to the lowest observed (290 ft) and the 90th percentile (320 ft) stages (DOE 2010, Section 7.2.9). The results show that a simulated decrease in the Ohio River stage minimally influences the particle traces representing the Northwest Plume and Northeast Plume. An increase in the Ohio River stage results in a westerly shift of the Northeast Plume particle traces with minimal effects on the plume trajectory. A more pronounced effect is observed in the Northwest Plume particle traces, which discharge to LBC instead of migrating to the Ohio River. Similar to the effects of decreasing the hydraulic conductivity (conductance) of the Ohio River, the result is increased predicted discharge to the creeks and decreased discharge to the Ohio River due to a shift in predicted groundwater gradients.

In summary, while increases and decreases in most parameter values result in minimal influence to simulated plume trajectories and minimal deviation from the observed locations of the Northeast and Northwest Plumes, the results of decreasing river hydraulic conductivity (conductance) and increasing Ohio River stage exhibit pronounced shifts in the plume trajectories near LBC and the Ohio River. This suggests that, while groundwater levels fluctuate in response to varying precipitation and anthropogenic recharge rates, the overall long-term PGDP Hydrologic Basin flow directions in the core of the Northeast and Northwest Plumes remain relatively constant. This assessment is supported by the temporally constant Northeast Plume and Northwest Plume geometries observed between 1994 and 2005 (DOE 2010, Figure 4.3) and the current plume configurations (Figure 6.17). On a short-term basis, which corresponds to transient fluctuations in the Ohio River stage, model results indicate a pronounced shift in the Northwest Plume trajectory at the toe of the plume near LBC during a high river stage (i.e., 320 ft amsl). The steady-state simulations used for this sensitivity analysis are not directly comparable to the typical short-term transient conditions present at the site during high Ohio River stages; however, the sensitivity analysis is useful for qualitatively evaluating short-term shifts in groundwater flow directions during short-term, transient site conditions. This hypothesis is supported by the early delineations of the Northwest Plume indicating migration toward LBC in plume delineations for 1994 to 2005 (DOE 2010, Figure 4.3).

6.8 SOURCE AREA FLOW PATH ANALYSIS

To evaluate near field flow paths in the plant area, particle track analysis was conducted by specifying starting particles at locations of known or suspected TCE and/or technetium-99 (Tc-99) source areas. The areas included in the analysis are described in Table 6.6 and illustrated in Figure 6.34. Note that source material must migrate through the UCRS before entering the RGA, and there is uncertainty regarding the points of contaminant entry into the RGA. Hence, the locations of source areas shown on Figure 6.34 are

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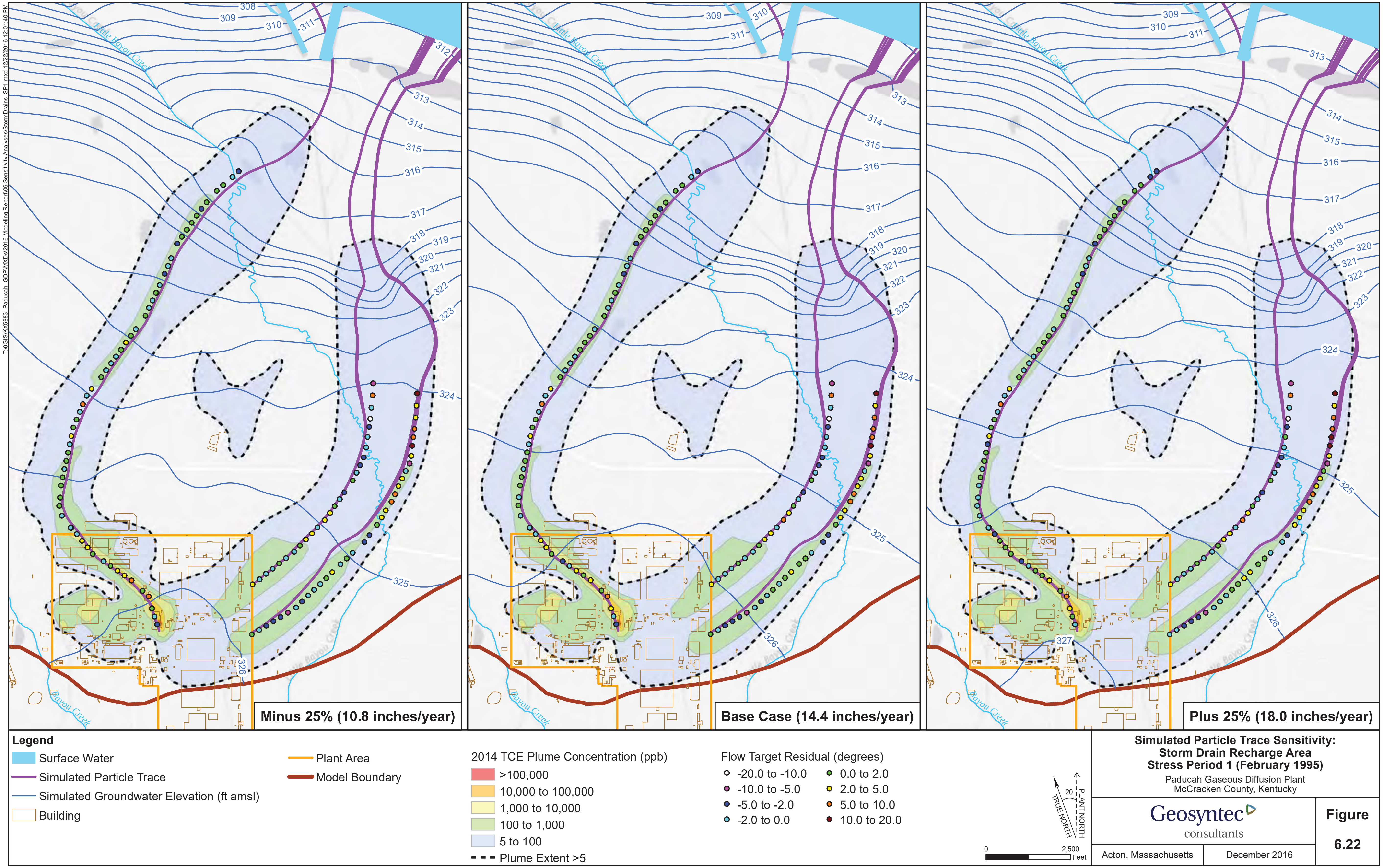
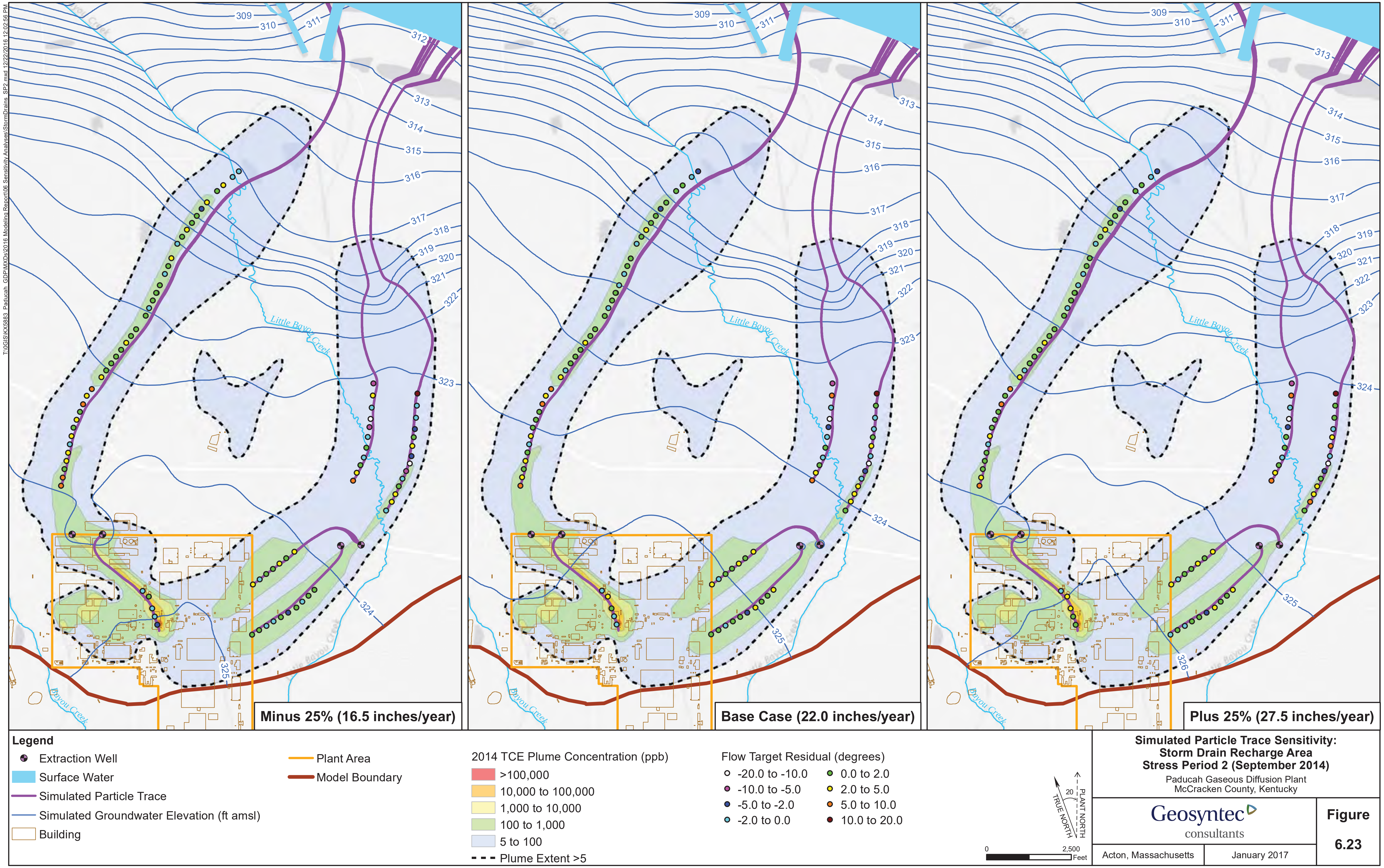


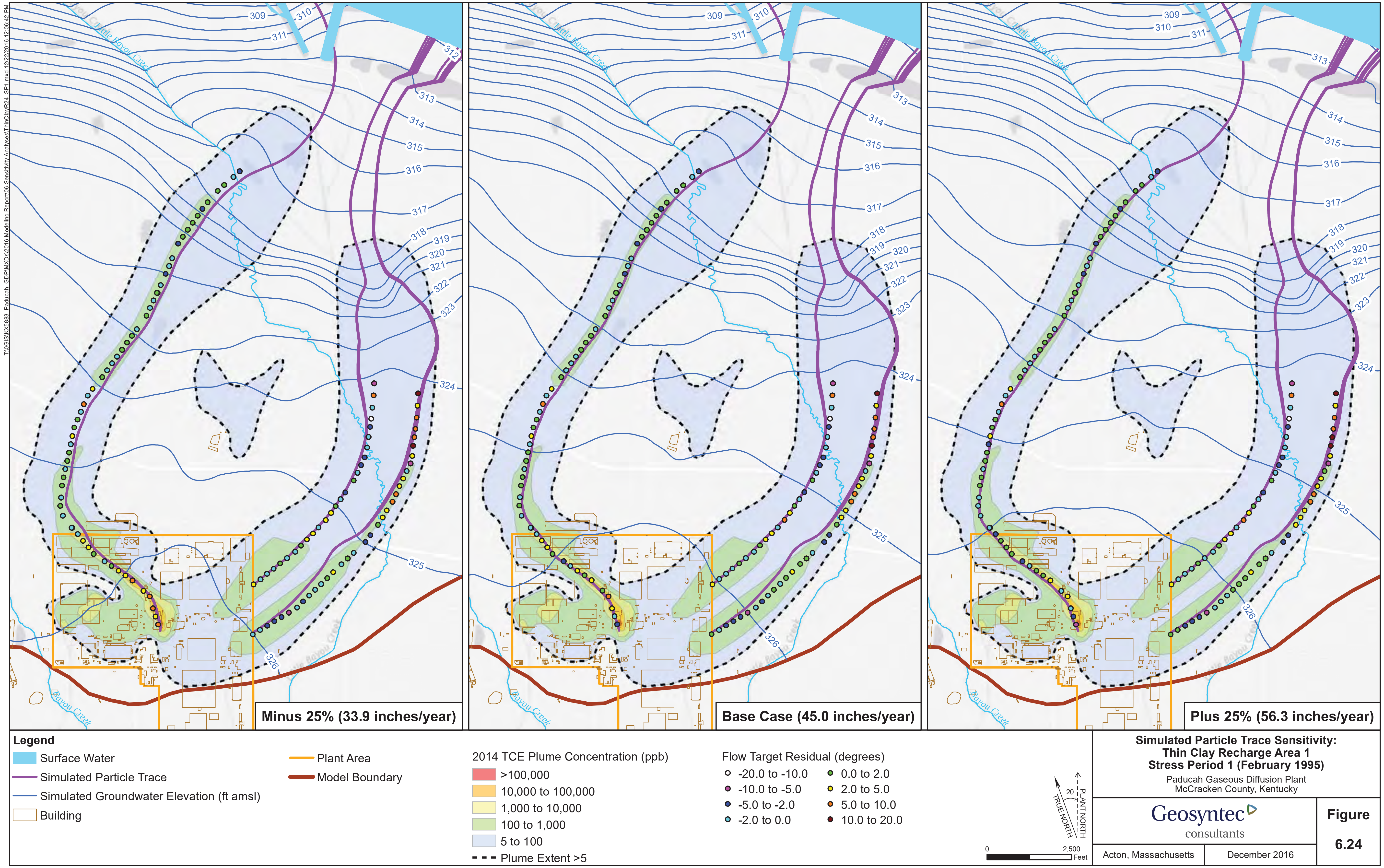
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.22. Simulated Particle Trace Sensitivity: Storm Drain Recharge Area, Stress Period 1 (February 1995)



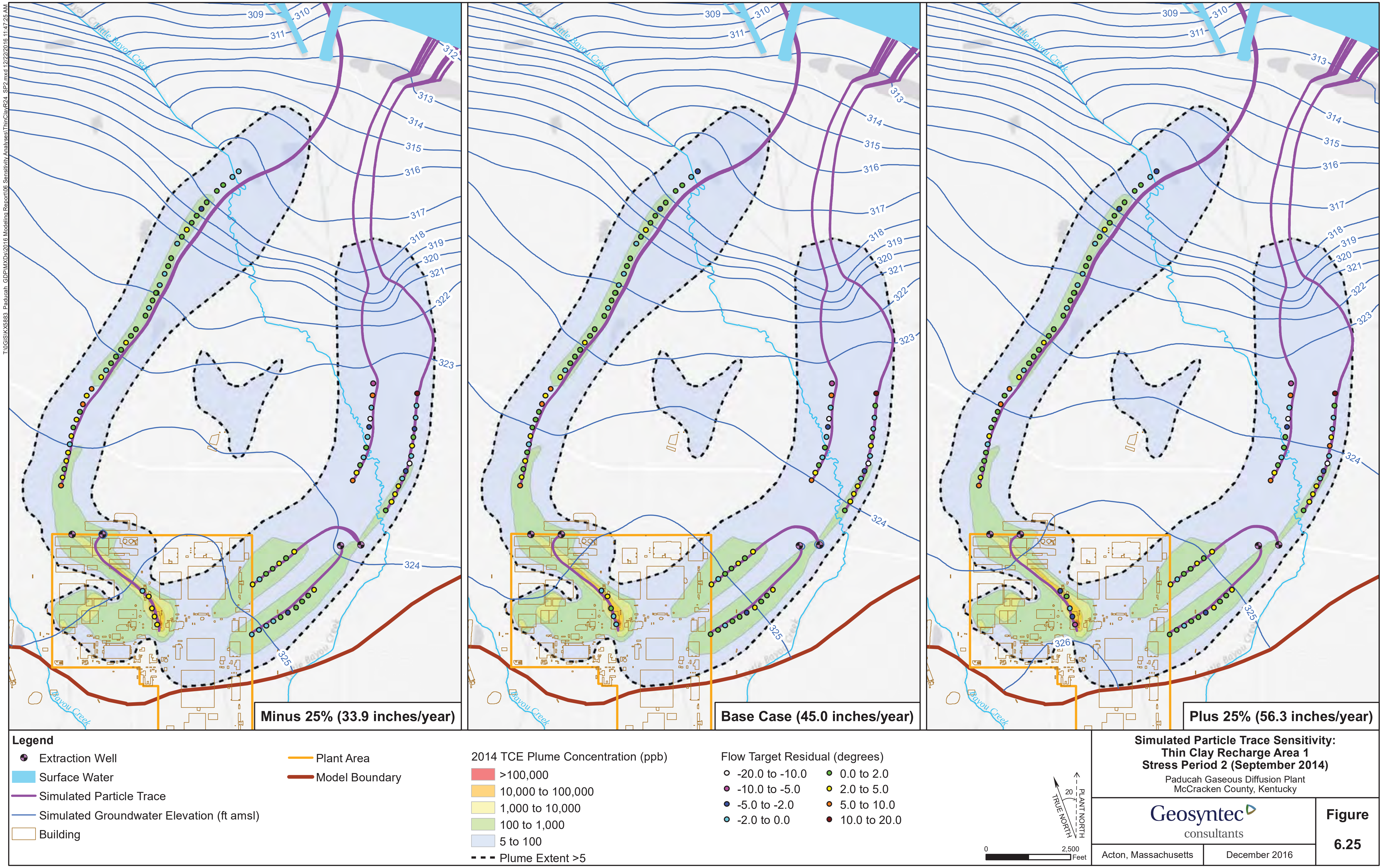
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.23. Simulated Particle Trace Sensitivity: Storm Drain Recharge Area, Stress Period 2 (September 2014)



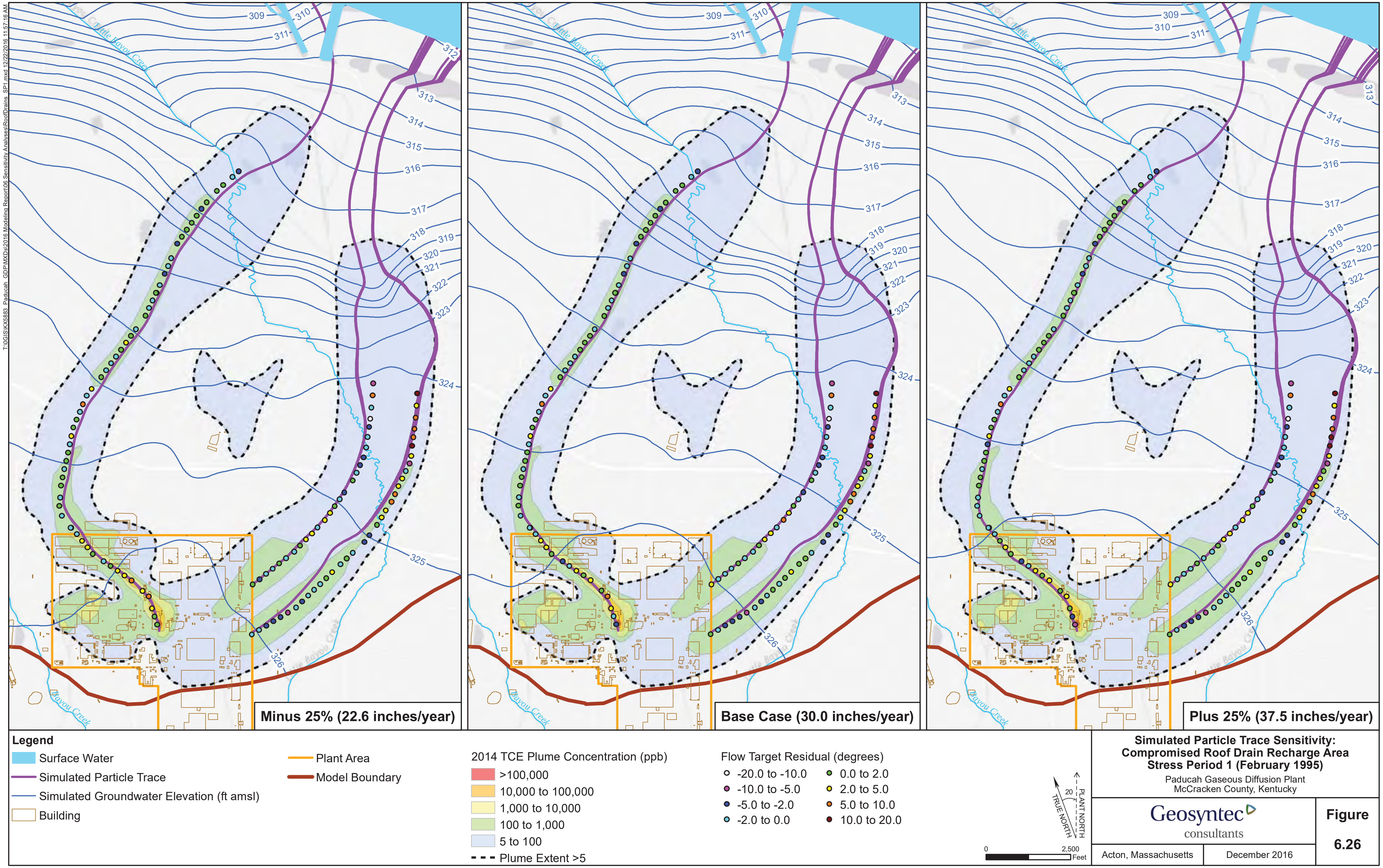
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.24. Simulated Particle Trace Sensitivity: Thin Clay Recharge Area 1, Stress Period 1 (February 1995)



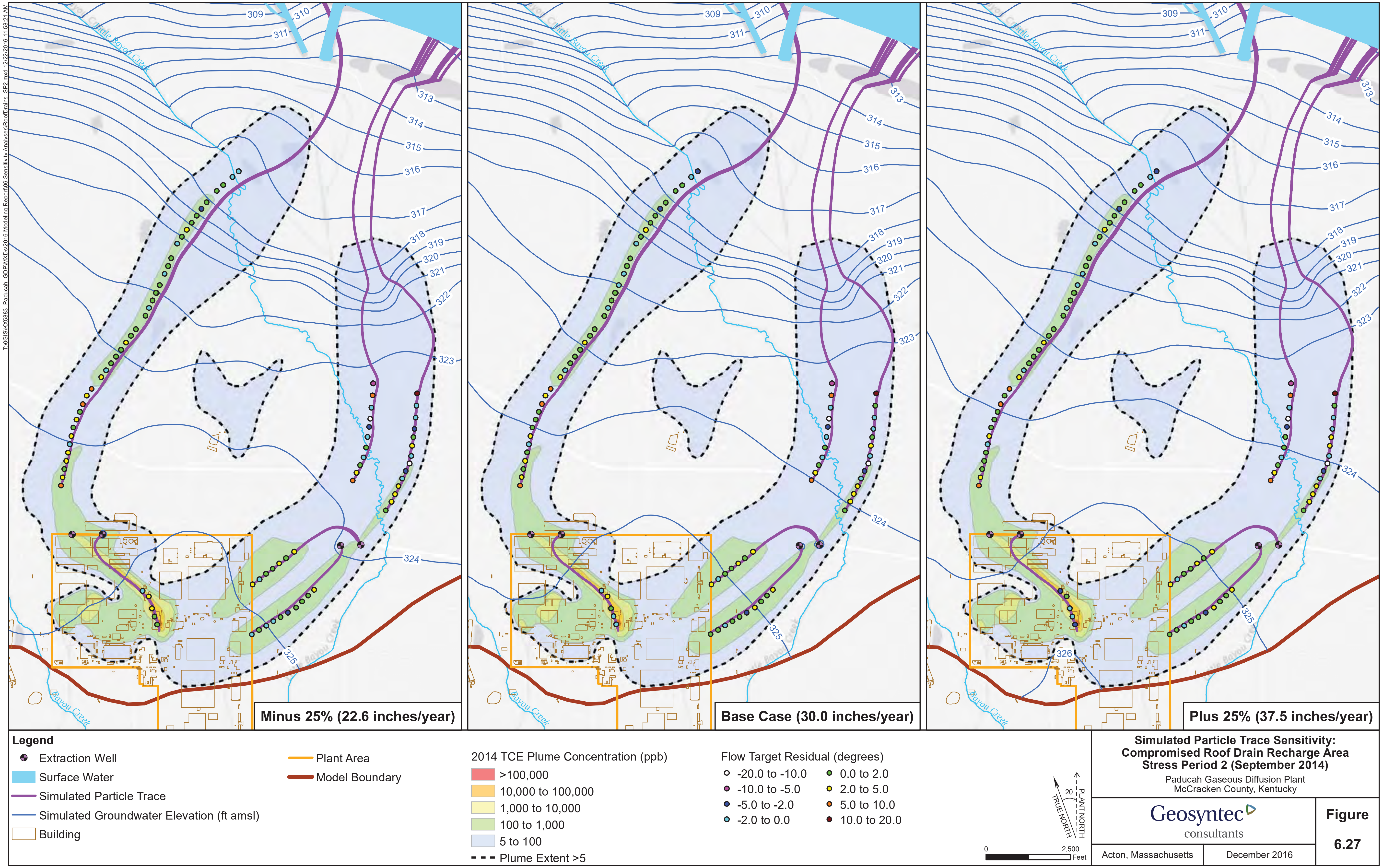
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.25. Simulated Particle Trace Sensitivity: Thin Clay Recharge Area 1, Stress Period 2 (September 2014)



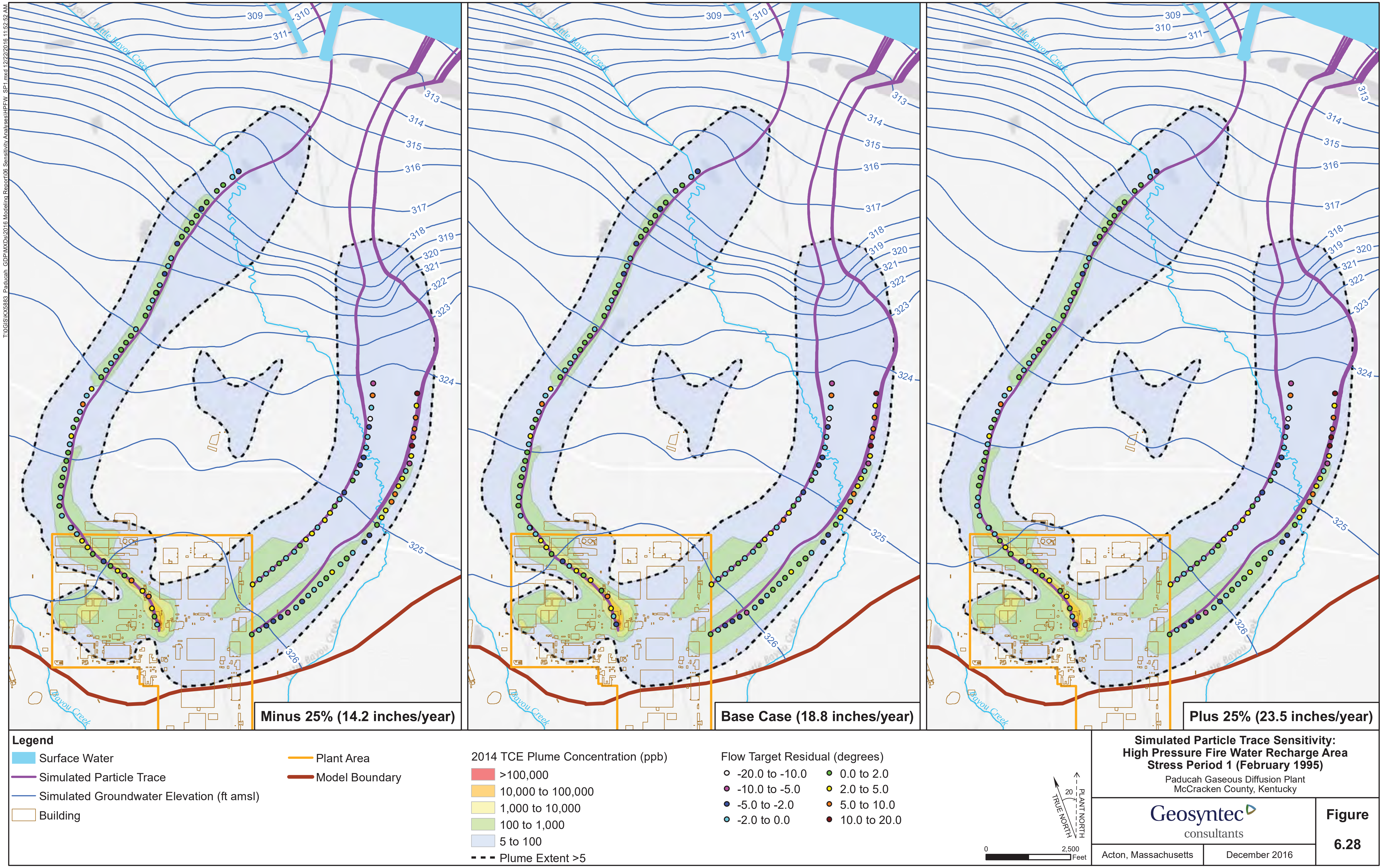
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.26. Simulated Particle Trace Sensitivity: Compromised Roof Drain Recharge Area, Stress Period 1 (February 1995)



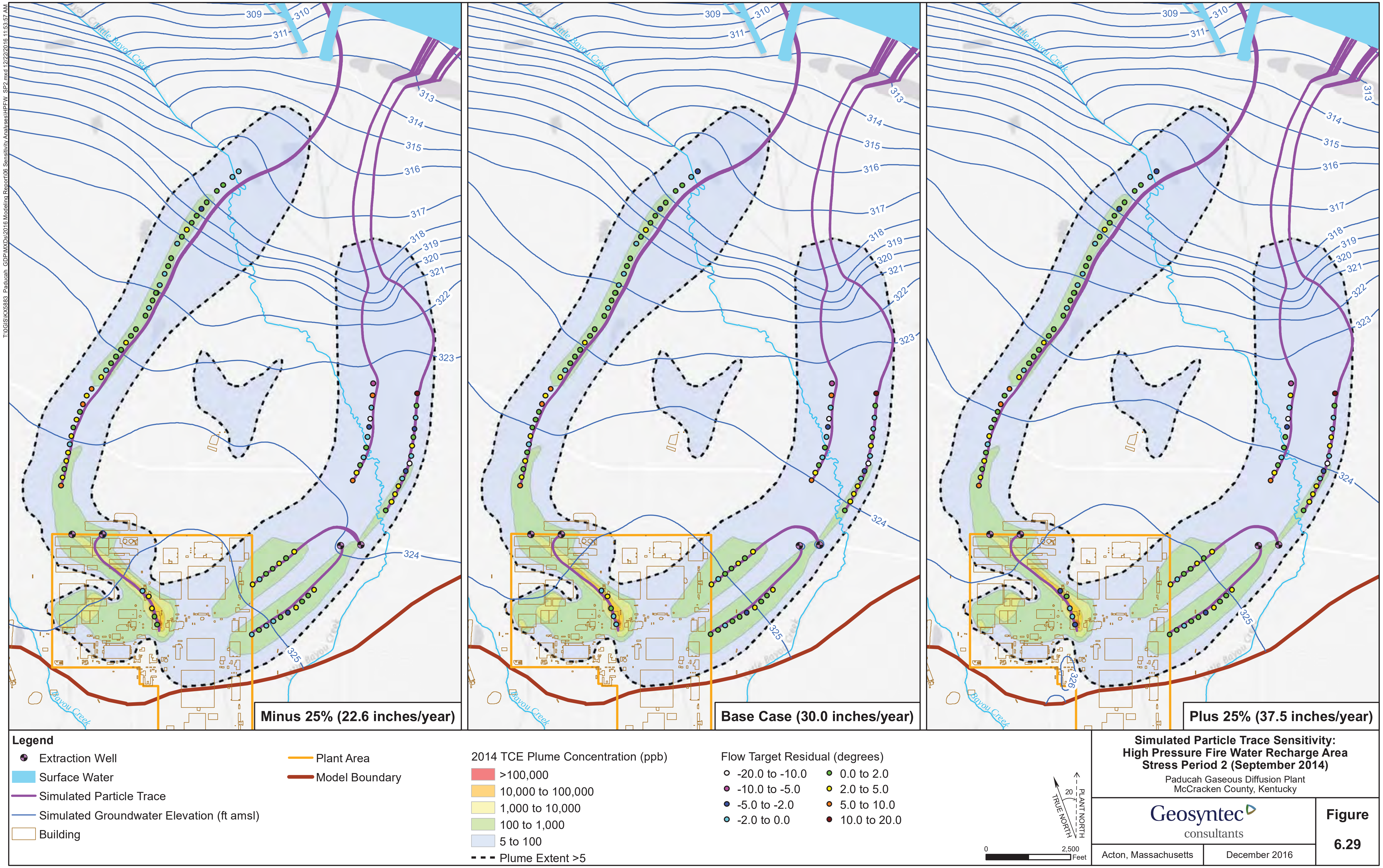
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.27. Simulated Particle Trace Sensitivity: Compromised Roof Drain Recharge Area, Stress Period 2 (September 2014)



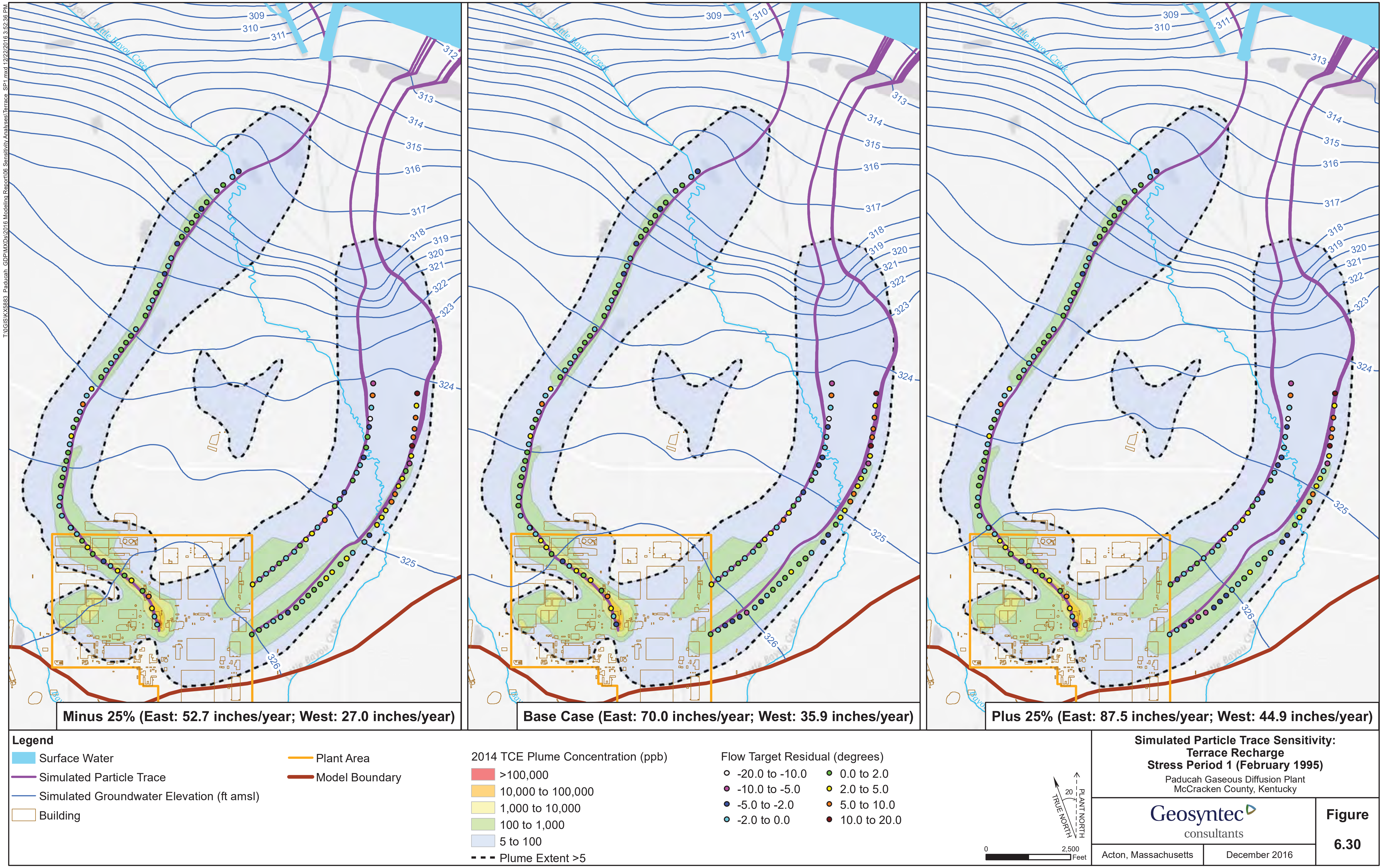
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.28. Simulated Particle Trace Sensitivity: High Pressure Fire Water Recharge Area, Stress Period 1 (February 1995)



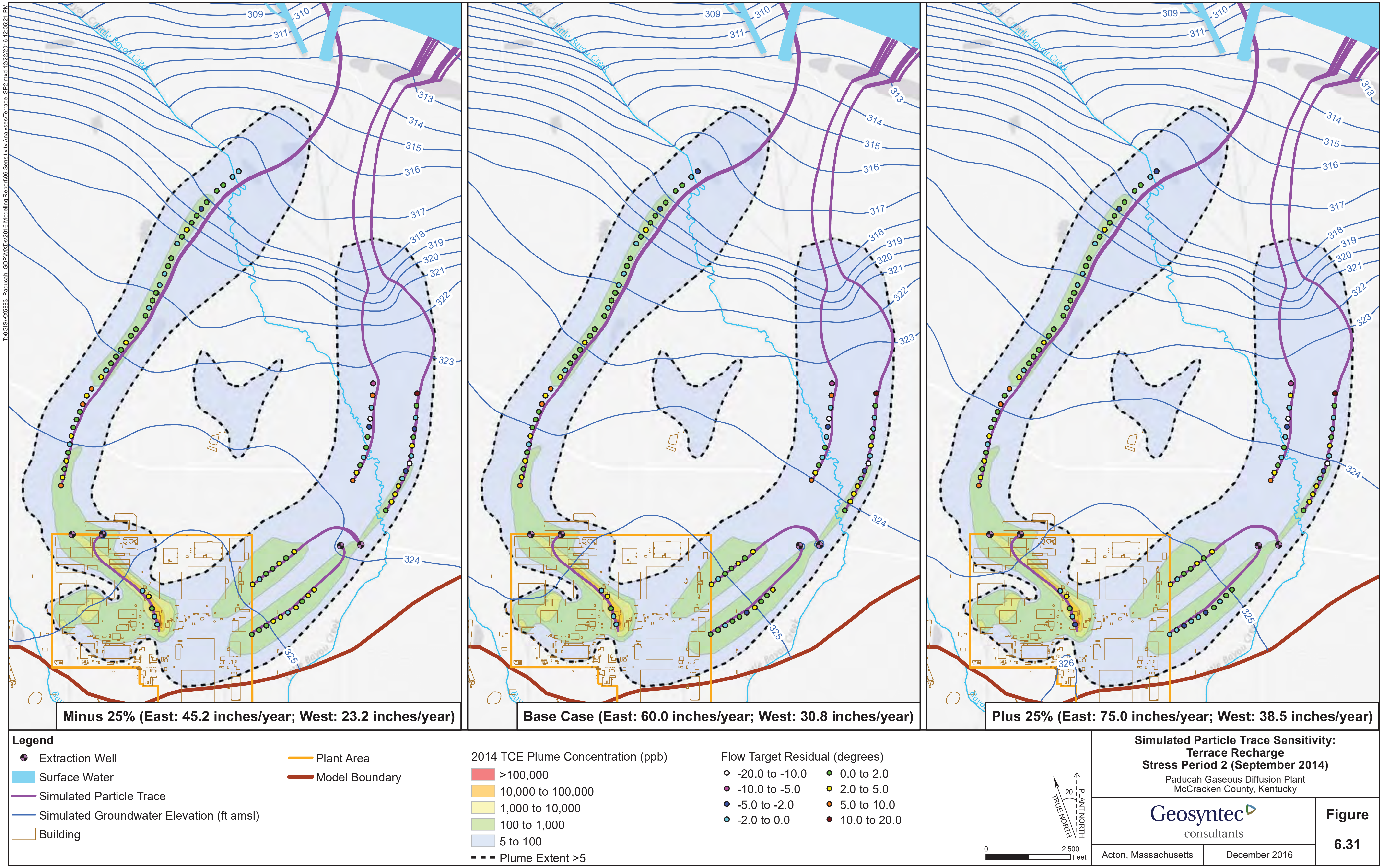
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.29. Simulated Particle Trace Sensitivity: High Pressure Fire Water Recharge Area, Stress Period 2 (September 2014)



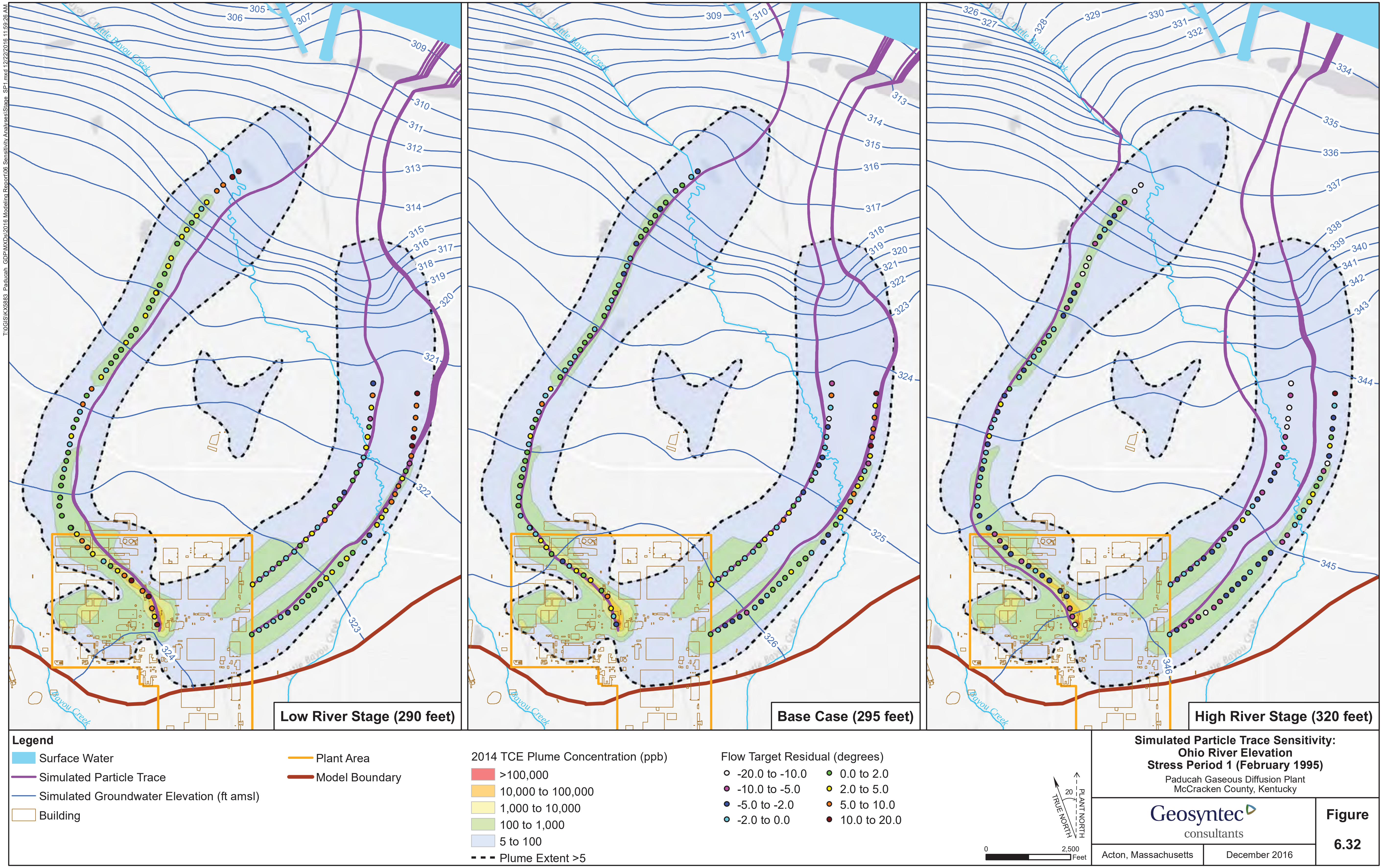
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.30. Simulated Particle Trace Sensitivity: Terrace Recharge, Stress Period 1 (February 1995)



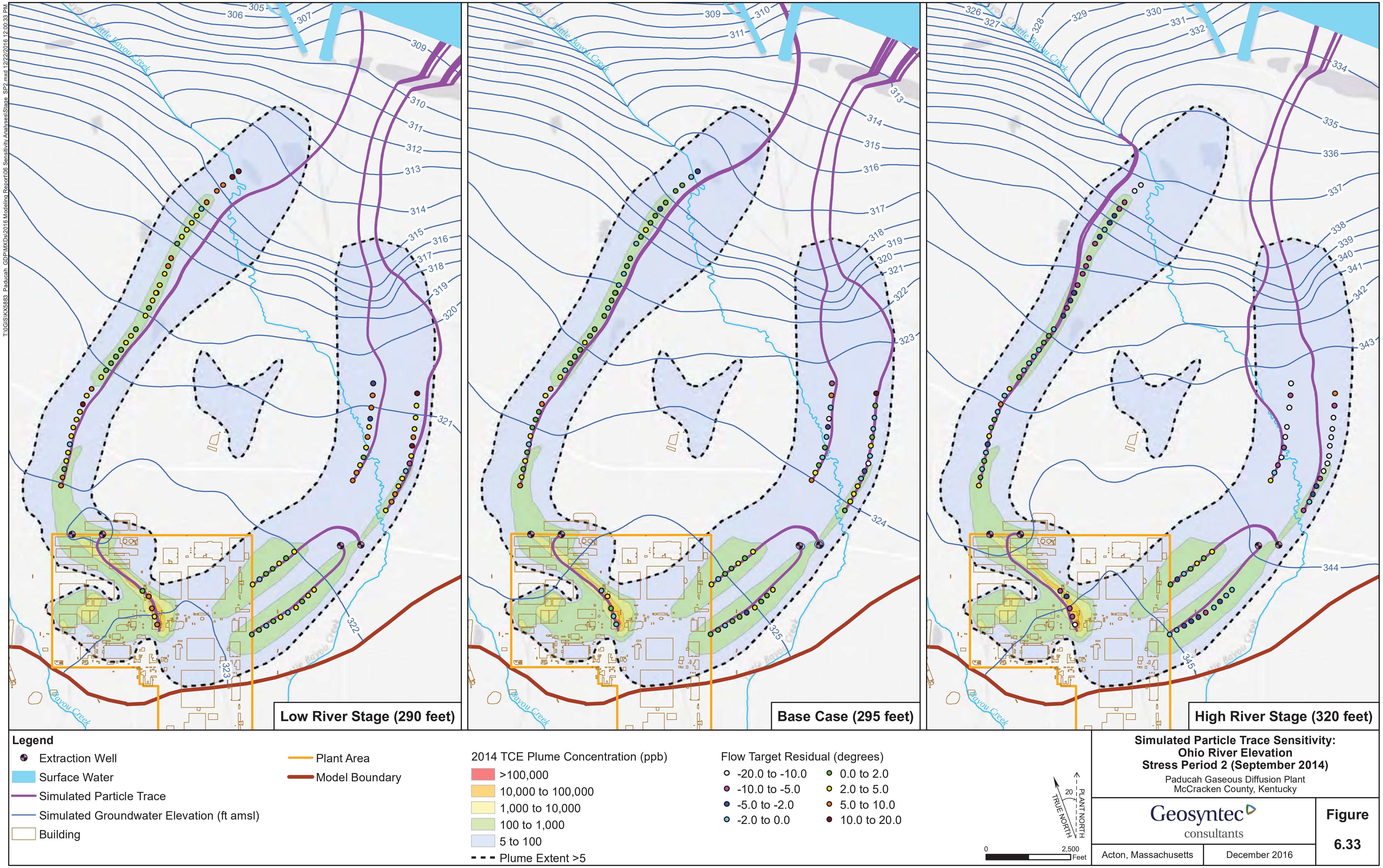
Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.31. Simulated Particle Trace Sensitivity: Terrace Recharge, Stress Period 2 (September 2014)



Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.32 Simulated Particle Trace Sensitivity: Ohio River Elevation, Stress Period 1 (February 1995)



Note: Trajectory target residuals and head contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015a; Figure C.2

Figure 6.33. Simulated Particle Trace Sensitivity: Ohio River Elevation, Stress Period 2 (September 2014)

Table 6.6. Known or Suspected Trichloroethene and Technetium Source Areas

Waste Area Group	Solid Waste Management Unit or Area of Concern	Description	Type(s) of Release	Primary Contaminants Present	Reference
Northeast Plume (AOC 202)					
6	SWMU 40	C-403 Neutralization Pit	Leak from former waste treatment facility (including UCRS DNAPL zone)	Trichloroethene and Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
28	SWMU 99	C-745 Kellogg Building Site	Leaching of contamination from materials storage yard	Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
28	AOC 204	Dykes Road Historical Staging Area	TCE leak into drainage ditch (including shallow soils DNAPL zone)	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
None Assigned	None assigned	Undefined Source	Near northeast corner of C-333	Trichloroethene	DOE 2001, Volume 1, Table 1.3
Northwest Plume (AOC 201)					
6	SWMU 11	C-400 TCE Leak Site	Leak from break in storm sewer	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
6	SWMU 47	C-400 Technetium Storage Tank Area	Leak/spill from former waste storage tank	Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
6	SWMU 203	C-400 Waste Discard Sump	Effluent pipeline sump	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
6	SWMU 533	TCE Spill Site from TCE Unloading Operations at C-400	Leak of TCE transfer pump	Trichloroethene	DOE 1999
22	SWMU 7	C-747-A Burial Ground	Leaching from waste burial cells (including UCRS DNAPL zone)	Trichloroethene and Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
22	SWMU 30	C-747-A Burn Area	Leaching from waste burial cells and foundation of former incinerator	Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
25	SWMU 59	North-South Diversion Ditch (inside plant security fence)	Leaching from contaminated sediments	Technetium	DOE 2001, Volume 2, Appendix A, Table 6.1
Southwest Plume (AOC 210)					
27	SWMU 1	C-747-C Oil Landfarm	Former oil landfarm (including UCRS DNAPL zone)	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
22	SWMU 2	C-749 Uranium Burial Ground	Leaking drum in uranium burial ground	Trichloroethene	DOE 2010
22	SWMU 3	C-404 Low-Level Radioactive Waste Burial Ground	RCRA-closed landfill	Trichloroethene and Technetium	DOE 2010
3	SWMU 4	C-747 Contaminated Burial Ground	Former burial ground	Trichloroethene	DOE 2016
27	SWMU 91	C-745-B Cylinder Drop Test Area	Former TCE dip tank (including UCRS DNAPL zone)	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
1	SWMU 136	C-740 TCE Spill Site	Raw materials storage shed	Trichloroethene	DOE 1996
27	SWMU 209	C-720 Compressor Shop Pit	Former waste liquids sump	Trichloroethene	DOE 2001, Volume 2, Appendix A, Table 6.1
27	SWMU 211-A	C-720 TCE Spill Site - Northeast	Unknown - multiple mechanisms possible	Trichloroethene	DOE 2013
27	SWMU 211-B	C-720 TCE Spill Site - Southeast	Unknown - multiple mechanisms possible	Trichloroethene	DOE 2013

References:

DOE 1996. Resource Conservation and Recovery Act Facility Investigation/Remedial Investigation Report for Waste Area Groupings 1 and 7 at Paducah Gaseous Diffusion Plant, Paducah Kentucky, Volume 1, April.

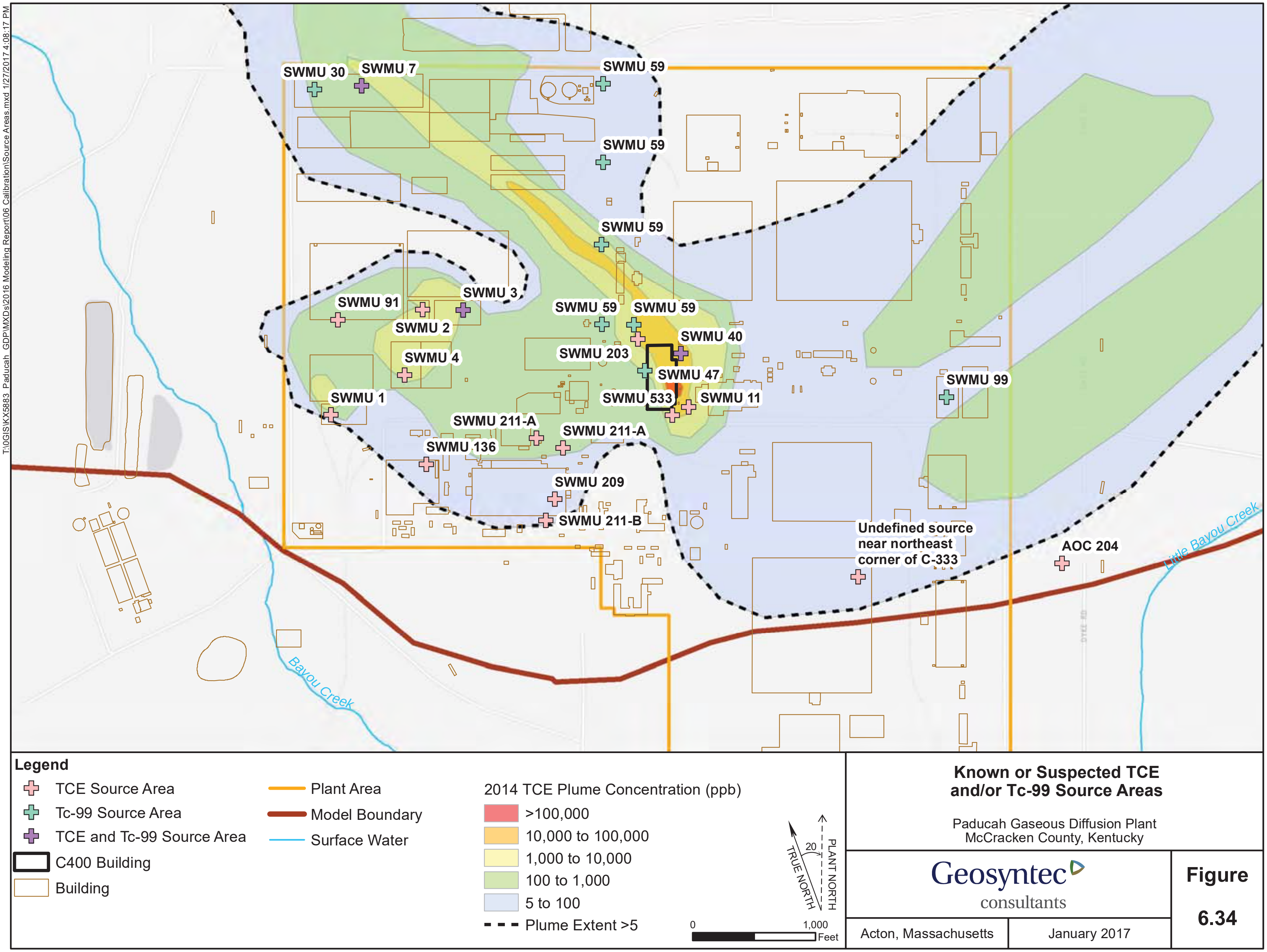
DOE 1999. Remedial Investigation Report for Waste Area Grouping 6 at Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Volume 1, May.

DOE 2001. Feasibility Study for the Groundwater Operable Unit at Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Volumes 1 and 2, August.

DOE 2010. Remedial Investigation Report for the Burial Grounds Operable Unit at Paducah Gaseous Diffusion Plant, Paducah, Kentucky, February.

DOE 2013. Final Characterization Report for Solid Waste Management Units 211-A and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, December.

DOE 2016. Addendum to the Remedial Investigation Report for the Burial Grounds Operable Unit Solid Waste Management Unit 4 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, August.



Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.34. Known or Suspected TCE and Tc-99 Source Areas

approximate relative to the model domain. The particles origination points were specified at the top, middle, and bottom of layers 1, 2, and 3 in the assessed locations and forward particle tracks were calculated for both SP1 (February 1995) and SP2 (September 2014).

The results of the analysis are illustrated in Figure 6.35. The pathlines generally align well with the 2014 TCE plume delineation for both the non-pumping (SP1) and pumping (SP2) stress periods with a few exceptions. Pathlines originating at Solid Waste Management Unit (SWMU) 59, Area of Concern (AOC) 204, and an undefined source near the northeast corner of the C-333 Building deviate from the known distribution of TCE as defined by the 2014 plume delineation. SWMU 59 is a diversion ditch with sediments contaminated by Tc-99 and was represented in the model as five particle release locations located along the ditch. Because SWMU 59 is a source area for Tc-99 and not TCE, the pathlines originating at the particle locations representing SWMU cannot be directly related to the 2014 TCE plume delineation. The pathlines originating at AOC 204 and the northeast corner of the C-333 building tend to travel in a more eastward direction than would be expected based on the 2014 TCE plume delineation. Particle tracks for these source areas begin near the periphery or outside of the 2014 plume extent as defined by the 5 ppb TCE contour; introducing more uncertainty in the assessment of the model-predicted flow path compared to the observed TCE distribution. Moreover, the entry points to the RGA from these sources are not known exactly. The source near the northeast corner of the C-333 building is undefined, and dense nonaqueous-phase liquid (DNAPL) could have migrated laterally on low permeability silt/clay layers in the UCRS prior to entering the RGA, which complicates interpretation of these particle tracks in terms of dissolved plume movement in the RGA.

6.9 MODEL VALIDATION

Validation of the model was conducted to evaluate model performance under varied site conditions. The validation approach was implemented by comparing the model calculated output to observed data from datasets identified in Section 3.4 to represent a range of site conditions including extreme flooding and transient hydrogeologic conditions related to seasonally transient boundary conditions (i.e., ambient recharge and river stage). The three data sets remaining from the five that were identified for calibration were also included in the validation. Table 6.7 summarizes the stress periods that were used for validation.

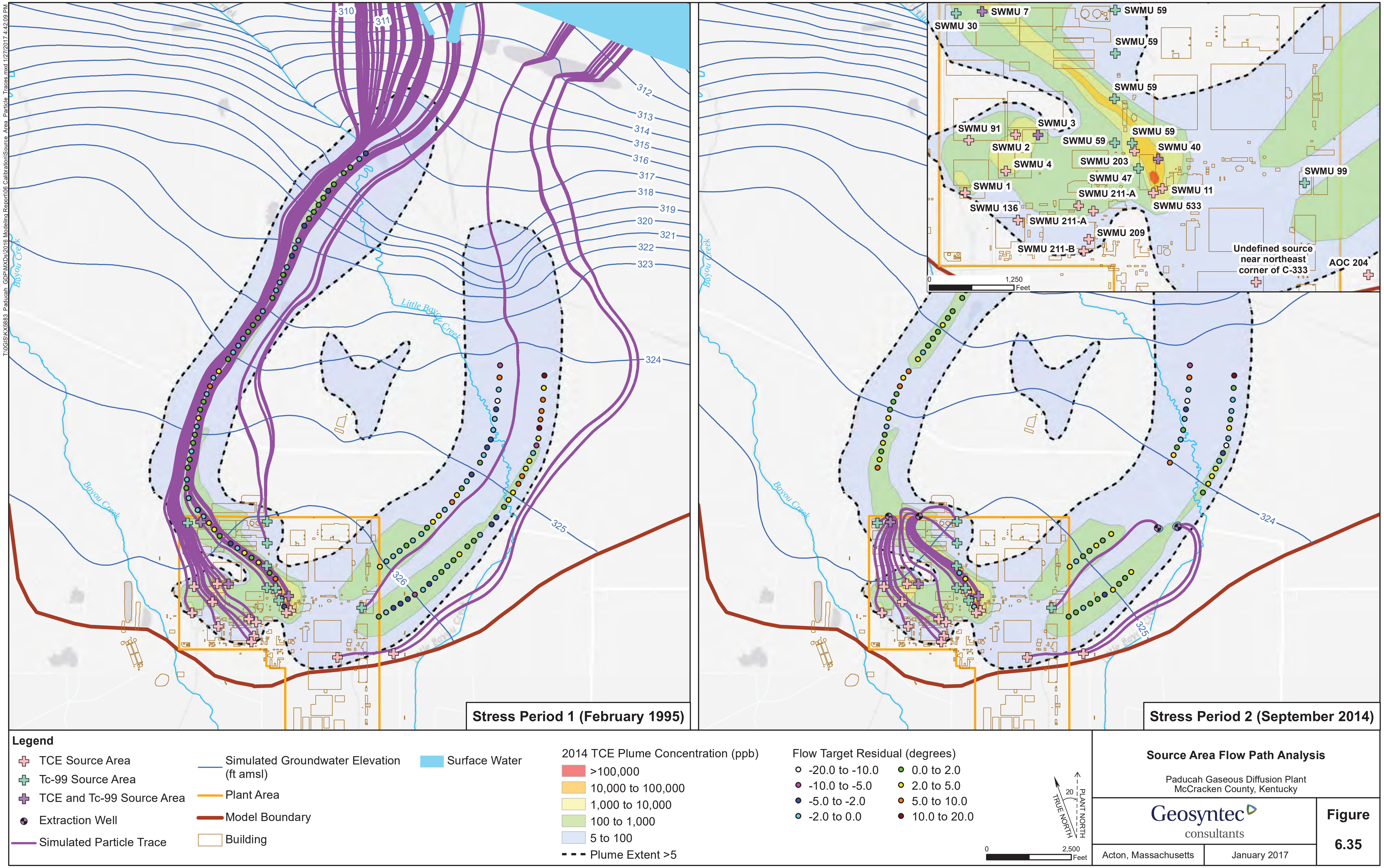
Two key metrics are identified to evaluate model performance and assess the uncertainty regarding use of the model as a tool to evaluate future remediation scenarios and identify data gaps.

1. Groundwater flow path lines to assess the model's ability to simulate the Northwest and Northeast Plumes migration.

2. Hydraulic gradient across the model domain to assess the change in water level elevation from the plant to the Ohio River.

The ability of the model to simulate the alternative site conditions defined by the validation datasets was assessed to provide insight to potential uncertainty in model predictions.

In addition to a visual match of path lines to plume centerlines, the predicted gradient across the model domain between the plant area and LBC in the direction of groundwater flow was evaluated.



Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.35. Source Area Flow Path Analysis

Table 6.7. Model Validation Monitoring Events

Monitoring Period	Number of Water Level Targets	Ohio River Stage[1] (ft amsl)	Monitoring Event Type	Annual Precipitation (inches/yr)	Rationale
3rd Quarter 2005	110	300.0[2]	Sitewide Synoptic	37.5	Representative of steady-state conditions, initial extraction well system in operation. Use to evaluate initial extraction well system configuration.
April 12, 2011	212	327.2	Sitewide Synoptic	74.8	High relative annual precipitation, river at flood stage at conditions that do not represent steady-state conditions. Use to evaluate extreme high river condition.
October 10, 2011	202	295.5	Sitewide Synoptic	74.8	Full synoptic data set representing steady-state conditions at high annual precipitation. Use to evaluate above average rainfall conditions.
July 17, 2012	184	290.0	Sitewide Synoptic	27.6	Full synoptic data set representing steady-state conditions at low annual precipitation and low river stage. Use to evaluate below average rainfall conditions and low river stage.
September 24, 2013	203	292.5	Sitewide Synoptic	60.3	Full synoptic data set representing steady-state conditions at high annual precipitation. Use to evaluate above average rainfall conditions.
September 1, 2015	205	296.7	Sitewide Synoptic	59.2	High relative annual precipitation and dropping river stage prior to monitoring event. Use to evaluate model prediction under non-steady state condition.
August 23, 2016	216	298.0[2]	Sitewide Synoptic	TBD[3]	Full synoptic data set representing steady-state conditions. Use to evaluate current conditions.

[1] Average Ohio River stage at the Metropolis station for 30 days prior to the water level measurement event except as otherwise noted.

[2] 30-day average Ohio River stage not used; see text for details (Section 3.4).

[3] To be determined: annual precipitation data not yet available for 2016.

6.9.1 Plume Trajectory

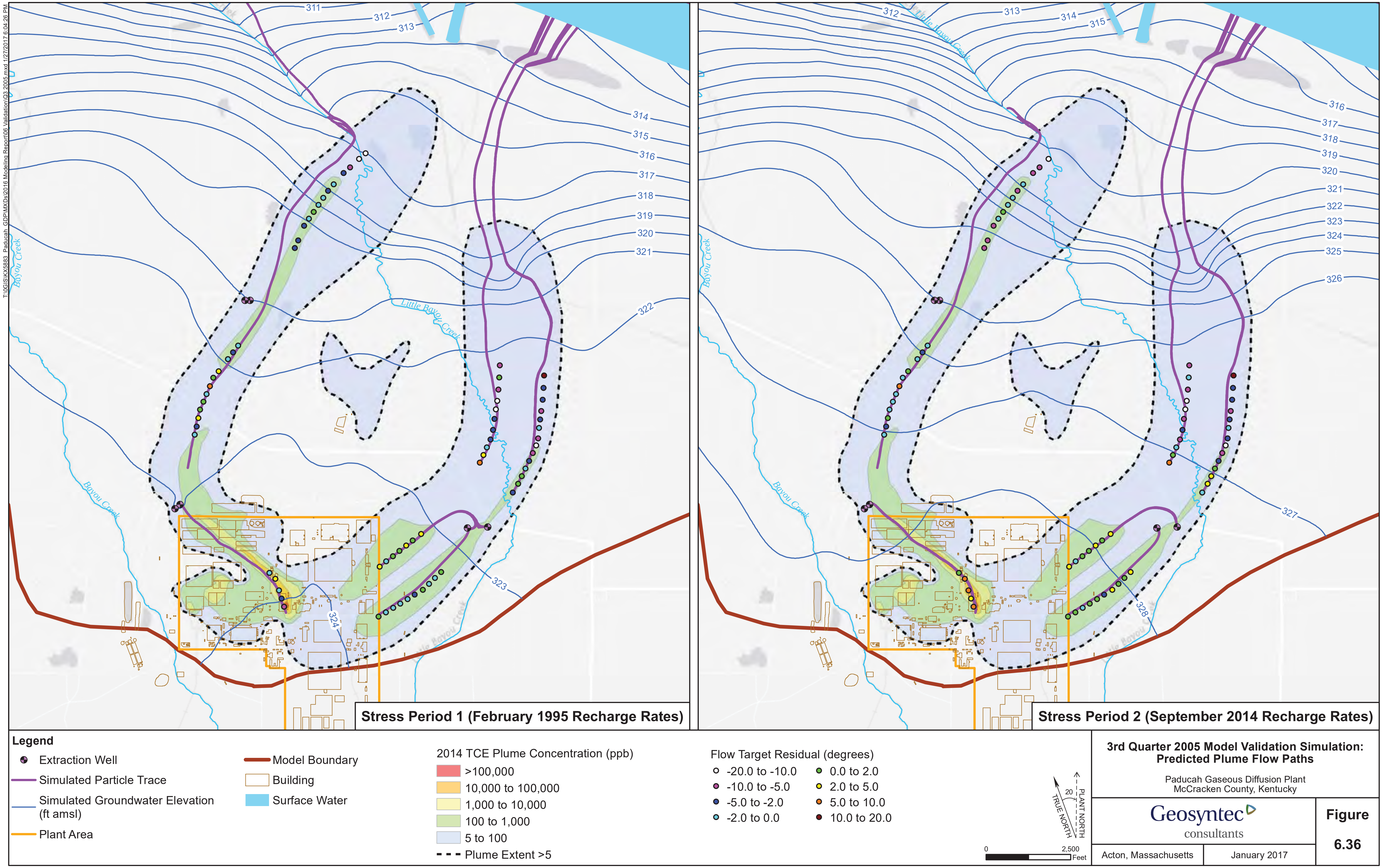
To assess the ability of the calibrated model to simulate alternative site conditions, the validation datasets were imported as water level targets into the calibrated model and the Ohio River stage was revised to the 30-day average, except as noted previously (see Section 3.4), for each validation period. The results of each validation simulation were evaluated using MODPATH to simulate the particle traces for SP1 and SP2 in order to assess the results under the range of recharge conditions simulated in the calibrated model. Unlike SP1, extraction wells were operating during all validation periods. To account for this site condition in the evaluation, pumping rates of extraction wells that were operational during the validation period were specified in SP1 and SP2. The particle traces for the seven validation periods evaluated are illustrated in Figures 6.36 to 6.42.

Site conditions range from extreme flooding conditions in April 2011 (with the river stage at 327.2 ft amsl) to the relative drought conditions in July 2012 (with the river stage at 290.0 ft amsl) as compared to the calibrated model river stage of 295.2 ft amsl. For all validation simulations, the plume trajectories exhibit similar responses between SP1 and SP2. The effects of alternative river stages are more prominent in the Northwest Plume trajectories with minimal deviation in the Northeast Plume trajectories compared to the calibrated flow paths (Figure 6.13).

In the Northwest Plume trajectories, the effect of higher than calibrated river stages is to deflect the flow paths westward towards the lower reach of LBC as groundwater discharge is diverted from the Ohio River to LBC due to a shift in gradients caused by the higher river level. The most extreme example is illustrated on Figure 6.37 for April 2011 with less extreme variations exhibited for third quarter (Q3) 2005 and August 2016 (Figure 6.36 and Figure 6.42; note that the variation in Q3 2005 is also due to pumping at EW228 and EW229, which are the northernmost extraction wells in the Northwest Plume that are not operational in any of the other calibration or validation periods). The effect of lower than calibrated river stages is to shift the particle traces slightly eastward as illustrated in Figures 6.39 and 6.40 for July 2012 and September 2013. For the simulation with a river stage close to that of the calibrated model, September 2015, the particle traces are similar to those simulated in calibrated model (Figures 6.41 and 6.13).

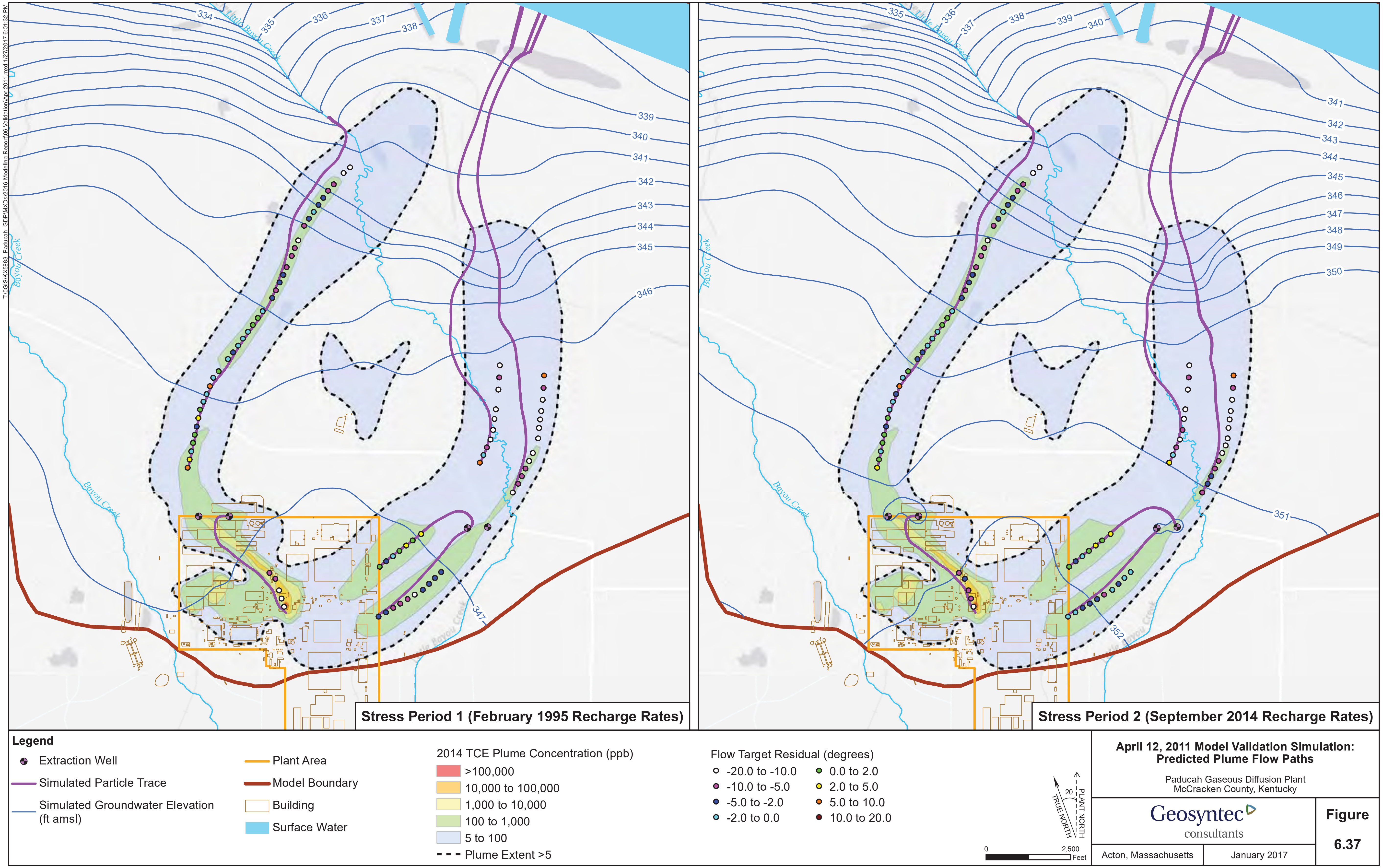
6.9.2 Gradient

To assess the ability of the model to simulate the gradient from the plant area to the furthest extent of the plume, the gradient between two monitoring wells, MW453 and MW445, was chosen to represent the gradient across the model. These wells are located in the Northwest Plume down gradient and beyond the influence of extraction well pumping in the NW corner of the plant area (Figure 6.43). Similar wells in the Northeast Plume were not selected for this analysis because available monitoring well locations did not provide for a substantial distance over which to evaluate the gradient. For the comparative analysis, results from the calibrated model SP2 (September 2014) were evaluated because they represent more recent site conditions than SP1 (February 1995), and SP2 represents a period of active pumping that is consistent with the seven validation data sets. The results of the gradient analysis are summarized in Table 6.8.



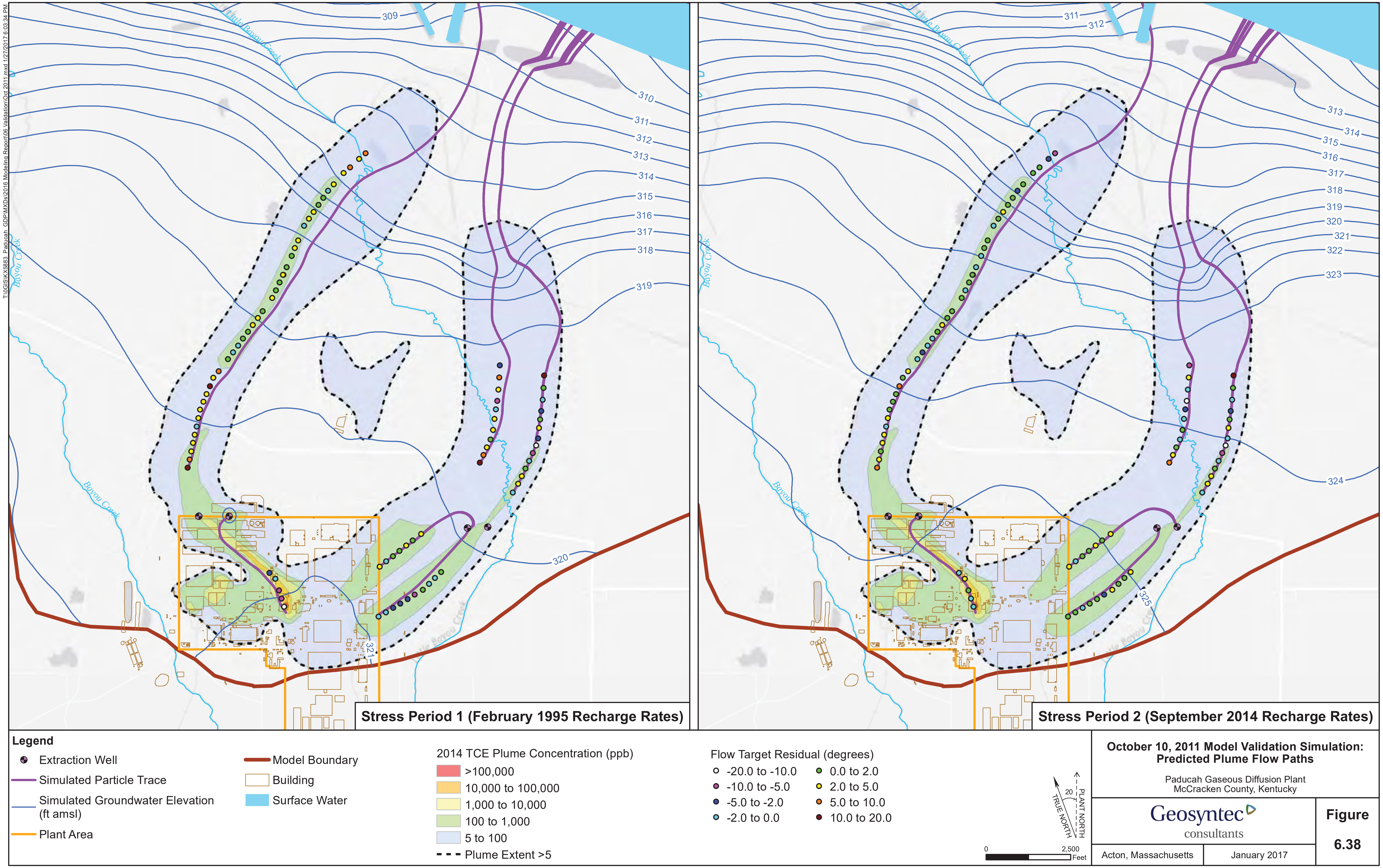
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.36. 3rd Quarter 2005 Model Validation Simulation: Predicted Plume Flow Paths



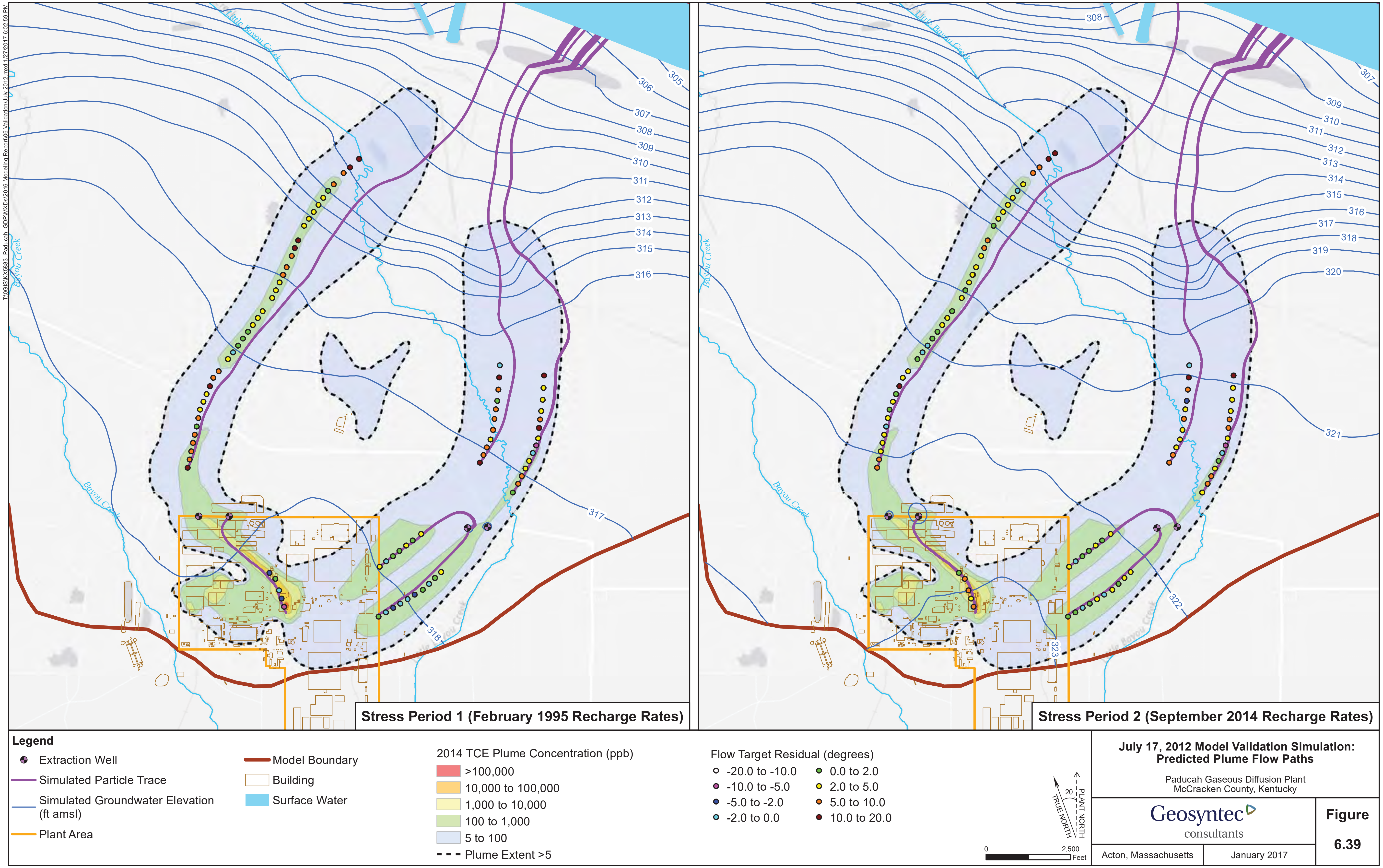
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.37. April 12, 2011, Model Validation Simulation: Predicted Plume Flow Paths



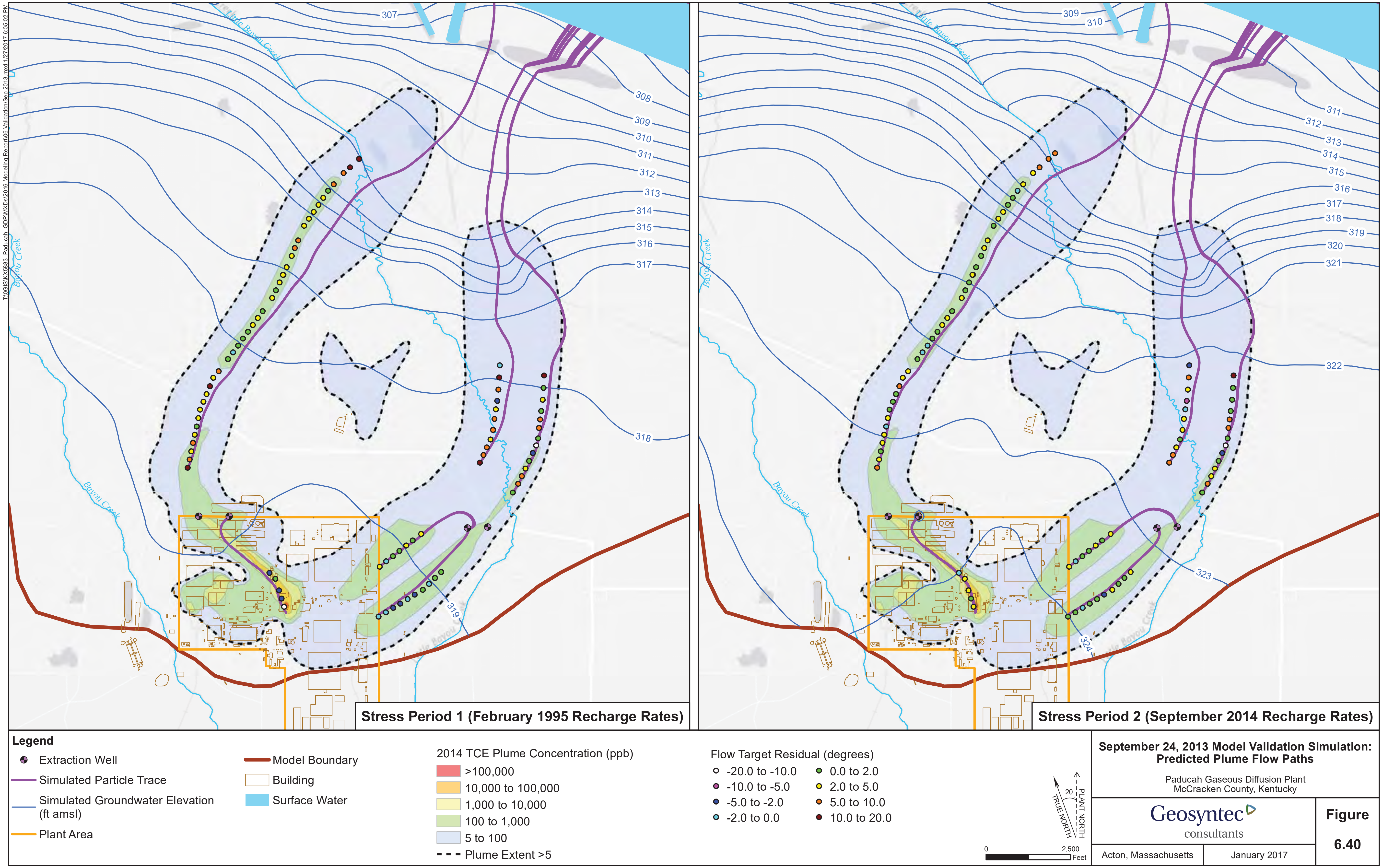
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.38. October 10, 2011, Model Validation Simulation: Predicted Plume Flow Paths



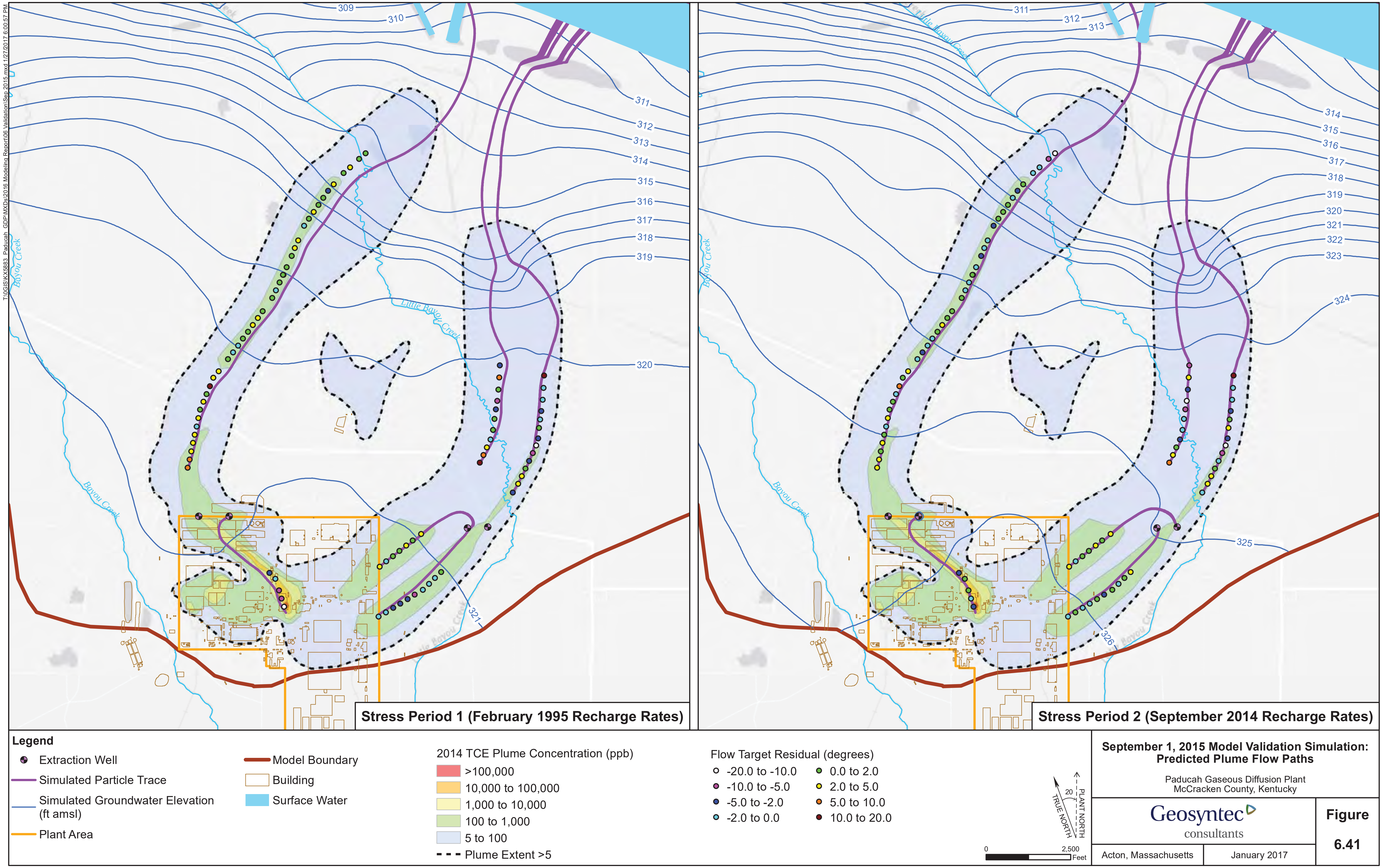
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.39. July 17, 2012, Model Validation Simulation: Predicted Plume Flow Paths



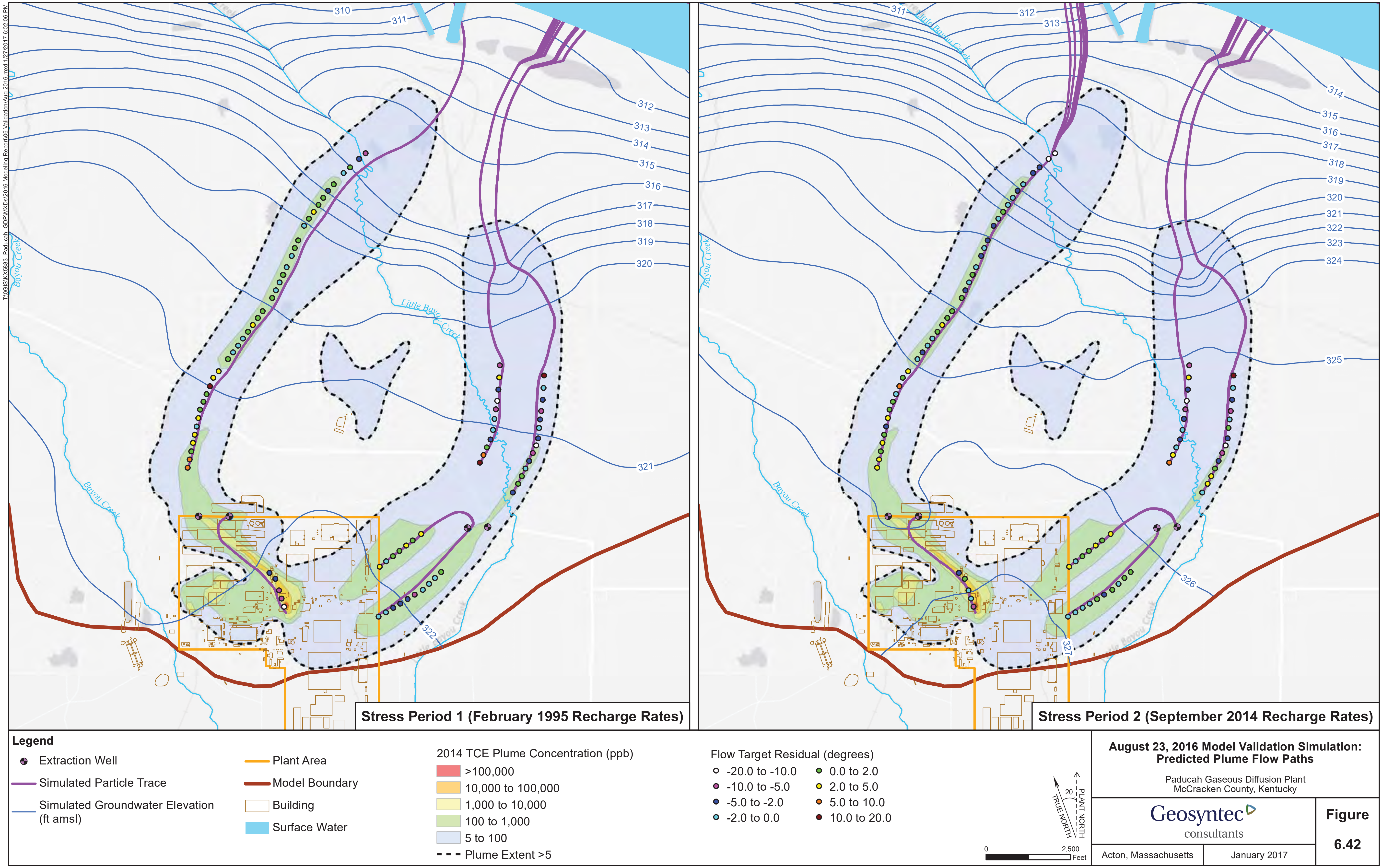
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.40. September 24, 2013, Model Validation Simulation: Predicted Plume Flow Paths



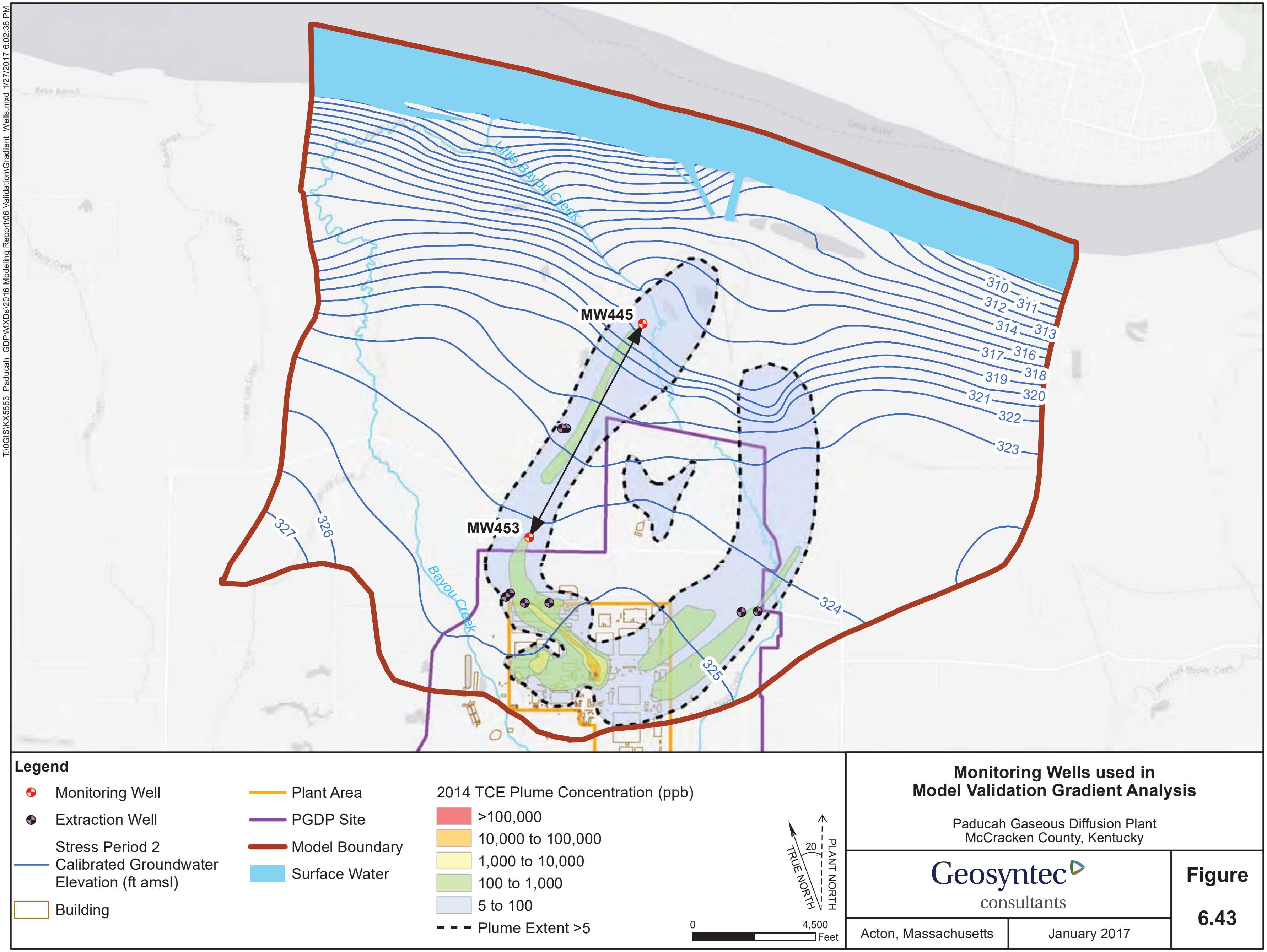
Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.41. September 1, 2015, Model Validation Simulation: Predicted Plume Flow Paths



Note: Trajectory target residuals and water level contours are from model layer 1. Particle traces are from model layers 1 through 3.
Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.42. August 23, 2016, Model Validation Simulation: Predicted Plume Flow Paths



Plume Contour Source: DOE, 2015; Figure C.2

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Figure 6.43. Monitoring Wells Used in Model Validation Gradient Analysis

Table 6.8. Model Validation Gradient Analysis

	Calibration		Validation						
Statistic	SP1 Feb 1995	SP2 Sept 2014	SP2 Q3 2005	SP2 Apr 2011	SP2 Oct 2011	SP2 July 2012	SP2 Sept 2013	SP2 Sept 2015	SP2 Aug 2016
River Stage Elevation[1]	295.2	295.2	300.0	327.2	295.5	290.0	292.5	296.7	298.0
Model Calculated Gradient[2]	0.00082	0.00074	0.00075	0.00071	0.00074	0.00077	0.00075	0.00074	0.00073
Observed Gradient[2]	NA[5]	0.00075	NA[5]	0.00032	0.00068	0.00067	0.00069	0.00088	0.00083
Percent Difference[3,4]	NA[5]	1.5%	NA[5]	-120.0%	-9.4%	-13.4%	-9.0%	16.4%	11.5%

[1] River stage elevation is in feet amsl.

[2] Gradient is calculated by dividing the distance between monitoring wells MW453 and MW445 into the calculated or observed head difference.

[3] Percent Difference = ((Observed gradient-calculated gradient)/observed gradient)*100.

[4] A negative percent difference denotes an overestimate and a positive percent difference denotes an underestimate.

[5] No observation data available for MW453 and MW445 on this date.

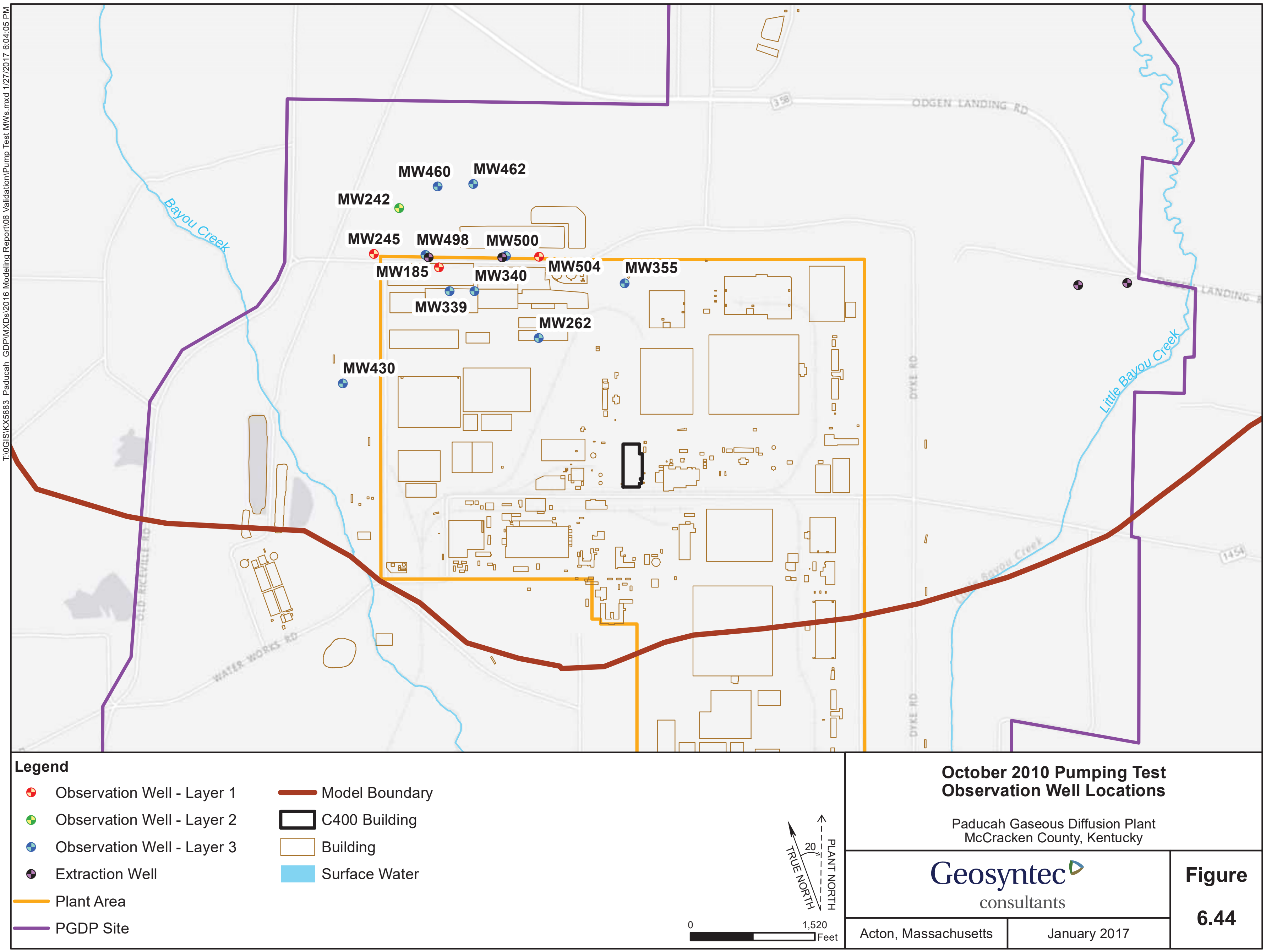
The model calculated gradients were compared among validation simulations, as well as to observed gradient within each validation period. The range of the calculated gradient for all validation periods, 0.00071 to 0.00077, compares well to the calibrated model calculated gradient in SP2 of 0.00074. This is expected because, while the recharge and hydraulic conductivity remain constant, simulated heads will adjust to the river stage such that the gradient across the site also will remain constant to balance model discharge with model recharge. For each validation period, comparison of the model calculated gradient to the observed gradient exhibits a range of variation from 11.5% to 120% (observed vs. calculated). Excluding the extreme flooding scenario (April 2011), the range of variation is -9.0% to 16.4%. The extreme flooding case illustrates the limitation of simulating transient conditions with a steady state model. In the transient state, there is a lag between the change in the river stage and changes in groundwater levels which propagate from areas close to the river inland such that greater groundwater level fluctuation will be observed closer to the river. The magnitude and rate of groundwater water level fluctuation typically observed in the spring season prevents the system from approaching steady-state conditions. The result of simulating the transient condition of high river levels with a steady state model is to overestimate the head, especially in areas farther away from the river (Figure 6.37). For the remaining simulations, with the river stage within approximately 5 ft of the river stage specified in the calibrated model, the percent difference may be attributed to differences in recharge rates, especially ambient recharge, between the validation periods and the calibration periods. For example, the river stage during the September 2015 (296 ft amsl) validation period was similar to SP2 of the calibrated model (295.2 ft amsl) but the percent difference in gradient is 16.4%. For the validation simulation, head residuals are 1.96 and 0.69 ft, for MW453 and MW445 (observed minus calculated), respectively. An adjustment to increase recharge to account for higher annual precipitation in 2015 compared to 2014 (46.8 inches/year versus 59.2 inches/year, Table 3.7) would have resulted in a better match between the observed and calculated heads and an improved match between the simulated gradient in the validation run versus the calibration run.

In summary, the calibrated model provides an accurate representation of the groundwater flow system within the PGDP Basin for steady-state conditions, which typically occur during the drier months of the year. The validation simulations show that for a river stage elevation less than 298 ft amsl, the model reasonably represents the hydraulic gradient from the Plant Area to the furthest extent of the NW Plume. In the case of more transient periods (e.g., the flooding conditions in April 2011) when the increased precipitation rates and higher and more variable Ohio River stages are observed, the steady state model is a less valid representation of site conditions.

6.10 TRANSIENT CALIBRATION

A supplemental transient calibration was conducted to evaluate transient conditions using the results from the October 2010 pumping test conducted at EW232 and EW233. The location of the 2010 pumping test head and drawdown targets are shown on Figure 6.44. The simulation included an initial steady-state stress period to establish initial heads followed by ten 1-day transient stress periods to simulate drawdown measured over the 10-day test period (Table 6.9). River stage for the initial steady-state stress period was specified based on the 30-day average of the Ohio River, and daily averages were used for the transient stress period river stages. Ambient recharge was adjusted to calibrate the model to water level targets in the initial stress period, and specific storage was manually adjusted to calibrate the model to the best match between calculated and observed drawdown.

Drawdown targets are based on the Northwest Plume Extraction System performance test, which included 36 RGA observation wells, two of which comprised background wells, and two recovery wells pumping at 110 gpm each (DOE 2011). The field event consisted of three phases:



Plume Contour Source: DOE, 2015; Figure C.2

Figure 6.44. October 2010 Pumping Test Observation Well Locations

Table 6.9. Transient Calibration Stress Periods

Monitoring Period	Stress Period Type	Number of Head Targets	Ohio River Stage[1] (ft amsl)	Annual Precipitation (inches/yr)
October 11, 2010	Steady-State	13	293.9	36.7
October 12, 2010	Transient	13	295.5	
October 13, 2010	Transient	13	295.5	
October 14, 2010	Transient	13	294.9	
October 15, 2010	Transient	13	294.5	
October 16, 2010	Transient	13	294.3	
October 17, 2010	Transient	13	293.8	
October 18, 2010	Transient	13	293.5	
October 19, 2010	Transient	13	293.1	
October 20, 2010	Transient	13	292.8	
October 21, 2010	Transient	13	292.7	

[1] A 30-day average Ohio River stage was used for October 11, 2010, and daily averages were used for the remaining monitoring dates.

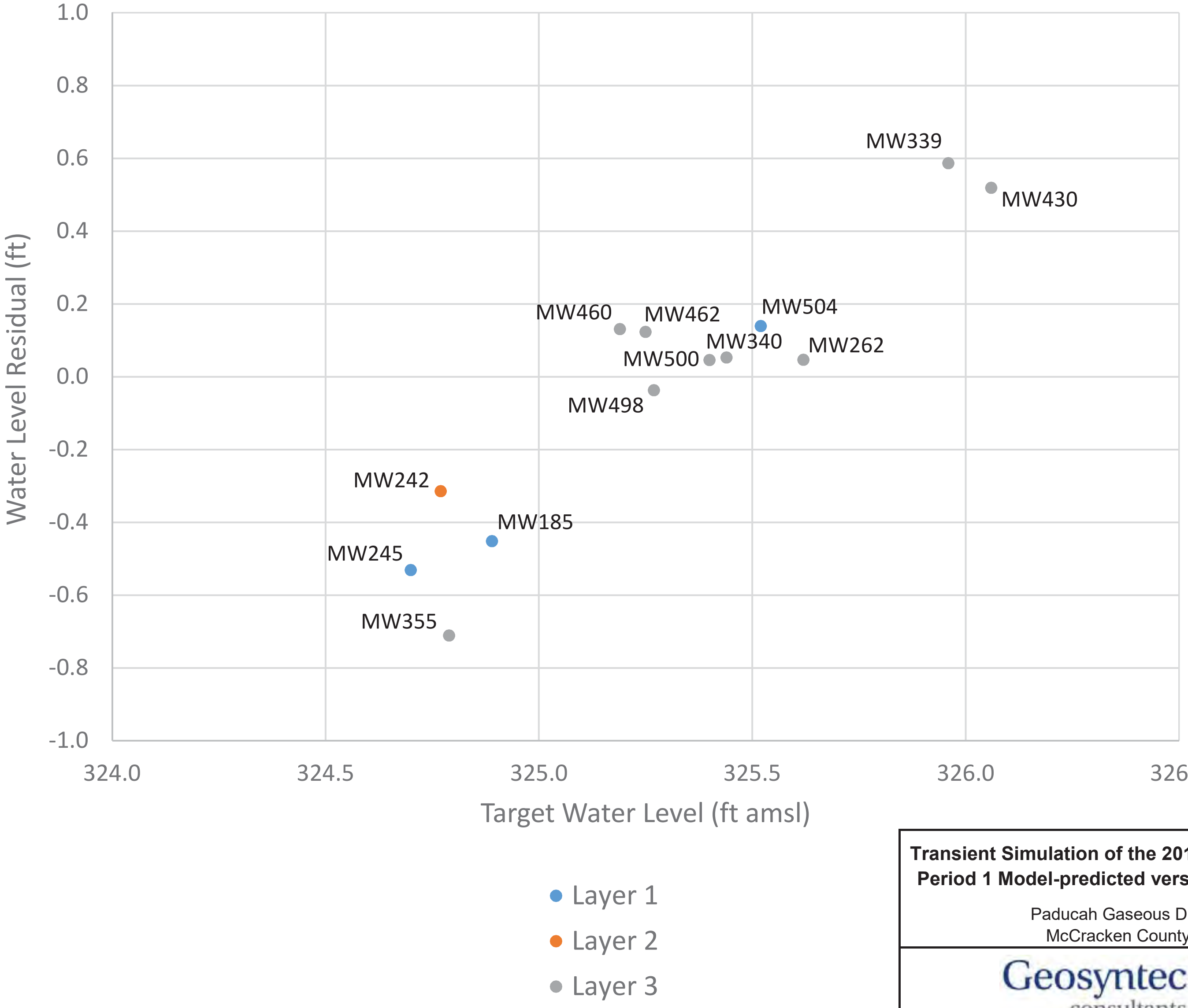
1. Pre-shutdown monitoring for a minimum of three days;
2. System shutdown monitoring for a minimum of ten days (referred to as Phase 1); and
3. Restart monitoring for a minimum of ten days (Phase 2).

6.10.1 Transient Calibration Statistics

The model was calibrated to water level targets in the initial steady-state stress period by adjusting ambient recharge. No other parameters were adjusted to match the target water levels. Through this process, an ambient recharge rate of 3.9 inches/year was assigned to the model. A chart of water level residuals versus target water levels is presented in Figure 6.45.

During the calibration process, comparison of model-predicted to observed drawdown was evaluated to determine model predicted storage. The calibrated specific storage assigned to the model was 0.0002 ft^{-1}. Using an approximate RGA thickness of 40 ft for the location of the October 2010 pumping test in the Northwest corner of the plant area (see Figure 3.4), this translates to a storativity of 0.008. This value matches the geometric mean storativity of 0.008 that was reported for the June 1996 pumping test performed at EW231 (approximately 740 ft west of EW232). A chart of drawdown residuals versus target drawdown is presented in Figure 6.46. A reasonable match of the drawdown targets was obtained, although the results show some bias with drawdown being underestimated early on in the simulation (residual mean of 0.08 ft during the first day of pumping) and overestimated later (residual mean of - 0.06 ft during the tenth day of pumping). This bias could not be corrected by adjusting model storage alone, and additional parameters such as recharge other than ambient would have to be modified to achieve a better fit. The model fit of drawdown at the most distal well, MW430, is noticeably poorer than the fit obtained for all other observation wells. It also was noted in the pumping test report that the response at MW430 was inconsistent with the response at the remaining observation wells.

Figure 6.45. Transient Simulation of the 2010 Pumping Test: Stress Period 1 Model-predicted versus Target Water Levels



Note:
Negative residuals denote overestimates and positive residuals denote underestimates.

Transient Simulation of the 2010 Pumping Test: Stress Period 1 Model-predicted versus Target Water Levels

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec consultants

Acton, Massachusetts | December 2016

Figure 6.45

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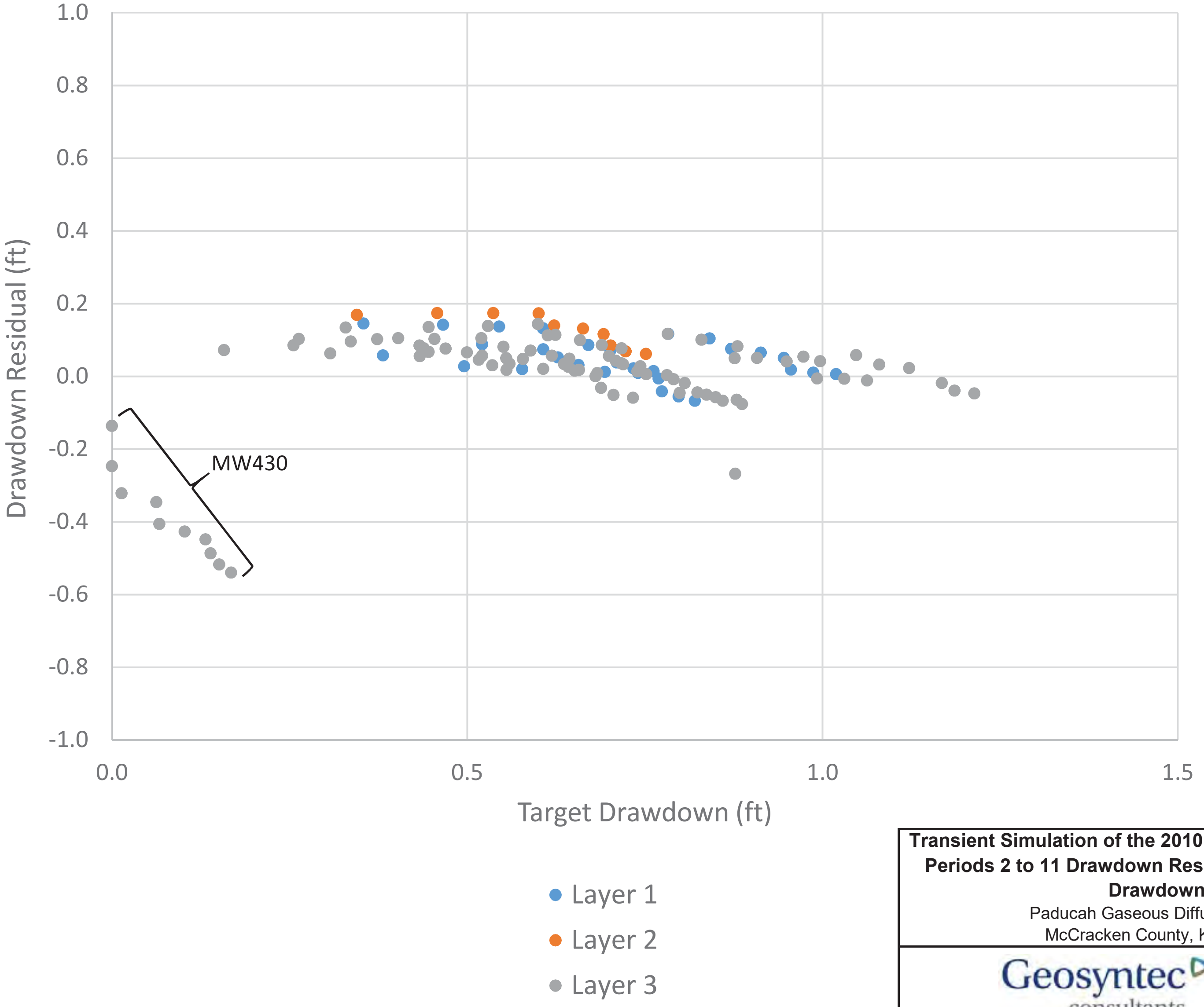

Note:
Negative residuals denote overestimates and positive residuals denote underestimates.

Transient Simulation of the 2010 Pumping Test: Stress Periods 2 to 11 Drawdown Residuals versus Target Drawdown
Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Geosyntec consultants

Acton, Massachusetts | December 2016

Figure 6.46

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Figure 6.46. Transient Simulation of the 2010 Pumping Test: Stress Periods 2 to 11 Drawdown Residuals versus Target Drawdown

7. CALIBRATION SUMMARY

7.1 CALIBRATION EVALUATION

The 2016 model reasonably matches target water level elevations in the plant area and across the model domain. In addition, based on particle traces, the model reasonably reproduces the Northeast and Northwest Plumes flow paths. Overall, this flow model honors the conceptual model with respect to recharge and discharge rates, relative recharge and discharge volumes, and the predicted range of RGA hydraulic conductivities. Also, the predicted RGA bulk hydraulic conductivity, as evidenced by the model domain hydraulic conductivity (622 ft/day), is close to the estimated range of bulk RGA hydraulic conductivity values derived from site data (713 ft/day to 2,063 ft/day) (DOE 2010, Section 4.5.2.).

Additionally, final predicted PEST sensitivities indicate that it is possible through calibration to obtain reasonably accurate parameter values for 1,072 of the 1,093 model input parameters (including K_x pilot points). Except for the capped landfill recharge, the remaining input parameters have sensitivities that indicate that it may be possible to obtain reasonably accurate parameter values through calibration. Overall, the calibrated model input parameters are reasonably accurate.

The model-predicted mass balance indicates the greatest source (approximately 81%) of recharge to the PGDP Hydrologic Basin is from precipitation. Anthropogenic recharge contributes approximately 13 to 14% of the total inflow to the PGDP Hydrologic Basin. Approximately 3% of the total basin inflow is contributed by creek recharge and approximately 2% is contributed by recharge from the Terrace Gravel. Most groundwater within the PGDP Hydrologic Basin discharges to the Ohio River (approximately 77% and 65% for SP1 and SP2, respectively), with the remaining groundwater discharging to the lower reaches of BC and LBC and extraction wells (SP2 only) during periods of average to low Ohio River stages.

Validation simulations show that the model reasonably reproduces the observed flow direction when the Ohio River stage is approximately 297 ft amsl or less and the site conditions are generally representative of steady state flow. For Ohio River stages above 297 ft amsl, predicted flow at the toe of the Northwest Plume migrates westward with increased discharge to LBC, rather than northward to the Ohio River. Validation simulations also show that the model reasonably represents the hydraulic gradient from the plant area to the furthest extent of the Northwest Plume, except in the case of extreme flooding conditions.

7.2 ASSUMPTIONS AND LIMITATIONS

The updated PGDP Sitewide Groundwater Flow Model presented in this report was developed by the MWG consisting of personnel from DOE, EPA, KDEP, KRCEE, and contractors Fluor Federal Services, Inc., Paducah Deactivation Project, Drummond Carpenter, Navarro, ESI, and Geosyntec. During the model development process, several items were identified as potentially affecting model uncertainty and warrant consideration during planning of future data collection efforts. It is recognized that it may not be possible to address all these issues; however, the following is provided to document the MWG discussions to provide continuity for future model updates.

The configuration and calibration of the 2016 PGDP Sitewide Groundwater Flow Model is based on the following key assumptions:

- The groundwater flow system is steady-state for periods where boundary conditions such as the Ohio River stage and precipitation rates are relatively constant.

- The model represents groundwater flow exclusively within the RGA as the primary conveyor of groundwater from the PGDP Site to the Ohio River.

- The McNairy is represented as a no-flow boundary because the groundwater flow rate through the McNairy Formation is negligible compared to the flow rate in the RGA.

- Groundwater flow in the UCRS is represented by a spatially varying recharge boundary condition to simulate recharge originating at land surface and infiltrating to the RGA based on the predominantly vertical flow in the UCRS.

PGDP Sitewide Groundwater Flow Model limitations include its formulation and calibration as a steady-state model, its regional scale, and its limited domain which does not include portions of the PGDP Site south of the RGA. Regarding use of the groundwater model for specific project needs, limits on the application of the model for site or project-specific requirements and determinations of the appropriate use of the model should be made by appropriate project personnel on a case-by-case basis. The following is a list of limitations identified by the MWG. Additional data collection to address some of the model limitations is described in Section 8.

- The basis for the maximum calibrated anthropogenic recharge values (maximum constraints between 29 inches/year and 83 inches/year) is the median UCRS vertical hydraulic conductivity based on slug tests and assumed vertical anisotropy on the order of 10:1. Consideration of the full range of values from the slug test data and alternative anisotropy ratios indicates potential calibrated anthropogenic recharge values less than and greater than the specified maximum calibration constraint limits. As with most groundwater models, the model configuration and calibrated input parameters are not a unique solution and it is recognized that lower model-predicted anthropogenic recharge rates potentially would have resulted if the model had used other reasonable values of lower hydraulic conductivity. Conversely, a model configuration allowing the reasonable use of higher hydraulic conductivity values potentially would result in higher model-predicted anthropogenic recharge rates.

- Characterization of the contact area between the Terrace Gravel and the UCRS in the vicinity of the southern model boundary is based on a limited number of monitoring wells.

- Limited data are available to quantify the volumetric flow rates in BC and LBC to determine where and in what quantities water enters and exits the creeks and characterize seasonal variability.

- Groundwater flow from the Terrace Gravel is an estimate from an evaluation of baseflow in upper BC.

- Limited seasonal data are available to assess the hydraulic connection of the RGA to the Ohio River and the nature of river bank storage to assess the impact of transient conditions.

- Limited data are available regarding plant operations and closure activities to support temporal and spatial assessment of anthropogenic recharge.

- Limited data are available (temporal and spatial) to assess seasonal groundwater flow patterns and to verify the occurrence of the inferred groundwater divide within the plant area.

- Some water supply systems in the plant area, including the recirculating cooling water and waste heat system, the sanitary water system, and the plant (nonsanitary) water system, are not well characterized with respect to potential for contribution to anthropogenic recharge.

- Flow, and therefore the potential for mass flux evaluation in future transport models from the McNairy Formation, is not explicitly accounted for in the model.

- The steady state model is calibrated to periods of relatively low river stage and provides a reasonable representation of transient conditions, but is a less valid representation of site conditions during periods of high precipitation rates when higher and more variable Ohio River stages are observed.

- Three of the five datasets that were identified as suitable for model calibration were not included in the calibration process due to run time limitations.

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8. CONCLUSIONS AND RECOMMENDATIONS

The 2016 PGDP Sitewide Groundwater Flow Model builds on the most recent version of the model (2012) and the knowledge gained from ongoing modeling efforts since 1990 (Section 1.3). This modeling effort is part of a continuous process to improve and update the model as additional site information becomes available. Future modeling efforts are expected to respond to potentially changing site conditions or the identification of areas of improvement based on additional data collection. The following are the key revisions included in the 2016 model:

- Revised RGA layer elevations based on additional boring data and analysis;
- Revised southern model boundary based on additional boring data and analysis;
- Revised anthropogenic recharge zonation based on enhanced knowledge of plant operations; and
- Added baseflow from the Terrace Gravel into the model domain.

8.1 CONCLUSIONS

The calibrated model provides an accurate representation of the groundwater flow system within the PGDP Hydrologic Basin for steady-state conditions, which typically occur during the drier months of the year. During more transient periods when the increased precipitation rates and higher and more variable Ohio River stages are observed, the steady state model is a less valid representation of site conditions. The calibration effort builds upon previous efforts of the 2012 model update, which included the use of up to seven stress periods. Future model calibration activities, including the five datasets identified in Section 3.4 as appropriate for use in calibration, may provide an even more accurate calibration.

Validation simulations show that the model reasonably reproduces the observed flow direction when the Ohio River stage is approximately 297 ft amsl or less and the site conditions are generally representative of steady state flow (Section 6.9.1). For higher Ohio River stages typical of more transient conditions, the model indicates a shift in flow toward LBC rather than the Ohio River in the Northwest Plume. Validation simulations also show that the model reasonably represents the hydraulic gradient from the plant area to the furthest extent of the Northwest Plume, except in the case of extreme flooding conditions (Section 6.9.2).

PGDP Sitewide Groundwater Flow Model limitations include its formulation and calibration as a steady-state model, its regional scale, and its limited domain, which does not include portions of the PGDP Site south of the RGA. Regarding use of the groundwater model for specific project needs, limits on the application of the model for site or project-specific requirements and determinations of the appropriate use of the model should be made by appropriate project personnel on a case-by-case basis.

8.2 RECOMMENDATIONS

The following recommendations and potential data collection needs were identified by the MWG for consideration in future model revisions. In some instances, additional data collection may mitigate some of these uncertainties, while not completely eliminating them.

- To reduce uncertainty at the contact area between the Terrace Gravel and the UCRS in the vicinity of the southern model boundary, additional monitoring well installation may be considered to collect water level and soil boring information.

- To quantify the volumetric rates at which water enters and exits streams, efforts may be made to gage flows in various portions of BC and LBC to determine where and in what quantities water enters and exits the creeks and to coordinate the stream gauging event with a sitewide water level synoptic measurement event.

- Evaluation of a more accurate method to quantify Terrace underflow to the RGA is recommended.

- The hydraulic connection of the RGA to the Ohio River and the nature of river bank storage remain important aquifer parameters potentially justifying further study to support the model and to assess the impact of transient conditions. Continuous RGA water level records are recommended over a period of a year in the vicinity of the Ohio River and along a transect of wells extending back to the PGDP industrial area.

- To evaluate changes in post closure site operation that may affect anthropogenic recharge in the plant area, monitoring and documentation (including dates) of the enacted utility optimization program (performed by others) are recommended.

- To evaluate groundwater flow patterns and to verify the occurrence of the inferred groundwater divide within the plant area, increased water level measurement events conducted during different seasons, in addition to annual events (conducted in September for the last three years), are recommended. The water level measurements should be synoptic and collected over a relatively short duration, ideally within one or two days. These measurements will provide information regarding seasonal variation and may be considered for use as calibration targets in a subsequent model update.

- If possible, measurement of the water level elevation at Metropolis Lake should be included in the sitewide water level synoptic event. Consideration also should be given to characterizing the thickness and hydraulic conductivity of the lake bottom sediments if the lake is to be simulated using river boundary condition in future modeling efforts.

- Assessing water level and water quality data collected from the newly installed transect of monitoring wells located east of C-400 Building is recommended. This assessment will facilitate better understanding of the groundwater elevation contours and flow directions that indicate an apparent groundwater divide near the new transect monitoring wells. This apparent groundwater divide is a key feature of the current model calibration.

- Two of the main water supply systems and the storm water and HPFW piping were included in the model as discreet recharge zones based on site information (see Section 3.3.2). Assessment of the remaining water supply systems in the plant area, which include the recirculating cooling water and waste heat system, the sanitary water system, and the plant (nonsanitary) water system, is recommended to evaluate potential for contribution to anthropogenic recharge.

- Anthropogenic recharge rates are estimated over a wide range of values (Section 3.3). As with most groundwater models, the model configuration and calibrated input parameters are not a unique solution. It is recommended that continuous water level recorders be deployed in select monitoring wells/piezometers within the plant area to assess recharge better and its impact on nearby water levels.

- Flow rate in the McNairy Formation is negligible compared to the RGA because the hydraulic conductivity is 2 to 3 orders of magnitude lower than in the RGA; however, the McNairy Formation may be significant for DNAPL source accumulation and contaminant transport. Future transport models based on the 2016 flow model will need to consider potential mass flux from the McNairy to the RGA resulting from back diffusion.

- The Olmsted Locks and Dam are scheduled to be operational in 2018. At that time, the lowest Ohio River stage at PGDP will be the upper pool height of the dam, 302 ft amsl. Seasonally low river stages at PGDP effectively will be increased 7 ft to 12 ft. Future groundwater modeling should consider evaluation of the calibrated model using a synoptic data set collected under steady conditions at the higher river stage anticipated to start in 2018.

- The groundwater system in the PGDP Hydrologic Basin is in a transient state for much of the year, except in dry periods typically experienced in the fall. The model simulates steady state conditions and is calibrated to periods with relatively low river stage. Validation simulations indicate that during higher Ohio River stages the Northwest Plume discharges to LBC and flows west parallel to the creek. This is consistent with early plume depictions, based on water quality data, showing the plume paralleling LBC (Figure 4.5 of DOE 2010). Consideration of transient seasonal conditions at high Ohio River stages should be considered in the use of the model for evaluating remedial strategies.

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APPENDIX A

MWG MEETING MINUTES

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Summary of Meetings

Date	Meeting Type	Minutes	Tear Sheet
4/29/2016	Bi-weekly call	X	
5/13/2016	Bi-weekly call	X	
6/3/2016	Interim Bi-weekly call	X	
6/10/2016	Biweekly call		
6/14/2016	Face-to-Face Meeting	X	X
6/24/2016	Bi-weekly Call	X	
7/8/2016	Bi-weekly Call	X	
8/5/2016	Bi-weekly Call	X	
8/16/2016	Bi-Weekly Call - Web-Ex	X	
8/24/2016	Face-to-Face Meeting	X	X
8/31/2016	8/24 Followup - Web-Ex	X	
9/16/2016	Bi-weekly Call	X	
9/30/2016	Bi-weekly Call - WebEx	X	
10/14/2016	Bi-weekly Call	X	
10/25/2016	Face-to-Face Meeting	X	X
12/13/2016	Bi-weekly Call	X	
1/6/2017	Bi-weekly Call	X	
1/20/2017	Bi-weekly Call	X	

Modeling Working Group
Meeting Minutes—April 29, 2016

1. **Attendees:** Eva Davis, Noman Ahsanuzzaman, Brian Begley, Nathan Garner, Gaye Brewer, Rich Bonczek, Martin Clauberg, Dave Dollins, Denise Tripp, Al Laase, Jim Rumbaugh, Chad Drummond, Kelly Layne, Ken Davis, Brad Montgomery, Craig Jones

2. **Call for Issues from Modeling Working Group (MWG) Members:**

   No issues were raised.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

   The following schedule was presented. No comments were made on presented information.

Start	End	Deliverable	Notes
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	
5/27/2016	5/27/2016	Bi-weekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
4/2/2016	6/3/2016	Model calibration	End date contingent on 6/14/16 meeting
4/11/2016	6/10/2016	Draft Modeling Report (D0)	End date contingent on 6/14/16 meeting
6/10/2016	6/10/2016	Biweekly call	
6/13/2016	6/24/2016	MWG Review of D0	2 weeks
6/24/2016	6/24/2016	Bi-weekly call	
6/27/2016	7/1/2016	Incorporate MWG comments to D0	1 week
7/15/2016	7/15/2016	Bi-weekly call	
7/4/2016	7/22/2016	DOE review of Draft Final Modeling Report (D1)	3 weeks
7/25/2016	7/29/2016	Incorporate comments to Final Modeling Report (D2)	1 week
7/29/2016	7/29/2016	Bi-weekly call	
7/31/2016	7/31/2016	Submit D2 to FFA managers	Changes discussed with MWG
7/31/2016	TBD	Final Modeling report with FFA comments (D2R1)	
9/1/2016	9/1/2016	Quarterly Meeting	Face-to-Face Meeting
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Discussion of Meeting Minutes

The MWG March 29th 2016, Meeting Minutes (Sent April 7th and April 8th, 2016) and MWG April 15th, 2016 Meeting Minutes were presented and opened for discussion. No comments were received on either.

5. Discussion of Action Item List

The Action Item List contains a listing of items that the MWG identified as necessary. The list is an effort to identify those items but also add detail as to which items are necessary to be completed preceding calibration efforts and which are necessary as part of the sensitivity analysis.

The MWG will also discuss how each item is dependent on other items as precursors, etc.

Denise Tripp discussed the Action Item list (*20160425 Draft Action Item List.xlsx*). EPA requested clarification on Item #9 ("Initial calibration using averaging of the lithologic information (harmonic averaging) over the depth of the UCRS"). EPA stated that the table of values presented at the March 29th, 2016, face-to-face meeting had not been concurred on to by EPA.

6. Discussion on "Slug Test" Information

The information on "Slug Test" emailed on April 26th, 2016 will be discussed in detail with participation from KRCEE.

Denise Tripp discussed the various tables regarding slug test data at the site (*20160425 Draft PGDP Slug_Test_Information_0425_2016.pdf*). Denise noted that if multiple wells were adjacent to each other the deeper well was used.

EPA had a question regarding Table 3. ("Permeameter Results for Samples with 80% or Greater Clay Content"). Ken Davis provided clarification on how the permeameter tests were performed (6-inch samples, Shelby tube samples, etc.). EPA voiced preference for using the data presented in Table 3 and indicated that MW127, 128, 129, and 130 are outside of the plant area and should not be used because those monitoring wells are not in the area of anthropogenic recharge. EPA suggested the team focus on MWs located within the plant area as well as the permeameter values presented in Table 3, and that MW129 and MW130 control the calculated vertical hydraulic conductivity value. EPA indicated that values in slide 26 (from the presentation used in the March 29th, 2016, face-to-face meeting) would be different if some values were removed.

EPA suggested using geometric mean for hydraulic conductivity.

Rich Bonczek asked for clarification regarding if the ranges are for the model domain or for just the plant area. Al Laase stated that all model data should be used within the model domain. Discussion ensued.

Brian Begley indicated that this step is very preliminary and he took the position that at this point in the process, the MWG should keep a "wide" recharge range to start.

Discussion ensued regarding volume of leaks. Noman Ahsanuzzaman contended that not all water that leaks will reach the RGA. Various other members of the MWG disagreed, with a focus on observed elevated temperatures indicating fast travel times through the RGA as well as the potentially likely large volumes of leakage.

DOE made a final decision to move forward using the entire dataset as presented. Discussion with EPA and KDEP will occur once initial simulations are performed. Results will be reviewed to verify if the utilized values match known values. Brian Begley concurred with this process. Noman Ahsanuzzaman reiterated his reservations, but concurred with the step-wise strategy to allow for calibration to proceed and then review the validity of that assumption.

7. Discussion of the "Isopach Map"

The information on the "Isopach Map" emailed on April 26th, 2016 will be discussed in detail.

Denise provided a summary of the isopach map (*20160425 R8_RGA_Isopach.pdf*). Denise indicated that the model will have an adjusted southern boundary. Moving the boundary might indicate that MW129 and MW130 should be reassessed as being in the model domain. A revised map will be provided showing how the isopach values were incorporated into the model. The plant boundary will also be added, as well as adding control points. The group agreed to add plume boundary to a separate figure that also shows control points.

Kelly Layne provided a final summary regarding action items.

Attachment:

20160425 Draft Action Item List

Draft Sitewide Groundwater Model MWG Action Items - April 25, 2016

Number	Description	Status	Targeted Completion Date	Calibration Requirement
1	Verify the use of vertical conductivity in the calculation ssignment maximum anthropogenic recharge from slug test data.	Verified. Kv assumed to be = 0.1*Kx	Complete	Y
2	Map and boring logs for wells with slug tetst data from single lithologic zones	To be discussed on 4/29/16 call	4/25/2016	N
3	Review C-400 Treatability Study K Data	Review in progress	4/29/2016	Y
4	Land use evaulation and development of qualitative anthropogenc recharge zones	In progress	5/23/2016	Y
5	Delineation map of HU3 greater than 2 feet thick to be completed with KRCEE R8 lithologic evaluation	In progress	4/29/2016	Y
6	Model RGA Isopach map to be completed with KRCEE R8 lithologic evaluation (include summary of approach).	To be discussed on 4/29/16 call	4/25/2016	N
7	Specifiy 7-day average river stage for synoptic stress periods (April 2010 to September 2015)	Model revised	Complete	Y
8	Revise southern model boundary consistent with KCREE R8 lithologic evaluation	In progress	4/29/2016	Y
9	Initial calibration using averaging of the lithologic information (harmonic averaging) over the depth of the UCRS	Waiting on model configuration	5/1/2016	Y
10	Alternative calibration using Kx= 4.62E-04 ft. /day (min) where lithologic data indicates greater than two (2) feet of HU3 materials, else harmonic averaging estimate	To be conducted after initial calibration	5/15/2016	Y
11	Reduce uncertainty in the model by installing monitoring wells and collecting soil borings information near the contact area between the Terrace Gravels and the UCRS		TBD	N
12	Install monitoring stations in the Creeks		TBD	N
13	Assess a more robust base flow evaluation to better quantify groundwater flow ranging north off the Terrace		TBD	N
14	Install transducers in select monitoring wells for evaluation of river stage and impact on RGA groundwater levels		TBD	N
15	Monitor the utility optimization program to assess the status of charged lines, etc		TBD	N
16	Increased synoptic water level events in addition to annual synoptic events conducted in September for the last 3 years to evaluate seasonal variation.		TBD	N

▨	Complete
🟨	Include with Agenda

Modeling Working Group
Meeting Minutes—May 13, 2016

1. **Attendees:** Eva Davis, Noman Ahsanuzzaman, Kelly Layne, Rich Bonczek, Al Laase, Chad Drummond, Denise Tripp, Ron Kent, Steve Hampson, Martin Clauberg, Craig Jones, Gaye Brewer, Brian Begley, Nathan Garner, Julie Corkran

2. **Call for Issues from Modeling Working Group (MWG) Members**

   No issues were raised.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

   The following schedule was presented. One variant of the calibrated model will be prepared for June 14 meeting. Julie Corkran mentioned that we needed to understand how the schedule and its use fit into decision making documents and those projects' schedules. References to D1, D2, etc. are to be removed from the schedule.

Start	End	Deliverable	Notes
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	
5/27/2016	5/27/2016	Bi-weekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
4/2/2016	6/17/2016	Model calibration	End date contingent on 6/14/16 meeting
4/11/2016	6/24/2016	Draft Modeling Report (D0)	End date contingent on 6/14/16 meeting
6/10/2016	6/10/2016	Bi-weekly call	
6/27/2016	7/1/2016	MWG Review of D0	1 week
6/24/2016	6/24/2016	Bi-weekly call	
7/4/2016	7/8/2016	Incorporate MWG comments to D0	1 week
7/15/2016	7/15/2016	Bi-weekly call	
7/11/2016	7/22/2016	DOE review of Draft Final Modeling Report (D1)	2 weeks
7/25/2016	7/29/2016	Incorporate comments to Final Modeling Report (D2)	1 week
7/29/2016	7/29/2016	Bi-weekly call	
7/31/2016	7/31/2016	Submit D2 to FFA managers	Changes discussed
7/31/2016	TBD	Final Modeling report with FFA comments (D2R1)	
9/1/2016	9/1/2016	Quarterly Meeting	Face-to-Face Meeting

12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Concurrence of Meeting Minutes

The MWG April 29th, 2016 Meeting Minutes (sent May 10th, 2016) were presented and opened for discussion. Rich Bonczek, Gaye Brewer and Noman Ahsanuzzaman expressed agreement that the minutes were accurately recorded.

5. Discussion of Action Item List Items

The Action Item List contains a listing of items that the MWG identified as necessary. The list is an effort to identify those items, add detail as to which items are necessary to be completed preceding calibration efforts and which are designated for post-calibration to address data gaps, and to provide a tool to track progress in addressing each item.

Denise Tripp reviewed the Action Item list (*20160509 Draft Action Item List.pdf*). There were no comments regarding the list.

6. Discussion on hydraulic conductivity data and anthropogenic recharge estimates (Item 2)

Denise Tripp discussed revisions to the tables and figures regarding slug test data at the site (*Draft PGDP Slug_Test_Information_05092016.pdf*). The revisions include correction to the reference well cited on Table 2 for MW163, exclusion of two monitoring wells (MW129 and MW130) that are located south of the revised southern model boundary, exclusion of the replicate slug test at MW170 due to short duration of the test, and recalculation of anthropogenic recharge including additional evaluation using the geometric mean. The proposed path forward was to proceed with calibration using the geometric mean for recharge pilot points, and then switch to the median maximum recharge if needed.

Noman Ahsanuzzaman asked if permeameter data would be used for the recharge pilot points. Denise Tripp clarified that permeameter data would not be used in for recharge pilot points, but provides a useful check on the assumption that the vertical hydraulic conductivity is one tenth of the horizontal hydraulic conductivity.

A footnote about the vertical to horizontal hydraulic conductivity ratio will be added to Table 3.

7. Discussion of the of the C-400 Treatability Study findings evaluation (Item 3)

Denise Tripp discussed the treatability study evaluation (*Draft C-400 Treatability Study Evaluation_05112016.pdf*). In the study, hydraulic conductivity of 100 and 300 feet per day were used for the upper and lower RGA, respectively. Pilot points near the C-400 area will be used to constrain hydraulic conductivity to similar values.

Pump test that showed 100 feet per day hydraulic conductivity was located about 1000 to 2000 feet from C-400. The exact distance will be confirmed and location placed on reference maps.

8. Discussion of the delineation of UCRS clay greater than 2 feet thick (Item 5)

Denise Tripp discussed the delineation of UCRS clay greater than 2 feet thick (*Draft HU3 Clay Thickness_05092016.pdf*). An isopach map of UCRS clay developed by KRCEE was provided as the basis for the delineation. Denise Tripp opened a discussion about whether or not the 2-feet thick clay criterion should be applied over the entire model domain to be consistent. Noman Ahsanuzzaman expressed concern that there are not enough data outside the plant area to apply the same criterion outside the plant boundary. Steve Hampson noted that the amount of data outside the plant area is extensive relative to many groundwater models but sparse relative to the data available within the plant boundary. Agreement was reached to only limit recharge within the plant boundary for this calibration approach. Item will be discussed further during next call. Denise Tripp noted the recharge constraint in the thicker clay zones, calculated with the lowest reported slug test hydraulic conductivity, would be 0.2 inches per year. Noman Ashanuzzaman expressed that a higher value such as 2 inches per year may be more representative.

9. Discussion of Model RGA isopach map (Item 6)

Denise Tripp discussed the revised model RGA isopach map (*Draft Model RGA Thickness_05092016.pdf*). Rich Bonczek questioned how the model layer thicknesses presented in the isopach map would influence the model results. Al Laase responded that the thickness affects transmissivity.

Noman Ahsanuzzaman asked why the model thickness was limited to 10 feet and how much of the model area is affected by the constraint. Denise Tripp responded that there are numerical concerns for thin model layers and that the constraint is primarily applied at the southern model boundary and at limited, individual borings within the model domain that represent variability within the bore logs; Steve Hampson agreed with the response. Rich Bonczek noted that the added model thickness might act as a surrogate for flow that actually goes into the UCRS or McNairy. Noman Ahsanuzzaman noted that the calibration might yield high hydraulic conductivity values at the thin layers to compensate. Denise Tripp and Noman Ahsanuzzaman agreed that the current layer elevations should be used moving forward and that thin model areas with high conductivities will be noted during the calibration process.

10. Discussion of the revised southern model boundary (Item 8)

The revised model RGA isopach map (Item 6) gave an illustration of the revised southern model boundary.

11. Closing

Denise Tripp provided a summary regarding action items.

Rich Bonczek requested that a thorough exercise be performed to consider the importance of anisotropy (noted in the C-400 treatability study evaluation) in the RGA.

Martin Clauberg requested that the action items be presented in a way that would show interactions between each item to allow for the completion of the calibration.

Next modeling meeting would be moved from May 27, 2016 to June 3, 2016.

Attachment:
05092016_Action Item List

Modeling Working Group
Meeting Minutes—June 3, 2016

1. Attendees:

Eva Davis, Noman Ahsanuzzaman, Rich Bonczek, Al Laase, Chad Drummond, Denise Tripp, Steve Hampson, Craig Jones, Nathan Garner, Julie Corkran, Jim Rumbaugh, Ken Davis, Tracey Taylor, Gaye Brewer, Martin Clauberg, Brad Montgomery, Josue Gallegos

2. Call for Issues from Modeling Working Group (MWG) Members

Denise Tripp and Al Laase provided an update on the model calibration; informed the group that a preliminary calibration run had been successfully performed, and that the next step is to post process and evaluate the results. Al Laase and Jim Rumbaugh informed Group that the model run took 2.5 days to complete using 25 processors. Post processing of data may take 3 to 5 days. The results of this calibration are not final but will be used to adjust the model for future calibration runs.

The Group agreed that Denise Tripp and Al Laase would provide a data package from the preliminary calibration run by close of business 6/9/2016. Rich Bonczek explained that this data package is not expected to be a fully-reviewed, DOE-formatted presentation, but that it will be identified and stamped as a draft, working product.

The Group discussed the expectations and goals for the upcoming 6/14/2016 meeting in Nashville. Rich Bonczek proposed that the focus of the meeting should be to discuss the model results, and evaluate if the path forward with the model needs to be changed. The Group agreed.

3. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The schedule below was presented. Noman Ahsanuzzaman expressed concern that the time allotted in the schedule for model calibration may not be sufficient, and commented that model calibration is the most important phase in model development. Noman Ahsanuzzaman suggested perhaps extending the model calibration timeline. Rich Bonczek disagreed, and commented that the timeline was aggressive but necessary to keep the project within budget. Rich Bonczek proposed that the schedule (with regards to model calibration) be readdressed at the 6/14/2016 meeting in Nashville.

Start	End	Deliverable	Notes
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
5/27/2016	5/27/2016	Bi-weekly call (cancelled)	NA
6/3/2016	6/3/2016	Interim Bi-weekly call	
6/10/2016	6/10/2016	Biweekly call (cancelled)	NA

6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
4/2/2016	6/17/2016	Model calibration	End date contingent on 6/14/16 meeting
4/11/2016	6/24/2016	Draft Modeling Report Issued to MWG	End date contingent on 6/14/16 meeting
6/27/2016	7/1/2016	MWG Review of Draft Modeling Report	1 week
6/24/2016	6/24/2016	Bi-weekly call	
7/4/2016	7/8/2016	Incorporate MWG comments to Draft Modeling Report	1 week
7/15/2016	7/15/2016	Bi-weekly call	
7/11/2016	7/29/2016	DOE review of Draft Final Modeling Report	3 weeks
7/29/2016	7/29/2016	Bi-weekly call	
7/31/2016	7/31/2016	Submit Modeling Report to FFA parties	Changes discussed with MWG
7/31/2016	8/30/16	FFA parties review Modeling Report	30 days
8/31/2016	9/29/2016	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days
9/1/2016	9/1/2016	Quarterly Meeting	Face-to-Face Meeting
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Concurrence of Meeting Minutes

The MWG May 13th, 2016 Meeting Minutes (sent May 27th, 2016) were presented and opened for discussion. The Group expressed agreement that the minutes were accurately recorded.

5. Discussion of Action Item List

The Action Item List contains a listing of items that the MWG identified as necessary. The list is an effort to identify those items, add detail as to which items are necessary to be completed preceding calibration efforts and which are designated for post-calibration to address data gaps, and to provide a tool to track progress in addressing each item.

Denise Tripp reviewed the Action Item list (*20160531 Draft Action Item List.pdf*) and pointed out those action items that were completed.

6. Discussion of Hydraulic Conductivity Data and Anthropogenic Recharge Estimates (Item 2)

Denise Tripp summarized the action item (#2) and data package (Draft PGDP Slug_Test_Information_05262016.pdf); indicated that the only revision since the last call was an added footnote to Table 3. Martin Clauberg noted that the footnote in Table 3 should read "*Assumed 10:1 horizontal:vertical anisotropy". Beyond this minor comment, the Group agreed that Item 2 is complete.

7. Discussion of Evaluation of C-400 Treatability Study Findings (Item 3)

The summary of the study findings and conclusions emailed on May 11th was updated to include a site map of historical pumping tests in the vicinity of the C-400 treatability study area (Draft C-400 Treatability Study Evaluation_05262016.pdf). Al Laase commented that data from the pumping tests will be used at pilot points that coincide with pump test locations. At pilot points that do not coincide with the pump test locations, K will be limited between 100 and 1500 feet per day. Al Laase and Noman Ahsanuzzaman discussed the appropriate use of PEST and Hydraulic Conductivity Pilot Points. Noman Ahsanuzzaman was concerned that during calibration, PEST Pilot Point results will go beyond reasonable range of K values and proposed using K zones as a more efficient way of calibrating the model. Al Laase discussed the benefits of using PEST pilot points as an appropriate method for model calibration. Julie Corkran pointed out that this conversation should perhaps be better picked up again during the 6/14/2016 Nashville meeting, Noman Ahsanuzzaman agreed. Denise discussed the vertical anisotropy determined by the study as input to the sitewide model. She concluded that the values from the C-400 study values were consistent with the 10:1 horizontal:vertical anisotropy specified in the sitewide model. After a brief discussion, the Group agreed that Item 3 is complete.

8. Discussion of Land Use Assessment for Qualitative Designation of Anthropogenic Recharge Zones (Item 4)

Denise Tripp summarized the action item and expressed that the action item was still in progress. Denise commented that the goal is to have one final figure that qualitatively characterizes estimated recharge with high, intermediate, and low recharge zones to be presented and discussed at the Nashville meeting (on 6/14/2016).

9. Discussion of Delineation of UCRS Clay Greater Than 2 Feet Thick (Item 5)

Denise Tripp summarized the action item and discussed areas identified within the plant for limited recharge input or anthropogenic recharge pilot points (See Figure 4, Draft HU3 Clay Thickness_05092016.pdf). Denise Tripp also discussed representative hydraulic conductivity values to assign to low recharge zone in areas of clay greater than 2 feet thick (0.2 inches per year based on lowest slug test results or a higher value such as 2 inches per year). Denise Tripp asked Noman Ahsanuzzaman what input value he felt was reasonable. Noman Ahsanuzzaman commented that 2 in/yr is more reasonable to use within the plant boundary in areas of clay greater than 2 ft thick. After discussing Noman Ahsanuzzaman's comment, the Group agreed that Item 5 is complete.

10. Discussion of Model RGA Isopach Map (Item 6)

Denise Tripp described how model calibration has been initiated using the reported layer configuration (see Draft Model RGA Thickness_05092016.pdf). Noman Ahsanuzzaman commented that the northern portion of the kriged isopach map (northwest and north of the property boundary) appeared very thin. Denise Tripp replied that she had reviewed the data that was used in the kriging and confirmed that the data supported the kriged thinness in the northern portion of the model and that thin model areas with high conductivities will be noted during the calibration process. No other comments were expressed and the Group agreed that Item 6 is complete.

11. Discussion of Revision of Southern Model Boundary (Item 8)

Denise Tripp also commented on and described how the reported layer configuration (see Draft Model RGA Thickness_05092016.pdf) had been used to address Item 8. No additional comments were made and the Group agreed that Item 8 is complete.

12. Closing

Brad Montgomery asked if a second calibration run would be ready for review at the Nashville meeting; Denise Tripp and Al Laase responded that it was unlikely.

The group agreed that the 6/14/2016 Nashville meeting will start at 8 am and should end by 5pm.

The Group planned a short call for 6/10/2016, from 9 am to about 10:30 am, to confirm the receipt of the data package of the first calibration run and for Denise and Al to briefly explain any significant findings/ discoveries.

Modeling Working Group
Meeting Minutes-June 10, 2016

A short meeting was held to confirm receipt of data and travel plans for the face-to-face meeting in Nashville four days later on June 14, 2016. Meeting minutes were not submitted to the MWG.

Modeling Working Group

Meeting Minutes - June 14, 2016

1. **Nashville Attendees:**

   Dave Dollins, Rich Bonczek, Noman Ahsanuzzaman, Brian Begley, Martin Clauberg, Kelly Layne, Todd Powers, Denise Tripp, Al Laase, Steve Hampson, and, Bryan Clayton

2. **Phone Attendees:**

   Julie Corkran, Tracy Taylor, Bruce Stearns, Eva Davis, Nathan Garner

3. **Presented Materials:**

   The following documents were distributed via email to the Modeling Working Group (MWG) team on June 9, 2016 for the team's review prior to the June 14, 2016 meeting:

   - PGDP Sitewide GW Model Review of Initial Calibration Run: PGDP_RGA_CAL_2016_02.GWV". (pdf file) (File name "Draft Review of PGDP_RGA_CAL_2016_02")
   - Drawdown Target Statistics Cal 2 (Excel file)
   - Flux Target Statistics Cal 2 (Excel file)
   - Kx PP Statistics Cal 2 (Excel file)
   - Recharge PP Statistics Cal 2 (Excel file)
   - Trajectory Target Statistics Cal 2 (Excel file)
   - WL Target Statistics Cal 2 (Excel file)

   On the day of the June 14, 2016 meeting, the additional file was transmitted via email to the MWG for discussion during the afternoon meeting time:

   - Draft Review of PGDP_RGA_CAL_2016_02 Part 2 (pdf file)

4. **Meeting Objectives:**

   - MWG approval to continue the calibration efforts as a result of the presented criteria.

Review of Presented Material: [Note: Captured actions are grouped into three "Action Group" categories: (1) Actions required before or as part of the first calibration and/or Actions required to be a part of the Draft Modeling Report (due 7/29/16), (2) Actions after the first calibration, and (3) Actions that are "Wish List" items.

- The MWG discussed the inclusion of all data sets presented in the differing stress periods. EPA expressed the concern that a subset of the data should be withheld from the calibration so as to use that subset for model validation. Kentucky and DOE expressed the concern that the entire data set should be included at the onset of the calibration efforts. The MWG reached an agreement to continue with the initial calibration using the full data set but the team should reserve the possibility to "weight" or perform an alternative calibration using either the transient or steady-state data set and reserving the second data set for validation of the model. (Action Group 2)

- The discussion on validation triggered a more programmatic discussion regarding validation strategy and the labor (and subsequent cost) associated with the validation. MWG identified an action: Need validation strategy but would be discussed following the July 29, 2016 report deliverable. (Action Group 2)
- The calibrated hydraulic conductivity analysis prompted the following actions, which needed to be vetted prior to the continuation of the calibration. MWG identified actions: Transmissivity analysis, and weighted plume trajectories (or "zoned" trajectories within certain areas where more information may be available to better weight the trajectory values). (Action Group 2)
- When reviewing Slide 16 of Draft Review of PGDP_RGA_CAL_2016_02.pdf, the MWG noted that the "Model Parameter" associated with PP373 should be revised from Very Upper LBC to Very Upper BC. (Action Group 1)
- The MWG spent considerable time noting information that needed to be captured in the modeling report. Topics for inclusion, where applicable and appropriate, included (All 11 items are Action Group 1):
    1) Keep scales consistent (and if scales should be adjusted – there should be notations highlighting the change).
    2) Scrub units and look for maps that are lacking in units
    3) Pump test locations (example, Slide 8-B) should be noted on maps of calibrated hydraulic conductivity (slides 8 to 13; Draft Review of PGDP_RGA_CAL_2016_02.pdf).
    4) Include a section in the modeling report with a discussion of how the model is a fluid or "living" model that requires periodic reviews and discussion from the MWG and the necessity for a "wish list" of data that would make for a better model that will be used for decision making purposes.
    5) Difference of units
    6) Mass balance information
    7) Flood sheets and elevations
    8) Add stress period dates
    9) Dry cell notations (Discussed during slides 30 -41)
    10) Denotations for well clusters should be vetted and discussed in the report

11) Consider splitting pages so as to show complementary information so that the reviewer does not have to “flip” back and forth between pages to perform a comparison when asked to do so within the verbiage of the report.

- The MWG discussed the impacts from the site’s change in operational status. The MWG concluded that current “operational” status of the site has not likely impacted the recharge. MWG identified two actions: Add plume trajectory into last two stress periods and evaluate the areas outside of the limited area that may need special recharge considerations (i.e., K002, C001, lagoons, etc). (Action Group 1)
- The MWG discussed the slides presenting water levels (slides 42 – 44; Draft Review of PGDP_RGA_CAL_2016_02.pdf) and thought that the layers should be combined. (This was an action for the MWG but also should be carried forward as a modeling report request as well.) Additionally, the MWG discussed the necessity to pull out data associated with MW430 (see slide 67) and if the data is removed that the rationale for the exclusion of the data should be fully discussed in the modeling report. (Action Group 1)
- The MWG continued with a lengthy discussion on water levels. The MWG took an action: For the residual versus observed water level, a 95% confidence level should be evaluated. (Action Group 1)
- The MWG discussed the land use and the importance for consideration while calibrating. The MWG took an action: Work with LeAnne (Garner) on the 2009 Land Use percentages. (Action Group 1)
- The evaluation of reuse of spare or unused water level gauge instruments that had been purchased for use at the Waste Disposal Alternative’s Site 11. (Action Group 3) Note: Other “Wish List” items have been mentioned as follow: Water level measurements in the gravel underneath the buildings, Strategy for increasing calibration run speed through cloud computing, etc.

5. Model Simulations:

The MWG evaluated the simulations of the results of the calibration efforts. The stress periods using the agreed upon criteria was used and the results from each were discussed in detail. The group concluded that the model required continued revisions based on the pre-defined weighted criteria and the sensitivity analyses discussed in more detail during the meeting.

6. Schedule and Objectives:

The MWG concluded with a discussion on the additional meetings needed to complete the MWG’s target dates. The following denotes the schedule and objectives reached by the MWG:

1. 7/29/16
    a. MWG review of report (include strategy, objectives, data analysis and add validation/verification)
2. 8/16-8/17
    a. Discuss draft report

    b. Discuss 4-6 calibration runs
    c. Validation strategy
3. Bi-weekly meetings- 6/24/16, 7/8/16, 8/5/16

In summary, the MWG agreed that no new information was presented that required the MWG to cease with calibration efforts. The bi-weekly meetings would be used to discuss the results of the action items identified in the June 14, 2016, meeting before finalizing the model.

①

P. 2 ⇒ (not a deal breaker) but possibly weight (or calibrate separately) the transient vs. steady state (or use one set to check the other).

~~[~~ ~~Conductivity, then~~ ~~leave in~~

~~[take out ⑤ 15, run model,~~ 2nd set of data to validate

~~sensitivity analysis on recharge~~ ~~]~~

~~- compare drawdowns~~

~~- will limit storage~~

~~(~10-15% drawdown checks, if fail, sensitivity~~

(EPA programmatic approach?)

- Need validation strategy (afer 7/31/16) ⇒ {

p. 2 & 66

②

- Use transient & steady state data sets to model.

Action: Need validation strategy (Concern ⇒ Funding & larger programmatic impacts at senior level)

p. 9 ③

- Transmissivity Analysis

~~p. 9~~

- Weighted ~~trajectory~~ plume trajectories

(for ~~ed~~ model report: check scales of maps)

- Add pump test locations (slide 8-13)
- look at "zoned" trajectory (calibration statistics within ~~the plume~~) "area specifics"

④

(p16 for model report => double check reference of location 373 ... its BC not LBC)

(model report: "wish list" inclusion & that the model is "living")

flood sheets & Elevations

(model report: Δ units, include mass balance info,)

add stress period dates

- ~~Keep~~

- ~~Plant ops real relevance due to pressurization (model plume trajectory~~

- Recharge: Add plume trajectory into last two stress periods b/c plant operation change likely hasn't impacted the recharge
- Look at areas outside LA that may need recharge considerations (ex. KOOl, COOl, ~~etc~~. , lagoons)

⑥

Potentiometric

-p. 30-41 (dry cell notation,
units

Water levels

- p. 42-44 - Combine ~~Layer~~ points
on the 3 layers

- pull out mw430 (see p. 67)
(document ↑ in model report)
rationale

⑦

Residual vs Observed H_2O Level

- 95% CL

- Denotation for well cluster ?
  Put thought into splitting pages to include complimentary info.

- 2009 Land Use - LeAnne on Percentage

Schedule & Obj.

① ~~7/8/16~~ 7/29/16 (Non-meeting)

- MWG Review of Draft Report (inc. strategy, objectives, Data Analysis) add validation/verification

② 8/16 - 8/17 (~~Tentative~~)

- Discuss Draft Report
- Discuss 4-6 cal runs
- Validation strategy

③ Biweekly meetings

6/24/16
~~6/24/16~~ 7/8/16
~~7/22/16~~ 8/5/16

Modeling Working Group
Meeting Minutes—June 24, 2016

1. **Attendees:** Jim Rumbaugh, Rich Bonczek, Noman Ahsanuzzaman, Denise Tripp, Chad Drummond, Brian Begley, Eva Davis, Martin Clauberg, Tracy Taylor, Todd Powers, Ron Kent, Bruce Stearns, Al Laase

2. **Call for Issues from Modeling Working Group (MWG) Members**
   a. Meeting minutes from Nashville meeting will be distributed early next week.
   b. Update on Model Calibration
      i. See below revised schedule. Schedule was revised in accordance with discussions held in Nashville. Denise asked if there were any comments. Martin asked if planning is occurring for next face to face on August 15-16. KDEP requested the city be chosen within 3-4 weeks. Denise asked if anyone had preferences. Nashville seems to be preferred. KDEP will put in their paperwork for the meeting to occur in Nashville.

         Denise noted that estimated completion dates are aggressive to push progress.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

Start	End	Deliverable	Notes
4/2/2016	8/16/2016	Model calibration	End date contingent on 8/16/16 meeting
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
5/27/2016	5/27/2016	Bi-weekly call (cancelled)	NA
6/3/2016	6/3/2016	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6/10/2016	6/10/2016	Biweekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
6/24/2016	6/24/2016	Conference Call with MWG	
7/8/16	7/8/16	Conference Call with MWG	
7/29/16	7/29/2016	Draft (Primary Components) Modeling Report Issued to MWG	
7/29/16	8/5/16	MWG Review of Draft (Primary Components) Modeling Report	1 week
8/5/16	8/5/16	Conference Call with MWG	
8/5/16	8/12/16	Incorporate MWG comments to Draft (Primary Components) Modeling Report	1 week
8/15/16	8/16/16	Meeting with EPA/KY to Discuss Modeling Results	Face to Face Meeting Location TBD

8/26/16	8/26/16	Conference Call with MWG	
8/26/16	8/26/16	Draft Modeling Report Issued to MWG	
8/26/16	9/2/16	MWG Review of Draft Modeling Report	1 week
9/2/16	9/2/16	Conference Call with MWG	
9/2/16	9/9/16	Incorporate MWG comments to Draft Modeling Report	1 week
9/9/16	9/30/16	DOE review of Draft Final Modeling Report	3 weeks
10/14/16	10/14/16	Submit Modeling Report to FFA parties	Changes discussed with MWG
10/7/16	11/13/16	FFA parties review Modeling Report	30 days
11/13/16	12/5/16	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days
12/5/16	1/5/17	FFA parties review and concur on Modeling Report	30 days
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Discussion of Action Item List Items

a. Action Item 4: Will pull together map from various sources to get a qualitative sense of anthropogenic recharge at the facility. Currently looking at information presented at Nashville meeting and putting all of the data on one map. Anticipating sending out draft version next week.

b. Action Item 17: Have received some recent water level data from Site 5a and 11. The data will be compiled and analyzed to evaluate areas of increased recharge. A summary data package is planned to be sent out for next call.

c. Action Item 10: Alternative calibration limiting recharge to estimates using Kx = 4.62E-04 ft/day (minimum) where lithologic data indicates greater than two (2) feet of clay in HU3. The alterative model calibration will be conducted after completion of the initial calibration process per discussion by Noman and Denise. Current estimate for completion is Aug 1.

d. Model revisions for the next calibration run were discussed and included:
    - Adding trajectory targets to stress periods 20 and 21
    - Evaluation of MW430 water level and drawdown residuals and consideration of revised recharge configuration in the vicinity of Outfall 001. Denise visited site on Wednesday June 16 and found evidence that this is an area of enhanced recharge.
    - Evaluation of reported pumping test results for MW79 and PW1, located in the NE quadrant of the plant area. Historical reports suggest that pumping wells may have been poorly constructed or not well developed prior to the test. These are the two lowest calculated K's (100 ft/day range).
    - Evaluation of additional targets to be added from other layers to improve coverage across the modeled area in all layers.

- The next calibration run is scheduled for next week.
- The model output will be processed the middle of the following week, but may not be complete for next call (Monday is a holiday).

Brian asked Denise if she found anything else of interest during her site visit. Denise noted that it had rained heavily for about an hour when she arrived at the site. Brian mentioned adding recharge points at outfall points but added that flow amounts are uncertain. Denise responded that she did not identify any areas other than outfall 001 that appeared to be areas of increased recharge.

Brian asked if she found any areas off of the terrace to indicate an area where the recharge may be greater than is currently modeled. Denise said she did not, and noted that not many water level targets are available in the vicinity of the Terrace recharge zone and that a sensitivity analysis is planned.

e. Developing a validation strategy. Denise will add this to the Action Item Lists as Item #18.

f. Martin asked if Al has found a way to speed up the calibration runtime. Al responded that the only way is to go to the cloud; however, he prefers to proceed with the current computer processing.

Attachment:

20160621 Action tem List.pdf

Modeling Working Group
Meeting Minutes—July 8, 2016

1. **Attendees:**

Kelly Layne, Dave Dollins, Eva Davis, Noman Ahsanuzzaman, Al Laase, Chad Drummond, Denise Tripp, Craig Jones, Nathan Garner, Jim Rumbaugh, Ken Davis, Tracy Taylor, Martin Clauberg, Brad Montgomery, Brian Begley, Todd Powers, Eva Davis

2. **Call for Issues from Modeling Working Group (MWG) Members**

Dave Dollins indicated there will not be a face to face August 15th but rather it will be a webex. Kelly Layne asked that this information get passed along to others that need to know that travel will not be necessary.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

The schedule below was presented. The schedule will be updated to indicate that the face meeting (that was reflected in the schedule for 8/15/16 and 8/16/16) will be replaced with a WebEx. The due date for the preliminary modeling report (primary components) is still July 29.

Noman Ahsanuzzaman asked if the second model configuration (Action Item #10) will be part of the model calibration. Denise Tripp said the initial calibration will be done using the current pilot point calibration and the second model calibration effort using clay thickness will come afterward. The intended schedule goal is August 1. Noman asked if "model calibration" included both model configurations (pilot point model and clay thickness model). Action Item 10 tasks will be discussed during August 15th WebEx. Martin Clauberg suggested the group keep the focus on the draft report for the August 5th bi-weekly call. MWG agreed that calibration results will not be included in the initial draft modeling report.

Start	End	Deliverable	Notes
4/2/2016	8/16/2016	Model calibration	End date contingent on 8/16/16 meeting
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
5/27/2016	5/27/2016	Bi-weekly call (cancelled)	NA
6/3/2016	6/3/2016	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6/10/2016	6/10/2016	Biweekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
6/24/2016	6/24/2016	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16
7/8/16	7/8/16	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16

7/29/16	7/29/2016	Draft (Primary Components) Modeling Report Issued to MWG	
7/29/16	8/5/16	MWG Review of Draft (Primary Components) Modeling Report	1 week
8/5/16	8/5/16	Bi-weekly Call	
8/5/16	8/12/16	Incorporate MWG comments to Draft (Primary Components) Modeling Report	1 week
8/15/16	8/16/16	Meeting with EPA/KY to Discuss Modeling Results	Face to Face Meeting Location TBD
8/26/16	8/26/16	Bi-weekly Call	
8/26/16	8/26/16	Draft Modeling Report Issued to MWG	
8/26/16	9/2/16	MWG Review of Draft Modeling Report	1 week
9/2/16	9/2/16	Bi-weekly Call	
9/2/16	9/9/16	Incorporate MWG comments to Draft Modeling Report	1 week
9/9/16	9/30/16	DOE review of Draft Final Modeling Report	3 weeks
10/14/16	10/14/16	Submit Modeling Report to FFA parties	Changes discussed with MWG
10/7/16	11/13/16	FFA parties review Modeling Report	30 days
11/13/16	12/5/16	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days
12/5/16	1/5/17	FFA parties review and concur on Modeling Report	30 days
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

1. Concurrence of Meeting Minutes

The MWG June 24th, 2016 Meeting Minutes (sent July 05, 2016) were presented and opened for discussion. The Group expressed agreement that the minutes were accurately recorded.

The MWG meeting minutes from the June 14th meeting in Nashville will be reviewed by DOE next week.

2. Discussion of Action Item List

Denise Tripp led the discussion. An updated Action Item List was provided on July 6th (20160706 Draft Action Item List.pdf). Updates include Action Items 4, 9, 17, 18.

Action Item 17 included a review of water level data from UCRS monitoring wells and comparison with maps of land use, pipe locations, and RGA water level maps (see 8-page pdf Draft UCRS WLE Assessment_0706 2016). A summary of the assessment process and description of data sources including the updated KRCEE database to include 2015 data from Sites 5A and 11 and several maps showing water levels, water temperature, and soil saturation information. The findings of the assessment are illustrated in Figure 1 and indicate a high UCRS level near TVA water supply line leak. Water levels from September 2014 in RGA also show impact of leak. The MWG agreed that there is a zone of higher recharge near TVA water supply and in the eastern portion of the plant.

Noman Ahsanuzzaman requested the use of hashed lines for contours in cones of depression and indicated that Figure 3 shows why the plumes are aligned the way they are. He also asked if the plume trajectory calibration is still needed given the area of higher recharge. His point is that model-predicted plume should be steered by higher recharge not high conductivity zone. Denise Tripp clarified that since we have better recharge data, the pilot points can be constrained to indicate areas of higher recharge. Al Laase indicated that trajectory targets have a weighting of 0.1 Head targets have weighting of 1.0.

Additional discussion regarding sources of anthropogenic recharge in the plant area included:

- Cooling towers which are about 50 ft across by 200 ft wide (15 feet deep). This is four modeling cells. Al Laase asked if they should be added as individual features in the model. Cooling tower lines are still under pressure to this day.
- Denise Tripp discussed a KPDES flow diagram indicating significant outflow in the form of steam while the plant was in operation and minimal difference in outflows before and after plant shut down. Denise will provide her summary to Kelly Layne who will look for additional information.
- After plant operations stop, the temperature signatures will likely go away. However, elevated recharge zones have not gone away.
- Martin Clauberg mentioned that temperature is only one line of evidence and that a little very hot water can create a large signature in the UCRS. The primary line of evidence is water level data.

The MWG agreed that the action item is complete (agreed to by KDEP and EPA) but findings will be updated if additional information become available.

Action Item 4, Land use evaluation and development of qualitative anthropogenic recharge zones, was summarized by Denise Tripp (see Draft Land Use Assessment_0706 2016.pdf). Four zones of increased recharge were identified:

3. TVA Raw Water line leak
4. Outfall 001 surface water
5. Lagoons C-616
6. Eastern portion of plant with 4 buildings connected to high pressure fire line and cooling towers

Brian Begley indicated that gravel under buildings (generally thought to be about 10

feet thick) can provide significant recharge from utility lines and roof drains. Noman Ahsanuzzaman stated that there are several UCRS wells near the buildings. Other members responded that the UCRS wells may not be in connection with effects of the gravel layers under the buildings. Noman responded that wells could be put in to evaluate UCRS water levels near the buildings (could use hand auger). However, if the gravel layers are 10 to 20 ft deep, then hand augers would not be feasible.
A discussion ensued regarding RGA plume delineation.

Brian Begley suggested additional monitoring wells near switchyard if conditions change in the future (high power lines). This is a wish list item. Piezometers under process buildings were also added to wish list.

The MWG agreed that the action item is complete (agreed to by KDEP and EPA) but findings will be updated if additional information become available.

Brian Begley stated that the compilation of anthropogenic recharge, which is also reflected in the figure, is an important contribution to the understanding of the site and is a significant advancement over the previous years' modeling efforts. The MWG concurred and acknowledged the progress made by the development team.

Action Item 9, initial calibration using anthropogenic recharge pilot points in the main plant area, is ongoing. The goal is another calibration run started next week. Model revisions being considered include:

- Excluding water level targets that are outliers based on a review of residuals
- Added recharge zonation in area of Outfall 001 and to represent buildings and cooling towers in the eastern portion of the plant
- Revising recharge target constraints to reflect sources recharge identified in Action items 4 and 17.
- Limiting boundary conditions to the divided along the centerline of the Ohio River. This would better align with the CSM.
- Specifying flux targets as brackets targets to allow for a range of flux at the seeps and the river. If model predicts flux outside of bracket it would be factored into the objective function. Jim Rumbaugh has enabled this in GW Vistas. This was discussed by MWG at last face-to-face meeting.

Action Item 18, development of a strategy for model validation, was added to the Action item list and will be included in Draft (Primary Components) Modeling Report.

Next teleconference will be August 5. Draft report will be submitted to the MWG team on July 29. The MWG agreed to have reviewed the Draft report by the August 5th teleconference so as to be able to raise and address issues.

Modeling Working Group
Meeting Minutes—August 5, 2016

1. Attendees

Kelly Layne, Gaye Brewer, Dave Dollins, Noman Ahsanuzzaman, Denise Tripp, Ron Kent, Martin Clauberg, Bruce Stearns, Chad Drummond, Jim Rumbaugh, Ken Davis, Eva Davis, Rich Bonczek, Steve Hampson, Al Laase

2. Call for Issues from Modeling Working Group (MWG) Members

Draft Modeling Report was submitted to members of MWG (7/29/2016). Gaye Brewer did not receive the modeling report and stated that Brian Begley probably did not receive report either (due to email issues). Kelly Layne will check and make sure copies of the draft modeling report are sent to members of the MWG from KDEP.

Rich Bonczek asked if anyone had any comments on the Draft (Primary Components) Modeling Report. Most have only skimmed the report. Ken Davis commented that the Draft Modeling Report needs sites and locations better defined. It was agreed that this is a common issue at PGDP. Rich Bonczek said that either verbal or written comments would be accepted prior to the upcoming WebEx meeting.

Kelly Layne asked if past modeling reports are available in proper places online. Kelly will check and provide an update to MWG at the WebEx meeting. Al Laase stated that there is a concise summary of past modeling reports in the 2008 report.

3. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The schedule below was presented. An all-day WebEx meeting had previously been scheduled for August 16 in lieu of a face-to-face meeting. Kelly Layne asked about everybody's availability for a face-to-face meeting in late August or early September in addition to the WebEx meeting. Everybody will check with their organization/management about attending a face-to-face meeting in Paducah on August 24 and solidify their plans by early next week. The purpose of the August 24 meeting will be to discuss written comments about the Draft (Primary Components) Modeling Report that was issued to MWG on 7/29/2016 and to discuss any additional modeling progress. Due dates for the Draft and Final Modeling Reports will be rescheduled pending comments received for the August 24th meeting. An alternative meeting date and location of September 20 in Lexington will be used if there is an issue with the August 24 date.

Martin Clauberg suggested that the MWG may want to have a tour of the site at the face-to-face meeting. Kelly Layne will arrange the tour. The meeting will likely be at Kevil facility but not the hotel. Kelly will send out a hotel list to the group. There are several hotels available at per diem rate.

The August 16th WebEx meeting will be changed from an all-day event to a 2-hour meeting from 10 AM to 12 PM Eastern time. Kelly Layne will send an updated meeting invite and the schedule will be updated.

Biweekly calls will be scheduled for August 19 through the end of September. Kelly will send an updated invite and the schedule will be updated. Calls will be cancelled as warranted.

Start	End	Deliverable	Notes
4/2/2016	8/16/2016	Model calibration	End date contingent on 8/16/16 meeting
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
5/27/2016	5/27/2016	Bi-weekly call (cancelled)	NA
6/3/2016	6/3/2016	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6/10/2016	6/10/2016	Biweekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
6/24/2016	6/24/2016	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16
7/8/16	7/8/16	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
7/29/16	7/29/2016	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16
7/29/16	8/5/16	MWG Review of Draft (Primary Components) Modeling Report	1 week
8/5/16	8/5/16	Bi-weekly Call	
8/5/16	8/12/16	Incorporate MWG comments to Draft (Primary Components) Modeling Report	1 week
8/15/16	8/16/16	Meeting with EPA/KY to Discuss Modeling Results	Online meeting
8/26/16	8/26/16	Bi-weekly Call	
8/26/16	8/26/16	Draft Modeling Report Issued to MWG	
8/26/16	9/2/16	MWG Review of Draft Modeling Report	1 week
9/2/16	9/2/16	Bi-weekly Call	
9/2/16	9/9/16	Incorporate MWG comments to Draft Modeling Report	1 week
9/9/16	9/30/16	DOE review of Draft Final Modeling Report	3 weeks
10/14/16	10/14/16	Submit Modeling Report to FFA parties	Changes discussed with MWG
10/7/16	11/13/16	FFA parties review Modeling Report	30 days
11/13/16	12/5/16	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days

12/5/16	1/5/17	FFA parties review and concur on Modeling Report	30 days
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Concurrence of Meeting Minutes

Kelly Layne asked for concurrence on meeting minutes from MWG June 14th meeting in Nashville (sent July 25, 2016) and MWG July 8th, 2016 Meeting Minutes (sent July 22, 2016). Eva Davis noted that she was listed as a phone attendee on the June 14th meeting minutes, but she was not in attendance and should be removed from the list. Kelly Layne will remove Eva's name from the June 14th meeting minutes.

5. Discussion of Action Item List Items

Denise Tripp led the discussion. An updated Action Item List was provided on August 3rd (20160801 Draft Action Item List.pdf). Action items 9, 10, and 18 are currently open.

Action Item 18, development of a strategy for model validation, was summarized by Denise Tripp (see Draft Summary of Validation Approaches_2016 0801.pdf). Two approaches were suggested for model validation: 1) exclude transient 2010 pumping test periods from calibration and use for validation, and 2) use data from alternative gauging events available from quarterly landfill permit monitoring.

Noman Ahsanuzzaman asked if the quarterly landfill permit monitoring wells are all situated in the RGA and if they are mostly in the upper or lower RGA. Denise Tripp responded that they are all located in the RGA and that they have an even distribution between the upper, mid, and lower RGA. Noman asked about extraction wells in the figure that he was unfamiliar with. Rich Bonczek and Ken Davis clarified that those extraction wells were turned off years ago. Denise Tripp responded that only pumping wells that are in use will be included in future versions of the figures.

Rich Bonczek asked if there was any reason not to use both validation strategies. Noman Ahsanuzzaman agreed that he would like to see both approaches used for validation. Al Laase responded that both strategies will be used for model validation

Steve Hampson noted that a storage term would need to be used for the transient 2010 pumping test periods, and that the calibration on steady-state stress periods would not provide this term. He requested that definitions for verification and validation be provided in the modeling report, and he mentioned that "post-audit" might be a better term. Jim Rumbaugh mentioned that an ASTM panel he was on did not arrive at a consensus for defining validation or verification. MWG will come up with a definition for validation for the modeling report.

Rich Bonczek asked which target types that are used in the model calibration will also be used for validation. The modelers will provide a recommendation.

Action Item #9, initial calibration, was summarized by Denise Tripp. The calibrated recharge values were not as expected. The approach moving forward will be to use only the September 2014 stress period for calibration initially, and then use the calibrated parameters from this stress period as initial values for calibration on the entire set of stress periods. The single stress period calibration will begin this weekend or early next week.

Modeling Working Group
WebEx Meeting Minutes—August 16, 2016

1. Attendees

Kelly Layne, Gaye Brewer, Noman Ahsanuzzaman, Denise Tripp, Ron Kent, Martin Clauberg, Bruce Stearns, Chad Drummond, Jim Rumbaugh, Eva Davis, Rich Bonczek, Steve Hampson, Al Laase, Nathan Garner, Craig Jones, Julie Corkran, Tracy Taylor, Brian Begley, Todd Powers, Bryan Clayton, Brad Montgomery

2. Discussion of Draft Modeling Report

Kelly Layne opened a discussion on the draft modeling report that had been sent to the MWG for review on 7/29/2016. Brian Begley will review the report and have comments ready at the 8/24/2016 face-to-face meeting in Paducah. Noman Ahsanuzzaman will review the report and discuss his comments with Julie Corkran on the Monday before the face-to-face meeting. Julie Corkran stated that EPA will not send written comments before the meeting, but will have items to discuss at the meeting. Rich Bonczek said he would save his remarks on the report for the face-to-face meeting. Rich clarified that it is not a comment resolution in the formal sense. The comments do not need to be written or formal and will not follow the traditional comment-response format. He requested that the discussion of the draft report focus on big picture issues.

3. Calibration Status Update

Denise Tripp presented an outline of the current work status as described in the PowerPoint presentation sent to the MWG on 8/11/2016 (*0816 2016 PGDP Sitewide GW Model Webex_Draft R1.pptx*). Recent model revisions include additional recharge zones to represent cooling towers, roof drains, and Outfall 001; expanded water level target network; limiting the Ohio River extent to the river's centerline to represent divide between discharge form the north and the south; and changing flux targets to bracket targets.

Denise Tripp reviewed simulated water levels and noted trends in the results that still need to be addressed. She reviewed particle tracking results for selected stress periods and noted that the TCE plume is not matched well in stress period 16. She summarized that the path forward would be to develop initial recharge estimates using a steady-state single stress period model (stress period 20), refine constraints for recharge pilot points using site data, and limit the number of stress periods used for the full calibration (stress period 4 would be removed because of limited data points, and stress periods 5 through 15 would be used for model validation instead). Steve Hampson suggested that some other stress periods prior to implementation of the pump-and-treat system should be excluded. Rich Bonczek agreed that simplifying the model would be a good path forward, and he emphasized the importance of matching the TCE plume.

4. Discussion of Roof Drains

Noman Ahsanuzzaman asked for clarification on the geometry of the roof drain recharge zones. Denise Tripp responded that they are modeled by the building footprint. Noman expressed concern about the size of the roof drain recharge zones and the amount of recharge applied to the zones. He said the roof drains are designed to carry water away from the buildings. Denise and Steve Hampson remarked that anecdotal evidence of flooded buildings indicates that the roof drains are not working as designed. Noman said there is no quantitative data showing that the roof drains are not working. Steve Hampson asked if site operations staff could be asked for more information about the roof drains. Kelly Layne responded that site operations staff could not provide quantitative information about the flooding, but she will take the action item to ask them for more information. Noman suggested that the current model recharge configuration assumes the drains are operating exactly opposite of their intended purpose. He asked about potential runoff and evaporation that would reduce the amount of recharge. Denise Tripp responded that the maximum recharge is being used as a pilot point constraint, but the calibrated recharge could be less than the maximum constraint and therefore the model configuration does not assume that the roof drains work exactly opposite of their intended design. She said the calibration is an iterative process and that if the recharge is at the maximum constraint during the calibration, then the reasonableness of the constraints would be revisited.

Noman Ahsanuzzaman said he thinks 52.6 inches per year is too high for the pilot point constraint on the roof drains based on the lithology. Denise Tripp replied that the value falls within the range of median vertical hydraulic conductivity values estimated for the UCRS lithology and represents a reasonable maximum constraint. Al Laase said that the reasonableness of the recharge values will be revisited once the model is calibrated. Noman said that all the precipitation would have to recharge the aquifer to have 52.6 inches per year of recharge, so the value is unrealistic because the roof drains should convey some runoff away from the buildings and there should be evaporative losses. Brian Begley noted that the recharge represents a combination of anthropogenic sources and precipitation, so not all the precipitation has to recharge the aquifer to achieve a recharge rate of 52.6 inches per year. Denise Tripp highlighted the head contour near the process buildings in question as evidence of elevated recharge in the area. Noman said that there is not a mound in the area because the gradient is not steep enough to be considered a mound. Al Laase said that it represents a significant amount of mounding considering the high hydraulic conductivity of the RGA. Noman said that the definition of a mound depends on the height of the water level rise and does not depend on hydraulic conductivity, and the spacing of the contours near the northwest corner of the plant is more indicative of a mound. Denise and others said that the spacing of the contours near the northwest corner of the plant is due to the presence of pumping wells. Rich Bonczek said that there must be a lot of water going in near the process buildings to cause the observed head contours. Noman asked if UCRS water levels are available for the area. Rich Bonczek and Steve Hampson replied that the UCRS is too heterogeneous for the water levels to be useful for that purpose.

5. Discussion of Ohio River Boundary Condition

Noman Ahsanuzzaman asked for clarification about the change of the Ohio River boundary condition. Denise Tripp responded that one half of the river was taken out of the model, and now the model boundary extends only to the centerline of the Ohio River to represent the groundwater divide that is conceptualized near the river's centerline. She said that based on a preliminary analysis the change does not seem to significantly affect the modeled discharge to the river.

6. Discussion of PZ-554

Brian Begley asked if the current model boundary takes into account recent information from PZ-554. This information could change the interpretation of the location of the Terrace slope and the southern model boundary. The model has not been updated with this information. Field work associated with the finding is ongoing, and the data needs to be checked against surveys before it can be finalized. Once the data from the field investigation is final, it will be reviewed to determine its impact on the model boundary. Efforts will be made to finalize the data by the face-to-face meeting on 8/24/2016.

7. Discussion of Hydraulic Conductivity Distribution

Denise Tripp presented information about the hydraulic conductivity distribution from the most recent calibration effort. Martin Clauberg asked about the high hydraulic conductivity zone in model layer 1 near the TVA plant. Denise responded that it represents Metropolis Lake.

Denise Tripp identified an area of Layer 2 where the interpolated hydraulic conductivity was higher than the pilot point constraints. She said the result would be corrected by adding more pilot points in the area to prevent the interpolation issue in future calibration efforts. Noman Ahsanuzzaman said the area might be an indication that the maximum pilot point constraints are too high. Denise Tripp responded that using a more restrictive range for the pilot points could lead to underestimates of hydraulic conductivity in areas of the plant where it should be high, and the interpolation issue would be resolved by using additional pilot points. Al Laase clarified that the model is not yet calibrated and that the hydraulic conductivity values will be checked for reasonableness throughout the calibration process.

8. Discussion of Recharge Zones

Denise Tripp presented information about the current status of recharge zones and recharge pilot points. She said that the recharge pilot point statistics indicate that the model might have too many variables. She noted that revisions are needed and the model is still not calibrated. Brian Begley asked if the location of Outfall 001 was based on Denise's site visit. Denise replied that it was. Steve Hampson asked if the oil control dam is located inside the perimeter road. Kelly Layne responded that it is between the perimeter road and the outfall. More information about the location of the dam will be gathered for the face-to-face meeting.

Steve Hampson asked if the cooling tower recharge zones were not used in the last stress periods because the plant was shut down. Brad Montgomery responded that the basins are still full of water even though the equipment is no longer operational.

9. Discussion of Fire Water and Raw Water Leaks

Brian Begley asked about the location of the fire water leak and how it was determined to be 40 gpm. Brad Montgomery replied that the amount of water that needs to be pumped to the water tower indicates that there is a 40 gpm leak somewhere in the system. The piping for the fire water system goes around the process buildings and is densest near the process buildings, so the 40 gpm is probably in that area. Otherwise, no information is available about the location of the leak and whether there is one big leak or many small leaks.

Brian Begley noted that a figure that had been presented in a previous meeting showed that several raw water leaks had been repaired in 2016. He asked if the raw water leak presented in the figure of the refined conceptual model for anthropogenic recharge (slide 13) had also been fixed. Brad Montgomery responded that the leak shown in the figure had not been located or quantified. Brian asked if information is available about the magnitude of the raw water leaks that had been repaired. Kelly Layne made an action item to get an update on the leak repairs. Denise Tripp clarified that the land use assessment figure was qualitative and the leak locations shown in the figure do not represent recharge locations in the model. The model recharge zones and pilot points are shown in two separate figures that were also presented (slides 15 and 16).

10. Discussion of Verification and Validation

Definitions of verification and validation were presented. Verification: Does the model perform as intended (i.e., the model is programmed correctly and does not contain errors, oversights, or bugs). Validation: Does the calibrated model represent and correctly reproduce the behaviors of the real world system? Al Laase said that the modelers are not ready for a discussion of validation yet, but the validation process is already in progress according to the descriptions of validation used in various DOE documents.

11. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The schedule below was presented. The bi-weekly call on 8/19/2016 will be cancelled. During the face-to-face meeting in Paducah on 8/24/2016, dates will be determined for the remaining items on the schedule.

7/29/16	TBD	MWG Review of Draft (Primary Components) Modeling Report	TBD
8/5/16	8/5/16	Bi-weekly Call	
8/5/16	TBD	Incorporate MWG comments to Draft (Primary Components) Modeling Report	TBD
8/16/16	8/16/16	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
8/19/16	8/19/16	Bi-weekly Call	
8/24/16	8/24/16	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
TBD	TBD	Draft Modeling Report Issued to MWG	
TBD	TBD	MWG Review of Draft Modeling Report	1 week
9/2/16	9/2/16	Bi-weekly Call	
TBD	TBD	Incorporate MWG comments to Draft Modeling Report	1 week
TBD	TBD	DOE review of Draft Final Modeling Report	3 weeks
TBD	TBD	Submit Modeling Report to FFA parties	Changes discussed with MWG
TBD	TBD	FFA parties review Modeling Report	30 days
TBD	TBD	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days
TBD	TBD	FFA parties review and concur on Modeling Report	30 days
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

Modeling Working Group
Face-to-Face Meeting Minutes—August 24, 2016

1. Attendees

Rich Bonczek, Dave Dollins, Julie Corkran, Noman Ahsanuzzaman, Brian Begley, Gaye Brewer, Nathan Garner, Steve Hampson, Martin Clauberg, Bryan Clayton, Chad Drummond, Al Laase, Denise Tripp, Kelly Layne, Ron Kent, Stefanie Fountain, Heather Lutz

2. Comments on the Draft Modeling Report

Kelly Layne opened a discussion on the draft modeling report that had been sent to the MWG for review on July 29, 2016. The draft was annotated during the meeting, and the annotated version is provided to the MWG as an attachment to these meeting minutes.

References

Recommendations: use detailed references including all data so that an independent third party could reproduce any of the work; include informal documents such as presentations as appendices; cite the KRCEE Revision 8 report; in-text citations should include table numbers, figure numbers, or page numbers; add year of plume delineation to figures that show the TCE plume boundary; cite the plume map document; add an appendix that includes all meeting minutes; tables and figures should include references to the sources of the data presented.

Definitions

Recommendations: hydrogeological terms such as recharge and mounding need to be defined; site-specific terms such as DOE property boundary, DOE industrial area, model domain, Site, and so forth need to be defined; boundaries should all be shown on figures at the beginning of the report to aid with definitions; an annotated list of definitions could be included at the beginning of the report similar to an annotated list of abbreviations.

Document Text

Clarification was given that much of the text in Sections 4, 5, and 6 of the draft report was placeholder text that needed to be updated. Much of the text is out of context if not referenced to the 2008 report. Discussion was had about whether citing the 2008 report would be sufficient or if substantial sections of text should be reproduced (e.g., for explaining the conceptual site model details such as the relative amounts of flow between the RGA and McNairy).

Recommendations: add discussion of why some data/outliers were excluded; provide a description of what the KRCEE database is and why it is used for this project; clarify that the 2012 modeling effort was project activities and not MWG activities; consistent units should be used; clarify why particular datasets were used (e.g., the 2014 water level contours or the 2012 plume map); a section on model assumptions and limitations is needed in the final report, including discussion of the steady-state assumption; final report should include a discussion of the metrics used to determine that the model is adequately calibrated; include in depth discussion of known and unknown anthropogenic recharge conditions and assumptions; need to clarify how 40 gpm fire water leak is interpreted in the model.

Figures and Tables

Recommendations: figures and tables that use units of volume per time to describe recharge should include a note citing the area used to convert from units of length per time; tables that reference a location should have an accompanying map that illustrates the location;; including coordinates in tables would be helpful; an interactive figure that allows the reader to turn on/off GIS layers and view GIS data would be helpful; legends showing discrete intervals are preferred over legends showing stretched scales (e.g., an elevation map should have a legend giving a different color for each elevation interval rather than a single, stretched elevation scale); scales should be consistent but still use enough contrast to highlight areas of interest; a figure should be included to explain the conceptual site model.

Table 3.3— the UCRS column should be removed and the title could be changed to “UCRS slug test results”; the note on reference wells is confusing and needs to be revised

Figure 3.7—both TVA supply lines should be bolded instead of just one; consider using a different color or no color for the plume boundary; figure needs to be revised to indicate that buildings are highlighted to show areas of increased recharge due to water retained in the gravel; figure needs to be revised to highlight fire water piping and associate the 40 gpm leak with the piping (not the buildings).

3. Discussion from Site Tour

All the buildings have sumps that provide hydraulic relief, and the sumps are operational. Information needed on how often the basement sumps run or under what conditions they run, and where they move the water. The gravel areas are smaller than the building footprints, and information is needed on the gravel drain specifications. Anecdotal evidence of “floating” buildings was excluded on site tour; however, current DOE expenditures on repairs to the process buildings demonstrates that the issue is real—the drains are not working correctly and water is not flowing away from the buildings.

The standing water from Outfall 001 extends beyond the fence and may need to be extended farther upstream in the model.

Discussion with Andy Anderson indicated a significant leak in the TVA lines. Water meters reportedly demonstrate a loss of nearly 2 million gallons per day between the intake and the plant; however, all of that loss may not be attributed to leaks but rather is used by the West Kentucky Wildlife Management group to fill small ponds within the West Kentucky Wildlife Management Area

Typically, 1.6 million gallons per day flows through the lagoon. The lagoon is 8 to 10 ft deep.

4. Discussion of Anthropogenic Recharge

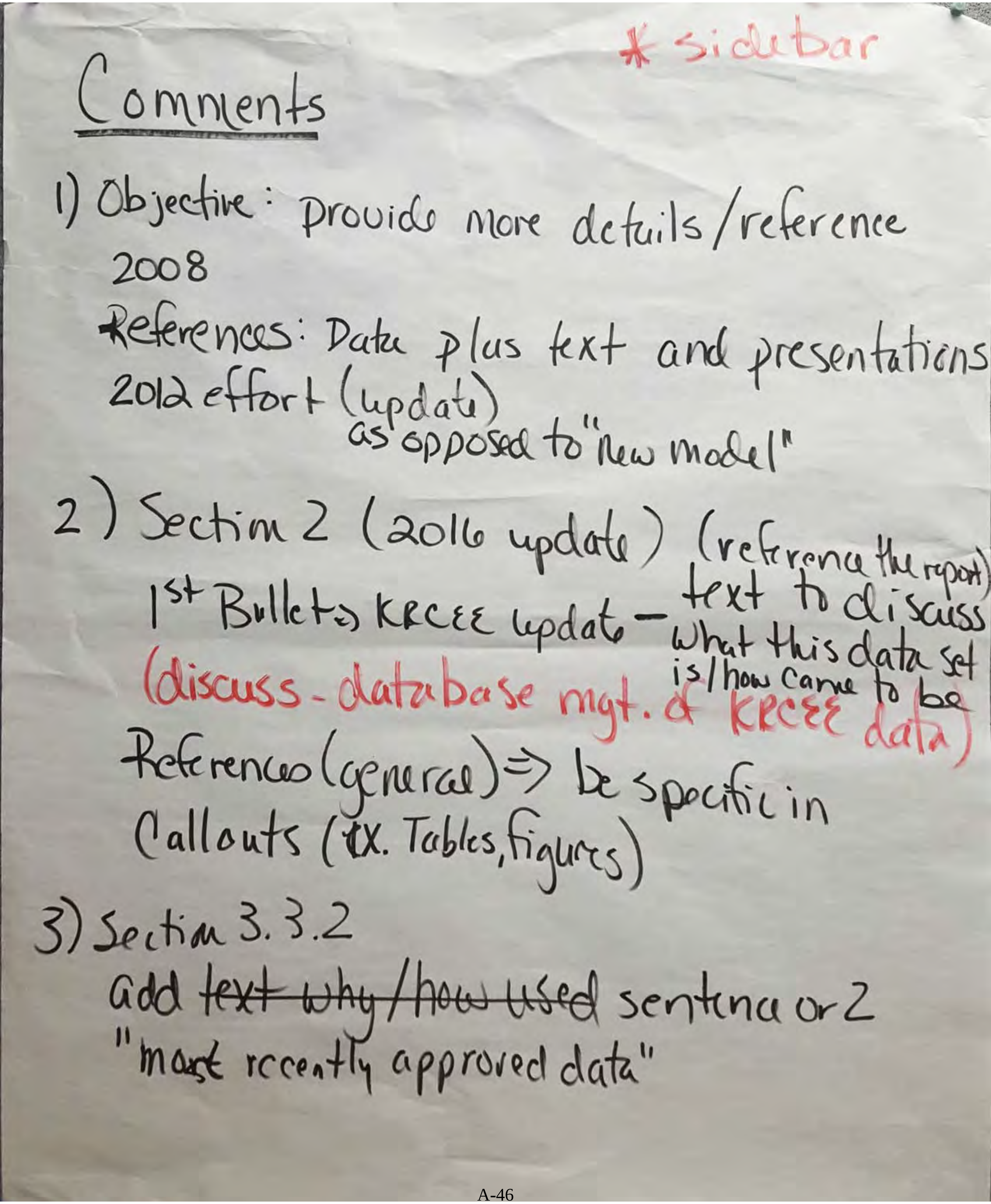
Noman Ahsanuzzaman asked how long the 40 gpm fire water leak has lasted, if 40 gpm is an average condition or a maximum condition, and where the location of the leak is. Andy Anderson needs to be asked about how long the leak has been going. 40-50 gpm is the average condition. Leak is associated with fire water piping, which is densest around the process buildings, but the exact location is unknown. Noman also asked if there is a known connection between the sumps and the RGA, or if the water still travels through low permeability UCRS materials. Al Laase noted that the water levels and flow directions provide evidence of leak locations. Steve Hampson noted that two wells have measured elevated temperatures that provide evidence of leaks.

5. Discussion of Model Calibration

Denise Tripp described calibration efforts that used one stress period without trajectory targets. Questions were raised about the need for flow trajectory targets and whether the plume path is due to preferential lithology or locations of enhanced recharge. Steve Hampson noted that in 2008 the plume trajectory could not be matched without flow direction targets and high permeability zones. He noted that there is some lithologic evidence for preferential pathways.

6. Schedule

Not all of the material prepared for the meeting was presented due to time limitations. A WebEx meeting was scheduled for August 31 to present the remaining material. Decisions about schedule and deliverable dates to be determined during the WebEx meeting.



* sidebar

Comments

1) Objective: provide more details/reference
2008
*References: Data plus text and presentations
2012 effort (update)
as opposed to "new model"

2) Section 2 (2016 update) (reference the report)
1st Bullet ⇒ KRCEE update – text to discuss what this data set is/how came to be
(discuss - database mgt. of KRCEE data)
References (general) ⇒ be specific in Callouts (ex. Tables, figures)

3) Section 3.3.2
add ~~text why/how used~~ sentence or 2
"most recently approved data"

4) General => Outlier discussion/
why something excluded

5) Add appendix with meeting
minutes

6) Consistent units (ex. gal/min or gal/day)
etc.
(ex. recharge per time) => where appropriate

7) General => Definitions (ex. recharge, mounding)
(DOC industrial site, limited area)
("industrial area") => land use map

8) Section 5.2 => "future activity"

9) * sidebar - Rich & Steve discuss referencing reproducibility of info used in report.

10) Sensitivity analysis => ~~ed~~ (e.g. conductance)

11) Section 1.2 => RMD reference sentence.

Tables General

12) Ensure MW references are shown on maps.

13) Table 3.3 (eliminate UCRS column & make UCRS in Title)

14) ✗ sidebar - maps presented in report. Further evaluate an electronic delivery (electronic-appendix) for layered viewing.

15) Table 3.3 => clarification "incl. lith log" not available.

Figures

16) General => need refrence on TCE plume map

17) General => elongate legend for more detail. (give range per color) per parameter \ explain, be consistent as possible

Figures (cont.)

18) General ⇒ consistent Color use throughout ^{3}/ explain, be consistent as possible

19) General ⇒ *Sidebar - alillie map mut. adobe file, scroll over and have Well identified

20) Figure 3.7 (label H_2O line)

21) Fire Water leaks ⇒ knowns & the date of ~~captured~~ known Conditions.

22) ** Sidebar - SWMU notifications (H_2O line repair)

Figures (cont.)

23) Figure 3.7 (plume map Ø blue)

Text.

describe how gravel under buildings retain H_2O from leaks

24) Section 5/3 => include a very ~~fu~~ indepth discussion of known ~~at~~ and unknown anthroprognic discharge conditions & assumptions made about it.

25) Figure 3.7. (delineate Fire H_2O ~~leak~~ line)

EPA - Text

26) Add limitations & assumptions - need a summary

27) 40 gpm leak - more detail &
/50 gpm
discussion (inc. any building w/ nuc material & C310 & C-315 & cooling towers) ⇒ highlight on Fig 3.7 & add to text

28) Section 4.0 - add photo for CSM for schematics

29) Summary in Section 4.0, discuss limitations. New ~~bullet~~: Noman text

EPA -Text(cnt.)

30) Section 4.0 => reference the 2008 ~~McNairy~~ Data Discussion ~~& reference~~ (give specific reference info) => (ex. McNairy)

31) Section 4.0 => biggest recharge... again, We may need to pull info from 2008 report

32) Section hydraulic conductivity

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33) General discussion Point: ~~#~~ Rainfall events vs. River Level

34) Noman - What makes the model good? Steve - process v. results - ??

Discussion from Site Tour

- all buildings have sumps, the sumps have hydraulic relief
- sumps operational

* how much gravel under buildings (look at specs)

* how often / under what conditions cause basement sumps to run & where does it go

* basement schematic vs. roof

Discussions from site tour (Cont.)

- River intake (4-4.5mg/day) & arriving (2.7 mg/ day)

* Add figure for different H_2O systems

* Extend recharge zone of koul further upstream

Schedule

10 - 1
8/31/16 – ~~9-12~~ (EST)

- Discuss Presentation
- Integrate what we learned today on site tour & Comment resolution

Modeling Working Group
Meeting Minutes—August 31, 2016

1. Attendees

Rich Bonczek, Dave Dollins, Julie Corkran, Noman Ahsanuzzaman, Tracy Taylor, Brian Begley, Gaye Brewer, Nathan Garner, Steve Hampson, Martin Clauberg, Ken Davis, Kelly Layne, Al Laase, Chad Drummond, Stefanie Fountain, Denise Tripp, Ron Kent

2. Call for Issues from Modeling Working Group (MWG) Members

There was an apparent miscommunication about a 2 million gallons per day loss in the TVA lines. An email communication from Andy Anderson stated, “There is not a way to determine any leakage on the line through metering at this time from the pump inlet to delivery at our site.” Rich Bonczek noted that some of the 2 million gallons per day “lost” water is used by the WKWMA for wetlands management and that the amount used in this way is unknown. Kelly Layne took the action item to follow up with an evaluation of the Water Withdrawal Permit for water withdrawn at the Ohio River.

3. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The schedule below was presented. Rich Bonczek noted that the contract period will end on July 1, 2017 and that the final modeling report will need to be finished on April 1, 2017. The FFA managers will need the report three weeks before that date in order to give acknowledgement by April 1, 2017. A modeling report will be due to the MWG by mid-November to leave enough time for two review cycles prior to submittal to the FFA managers. Martin Clauberg clarified that all future draft reports will be full reports. The model calibration will need to be done by the end of October. A list of consensus items will be prepared and final consensus on all items achieved in September meeting.

The September 2, 2016 meeting was cancelled. A biweekly call will be held on September 16, 2016, a WebEx meeting will be scheduled for the week of September 26, 2016, and the next face-to-face meeting will be held around October 24, 2016.

Start	End	Deliverable	Notes
4/2/2016	8/16/2016	Model calibration	End date contingent on 8/16/16 meeting
4/29/2016	4/29/2016	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
5/13/2016	5/13/2016	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
5/27/2016	5/27/2016	Bi-weekly call (cancelled)	NA
6/3/2016	6/3/2016	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6/10/2016	6/10/2016	Biweekly call	
6/14/2016	6/14/2016	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
6/24/2016	6/24/2016	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16

7/8/16	7/8/16	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
7/29/16	7/29/2016	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16
7/29/16	8/24/16	MWG Review of Draft (Primary Components) Modeling Report	Discussed in 8/24/16 meeting in Paducah
8/5/16	8/5/16	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
8/16/16	8/16/16	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
8/19/16	8/19/16	Bi-weekly Call	Cancelled
8/24/16	8/24/16	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
8/24/16	TBD	Incorporate MWG comments to Draft (Primary Components) Modeling Report	TBD
8/31/16	8/31/16	Meeting with EPA/KY to Discuss Modeling Results	3 hour WebEx
9/16/16	9/16/16	Bi-weekly Call	
9/30/16	9/30/16	Bi-weekly Call	
TBD	TBD	Draft Modeling Report Issued to MWG (Full Report)	TBD
TBD	TBD	MWG Review of Draft Modeling Report	TBD
TBD	TBD	Incorporate MWG comments to Draft Modeling Report	1 week
TBD	TBD	DOE review of Draft Final Modeling Report	3 weeks
TBD	TBD	Submit Modeling Report to FFA parties	Changes discussed
TBD	TBD	FFA parties review Modeling Report	30 days
TBD	TBD	DOE reviews FFA parties' comments, resubmits Final Report to FFA parties.	30 days
TBD	TBD	FFA parties review and concur on Modeling Report	30 days
12/1/2016	12/1/2016	Quarterly Meeting	Face-to-Face Meeting
3/1/2017	3/1/2017	Quarterly Meeting	Face-to-Face Meeting
6/1/2017	6/1/2017	Quarterly Meeting	Face-to-Face Meeting

4. Meeting Minutes

Kelly Layne will send out the August 16, 2016 meeting minutes and the tear sheets from the August 24, 2016 face-to-face meeting in Paducah.

5. Continuation of August 24th Paducah Meeting Presentation

The remainder of the presentation from the August 24, 2016 face-to-face meeting in Paducah was reviewed and discussed. (August 25, 2016 Face to Face Paducah Meeting PGDP Sitewide GW Model Paducah_Draft_Rev 2.pdf, sent August 25, 2016).

Soil Moisture Data

Denise Tripp presented a figure of soil moisture data. Brian Begley commented that adding sources to the maps is helpful for understanding the data that is presented, and he asked where the data in the figure came from. Ken Davis explained that it is based on a subjective determination of soil moisture content from boring logs. Denise Tripp said that it is only available for a subset of boring logs. Noman Ahsanuzzaman asked what the depth is for the moisture content descriptions. Chad Drummond responded that the depth is 0 to 16 feet below land surface. Noman asked why dry points are adjacent to saturated points in some cases. Al Laase responded that the temporal component of the data complicates the interpretation. Noman said that the temporal component would not be important if the leaks are happening all year, and he asked about the usefulness of the moisture content as a line of evidence for leaks. Denise Tripp clarified that the figure was presented to show the distribution of the logs because MWG had asked about the distribution of data in previous meetings. The figure shows data is sparser in the area of the process buildings, partly due to the size of the buildings.

Outfalls

Questions were asked about how much of the water from the northeast plume treatment goes to Outfall 001. Kelly Layne responded that it formerly went to the lagoon, but not anymore. Rich Bonczek noted that it will go to an eastern outfall in the future, but the model is being calibrated to historical data and needs to match the time period being modeled.

Boring Logs

Two boring logs drilled through the floor of the C400 building were reviewed. The logs provide evidence of the thickness of the gravel backfill beneath the buildings—apparently 8 ft and 12 ft of backfill in the two borings. Noman Ahsanuzzaman commented on 5 ft of clay separating the backfill from the RGA in one of the logs, which could limit recharge. The clay was absent in the other log, demonstrating the variability of the UCRS.

PZ554 was also reviewed. Denise Tripp said that she does not think the boring log is inconsistent with the current model layering. Other MWG members agreed. The model will not be updated with the information from this log during the current effort.

Hydraulic Conductivity

Ken Davis asked about the bullseye in the hydraulic conductivity distribution to the northwest of the plant. The point used the 3,600 ft/d value measured by a pumping test, but the surrounding pilot points had a maximum constraint of 1,500 ft/d. There was a miscommunication previously, and the group agreed that the maximum constraint would be 1,500 ft/d for pilot points within the plant boundary and 3,660 ft/d for pilot points outside the plant boundary. Clarification was given that values determined by pumping tests were used for pilot points at the location of pumping tests. Kelly Layne took the action item to distribute the pumping test reports to the MWG via ftp site.

Creek and River Boundary Conditions

Noman Ahsanuzzaman asked for clarification on the creek boundary conditions. Denise Tripp and Al Laase responded that recharge boundary conditions are used for upstream creek segments and that river boundary conditions are used for downstream creek segments (starting at the seeps for Little Bayou Creek). Al said that the creeks only contact the RGA near the Ohio River. Ken Davis said that Little Bayou Creek is incised 8 ft, but the water is generally 1 to 2 ft deep, and that Bayou Creek is perennial but Little Bayou Creek is intermittent (except it usually has flow because of discharge from outfalls). Noman suggested that the creeks should be modeled as river boundary conditions along their entire lengths. Others noted that the model is configured according to the available data. Denise Tripp said she would provide the 1989 USGS study of the creeks to the group.

Denise presented figures that indicate a 7-day average river stage might not be appropriate for the Ohio River boundary condition, and a longer average (e.g., a 30-day average) should be used instead. The group agreed.

Stress Periods

Denise Tripp asked for agreement on removing stress periods 2 (not a synoptic event), 3 (not a synoptic event), 4 (limited data points), and 5 through 15 (transient pumping test stress periods to be used for validation) from the calibration. Steve Hampson suggested that the April 2011 dataset should also be excluded because it was an unusual year with a high river stage. MWG agreed that these stress periods would be removed from the calibration run. Brian Begley requested that descriptions be added to the table of stress periods so that the rationale for removing certain stress periods would not be lost.

6. Review and Update of Current Action Item List

An updated Action Item List was provided (20160830 Draft Action Item List.pdf).

Action Item #18, development of a strategy for model validation, was included in the Draft (Primary Components) Modeling Report issued to MWG on July 29, 2016 (Section 6.7). In that report, two approaches were suggested: 1) exclude transient 2010 pumping test periods from calibration and use for validation, and 2) use data from alternative gauging events available from quarterly land fill permit monitoring. Two new suggestions were given: (1) use the April 2016 synoptic event as a validation dataset, and (2) use the April 2011 dataset for validation under extreme conditions (possibly illustrating model limitations for non-steady-state conditions). The validation could be added as an appendix to the report and could be finished in January.

Action Item #19, development of revised recharge zonation in the plant area based on continued updates of land use and operational information (Action Item #17). Consideration of reconfiguring recharge in the plant area as discreet recharge zones in place of a dense grid of recharge pilot points. Rough estimates of recharge rates for different zones were presented.

Question was asked about liners in the lagoon and TVA ponds. During the call, an email from Andy Anderson was received, and he confirmed through a personal interview that the C-616 lagoon does not have a liner. (The USGS evaluation showed that a natural amount of clay present at the location was sufficient and no additional “lining” was needed). Martin Clauberg requested documentation. Kelly Layne will follow up to retrieve the “as builts” from Andy. Brian Begley asked if the lagoon had ever been dredged. Kelly and Rich Bonczek replied that to the best of their knowledge it had not been dredged.

Noman Ahsanuzzaman suggested that the maximum recharge constraints under the lagoon and other enhanced recharge zones should still be limited by UCRS lithology. Al Laase said that the vertical hydraulic conductivity is not well known, which results in uncertainty in recharge rates based on lithology. Noman said that hydraulic conductivity will calibrate at the high end of the range without a tighter constraint on the recharge. Al suggested calibrating and then assessing afterward whether the recharge rates are reasonable.

Modeling Working Group
Meeting Minutes-September 16, 2016

1. **Attendees:** Eva Davis, Noman Ahsanuzzaman, Gaye Brewer, Nathan Garner, Dave Dollins, Martin Clauberg, Chad Drummond, Denise Tripp, Steve Hampson, Craig Jones, Ken Davis, Todd Powers, Tracy Taylor

2. **Call for Issues from Modeling Working Group (MWG) Members**

   No issues were raised.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

   The below schedule was presented. The upcoming 9/16/2016 Bi-weekly call and the 9/30/2016 WebEx meeting were discussed. It was mentioned that the 10/25/2016 meeting would be a face-to-face (in-person) meeting and the calibration is scheduled to be complete on 10/31/2016.

ID	Start	End	Duration (days)	Deliverable	Notes
1	4/2/2016	8/16/2016	136	Model calibration	End date contingent on 8/16/16 meeting
2	4/29/2016	4/29/2016	1	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
3	5/13/2016	5/13/2016	1	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
4	5/27/2016	5/27/2016	1	Bi-weekly call (cancelled)	NA
5	6/3/2016	6/3/2016	1	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6	6/10/2016	6/10/2016	1	Biweekly call	
7	6/14/2016	6/14/2016	1	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
8	6/24/2016	6/24/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16
9	7/8/2016	7/8/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
10	7/29/2016	7/29/2016	1	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16
11	7/29/2016	8/24/2016	1	MWG Review of Draft (Primary Components) Modeling Report	Discussed in 8/24/16 meeting in Paducah
12	8/5/2016	8/5/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
13	8/16/2016	8/16/2016	1	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
14	8/19/2016	8/19/2016	1	Bi-weekly Call	Cancelled
15	8/24/2016	8/24/2016	1	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
16	8/24/2016	11/7/2016	75	Incorporate MWG comments to Draft (Primary Components) Modeling Report	Incorporate into Full Report to be issued to the MWG

17	8/31/2016	8/31/2016	1	Meeting with EPA/KY to Discuss Modeling Results	3 hour WebEx
18	9/16/2016	9/16/2016	1	Bi-weekly Call	
19	9/30/2016	9/30/2016	1	Bi-weekly Call	3 hour WebEx
20	10/14/2016	10/14/2016	1	Bi-weekly Call	
21	10/25/2016	10/25/2016	1	Face-to-Face Meeting	Draft final calibration
22	10/31/2016	10/31/2016	1	Calibration Complete	
23	11/7/2016	11/7/2016	1	Submit Draft 2 Modeling Report to MWG for review	Full Report, incorporating response to comments re: Primary Components
24	11/11/2016	11/11/2016	1	Bi-weekly Call	
25	11/7/2016	11/28/2016	21	MWG Review Draft 2 Modeling Report	3 weeks
26	11/28/2016	11/28/2016	1	MWG Comments Provided on Draft 2 Modeling Report	MWG concurs on final model calibration
27	11/28/2016	12/28/2016	30	Prepare Draft 3 Modeling Report	Includes model validation
28	12/13/2016	12/13/2016	1	Quarterly Meeting	Face-to-Face Meeting
29	12/28/2016	12/28/2016	1	Draft 3 Modeling Report Issued to MWG (Full Report)	Incorporating response to comments re: Draft 2 Modeling Report
30	12/28/2016	1/11/2017	14	MWG Review of Draft 3 Modeling Report	2 weeks
31	1/6/2017	1/6/2017	1	Bi-weekly Call	
32	1/11/2017	1/25/2017	14	Incorporate MWG comments to Draft 3 Modeling Report (Prepare D1 Report)	2 weeks
33	1/20/2017	1/20/2017	1	Bi-weekly Call	
34	1/25/2017	2/8/2017	14	DOE review of D1 Modeling Report	2 weeks
35	2/3/2017	2/3/2017	1	Bi-weekly Call	
36	2/8/2017	3/1/2017	21	Finalize D1 Modeling Report	3 weeks
37	2/17/2017	2/17/2017	1	Bi-weekly Call	
38	3/1/2017	3/1/2017	1	Submit D1 Modeling Report to FFA parties	Changes discussed with MWG
39	3/1/2017	3/31/2017	30	FFA parties review D1 Modeling Report	30 days
40	3/3/2017	3/3/2017	1	Bi-weekly Call	
41	3/14/2017	3/14/2017	1	Quarterly Meeting	Face-to-Face Meeting
42	3/31/2017	3/31/2017	1	Bi-weekly Call	
43	3/31/2017	3/31/2017	1	FFA parties respond to D1 Modeling Report to DOE	
44	3/31/2017	5/1/2017	31	DOE response to FFA Parties' comments on the D1 Modeling Report and Prepare D2 Report	Additional day added to have End Date on Monday

45	4/7/2017	4/7/2017	1	FFA parties meet to discuss D2 Report prior to submittal	Conference Call
46	4/18/2017	4/18/2017	1	Quarterly Meeting	Face-to-Face Meeting
47	5/1/2017	5/1/2017	1	DOE submit D2 Modeling Report to FFA Parties	
48	5/1/2017	5/31/2017	30	FFA parties review and concur on Modeling Report	30 days

Note: Durations are in calendar days.

4. Concurrence of Meeting Minutes

Attendees discussed the MWG August 24, 2016 Face-to- Face Meeting Minutes. Attendees from EPA, KDEP, and DOE were asked if they had any comments on the meeting minutes. None were voiced. The MWG August 24, 2016 Meeting Minutes are finalized as distributed to the MWG.

5. Update of Current Action Item List

An updated Action Item List was provided to the MWG (*20160912_Draft Action Item List.pdf*). Ms. Denise Tripp presented the Action Items to the MWG, with a particular focus on the Action Items described below.

Ms. Tripp also briefly described the pdf files that were emailed to MWG members. These files include:

- *20160912_Draft Action Item List.pdf*
- *Draft Summary of Validation Approaches 2016 0912.pdf*
- *Draft Land Use Assessment 0912 2016.pdf*
- *Draft Model Recharge Zonation 2016 0912.pdf*

6. Action Item 4

Ms. Tripp presented to the MWG that Action Item #4, land use evaluation and development of qualitative anthropogenic recharge zones, has been updated to include additional information from the 8/24/2016 site tour with the facilities manager, Andy Anderson. Initial findings indicate zones of increased recharge near the TVA supply line, Outfall 001, 601 Lagoon, cooling towers, and process building roof drains. Agreement was reached on 7/8/2016 that item #4 was complete but would be updated as more information became available. Additional data and information were provided on the 8/24/2016 site tour, with research into details ongoing. Ms. Tripp indicated to the MWG that a summary of current information is provided in *Draft Land Use Assessment 0912 2016.pdf*.

7. Action Item 18

A discussion then ensued regarding the water level data sets to be used for the model calibration. Mr. Steve Hampson indicated that the current list of stress periods provided in *Draft Land Use Assessment 0912 2016.pdf* may be biased toward lower water levels. Ms. Tripp presented that the listed data sets (i.e., stress periods) were picked previously by the MWG because they are the most complete data sets over the time period used for the model calibration. Dr. Noman Ahsanuzzaman suggested that Ms. Tripp review the data, consider including data collected from different time periods during the year (particularly wetter time periods), and make a recommendation to the MWG. Dr. Ahsanuzzaman recommended using data that represents a spread of aquifer conditions. Mr. Steve Hampson opined that 2011 contained an “extreme” flood event and that during 2010 a less extreme flood event occurred. Ms. Tripp agreed to discuss suitable datasets with Mr. Al Laase (not on call) to add more “seasonality” to the overall calibration data set. They will also discuss data available for use during the model validation. Mr. Chad Drummond suggested that Ms. Tripp confer with Mr. Laase and email their recommendation to the MWG to expedite the process given the tight schedule. Mr. Martin Clauberg agreed with emailing the recommendation to the MWG prior to the next teleconference. Regarding data, Dr. Ahsanuzzaman and Ms. Tripp agreed that not all available data will be used for the model calibration.

Mr. Hampson mentioned that he is concerned there is a discrepancy with the elevation datum used for the Pegasus data repository. He and Mr. Ken Davis agreed to evaluate the data to see if a discrepancy exists. However, as voiced by Ms. Tripp, any potential datum discrepancy in Pegasus will not affect the groundwater modeling effort because data from Pegasus was not used to develop, calibrate, or validate the model.

8. Action Item 19

Ms. Tripp indicated that Action Item #19 consists of developing recharge zonation in the plant area based on land use and operational information (Action Item #4). Action Item #19 was added to the 9/16/2016 action item list to include consideration of a simplified recharge reconfiguration in the plant area. The reconfiguration includes discreet recharge zones in place of a dense grid of recharge pilot points (see *Draft Model Recharge Zonation 2016 0912.pdf*).

Ms. Tripp provided a description of each figure in the handout *Draft Land Use Assessment 0912 2016.pdf*. One particular figure of interest to MWG members was Figure 3, which shows four indicated areas of inferred greater recharge. A discussion among members of the MWG ensued regarding the ellipse located east of Building C-400. MWG members agreed that the area has the potential for greater recharge. Dr. Ahsanuzzaman cautioned that plume trajectories will need to be honored to ensure the plume location matches available data.

To assist with assessing recharge east of Building C-400, water level data from a recently emplaced transect of seven RGA monitoring wells at six locations will be evaluated. However, Mr. Todd Powers stated that data will not be available for several months, which will be after the model update is complete. Mr. Clauberg reminded the MWG members that the model is a “living model” and will be updated in the future as needed to incorporate new data. Dr. Eva Davis stated that the transect data will assist with verifying the source of the Northeast (NE) plume.

During a discussion of page 2 in the handout *Draft Model Recharge Zonation 2016 0912.pdf*, Ms. Tripp reminded MWG members that the calibration effort may use pilot points in place of the indicated recharge zones.

9. Additional Action Item

Ms. Tripp will add Action Item #20 which will consist of explaining the rationale for selected stress periods used for model calibration and validation.

Ms. Tripp will also add Action Item #21 to evaluate RGA monitoring well transect data from newly installed wells once the data becomes available.

Modeling Working Group
Meeting Minutes-September 30, 2016

1. **Attendees:** Rich Bonczek, David Dollins , Martin Clauberg, Noman Ahsanuzzaman, Eva Davis, Brian Begley, Gaye Brewer, Nathan Garner, Kelly Layne, Ken Davis, Todd Powers, Tracy Taylor, Bruce Sterns, Chad Drummond, Al Laase, Denise Tripp, Josue Gallegos.

2. **Call for Issues from Modeling Working Group (MWG) Members**

Brian Begley asked for clarification of a discussion initiated by Steve Hampson on the September 16 call regarding an apparent discrepancy between the control point elevations listed in Pegasis and those used in the September 2014 RGA potentiometric surface map. Kelly Layne explained the issue had been resolved and noted an action item to forward an email from Steve Hampson describing the resolution to the MWG. No other issues were raised by the MWG.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

Denise Tripp confirmed commitment to Oct 31, 2016 calibration deadline. Discussion ensued on timing of next face-to-face meeting and the schedule for validation to be complete on 12/28/2016. Rich Bonczek stated that the validation will still be documented as an appendix in the report. Noman Ahsanuzzaman requested that some validation runs be completed for discussion at the next face-to-face meeting. MWG discussed the appropriateness of performing validation in conjunction with calibration. Rich Bonczek raised a concern about not having an agreed upon validation work plan for the team to follow, and he noted that the approach discussed in July was to develop the validation work plan in November after submittal of the second draft modeling report to the MWG. Todd Powers noted that model validation for the C-400 Steam Treatability Test model was performed after the model was calibrated. No consensus was reached by the group on whether the validation approach or validation schedule should be changed. The Oct 25th meeting was confirmed with the location to be determined.

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1	4/2/2016	8/16/2016	136	Model calibration	End date contingent on 8/16/16 meeting
2	4/29/2016	4/29/2016	1	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
3	5/13/2016	5/13/2016	1	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
4	5/27/2016	5/27/2016	1	Bi-weekly call (cancelled)	NA
5	6/3/2016	6/3/2016	1	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6	6/10/2016	6/10/2016	1	Biweekly call	
7	6/14/2016	6/14/2016	1	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
8	6/24/2016	6/24/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16
9	7/8/2016	7/8/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
10	7/29/2016	7/29/2016	1	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16

11	7/29/2016	8/24/2016	1	MWG Review of Draft (Primary Components) Modeling Report	Discussed in 8/24/16 meeting in Paducah
12	8/5/2016	8/5/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
13	8/16/2016	8/16/2016	1	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
14	8/19/2016	8/19/2016	1	Bi-weekly Call	Cancelled
15	8/24/2016	8/24/2016	1	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
16	8/24/2016	11/7/2016	75	Incorporate MWG comments to Draft (Primary Components) Modeling Report	Incorporate into Full Report to be issued to the MWG
17	8/31/2016	8/31/2016	1	Meeting with EPA/KY to Discuss Modeling Results	3 hour WebEx
18	9/16/2016	9/16/2016	1	Bi-weekly Call	
19	9/30/2016	9/30/2016	1	Bi-weekly Call	3 hour WebEx
20	10/14/2016	10/14/2016	1	Bi-weekly Call	
21	10/25/2016	10/25/2016	1	Face-to-Face Meeting	Draft final calibration
22	10/31/2016	10/31/2016	1	Calibration Complete	
23	11/7/2016	11/7/2016	1	Submit Draft 2 Modeling Report to MWG for review	Full Report, incorporating response to comments re: Primary Components
24	11/11/2016	11/11/2016	1	Bi-weekly Call	
25	11/7/2016	11/28/2016	21	MWG Review Draft 2 Modeling Report	3 weeks
26	11/28/2016	11/28/2016	1	MWG Comments Provided on Draft 2 Modeling Report	MWG concurs on final model calibration
27	11/28/2016	12/28/2016	30	Prepare Draft 3 Modeling Report	Includes model validation
28	12/13/2016	12/13/2016	1	Quarterly Meeting	Face-to-Face Meeting
29	12/28/2016	12/28/2016	1	Draft 3 Modeling Report Issued to MWG (Full Report)	Incorporating response to comments re: Draft 2 Modeling Report
30	12/28/2016	1/11/2017	14	MWG Review of Draft 3 Modeling Report	2 weeks
31	1/6/2017	1/6/2017	1	Bi-weekly Call	
32	1/11/2017	1/25/2017	14	Incorporate MWG comments to Draft 3 Modeling Report (Prepare D1 Report)	2 weeks
33	1/20/2017	1/20/2017	1	Bi-weekly Call	
34	1/25/2017	2/8/2017	14	DOE review of D1 Modeling Report	2 weeks
35	2/3/2017	2/3/2017	1	Bi-weekly Call	
36	2/8/2017	3/1/2017	21	Finalize D1 Modeling Report	3 weeks
37	2/17/2017	2/17/2017	1	Bi-weekly Call	
38	3/1/2017	3/1/2017	1	Submit D1 Modeling Report to FFA parties	Changes discussed with MWG

39	3/1/2017	3/31/2017	30	FFA parties review D1 Modeling Report	30 days
40	3/3/2017	3/3/2017	1	Bi-weekly Call	
41	3/14/2017	3/14/2017	1	Quarterly Meeting	Face-to-Face Meeting
42	3/31/2017	3/31/2017	1	Bi-weekly Call	
43	3/31/2017	3/31/2017	1	FFA parties respond to D1 Modeling Report to DOE	
44	3/31/2017	5/1/2017	31	DOE response to FFA Parties' comments on the D1 Modeling Report and Prepare D2 Report	Additional day added to have End Date on Monday
45	4/7/2017	4/7/2017	1	FFA parties meet to discuss D2 Report prior to submittal	Conference Call
46	4/18/2017	4/18/2017	1	Quarterly Meeting	Face-to-Face Meeting
47	5/1/2017	5/1/2017	1	DOE submit D2 Modeling Report to FFA Parties	
48	5/1/2017	5/31/2017	30	FFA parties review and concur on Modeling Report	30 days

Note: Durations are in calendar days.

4. Concurrence of Meeting Minutes

Discussed MWG August 31, 2016 and September 16, 2016 Meeting Minutes sent September 29 2016.EPA has not reviewed meeting minutes. KDEP has reviewed the meeting minutes and had one comment on the September 16 Meeting Minutes regarding a discussion led by Steve Hampson regarding the Pegasis database (resulted in new action item #22 to be discussed during the meeting but since Steve Hampson was not in attendance – the action item was postponed. Kelly Layne will forward email from Steve Hampson where he discussed the use of the data sets).

5. Review and Update of Current Action Item List

An updated Action Item List was provided (20160926_Draft Action Item List.pdf). Action Item #20, development of rationale for selected stress periods used for model calibration and validation, and Acton Item #21, evaluation of RGA monitoring well transect data from newly installed were added to the list during the 9/16 call. In addition, Action Item #22 was added to document the resolution of measure point elevation data discrepancies identified by Steve Hampson on the 9/16 call.

6. Review Action Item 4

Action Item #4, land use evaluation and development of qualitative anthropogenic recharge zones, was summarized in Draft Land Use Assessment 0912 2016.pdf.

Denise Tripp discussed page 3 which identifies areas of potentially increased recharge. Areas take into account the lithology of the UCRS, water level contours, and potential for anthropogenic recharge based on site operations. The identified areas were incorporated in to the recharge zonation of the model. The MWG agreed that this action item is complete.

7. Review Action Item 18

Action Item #18, development of a strategy for model validation, was discussed on the 9/16 call. A new action Item was identified for the evaluation of suitable datasets with for calibration and validation to include more "seasonality" to the overall calibration data set (Action Item #20). Discussion of this Action Item was discussed in conjunction with Action Item #20 (see below).

8. Review Action Item 19

Action Item #19, development of recharge zonation in plant area based on land use and operational information (Action Item #4), was presented on the 9/16 call. Consideration of a simplified recharge reconfiguration in the plant area including discreet recharge zones in place of a dense grid of recharge pilot points was discussed. A two-stress period model with the discreet zones is currently being used to develop estimates of initial values for a subsequent model to include more stress periods.

Denise Tripp reviewed map of recharge zones provided in Draft September 30 2016 WebEx.pdf, specifically pages 12 and 13 which showed areas of higher recharge and approximate zonation, based on calculated geometric mean and lithology. Martin Clauberg requested that in the future, zone numbers be added to the map legend. Brian Begley stated he is comfortable with the interpretations shown. Noman Ahsanuzzaman inquired about the two "blue" areas north and west of Building C-400 and noted that these two areas will be important regarding predicted plume migration. After further discussion, EPA, KDEP, and DOE approved the presented recharge zonation and agreed that Action Item #19 is complete.

9. Review Action Item 20

Action Item #20, develop a list of calibration and validation datasets with rationale, was added on the 9/16 call. The purpose is to evaluate all available datasets for use in calibration or validation to include more "seasonality" to the overall calibration data set. A summary of available data and recommendations for use in the modeling process (Draft Evaluation of Water Level Gauging Events 0922 2016.pdf) was sent to the MWG on 9/27/16.

Denise Tripp reviewed graphs provided in Draft Evaluation of Water Level Gauging Events 0922 2016.pdf, and presented rationale for selecting proposed stress periods for the model. For proposed calibration and validation datasets, only data considered representative of steady-state aquifer conditions was used (except 1995 to ensure inclusion of a non-pumping dataset). On Figure 1, DOE requested that x-axis be corrected by removing the first January label. EPA requested that "gauging event" label be changed to "water level event" in all graphs, and that future graphs indicate which events correspond to calibration or validation data sets. Brian Begley requested that from 2011 forward, "synoptic" should be changed to "sitewide" in table 1.

Significant discussion occurred regarding how many and which data sets to use. Noman Ahsanuzzaman expressed dissatisfaction that so many data sets were omitted from the proposed calibration data sets. Denise Tripp described the criteria used to select the proposed group of data sets from the available data to supporting the calibration and validation process. MWG also discussed how landfill monitoring data is localized data and may not be representative of the entire model domain; based on this, the landfill monitoring data set may not be useful for calibrating. Rich Bonczek stated that the report will need to include maps showing the wells providing data for each calibration stress period so that it is clear how the selected datasets encompass the model domain.

Further discussion by MWG resulted in the decision to further consider the addition of September 24, 2013 and October 20, 2015 data sets as a calibration data set. Rich Bonczek noted that the addition of these data sets for the calibration of the model will be balanced against the information the data set could provide to the calibration, the alternative benefit of having these data sets for validation of the calibrated model, and the project cost/schedule. DOE did not agree to add the data sets to the calibration effort without these further considerations. The list of calibration stress periods that was proposed (Table 1) was not finalized on the call. Denise Tripp will update Table 1 to include the number of data points for each data set; number of data points per data set will be provided to Denise Tripp by Ken Davis. Once Table 1 is updated, the table will be provided to Noman Ahsanuzzaman (EPA) no later than next Wednesday, for his review. Finalization of the proposed calibration stress periods will be discussed on the call next week.

Denise Tripp briefly covered the remainder of the slides in 20160930_PGDP Sitewide GW Model WebEx.pdf and discussed the current calibration results using the two stress period model.

10. Review Action Item 21

Action Item #21, review NS Transect data in context of the calibrated model, will be conducted to evaluate the RGA monitoring well transect data from newly installed wells once the data becomes available. Ken Davis communicated that wells would be sampled in October. Also, it was noted that these data would not be available until December. Therefore, these data cannot be used to calibrate the current model and will need to be considered in some other way in the modeling report.

11. Review Action Item 22

Action Item #22, resolve apparent MPE discrepancy between Pegasis and September 2014 RGA potentiometric data set. Action item was postponed to next meeting.

12. Additional Action Item

Ken Davis will provide Denise Tripp with number of data points for each data set shown in Table 1 from Draft Evaluation of Water Level Gauging Events 0922 2016.pdf. Denise will then update Table 1 and send the table to Noman Ahsanuzzaman (EPA) by next Thursday.

Denise Tripp will send Noman Ahsanuzzaman a copy of the excel spreadsheet used to generate the river stage graphs shown in Draft Evaluation of Water Level Gauging Events 0922 2016.pdf.

Modeling Working Group
Meeting Minutes—October 14, 2016

1. **Attendees:**

   Noman Ahsanuzzaman, Eva Davis, Nathan Garner , Dave Dollins , Martin Clauberg, Brad Montgomery, Ken Davis, Kelly Layne, Todd Powers, Tracy Taylor, Steve Hampson, Chad Drummond, Al Laase, Denise Tripp, Josue Gallegos.

2. **Call for Issues from Modeling Working Group (MWG) Members**

   Kelly Layne asked if EPA had reviewed the past three sets of meeting minutes. Noman indicated that he had not reviewed those meeting minutes and he is using his own set of meeting notes. Ms. Layne will discuss with Julie Corkran EPA's review and concurrence of meeting minutes.

   Kelly brought up briefly that the modeling report is not a Primary Document. The plan is to follow FFA process and submit as a Report.

3. **Remaining Fiscal Year (FY) 2016 Schedule/Work Plan**

ID	Start	End	Duration (days)	Deliverable	Notes
1	4/2/2016	8/16/2016	136	Model calibration	Discussed status at 8/24/16 face-to-face meeting in Paducah
2	4/29/2016	4/29/2016	1	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
3	5/13/2016	5/13/2016	1	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
4	5/27/2016	5/27/2016	1	Bi-weekly call (cancelled)	NA
5	6/3/2016	6/3/2016	1	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6	6/10/2016	6/10/2016	1	Biweekly call	
7	6/14/2016	6/14/2016	1	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville
8	6/24/2016	6/24/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16
9	7/8/2016	7/8/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
10	7/29/2016	7/29/2016	1	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16
11	7/29/2016	8/24/2016	1	MWG Review of Draft (Primary Components) Modeling Report	Discussed in 8/24/16 meeting in Paducah
12	8/5/2016	8/5/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16

13	8/16/2016	8/16/2016	1	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
14	8/19/2016	8/19/2016	1	Bi-weekly Call	Cancelled
15	8/24/2016	8/24/2016	1	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
16	8/24/2016	11/14/2016	82	Incorporate MWG comments to Draft (Primary Components) Modeling Report	Incorporate into Full Report to be issued to the MWG
17	8/31/2016	8/31/2016	1	Meeting with EPA/KY to Discuss Modeling Results	3 hour WebEx
18	9/16/2016	9/16/2016	1	Bi-weekly Call	
19	9/30/2016	9/30/2016	1	Bi-weekly Call	3 hour WebEx
20	10/14/2016	10/14/2016	1	Bi-weekly Call	
21	10/25/2016	10/25/2016	1	Face-to-Face Meeting	Draft final calibration presented at face-to-face meeting in Nashville
22	11/7/2016	11/7/2016	1	Calibration Complete	
24	11/11/2016	11/11/2016	1	Bi-weekly Call	
23	11/14/2016	11/14/2016	1	Submit Draft 2 Modeling Report to MWG for review	Full Report, incorporating response to comments re: Primary Components
25	11/14/2016	12/5/2016	21	MWG Review Draft 2 Modeling Report	3 weeks
26	12/5/2016	12/5/2016	1	MWG Comments Provided on Draft 2 Modeling Report	MWG concurs on final model calibration
27	12/5/2016	12/28/2016	23	Prepare Draft 3 Modeling Report	Includes model validation
28	12/13/2016	12/13/2016	1	Quarterly Meeting	Face-to-Face Meeting
29	12/28/2016	12/28/2016	1	Draft 3 Modeling Report Issued to MWG (Full Report)	Incorporating response to comments re: Draft 2 Modeling Report
30	12/28/2016	1/11/2017	14	MWG Review of Draft 3 Modeling Report	2 weeks
31	1/6/2017	1/6/2017	1	Bi-weekly Call	
32	1/11/2017	1/25/2017	14	Incorporate MWG comments to Draft 3 Modeling Report (Prepare D1 Report)	2 weeks
33	1/20/2017	1/20/2017	1	Bi-weekly Call	
34	1/25/2017	2/8/2017	14	DOE review of D1 Modeling Report	2 weeks
35	2/3/2017	2/3/2017	1	Bi-weekly Call	
36	2/8/2017	3/1/2017	21	Finalize D1 Modeling Report	3 weeks
37	2/17/2017	2/17/2017	1	Bi-weekly Call	
38	3/1/2017	3/1/2017	1	Submit D1 Modeling Report to FFA parties	Changes discussed with MWG
39	3/1/2017	3/31/2017	30	FFA parties review D1 Modeling Report	30 days
40	3/3/2017	3/3/2017	1	Bi-weekly Call	

41	3/14/2017	3/14/2017	1	Quarterly Meeting	Face-to-Face Meeting
42	3/31/2017	3/31/2017	1	Bi-weekly Call	
43	3/31/2017	3/31/2017	1	FFA parties respond to D1 Modeling Report to DOE	
44	3/31/2017	5/1/2017	31	DOE response to FFA Parties' comments on the D1 Modeling Report and Prepare D2 Report	Additional day added to have End Date on Monday
45	4/7/2017	4/7/2017	1	FFA parties meet to discuss D2 Report prior to submittal	Conference Call
46	4/18/2017	4/18/2017	1	Quarterly Meeting	Face-to-Face Meeting
47	5/1/2017	5/1/2017	1	DOE submit D2 Modeling Report to FFA Parties	
48	5/1/2017	5/31/2017	30	FFA parties review and concur on Modeling Report	30 days

4. Concurrence of Meeting Minutes

Brief discussion of MWG September 30, 2016 Meeting Minutes sent October 11, 2016. Martin Clauberg provided suggestions on the meeting minutes. Ms. Layne will review and incorporate as appropriate. Neither EPA nor KDEP have reviewed the MWG September 30, 2016 Meeting Minutes.

5. Discussion of Action Item List

An updated Action Item List was provided (20161010_Draft Action Item List.pdf), including further discussion on the exclusion of September 2013 and October 2015 data sets.

Denise Tripp provided an update on the Action Item List. Denise explained that the September 2013 data set will not be used for calibration since the data is not unique enough to add value to the calibration effort. Denise also explained that the October 2015 data set will not be used for calibration because the data is too sparse.

Noman Ahsanuzzaman asked about the September 21, 2015 dataset, which he believes is suitable for validation. Ms. Tripp said it was excluded because it does not represent steady-state aquifer conditions. Noman countered that just because the Ohio River stage is changing that does not mean the aquifer is unsteady. Ms. Tripp added that the September 2015 dataset is not unique compared to the other fall datasets. Martin Clauberg thanked Noman for his input which has spurred much discussion and caused the MWG to reconsider all of the datasets. Based on this, DOE's modelers have decided that the five proposed datasets are the proper path forward based on technical, budget, and schedule considerations. Dr. Ahsanuzzaman stated his opinion that the calibration datasets are skewed to low river stages. The October 2015 dataset is already included as a validation dataset. The MWG agreed to consider the September 2015 dataset as a validation dataset. Al Laase described how the response times of surface water and groundwater are different and how that complicates the steady-state calibration; therefore, it is best to calibrate to steady state conditions which correspond to lower river stages. The validation can then be used to qualitatively assess strengths and weaknesses of the model under different conditions. An extended discussion ensued regarding the impact of changing river levels on the model calibration. Mr. Clauberg assured the MWG that EPA's concerns have been heard and the calibration needs to move forward. The calibration will be presented at the face-to-face meeting. The MWG agreed to move forward with the five calibration datasets and discuss results at the face-to-face meeting. The MWG will not include the September 2015 dataset as part of the calibration effort.

Action Item 23 has been completed. The MWG agreed that Action Item 23 is complete.

Steve Hampson provided an update on perceived discrepancies regarding measuring point elevations. Mr. Hampson has been getting updated measuring point elevations from various people and has included them in his work. Now that he has a complete set of MPE data the perceived discrepancy has been resolved.

Steve Hampson requested a conference call with Denise Tripp and others later today regarding LiDAR data. Steve will send out preliminary data before the call which is tentatively scheduled for 2:30 pm EST today.

Martin Clauberg requested that a system for tracking miscellaneous action items such as adding zone numbers to the legend on model recharge maps and including meeting minutes as an appendix in the modeling report be considered. Kelly Layne agreed to look into it.

6. Upcoming face to face meeting

Ms. Layne will set this up as a WebEx to facilitate attendance remotely. There have been issues with the hotel but those have been resolved. Ms. Layne provided meeting information in an email dated 12 October 2016 and also summarized meeting logistics to MWG members. Ms. Layne will send out an agenda with specific meeting times.

Paducah Gaseous Diffusion Plant Modeling Working Group (MWG)

Nashville, Tennessee - 25 October 2016

Attendees

In-person: Kelly Layne, Al Laase, Denise Tripp, Rich Bonczek, Martin Clauberg, Chris Young (KDEP), Brian Begley, Ken Davis, Dave Dollins, Nathan Garner, Noman Ahsanuzzaman

Remote: Eva Davis, Chad Drummond, Steve Hampson, Bruce Stearns

Handouts:

Two handouts were provided with the Microsoft Outlook invitation. Filenames are provided below.

- *20161023_ PGDP MWG Meeting Nashville_Oct 25.pdf*
- *Draft Evaluation of Water Level Gauging Events 0922 2016_Rev1.pdf*

Agenda

Modelers are proceeding with modeling tasks. To meet project deadlines, MWG decisions must occur to allow modeling to proceed unimpeded. The meeting agenda consists of the below topics.

- Status of Calibration
- Validation Approach
- Proposed Project Schedule

Objective

Ms. Layne provided the Objective of the meeting. Today we need to resolve questions regarding how the MWG team is moving forward. Therefore, any questions or concerns regarding calibration and validation need to be resolved today.

Presentation

Presentation materials were provided to members of the MWG prior to the meeting (*20161023_ PGDP MWG Meeting Nashville_Oct 25.pdf*). Ms. Tripp went through the presentation materials once without entertaining questions. After the presentation was completed, questions were answered during the discussion period. Highlights of the presentation are listed below.

- Ms. Tripp reminded the MWG that the calibration is not complete, but good progress has been made and simulations have informed the modelers as to how the model responds to changes in parameter inputs.
- Slide 3: Calibration activities were performed including two stress periods – February 1995 and September 2014 as well as a single stress period (September 2014). Calibration simulations are being performed with acceptable simulation run times (which was not the case in the past).
- Slide 4: Run 21 provides a good match to data regarding plume trajectory and head targets.
- Slide 5: Maximum horizontal hydraulic conductivity (K_h) of 1,500 ft/day onsite (see bottom 3 panels). Maximum K_h of 3,660 for entire model domain (top 3 panels).

- Slide 6: Single Stress Period (SP) model (Run 23). Used K_h from two SP model calibration (Run 21). Had good match to heads and trajectory. However, Ohio River flux target exhibiting greater contribution to residual statistics. Ambient recharge was at maximum of range, which may be too high for September data set.
- Slide 7: Ran simulation (Run 29) with K_h =300 ft/day except in locations where pump test data exists. Had good head match (i.e., head residuals generally +/- 0.5 feet) but poor trajectory match (i.e., the flow path from the C400 building did not have the pronounced westward component observed in the Northwest Plume).
- Slide 8: Note more subdued and lower K_h values compared to panels presented in slide 5.
- Slide 9: Presentation of single stress period calibration water level residuals. Results indicate a slight bias toward eastern portion of model. Calibration statistics are appropriate.
- Slide 10: Recharge zonation shown. Zone 16 has thin clay and greater recharge potential, this correlates well with observed water level data.
- Slide 11: Some of the recharge values (ambient is 4.1 in/yr) are at extreme (min/max) values including Zone 8 and Zone 16. Zone 12 calibrated recharge is at the minimum constraint value.
- Slide 12: Trajectory targets have a good match to observed plume data.
- Slide 13: Overall mass balance looks good. Ambient recharge and Ohio River Flux values are most sensitive. Next most sensitive is anthropogenic recharge.
- Slide 14: Discussed proposed calibration approach going forward.
  - Use K_h distribution from single SP run 29 as initial input to multi-stress period model
  - Correlate ambient recharge to plant recharge
  - Exclude river flux target
  - Calibrate with trajectory weight = 1
  - Refine head match with trajectory weight = 0.1
- Slide 15: Discussed evaluation criteria for calibration and validation data sets. Criteria included that Ohio River stage was steady for at least one month prior to observation date of data set. Also desired steady cumulative precipitation prior to data set. Note “1993” on slide should be “1995.”
- Slide 16: Rows shaded grey are events determined to not be steady-state or unique.
- Slide 17: Same chart as 16 with unused events removed. Presents proposed calibration and validation data. Table legend is provided on bottom of slide.
- Slide 18: Ms. Tripp presented a summary of the evaluation criteria for model calibration.
  - Representative of steady state conditions
    – Steady river stage approximately 1 month prior
    – Steady trend in cumulative rainfall
  - Representative of unique period of site operation
  - Representative of the range of annual precipitation
  - Model domain distribution of target locations
- Slide 19: Current multi stress period data sets:
  - February 1995 (day unavailable)
  - 3rd Quarter 2005 (month and day unavailable)
  - October 10, 2011
  - July 17, 2012
  - September 29, 2014

- Slide 20: October 28, 2015 data set not recommended due to limited monitoring locations across the model domain and would likely confound calibration.
- Slide 21: September 24, 2013 data set not recommended because it is similar to September 29, 2014 site conditions. Therefore, the increased runtime and data processing resultant from using this data set are not justified.
- Slide 22: Shows cumulative precipitation for stress periods for use during calibration.
- Slide 23: Validation approach for steady-state simulations was presented as shown on slide.
    - Run calibrated multiple stress period simulation
    - Specify data sets as targets for all stress periods
    - Revise Ohio River and creek stages to 30-day average for all stress periods
    - For each stress period assess gradient between the plant and Ohio River, flow direction (use pathlines), and match between observed and model-predicted heads.
- Slide 24: Validation approach for transient simulations was presented as shown on slide.
- Slide 25: Ms. Tripp presented the proposed project schedule. November 7 is due date for calibration. If meeting objectives are met then it is likely that the MWG will meet that due date.
- Slide 27: Background slide showing pumping test locations.
- Slide 28: Background slide showing max potential recharge based on lithology.
- Slide 29: Background slide presenting map of anthropogenic recharge.

Discussion

Upon completing the presentation, Ms. Tripp entertained questions from other members of the MWG.

- Dr. Clauberg referred members of the MWG to slide 3. He asked if the reason for starting with a single stress period is to use a most representative data set for steady-state simulations to remove “fuzziness.” Ms. Tripp confirmed that is the reason for starting with a single stress period, including that it takes 24 hours to run each simulation and process data. Ms. Layne asked if anyone else had comments on this approach. Al Laase provided a summary of why it takes approximately 24 hours to get a single stress period model to be completed and data processed. Ms. Tripp stated that it takes a couple of hours to process and assess the data.
- Dave Dollins had a question regarding the recharge zonation shown on slide 10, particularly Zone 16 east of Building C-400 and its location between the lobes of the plumes. Ms. Tripp indicated that this location matches with water level contours. Mr. Begley asked if this changes the CSM that there is one source of contamination for both plumes. Mr. Hampson agreed with the location of Zone 16 and that it aligns with locations of water utilities. Mr. Davis provided a summary of the transect of wells between the plumes. Mr. Begley voiced his support for the figure shown on Slide 10. Dr. Ahsanuzzaman mentioned that he will have a question later regarding recharge value used in Zone 16, but that he agrees with the location of Zone 16. Data available later from the newly-installed monitoring well transect will be evaluated once available, but the data will not be available until after the model is updated.
- Mr. Davis asked about the trajectory target locations shown on Slide 4. Mr. Laase presented that there are not trajectory targets located at the northern ends of the plume where the plume location is less certain. Dr. Ahsanuzzaman opined that matching heads is more important than

matching plume trajectories due to the various parameters that can affect plume location. Dr. Bonczek stated that using composite targets (such as plume trajectory) is a good method for calibration from a statistician's point of view compared to using point targets such as water levels with constrained ranges. Dr. Ahsanuzzaman requested that the weight of head targets in the plant area be increased. The group discussed and it was concluded that a uniform weight for head targets across the model domain is more appropriate but that alternate weight would be considered, if necessary for calibration.

- Slide 5: Dr. Ahsanuzzaman requested use of a consistent scale range for the color schemes in the report (**Action Item**). Members of the MWG agreed that a consistent scale is preferable. Dr. Ahsanuzzaman asked about higher K_h values at boundaries of the model domain. Dr. Bonczek mentioned that these areas are outside of the areas of interest. Ms. Tripp stated that effort will be made to minimize areas of high K_h at model boundaries in the final calibrated model.
- Extensive discussion ensued regarding the methodology, assignment, and prediction of recharge across the model domain. **Action Item** is to reassess recharge at various locations and increase the number of recharge zones using professional judgement. Care will be taken to ensure the model is not overly constrained. MWG consensus is that more water needs to be added to the model domain within the plant area.
- Ms. Layne asked if anyone had issues with Slides 1-11. No one voiced any concerns.
- Discussion occurred regarding the impact of Ohio River stage on groundwater levels. Mr. Garner and Mr. Davis discussed the selection of data sets based on changing Ohio River water levels. Mr. Hampson recommended that because the Ohio River control elevation will be increased soon, groundwater levels should be evaluated for the amount of impact the Ohio River has on them during early 2018 (after this modeling effort).
- Slide 16: Mr. Begley asked what comprises a synoptic event. He indicated that synoptic events should be sitewide, not just at the landfill. A discussion ensued on the five selected calibration datasets (see Slide 17). Evaluation criteria are shown on Slide 19. MWG consensus was to consider any dataset not used for calibration for validation.
- Dr. Bonczek stated that the MWG needs to define what the validation is supposed to achieve and what is our evaluation process. He stated that the objectives are to identify the conditions the model needs to meet and to specify how the model will be assessed regarding how it meets those conditions. Restated, the MWG needs to validate the flow model to accurately predict downgradient impacts from source releases. The MWG then discussed the definition of model validation and stated the objective of validation is to evaluate the robustness of the model and demonstrate a satisfactory range of accuracy consistent with the intended application of the model. Four of the more complete datasets were discussed, and it was decided that Mr. Laase and Ms. Tripp will assess the datasets for validation suitability (**Action Item**):
    - April 24, 2011 – High Precip, High River Stage
    - September 24, 2013 – High Precip, Decreasing River Stage
    - September 1, 2015 – High Precip, Decreasing water levels
    - August 23, 2016 – High Precip, Variable River Stages

  Mr. Laase and Ms. Tripp will also assess the suitability of performing a transient analysis and will present results at next meeting (**Action Item**).

- Metrics for validation were discussed including:
    - Do we mimic the plume?
    - How does gradient and water level match?

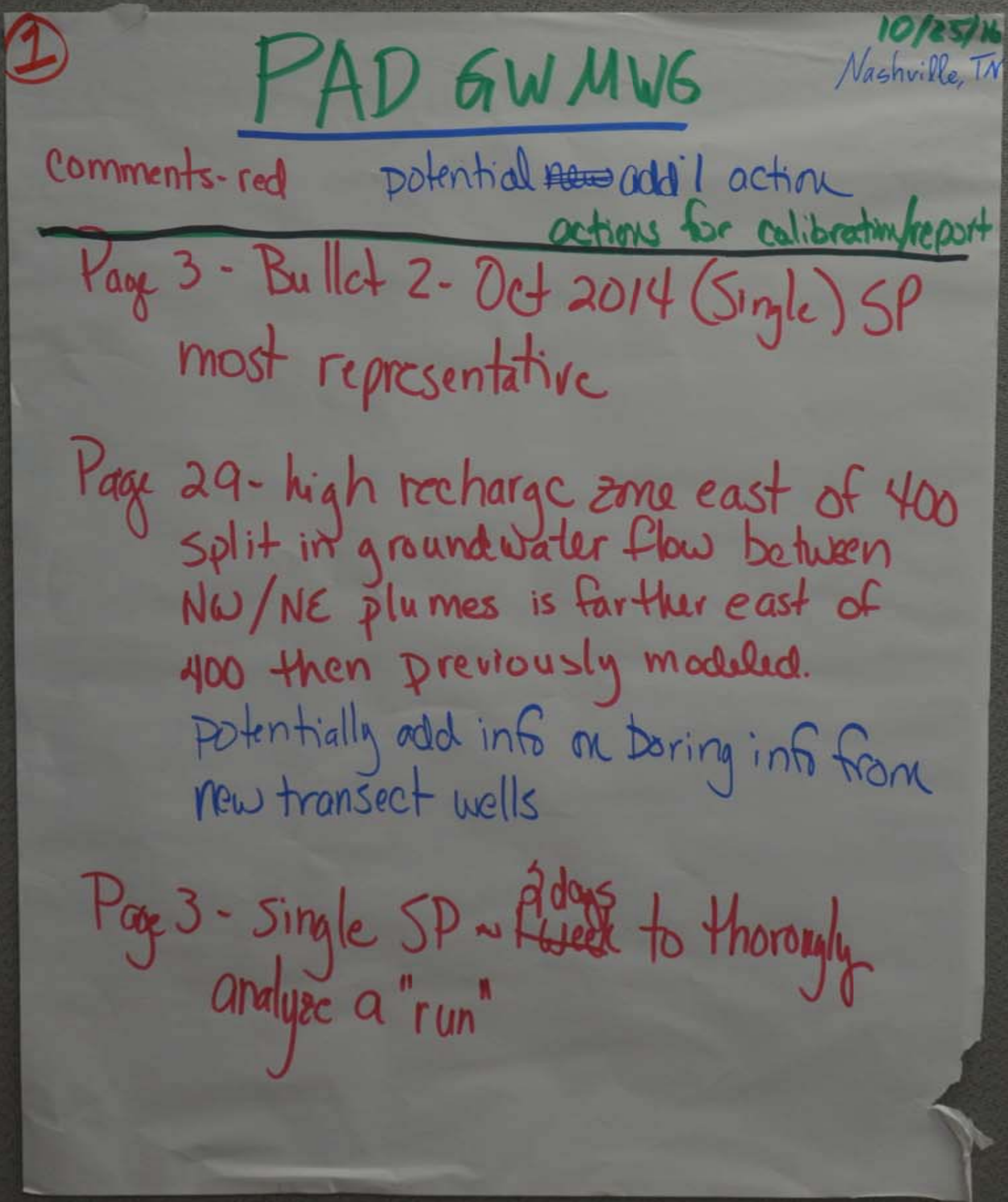
  The MWG agreed that it is appropriate to compare validation model results to calibration metrics and perform a qualitative analysis. If the validation shows the model is not suitable under some circumstances, this will need to be documented in the report.
- Discussion then focused on the upcoming schedule. Dr. Ahsanuzzaman voiced concerns regarding having sufficient time for reviews. Mr. Begley stated that with the collaborative process that has occurred the review should go "easier." Mr. Begley also reminded the MWG that November 11 is a holiday and the call scheduled for that day will need to be rescheduled. Dr. Bonczek mentioned that some members of the MWG will be at DOE meetings in Las Vegas the week of November 14, if the call is scheduled for that week then the call will need to occur early in the morning. A call at 10:00 am eastern on November 21 is tentatively planned.

  Dr. Bonczek mentioned that he does not want to sacrifice report quality due to schedule. As appropriate, the DOE internal team will meet with Ms. Tripp and Ms. Layne to discuss potentially moving the report due date (November 2 or 3).
- A face-to-face meeting is scheduled for December 13 in Paducah, KY. The MWG will consider moving that meeting if necessary at a later time.

Attachments:

- *20161023_ PGDP MWG Meeting Nashville_Oct 25.pdf*
- *Draft Evaluation of Water Level Gauging Events 0922 2016_Rev1.pdf*
- *1025 2016 mtng Tear Sheet Photo.pdf*
- *20170103_Draft Action Item List.pdf*

October 25th, 2016 MWG Meeting in Nashville
Tear Sheets



①

PAD GW MWG

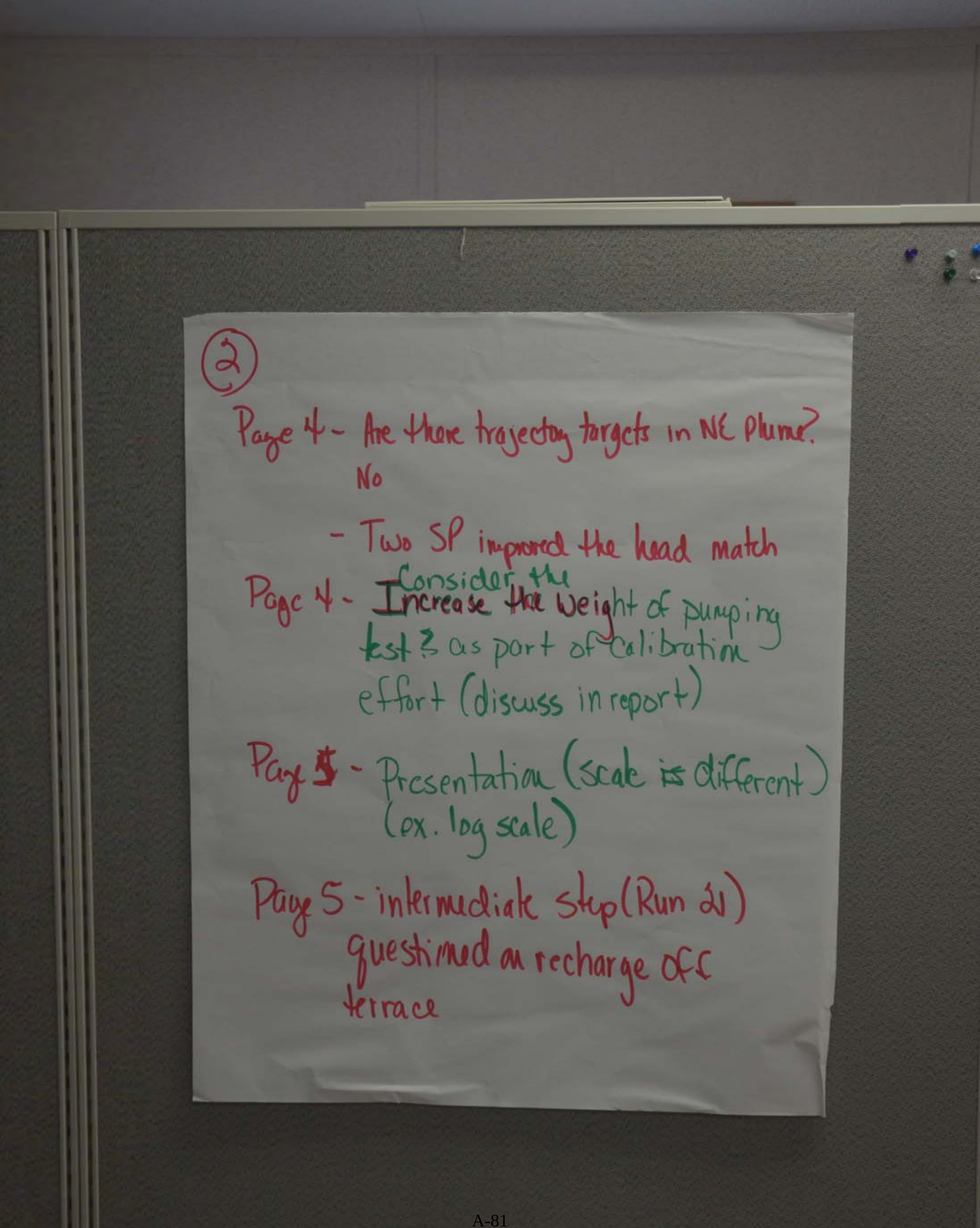
10/25/16
Nashville, TN

comments - red   potential ~~new~~ add'l action
actions for calibration/report

Page 3 - Bullet 2 - Oct 2014 (Single) SP most representative

Page 29 - high recharge zone east of 400 split in groundwater flow between NW/NE plumes is farther east of 400 then previously modeled.
Potentially add info on boring info from new transect wells

Page 3 - Single SP ~ ~~1 week~~ 2 days to thoroughly analyze a "run"



②

Page 4 - Are there trajectory targets in NE Plume?

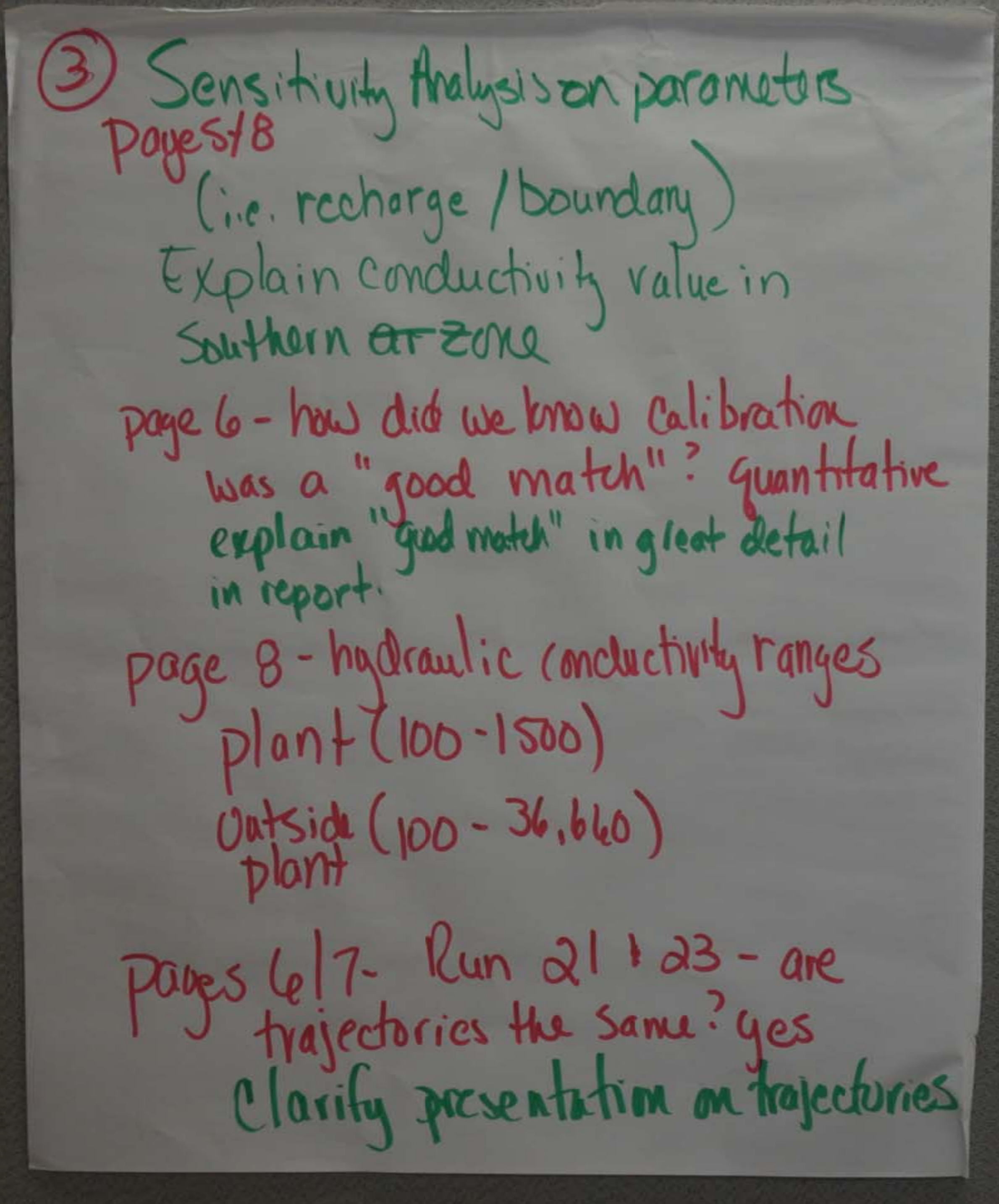
No

- Two SP improved the head match

Page 4 - ~~Increase the~~ Consider the weight of pumping test? as part of calibration effort (discuss in report)

Page 5 - Presentation (scale ~~is~~ different) (ex. log scale)

Page 5 - intermediate step (Run 21) guestimated an recharge off terrace

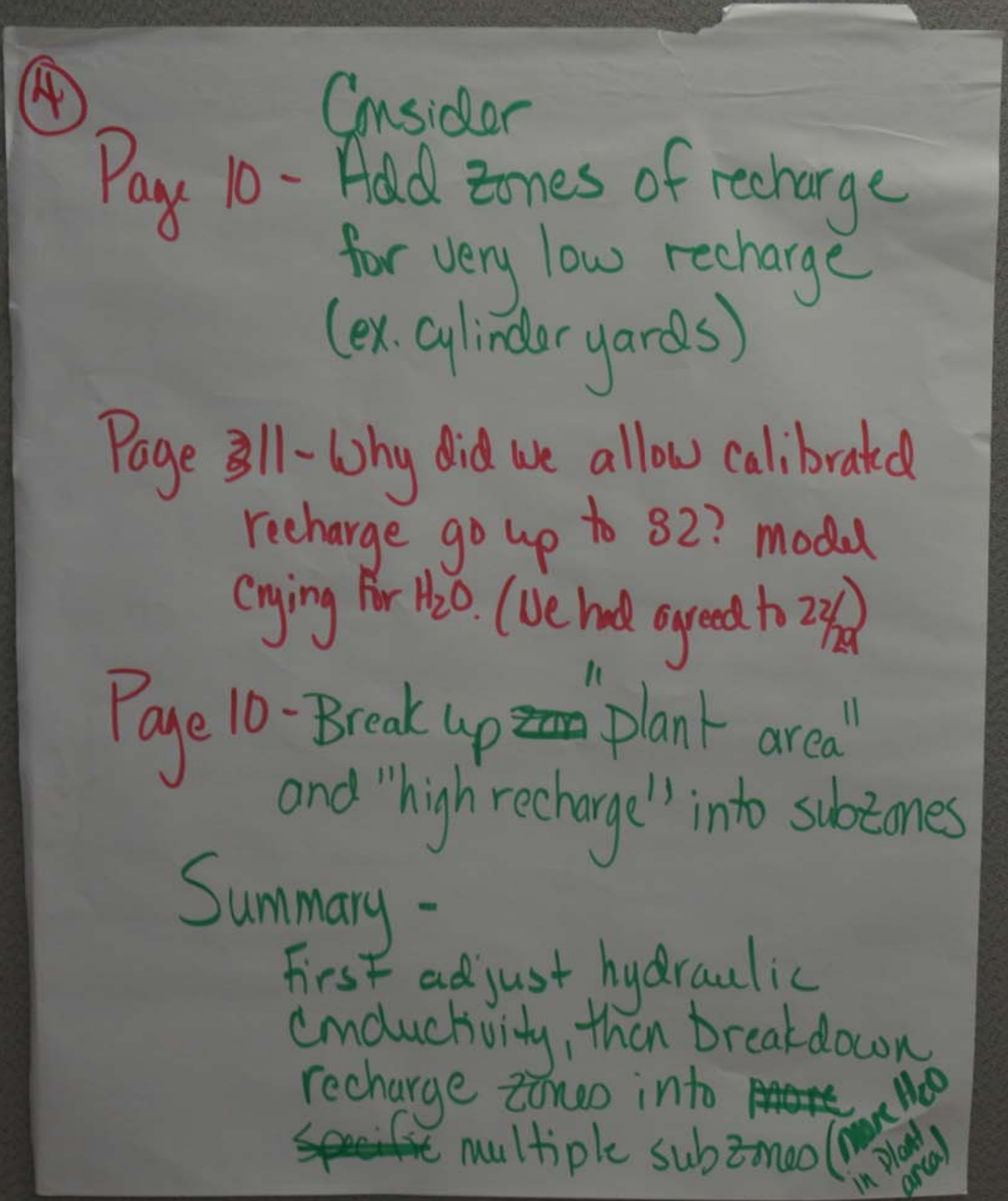


③ Sensitivity Analysis on parameters
Pages 7/8
(i.e. recharge / boundary)
Explain conductivity value in
Southern ~~ar~~ zone

page 6 - how did we know calibration
was a "good match"? quantitative
explain "good match" in great detail
in report.

page 8 - hydraulic conductivity ranges
plant (100-1500)
Outside plant (100 - 36,660)

Pages 6/7 - Run 21 & 23 - are
trajectories the same? yes
Clarify presentation on trajectories



④

Consider

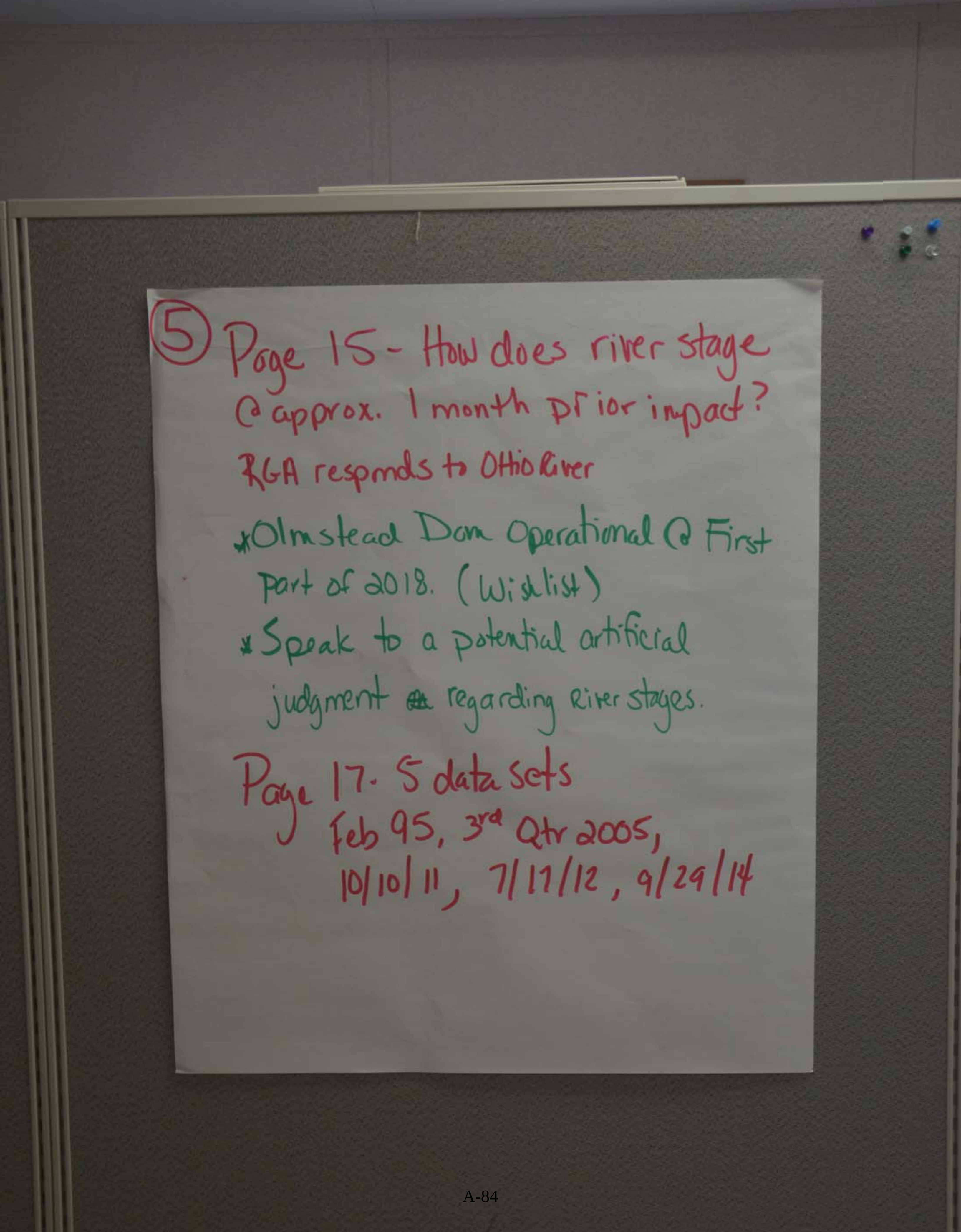
Page 10 - Add zones of recharge for very low recharge (ex. cylinder yards)

Page ~~3~~11 - Why did we allow calibrated recharge go up to 82? model crying for H_2O. (We had agreed to 22/24)

Page 10 - Break up ~~zone~~ "plant area" and "high recharge" into subzones

Summary -

First adjust hydraulic conductivity, then breakdown recharge zones into ~~more~~ ~~specific~~ multiple subzones (more H_2O in plant area)



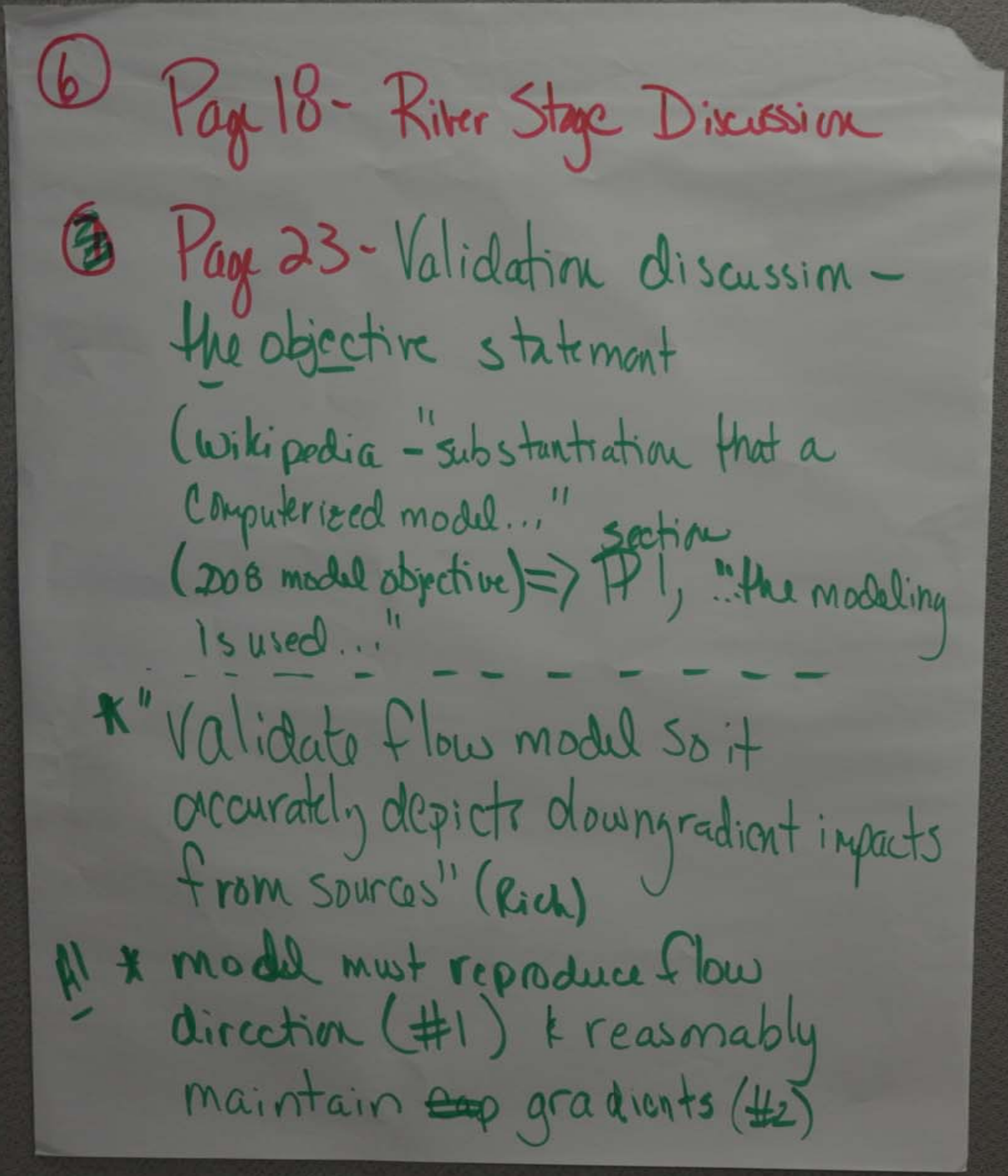
⑤ Page 15 - How does river stage @ approx. 1 month prior impact?

RGA responds to Ohio River

*Olmstead Dam Operational @ First part of 2018. (Wishlist)

*Speak to a potential artificial judgment regarding River stages.

Page 17. 5 data sets
Feb 95, 3rd Qtr 2005,
10/10/11, 7/17/12, 9/29/14



⑥ Page 18 - River Stage Discussion

⑦ Page 23 - Validation discussion - the objective statement

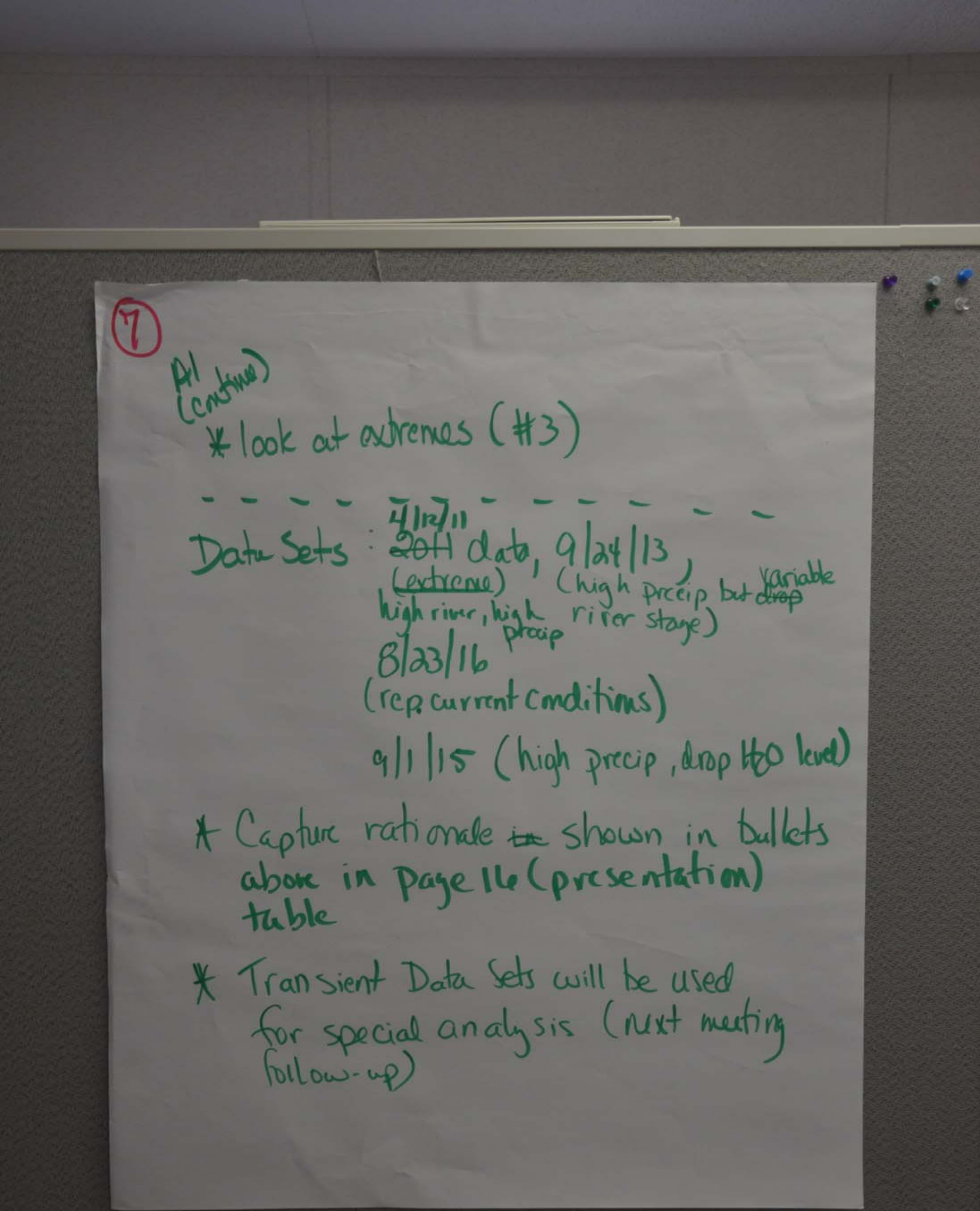
(wikipedia - "substantiation that a Computerized model...,"

(2008 model objective) => section ¶1, "the modeling Is used..."

\- - - - - - - - - - - -

* "Validate flow model so it accurately depicts downgradient impacts from sources" (Rich)

A! * model must reproduce flow direction (#1) & reasonably maintain ~~exp~~ gradients (#2)



⑦

A1
(continue)

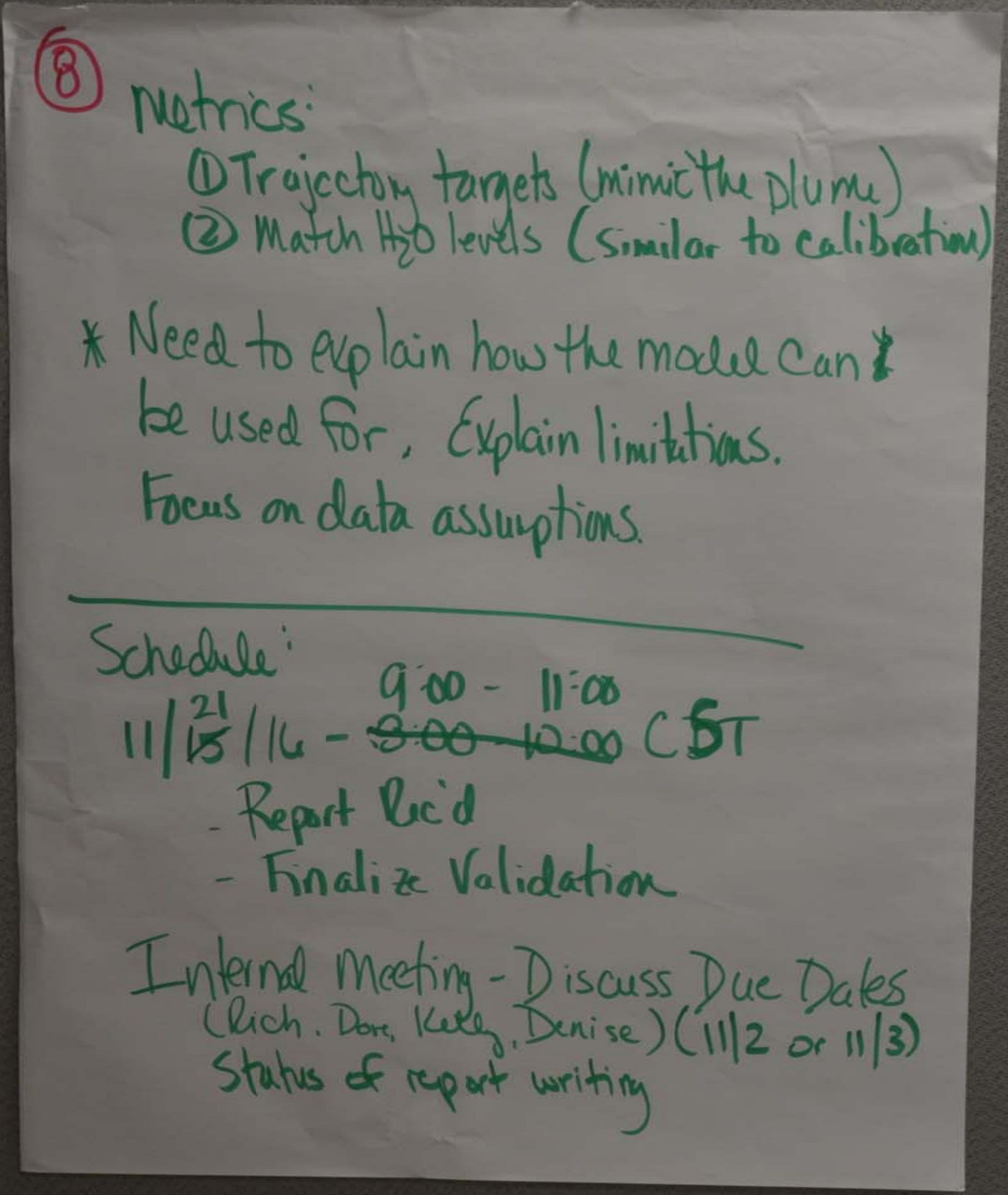
* look at extremes (#3)

\- - - - - - - - - - -

Data Sets: ~~2011~~ 4/12/11 data, 9/24/13,
(extreme) (high precip but ~~drop~~ variable river stage)
high river, high precip
8/23/16
(rep. current conditions)
9/1/15 (high precip, drop H_2O level)

* Capture rationale ~~in~~ shown in bullets above in Page 16 (presentation) table

* Transient Data Sets will be used for special analysis (next meeting follow-up)



⑧ Metrics:

① Trajectory targets (mimic the plume)
② Match H_2O levels (similar to calibration)

* Need to explain how the model can be used for, Explain limitations. Focus on data assumptions.

Schedule:
11/~~15~~ 21/16 - ~~8:00 - 10:00~~ 9:00 - 11:00 CST
- Report Rec'd
- Finalize Validation

Internal Meeting - Discuss Due Dates
(Rich. Dore, Kelly, Denise) (11/2 or 11/3)
Status of report writing

Modeling Working Group
Meeting Minutes-December 13, 2016

1. **Attendees:** Rich Bonczek, David Dollins , Martin Clauberg, Julie Corkran, Noman Ahsanuzzaman, Eva Davis, Brian Begley, Gaye Brewer, Nathan Garner, Kelly Layne, Ken Davis, Bruce Sterns, Chad Drummond, Al Laase, Denise Tripp, Ron Kent.

2. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The MWG agreed that Draft 3 of the modeling report would be submitted to the MWG on December 28, 2016, the MWG would have comments and feedback prepared by January 11, 2017, and the D1 report would be due to DOE from FPDP on January 25, 2017. The next quarterly face-to-face meeting will be held in March 2017   The group will continue to have bi-weekly calls.

3. Discussion of Draft 2 Modeling Report

Comments provided by EPA and KYDEP were discussed during the call. KYDEP provided additional editorial comments after the call. Rich Bonczek emphasized that the model will continue to evolve even after the report is submitted. The intent of the report is to document the status of the model before the contract transition. Julie Corkran noted that the EPA would assume that the version of the model described in the report will be used and would document their outstanding concerns about the model. Kelly Layne asked for clarification regarding when EPA would issue their concerns, and specifically if it would be done as part of the FFA review process. Julie responded that she would need to consider the schedule and other factors before she could answer the question.

The remainder of the minutes is provided in the attached annotated version of comments received from EPA.

EPA R4 comments on DOE's draft "D2" GW Model Update Report for the Paducah GDP

EPA ID KY8890008982, McCracken County, KY

Submitted 12 08 2016 by J Corkran (404-562-8547/corkran.julie@epa.gov)

Comments from Eva Davis, ORD/ADA

1. The Work Group (WG) has discussed calibrating to as many stress periods as possible, however, now DOE is presenting a model that is calibrated to only 2 stress periods, less than originally committed to. Additional calibration is just left to future modeling efforts (see Kelly's email). I really don't know how 'robust' that makes this model.

Notes: It was noted that the model only uses 2 stress periods. Eva Davis asked what the impact is regarding using only 2 stress periods. Noman Ahsanuzzaman asked for an explanation regarding why the model only used 2 versus 5 stress periods.

Denise Tripp said that as modeling progressed it was determined that the two stress period model is robust, with the 2014 stress period representative of the other 3 stress periods. She also noted the need for the 1995 pre-pumping stress period. Including 5 stress periods was taking too long given computing, processing, and result evaluation requirements. Regarding the 2014 dataset being representative of other datasets, Denise stated that the dataset was measured under steady-state conditions and is representative of fall conditions with similar river stage and groundwater levels as other datasets.

Rich explained that five stress periods was too ambitious. He also described that the computational requirements and evaluation of model results are extensive. Rich said datasets not used for calibration (7 in total) should be assessed as part of model validation, unless some of the datasets are "not unique."

Noman stated that the model's strengths and weaknesses need to be documented, including the limitation due to excluding the other three potential calibration datasets. He also noted that the model was calibrated to dry season conditions. Noman asked why the 2014 dataset was used instead of one of the other potential calibration datasets. Denise responded that the 2014 dataset was used as a good representation of a steady-state stress period, and that it was not necessarily better or worse than other potential calibration datasets that could have been used.

2. The modelers were emphatic about wanting to calibrate to steady state conditions, but now it appears that the stress periods they used are not steady state (see Section 3.4). So – how does this affect the calibration? What percentage of the time is the groundwater system assumed to be at steady state versus some transient condition?

Notes: Eva asked if the model stress periods represented steady-state or transient conditions. Denise Tripp responded that the September 2014 dataset is representative of steady-state conditions and the February 1995 stress period is not; nevertheless, the February 1995 stress period needed to be included to incorporate all the direction targets into the model calibration because it is the only available pre-pumping dataset.

Eva asked what percentage of the time the system would be in transient conditions. Denise responded that it would mostly be during the wet season. Eva asked for clarification that the wet season might be three or four months out of the year, and Denise agreed that it would be. Noman requested that the limitations should be outlined in the report to specify that the model was not calibrated to high river stage conditions or wet period conditions.

3. Section 1.1 on Objectives states that one of the objectives of the model is to calculate cleanup criteria in decision documents. I have never seen a model like this used to calculate cleanup criteria. DOE's intent behind this language in the model needs to be clarified.

Notes: Eva, Noman, and Julie Corkran expressed concern about the language "calculating cleanup criteria in decision documents". Rich Bonczek mentioned that in the Risk Methods Document models (first analytical such as SESOIL then numerical models) are described as being part of the suite to support making cleanup decisions. He noted that the models don't stand alone, but are used as an input in the determination of cleanup criteria. Martin Clauberg noted that the language is correct because the text says that the model "can be relied on to ***assist in*** . . . calculating cleanup criteria" (emphasis added). Julie Corkran was still not comfortable with the way it was presented. Julie will review Risk Methods Document to see if she is comfortable with the language. The MWG agreed that the text would be softened—"developing" would be used instead of "calculating".

4. Section 6.7 (last paragraph) states that the NE and NW plumes were constant between 1994 and 2005 and the current plume configuration. The Work Group should remember that if you are always sampling the same wells, and they aren't located appropriately, changes in the plume can go undetected. It is difficult to prove that the plume is stable.

Notes: Eva stated that she believes the new transect data may change the plume maps. She also stated that there may be a connection between C-400 and the NE Plume. Ken Davis also agreed that the plume map will change. Brian Begley indicated that he would like to see a MW installed north of the current transect.

5. The first round of groundwater data (October 2016) from the new NE Plume transect wells is now available. I would like to understand why DOE anticipated that the TCE levels in these wells would be 600 ug/l – as far as I can tell from trying to place these wells on the plume map, it appears that the concentration in these wells is assumed to be between 5 and 100 ug/l. Two of the wells in the middle RGA exceeded 100 ug/l – MW 525 had a TCE concentration of 403 ug/l, and MW 526 had a concentration of 145 ug/l. This new data I believe will make the biggest changes to the plume map that they/we have seen in some time. The concentration in MW 525 opens up the possibility – or likelihood – of some groundwater flow from the C-400 area to the NE (north) plume, although the model now shows a groundwater divide in this area. The modeling Work Group has continuously said that this new NE Plume transect well data will not be incorporated into this model. This to me is ignoring what appears to be critical data in an important portion of the model. Ken Davis commented during one meeting that the NE (south) plume is decreasing, as if the source is depleted, while the NE (north) plume appears to have a continuing source. If this is true, this data

could be showing us that the C-400 area is indeed a continuing source to this plume. It's not clear that the model they have now reproduces that.

Notes: Rich stated that the new data need to be included in this or other modeling effort. He would like an estimate for including these data in the current modeling effort. Al Laase stated that these data were not collected as part of a sitewide synoptic water level event and therefore are not useful as a calibration dataset. Kelly mentioned that the next synoptic event will occur in late August or early September, with data likely available in early 2018. Noman asked about the lithology in the transect wells, and he requested that a discussion of the transect wells including what they tell us should be added to the report. Al suggested that the boring logs regarding the transect wells should be sent to Noman instead of including this information in the modeling report. Noman agreed.

End of ORD Comments

Comments from Noman Ahsanuzzaman, R4 Superfund/SSS

1. Pg-1: Calculation of cleanup criteria are driven by risk assessment, not modeling. Modeling objectives should not include this.

Notes: The MWG agreed that this comment had been adequately addressed during the discussion of ORD/ADA Comment #3 above.

2. Pg-2: Horizontal flow through UCRS could be significant near the creeks, where the groundwater could get discharged. Need to elaborate the discussion on why some section of the creeks are assumed to be recharge zones and the others to be drains. Also, include how discharge from the UCRS could be possible or not.

Notes: Denise stated that conceptual model to date has been consistent since 2008. Closer to river is River Package; closer to plant is recharge boundary condition. The basis for these boundary conditions will be added to the report text. Responding to Noman's question, Denise confirmed that drain boundary conditions are not included in the model.

3. Pg-10: Based on the minimum clay/silt of 30-35% in the entire model domain, the maximum recharge allowed within the site is 29 in/yr. Figure 3.8 (text has wrong reference to Figure 3.7) shows only a few green dots representing clay/sit between 40-50% range. That means the maximum recharge should not be more than 22 in/yr. In fact, 22 in/yr is the number the MWG agreed to use. Figure 3.8 does not justify using any higher maximum recharge rate.

Notes: Noman asked why recharge was allowed to be increased to greater than 22 in/yr. Denise stated that the calibration process started using the recharge values estimated with the geometric mean UCRS vertical hydraulic conductivity as a constraint, but the model as configured required higher recharge values. So the recharge constraints were increased using the constraints calculated with the median UCRS hydraulic conductivity. The MWG agreed that text will be added describing that recharge could be lower if the model hydraulic conductivity is lower and that model calibrations are non-unique.

4. Pg-11: Ratio of the horizontal to vertical hydraulic conductivity does not show a value of 10, as explained in the text. Closer comparison between the data presented in Table 3.4 and 3.6 shows the

ratio to be 14 and 20 when the arithmetic and geometric means were compared, respectively. Does the ratio match with that found from the treatability study for steam injection?

Notes: Denise stated that this discussion is provided in the text to support the assumption of 10:1 vertical anisotropy that was used to calculate maximum recharge in the UCRS. She emphasized that it was an order of magnitude estimate, a commonly used approach used to estimate vertical hydraulic conductivity from horizontal conductivity measurements. She also noted that a 10:1 vertical anisotropy was used for the UCRS in the treatability study for steam injection. The MWG agreed the statement in the text will be softened.

5. Pg-11: Figure 3.11 should be updated by incorporating the recent transect well data. Since the transect wells are located within the high recharge zone (Zone 24) with less than 2ft clay thickness, it is highly critical to include this data in the analysis.

Notes: The MWG agreed that this comment had been adequately addressed during the discussion of ORD/ADA Comment #5 above.

6. Pg-15: Although the McNairy formation has 2 to 3 order of lower hydraulic conductivity, it would still be a significant formation for DNAPL source accumulation and plume migration within the McNairy formation. Exclusion of this potential source zone is a major limitation for simulation of solute transport.

Notes: The MWG agreed that exclusion of the McNairy formation would be described in the Limitations section of the report.

7. Pg-16: Need to elaborate discussion of the following statement, "A comprehensive analysis of RGA water level data, UCRS lithology and moisture content, and land use (see Section 3.3) indicates areas of increased recharge and a groundwater divide in the Plant Area are associated with roof drains, surface water discharges, and leaks in the TVA supply line (see Figure 3.8)." Is the reference to Figure 3.8 correct?

Notes: The MWG agreed to add clarification about how anthropogenic recharge is the reason for the divide. The text will refer the reader to Section 3.3.2. The figure reference will be corrected.

Brian Begley asked where the groundwater divide would be drawn and how it is affected by the leak in the TVA line and surface water discharges. Denise responded that the text would be corrected to reflect that the TVA supply line and surface water discharge are not in the area of the groundwater divide. Brian asked for clarification on the operational time of the sumps. Denise said that the text would be revised to elaborate on the sump operation.

8. Pg-19: How does the extraordinarily high K value (50,000 ft/d) of the Metropolis lake impact the model. Such a high value may result in driving the groundwater in the direction of the lake.

Notes: Noman expressed concern that the high K value in Metropolis Lake might have too much effect on the particle flow path directions. Al noted that it is common to model lakes as high conductivity features and that there is uncertainty regarding the correct water level to use. Steve Hampson said that TVA data indicate that lake levels range from 314 to 317 ft. Rich requested that, if possible, lake water elevations should be measured during the next synoptic water event. Al said to also consider obtaining bottom sediment conductance measurements.

9. Pg-21: Is specific yield of 0.01 justified?

Notes: The reported 0.01 is not used in the model because the model is steady state. This value will be updated in the transient simulation. The text will be updated.

10. Pg-23: What is the reason for leaving the three water level datasets from calibration? MWG agreed to use at least five stress periods for model calibration.

Notes: The MWG agreed that this comment had been adequately addressed during the discussion of ORD/ADA Comment #1 above.

11. Pg-26: Why is the calibrated recharge rate for Zone 24 (i.e., 45 in/yr) greater than 22 in/yr? Recharge rate should be limited to the soil type, not to the potential volume of source water.

Notes: Denise noted that this comment was partially addressed in response to Noman's Comment #3 above. Additional discussion will be included in the report.

12. Pg-26: It does not look like the recharge zone for the storm drain (Zone 16) followed the footprint of the HU3 clay unit (see Figure 5.5 and Table 6.2).

Notes: Noman believes the drains in Zone 16 do not match with thicker clay. Denise stated the areas of thin clay are configured in the model separately from the potential recharge associated with the leaks in the storm drain piping as had been agreed on by the MWG in the September 25, 2016 MWG Meeting. Ken Davis clarified that the dense storm drain network north of the process buildings is because of a transformer yard. More detail regarding the layout of storm drains will be included in the report.

13. Figure 6.4: Range of color distribution should be limited to 1500 ft/d within the site and to 3600 ft/d outside.

Notes: The figure color scheme will be modified if appropriate to improve ability to discern spatial variability.

14. Figure 6.5: Why is the transmissivity so drastically different? Is it resulted from the trajectory targets used along the plume to create a highly conductive channel along that path? Why is the transmissivity so high on the east of the NE plume and near the tips of the two plumes?

Notes: Discussion of how the transmissivity contrast is a result of the model calibration and how the model needed to match the plume trajectory. Clarifying language will be added to the report.

15. Figures 6.7 and 6.8: Need to improve the residual values within the property boundary.

Notes: Clarifying language will be added to the report explaining why the calibration is sufficient.

16. Figure 6.11: Particle tracking during Stress Period 2 show some deviation from the plume trajectory. Need explanation?

Notes: The extraction wells were operation during Stress Period 2, and that is why the particle tracks are different. Explanation will be added regarding particle capture by the NE extractions wells.

17. Modeling assumptions should be outlined in detail.

Notes: As discussed during previous comments, additional discussion of modeling assumptions and limitations will be added to the report.

18. No mention of the UCRS considered as recharge zone as a model limitation or assumption.

Notes: As discussed during previous comments, additional discussion of modeling assumptions and limitations will be added to the report.

End of R4 SFD/SSS Comments

Overarching Notes: Next quarterly meeting will be in March 2017. Kelly will send out proposed dates. Report is due December 28 (D3). MWG will have two weeks for review (January 11, 2017). The Draft D1 (D0) report is due to DOE from FPDP on January 25, 2017. KDEP will provide editorial comments after call.

Rich Bonczek noted the intent of the report is to document the status of the model before the contract transition. Julie Corkran noted that the EPA would document outstanding concerns about the model on a to-be-determined schedule (See item #3 above)..

Modeling Working Group
Meeting Minutes - January 6, 2017

1. **Attendees:** Rich Bonczek, Martin Clauberg, Julie Corkran, Noman Ahsanuzzaman, Eva Davis, Chris Jung, Gaye Brewer, Nathan Garner, Kelly Layne, Ken Davis, Tracy Taylor, Bruce Sterns, Steve Hampson, Chad Drummond, Al Laase, Denise Tripp, Ron Kent, Dave Dollins

2. Call for Issues from Modeling Working Group (MWG) Members

Julie Corkran requested clarification on the schedule and the anticipated version nomenclature. Kelly Layne replied that previous versions of the document had been submitted as a report and not as part of a primary or secondary document. Rich Bonczek responded that the typical nomenclature is D(-1) Rev 3 for the current draft under review, which is typically not provided for regulatory input, D0 for the version to be submitted by Fluor to DOE, D1 for the first draft submitted by DOE to FFA parties, and D2 for the second draft submitted by DOE to FFA parties. The scheduled submittal dates are January 25 for D0, March 1 for D1, and May 1 for D2.

Julie clarified that EPA will not “approve” the document because it is not part of a primary or secondary document. Rich noted that the model is not final and will continue to be updated. Julie asked what the first project would be that the new model would be used on. Rich replied that an assessment of the Northeast extraction wells will likely be performed using the new model with a goal of achieving 95% capture. Julie noted that the model might be used before the modeling report review is complete and that EPA would like to have their outstanding concerns formally documented before the model is used.

3. Remaining Fiscal Year (FY) 2016 Schedule/Work Plan

The schedule below was reviewed. The schedule for submittal of draft reports was discussed as part of the call for issues. The March 14, 2017 face-to-face meeting was rescheduled for March 21, 2017, and it will potentially be held in Nashville. The purpose of the meeting will be to discuss comments on the D1 report and to solicit input regarding future model updates. Chris Young will check with Brian Begley if he will be available on that date. The next biweekly call is scheduled for January 20, 2017.

ID	Start	End	Duration (days)	Deliverable	Notes
1	4/2/2016	8/16/2016	136	Model calibration	End date contingent on 8/16/16 meeting
2	4/29/2016	4/29/2016	1	Bi-weekly call	Agenda and Info Packet Sent 4/26/16
3	5/13/2016	5/13/2016	1	Bi-weekly call	Agenda and Info Packet Sent 5/11/16
4	5/27/2016	5/27/2016	1	Bi-weekly call (cancelled)	NA
5	6/3/2016	6/3/2016	1	Interim Bi-weekly call	Agenda and Info Packet Sent 5/31/16
6	6/10/2016	6/10/2016	1	Biweekly call	
7	6/14/2016	6/14/2016	1	Meeting with EPA/KY to Discuss Preliminary Modeling Results	Face to Face Meeting – Nashville – Invite Sent
8	6/24/2016	6/24/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 6/22/16

9	7/8/2016	7/8/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
10	7/29/2016	7/29/2016	1	Draft (Primary Components) Modeling Report Issued to MWG	Report sent 7/29/16
11	7/29/2016	8/24/2016	1	MWG Review of Draft (Primary Components) Modeling Report	Discussed in 8/24/16 meeting in Paducah
12	8/5/2016	8/5/2016	1	Bi-weekly Call	Agenda and Info Packet Sent 7/6/16
13	8/16/2016	8/16/2016	1	Meeting with EPA/KY to Discuss Modeling Results	2 hour WebEx
14	8/19/2016	8/19/2016	1	Bi-weekly Call	Cancelled
15	8/24/2016	8/24/2016	1	Meeting with EPA/KY to Discuss Modeling Results	Face-to-face in Paducah
16	8/24/2016	11/28/2016	96	Incorporate MWG comments to Draft (Primary Components) Modeling Report	Incorporate into Full Report to be issued to the MWG
17	8/31/2016	8/31/2016	1	Meeting with EPA/KY to Discuss Modeling Results	3 hour WebEx
18	9/16/2016	9/16/2016	1	Bi-weekly Call	
19	9/30/2016	9/30/2016	1	Bi-weekly Call	3 hour WebEx
20	10/14/2016	10/14/2016	1	Bi-weekly Call	
21	10/25/2016	10/25/2016	1	Face-to-Face Meeting	Draft final calibration
22	11/7/2016	11/7/2016	1	Calibration Complete	
24	11/11/2016	11/11/2016	1	Bi-weekly Call	Rescheduled to 11/10 then cancelled
23	11/28/2016	11/28/2016	1	Submit Draft 2 Modeling Report to MWG for review	Full Report, incorporating response to comments re: Primary Components
25	11/28/2016	12/7/2016	9	MWG Review Draft 2 Modeling Report	1 week, 2 days
26	12/7/2016	12/7/2016	1	MWG Comments Provided on Draft 2 Modeling Report	MWG concurs on final model calibration
27	12/7/2016	12/28/2016	21	Prepare Draft 3 Modeling Report	Includes model validation
28	12/13/2016	12/13/2016	1	Quarterly Meeting	Face-to-Face Meeting
29	12/28/2016	12/28/2016	1	Draft 3 Modeling Report Issued to MWG (Full Report)	Incorporating response to comments re: Draft 2 Modeling Report
30	12/28/2016	1/11/2017	14	MWG Review of Draft 3 Modeling Report	2 weeks
31	1/6/2017	1/6/2017	1	Bi-weekly Call	

32	1/11/2017	1/25/2017	14	Incorporate MWG comments to Draft 3 Modeling Report (Prepare D1 Report)	2 weeks
33	1/20/2017	1/20/2017	1	Bi-weekly Call	
34	1/25/2017	2/8/2017	14	DOE review of D1 Modeling Report	2 weeks
35	2/3/2017	2/3/2017	1	Bi-weekly Call	
36	2/8/2017	3/1/2017	21	Finalize D1 Modeling Report	3 weeks
37	2/17/2017	2/17/2017	1	Bi-weekly Call	
38	3/1/2017	3/1/2017	1	Submit D1 Modeling Report to FFA parties	Changes discussed with MWG
39	3/1/2017	3/31/2017	30	FFA parties review D1 Modeling Report	30 days
40	3/3/2017	3/3/2017	1	Bi-weekly Call	
41	3/14/2017	3/14/2017	1	Quarterly Meeting	Face-to-Face Meeting
42	3/31/2017	3/31/2017	1	Bi-weekly Call	
43	3/31/2017	3/31/2017	1	FFA parties respond to D1 Modeling Report to DOE	
44	3/31/2017	5/1/2017	31	DOE response to FFA Parties' comments on the D1 Modeling Report and Prepare D2 Report	Additional day added to have End Date on Monday
45	4/7/2017	4/7/2017	1	FFA parties meet to discuss D2 Report prior to submittal	Conference Call
46	4/18/2017	4/18/2017	1	Quarterly Meeting	Face-to-Face Meeting
47	5/1/2017	5/1/2017	1	DOE submit D2 Modeling Report to FFA Parties	
48	5/1/2017	5/31/2017	30	FFA parties review and concur on Modeling Report	30 days

Notes:
Durations are in calendar days.

4. Draft Modeling Report Discussion

Kelly Layne asked if everyone had received the complete draft report that Denise Tripp had sent to the MWG as attachments to a chain of twelve emails on December 28, 2016. Nobody on the call voiced that they do not have all the files.

Kelly asked for questions or comments on the report. Ken Davis asked a question regarding Table 6.1: Calibrated Hydraulic Conductivity Statistics. He asked for a distinction between the "Model Domain" and "All Hydraulic Conductivity Pilot Points" portions of the table. Denise Tripp clarified that the "All Hydraulic Conductivity Pilot Points" section of the table only refers to the values at pilot points, but the "Model Domain" section of the table includes statistics for all computational cells.

Martin Clauberg asked if comments and responses will be documented in Adobe PDF instead of Word in the future. Kelly replied that the report would be submitted in the standard PDF format when it is transmitted by Fluor for DOE review.

Noman Ahsanuzzaman asked if all water level targets are shown in Figure 6.9 of the report. He noted that more monitoring well locations seem to be shown on other figures. Denise Tripp responded that all wells that were used as targets are shown on the figure. Denise clarified that the figure divides the well set between the top, middle, and bottom model rows. She noted that fewer targets were available for stress period 1 and referenced Figure 6.10 to demonstrate that more targets were available for stress period 2.

5. Meeting Minutes

Kelly Layne commented that two outstanding sets of meeting minutes (October 25, 2016 and December 13, 2016) will be sent out to the MWG.

APPENDIX B

PRESENTATION OF 2012 UPDATE TO THE 2008 MODEL

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PGDP Modeling Group Meeting

29 and 30 January 2014\

Lexington, Kentucky

Outline

- PGDP model recalibration summary
- Evaluations performed using the recalibrated PGDP model
- Future flow model updates
- Transport modeling
- Modeling innovations

PGDP Model Recalibration Summary

Recalibration

- Calibrated 3 model variants
  - NW Plume centroid migrated eastward with time, KCREE lithologic pilot point constraints
  - NW Plume centroid remained constant, KCREE lithologic pilot point constraints
  - NW Plume centroid remained constant, didn’t use KCREE lithologic pilot point constraints
- Model consists of 7 steady-state stress periods and 10 transient stress periods

Recalibration

- Steady-State
  - February 1995
  - 3rd Quarter 2005
  - 1st Quarter 2007
  - April 2010
  - October 11, 2010
  - April 2011
  - October 2011
- Transient
  - October 12 – 21, 2011
- Ohio River stage ranged from 292.5 to 327.2 ft msl

Recalibration

- Outcome
  - Hydraulic conductivity field that is ”best” for the 7 steady-state and 10 transient stress periods
  - 7 unique recharge regimes corresponding to the 7 steady-state stress periods
  - The 10 transient stress periods use the same recharge distribution as stress period 5

Recalibration

- Each calibration was accomplished using 11 i7 processors running in parallel

  ~ 10 times decrease in run times

- Used PEST-SVD for additional speed

  ~ 10 times decrease in run time

- Calibration accomplished in approximately 5 days

  - Using a single processor and regular PEST calibration would have taken approximately 500 days

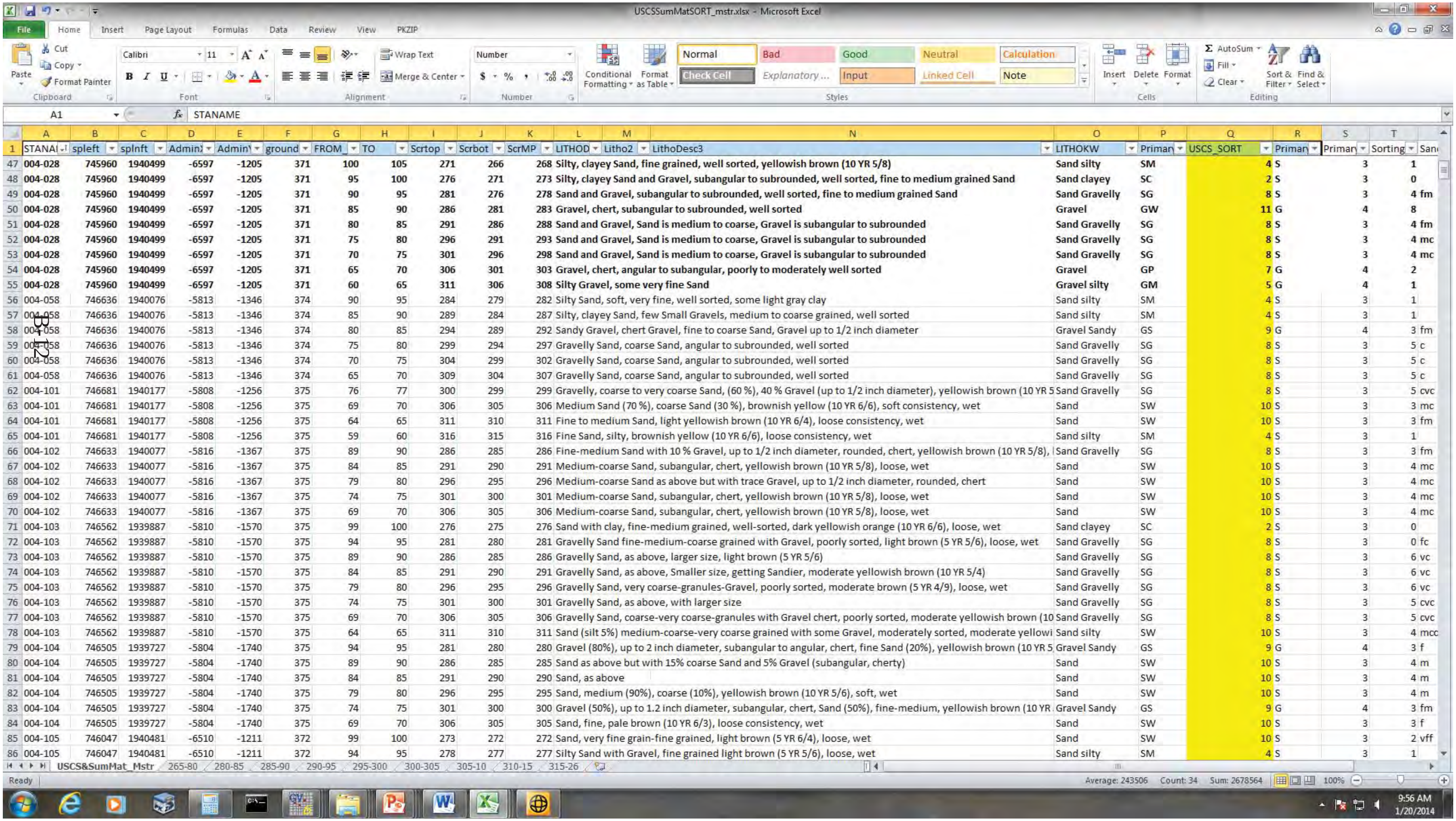
Stress Period Setup

Collection Period	Stress Period Number	Stress Period Type	Stress Period Length, days	Cumulative Time, days	Number of Targets	Target Type	Ohio River Stage, ft msl
February 1995	1	Steady-State	1	1	76	Head, Trajectory, Flux	297.4
3rd Quarter 2005	2	Steady-State	1	2	110	Head, Trajectory, Flux	301.3
1st Quarter 2007	3	Steady-State	1	3	110	Head, Trajectory, Flux	313.0
April 2010	4	Steady-State	1	4	38	Head, Trajectory, Flux	327.2
October 11, 2010	5	Steady-State	1	5	13	Head, Trajectory, Flux	294.8
October 12, 2010	6	Transient	1	6	13	Drawdown, Flux	295.5
October 13, 2010	7	Transient	1	7	13	Drawdown, Flux	295.5
October 14, 2010	8	Transient	1	8	13	Drawdown, Flux	294.9
October 15, 2010	9	Transient	1	9	13	Drawdown, Flux	294.5
October 16, 2010	10	Transient	1	10	13	Drawdown, Flux	294.3
October 17, 2010	11	Transient	1	11	13	Drawdown, Flux	293.8
October 18, 2010	12	Transient	1	12	13	Drawdown, Flux	293.5
October 19, 2010	13	Transient	1	13	13	Drawdown, Flux	293.1
October 20, 2010	14	Transient	1	14	13	Drawdown, Flux	292.8
October 21, 2010	15	Transient	1	15	13	Drawdown, Flux	292.7
April 2011	16	Steady-State	1	16	212	Head, Trajectory, Flux	320.6
October 2011	17	Steady-State	1	17	202	Head, Trajectory, Flux	292.5

Calibrated Parameters

- Recharge
  - 273 zones, 266 represent anthropogenic recharge and change values (calibrated) every steady-state stress period
- Hydraulic Conductivity
  - 1,394 pilot points representing calibrated hydraulic conductivities at specific locations within the RGA
  - For V1 and V2 models, majority of pilot point values are constrained based on KCREE’s lithologic evaluation
  - For V3 assumed pilot points could range between 10 and 5,000 ft/d

Lithological Evaluation



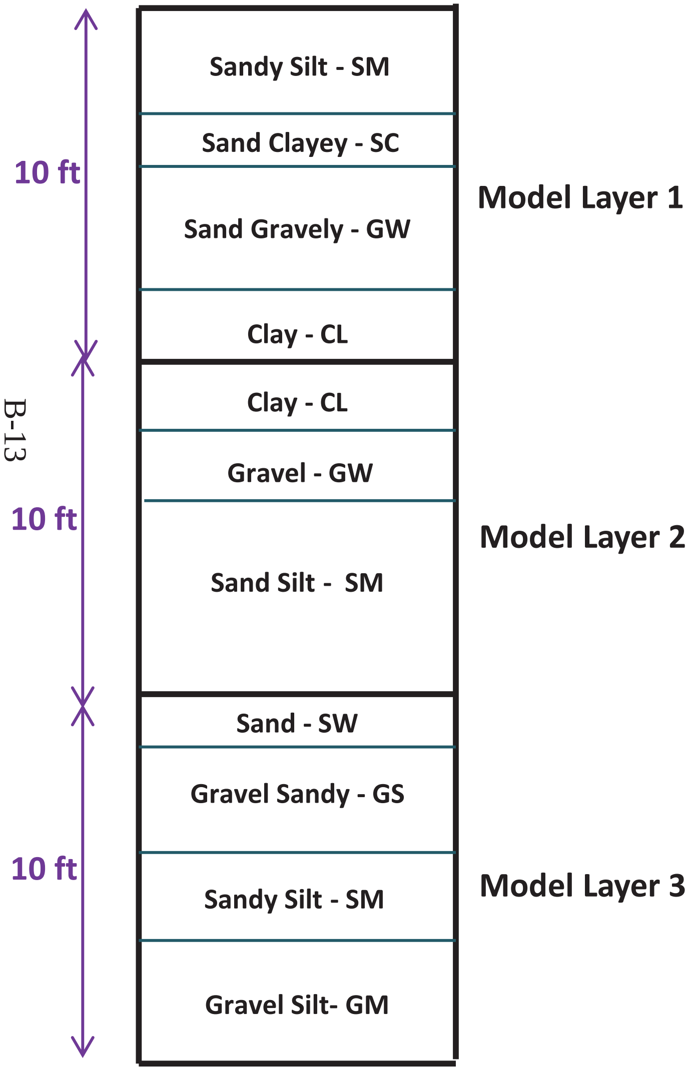
A1 STANAME

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	STANAI	spleft	splnft	AdminX	AdminY	ground	FROM_	TO	Scrtop	Scrbot	ScrMP	LITHOD	Litho2	LithoDesc3	LITHOKW	Priman	USCS_SORT	Priman	Priman	Sorting	San
47	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**100**	**105**	**271**	**266**	**268**	**Silty, clayey Sand, fine grained, well sorted, yellowish brown (10 YR 5/8)**			**Sand silty**	**SM**	**4**	**S**	**3**	**1**	
48	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**95**	**100**	**276**	**271**	**273**	**Silty, clayey Sand and Gravel, subangular to subrounded, well sorted, fine to medium grained Sand**			**Sand clayey**	**SC**	**2**	**S**	**3**	**0**	
49	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**90**	**95**	**281**	**276**	**278**	**Sand and Gravel, subangular to subrounded, well sorted, fine to medium grained Sand**			**Sand Gravelly**	**SG**	**8**	**S**	**3**	**4**	**fm**
50	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**85**	**90**	**286**	**281**	**283**	**Gravel, chert, subangular to subrounded, well sorted**			**Gravel**	**GW**	**11**	**G**	**4**	**8**	
51	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**80**	**85**	**291**	**286**	**288**	**Sand and Gravel, Sand is medium to coarse, Gravel is subangular to subrounded**			**Sand Gravelly**	**SG**	**8**	**S**	**3**	**4**	**fm**
52	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**75**	**80**	**296**	**291**	**293**	**Sand and Gravel, Sand is medium to coarse, Gravel is subangular to subrounded**			**Sand Gravelly**	**SG**	**8**	**S**	**3**	**4**	**mc**
53	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**70**	**75**	**301**	**296**	**298**	**Sand and Gravel, Sand is medium to coarse, Gravel is subangular to subrounded**			**Sand Gravelly**	**SG**	**8**	**S**	**3**	**4**	**mc**
54	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**65**	**70**	**306**	**301**	**303**	**Gravel, chert, angular to subangular, poorly to moderately well sorted**			**Gravel**	**GP**	**7**	**G**	**4**	**2**	
55	**004-028**	**745960**	**1940499**	**-6597**	**-1205**	**371**	**60**	**65**	**311**	**306**	**308**	**Silty Gravel, some very fine Sand**			**Gravel silty**	**GM**	**5**	**G**	**4**	**1**	
56	004-058	746636	1940076	-5813	-1346	374	90	95	284	279	282	Silty Sand, soft, very fine, well sorted, some light gray clay			Sand silty	SM	4	S	3	1	
57	004-058	746636	1940076	-5813	-1346	374	85	90	289	284	287	Silty, clayey Sand, few Small Gravels, medium to coarse grained, well sorted			Sand silty	SM	4	S	3	1	
58	004-058	746636	1940076	-5813	-1346	374	80	85	294	289	292	Sandy Gravel, chert Gravel, fine to coarse Sand, Gravel up to 1/2 inch diameter			Gravel Sandy	GS	9	G	4	3	fm
59	004-058	746636	1940076	-5813	-1346	374	75	80	299	294	297	Gravelly Sand, coarse Sand, angular to subrounded, well sorted			Sand Gravelly	SG	8	S	3	5	c
60	004-058	746636	1940076	-5813	-1346	374	70	75	304	299	302	Gravelly Sand, coarse Sand, angular to subrounded, well sorted			Sand Gravelly	SG	8	S	3	5	c
61	004-058	746636	1940076	-5813	-1346	374	65	70	309	304	307	Gravelly Sand, coarse Sand, angular to subrounded, well sorted			Sand Gravelly	SG	8	S	3	5	c
62	004-101	746681	1940177	-5808	-1256	375	76	77	300	299	299	Gravelly, coarse to very coarse Sand, (60 %), 40 % Gravel (up to 1/2 inch diameter), yellowish brown (10 YR 5			Sand Gravelly	SG	8	S	3	5	cvc
63	004-101	746681	1940177	-5808	-1256	375	69	70	306	305	306	Medium Sand (70 %), coarse Sand (30 %), brownish yellow (10 YR 6/6), soft consistency, wet			Sand	SW	10	S	3	3	mc
64	004-101	746681	1940177	-5808	-1256	375	64	65	311	310	311	Fine to medium Sand, light yellowish brown (10 YR 6/4), loose consistency, wet			Sand	SW	10	S	3	3	fm
65	004-101	746681	1940177	-5808	-1256	375	59	60	316	315	316	Fine Sand, silty, brownish yellow (10 YR 6/6), loose consistency, wet			Sand silty	SM	4	S	3	1	
66	004-102	746633	1940077	-5816	-1367	375	89	90	286	285	286	Fine-medium Sand with 10 % Gravel, up to 1/2 inch diameter, rounded, chert, yellowish brown (10 YR 5/8),			Sand Gravelly	SG	8	S	3	3	fm
67	004-102	746633	1940077	-5816	-1367	375	84	85	291	290	291	Medium-coarse Sand, subangular, chert, yellowish brown (10 YR 5/8), loose, wet			Sand	SW	10	S	3	4	mc
68	004-102	746633	1940077	-5816	-1367	375	79	80	296	295	296	Medium-coarse Sand as above but with trace Gravel, up to 1/2 inch diameter, rounded, chert			Sand	SW	10	S	3	4	mc
69	004-102	746633	1940077	-5816	-1367	375	74	75	301	300	301	Medium-coarse Sand, subangular, chert, yellowish brown (10 YR 5/8), loose, wet			Sand	SW	10	S	3	4	mc
70	004-102	746633	1940077	-5816	-1367	375	69	70	306	305	306	Medium-coarse Sand, subangular, chert, yellowish brown (10 YR 5/8), loose, wet			Sand	SW	10	S	3	4	mc
71	004-103	746562	1939887	-5810	-1570	375	99	100	276	275	276	Sand with clay, fine-medium grained, well-sorted, dark yellowish orange (10 YR 6/6), loose, wet			Sand clayey	SC	2	S	3	0	
72	004-103	746562	1939887	-5810	-1570	375	94	95	281	280	281	Gravelly Sand fine-medium-coarse grained with Gravel, poorly sorted, light brown (5 YR 5/6), loose, wet			Sand Gravelly	SG	8	S	3	0	fc
73	004-103	746562	1939887	-5810	-1570	375	89	90	286	285	286	Gravelly Sand, as above, larger size, light brown (5 YR 5/6)			Sand Gravelly	SG	8	S	3	6	vc
74	004-103	746562	1939887	-5810	-1570	375	84	85	291	290	291	Gravelly Sand, as above, Smaller size, getting Sandier, moderate yellowish brown (10 YR 5/4)			Sand Gravelly	SG	8	S	3	6	vc
75	004-103	746562	1939887	-5810	-1570	375	79	80	296	295	296	Gravelly Sand, very coarse-granules-Gravel, poorly sorted, moderate brown (5 YR 4/9), loose, wet			Sand Gravelly	SG	8	S	3	6	vc
76	004-103	746562	1939887	-5810	-1570	375	74	75	301	300	301	Gravelly Sand, as above, with larger size			Sand Gravelly	SG	8	S	3	5	cvc
77	004-103	746562	1939887	-5810	-1570	375	69	70	306	305	306	Gravelly Sand, coarse-very coarse-granules with Gravel chert, poorly sorted, moderate yellowish brown (10			Sand Gravelly	SG	8	S	3	5	cvc
78	004-103	746562	1939887	-5810	-1570	375	64	65	311	310	311	Sand (silt 5%) medium-coarse-very coarse grained with some Gravel, moderately sorted, moderate yellowi			Sand silty	SW	10	S	3	4	mcc
79	004-104	746505	1939727	-5804	-1740	375	94	95	281	280	280	Gravel (80%), up to 2 inch diameter, subangular to angular, chert, fine Sand (20%), yellowish brown (10 YR 5			Gravel Sandy	GS	9	G	4	3	f
80	004-104	746505	1939727	-5804	-1740	375	89	90	286	285	285	Sand as above but with 15% coarse Sand and 5% Gravel (subangular, cherty)			Sand	SW	10	S	3	4	m
81	004-104	746505	1939727	-5804	-1740	375	84	85	291	290	290	Sand, as above			Sand	SW	10	S	3	4	m
82	004-104	746505	1939727	-5804	-1740	375	79	80	296	295	295	Sand, medium (90%), coarse (10%), yellowish brown (10 YR 5/6), soft, wet			Sand	SW	10	S	3	4	m
83	004-104	746505	1939727	-5804	-1740	375	74	75	301	300	300	Gravel (50%), up to 1.2 inch diameter, subangular, chert, Sand (50%), fine-medium, yellowish brown (10 YR			Gravel Sandy	GS	9	G	4	3	fm
84	004-104	746505	1939727	-5804	-1740	375	69	70	306	305	305	Sand, fine, pale brown (10 YR 6/3), loose consistency, wet			Sand	SW	10	S	3	3	f
85	004-105	746047	1940481	-6510	-1211	372	99	100	273	272	272	Sand, very fine grain-fine grained, light brown (5 YR 6/4), loose, wet			Sand	SW	10	S	3	2	vff
86	004-105	746047	1940481	-6510	-1211	372	94	95	278	277	277	Silty Sand with Gravel, fine grained light brown (5 YR 5/6), loose, wet			Sand silty	SM	4	S	3	1	

Average: 243506 Count: 34 Sum: 2678564

B-12

Constraining Lithological Pilot Points



Sandy Silt - SM
Sand Clayey - SC
Sand Gravely - GW
Clay - CL

Model Layer 1

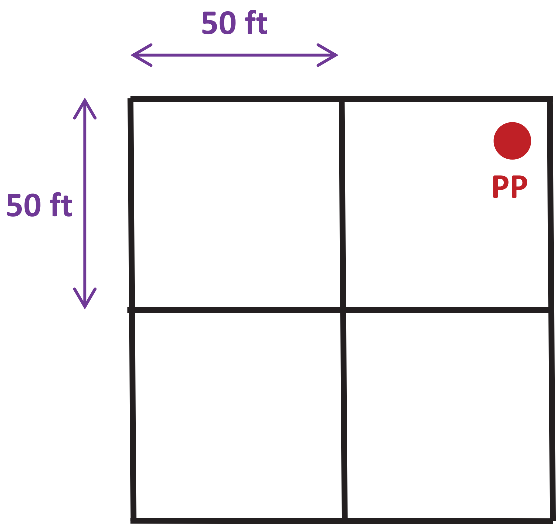
Clay - CL
Gravel - GW
Sand Silt - SM

Model Layer 2

Sand - SW
Gravel Sandy - GS
Sandy Silt - SM
Gravel Silt- GM

Model Layer 3

Vertical Discretization



Horizontal Discretization

Model Layer 1: K allowed to vary from the minimum Clay K value to the maximum Sand Gravely K value
Model Layer 2: K allowed to vary from the minimum Clay K value to the maximum Gravel K value
Model Layer 3: K allowed to vary from the minimum Sandy Silt K value to the maximum Gravel Sandy K value

Pumping Test Pilot Points

- Assign the pumping test derived K_x value as the initial PP K_x value
- Minimum and maximum allowable K_x value are assigned values equal to +/- 10% of the calibrated value

Model Configuration

- Essentially the same as previous model:
  - Only RGA simulated
  - Three layers (each ~10 ft thick)
  - Uniform 50 ft x 50 ft grid cells
- Some changes:
  - Ohio River only in model layer 1
  - Revised bottom and top RGA elevations based on KCREE data
  - Assumed 10 ft minimum RGA thickness

Configuration - Layer 1 Head Targets

Configuration - Layer 2 Head Targets

-¦- **Water-Level Elevation Target**

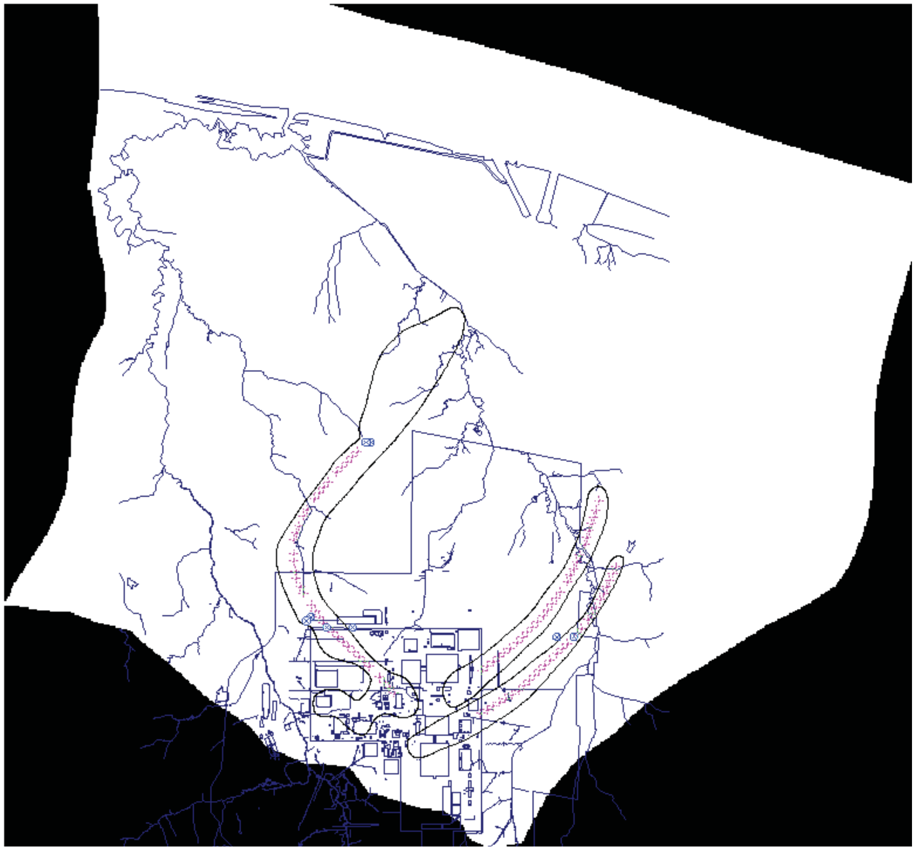
Configuration - Layer 3 Head Targets

B-18

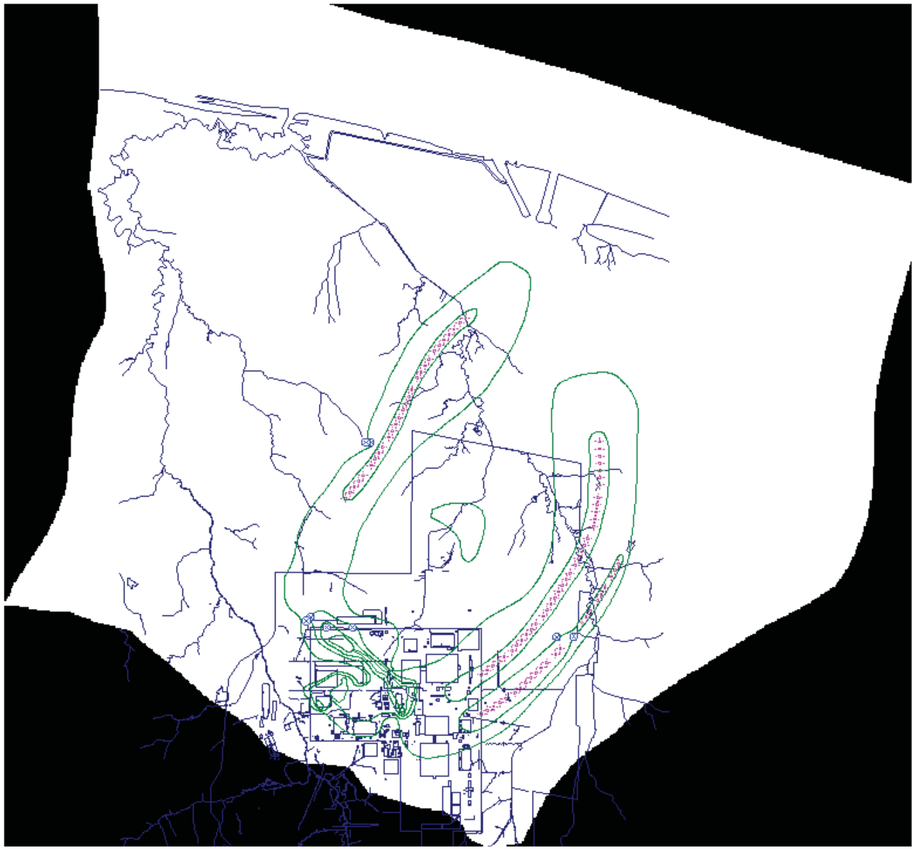
-✦- **Water-Level Elevation Target**

Configuration – V1 Trajectory Targets

Targets in all three model layers



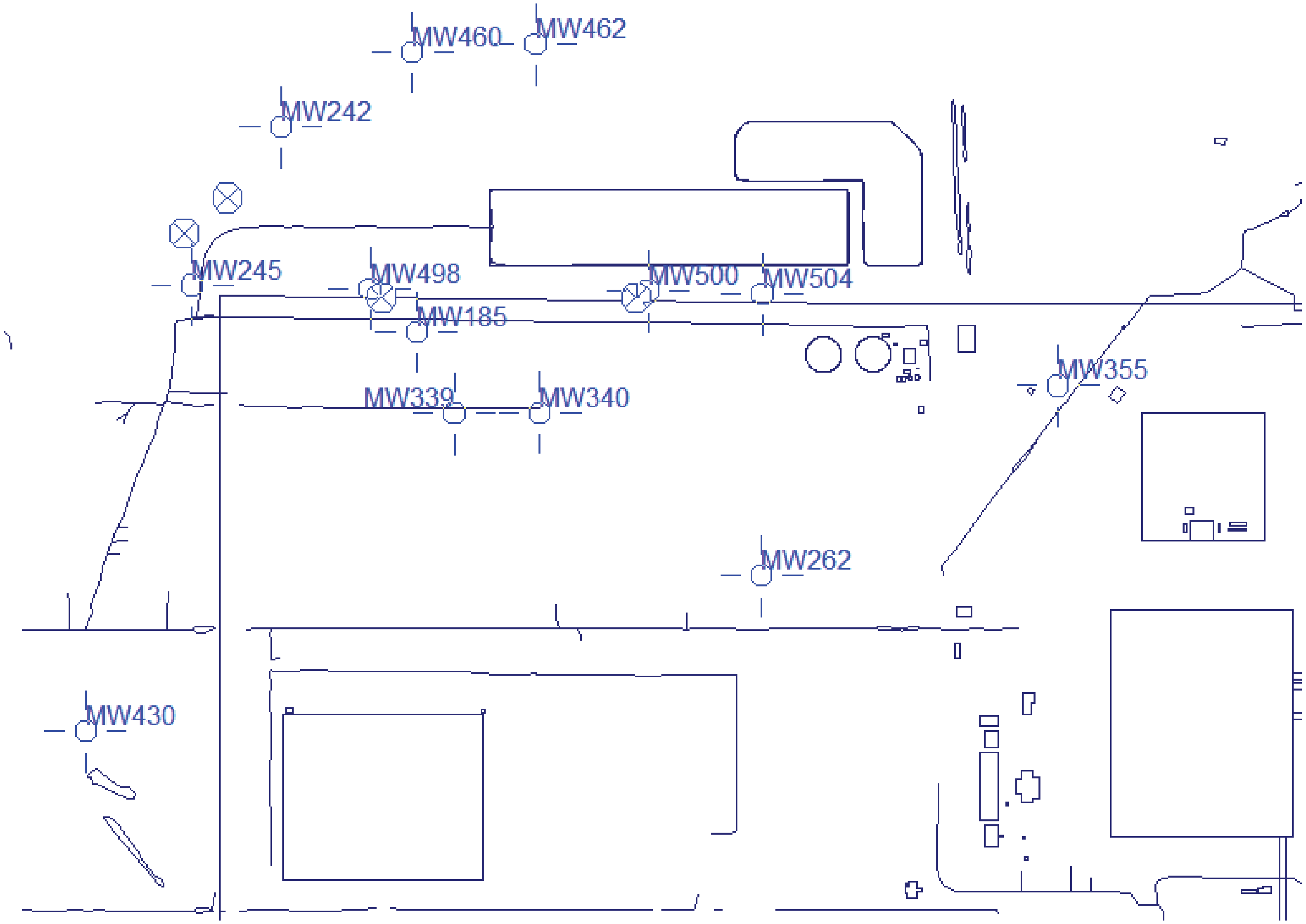
1995



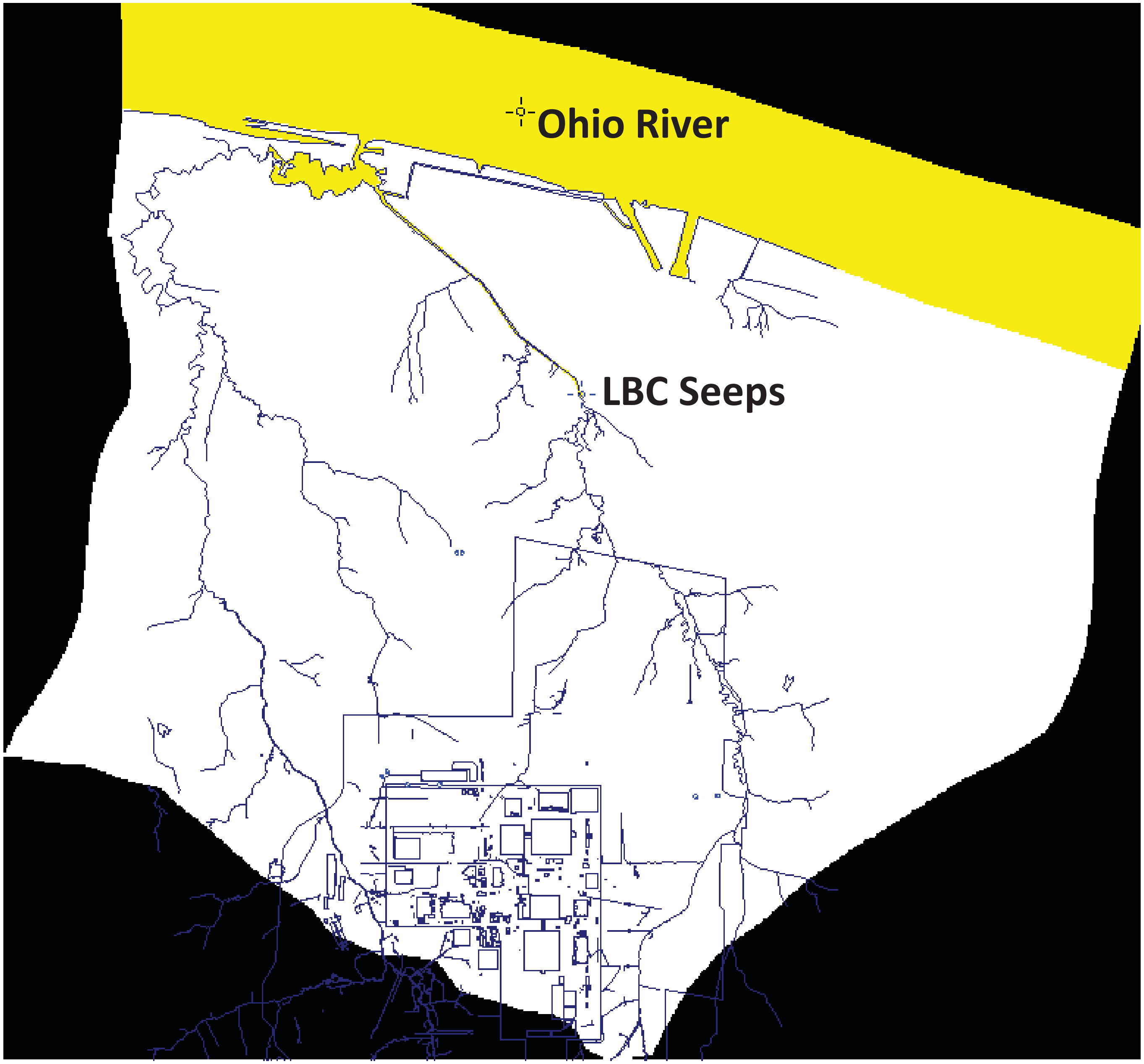
2010

✚ **Trajectory Target**

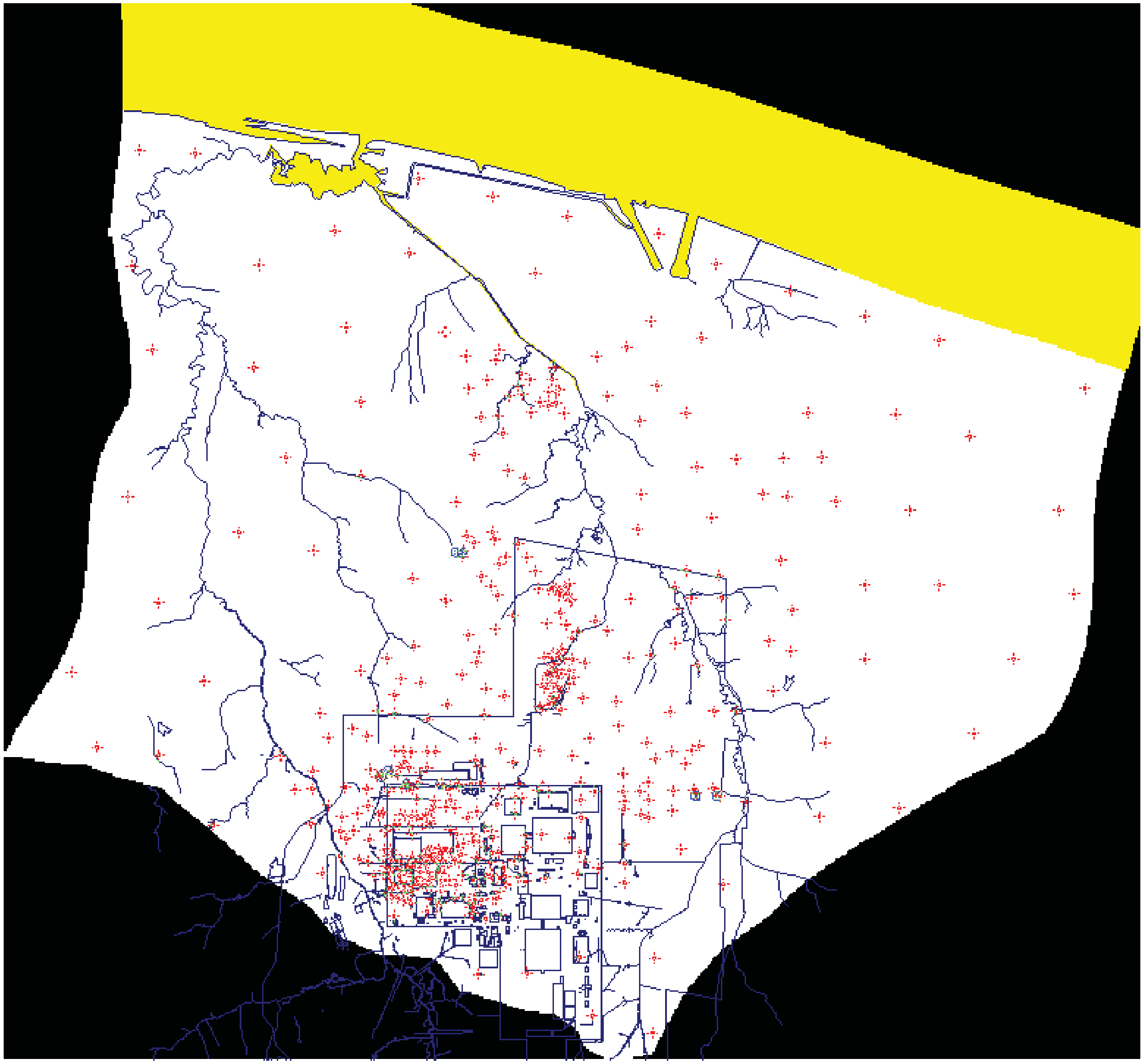
Configuration - Drawdown Targets



Configuration - Flux Targets



Configuration - Layer 1 Hydraulic Conductivity Pilot Points

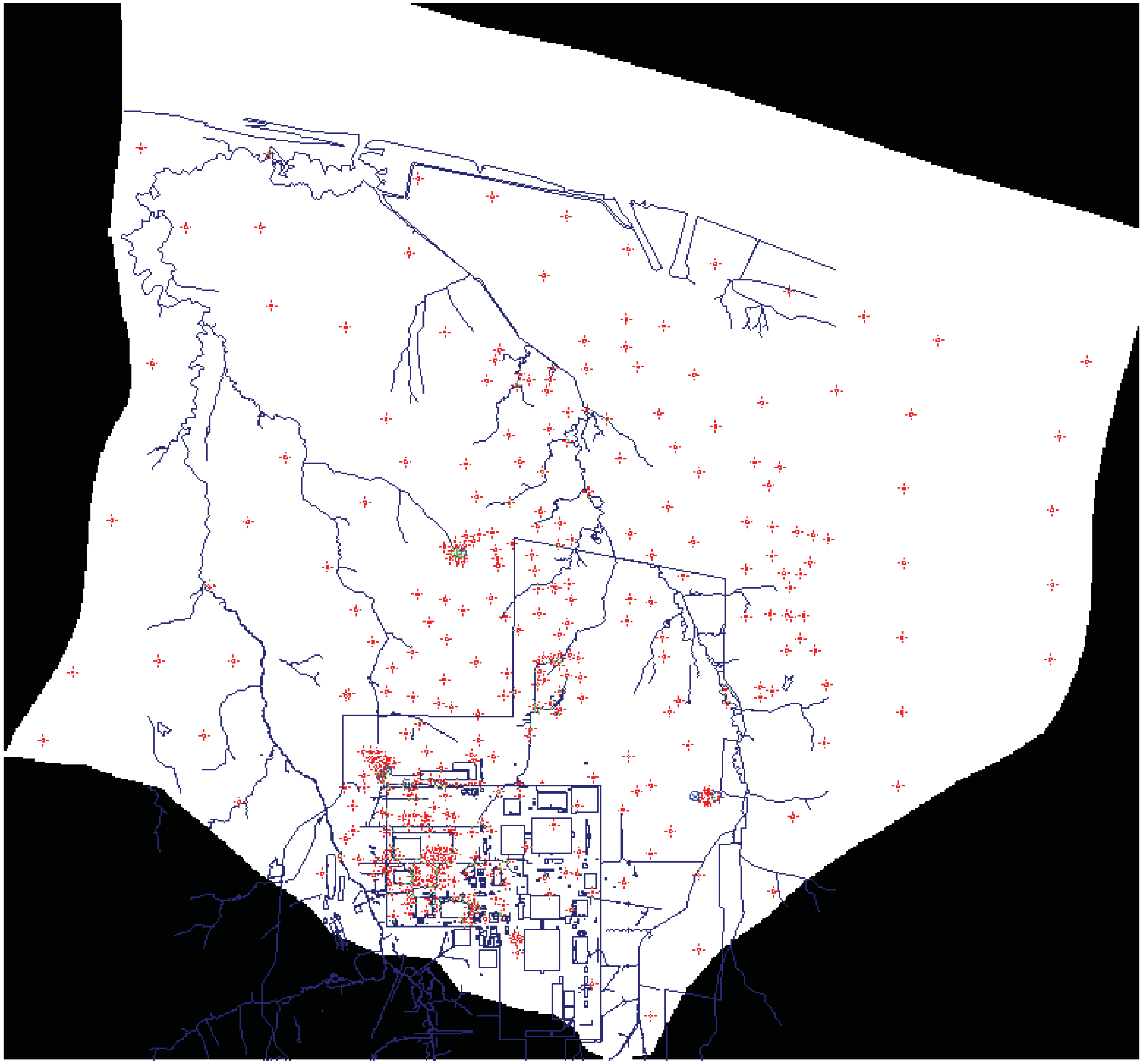


A pilot point is a location within the model where hydraulic conductivity is estimated.

The estimated pilot point hydraulic values are kriged to generate a continuous hydraulic conductivity field.

Pilot points can be constrained using minimum and maximum allowable values.

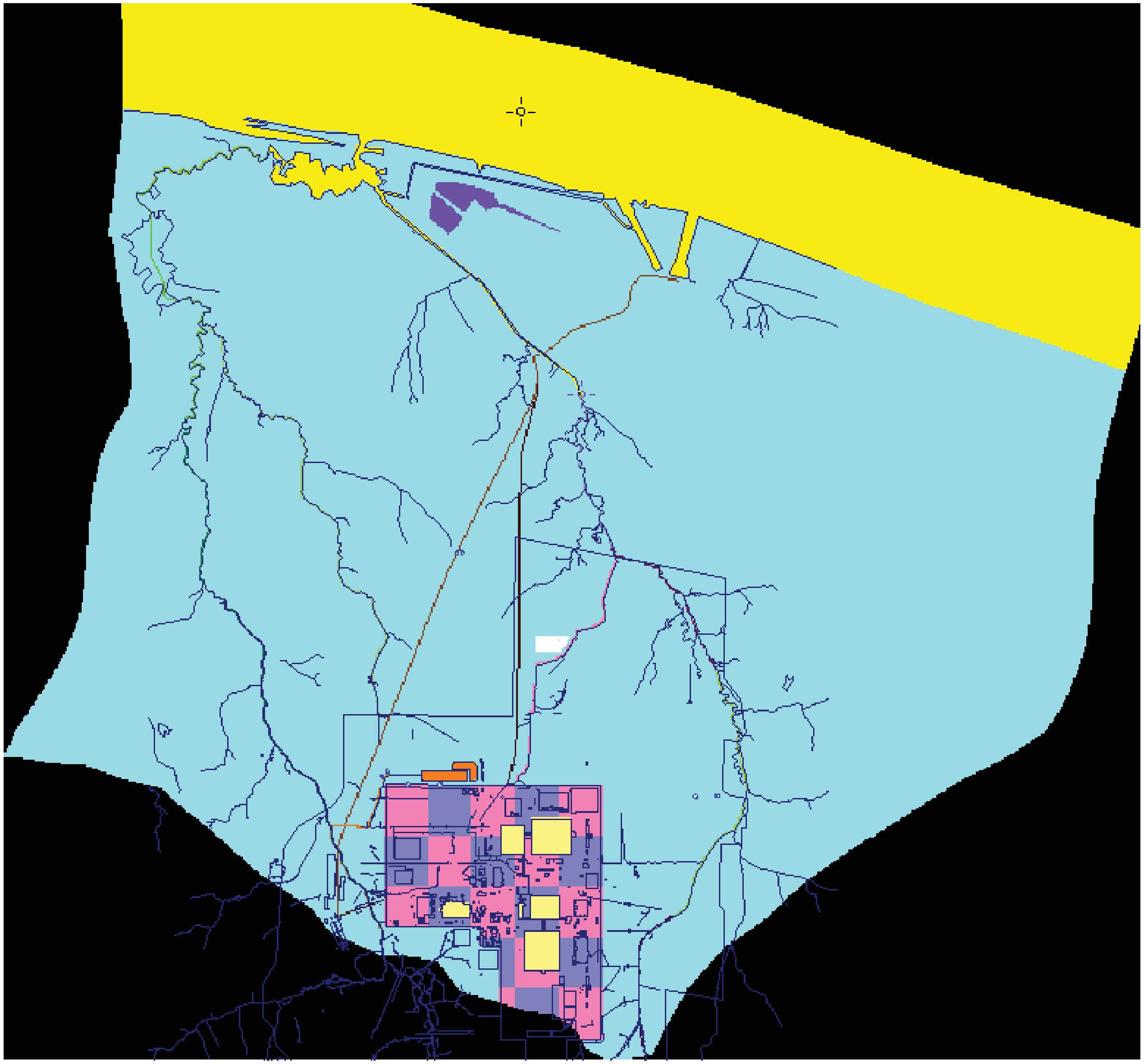
Configuration - Layer 2 Hydraulic Conductivity Pilot Points

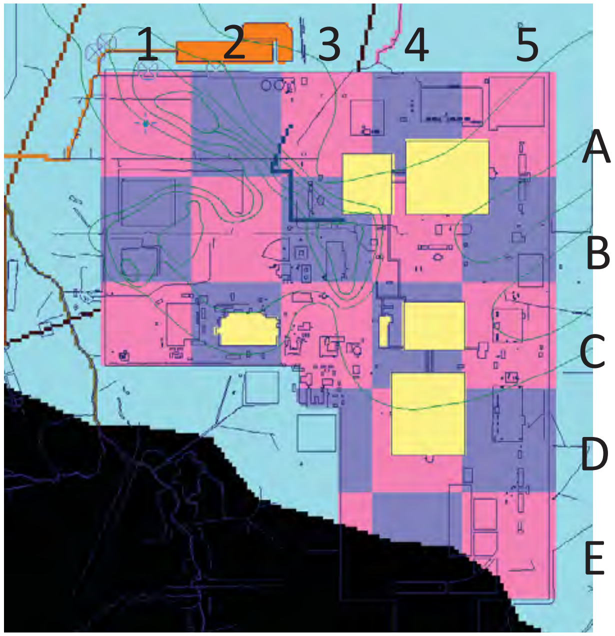


B-23

Configuration - Layer 3 Hydraulic Conductivity Pilot Points

Configuration - Recharge





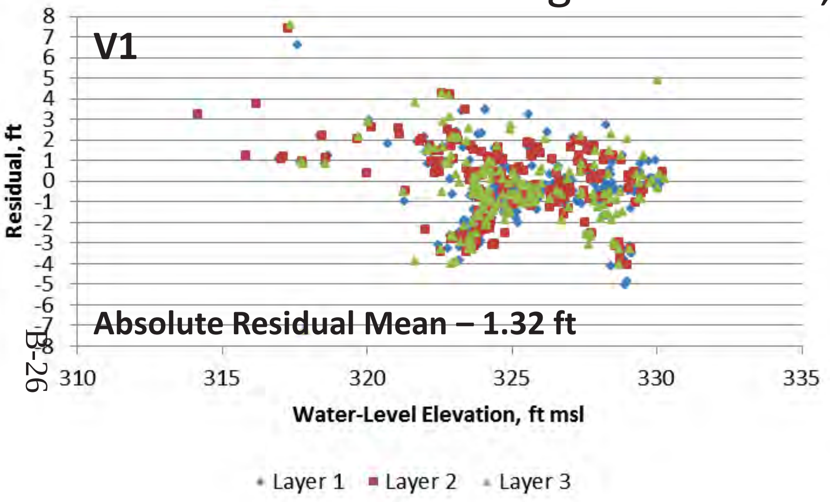
Originally planned to use recharge pilot points but discovered that the code doesn't support different recharge pilot points for each stress period

Switched to lots of small zones but discovered the code is limited to 300 parameter zones

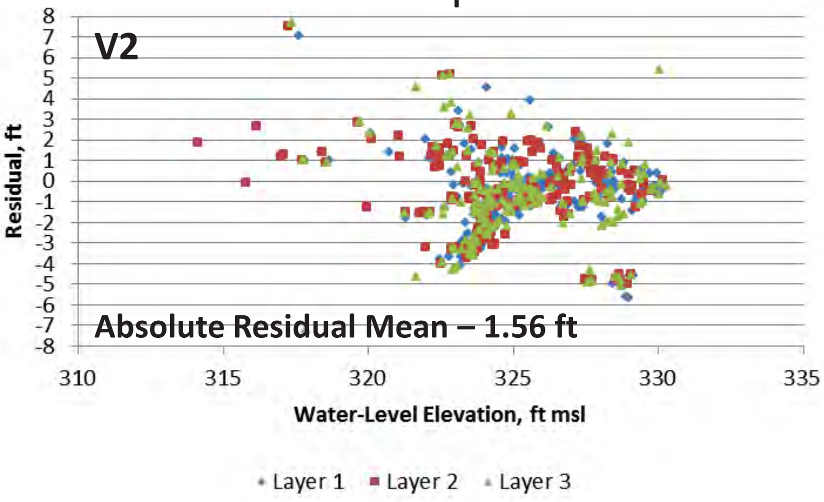
Calibration Results – Water Levels

Revised Models

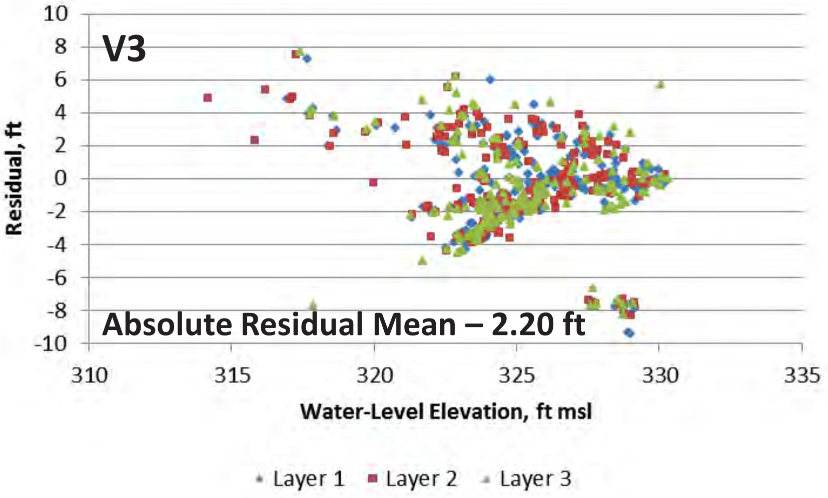
233 target locations, 725 water-levels and 7 time periods



Absolute Residual Mean – 1.32 ft



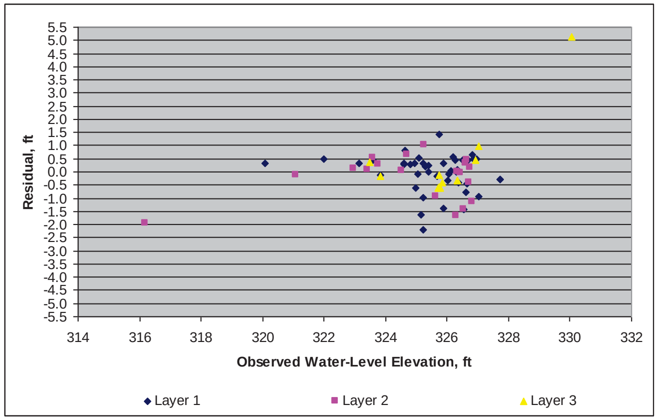
Absolute Residual Mean – 1.56 ft



Absolute Residual Mean – 2.20 ft

Previous Model

Absolute Residual Mean – 0.58 ft

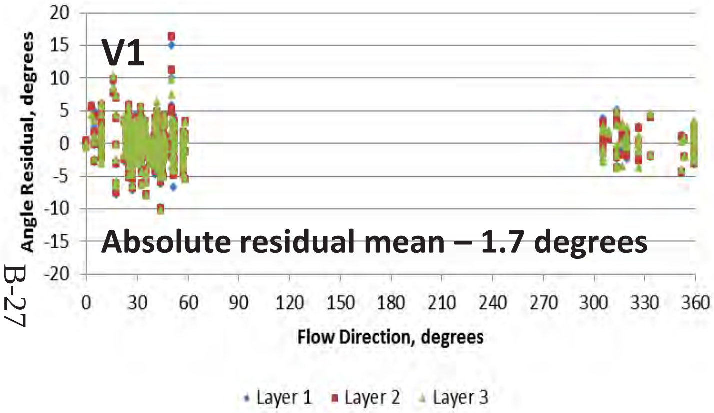


76 target locations, 76 water-levels and 1 time period

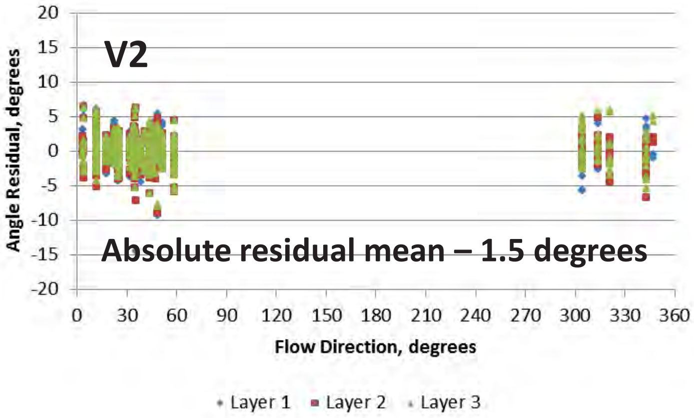
Calibration Results – Trajectory

Revised Model

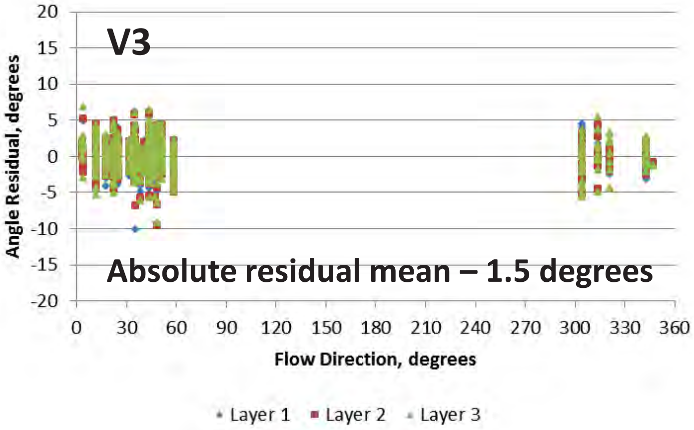
V1 - 1,785 trajectory target locations, V2 and V3 - 1953 trajectory target locations


V1

Absolute residual mean – 1.7 degrees


V2

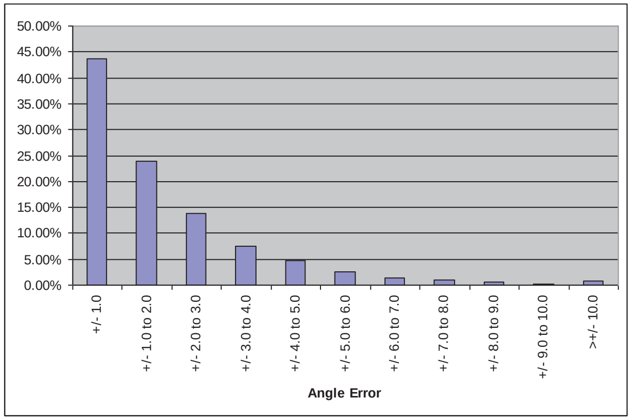
Absolute residual mean – 1.5 degrees


V3

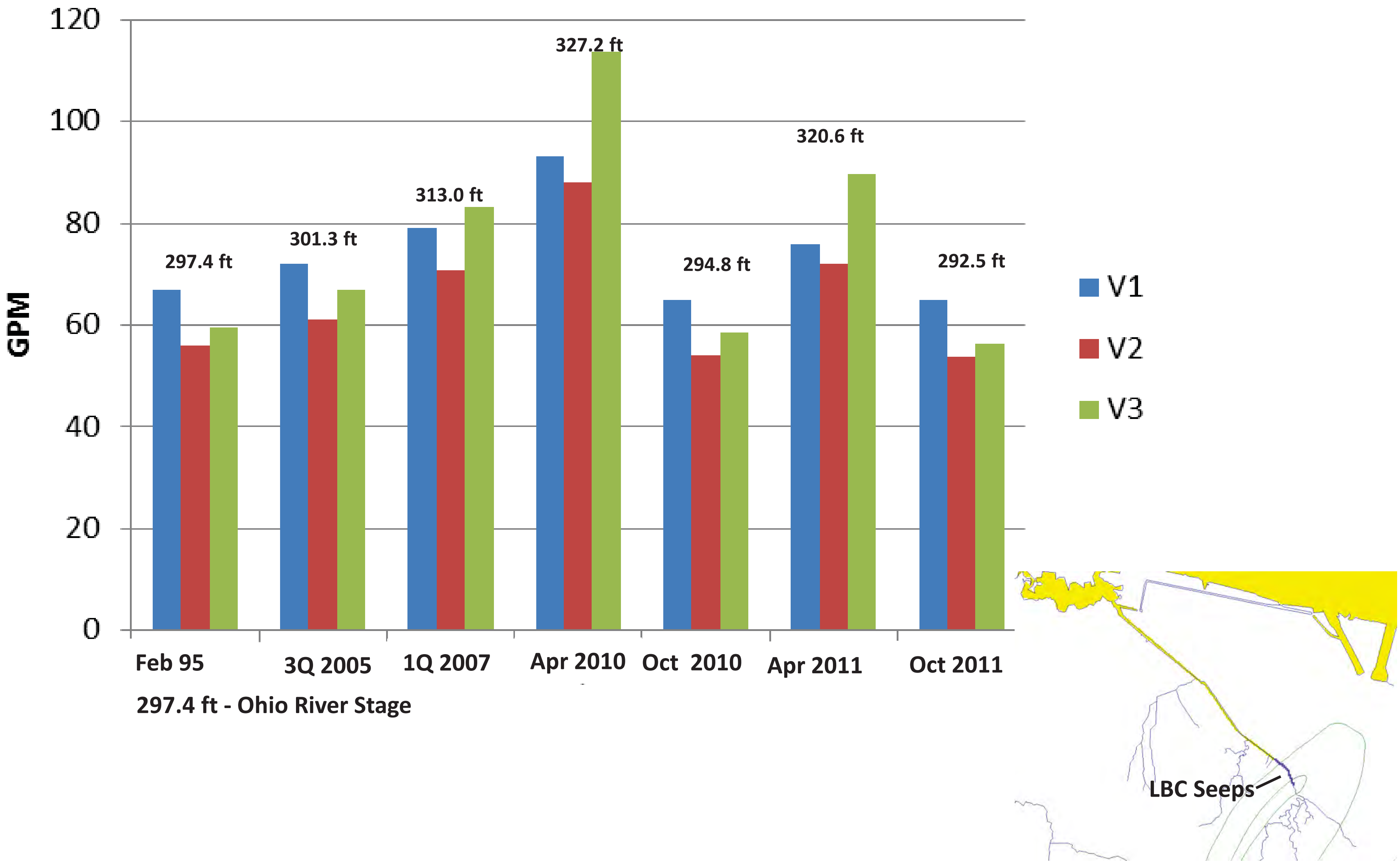
Absolute residual mean – 1.5 degrees

Previous Model

1,704 angle target locations (three-point)
Absolute residual mean – 1.8 degrees

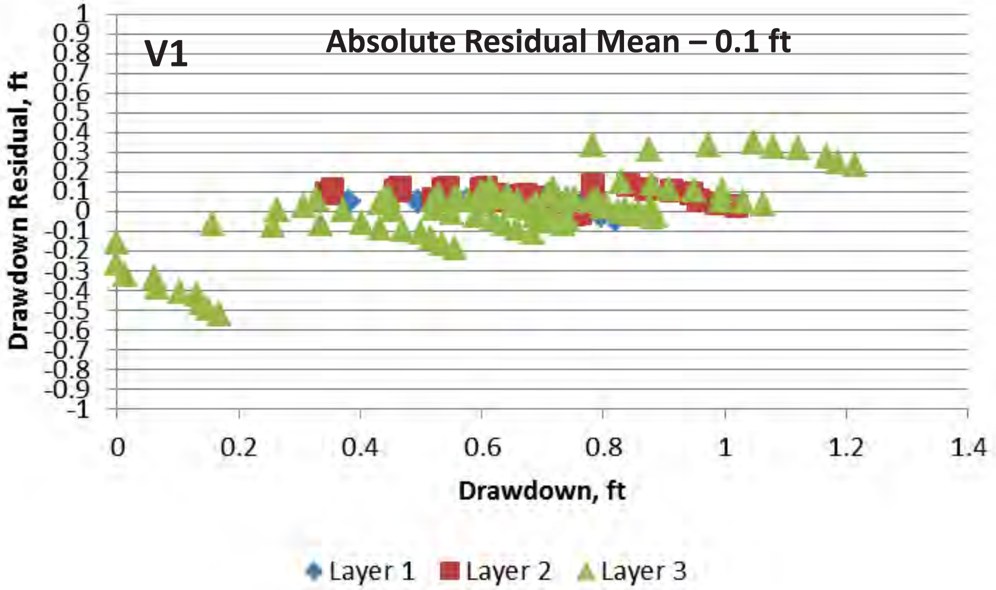


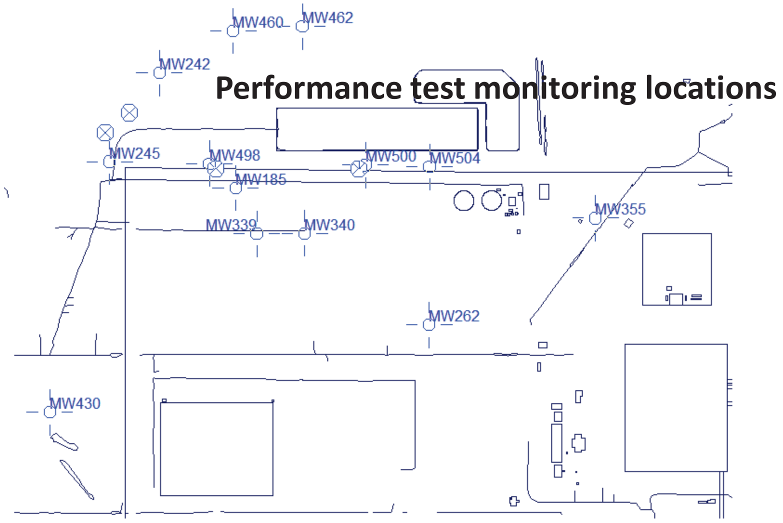
Calibration Results – LBC Seeps Flux



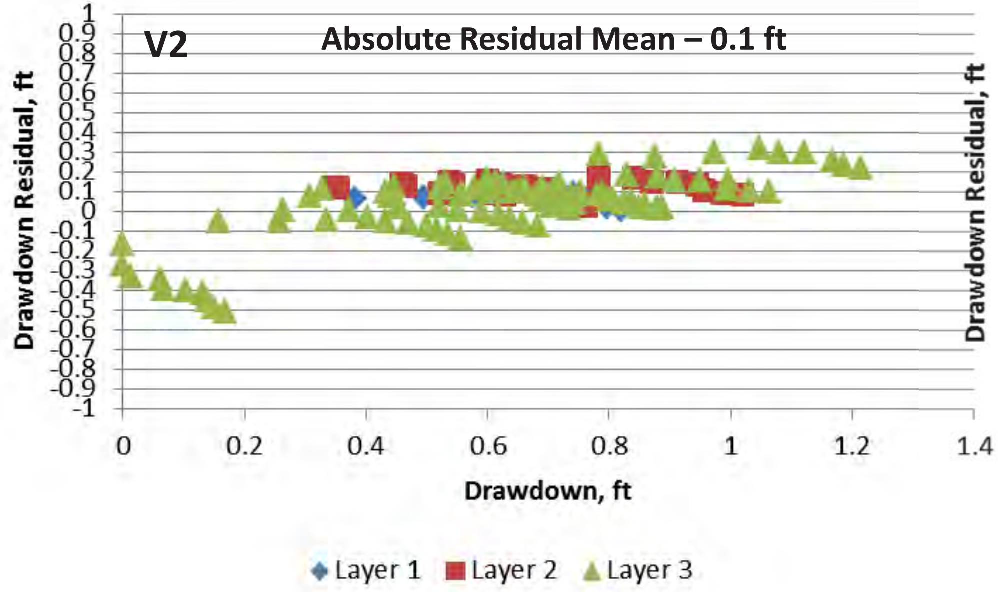
297.4 ft - Ohio River Stage

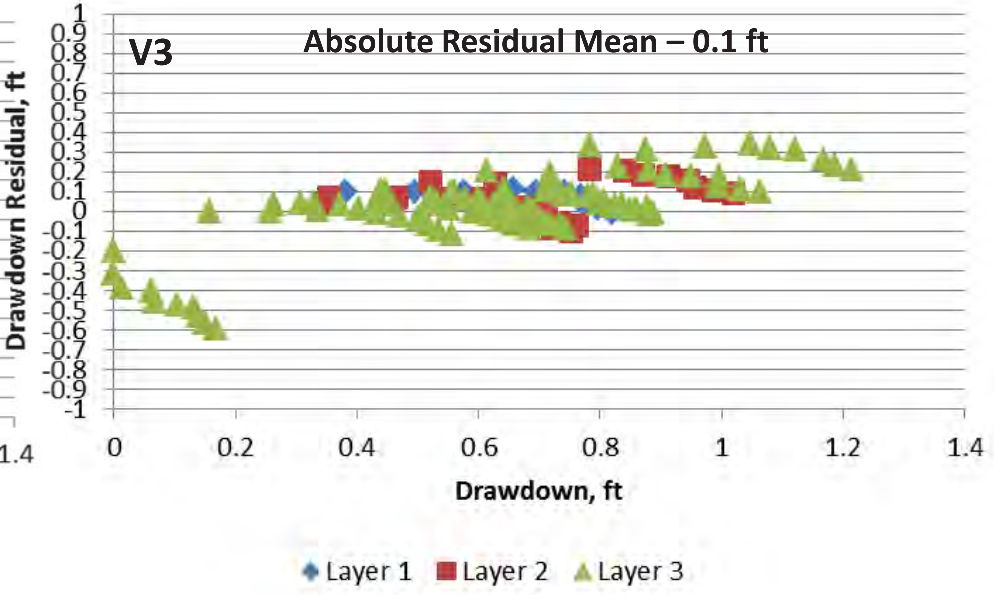
Calibration Results – Drawdown



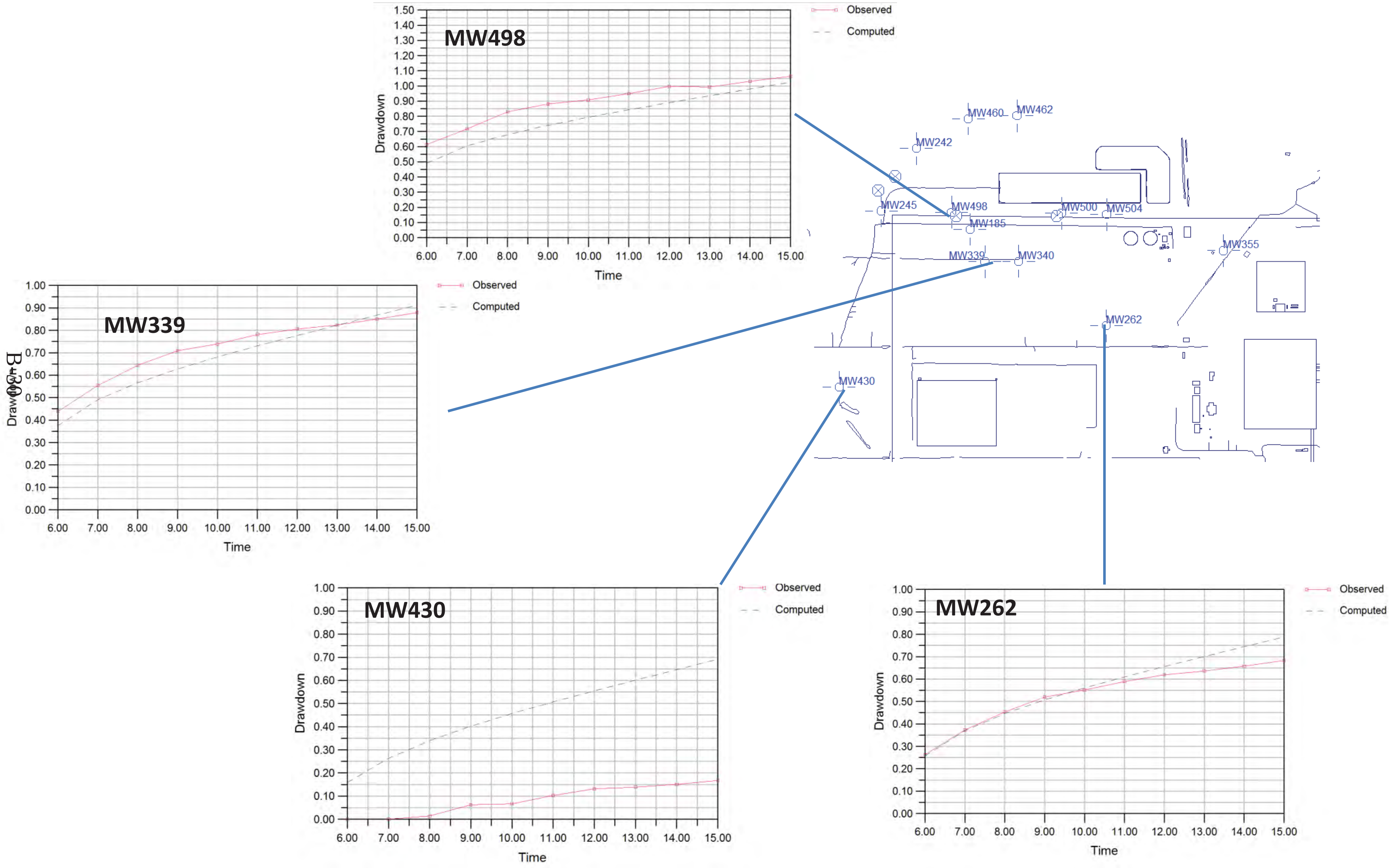


Performance test monitoring locations



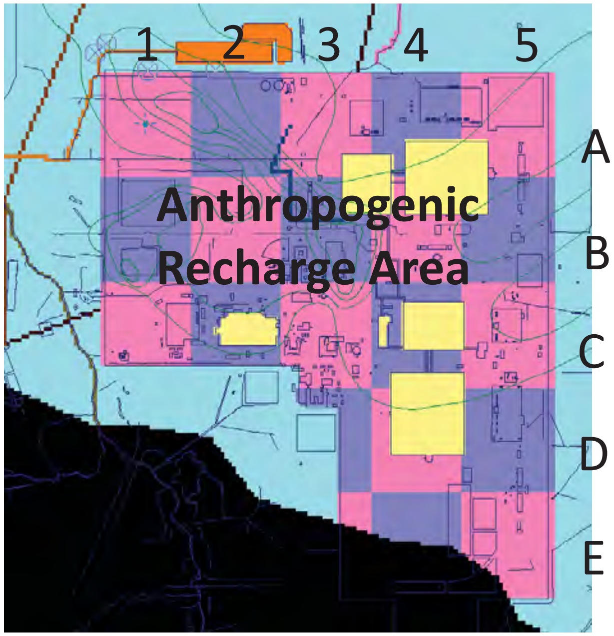


Calibration Results – Drawdown

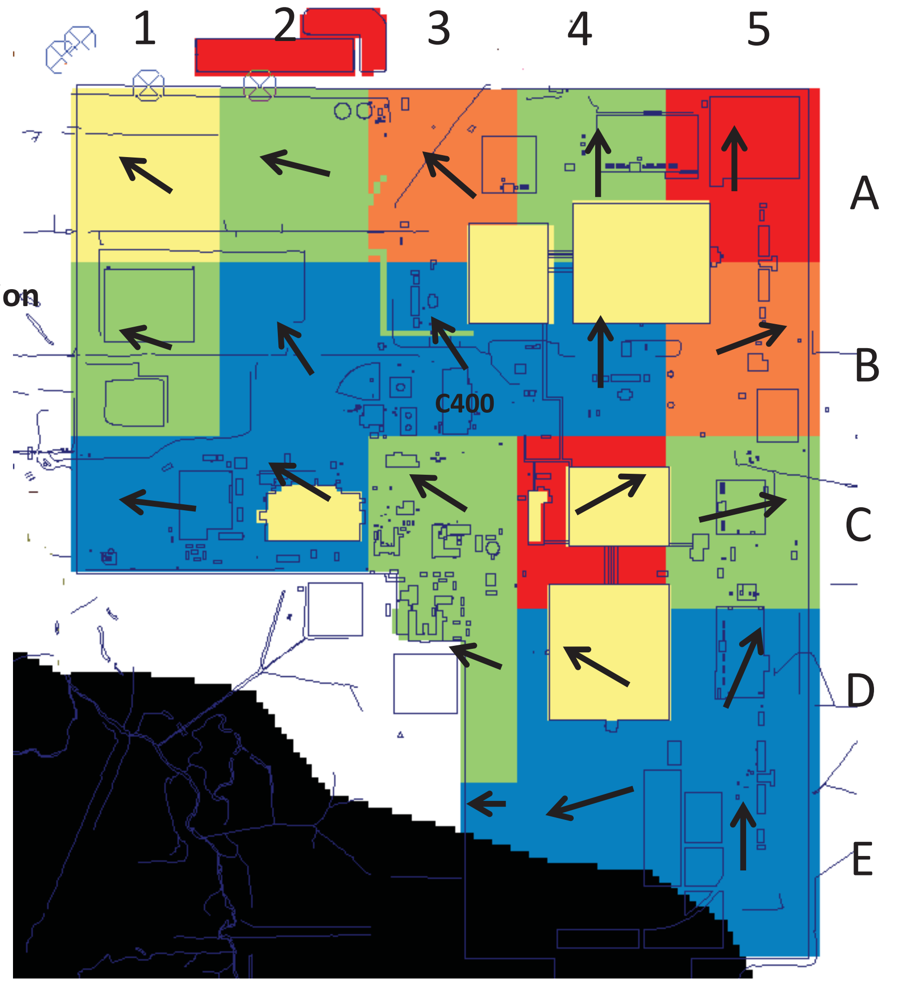


Model Predicted Anthropogenic Recharge

Date	Anthropogenic Recharge, gpm		
	V1	V2	V3
Feb 1995	884	1,152	1,442
3Q 2005	1,204	1,337	1,525
1Q 2007	931	1,042	1,048
April 2010	1,065	678	978
Oct 2010	977	1,317	1,725
April 2011	831	599	491
Oct 2011	1,148	1,420	1,758
Mean	1,006	1,078	1,281
Median	977	1,152	1,442



Calibration Results - Anthropogenic Recharge



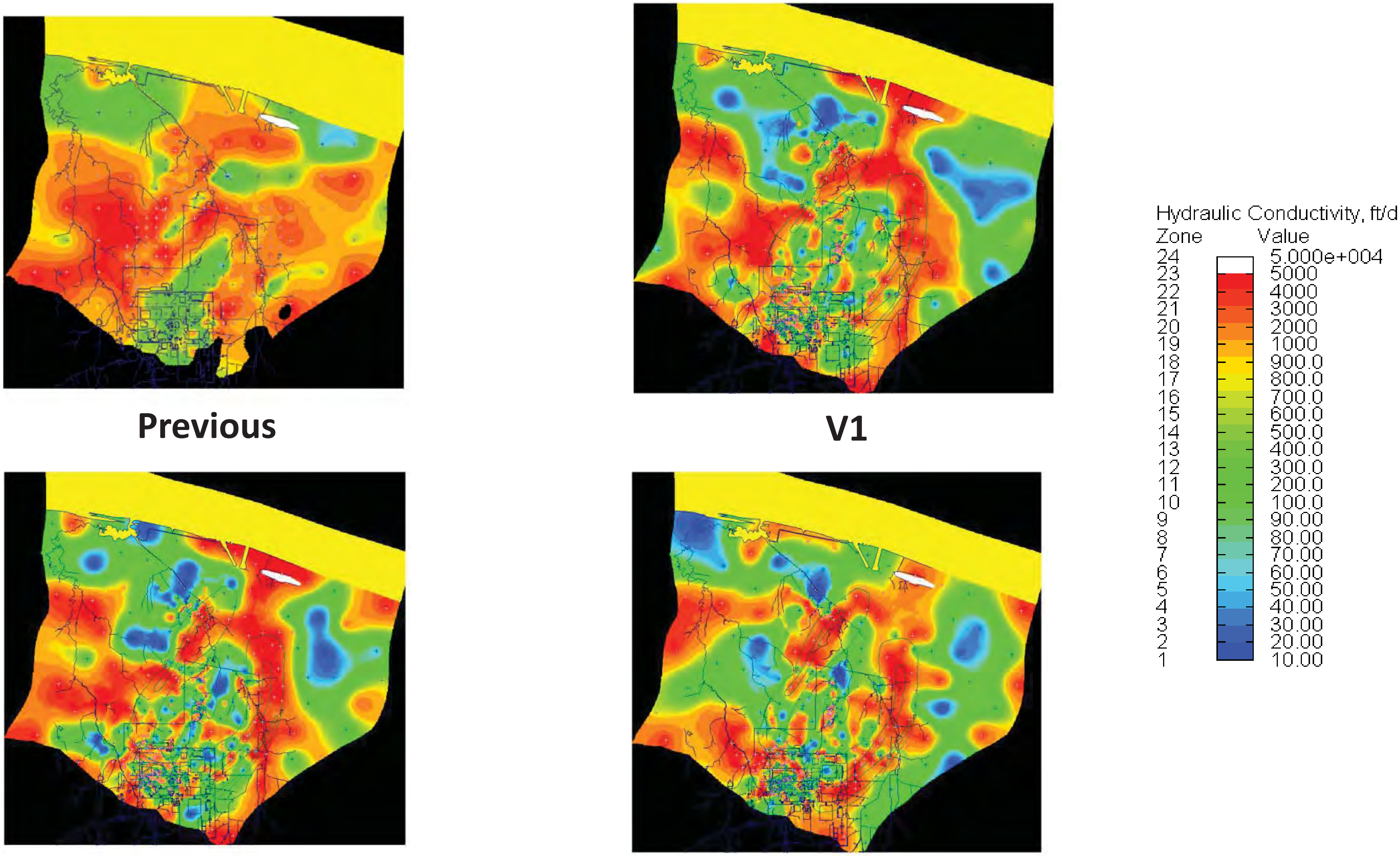
↘ **Typical Flow Direction**

Annual Recharge	
0 to 5 inches	🟦
5 to 20 inches	🟩
20 to 50 inches	🟨
50 to 100 inches	🟧
100+ inches	🟥

	A1		A2		A3		A4		A5		B1		B2		B3		B4		B5		C1		C2		C3		C4		C5		D3		D4		D5		E3		E4		E5	
	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr	D°	In/yr
Feb-95 *	326	25.6	319	4.3	334	71.4	37	17.2	53	65.1	320	9.4	307	0.0	323	0.0	39	0.0	49	41.5	302	0.2	304	2.8	309	6.4	35	114.8	50	12.4	301	55.5	353	1.7	-	0.0	-	0.0	-	0.2	-	0.1
Feb-95	313	46.4	312	1.2	328	70.1	3	4.1	1	114.8	294	6.3	321	0.0	322	0.0	350	0.0	56	114.8	286	0.1	297	1.6	307	3.0	39	114.8	63	3.6	283	3.0	10	0.8	14	0.0	271	0.0	279	0.1	337	0.0
3rd Q 2005	318	12.5	307	6.6	329	78.4	8	11.5	11	114.8	300	20.9	331	0.0	322	0.0	18	0.0	59	104.3	285	0.2	300	3.6	315	13.8	40	114.8	59	13.7	276	13.8	355	1.1	37	0.0	272	0.0	184	0.5	46	0.0
1st Q 2007	316	25.2	306	3.9	326	50.9	5	33.1	7	114.8	298	9.8	326	0.0	320	0.0	352	0.0	56	100.3	285	0.1	296	4.0	302	18.2	37	114.8	55	21.6	271	18.2	339	1.8	22	0.0	274	0.0	271	0.1	337	0.1
Apr-10	315	68.0	311	6.3	325	91.5	15	24.7	4	91.4	288	27.4	318	0.0	321	0.0	5	0.0	54	92.1	279	0.4	296	4.6	314	8.1	40	114.8	54	14.0	276	8.1	12	1.8	15	0.0	270	0.0	276	0.4	341	0.1
Oct-10	311	12.1	302	11.8	325	98.7	23	24.8	14	81.9	295	14.0	313	0.0	318	0.0	18	0.0	57	114.8	284	0.3	297	4.2	306	6.5	41	114.8	59	16.7	280	6.5	350	1.5	25	0.0	274	0.0	263	0.2	349	0.1
Apr-11	341	28.6	315	3.0	323	34.9	346	8.4	357	84.2	303	3.8	334	0.0	321	0.0	336	0.0	53	94.4	286	0.2	298	0.8	307	5.4	32	114.8	58	5.0	277	5.4	357	0.8	26	0.0	270	0.0	244	0.1	357	0.0
Oct-11	336	37.0	312	7.1	320	114.8	17	29.2	15	114.8	302	12.3	329	0.0	323	0.0	27	0.0	58	68.9	287	0.3	300	5.2	324	13.3	42	114.8	53	20.4	283	13.3	9	1.8	25	0.0	270	0.0	161	0.5	8	0.1

* Previous Model

Calibration Results – Layer 1 Hydraulic Conductivity



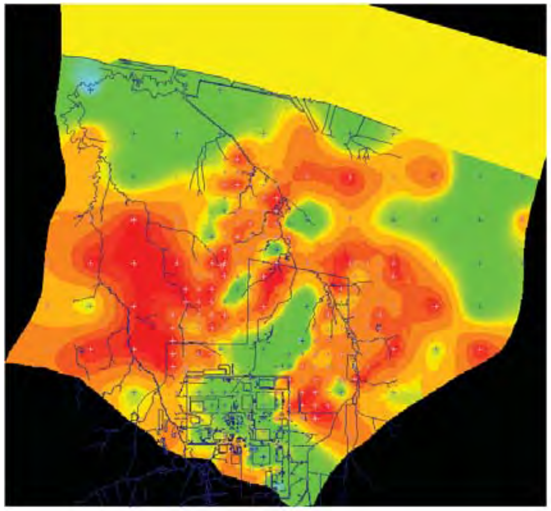
Previous

V1

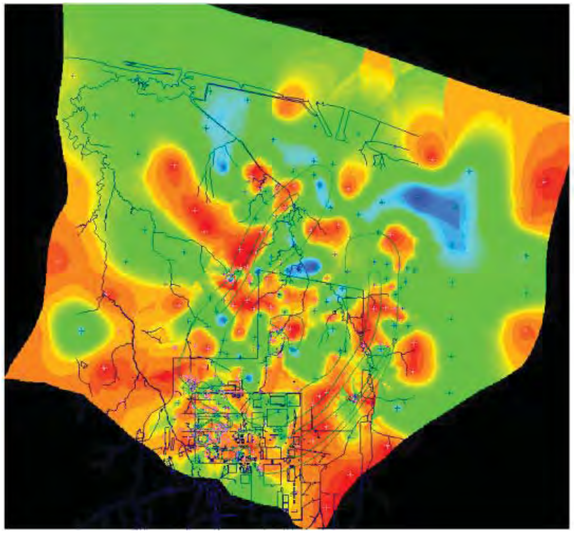
V2

V3

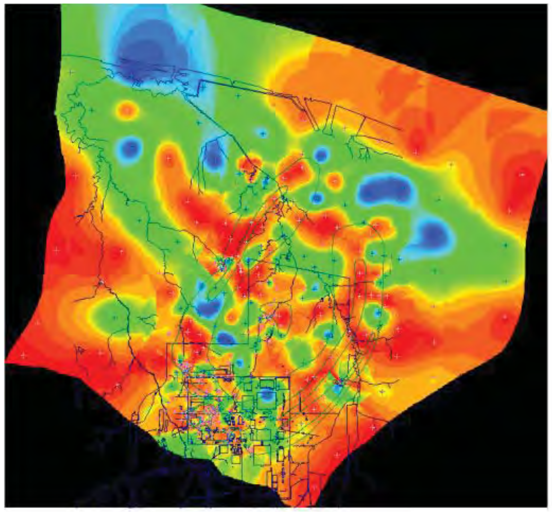
Calibration Results – Layer 2 Hydraulic Conductivity



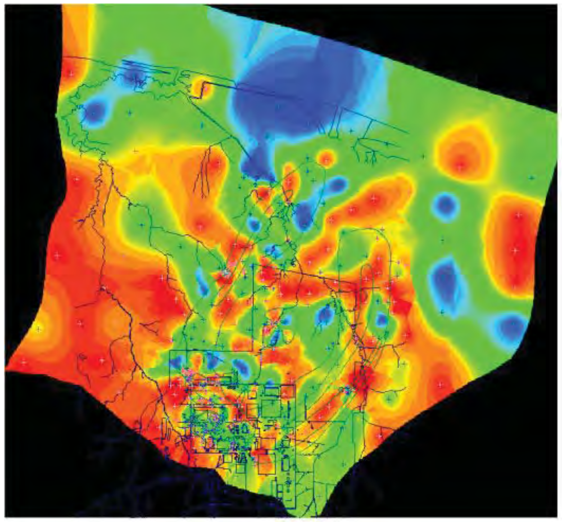
Previous



V1



V2

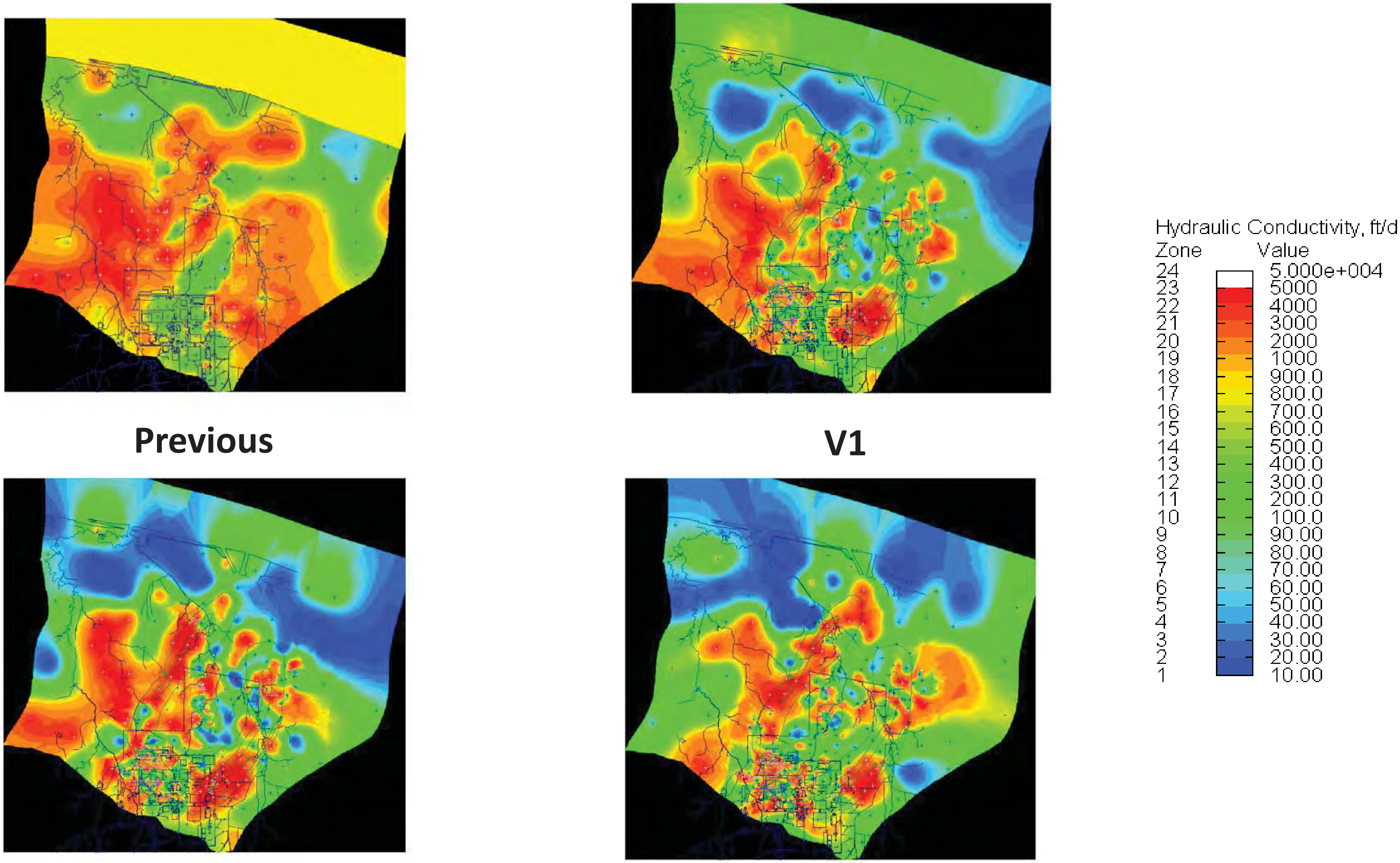


V3

Hydraulic Conductivity, ft/d

Zone		Value
24	⬜	5.000e+004
23	🟥	5000
22	🟥	4000
21	🟥	3000
20	🟧	2000
19	🟧	1000
18	🟨	900.0
17	🟨	800.0
16	🟨	700.0
15	🟩	600.0
14	🟩	500.0
13	🟩	400.0
12	🟩	300.0
11	🟩	200.0
10	🟩	100.0
9	🟩	90.00
8	🟦	80.00
7	🟦	70.00
6	🟦	60.00
5	🟦	50.00
4	🟦	40.00
3	🟦	30.00
2	🟦	20.00
1	🟦	10.00

Calibration Results – Layer 3 Hydraulic Conductivity



Previous

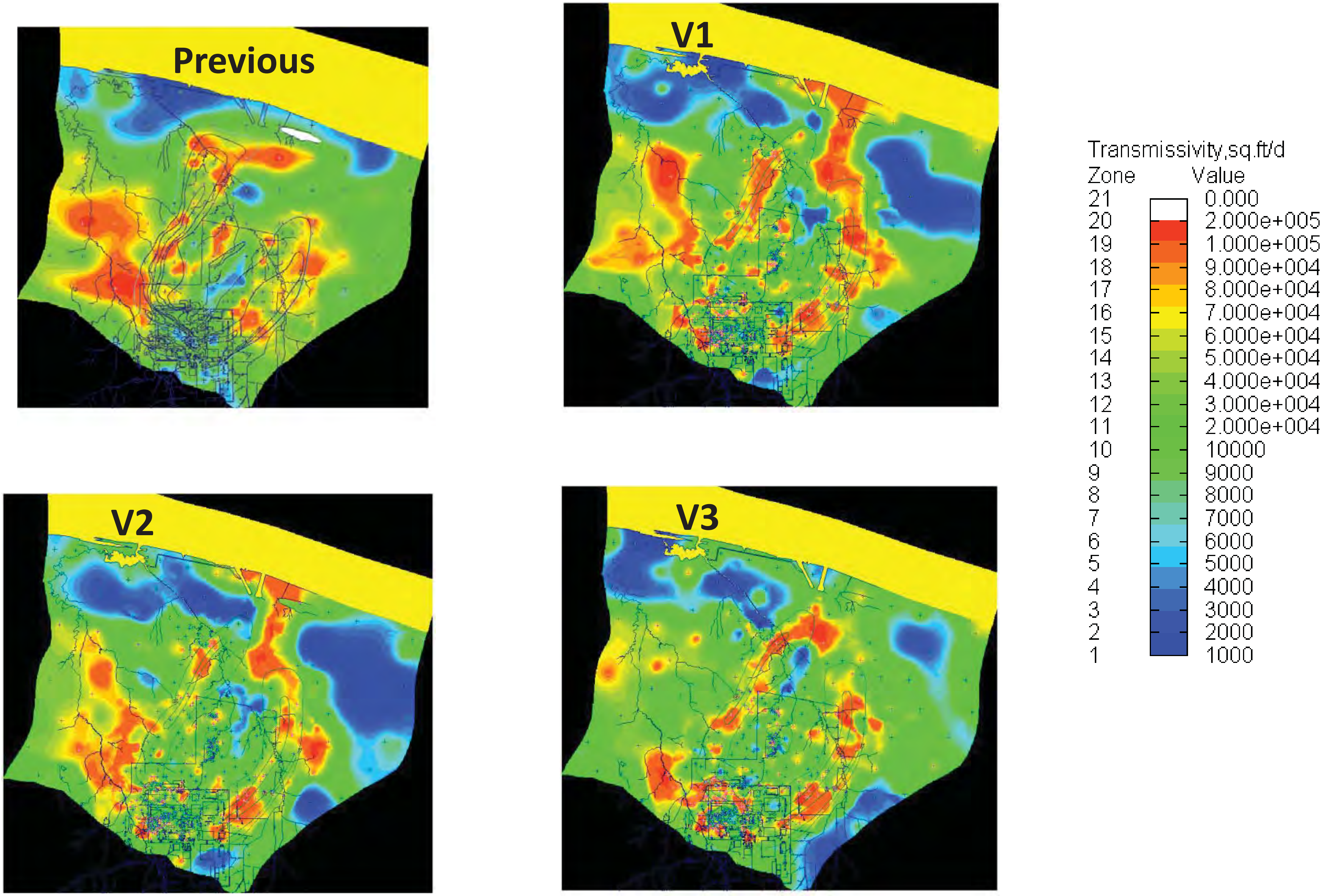
V1

V2

V3

Previous Model

Calibration Results – Transmissivity



Calibration Results – Hydraulic Conductivity Summary Statistics

V1 Model

Percentile	Layer 1	Layer 2	Layer 3	Combined
1	25	39	13	17
5	44	77	21	36
10	78	115	33	63
15	120	148	49	94
20	165	185	69	121
25	223	229	90	154
30	297	282	107	197
35	375	338	125	255
40	456	404	151	323
45	537	471	191	395
50	642	546	253	476
55	815	633	327	559
60	1,006	746	407	683
65	1,259	893	507	861
70	1,584	1,046	632	1,071
75	1,986	1,242	879	1,352
80	2,473	1,496	1,257	1,717
85	3,138	1,819	1,743	2,197
90	4,001	2,275	2,423	2,844
95	5,054	3,009	3,225	3,928
99	6,563	4,368	4,805	5,723
100	7,725	7,649	5,968	7,725
Mean	1,366	911	746	1,008

V2 Model

Percentile	Layer 1	Layer 2	Layer 3	Combined
1	18	21	10	12
5	42	44	14	23
10	79	79	20	41
15	122	134	28	64
20	169	197	39	92
25	226	276	52	132
30	300	371	67	183
35	383	483	84	251
40	490	615	106	340
45	643	786	140	446
50	839	989	188	584
55	1,060	1,212	259	771
60	1,321	1,488	359	1,002
65	1,643	1,796	494	1,287
70	1,988	2,089	677	1,642
75	2,399	2,416	939	2,035
80	2,914	2,725	1,370	2,477
85	3,570	3,129	1,989	2,999
90	4,251	3,731	2,870	3,744
95	5,049	4,442	4,086	4,586
99	7,130	5,107	5,248	5,886
100	8,494	18,374	9,294	18,374
Mean	1,551	1,482	827	1,287

V3 Model

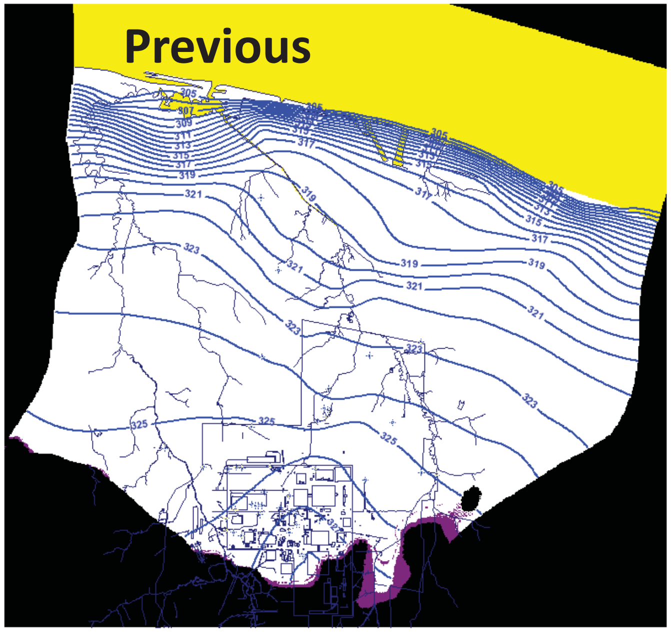
Percentile	Layer 1	Layer 2	Layer 3	Combined
1	19	11	10	12
5	42	26	18	23
10	73	48	24	38
15	116	80	32	58
20	164	126	42	89
25	220	171	57	128
30	280	233	78	172
35	356	313	105	226
40	448	388	139	289
45	548	467	179	365
50	649	553	225	454
55	784	686	278	555
60	949	844	349	687
65	1,126	1,034	441	857
70	1,342	1,305	569	1,070
75	1,606	1,670	748	1,343
80	1,908	2,110	1,011	1,710
85	2,336	2,729	1,405	2,168
90	2,959	3,380	2,012	2,876
95	3,803	4,095	2,995	3,788
99	5,218	4,941	4,633	4,928
100	12,803	11,868	7,463	12,803
Mean	1,122	1,146	653	973

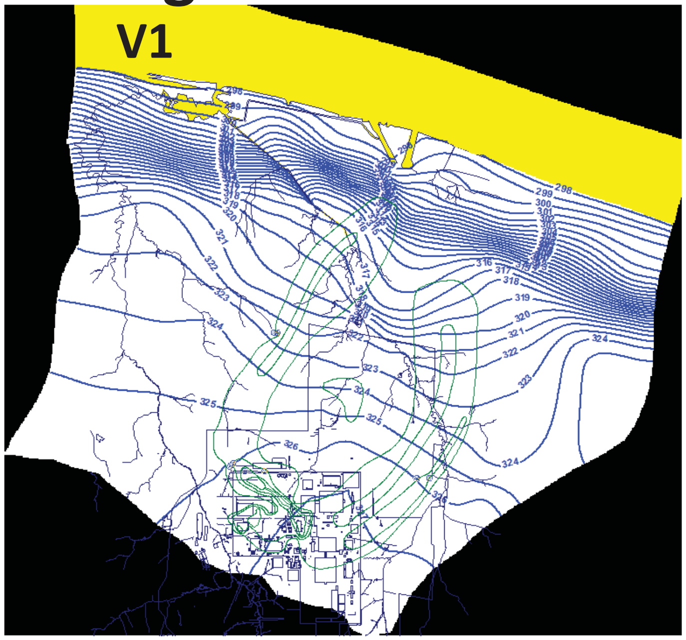
Previous Model

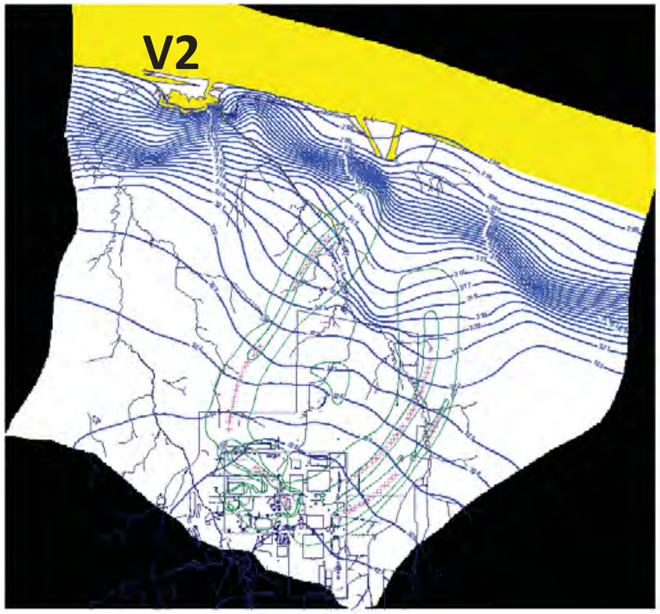
Hydraulic Conductivity, ft/d	All Layers	Layer 1	Layer 2	Layer 3
Average	1906	1947	1874	1899
Median	1497	1531	1379	1535
Standard Deviation	1582	1576	1583	1590
Maximum	5000	5000	5000	5000
Minimum	50	50	50	50
Range	4950	4950	4950	4950

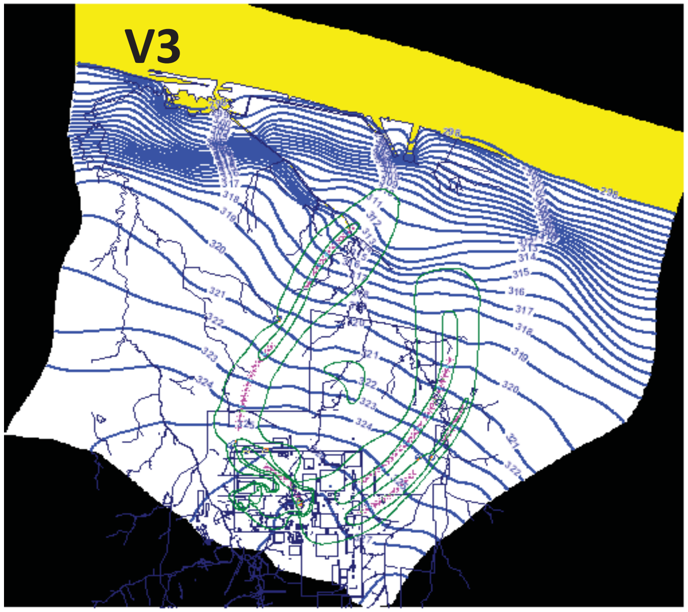
Calibration Results – Potentiometric Surface

February 1995, Ohio River Stage – 297.4 ft msl



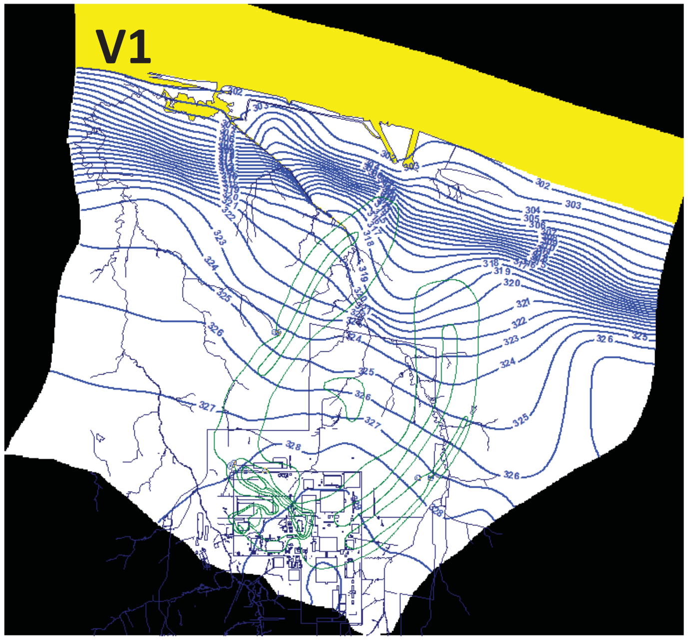


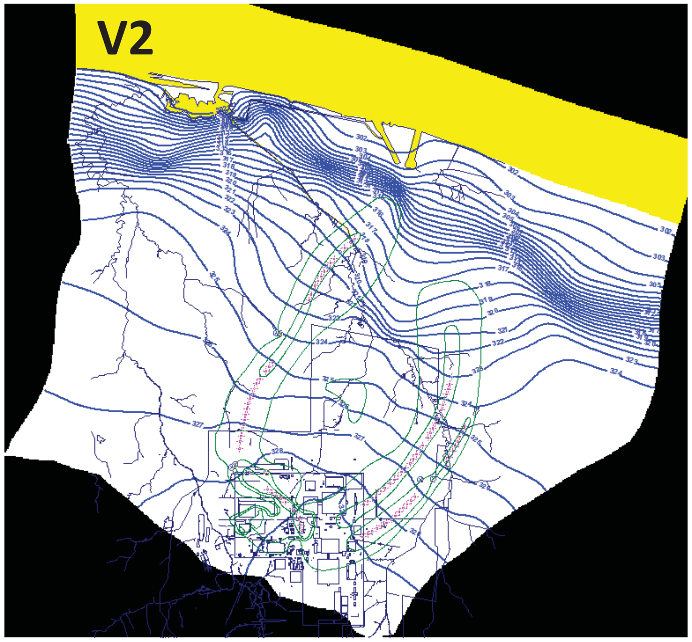


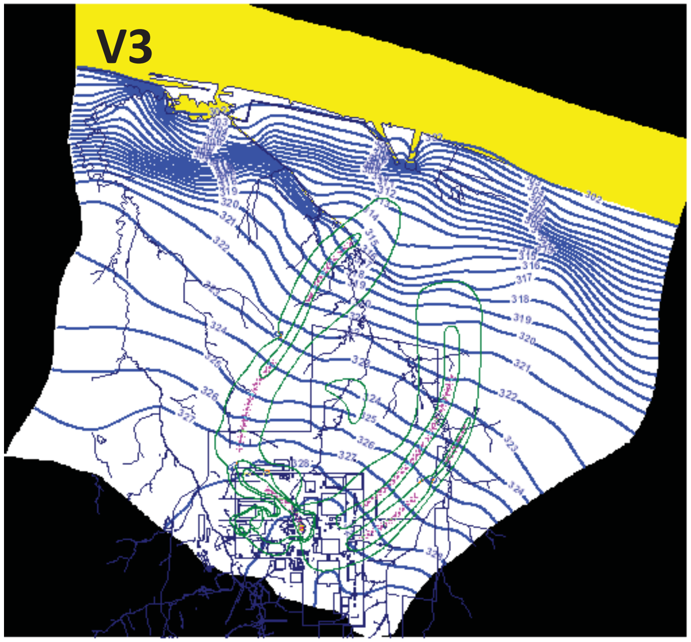


Calibration Results – Potentiometric Surface

3Q 2005, Ohio River Stage – 301.3 ft msl

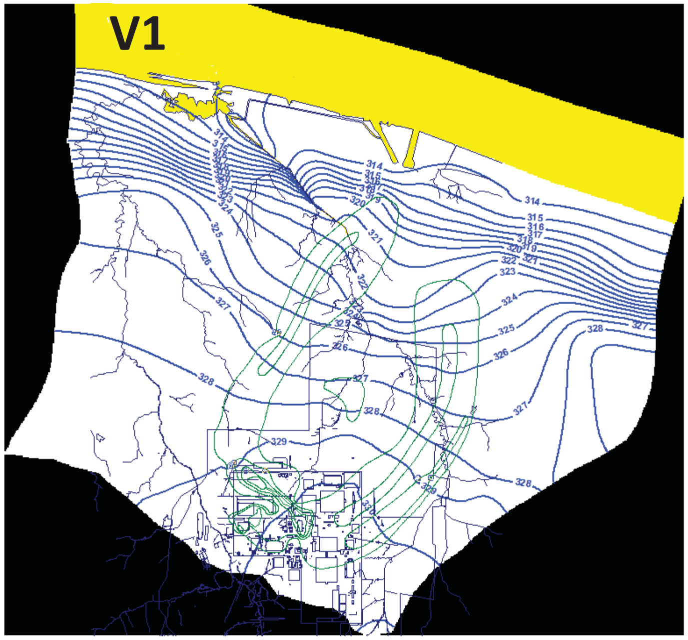


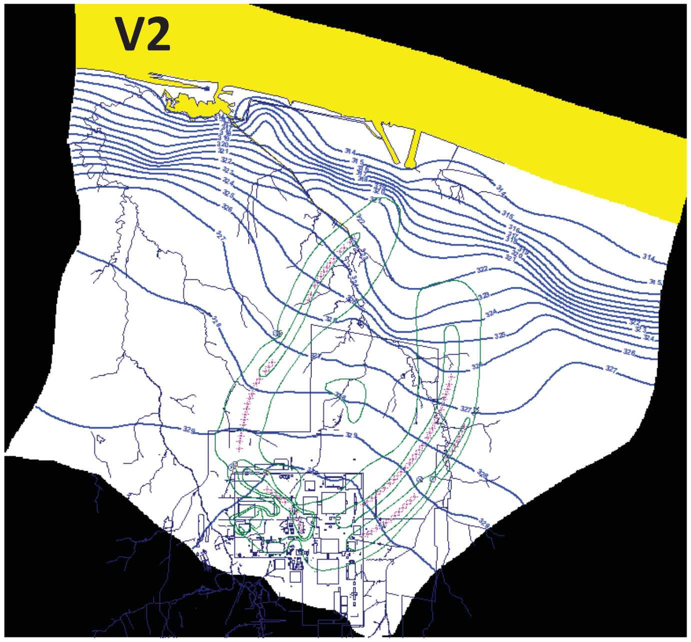


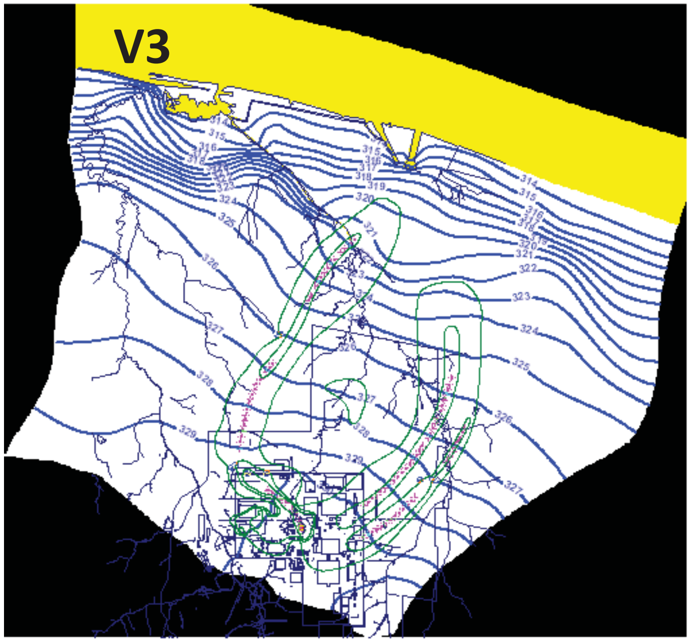


Calibration Results – Potentiometric Surface

1Q 2007, Ohio River Stage – 313.0 ft msl

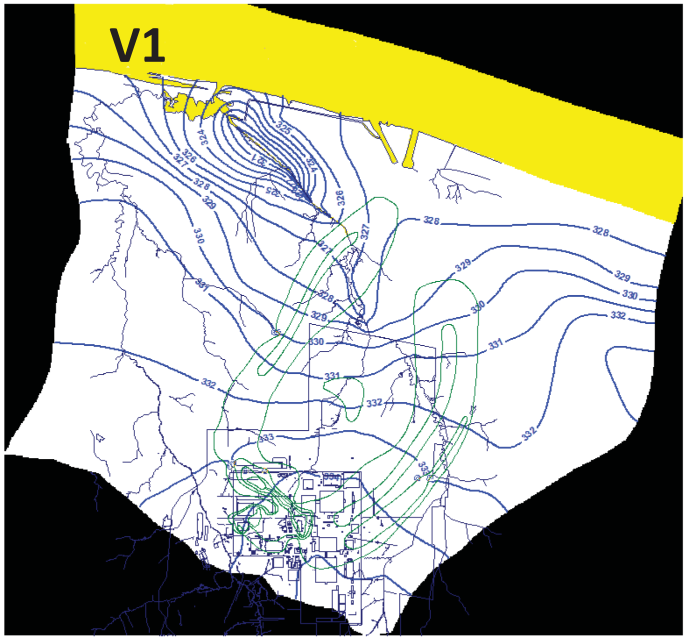


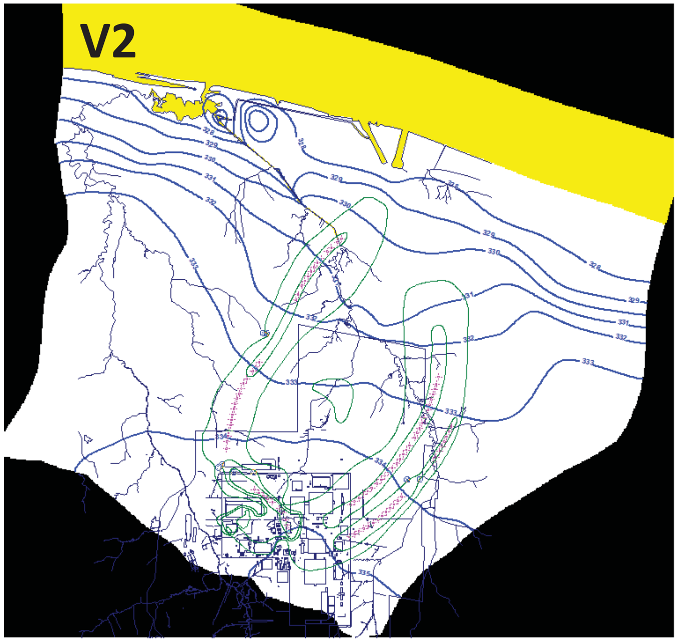


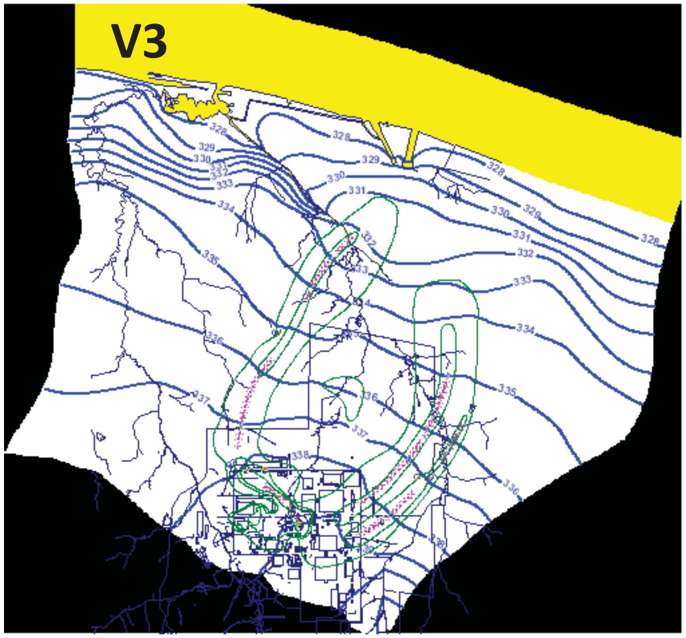


Calibration Results – Potentiometric Surface

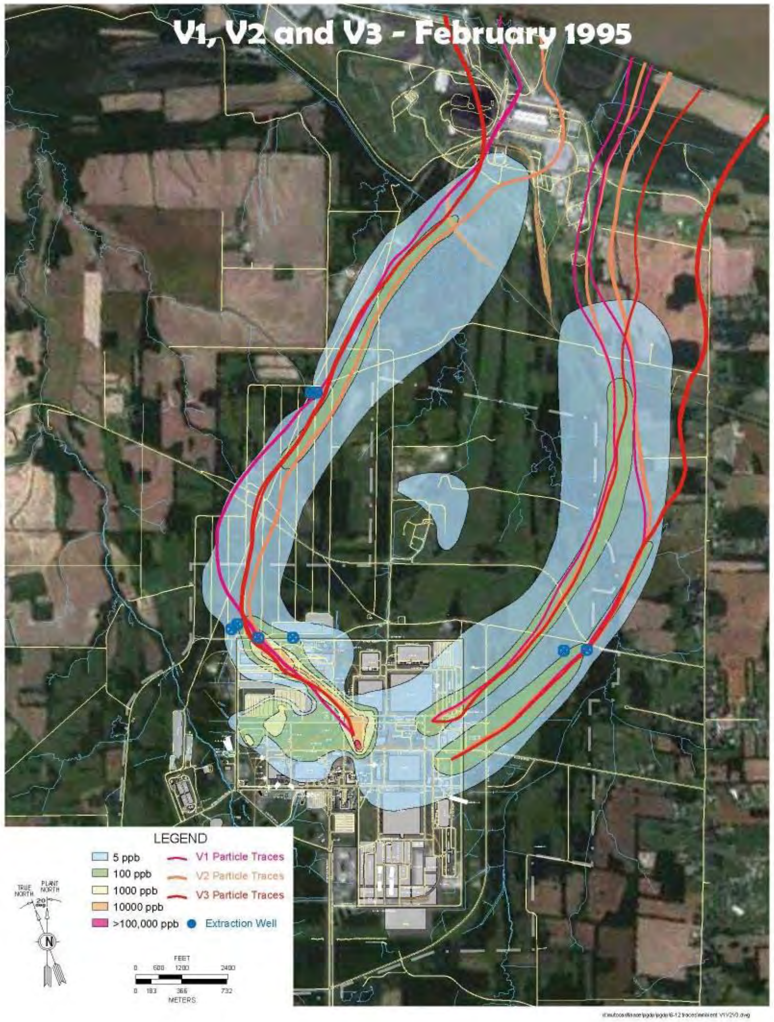
April 2010, Ohio River Stage – 327.2 ft msl

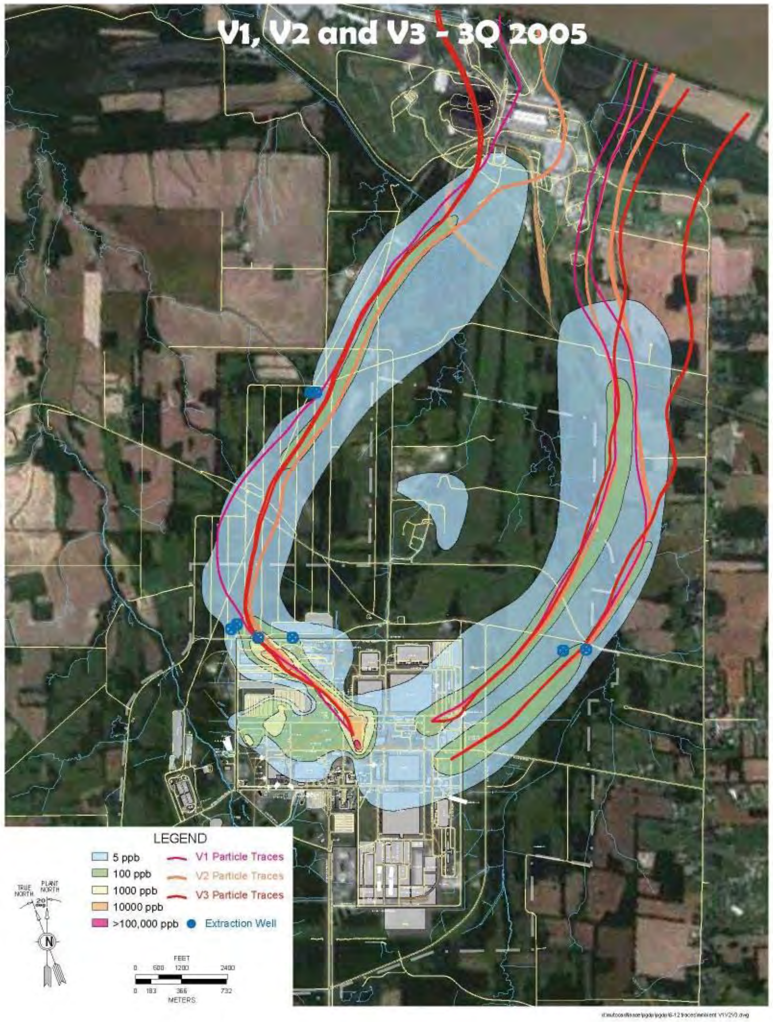




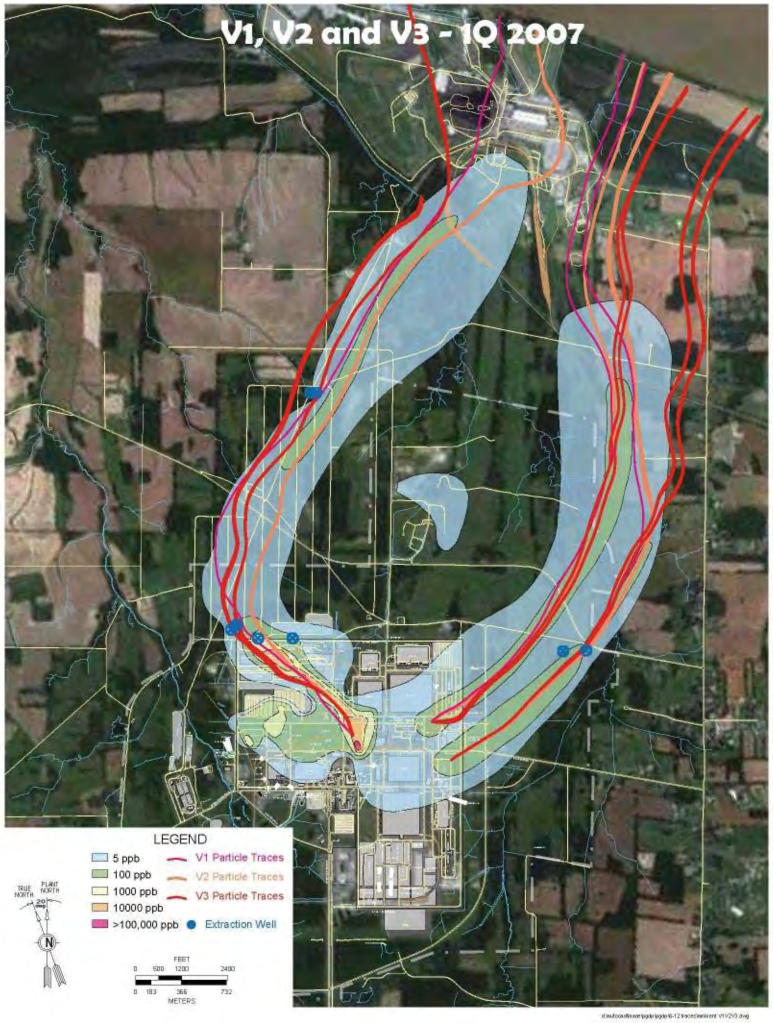


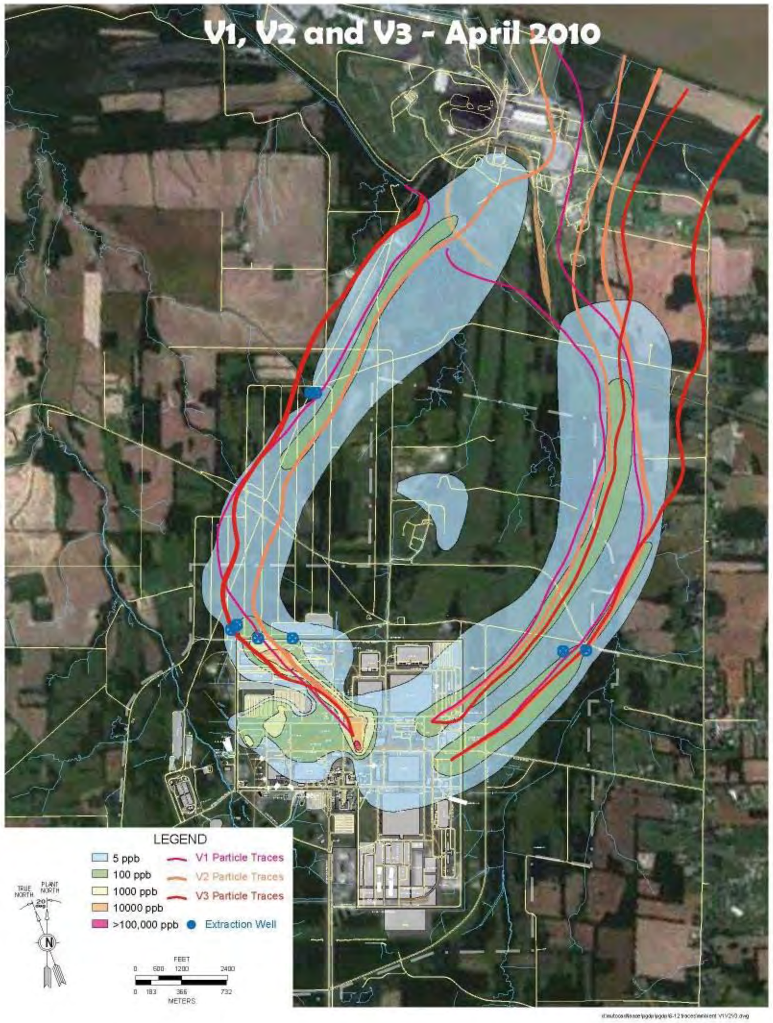
Model-Predicted Ambient Particle Traces



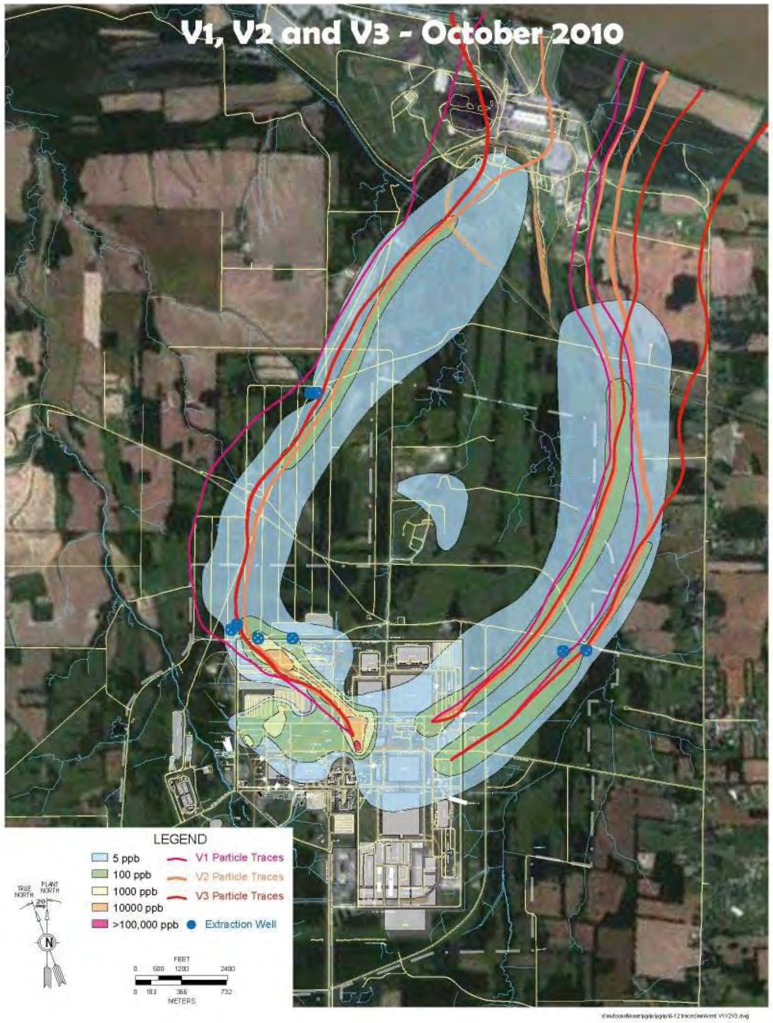


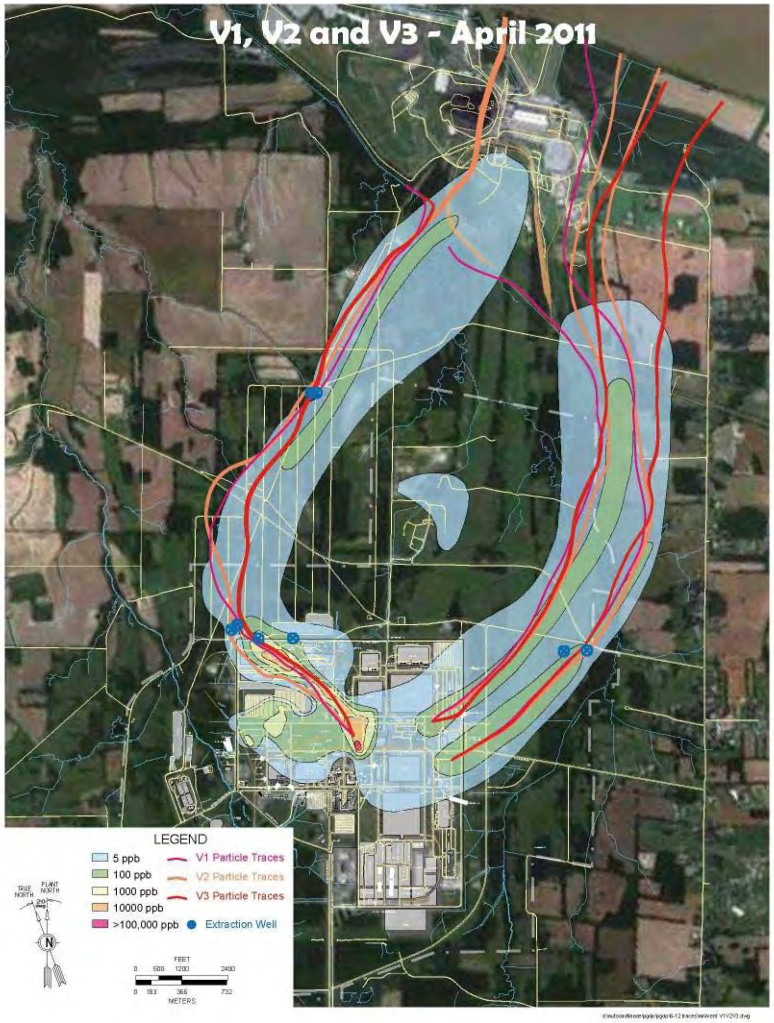
Model-Predicted Ambient Particle Traces



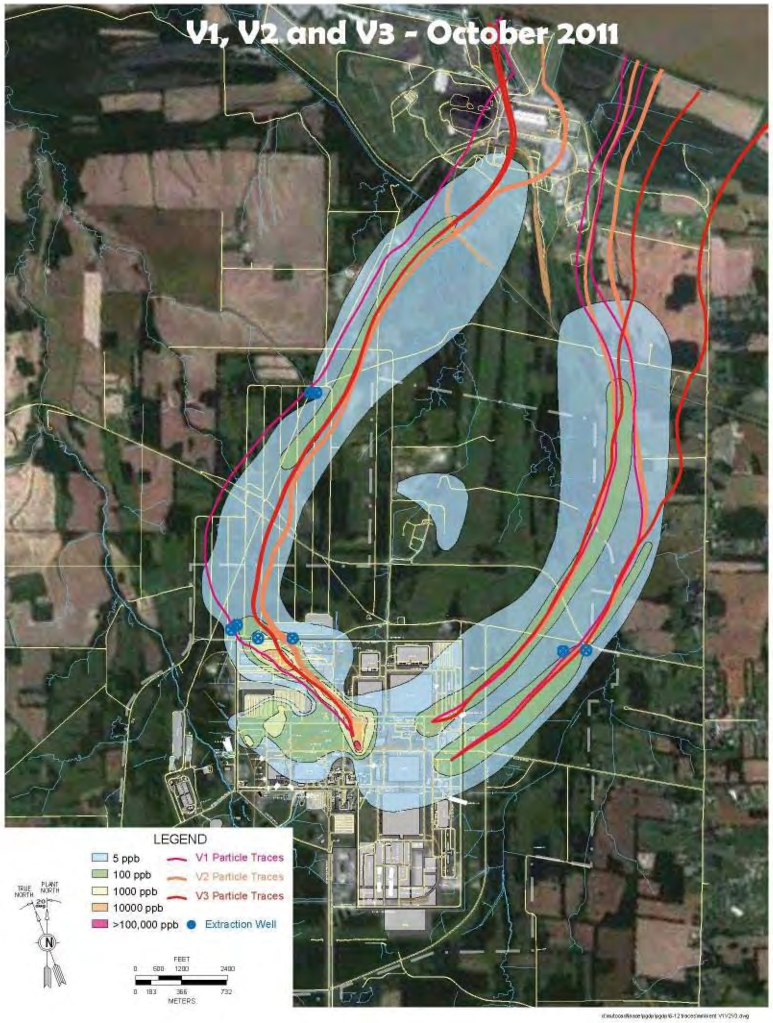


Model-Predicted Ambient Particle Traces

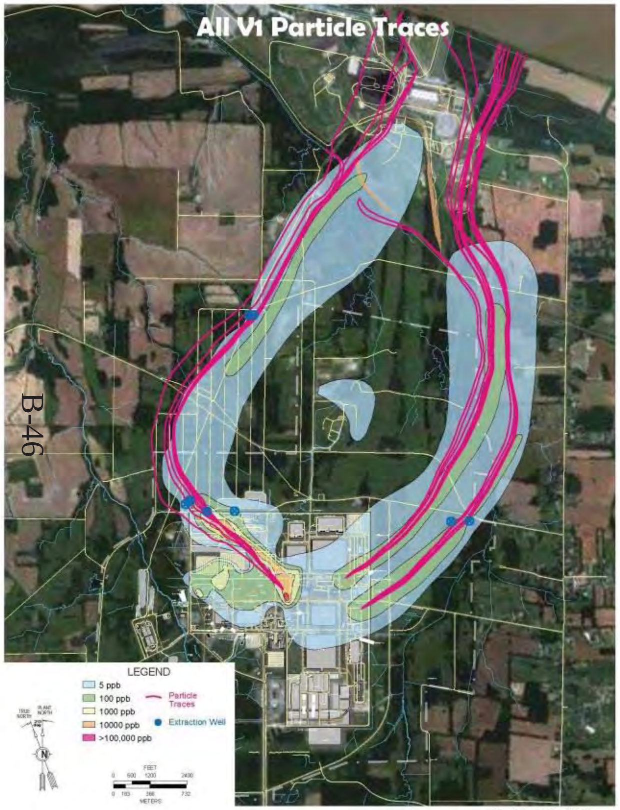


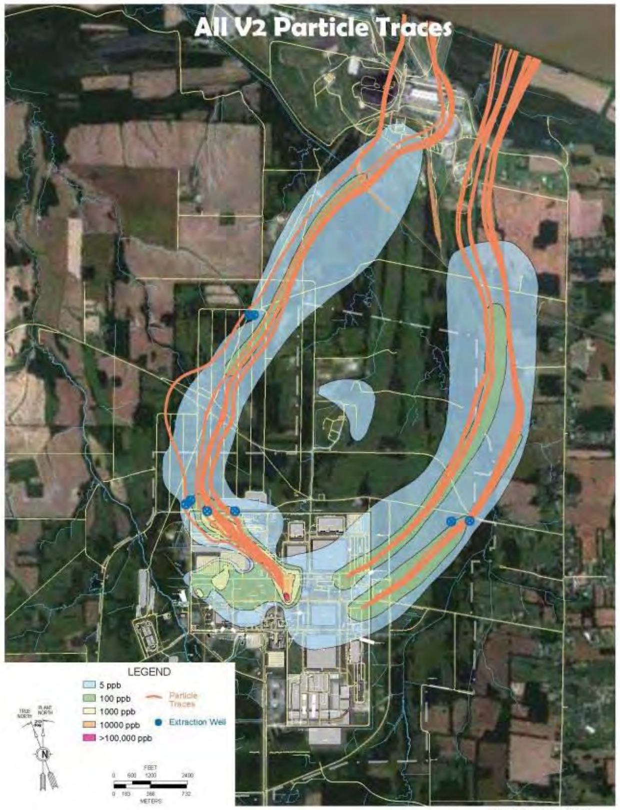


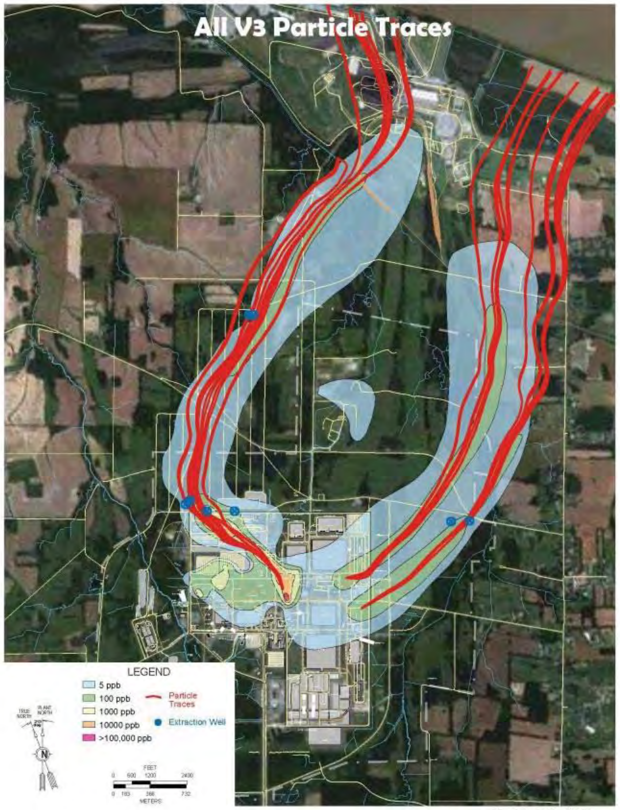
Model-Predicted Ambient Particle Traces



Model-Predicted Ambient Particle Traces







Summary

- All three models reasonably represent the PGDP groundwater flow system
- Model variants 2 and 3 better match the NW Plume trajectory than model variant 1
- Model variants 1 and 2 better match NE Plume trajectory than model variant 3
- Based on the above two bullets, model variant 2 is the “best”

Summary

- Models predict anthropogenic recharge varies between 491 and 1,758 gpm
- Variability in anthropogenic recharge doesn’t significantly effect groundwater flow directions at the PGDP
- To reduce head residuals will require finer discretization of recharge

Evaluations Performed Using the Updated PGDP Model

Evaluations Performed Using the Updated PGDP Model

- Evaluate the performance of the new NW Plume extraction wells under variable anthropogenic recharge conditions
- Design and evaluate the new Northwest Plume extraction system
- Understanding TCE presence and concentrations downgradient of extraction wells 232 and 233
- Miscellaneous – not presented
  - Simulate expected drawdown for new NE Plume extraction well system to help determine which wells to monitor for drawdown
  - Backwards particle tracking from monitoring wells to determine upgradient area monitored

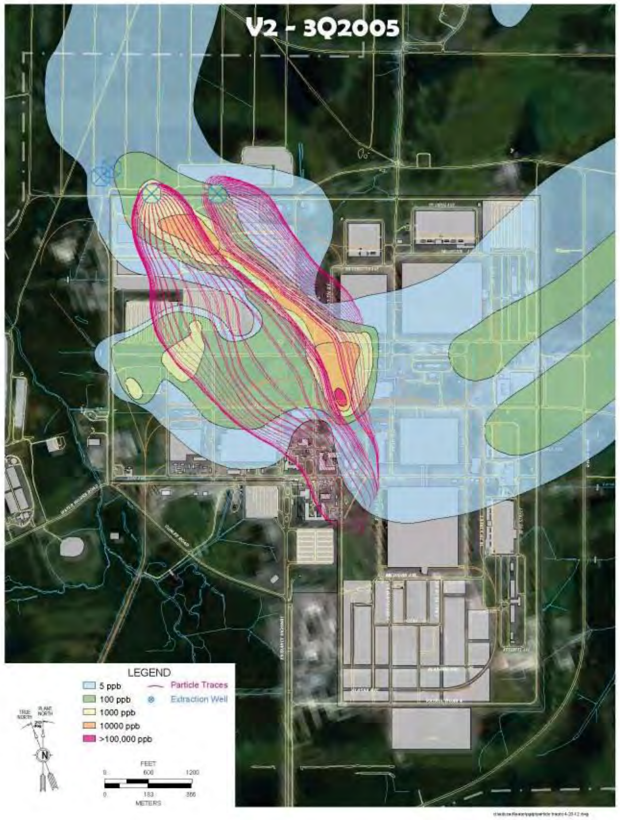
Evaluation of NW Plume Extraction System Using Updated Model

Evaluation of NW Plume Extraction System Using Updated Model

- Performed evaluation to characterize performance of the system under updated model recharge and hydraulic conductivity regimes
- Are system adjustments required?

Model Variant 2 NW Plume Extraction System Capture Zone Evaluation

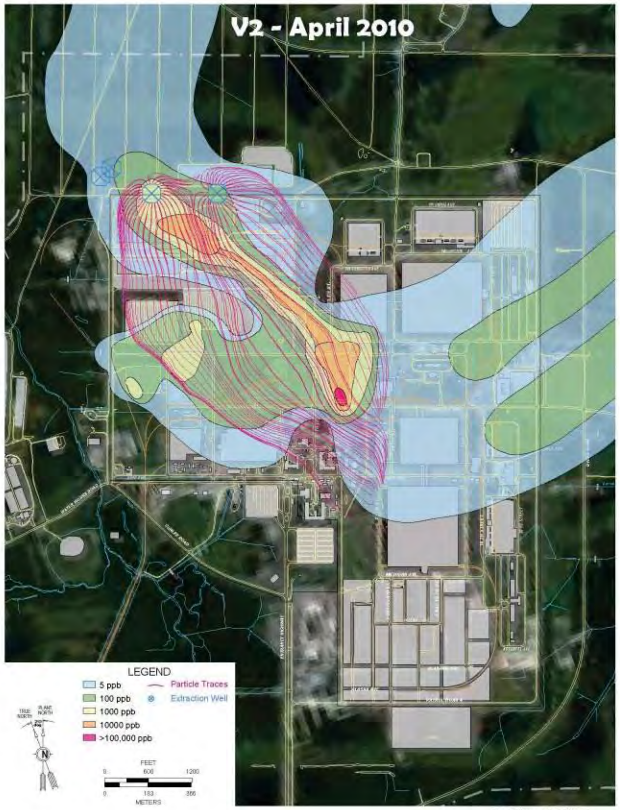

V2 - February 1995

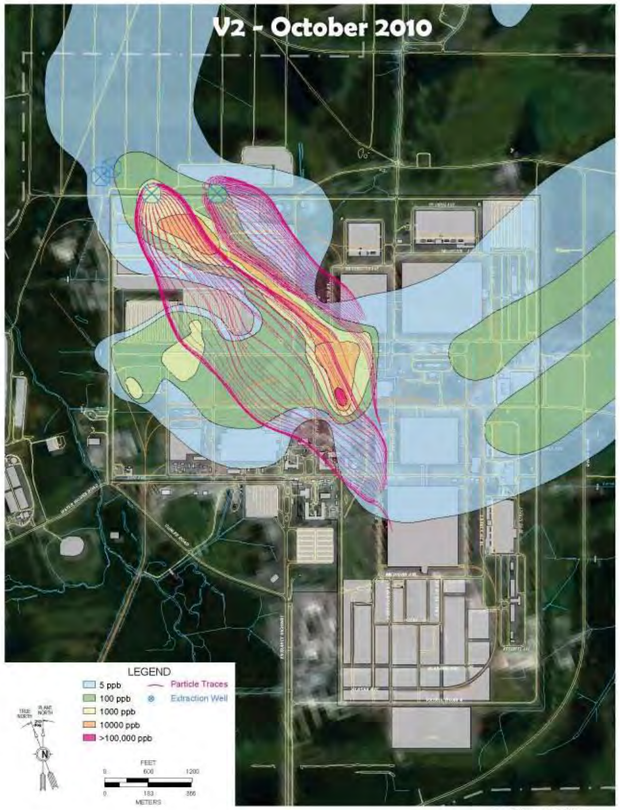

V2 - 3Q2005


V2 - 1Q2007

Date	Anthropogenic Recharge, gpm		
	V1	V2	V3
Feb 1995	884	1,152	1,442
3Q 2005	1,204	1,337	1,525
1Q 2007	931	1,042	1,048
April 2010	1,065	678	978
Oct 2010	977	1,317	1,725
April 2011	831	599	491
Oct 2011	1,148	1,420	1,758
Mean	1,006	1,078	1,281
Median	977	1,152	1,442

Model Variant 2 NW Plume Extraction System Capture Zone Evaluation





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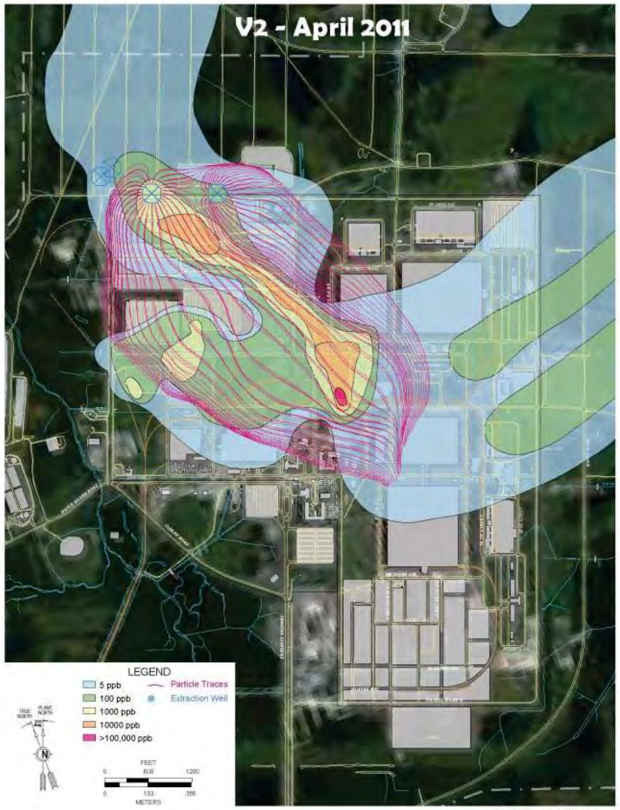

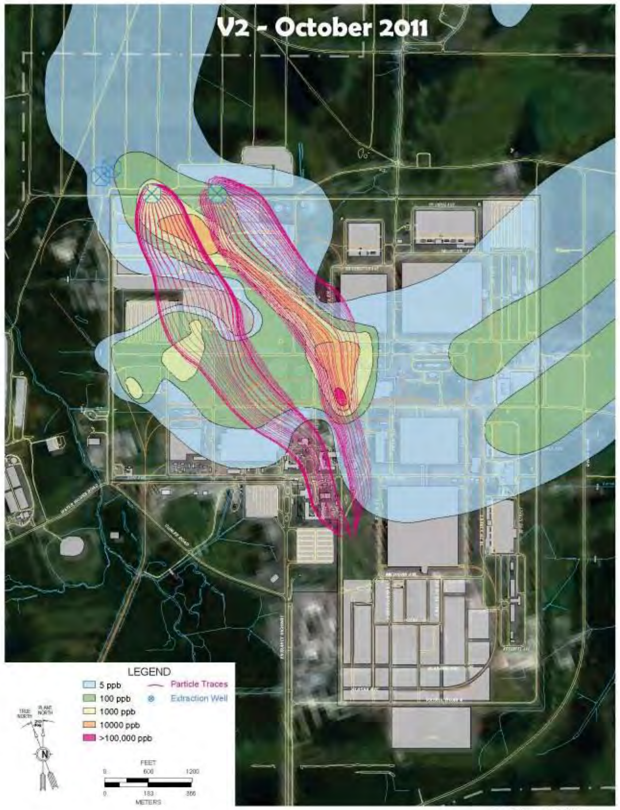

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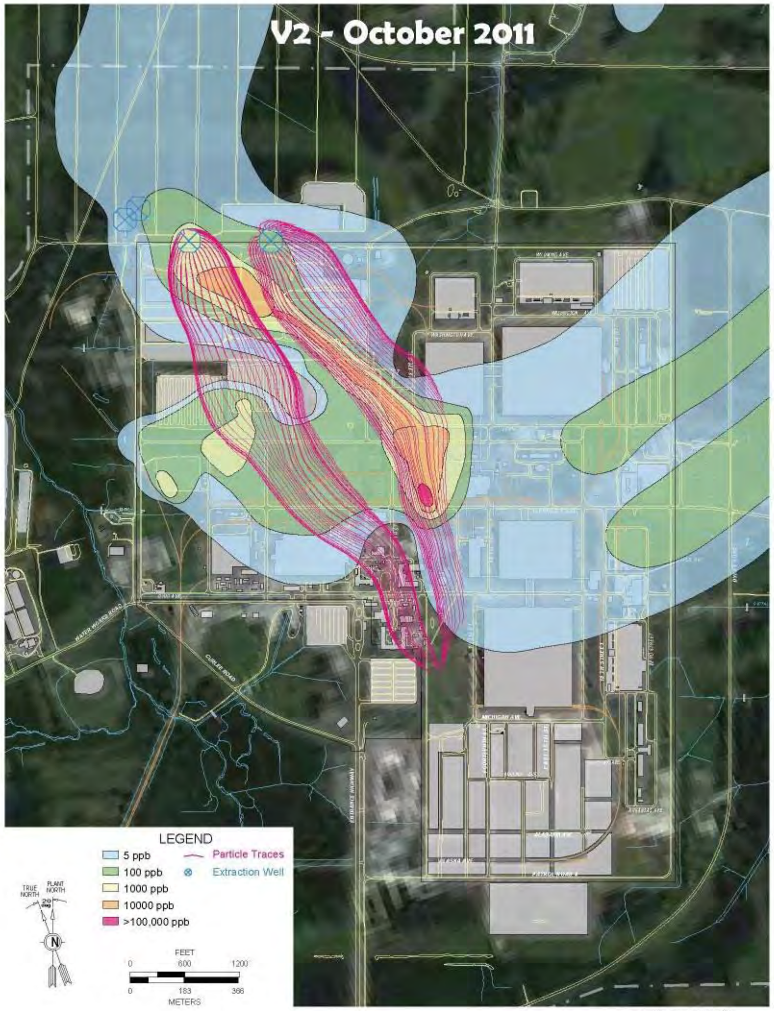
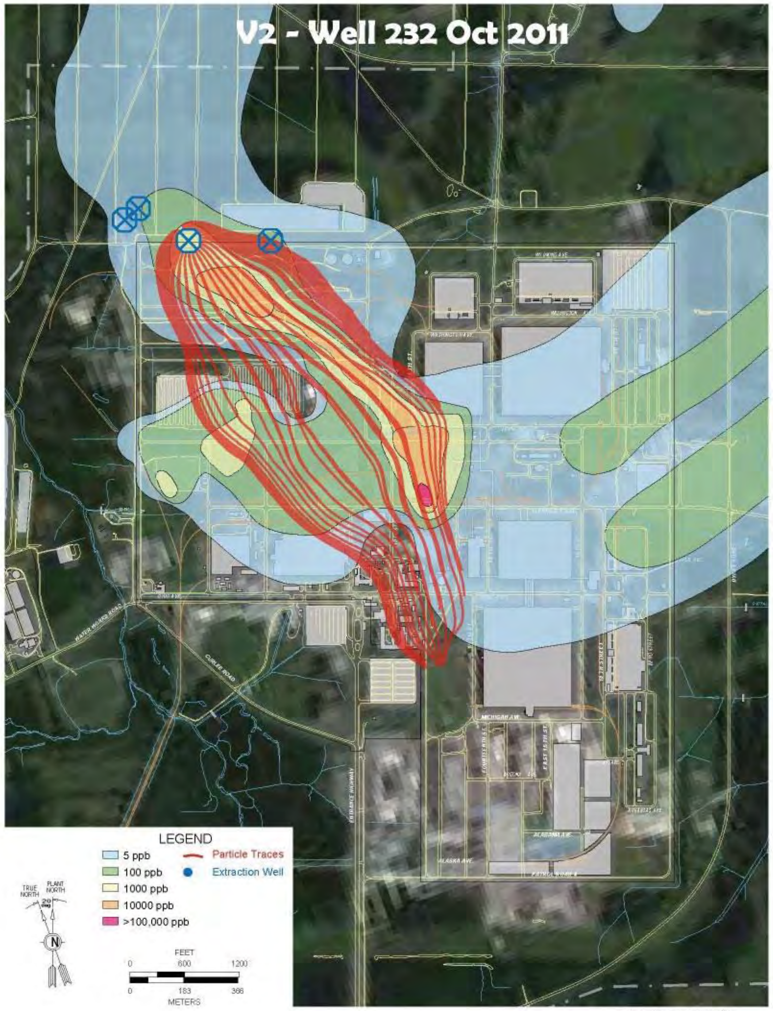
New NW Plume Extraction Well Capture Zone Evaluation Summary

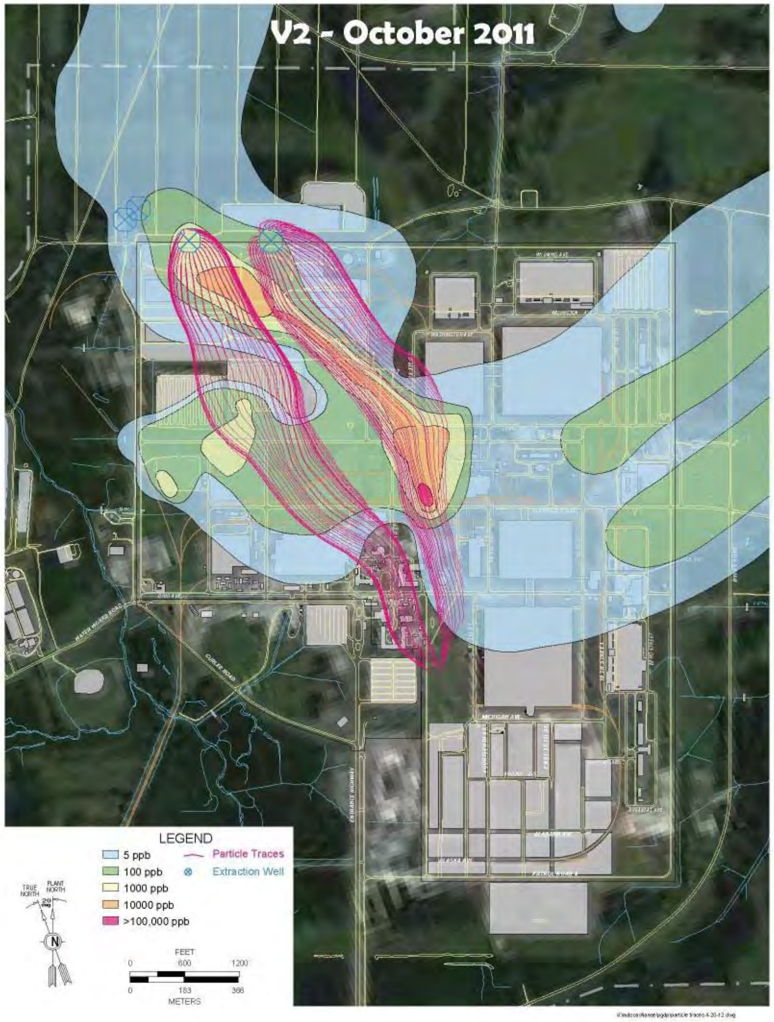
- Capture zone width and orientation is a function of the volume and location of anthropogenic recharge
- Each of the 7 modeled periods represents a snap shot in time of anthropogenic recharge conditions
- Reality is anthropogenic recharge is constantly changing between these realizations and possibly beyond the simulated values
- There is no way to know which of the anthropogenic recharge scenarios is dominant
- **The challenge is to design a robust extraction system that accounts for anthropogenic recharge variability**

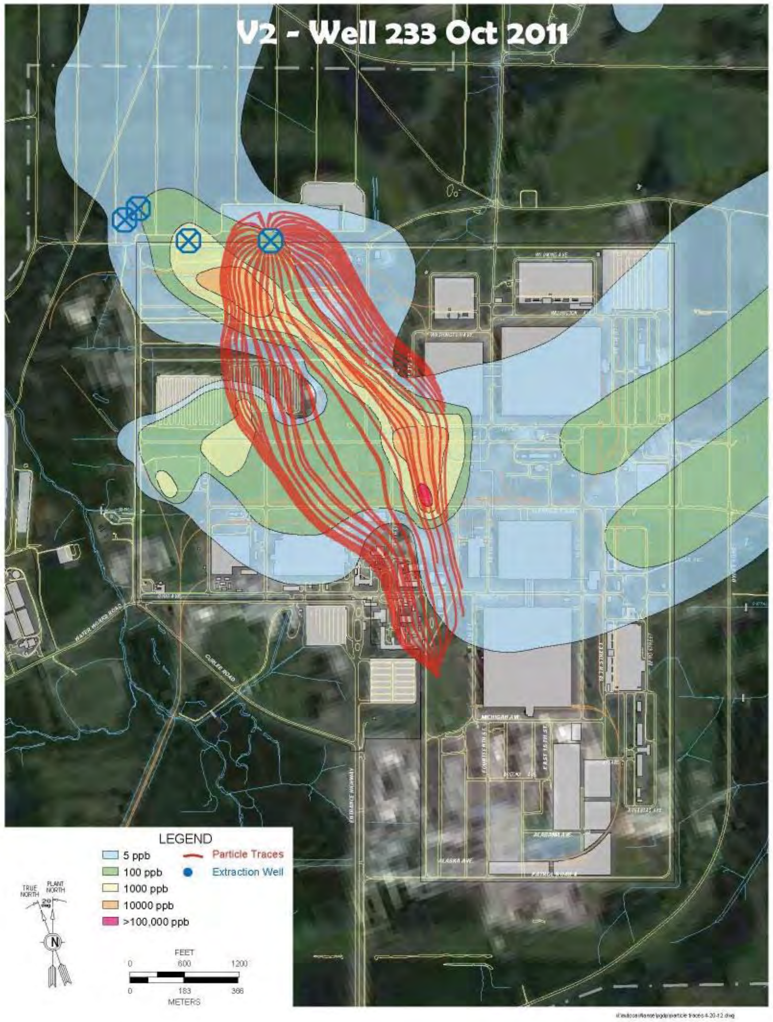
EW 232 Capture at 220 gpm





EW 233 Capture at 220 gpm





Model Variant 2 NW Plume Extraction System Capture Zone Evaluation

- Operate individually either EW232 or EW233 at 220 gpm (current treatment capacity)
- Individual capture zones envelope C400, the primary source of NW Plume dissolved contamination
- NE Plume designs will assume either EW232 or EW233 will be operational, but not both

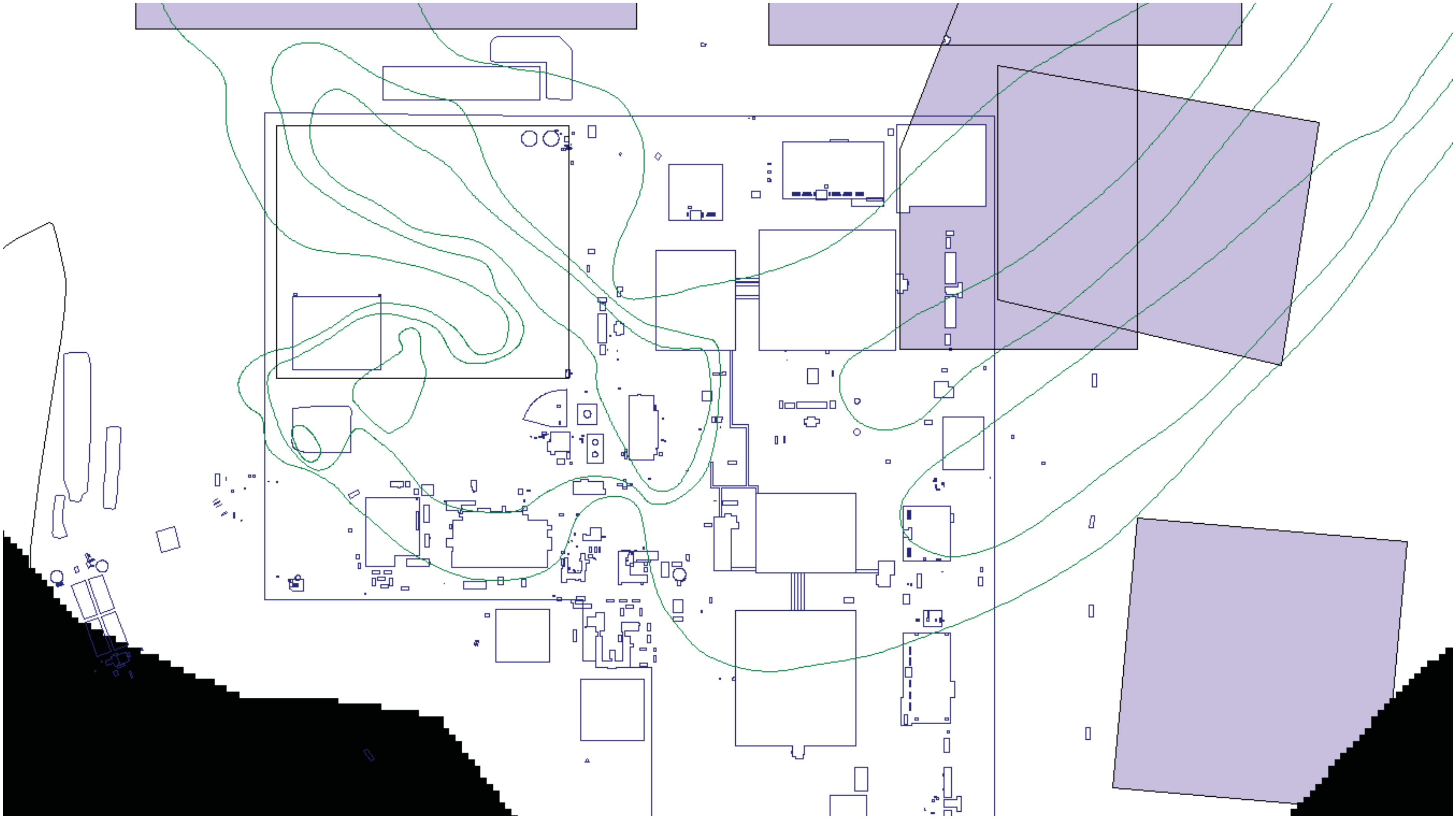
Design and Evaluation of NE Plume Extraction System

NE Plume Extraction System Design Constraints

- Minimize trajectory impacts at C400
- Complement NW Extraction Well capture zones
- Avoid potential CERCLA Cell locations
- Manage anthropogenic recharge variability
- Design for both anthropogenic and no anthropogenic recharge conditions to the extent possible (PGDP vs Post-PGDP)

NOTE: There is uncertainty associated with Post-PGDP conditions

Potential CERCLA Cell Locations

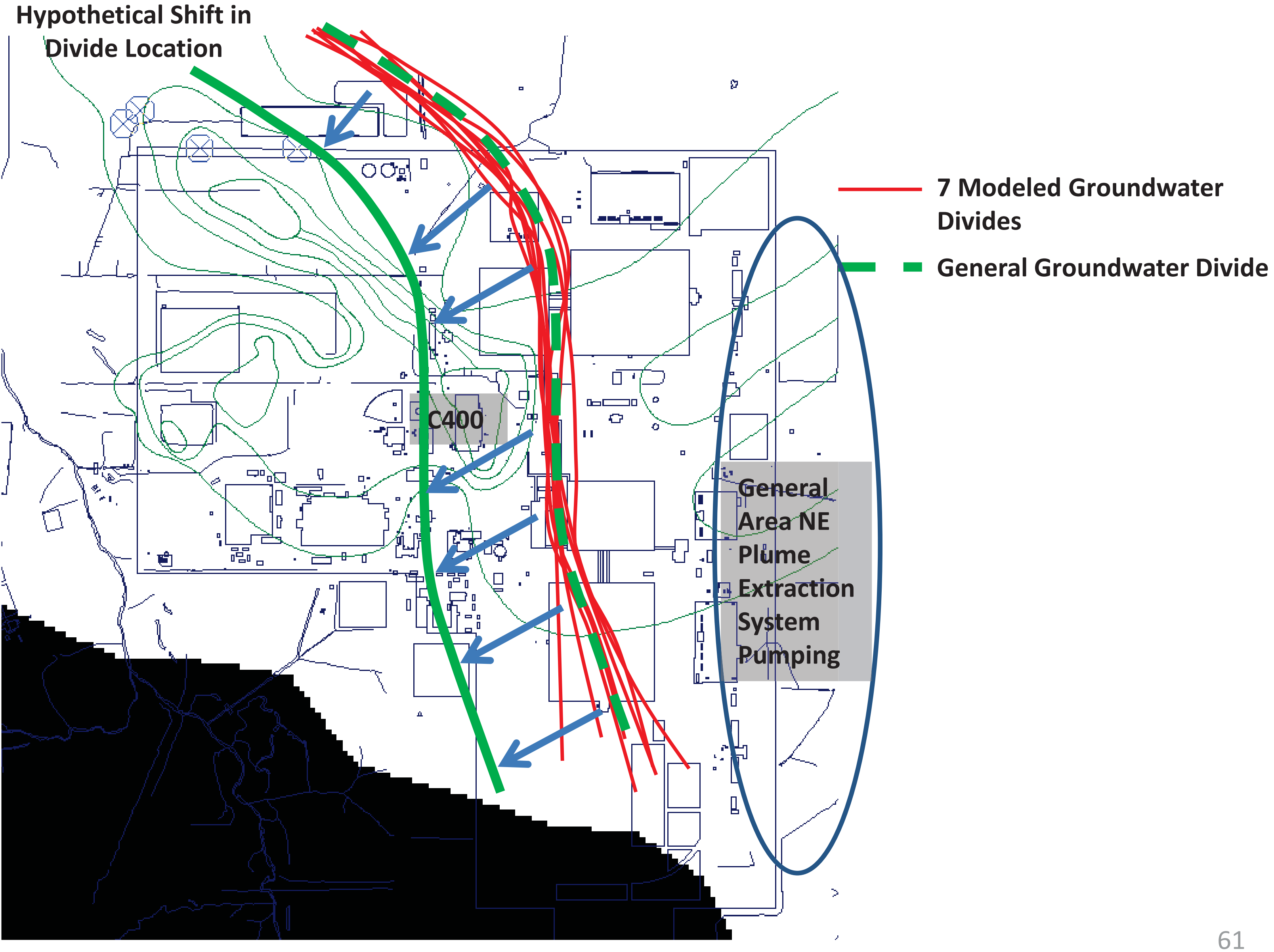


▨ Potential CERCLA Cell Locations

Maintain NW Plume Trajectory

Do not want to shift the divide location westward in response to pumping

Doing so will cause higher concentration portions of the plume to flow eastward and contaminate lower concentration portions of the RGA

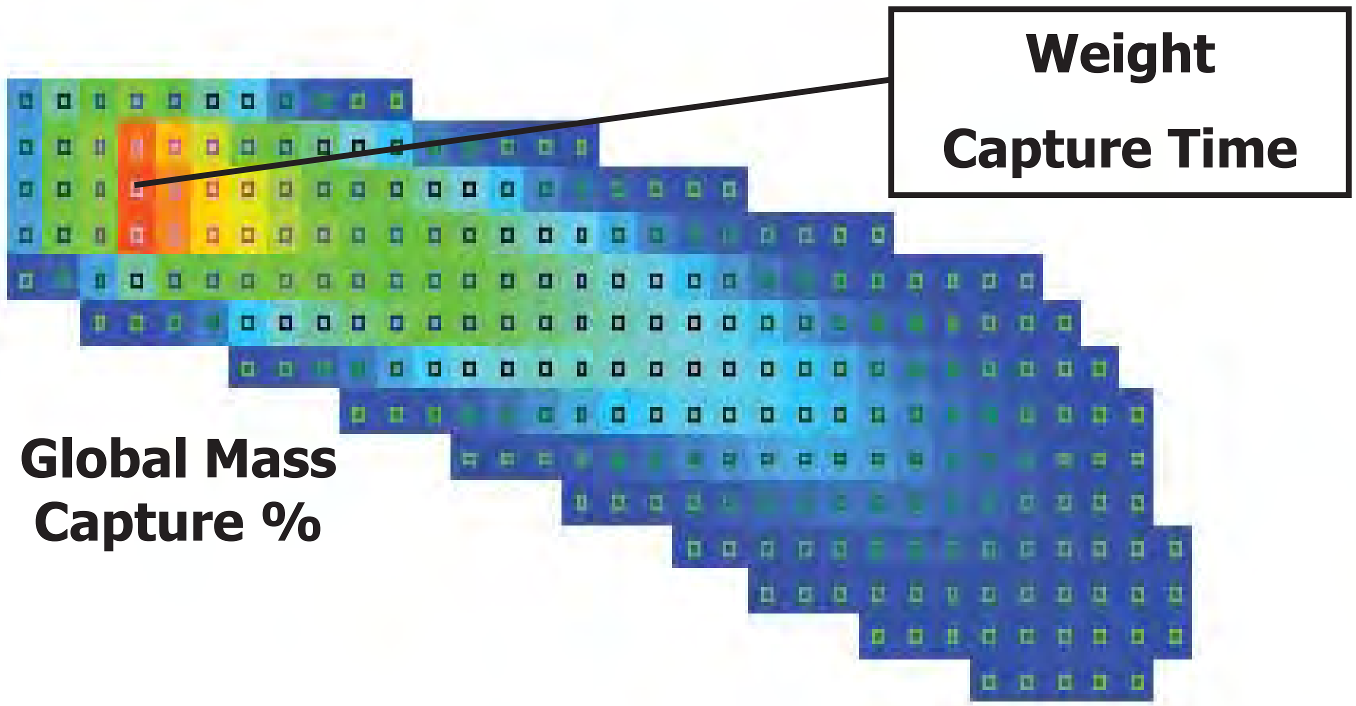


Design and Evaluation of NE Plume Extraction System

- Use Version 2 Calibrated Model, October 2011 Recharge Regime for Design and Evaluation
- October 2011 Represents Maximum Anthropogenic Recharge
- Use *Brute Force* Particle Tracking Optimization Algorithm, Same as was Used for NW Plume Extraction System Design

Code: Brute Force

- Developed by Laase and Rumbaugh
- Sequential MODFLOW and MODPATH runs
- Uses particles as surrogates for contamination
- Constraint is global mass capture percentage



Code: Brute Force

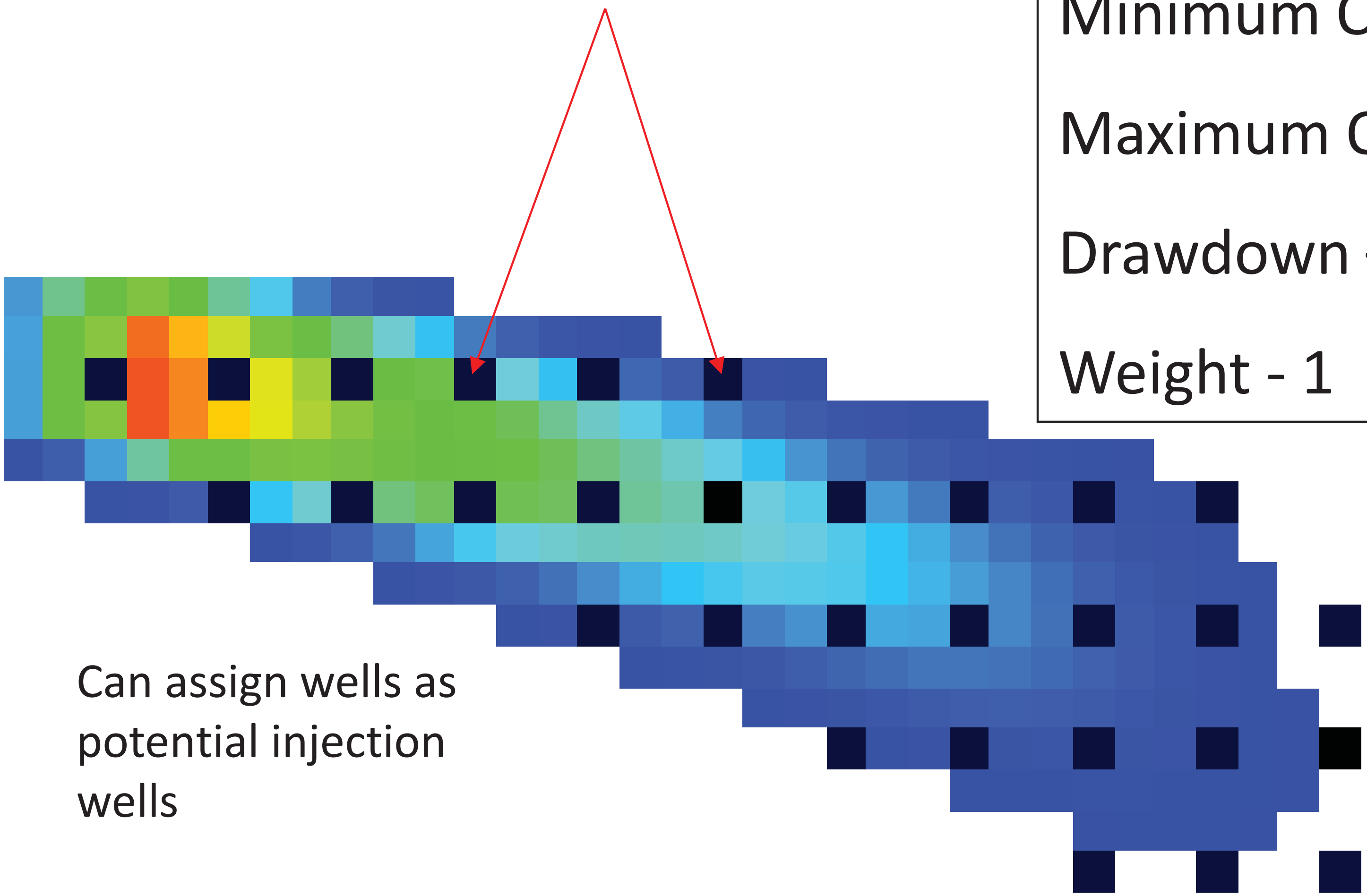
Unit stimuli – 100 gpm

Minimum Q – 20 gpm

Maximum Q - 200 gpm

Drawdown – 3 ft

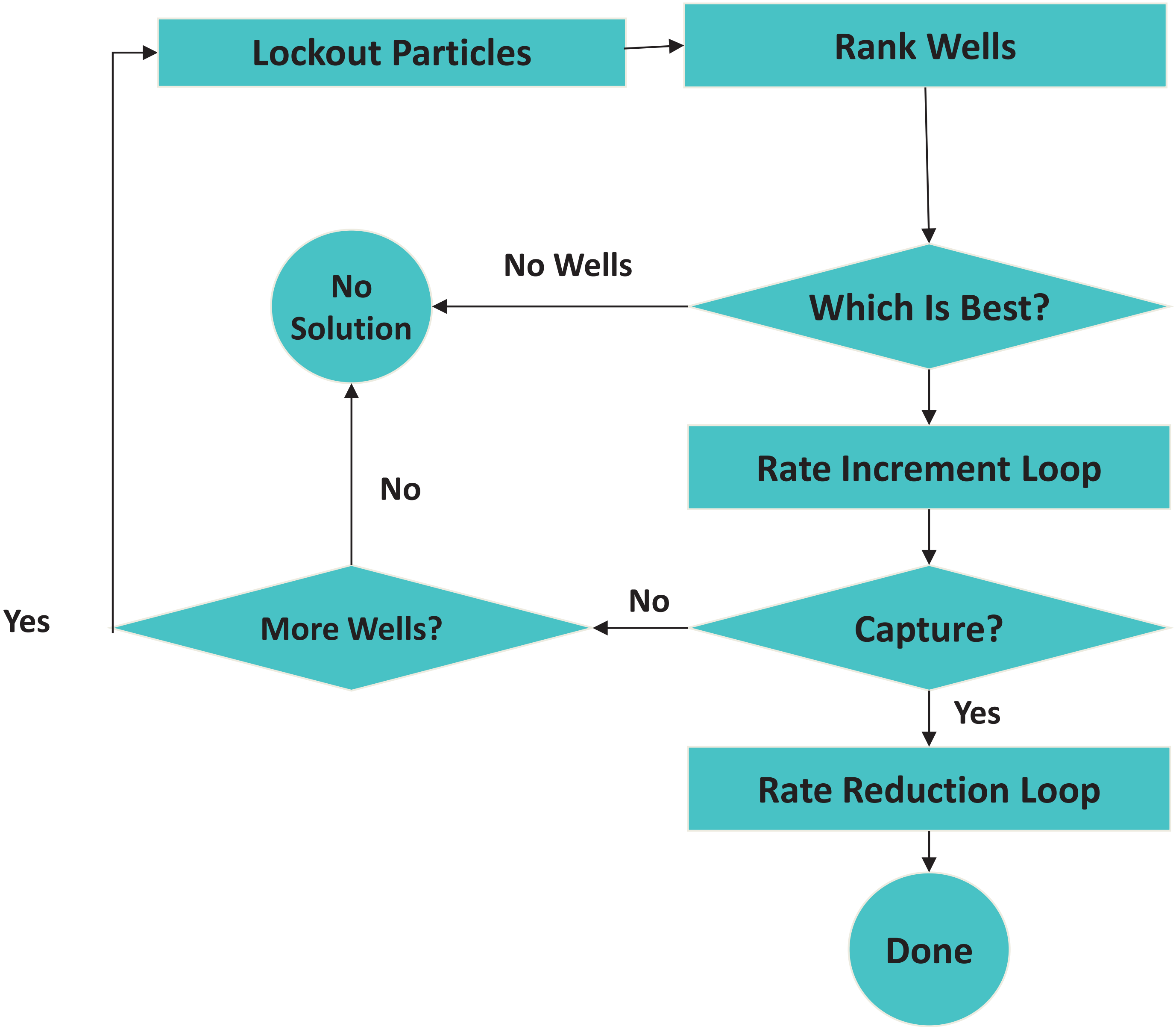
Weight - 1



Candidate Wells

Can assign wells as potential injection wells

Brute Force Algorithm



Find the well that captures the most particles with one simulation per well.

Systematically increase the rate for the chosen well to see if complete capture can be achieved.

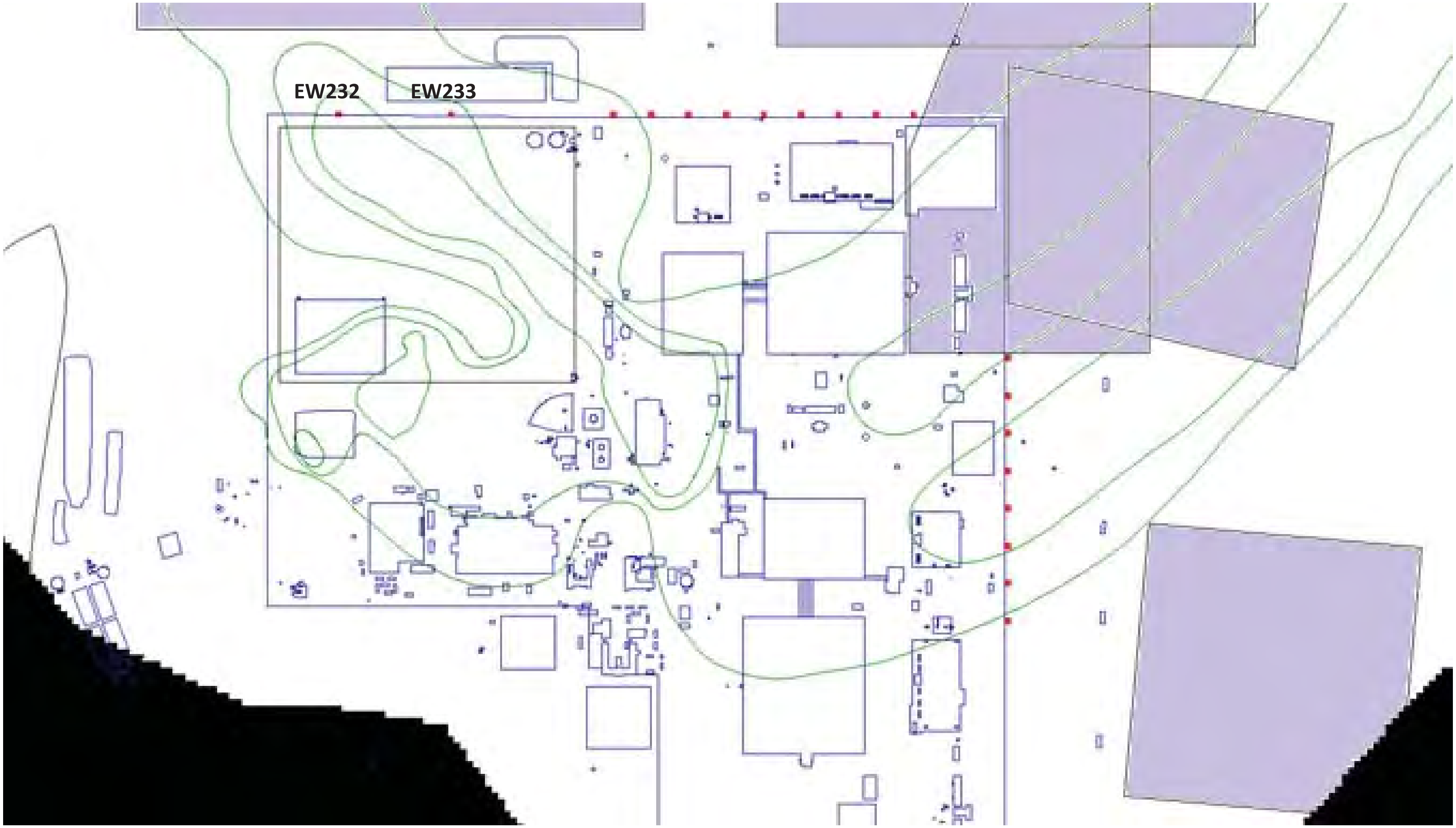
Systematically decrease the rates for all chosen wells to see if capture can be maintained at
lower pumping rate.

Design and Evaluation of NE Plume Extraction System

- After Developing a NE Plume Well Field Configuration and Pumping Schedule Using Maximum Anthropogenic Recharge Conditions, Evaluate the Design using Minimum and Average Anthropogenic Recharge Regimes and Post-PGDP Recharge Regimes
- **NOTE:** Dozens of Extraction Well Configurations Were Evaluated, Only a Few Relevant Designs Will Be Presented

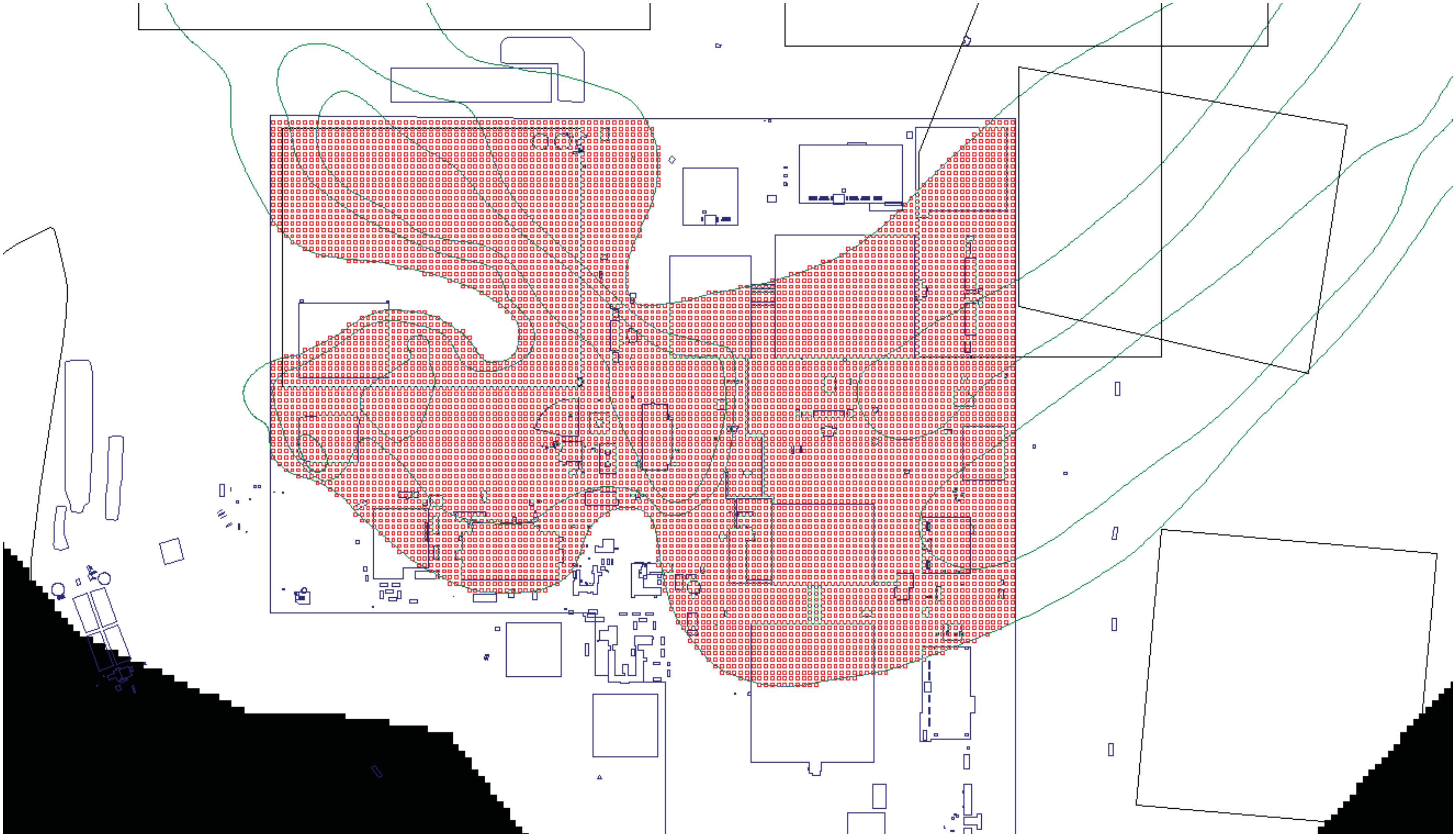
NE Extraction Wells Along Fence Line

Candidate Well Locations

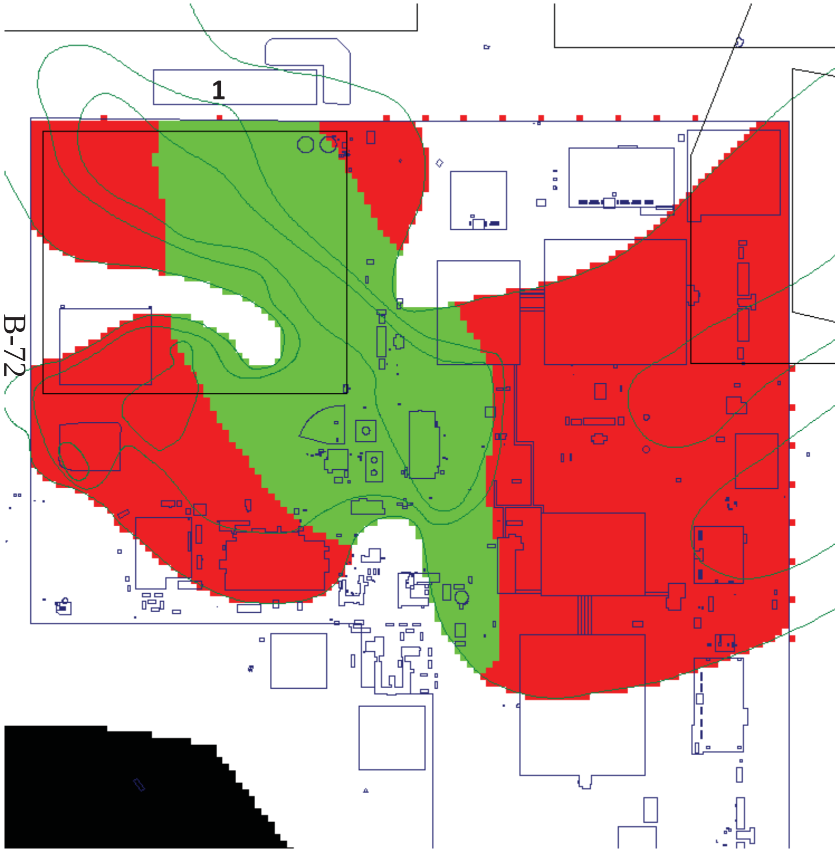


▨ **Proposed CERCLA Cell Locations** 🟥 **Candidate Well Locations**

Particles Representing Dissolved Mass



NE Extraction System Design and Evaluation



🟥 Not Captured 🟩 Captured

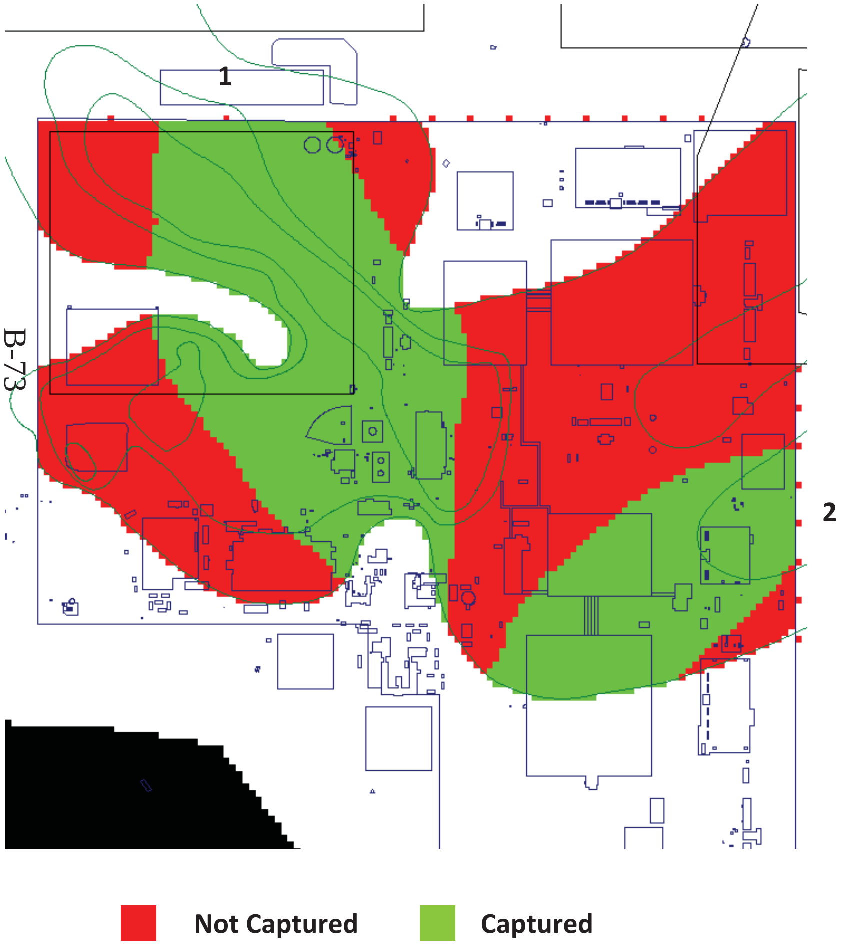
Pumping Rate, gpm

Well	Iteration						
	1	2	3	4	5	6	7
1	**220**	220	220	220	220	220	220
2		250	250	250	250	250	250
3			250	250	250	250	250
4				250	250	250	250
5					250	250	250
6						250	250
7							250
TOTAL	**220**	470	720	970	1,220	1,470	1,720

Mass Captured

Well	Iteration						
	1	2	3	4	5	6	7
1	**88.2%**	83.4%	51.4%	32.4%	29.0%	27.3%	24.6%
2		0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
3			42.2%	5.9%	0.9%	0.5%	0.5%
4				44.9%	42.3%	32.9%	30.1%
5					20.7%	0.3%	0.5%
6						37.9%	43.7%
7							0.2%
TOTAL	**88.2%**	83.8%	94.0%	83.6%	93.3%	99.3%	99.9%

NE Extraction System Design and Evaluation



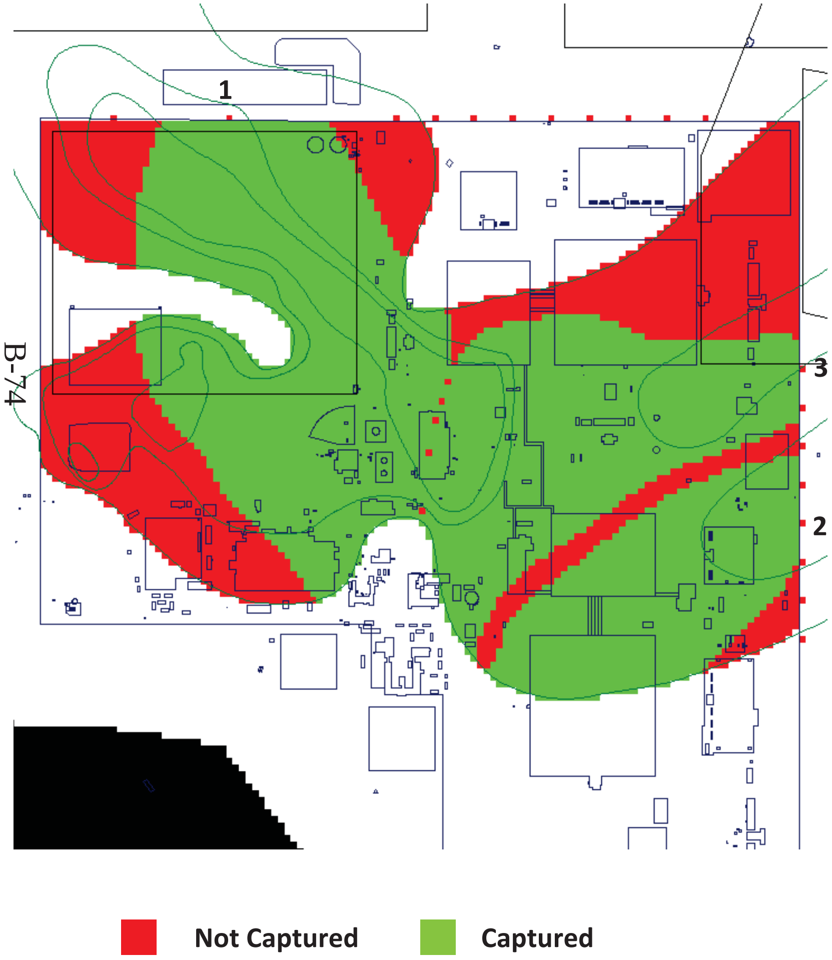
Pumping Rate, gpm

Well	Iteration						
	1	**2**	3	4	5	6	7
1	220	**220**	220	220	220	220	220
2		**250**	250	250	250	250	250
3			250	250	250	250	250
4				250	250	250	250
5					250	250	250
6						250	250
7							250
TOTAL	220	**470**	720	970	1,220	1,470	1,720

Mass Captured

Well	Iteration						
	1	**2**	3	4	5	6	7
1	88.2%	**83.4%**	51.4%	32.4%	29.0%	27.3%	24.6%
2		**0.4%**	0.4%	0.4%	0.4%	0.4%	0.4%
3			42.2%	5.9%	0.9%	0.5%	0.5%
4				44.9%	42.3%	32.9%	30.1%
5					20.7%	0.3%	0.5%
6						37.9%	43.7%
7							0.2%
TOTAL	88.2%	**83.8%**	94.0%	83.6%	93.3%	99.3%	99.9%

NE Extraction System Design and Evaluation



Pumping Rate, gpm

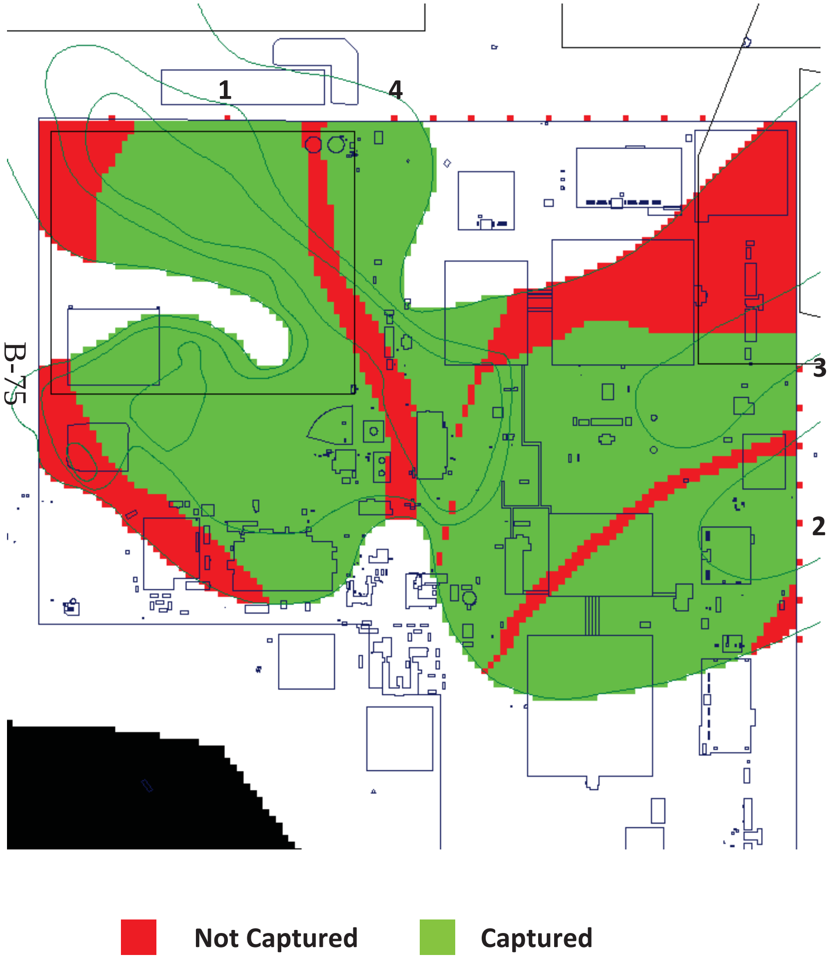
Well	Iteration						
	1	2	**3**	4	5	6	7
1	220	220	**220**	220	220	220	220
2		250	**250**	250	250	250	250
3			**250**	250	250	250	250
4				250	250	250	250
5					250	250	250
6						250	250
7							250
TOTAL	220	470	**720**	970	1,220	1,470	1,720

Mass Captured

Well	Iteration						
	1	2	**3**	4	5	6	7
1	88.2%	83.4%	**51.4%**	32.4%	29.0%	27.3%	24.6%
2		0.4%	**0.4%**	0.4%	0.4%	0.4%	0.4%
3			**42.2%**	5.9%	0.9%	0.5%	0.5%
4				44.9%	42.3%	32.9%	30.1%
5					20.7%	0.3%	0.5%
6						37.9%	43.7%
7							0.2%
TOTAL	88.2%	83.8%	**94.0%**	83.6%	93.3%	99.3%	99.9%

Violated Design Tenant: Maintain NW Plume Trajectory

NE Extraction System Design and Evaluation



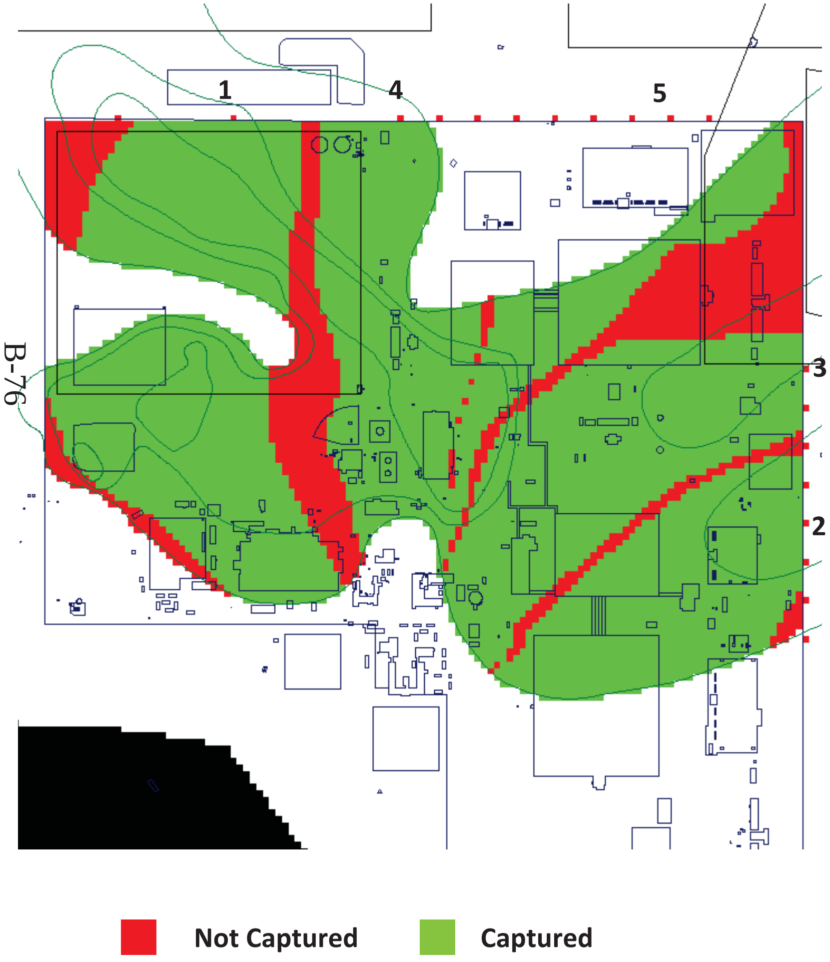
Pumping Rate, gpm

Well	Iteration						
	1	2	3	**4**	5	6	7
1	220	220	220	**220**	220	220	220
2		250	250	**250**	250	250	250
3			250	**250**	250	250	250
4				**250**	250	250	250
5					250	250	250
6						250	250
7							250
TOTAL	220	470	720	**970**	1,220	1,470	1,720

Mass Captured

Well	Iteration						
	1	2	3	**4**	5	6	7
1	88.2%	83.4%	51.4%	**32.4%**	29.0%	27.3%	24.6%
2		0.4%	0.4%	**0.4%**	0.4%	0.4%	0.4%
3			42.2%	**5.9%**	0.9%	0.5%	0.5%
4				**44.9%**	42.3%	32.9%	30.1%
5					20.7%	0.3%	0.5%
6						37.9%	43.7%
7							0.2%
TOTAL	88.2%	83.8%	94.0%	**83.6%**	93.3%	99.3%	99.9%

NE Extraction System Design and Evaluation



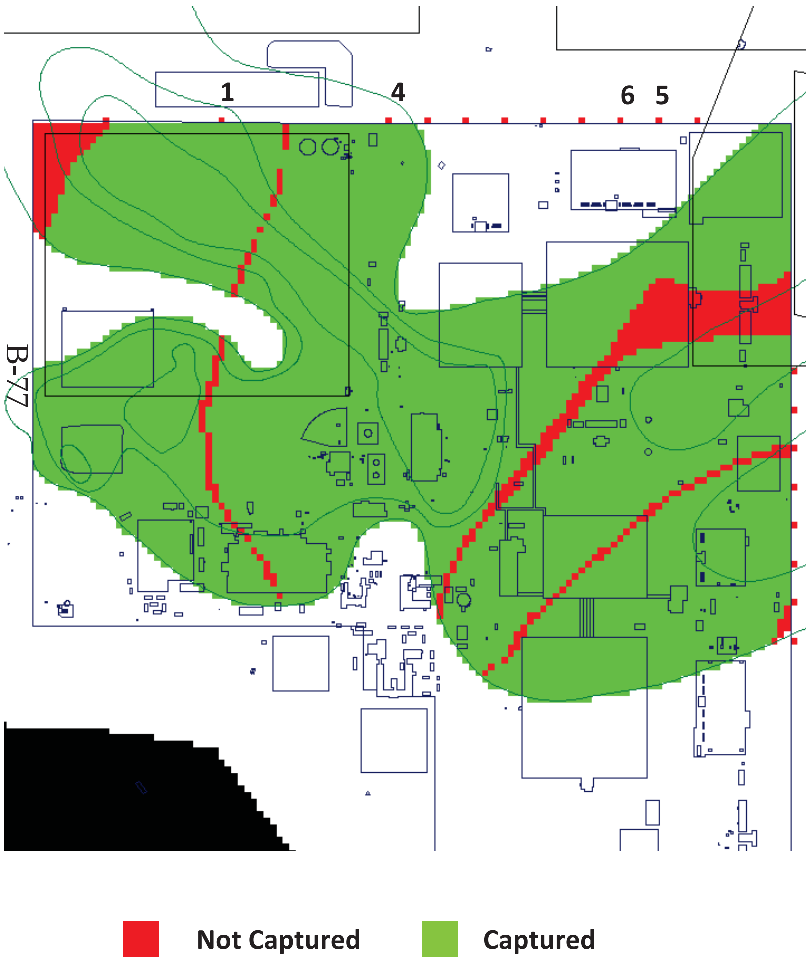
Pumping Rate, gpm

Well	Iteration						
	1	2	3	4	**5**	6	7
1	220	220	220	220	**220**	220	220
2		250	250	250	**250**	250	250
3			250	250	**250**	250	250
4				250	**250**	250	250
5					**250**	250	250
6						250	250
7							250
TOTAL	220	470	720	970	**1,220**	1,470	1,720

Mass Captured

Well	Iteration						
	1	2	3	4	**5**	6	7
1	88.2%	83.4%	51.4%	32.4%	**29.0%**	27.3%	24.6%
2		0.4%	0.4%	0.4%	**0.4%**	0.4%	0.4%
3			42.2%	5.9%	**0.9%**	0.5%	0.5%
4				44.9%	**42.3%**	32.9%	30.1%
5					**20.7%**	0.3%	0.5%
6						37.9%	43.7%
7							0.2%
TOTAL	88.2%	83.8%	94.0%	83.6%	**93.3%**	99.3%	99.9%

NE Extraction System Design and Evaluation



Pumping Rate, gpm

Well	Iteration						
	1	2	3	4	5	**6**	7
1	220	220	220	220	220	**220**	220
2		250	250	250	250	**250**	250
3			250	250	250	**250**	250
4				250	250	**250**	250
5					250	**250**	250
6						**250**	250
7							250
TOTAL	220	470	720	970	1,220	**1,470**	1,720

Mass Captured

Well	Iteration						
	1	2	3	4	5	**6**	7
1	88.2%	83.4%	51.4%	32.4%	29.0%	**27.3%**	24.6%
2		0.4%	0.4%	0.4%	0.4%	**0.4%**	0.4%
3			42.2%	5.9%	0.9%	**0.5%**	0.5%
4				44.9%	42.3%	**32.9%**	30.1%
5					20.7%	**0.3%**	0.5%
6						**37.9%**	43.7%
7							0.2%
TOTAL	88.2%	83.8%	94.0%	83.6%	93.3%	**99.3%**	99.9%

NE Extraction System Design and Evaluation

Pumping Rate, gpm

Well	Iteration						
	1	2	3	4	5	6	**7**
1	220	220	220	220	220	220	**220**
2		250	250	250	250	250	**250**
3			250	250	250	250	**250**
4				250	250	250	**250**
5					250	250	**250**
6						250	**250**
7							**250**
TOTAL	220	470	720	970	1,220	1,470	**1,720**

Mass Captured

Well	Iteration						
	1	2	3	4	5	6	**7**
1	88.2%	83.4%	51.4%	32.4%	29.0%	27.3%	**24.6%**
2		0.4%	0.4%	0.4%	0.4%	0.4%	**0.4%**
3			42.2%	5.9%	0.9%	0.5%	**0.5%**
4				44.9%	42.3%	32.9%	**30.1%**
5					20.7%	0.3%	**0.5%**
6						37.9%	**43.7%**
7							**0.2%**
TOTAL	88.2%	83.8%	94.0%	83.6%	93.3%	99.3%	**99.9%**

Summary NE Extraction Wells Along Fence Line

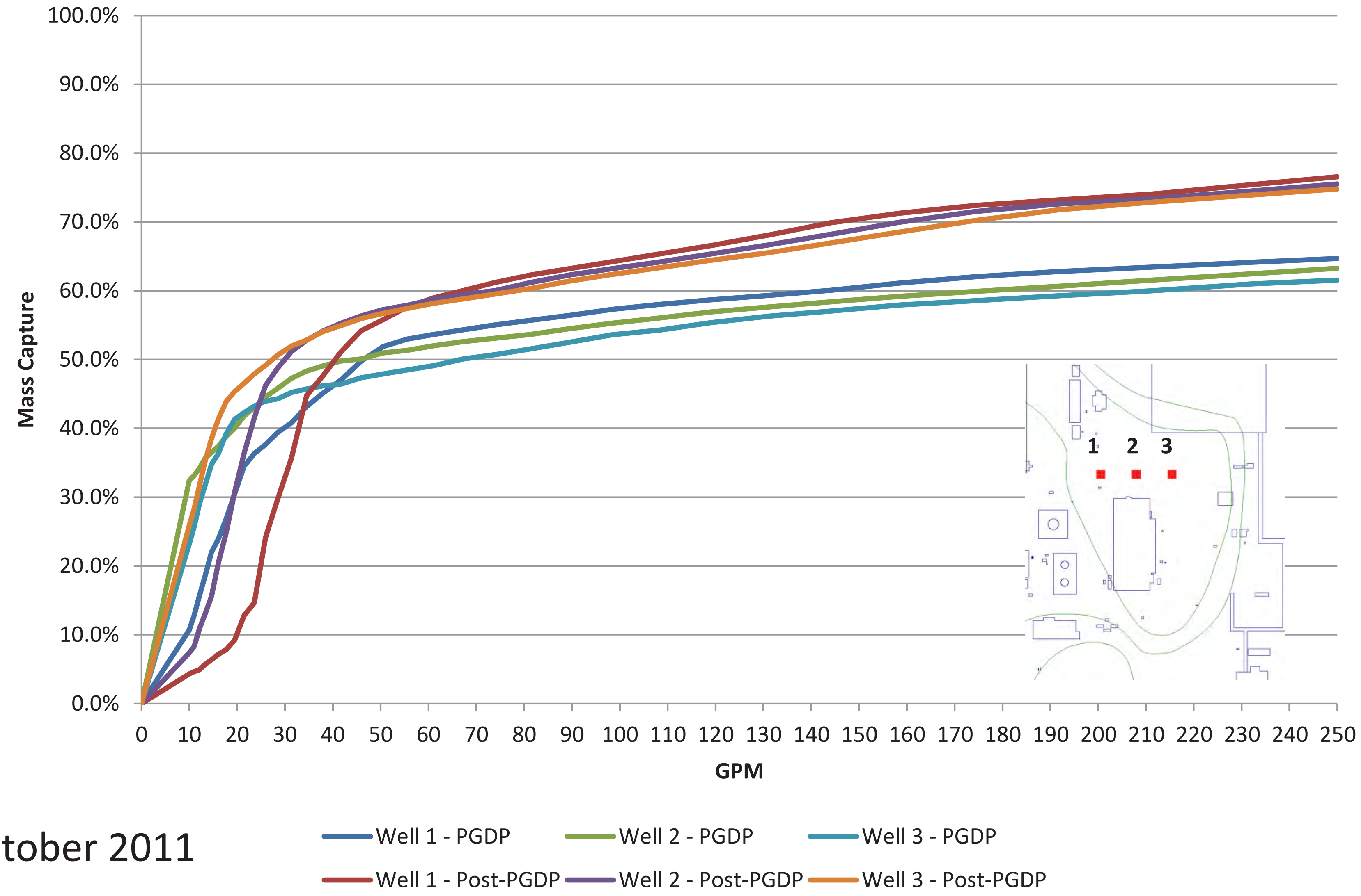
- Issues:
  - **Change NW Plume Trajectory**
  - Lots of Wells
  - High Extraction Rates
- Challenges:
  - How to keep from spreading dissolved contamination?

C400 Extraction Well Coupled with NE Extraction Wells Along Fence Line

NE Extraction System Design and Evaluation

- Is an Extraction Well Located at C400 Capable of “Pinning” Contamination at That Location?
- In Other Words, Will Use of a C400 Extraction Well Halt Unintended Spreading of Dissolved Contamination?
- How Much Should the Extraction Well be Pumped And Where Should It be Located?

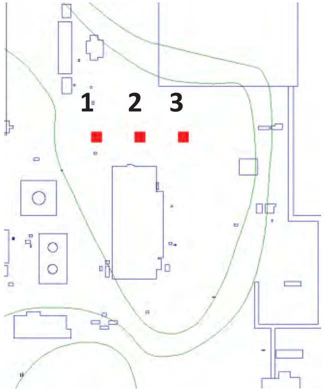
C400 Mass Capture Performance



October 2011

NE Extraction System Design and Evaluation

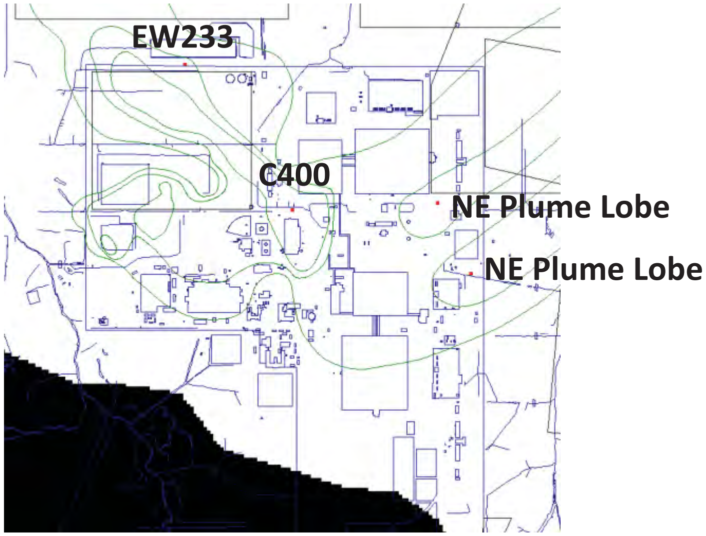
- After 60 gpm There isn't Much Difference in Mass Capture Performance Between the Three C400 Extraction Well Locations
- Evaluate Designs Which Have the C400 Extraction Well Operating at 80 gpm Because That is the Existing Treatment Capability



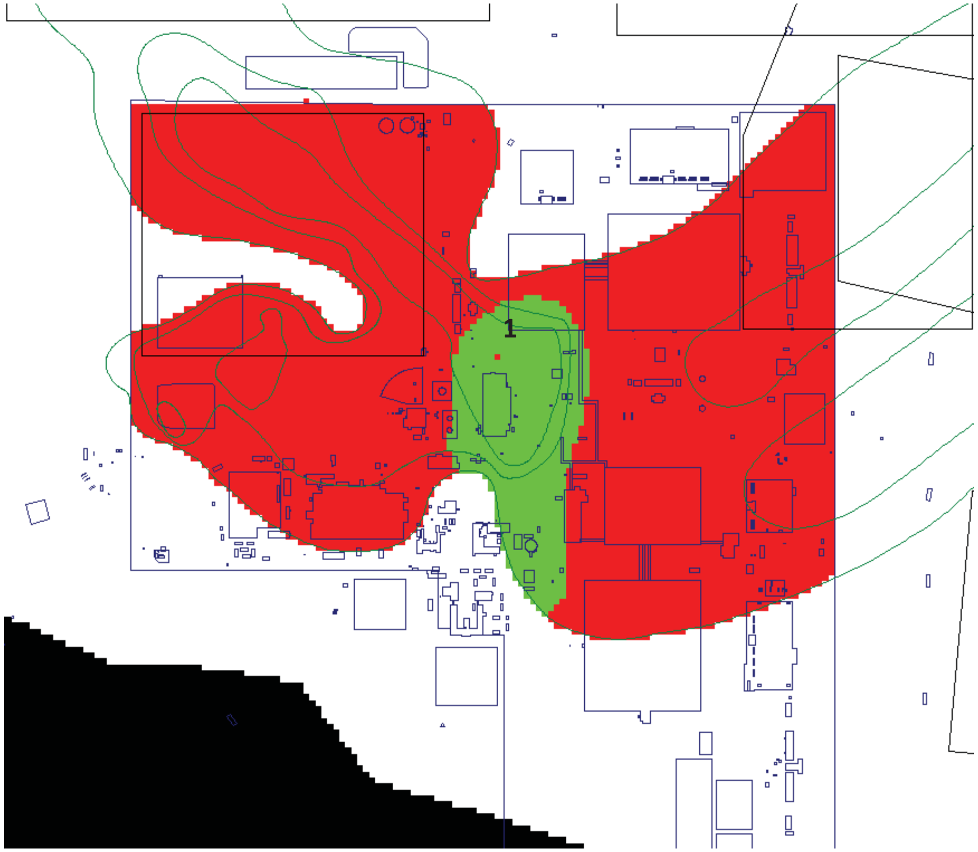
PGDP
Four Extraction Wells
EW233, C400 and 2 NE Extraction Wells at NE Plume Lobes

NE Extraction System Design and Evaluation

- Locate NE Plume Extraction Wells Immediately Down Gradient of the Higher Concentration Lobes
- Evaluate Mass Capture Performance for 50, 100, 150, 200 and 250 gpm/Well Rates



C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			50	50
4				50
Total	80	300	350	400

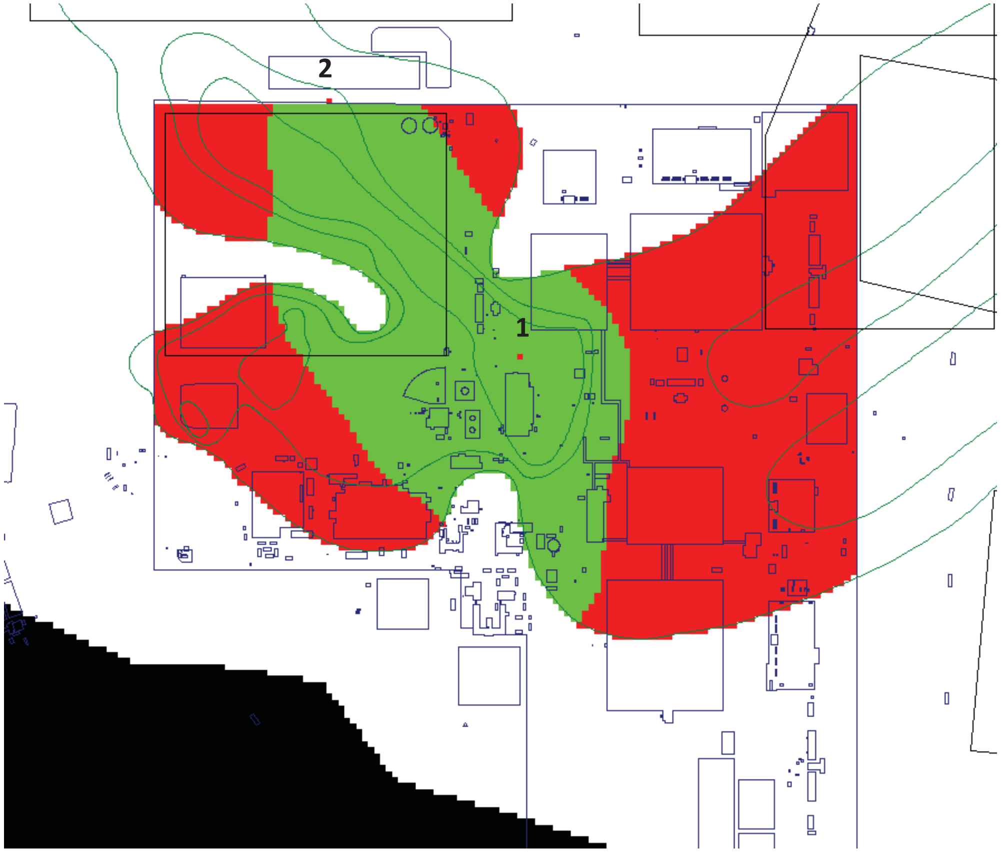
Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	51.90%	52.24%
2		37.82%	38.11%	38.67%
3			0.13%	0.13%
4				0.12%
Total	53.58%	89.50%	90.14%	91.17%

It is possible to pin C400 dissolved contamination

50 GPM

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

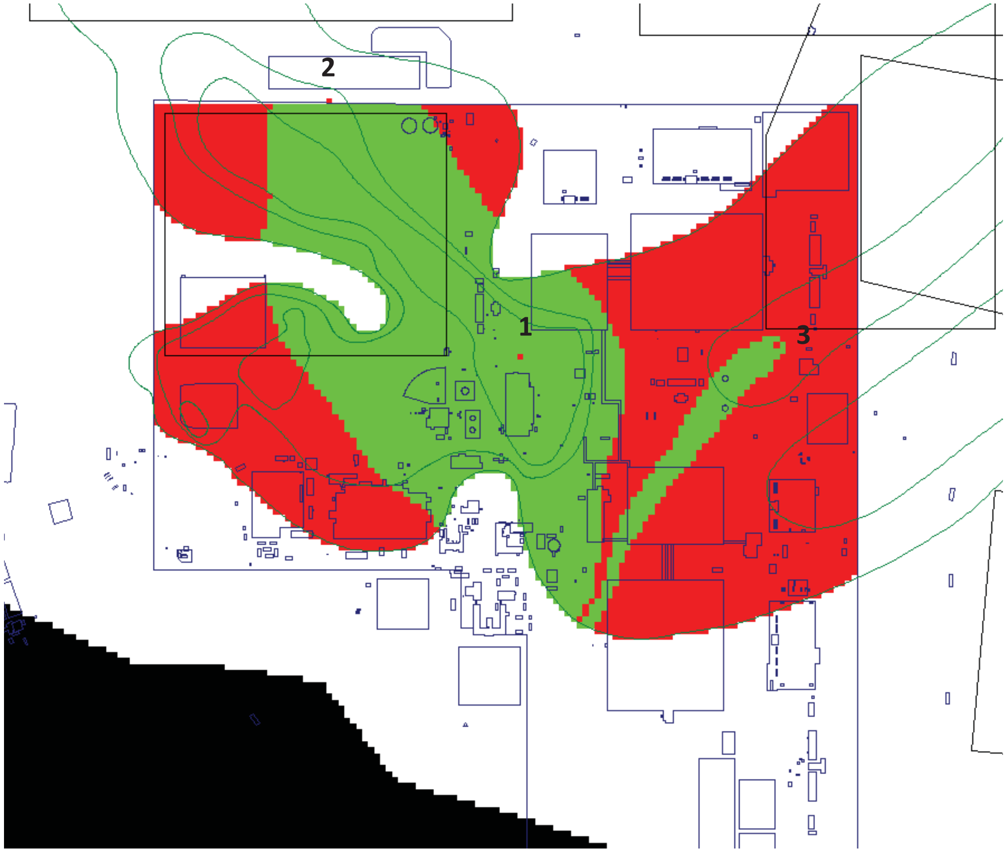
Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			50	50
4				50
Total	80	300	350	400

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	51.90%	52.24%
2		37.82%	38.11%	38.67%
3			0.13%	0.13%
4				0.12%
Total	53.58%	89.50%	90.14%	91.17%

50 GPM

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

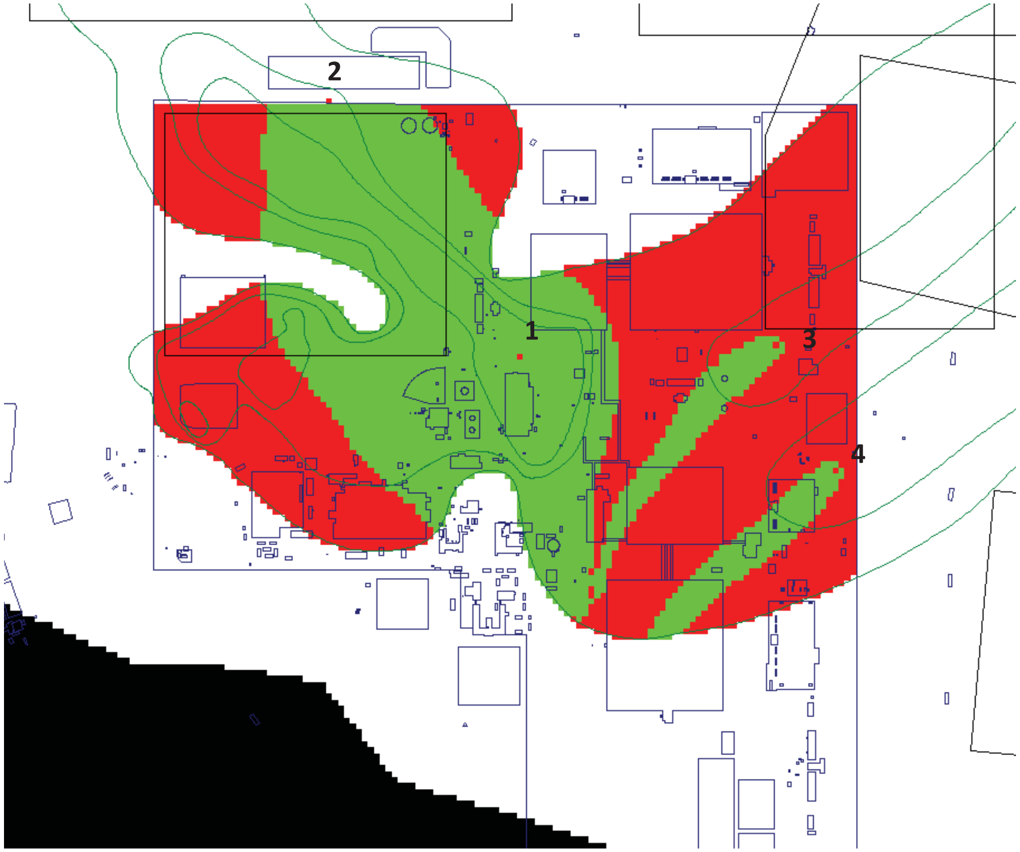
Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			50	50
4				50
Total	80	300	350	400

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	51.90%	52.24%
2		37.82%	38.11%	38.67%
3			0.13%	0.13%
4				0.12%
Total	53.58%	89.50%	90.14%	91.17%

50 GPM

C400 Extraction Well Evaluation : PGDP



🟥 Not Captured 🟩 Captured

GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			50	50
4				50
Total	80	300	350	400

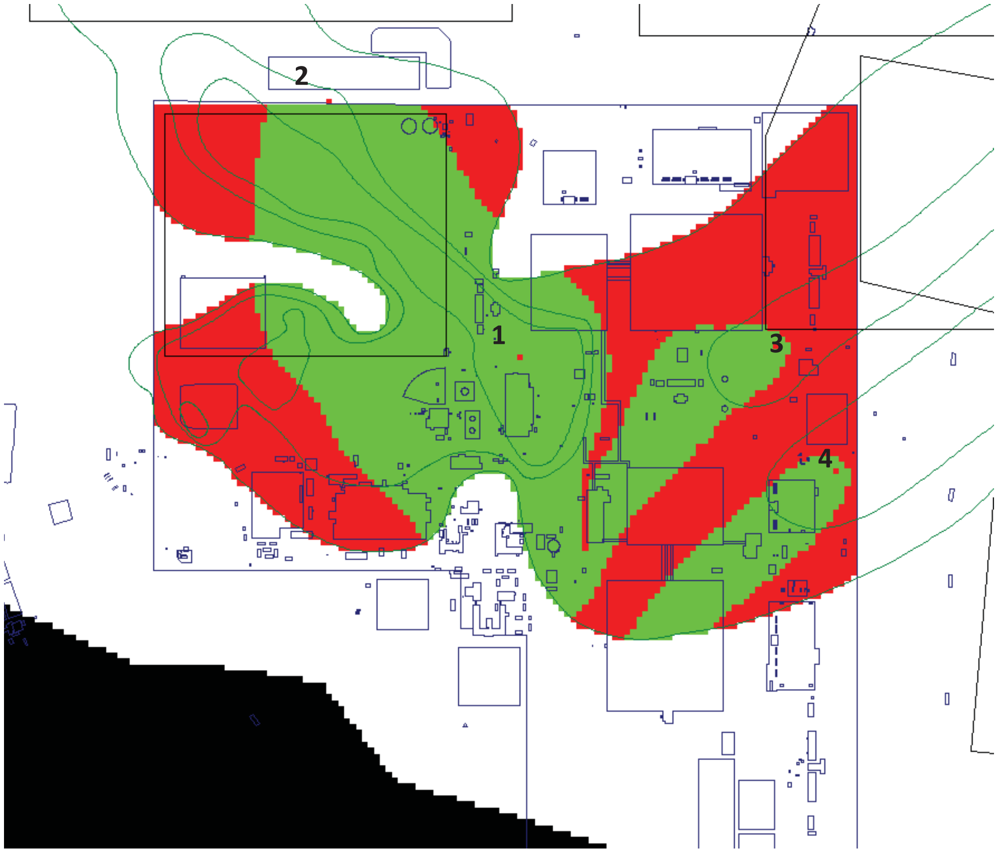
Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	51.90%	52.24%
2		37.82%	38.11%	38.67%
3			0.13%	0.13%
4				0.12%
Total	53.58%	89.50%	90.14%	91.17%

50 GPM

October 2011 – Maximum Anthropogenic Recharge

C400 Extraction Well Evaluation : PGDP



GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			100	100
4				100
Total	80	300	400	500

Mass Capture

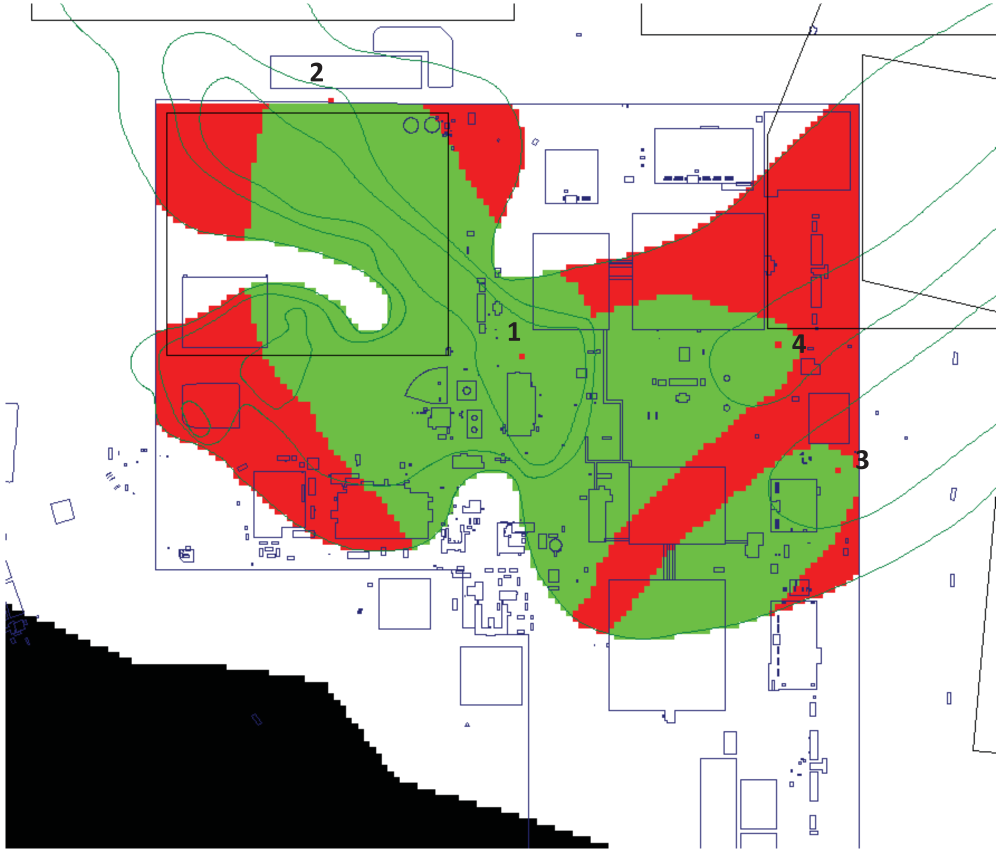
Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	52.17%	53.18%
2		37.82%	38.80%	38.65%
3			0.23%	0.25%
4				0.22%
Total	53.58%	89.50%	91.20%	92.30%

🟥 **Not Captured** 🟩 **Captured**

100 GPM

October 2011 – Maximum Anthropogenic Recharge

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

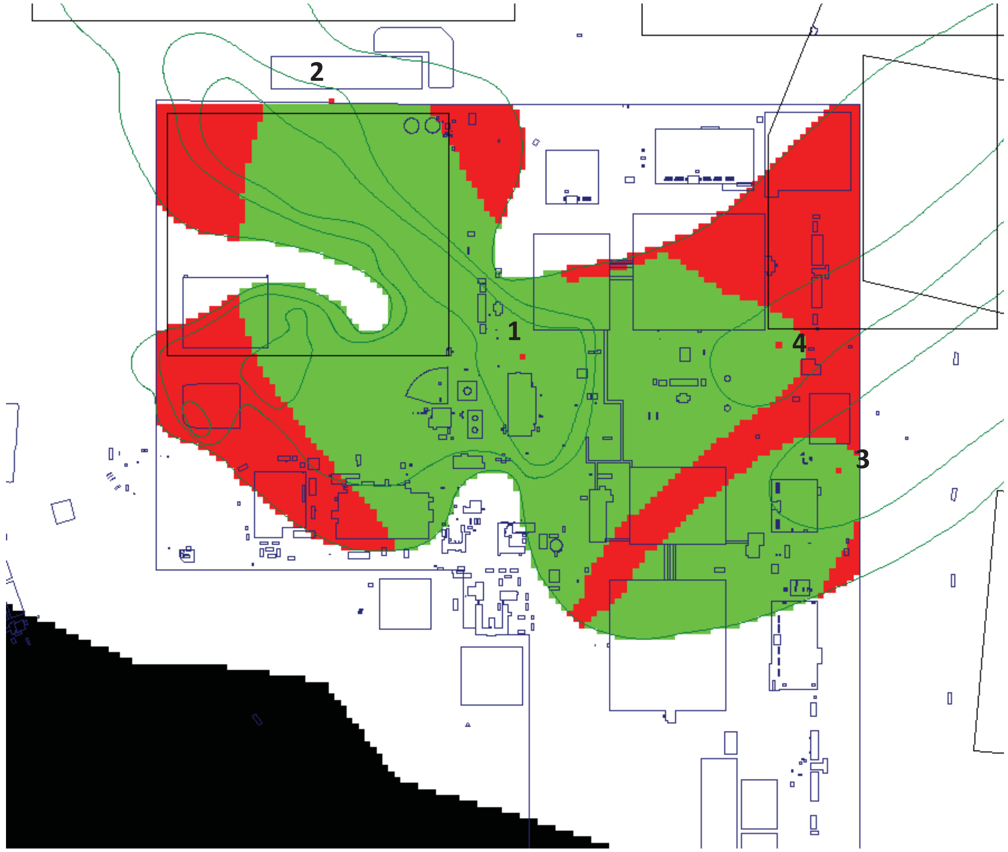
Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			150	150
4				150
Total	80	300	450	600

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	52.83%	54.34%
2		37.82%	38.30%	38.67%
3			0.31%	0.31%
4				0.33%
Total	53.58%	89.50%	91.44%	93.65%

150 GPM

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

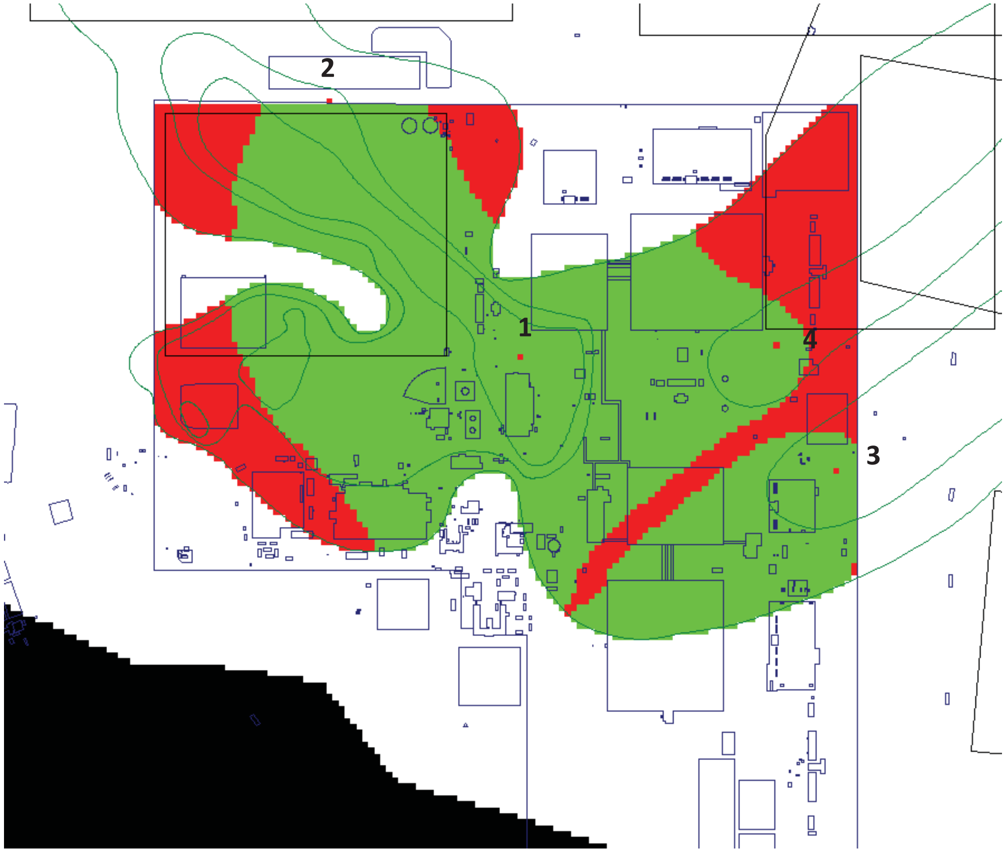
Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			200	200
4				200
Total	80	300	500	700

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	53.29%	55.91%
2		37.82%	38.51%	38.18%
3			0.36%	0.37%
4				0.52%
Total	53.58%	89.50%	92.16%	94.98%

200 GPM

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

October 2011 – Maximum Anthropogenic Recharge

GPM

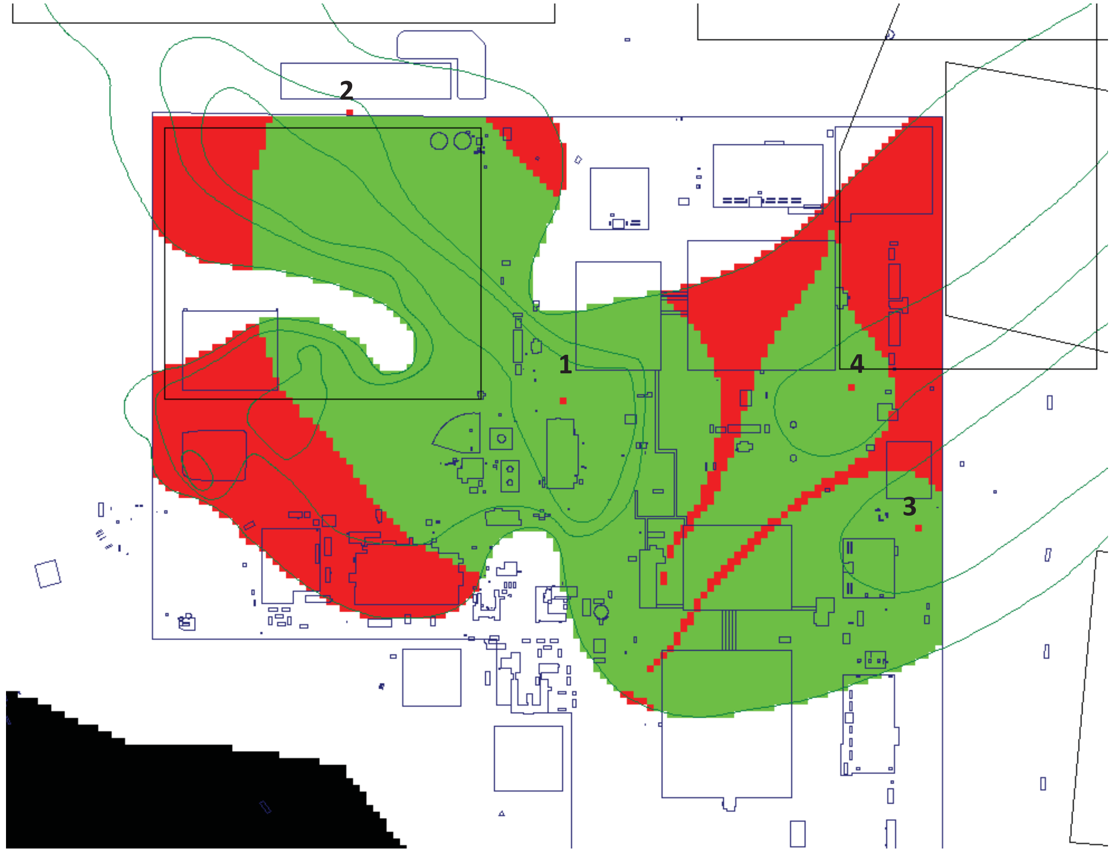
Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			250	250
4				250
Total	80	300	550	800

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.58%	51.68%	53.77%	57.34%
2		37.82%	38.48%	37.35%
3			0.40%	0.40%
4				1.09%
Total	53.58%	89.50%	92.65%	96.18%

250 GPM

C400 Extraction Well Evaluation : PGDP



🟥 **Not Captured** 🟩 **Captured**

1Q 2007 – Average Anthropogenic Recharge

GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			150	150
4				150
Total	80	300	450	600

Mass Capture

Well	Iteration			
	1	2	3	4
1	53.55%	51.65%	52.85%	54.81%
2		37.99%	38.83%	38.97%
3			0.41%	0.41%
4				0.42%
Total	53.55%	89.64%	92.08%	94.62%

150 GPM

C400 Extraction Well Evaluation : PGDP

GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			150	150
4				150
Total	80	300	450	600

Mass Capture

Well	Iteration			
	1	2	3	4
1	56.02%	52.65%	54.31%	57.44%
2		43.95%	43.86%	41.46%
3			0.54%	0.45%
4				0.53%
Total	56.02%	96.60%	98.71%	99.89%

🟥 **Not Captured** 🟩 **Captured**

150 GPM

April 2012 – Minimum Anthropogenic Recharge Conditions

C400 Extraction Well Evaluation : PGDP

🟥 **Not Captured** 🟩 **Captured**

October 2012 – No Anthropogenic Recharge

GPM

Well	Iteration			
	1	2	3	4
1	80	80	80	80
2		220	220	220
3			150	150
4				150
Total	80	300	450	600

Mass Capture

Well	Iteration			
	1	2	3	4
1	62.89%	57.94%	60.59%	62.02%
2		36.30%	31.68%	27.07%
3			0.84%	7.03%
4				0.42%
Total	62.89%	94.25%	93.11%	96.54%

150 GPM

Performance Comparison Tables

50 GPM/Lobe Well	April 2011	1Q 2007	Oct 2011	No Anthropogenic Rechage
0	0.00%	0.00%	0.00%	0.00%
80	56.02%	53.50%	53.58%	62.89%
300	96.60%	89.47%	89.50%	94.25%
350	97.61%	90.38%	91.40%	93.85%
400	98.41%	90.92%	91.17%	93.44%

100 GPM/Lobe Well	April 2011	1Q 2007	Oct 2011	No Anthropogenic Recharge
0	0.00%	0.00%	0.00%	0.00%
80	56.02%	53.50%	53.58%	62.89%
300	96.60%	89.47%	89.50%	94.25%
400	98.30%	91.07%	91.25%	93.42%
500	99.59%	92.96%	92.30%	93.08%

150 GPM/Lobe Well	April 2011	1Q 2007	Oct 2011	No Anthropogenic Recharge
0	0.00%	0.00%	0.00%	0.00%
80	56.02%	53.50%	53.58%	62.89%
300	96.60%	89.47%	89.50%	94.25%
450	98.71%	92.08%	91.44%	93.11%
600	99.89%	94.62%	93.65%	96.54%

200 GPM/Lobe Well	April 2011	1Q 2007	Oct 2011	No Anthropogenic Recharge
0	0.00%	0.00%	0.00%	0.00%
80	56.02%	53.50%	53.58%	62.89%
300	96.60%	89.47%	89.50%	94.25%
500	99.49%	92.82%	92.16%	93.82%
700	99.98%	96.06%	94.98%	

250 GPM/Lobe Well	April 2011	1Q 2007	Oct 2011	No Anthropogenic Recharge
0	0.00%	0.00%	0.00%	0.00%
80	56.02%	53.50%	53.58%	62.89%
300	96.60%	89.47%	89.50%	94.25%
550	99.79%	93.58%	92.65%	95.38%
800	99.99%	96.70%	96.18%	

Satisfying Design Constraints

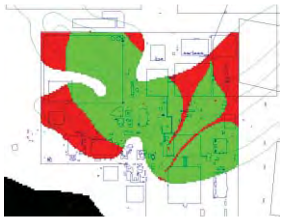
- Minimize trajectory impacts at C400 (YES)
- Complement NW Extraction Well capture zones (YES)
- Avoid potential CERCLA Cell locations (YES)
- Manage anthropogenic recharge variability (YES)
- Design for both anthropogenic and no anthropogenic recharge conditions to the extent possible (PGDP vs Post-PGDP) (YES)

Extraction System Design

- EW 232 Pumping at 220 gpm
- C400 Extraction Well Pumping at 80 gpm
- Two NE Plume Higher Concentration Lobe Wells Pumping at 150 gpm/well
- Cumulative Extraction Rate is 600 gpm
- System performance monitoring, both water-levels and concentrations

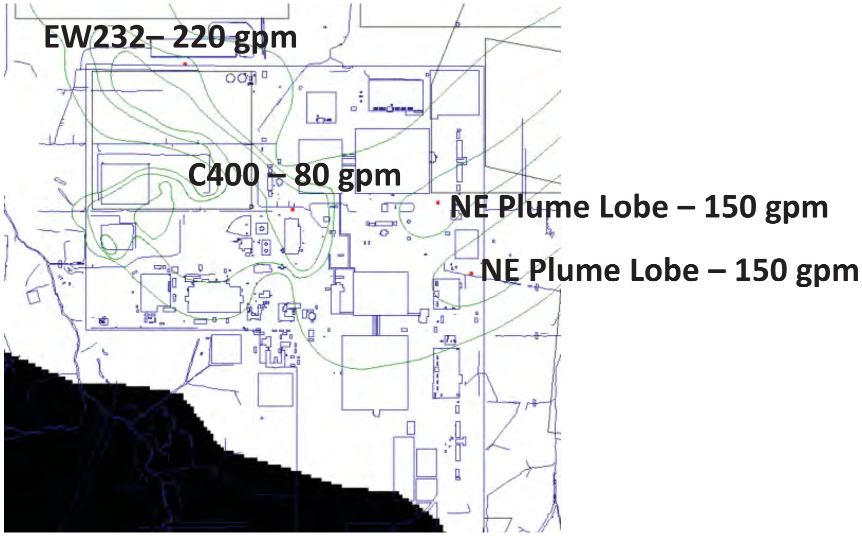
Maximum

Average



Minimum

Post-PGDP

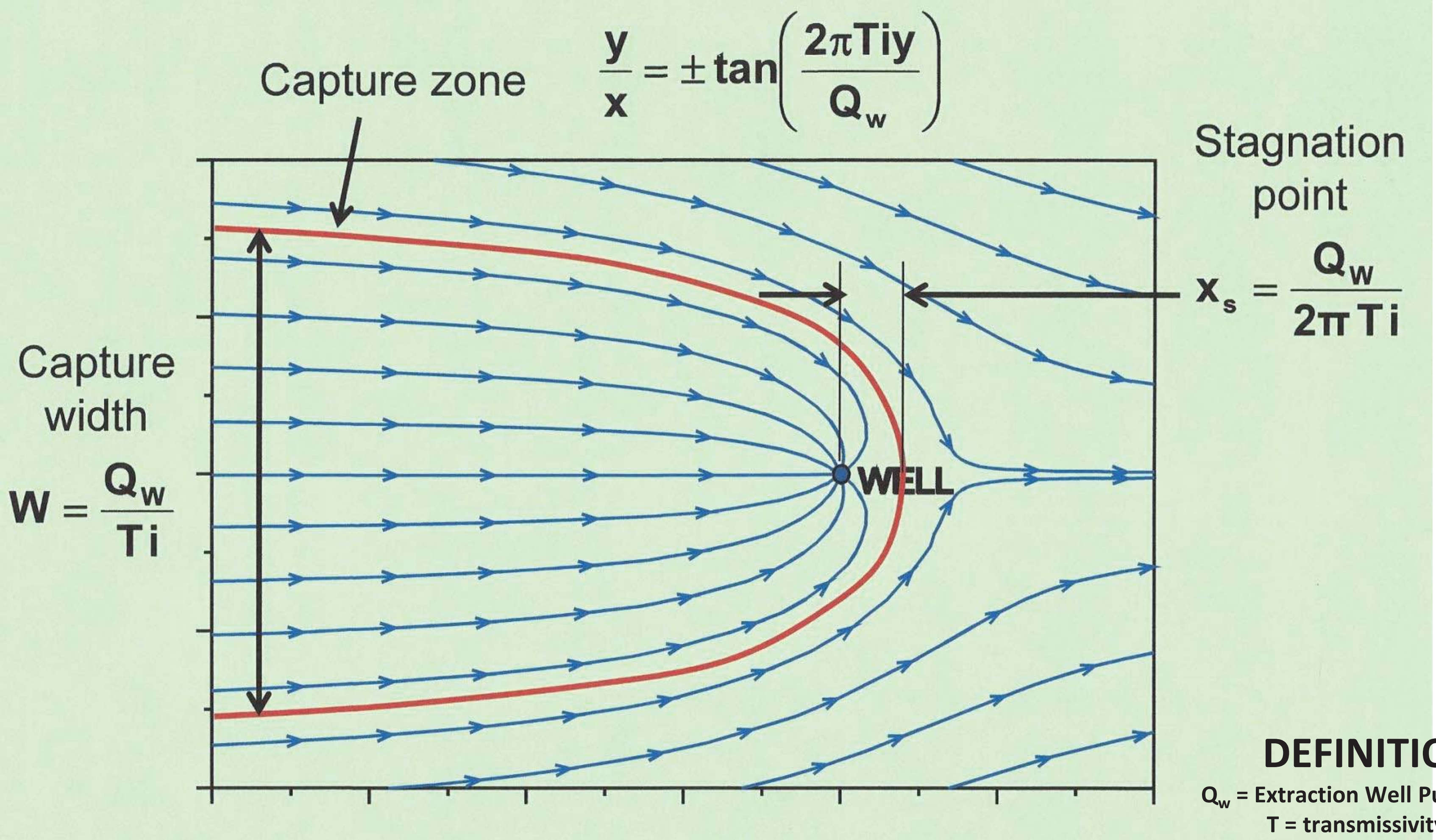


System Performance Monitoring

- Water-levels versus water quality samples
  - Groundwater levels respond as a function of storage (1e-4 to 1e-6) while dissolved contamination responds as a function of porosity (1e-1)
  - Thus, while groundwater levels respond to pumping in days, plume responses will potentially take thousands of days to observe

Understanding TCE presence and concentrations fluctuations downgradient of Extraction Wells 232 and 233

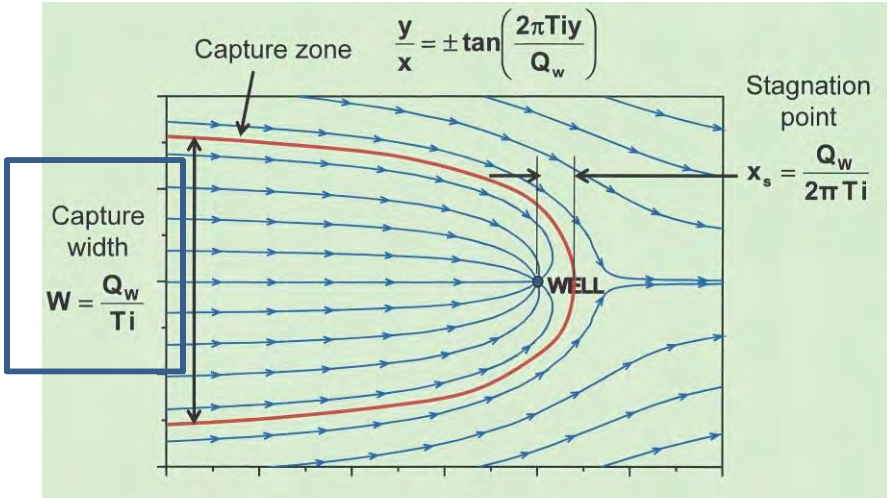
Capture Zone Equations



DEFINITIONS

Q_w = Extraction Well Pumping Rate
T = transmissivity = Kb
i = horizontal hydraulic gradient

Capture Zone Width



T = transmissivity
T = Kb
K = hydraulic conductivity
b = aquifer thickness

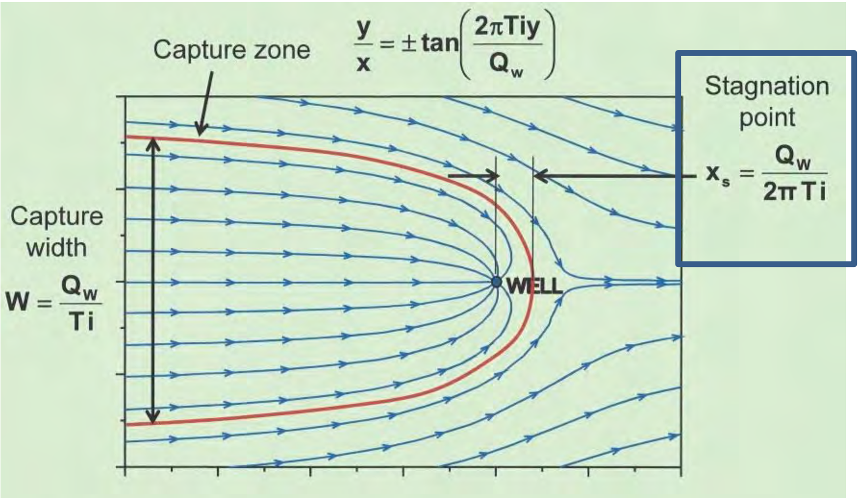
Capture Zone Relationships

- As Q increase W increases
- As T increase W decreases
- As T decreases W increases
- As i increases W decreases
- As i decreases W increases

Horizontal Hydraulic Gradient

- i within the PGDP is a function of anthropogenic recharge volumes and locations
- Anthropogenic recharge is spatially and temporally variable
- It follows that capture zones (orientation, width and stagnation point) will also be temporally variable

Capture Zone Stagnation Point



T = transmissivity

T = Kb

K = hydraulic conductivity

b = aquifer thickness

Stagnation point represents the down gradient extent of capture

Capture Zone Relationships

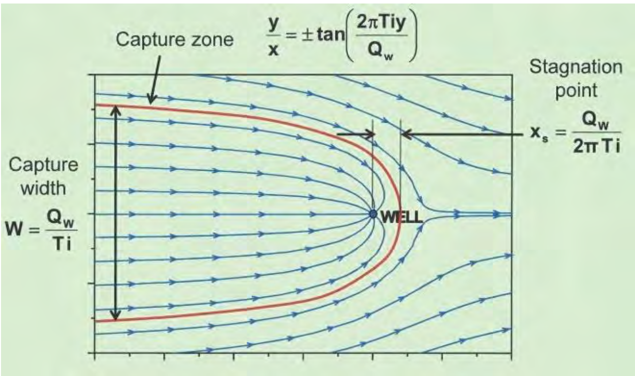
- As Q increase the distance from the extraction well to X_s increases
- As T increase the distance from the extraction well to X_s decreases
- As T decreases the distance from the extraction well to X_s increases
- As i increases the distance from the extraction well to X_s decreases
- As i decreases the distance from the extraction well to X_s increases

Horizontal Hydraulic Gradient

- i within the PGDP is a function of anthropogenic recharge volumes and locations
- Anthropogenic recharge is spatially and temporally variable
- It follows that capture zones (orientation, width and stagnation point) will also be temporally variable

Capture Zone Width and Stagnation Point Relationship

- As capture zone width increases the stagnation point moves away from the extraction well
- As capture zone width decreases the stagnation point moves closer to the extraction well



Model Predicted Anthropogenic Recharge Rates

Date	Anthropogenic Recharge, gpm
February 1995	1,152
3rd Quarter 2005	1,337
1st Quarter 2007	1,042
April 2010	678
October 2010	1,317
April 2011	599
October 2011	1,420
Mean	1,078
Median	1,152

- Anthropogenic recharge occurs in the plant area
- Anthropogenic recharge sources include
  - Leaking underground water supply and fire protection lines
  - Leakage from cooling towers
  - Parking lot run off
  - Building roof run off
  - Infiltration from drainage ditches
  - Leakage from lagoons
- Anthropogenic recharge is both spatially and temporally variable
- There is no way of determining “typical” anthropogenic recharge rates
- Anthropogenic recharge likely has not been constant over time

Simulated Extraction Well Discharge Rates

- EW230 – 63 gpm, EW231 – 53 gpm
- EW 232 – 110 gpm, EW233 – 110 gpm
- EW232 – 220 gpm

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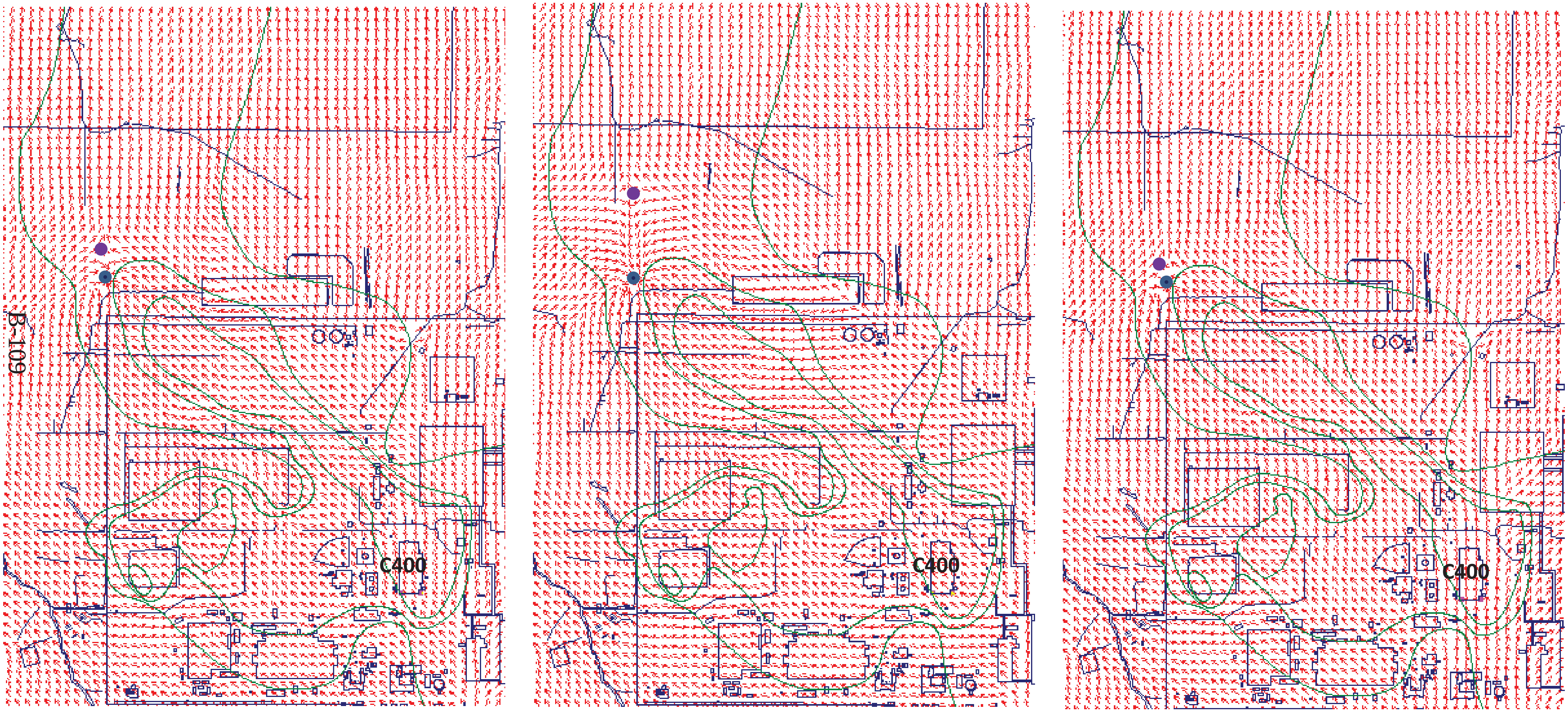
Vector Analysis

EW230 and EW231 Vector Plots



1Q 2007

Average Anthropogenic Recharge

April 2011

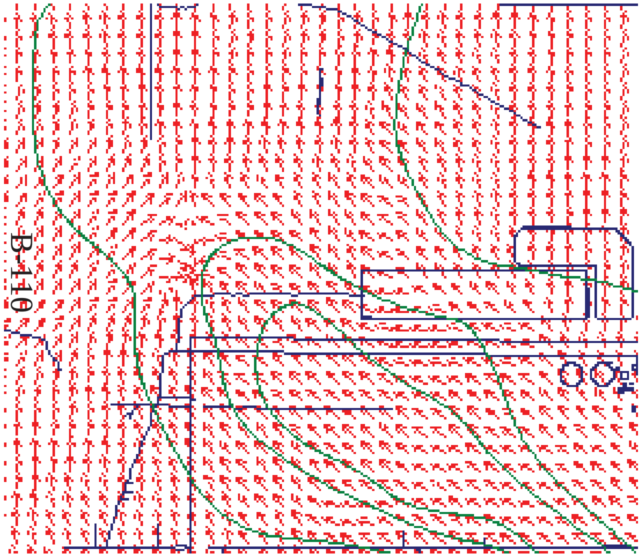
Minimum Anthropogenic Recharge

October 2011

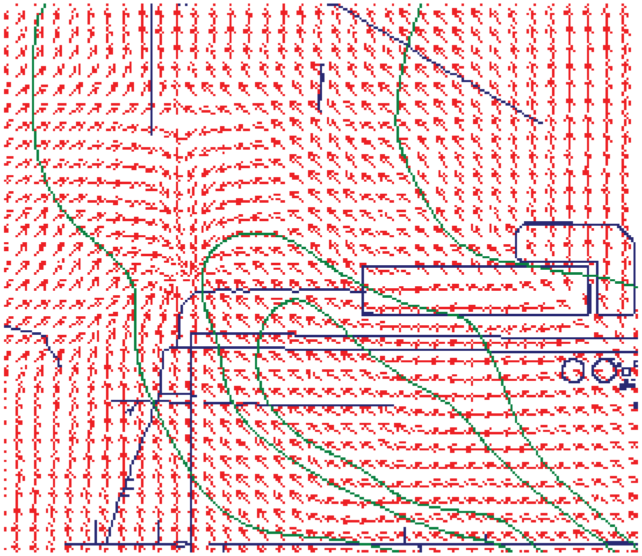
Maximum Anthropogenic Recharge

● **EW230 and EW231** ● **Stagnation Point**

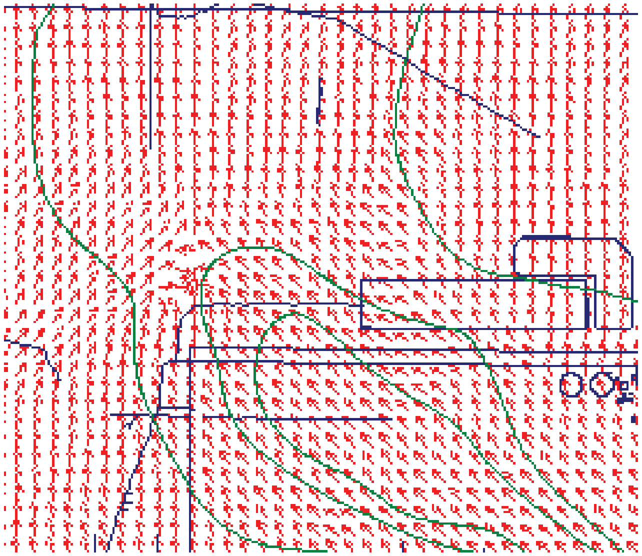
EW230 and EW231 Vector Plots



1Q 2007
Average Anthropogenic Recharge



April 2011
Minimum Anthropogenic Recharge



October 2011
Maximum Anthropogenic Recharge

NOTE: Extraction well locations and stagnation points are not shown to provide a better view of flow vectors

EW230 and EW231 Vector Plot Summary

- Extraction wells EW230 and EW231 are not located along the axis of the Northwest Plume as a result the capture zone is not centered over the plume
- Following vectors origination at C400 shows that with the exception of low anthropogenic recharge conditions (April 2011) groundwater contamination bypasses the extraction wells
- Based on stagnation point locations, the EW230 and EW231 capture zone is largest during low anthropogenic recharge conditions and smallest during high anthropogenic recharge conditions

EW232 and EW233 Backwards Particle Trace Capture Zones

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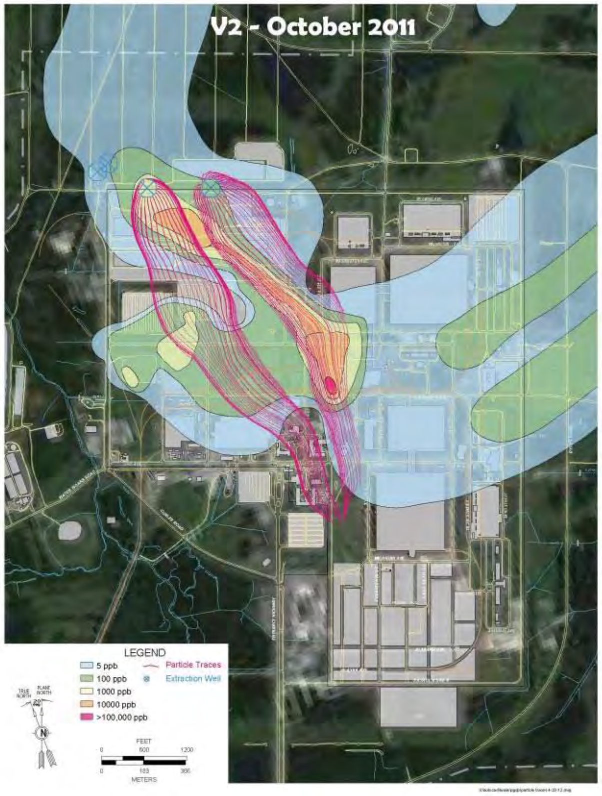
1Q 2007

"Average" Anthropogenic Recharge

April 2011

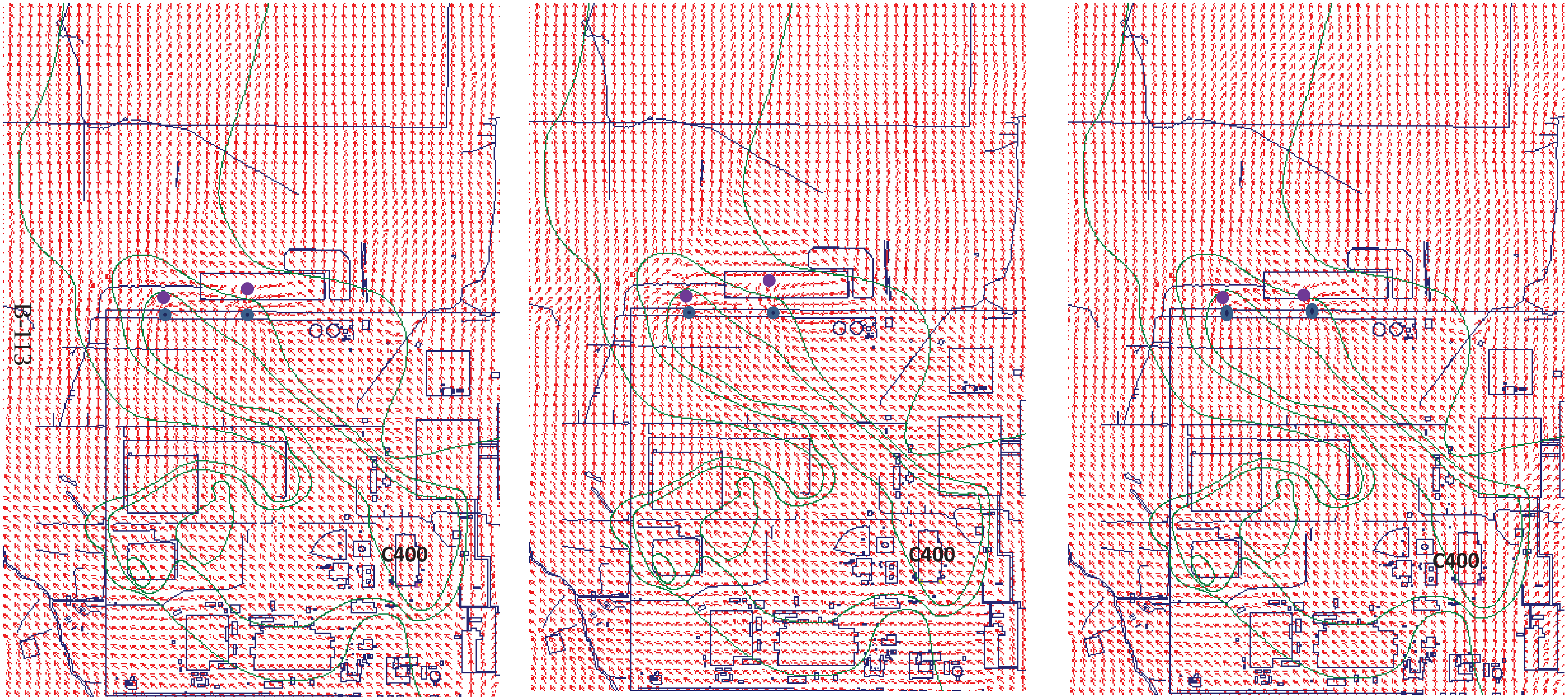
Minimum Anthropogenic Recharge



October 2011

Maximum Anthropogenic Recharge

EW232 and EW233 Vector Plots



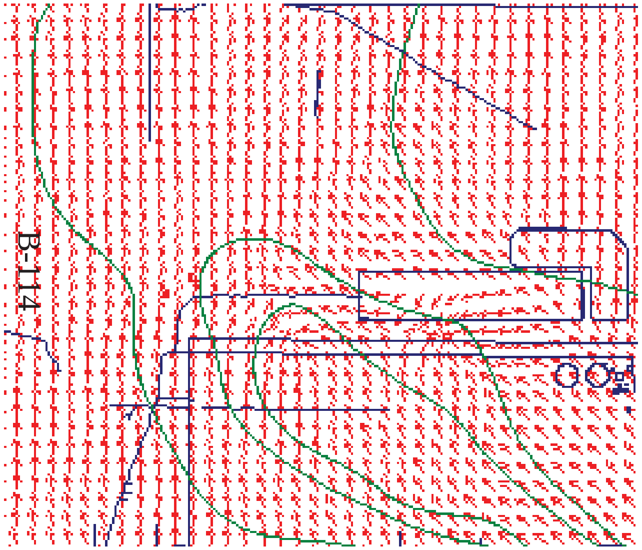
1Q 2007
Average Anthropogenic Recharge

April 2011
Minimum Anthropogenic Recharge

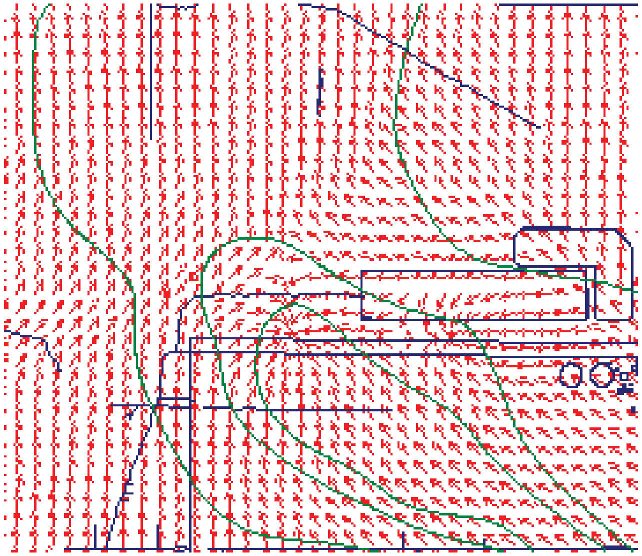
October 2011
Maximum Anthropogenic Recharge

● **EW232 and EW233** ● **Stagnation Point**

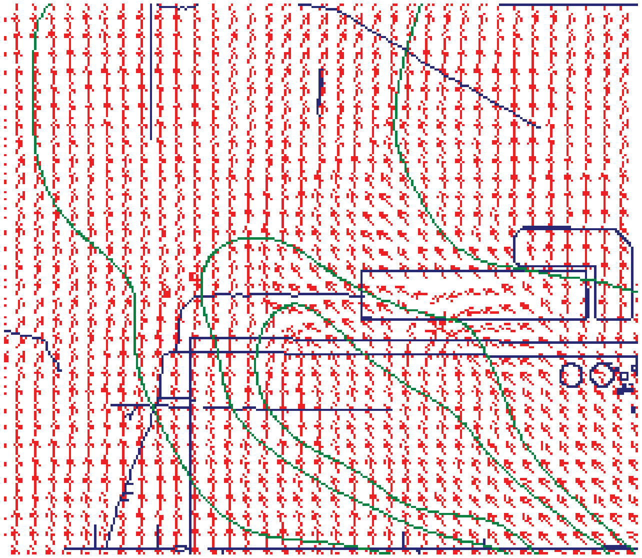
EW232 and EW233 Vector Plots



1Q 2007
Average Anthropogenic Recharge



April 2011
Minimum Anthropogenic Recharge



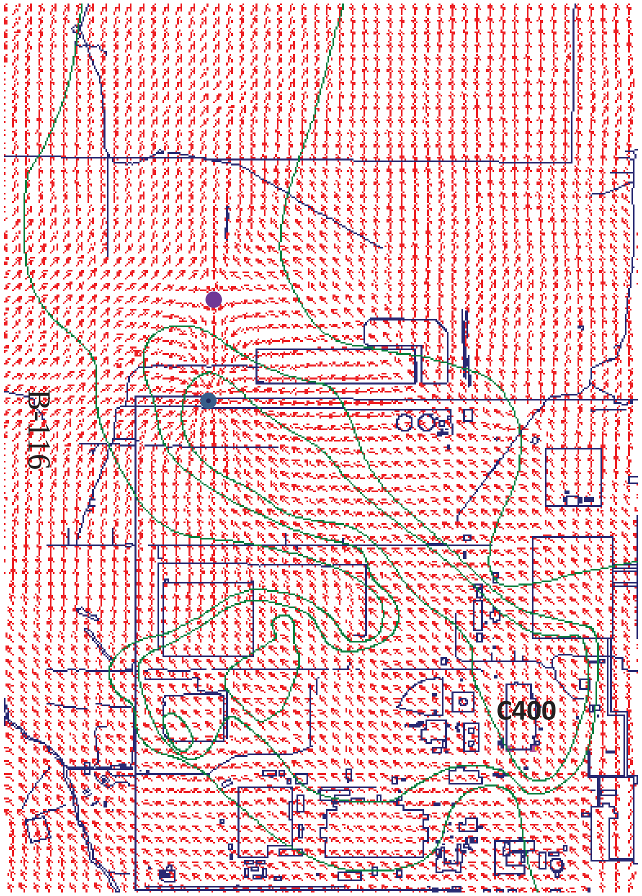
October 2011
Maximum Anthropogenic Recharge

NOTE: Extraction well locations and stagnation points are not shown to provide a better view of flow vectors

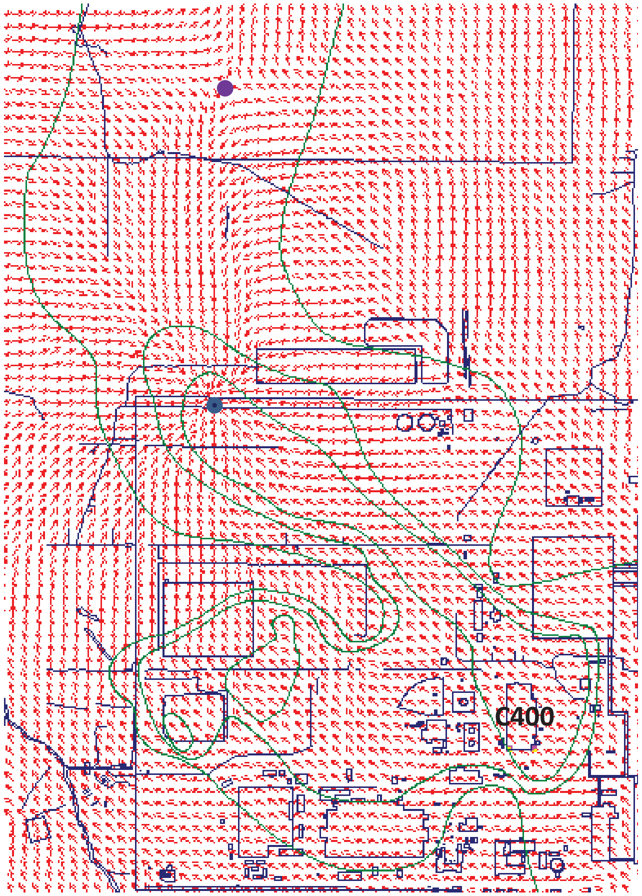
EW232 and EW233 Vector Plot Summary

- Following vectors origination at C400 shows that some groundwater contamination passes between the two extraction wells during average and high anthropogenic recharge conditions
- Following vectors origination at C400 shows that groundwater contamination is captured by the two extraction wells during low anthropogenic recharge conditions
- Reverse particle tracking capture zones supports the above two bullets
- Based on stagnation point locations, the EW232 and EW233 capture zones are largest during low anthropogenic recharge conditions and smallest during high anthropogenic recharge conditions

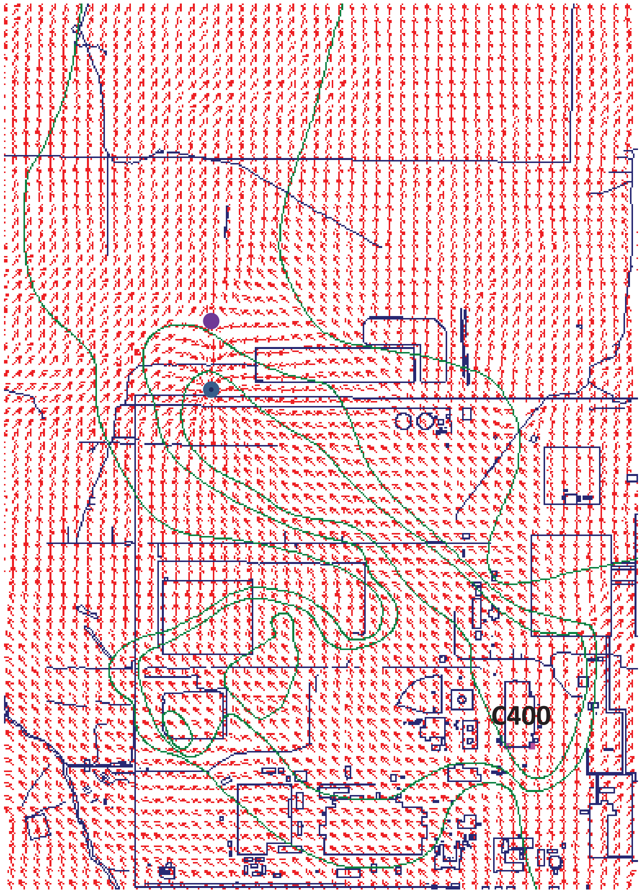
EW232 Vector Plots



1Q 2007
Average Anthropogenic Recharge



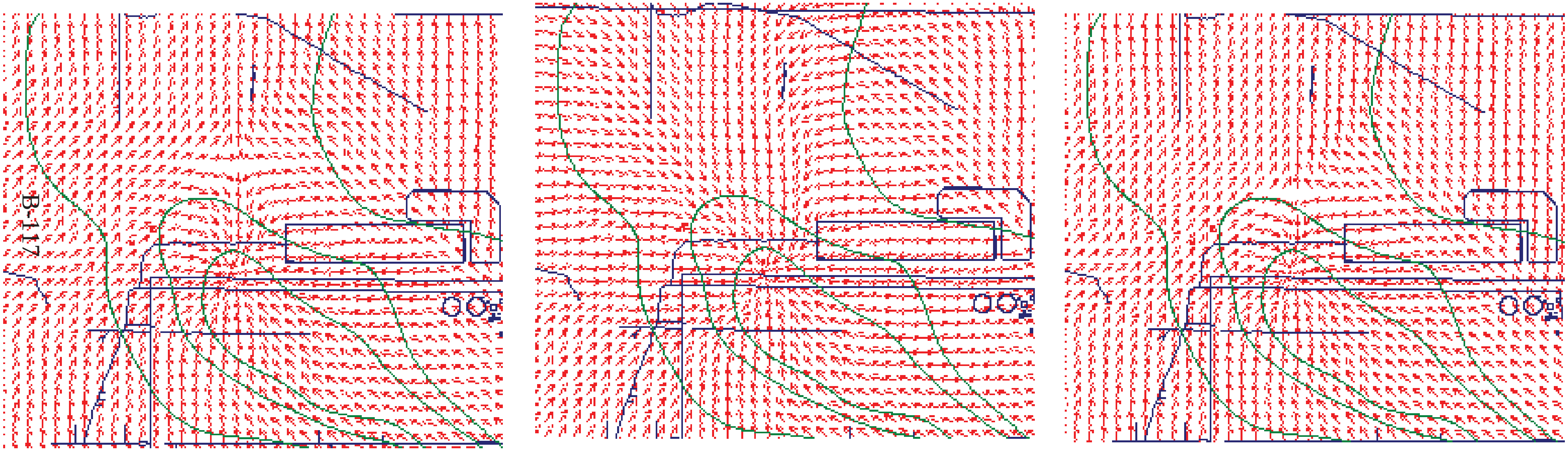
April 2011
Minimum Anthropogenic Recharge



October 2011
Maximum Anthropogenic Recharge

● **EW232** ● **Stagnation Point**

EW232 Vector Plots



1Q 2007
Average Anthropogenic Recharge

April 2011
Minimum Anthropogenic Recharge

October 2011
Maximum Anthropogenic Recharge

NOTE: Extraction well locations and stagnation points are not shown to provide a better view of flow vectors

EW232 Vector Plot Summary

- Following vectors origination at C400 shows groundwater contamination is captured by the EW232 for all ranges of anthropogenic recharge conditions
- Based on stagnation point locations, the EW232 capture zone is largest during low anthropogenic recharge conditions and smallest during high anthropogenic recharge conditions

Overall Vector Plot Summary

- Variability in TCE concentrations downgradient of the extraction wells is likely due to contamination escaping between EW232 and EW233 as a result of anthropogenic recharge variability
- Plume capture can be achieved for the range of anthropogenic recharge conditions simulated by operating EW232 at 220 gpm
- **COMMENT** – anthropogenic recharge conditions have changed as a result of PGDP shutdown and the changing conditions could potentially change plume trajectory and extraction well performance

Future Flow Model Updates

Discussion Items

- What will the model be used for?
  - Evaluating the performance of active groundwater remedies
  - Supporting remedial design efforts
  - Predicting future contaminant concentrations
  - Other?
- Should the model domain be expanded horizontally and vertically?
  - Should the Terrace be included in the model?
  - Should the UCRS be included in the model?
  - Should the McNairy be included in the model?

Discussion Items

- How will PGDP decommissioning impact the groundwater flow regime?
  - What data can be used to evaluate the impact?
  - Required temporal scale of the data?
- What "decommissioning" model input parameters will need to be configured and calibrated?
  - Recharge
  - Others?
- When should recalibration be performed?
- If so, how should the flow model be recalibrated?
  - Adopt the K field and just recalibrate present day recharge?
  - Add the decommissioning scenario(s) to the end of the current 17 stress period calibration configuration and recalibrate recharge and K?

Discussion Items

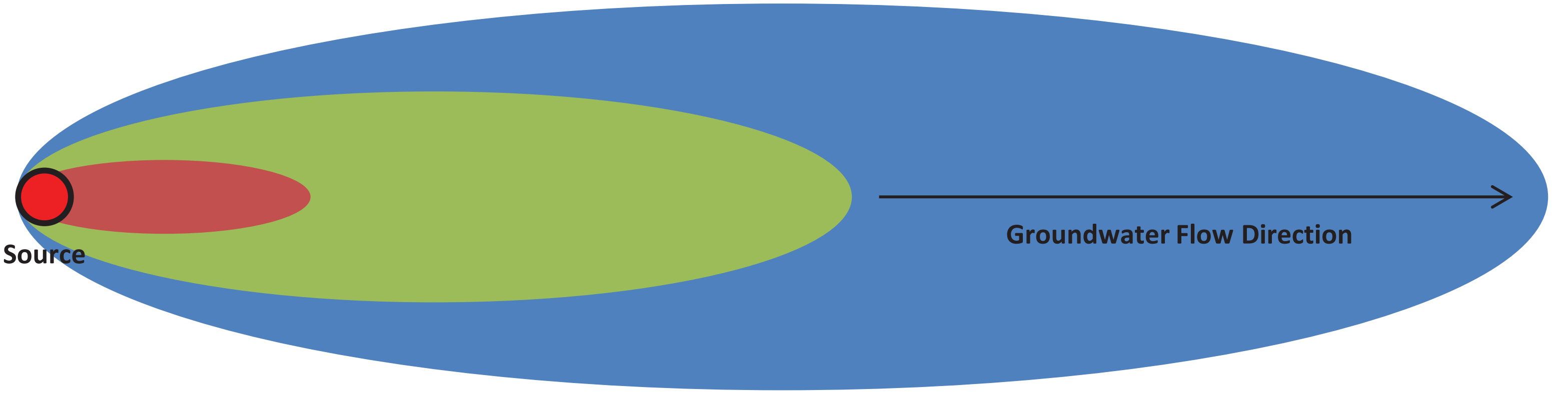
- How and/or do we include TVA data into the updated model?
  - TVA model is a TMR model
  - Paste calibrated parameter values into model?
  - Recalibrate using the TMR model configuration and calibrated values as constraints?
- When is enough, enough?
  - Will additional detail result in additional prediction accuracy?
- What degree of uncertainty evaluation is appropriate?
  - Full fledge stochastic analysis?
  - Prediction sensitivity analysis?

Transport Modeling

Factors Influencing Plume Migration

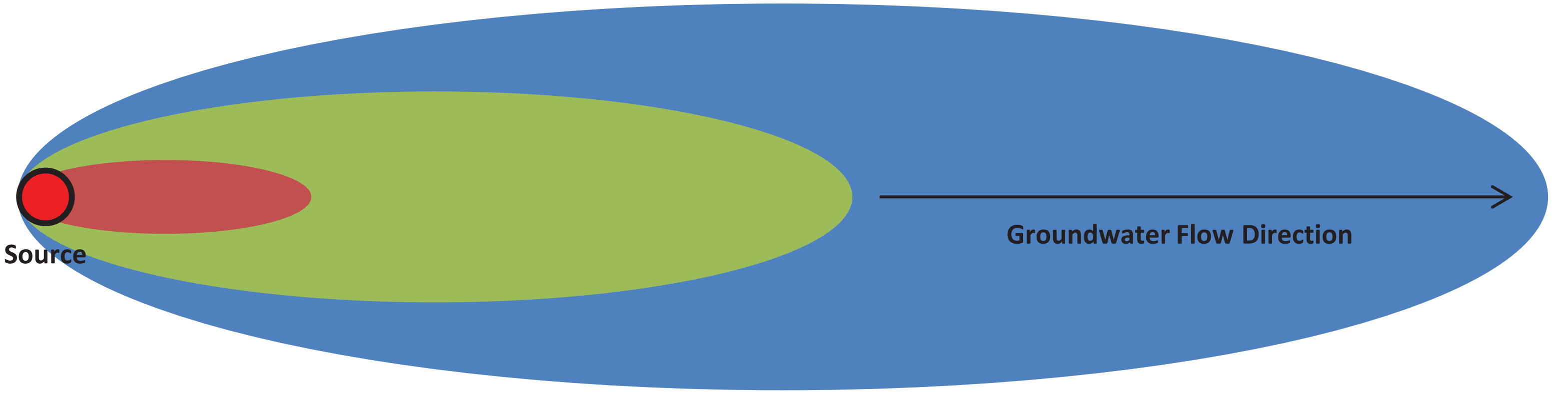
- Parameters
  - Source Locations and Concentrations
  - Distribution Coefficient – K_d
  - Effective Porosity – n_e
  - Dispersivity – α
  - Diffusion – D
  - Biological Half-Life – H_L
  - Initial dissolved/sorbed contaminant distribution

Anatomy of a Plume



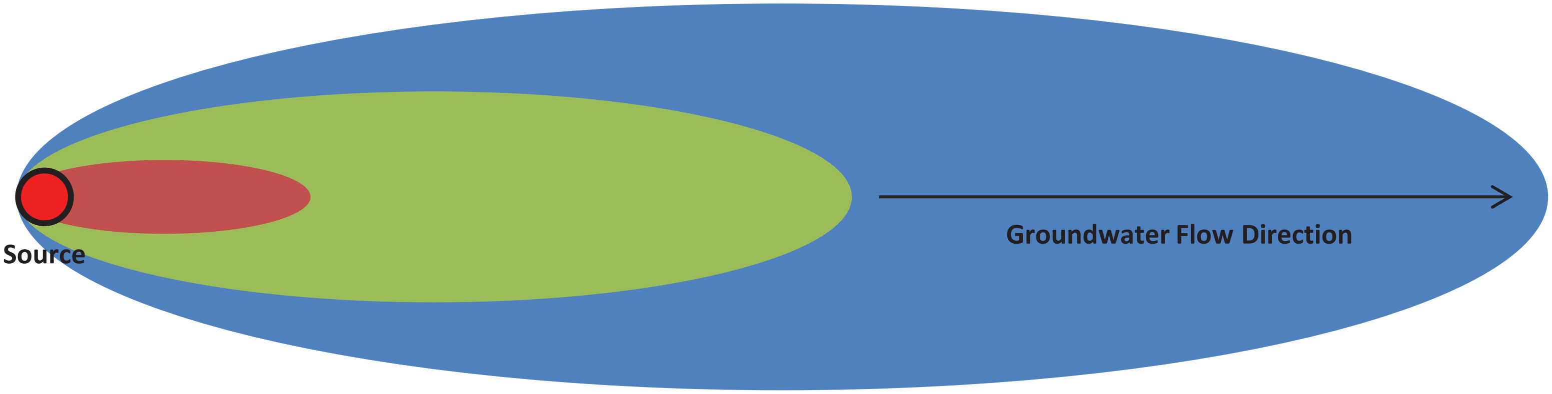
- Source : Feeds the plume
  - Where is the source located?
  - What is the source strength?
  - Does the strength vary temporally?
  - How long will the source be active?

Anatomy of a Plume



- K_d : Ratio of contamination attached to soil/dissolved in water
  - K_d slows plume migration
  - Retardation Factor = $v_{gw}/v_c = 1 + (\rho_b \times K_d/n_e)$
  - RGA TCE retardation factor is 1.1
  - For every 1 ft groundwater migrates, TCE will migrate 0.91 ft in the same time period
  - Linear K_d: attachment – detachment rate from soil is same
  - Non-Linear K_d: attachment rate is faster than detachment rate (tailing effects)

Anatomy of a Plume



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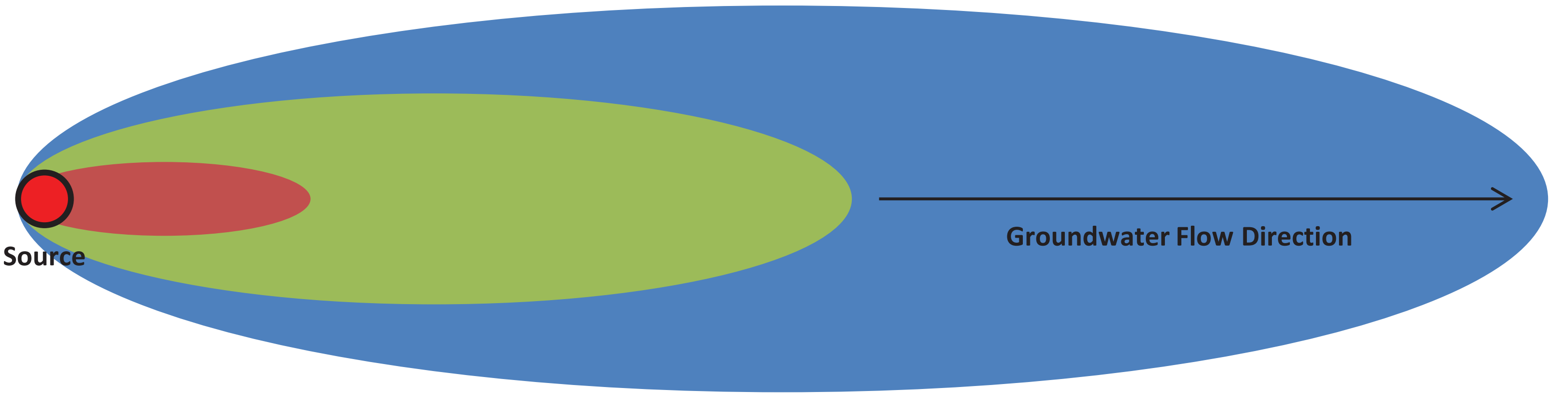
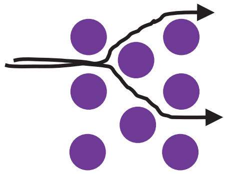
- Effective porosity – Controls groundwater migration rate
  - Effective porosity (n_e) is the portion of the aquifer that transmits water
  - Porosity (n) is the volume of voids/volume of aquifer
  - n_e is equal to or less than n
  - Groundwater velocity = $v_{gw} = K \times dh/dl \div n_e$
  - As n_e decreases, v_{gw} increases

Anatomy of a Plume

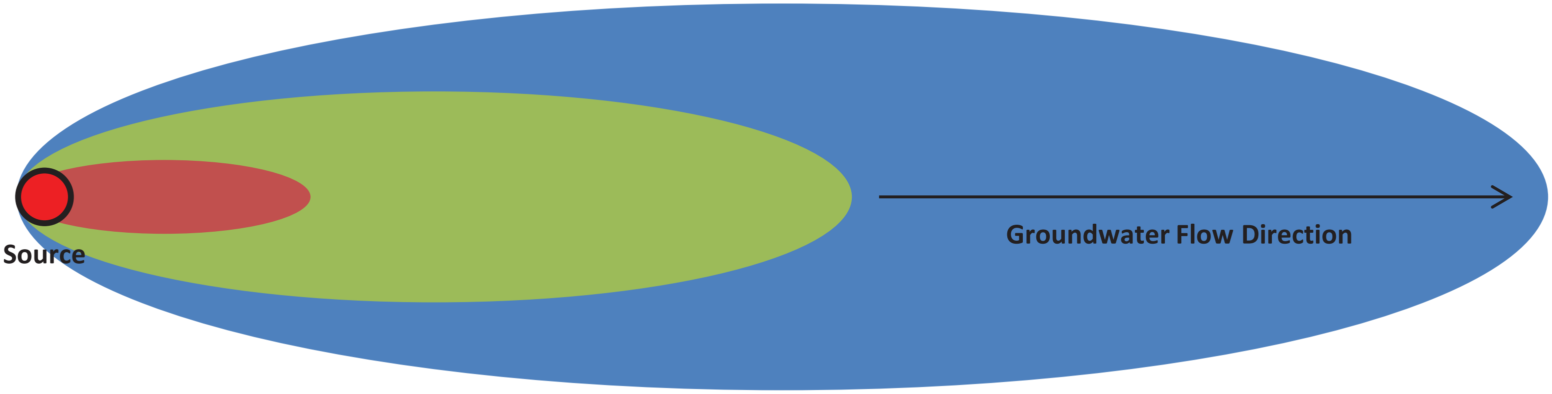


- Dispersivity : Spreads out the plume
  - Dispersivity (α) results because of differing groundwater flow rates and flow paths

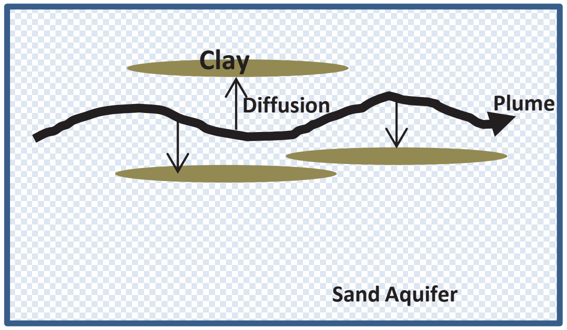


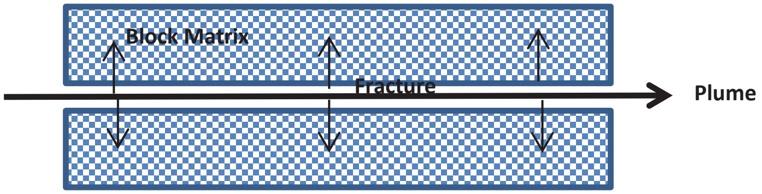
  - Dispersivity occurs along the axis of the plume (longitudinal - α_L), horizontally perpendicular to the axis of the plume (transverse – α_T) and vertically perpendicular to the axis of the plume (vertical – α_V)
  - In general $\alpha_L > \alpha_T > \alpha_V$
  - In modeling the application of α has changed over time

Anatomy of a Plume



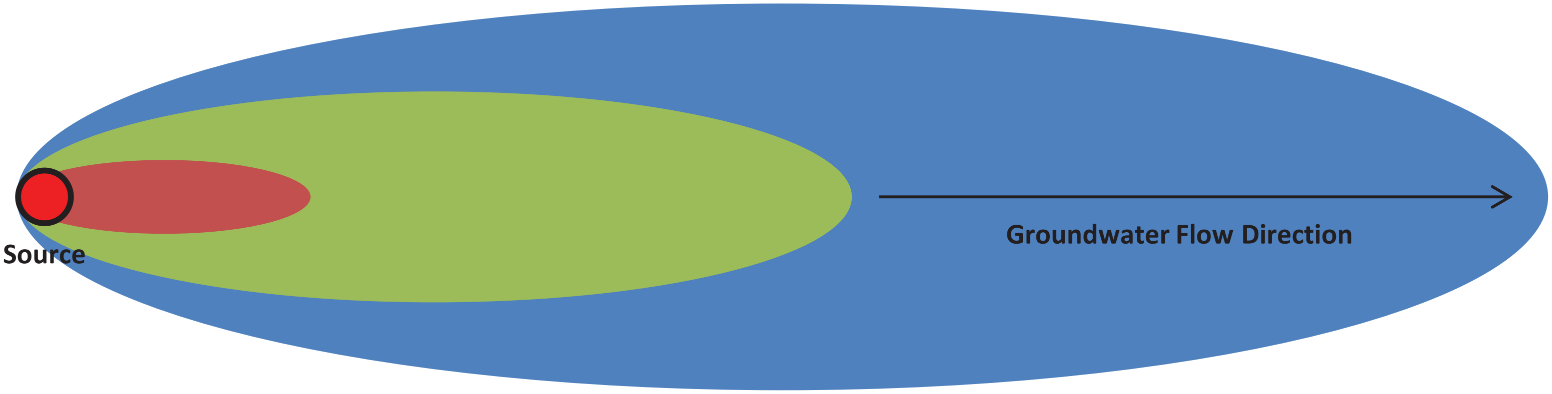
- Diffusion : Concentration gradient driven contaminant migration





  - Slow process relative to advective transport
  - Post remediation: Can result in chronic low level concentrations (tailing effect)
  - Usually do not include in porous media simulations

Anatomy of a Plume



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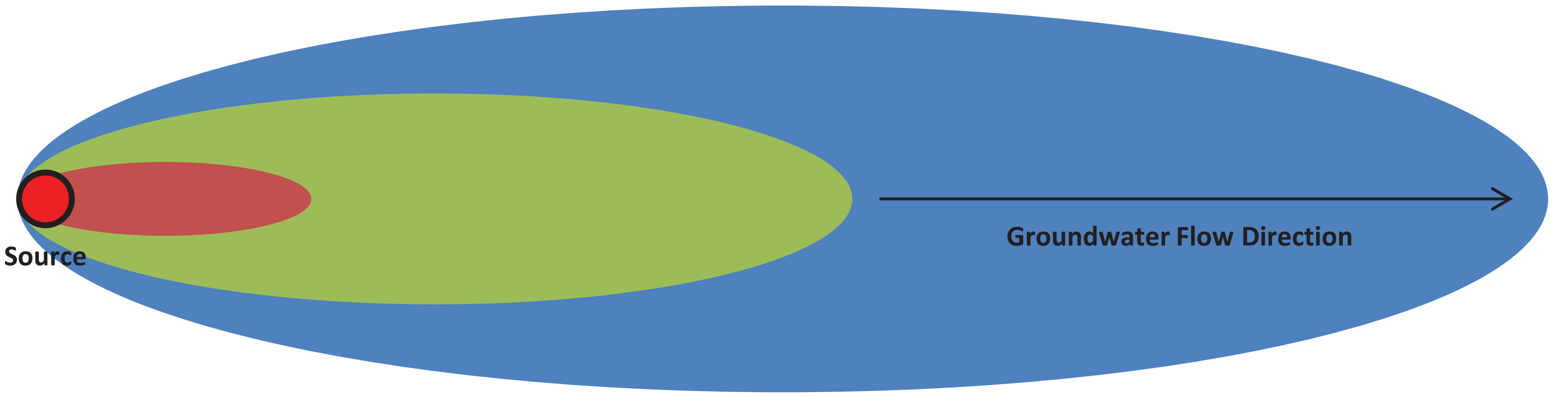
- Biodegradation : Removes contaminant mass
  - Only process that removes contaminant mass
  - Can transform one contaminant to another contaminant (**TCE → DCE → VC**)
  - Characterized by half-life, the time required to reduce the original mass in half
  - RGA TCE half-life is 3,650 days (10 years)

Anatomy of a Plume



- Initial Concentration Distribution:
  - Typically the current plume concentration and geometry
  - Migrate the initial plume forward to predict future concentrations
  - Initial concentration distribution doesn't always represent reality

Transport Modeling

- Calibration
  - Two schools of thought:
    - Inverse modeling – try and match todays plume from source activation to present, thus insuring representative transport parameters (temporal source strength and duration, K_d and half-life)
    - Forward modeling – initiate transport simulation using the current observed initial concentrations
- Log transform concentration targets or not?
  - Yes, typically get better matches with the lower concentration targets
  - No, typically get better matches with the higher concentration targets
- Will never obtain as good a match to concentration targets as to head targets

Transport Modeling

- Other calibration targets
  - Plume mass and concentration statistics

Data from a Chemical Manufacturing Facility in Australia

EDC plume mass comparison

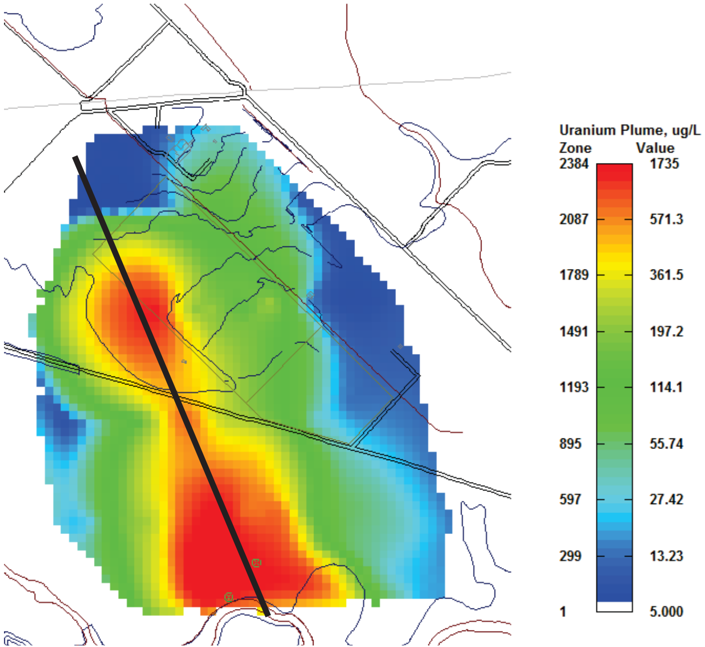
Model Layer	January 2005 EDC Plume Mass, Kg	September 2013 EDC Plume Mass, Kg	Difference, Kg
1	46,466	107	46,359
2	112,817	12,430	100,387
3	559,784	46,001	513,783
4	645,527	174,391	471,136
TOTAL	1,364,594	232,930	1,131,664

EDC plume concentration statistics

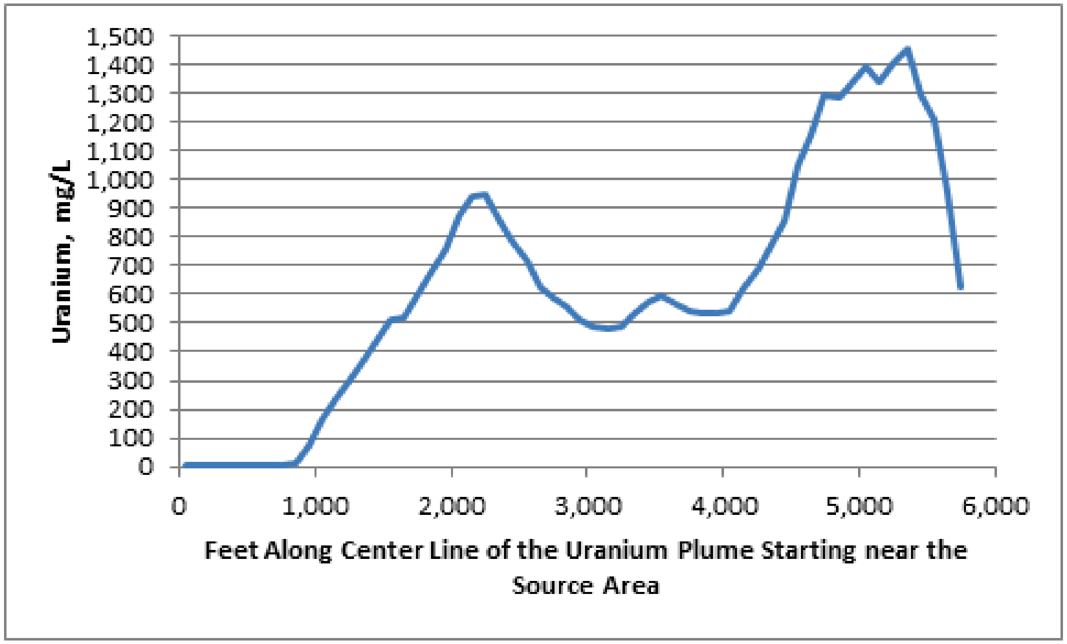
Percentile	January 2005	September 2013
	EDC Concentration, mg/L	EDC Concentration, mg/L
1	0.06	0.001
5	0.5	0.003
10	1	0.007
25	6	0.1
50	20	2
75	90	20
90	300	60
95	600	100
99	1,000	500
Average	107	28
Maximum	6,000	5,000

Transport Modeling

- Other calibration targets
  - Plume center line concentrations



Plume Center Line



Riverton, Wyoming

Transport Modeling

- MT3D source representation
  - – Don’t simulate free phase, rather a concentration
    - Constant concentration - RGA
    - Recharge concentration – UCRS
- Major PGDP Sources

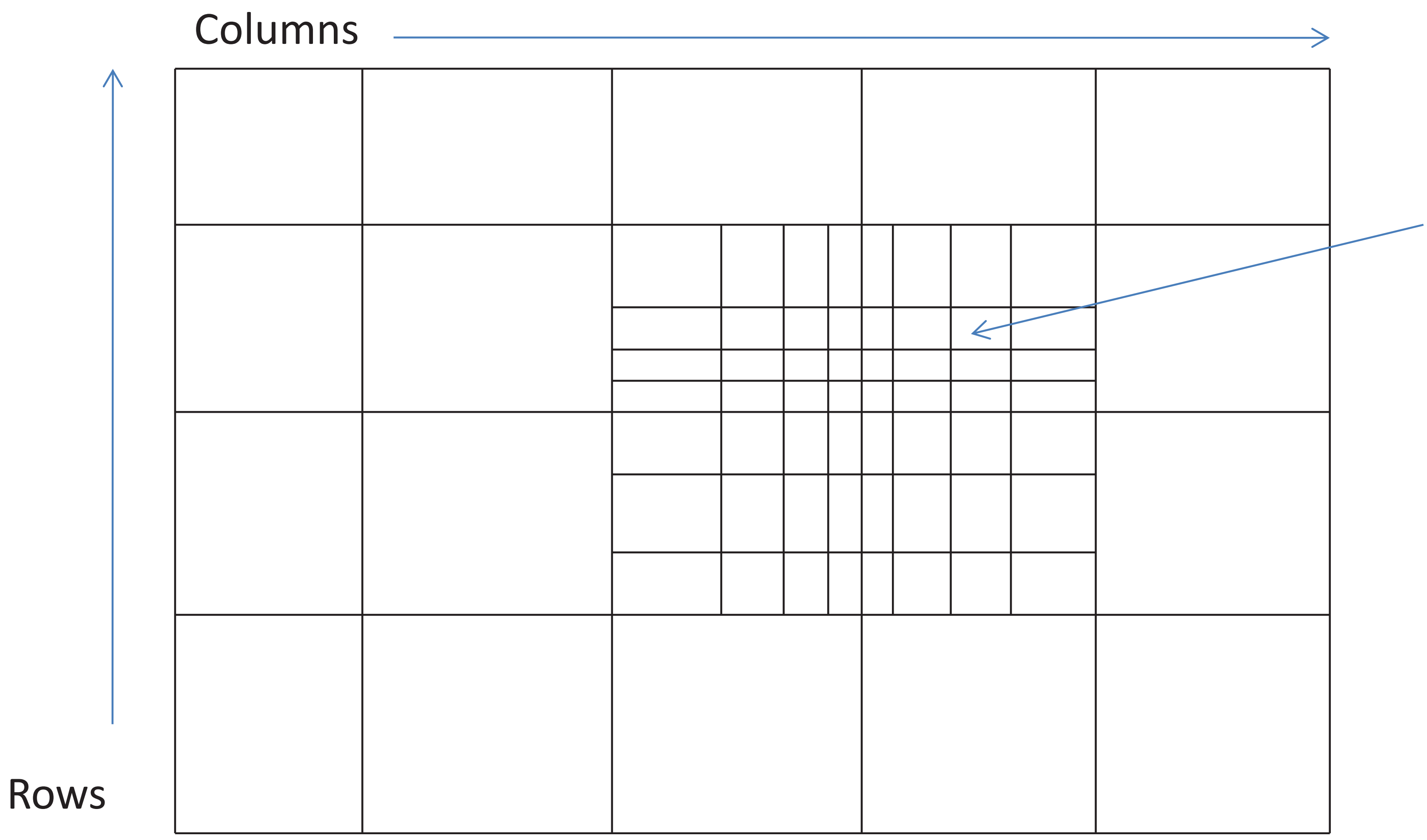
Modeling Innovations

MODFLOW-USG

- USG – unstructured grids
- Overcomes finite-difference grid limitations
- Includes MODFLOW processes and packages with finite-element flexibility
- Developed by Sorab Panday, author of MODFLOW-Surfact
- Public domain code maintained by the USGS
- Supports all MODFLOW-Surfact features
- Supports all MODFLOW packages including NWT, Conduit Domain Flow (CDF)

MODFLOW-USG

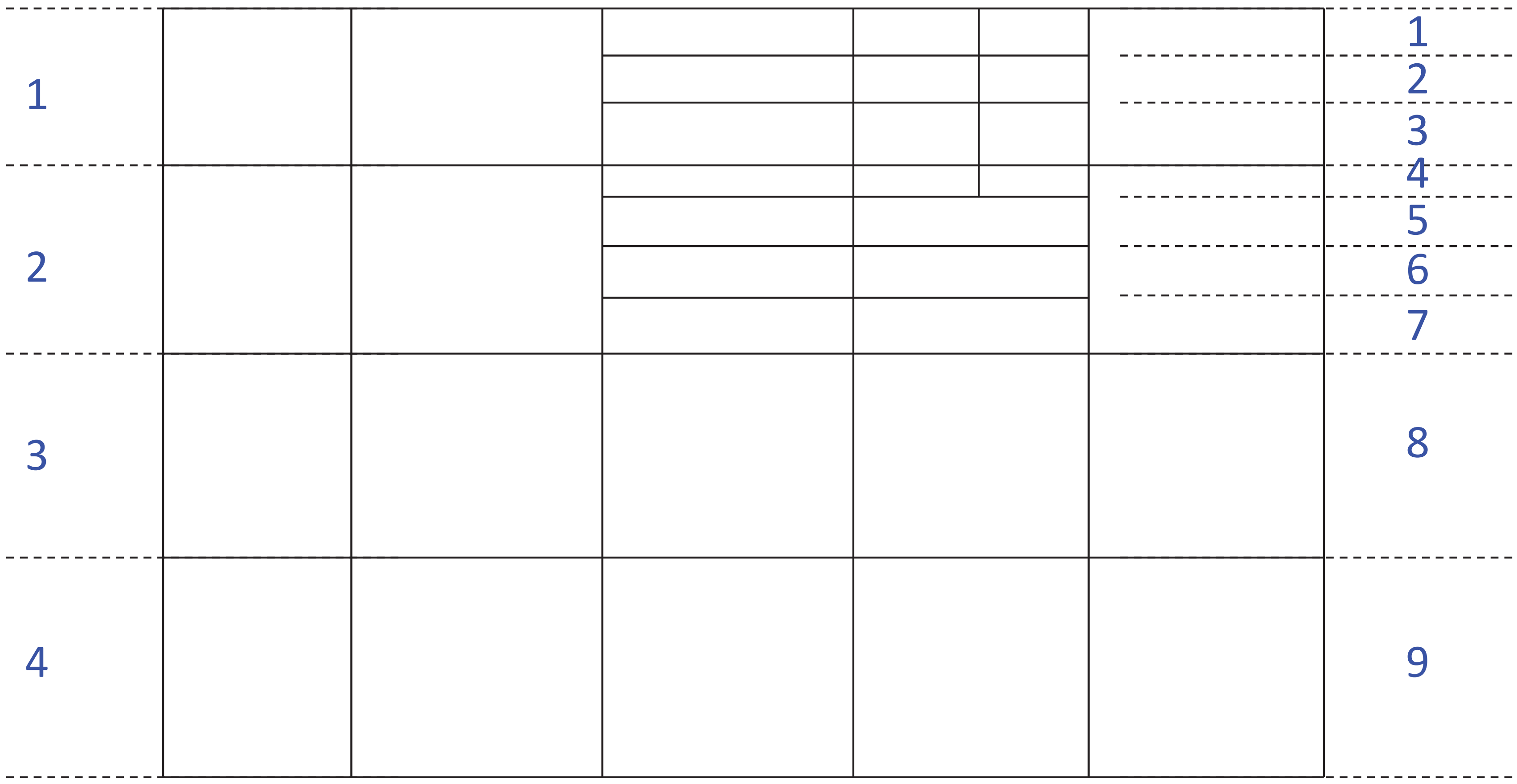
Horizontal Discretization



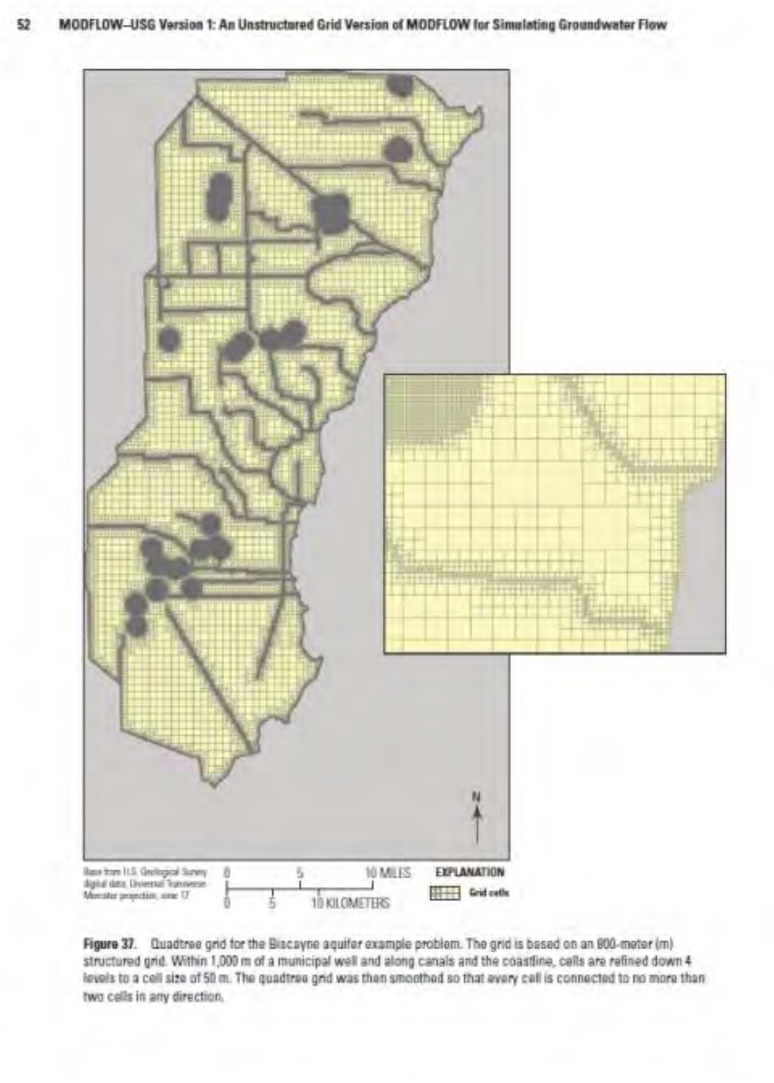
Can have any number of nested grids in the parent model domain

MODFLOW-USG

Vertical Discretization



MODFLOW-USG


52 MODFLOW–USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow

Base from U.S. Geological Survey digital data; Universal Transverse Mercator projection, zone 17

Figure 37. Quadtree grid for the Biscayne aquifer example problem. The grid is based on an 800-meter (m) structured grid. Within 1,000 m of a municipal well and along canals and the coastline, cells are refined down 4 levels to a cell size of 50 m. The quadtree grid was then smoothed so that every cell is connected to no more than two cells in any direction.

- Example MODFLOW-USG grid

Status of MODFLOW-USG

- Still being developed (mostly done) in parallel with the USGS
- Flow model active
- Transport is active
- Particle tracking is not currently available, expected in the next couple of months
- Supported by commercial modeling per- and post-processors

Connected Linear Network (CLN) Boundary

- **Swiss Army Knife** of boundary conditions
- Needed in MODFLOW-USG because grid dimensions potentially can change between simulations (turn on or off grid refinement areas)
- Couple CLN with other boundary conditions
- For example, a CLN could be oriented vertically to represent a well with a well cell placed at an elevation representing the pump elevation
- A conductance term is applied to the CLN to represent well efficiency
- An interesting feature is the CLN cell allows flow up and down the well bore depending on the rate of pumping
- In the absence of pumping contamination can enter the well screen and flow up or down the well bore before exiting

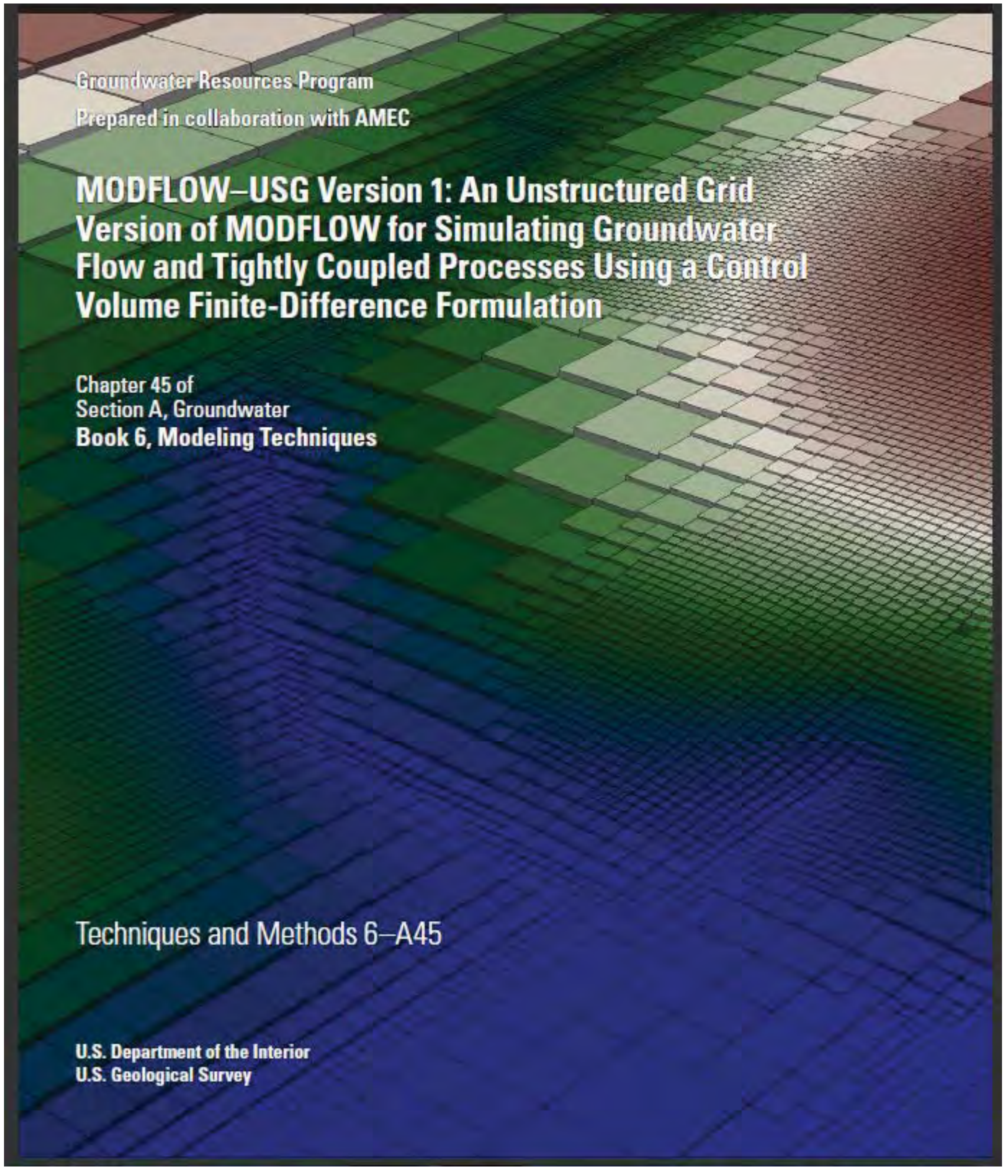
Connected Linear Network (CLN) Boundary

- CLNs can have 2D architecture
- For example, CLNs could be configured to represent the bathymetry of tidal creeks
- A conductance term represents the connection of the creek with aquifer
- A single constant head cell with temporal elevations corresponding to tide elevations would flood and drain the creek as a function of the creek bottom elevation

Connected Linear Network (CLN) Boundary

- CLNs can be used to represent fractures and/or faults
- 3D configurations can be used to represent karst features or basalt tubes
- In concept there isn't much that can't be done with CLNs
- Reality it is a complex boundary condition to code and is currently implemented in a rudimentary form but expect great things

Modflow-USG Reference



Groundwater Resources Program

Prepared in collaboration with AMEC

MODFLOW–USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation

Chapter 45 of
Section A, Groundwater
Book 6, Modeling Techniques

Techniques and Methods 6–A45

U.S. Department of the Interior
U.S. Geological Survey

APPENDIX C

CALIBRATION TARGET DATA

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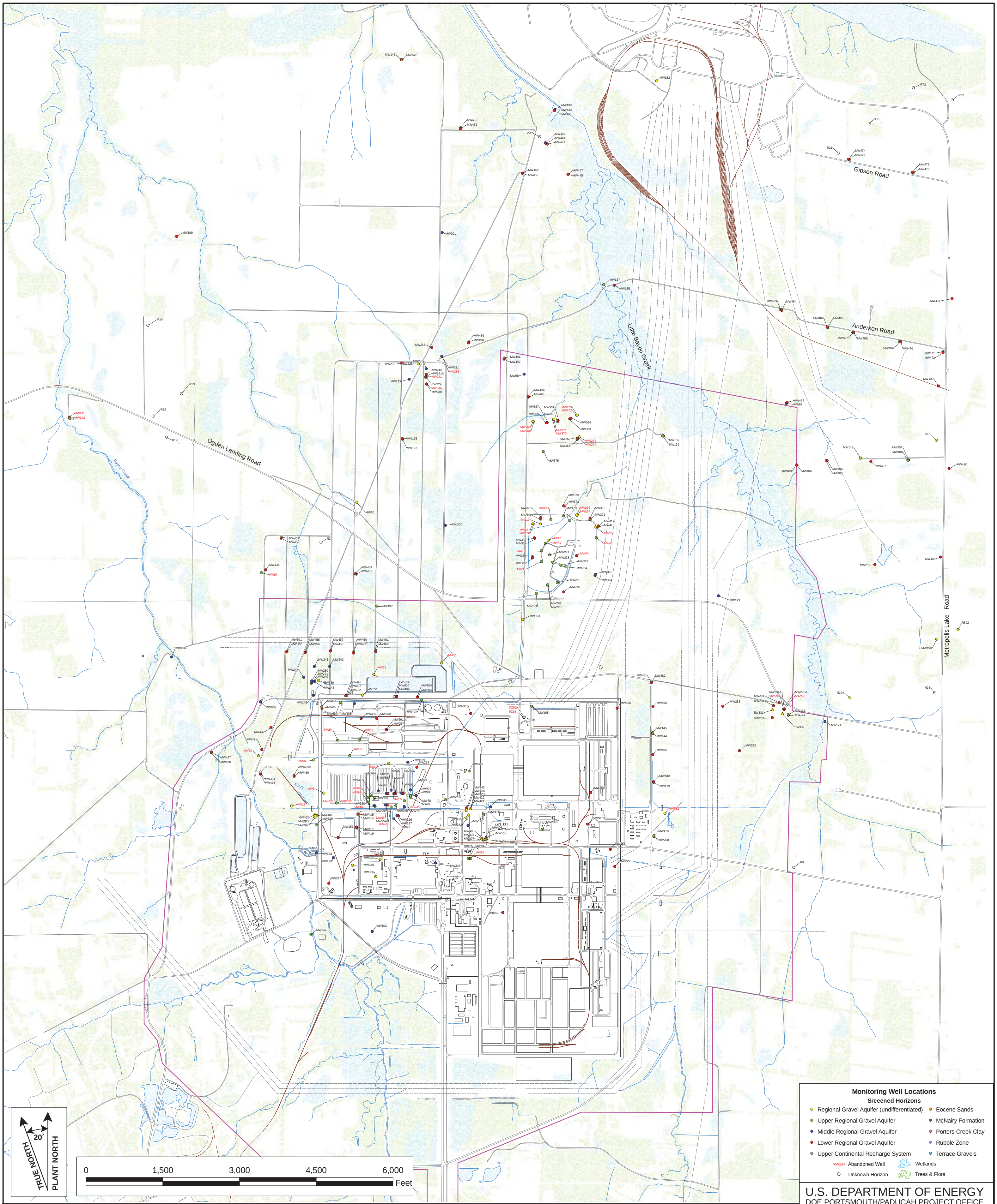

Monitoring Well Locations

Srceened Horizons

- ● Regional Gravel Aquifer (undifferentiated)
- ● Upper Regional Gravel Aquifer
- ● Middle Regional Gravel Aquifer
- ● Lower Regional Gravel Aquifer
- ● Upper Continental Recharge System
- MW294 Abandoned Well
- ○ Unknown Horizon
- ● Eocene Sands
- ● McNairy Formation
- ● Porters Creek Clay
- ● Rubble Zone
- ● Terrace Gravels
- Wetlands
- Trees & Flora

U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

Well Location Map - RGA Wells

PRS
Paducah Remediation Services, LLC

FIGURE No. EMSU_Base_RGA_r1.mxd
DATE 05-04-2010

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW123	1	1	323.9	323.9	-0.01
MW126	1	1	325.3	325.2	0.07
MW137	1	1	321.1	320.7	0.36
MW142_(L2toL1)	1	1	325.3	324.9	0.38
MW147	1	1	320.1	317.9	2.21
MW150_(L2toL1)	1	1	324.7	324.6	0.08
MW156	1	1	326.6	326.6	0.05
MW159	1	1	326.5	326.1	0.38
MW165	1	1	326.3	326.2	0.12
MW168	1	1	326.4	326.3	0.02
MW173	1	1	326.3	326.0	0.28
MW178	1	1	326.7	326.5	0.18
MW181	1	1	325.0	325.1	-0.11
MW185	1	1	326.2	325.9	0.31
MW193	1	1	325.1	325.0	0.15
MW194_(L2toL1)	1	1	325.4	325.8	-0.40
MW197	1	1	325.1	325.3	-0.23
MW199_(L2toL1)	1	1	323.8	323.4	0.35
MW205	1	1	325.2	326.3	-1.18
MW206	1	1	325.9	326.5	-0.62
MW222	1	1	324.6	324.9	-0.36
MW223	1	1	324.6	325.0	-0.37
MW224	1	1	325.7	324.9	0.80
MW327_(L3toL1)	1	1	326.6	326.4	0.24
MW329	1	1	326.1	326.2	-0.04
MW63	1	1	325.9	325.8	0.08
MW66	1	1	325.0	325.8	-0.86
MW71	1	1	325.2	326.6	-1.35
PZ107	1	1	327.7	326.6	1.10
MW106	1	2	325.4	325.7	-0.31
MW139	1	2	323.6	323.6	-0.06
MW142	1	2	325.3	324.9	0.38
MW145	1	2	325.7	325.8	-0.17
MW150	1	2	324.7	324.6	0.08
MW152	1	2	316.2	316.5	-0.29
MW161	1	2	326.7	326.2	0.44
MW169	1	2	325.2	326.2	-0.96
MW175	1	2	326.7	326.5	0.21
MW179	1	2	324.7	324.8	-0.17
MW188	1	2	326.7	326.3	0.40
MW191	1	2	325.2	325.2	0.05
MW194	1	2	325.4	325.8	-0.40
MW199	1	2	323.8	323.4	0.35
MW200	1	2	324.5	324.6	-0.07

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW201	1	2	322.0	321.7	0.30
MW202	1	2	323.4	323.1	0.28
MW225	1	2	324.8	325.0	-0.20
MW227	1	2	327.0	326.3	0.67
MW325	1	2	325.6	326.4	-0.75
MW328	1	2	326.1	326.2	-0.16
MW330	1	2	326.9	326.4	0.51
MW67	1	2	326.8	326.1	0.69
MW79	1	2	326.4	326.3	0.16
MW84	1	2	326.3	326.2	0.18
MW87	1	2	326.3	326.2	0.13
MW90	1	2	326.0	326.2	-0.21
MW93	1	2	326.3	326.2	0.10
MW98	1	2	323.0	322.5	0.46
MW99	1	2	323.1	323.0	0.14
PZ109	1	2	326.6	326.6	-0.06
PZ110	1	2	326.5	326.6	-0.08
PZ117	1	2	327.0	326.6	0.41
PZ118	1	2	326.3	326.6	-0.31
W108	1	2	326.8	326.6	0.20
MW125	1	3	323.8	323.9	-0.03
MW132	1	3	323.5	323.6	-0.16
MW142_(L2toL3)	1	3	325.3	324.9	0.38
MW144	1	3	325.7	325.9	-0.11
MW148	1	3	323.6	324.2	-0.61
MW150_(L2toL3)	1	3	324.7	324.6	0.08
MW152_(L2toL3)	1	3	316.2	316.5	-0.29
MW158	1	3	327.0	326.1	0.91
MW163	1	3	326.4	326.3	0.03
MW191_(L2toL3)	1	3	325.2	325.2	0.05
MW194_(L2toL3)	1	3	325.4	325.8	-0.40
MW199_(L2toL3)	1	3	323.8	323.4	0.35
MW226	1	3	326.9	326.3	0.63
MW326	1	3	326.8	326.5	0.28
MW327	1	3	326.6	326.4	0.24
MW86	1	3	325.9	326.2	-0.32
MW89	1	3	325.8	326.2	-0.45
MW92	1	3	325.8	326.2	-0.45
MW95	1	3	325.7	326.2	-0.51
PZ110_(L2toL3)	1	3	326.5	326.6	-0.08
MW103_(L3toL1)	2	1	325.9	325.8	0.16
MW123	2	1	323.2	323.4	-0.13
MW126	2	1	323.4	324.0	-0.53
MW137	2	1	320.3	320.5	-0.14

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW147	2	1	318.6	317.9	0.78
MW150_(L2toL1)	2	1	323.8	323.8	-0.06
MW156	2	1	325.8	325.7	0.04
MW165	2	1	325.3	325.3	0.03
MW168	2	1	325.1	325.4	-0.25
MW173	2	1	324.7	324.7	0.00
MW178	2	1	325.5	325.6	-0.02
MW185	2	1	324.3	324.5	-0.18
MW193	2	1	324.3	324.1	0.25
MW194_(L2toL1)	2	1	324.9	324.9	0.02
MW197	2	1	324.0	324.4	-0.38
MW199_(L2toL1)	2	1	322.6	323.2	-0.62
MW205	2	1	325.1	325.3	-0.27
MW220	2	1	324.7	324.3	0.46
MW222	2	1	324.4	324.2	0.22
MW224	2	1	324.5	324.2	0.28
MW245	2	1	324.4	324.6	-0.19
MW293A	2	1	323.5	324.0	-0.49
MW327_(L3toL1)	2	1	325.9	325.4	0.44
MW329	2	1	325.8	325.1	0.68
MW354	2	1	325.7	325.0	0.72
MW357	2	1	323.0	322.8	0.15
MW360	2	1	322.8	322.8	0.06
MW366	2	1	323.0	323.2	-0.20
MW369	2	1	324.3	324.1	0.21
MW372	2	1	324.3	324.0	0.24
MW411	2	1	321.3	321.8	-0.53
MW416	2	1	325.3	325.2	0.03
MW426	2	1	325.6	325.0	0.60
MW429A	2	1	325.7	324.9	0.71
MW433	2	1	318.5	318.8	-0.34
MW439	2	1	316.5	317.0	-0.47
MW445	2	1	317.4	317.7	-0.25
MW448	2	1	318.5	318.4	0.11
MW451	2	1	324.2	324.2	-0.02
MW453	2	1	324.1	324.2	-0.14
MW457	2	1	324.4	324.5	-0.11
MW459	2	1	324.6	324.5	0.09
MW463	2	1	317.9	318.4	-0.58
MW478	2	1	325.5	325.2	0.32
MW479	2	1	325.1	325.0	0.09
MW481	2	1	324.7	324.6	0.17
MW483	2	1	323.6	323.5	0.09
MW489	2	1	322.1	322.2	-0.15

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW497	2	1	324.2	324.1	0.12
MW501	2	1	324.4	324.6	-0.19
MW504	2	1	324.9	324.7	0.20
MW505	2	1	325.8	325.7	0.09
MW63	2	1	324.4	324.6	-0.26
MW66	2	1	324.3	324.5	-0.24
MW71	2	1	325.9	325.7	0.14
PZ349	2	1	325.0	324.8	0.21
MW103_(L3toL2)	2	2	325.9	325.8	0.16
MW106	2	2	324.6	324.7	-0.15
MW139	2	2	322.9	323.0	-0.20
MW145	2	2	325.0	324.9	0.11
MW146_(L3toL2)	2	2	318.6	317.9	0.76
MW150	2	2	323.8	323.8	-0.06
MW169	2	2	324.8	325.1	-0.27
MW175	2	2	325.9	325.6	0.26
MW188	2	2	325.9	325.3	0.54
MW194	2	2	324.9	324.9	0.02
MW199	2	2	322.6	323.2	-0.62
MW200	2	2	324.0	324.0	0.03
MW201	2	2	320.9	321.4	-0.55
MW203	2	2	325.8	325.8	0.05
MW221	2	2	324.4	324.2	0.17
MW225	2	2	324.6	324.3	0.33
MW233	2	2	322.7	322.8	-0.12
MW236	2	2	322.6	322.4	0.24
MW238	2	2	322.7	322.6	0.06
MW242	2	2	324.4	324.5	-0.18
MW243	2	2	324.4	324.6	-0.18
MW248	2	2	324.3	324.6	-0.26
MW249	2	2	324.3	324.6	-0.28
MW250	2	2	324.4	324.6	-0.18
MW257	2	2	324.7	324.7	-0.06
MW288	2	2	323.7	324.0	-0.38
MW291	2	2	323.5	324.0	-0.50
MW325	2	2	325.9	325.5	0.39
MW328	2	2	325.8	325.2	0.63
MW330	2	2	325.9	325.4	0.46
MW333	2	2	325.6	325.2	0.45
MW337	2	2	325.4	325.1	0.37
MW338	2	2	325.4	325.1	0.30
MW361	2	2	322.8	322.8	0.04
MW363	2	2	322.8	322.7	0.08
MW380	2	2	322.7	322.7	-0.07

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW384	2	2	323.8	324.2	-0.40
MW387	2	2	324.4	324.2	0.22
MW391	2	2	324.3	324.0	0.24
MW394	2	2	324.6	324.2	0.38
MW409	2	2	323.6	323.7	-0.17
MW414	2	2	325.4	325.1	0.25
MW418	2	2	324.2	324.1	0.16
MW420	2	2	325.5	325.3	0.22
MW421	2	2	325.4	325.5	-0.07
MW422	2	2	325.4	325.5	-0.06
MW423	2	2	325.4	325.5	-0.11
MW424	2	2	325.5	325.5	-0.02
MW425	2	2	325.5	325.5	0.00
MW426_(L1toL2)	2	2	325.6	325.0	0.60
MW440	2	2	316.5	317.0	-0.52
MW442	2	2	317.5	317.6	-0.17
MW443	2	2	317.4	317.7	-0.27
MW455	2	2	324.6	324.6	-0.01
MW461	2	2	324.5	324.5	-0.04
MW464	2	2	318.3	318.5	-0.21
MW465	2	2	319.8	319.7	0.13
MW466	2	2	319.7	319.6	0.10
MW471	2	2	322.8	322.9	-0.10
MW473	2	2	317.2	316.3	0.90
MW488	2	2	323.5	323.4	0.09
MW490	2	2	322.2	322.2	-0.10
MW491	2	2	322.6	322.2	0.45
MW493	2	2	322.3	322.3	0.00
MW499	2	2	324.3	324.1	0.18
MW506	2	2	325.8	325.7	0.08
MW67	2	2	325.2	325.0	0.13
MW72	2	2	325.1	325.1	-0.03
MW76	2	2	325.4	325.3	0.01
MW77	2	2	325.7	325.3	0.39
MW79	2	2	325.0	325.3	-0.25
MW80	2	2	325.0	325.3	-0.24
MW81	2	2	325.0	325.3	-0.25
MW84	2	2	325.3	325.1	0.19
MW87	2	2	325.1	325.1	-0.04
MW90A	2	2	325.0	325.2	-0.20
MW93	2	2	325.6	325.2	0.34
MW98	2	2	322.6	322.1	0.40
MW99	2	2	322.6	322.5	0.11
PZ109	2	2	325.9	325.8	0.12

Well Name	Stress Period	Layer	Observed	Computed	Residual
PZ110	2	2	325.9	325.8	0.11
W108	2	2	325.9	325.8	0.13
MW100	2	3	322.9	323.0	-0.12
MW103	2	3	325.9	325.8	0.16
MW124	2	3	323.6	324.0	-0.35
MW125	2	3	323.3	323.4	-0.10
MW132	2	3	322.9	323.0	-0.17
MW134	2	3	324.2	324.4	-0.15
MW135	2	3	320.2	320.2	0.06
MW144	2	3	325.0	324.9	0.06
MW146	2	3	318.6	317.9	0.76
MW150_(L2toL3)	2	3	323.8	323.8	-0.06
MW155	2	3	325.7	325.7	-0.01
MW163	2	3	325.5	325.4	0.09
MW194_(L2toL3)	2	3	324.9	324.9	0.02
MW199_(L2toL3)	2	3	322.6	323.2	-0.62
MW226	2	3	325.7	325.4	0.30
MW255	2	3	325.5	325.4	0.09
MW256	2	3	325.5	325.4	0.11
MW260	2	3	325.4	325.2	0.20
MW261	2	3	324.6	324.7	-0.10
MW262	2	3	324.9	325.1	-0.18
MW284	2	3	323.5	324.0	-0.59
MW294A	2	3	323.5	324.0	-0.45
MW326	2	3	325.9	325.6	0.33
MW327	2	3	325.9	325.4	0.44
MW340	2	3	324.4	324.6	-0.13
MW341	2	3	325.6	325.5	0.08
MW342	2	3	325.6	325.6	0.03
MW343	2	3	325.4	325.5	-0.06
MW353	2	3	325.1	324.5	0.65
MW355	2	3	325.3	325.2	0.09
MW358	2	3	322.9	322.8	0.06
MW364	2	3	322.7	322.7	0.01
MW367	2	3	323.0	323.2	-0.21
MW370	2	3	324.3	324.1	0.21
MW373	2	3	324.3	324.0	0.23
MW385	2	3	324.4	324.2	0.15
MW388	2	3	324.4	324.2	0.23
MW392	2	3	324.3	324.0	0.21
MW395	2	3	324.6	324.2	0.45
MW397	2	3	324.6	324.3	0.33
MW415	2	3	325.1	325.1	0.00
MW417	2	3	325.1	325.2	-0.11

Well Name	Stress Period	Layer	Observed	Computed	Residual
MW419	2	3	324.2	324.0	0.12
MW427	2	3	325.6	325.0	0.58
MW428	2	3	325.7	325.0	0.67
MW430	2	3	325.7	325.0	0.74
MW431	2	3	325.6	324.9	0.69
MW432	2	3	325.3	324.8	0.49
MW435	2	3	318.5	318.8	-0.34
MW441	2	3	316.4	317.1	-0.66
MW444	2	3	317.4	317.6	-0.27
MW447	2	3	317.5	317.7	-0.15
MW450	2	3	318.7	318.4	0.27
MW452	2	3	324.2	324.2	-0.02
MW454	2	3	324.1	324.2	-0.12
MW456	2	3	324.4	324.6	-0.18
MW458	2	3	324.4	324.5	-0.11
MW460	2	3	324.2	324.5	-0.29
MW462	2	3	324.5	324.5	-0.05
MW472	2	3	322.8	322.9	-0.10
MW474	2	3	317.3	316.2	1.07
MW476	2	3	317.4	316.8	0.63
MW477	2	3	322.5	322.4	0.09
MW480	2	3	325.1	325.0	0.10
MW482	2	3	324.7	324.6	0.15
MW484	2	3	323.5	323.6	-0.06
MW487	2	3	323.5	323.5	-0.03
MW494	2	3	322.2	322.3	-0.10
MW495	2	3	325.0	325.0	0.03
MW496	2	3	324.9	324.7	0.13
MW498	2	3	324.2	324.4	-0.21
MW500	2	3	324.2	324.2	-0.02
MW502	2	3	324.4	324.6	-0.18
MW503	2	3	324.7	324.7	0.04
MW507	2	3	325.8	325.7	0.10
MW65	2	3	324.0	324.6	-0.65
MW78	2	3	325.0	325.3	-0.30
MW86	2	3	325.3	325.1	0.14
MW89	2	3	325.1	325.2	-0.08
MW92	2	3	325.1	325.2	-0.07
MW95A	2	3	325.5	325.2	0.31
PZ110_(L2toL3)	2	3	325.9	325.8	0.11