ECF-200E-19-0129
Revision 0

Groundwater Flow and Migration Calculations to Support the Assessment of the LLBG Trench 94 Monitoring Network

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CPCCo
Central Plateau
Cleanup Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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APPROVED
By Julia Raymer at 7:29 am, Feb 18, 2021

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ENVIRONMENTAL CALCULATION COVER PAGE

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SECTION 2 - Completed by Preparer

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Terms

ASCII	American Standard Code for Information Interchange
CHPRC	CH2M HILL Plateau Remediation Company
CRBG	Columbia River Basalt Group
CY	calendar year
DWMU	dangerous waste management unit
ECF	environmental calculation file
HISI	Hanford Information Systems Inventory
LLBG	Low-Level Burial Grounds
MEUK	multi-event universal kriging
SSP&A	S.S. Papadopulos and Associates, Inc.
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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1 Purpose

This environmental calculation file (ECF) describes calculations made to evaluate the groundwater monitoring network associated with the dangerous waste management unit (DWMU) Low-Level Burial Ground (LLBG) Trench 94. The interim status monitoring network that is evaluated herein is described in Table 2-42 of DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*. The network is designed to detect significant increases in groundwater contamination that might result from a release from the regulated unit. The calculations support evaluation of the groundwater monitoring network's suitability for detecting releases from LLBG Trench 94 and help determine if additional monitoring locations are required.

LLBG Trench 94 is located within the LLBG Waste Management Area (WMA)-2 boundary in the 200 East Area of the Hanford Site Central Plateau (Figure 1).

2 Background

LLBG Trench 94, located within LLBG WMA-2 in the northeastern part of the 200 East Area, consists of one active uncovered trench. The LLBG Trench 94 area contains defueled and decommissioned naval reactor components. This ECF presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from LLBG Trench 94 at existing and potential new monitoring well locations.

The interim status groundwater monitoring network for LLBG WMA-2 was developed as a result of previous investigations and data quality objective equivalent studies. Groundwater monitoring is ongoing in accordance with interim status regulations. There is no interim status monitoring network specific to LLBG Trench 94 because LLBG Trench 94 lies within LLBG WMA-2. The interim status monitoring network wells for LLBG WMA-2 that are closest to LLBG Trench 94 are shown in Figure 2. For the purpose of this ECF, these select interim status monitoring network wells for LLBG WMA-2 that are most relevant to address a release from LLBG Trench 94 were evaluated. Those wells consist of wells 299-E34-2, 299-E27-8, 299-E27-9, 299-E27-10, and 299-E27-11, most of which are screened across the top of the unconfined aquifer (DOE/RL-2016-66). Well 299-E34-2 is classified as an upgradient well for the LLBG WMA-2 monitoring network; however, the initial results of water-level mapping and particle-tracking calculations performed for this ECF indicated that this well was located crossgradient to particle pathlines simulated to arise from hypothetical releases at LLBG Trench 94. Because of this, for purposes of the LLBG Trench 94 evaluation, well 299-E34-2 is considered a crossgradient well.

2.1 Geology and Hydrology

This section discusses the uppermost aquifers beneath LLBG Trench 94.

LLBG Trench 94 overlies a hydrogeologic boundary between two aquifers that exhibit substantially different hydrogeological properties. Basalts of the Elephant Mountain Member of the Saddle Mountains Basalt Formation underlie the majority of LLBG Trench 94. However, southern portions of LLBG Trench 94 overlie or are located slightly north of the northern extent of the unconfined Hanford formation unconsolidated sediments. The exact location where the basalts subcrop, and may locally contain, the water table is not perfectly known.

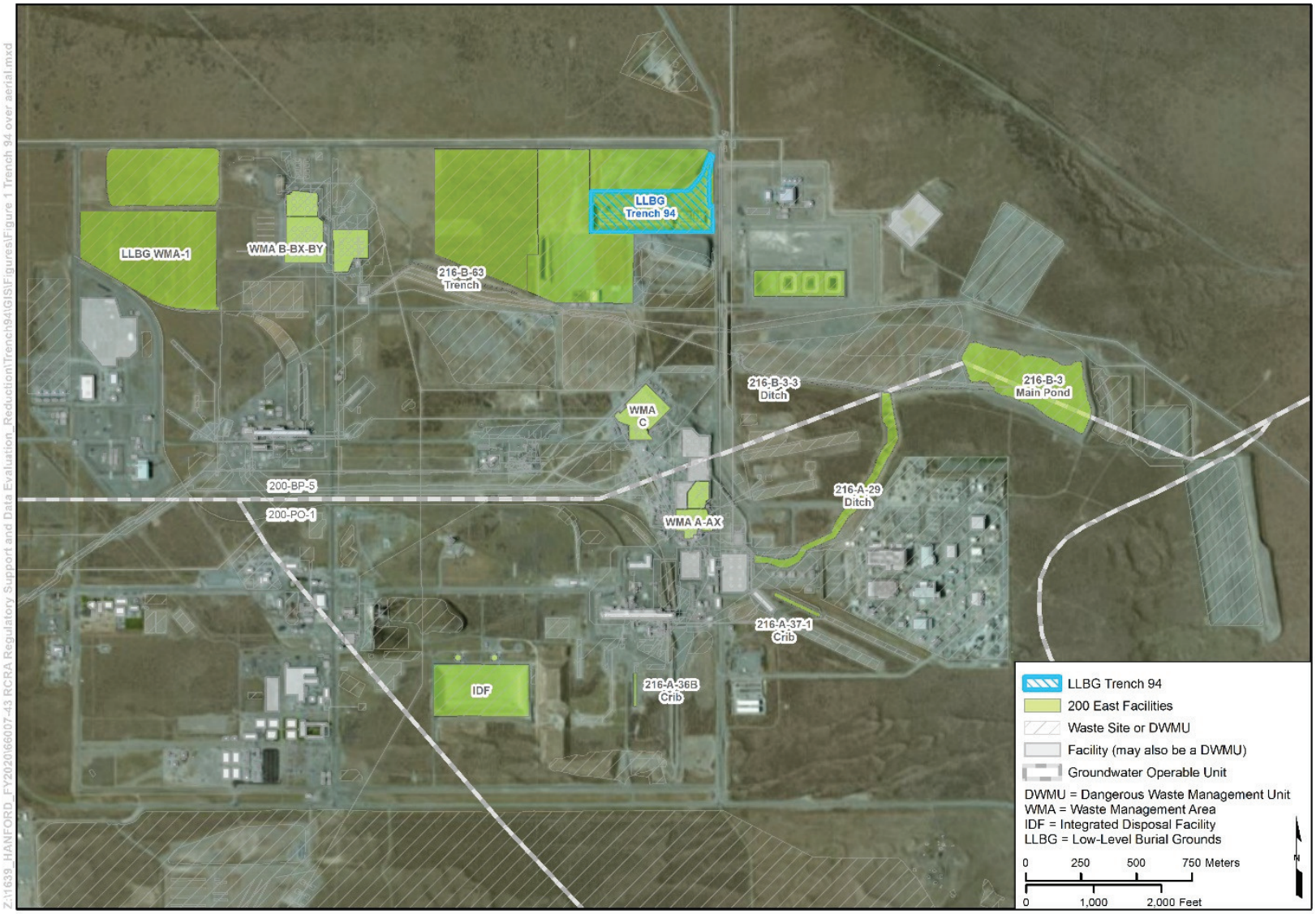

Figure 1. Location of LLBG Trench 94 Within the 200 East Area

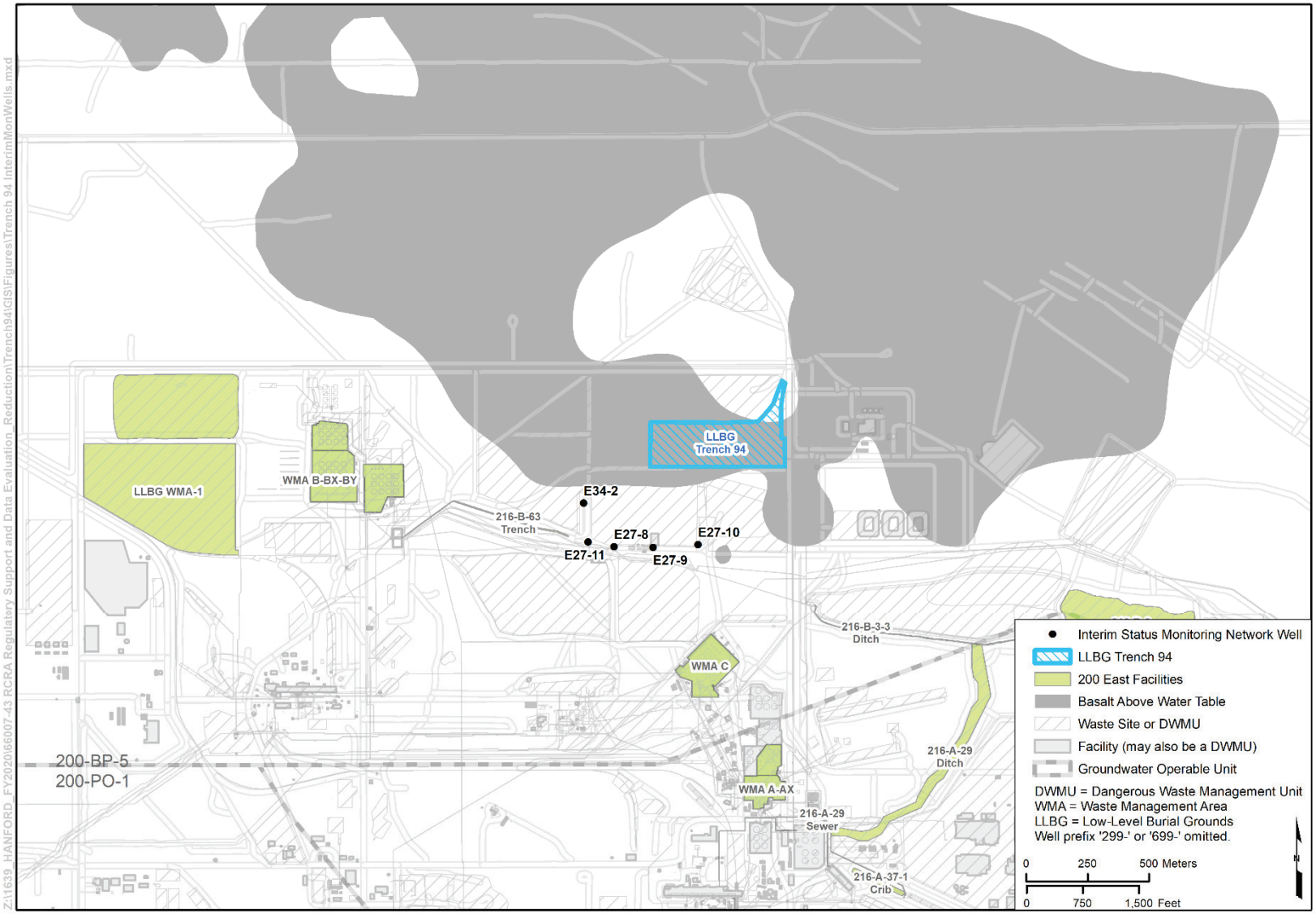

Figure 2. Locations of Interim Status Groundwater Monitoring Wells at LLBG Trench 94 (Well Network Associated with LLBG WMA-2)

The Columbia River Basalt Group (CRBG) as described in Section 3.3.1 of WHC-SD-EN-EV-024, *Site Characterization for the Liquid Effluent Retention Facility*, is an assemblage of continental flood basalts that cover an area of more than 63,000 mi^2 (161.157 km^2) in Washington, Oregon, and Idaho. The CRBG is divided from oldest to youngest into five formations: Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. The Saddle Mountains Basalt Formation, the uppermost basalt at the Hanford Site, is divided into (from oldest to youngest) the Umatilla, Wilbur Creek, Asotin, Esquatzel, Pomona, Elephant Mountain, and Ice Harbor Members. Hydraulic conductivities of the CRBG flow interiors are extremely low, ranging from 10^{-9} to 10^{-3} ft/d (10^{-15} to 10^{-9} m/s) (Section 3.9.2.1 in Volume 8 of DOE/RW-0164, *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*). Beneath LLBG Trench 94 lies the Elephant Mountain Member of the Saddle Mountains Basalt Formation. Section 5.4.1 of WHC-SD-EN-EV-024 describes the Elephant Mountain Member as having medium- to fine-grained texture with abundant microphenocrysts of plagioclase.

Section 5.4.1 of WHC-SD-EN-EV-024 also indicates that there are three intraflow structures typically identified in the Elephant Mountain Member flows: basal colonnade, entablature, and flowtop. The colonnade makes up approximately one-third of the flow. Its base is nonvesicular with cross fractures and joints. Above this, the colonnade grades from moderate- and well-developed columns into a cross-fractured colonnade and then into a hackly entablature. The entablature has numerous irregular cross-fractures, vertical fractures, and scattered vesicles near its top. The flowtop is characterized by abundant vesicles and is brecciated or palagonitic. The average hydraulic conductivity in the flowtop is approximately 5 orders of magnitude greater than in the CRBG flow interior (Section 3.9.2.1 of Volume 8 of DOE/RW-0164).

During drilling of LLBG WMA-2 wells, some of the drilling extended into the upper portion of the Elephant Mountain Member. Examination of basalt drill cuttings found no vesicles in basalt chips from two wells (PNL-6820, *Hydrogeology of Low-Level Burial Grounds -- An Interim Report*). Based on this information, it was concluded that past fluvial events removed part of or the entire flowtop from the Elephant Mountain Member in this area (Section 2.4 of DOE/RL-2009-76, *Interim Status Groundwater Monitoring Plan for the LLBG WMA-2*).

As described in ECF-200E-19-0081, *Groundwater Elevation Mapping for 200 East Area – Quarter 1 Calendar Year 2019*, the majority of the unconfined aquifer beneath the 200 East Area of the Central Plateau occurs in a buried paleochannel consisting of highly permeable sediments of the Hanford formation and Cold Creek unit that overlie the basalts. Initial transmissivity estimates from LLBG WMA-2 boreholes within the Hanford formation varied from 1,300 m^2/d (14,000 ft^2/d) to 7,900 m^2/d (85,000 ft^2/d). Due to the highly permeable nature of aquifer sediments, the groundwater gradient has historically been very small beneath LLBG WMA-2.

The analyses in this ECF examine horizontal directions of groundwater flow. Estimates of groundwater velocities and travel times are used in calculations; however, the estimates are not presented because of the strongly contrasting properties of the different hydrogeologic units and the uncertainties regarding the boundaries between these units.

3 Calculation Methods

This chapter describes the calculation methods used to support this ECF. Groundwater elevation mapping and particle-tracking calculations were conducted to evaluate the efficacy of the current interim groundwater monitoring network for detecting significant increases in groundwater contamination that might occur from a hypothetical release at LLBG Trench 94, and identifying locations for potential additional wells to supplement the existing network.

Groundwater elevation mapping for 2017 through 2019 was performed for the 200 East Area using a regularized inverse interpolation technique that hereinafter is referred to as the Tikhonov Regularized Inverse Method (TRIM). TRIM was developed to evaluate the well networks for DWMUs in the 200 East Area in ECF-200E-18-0066, *Groundwater Flow and Migration Calculations to Assess Monitoring Networks in the 200 East Area Dangerous Waste Management Units*. An advantage of using TRIM is that it uses a simplified groundwater flow simulator as the underlying mechanism to interpolate between measured water levels resulting in piecewise, continuous groundwater elevation grids that conserve flow and are suitable for tracking particles to evaluate likely groundwater flow paths. Groundwater elevation mapping using TRIM is updated on a quarterly basis in the 200 East Area. TRIM implementation details and quarterly results of TRIM calculations for the first quarters of 2017 and 2018 are included in Appendix A. Results of the calculations for the first quarter of 2019 are included in ECF-200E-19-0081. Figures 3 through 5 show the results of mapping using TRIM in the 200 East Area for the first quarters of 2017, 2018, and 2019.

The lateral domain of the simplified groundwater flow simulator that underlies the TRIM calculations does not extend fully beneath the location of LLBG Trench 94 because TRIM was developed to evaluate water levels in the unconsolidated sediments, whereas most of LLBG Trench 94 is located over the basalt subcrop. For this reason, a method was developed to evaluate dominant groundwater flow directions within the basalt and combine this together with the results of TRIM analyses of the groundwater levels and flow within the unconfined Hanford formation. After the grids were produced from the groundwater elevation mapping, these were used to perform particle tracking assuming advection and dispersion to illustrate general patterns of migration for a hypothetical release that reaches the underlying water table from LLBG Trench 94. Details of these analyses follow.

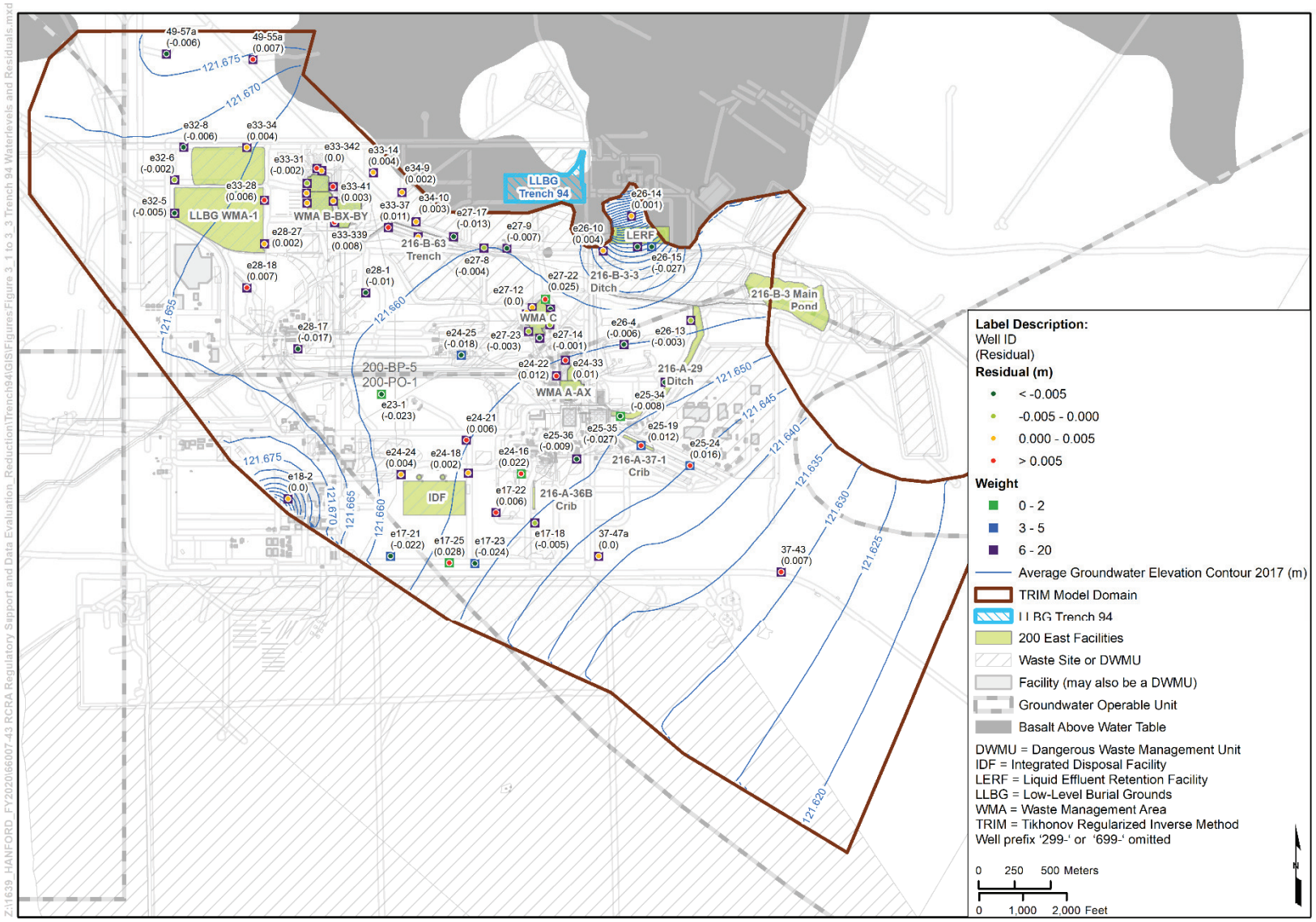

Figure 3. TRIM-Mapped Groundwater Elevations and Calibration Residuals (2017)

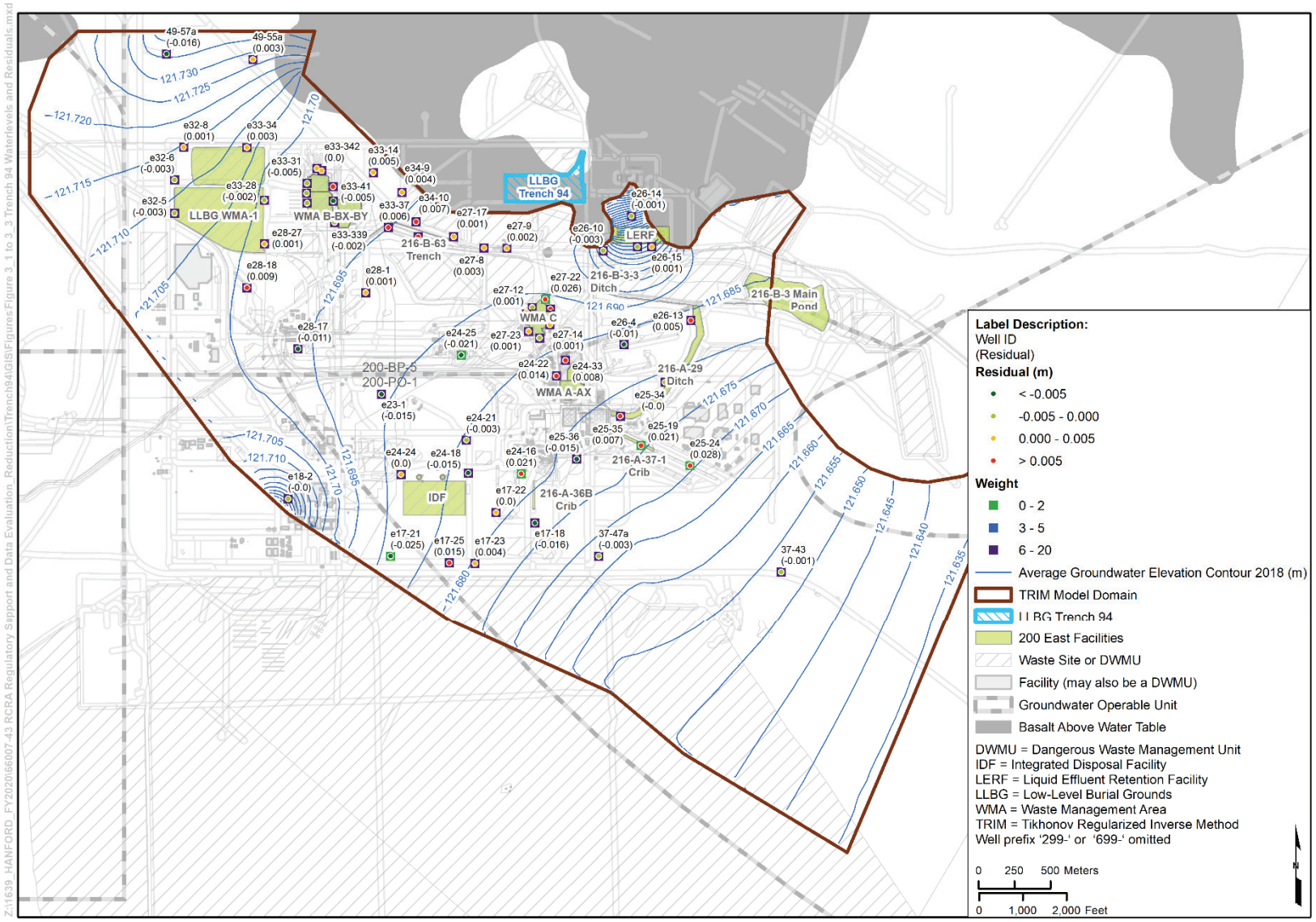

Figure 4. TRIM-Mapped Groundwater Elevations and Calibration Residuals (2018)

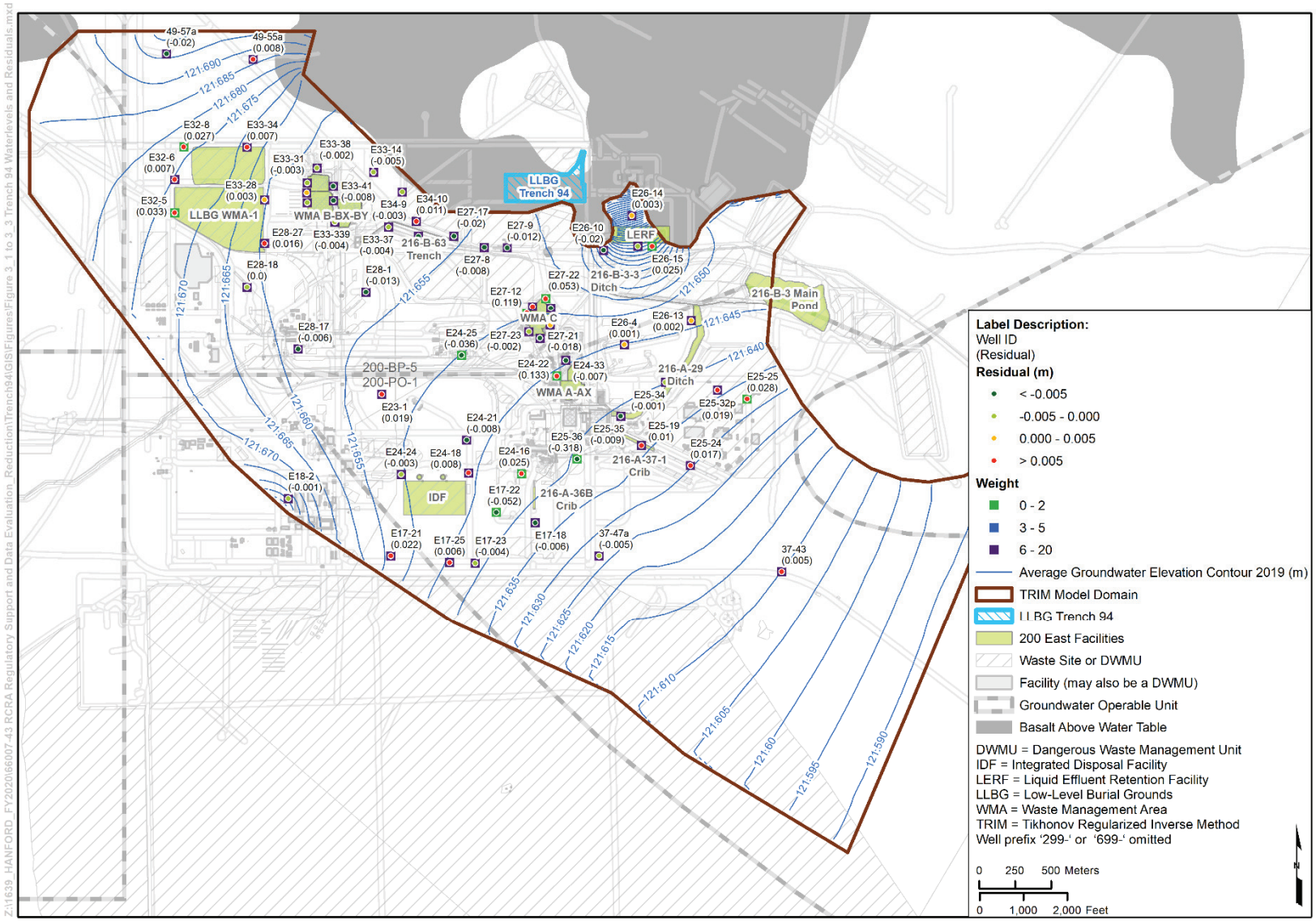

Figure 5. TRIM-Mapped Groundwater Elevations and Calibration Residuals – Average January Through March 2019

3.1 Groundwater Elevation Mapping

Groundwater elevation mapping for the majority of the 200 East Area (i.e., where the water table lies within the unconsolidated sedimentary aquifer materials) was performed using TRIM. Map production for the first quarters of calendar years (CY) 2017 and 2018 are described in Appendix A. Map production for the first quarter of CY 2019 is described in ECF-200E-19-0081. The geographic domain of the simplified groundwater flow simulator underlying TRIM does not extend into the area of the basalt subcrop beneath LLBG Trench 94. For this reason, the universal kriging method implemented in MEUK (Tonkin et al., 2016, "Multi-Event Universal Kriging (MEUK)") was used to create groundwater elevation maps in the area of the basalt subcrop to combine and interpret together with the maps of groundwater flow patterns where the water table lies within the unconsolidated sediments.

MEUK is a mapping technique combining universal kriging and the analytic element method, based upon that first documented in the water-level kriging program KT3D-H2O (Karanovic et al., 2009, "KT3D_H20: A Program for Kriging Water-Level Data Using Hydrologic Drift Terms"). MEUK is designed to create one or more groundwater elevation maps, each corresponding to a specific event, that can exhibit spatial relationships that persist over time. MEUK assumes that multi-event data can be described by a combination of trends that vary over time, trends that are invariant over time, and residuals from those two trends. MEUK comprises two procedures. The first is estimation using generalized least squares regression to obtain trend coefficients ("calibration"). The second is prediction using the coefficients estimated through to predict water levels at intermediate locations or times and make maps. Although MEUK supports multi-event analysis, for the water-level mapping described in this document, MEUK is used to map water levels for each year individually, expressing the groundwater level surface as the sum of two terms — a global-mean "offset" used to allow for an areawide adjustment in the mean evaluation between events, and a linear drift to represent the general underlying trend within the Elephant Mountain Member basalts. To provide a smooth transition between areas where the water table lies within the basalts (mapped as described above) and where it lies within the unconsolidated sediments (mapped using TRIM), water levels extracted from TRIM maps along the line representing the margins of the basalt subcrop were added to water levels measured within basalt wells for use as input to the MEUK calculations.

3.2 Semivariogram Parameters

As described in Section 4.1.5 of SGW-42305, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance,* the procedure of computing an experimental semivariogram and fitting a semivariogram model is generally stepwise or iterative in universal kriging, beginning with trend fitting and evaluation of the range of the variogram of the residuals in order to produce a useful map. The variogram parameters selected for use in the water-level mapping within the Elephant Mountain Member basalts are as follows:

- Variogram model: Spherical
- Range length: 3,000 m (9,842 ft)
- Sill: 0.04
- Nugget: 0.005

3.3 Particle Tracking

Groundwater elevation maps produced using TRIM and MEUK, when combined together, depict general patterns of hydraulic gradients and groundwater flow and, therefore, the likely directions of contaminant migration if a contaminant release from a facility reaches the water table. Particle tracking provides a method of visualizing these directions and potential paths of contaminant migration, enabling a more detailed assessment of monitoring well locations. After the grids of groundwater elevations were created using TRIM and MEUK, they were "merged" together and used as the base for particle tracking. Merging of the grids was completed using Surfer® (Version 12), and particle tracking was performed using mod-PATH3DU and considering advective only or advective and dispersive transport mechanisms (Muffels, et al., 2018, *User's Guide for mod-PATH3DU: A Groundwater Path and Travel-Time Simulator*). The parameters used to calculate particle pathlines assume migration of a conservative (i.e., nonreactive) dissolved contaminant under representative conditions.

Calculated particle pathlines provide a way to visualize how a hypothetical release to the water table from the facility would move and spread under conditions represented in each of the three mapped years (2017, 2018, and 2019). Particle-tracking calculations specific to a facility that assume advective-dispersive transport produce both particle pathlines and particle density counts as detailed below.

3.3.1 Advective-Dispersive Particle Tracking

Particle tracking considering both advection and dispersion was performed to examine how a potential release that might reach the underlying water table from a facility would realistically move and spread downgradient under conditions represented by each of the three mapped events (CY 2017, 2018, and 2019). A large number of particles were released to produce many pathlines, each of which depicts the potential path of a particle of dissolved contaminant released at the water table beneath the facility. The particle pathlines simulate the one-time release of a large number of particles representing an instantaneous release to the water table. Because vadose zone travel time is ignored in these calculations, the particle release year represents the year that hypothetical contamination reaches the water table.

In addition to the presentation of particle pathlines, the particle paths were post-processed following the series of steps described in Chapter 6 to provide additional depictions and calculations including particle counts at well locations and maps of particle density (particle count maps) as described below.

3.3.2 Particle Counts

Calculated particle counts can be used as a surrogate for contaminant concentration to evaluate the relative efficacy of the interim status groundwater monitoring wells and the need for and suitability of any proposed new monitoring wells. Relative particle counts at well locations were calculated by counting the number of particles that pass through the vicinity of an existing or potential new monitoring well location. A radius of 20 m (66 ft) around each well location was used to count particles as they arrived and passed through the area. Particle counts were used to create particle count maps that depict areas of relatively higher and lower potential impact from a release that reaches the water table from a given facility. Contour maps of particle counts were generated by counting the number of particles that pass through a predefined uniform calculational grid. The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells that are oriented parallel to the predominant groundwater flow direction under the facility.

® Surfer is a registered trademark of Golden Software, LLC, Golden, Colorado.

4 Assumptions and Inputs

Assumptions and inputs used for groundwater elevation mapping and particle tracking are discussed in the following sections.

4.1 Assumptions

Assumptions used for groundwater elevation mapping, groundwater flow modeling, and particle tracking are also discussed in the following sections.

4.1.1 Groundwater Elevation Mapping

As discussed in ECF-200E-18-0066, water-level contour maps in the 200 East Area were constructed using a method that combines the use of a simplified model of groundwater flow together with the use of Tikhonov regularization. The resulting groundwater elevation contour maps provide plausible interpretations of groundwater levels and hydraulic gradients between measured locations that match measured water levels and monitoring wells to a degree consistent with the trade-off between that fit and model complexity, and that achieve flow conservation through the use of the underlying groundwater model as the interpolation mechanism between measurement locations. The accuracy of the contours, however, is influenced by several factors, including the following:

- The accuracy of the measured or recorded water levels.
- The number, distribution, and location of monitoring wells

While accounting for the water levels measured at each well, the resulting contour maps provide a plausible interpretation of groundwater levels and hydraulic gradients between measured locations. The accuracy of the contours is influenced, however, by various factors, including the following:

- The degree of adherence to or violation of assumptions that underlie the mapping method (as outlined in SGW-42305)
- The accuracy of the measured or recorded water levels
- The number, distribution, and location of monitoring wells
- The relationship between the vertical open interval(s) of the monitoring wells and those of any extraction and injection wells
- The presence, continuity, and contrasts in hydraulic properties between large-scale aquifer zones

These potential sources of error mean that the interpolated maps only approximate actual conditions. The water-level and particle path maps are considered reasonable approximations that provide value when interpreting the likely directions and rates of groundwater movement. The maps also help identify areas downgradient of 200 East Area facilities that likely would be impacted by a release that reached the underlying water table. The use of multiple groundwater elevation events in the analysis helps in developing a reasonable estimate of potential migration pathways.

4.1.2 Particle Tracking

Particle tracking relies upon the outputs (i.e., grids of mapped groundwater elevations) computed using TRIM and universal kriging. As a result, the assumptions and limitations that underlie the preparation of those maps are implied in any subsequent particle tracking.

Particle tracking that considers advection and dispersion relies upon the assumption that the values of the dispersion coefficients in the two principal directions (longitudinal and transverse) are representative of physical processes that act to disperse dissolved constituents in groundwater at the scale of the calculations.

4.2 Input Data

This section summarizes the general input requirements for the calculations described in this ECF.

4.2.1 Groundwater Elevation Mapping Input

Quarterly average water levels from the low-gradient monitoring network were used as the inputs for water-level mapping using the TRIM method. These inputs are included in Appendix A and in ECF-200E-19-0081. Table 1 lists the individual water-level measurements in wells screened within basalt formation for CY 2017, 2018, and 2019, which are inputs to the water-level mapping using the MEUK method.

Table 1. Water-Level Measurements in Monitoring Wells Located Within the Basalt Formation

Well Name	2017 Water Level (m)	2018 Water Level (m)	2019 Water Level (m)
299-E26-11	122.449*	--	122.538
299-E26-77	121.698	121.741	121.717
699-46-91	122.841	122.830	122.814
699-47-50	122.084	122.109	122.093
699-48-50	122.095	122.110	122.097
699-50-45	122.823	122.768	122.721
699-50-48B	122.376	122.364	122.332
699-51-46	122.556	122.520	122.485
699-52-48	122.353	122.392	122.352

*Outlier; value not used in analysis.

To create a smooth transition between the basalt water table and the TRIM water-level map, water levels from TRIM maps were extracted along the line representing the water table above the basalt formation and used as a control points and added to the measured water levels as an input for MEUK kriging. Locations of control points are depicted in Figure 6, and the control point groundwater elevations are listed in Table B-1 of Appendix B.

4.2.2 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of particle-starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For LLBG Trench 94, 888 release locations were specified throughout the trench (Figure 6). Ten particles were released and tracked from each release location to provide the density of particles in space and time required for the calculations, randomizing the seed values for the dispersion calculations. Thus, 8,880 (8,880 = 888 [release locations] × 10 [releases]) particles were tracked for each of the three simulations.

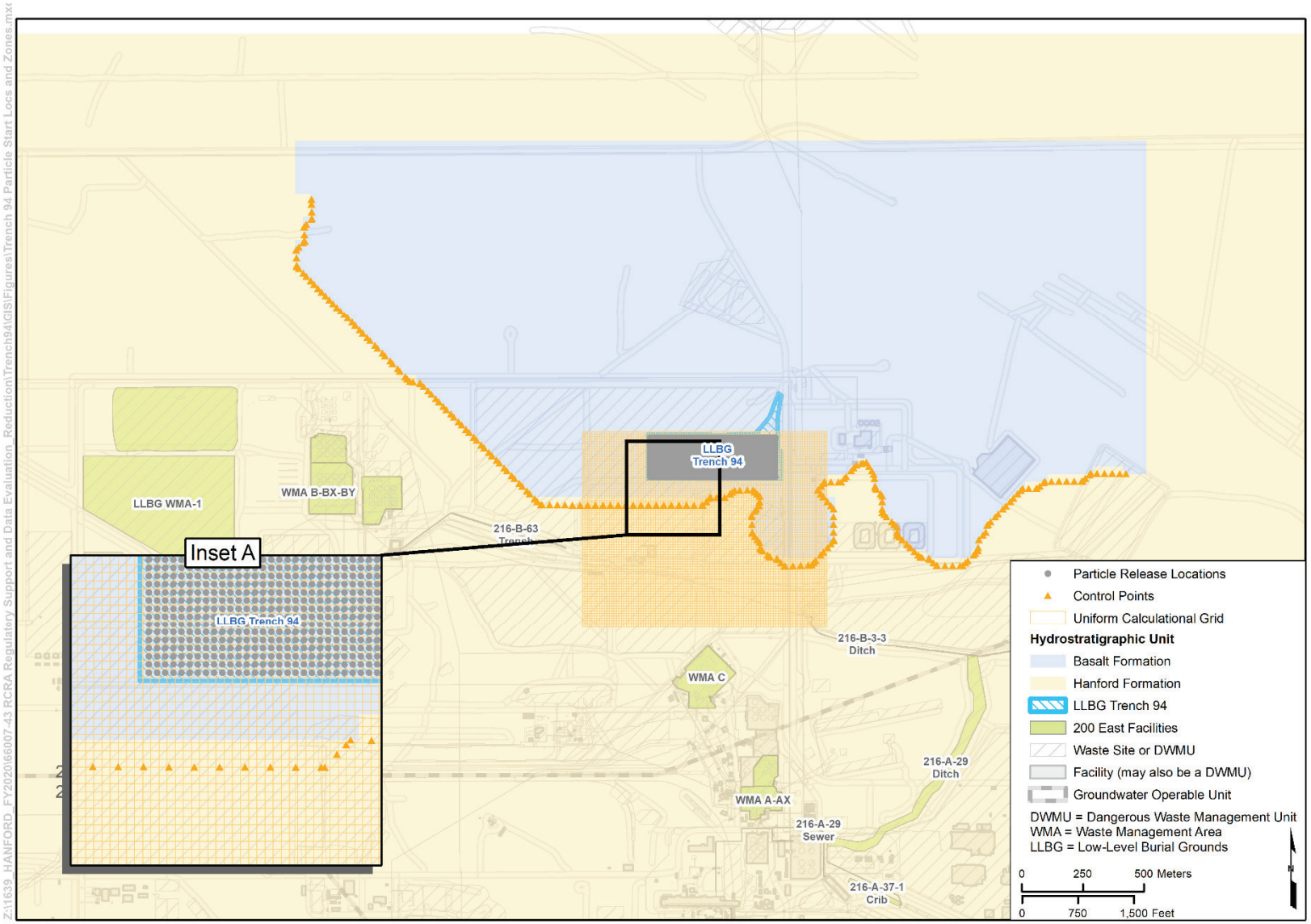

Figure 6. Control Points, Uniform Calculational Grid, and Release Locations at LLBG Trench 94

Contour maps of particle counts were generated by counting the number of particles that pass through a predefined uniform calculational grid (Figure 6). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at LLBG Trench 94.

4.2.3 Migration Parameters

Only a few parameters are required for the migration calculations performed using the groundwater level maps and particle-tracking methods. The mobile porosity and hydraulic conductivity values were defined specific to each hydrostratigraphic unit detailed in CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*, and WHC-SD-EN-EV-024. The values for each hydrostratigraphic unit are listed in Table 2. Dispersivity values are assumed constant throughout the entire modeled domain and are listed in Table 2.

Table 2. Aquifer Transport Parameter Values

Property		Value	Comments
Hydraulic conductivity	Hanford formation	15000 m/d (49,213 ft/d)	CP-47631
	Basalt formation	1.5 m/d (4.9 ft/d)	Based on transmissivity value of 46 m^2/d reported in WHC-SD-EN-EV-024 and approximate thickness of 30 m for basalt Elephant Mountain Member reported in the same report.
Effective porosity	Hanford formation	0.25	CP-47631
	Basalt formation	0.04	Table 6-1 in WHC-SD-EN-EV-024; value for Saddle Mountain Basalt flowtop (<5%)
Longitudinal dispersivity		3.5 m (11.5 ft)	Zheng and Wang, 1999
Transverse dispersivity		0.7 m (2.3 ft)	20% of longitudinal (DOE/RL-2008-56)
Vertical dispersivity		0.0 m (0.0 ft)	DOE/RL-2008-56

Note: Complete reference citations are provided in Chapter 8.

The primary purpose of the assessment presented in this ECF is to estimate directions of potential contaminant migration in order to assess the efficacy of the monitoring well networks. The values assigned to the hydraulic conductivity and mobile (effective) porosity for the calculations for the 200 East Area facilities do not impact the assessment of the monitoring network efficacy. The values assigned to those parameters do, however, impact the calculations of (relative) arrival times at existing and proposed monitoring locations.

Appropriate values for dispersivity in transport calculations are generally recognized to be scale dependent. For purposes of the engineering evaluations, the simulations of transport in the saturated zone assume values for dispersivity in all three directions (longitudinal [3.5 m (11.5 ft)], transverse [0.7 m (2.3 ft)], and vertical [0.0 m (0.0 ft)]). These values are on the lower end of values identified as typical of field-scale sites by, among others, Gelhar et al., 1992, "A Critical Review of Data on Field-Scale Dispersion in Aquifers," and Xu and Eckstein, 1995, "Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale." The values are considered to be on the lower end primarily for the following primary reasons:

- First, the dominant mechanisms leading to spreading of contamination at the Central Plateau historically are likely to have been hydraulic transients and subsurface heterogeneity. To some degree, those mechanisms are represented in the Central Plateau model because it is a transient, heterogeneous groundwater model.
- Second, although the historical groundwater plumes of the Central Plateau are on the order of hundreds of meters in length and/or width, the distance or scale relevant to specifying dispersion lengths for the engineering evaluations is the typical distance from potential release locations to downgradient monitoring wells, which is substantially less than the scale of the historical plumes.

The range of values listed below for longitudinal dispersion are based on a typical migration distance from potential source to a monitoring network of about 200 m (656 ft) and the recommendations of Gelhar et al., 1992, and Xu and Eckstein, 1995, as incorporated in the U.S. Environmental Protection Agency online calculator, EPA, 2016, "Estimated Longitudinal Dispersivity" (https://www3.epa.gov/ceampubl/learn2model/part-two/onsite/longdisp.html):

- 0.37 m (1.2 ft) (lower limit: Gelhar et al., 1992)
- 1100 m (3609 ft) (upper limit: Gelhar et al., 1992)
- 6.21 m (20.4 ft) (Xu and Eckstein, 1995)
- 20 m (66 ft) (1/10th of migration distance, "rule-of-thumb")

The values for longitudinal dispersivity used in the engineering evaluation calculations (3.5 m [11.5 ft]) are at the lower end, as noted above. The assumption of a lower-end value for longitudinal dispersivity has two implications for evaluating the efficacy of a monitoring network for detecting a release: first, lower-end values result in relatively narrower plumes than would higher-end values; and s econd, the lower values result in relatively higher detectability for monitoring wells that are located directly in the path of a release. Given the objective of identifying a suitable spatial distribution of monitoring wells, emphasis was placed upon producing results that do not overestimate the likely width of groundwater effects resulting from a hypothetical release

5 Software Applications, Descriptions, Installation and Checkout, and Statements of Validity

Software used to perform the calculations for this ECF was in accordance with CH2M HILL Plateau Remediation Company's (CHPRC's) controlled software management procedure, which implements DOE O 414.1d, *Quality Assurance*.

5.1 Approved Software

The software used to perform the calculations for this ECF is approved, managed, and used consistent with CHPRC's controlled software management procedure under the following software lifecycle documentation:

- CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
- CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
- CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
- CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
- CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*
- CHPRC-02839, *KT3D_H2O and MEUK Integrated Software Management Plan: KT3D_H2O Version 3.5.1 and MEUK Version 0.2.2*

CHPRC-00258 distinguishes between safety software and support software based on whether the software calculates reportable results or provides run support, visualization, or similar functions. Brief descriptions of the software are provided below.

5.2 Software Description

MEUK was used to perform groundwater elevation mapping using measured groundwater levels. MEUK is classified as safety software and graded Level C based on responses to the Software Grading Checklist in CHPRC's controlled software management procedure. Use of this software at the Hanford Site is managed under the integrated software management plan (CHPRC-02839):

- Software title: MEUK (S.S. Papadopulos & Associates, Inc. (SSP&A), 2016, Version 0.2.2).
- Software version: CHPRC Build 2 (Version 0.2.2).
- Hanford Information Systems Inventory (HISI) identification number: 2832 (safety software, graded Level C).
- Workstation type and property number (from which software is run): SSP&A and FE449.

MEUK is programmed in the R language (R Core Team, *R: A Language and Environment for Statistical Computing*) and uses the gstat package (Pebesma, 2004, "Multivariable Geostatistics in S: the gstat Package"). MEUK can be supplemented or validated using KT3D_H2O (Karanovic et al., 2009).

A controlled calculation software, MODFLOW-USG (Panday et al., 2013, *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*), was used for the calculations that support this ECF.

- Software title: MODFLOW-USG, *An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation*.
- Software version: 1.2.00, approved as CHPRC Build 8 compiled to default single precision
- Executable Name: mfusg-chprc08spv.exe
- HISI identification number: 2517
- Workstation type and property number (from which software is run): SSP&A, FE616

5.3 Support Software

The software programs discussed below are classified as support software by CHPRC-00258:

- ArcGIS®: Visualization and post-processing tool for assessing simulated plume distributions, identifying extraction/injection well coordinates, and mapping auxiliary data (Mitchell, 1999, *The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns & Relationships*).
- R: The R programming environment for statistical computing and graphics (R Core Team, 2014, and Ihaka and Gentleman, 1996, *R: A Language for Data Analysis and Graphics*) was used to perform a variety of data processing including post-processing of calculation results and generating plots of aggregate data time series. The following R packages were also used as follows:
  - Package GSTAT provided the kriging engine for water levels.
  - Package SSPAMEUK provided functions for the generation of water-level kriging drifts.
  - Package raster was used to generate water-level American Standard Code for Information Interchange (ASCII) grids and raster calculations.
- Surfer: Data interpolation for visualization, model implementation, and quality assurance purposes.
- mod-PATH3DU: Particle-tracking code for calculating the three-dimensional flow pathlines and travel times of solute particles.
- Python™: The calculation and visualization of particle counts utilized Python, an interpreted, object-oriented programming language, with scripts executed using the Anaconda[1] freeware distribution Python Version 2.7.11, distributed with Anaconda 4.1.1 (64 bit).

5.4 Software Installation and Checkout

Safety software installations are checked and tested in accordance with CHPRC-00258 using the installation tests provided in CHPRC-00259. Executables are obtained from the CHPRC software owner (who maintains the configuration-managed copies in MKS Integrity®). Software installation and checkout forms are required and must be approved for installations used to perform model runs. Approved users are registered in HISI authorized users list for safety software.

® ArcGIS is a registered trademark of the Environmental Systems Research Institute, Inc., Redlands, California.
™Python is a registered trademark of Python Software Foundation, Beaverton, Oregon 97008 (www.python.org).
[1]Continuum Analytics, Austin, Texas 78701 (https://store.continuum.io/cshop/anaconda).
® MKS Integrity is a registered trademark of MKS, Inc., Ontario, Canada.

5.4.1 Statement of Valid Software Application

The software identified above was used consistent with intended uses for CHPRC, as identified in CHPRC-02839, and is a valid use of this software for this application. The software was used within its limitations, as identified in CHPRC-02839.

6 Calculation Steps and Output

This chapter describes the calculations performed to produce the results presented in this ECF.

6.1 Groundwater Elevation Mapping

The following steps were taken to produce the groundwater elevation maps that were used in all subsequent particle-tracking calculations.

6.1.1 TRIM Groundwater Level Maps

TRIM groundwater level maps are being updated on a quarterly basis in the 200 East Area since 2019. Methods and steps needed to perform the TRIM calculations for the first quarters of 2017 and 2018 needed for this analysis were identical to those included in ECF-200E-19-0081 and are described in Appendix A.

6.1.2 Multi-Event Universal Kriging Groundwater Level Maps

Input data were compiled from retrieved database sources. Measured groundwater elevations were obtained for March 2017, 2018, and 2019. Because water levels for well 699-46-91 were not sampled in March, water levels measured in July were used instead.

To create smooth transition between the basalt water table map and the TRIM water-level map, water levels from TRIM maps extracted along the line representing basalt subcropping the water table were added to the measured water levels as input for MEUK kriging. The locations of these points are depicted in Figure 6.

MEUK was executed and kriging results were saved in ArcGIS ASCII (*.asc) grid format.

Water-level grids produced by TRIM and MEUK were merged together using Surfer then exported as a single water-level grid encompassing the basalt formation on the north and Hanford Site sediments on the south for use as input to the particle tracking calculations.

After ASCII (*.asc) grid files were imported in Surfer, water-level contours were generated in ArcGIS shapefile format.

6.2 Particle Tracking

The steps were used to develop the necessary input files, perform the calculations, and post-process the outputs to produce results specific to potential releases at LLBG Trench 94.

For the particle-tracking calculations presented in this ECF, an input file representing particle starting locations (release points) was prepared in an ArcGIS shapefile format. Particle starting locations (Figure 6) represent release points equally spaced throughout the extent of LLBG Trench 94. The ArcGIS shapefile was then used as input to the mod-PATH3DU program.

For each water-level mapping event (CY 2017, 2018, and 2019), the following steps were implemented:

1. A mod-PATH3DU particle-tracking input file that included dispersion parameters was generated. For analysis described in this ECF, calculations were made considering advection and dispersion.

To simulate dispersion with particle tracking, the random-walk particle tracking option implemented within mod-PATH3DU was used. As described in the software documentation (CHPRC-00261), for consistency, this random-walk module reads and uses the same dispersion inputs as the Hanford Site version of the transport simulator Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems (MT3DMS).

2. Two ASCII files were generated representing the basalt and sediment's mobile porosity and hydraulic conductivity distributions based on the hydrostratigraphic unit zones depicted in Figure 6 and values from Table 2.

3. The maximum tracking time was set to 20,000 days (~54.7 years) to allow the vast majority of the particles released to migrate beyond the basalt formation during the calculations.

4. Particles were released and tracked from each particle starting location as follows:

– Ten particles were released from each starting location to provide the high density of particles in space and time required for the detailed facility-specific calculations. This process resulted in a total of 8,880 (8,880 = 888 [release locations] × 10 [releases]) particles released at LLBG Trench 94.

– mod-PATH3DU was executed to make the particle-tracking calculations and produce a binary pathline output file containing the pathline for each tracked particle. For purposes of the particle-tracking calculations considering dispersion, particles were tracked from each starting location using a different random seed value for the dispersion calculations.

5. A post-processing program (writep3doutput.exe) was executed to convert the mod-PATH3DU binary pathline output file into ArcGIS Shapefile format.

The resulting particle tracks were superimposed upon figures that showed monitoring well locations to determine whether monitoring locations lie in the migration pathway of the simulated releases from the facilities.

6.3 Particle Counts

Particle counts were calculated to create maps that illustrate the relative particle density downgradient of each facility. The steps to create this output are described below.

For the maps of particle counts:

1. An ArcGIS shapefile grid was defined. The grid was large enough to envelop all pathlines generated in the previous step and was composed of cells that were 10 by 10 m (33 by 33 ft).

2. For each mapped event, the ArcGIS "Spatial Join" tool was used to intersect the pathlines with the regular grid and determine the count of unique pathlines intersecting each subgrid cell.

3. This grid of pathline counts was converted to an ASCII grid format and imported in ArcGIS, after which bilinear interpolation was used to develop the particle density (particle count) maps.

7 Results

This chapter presents the results of the calculations, including groundwater elevation contours prepared in the vicinity of LLBG Trench 94 using a combination of the TRIM and MEUK methods, and the outputs of the particle tracking and particle count calculations, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the three years (CY2017, 2018, and 2019). These are presented at the facility-specific scale considering advective and dispersive migration.
- Maps of particle counts downgradient of LLBG Trench 94 based on the flow conditions determined for each of the three years.

7.1 Groundwater Elevation Contours

Figures 7 through 9 show the results of mapping using TRIM and MEUK for first quarters of 2017, 2018, and 2019. These groundwater elevation contours and associated hydraulic gradients form the basis for the particle-tracking calculations performed for this ECF.

7.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise, continuous elevation grids were prepared using TRIM and MEUK and merged together, particle tracking was implemented using both advection and dispersion. The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near LLBG Trench 94 for the flow conditions calculated for CY 2017, 2018, and 2019. Figures 10 through 12 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area. The resulting maps were prepared based on the release of 10 particles from each starting location to provide the high density of particles in space and time required for these calculations. The figures depict the particle pathlines calculated after 20,000 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures 10 through 12 depict an instantaneous release to the water table from the release locations in LLBG Trench 94 to illustrate the adequacy of the well network for monitoring the entire facility.

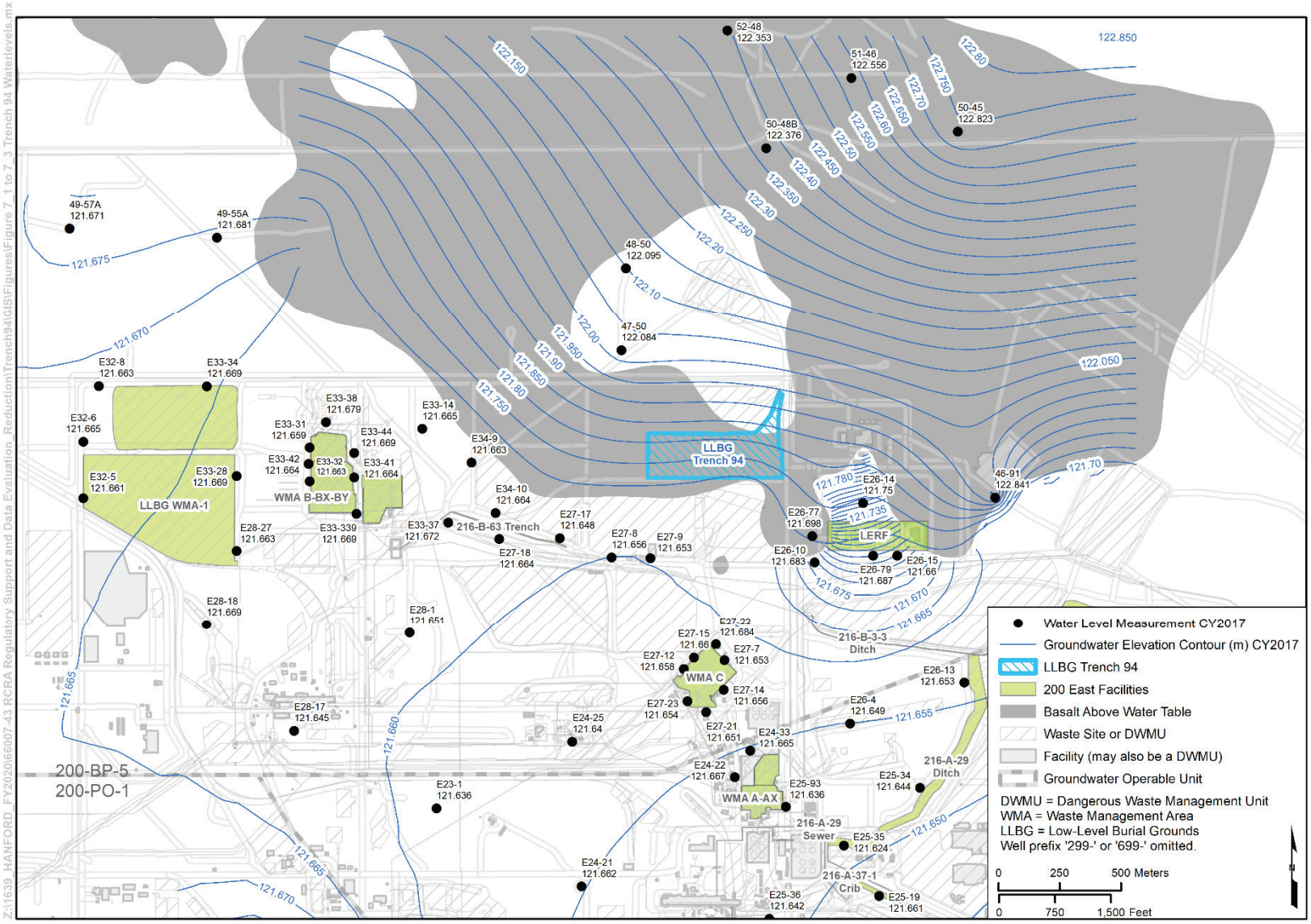

Figure 7. Groundwater Elevation Map for LLBG Trench 94 (2017)

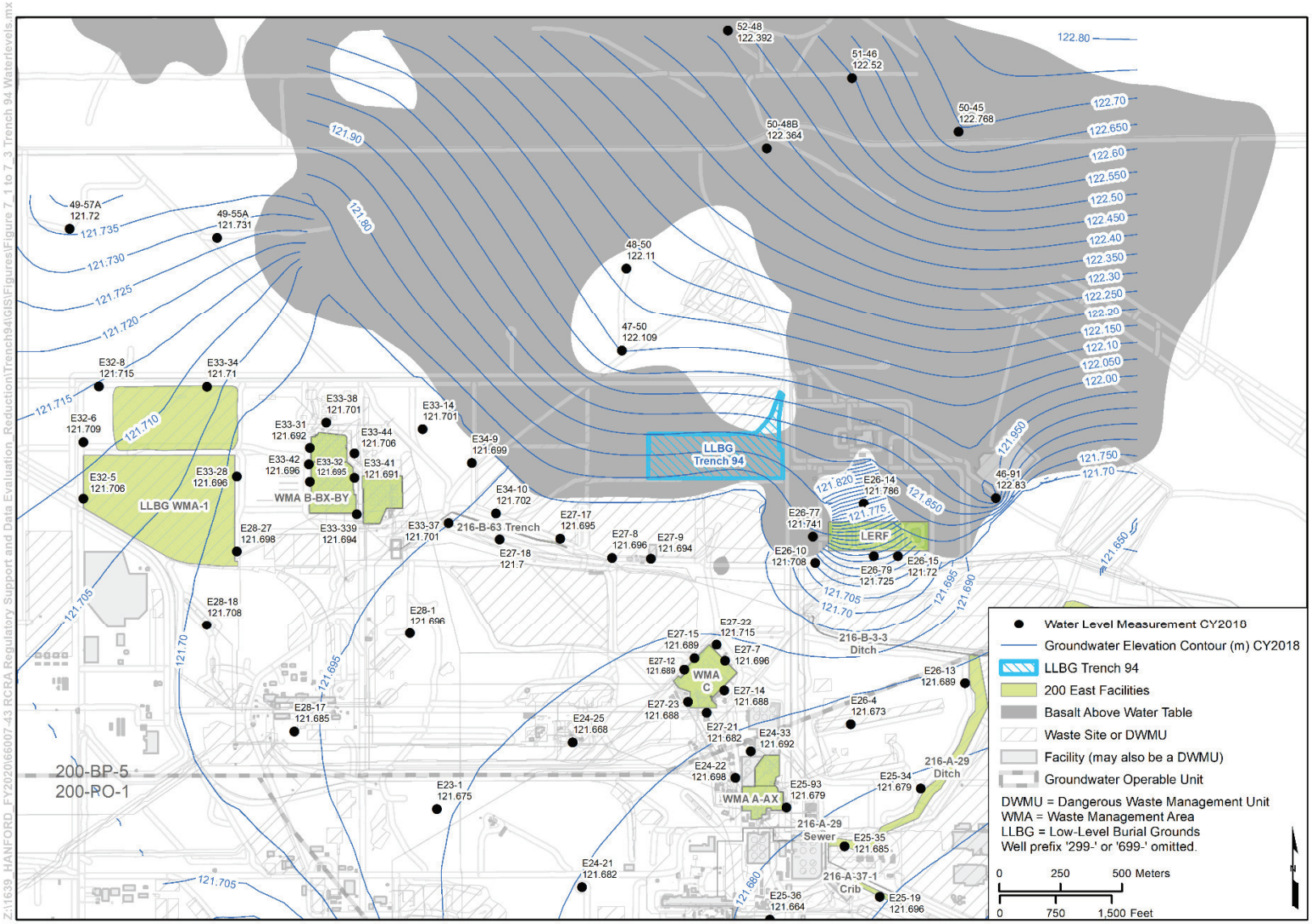

Figure 8. Groundwater Elevation Map for LLBG Trench 94 (2018)

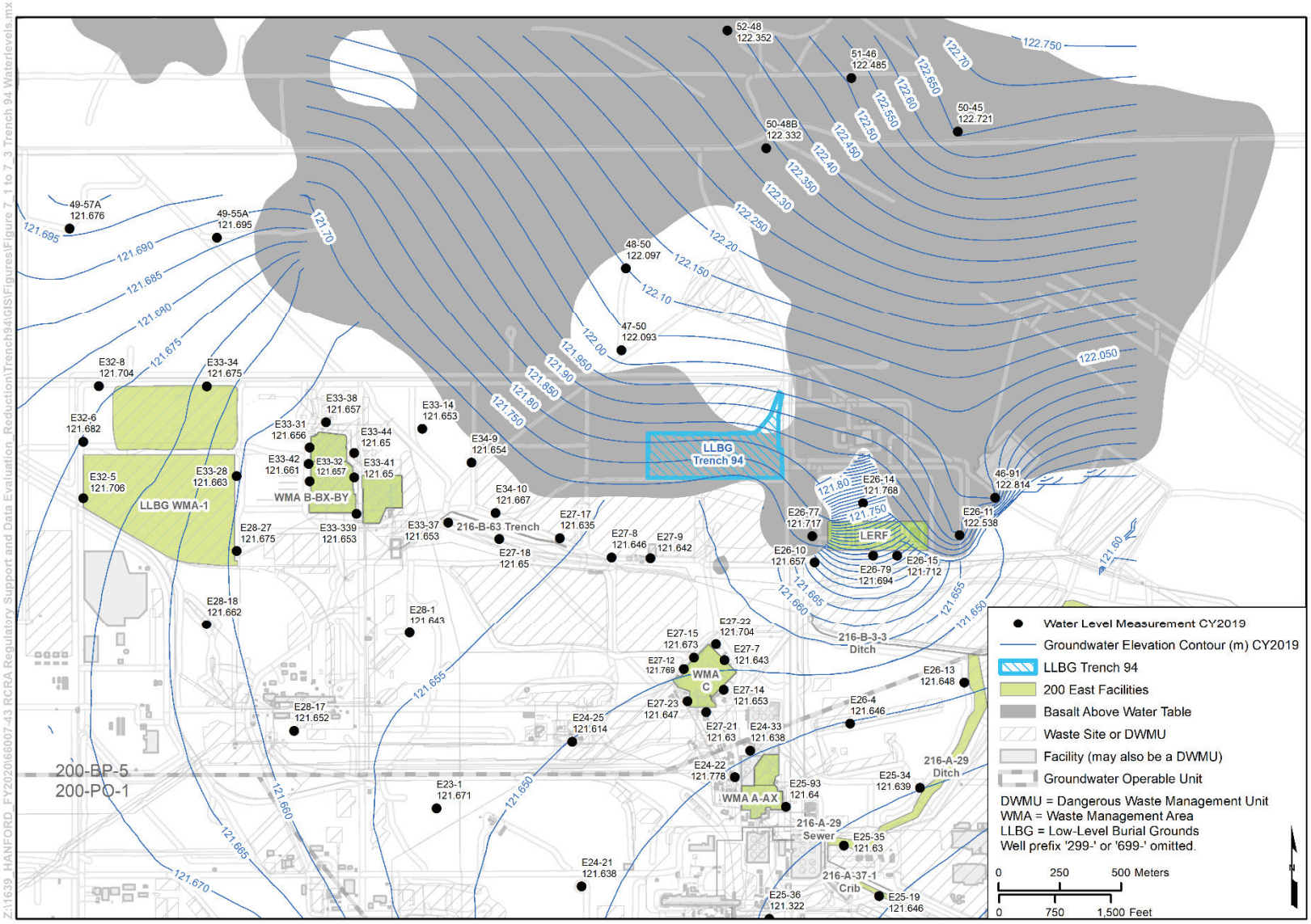

Figure 9. Groundwater Elevation Map for LLBG Trench 94 (2019)

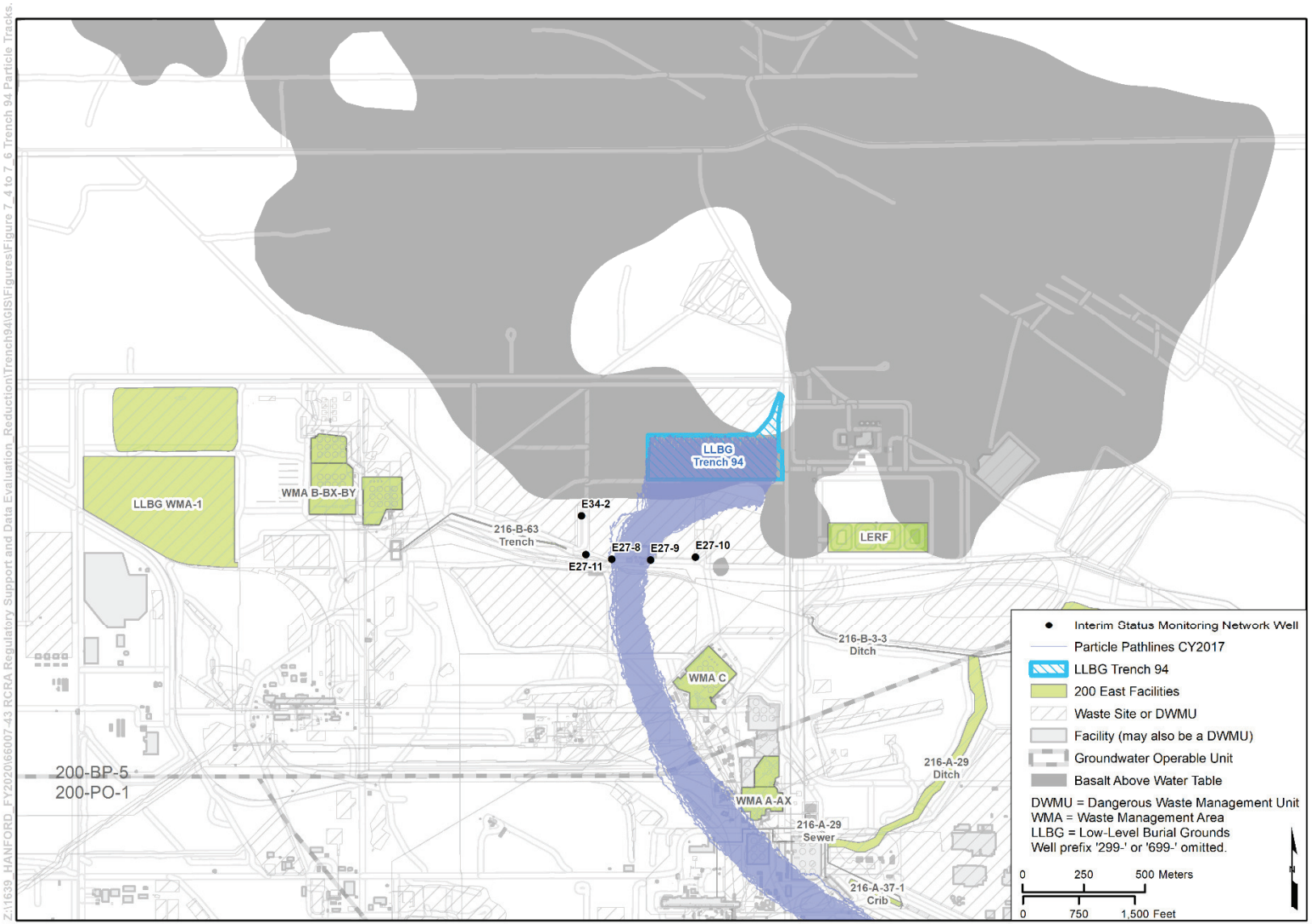

Figure 10. Local-Scale Particle Pathlines, Advection, and Dispersion – LLBG Trench 94 (2017)

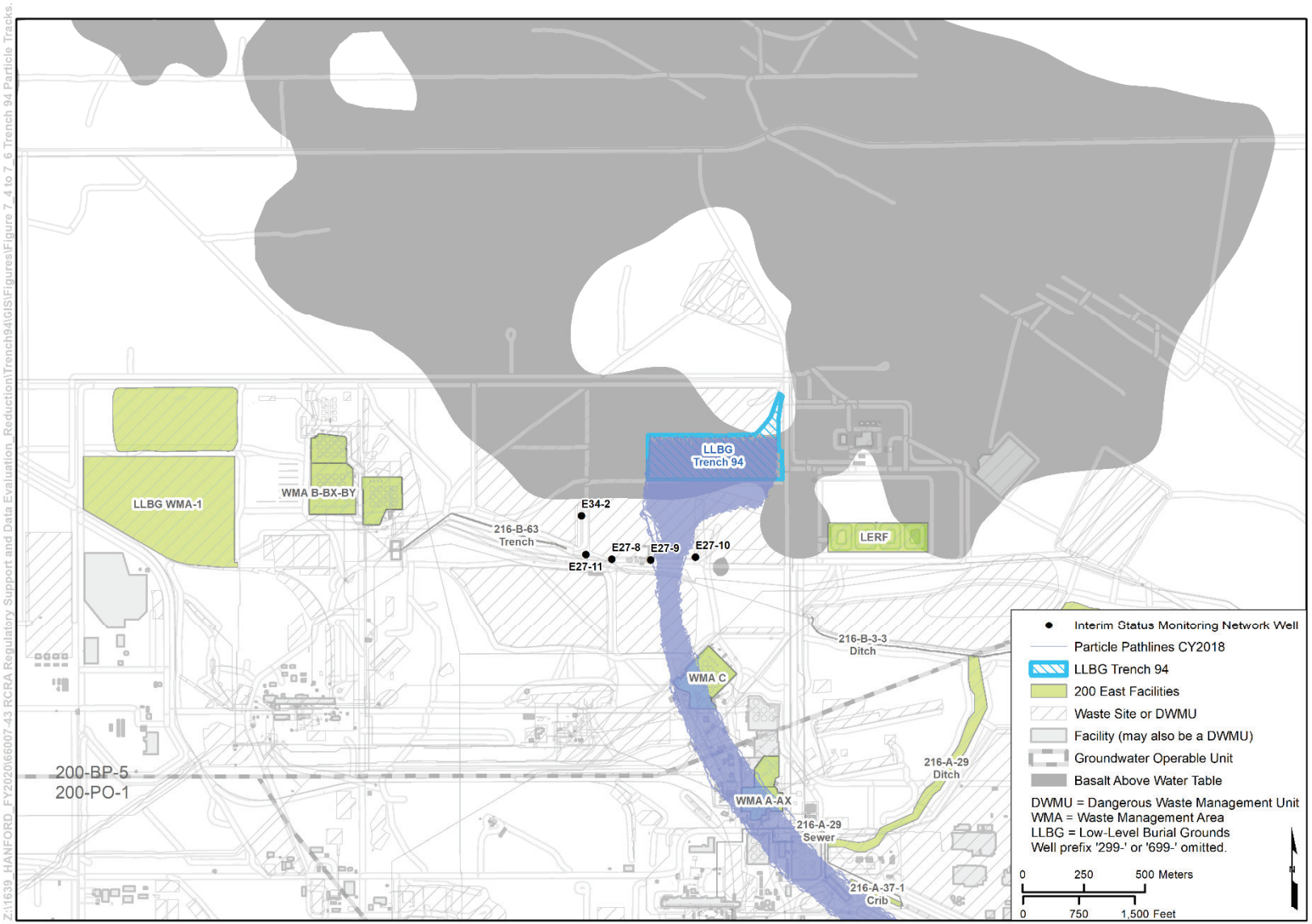

Figure 11. Local-Scale Particle Pathlines, Advection, and Dispersion – LLBG Trench 94 (2018)

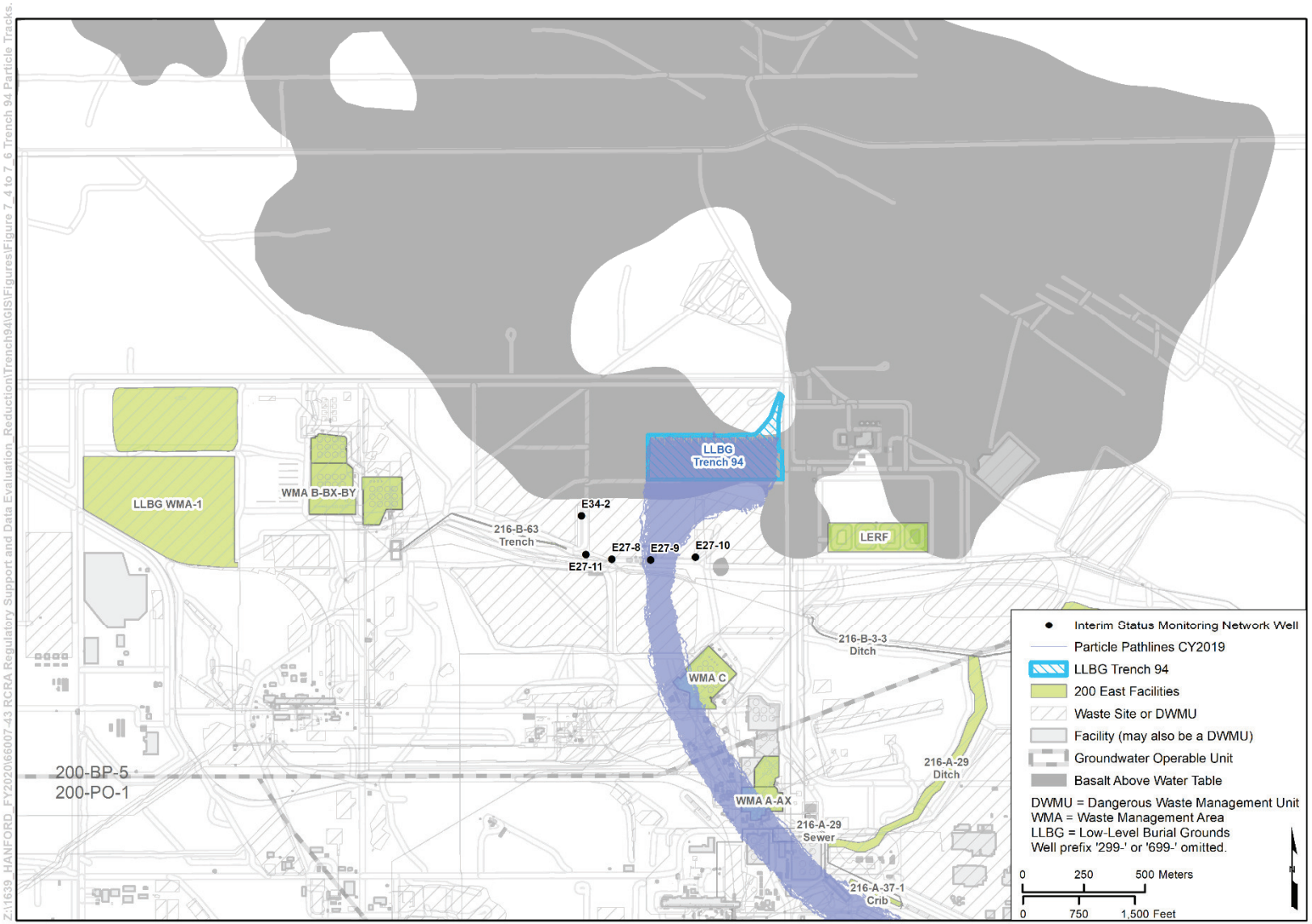

Figure 12. Local-Scale Particle Pathlines, Advection, and Dispersion – LLBG Trench 94 (2019)

7.3 Particle Counts

To compare the relative density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 and particle count maps were generated. Figures 13 through 15 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table for conditions represented by CY 2017, 2018, and 2019. Figures 13 through 15 depict the particle density after 20,000 days of calculated travel, by which time it was determined that the majority of particles would have arrived at or passed by the interim status groundwater monitoring wells.

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from the LLBG Trench 94. The particle count maps (Figures 13 through 15) show that under the evaluated range of conditions, there is an area of particle counts south of the eastern portion of LLBG Trench 94 where there is no corresponding monitoring well. As stated, the goal of the well placement is to span the range of the particle tracks. Placement of the well at the edge of the particle track area is in line with this goal. While moving the well in to the higher particle count area to the west may appear more likely to detect particles, it is believed that once there is better information about flow in the area between LLBG Trench 94 and Liquid Effluent Retention Facility, the particle tracks will likely not curve toward the west as significantly as they appear to in these analyses. This well is expected to be in an area of higher particle density. In addition, physical limitations, including the presence of a significant soil stockpile and the extent of the basalt subcrop north of the well's location (and the associated potential for the well to have sufficient water) were also considered when placing this well. Locating a well in this area will have the added benefit of increasing the understanding of groundwater flow direction in this complicated area. The location of the proposed well (Trench_94_PW-1) is shown in Figures 13 through 15. Locating the well closer to the facility will increase the probability to detect leaks; however, the further north the well is installed, the higher the risk of encountering basalt above the water table. Because of this, an area within which the well might be placed is included on the figures. The final location will be based on additional consideration of the extent of the basalt.

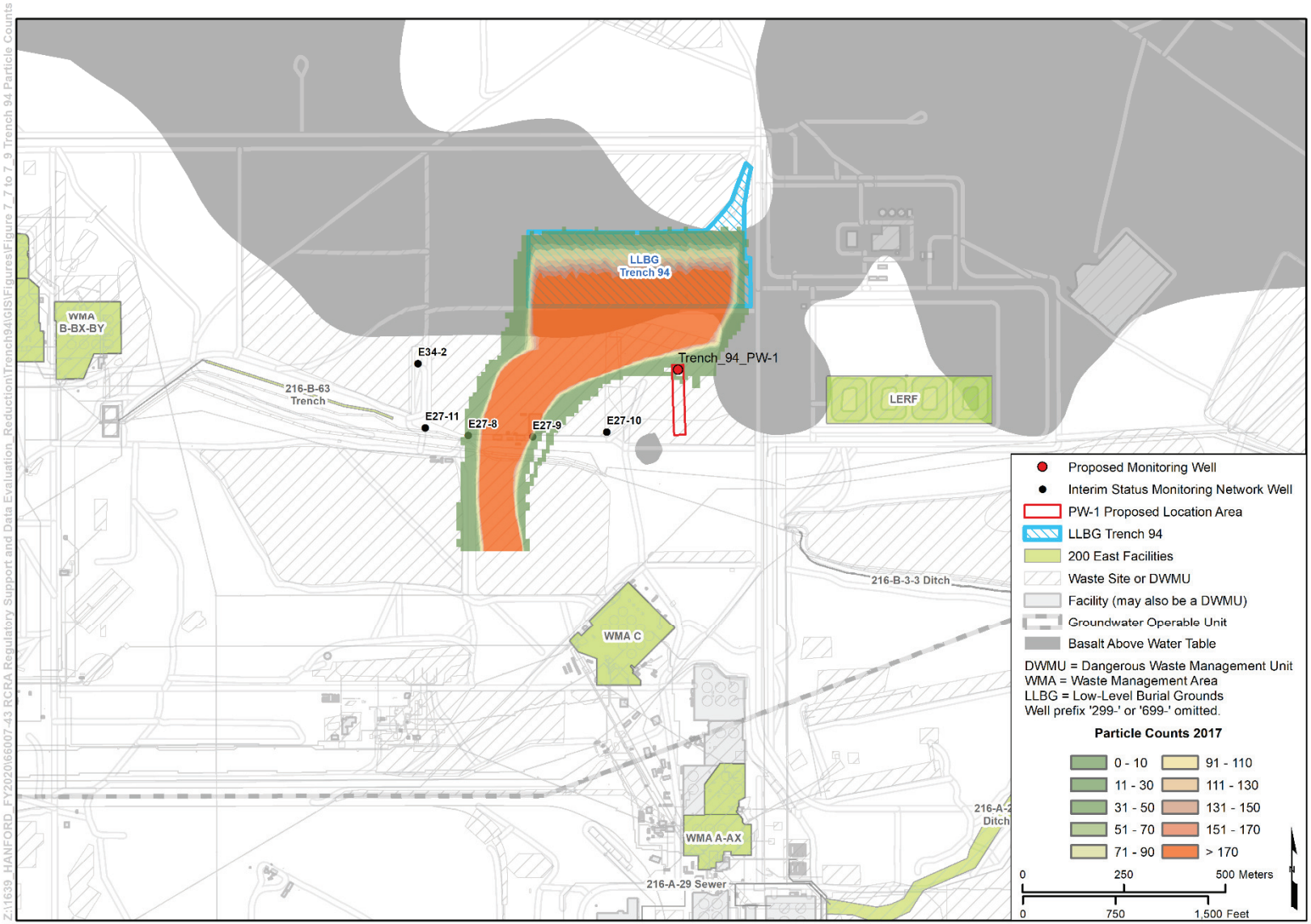

Figure 13. Particle Count Map – LLBG Trench 94 (2017)

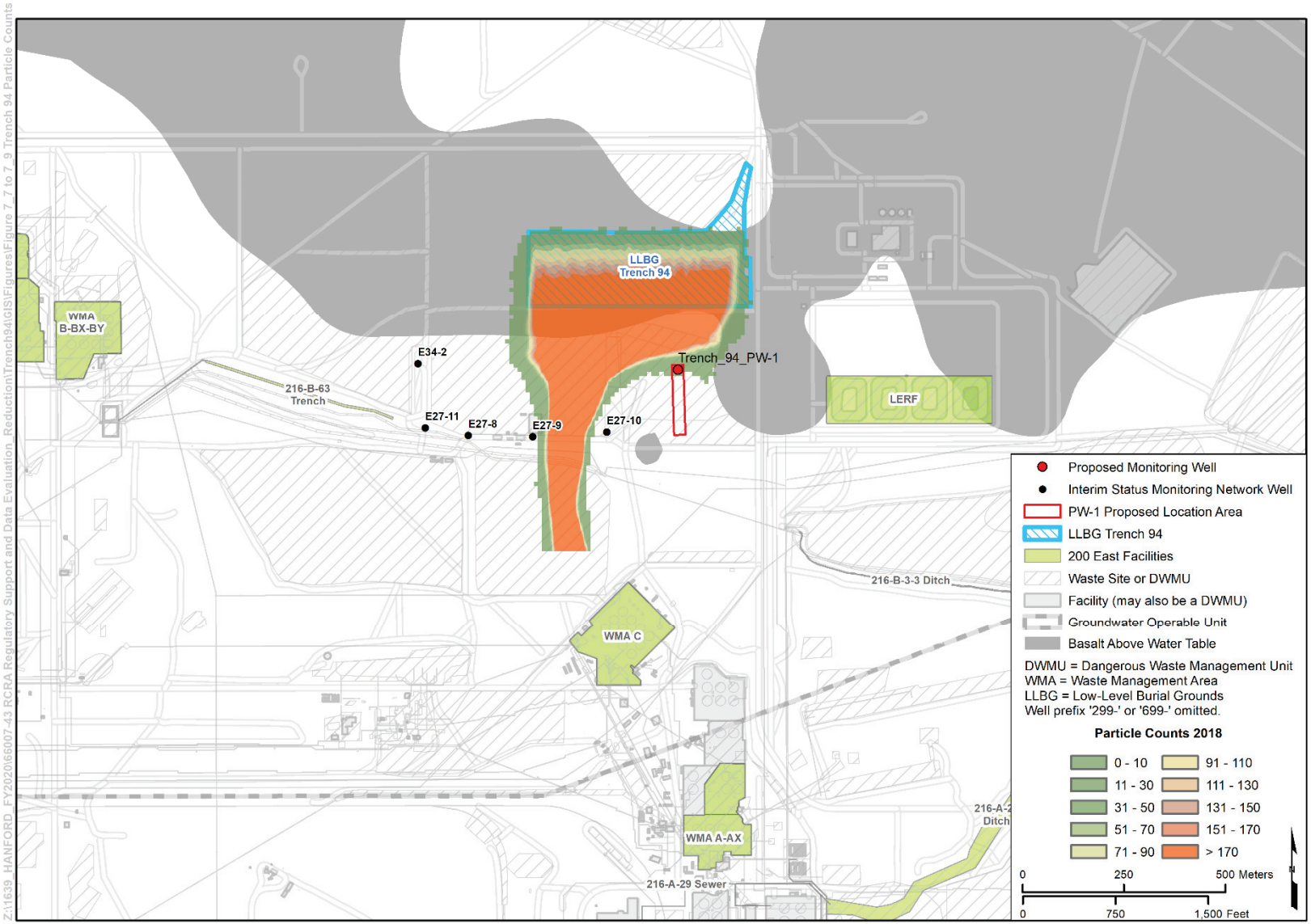

Figure 14. Particle Count Map – LLBG Trench 94 (2018)

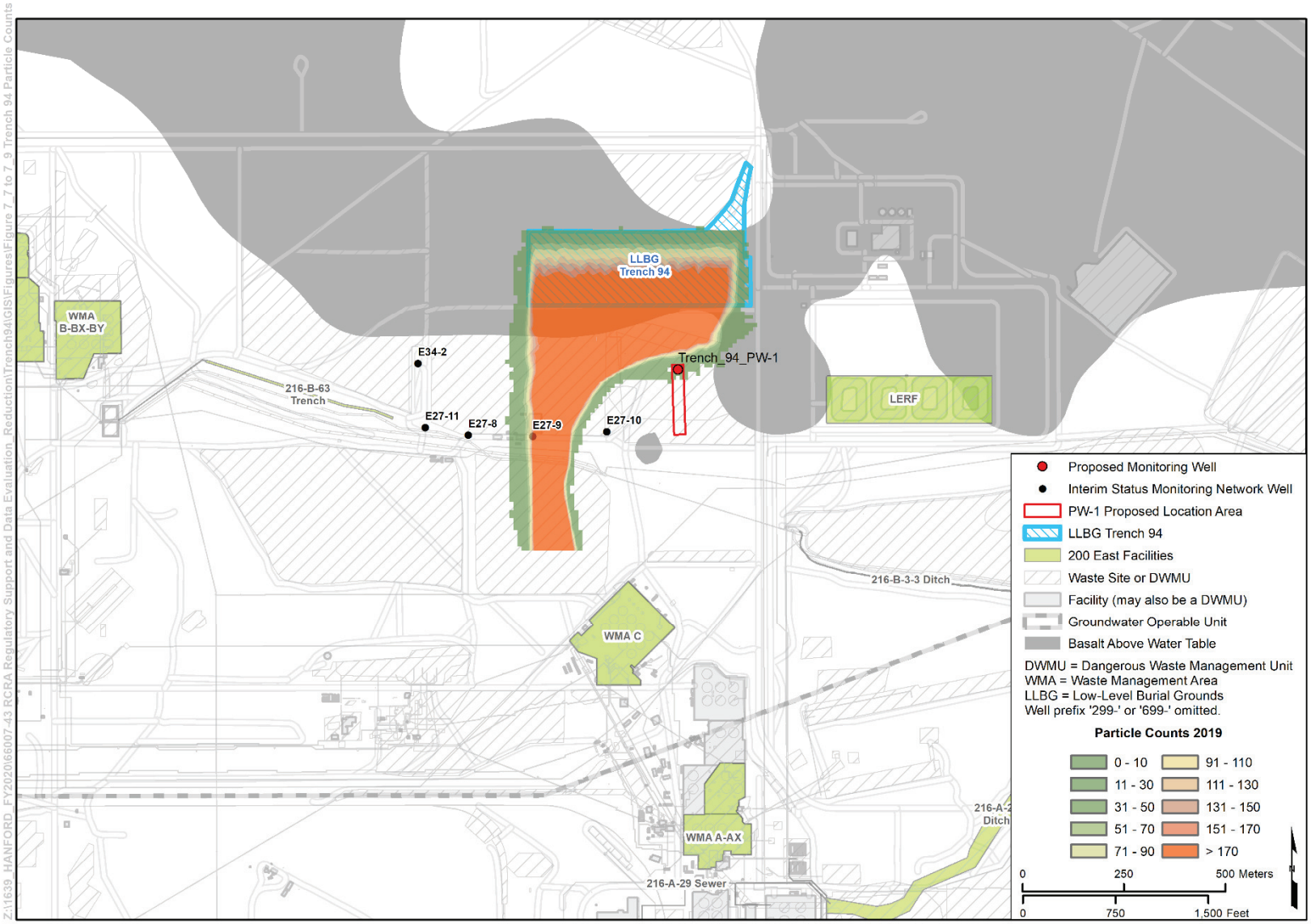

Figure 15. Particle Count Map – LLBG Trench 94 (2019)

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Appendix A

200 East Groundwater Elevation Mapping for First Quarters of Calendar Years 2017 and 2018

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Terms

CCU	Cold Creek unit
CHPRC	CH2M HILL Plateau Remediation Company
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
HEIS	Hanford Environmental Information System
HISI	Hanford Information Systems Inventory
HSU	hydrostratigraphic unit
SME	subject matter expert
TRIM	Tikhonov Regularized Inverse Method

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A1 Purpose

This environmental calculation file (ECF) describes calculations made to generate water-level maps for the first quarters of calendar years (CYs) 2017 and 2018 in the 200 East Area at the Hanford Site Central Plateau (Figure A-1). This ECF provides the conceptual and methodological basis for the calculations performed, details the specific methods and codes used to undertake the calculations, and presents results of the calculations.

A2 Background

Historically, groundwater elevations in the 200 East Area varied greatly in response to discharges of water from the Hanford Site operations to many large wastewater receiving features such as the 216-B-3 Pond and 216-A-25 Pond. The 200 East Area groundwater elevations also responded to historical discharges in the 200 West Area. Most of those discharges ceased by the mid-1990s, after which groundwater elevations in the 200 East Area fell steadily in areas where discharges formerly occurred. In recent years, changes in groundwater elevations and in corresponding hydraulic gradients and flow directions have been less evident from year to year, as groundwater elevations asymptotically approach a quasi-steady-state condition.

As described in ECF-200E-19-0081, *Groundwater Elevation Mapping for 200 East Area - Quarter 1 Calendar Year 2019*, the majority of the unconfined aquifer beneath the 200 East Area of the Central Plateau occurs in a buried paleochannel consisting of highly permeable sediments of the Hanford formation and Cold Creek unit (CCU) overlying basalt. The high permeabilities cause the water table to exhibit a very low-magnitude hydraulic gradient (i.e., the water table is flat). Local variations in water-level measurements in such a low-gradient setting obscure differences in the true water table, and resulting estimates of hydraulic gradients are subject to uncertainty from a low signal-to-noise ratio. To improve the accuracy of depth-to-groundwater measurements and corresponding groundwater elevation (i.e., water table) maps in the 200 East Area, a network of wells was established for which steps were taken to reduce water-level measurement error. The collection of monthly water-level measurements from this network began during May 2013. Over time, the well network was expanded so that eventually a single low-gradient well network was established encompassing much of the 200 East Area.

Various groundwater extraction wells have operated within the main unconfined aquifer in the 200 East Area to address groundwater contamination at the 200 BP-5 Groundwater Operable Unit. Due to the high transmissivity of the gravel of the CCU, the effects of groundwater extraction at the well only influences hydraulic gradients and corresponding groundwater flow directions and rates measurably in the immediate vicinity of extraction wells.

A3 Calculation Methods

Calculations were completed to develop groundwater elevation maps for the 200 East Area. The calculation approach and tools developed for ECF-200E-19-0081 were used to meet the objectives of this ECF. The method detailed in ECF-200E-19-0081 combined a simplified groundwater flow simulator with statistical methods to obtain a best-estimate of groundwater flow patterns in the vicinity of each dangerous waste management unit in the 200 East Area (the 200 East Area facilities shown on Figure A-1). The parameters of the underlying flow simulator were determined through a regularized inverse interpolation technique referred to as the Tikhonov Regularized Inverse Method (TRIM).

Using the data and methods described in the following sections, regularized inverse water-level mapping was performed to produce continuous gridded depictions of groundwater elevations that conserve flow throughout the 200 East Area and are consistent with measured groundwater levels.

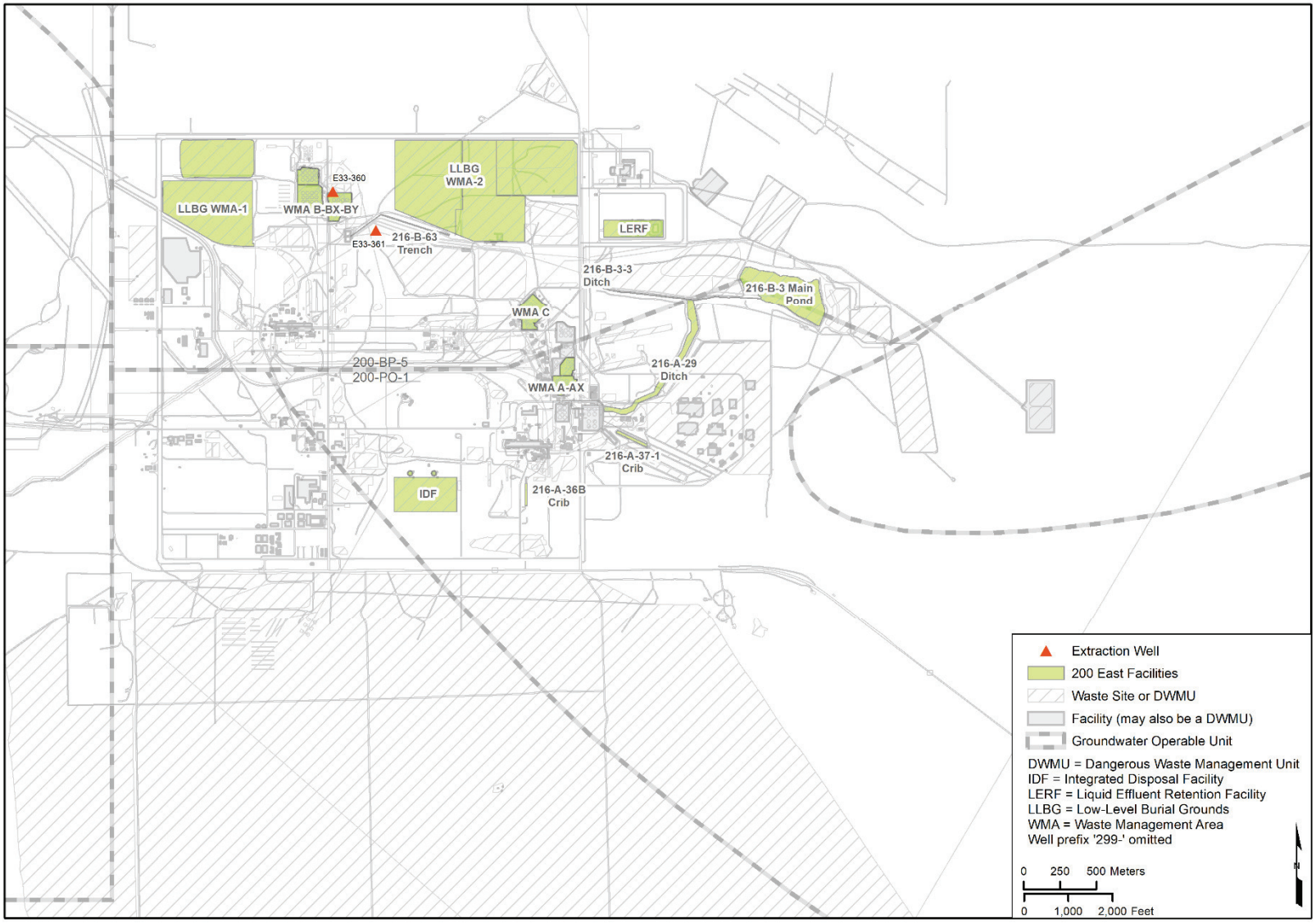

Figure A-1. Hanford Site 200 East Area and Associated Waste Sites

A3.1 Data Used

Maps of groundwater levels in the 200 East Area rely on measurements obtained primarily from the wells of the low-gradient network. Groundwater elevations for each well in the low-gradient network were acquired when available from the Hanford Environmental Information System (HEIS) database for January, February, and March 2017 and for January, February, and March 2018. The data were corrected for borehole deviation from vertical and were used to prepare piecewise, continuous grids of groundwater elevations for the first quarter of CY 2017 and 2018. Groundwater elevations from wells outside the low-gradient network are used when necessary to control contours at the TRIM boundaries or in the vicinity of the 200 East Facilities. When used, these measurements are assigned lower weights during the calibration process due to lower confidence in the accuracy of their measurements. The process of assigning weights during calibration allows these measurements to be included where needed, but to have less influence on the overall results than the data from the low-gradient network wells.

Tables A-1 through A-6 present the data used in the calculations. The data was retrieved from the HEIS database on November 19, 2019. Measured water levels presented in these tables are based on the NAVD88, *North American Vertical Datum of 1988*. Spatial coordinates of well locations are presented in the NAD83, *North America Datum of 1983* State Plane, Washington South Federal Information Processing Standards 4602 coordinate system.

Table A-1. Water-Level Data Used for Water-Level Mapping: January 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
699-37-43	576829	134783	1/17/17 10:31 AM	121.666
299-E32-5	572600	137285	1/25/17 7:49 AM	121.667
299-E32-6	572600	137515	1/25/17 7:55 AM	121.674
299-E28-27	573227	137070	1/25/17 8:10 AM	121.669
299-E28-18	573104	136768	1/25/17 8:19 AM	121.677
299-E28-17	573461	136332	1/25/17 8:29 AM	121.650
299-E28-1	573933	136733	1/25/17 8:38 AM	121.651
299-E23-1	574043	136017	1/25/17 8:50 AM	121.633
299-E18-2	573392	135291	1/25/17 9:04 AM	121.705
299-E17-21	574107	134893	1/25/17 9:28 AM	121.607
299-E17-25	574515	134846	1/25/17 9:38 AM	121.681
299-E17-23	574694	134842	1/25/17 9:50 AM	121.601
299-E33-339	573717	137222	1/25/17 10:21 AM	121.671
299-E33-32	573525	137354	1/25/17 10:29 AM	121.666
299-E33-42	573521	137424	1/25/17 10:35 AM	121.668
299-E33-31	573525	137491	1/25/17 10:46 AM	121.665
299-E33-28	573226	137375	1/25/17 10:59 AM	121.674

Table A-1. Water-Level Data Used for Water-Level Mapping: January 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E33-34	573104	137740	1/25/17 11:06 AM	121.671
299-E33-38	573591	137594	1/25/17 11:16 AM	121.672
299-E33-44	573706	137469	1/25/17 11:30 AM	121.668
299-E33-41	573707	137370	1/25/17 11:35 AM	121.667
299-E33-14	573986	137567	1/25/17 11:42 AM	121.667
299-E24-24	574180	135459	1/25/17 11:53 AM	121.666
299-E24-21	574636	135698	1/25/17 12:01 PM	121.668
299-E24-16	575018	135464	1/25/17 12:16 PM	121.679
299-E17-22	574841	135196	1/25/17 12:25 PM	121.665
299-E24-18	574647	135470	1/25/17 12:34 PM	121.662
299-E17-18	575112	135124	1/25/17 12:43 PM	121.651
699-37-47A	575557	134893	1/25/17 12:52 PM	121.644
299-E25-36	575404	135566	1/25/17 1:00 PM	121.653
699-49-57A	572544	138389	1/25/17 1:17 PM	121.675
699-49-55A	573146	138352	1/25/17 1:25 PM	121.680
299-E27-21	575145	136407	1/27/17 8:47 AM	121.641
299-E33-37	574091	137185	1/27/17 9:09 AM	121.675
299-E27-23	575069	136452	1/27/17 9:20 AM	121.648
299-E27-12	575054	136584	1/27/17 9:27 AM	121.656
299-E27-15	575095	136630	1/27/17 9:35 AM	121.659
299-E27-22	575185	136685	1/27/17 9:48 AM	121.681
299-E27-7	575221	136619	1/27/17 9:53 AM	121.641
299-E27-14	575217	136498	1/27/17 10:06 AM	121.648
299-E27-8	574759	137044	1/27/17 10:29 AM	121.661
299-E27-9	574918	137041	1/27/17 10:37 AM	121.654
299-E34-10	574284	137225	1/27/17 10:55 AM	121.673
299-E27-17	574547	137122	1/27/17 11:01 AM	121.652
299-E34-9	574186	137430	1/27/17 11:06 AM	121.668
299-E27-18	574300	137119	1/27/17 11:14 AM	121.670
299-E24-25	574599	136287	1/27/17 11:47 AM	121.649
299-E25-34	576019	136100	1/27/17 11:57 AM	121.643
299-E26-13	576199	136529	1/27/17 12:06 PM	121.653

Table A-1. Water-Level Data Used for Water-Level Mapping: January 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E25-35	575708	135865	1/27/17 12:34 PM	121.614
299-E25-19	575852	135659	1/27/17 1:02 PM	121.664
699-37-43	576829	134783	1/27/17 1:16 PM	121.615
299-E26-4	575734	136361	1/27/17 1:40 PM	121.646

Reference: NAVD88, 1988, *North American Vertical Datum of 1988*.

Table A-2. Water-Level Data Used for Water-Level Mapping: February 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E23-1	574043	136017	2/28/17 7:55 AM	121.613
699-37-43	576829	134783	2/25/17 8:54 AM	121.627
299-E25-35	575708	135865	2/28/17 9:01 AM	121.631
299-E24-25	574599	136287	2/25/17 11:54 AM	121.636
699-37-43	576829	134783	2/25/17 11:16 AM	121.637
299-E17-18	575112	135124	2/25/17 9:35 AM	121.640
699-37-47A	575557	134893	2/25/17 9:01 AM	121.641
299-E25-93	575472	136022	2/28/17 9:32 AM	121.645
299-E25-36	575404	135566	2/25/17 10:27 AM	121.651
299-E24-18	574647	135470	2/25/17 9:58 AM	121.652
299-E28-17	573461	136332	2/25/17 8:09 AM	121.652
299-E25-34	576019	136100	2/25/17 11:44 AM	121.654
299-E26-4	575734	136361	2/25/17 11:34 AM	121.656
299-E26-13	576199	136529	2/25/17 11:25 AM	121.658
299-E17-22	574841	135196	2/25/17 9:41 AM	121.660
299-E17-23	574694	134842	2/25/17 9:29 AM	121.662
299-E28-27	573227	137070	2/25/17 7:54 AM	121.663
299-E24-24	574180	135459	2/25/17 10:16 AM	121.665
299-E32-5	572600	137285	2/25/17 7:44 AM	121.667
299-E28-1	573933	136733	2/25/17 8:32 AM	121.668
299-E32-6	572600	137515	2/25/17 7:40 AM	121.668
299-E27-8	574759	137044	2/25/17 12:01 PM	121.672

Table A-2. Water-Level Data Used for Water-Level Mapping: February 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E28-18	573104	136768	2/25/17 8:02 AM	121.673
699-49-57A	572544	138389	2/25/17 7:11 AM	121.673
299-E33-28	573226	137375	2/26/17 10:42 AM	121.674
299-E34-10	574284	137225	2/25/17 12:15 PM	121.674
299-E27-18	574300	137119	2/25/17 12:24 PM	121.675
299-E27-17	574547	137122	2/25/17 12:10 PM	121.676
299-E25-19	575852	135659	2/25/17 10:35 AM	121.678
299-E33-342	573626	137580	2/26/17 9:20 AM	121.678
299-E33-32	573525	137354	2/26/17 10:01 AM	121.679
299-E33-339	573717	137222	2/26/17 9:48 AM	121.679
299-E33-41	573707	137370	2/26/17 9:40 AM	121.679
299-E27-9	574918	137041	2/25/17 12:05 PM	121.680
299-E25-24	576194	135521	2/25/17 10:43 AM	121.681
299-E33-34	573104	137740	2/26/17 8:51 AM	121.682
299-E33-42	573521	137424	2/26/17 10:08 AM	121.682
299-E17-21	574107	134893	2/25/17 9:21 AM	121.684
299-E26-10	575589	137023	2/28/17 8:49 AM	121.684
299-E27-15	575095	136630	2/26/17 12:27 PM	121.684
299-E33-31	573525	137491	2/26/17 10:17 AM	121.684
699-49-55A	573146	138352	2/25/17 7:25 AM	121.684
299-E33-14	573986	137567	2/26/17 11:15 AM	121.685
299-E34-9	574186	137430	2/25/17 12:19 PM	121.685
299-E24-16	575018	135464	2/25/17 9:51 AM	121.686
299-E27-12	575054	136584	2/26/17 12:21 PM	121.689
299-E27-23	575069	136452	2/26/17 12:11 PM	121.689
299-E33-37	574091	137185	2/26/17 11:27 AM	121.689
299-E27-21	575145	136407	2/26/17 11:52 AM	121.690
299-E27-14	575217	136498	2/26/17 12:03 PM	121.692
299-E26-79	575828	137052	2/28/17 8:31 AM	121.694
299-E27-7	575221	136619	2/26/17 12:51 PM	121.699
299-E24-22	575263	136143	2/26/17 1:13 PM	121.705
299-E33-44	573706	137469	2/26/17 9:31 AM	121.705

Table A-2. Water-Level Data Used for Water-Level Mapping: February 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E24-33	575325	136251	2/26/17 1:02 PM	121.707
299-E33-38	573591	137594	2/26/17 9:13 AM	121.707
299-E18-2	573392	135291	2/25/17 8:22 AM	121.710
299-E27-22	575185	136685	2/26/17 12:42 PM	121.711
299-E26-14	575786	137265	2/28/17 8:15 AM	121.757

Reference: NAVD88, 1988, *North American Vertical Datum of 1988*.

Table A-3. Water-Level Data Used for Water-Level Mapping: March 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E32-5	572600	137285	3/19/17 6:37 AM	121.650
299-E33-339	573717	137222	3/19/17 6:39 AM	121.657
299-E32-6	572600	137515	3/19/17 6:42 AM	121.654
299-E32-8	572663	137741	3/19/17 6:48 AM	121.663
299-E34-9	574186	137430	3/19/17 6:56 AM	121.635
299-E33-32	573525	137354	3/19/17 7:03 AM	121.645
299-E34-10	574284	137225	3/19/17 7:05 AM	121.644
299-E33-42	573521	137424	3/19/17 7:08 AM	121.643
299-E27-17	574547	137122	3/19/17 7:10 AM	121.615
299-E33-31	573525	137491	3/19/17 7:14 AM	121.629
299-E27-8	574759	137044	3/19/17 7:18 AM	121.636
299-E27-9	574918	137041	3/19/17 7:24 AM	121.626
299-E33-28	573226	137375	3/19/17 7:26 AM	121.658
299-E33-34	573104	137740	3/19/17 7:43 AM	121.655
699-49-57A	572544	138389	3/19/17 8:03 AM	121.665
299-E33-38	573591	137594	3/19/17 8:04 AM	121.658
299-E33-342	573626	137580	3/19/17 8:08 AM	121.646
299-E33-44	573706	137469	3/19/17 8:16 AM	121.633
699-49-55A	573146	138352	3/19/17 8:19 AM	121.679
299-E33-41	573707	137370	3/19/17 8:23 AM	121.647
299-E33-14	573986	137567	3/19/17 9:36 AM	121.644

Table A-3. Water-Level Data Used for Water-Level Mapping: March 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E33-37	574091	137185	3/19/17 9:45 AM	121.652
299-E27-21	575145	136407	3/19/17 10:01 AM	121.622
299-E27-7	575221	136619	3/19/17 10:50 AM	121.619
299-E27-22	575185	136685	3/19/17 10:57 AM	121.659
299-E18-2	573392	135291	3/19/17 10:58 AM	121.688
299-E27-15	575095	136630	3/19/17 11:03 AM	121.636
299-E27-12	575054	136584	3/19/17 11:09 AM	121.630
299-E27-14	575217	136498	3/19/17 11:16 AM	121.627
299-E24-33	575325	136251	3/19/17 11:23 AM	121.622
299-E24-22	575263	136143	3/19/17 11:30 AM	121.628
299-E17-21	574107	134893	3/19/17 11:39 AM	121.617
299-E25-93	575472	136022	3/19/17 11:39 AM	121.626
299-E27-23	575069	136452	3/19/17 11:48 AM	121.624
299-E17-23	574694	134842	3/19/17 11:58 AM	121.620
299-E27-18	574300	137119	3/19/17 12:05 PM	121.648
299-E24-16	575018	135464	3/19/17 12:07 PM	121.660
299-E24-18	574647	135470	3/19/17 12:13 PM	121.655
299-E28-1	573933	136733	3/19/17 12:13 PM	121.634
299-E24-24	574180	135459	3/19/17 12:22 PM	121.654
299-E28-17	573461	136332	3/19/17 12:22 PM	121.632
299-E28-18	573104	136768	3/19/17 12:30 PM	121.658
299-E25-35	575708	135865	3/19/17 12:33 PM	121.628
299-E25-19	575852	135659	3/19/17 12:41 PM	121.641
299-E25-24	576194	135521	3/19/17 12:47 PM	121.642
299-E28-27	573227	137070	3/19/17 12:55 PM	121.658
299-E17-18	575112	135124	3/19/17 12:59 PM	121.644
299-E17-22	574841	135196	3/19/17 1:05 PM	121.651
299-E24-21	574636	135698	3/19/17 1:11 PM	121.655
299-E25-34	576019	136100	3/19/17 1:33 PM	121.635
299-E26-13	576199	136529	3/19/17 1:38 PM	121.648
299-E26-4	575734	136361	3/19/17 1:45 PM	121.645
299-E24-25	574599	136287	3/19/17 1:57 PM	121.635

Table A-3. Water-Level Data Used for Water-Level Mapping: March 2017

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
699-37-43	576829	134783	3/21/17 7:53 AM	121.645
699-37-47A	575557	134893	3/21/17 8:01 AM	121.643
299-E25-36	575404	135566	3/21/17 8:22 AM	121.640
299-E23-1	574043	136017	3/21/17 8:41 AM	121.661
299-E26-79	575828	137052	3/21/17 9:27 AM	121.680
299-E26-14	575786	137265	3/21/17 9:59 AM	121.742
299-E26-10	575589	137023	3/21/17 10:35 AM	121.682
299-E25-36	575404	135566	3/22/17 7:13 AM	121.624
299-E26-15	575926	137051	3/30/17 1:16 PM	121.660

Reference: NAVD88, 1988, *North American Vertical Datum of 1988*.

Table A-4. Water-Level Data Used for Water-Level Mapping: January 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
699-49-55A	573146	138352	1/22/18 8:27 AM	121.745
699-49-57A	572544	138389	1/22/18 8:36 AM	121.733
699-37-47A	575557	134893	1/22/18 8:54 AM	121.672
299-E24-16	575018	135464	1/22/18 9:07 AM	121.704
299-E17-21	574107	134893	1/22/18 9:30 AM	121.649
299-E18-2	573392	135291	1/22/18 9:44 AM	121.740
299-E23-1	574043	136017	1/22/18 9:57 AM	121.669
299-E28-1	573933	136733	1/22/18 10:08 AM	121.691
299-E28-17	573461	136332	1/22/18 10:23 AM	121.689
299-E28-18	573104	136768	1/22/18 10:34 AM	121.713
299-E28-27	573227	137070	1/22/18 10:43 AM	121.708
299-E32-5	572600	137285	1/22/18 10:56 AM	121.718
299-E32-6	572600	137515	1/22/18 11:01 AM	121.724
299-E32-8	572663	137741	1/22/18 11:11 AM	121.731
299-E33-38	573591	137594	1/22/18 11:37 AM	121.715
299-E33-41	573707	137370	1/22/18 11:47 AM	121.704
299-E33-339	573717	137222	1/22/18 11:55 AM	121.709

Table A-4. Water-Level Data Used for Water-Level Mapping: January 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E33-32	573525	137354	1/22/18 12:05 PM	121.707
299-E33-42	573521	137424	1/22/18 12:11 PM	121.709
299-E33-31	573525	137491	1/22/18 12:17 PM	121.705
299-E33-34	573104	137740	1/22/18 12:24 PM	121.720
699-37-43	576829	134783	1/23/18 7:48 AM	121.674
299-E25-19	575852	135659	1/23/18 7:59 AM	121.723
299-E25-24	576194	135521	1/23/18 8:08 AM	121.719
299-E25-35	575708	135865	1/23/18 8:19 AM	121.711
299-E25-34	576019	136100	1/23/18 8:27 AM	121.693
299-E26-13	576199	136529	1/23/18 8:35 AM	121.701
299-E26-14	575786	137265	1/23/18 8:54 AM	121.799
299-E26-15	575926	137051	1/23/18 9:07 AM	121.730
299-E26-10	575589	137023	1/23/18 9:16 AM	121.722
299-E24-25	574599	136287	1/23/18 9:27 AM	121.683
299-E27-8	574759	137044	1/23/18 9:38 AM	121.717
299-E27-17	574547	137122	1/23/18 9:44 AM	121.715
299-E27-18	574300	137119	1/23/18 9:52 AM	121.716
299-E33-37	574091	137185	1/23/18 9:58 AM	121.719
299-E34-9	574186	137430	1/23/18 10:05 AM	121.717
299-E34-10	574284	137225	1/23/18 10:26 AM	121.722
299-E33-14	573986	137567	1/23/18 10:34 AM	121.714
299-E33-342	573626	137580	1/23/18 10:45 AM	121.712
299-E33-44	573706	137469	1/23/18 10:53 AM	121.726
299-E33-28	573226	137375	1/23/18 11:12 AM	121.701
299-E27-12	575054	136584	1/23/18 11:24 AM	121.706
299-E27-15	575095	136630	1/23/18 11:31 AM	121.705
299-E26-79	575828	137052	1/23/18 11:48 AM	121.733
299-E27-9	574918	137041	1/23/18 11:57 AM	121.713
299-E27-22	575185	136685	1/23/18 12:18 PM	121.730
299-E27-7	575221	136619	1/23/18 12:25 PM	121.722
299-E27-21	575145	136407	1/23/18 12:38 PM	121.707
299-E27-23	575069	136452	1/23/18 12:44 PM	121.712

Table A-4. Water-Level Data Used for Water-Level Mapping: January 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E27-14	575217	136498	1/23/18 12:51 PM	121.711
299-E24-33	575325	136251	1/23/18 12:59 PM	121.727
299-E24-22	575263	136143	1/23/18 1:08 PM	121.723
299-E25-93	575472	136022	1/23/18 1:16 PM	121.700

Reference: NAVD88, 1988, North American Vertical Datum of 1988.

Table A-5. Water-Level Data Used for Water-Level Mapping: February 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
699-37-47A	575557	134893	2/20/18 8:49 AM	121.658
699-37-43	576829	134783	2/20/18 8:57 AM	121.638
699-49-57A	572544	138389	2/20/18 9:25 AM	121.708
699-49-55A	573146	138352	2/20/18 9:33 AM	121.715
299-E32-5	572600	137285	2/20/18 9:51 AM	121.692
299-E32-6	572600	137515	2/20/18 9:57 AM	121.697
299-E32-8	572663	137741	2/20/18 10:03 AM	121.703
299-E34-9	574186	137430	2/20/18 10:14 AM	121.687
299-E34-10	574284	137225	2/20/18 10:21 AM	121.691
299-E25-34	576019	136100	2/20/18 10:43 AM	121.668
299-E25-35	575708	135865	2/20/18 10:54 AM	121.672
299-E25-19	575852	135659	2/20/18 11:04 AM	121.684
299-E25-24	576194	135521	2/20/18 11:10 AM	121.686
299-E17-21	574107	134893	2/20/18 12:01 PM	121.688
299-E17-25	574515	134846	2/20/18 12:20 PM	121.696
299-E17-23	574694	134842	2/20/18 12:30 PM	121.684
299-E17-18	575112	135124	2/20/18 12:39 PM	121.661
299-E17-22	574841	135196	2/20/18 12:47 PM	121.679
299-E24-16	575018	135464	2/20/18 12:56 PM	121.698
299-E23-1	574043	136017	2/20/18 1:21 PM	121.677
299-E28-1	573933	136733	2/20/18 1:35 PM	121.695
299-E28-17	573461	136332	2/20/18 1:45 PM	121.679

Table A-5. Water-Level Data Used for Water-Level Mapping: February 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E28-18	573104	136768	2/20/18 1:53 PM	121.702
299-E18-2	573392	135291	2/20/18 2:10 PM	121.732
299-E28-27	573227	137070	2/20/18 2:28 PM	121.691
299-E24-21	574636	135698	2/20/18 3:00 PM	121.682
299-E24-18	574647	135470	2/20/18 3:06 PM	121.672
299-E24-24	574180	135459	2/20/18 3:12 PM	121.686
299-E26-13	576199	136529	2/21/18 7:55 AM	121.676
299-E24-25	574599	136287	2/21/18 8:23 AM	121.664
299-E27-8	574759	137044	2/21/18 8:35 AM	121.682
299-E27-9	574918	137041	2/21/18 8:42 AM	121.682
299-E26-10	575589	137023	2/21/18 8:49 AM	121.697
299-E26-79	575828	137052	2/21/18 8:57 AM	121.721
299-E26-14	575786	137265	2/21/18 9:09 AM	121.778
299-E25-93	575472	136022	2/21/18 9:33 AM	121.669
299-E24-22	575263	136143	2/21/18 9:42 AM	121.672
299-E24-33	575325	136251	2/21/18 9:53 AM	121.676
299-E27-14	575217	136498	2/21/18 10:00 AM	121.676
299-E27-23	575069	136452	2/21/18 10:06 AM	121.674
299-E27-12	575054	136584	2/21/18 10:15 AM	121.679
299-E27-15	575095	136630	2/21/18 10:30 AM	121.681
299-E27-22	575185	136685	2/21/18 10:41 AM	121.709
299-E27-7	575221	136619	2/21/18 10:51 AM	121.684
299-E27-21	575145	136407	2/21/18 11:11 AM	121.676
299-E33-37	574091	137185	2/21/18 11:23 AM	121.695
299-E33-339	573717	137222	2/21/18 11:32 AM	121.687
299-E33-41	573707	137370	2/21/18 11:38 AM	121.684
299-E33-44	573706	137469	2/21/18 11:44 AM	121.689
299-E33-342	573626	137580	2/21/18 11:52 AM	121.688
299-E33-38	573591	137594	2/21/18 11:58 AM	121.693
299-E33-14	573986	137567	2/21/18 12:07 PM	121.690
299-E33-28	573226	137375	2/21/18 12:18 PM	121.691

Table A-5. Water-Level Data Used for Water-Level Mapping: February 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E33-34	573104	137740	2/21/18 12:27 PM	121.701
299-E33-31	573525	137491	2/21/18 12:42 PM	121.698
299-E33-42	573521	137424	2/21/18 12:48 PM	121.692
299-E33-32	573525	137354	2/21/18 12:53 PM	121.691
299-E27-18	574300	137119	2/21/18 1:02 PM	121.693
299-E27-17	574547	137122	2/21/18 1:08 PM	121.692

Reference: NAVD88, 1988, *North American Vertical Datum of 1988*.

Table A-6. Water-Level Data Used for Water-Level Mapping: March 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E33-14	573986	137567	3/15/18 6:38 AM	121.698
299-E33-28	573226	137375	3/15/18 6:47 AM	121.697
299-E24-24	574180	135459	3/15/18 7:06 AM	121.691
299-E24-18	574647	135470	3/15/18 7:14 AM	121.666
299-E24-21	574636	135698	3/15/18 7:26 AM	121.681
299-E24-16	575018	135464	3/15/18 7:36 AM	121.705
299-E17-22	574841	135196	3/15/18 7:43 AM	121.684
299-E17-18	575112	135124	3/15/18 7:50 AM	121.662
699-37-47A	575557	134893	3/15/18 7:57 AM	121.662
299-E17-23	574694	134842	3/15/18 8:05 AM	121.684
299-E17-25	574515	134846	3/15/18 8:34 AM	121.698
299-E17-21	574107	134893	3/15/18 8:43 AM	121.654
299-E18-2	573392	135291	3/15/18 9:10 AM	121.739
299-E23-1	574043	136017	3/15/18 9:20 AM	121.680
299-E28-17	573461	136332	3/15/18 10:01 AM	121.686
299-E28-18	573104	136768	3/15/18 10:09 AM	121.708
299-E28-1	573933	136733	3/15/18 10:33 AM	121.702
299-E28-27	573227	137070	3/15/18 10:42 AM	121.696
299-E33-34	573104	137740	3/15/18 11:05 AM	121.709

Table A-6. Water-Level Data Used for Water-Level Mapping: March 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E32-8	572663	137741	3/15/18 11:11 AM	121.712
299-E32-6	572600	137515	3/15/18 11:17 AM	121.705
299-E32-5	572600	137285	3/15/18 11:22 AM	121.707
699-49-57A	572544	138389	3/15/18 11:34 AM	121.718
699-49-55A	573146	138352	3/15/18 11:43 AM	121.732
299-E26-79	575828	137052	3/15/18 12:48 PM	121.721
299-E26-15	575926	137051	3/15/18 12:52 PM	121.710
299-E26-14	575786	137265	3/15/18 1:01 PM	121.782
299-E26-10	575589	137023	3/15/18 1:10 PM	121.704
299-E26-4	575734	136361	3/15/18 1:29 PM	121.673
299-E26-13	576199	136529	3/15/18 1:52 PM	121.690
699-37-43	576829	134783	3/16/18 6:46 AM	121.645
299-E25-24	576194	135521	3/16/18 7:03 AM	121.691
299-E25-19	575852	135659	3/16/18 7:11 AM	121.682
299-E25-34	576019	136100	3/16/18 7:21 AM	121.675
299-E27-9	574918	137041	3/16/18 7:46 AM	121.688
299-E27-8	574759	137044	3/16/18 7:53 AM	121.688
299-E27-17	574547	137122	3/16/18 8:02 AM	121.677
299-E33-37	574091	137185	3/16/18 8:16 AM	121.689
299-E27-18	574300	137119	3/16/18 8:24 AM	121.690
299-E34-10	574284	137225	3/16/18 8:31 AM	121.693
299-E34-9	574186	137430	3/16/18 8:39 AM	121.693
299-E33-339	573717	137222	3/16/18 8:58 AM	121.686
299-E33-32	573525	137354	3/16/18 9:12 AM	121.687
299-E33-42	573521	137424	3/16/18 9:18 AM	121.686
299-E33-31	573525	137491	3/16/18 9:24 AM	121.674
299-E33-38	573591	137594	3/16/18 9:32 AM	121.695
299-E33-41	573707	137370	3/16/18 9:41 AM	121.684
299-E33-342	573626	137580	3/16/18 10:15 AM	121.692
299-E33-44	573706	137469	3/16/18 10:40 AM	121.704
299-E27-21	575145	136407	3/19/18 11:11 AM	121.664
299-E24-33	575325	136251	3/19/18 11:20 AM	121.674

Table A-6. Water-Level Data Used for Water-Level Mapping: March 2018

Name	Easting	Northing	Date-Time	Measured Water Level (m NAVD88)
299-E25-93	575472	136022	3/19/18 11:28 AM	121.668
299-E25-35	575708	135865	3/19/18 11:38 AM	121.673
299-E25-36	575404	135566	3/19/18 11:47 AM	121.664
299-E27-23	575069	136452	3/19/18 12:00 PM	121.677
299-E27-14	575217	136498	3/19/18 12:10 PM	121.678
299-E27-12	575054	136584	3/19/18 12:22 PM	121.683
299-E27-15	575095	136630	3/19/18 12:29 PM	121.680
299-E27-22	575185	136685	3/19/18 12:41 PM	121.706
299-E27-7	575221	136619	3/19/18 12:52 PM	121.682
299-E24-25	574599	136287	3/20/18 10:36 AM	121.658

Reference: NAVD88, 1988, *North American Vertical Datum of 1988*.

A3.2 Method Description

TRIM was used to obtain a piecewise, continuous grid of groundwater elevations using a simplified groundwater flow simulator as the mechanism to interpolate between measured water levels. TRIM is a formal mathematical technique that is used to trade the complexity of a method or parameterization that is being used to analyze measured data against the "fit" obtained to those data. When used with a deterministic model, Tikhonov regularization (Tikhonov and Arsenin, 1977, *Solutions of Ill-Posed Problems*) is used to constrain the parameters of the model while attempting to attain a satisfactory fit to the measured data that comports with independent subject matter expert (SME) knowledge and information.

As described in ECF-200E-19-0081, this was accomplished by developing a single-layer (i.e., two-dimensional) steady-state simulation approximating dominant groundwater flow characteristics over an area encompassing the 200 East Area facilities, and then using Tikhonov regularization to constrain parameter complexity and prevent overfitting to the measured water-level data. The advantage of using a simplified groundwater flow simulator as the mechanism to interpolate between the measured water levels is that the resulting groundwater elevation grids conserve flow and are suitable for tracking particles to evaluate likely paths of groundwater movement.

A3.2.1 Development of Single-Layer Simulator

The simplified two-dimensional groundwater flow simulator was inherited from the TRIM analysis work completed for and described in ECF-200E-18-0085, *Water Level Mapping and Hydraulic Gradient Calculations for 200 East Area RCRA Sites, 2018*. Throughout the 200 East Area, the predominant factors that impact area-wide groundwater flow patterns are (1) the high hydraulic conductivity sediments that comprise the Hanford formation and the CCU, (2) the location of lower hydraulic conductivity sediments and basalts that are lateral to or a subcrop within the high-conductivity sediments, and (3) lateral sources and sinks (inflows and outflows) of water particularly along the northwest and southeast extents of the 200 East Area.

These predominant factors were represented in the simplified single-layer (two-dimensional) steady-state simulator of groundwater flow using the unstructured grid release of the MODFLOW program, MODFLOW-USG. The MODFLOW-USG simulation code is a control-volume finite difference formulation of the commonly used finite-difference U.S. Geological Survey MODFLOW groundwater flow simulator. MODFLOW-USG can support a Voronoi grid, which is well suited to the purpose of these calculations because a much smaller number of cells is needed to discretize the area encompassing the 200 East Area facilities, and a correspondingly smaller number of regularization equations are needed to specify relations between the parameter value in each cell and that of its neighbors. The simplified two-dimensional simulator of groundwater flow conditions was constructed with the resolution of the mesh refined in areas of particular interest, such as near groups of monitoring wells.

Based on SME knowledge, the hydraulic conductivity of the sediments within which the water table resides was discretized into three hydrostratigraphic unit (HSU) zones, representing the Hanford formation, CCU gravel, and the Ringold Formation member of Wooded Island – unit E. Delineation of HSUs at the elevation of the water table was prepared by intersecting the Central Plateau Groundwater Model (CPGWM) water-table grid with a three-dimensional geological model (ECF-HANFORD-13-0029, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington*). Within each of these delineated HSU zones, the hydraulic conductivity was defined as homogeneous for purposes of defining initial parameter values (this represents the "preferred system condition" at the commencement of the Tikhonov regularization that followed). The resulting grid, boundaries, and hydraulic conductivity zones are shown in Figure A-2.

A3.2.2 Tikhonov Regularization

The program PEST (Doherty, 2015, *Calibration and Uncertainty Analysis for Complex Environmental Models, PEST: Complete Theory and What it Means for Modelling the Real World*) was used for the implementation of Tikhonov regularization. The PEST software can implement Tikhonov regularization in two modes of operation, the regularization and pareto modes. When operating in the regularization mode, the PEST program calculates updates to the initial values of the parameters that provide an improved fit to the measured values and also determines a global regularization weight parameter. The weight parameter enables the regularization to meet a target value ascribed by the user as representing an "acceptable" fit (Doherty, 2015). When operating in the pareto mode, the PEST program calculates updates to the values of the parameters that explores the relationship between the regularization objective function, the global regularization weight parameter, and measurement objective function. These two modes allow for the tradeoff between the complexity of the simulator or its parameterization versus the fit obtained to the measured data.

A3.2.3 Limitations

The simplified two-dimensional groundwater flow simulator that underlies TRIM, developed using the MODFLOW-USG code for purposes of this ECF, was implemented specifically for the purpose of providing a mechanism to interpret groundwater level data and obtain groundwater elevation contours depicting directions of groundwater flow and potential migration pathways based upon those measured data. The groundwater elevation contours are obtained by trading-off the complexity of the parameterization of the groundwater simulator versus the fit that is obtained to the measured groundwater elevation data, effectively using the groundwater simulator as an alternative to distance-weighted interpolation (such as kriging) to interpolate between the measured groundwater level data. Because the resulting piecewise, continuous groundwater elevation grids depict hydraulic gradients that comport with independent SME knowledge of subsurface conditions, they are suitable for particle-tracking analyses to depict approximate rates and directions of groundwater flow and potential contaminant migration in the vicinity of the 200 East Area facilities.

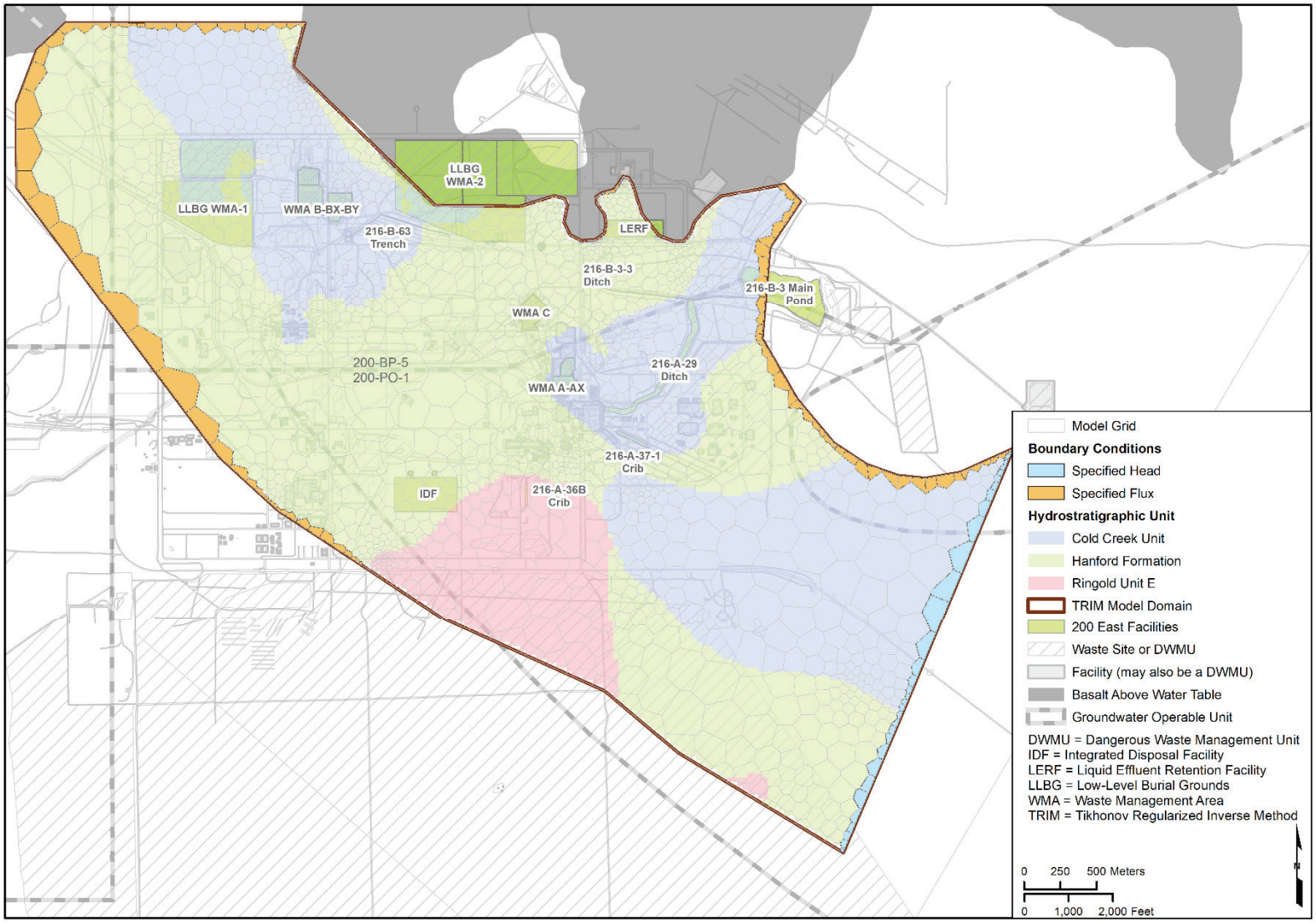

Figure A-2. Two-Dimensional Simulator Boundary Conditions and HSU Zones

The simplified two-dimensional groundwater flow simulator that underlies TRIM is not a substitute for existing three-dimensional groundwater flow and contaminant transport models at the Hanford Site (i.e., the CPGWM and the Plateau to River model). There are many simplifications in the underlying groundwater flow simulator developed for purposes of this ECF, which include use of a single layer representing only water-table conditions, the regularization objective sought in TRIM of homogeneity without specific regard for the values or physical meaning of the resulting parameters, and the simplified representation of the lateral boundaries of the area of interest. Because of these and other simplifications and limitations, the MODFLOW-USG simulator underlying TRIM should not be used as an alternative to the existing three-dimensional groundwater flow and contaminant transport models (i.e., the CPGWM and Plateau to River model) for mass-conserved simulations of contaminant transport.

A4 Assumptions and Inputs

This chapter outlines the assumptions and inputs that underlie the calculations presented in this ECF.

A4.1 Assumptions

Assumptions used for the groundwater flow analysis and groundwater elevation mapping are discussed in this section. Water-level contour maps were constructed using the simplified simulator of groundwater flow together with the use of PEST for model calibration and implementation of Tikhonov regularization. The resulting groundwater elevation contour maps provide plausible interpretations of groundwater levels and hydraulic gradients between measured locations. The accuracy of the contours is influenced by several factors contributing uncertainty to the analysis, including the following:

- The accuracy of the measured or recorded water levels (i.e., in some instances the measurement error may be of similar magnitude to the elevation difference between separate measurement locations at the observed low gradient)
- The number, distribution, and location of monitoring wells (i.e., wells have been installed for other purposes than determining regional groundwater elevation and resulting unmeasured segments of the aquifer may be quite large)
- The relationship between the vertical open interval(s) of the monitoring wells and those of any extraction and injection wells (i.e., operation of extraction and/or injection wells can directly influence groundwater elevations in nearby wells)

These potential sources of error mean that the maps are interpreted as reasonable approximations that provide useful inference in the interpretation of likely directions and rates of groundwater movement particularly in regions of low hydraulic gradients. The water-level analysis presented in this ECF incorporates the working assumption that the potential errors imposed by these conditions are understood and the resulting effects are acceptable to the overall interpretation of groundwater elevation. Based on SME knowledge and understanding of the groundwater system in 200 East Area, these estimates are assumed to be representative of observed conditions.

A4.2 Input Data

This section summarizes the general input requirements for the calculations described in this ECF.

Water-level data were retrieved from the HEIS database for 61 low-gradient network monitoring wells and one additional well, 299-E26-10. Data were limited to those used specifically for water-table mapping. Table A-7 lists data for the first quarters of CYs 2017 and 2018 and the calculated average

water-level elevations for that period. Full sets of data for the first quarters of CYs 2017 and 2018 are included in Tables A-1 through A-6.

Table A-7. Water-Level Measurements

Well Name	Average Measured Water Levels	
	January to March 2017 (NAVD88 m)	January to March 2018 (NAVD88 m)
299-E17-18	121.645	121.662
299-E17-21	121.636	121.664
299-E17-22	121.659	121.682
299-E17-23	121.628	121.684
299-E17-25	121.681	121.697
299-E18-2	121.701	121.737
299-E23-1	121.636	121.675
299-E24-16	121.675	121.702
299-E24-18	121.656	121.669
299-E24-21	121.662	121.682
299-E24-22	121.667	121.698
299-E24-24	121.662	121.689
299-E24-25	121.640	121.668
299-E24-33	121.665	121.692
299-E25-19	121.661	121.696
299-E25-24	121.662	121.699
299-E25-34	121.644	121.679
299-E25-35	121.624	121.685
299-E25-36	121.642	121.664
299-E25-93	121.636	121.679
299-E26-10	121.683	121.708
299-E26-13	121.653	121.689
299-E26-14	121.750	121.786
299-E26-15	121.660	121.720
299-E26-4	121.649	121.673
299-E26-79	121.687	121.725
299-E27-12	121.658	121.689
299-E27-14	121.656	121.688
299-E27-15	121.660	121.689

Table A-7. Water-Level Measurements

Well Name	Average Measured Water Levels	
	January to March 2017 (NAVD88 m)	January to March 2018 (NAVD88 m)
299-E27-17	121.648	121.695
299-E27-18	121.664	121.700
299-E27-21	121.651	121.682
299-E27-22	121.684	121.715
299-E27-23	121.654	121.688
299-E27-7	121.653	121.696
299-E27-8	121.656	121.696
299-E27-9	121.653	121.694
299-E28-1	121.651	121.696
299-E28-17	121.645	121.685
299-E28-18	121.669	121.708
299-E28-27	121.663	121.698
299-E32-5	121.661	121.706
299-E32-6	121.665	121.709
299-E32-8	121.663	121.715
299-E33-14	121.665	121.701
299-E33-28	121.669	121.696
299-E33-31	121.659	121.692
299-E33-32	121.663	121.695
299-E33-339	121.669	121.694
299-E33-342	121.662	121.697
299-E33-34	121.669	121.710
299-E33-37	121.672	121.701
299-E33-38	121.679	121.701
299-E33-41	121.664	121.691
299-E33-42	121.664	121.696
299-E33-44	121.669	121.706
299-E34-10	121.664	121.702
299-E34-9	121.663	121.699
699-37-43	121.638	121.652

Table A-7. Water-Level Measurements

Well Name	Average Measured Water Levels	
	January to March 2017 (NAVD88 m)	January to March 2018 (NAVD88 m)
699-37-47A	121.643	121.664
699-49-55A	121.681	121.731
699-49-57A	121.671	121.720

Reference: NAVD88, *North American Vertical Datum of 1988.*

A5 Software Applications, Descriptions, Installation and Checkout, and Statements of Validity

Software used to perform the calculations for this ECF was in accordance with CH2M HILL Plateau Remediation Company's (CHPRC's) controlled software management procedure, which implements DOE O 414.1d, *Quality Assurance*.

A5.1 Approved Software

The software used for this ECF is approved, managed, and used consistent with CHPRC's controlled software management procedure under the following software lifecycle documentation:

- CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
- CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
- CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
- CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
- CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

CHPRC-00258 distinguishes between safety software and support software based on whether the software calculates reportable results or provides run support, visualization, or similar functions. Brief descriptions of the software are provided in Section A5.2.

A5.2 Software Description

A controlled calculation software, MODFLOW-USG (Panday et al., 2013, *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*), was used for the calculations that support this ECF.

- Software title: MODFLOW-USG, *An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation*
- Software version: 1.2.00, approved as CHPRC Build 8 compiled to default single precision
- Executable Name: mfusg-chprc08spv.exe

- Hanford Information Systems Inventory (HISI) identification number: 2517
- Workstation type and property number (from which software is run): SSP&A and FE616

A5.3 Support Software

The following software programs are classified as support software by CHPRC-00258:

- PEST: (Doherty, 2015) Estimates parameter values that minimize the objective function(s) to calibrate models using inverse theory.
- Groundwater Vistas™: Rumbaugh and Rumbaugh, 2017, *Groundwater Vistas Version 7*. Provided graphical tools used for model quality assurance and model input/output review.
- ArcGIS®: Visualization and post-processing tool for assessing simulated plume distributions, identifying extraction/injection well coordinates, and mapping auxiliary data (Mitchell, 1999, *The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns & Relationships*).
- Surfer®: Data interpolation for visualization, model implementation, and quality assurance.
- AlgoMesh®: A mesh-generating software used for creating unstructured triangular and Voronoi grids for MODFLOW-USG: AlgoMesh Version 1.2.0.37827 (64 bit) (HydroAlgorithmics, 2016, *AlgoMesh User Guide*).

A5.4 Software Installation and Checkout

Safety software installations are checked and tested in accordance with CHPRC-00258 using the installation tests provided in CHPRC-00259. Executables are obtained from the CHPRC software owner (who maintains the configuration-managed copies in MKS Integrity®). Software installation and checkout forms are required and must be approved for installations used to perform model runs. Approved users are registered in HISI authorized users list for safety software.

A5.4.1 Statement of Valid Software Application

The software identified above was used consistent with intended uses, as identified in CHPRC-00257, and is a valid use of this software for this application. The software was used within its limitations, as identified in CHPRC-00257.

™ Groundwater Vistas is a trademark of Environmental Simulations, Inc., Reinholds, Pennsylvania.

® ArcGIS is a registered trademark of the Environmental Systems Research Institute, Inc., Redlands, California.

® Surfer is a registered trademark of Golden Software, LLC, Golden, Colorado.

® AlgoMesh is registered trademark of HydroAlgorithmics Pty Ltd, Canberra, Australia.

® MKS Integrity is a registered trademark of MKS, Inc., Needham, Massachusetts.

A6 Calculations

This chapter describes the calculations and steps performed to develop the necessary input files, perform the calculations, and post-process the outputs to produce the results presented in this ECF.

Groundwater elevation maps presented in this ECF were produced in a two-step process:

1. Data compilation: Input data were compiled from retrieved database sources. Outliers were flagged from constructing trend plots of all measured data and excluded from calculations. Average groundwater elevations were then calculated for the first quarters of CYs 2017 and 2018 based on the filtered monthly measurements and used to define the targets for the calibration process.

2. Calibration: The boundary conditions of the simplified two-dimensional groundwater flow simulator, described in Chapter 3, were then used as parameters for PEST in estimation mode to approximate measured groundwater levels for the first quarters of CYs 2017 and 2018. Targets corresponding to the northwest, north, southeast, and south of the model domain boundaries were assigned higher weights during the calibration process such that the overall average measured gradient across the 200 East Area is respected.

   The calibration targets and their associated weights are listed in Tables A-8 and A-9 for CYs 2017 and 2018, respectively. During the calibration process, wells that were repeatedly registering high residuals were flagged and compared to adjacent measurements. Based on understandings of any nearby stresses, surrounding geology, and inferred flow directions (i.e., upgradient versus downgradient), these wells and/or surrounding wells were assigned lower weights due to lower confidence in the accuracy of their measurements.

   Tables A-8 and A-9 also list the final residuals obtained for the calibration targets. A residual, or estimated error, value for each measured point was calculated as the difference between the measured value and the value interpolated by the calculation. Tables A-8 and A-9 show the residuals are all low with absolute values within 0.03 m of average measured groundwater levels for the first quarters of CYs 2017 and 2018. Figures A-3 and A-4 illustrate the cumulative frequency plot of the absolute residuals obtained from the calibration for all high-weighted targets (weight greater than 5) for the first quarters of CYs 2017 and 2018, respectively. The calibration of this interpolation is deemed acceptable and the results are usable for the purposes of this evaluation.

Table A-8. Calibration Targets for the First Quarter of CY 2017

Well Name	Average Measured Water Level (m NAV88)	Grid Interpolated Water Level (m NAV88)	Residual (Estimated Error) (m)	Calibration Weight
299-E17-18	121.645	121.650	-0.005	10
299-E17-21*	121.636	121.658	-0.022	4
299-E17-22	121.659	121.653	0.006	10
299-E17-23*	121.628	121.651	-0.024	4
299-E17-25*	121.681	121.653	0.028	0
299-E18-2	121.701	121.701	0.000	20
299-E23-1*	121.636	121.659	-0.023	0

Table A-8. Calibration Targets for the First Quarter of CY 2017

Well Name	Average Measured Water Level (m NAV88)	Grid Interpolated Water Level (m NAV88)	Residual (Estimated Error) (m)	Calibration Weight
299-E24-16*	121.675	121.653	0.022	0
299-E24-18	121.656	121.655	0.002	10
299-E24-21	121.662	121.655	0.006	10
299-E24-22	121.667	121.654	0.012	10
299-E24-24	121.662	121.658	0.004	10
299-E24-25	121.640	121.658	-0.018	5
299-E24-33	121.665	121.655	0.010	10
299-E25-19	121.661	121.649	0.012	5
299-E25-24	121.662	121.645	0.016	5
299-E25-34	121.644	121.652	-0.008	10
299-E25-35*	121.624	121.651	-0.027	0
299-E25-36	121.642	121.651	-0.009	10
299-E25-93	121.636	121.653	-0.017	10
299-E26-10	121.683	121.679	0.004	10
299-E26-13	121.653	121.656	-0.003	10
299-E26-14	121.750	121.748	0.001	20
299-E26-15*	121.660	121.687	-0.027	4
299-E26-4	121.649	121.655	-0.006	10
299-E26-79	121.687	121.695	-0.008	10
299-E27-12	121.658	121.658	0.000	10
299-E27-14	121.656	121.657	-0.001	10
299-E27-15	121.660	121.658	0.001	10
299-E27-17	121.648	121.660	-0.013	10
299-E27-18	121.664	121.661	0.004	10
299-E27-21	121.651	121.657	-0.005	10
299-E27-22*	121.684	121.659	0.025	0
299-E27-23	121.654	121.657	-0.003	10
299-E27-7	121.653	121.658	-0.005	10
299-E27-8	121.656	121.660	-0.004	10
299-E27-9	121.653	121.660	-0.007	10
299-E28-1	121.651	121.661	-0.010	10

Table A-8. Calibration Targets for the First Quarter of CY 2017

Well Name	Average Measured Water Level (m NAV88)	Grid Interpolated Water Level (m NAV88)	Residual (Estimated Error) (m)	Calibration Weight
299-E28-17	121.645	121.662	-0.017	10
299-E28-18	121.669	121.663	0.007	10
299-E28-27	121.663	121.662	0.002	10
299-E32-5	121.661	121.666	-0.005	10
299-E32-6	121.665	121.667	-0.002	10
299-E32-8	121.663	121.669	-0.006	10
299-E33-14	121.665	121.661	0.004	10
299-E33-28	121.669	121.662	0.006	10
299-E33-31	121.659	121.662	-0.002	10
299-E33-32	121.663	121.661	0.002	10
299-E33-339	121.669	121.661	0.008	10
299-E33-34	121.669	121.666	0.004	10
299-E33-342	121.662	121.662	0.000	10
299-E33-37	121.672	121.661	0.011	10
299-E33-38	121.679	121.662	0.017	10
299-E33-41	121.664	121.661	0.003	10
299-E33-42	121.664	121.661	0.003	10
299-E33-44	121.669	121.661	0.007	10
299-E34-10	121.664	121.661	0.003	10
299-E34-9	121.663	121.661	0.002	10
699-37-43	121.638	121.631	0.007	10
699-37-47A	121.643	121.642	0.000	10
699-49-55A	121.681	121.674	0.007	20
699-49-57A	121.671	121.677	-0.006	20

Reference: NAV88, *North American Vertical Datum of 1988.*

*Well assigned a low weight for PEST calibration.

Table A-9. Calibration Targets for the First Quarter of CY 2018

Well Name	Average Measured Water Level (m NAV88)	Grid Interpolated Water Level (m NAV88)	Residual (Estimated Error) (m)	Calibration Weight
299-E17-18	121.662	121.677	-0.016	10
299-E17-21*	121.664	121.689	-0.025	2
299-E17-22	121.682	121.681	0.000	10
299-E17-23	121.684	121.680	0.004	10
299-E17-25	121.697	121.682	0.015	10
299-E18-2	121.737	121.737	0.000	20
299-E23-1	121.675	121.691	-0.015	10
299-E24-16*	121.702	121.682	0.021	0
299-E24-18	121.669	121.684	-0.015	10
299-E24-21	121.682	121.685	-0.003	10
299-E24-22	121.698	121.683	0.014	10
299-E24-24	121.689	121.688	0.000	10
299-E24-25*	121.668	121.689	-0.021	0
299-E24-33	121.692	121.684	0.008	10
299-E25-19*	121.696	121.675	0.021	0
299-E25-24*	121.699	121.671	0.028	0
299-E25-34	121.679	121.679	0.000	10
299-E25-35	121.685	121.678	0.007	10
299-E25-36	121.664	121.679	-0.015	10
299-E25-93	121.679	121.681	-0.002	10
299-E26-10	121.708	121.711	-0.003	10
299-E26-13	121.689	121.684	0.005	10
299-E26-14	121.786	121.787	-0.001	10
299-E26-15	121.720	121.719	0.001	10
299-E26-4	121.673	121.683	-0.010	10
299-E26-79	121.725	121.728	-0.003	10
299-E27-12	121.689	121.689	0.001	10
299-E27-14	121.688	121.687	0.001	10
299-E27-15	121.689	121.689	0.000	10
299-E27-17	121.695	121.694	0.001	10
299-E27-18	121.700	121.694	0.005	10
299-E27-21	121.682	121.686	-0.004	10

Table A-9. Calibration Targets for the First Quarter of CY 2018

Well Name	Average Measured Water Level (m NAV88)	Grid Interpolated Water Level (m NAV88)	Residual (Estimated Error) (m)	Calibration Weight
299-E27-22*	121.715	121.689	0.026	0
299-E27-23	121.688	121.687	0.001	10
299-E27-7	121.696	121.689	0.007	10
299-E27-8	121.696	121.693	0.003	10
299-E27-9	121.694	121.692	0.002	10
299-E28-1	121.696	121.695	0.001	10
299-E28-17	121.685	121.696	-0.011	10
299-E28-18	121.708	121.699	0.009	10
299-E28-27	121.698	121.697	0.001	10
299-E32-5	121.706	121.709	-0.003	10
299-E32-6	121.709	121.712	-0.003	10
299-E32-8	121.715	121.715	0.001	10
299-E33-14	121.701	121.696	0.005	10
299-E33-28	121.696	121.698	-0.002	10
299-E33-31	121.692	121.697	-0.005	10
299-E33-32	121.695	121.696	-0.001	10
299-E33-339	121.694	121.696	-0.002	10
299-E33-34	121.710	121.707	0.003	10
299-E33-342	121.697	121.697	0.000	10
299-E33-37	121.701	121.695	0.006	10
299-E33-38	121.701	121.697	0.004	10
299-E33-41	121.691	121.696	-0.005	10
299-E33-42	121.696	121.696	-0.001	10
299-E33-44	121.706	121.696	0.010	10
299-E34-10	121.702	121.695	0.007	10
299-E34-9	121.699	121.695	0.004	10
699-37-43	121.652	121.653	-0.001	20
699-37-47A	121.664	121.668	-0.003	10
699-49-55A	121.731	121.727	0.003	20
699-49-57A	121.720	121.736	-0.016	10

Reference: NAV88, *North American Vertical Datum of 1988.*

*Well assigned a low weight for PEST calibration.

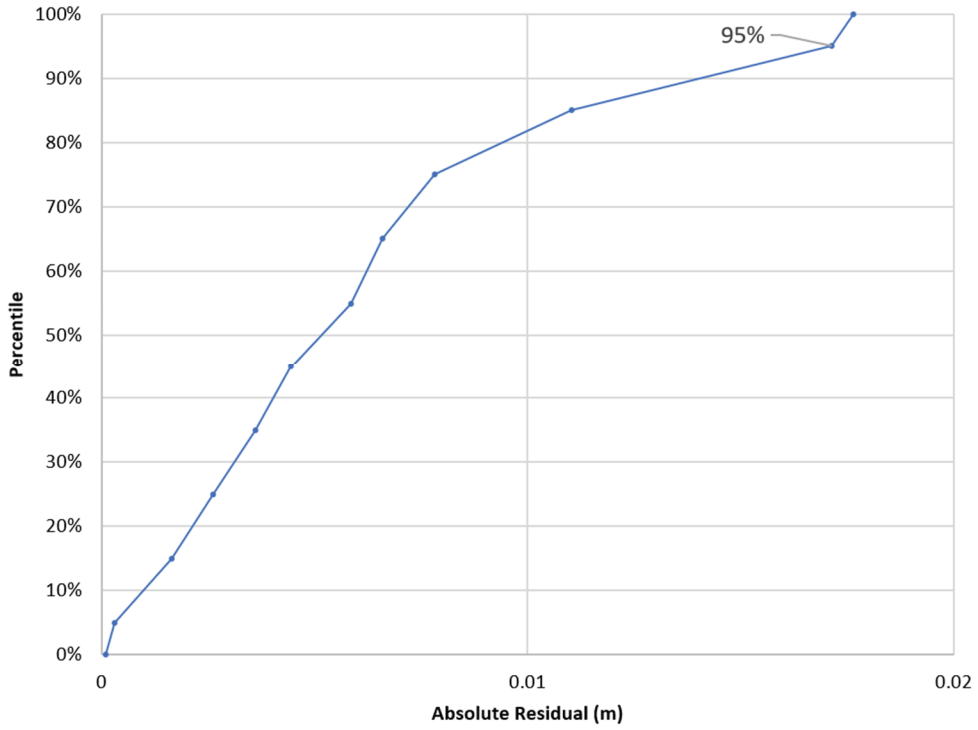

Figure A-3. Cumulative Relative Frequency of Absolute Residuals – First Quarter 2017

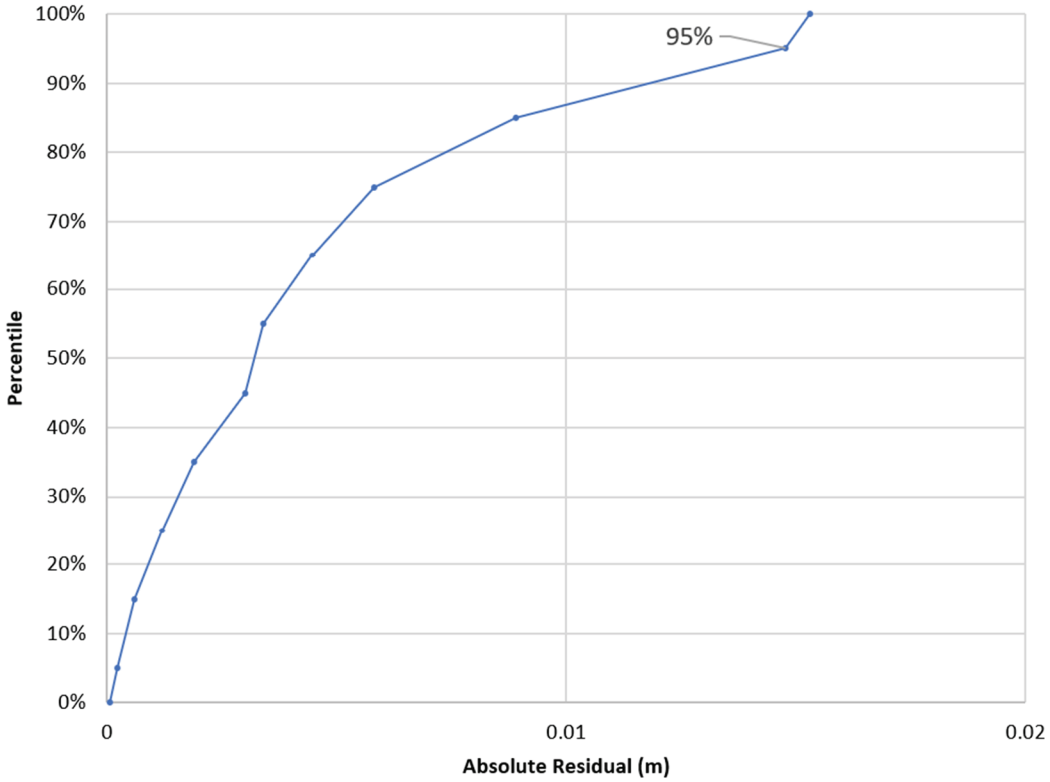

Figure A-4. Cumulative Relative Frequency of Absolute Residuals – First Quarter 2018

A7 Results

This chapter presents the results of the calculations described and the 200 East Area water-level map for average water levels for the first quarters of CYs 2017 and 2018.

After the calibration steps described in Chapter 6 are performed, a scatter plot that compares the calculated groundwater elevations with the measured groundwater elevations was prepared. Figures A-5 and A-6 show the simulated versus the measured groundwater elevations for the first quarters of CYs 2017 and 2018, respectively[1].

Figures A-7 and A-8 depict the groundwater elevation contours throughout the 200 East Area that were generated using average water levels for the first quarters of CYs 2017 and 2018. The figures also illustrate calibration weights and calibration residuals for monitoring wells included in the calibration process.

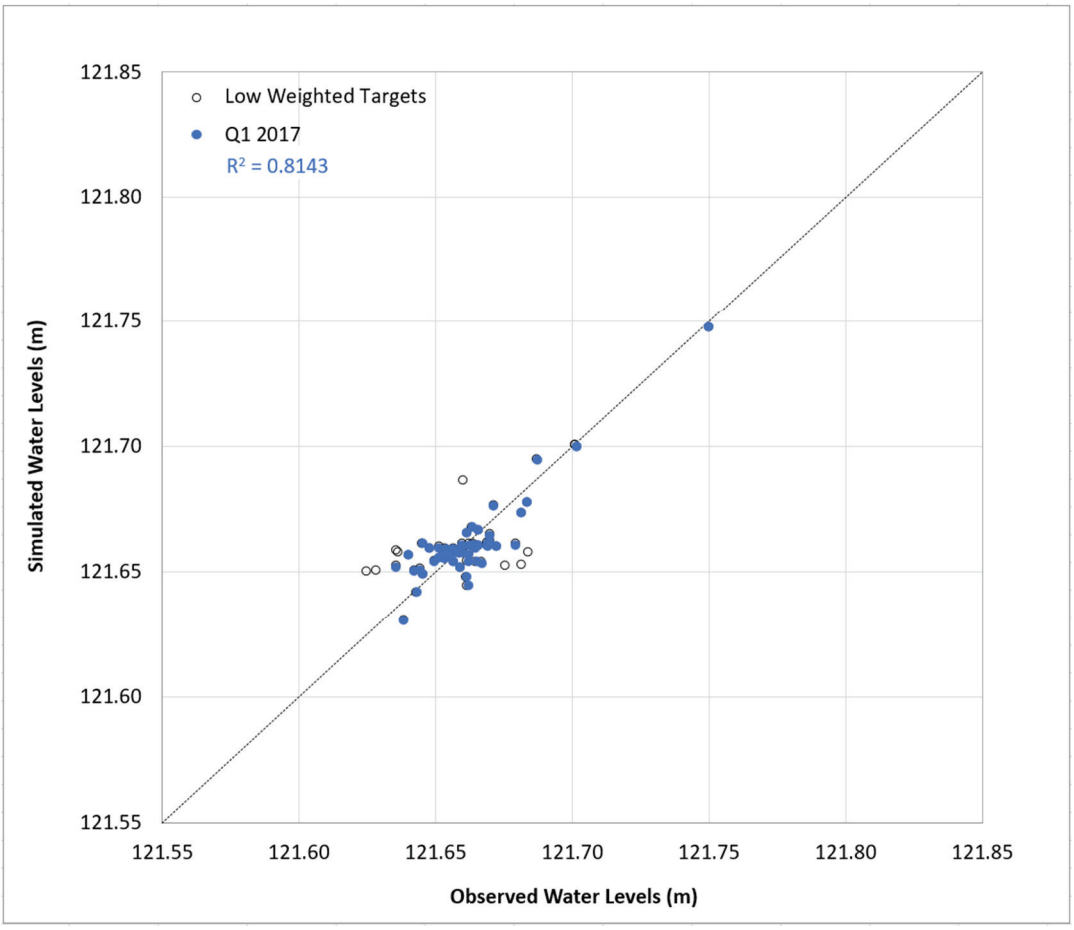

Figure A-5. Comparison of Observed Versus Simulated Water Levels – January Through March 2017

[1] Note: The squared Pearson product-moment correlation coefficient, or R^2 value, indicated on this plot only corresponds to the high-weighted targets.

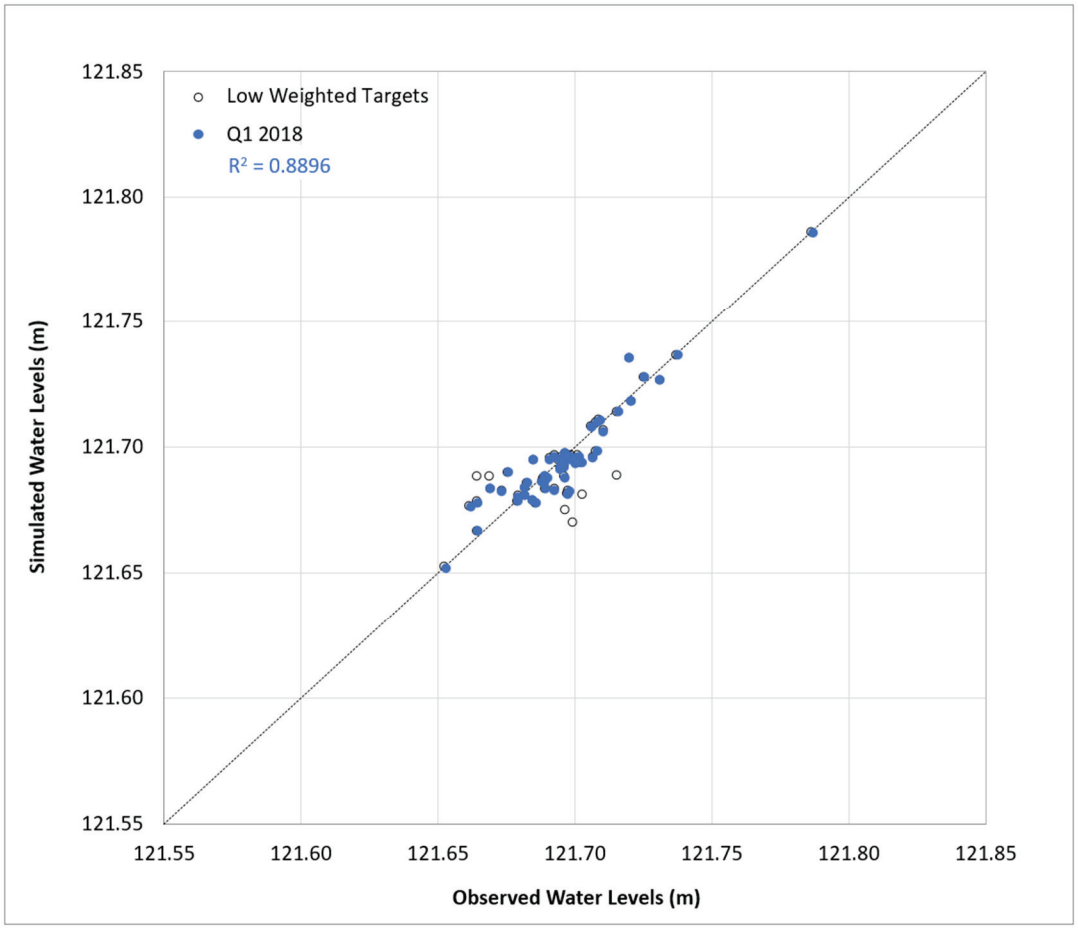

Figure A-6. Comparison of Observed Versus Simulated Water Levels – January Through March 2018

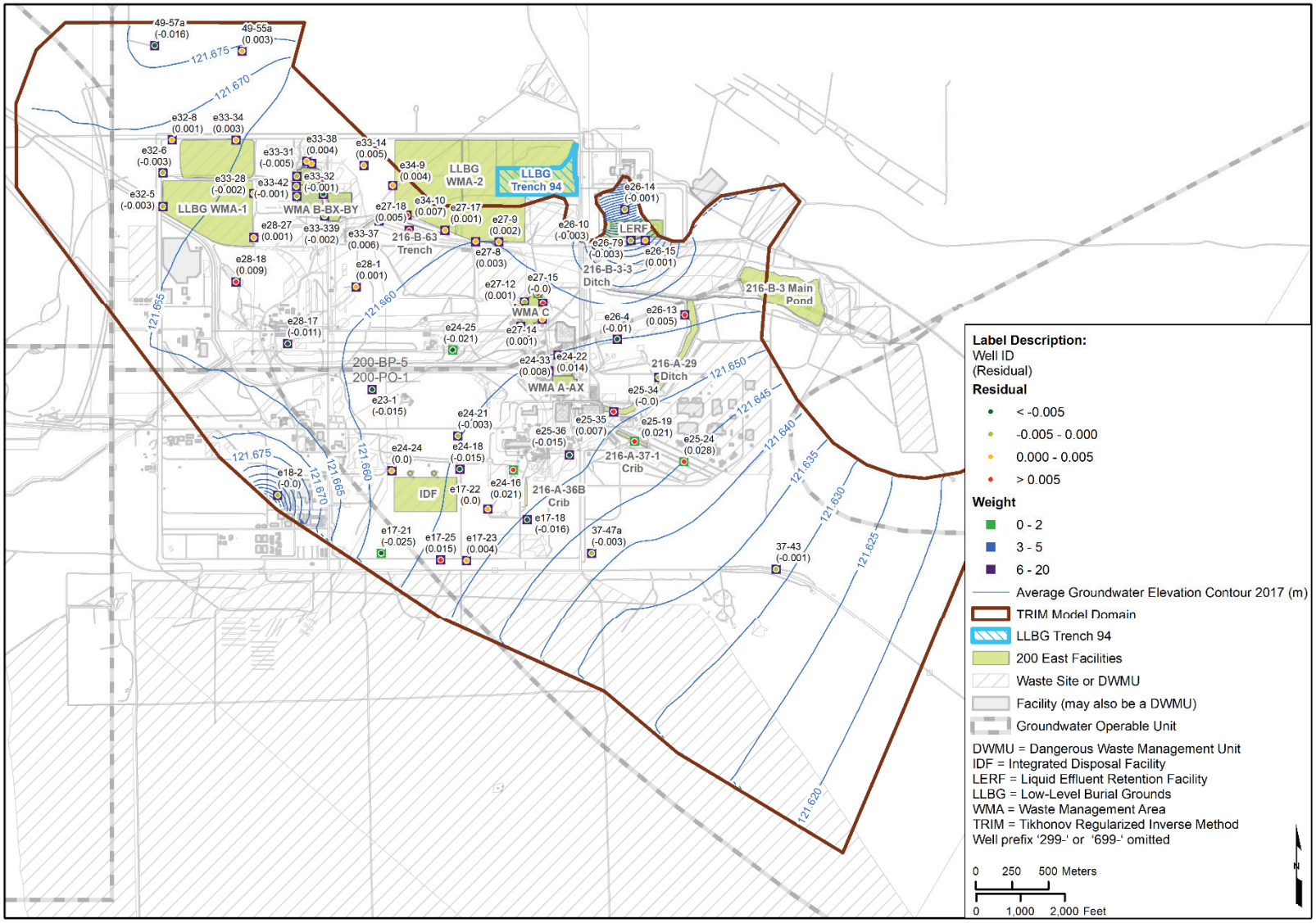

Figure A-7. Mapped Groundwater Elevations and Calibration Residuals – Average January Through March 2017

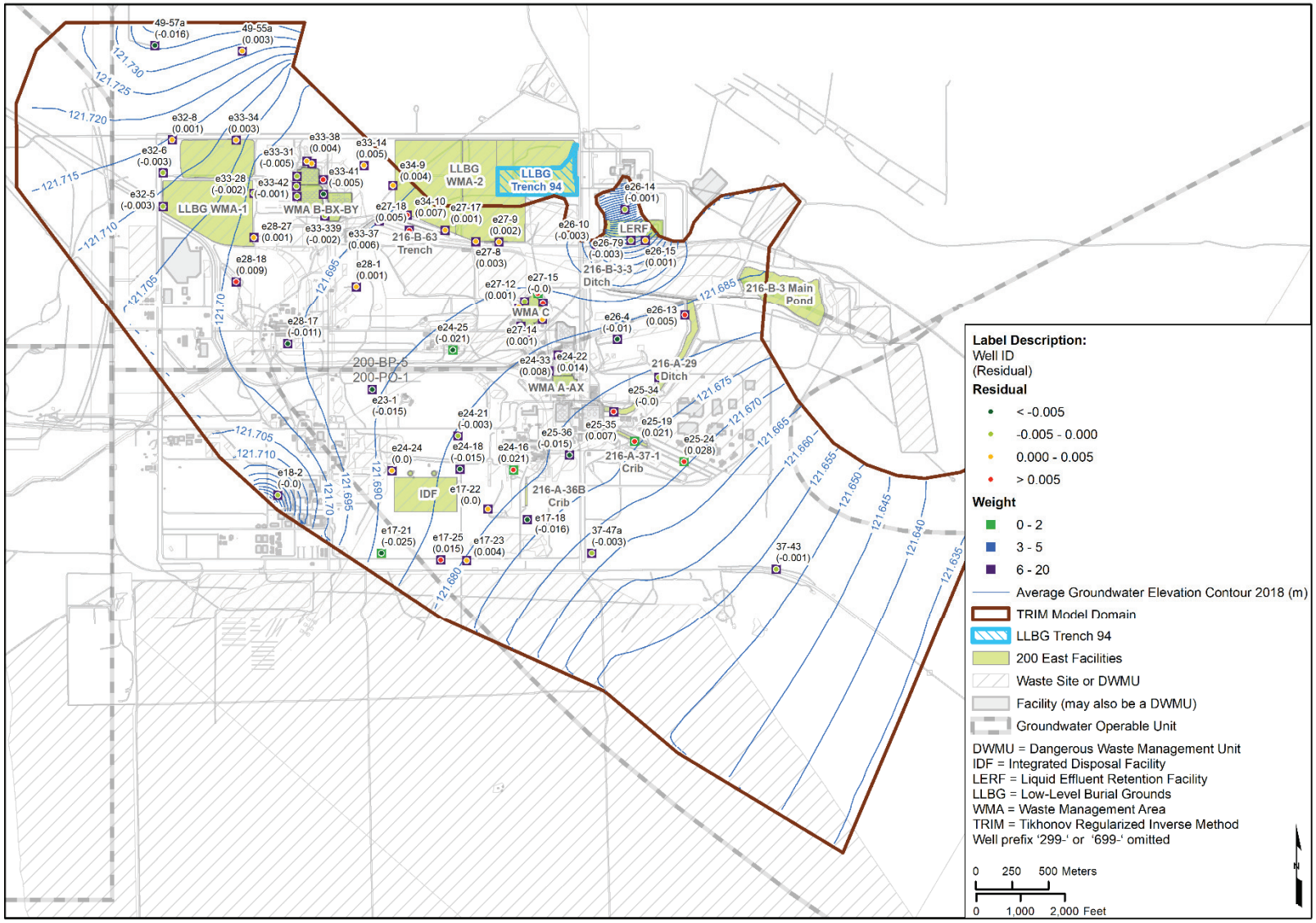

Figure A-8. Mapped Groundwater Elevations and Calibration Residuals – Average January Through March 2018

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Appendix B

Control Points and Their Groundwater Elevations

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Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_1	573533.1	138513.8	121.679	121.739	121.697
CP_2	573533.8	138493.6	121.678	121.736	121.694
CP_3	573534.9	138462.4	121.677	121.733	121.692
CP_4	573535.9	138434.7	121.676	121.730	121.689
CP_5	573532.3	138431.2	121.676	121.730	121.689
CP_6	573512.7	138411.5	121.674	121.727	121.686
CP_7	573504	138402.8	121.674	121.727	121.686
CP_8	573504.1	138399.9	121.674	121.727	121.686
CP_9	573504.8	138368.7	121.673	121.724	121.683
CP_10	573505.4	138343.2	121.671	121.721	121.680
CP_11	573499.9	138337.5	121.671	121.721	121.680
CP_12	573481.6	138318.5	121.670	121.717	121.677
CP_13	573470.7	138307.2	121.670	121.717	121.677
CP_14	573470.8	138306.2	121.670	121.717	121.677
CP_15	573472	138275	121.668	121.712	121.672
CP_16	573473.3	138243.8	121.665	121.706	121.667
CP_17	573473.5	138239.2	121.665	121.706	121.667
CP_18	573481.6	138230.9	121.665	121.706	121.667
CP_19	573499.4	138212.6	121.664	121.702	121.663
CP_20	573512.7	138198.9	121.664	121.702	121.663
CP_21	573529.8	138181.3	121.663	121.701	121.662
CP_22	573543.8	138167	121.663	121.701	121.662
CP_23	573560.2	138150.1	121.663	121.700	121.662
CP_24	573574.9	138135.1	121.663	121.700	121.662
CP_25	573590.6	138118.9	121.663	121.700	121.661
CP_26	573605.9	138103.2	121.663	121.700	121.661
CP_27	573621	138087.7	121.663	121.700	121.661
CP_28	573637	138071.2	121.663	121.699	121.661
CP_29	573651.4	138056.4	121.663	121.699	121.661
CP_30	573668.1	138039.3	121.662	121.699	121.660
CP_31	573681.8	138025.2	121.662	121.699	121.660
CP_32	573699.2	138007.4	121.662	121.699	121.660
CP_33	573712.3	137994	121.662	121.699	121.660
CP_34	573730.3	137975.5	121.662	121.698	121.660
CP_35	573742.7	137962.8	121.662	121.698	121.660
CP_36	573761.4	137943.5	121.662	121.698	121.660

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_37	573773.1	137931.5	121.662	121.698	121.660
CP_38	573792.5	137911.6	121.662	121.698	121.659
CP_39	573803.5	137900.3	121.662	121.698	121.659
CP_40	573823.5	137879.7	121.662	121.697	121.659
CP_41	573833.9	137869.1	121.662	121.697	121.659
CP_42	573854.6	137847.8	121.662	121.697	121.659
CP_43	573864.3	137837.8	121.662	121.697	121.659
CP_44	573885.7	137815.8	121.662	121.697	121.659
CP_45	573894.7	137806.6	121.662	121.697	121.659
CP_46	573916.8	137783.9	121.662	121.697	121.659
CP_47	573925.1	137775.4	121.662	121.697	121.659
CP_48	573935.3	137764.9	121.662	121.697	121.658
CP_49	573947.9	137763.2	121.662	121.697	121.658
CP_50	573976.9	137759.3	121.661	121.697	121.658
CP_51	573979	137757.3	121.661	121.697	121.658
CP_52	573992	137744.2	121.661	121.697	121.658
CP_53	574010	137725.9	121.661	121.696	121.658
CP_54	574022.9	137712.9	121.661	121.696	121.658
CP_55	574041.1	137694.6	121.661	121.696	121.658
CP_56	574053.9	137681.7	121.661	121.696	121.658
CP_57	574072.2	137663.3	121.661	121.696	121.658
CP_58	574084.9	137650.5	121.661	121.696	121.658
CP_59	574103.3	137631.9	121.661	121.696	121.658
CP_60	574115.8	137619.3	121.661	121.696	121.658
CP_61	574134.4	137600.6	121.661	121.696	121.658
CP_62	574146.8	137588	121.661	121.696	121.658
CP_63	574165.5	137569.2	121.661	121.696	121.657
CP_64	574177.8	137556.8	121.661	121.696	121.657
CP_65	574196.5	137537.9	121.661	121.696	121.657
CP_66	574208.7	137525.6	121.661	121.696	121.657
CP_67	574227.6	137506.5	121.661	121.695	121.657
CP_68	574239.7	137494.3	121.661	121.695	121.657
CP_69	574258.7	137475.2	121.661	121.695	121.657
CP_70	574270.7	137463.1	121.661	121.695	121.657
CP_71	574289.8	137443.8	121.661	121.695	121.657
CP_72	574301.6	137431.9	121.661	121.695	121.657

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_73	574320.9	137412.5	121.661	121.695	121.657
CP_74	574332.6	137400.7	121.661	121.695	121.657
CP_75	574352	137381.1	121.661	121.695	121.657
CP_76	574363.6	137369.4	121.661	121.695	121.657
CP_77	574383	137349.8	121.661	121.695	121.656
CP_78	574394.5	137338.2	121.661	121.695	121.656
CP_79	574414.1	137318.4	121.661	121.695	121.656
CP_80	574425.5	137307	121.661	121.695	121.656
CP_81	574445.2	137287.1	121.661	121.694	121.656
CP_82	574456.5	137275.8	121.661	121.694	121.656
CP_83	574470.7	137261.4	121.661	121.694	121.656
CP_84	574476.3	137261.4	121.661	121.694	121.656
CP_85	574507.4	137261.4	121.660	121.694	121.656
CP_86	574538.5	137261.3	121.660	121.694	121.656
CP_87	574569.5	137261.2	121.660	121.694	121.655
CP_88	574600.6	137261.2	121.660	121.694	121.655
CP_89	574631.7	137261.1	121.660	121.693	121.655
CP_90	574662.8	137261	121.660	121.693	121.655
CP_91	574693.9	137261	121.660	121.693	121.655
CP_92	574725	137260.9	121.660	121.693	121.655
CP_93	574756.1	137260.9	121.660	121.693	121.655
CP_94	574787.1	137260.8	121.660	121.693	121.655
CP_95	574818.2	137260.7	121.660	121.693	121.655
CP_96	574849.3	137260.7	121.660	121.693	121.655
CP_97	574880.4	137260.6	121.660	121.693	121.655
CP_98	574911.5	137260.5	121.660	121.693	121.655
CP_99	574942.6	137260.5	121.660	121.693	121.655
CP_100	574973.6	137260.4	121.660	121.693	121.655
CP_101	575004.7	137260.3	121.661	121.693	121.655
CP_102	575035.8	137260.3	121.661	121.693	121.655
CP_103	575066.9	137260.2	121.661	121.693	121.655
CP_104	575098	137260.1	121.661	121.693	121.655
CP_105	575129.1	137260.1	121.661	121.693	121.655
CP_106	575133.6	137260.1	121.661	121.693	121.655
CP_107	575148.6	137275.8	121.661	121.693	121.655
CP_108	575160.1	137287.8	121.661	121.693	121.655

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_109	575165.5	137293.3	121.661	121.693	121.655
CP_110	575191.2	137292.7	121.661	121.693	121.655
CP_111	575222.3	137292	121.661	121.693	121.655
CP_112	575223.7	137292	121.661	121.693	121.655
CP_113	575244.5	137307	121.661	121.693	121.655
CP_114	575253.4	137313.4	121.661	121.693	121.655
CP_115	575263.9	137321.1	121.661	121.693	121.655
CP_116	575284.5	137321.5	121.661	121.693	121.655
CP_117	575315.6	137322	121.661	121.693	121.655
CP_118	575338.8	137322.5	121.661	121.693	121.655
CP_119	575346.6	137315.4	121.661	121.693	121.655
CP_120	575356	137307	121.661	121.693	121.655
CP_121	575366.6	137297.5	121.661	121.693	121.656
CP_122	575365	137275.8	121.661	121.693	121.656
CP_123	575363.8	137258.7	121.665	121.697	121.660
CP_124	575353.1	137244.5	121.661	121.693	121.656
CP_125	575346.6	137236.1	121.661	121.693	121.656
CP_126	575333.3	137218.5	121.662	121.693	121.656
CP_127	575333.5	137213.3	121.662	121.693	121.656
CP_128	575334.7	137182.1	121.662	121.693	121.656
CP_129	575335.9	137150.9	121.662	121.693	121.656
CP_130	575336.1	137146.3	121.662	121.693	121.656
CP_131	575346.6	137132.7	121.662	121.694	121.656
CP_132	575356.8	137119.6	121.662	121.694	121.656
CP_133	575365.2	137108.9	121.662	121.694	121.657
CP_134	575368.3	137088.4	121.663	121.694	121.657
CP_135	575369.3	137081.2	121.663	121.694	121.657
CP_136	575377.7	137074.1	121.663	121.694	121.657
CP_137	575397.7	137057.2	121.664	121.695	121.658
CP_138	575405.4	137050.6	121.664	121.695	121.658
CP_139	575408.8	137049.9	121.664	121.695	121.658
CP_140	575435.9	137043.7	121.665	121.697	121.660
CP_141	575439.9	137039.5	121.665	121.697	121.660
CP_142	575452.9	137025.9	121.665	121.697	121.660
CP_143	575466.4	137011.8	121.667	121.698	121.662
CP_144	575471	137012	121.667	121.698	121.662

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_145	575502.1	137013.6	121.669	121.701	121.665
CP_146	575533.2	137015.1	121.672	121.704	121.668
CP_147	575564.2	137016.6	121.675	121.707	121.673
CP_148	575578.8	137017.4	121.675	121.707	121.673
CP_149	575586.6	137025.9	121.680	121.712	121.678
CP_150	575595.3	137035.4	121.680	121.712	121.678
CP_151	575615.2	137057.2	121.688	121.721	121.688
CP_152	575626.4	137069.4	121.688	121.721	121.688
CP_153	575643.8	137088.4	121.699	121.732	121.702
CP_154	575657.5	137103.3	121.699	121.732	121.702
CP_155	575668.9	137115.8	121.708	121.743	121.714
CP_156	575668.9	137119.6	121.708	121.743	121.714
CP_157	575668.5	137150.9	121.720	121.756	121.729
CP_158	575668.2	137182.1	121.731	121.768	121.744
CP_159	575667.9	137213.3	121.745	121.784	121.762
CP_160	575667.5	137244.5	121.754	121.793	121.773
CP_161	575667.5	137246.2	121.754	121.793	121.773
CP_162	575657.5	137258.2	121.754	121.793	121.773
CP_163	575642.8	137275.8	121.763	121.803	121.784
CP_164	575626.4	137295.4	121.773	121.815	121.797
CP_165	575616.7	137307	121.773	121.815	121.797
CP_166	575603.7	137322.5	121.777	121.818	121.801
CP_167	575616.8	137338.2	121.780	121.822	121.806
CP_168	575626.4	137349.7	121.780	121.822	121.806
CP_169	575631.5	137355.8	121.787	121.829	121.814
CP_170	575657.5	137355.2	121.783	121.825	121.809
CP_171	575688.6	137354.6	121.783	121.825	121.809
CP_172	575699.4	137354.4	121.783	121.825	121.809
CP_173	575712.7	137369.4	121.781	121.824	121.807
CP_174	575719.7	137377.3	121.781	121.824	121.807
CP_175	575740.3	137400.7	121.790	121.833	121.818
CP_176	575750.7	137412.5	121.790	121.833	121.818
CP_177	575761.8	137425.1	121.800	121.844	121.830
CP_178	575781.8	137429.9	121.797	121.841	121.827
CP_179	575790	137431.9	121.797	121.841	121.827
CP_180	575802	137434.8	121.794	121.838	121.823

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_181	575803.9	137431.9	121.794	121.838	121.823
CP_182	575812.9	137418	121.794	121.838	121.823
CP_183	575824.1	137400.7	121.785	121.827	121.812
CP_184	575832.6	137387.7	121.783	121.825	121.809
CP_185	575834.8	137369.4	121.773	121.814	121.797
CP_186	575838.6	137338.2	121.764	121.804	121.785
CP_187	575839.5	137330.8	121.764	121.804	121.785
CP_188	575844	137325.6	121.764	121.804	121.785
CP_189	575860.2	137307	121.752	121.791	121.770
CP_190	575867.2	137298.9	121.752	121.791	121.770
CP_191	575867.2	137275.8	121.744	121.782	121.759
CP_192	575867.2	137244.5	121.734	121.772	121.748
CP_193	575867.2	137230.9	121.734	121.772	121.748
CP_194	575875.1	137223.3	121.726	121.762	121.737
CP_195	575885.3	137213.3	121.726	121.762	121.737
CP_196	575906.2	137192.9	121.714	121.749	121.722
CP_197	575917.3	137182.1	121.714	121.749	121.722
CP_198	575926.9	137172.7	121.710	121.745	121.717
CP_199	575928.7	137150.9	121.704	121.738	121.709
CP_200	575929.6	137139.4	121.704	121.738	121.709
CP_201	575937.2	137132	121.698	121.732	121.702
CP_202	575950	137119.6	121.698	121.732	121.702
CP_203	575968.3	137101.9	121.691	121.723	121.692
CP_204	575982.2	137088.4	121.691	121.723	121.692
CP_205	575999.4	137071.7	121.683	121.714	121.682
CP_206	576014.4	137057.2	121.683	121.714	121.682
CP_207	576022.6	137049.3	121.680	121.711	121.677
CP_208	576030.5	137048	121.680	121.711	121.677
CP_209	576057.2	137043.7	121.676	121.707	121.673
CP_210	576061.6	137039.7	121.674	121.704	121.670
CP_211	576076.7	137025.9	121.674	121.704	121.670
CP_212	576089.1	137014.6	121.671	121.701	121.666
CP_213	576092.7	137014.6	121.671	121.701	121.666
CP_214	576123.7	137014.6	121.668	121.698	121.662
CP_215	576154.8	137014.6	121.665	121.694	121.658
CP_216	576185.9	137014.6	121.663	121.691	121.655

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_217	576195.9	137014.6	121.663	121.691	121.655
CP_218	576207.8	137025.9	121.661	121.689	121.652
CP_219	576217	137034.7	121.661	121.689	121.652
CP_220	576240.5	137057.2	121.660	121.689	121.651
CP_221	576248.1	137064.4	121.660	121.689	121.651
CP_222	576258.3	137074.2	121.660	121.688	121.651
CP_223	576259.6	137088.4	121.660	121.688	121.651
CP_224	576262.5	137119.6	121.660	121.688	121.651
CP_225	576262.5	137120	121.660	121.688	121.651
CP_226	576279.2	137138.3	121.659	121.688	121.650
CP_227	576290.2	137150.5	121.659	121.688	121.650
CP_228	576290.3	137150.9	121.659	121.688	121.650
CP_229	576295.8	137178.2	121.659	121.687	121.650
CP_230	576299.5	137182.1	121.659	121.687	121.650
CP_231	576310.2	137193.1	121.659	121.687	121.650
CP_232	576329.9	137213.3	121.659	121.687	121.650
CP_233	576341.3	137225.1	121.659	121.687	121.650
CP_234	576360.2	137244.5	121.659	121.687	121.650
CP_235	576372.4	137257.1	121.659	121.687	121.650
CP_236	576390.6	137275.8	121.659	121.687	121.649
CP_237	576403.5	137289	121.659	121.687	121.649
CP_238	576420.9	137307	121.659	121.687	121.649
CP_239	576434.6	137321	121.659	121.687	121.649
CP_240	576441.4	137328	121.663	121.692	121.655
CP_241	576465.7	137328	121.659	121.687	121.649
CP_242	576496.8	137328	121.659	121.687	121.649
CP_243	576499.6	137328	121.659	121.687	121.649
CP_244	576511.3	137338.2	121.659	121.687	121.649
CP_245	576527.8	137352.7	121.659	121.687	121.649
CP_246	576532.9	137357.1	121.667	121.696	121.660
CP_247	576558.9	137357.4	121.663	121.692	121.655
CP_248	576590	137357.7	121.660	121.688	121.650
CP_249	576621.1	137357.9	121.658	121.687	121.649
CP_250	576652.2	137358.2	121.658	121.687	121.649
CP_251	576683.3	137358.5	121.658	121.687	121.649
CP_252	576686.9	137358.5	121.658	121.687	121.649

Table B-1. Control Points Groundwater Elevations Used for Water-Level Mapping

Name	Easting	Northing	CY 2017 Elevation (m)	CY 2018 Elevation (m)	CY 2019 Elevation (m)
CP_253	576698.3	137369.4	121.658	121.687	121.649
CP_254	576714.3	137384.9	121.658	121.687	121.649
CP_255	576720.2	137390.4	121.666	121.695	121.658
CP_256	576745.4	137390.2	121.662	121.691	121.654
CP_257	576776.5	137389.9	121.659	121.687	121.650
CP_258	576807.6	137389.6	121.658	121.687	121.649
CP_259	576838.7	137389.3	121.658	121.686	121.649
CP_260	576864.4	137389	121.658	121.686	121.649

Reference: NAVD88, *North American Vertical Datum 1988*.

CY = calendar year