ECF-200E-19-0130
Revision 0

Groundwater Elevation Mapping for 200 East Area - Quarter 3 Calendar Year 2019

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Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
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APPROVED
By Sarah Harrison at 12:45 pm, Nov 05, 2020

Release Approval　　　Date

ENVIRONMENTAL CALCULATION COVER PAGE

<u>SECTION 1</u> - Completed by the Responsible Manager

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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SECTION 2 - Completed by Preparer

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SECTION 4 - Document Review and Approval

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

SECTION 5 - Applicable if Calculation is a Risk Assessment or Uses an Environmental Model

Prior to Initiating Modeling:

Required training for modelers completed:
Integration Lead:

Print First and Last Name	*Signature*	*Date*

Safety Software Approved:
Integration Lead:

Print First and Last Name	*Signature*	*Date*

Calculation Approved:
Risk/Modeling Integration Manager:

Print First and Last Name	*Signature*	*Date*

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Contents

Appendix

Figures

Tables

Terms

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

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1 Purpose

This environmental calculation file (ECF) describes calculations made to generate water-level maps for the third quarter of calendar year (CY) 2019 in the 200 East Area at the Hanford Site Central Plateau (Figure 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 calculations. These water-level maps are used in a variety of calculations and reports for the different *Resource Conservation and Recovery Act of 1976* dangerous waste management units (DWMUs) and *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* groundwater operable units (OUs) located within the 200 East Area. A separate ECF is being prepared to present calculations of groundwater hydraulic gradients and average linear velocities at the individual DWMUs.

2 Background

Historically, groundwater elevations in the 200 East Area varied greatly in response to discharges of water from 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.

Two groundwater extraction wells (Figure 1) are operating within the main unconfined aquifer in the 200 East Area to address groundwater contamination at the 200-BP-5 Groundwater OU. 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.

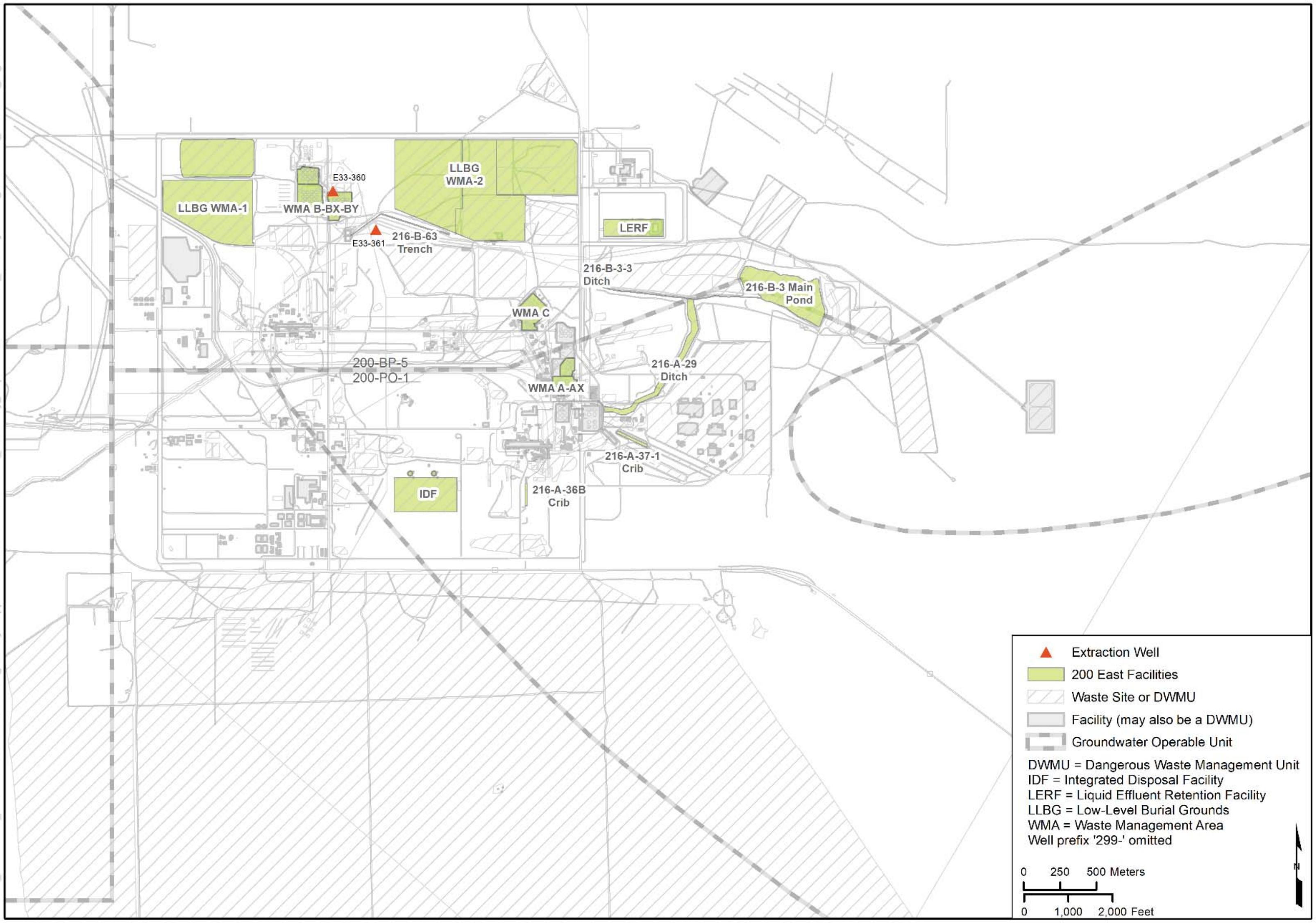

Figure 1. Hanford Site 200 East Area and Associated Waste Sites

3 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 facility. 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.

3.1 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 July, August, and September 2019. The data were corrected for borehole deviation from vertical and were used to prepare piecewise, continuous grids of groundwater elevations for each month of the third quarter of CY 2019. From these data, a set of averaged groundwater elevations were also calculated and used to prepare a groundwater elevation grid for the third quarter of CY 2019. Groundwater elevations from wells outside the low-gradient network are used when necessary to control contours at the boundaries or in the vicinity of the DWMUs. 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.

3.2 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 over-fitting 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.

3.2.1 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 affect areawide 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[1] (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*) 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 is 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 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 2.

3.2.2 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.

[1] MODFLOW is a product of the U.S. Geological Survey, Reston, Virginia.

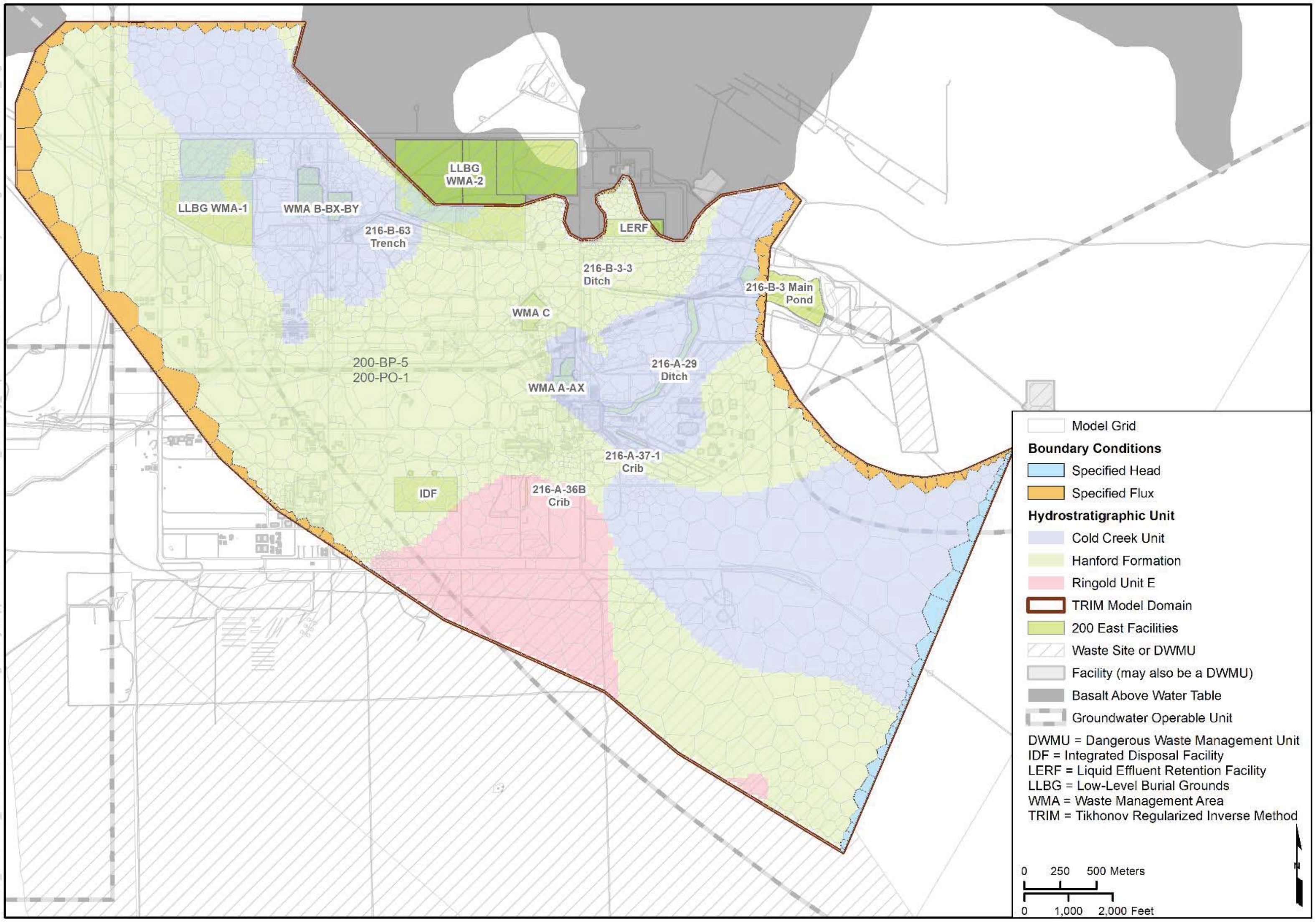

Figure 2. Two-Dimensional Simulator Boundary Conditions and HSU Zones

3.2.3 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 on 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 (e.g., 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, the grids 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.

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 (e.g., 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 (e.g., the CPGWM and Plateau to River model) for mass-conserved simulations of contaminant transport.

4 Assumptions and Inputs

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

4.1 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 to 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 the 200 East Area, these estimates are assumed to be representative of observed conditions.

4.2 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 63 low-gradient network monitoring wells and one additional well, 299-E26-10. Data were limited to those used specifically for water-table mapping. Table 1 lists data for the third quarter of CY 2019 and the calculated average water-level elevations for that period. A full set of data for the third quarter of CY 2019 is included in Appendix A.

Table 1. Water-Level Measurements

Well Name	Average Measured Water Levels (m NAVD 88)			Average
	Jul-2019	Aug-2019	Sep-2019	Jul-to-Sep-2019
299-E17-18	121.612	121.601	121.592	121.602
299-E17-21	121.655	121.639	121.618	121.637
299-E17-22	121.620	121.618	121.613	121.617
299-E17-23	NM	121.615	121.612	121.614
299-E17-25	NM	121.628	121.631	121.630
299-E18-2	121.655	121.675	121.663	121.664
299-E23-1	121.546	NM	121.593	121.570
299-E24-16	121.628	121.637	121.632	121.632
299-E24-18	NM	NM	NM	--
299-E24-21	121.630	121.619	121.613	121.621
299-E24-22	121.610	121.595	121.598	121.601
299-E24-24	121.627	121.623	121.621	121.624
299-E24-25	121.602	121.593	121.601	121.599
299-E24-33	121.612	121.594	121.601	121.602
299-E25-19	121.636	121.633	121.636	121.635
299-E25-24	121.628	121.620	121.633	121.627
299-E25-25	121.663	NM	NM	121.663
299-E25-32P	121.625	NM	NM	121.625

Table 1. Water-Level Measurements

Well Name	Average Measured Water Levels (m NAVD 88)			Average
	Jul-2019	Aug-2019	Sep-2019	Jul-to-Sep-2019
299-E25-34	121.617	121.616	121.622	121.618
299-E25-35	121.626	121.623	121.626	121.625
299-E25-36	121.613	121.617	121.604	121.611
299-E25-93	121.615	121.595	121.603	121.604
299-E26-10	121.650	NM	NM	121.650
299-E26-13	121.625	121.625	121.632	121.627
299-E26-14	121.739	121.737	121.722	121.733
299-E26-15	121.653	NM	121.636	121.645
299-E26-4	121.627	121.626	121.624	121.626
299-E26-79	121.668	121.668	121.659	121.665
299-E27-12	121.621	121.603	121.612	121.612
299-E27-14	121.619	121.600	121.604	121.608
299-E27-15	121.623	121.608	121.606	121.612
299-E27-17	121.643	121.627	121.627	121.632
299-E27-18	121.640	121.631	121.629	121.633
299-E27-21	121.614	121.592	121.597	121.601
299-E27-22	121.650	121.628	121.633	121.637
299-E27-23	121.613	121.599	121.613	121.608
299-E27-7	121.616	121.595	121.604	121.605
299-E27-8	121.639	121.610	121.628	121.626
299-E27-9	121.651	121.614	121.614	121.626
299-E28-1	NM	121.615	121.634	121.625
299-E28-17	121.622	121.617	121.613	121.617
299-E28-18	121.630	121.633	121.634	121.632
299-E28-27	121.622	121.631	121.625	121.626
299-E32-5	121.630	121.631	121.630	121.630
299-E32-6	121.633	121.635	121.630	121.633
299-E32-8	121.635	121.640	121.637	121.637
299-E33-14	121.617	121.627	121.626	121.623

Table 1. Water-Level Measurements

Well Name	Average Measured Water Levels (m NAVD 88)			Average
	Jul-2019	Aug-2019	Sep-2019	Jul-to-Sep-2019
299-E33-28	121.627	121.629	121.617	121.624
299-E33-31	121.607	121.625	121.619	121.617
299-E33-32	121.614	121.624	121.617	121.618
299-E33-339	121.620	121.627	121.625	121.624
299-E33-34	121.628	121.632	121.632	121.631
299-E33-342	121.620	NM	121.621	121.621
299-E33-37	121.635	121.649	121.619	121.634
299-E33-38	121.626	121.634	121.701	121.654
299-E33-41	121.617	121.623	121.615	121.618
299-E33-42	121.615	121.627	121.620	121.621
299-E33-44	121.601	121.629	121.612	121.614
299-E34-10	121.640	121.634	121.630	121.635
299-E34-9	121.647	121.636	121.629	121.637
699-37-43	121.595	121.585	121.593	121.591
699-37-47A	121.598	121.606	121.603	121.602
699-49-55A	121.654	121.665	121.663	121.661
699-49-57A	121.636	121.639	121.639	121.638

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

NAVD88 = *North American Vertical Datum of 1988*

NM = not measured

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 Chg 1 (Admin Chg), *Quality Assurance*.

5.1 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 5.2.

5.2 Software Description

A controlled calculation software, MODFLOW-USG, was used for the calculations that support this ECF as follows:

- Software title: *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*
- 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, FE616

5.3 Support Software

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

- PEST: Estimates parameter values that minimize the objective function(s) to calibrate models using inverse theory (Doherty, 2015).
- Groundwater Vistas™: Provided graphical tools used for model quality assurance and model input/output review (Rumbaugh and Rumbaugh, 2017, *Groundwater Vistas Version 7*).
- 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*).

™ 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.

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 the HISI authorized users list for safety software.

5.4.1 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.

6 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 the following two-step process:

1. Data Compilation: Input data were compiled from retrieved database sources. Outliers (noted in Appendix A) were flagged from constructing trend plots of all measured data and excluded from calculations. Average groundwater elevations were then calculated for the third quarter of CY 2019 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 third quarter of CY 2019. 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 Table 2. 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.

Table 2. Calibration Targets for the Third Quarter of CY 2019

Well Name	Average Measured Water Level (m NAVD88)	Grid Interpolated Water Level (m NAVD88)	Residual (Estimated Error) (m)	Calibration Weight
299-E17-18	121.602	121.612	-0.010	10
299-E17-21	121.637	121.632	0.005	10
299-E17-22	121.617	121.616	0.001	10
299-E17-23	121.614	121.616	-0.002	10

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Table 2. Calibration Targets for the Third Quarter of CY 2019

Well Name	Average Measured Water Level (m NAVD88)	Grid Interpolated Water Level (m NAVD88)	Residual (Estimated Error) (m)	Calibration Weight
299-E17-25	121.630	121.620	0.010	10
299-E18-2	121.664	121.663	0.001	10
299-E23-1*	121.570	121.624	-0.054	0
299-E24-16*	121.632	121.616	0.016	0
299-E24-21	121.621	121.619	0.002	10
299-E24-22	121.601	121.617	-0.016	10
299-E24-24	121.624	121.624	0.000	10
299-E24-25*	121.599	121.622	-0.023	0
299-E24-33	121.602	121.618	-0.016	10
299-E25-19*	121.635	121.610	0.025	0
299-E25-24*	121.627	121.605	0.022	0
299-E25-25*	121.663	121.607	0.056	0
299-E25-32P	121.625	121.610	0.015	10
299-E25-34	121.618	121.614	0.004	10
299-E25-35	121.625	121.613	0.012	10
299-E25-36	121.611	121.613	-0.002	10
299-E25-93	121.604	121.615	-0.011	10
299-E26-10	121.650	121.647	0.003	10
299-E26-13	121.627	121.619	0.008	10
299-E26-14	121.733	121.731	0.002	20
299-E26-15	121.645	121.657	-0.012	10
299-E26-4	121.626	121.618	0.008	10
299-E26-79	121.665	121.667	-0.002	10
299-E27-12	121.612	121.622	-0.010	10
299-E27-14	121.608	121.621	-0.013	10
299-E27-15	121.612	121.622	-0.010	10
299-E27-17	121.632	121.625	0.007	10
299-E27-18	121.633	121.626	0.007	10
299-E27-21*	121.601	121.620	-0.019	0

Table 2. Calibration Targets for the Third Quarter of CY 2019

Well Name	Average Measured Water Level (m NAVD88)	Grid Interpolated Water Level (m NAVD88)	Residual (Estimated Error) (m)	Calibration Weight
299-E27-22	121.637	121.623	0.014	10
299-E27-23	121.608	121.621	-0.013	10
299-E27-7*	121.605	121.622	-0.017	2
299-E27-8	121.626	121.625	0.001	10
299-E27-9	121.626	121.625	0.001	10
299-E28-1	121.625	121.626	-0.001	10
299-E28-17	121.617	121.628	-0.011	10
299-E28-18	121.632	121.630	0.003	10
299-E28-27	121.626	121.627	-0.001	10
299-E32-5	121.630	121.634	-0.004	10
299-E32-6	121.633	121.635	-0.002	10
299-E32-8	121.637	121.636	0.001	10
299-E33-14	121.623	121.627	-0.004	10
299-E33-28	121.624	121.628	-0.004	10
299-E33-31	121.617	121.627	-0.010	10
299-E33-32	121.618	121.627	-0.009	10
299-E33-339	121.624	121.626	-0.002	10
299-E33-34	121.631	121.632	-0.001	10
299-E33-342	121.621	121.627	-0.006	10
299-E33-37	121.634	121.626	0.008	10
299-E33-38*	121.654	121.627	0.027	0
299-E33-41	121.618	121.627	-0.009	10
299-E33-42	121.621	121.627	-0.006	10
299-E33-44	121.614	121.627	-0.013	10
299-E34-10	121.635	121.626	0.009	10
299-E34-9	121.637	121.626	0.011	10
699-37-43	121.591	121.587	0.004	20
699-37-47A	121.602	121.602	0.000	10
699-49-55A	121.661	121.644	0.017	20

Table 2. Calibration Targets for the Third Quarter of CY 2019

Well Name	Average Measured Water Level (m NAVD88)	Grid Interpolated Water Level (m NAVD88)	Residual (Estimated Error) (m)	Calibration Weight
699-49-57A	121.638	121.647	-0.009	20

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

*Well assigned a low weight for PEST software calibration.

NAV88 = *North American Vertical Datum of 1988*

Table 2 also lists 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. The target residual, that which would indicate acceptable calibration, is an absolute value of less than 0.03 m. Figure 3 illustrates the cumulative frequency plot of the absolute residuals obtained from the calibration for all nonzero weighted targets. One hundred percent of the residuals are within 0.03 m of average measured groundwater levels for the third quarter of CY 2019. Thus, the calibration of this interpolation is deemed acceptable and the results are usable for the purposes of this evaluation.

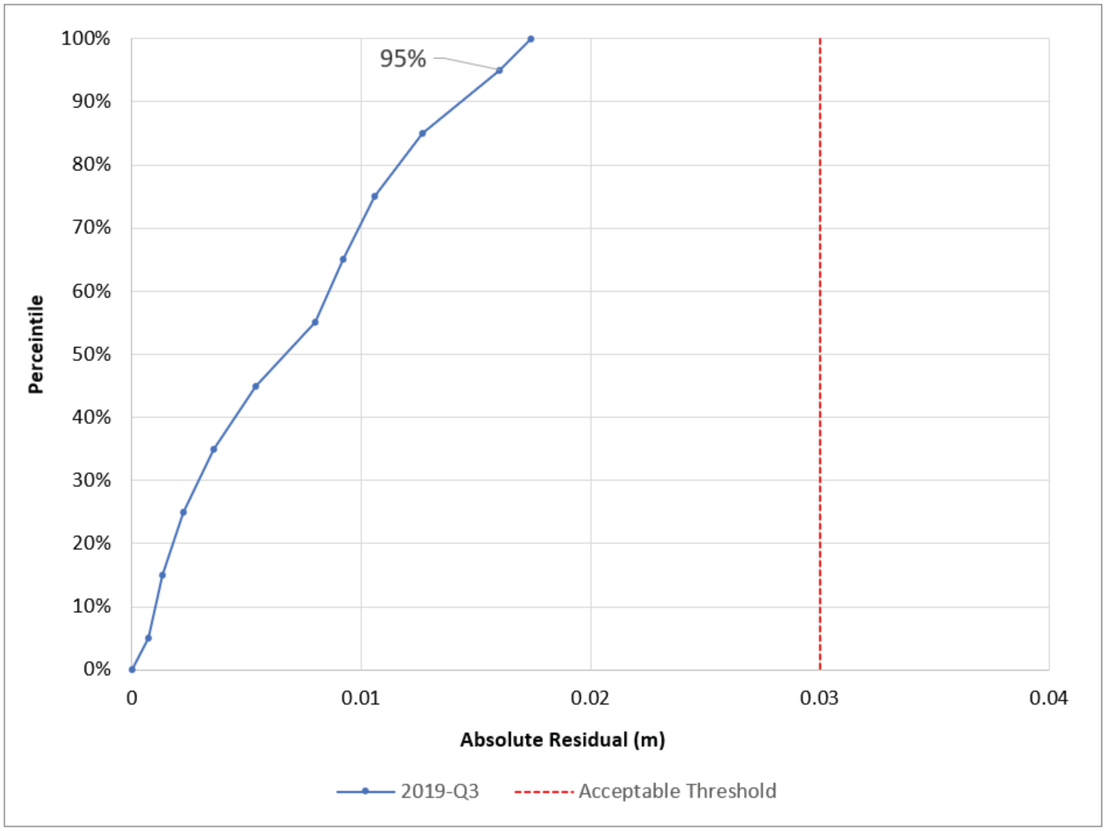

Figure 3. Cumulative Relative Frequency of Absolute Residuals

7 Results

This chapter presents outputs from the described calculations, which include the 200 East Area water-level mapping results for each month in the third quarter of CY 2019 and a 200 East Area water-level map for average water levels for the third quarter of CY 2019.

After the calibration steps described in Chapter 6, scatter plots that compare the calculated groundwater elevations with the measured groundwater elevations were prepared. Figures 4 through 6 depict the monthly calibration results for July, August, and September 2019, and Figure 7 shows the simulated versus the measured groundwater elevations for the third quarter of CY 2019. Note, the squared Pearson product-moment correlation coefficient, or R^2 value, indicated on these plots only correspond to the high-weighted targets.

Figures 8 through 10 depict the groundwater elevation contours throughout the 200 East Area for July through September and were prepared using the methods and inputs described previously. Figure 11 depicts the groundwater elevation contours throughout the 200 East Area that were generated using average water levels for the third quarter of CY 2019. All water-level map figures also illustrate calibration weights and calibration residuals for monitoring wells included in the calibration process.

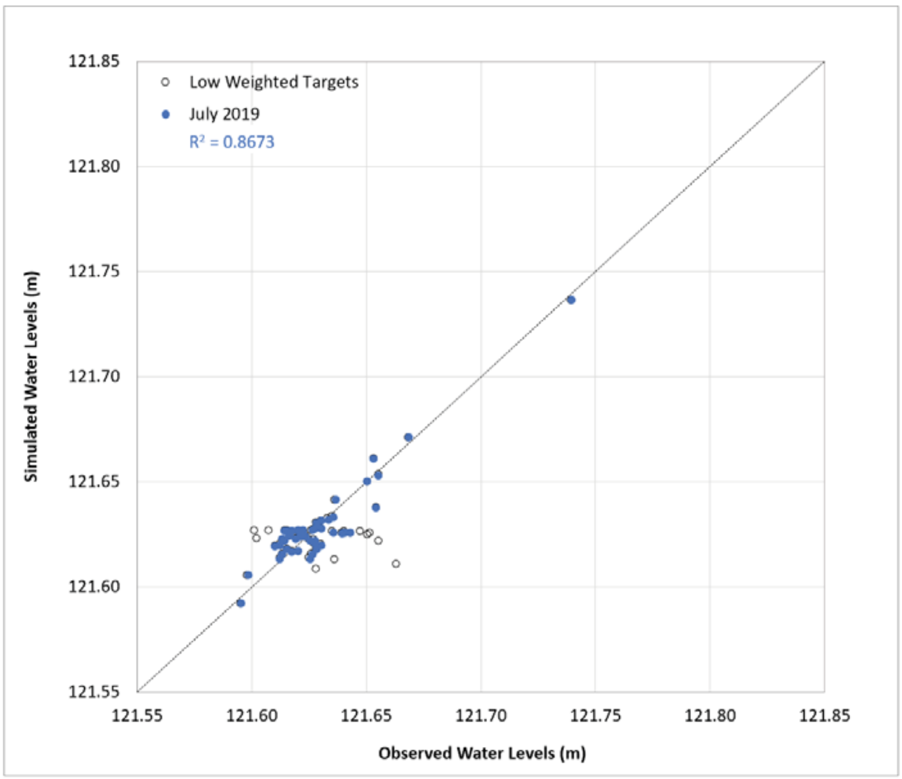

Figure 4. Monthly Observed vs. Simulated Calibration Plots – July 2019

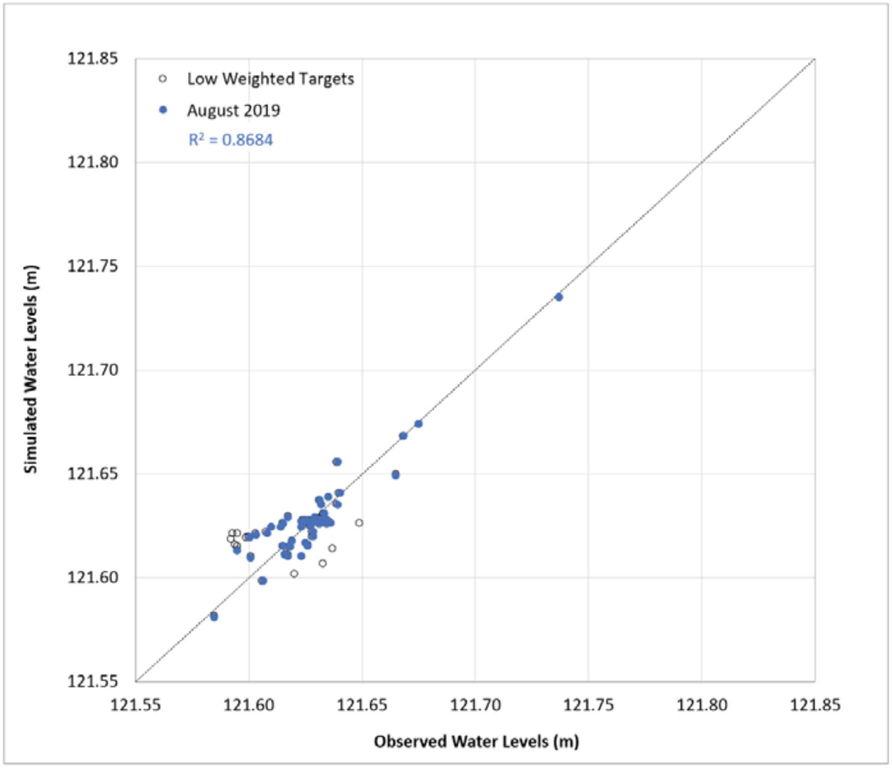

Figure 5. Monthly Observed vs. Simulated Calibration Plots – August 2019

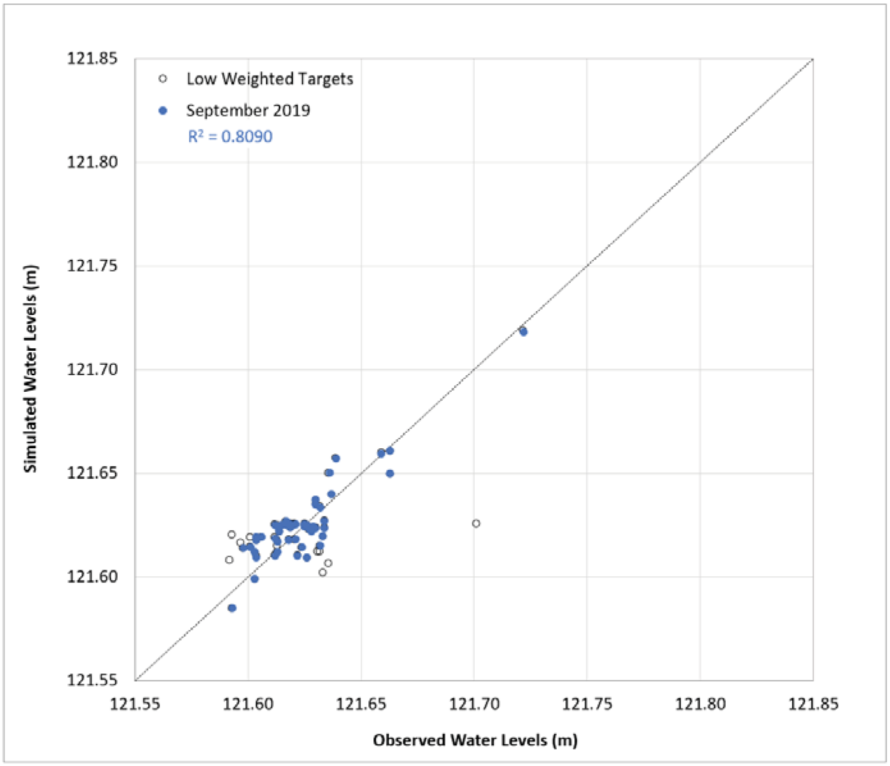

Figure 6. Monthly Observed vs. Simulated Calibration Plots – September 2019

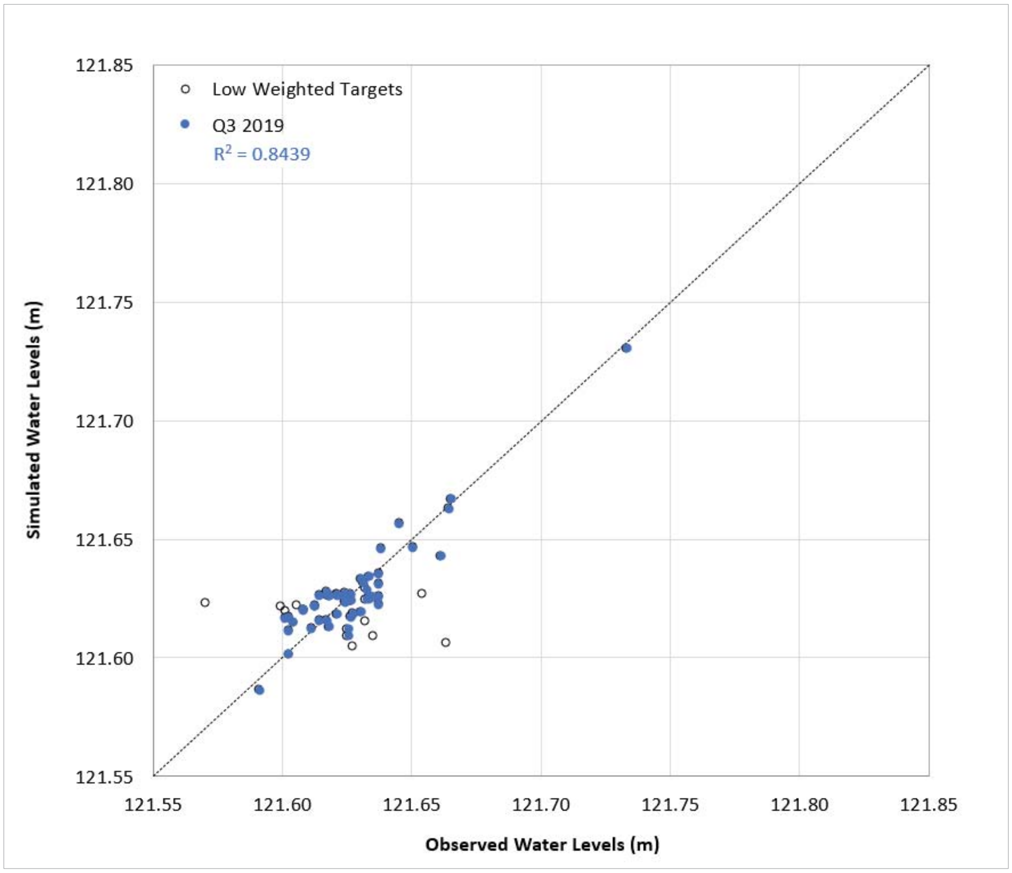

Figure 7. Comparison of Observed vs. Simulated Water-Levels – July through September 2019

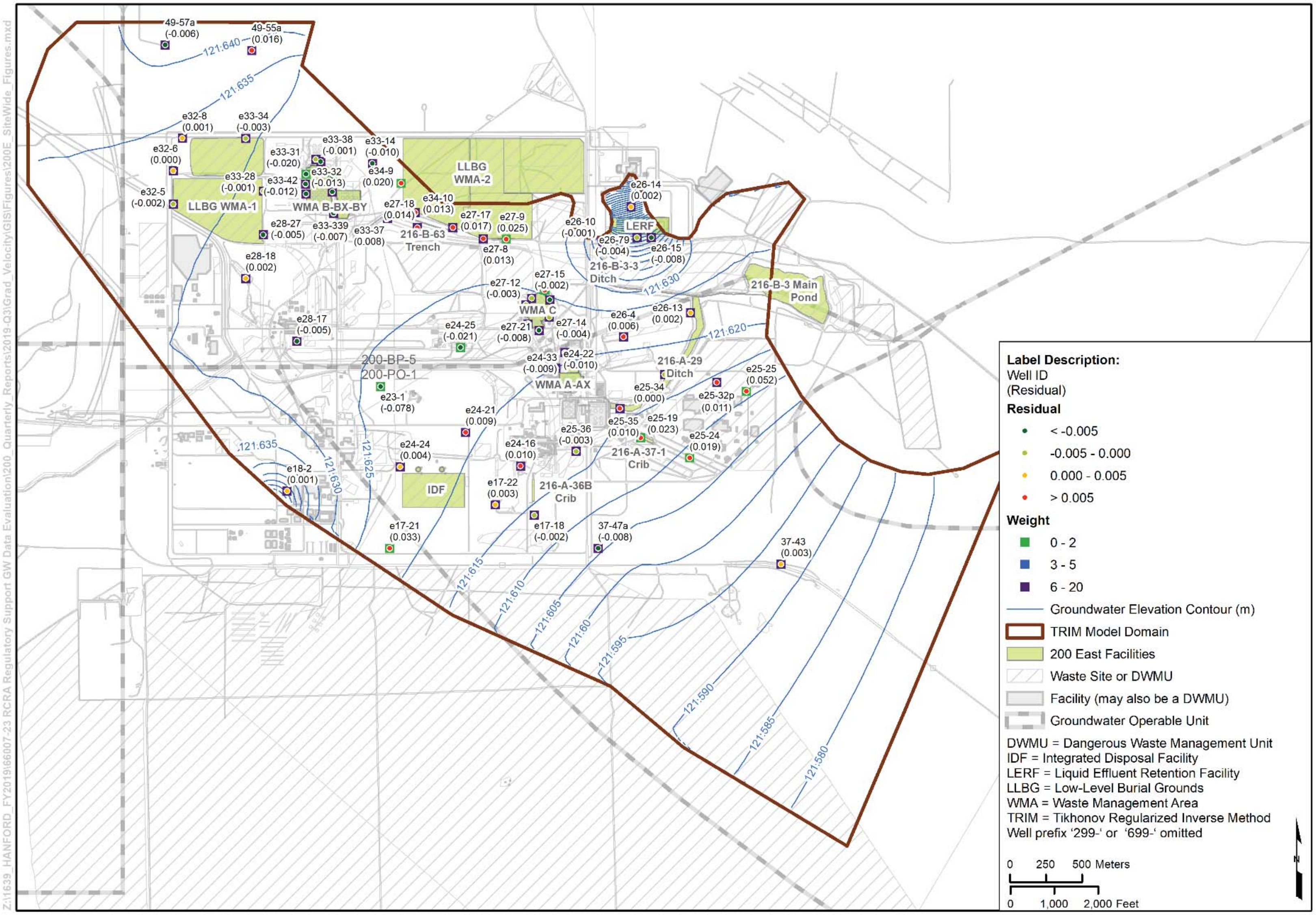

Figure 8. Mapped Groundwater Elevations and Calibration Residuals – July 2019

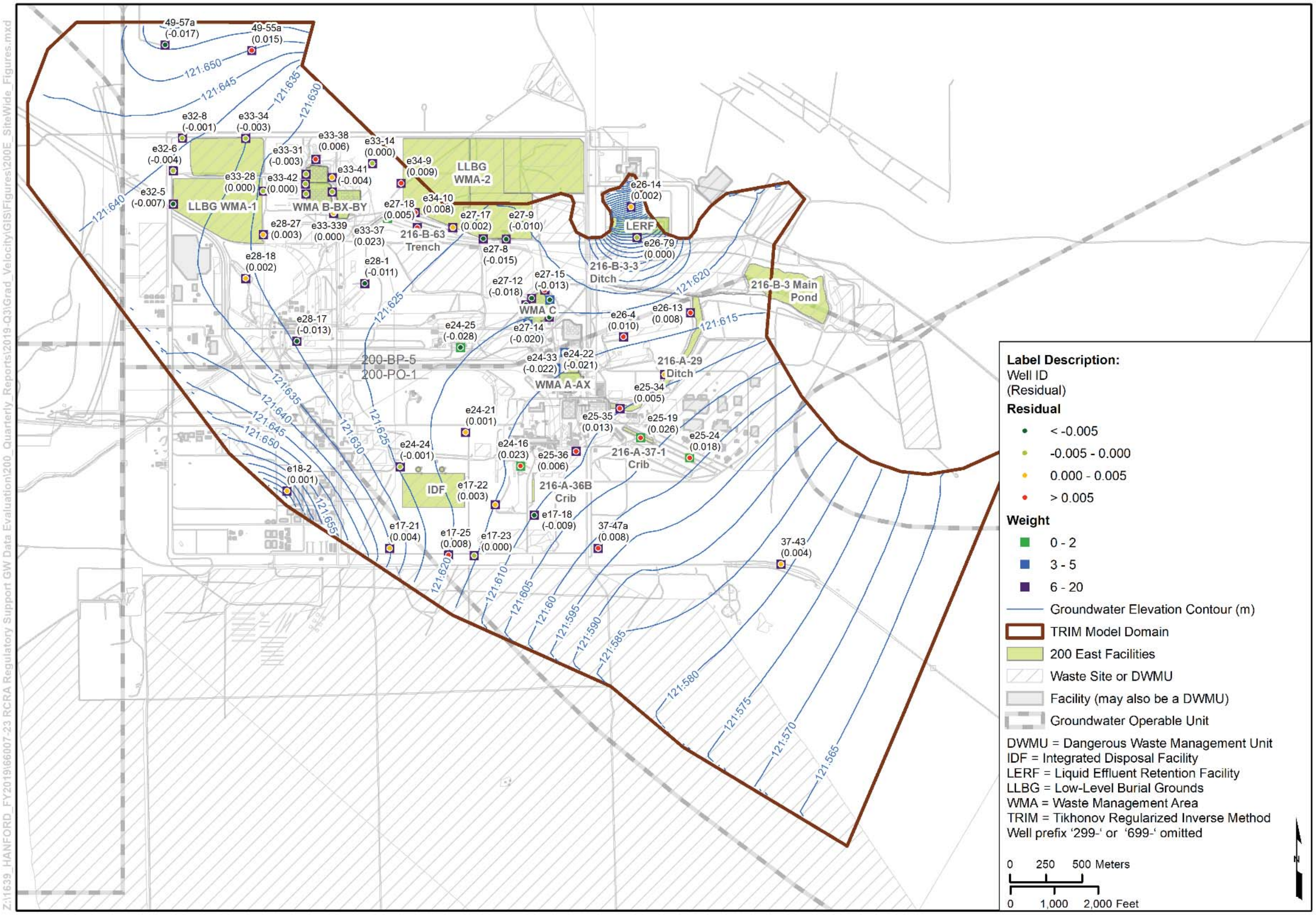

Figure 9. Mapped Groundwater Elevations and Calibration Residuals – August 2019

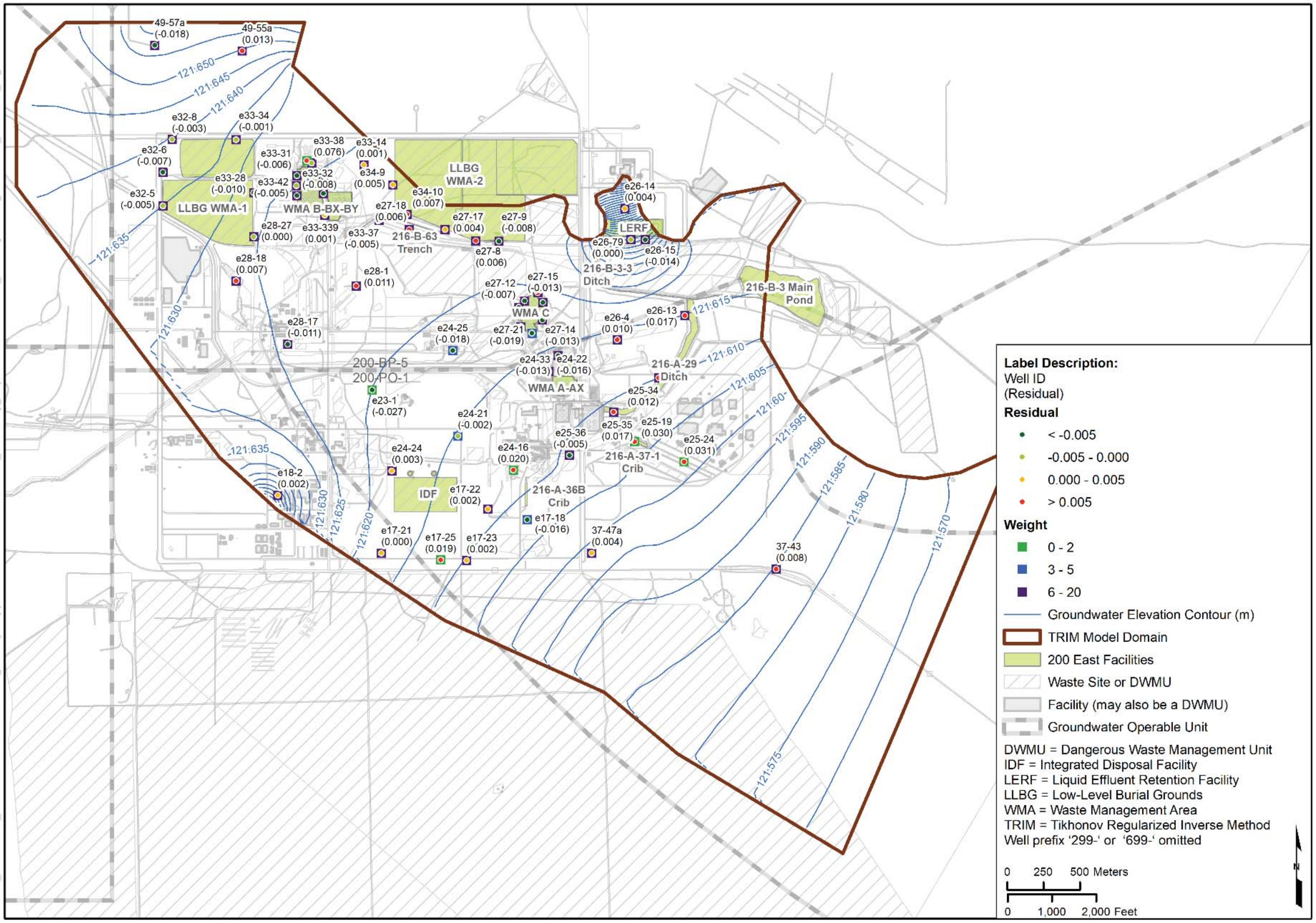

Figure 10. Mapped Groundwater Elevations and Calibration Residuals – September 2019

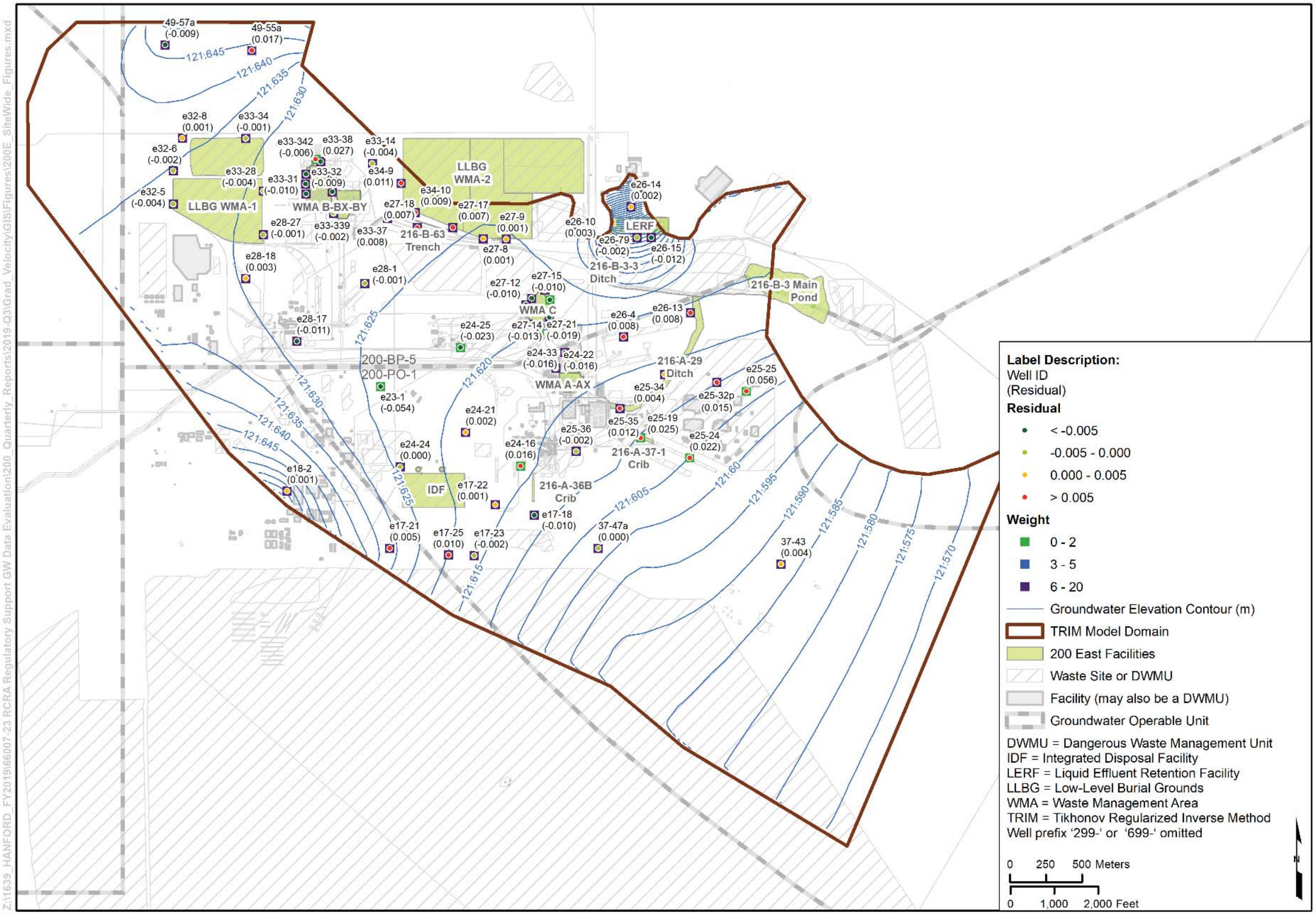

Figure 11. Mapped Groundwater Elevations and Calibration Residuals – Average July Through September 2019

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Appendix A

Groundwater Elevations in Monitoring Wells

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Table A-1. Water-Level Data Used for Water-Level Mapping: July 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
299-E33-339	573717	137222	7/24/19 7:18 AM	121.620
299-E33-41	573707	137370	7/24/19 7:24 AM	121.617
299-E33-342	573626	137580	7/24/19 7:34 AM	121.620
299-E33-44	573706	137469	7/24/19 7:40 AM	121.601
299-E33-38	573591	137594	7/24/19 7:49 AM	121.626
299-E33-31	573525	137491	7/24/19 7:56 AM	121.607
299-E33-42	573521	137424	7/24/19 8:01 AM	121.615
299-E33-32	573525	137354	7/24/19 8:07 AM	121.614
299-E33-28	573226	137375	7/24/19 8:15 AM	121.627
299-E28-27	573227	137070	7/24/19 8:23 AM	121.622
299-E28-18	573104	136768	7/24/19 8:32 AM	121.630
299-E33-14	573986	137567	7/24/19 8:42 AM	121.617
299-E28-1*	573933	136733	7/24/19 8:53 AM	121.582
299-E23-1	574043	136017	7/24/19 9:14 AM	121.546
299-E18-2	573392	135291	7/24/19 9:27 AM	121.655
699-37-47A	575557	134893	7/24/19 9:51 AM	121.598
299-E17-22	574841	135196	7/24/19 10:25 AM	121.620
299-E17-18	575112	135124	7/24/19 10:32 AM	121.612
299-E24-16	575018	135464	7/24/19 10:41 AM	121.628
299-E24-21	574636	135698	7/24/19 10:50 AM	121.630
299-E24-24	574180	135459	7/24/19 10:58 AM	121.627
299-E28-17	573461	136332	7/24/19 11:12 AM	121.622
299-E33-34	573104	137740	7/24/19 12:16 PM	121.628
299-E32-5	572600	137285	7/24/19 12:25 PM	121.630
299-E32-6	572600	137515	7/24/19 12:31 PM	121.633
299-E32-8	572663	137741	7/24/19 12:37 PM	121.635
699-49-57A	572544	138389	7/24/19 12:51 PM	121.636
699-49-55A	573146	138352	7/24/19 1:03 PM	121.654
699-37-43	576829	134783	7/25/19 10:18 AM	121.595

Table A-1. Water-Level Data Used for Water-Level Mapping: July 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
299-E25-24	576194	135521	7/25/19 10:27 AM	121.628
299-E25-19	575852	135659	7/25/19 10:33 AM	121.636
299-E25-35	575708	135865	7/25/19 10:41 AM	121.626
299-E25-34	576019	136100	7/25/19 10:49 AM	121.617
299-E26-13	576199	136529	7/25/19 11:11 AM	121.625
299-E26-4	575734	136361	7/25/19 11:18 AM	121.627
299-E25-36	575404	135566	7/25/19 11:27 AM	121.613
299-E26-10	575589	137023	7/25/19 11:37 AM	121.650
299-E26-14	575786	137265	7/25/19 11:44 AM	121.739
299-E26-79	575828	137052	7/25/19 11:55 AM	121.668
299-E27-9	574918	137041	7/25/19 12:47 PM	121.651
299-E27-8	574759	137044	7/25/19 12:53 PM	121.639
299-E27-17	574547	137122	7/25/19 1:00 PM	121.643
299-E34-10	574284	137225	7/25/19 1:06 PM	121.640
299-E34-9	574186	137430	7/25/19 1:13 PM	121.647
299-E27-18	574300	137119	7/25/19 1:21 PM	121.640
299-E24-25	574599	136287	7/25/19 1:37 PM	121.602
299-E25-93	575472	136022	7/31/19 6:47 AM	121.615
299-E24-22	575263	136143	7/31/19 6:56 AM	121.610
299-E24-33	575325	136251	7/31/19 7:01 AM	121.612
299-E27-23	575069	136452	7/31/19 7:09 AM	121.613
299-E27-12	575054	136584	7/31/19 7:17 AM	121.621
299-E27-15	575095	136630	7/31/19 7:22 AM	121.623
299-E27-22	575185	136685	7/31/19 7:27 AM	121.650
299-E27-7	575221	136619	7/31/19 7:32 AM	121.616
299-E17-21	574107	134893	7/31/19 7:40 AM	121.655
299-E27-14	575217	136498	7/31/19 7:44 AM	121.619
299-E27-21	575145	136407	7/31/19 8:44 AM	121.614
299-E33-37	574091	137185	7/31/19 8:54 AM	121.635

Table A-1. Water-Level Data Used for Water-Level Mapping: July 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
299-E26-15	575926	137051	7/31/19 10:18 AM	121.653
299-E25-25	576589	135984	7/31/19 11:12 AM	121.663
299-E25-32P	576382	136044	7/31/19 11:19 AM	121.625

References: NAD 83, 1991, *North American Datum of 1983*.

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

Notes: The data were retrieved from the Hanford Environmental Information System database on November 14, 2019.

Water levels shown with an asterisk (*) represent outliers and were not included in the water-level mapping dataset.

Spatial coordinates of well locations are presented in NAD 83 State Plane, Washington South FIPS 4602 coordinate system.

NAD 83 = *North American Datum of 1983*

NAVD88 = *North American Vertical Datum of 1988.*

Table A-2. Water-Level Data Used for Water-Level Mapping: August 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAV88)
299-E33-44	573706	137469	8/23/19 5:56 AM	121.629
299-E33-342*	573626	137580	8/23/19 6:04 AM	121.129
299-E33-38	573591	137594	8/23/19 6:11 AM	121.634
299-E33-31	573525	137491	8/23/19 6:19 AM	121.625
299-E33-42	573521	137424	8/23/19 6:25 AM	121.627
299-E33-32	573525	137354	8/23/19 6:30 AM	121.624
299-E33-339	573717	137222	8/23/19 6:37 AM	121.627
299-E33-41	573707	137370	8/23/19 6:43 AM	121.623
299-E33-34	573104	137740	8/23/19 6:51 AM	121.632
299-E32-8	572663	137741	8/23/19 7:02 AM	121.640
299-E32-6	572600	137515	8/23/19 7:08 AM	121.635
299-E32-5	572600	137285	8/23/19 7:13 AM	121.631
299-E28-1	573933	136733	8/23/19 7:28 AM	121.615
299-E28-17	573461	136332	8/23/19 7:45 AM	121.617
299-E28-18	573104	136768	8/23/19 7:53 AM	121.633

Table A-2. Water-Level Data Used for Water-Level Mapping: August 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAV88)
299-E28-27	573227	137070	8/23/19 8:01 AM	121.631
299-E18-2	573392	135291	8/23/19 8:16 AM	121.675
299-E17-21	574107	134893	8/23/19 8:26 AM	121.639
299-E33-14	573986	137567	8/23/19 8:42 AM	121.627
299-E33-28	573226	137375	8/23/19 8:56 AM	121.629
299-E17-25	574515	134846	8/23/19 9:10 AM	121.628
299-E17-23	574694	134842	8/23/19 9:18 AM	121.615
299-E17-18	575112	135124	8/23/19 9:26 AM	121.601
299-E17-22	574841	135196	8/23/19 9:33 AM	121.618
299-E24-16	575018	135464	8/23/19 9:44 AM	121.637
299-E24-21	574636	135698	8/23/19 9:51 AM	121.619
299-E24-24	574180	135459	8/23/19 9:58 AM	121.623
699-37-47A	575557	134893	8/23/19 10:08 AM	121.606
699-49-57A	572544	138389	8/23/19 11:02 AM	121.639
699-49-55A	573146	138352	8/23/19 11:15 AM	121.665
299-E33-37	574091	137185	8/26/19 7:26 AM	121.649
299-E27-21	575145	136407	8/26/19 7:55 AM	121.592
299-E27-12	575054	136584	8/26/19 8:03 AM	121.603
299-E27-23	575069	136452	8/26/19 8:10 AM	121.599
299-E27-15	575095	136630	8/26/19 8:19 AM	121.608
299-E27-22	575185	136685	8/26/19 8:33 AM	121.628
299-E27-7	575221	136619	8/26/19 8:39 AM	121.595
299-E27-14	575217	136498	8/26/19 8:47 AM	121.600
299-E24-33	575325	136251	8/26/19 9:01 AM	121.594
299-E25-93	575472	136022	8/26/19 9:16 AM	121.595
299-E24-22	575263	136143	8/26/19 9:28 AM	121.595
299-E27-8	574759	137044	8/26/19 9:43 AM	121.610
299-E27-9	574918	137041	8/26/19 9:56 AM	121.614
299-E24-25	574599	136287	8/26/19 10:10 AM	121.593

Table A-2. Water-Level Data Used for Water-Level Mapping: August 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAV88)
699-37-43	576829	134783	8/26/19 10:46 AM	121.585
299-E25-36	575404	135566	8/26/19 10:56 AM	121.617
299-E25-24	576194	135521	8/26/19 11:04 AM	121.620
299-E25-34	576019	136100	8/26/19 11:22 AM	121.616
299-E26-4	575734	136361	8/26/19 11:29 AM	121.626
299-E26-13	576199	136529	8/26/19 11:37 AM	121.625
299-E26-14	575786	137265	8/26/19 11:52 AM	121.737
299-E26-79	575828	137052	8/26/19 12:07 PM	121.668
299-E25-35	575708	135865	8/26/19 12:21 PM	121.623
299-E25-19	575852	135659	8/26/19 12:31 PM	121.633
299-E27-17	574547	137122	8/26/19 12:46 PM	121.627
299-E34-10	574284	137225	8/26/19 12:51 PM	121.634
299-E27-18	574300	137119	8/26/19 1:02 PM	121.631
299-E34-9	574186	137430	8/26/19 1:16 PM	121.636

References: NAD 83, 1991, *North American Datum of 1983*.

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

Notes: The data was retrieved from the Hanford Environmental Information System database on November 14, 2019.

Water levels shown with an asterisk (*) represent outliers and were not included in the water-level mapping dataset.

Spatial coordinates of well locations are presented in NAD 83 State Plane, Washington South FIPS 4602 coordinate system.

NAD 83 = *North American Datum of 1983*

NAVD88 = *North American Vertical Datum of 1988.*

Table A-3. Water-Level Data Used for Water-Level Mapping: September 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
299-E18-2	573392	135291	9/27/19 6:21 AM	121.663
299-E17-21	574107	134893	9/27/19 6:28 AM	121.618
299-E17-25	574515	134846	9/27/19 6:50 AM	121.631
299-E17-23	574694	134842	9/27/19 6:59 AM	121.612

Table A-3. Water-Level Data Used for Water-Level Mapping: September 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
699-37-43	576829	134783	9/27/19 7:07 AM	121.593
699-37-47A	575557	134893	9/27/19 7:13 AM	121.603
299-E17-18	575112	135124	9/27/19 7:19 AM	121.592
299-E17-22	574841	135196	9/27/19 7:26 AM	121.613
299-E24-16	575018	135464	9/27/19 7:33 AM	121.632
299-E24-21	574636	135698	9/27/19 7:39 AM	121.613
299-E24-24	574180	135459	9/27/19 7:45 AM	121.621
299-E25-36	575404	135566	9/27/19 7:52 AM	121.604
299-E25-24	576194	135521	9/27/19 8:00 AM	121.633
299-E25-19	575852	135659	9/27/19 8:04 AM	121.636
299-E25-35	575708	135865	9/27/19 8:11 AM	121.626
299-E25-34	576019	136100	9/27/19 8:19 AM	121.622
299-E26-13	576199	136529	9/27/19 8:25 AM	121.632
299-E26-4	575734	136361	9/27/19 8:31 AM	121.624
299-E27-8	574759	137044	9/27/19 8:43 AM	121.628
299-E27-17	574547	137122	9/27/19 8:52 AM	121.627
299-E34-10	574284	137225	9/27/19 8:59 AM	121.630
299-E34-9	574186	137430	9/27/19 9:04 AM	121.629
299-E27-18	574300	137119	9/27/19 9:10 AM	121.629
299-E28-1	573933	136733	9/27/19 9:16 AM	121.634
299-E24-25	574599	136287	9/27/19 9:23 AM	121.601
299-E28-17	573461	136332	9/27/19 9:30 AM	121.613
299-E28-18	573104	136768	9/27/19 9:38 AM	121.634
299-E28-27	573227	137070	9/27/19 9:44 AM	121.625
299-E33-34	573104	137740	9/27/19 9:51 AM	121.632
299-E32-8	572663	137741	9/27/19 9:57 AM	121.637
299-E32-6	572600	137515	9/27/19 10:01 AM	121.630
299-E32-5	572600	137285	9/27/19 10:07 AM	121.630
699-49-57A	572544	138389	9/27/19 10:16 AM	121.639

Table A-3. Water-Level Data Used for Water-Level Mapping: September 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)
699-49-55A	573146	138352	9/27/19 10:26 AM	121.663
299-E33-339	573717	137222	9/30/19 7:35 AM	121.625
299-E33-32	573525	137354	9/30/19 7:42 AM	121.617
299-E33-42	573521	137424	9/30/19 7:48 AM	121.620
299-E33-31	573525	137491	9/30/19 7:53 AM	121.619
299-E33-38	573591	137594	9/30/19 8:01 AM	121.701
299-E33-41	573707	137370	9/30/19 8:08 AM	121.615
299-E33-28	573226	137375	9/30/19 8:21 AM	121.617
299-E33-342	573626	137580	9/30/19 8:33 AM	121.621
299-E33-44	573706	137469	9/30/19 8:40 AM	121.612
299-E33-14	573986	137567	9/30/19 8:47 AM	121.626
299-E33-37	574091	137185	9/30/19 8:56 AM	121.619
299-E27-21	575145	136407	9/30/19 9:06 AM	121.597
299-E27-14	575217	136498	9/30/19 9:12 AM	121.604
299-E27-23	575069	136452	9/30/19 9:17 AM	121.613
299-E27-12	575054	136584	9/30/19 9:23 AM	121.612
299-E27-15	575095	136630	9/30/19 9:29 AM	121.606
299-E27-22	575185	136685	9/30/19 9:34 AM	121.633
299-E27-7	575221	136619	9/30/19 9:41 AM	121.604
299-E24-22	575263	136143	9/30/19 9:50 AM	121.598
299-E24-33	575325	136251	9/30/19 9:56 AM	121.601
299-E25-93	575472	136022	9/30/19 10:05 AM	121.603
299-E23-1	574043	136017	9/30/19 10:21 AM	121.593
299-E26-14	575786	137265	9/30/19 10:38 AM	121.722
299-E26-79	575828	137052	9/30/19 10:50 AM	121.659
299-E26-15	575926	137051	9/30/19 10:56 AM	121.636
299-E27-9	574918	137041	9/30/19 11:34 AM	121.614

References: NAD 83, 1991, *North American Datum of 1983*.

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

Table A-3. Water-Level Data Used for Water-Level Mapping: September 2019

Name	Easting (m NAD 83)	Northing (m NAD 83)	Date-Time	Measured Water Level (m NAVD88)

Notes: The data was retrieved from the Hanford Environmental Information System database on November 14, 2019.

Water levels shown with an asterisk (*) represent outliers and were not included in the water-level mapping dataset.

Spatial coordinates of well locations are presented in NAD 83 State Plane, Washington South FIPS 4602 coordinate system.

NAD 83 = *North American Datum of 1983*

NAVD88 = *North American Vertical Datum of 1988*.