ECF-200W-19-0082
Revision 0

Groundwater Elevation Mapping for 200 West Area - Quarter 1 Calendar Year 2019

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

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
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ENVIRONMENTAL CALCULATION COVER PAGE

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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Terms

ASCII	American Standard Code for Information Interchange
AWLN	automated water-level network
CCU	Cold Creek unit
CPGWM	Central Plateau Groundwater Model
CY	calendar year
DWMU	dangerous waste management unit
ECF	environmental calculation file
GLS	generalized least squares
MEUK	multi-event universal kriging
OU	operable unit
P&T	pump and treat
Rwie	Ringold Formation member of Wooded Island – unit E
SALDS	State Approved Land Disposal Site

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1 Purpose

This environmental calculation file (ECF) describes calculations made to generate water-level maps for the first quarter of calendar year (CY) 2019 in the 200 West Area at the Hanford Site Central Plateau (Figure 1-1). 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 those calculations. These water-level maps are used in 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* (CERCLA) groundwater operable units (OUs) located within the 200 West Area. A separate ECF is being prepared to present calculations of groundwater hydraulic gradients and average linear velocities at the individual DWMUs.

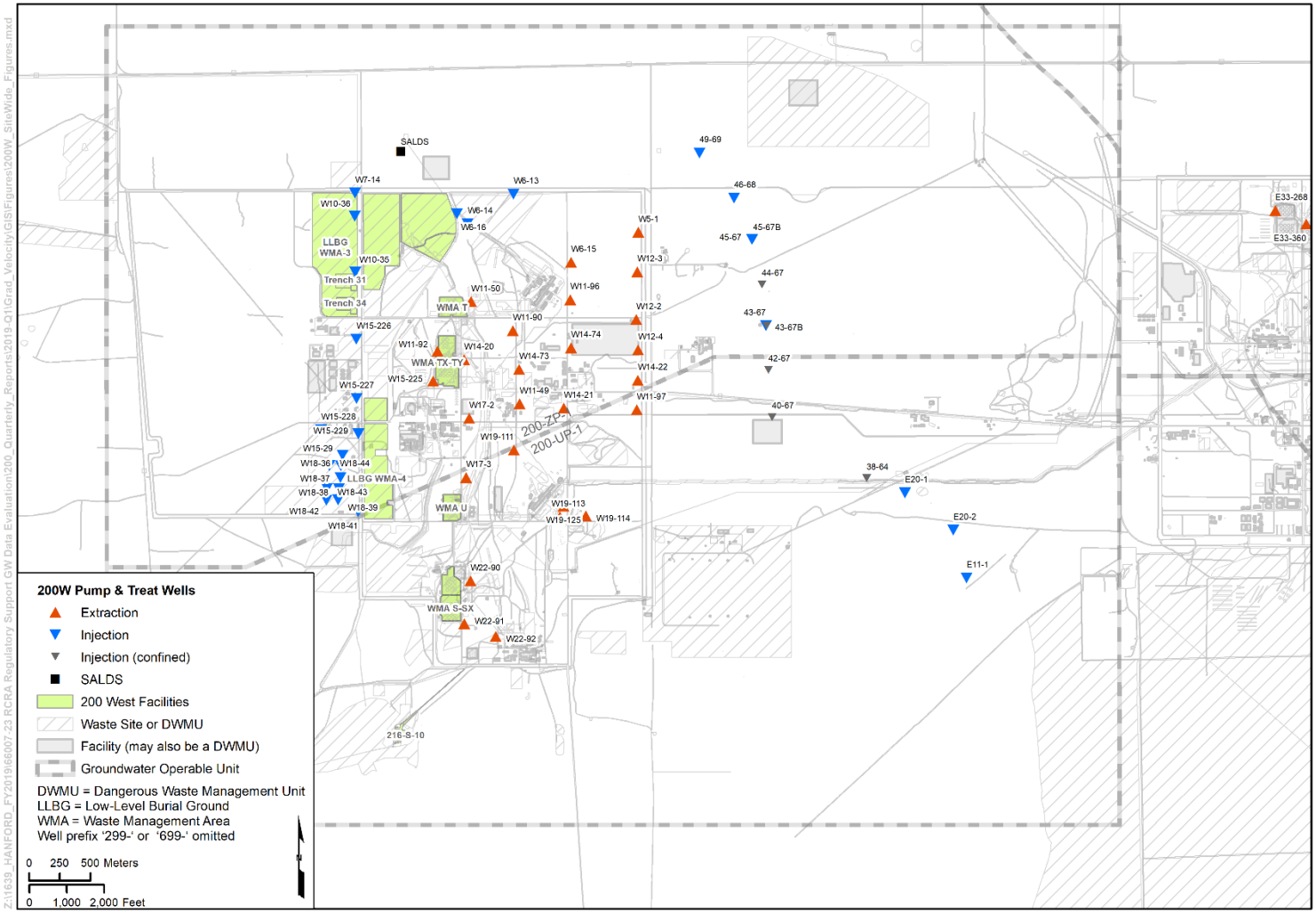

Figure 1-1. Hanford Site 200 West Area, Groundwater OUs, and Groundwater Extraction and Injection Wells

2 Background

In the 200 West Area, groundwater pump and treat (P&T) technology is an element of the selected final CERCLA groundwater remedy for the 200-ZP-1 OU and the interim groundwater remedy for the 200-UP-1 OU. Groundwater extracted from the 200-ZP-1 and 200-UP-1 P&T remedies is ultimately combined and treated at a single facility referred to hereinafter as the 200 West Area P&T treatment facility. DOE/RL-2008-78, *200 West Area 200-ZP-1 Pump-and-Treat Remedial Design/Remedial Action Work Plan*, discusses the plan and schedule for the design, installation, and operation of the remedy set forth in the 200-ZP-1 OU record of decision (EPA et al., 2008, *Record of Decision, Hanford 200 Area 200-ZP-1 Superfund Site, Benton County, Washington*). As part of the 200 West Area P&T system, as many as 30 injection wells and 26 extraction wells have operated at various times since June 2012. An interim remedial measure P&T system operated on a smaller scale in the 200-ZP-1 OU from 1994 (DOE/RL-2008-78) until a short time before the startup of the final 200 West Area P&T system in 2012.

Groundwater flow directions and rates in the 200 West Area are impacted by groundwater extraction and injection from the P&T systems. The Central Plateau Groundwater Model (CPGWM) is the principal tool used to design, evaluate, and predict the performance of the 200 West P&T groundwater remedies. The CPGWM was developed primarily to support decisions made with regard to the 200-ZP-1 and adjacent 200-UP-1 groundwater remedies and is used to predict or assess the performance of the P&T remedies. The goal of this ECF, however, is to create water-level maps to independently interpret groundwater level and pumping information based on measurements made during the first quarter of CY 2019. For this purpose, a regression-based technique that incorporates underlying regression-based trend terms is used to interpret the measured water-level data and prepare depictions of hydraulic gradients and likely flow directions.

For the purposes of this analysis, the regression-based multi-event universal kriging (MEUK) technique (Tonkin et al., 2016, "Multi-Event Universal Kriging (MEUK)") is used to obtain a piecewise, continuous grid and corresponding map of groundwater elevations. MEUK is an extension of the hybrid mapping technique that is implemented in the water-level kriging program, KT3D_H2O, that is described in the technical report SGW-42305, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*, and further described by Karanovic et al., 2009 ("KT3D_H20: A Program for Kriging Water Level Data Using Hydrologic Drift Terms"), that combines universal kriging with the analytic element method to interpret water-level data. The method incorporated in MEUK has been used along with the CPGWM for several years in the 200 West Area as a line of evidence to evaluate the 200 West Area P&T remedy performance, and for this reason is well suited to the purposes of the analysis detailed in this ECF.

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3 Calculation Methods

This chapter describes the calculation methods used to support this ECF. Assumptions underlying the methods and inputs for the calculations are presented in Chapter 4.

3.1 Water-Level Mapping Using Multi-Event Universal Kriging via MEUK

MEUK is designed to create a series of related 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 a stationary spatial correlation among residuals from the trend(s). In most applications, MEUK leads to improved water-level maps when the spatial distribution of monitoring locations varies from event to event and when there is an uncertain level of noise in the data.

Expressions that describe the groundwater-level response to features or stresses are incorporated into MEUK using superposition of trend terms so that the complete form of the underlying trend is the summation of these terms. The MEUK technique includes the following two distinct processes:

- Estimation: Use of generalized least squares (GLS) regression to obtain trend term coefficients ("calibration")
- Prediction: Solution of the MEUK system of equations using the coefficients obtained through step 1 to predict water levels at intermediate locations or times, such as when producing a grid for contouring ("mapping")

During step 1, the trend coefficients are estimated using GLS, and during step 2, groundwater levels are calculated on a regular grid using the estimated trend coefficients. The resultant grid of water levels is then used to prepare contour maps for visualization.

Before applying MEUK, an underlying trend must be proposed based on independent information about the site. Components of the trend are specified as global or local: "global" trend components are assumed to apply throughout the period represented by the monitored dataset, whereas "local" trend components are assumed to apply only to individual events and to change between events based on internal or external stresses. For example, aquifer transmissivity may be considered fairly constant over time (i.e., for all events) and is a candidate for a global trend component. However, if there is groundwater pumping, the effect of pumping can be varied by specifying that the pumping rate differs among events, reflecting a local trend. SGW-42305 presents the general form of the trend equations that are solved when constructing groundwater-level maps using these techniques.

Using MEUK, all occasions when water levels are measured can be interpolated simultaneously through the solution of a single block-diagonal "multi-event" universal kriging matrix that enables trend coefficients and resultant maps to be conditioned on the entire dataset or independently (by event). The GLS regression enables trend terms to be included and the estimated coefficients of those trend terms to be evaluated in reference to independent information. Furthermore, single point cross validation can be used to evaluate the role that each measured value or location has in the prediction.

3.1.1 Specific Trend Terms

To prepare groundwater-elevation maps for the 200 West Area, the trend incorporates the effect of the following on the water levels:

- Extraction and injection at wells
- Discharges at the State-Approved Land Disposal Site (SALDS)
- Large-scale transitions in aquifer properties between the Ringold Formation member of Wooded Island – unit E (Rwie) in the west and the Hanford formation and Cold Creek unit (CCU) in the east dictating regional patterns of flow

Using superposition to sum the effects of these terms, the head (H) is estimated at any location (x,y), as shown in Eq. 1:

$$H(x,y) = A + Bx + Cy + D\sum_{1}^{n} Q_i + E\sum_{1}^{m} L_j + \varepsilon(x,y) \qquad \textbf{(Eq. 1)}$$

In Eq. 1, A, B, C, D, and E are regression coefficients; n is the number of extraction and injection wells; m is the number of line drift segments. Furthermore, Q_i describes the effect on heads by pumping at well i; L_j describes the effect on head by reach j of the line representing the transition in aquifer properties between the Rwie in the west and the Hanford unit and CCU in the east. The final term, $\varepsilon(x,y)$, is the zero-mean residual error (i.e., the difference between the trend and the measured values at monitored locations) that is described using a semivariogram.

The following drift terms were used for the MEUK analysis of the elevation data:

- Unbias term (i.e., global-mean "offset") – used to allow for an area-wide adjustment in the mean evaluation of events. Allowed to vary for each event (i.e., specified as a local trend term).
- Linear drift– used to represent the general underlying water level trend within the Hanford and Cold Creek sediments in the 200 East Area. Constant for all events (i.e., specified as a global trend term).
- Well drift – used to represent extraction and injection wells at 200W P&T system and discharge releases at the SALDS, if any.
- Line drift – used to represent large-scale transitions in aquifer properties.

3.1.2 Semivariogram Parameters

Practice and theory indicate that the procedure of computing an experimental semivariogram and then fitting a semivariogram model is not quite so clear in the case of a trend as is the case here (this is also described in Section 4.1.5 of SGW-42305). The analysis starts with trend fitting and evaluation of the range of the variogram of the residuals; however, the final procedure generally concludes with selection of a variogram (including the nugget) that reflects sources of error that are only qualitatively known and results in a surface that reflects independent sources of information. In this context, the use of kriging is to produce a useful map, not to undertake a quantitative geostatistical analysis of groundwater-level data. The variogram parameters selected for use in the groundwater elevation mapping were as follows:

- Variogram model: Spherical
- Range length: 3,000 m (9,842 ft)
- Sill: 8
- Nugget: 0.1

4 Assumptions and Inputs

This chapter outlines those 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 the following sections.

4.1.1 Groundwater Elevation Mapping

Water-level contour maps were constructed using MEUK that incorporates the effects of drawdown and mounding due to groundwater extraction and reinjection, respectively. While accounting for the values of water levels measured at each well, the resulting contour maps provide plausible interpretations of groundwater levels and hydraulic gradients between measured locations. The accuracy of the contours is influenced by various factors, including the following:

- The accuracy of the measured or recorded water levels
- The number, distribution, and location of monitoring wells
- The degree of adherence to, or violation of, assumptions that underlie the mapping method (as outlined in SGW-42305):
  - The aquifer is homogeneous, isotropic, and of infinite areal extent.
  - The aquifer transmissivity is uniform and unchanging. If the aquifer is unconfined, drawdowns should be a reasonably small fraction of the aquifer saturated thickness.
  - Pumping wells penetrate and receive water from the entire saturated thickness of the aquifer (i.e., the well is not partially penetrating).
  - Drawdown and mounding have reached a (quasi-state) steady state condition. If this is not the case, the rate of change in hydraulic gradients should approach zero.
- The relationship between the vertical open interval(s) of the monitoring wells and those of any extraction and injection wells
- The presence, continuity, and transitions in aquifer properties between the Rwie on the west and the Hanford formation and CCU on the east

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. The results presented assume that vertical flow is negligible compared to horizontal flow, which is usually a reasonable assumption at some distance from pumping wells in regions of low recharge.

4.1.2 200-UP-1 Iodine Injection Well Area

As indicated in Sections 3.1 and 3.2, the trend terms incorporated in the MEUK analysis include the effects of groundwater extraction and injection; and, that the effects of groundwater extraction and injection are proportional to the value of the aquifer transmissivity. As detailed in SGW-42305, the value of the aquifer transmissivity can under some circumstances be inferred from the coefficient calculated for the pumping-related trend term(s) shown in Eq. 1. Using the superposition approach that underlies MEUK and the assumptions of the Cooper-Jacob equation that underlies derivation of the pumping-effects trend term (both detailed in SGW-42305), the relative effects of groundwater pumping

that takes place in regions of an aquifer that exhibit different transmissivities can be incorporated in the analysis by scaling the pumping rates accordingly. For example: if pumping at a rate of Q occurs in an area with a transmissivity of T, this will result in an equivalent effect as pumping of 2Q in an area with a transmissivity of 2T, or pumping of 0.5 x Q in an area with a transmissivity of 0.5 x T.

During the initial analysis of groundwater levels detailed in this ECF, it was determined by independent subject matter expert review that the extent and degree of mounding in the vicinity of the 200-UP-1 iodine injection wells (299-E20-1, 299-E20-2, and 299-E11-1) was notably smaller than either estimated using the CPGWM or interpreted based on independent distance drawdown analyses using local aquifer parameters. The difference was interpreted as resulting from a combination of lower transmissivity in the area of the iodine injection wells compared to the broader area of the 200-ZP-1 P&T system, and relatively lower-density water-level monitoring in the area. Specifically, the transmissivity represented in the CPGWM at the location of iodine injection well 299-E11-1 is approximately 64 m^2/d, which is less than 25% of the transmissivity represented in the broader area of the 200-ZP-1 P&T system and also less than 25% of the transmissivity estimated using the MEUK GLS (i.e., 253 m^2/d) when all pumping is lumped into a single pumping trend term in Eq. 1.

Based on the foregoing, to improve the representation of the hydraulic response to injection and the resulting mapped water levels in the vicinity of the iodine injection wells, injection rates used as input to MEUK for wells 299-E20-1, 299-E20-2, and 299-E11-1 for purposes of water-level mapping were set equal to the reported rates multiplied by four.

4.1.3 State Approved Land Disposal Site

Previous studies have indicated that the stratified geologic sequence encountered within the vadose zone beneath the SALDS facility can result in discharge water from the SALDS intercepting the water table at a location that is laterally displaced from the above-ground facility location (PNNL-13121, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site;* and SGW-42604, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2009)*. The interpretation of the monitoring well hydraulic response to SALDS discharges is that the carbonate-cemented horizons of the CCU that occur within the vadose zone a few feet below the bottom of the SALDS drain field results in this lateral displacement of the discharged wastewater. A groundwater flow analysis using superposition was previously performed to evaluate this phenomenon as detailed in Appendix B of SGW-42604. That analysis estimated “best-fit” coordinates of the actual location where the SALDS discharges reached the water table, resulting in estimates of 566395.40 m easting and 137979.33 m northing (in North American Datum [NAD] 1983 State Plane, Washington South FIPS 4062).

These previously determined “best-fit” coordinates were used in the analyses performed herein as the assumed location at which discharges from the SALDS impact the water table. To represent the resulting mounding in the water-level mapping analysis, for each of the monthly averaged water-level datasets, a point-source drift term (refer to SGW-42305 and Eq. 1 herein) was included in MEUK at the best-fit location of the estimated SALDS arrival at the water table. Because of lateral displacement and delay time for discharged water to reach the water table, the SALDS monthly recharge rates are simplified and an average monthly recharge rate is used. However, SALDS had no discharge for the first quarter of CY 2019 and, as such, was omitted from the analysis.

4.2 Input Data

This section summarizes the general input requirements for the calculations described in this ECF. Inputs to the mapping include the following:

- Groundwater elevations measured at monitoring wells
- Line drift inputs to represent the lateral transition of the water table from within the Rwie in the west to within the Hanford formation and CCU to the east
- Extraction and injection rates at 200 West Area P&T pumping wells for use as inputs to point sink and source trend terms

These are each described below.

4.2.1 Groundwater Elevations

Groundwater-level data obtained during first quarter of CY 2019 included manual water-level measurements obtained during or concurrent with synoptic water-level surveys, and water levels that were obtained at various locations on a high-frequency basis (i.e., hourly) from wells equipped with transducers and data loggers. The latter, collectively referred to as part of the Hanford Site automated water-level network (AWLN), comprises a smaller number of wells than is measured during synoptic surveys. Manual measurements are obtained for some of the AWLN wells as well for validation purposes.

The most comprehensive synoptic water-level event for the 200 West Area and surrounding area occurred during March 2019 when water levels were obtained from 124 monitoring wells. In contrast, water-level measurements were obtained from only 40 monitoring wells in February 2019. Throughout 2019, water levels were recorded using data loggers and transducers installed in 32 monitoring wells throughout the 200 West Area. In addition to the monitoring well data, water levels were recorded with data loggers in the extraction and injection wells that were actively operating during the first quarter of CY 2019; the number of wells monitored varied throughout the year.

To generate the monthly water-level mapping datasets, water-level measurements were averaged over the month for each well. Where manual measurements were available for AWLN wells, the manual measurement was used in the mapping dataset instead of the averaged AWLN measurement because the manual measurements are considered to be more reliable. Table 4-1 lists the average monthly water-level measurements that were used as input to generate water-level maps for the first quarter of CY 2019. The full set of data used for the first quarter of CY 2019 is included in Appendix A with the exception of AWLN data. Since the AWLN data is collected hourly, it was excluded from Appendix A.

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
299-E28-18	121.662	--	NM/NA	--	NM/NA	--	121.662
299-E32-5	121.706	--	NM/NA	--	NM/NA	--	121.706
299-E32-6	121.682	--	NM/NA	--	NM/NA	--	121.682
299-E32-8	121.704	--	NM/NA	--	NM/NA	--	121.704

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
299-E33-34	121.675	121.708*	NM/NA	121.696	NM/NA	121.685	121.685
299-W10-1	NM/NA	--	NM/NA	--	132.286	--	132.286
299-W10-14	NM/NA	--	NM/NA	--	136.867	--	136.867
299-W10-23	NM/NA	--	NM/NA	--	130.983	--	130.983
299-W10-24	NM/NA	--	NM/NA	--	130.605	--	130.605
299-W10-26	130.399	--	NM/NA	--	129.959	--	130.179
299-W10-27	130.438	--	NM/NA	--	130.015	--	130.227
299-W10-28	NM/NA	--	NM/NA	--	131.626	--	131.626
299-W10-29	NM/NA	--	NM/NA	--	136.43	--	136.430
299-W10-30	NM/NA	136.834*	NM/NA	136.762*	136.498	136.641*	136.498
299-W10-31	NM/NA	--	NM/NA	--	135.72	--	135.720
299-W11-13	NM/NA	128.686	NM/NA	128.586	NM/NA	128.591	128.621
299-W11-18	NM/NA	--	130.169	--	130.155	--	130.162
299-W11-39	NM/NA	--	NM/NA	--	130.423	--	130.423
299-W11-40	NM/NA	--	NM/NA	--	130.152	--	130.152
299-W11-41	130.513	--	NM/NA	--	130.149	--	130.331
299-W11-42	NM/NA	--	NM/NA	--	130.498	--	130.498
299-W11-43	NM/NA	128.646	128.437	128.52*	128.466	128.49*	128.516
299-W11-45	NM/NA	--	NM/NA	--	129.901	--	129.901
299-W11-47	NM/NA	--	NM/NA	--	130.053	--	130.053
299-W11-48	NM/NA	127.768*	NM/NA	127.751*	130.526	NM/NA	130.526
299-W11-87	NM/NA	123.943	NM/NA	124.096	124.258	124.272*	124.099
299-W11-88	NM/NA	125.75	125.879	125.81*	125.706	125.896*	125.778
299-W13-1	NM/NA	124.776	124.936	124.786*	124.115*	124.825	124.846
299-W14-11	128.815	--	NM/NA	--	127.976	--	128.396
299-W14-13	129.05	--	NM/NA	--	128.502	--	128.776
299-W14-14	NM/NA	NM/NA	NM/NA	NM/NA	129.752	129.873*	129.752
299-W14-15	NM/NA	--	NM/NA	--	129.37	--	129.370

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
299-W14-16	NM/NA	--	NM/NA	--	129.141	--	129.141
299-W14-17	NM/NA	--	NM/NA	--	129.091	--	129.091
299-W14-18	129.721	--	NM/NA	--	129.21	--	129.466
299-W14-19	NM/NA	--	NM/NA	--	129.793	--	129.793
299-W14-71	NM/NA	127.299	NM/NA	127.214	NM/NA	127.261	127.258
299-W14-72	NM/NA	126.402	NM/NA	126.832	NM/NA	126.792	126.675
299-W15-32	NM/NA	132.183	NM/NA	131.947	NM/NA	131.995	132.042
299-W15-37	NM/NA	132.994	NM/NA	132.979	NM/NA	132.922	132.965
299-W15-44	NM/NA	133.276	NM/NA	133.183	131.551	133.009*	132.670
299-W15-49	NM/NA	133.13*	NM/NA	133.077*	NM/NA	132.881*	NVM
299-W15-763	NM/NA	--	NM/NA	--	131.142	--	131.142
299-W15-765	NM/NA	--	NM/NA	--	130.225	--	130.225
299-W17-1	137.502*	--	NM/NA	--	NM/NA	--	137.502
299-W18-15	134.685	--	NM/NA	--	NM/NA	--	134.685
299-W18-260	132.243	--	NM/NA	--	NM/NA	--	132.243
299-W18-40	133.274	--	NM/NA	--	NM/NA	--	133.274
299-W19-101	127.915	127.927*	NM/NA	127.699	127.612	127.623*	127.742
299-W19-105	129.907	--	129.907	--	129.827	--	129.880
299-W19-107	NM/NA	127.732	NM/NA	127.659	127.479	127.618*	127.623
299-W19-115	130.262	--	130.264	--	NM/NA	--	130.263
299-W19-116	128.6	--	NM/NA	--	NM/NA	--	128.600
299-W19-12	132.206	--	NM/NA	--	NM/NA	--	132.206
299-W19-123	NM/NA	--	129.405	--	NM/NA	--	129.405
299-W19-36	128.776	128.812*	128.774	128.76*	NM/NA	128.729	128.760
299-W19-39	128.974	--	NM/NA	--	NM/NA	--	128.974
299-W19-41	132.234	--	NM/NA	--	NM/NA	--	132.234
299-W19-42	132.222	--	NM/NA	--	NM/NA	--	132.222
299-W19-43	127.348	--	127.281	--	127.225	--	127.285

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
299-W19-44	132.162	--	NM/NA	--	NM/NA	--	132.162
299-W19-45	132.169	--	NM/NA	--	NM/NA	--	132.169
299-W19-46	129.395	--	NM/NA	--	129.274	--	129.335
299-W19-47	132.221	--	NM/NA	--	NM/NA	--	132.221
299-W19-48	128.922	128.856*	NM/NA	128.719*	128.738	128.675*	128.830
299-W19-49	129.584	--	129.555	--	129.49	--	129.543
299-W21-2	NM/NA	--	NM/NA	--	129.568	--	129.568
299-W21-3	NM/NA	--	NM/NA	--	129.908	--	129.908
299-W22-113	132.092	--	NM/NA	--	132.099	--	132.096
299-W22-115	132.037	--	NM/NA	--	132.076	--	132.057
299-W22-116	132.091	131.551*	NM/NA	131.551*	132.1	131.547*	132.096
299-W22-47	132.079	--	NM/NA	--	132.049	--	132.064
299-W22-69	131.239	--	131.284	--	131.255	--	131.259
299-W22-72	131.213	--	NM/NA	--	131.211	--	131.212
299-W22-79	NM/NA	--	NM/NA	--	129.863	--	129.863
299-W22-80	132.311	--	NM/NA	--	132.311	--	132.311
299-W22-81	131.772	--	NM/NA	--	131.8	--	131.786
299-W22-82	131.844	--	NM/NA	--	131.871	--	131.858
299-W22-83	NM/NA	--	NM/NA	--	131.803	--	131.803
299-W22-84	131.775*	131.84*	NM/NA	131.945*	131.845*	131.977*	NVM
299-W22-85	132.208*	132.216*	NM/NA	132.23	132.231*	132.233*	132.230
299-W22-86	131.239*	131.237*	131.242	131.225*	131.233*	131.211*	131.242
299-W22-87	130.157	--	NM/NA	--	130.094	--	130.126
299-W22-88	NM/NA	130.182*	NM/NA	130.288*	129.959	NM/NA	129.959
299-W22-89	132.095	--	NM/NA	--	132.076	--	132.086
299-W22-93	NM/NA	--	NM/NA	--	131.789	--	131.789
299-W22-94	131.652	131.495*	NM/NA	131.593	131.723	131.614*	131.656
299-W22-95	131.251	--	NM/NA	--	131.037	--	131.144

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
299-W22-96	131.009	--	NM/NA	--	NM/NA	--	131.009
299-W23-20	132.904	--	NM/NA	--	132.917	--	132.911
299-W23-21	133.023	--	NM/NA	--	133.032	--	133.028
299-W23-236	132.572	--	NM/NA	--	132.576	--	132.574
299-W23-4	NM/NA	--	NM/NA	--	133.52	--	133.520
299-W26-13	NM/NA	--	NM/NA	--	133.411	--	133.411
299-W26-14	NM/NA	--	NM/NA	--	132.746	--	132.746
299-W27-2	NM/NA	--	NM/NA	--	132.116	--	132.116
299-W6-11	131.209*	--	NM/NA	--	131.209	--	131.209
299-W6-12	132.668*	--	NM/NA	--	132.668	--	132.668
299-W6-3	NM/NA	--	NM/NA	--	131.551	--	131.551
299-W6-6	131.561	--	NM/NA	--	131.261	--	131.411
299-W7-3	134.431	--	NM/NA	--	134.134	--	134.283
299-W7-4	NM/NA	--	NM/NA	--	134.316	--	134.316
299-W8-1	136.223	--	NM/NA	--	136.15	--	136.187
299-W9-2	NM/NA	--	NM/NA	--	136.8	--	136.800
699-27-68	129.869	--	NM/NA	--	NM/NA	--	129.869
699-29-66	129.24	--	NM/NA	--	129.225	--	129.233
699-30-63	128.415	--	NM/NA	--	NM/NA	--	128.415
699-30-66	NM/NA	--	NM/NA	--	129.195	--	129.195
699-30-73	130.739	--	NM/NA	--	NM/NA	--	130.739
699-31-68	129.423	--	NM/NA	--	129.432	--	129.428
699-32-62	NM/NA	--	NM/NA	--	127.478	--	127.478
699-32-64	128.358	--	NM/NA	--	NM/NA	--	128.358
699-32-70B	NM/NA	--	NM/NA	--	130.437	--	130.437
699-32-72A	NM/NA	--	NM/NA	--	130.558	--	130.558
699-32-72B	NM/NA	--	NM/NA	--	130.589	--	130.589
699-33-56	121.757	--	NM/NA	--	NM/NA	--	121.757

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
699-33-74	NM/NA	--	NM/NA	--	130.989	--	130.989
699-34-61	125.915	--	NM/NA	--	125.988	--	125.952
699-34-72	130.369	--	NM/NA	--	130.382	--	130.376
699-35-66A	128.893	--	NM/NA	--	128.988	--	128.941
699-35-78A	NM/NA	135.215	NM/NA	135.207	135.156	135.146*	135.193
699-36-61A	123.996	124.288*	NM/NA	124.294	124.075	124.297*	124.122
699-36-63B	127.6	--	NM/NA	--	127.815	--	127.708
699-36-66B	128.926	--	NM/NA	--	129.034	--	128.980
699-36-70B	NM/NA	--	NM/NA	--	129.359	--	129.359
699-37-66	128.721	--	NM/NA	--	128.742	--	128.732
699-38-61	123.768	123.807*	NM/NA	123.831	123.818	123.839*	123.806
699-38-64B	NM/NA	--	NM/NA	--	129.153*	--	NVM
699-38-65	128.832	130.995*	NM/NA	131.025	128.871	131.054*	129.576
699-38-68A	NM/NA	--	NM/NA	--	129.184	--	129.184
699-38-70C	NM/NA	--	NM/NA	--	132.967	--	132.967
699-40-62	122.459	--	NM/NA	--	122.639	--	122.549
699-40-65	126.711	126.776*	NM/NA	126.823	127.776	126.832*	127.103
699-43-69	NM/NA	127.486	NM/NA	127.627	127.026	127.669*	127.380
699-44-64	NM/NA	--	NM/NA	--	122.992	--	122.992
699-45-69C	NM/NA	127.489	NM/NA	127.632	127.515	127.704*	127.545
699-47-60	NM/NA	--	NM/NA	--	121.79	--	121.790
699-48-71	128.858	127.929*	NM/NA	NM/NA	128.564	NM/NA	128.711
699-48-77C	133.911	--	NM/NA	--	NM/NA	--	133.911
699-48-77D	134.139	--	NM/NA	--	NM/NA	--	134.139
699-49-55A	121.7	--	NM/NA	--	121.689	--	121.695
699-49-55B	121.751	--	NM/NA	--	121.732	--	121.742
699-49-57A	121.684	--	NM/NA	--	121.667	--	121.676
699-49-79	134.821	--	NM/NA	--	NM/NA	--	134.821

Table 4-1. Water-Level Measurements

Well Name	Averaged Measured Water Levels (NAVD 88 m)						2019 Q1 Average Measured Water Level (NAVD88 m)
	Jan-2019		Feb-2019		Mar-2019		
	Manual	AWLN	Manual	AWLN	Manual	AWLN	
699-50-56	121.736	--	NM/NA	--	121.7	--	121.718
699-51-63	121.999	--	NM/NA	--	NM/NA	--	121.999
699-51-75	131.895	--	NM/NA	--	NM/NA	--	131.895
699-52-55	121.789	--	NM/NA	--	121.754	--	121.772
699-55-60A	121.245	--	NM/NA	--	121.701	--	121.473
699-57-59	121.722	--	NM/NA	--	121.677	--	121.700
699-59-58	121.738	--	NM/NA	--	NM/NA	--	121.738
699-60-60	121.239	--	121.688	--	121.677	--	121.535
699-61-62	121.246	--	NM/NA	--	121.686	--	121.466
699-61-66	121.502	--	121.695	--	121.676	--	121.624

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

*Outliers not included in the water-level mapping dataset.

AWLN = automated water-level network

NAVD88 = North American Vertical Datum 1988

NVM = no valid measurements

NM/NA = not measured/not available at time of data pull

4.2.2 Line Drift Input

Table B-1 in Appendix B includes the line drift inputs representing large-scale transitions in aquifer properties between the Rwie on the west and the Hanford formation and CCU on the east. Locations of line drift points are depicted in Figure 4-1.

4.2.3 Extraction and Injection Rates at Wells

Monthly average groundwater extraction and injection flow rates for the 200 West Area P&T wells first quarter of CY 2019 used as an input for the water-level mapping are provided in Table B-2 in Appendix B. Figure 4-1 depicts locations for the 200 West Area P&T treatment system wells.

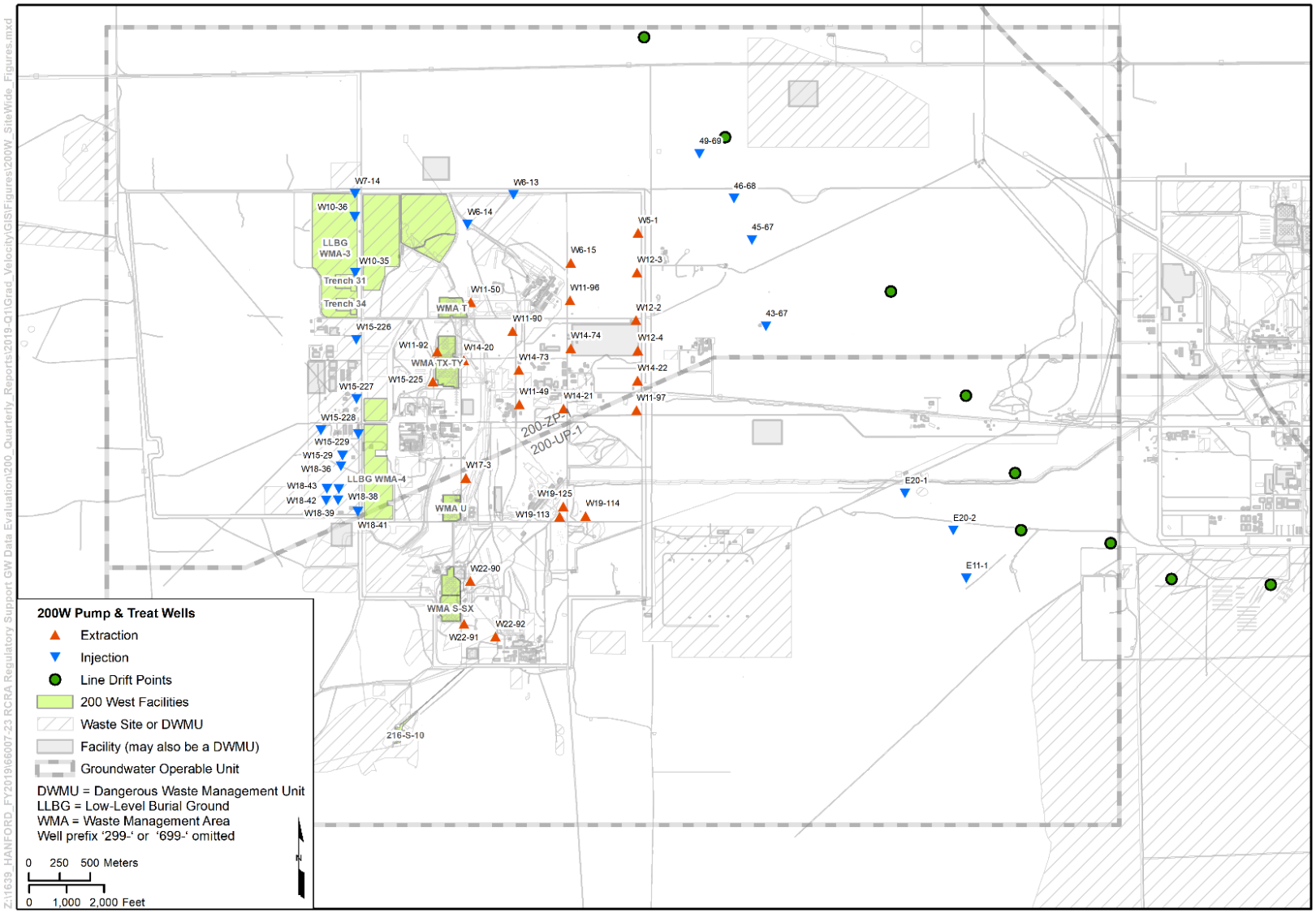

Figure 4-1. Location of 200 West Area P&T Pumping Wells and Line Drift Points for First Quarter of 2019

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

Software used to perform the calculations for this ECF was in accordance with PRC-PRO-IRM-309, *Controlled Software Management*.

5.1 Approved Software

The software used for this ECF was approved and complies with PRC-PRO-IRM-309. The software is managed consistent with PRC-PRO-IRM-309 based on:

- CHPRC-02839, *KT3D_H2O and MEUK Integrated Software Management Plan: KT3D_H2O Version 3.5.1 and MEUK Version 0.2.2*

PRC-PRO-IRM-309 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

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 PRC-PRO-IRM-309. Use of this software at the Hanford Site is managed under the integrated software management plan (CHPRC-02839):

- Software title: MEUK (S.S. Papadopulos and Associates, Inc., 2016, Version 0.2.2)
- Software version: CH2M HILL Plateau Remediation Company (CHPRC) Build 2 (Version 0.2.2)
- Hanford Information Systems Inventory identification number: 2517 (safety software and graded level C)
- Workstation type and property number (from which software is run): SSPA and FE449

MEUK is programmed in the R language (R Development Core Team, 2013, *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).

5.3 Support Software

The following software programs are classified as support software.

- 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*).

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

- R: The R programming environment for statistical computing and graphics (R Development Core Team, 2013; Ihaka and Gentleman, 1996, "R: A Language for Data Analysis and Graphics"), was used to perform a variety of data processing, including post-processing calculation results and generating plots of aggregate data time series. The following R packages were also used:
  - 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.

5.4 Software Installation and Checkout

Safety software is checked out in accordance with procedures specified in PRC-PRO-IRM-309. Executables are obtained from the CH2M HILL Plateau Remediation Company software owner (who maintains the configuration-managed copies in MKS Integrity®). Installation tests identified in CHPRC-02839 are performed on the software and successful installation confirmed. Software installation and checkout forms are required and must be approved for installations used to perform model runs. Approved users are registered in Hanford Information Systems Inventory 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-02839, and is a valid use of this software for this application. The software was used within its limitations, as identified in CHPRC-02839.

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

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

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 develop the groundwater-level maps using MEUK through the R environment.

6.1 Water-Level Analysis Using MEUK

The following steps were taken to produce the groundwater elevation maps presented in this ECF:

1. Input data were compiled from retrieved database sources. Measured groundwater elevations were obtained for each month in the first quarter of CY 2019. Water levels for which there were multiple measurements (such as for the AWLN wells) were averaged so that one value was assigned to each monitoring well for each month.

   To do this, the AWLN data were compared to manual measurements to test the reliability of the transducer measurements. During this analysis, it was noted that three AWLN wells (299-W15-37, 299-W15-44, and 699-36-61A) exhibited relatively constant discrepancies between transducer data and manual measurements, in which case transducer data were adjusted to match manual measurements. Figure 6-1 shows adjustments applied to well 299-W15-44 for the period of CY 2016 through CY 2018. The other wells with constant discrepancies were adjusted in a similar manner. At the conclusion of the AWLN adjustments, monthly averaged data were compiled into tables suitable for mapping.

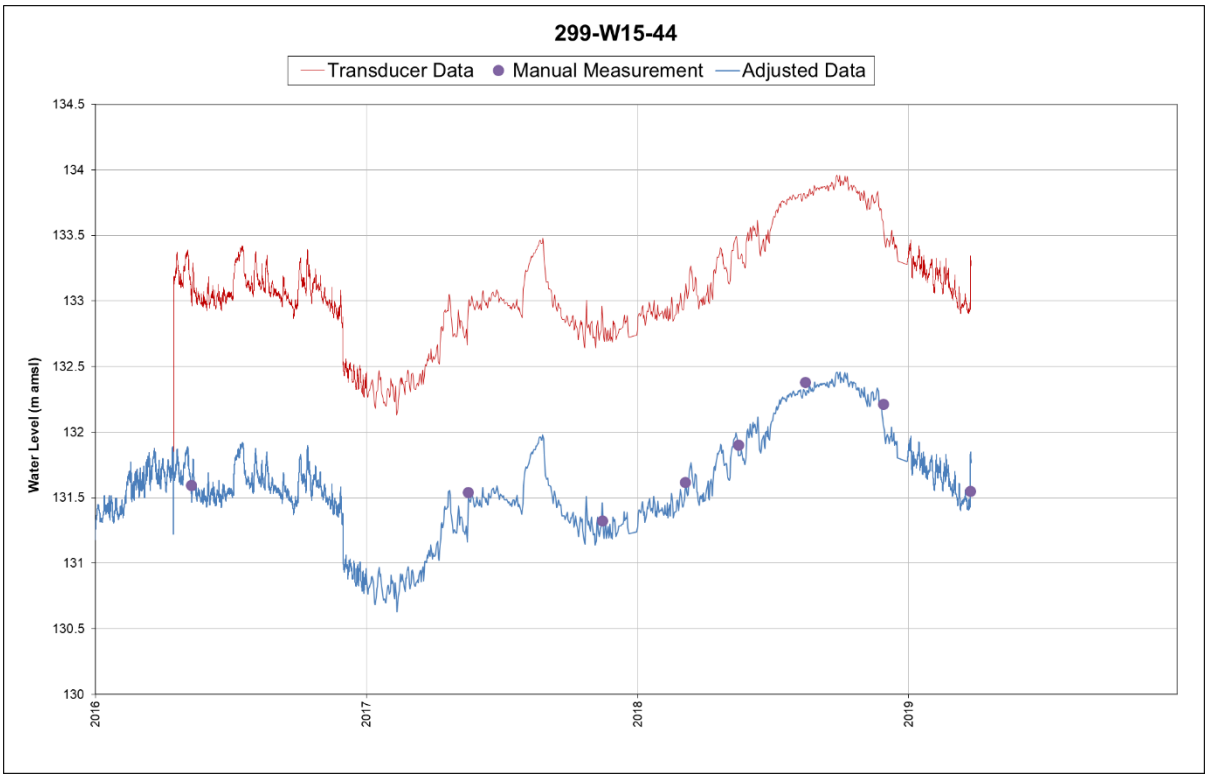

Figure 6-1. Example of AWLN Data Adjustment

Cross-validation analyses were then performed to find the wells with the highest residual values. The water levels at these wells with the highest residuals were considered suspect and subject to systematic error, which may be attributable to the wells deviating from vertical or to error in manual and/or transducer measurements. In some cases, the wells were screened in deeper aquifers with different flow conditions. Based on the results from the cross-validation analysis, several measurements were excluded from the mapping process, and the excluded water levels are indicated with an asterix (*) in Table A-1 in Appendix A, The excluded wells include the following:

a. Wells 299-W11-48, 299-W15-49, 299-W10-30, 299-W22-88, 299-W22-84, 299-W22-116, and 699-37-47A consistently produced high kriging residuals, which were manifested as unrealistic artefacts in the water-level maps. As such, water-level measurements for these wells were considered unreliable and removed from the kriging dataset.

b. Monitoring wells 299-W10-14, 299-W11-43, 299-W11-88, 299-W14-71, 299-W14-72, 299-W27-2, 299-W6-3, 299-W6-6, 299-W7-3, 699-38-70C, 699-43-69, and 699-48-77C have screen intervals located deeper in the aquifer (i.e., not at or near the water table). Because of the depth of their screens, these wells were removed from kriging dataset.

2. To represent large-scale transitions in aquifer properties between the Rwie on the west and the Hanford formation and CCU on the east, line drift points were created approximately along the line where the water table crosses the top of the Rwie. Line drift points, included in Table B-2 in Appendix B, were set constant for all events (i.e., specified as global trend terms).

3. Pumping data for first quarter of CY 2019 extraction and injection rates for 200-ZP-1 and 200-UP-1 P&T remedies were assembled as a monthly average pumping rates listed in Table B-2 in Appendix B.

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

5. Water level ASCII (*.asc) grid files were imported into Surfer, then water-level contours were exported in ArcGIS shapefile format.

7 Results

This chapter presents outputs from the described calculations. The water-level maps for each month of the first quarter of CY 2019 were created using MEUK. Figures 7-1 through 7-3 depict the groundwater elevation contours for each month of the first quarter of CY 2019 throughout the 200 West Area that were prepared using the methods and inputs previously described. As discussed in Section 4.2.1, there are significant differences in the number of groundwater elevation measurements collected each month. The water-level maps produced during months with more comprehensive sets of measurements are likely more reliable representations. Figure 7-4 depicts the average groundwater elevation contours for the first quarter of CY 2019 throughout the 200 West Area. The figures depict the locations of the monitoring wells with measured water levels and the general patterns of groundwater elevations and hydraulic gradients for conditions representative of the first quarter of CY 2019.

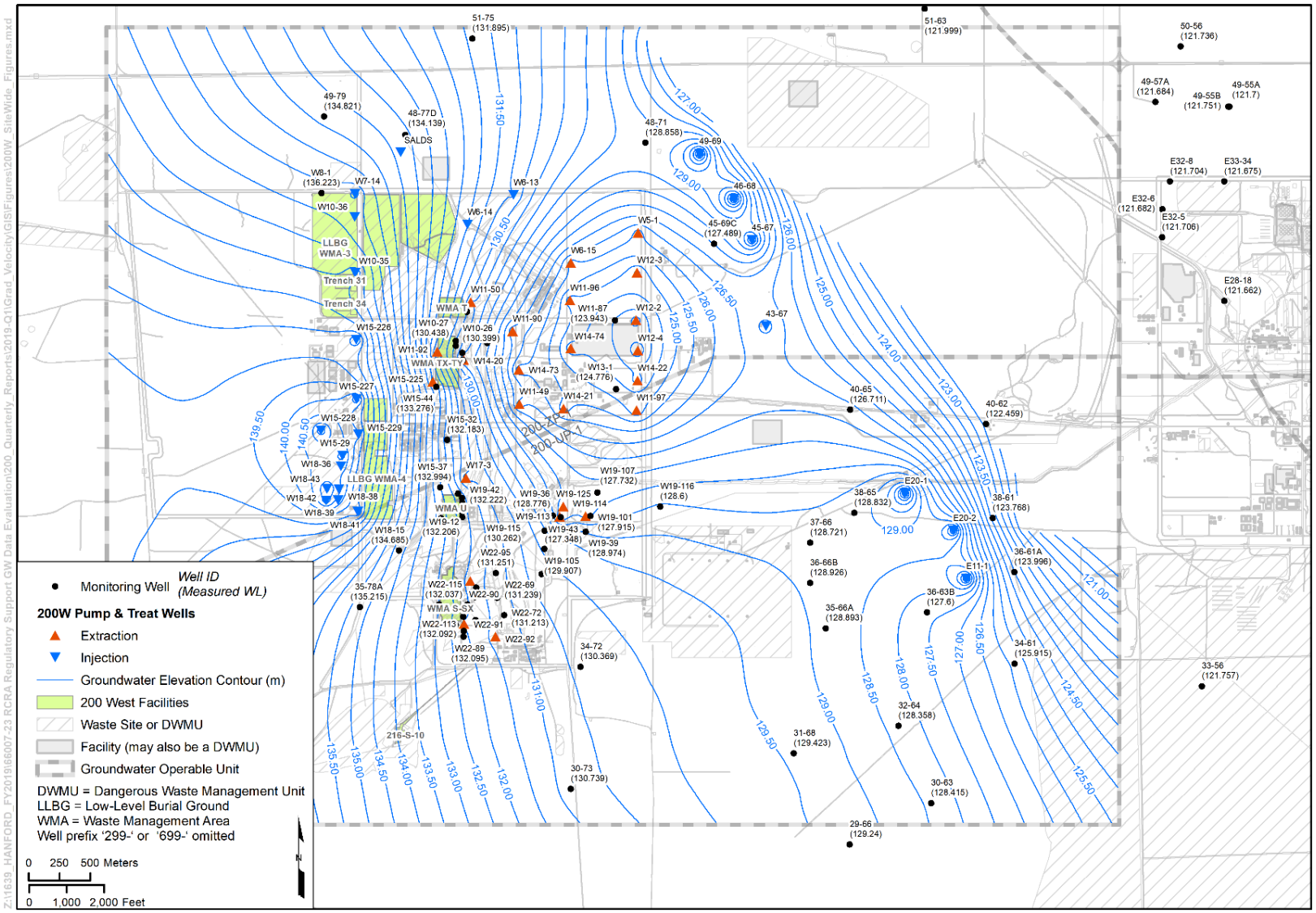

Figure 7-1. Mapped Groundwater Elevations – January 2019

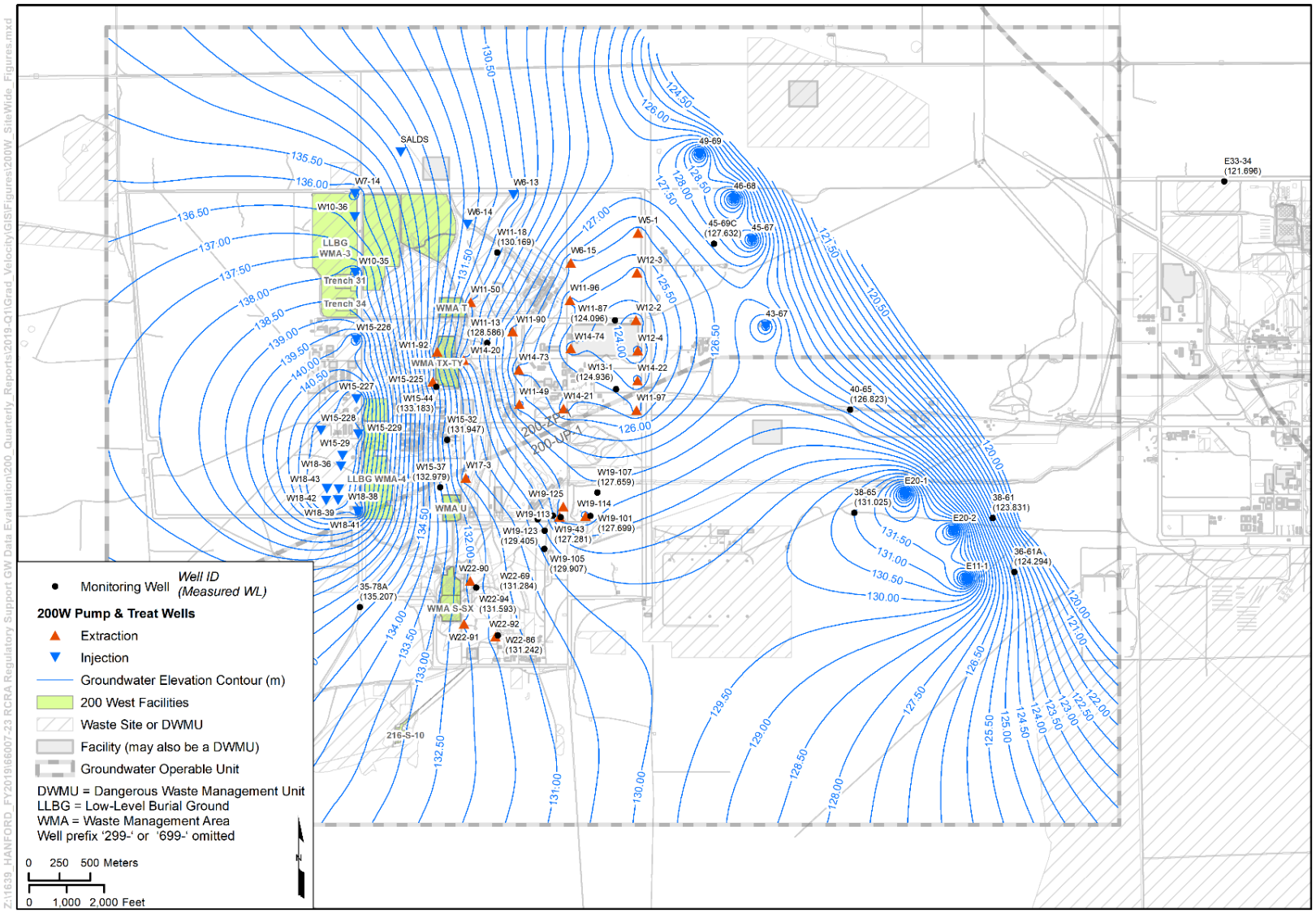

Figure 7-2. Mapped Groundwater Elevations – February 2019

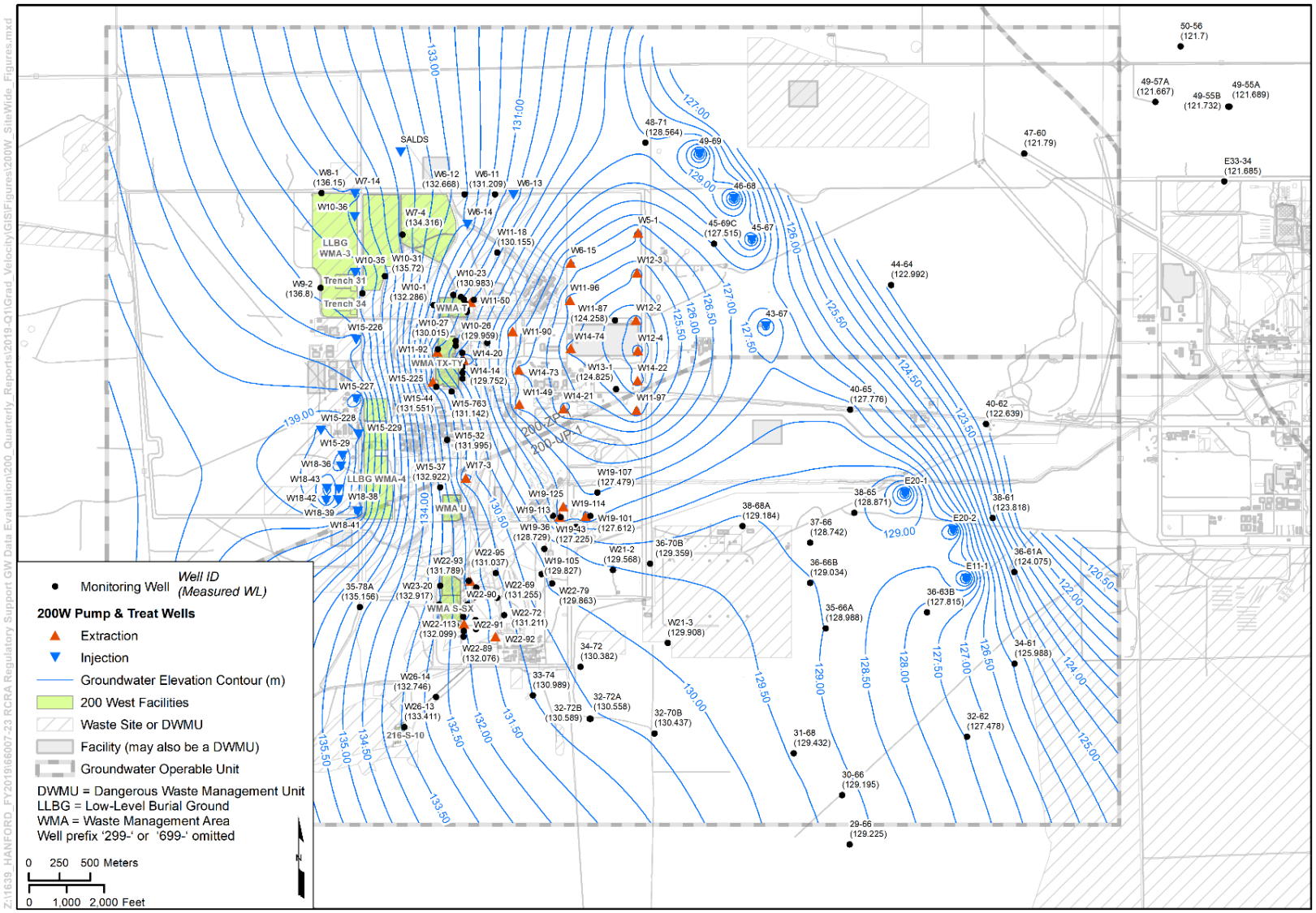

Figure 7-3. Mapped Groundwater Elevations – March 2019

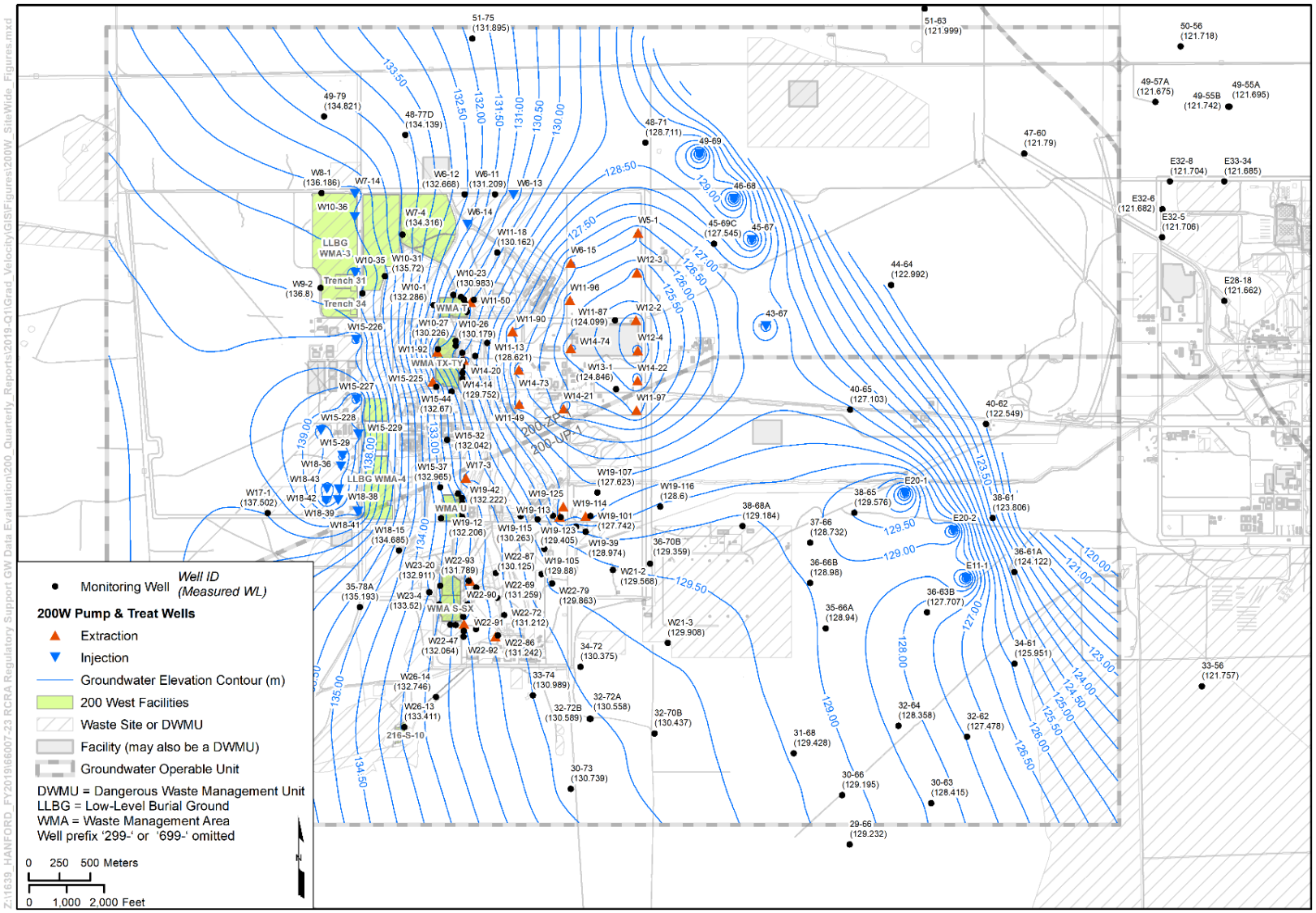

Figure 7-4. Mapped Groundwater Elevations – Average for January Through March 2019

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Appendix A

Groundwater Elevations in Monitoring Wells

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A1 Introduction

Tables A-1 through A-3 present the data used in the calculations. Data obtained as part of the Hanford Site automated water-level network (AWLN) are excluded from the tables since measurements are collected on an hourly basis. The monthly averaged AWLN data used as input for the water-level mapping are provided in Table 4-1 of the main text.

Table A-1. Measured Groundwater Elevations Used for Water-Level Mapping: January 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-E28-18	573104	136768	1/24/2019 9:42 AM	121.662
299-E32-5	572600	137285	1/9/2019 9:20 AM	121.700
299-E32-5	572600	137285	1/24/2019 10:03 AM	121.712
299-E32-6	572600	137515	1/9/2019 11:15 AM	121.699
299-E32-6	572600	137515	1/24/2019 9:59 AM	121.665
299-E32-8	572663	137741	1/14/2019 8:46 AM	121.695
299-E32-8	572663	137741	1/24/2019 9:54 AM	121.713
299-E33-34	573104	137740	1/14/2019 11:18 AM	121.691
299-E33-34	573104	137740	1/28/2019 8:07 AM	121.659
299-W10-26	566843	136401	1/23/2019 12:07 PM	130.399
299-W10-27	566844	136442	1/23/2019 12:30 PM	130.438
299-W11-41	566936	136678	1/23/2019 7:54 AM	130.513
299-W14-11	566902	136288	1/22/2019 10:35 AM	128.815
299-W14-13	566902	136282	1/23/2019 10:49 AM	129.050
299-W14-18	566897	136344	1/23/2019 9:30 AM	129.721
299-W18-15	566380	134733	1/11/2019 10:06 AM	134.685
299-W18-260	566863	135197	1/22/2019 9:52 AM	132.243
299-W18-40	566723	134996	1/21/2019 11:05 AM	133.274
299-W19-101	567939	135014	1/11/2019 11:59 AM	127.915
299-W19-105	567565	134745	1/11/2019 11:06 AM	129.907
299-W19-115	567372	135012	1/11/2019 11:12 AM	130.262
299-W19-116	568510	135090	1/11/2019 12:07 PM	128.600
299-W19-12	566897	135059	1/21/2019 8:30 AM	132.206
299-W19-36	567635	135017	1/11/2019 8:38 AM	128.776
299-W19-39	567902	134887	1/11/2019 11:45 AM	128.974
299-W19-41	566897	135005	1/21/2019 10:26 AM	132.234

Table A-1. Measured Groundwater Elevations Used for Water-Level Mapping: January 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W19-42	566897	135123	1/22/2019 8:41 AM	132.222
299-W19-43	567699	135004	1/11/2019 11:34 AM	127.348
299-W19-44	566897	135042	1/21/2019 9:59 AM	132.162
299-W19-45	566898	135088	1/22/2019 8:11 AM	132.169
299-W19-46	567783	134842	1/11/2019 11:40 AM	129.395
299-W19-47	566895	135162	1/22/2019 9:23 AM	132.221
299-W19-48	567823	134926	1/11/2019 11:50 AM	128.922
299-W19-49	567568	134894	1/11/2019 8:21 AM	129.584
299-W22-113	566905	134193	1/11/2019 9:19 AM	132.092
299-W22-115	566939	134292	1/11/2019 9:07 AM	132.037
299-W22-116	566901	134140	1/11/2019 9:39 AM	132.091
299-W22-47	566909	134076	1/11/2019 10:14 AM	132.079
299-W22-69	567180	134348	1/11/2019 10:36 AM	131.239
299-W22-72	567237	134207	1/11/2019 10:52 AM	131.213
299-W22-80	566843	134126	1/11/2019 9:45 AM	132.311
299-W22-81	567000	134354	1/11/2019 11:20 AM	131.772
299-W22-82	567005	134167	1/11/2019 10:19 AM	131.844
299-W22-84	566979	134548	1/11/2019 9:01 AM	131.775
299-W22-85	566903	134261	1/11/2019 9:12 AM	132.208
299-W22-86	567187	134041	1/11/2019 10:42 AM	131.239
299-W22-87	567542	134540	1/11/2019 10:59 AM	130.157
299-W22-89	566907	134032	1/11/2019 11:25 AM	132.095
299-W22-94	567010	134430	1/11/2019 10:25 AM	131.652
299-W22-95	567171	134549	1/11/2019 10:31 AM	131.251
299-W22-96	567352	134146	1/11/2019 10:47 AM	131.009
299-W23-20	566718	134446	1/11/2019 9:59 AM	132.904
299-W23-21	566708	134294	1/11/2019 9:56 AM	133.023
299-W23-236	566799	134128	1/11/2019 9:49 AM	132.572
299-W6-6	567319	137639	1/17/2019 10:39 AM	131.626
299-W6-6	567319	137639	1/22/2019 8:18 AM	131.495
299-W7-3	566292	137639	1/17/2019 11:26 AM	134.513

Table A-1. Measured Groundwater Elevations Used for Water-Level Mapping: January 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W7-3	566292	137639	1/22/2019 9:38 AM	134.349
299-W8-1	565749	137647	1/22/2019 10:54 AM	136.223
699-27-68	569325	131676	1/8/2019 10:20 AM	129.869
699-29-66	570054	132337	1/28/2019 12:06 PM	129.240
699-30-63	570717	132675	1/28/2019 10:02 AM	128.415
699-30-73	567782	132789	1/8/2019 9:36 AM	130.739
699-31-68	569598	133081	1/28/2019 11:22 AM	129.423
699-32-64	570451	133304	1/28/2019 10:21 AM	128.358
699-33-56	572923	133627	1/8/2019 11:17 AM	121.757
699-34-61	571396	133810	1/24/2019 8:40 AM	125.915
699-34-72	567860	133785	1/28/2019 8:40 AM	130.369
699-35-66A	569858	134099	1/24/2019 7:49 AM	128.893
699-36-61A	571395	134557	1/24/2019 8:33 AM	123.996
699-36-63B	570684	134229	1/24/2019 8:21 AM	127.600
699-36-66B	569731	134469	1/24/2019 7:44 AM	128.926
699-37-66	569730	134797	1/24/2019 7:54 AM	128.721
699-38-61	571219	134997	1/24/2019 8:27 AM	123.739
699-38-61	571219	134997	1/28/2019 8:28 AM	123.796
699-38-65	570090	135040	1/24/2019 8:14 AM	128.832
699-40-62	571164	135764	1/21/2019 8:34 AM	122.376
699-40-62	571164	135764	1/24/2019 8:50 AM	122.541
699-40-65	570057	135881	1/24/2019 8:03 AM	126.711
699-48-71	568388	138057	1/24/2019 10:51 AM	128.858
699-48-77C	566469	138087	1/7/2019 11:33 AM	133.867
699-48-77C	566469	138087	1/23/2019 8:02 AM	133.955
699-48-77D	566433	138119	1/7/2019 11:37 AM	134.139
699-49-55A	573146	138352	1/24/2019 11:01 AM	121.700
699-49-55B	573139	138351	1/21/2019 1:10 PM	121.751
699-49-57A	572544	138389	1/24/2019 10:52 AM	121.684
699-49-79	565771	138271	1/23/2019 11:37 AM	134.821
699-50-56	572748	138842	1/24/2019 10:57 AM	121.736

Table A-1. Measured Groundwater Elevations Used for Water-Level Mapping: January 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
699-51-63	570664	139148	1/7/2019 11:54 AM	121.999
699-51-75	566978	138906	1/23/2019 9:45 AM	131.895
699-52-55	573102	139443	1/7/2019 12:26 PM	121.789
699-55-60A	571564	140268	1/7/2019 11:06 AM	121.245
699-57-59	571830	140924	1/7/2019 12:02 PM	121.722
699-59-58	572274	141415	1/7/2019 10:36 AM	121.738
699-60-60	571589	141764	1/7/2019 10:30 AM	121.239
699-61-62	570915	141922	1/7/2019 10:23 AM	121.246
699-61-66	569788	142008	1/7/2019 10:13 AM	121.268
699-61-66	569788	142008	1/22/2019 8:52 AM	121.736

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

Table A-2. Measured Groundwater Elevations Used for Water-Level Mapping: February 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W11-18	567182	137161	2/20/2019 10:15 AM	130.169
299-W11-43	567270	136971	2/20/2019 9:22 AM	128.437
299-W11-88	567875	137113	2/20/2019 11:46 AM	125.879
299-W13-1	568149	136049	2/20/2019 7:44 AM	124.936
299-W19-105	567565	134745	2/20/2019 8:46 AM	129.932
299-W19-105	567565	134745	2/27/2019 7:56 AM	129.881
299-W19-115	567372	135012	2/27/2019 7:34 AM	130.264
299-W19-123	567511	134988	2/20/2019 11:20 AM	129.405
299-W19-36	567635	135017	2/20/2019 9:00 AM	128.806
299-W19-36	567635	135017	2/27/2019 7:44 AM	128.741
299-W19-43	567699	135004	2/27/2019 7:28 AM	127.281
299-W19-49	567568	134894	2/27/2019 7:50 AM	129.555
299-W22-69	567180	134348	2/27/2019 8:06 AM	131.284
299-W22-86	567187	134041	2/27/2019 8:18 AM	131.242
699-60-60	571589	141764	2/21/2019 8:58 AM	121.688
699-61-66	569788	142008	2/21/2019 8:49 AM	121.695

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

Table A-3. Measured Groundwater Elevations Used for Water-Level Mapping: March 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W10-1	566663	136735	3/26/2019 7:01 AM	132.374
299-W10-1	566663	136735	3/27/2019 9:20 AM	132.198
299-W10-14	566017	136609	3/25/2019 12:21 PM	136.787
299-W10-14	566017	136609	3/31/2019 8:02 AM	136.946
299-W10-23	566824	136815	3/26/2019 10:20 AM	130.973
299-W10-23	566824	136815	3/27/2019 9:36 AM	130.993
299-W10-24	566885	136799	3/25/2019 7:03 AM	130.596
299-W10-24	566885	136799	3/27/2019 9:11 AM	130.614
299-W10-26	566843	136401	3/26/2019 8:39 AM	129.959
299-W10-27	566844	136442	3/26/2019 9:15 AM	130.015
299-W10-28	566702	136710	3/26/2019 8:29 AM	131.620
299-W10-28	566702	136710	3/27/2019 9:28 AM	131.631
299-W10-29	566083	136829	3/13/2019 8:48 AM	136.392
299-W10-29	566083	136829	3/25/2019 12:13 PM	136.468
299-W10-30	566083	136739	3/13/2019 8:00 AM	136.476
299-W10-30	566083	136739	3/25/2019 12:08 PM	136.519
299-W10-31	566266	136968	3/13/2019 7:00 AM	135.703
299-W10-31	566266	136968	3/25/2019 12:02 PM	135.736
299-W11-18	567182	137161	3/25/2019 12:55 PM	130.155
299-W11-39	566908	136780	3/25/2019 7:39 AM	130.418
299-W11-39	566908	136780	3/27/2019 8:55 AM	130.427
299-W11-40	566927	136710	3/25/2019 8:43 AM	130.265
299-W11-40	566927	136710	3/27/2019 8:44 AM	130.039
299-W11-41	566936	136678	3/25/2019 9:27 AM	130.145
299-W11-41	566936	136678	3/27/2019 8:33 AM	130.152
299-W11-42	566920	136746	3/25/2019 8:17 AM	130.493
299-W11-42	566920	136746	3/27/2019 8:50 AM	130.503
299-W11-43	567270	136971	3/25/2019 1:09 PM	128.466
299-W11-45	566993	136776	3/25/2019 1:18 PM	129.932
299-W11-45	566993	136776	3/26/2019 11:04 AM	129.870
299-W11-47	566934	136681	3/26/2019 10:16 AM	130.053

Table A-3. Measured Groundwater Elevations Used for Water-Level Mapping: March 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W11-48	566882	136846	3/27/2019 9:02 AM	130.526
299-W11-87	568141	136609	3/25/2019 11:12 AM	124.278
299-W11-87	568141	136609	3/27/2019 10:15 AM	124.238
299-W11-88	567875	137113	3/25/2019 11:21 AM	125.706
299-W13-1	568149	136049	3/25/2019 11:02 AM	124.115
299-W14-11	566902	136288	3/26/2019 6:36 AM	127.976
299-W14-13	566902	136282	3/26/2019 7:07 AM	128.502
299-W14-14	566898	136181	3/28/2019 7:36 AM	129.752
299-W14-15	566900	136231	3/28/2019 7:07 AM	129.370
299-W14-16	567001	136318	3/27/2019 8:27 AM	129.141
299-W14-17	567007	136218	3/28/2019 6:24 AM	129.091
299-W14-18	566897	136344	3/27/2019 10:00 AM	129.210
299-W14-19	566899	136135	3/28/2019 8:32 AM	129.793
299-W15-44	566685	136066	3/27/2019 7:04 AM	131.551
299-W15-763	566809	136029	3/27/2019 7:44 AM	131.142
299-W15-765	566697	136373	3/28/2019 9:07 AM	130.225
299-W19-101	567939	135014	3/28/2019 6:57 AM	127.612
299-W19-105	567565	134745	3/28/2019 10:49 AM	129.827
299-W19-107	567998	135206	3/28/2019 6:46 AM	127.485
299-W19-107	567998	135206	3/31/2019 6:44 AM	127.473
299-W19-43	567699	135004	3/28/2019 10:37 AM	127.225
299-W19-43	567699	135004	3/31/2019 6:08 AM	127.225
299-W19-46	567783	134842	3/28/2019 7:27 AM	129.274
299-W19-48	567823	134926	3/28/2019 7:17 AM	128.738
299-W19-49	567568	134894	3/28/2019 10:58 AM	129.490
299-W21-2	568124	134574	3/28/2019 7:45 AM	129.568
299-W21-3	568571	133980	3/28/2019 7:31 AM	129.933
299-W21-3	568571	133980	3/31/2019 7:17 AM	129.883
299-W22-113	566905	134193	3/24/2019 8:24 AM	132.099
299-W22-115	566939	134292	3/25/2019 9:12 AM	132.076
299-W22-116	566901	134140	3/25/2019 10:04 AM	132.100

Table A-3. Measured Groundwater Elevations Used for Water-Level Mapping: March 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W22-47	566909	134076	3/24/2019 6:27 AM	132.033
299-W22-47	566909	134076	3/28/2019 1:18 PM	132.065
299-W22-69	567180	134348	3/25/2019 11:19 AM	131.288
299-W22-69	567180	134348	3/28/2019 11:16 AM	131.221
299-W22-72	567237	134207	3/25/2019 11:40 AM	131.234
299-W22-72	567237	134207	3/28/2019 11:33 AM	131.187
299-W22-79	567630	134465	3/28/2019 11:52 AM	129.863
299-W22-80	566843	134126	3/24/2019 11:43 AM	132.311
299-W22-81	567000	134354	3/25/2019 7:51 AM	131.807
299-W22-81	567000	134354	3/28/2019 1:06 PM	131.793
299-W22-82	567005	134167	3/27/2019 6:48 AM	131.871
299-W22-83	567009	134093	3/25/2019 10:53 AM	131.822
299-W22-83	567009	134093	3/28/2019 1:25 PM	131.783
299-W22-84	566979	134548	3/24/2019 6:49 AM	131.845
299-W22-85	566903	134261	3/24/2019 7:33 AM	132.231
299-W22-86	567187	134041	3/25/2019 11:40 AM	131.252
299-W22-86	567187	134041	3/28/2019 11:41 AM	131.213
299-W22-87	567542	134540	3/28/2019 11:59 AM	130.094
299-W22-88	568046	134391	3/28/2019 7:36 AM	129.959
299-W22-89	566907	134032	3/24/2019 7:14 AM	132.076
299-W22-93	566949	134486	3/25/2019 8:21 AM	131.789
299-W22-94	567010	134430	3/25/2019 7:10 AM	131.723
299-W22-95	567171	134549	3/25/2019 10:18 AM	131.037
299-W23-20	566718	134446	3/24/2019 8:22 AM	132.917
299-W23-21	566708	134294	3/24/2019 9:30 AM	133.032
299-W23-236	566799	134128	3/24/2019 11:22 AM	132.576
299-W23-4	566628	134392	3/27/2019 8:09 AM	133.520
299-W26-13	566424	133294	3/28/2019 8:34 AM	133.411
299-W26-14	566683	133539	3/28/2019 8:25 AM	132.746
299-W27-2	566908	133670	3/28/2019 8:19 AM	132.116
299-W6-11	567163	137635	3/25/2019 11:33 AM	131.209

Table A-3. Measured Groundwater Elevations Used for Water-Level Mapping: March 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
299-W6-12	566916	137635	3/25/2019 11:38 AM	132.668
299-W6-3	567118	137299	3/25/2019 12:48 PM	132.264
299-W6-3	567118	137299	3/31/2019 10:23 AM	130.837
299-W6-6	567319	137639	3/25/2019 11:28 AM	131.261
299-W7-3	566292	137639	3/25/2019 11:45 AM	134.134
299-W7-4	566409	137308	3/25/2019 11:55 AM	134.316
299-W8-1	565749	137647	3/25/2019 12:38 PM	136.150
299-W9-2	565742	136873	3/13/2019 10:22 AM	136.766
299-W9-2	565742	136873	3/25/2019 12:32 PM	136.834
699-29-66	570054	132337	3/28/2019 12:25 PM	129.225
699-30-66	569991	132739	3/28/2019 12:20 PM	129.195
699-31-68	569598	133081	3/28/2019 12:30 PM	129.432
699-32-62	571010	133216	3/28/2019 12:11 PM	127.478
699-32-70B	568462	133242	3/28/2019 7:50 AM	130.437
699-32-72A	567943	133363	3/28/2019 7:39 AM	130.558
699-32-72B	567935	133362	3/28/2019 7:44 AM	130.589
699-33-74	567473	133552	3/28/2019 8:06 AM	130.989
699-34-61	571396	133810	3/28/2019 11:56 AM	125.988
699-34-72	567860	133785	3/28/2019 7:55 AM	130.382
699-35-66A	569858	134099	3/18/2019 8:12 AM	129.009
699-35-66A	569858	134099	3/28/2019 7:00 AM	128.967
699-35-78A	566064	134271	3/31/2019 6:08 AM	135.156
699-36-61A	571395	134557	3/28/2019 11:49 AM	124.075
699-36-63B	570684	134229	3/28/2019 12:46 PM	127.815
699-36-66B	569731	134469	3/18/2019 9:12 AM	129.039
699-36-66B	569731	134469	3/28/2019 6:54 AM	129.028
699-36-70B	568428	134626	3/28/2019 9:54 AM	129.359
699-37-66	569730	134797	3/18/2019 10:23 AM	128.751
699-37-66	569730	134797	3/28/2019 7:08 AM	128.732
699-38-61	571219	134997	3/28/2019 11:41 AM	123.818
699-38-64B	569900	135320	3/31/2019 7:45 AM	129.153

Table A-3. Measured Groundwater Elevations Used for Water-Level Mapping: March 2019

Well Name	Easting	Northing	Date-Time	Measured Water Level (NAVD88 m)
699-38-65	570090	135040	3/28/2019 8:56 AM	128.871
699-38-68A	569180	134932	3/28/2019 9:53 AM	129.184
699-38-70C	569084	135326	3/28/2019 8:20 AM	132.967
699-40-62	571164	135764	3/28/2019 11:19 AM	122.639
699-40-65	570057	135881	3/28/2019 11:06 AM	127.776
699-43-69	568967	136488	3/28/2019 10:25 AM	127.026
699-44-64	570391	136897	3/28/2019 10:55 AM	122.992
699-45-69C	568947	137234	3/28/2019 9:41 AM	127.515
699-47-60	571474	137969	3/28/2019 11:29 AM	121.790
699-48-71	568388	138057	3/28/2019 9:21 AM	128.564
699-49-55A	573146	138352	3/29/2019 7:16 AM	121.689
699-49-55B	573139	138351	3/29/2019 7:19 AM	121.732
699-49-57A	572544	138389	3/29/2019 7:27 AM	121.667
699-50-56	572748	138842	3/29/2019 7:33 AM	121.700
699-52-55	573102	139443	3/27/2019 10:11 AM	121.754
699-55-60A	571564	140268	3/27/2019 10:32 AM	121.701
699-57-59	571830	140924	3/27/2019 10:41 AM	121.677
699-60-60	571589	141764	3/27/2019 11:03 AM	121.677
699-61-62	570915	141922	3/27/2019 11:10 AM	121.686
699-61-66	569788	142008	3/27/2019 11:20 AM	121.676

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

A2 Reference

NAVD88, 1988, *North American Vertical Datum of 1988*, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland. Available at: https://www.ngs.noaa.gov/datums/vertical/.

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Appendix B

200 West Water-Level Mapping Drift Input Data for First Quarter of Calendar Year 2019

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Table B-1. Line Drift Input Data

X1	X2	Y1	Y2	NAME	TERM	EVENT	VAL
568378	569038	138917	138102	A0	34	All Events	100
569038	570389	138102	136845	A1	34	All Events	100
570389	571000	136845	135995	A2	34	All Events	100
571000	571400	135995	135363	A3	34	All Events	100
571400	571450	135363	134900	A4	34	All Events	100
571450	572180	134900	134793	A5	34	All Events	100
572180	572676	134793	134500	A6	34	All Events	100
572676	573483	134500	134455	A7	34	All Events	100
573483	573961	134455	134642	A8	34	All Events	100

Table B-2. Average Monthly Pumping Rates (gal/min) for 200-ZP-1 and 200-UP-1 Pump and Treat Remedies During Calendar Year 2019

Well Name	Well Identification	Easting (m)	Northing (m)	Drift Term	Jan	Feb	Mar	Quarter 1
299-W15-225	YE-01	566657	136109	30	75.3	70.4	99.6	81.8
299-W14-20	YE-02	566909	136284	30	71.6	106.9	103.6	94.0
299-W14-73	YE-03	567359	136205	30	136.0	128.1	90.3	118.1
299-W14-74	YE-04	567781	136381	30	105.2	104.3	74.8	94.8
299-W12-2	YE-05	568313	136610	30	104.5	89.7	79.9	91.3
299-W11-50	YE-06	566966	136757	30	59.8	59.6	61.1	60.2
299-W11-90	YE-07	567307	136520	30	98.2	73.0	61.5	77.6
299-W11-96	YE-08	567775	136772	30	97.7	69.7	71.6	79.7
299-W17-3	YE-09	566926	135325	30	107.7	86.7	105.7	100.0
299-W11-49	YE-12	567362	135925	30	118.1	85.0	102.6	101.9
299-W11-97	YE-13	568318	135876	30	106.0	85.9	105.5	99.1
299-W6-15	YE-14	567782	137076	30	90.5	71.2	71.9	77.8
299-W14-21	YE-15	567722	135890	30	95.8	91.8	98.6	95.4
299-W11-92	YE-16	566693	136352	30	85.8	91.4	110.1	95.8
299-W5-1	YE-17	568330	137321	30	89.8	69.9	73.9	77.9
299-W12-3	YE-18	568322	136998	30	94.6	70.2	74.4	79.7
299-W12-4	YE-19	568327	136364	30	128.2	117.8	130.0	125.3
299-W14-22	YE-20	568325	136117	30	90.5	106.9	117.7	105.0

Table B-2. Average Monthly Pumping Rates (gal/min) for 200-ZP-1 and 200-UP-1 Pump and Treat Remedies During Calendar Year 2019

Well Name	Well Identification	Easting (m)	Northing (m)	Drift Term	Jan	Feb	Mar	Quarter 1
299-W22-90	YE-21	566961	134483	33	24.9	4.8	3.0	10.9
299-W22-91	YE-22	566912	134135	33	30.0	29.7	29.9	29.9
299-W22-92	YE-23	567168	134030	33	25.0	24.9	25.0	25.0
299-W19-125	YE-24	567720	135091	30	49.9	43.0	45.0	45.9
299-W19-113	YE-25	567690	135008	30	49.9	51.5	49.8	50.4
299-W19-114	YE-26	567902	135013	30	50.9	79.6	74.7	68.4
299-W6-13	YJ-01	567313	137631	29	40.2	40.2	42.2	40.9
299-W6-14	YJ-02	566940	137389	29	6.7	0.0	43.3	16.7
299-W10-36	YJ-03	566019	137452	29	0.0	0.0	0.0	0.0
299-W10-35	YJ-04	566025	136995	29	113.6	87.4	101.9	101.0
299-W15-226	YJ-05	566033	136450	29	158.7	123.3	119.3	133.8
299-W15-227	YJ-06	566034	135967	29	171.9	199.5	177.4	182.9
299-W15-228	YJ-07	565745	135711	29	147.9	43.2	41.7	77.6
299-W18-41	YJ-08	566045	135049	29	115.6	121.8	115.3	117.6
699-49-69	YJ-09	568830	137967	32	63.0	59.8	70.3	64.4
699-45-67	YJ-11	569257	137263	32	48.4	49.1	50.8	49.4
699-43-67	YJ-13	569370	136560	32	16.6	30.6	33.0	26.7
299-W15-29	YJ-18	565921	135506	29	79.8	79.7	81.9	80.5
299-W18-36	YJ-19	565909	135419	29	49.8	61.0	60.4	57.1
299-W18-38	YJ-21	565892	135233	29	27.2	0.0	0.0	9.1
299-W18-39	YJ-22	565886	135141	29	6.4	14.9	9.0	10.1
699-46-68	YJ-23	569110	137601	32	66.9	65.8	69.6	67.4
299-W15-229	YJ-24	566049	135679	29	74.8	75.3	79.7	76.6
299-W7-14	YJ-25	566022	137639	29	87.3	60.9	62.9	70.4
299-E20-1	YJ-26	570503	135200	29	86.4	81.9	83.6	84.0
299-E20-2	YJ-27	570898	134896	29	75.4	76.4	71.2	74.4
299-E11-1	YJ-28	571003	134505	29	80.9	80.6	81.0	80.8
299-W18-43	YJ-31	565794	135234	29	108.2	113.2	103.7	108.4
299-W18-42	YJ-32	565788	135139	29	118.2	106.2	105.1	109.8

Note: Injection rates of iodine wells were multiplied by four to adjust for lower transmissivity.