3.0 Overview of Groundwater Flow

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This chapter provides a regional overview of groundwater flow beneath the Hanford Site. The uppermost aquifer beneath most of the site is unconfined and is composed of unconsolidated to semiconsolidated sediment of the Hanford formation, Cold Creek unit (CCU), and Ringold Formation, which overlie the basalt bedrock. In some areas, deeper portions of the aquifer are confined locally by layers of silt and clay. Deeper confined aquifers also occur within the underlying basalt and associated sedimentary interbeds (see Chapter 2.0). Wells in the 600 Area, which cover portions of the site other than the former operational areas, are shown in Figure 3-1. More detailed well location maps for specific areas are included in Chapters 4.0 through 15.0.

During March 2010, a total of 808 water-level measurements were collected across the Hanford Site. This information helps scientists understand the direction and rate of groundwater flow.

During March 2010, a total of 808 water-level measurements were collected from wells monitoring the unconfined aquifer system and the underlying confined aquifers beneath the Hanford Site. The data were used for the following purposes:

- Prepare contour maps that indicate the general direction of groundwater movement within an aquifer
- Determine hydraulic gradients, which in conjunction with the hydraulic properties of the aquifer, are used to estimate groundwater flow velocities
- Interpret sampling results.

This chapter describes the results of a regional-scale analysis of these data for the unconfined aquifer, which is the aquifer most affected by Hanford Site operations. Local groundwater flow in each groundwater operable unit (OU) and/or interest area is described in Chapters 4.0 through 14.0. The flow characteristics in the confined aquifers that are present in the lower Ringold Formation and in the upper basalt-confined aquifer system are discussed in Chapter 15.0. The collection and analysis of manual water-level measurements at the Hanford Site are described in *Water-Level Monitoring Plan for the Hanford Site Soil and Groundwater Remediation Project* (SGW-38815).

3.1 March 2010 Water Table and Changes from 2009

Figure 3-2 presents the Hanford Site water table map for March 2010. The water table mapping methodology is described in Chapter 4.0 of SGW-38815 (the water-level monitoring plan). In general, water-level measurements are displayed on a map using a geographic information system and contours are hand-drawn by a hydrogeologist. Generation of the March 2010 map differed from the methodology described in SGW-38815 by using a software numerical-grid generation algorithm to guide the hand-generation of contours near the groundwater pump-and-treat systems. This resulted in a better representation of water table drawdown and buildup around extraction and injection wells, respectively. The software (KT3D_H2O) uses the statistical, kriging numerical-grid generation method and includes additional drift terms in the kriging equation to represent extraction and injection wells ("KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms" [Karanovic et al., 2009]; SGW-42305, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*). Details of the water table configuration near the pump-and-treat systems are not evident in

Groundwater in the unconfined aquifer generally flows from the west toward the east beneath the Hanford Site and discharges to the Columbia River.

Figure 3-2 because of the small scale of the map but are evident on the larger scale water table maps presented in other chapters of this report.

Groundwater in the unconfined aquifer generally flows from upland areas in the west toward the regional discharge area north and east along the Columbia River. Steep hydraulic gradients occur in the west, east, and north regions of the Hanford Site. Shallow gradients occur southeast of the 100-F Area and in a broad arc extending from west of the 100-B/C Area, toward the southeast between Gable Butte and Gable Mountain (Gable Gap), through the 200 East Area and on into the central portion of the site. The steep gradients in the west and east are associated with low-permeability sediment of the Ringold Formation at the water table, while the low gradients are generally associated with highly permeable sand and gravel of the Hanford formation as well as the gravel-dominated facies of the CCU at the water table (PNNL-19702, *Hydrogeologic Model of the Gable Gap Area, Hanford Site*, Chapter 7.0).

North of Gable Butte and Gable Mountain, groundwater flow directions vary from northwest to east depending on location. Groundwater enters this region through the gaps between Gable Mountain, Gable Butte, and Umtanum Ridge (Figure 3-2), as well as from natural recharge. The Columbia River also recharges the unconfined aquifer west of the 100-B/C Area. Water flowing north through Gable Gap fans out and flows north-northwest toward the Columbia River, as well as toward the northeast and east along the north side of Gable Mountain. Recharge water from the Columbia River and the gap between Umtanum Ridge and Gable Butte is thought to flow east toward the 100-B/C Area and discharge to the river near that area. In the 100 Area, the local groundwater flow is generally toward the Columbia River, although this pattern is altered locally by groundwater pump-and-treat remediation systems in the 100-K, 100-D, and 100-H Areas.

Daily, monthly, and seasonal changes in Columbia River stage affect the flow of groundwater in the near river environment. During periods of high river stage, the Columbia River temporarily recharges the adjacent aquifer all along the river (bank storage effects), whereas during periods of low river stage, groundwater discharges from the aquifer to the river. River stage changes cause a mixing zone to occur in the aquifer along the river. At any given time, water discharging from the aquifer to the river can be composed of nearly all river water in bank storage, nearly all aquifer water, or some mixture depending on the recent history of river stage changes (PNNL-13674, *Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River*). Modeling results indicate that groundwater flowing into the near river environment generally moves downward at the shoreline in response to river stage effects and then enters the river between ~30 to ~60 meters offshore (PNNL-13674), although areas of groundwater upwelling have been identified in the center of the river channel (WCH-380, *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington*).

An apparent groundwater mound exists ~2 kilometers north of Gable Mountain and is associated with low-conductivity Ringold Formation mud at the water table. This mound is contoured as if it were part of the unconfined aquifer (Figure 3-2), but it could represent a perched water table above the regional water table. Additional data are needed to distinguish between these alternatives. Water-level elevations indicate that groundwater moving toward the east along the north side of Gable Mountain flows around this apparent mound.

South of Gable Butte and Gable Mountain, natural recharge to the aquifer comes from the Cold Creek Valley, Dry Creek Valley, Rattlesnake Hills, Yakima River, and infiltrating precipitation. Groundwater generally flows from west to east, although some of the flow from the 200 West Area and/or north of the 200 West Area turns north and flows through Gable Gap. Previous effluent discharges at U Pond and other facilities caused a groundwater mound to form beneath the 200 West Area that significantly affected regional flow patterns in the past (e.g., see Figures 4 through 10 in PNNL-16069, *Development of Historical Water Table Maps of the 200 West Area of the Hanford Site [1950-1970]*). These discharges largely ceased in the mid-1990s but a remnant mound remains, which is apparent from the shape of the water table contours passing through the 200 West Area. Currently, the water table elevation is ~10 meters above the estimated water table elevation prior to the start of Hanford Site operations.[1] Equilibrium conditions will be re-established in the aquifer after dissipation of the mound caused by artificial recharge. When this occurs, the water table may still be ~5 to 7 meters higher than before Hanford Site operations began because of increased irrigation activities west of the site. The water table beneath the 200 West Area is perturbed locally by current discharges from the State-Approved Land Disposal Site, as well as by operation of a groundwater pump-and-treat remediation system at the 200-ZP-1 OU. The water table is expected to be further altered by the expansion of the 200-ZP-1 pump-and-treat system, which is planned to startup in late 2011.

The water table in the 200 East Area is very flat, which makes determination of flow direction difficult.

Groundwater flow in the central portion of the Hanford Site (encompassing the 200 East Area) is substantially affected by the presence of highly permeable buried paleochannels, which lie in a northwest to southeast orientation (PNNL-19702, Section 6.2; PNNL-12261, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*, Chapter 4.0). The water table in this area is very flat (i.e., the magnitude of the hydraulic gradient is estimated to be ~10^{-5} m/m or less) because of the high permeability of the Hanford formation/CCU sediments. Groundwater flow in this region is affected by the presence of low-permeability sediment (i.e., muds) of the Ringold Formation at the water table east and northeast of the 200 East Area, as well as basalt above the water table. These features generally constitute barriers to groundwater flow, although the unconfined aquifer can occur in the fractured and rubbly basalt flow top where it has not been removed by erosion. The extent of the basalt units above the water table continues to increase slowly because of the declining water table, resulting in an even greater effect on groundwater flow in this area. In Figure 3-2, the depiction of basalt above the water table in the Gable Gap and 200 East Area vicinity was revised for this annual report to be consistent with a recent reinterpretation of the top of basalt (PNNL-19702, Figure 2-5). The water table beneath the 200 East Area is ~1.9 meters higher than estimated pre-Hanford conditions.[2] When equilibrium conditions are re-established, the water table in the 200 East Area is expected to return to very near the pre-Hanford elevation.

1 Based on the March 2010 water-level elevation in well 299-W18-15 (135.6 meters North American Vertical Datum of 1988 [NAVD88]) and the pre-Hanford water table elevation at the location of this well estimated from *Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation* (BNWL-B-360) (~125.1 meters NAVD88). The peak historical water-level elevation in the 200 West Area occurred at well 299-W18-15 in 1984 (149.1 meters NAVD88).

2 Based on the average water-level elevation measured in 46 wells within the 200 East Area during March 2010, all of which have been corrected for deviations of the boreholes from true vertical (121.87 meters NAVD88) and the pre-Hanford water table elevation for the 200 East Area estimated from BNWL-B-360 (~120 meters NAVD88).

Water enters the 200 East Area and vicinity from the west and southwest, as well as from beneath the mud units to the east and from the underlying aquifers where the confining units have been removed or thinned by erosion. The flow of water divides beneath the 200 East Area, with some water flowing toward the north through Gable Gap and some flowing southeast toward the central portion of the site. The specific location of the groundwater flow divide is not certain because the flat nature of the water table in the 200 East Area makes determining flow directions difficult (see Section 3.2 for more information). It is known that groundwater flows north through Gable Gap because the hydraulic gradient magnitude within the gap area is large enough to be determined using water-level data. During 2010, the gradient magnitude in Gable Gap averaged 9.3 x 10^{-5} m/m along a north flow direction, but flow conditions vary during the year due to changes in river stage (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*, Section 2.1.4). Groundwater is inferred to flow southeast within the region between the 200 East Area and the Hanford Central Landfill because the average water-level elevation at the landfill (121.75 meters North American Vertical Datum of 1988 [NAVD88] for March 2010) is 0.12 meters lower than the average elevation in the 200 East Area (121.87 meters NAVD88 for March 2010). This yields a regional hydraulic gradient magnitude of ~1.5 x 10^{-5} m/m.

The water table continued to decline over much of the Hanford Site. The decline is due to the reduction of effluent discharges to the ground during the 1980s and 1990s.

The hydraulic gradient magnitude in the 300 Area is also very low due to the presence of the highly permeable sediments of the Hanford formation at the water table. Groundwater flow converges on the 300 Area from the northwest, west, and southwest, then generally moves toward the southeast and discharges to the Columbia River (PNNL-15127, *Contaminants of Potential Concern in the 300-FF-5 Operable Unit: Expanded Annual Groundwater Report for Fiscal Year 2004*, Section 3.1.2). As in the 100 Areas, flow in the 300 Area is also affected by Columbia River stage changes.

The water table elevation continued to decline over much of the Hanford Site from March 2009 to March 2010. The decline is a result of the reduction of effluent discharges to the ground during the 1980s and 1990s. Outside of regions affected by groundwater pump-and-treat systems, the largest widespread declines occurred from west of the 200 West Area to the Cold Creek Valley, where the decrease in water levels ranged from 0.20 to 0.46 meters. Within the 200 West Area, water-level declines averaged 0.21 meters in areas away from the pump-and-treat systems. Water-level elevations increased slightly in Dry Creek Valley (i.e., 0.02 to 0.05 meters). The water table elevation also increased in the Richland area between the Yakima and Columbia Rivers. When considering only those wells not associated with pump-and-treat systems, the largest increase was 0.59 meters in well 699-S34-E15 located in North Richland not far from the Columbia River, and the largest decrease was 1.95 meters in well 1199-39-15 at the city of Richland North Well Field. These changes are attributed to operation of the well field and/or changes in river stage.

In the 200 East Area, the elevation of the water table declined by an average of 0.05 meters between March 2009 and March 2010, compared to a decline of 0.09 meters from March 2008 to March 2009 (DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2*, Section 2.2). The smaller decline is attributed to increased effluent discharges at the Treated Effluent Disposal Facility (TEDF) (1.3 x 10^9 liters from March 2009 to February 2010) compared to the previous one-year period (2.6 x 10^8 liters from March 2008 to February 2009). This facility is located east of the 200 East Area, and it has been previously documented that higher than normal discharges to this

facility cause water-table fluctuations in the 200 East Area (PNNL-16346, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*, Section 2.1.3). During 2010, the discharge volume to this facility was elevated in April and May and again from August to October. This caused two separate fluctuations in the 200 East Area water table elevation during the year, as shown in Figure 3-3. In fact, the water table elevation in the 200 East Area was essentially the same in January and December 2010 (i.e., no net change occurred in water table elevation during 2010) as a consequence of the TEDF discharges.

3.2 200 East Area Hydraulic Gradient Evaluation

In the previous annual report (DOE/RL-2010-11, Section 2.3), efforts to measure the hydraulic gradient in the 200 East Area at Low-Level Waste Management Area 1 (LLWMA-1) and at the Integrated Disposal Facility (IDF)/Plutonium Uranium Extraction (PUREX) Cribs were described and the results to date were provided. This work continued during 2010. This section provides an update of the study, including the analyses performed during 2010 and a discussion of efforts to measure the hydraulic gradient at an additional location, the area of LLWMA-2/216-B-63 Trench. This discussion emphasizes the collection and analysis of water-level data and the usefulness of the data for determining hydraulic gradients. A more detailed integration of these analyses with the groundwater sampling results is provided in site-specific sections of this report (see Chapter 9.0, Section 9.3.1 for LLWMA-1, Section 9.3.2 for LLWMA-2, and Section 9.3.6 for the 216-B-63 Trench; and see Chapter 10.0, Section 10.3.1 for the IDF and Section 10.3.2 for the PUREX Cribs).

As described in Section 3.1, the water table in the 200 East Area is very flat due primarily to the high permeability of the Hanford formation and CCU, as well as the presence of a groundwater flow divide in this area. The estimated regional hydraulic gradient magnitude of ~1.5×10^{-5} m/m (Section 3.1) equates to a change of 1.5 centimeters in water table elevation per kilometer. The distance from the northwest to the southeast corners of the 200 East Area is ~4 kilometers, so the water table elevation is expected to change no more than ~6 centimeters in the 200 East Area if the hydraulic gradient was uniform. However, because a flow divide is interpreted to exist within this area, the actual water table elevation change is less. Figure 9-4 in Chapter 9.0 indicates that water-level elevations generally vary by ~2 to ~3 centimeters from northwest to southeast across the 200 East Area. Without correcting for the error caused by wellbore deviations from vertical, water-level data collected from the 200 East Area exhibit a range of ~10 centimeters. Thus, uncorrected water-level data are not accurate enough to determine hydraulic gradients within the 200 East Area.

A study is being conducted to determine groundwater flow directions in the 200 East Area to support groundwater monitoring at RCRA waste sites.

Several *Resource Conservation and Recovery Act of 1976* (RCRA) treatment, storage, and disposal (TSD) units are located within the 200 East Area. Groundwater monitoring under RCRA regulations requires that the groundwater flow direction be determined beneath each RCRA TSD unit to distinguish between upgradient and downgradient monitoring wells (e.g., 40 CFR 265.91[a], "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," "Ground-Water Monitoring System," as referenced by WAC 173-303-400, "Dangerous Waste Regulations," "Interim Status Facility Standards," for sites monitored under interim status regulations). Therefore, a study has been ongoing since September 2005 to improve the accuracy of water-level measurements in the 200 East Area so groundwater flow directions beneath the RCRA TSD units can be determined.

This study is being performed at three locations within the 200 East Area: LLWMA-1, the IDF/PUREX Cribs, and LLWMA-2/216-B-63 Trench. A network of wells was established at each site, with the wells chosen so long screen intervals were avoided where possible. The well networks for each site are shown in Figure 3-4 for LLWMA-1, Figure 3-5 for the IDF/PUREX Cribs, and Figure 3-6 for LLWMA-2/216-B-63 Trench. The network for LLWMA-1 initially consisted of ten wells, but four additional wells (299-E28-1, 299-E28-17, 699-49-55A, and 699-50-56) were added in early 2008, forming a network of fourteen wells.

The accuracy of water-level measurements in the 200 East Area was improved by conducting wellbore deviation surveys and highly accurate casing elevation surveys.

Gyroscope and elevation surveys were performed for each well to improve the accuracy of the water-level measurements. The gyroscope surveys were performed to correct for deviations of the wellbores from vertical. Such deviations result in a measured depth to water that is larger than the true vertical depth to water and, therefore, a calculated water-level elevation that is lower than the true elevation. A gyroscope survey is used to map the position of the wellbore in three-dimensional space, which allows for the difference between the measured and true vertical depths to water to be determined. The largest correction value during this study was 0.367 meters (36.7 centimeters), and the average correction value was 0.040 meters (4.0 centimeters).

Casing elevation surveys were performed to a higher degree of accuracy than normally performed for monitoring wells at the Hanford Site. Leveling surveys were performed for each well network using an infrared sighting device and a one-piece invar rod; double runs were performed between wells and the results were averaged. All of the wells resurveyed in the 200 East Area were referenced to a single benchmark. All surveys were performed in loops that closed on the starting point, allowing for misclosure values[3] to be determined. The largest misclosure value was 0.003 meters (0.3 centimeters) and the average misclosure was 0.0011 meters (0.11 centimeters), indicating that high accuracy was achieved.

Water-level measurements were collected using measuring tapes dedicated for this study. The initial measuring tape used was calibrated by a standards laboratory and found to be accurate to within 0.001 meter (1 millimeter) throughout its length.

The water-level measurements were analyzed by trend-surface analysis, in which a plane is fitted to a set of water-level measurements by least-squares regression. The interpreted hydraulic gradient direction corresponds to the dip direction of the fitted plane, and the amount of dip represents the hydraulic gradient magnitude. The degree to which the plane represented the data (i.e., the goodness of fit) was assessed by an analysis of variance statistical test. This test is used to determine whether the data exhibit a true spatially dependent trend to an acceptable probability of error (i.e., the level of significance), which was chosen to be 0.05 for this study (i.e., a 95% confidence level). It should be emphasized that the fitting of a first-degree trend surface (i.e., a plane) is a method that reveals the overall linear trend in the measurements across an entire study area; local deviations from the linear trend can occur within any study area.

3 A misclosure value is the difference in elevation between the starting and ending values of a survey loop that closes on the starting point. Ideally, the misclosure value should be zero, but this is rarely achieved because measurements always have some uncertainty. Thus, the misclosure value provides an indication of the uncertainty in a survey loop. Small misclosure values indicate high accuracy. The misclosure is typically distributed linearly throughout the survey loop to determine final elevations.

3.2.1 Low-Level Waste Management Area 1

Water-level measurements for this study have been periodically collected at LLWMA-1 since September 2005, and the trend-surface analysis results are shown in Table 3-1. The results of the statistical test are given as the *p* value, which is the probability that the degree of an apparent spatially dependent trend observed in the data (or a trend of even greater degree) would occur solely by random chance. Where this value is less than 0.05, the trend-surface analysis result is deemed statistically significant at the 95% confidence level (i.e., it is accepted that the fitted trend surface is a good approximation of the overall hydraulic gradient across the study area for the set of measurements being analyzed).

Eleven sets of water-level measurements were collected at LLWMA-1 from September 2005 through June 2008, and all but two of the measurements yielded a statistically significant result, indicating a gradient direction between northwest and north (Table 3-1). The *p* values for the two data sets not deemed statistically significant were 0.060 and 0.070, which are only slightly above 0.05. Using all of the trend-surface analysis results, the average hydraulic gradient magnitude during this time was 8.2×10^{-6} m/m ($\pm 0.7 \times 10^{-6}$ m/m) and the average direction was toward the north-northwest at 338 degrees azimuth (±9 degrees). This interpretation is in general agreement with the orientation of contaminant plumes emanating from nearby Waste Management Area B-BX-BY and the BY Cribs.

At LLWMA-1 in the northwestern portion of the 200 East Area, the long-term groundwater flow direction is toward the north-northwest, although temporary flow reversals can occur due to seasonal changes in Columbia River stage.

The collection of water-level measurements on a monthly basis began at LLWMA-1 during June 2008, and beginning in July 2008, the hydraulic gradient results began to change. The results in July 2008 were not statistically significant with a very high *p* value (Table 3-1). During August, September, and October, the results were statistically significant, with flow directions toward the south for all 3 months. Although the results for November and December were not statistically significant, gradient directions toward the south were indicated with only moderately high *p* values. During January, February, and March 2009, the results were not statistically significant with very high *p* values. Indications of a gradient direction toward the north began again during April and May with moderately high *p* values, and finally a statistically significant northern gradient direction was indicated for July 2009. These results indicate that a temporary reversal in groundwater flow direction occurred, with flow toward the south occurring from August through October 2008, and perhaps into December. The months with high *p* values, (i.e., July 2008 and January, February, and March 2009) indicate periods of transition between northward and southward flow. The mean gradient magnitude and direction was not calculated for the data sets after June 2008 because it would not be representative of groundwater flow during a period of changing flow conditions.

Previous work has suggested that in addition to the long-term decline in water levels due to the reduction of effluent discharges at the Hanford Site, the water table elevation in the 200 East Area is potentially affected by two other stressors: seasonal changes in river stage, and discharges to the TEDF east of the 200 East Area (PNNL-16346, Section 2.1.3). It is feasible for changes in the river stage to affect the water table in the 200 East Area because the aquifer in this area and to the north through Gable Gap is highly transmissive. The two stressors are expected to have opposite effects on the hydraulic gradient at LLWMA-1. Because the TEDF is located southeast of LLWMA-1, discharges to the TEDF should increase the magnitude of the northward hydraulic gradient. In contrast, river stage increases propagating inland from the north should decrease the northward gradient or cause a gradient reversal at LLWMA-1. The flow reversal documented at LLWMA-1 appears to be a result of

high river stage during the summer of 2008 combined with the lack of large-volume discharges to the TEDF that year.

Between September 2009 and May 2010, the hydraulic gradient at LLWMA-1 was not discernable. As shown in Table 3-1, the *p* values during this timeframe were high and the dip direction of the fitted trend surfaces had values in all four quadrants of the compass. This suggests that the hydraulic gradient was extremely low and that flow was stagnant, or nearly stagnant, within the study area during this time. This situation corresponds to a period of low discharge volumes to the TEDF from July 2009 to March 2010 (Figure 3-3).

The measurements collected during June 2010 exhibited a statistically significant gradient direction toward the north. Subsequent measurements in July, September, and in January 2011 indicate northward directions, with *p* values lower than the values in late 2009/early 2010, although none of the results were statistically significant. However, because the *p* values were relatively low during this time, the hydraulic gradient is interpreted to be toward the north throughout the latter half of 2010. This corresponds to a period of high-discharge volumes to the TEDF from April to October 2010 (Figure 3-3).

The remaining error in the water-level elevation determinations was estimated using the six wells in this study that are located around the perimeter of LLWMA-1: 299-E28-27, 299-E32-5, 299-E32-6, 299-E32-8, 299-E33-28, and 299-E33-34. These wells were used because trend-surface analyses on only these six wells indicate that the water table is too flat directly beneath LLWMA-1 to be measured. Thus, it was assumed that all of the variability exhibited by these measurements (on any given measurement date) was due solely to measurement error. Based on the standard deviation of the water-level elevations determined for these wells since June 2008,[4] the 90% confidence interval is ±0.006 meters (i.e., ±6 millimeters), for a total range of 0.012 meters. This represents an upper bound on the total remaining variability in the water-level measurements (because some of the variability could be due to a very low hydraulic gradient magnitude). Sources of this variability include the accuracy limit of the gyroscope and casing elevation surveys, differences in water-level fluctuations between wells due to barometric pressure changes, and the accuracy of the depth-to-water measurements.

3.2.2 Integrated Disposal Facility/PUREX Cribs

At the IDF/PUREX Cribs, water-level measurements have been collected for this study since June 2008. The measurements at this site exhibit more variability than those from LLWMA-1. Many of the wellbores at the IDF/PUREX Cribs are more substantially deviated from vertical. This results in more friction when a measuring tape is lowered into the well, which makes obtaining an accurate depth-to-water measurement more difficult. In addition, field observations indicate a greater amount of air movement through the wellbores in response to atmospheric pressure changes than has been observed at LLWMA-1, so water-level changes caused by barometric pressure fluctuations could be greater.

At the IDF/PUREX Cribs in the southeastern portion of the 200 East Area, water-level data indicate that the groundwater flow direction is toward the east.

The trend-surface analysis results for IDF/PUREX Cribs are provided in Table 3-2. When all of the wells were used in the trend-surface analyses, statistically significant results were not obtained for any set of measurements. To obtain the results shown

4 This analysis considered only the difference of each water-level elevation value from the mean value of all six wells for each measurement date. Thus, changes in the water table elevation over time due to the long-term water-level decline or temporary fluctuations were not included as part of the measurement variability.

in Table 3-2, each data set was analyzed by repeatedly removing the well with the highest residual (i.e., the measurement having the largest difference from the fitted plane) until the dip direction stabilized and the trend-surface result was statistically significant. Three wells were removed from the analyses much more frequently than the others: 299-E17-18 (removed from ten of the sixteen analyses; always biased low), 299-E24-16 (removed from fifteen of the sixteen analyses; always biased high), and 299-E24-18 (removed from thirteen of the sixteen analyses; always biased low). All three wells were drilled by cable tool and constructed with 4-inch-diameter screens inside 8-inch-diameter telescoping screens. However, one other well in the network, 299-E25-36, was drilled and completed in the same manner but its water levels did not exhibit a bias (it was removed from only one of the sixteen data sets). Thus, well construction does not seem to be the cause of the bias. If the bias was due to barometric pressure effects, it is expected that the values would be biased both high and low in the same well depending on whether the barometric pressure was increasing or decreasing at the time of measurement. However, water levels from each of the three wells are always biased either high or low. This suggests that the measurements from these wells are affected by some residual systematic source of bias, either in the well casing elevation surveys, the gyroscope surveys, or that the water level in the well is not representative of the water table for some undetermined reason (to the degree of accuracy needed for this study). From the trend-surface analyses, the resulting hydraulic gradient directions range from northeast (29 degrees azimuth) to south (173 degrees azimuth). The average direction was toward the east at 80 degrees (±17 degrees), and the average gradient magnitude was 2.0×10^{-5} m/m ($\pm 0.2 \times 10^{-5}$ m/m). The average gradient magnitude is in close agreement with the estimated regional gradient magnitude of $\sim 1.5 \times 10^{-5}$ m/m (Section 3.1), and the average direction is in reasonable agreement with previous interpretations of flow toward the east/southeast based on the geometry of contaminant plumes (see Chapter 10.0, Sections 10.3.1 and 10.3.2).

3.2.3 Low-Level Waste Management Area 2 and 216-B-63 Trench

Work has been ongoing to determine the hydraulic gradient at a third location in the 200 East Area, the LLWMA-2 and 216-B-63 Trench vicinity; however, to date, this effort has not been successful. At this location, a network of eight wells was established (Figure 3-6) and gyroscope and casing elevation surveys were performed. The collection of water-level measurements began in March 2009 and continued during 2010. Only two of the trend-surface analysis results were statistically significant out of seventeen data sets. The remaining data sets had p values ranging from 0.2 to 0.9. When using the technique employed for the IDF/PUREX network of removing the measurement with the highest residual and repeating the trend-surface analyses until convergence (Section 3.2.2), nine of the seventeen data sets exhibited statistically significant results. Of these nine data sets, two had dip directions toward the west and the remaining seven had dip directions to the north-northeast toward a basalt subcrop above the water table, which is interpreted as a no-flow boundary. Thus, the trend-surface analyses are considered inconclusive.

Furthermore, the water-level elevations determined for the LLWMA-2/216-B-63 Trench well network exhibited an average range of 0.013 meters on any given measurement date. This range is nearly equal to the estimated error range in the water-level elevations determined for LLWMA-1 of 0.012 meters (Section 3.2.1). It appears that all, or nearly all, of the variability in the LLWMA-2/216-B-63 Trench water-level elevations can be attributed to residual

The hydraulic gradient magnitude is currently too low to measure at the LLWMA-2/216-B-63 Trench site.

error, which explains the unsatisfactory trend-surface analysis results. Therefore, it is concluded that the hydraulic gradient magnitude at LLWMA-2/216-B-63 Trench is currently too low to measure. Data collection and analysis will continue at this site during 2011.

Table 3-1. Hydraulic Gradient Determinations for Low-Level Waste Management Area 1

Measurement Date	Gradient Magnitude (m/m)	Gradient Direction (Azimuth)[a]	*p* Value[b]	Statistically Significant?
Ten-Well Network				
9/1/05	7.7×10^{-6}	312	0.020	Yes
9/12/05	8.2×10^{-6}	329	0.017	Yes
10/11/05	8.0×10^{-6}	356	0.005	Yes
10/25/05	6.4×10^{-6}	320	0.060	No
11/23/05	6.9×10^{-6}	336	0.017	Yes
12/29/05	1.0×10^{-5}	13	0.014	Yes
2/2/06	9.7×10^{-6}	350	0.011	Yes
3/8/06	7.8×10^{-6}	332	0.070	No
6/8/06	1.0×10^{-5}	347	0.009	Yes
1/25/07	7.3×10^{-6}	336	0.015	Yes
Fourteen-Well Network				
6/16/08	8.1×10^{-6}	324	0.005	Yes
Mean (through June 2008)	***8.2×10^{-6} ($\pm 0.7 \times 10^{-6}$)***	***338 (±9)***	--	--
7/21/08	1.3×10^{-6}	97	0.964	No
8/29/08	1.3×10^{-5}	213	0.004	Yes
9/11/08	9.3×10^{-6}	156	0.001	Yes
10/23/08	1.1×10^{-5}	226	0.038	Yes
11/26/08	1.1×10^{-5}	225	0.127	No
12/23/08	5.7×10^{-6}	160	0.289	No
1/12/09	8.9×10^{-7}	130	0.945	No
2/23/09	5.3×10^{-6}	149	0.516	No
3/24/09	6.3×10^{-7}	106	0.974	No
4/13/09	4.7×10^{-6}	316	0.271	No
5/28/09	8.2×10^{-6}	310	0.234	No
7/17/09	2.0×10^{-5}	335	0.013	Yes
9/21/09	3.7×10^{-6}	8	0.573	No
10/27/09	6.0×10^{-6}	100	0.578	No
11/12/09	3.5×10^{-6}	259	0.893	No
1/21/10	1.1×10^{-5}	243	0.675	No
5/23/10	6.3×10^{-6}	358	0.502	No
6/30/10	1.8×10^{-5}	353	0.021	Yes
7/13/10	1.0×10^{-5}	357	0.338	No
9/15/10	7.6×10^{-6}	315	0.065	No
1/4/11	1.1×10^{-5}	2	0.144	No

a. Degrees clockwise from true north; 90 = east, 180 = south, 270 = west, 0 and/or 360 = north.

b. The probability that the degree of an apparent spatially dependent trend observed in the data (or a trend of even greater degree) would occur solely by random chance. If the *p* value is less than 0.05, the fitted trend surface is deemed statistically significant.

Table 3-2. Hydraulic Gradient Determinations for Integrated Disposal Facility/PUREX Cribs

Measurement Date	Gradient Magnitude (m/m)	Gradient Direction (azimuth)[a]	*p* Value[b]	Statistically Significant	Number of Wells[c]
6/16/08	1.7×10^{-5}	61	0.012	Yes	9
8/1/08	2.9×10^{-5}	149	0.004	Yes	8
8/29/08	2.1×10^{-5}	59	0.007	Yes	8
9/11/08	2.7×10^{-5}	173	0.001	Yes	7
10/23/08	2.3×10^{-5}	52	0.026	Yes	7
11/26/08	1.1×10^{-5}	102	0.007	Yes	5
12/22/08	1.3×10^{-5}	91	0.043	Yes	7
1/26/09	1.6×10^{-5}	115	0.006	Yes	7
2/5/09	2.0×10^{-5}	51	0.008	Yes	8
3/24/09	2.0×10^{-5}	46	0.014	Yes	8
6/29/09	2.4×10^{-5}	29	0.010	Yes	5
9/22/09	2.7×10^{-5}	54	0.011	Yes	8
12/30/09	2.8×10^{-5}	84	0.004	Yes	9
3/16/10	2.2×10^{-5}	41	0.007	Yes	8
6/30/10	1.3×10^{-5}	103	0.019	Yes	8
9/14/10	1.2×10^{-5}	68	0.006	Yes	7
Mean	***2.0×10^{-5} ($\pm 0.2 \times 10^{-5}$)***	***80 (±17)***	--	--	--

a. Degrees clockwise from true north; 90 = east, 180 = south, 270 = west, 0 and/or 360 = north.

b. The probability that the degree of an apparent spatially dependent trend observed in the data (or a trend of even greater degree) would occur solely by random chance. If the *p* value is less than 0.05, the fitted trend surface is deemed statistically significant.

c. A total of eleven wells are in the IDF/PUREX water-level network, but to achieve statistically significant trend surface results, wells with the highest residuals were removed in sequence until a statistically significant result was achieved and the gradient direction stabilized.

Figure 3-1. Groundwater Monitoring Wells on the Hanford Site

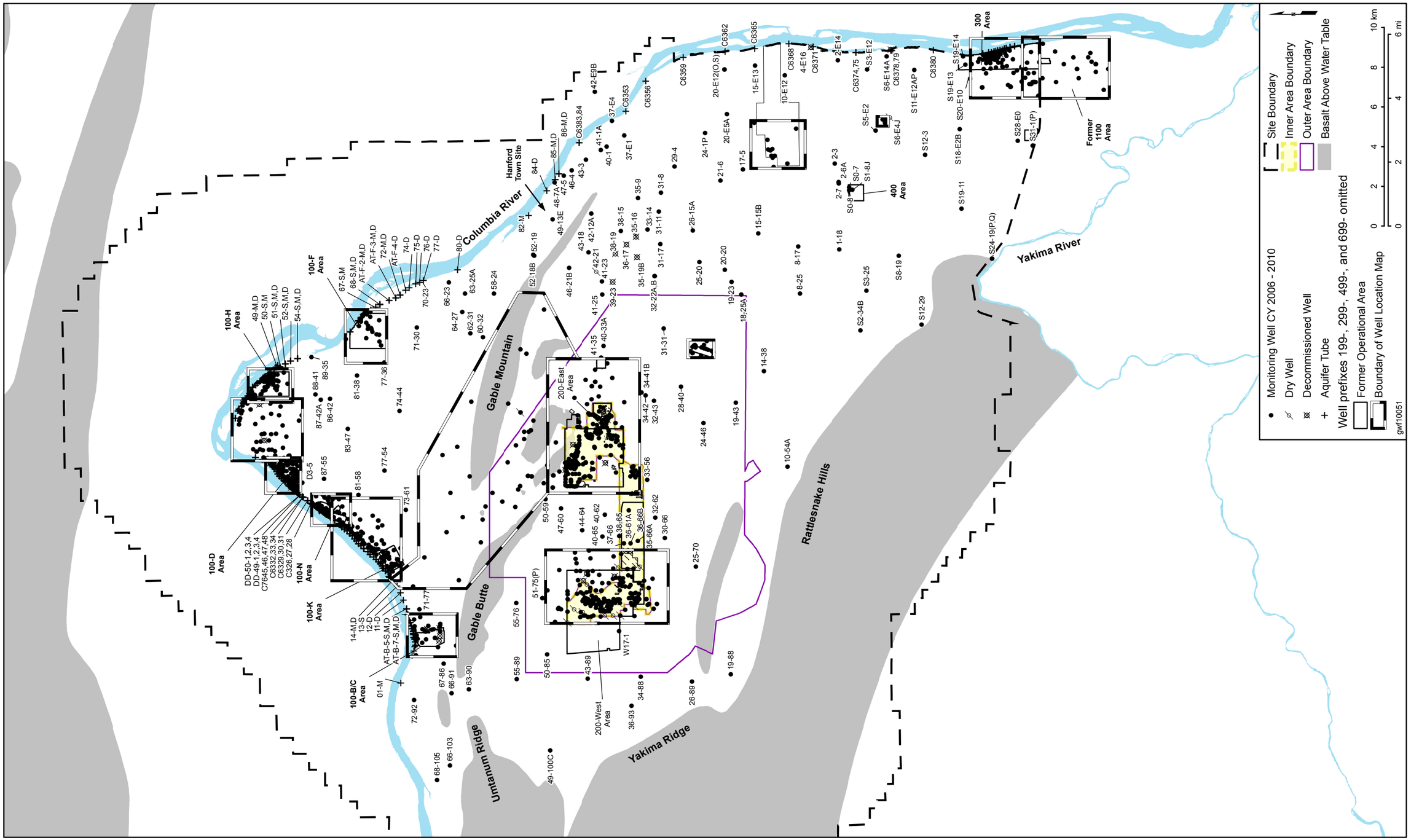

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Figure 3-2. Hanford Site Water Table Map, March 2010

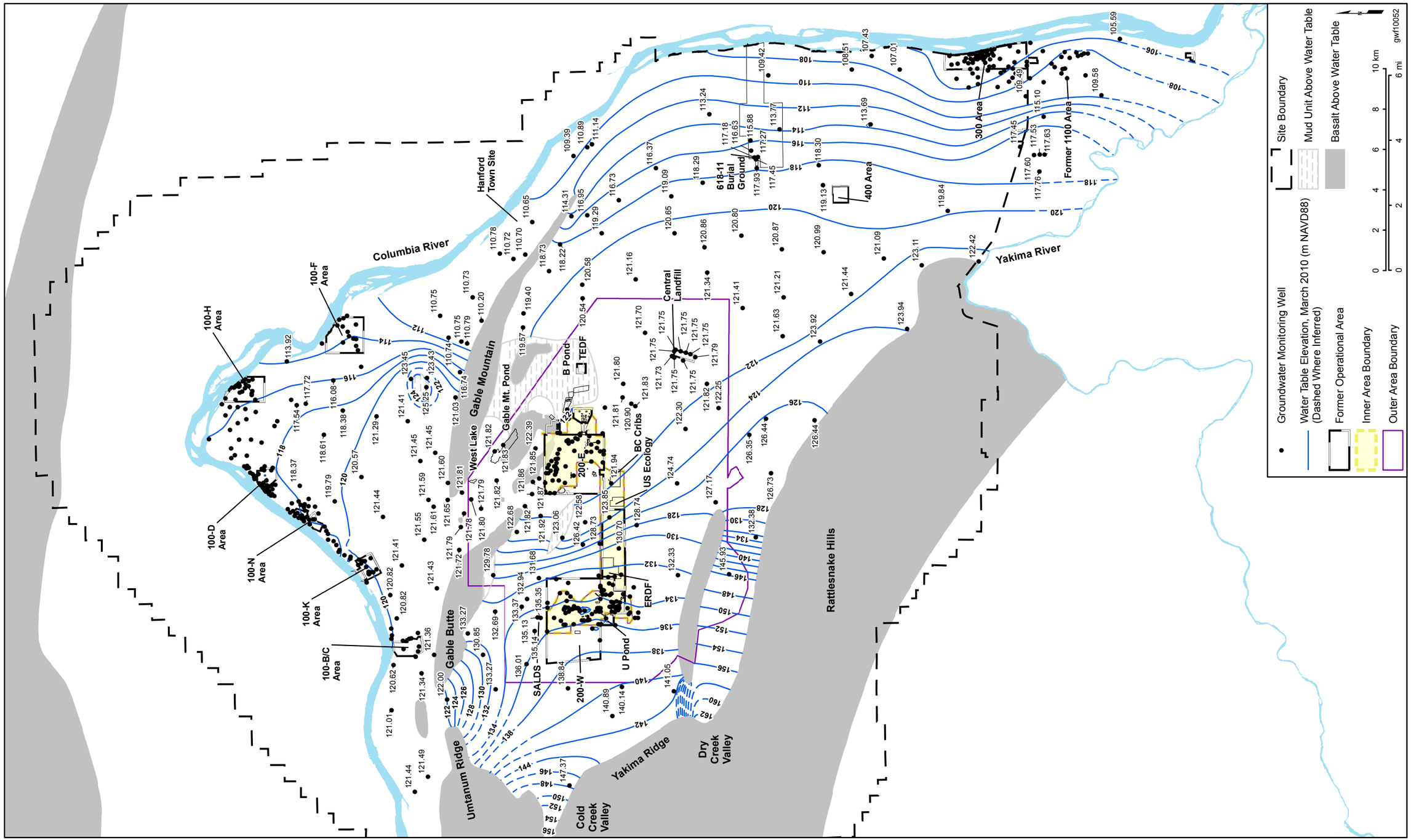

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Figure 3-3. 200 East Area Water Table Elevations and Monthly Disposal Volumes at the Treated Effluent Disposal Facility, Calendar Years 2009 and 2010

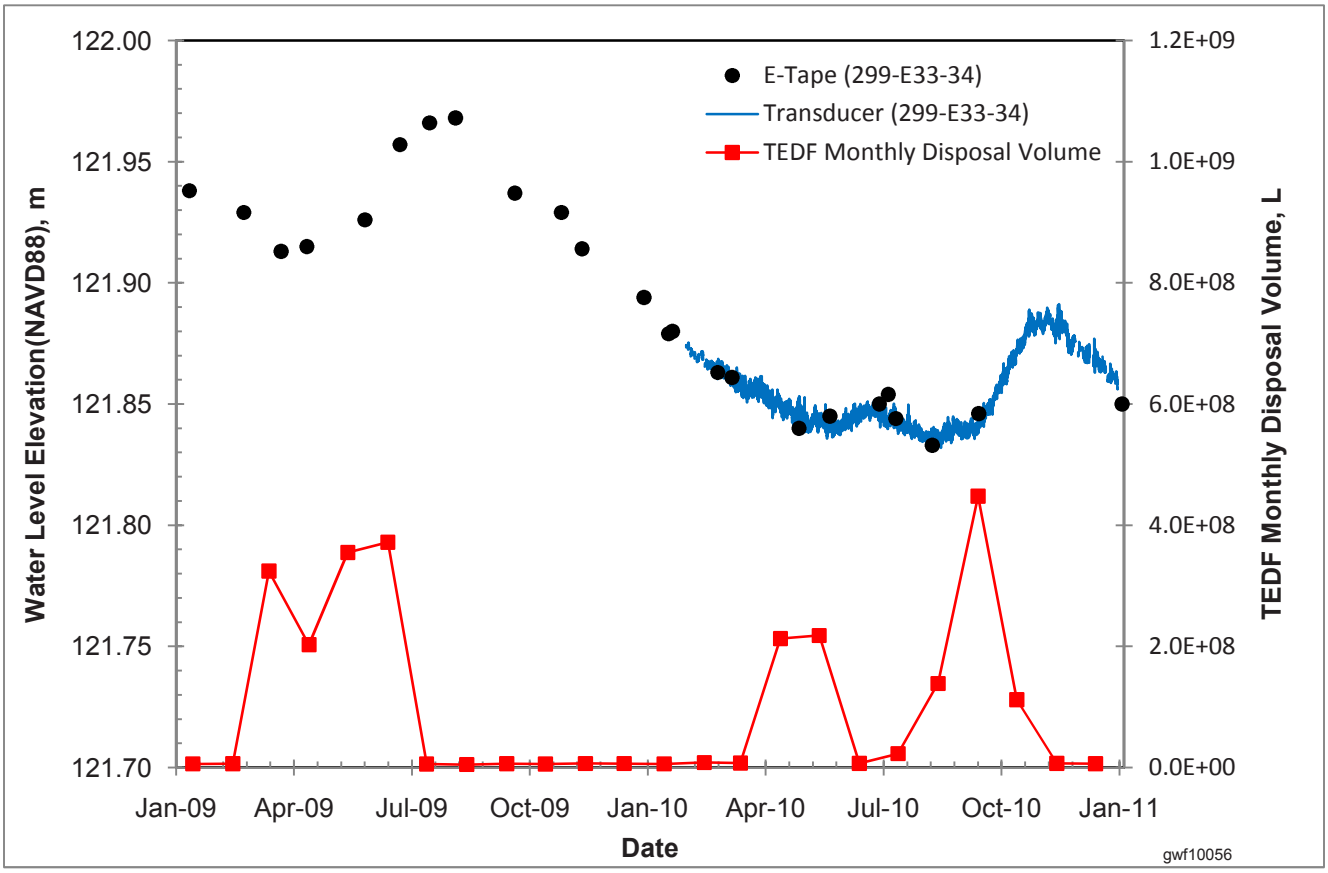

Figure 3-4. Low-Level Waste Management Area 1 Water-Level Monitoring Well Network

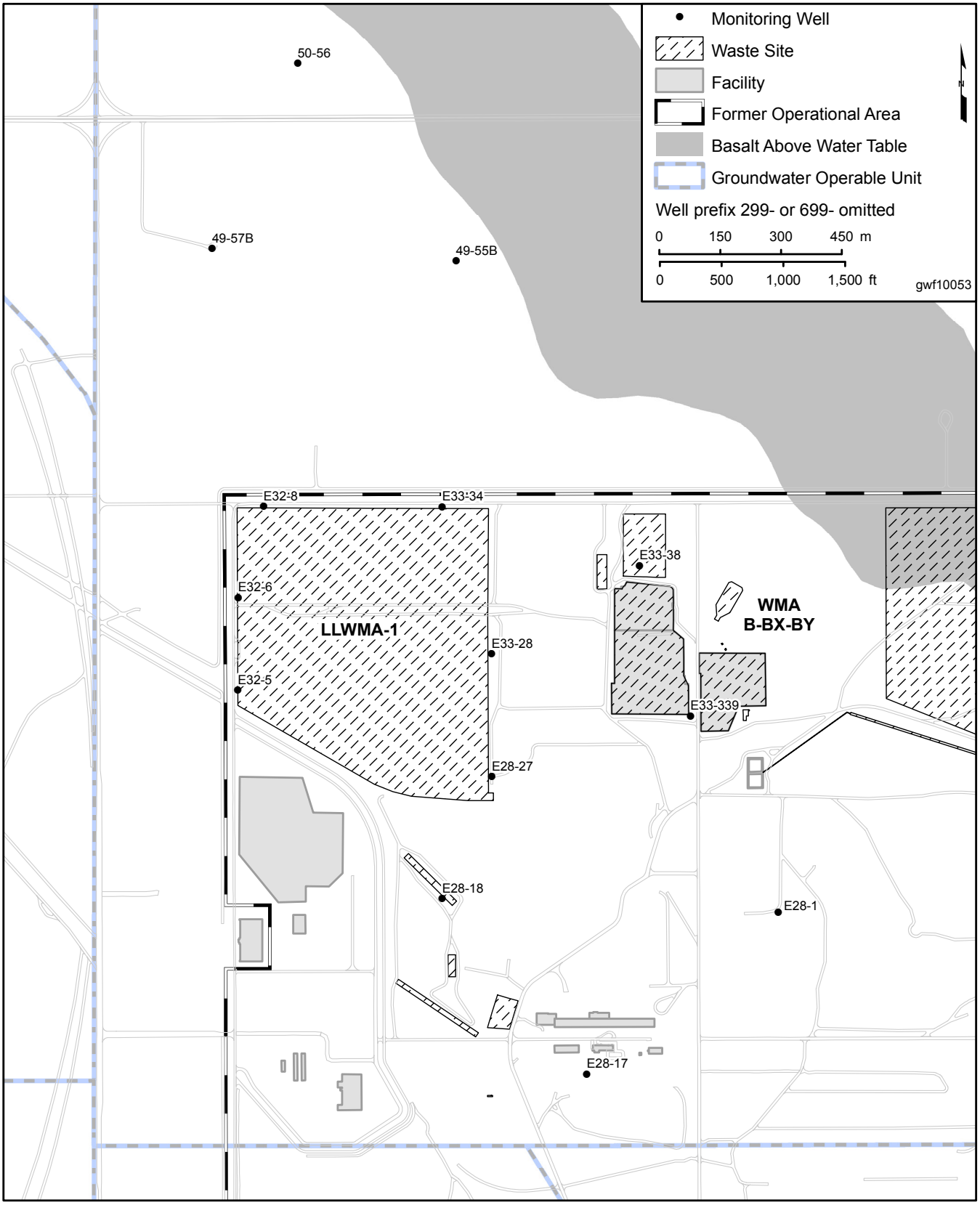

Figure 3-5. Integrated Disposal Facility/PUREX Cribs Water-Level Monitoring Well Network

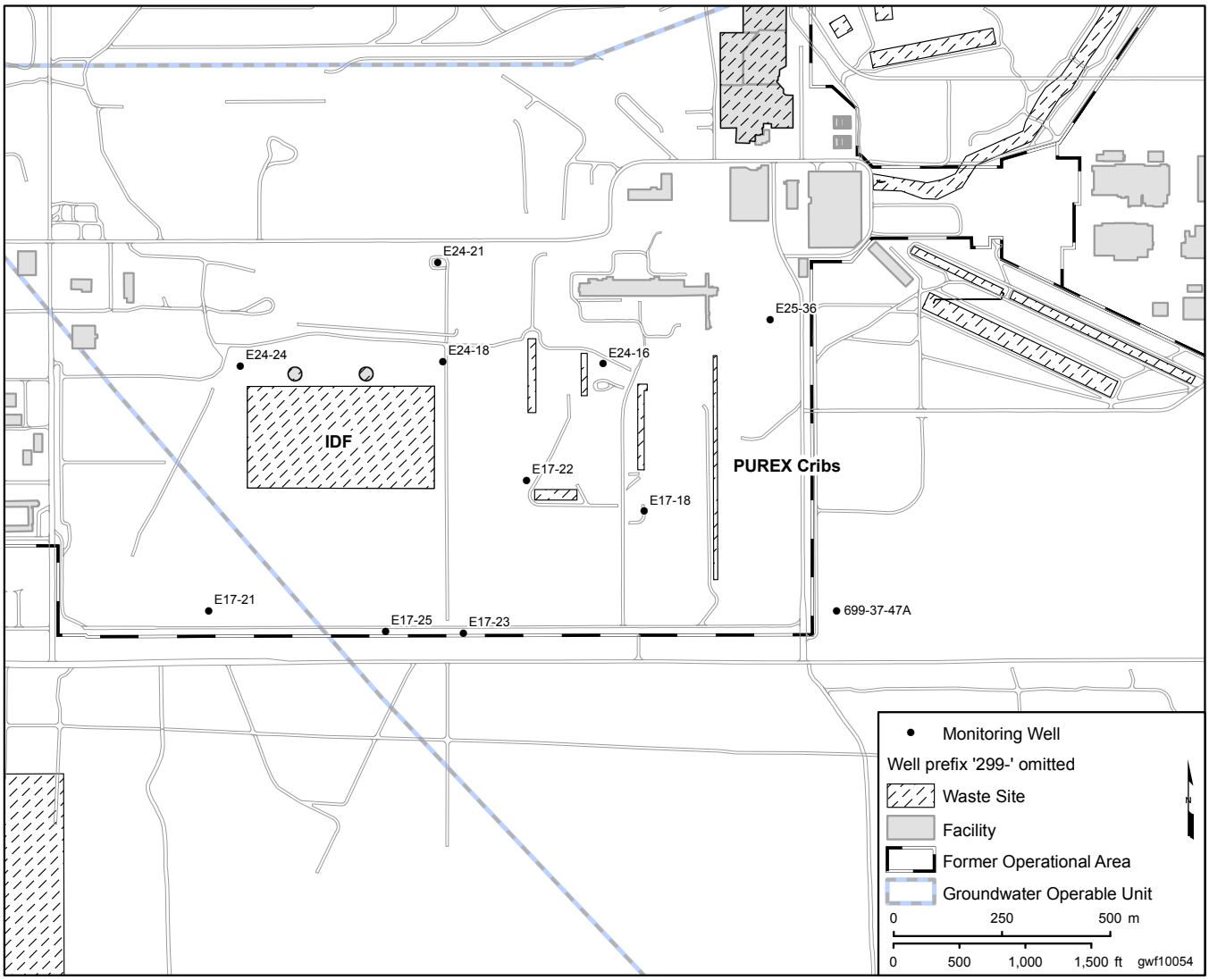
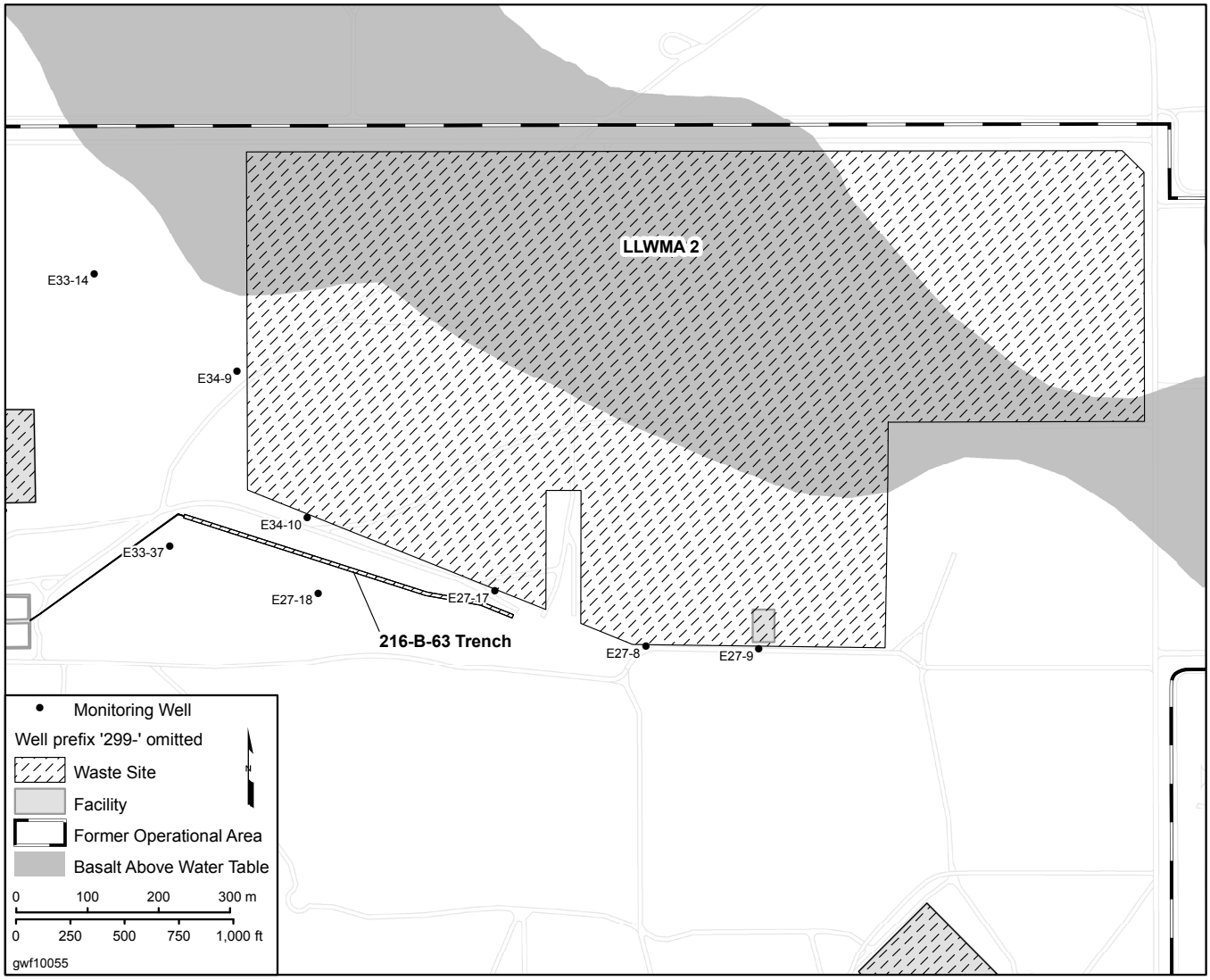
Figure 3-6. Low-Level Waste Management Area 2/216-B-63 Trench Water-Level Monitoring Well Network