2.1 Overview of Groundwater Flow

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This section provides a broad picture of groundwater flow beneath the Hanford Site. The uppermost aquifer beneath most of the Hanford Site is unconfined and is composed of unconsolidated to semi-consolidated sediment of the Hanford formation and Ringold Formation, which was deposited on the basalt bedrock. In some areas, deeper parts 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. Well location maps for each geographic region are included in Sections 2.2 through 2.14. Wells in the 600 Area, which cover portions of the Hanford Site other than the former operational areas, are shown in Figure 2.1-1.

During March 2007, 882 water-level measurements were collected from wells monitoring the unconfined aquifer system and the underlying confined aquifers beneath the Hanford Site. These data were used to (1) prepare contour maps that indicate the general direction of groundwater movement within an aquifer; (2) determine hydraulic gradients, which in conjunction with the hydraulic properties of the aquifer, are used to estimate groundwater flow velocities; (3) support conceptual and numerical groundwater model development, modification, and maintenance; and (4) interpret sampling results. This section describes the results of a regional-scale analysis of these data for the unconfined aquifer, which is the aquifer most affected by Hanford operations. Local groundwater flow in each groundwater operable unit is described in Sections 2.2 through 2.13. Flow characteristics in the confined aquifers present in the lower Ringold Formation and in the upper basalt aquifer system are discussed in Section 2.14.

During March 2007, 882 water-level measurements were collected across the Hanford Site. This information helps scientists understand the direction and velocity of groundwater flow.

2.1.1 Water-Table Interpretation for March 2007

Figure 2.1-2 presents the Hanford Site water-table map representative of conditions during March 2007. 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 gradients occur in the west, east, and north regions of the site. Shallow gradients occur southeast of the 100-F Area and in a broad arc extending from west of the 100-B/C Area to the southeast between Gable Butte and Gable Mountain (Gable Gap), and through the 200 East Area into the central portion of the site. The steep gradients in the west and east are due to the presence of the relatively low permeability sediment of the Ringold Formation at the water table, while the low gradients are associated with areas where the highly permeable sand and gravel of the Hanford formation is present at the water table.

North of Gable Butte and Gable Mountain, groundwater flow directions vary from northwest to east depending on the location. Groundwater enters this region through the gaps between Gable Mountain, Gable Butte, and Umtanum Ridge, as well as from natural recharge. The Columbia River also recharges the unconfined aquifer west of the 100-B/C Area. Groundwater flow patterns suggest that Gable Gap is the dominant source of recharge. Water flowing north through Gable Gap spreads 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

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

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. In the 100 Areas, the local groundwater flow is generally toward the Columbia River, although this pattern is altered to varying degrees by pump-and-treat remediation systems in the 100-K, 100-D, and 100-H Areas.

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 2.1-2), but it could also represent a perched water table above the regional water table. There is insufficient information to distinguish between these alternatives. Water-level elevations indicate that groundwater moving east along Gable Mountain flows around this apparent mound.

South of Gable Butte and Gable Mountain, 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 or north of the 200 West Area is thought to turn north and flow through Gable Gap. Past 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. These discharges largely ceased by 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 ~11 meters above an estimated water-table elevation prior to the start of Hanford operations.[a] When equilibrium conditions are once again established in the aquifer after dissipation of the mounding caused by artificial recharge, computer simulations suggest that the water table may still be ~5 to ~7 meters higher than the pre-Hanford water table (PNNL-14753). This may be due to modeling uncertainties, recent artificial recharge generated by increased irrigation activities in the region west of the Hanford Site, or the fact that Columbia River conditions are different than in pre-Hanford times due to the construction of hydroelectric dams. The water table beneath the 200 West Area is locally perturbed by 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 Operable Unit.

Groundwater flow in the central portion of the Hanford Site, encompassing the 200 East Area, is significantly affected by the presence of a buried flood channel, which lies in a northwest to southeast orientation (PNNL-12261). The water table in this area is very flat (i.e., the hydraulic gradient is estimated to be $\sim 10^{-5}$) due to the high permeability of the Hanford formation. Groundwater flow in this region is significantly 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 constitute barriers to groundwater flow. The extent of the basalt units above the water table continues to increase slowly due to the declining water table, resulting in an even greater effect on groundwater flow in this area. The mapped extent of the basalt units above the water

(a) Based on the March 2007 water-level elevation in well 299-W18-15 (136.5 meters NAVD88) and the pre-Hanford water-table elevation at the location of this well estimated from BNWL-B-360 (~125.1 meters NAVD88). The peak historical water-level elevation within the 200 West Area occurred at well 299-W18-15 in 1984 (149.1 meters NAVD88).

table was revised during FY 2007 to account for the water-table decline over the past several years. The water table beneath the 200 East Area is ~2.0 meters higher than estimated pre-Hanford conditions.[b] Simulations of equilibrium conditions after site closure suggest that the water table in the 200 East Area will be near its pre-Hanford elevation (PNNL-14753).

The flat nature of the water table (i.e., very low hydraulic gradient) in the 200 East Area and vicinity makes determination of the flow direction difficult. This is because the uncertainty in the water-level elevation measurements is greater than the water-table relief. Therefore, determining the groundwater flow direction based on these data is problematic, so other evidence is used to infer flow directions. 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, with some migrating to the north through Gable Gap and some moving southeast toward the central part of the site. The specific location of the groundwater flow divide is currently not known. It is known that groundwater flows north through Gable Gap, because the hydraulic gradient within the gap area is large enough to be determined using water-level data. During FY 2007, the gradient in Gable Gap averaged 7.2×10^{-5} along a north flow direction, but flow conditions vary during the year due to changes in Columbia River stage (see Section 2.1.4). Groundwater is inferred to flow southeast within the region between the 200 East Area and the Central Landfill, because the average water-level elevation at the landfill (121.89 meters NAVD88 for March 2007) is 0.14 meter less than the average elevation in the 200 East Area (122.03 meters NAVD88 for March 2007). This yields a regional hydraulic gradient of 1.8×10^{-5}. Efforts are underway to improve the accuracy of the water-level measurements so that hydraulic gradients can be determined for the 200 East Area.

The flat water table in the 200 East Area makes returning flow direction difficult.

Between the area southeast of the Central Landfill to the 300 Area, the highly permeable sediments of the Hanford formation occur above the water table. These sediments intercept the water table again at the 300 Area. For this reason, the hydraulic gradient in the 300 Area is also very low. Groundwater flow converges on the 300 Area from the northwest, west, and southwest, then generally moves along a southeast flow path and discharges to the Columbia River (PNNL-15127).

In addition to the Hanford Site water table, Figure 2.1-2 depicts the water table north and east of the Columbia River (using a 50-meter-contour interval), based on water-level measurements collected during March 2005. The offsite water table is heavily influenced by irrigation practices, and its configuration is significantly controlled by topography. Many of the contour flexures and mounds coincide with topographic valleys and higher plateau areas. Hydraulic heads north and east of the Columbia River are significantly higher than on the Hanford Site, as evidenced by the proximity of the 150-meter contour to the Columbia River. Therefore, it is unlikely that groundwater contaminants from the Hanford Site would migrate underneath the Columbia River to these offsite areas. PNL-8122 contains a more complete discussion of the offsite water table.

(b) Based on the average water-level elevation measured in 27 wells within the 200 East Area during March 2007, all of which have been corrected for deviations of the boreholes from vertical (122.03 meters NAVD88), and the pre-Hanford water-table elevation for the 200 East Area estimated from BNWL-B-360 (~120 meters NAVD88).

2.1.2 Water-Table Change from FY 2006

Over much of the Hanford Site, the water table continued to decline. The declining water table caused some monitoring wells to go dry; new wells are being installed.

The water-table elevation continued to decline over much of the site from April/May 2006 to March 2007. The decline is a result of the curtailment of effluent discharges to the ground during the 1980s and 1990s. The largest, widespread decline occurred in the 200 West Area, where the water table declined by an average of 0.31 meter (in those areas not influenced by the 200-ZP-1 pump-and-treat system) from April 2006 to March 2007. This amount is the same as was observed from March 2005 to April 2006 (PNNL-16346). Similar to previous years, the water-table elevation increased in Dry Creek Valley and along the Yakima River, signifying increased recharge to the aquifer from these areas. Water levels were also higher along the Columbia River due to a slightly higher river stage during early 2007 compared to 2006.

In the 200 East Area, the elevation of the water table declined by an average of 0.06 meter from April 2006 to March 2007. This is similar to the decline observed the previous year (PNNL-16346). The water-table elevation increased over much of the 200 East Area beginning in July 2007. The water-table elevation is known to respond to effluent discharges at the Treated Effluent Disposal Facility (PNNL-SA-49780), and discharges at this facility increased significantly during June 2007. The water-table elevation increase is shown in Figure 2.1-3 for well 299-E33-337 (northwest 200 East Area) and well 299-E24-24 (southeast 200 East Area). Work is ongoing to understand the effect that periods of increased discharges may have on groundwater flow in the 200 East Area.

2.1.3 Water-Table Change from 1979 to 2007

To gain a perspective on the amount that the water-table has declined at Hanford over the past ~3 decades, a map depicting the change in the water-table elevation between 1979 and 2007 was prepared (Figure 2.1-4). Between 1944 and 1979, the water-table elevation had increased significantly at Hanford due to the disposal of large volumes of effluent to the soil column. Effluent discharge volumes have been greatly reduced since 1979, and the water-table has responded by declining in elevation. The largest declines, almost 10 meters, occurred in the 200 West Area associated with the dissipation of the U Pond groundwater mound. As stated in Section 2.1.1, the water-table elevation beneath the 200 West Area is currently estimated to be ~11 meters higher than pre-Hanford conditions.

The water-table elevation in the 200 East Area has declined by ~1.8 meters between 1979 and 2007. This smaller decline, compared to the 200 West Area, results from a smaller increase between 1944 and 1979. The aquifer sediments in the 200 East Area are much more transmissive than in the 200 West Area, so the water table did not increase as much in elevation prior to 1979. The water-table elevation beneath the 200 East Area is currently estimated to be ~2.0 meters above pre-Hanford conditions.

North of Gable Butte and Gable Mountain, the water-table elevation decline since 1979 has been generally less than 1 meter. The water-table elevation increased in the Dry Creek valley, along the Rattlesnake Hills, and in the southern portion of the site between the Yakima and Columbia Rivers. These increases may be attributable to offsite irrigation practices.

2.1.4 Results of Water-Level Monitoring in Gable Gap

Beginning in June 2006, water-level measurements were collected twice monthly from a network of six wells within Gable Gap. The purpose of these measurements was to determine the hydraulic gradient response to seasonal changes in Columbia River stage, because Gable Gap may represent a transport pathway for contaminants migrating north from the 200 East Area. It has also been hypothesized that changes in groundwater flow through Gable Gap may affect the water-table elevation within the 200 East Area (PNNL-SA-49780). The six wells used for this study were 699-60-60, 699-61-62, 699-61-66, 699-64-62, 699-65-72, and 699-66-64 (Figure 2.1-5).

The water-level elevation data were analyzed using trend-surface analysis, in which a plane is fitted to the data using least squares regression. The direction and magnitude of the dip of the plane approximates the regional hydraulic gradient within the study area. During the initial analysis on all six wells, it was found that most of the results were not statistically significant, which meant that a plane was not a good representation of the water table across all six wells. Further examination indicated that well 699-65-72 exerted a significant influence on the trend surface results since it responds more quickly to river stage changes than the other wells (Figure 2.1-6). Further, this well is located more to the west of Gable Gap and closer to the river than the other wells. For these reasons, well 699-65-72 was omitted from the final trend-surface analyses. Of the 23 water-level data sets analyzed by trend surface analysis for FY 2007, 17 of the results were statistically significant with well 699-65-72 omitted.

Groundwater levels in Gable Gap vary in response to seasonal changes in Columbia River stage.

The water-table elevation within the Gable Gap area responds to seasonal changes in Columbia River stage, but there is a time lag associated with the response (Figure 2.1-6). The data for well 699-65-72 exhibits a ~2-month time lag, while the remaining wells exhibit a ~3- to ~4-month time lag. The magnitude and direction of the hydraulic gradient also change in response to the seasonal fluctuation of water levels (Figure 2.1-7). The largest gradient magnitudes of $\sim 1.1 \times 10^{-4}$ are associated with periods of low river stage, while the smallest gradients of $\sim 4 \times 10^{-5}$ occur with periods of high river stage (following a 3- to 4-month time lag). The direction of the gradient also changes seasonally. A flow direction to the north is associated with low river stage, while a northeast flow direction occurs in response to high river stage. Figure 2.1-8 presents a rose diagram of groundwater flow directions in Gable Gap for the fiscal year. The figure depicts the percentage of time during the year in which groundwater flowed in various directions in 10-degree intervals. The average hydraulic gradient in Gable Gap during FY 2007 was calculated to be 7.2×10^{-5} and the average direction (time weighted) was 011 degrees azimuth (north-northeast).

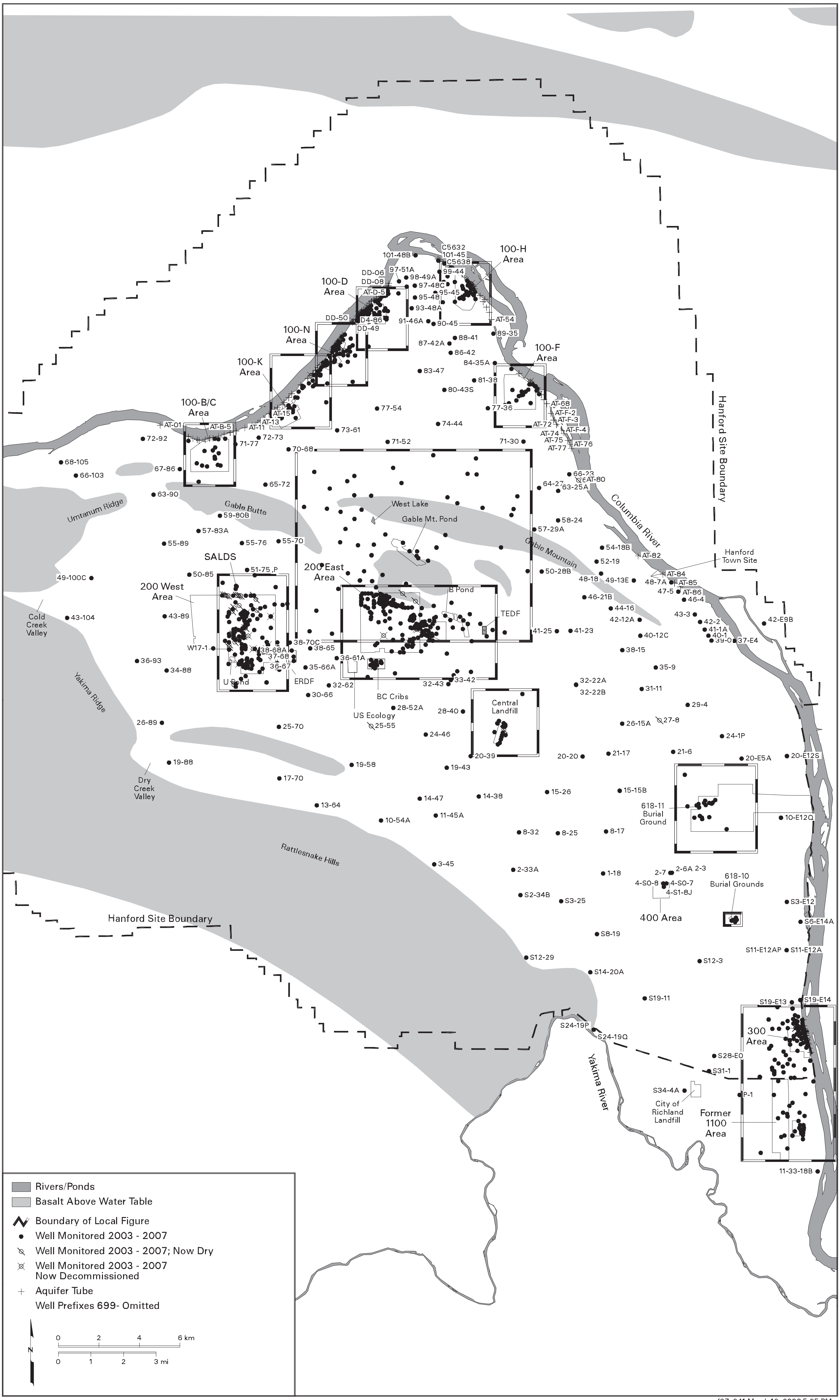

Figure 2.1-1 Groundwater Monitoring Wells on the Hanford Site

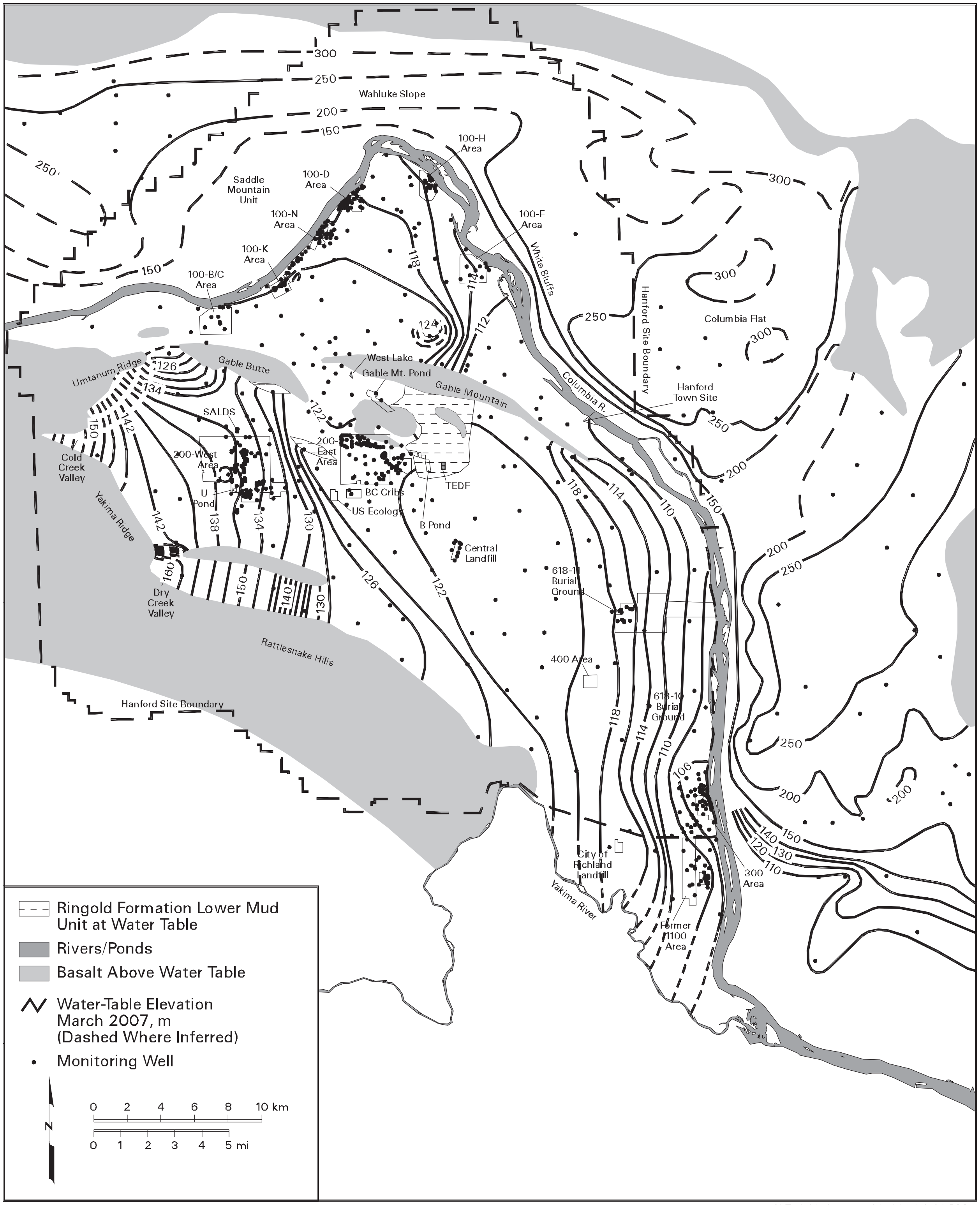

Figure 2.1-2. Hanford Site and Outlying Areas Water-Table Map, March 2007

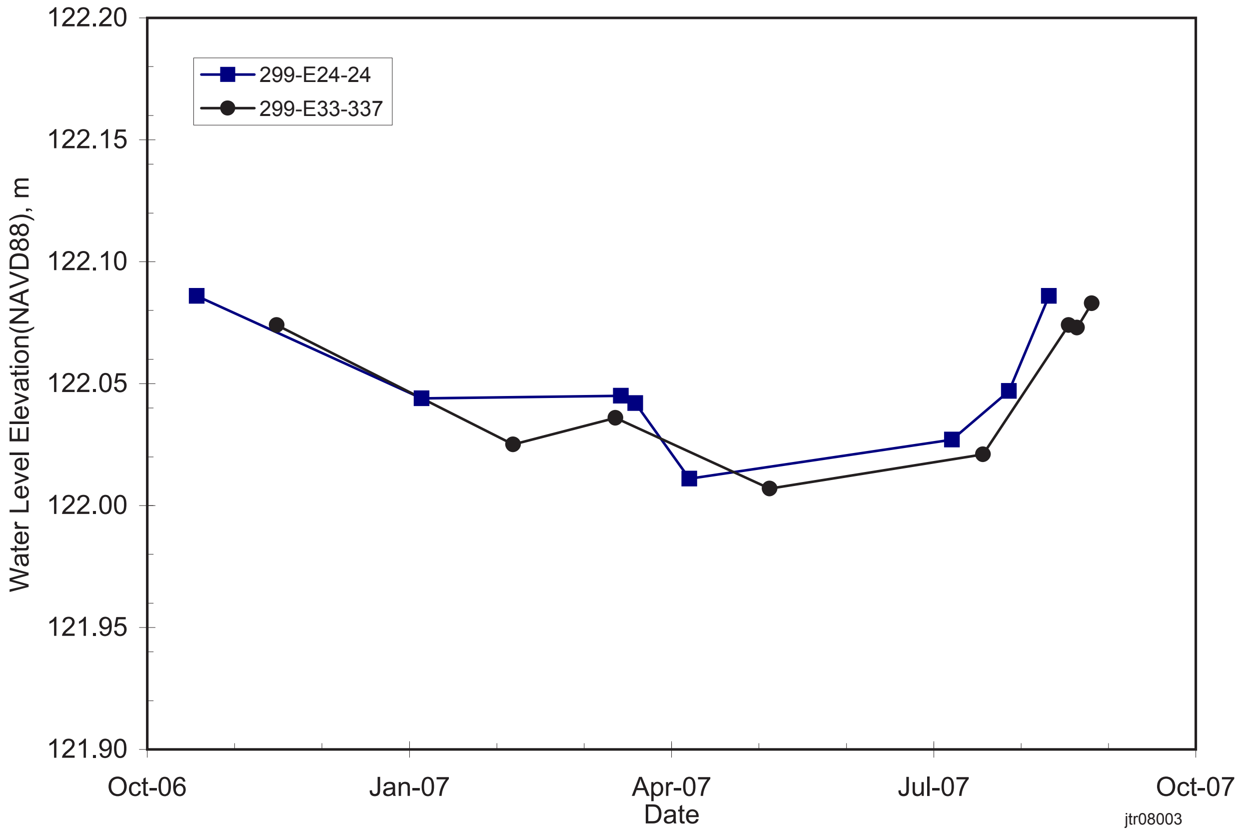

Figure 2.1-3. Water-Table Elevation in 200 East Area, FY 2007

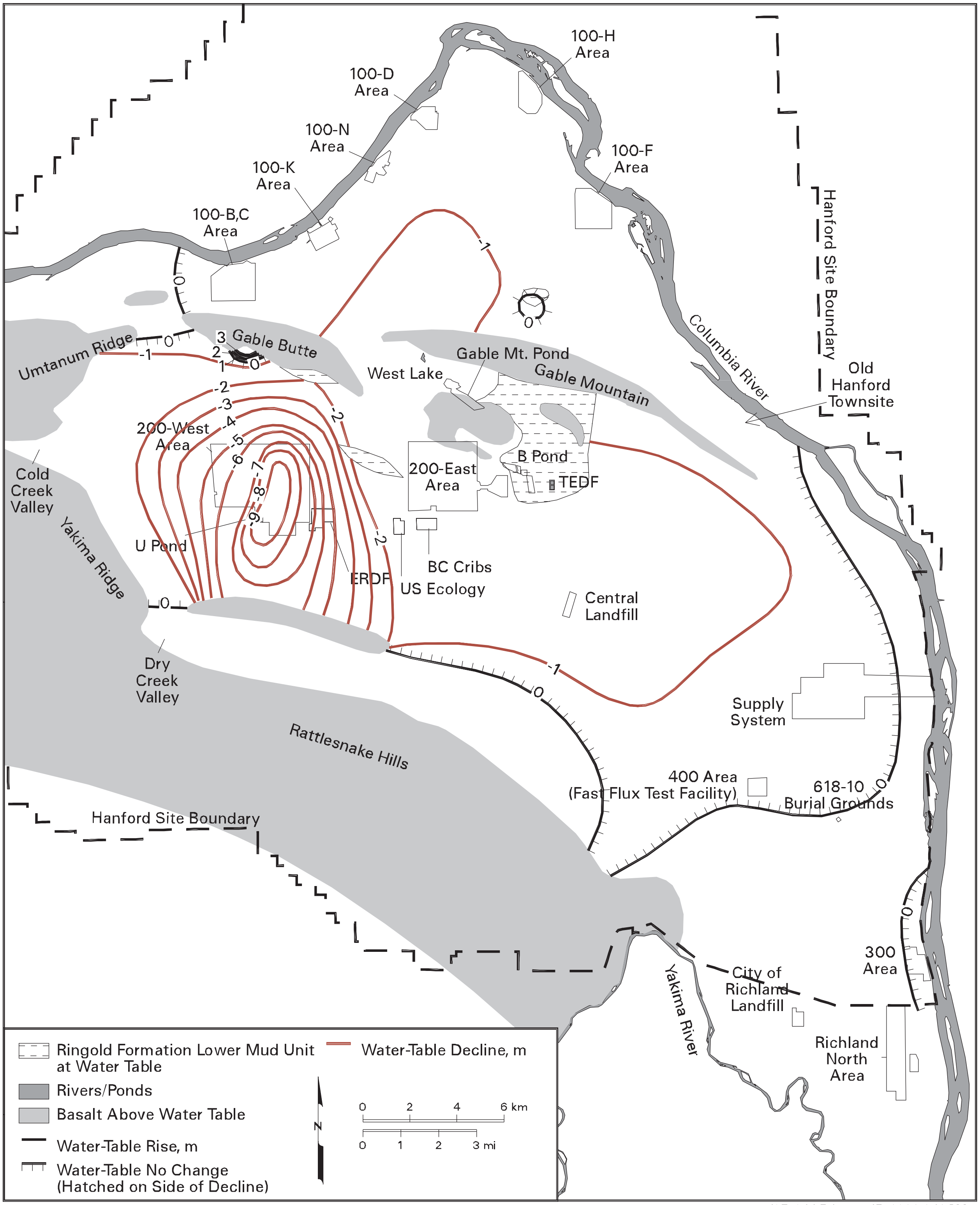

Figure 2.1-4. Changes in Water-Table Elevations at Hanford, 1979 through 2007

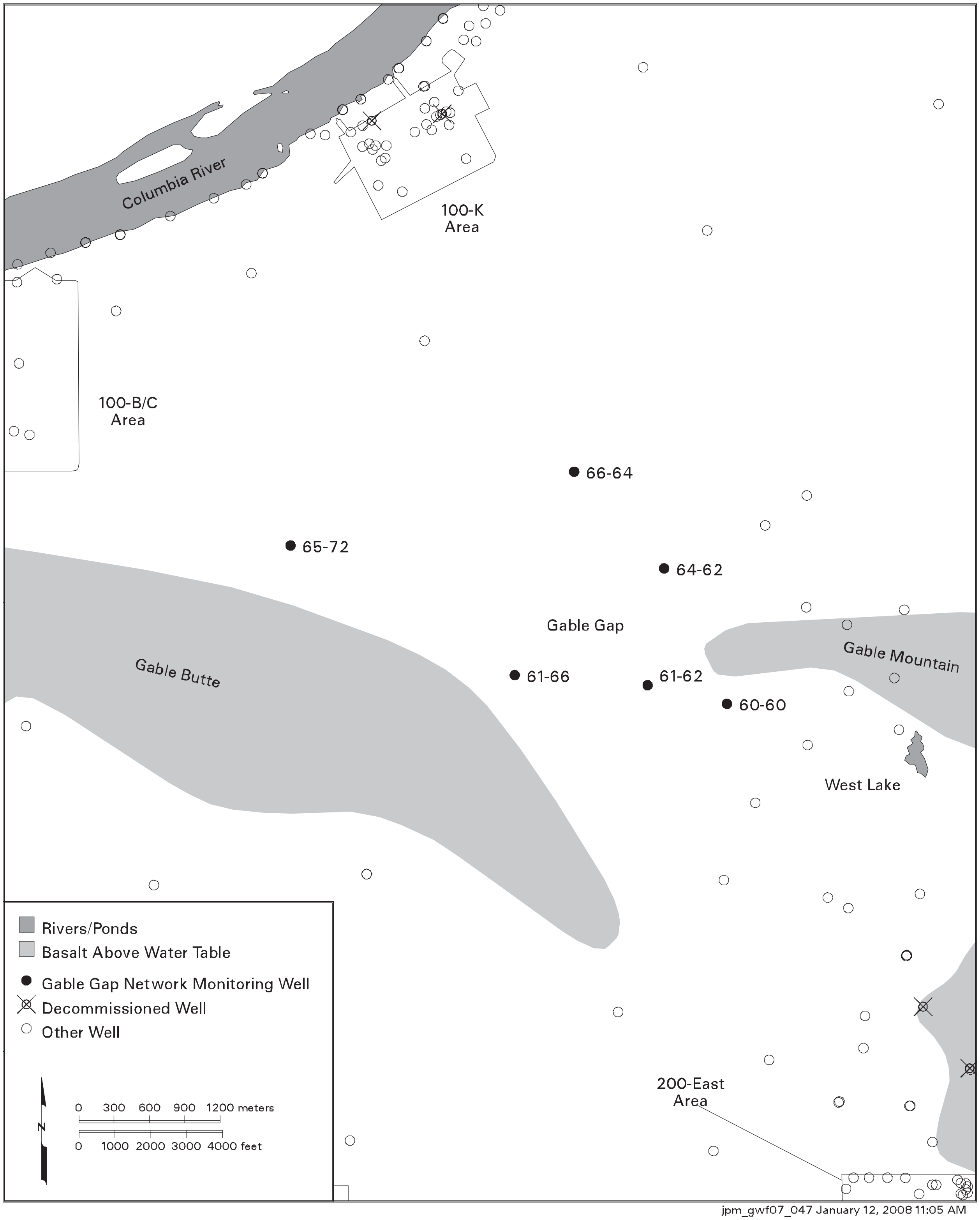

Figure 2.1-5. Wells Used for Water-Level Monitoring Study in Gable Gap

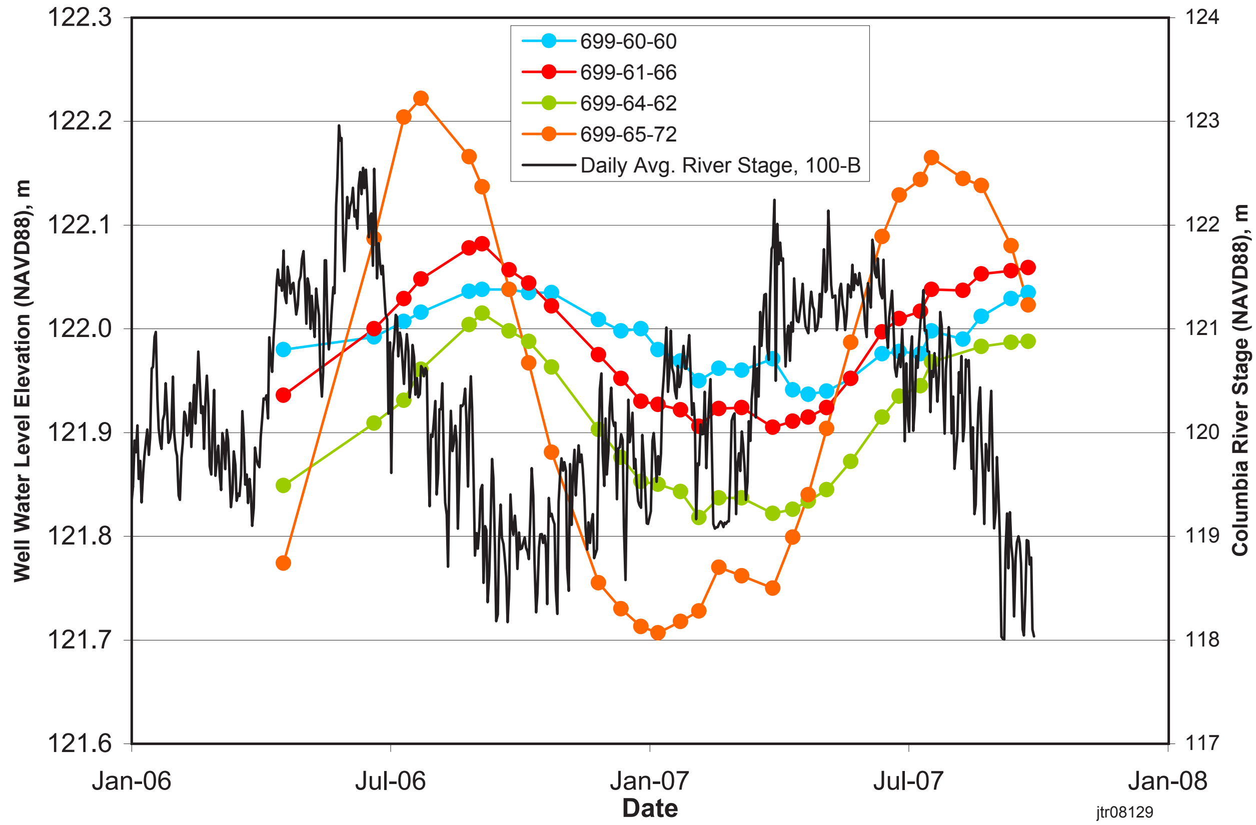

Figure 2.1-6. Association Between Columbia River Stage and Water-Level Elevations in Gable Gap

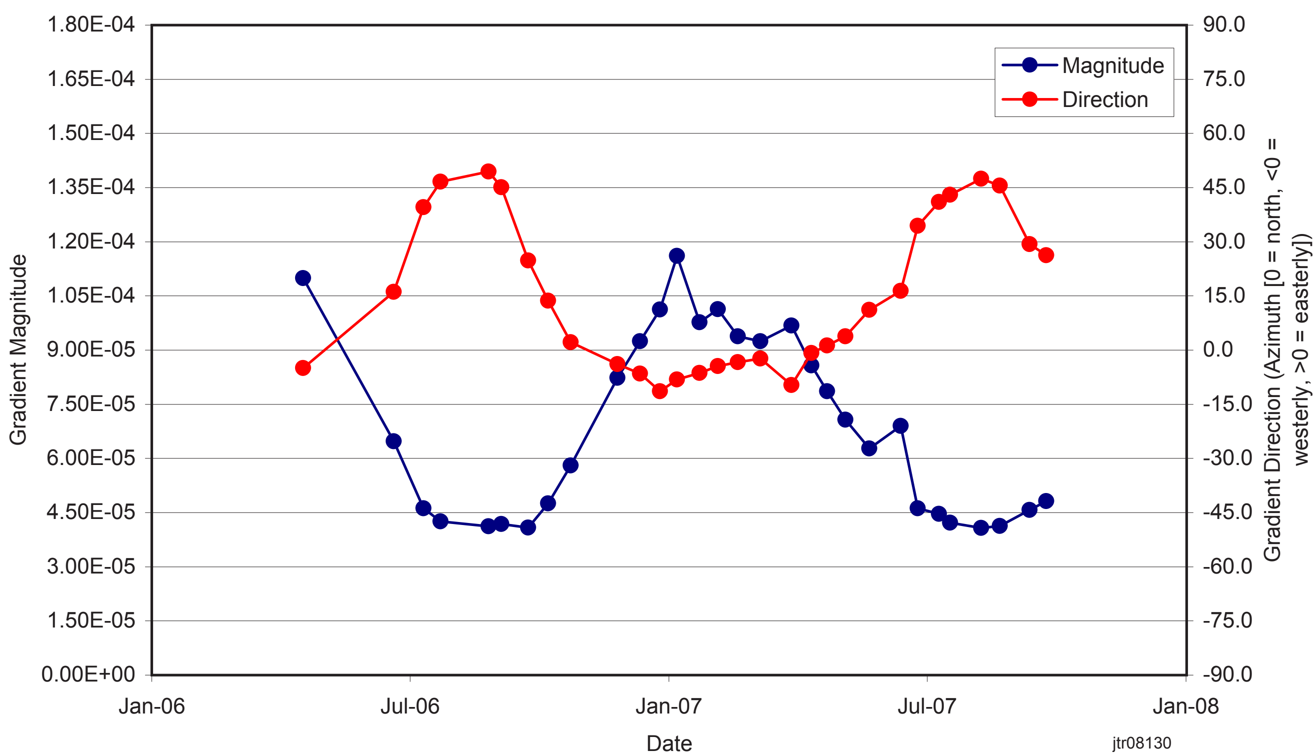

Figure 2.1-7. Variability of the Magnitude and Direction of the Hydraulic Gradient in Gable Gap

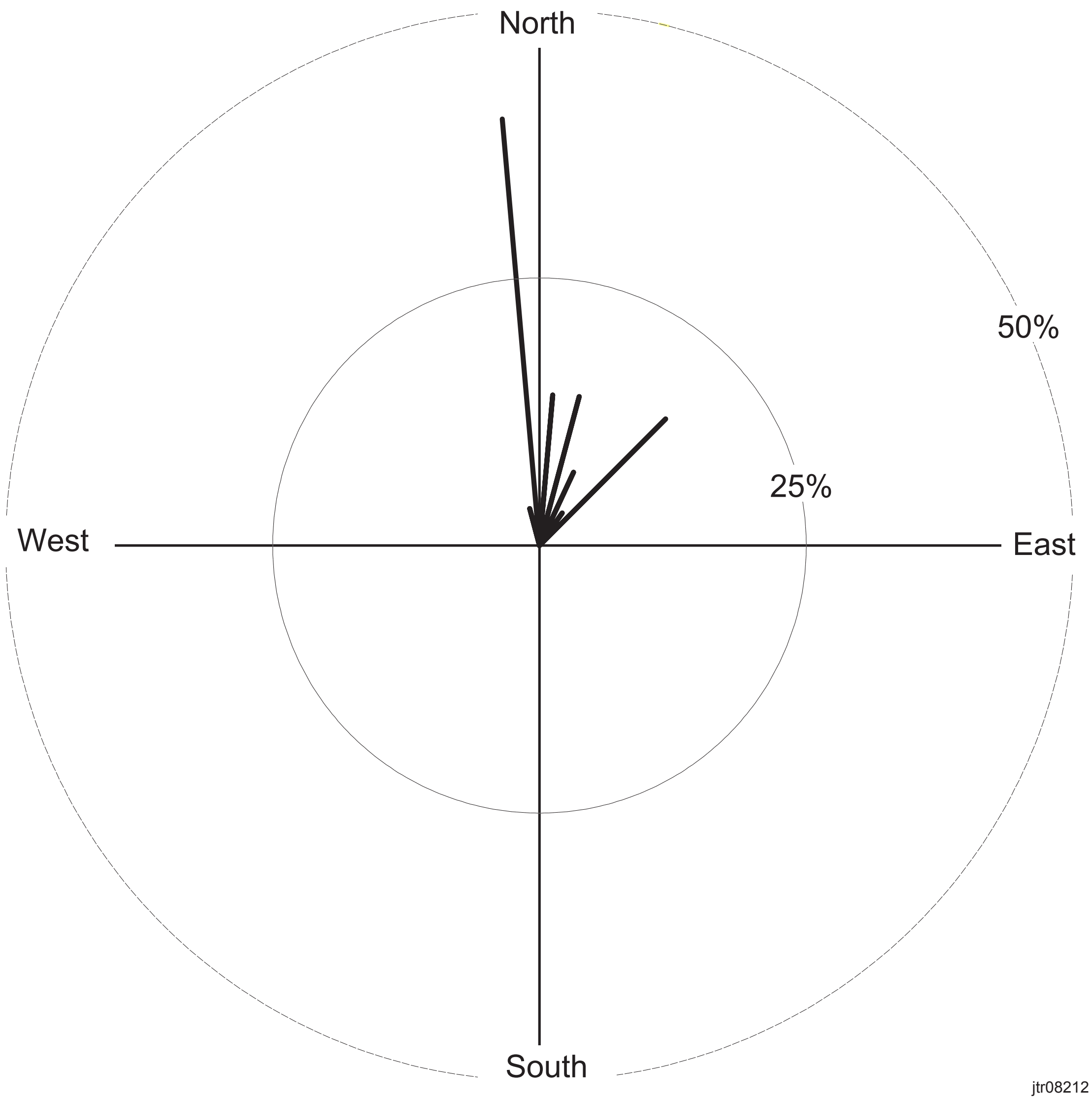

Figure 2.1-8. Rose Diagram of Groundwater Flow Directions in Gable Gap, FY 2007