2.1 Overview of Groundwater Flow

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This section 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 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 Site other than the former operational areas, are shown in Figure 2.1-1.

During March 2008, 873 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 for the following:

- 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.

During March 2008, 873 water-level measurements were collected across the Hanford Site. This information helps scientists understand the direction and rate of groundwater flow.

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 Site operations. Local groundwater flow in each groundwater operable unit is described in Sections 2.2 through 2.13. Flow characteristics in the confined aquifer present in the lower Ringold Formation and in the upper basalt-confined aquifer system are discussed in Section 2.14.

2.1.1 March 2008 Water-Table Map

Figure 2.1-2 presents the Hanford Site water-table map for March 2008. 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 toward the southeast between Gable Butte and Gable Mountain (Gable Gap) and the 200 East Area into the central portion of the Site. The steep gradients in the west and east are associated with low permeability sand and gravel of the Ringold Formation at the water table, while the low gradients are associated with highly permeable sand and gravel of the Hanford formation at the water table.

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

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. 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 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 Area,

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

An apparent groundwater mound exists ~2 km 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 represent a perched water table above the regional water table. More data is needed 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, 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 or north of the 200 West Area turns north and flows 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 m 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 m higher than in pre-Hanford times because of increased irrigation activities west of the Site. The water table beneath the 200 West Area is perturbed locally 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 affected significantly by the presence of a buried flood channel, which is oriented from the northwest to the southeast (PNNL-12261, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*). The water table in this area is very flat (i.e., the hydraulic gradient is estimated to be ~10^{-5} or less) because of the high permeability of the Hanford formation. Groundwater flow in this region is affected significantly 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 because of the declining water table, resulting in an even greater effect on groundwater flow in this area. The water table beneath the 200 East Area is ~2.0 m higher than estimated pre-Hanford Site conditions.[2] When equilibrium conditions are re-established, the water table in the 200 East Area is expected to return to the pre-Hanford Site elevation.

1 Based on the March 2008 water-level elevation in well 299-W18-15 (136.2 m NAVD88) and the pre-Hanford Site water table elevation at the location of this well estimated from BNWL-B-360 (~125.1 m NAVD88). The peak historical water-level elevation within the 200 West Area occurred at well 299-W18-15 in 1984 (149.1 m NAVD88).

2 Based on the average water-level elevation measured in 31 wells within the 200 East Area during March 2008, all of which have been corrected for deviations of the boreholes from true vertical (122.02 m NAVD88), and the pre-Hanford Site water table elevation for the 200 East Area estimated from BNWL-B-360 (~120 m 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, with some flowing to the north through Gable Gap and some flowing southeast toward the central part 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 (Section 2.1.3). 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 fiscal year (FY) 2008, the gradient in Gable Gap averaged 8.1 x 10^{-5} along a north flow direction, but flow conditions vary during the year because of changes in the Columbia River stage (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 (121.88 m NAVD88 for March 2008) is 0.14 m less than the average elevation in the 200 East Area (122.02 m NAVD88 for March 2008). This yields a regional hydraulic gradient of 1.8 x 10^{-5}.

The flat water table in the 200 East Area makes determination of flow directions 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, *Contaminants of Potential Concern in the 300-FF-5 Operable Unit: Expanded Annual Groundwater Report for Fiscal Year 2004*).

2.1.2 Water Table Change from FY 2007

The water-table elevation continued to decline over much of the Site from March 2007 to March 2008. The decline is a result of the curtailment of effluent discharges to the ground during the 1980s and 1990s. (DOE/RL-2008-01, Section 2.1.3 provides a discussion of the water table change from 1979 to 2007.) The largest widespread decreases occurred to the west of the 200 West Area, where the water-table elevation decreased by an average of 0.42 m. In previous years, the water-table elevation had increased in Dry Creek Valley and along the Yakima River, signifying increased recharge to the aquifer from these areas. During FY 2008, declines from 0.01 to 0.04 m were observed in all but one well in these areas. Water levels also increased in places along the Columbia River because of river stage fluctuations.

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.

In the 200 West Area, the water table declined by an average of 0.27 m (in areas not influenced by the 200-ZP-1 Pump-and-Treat System). Larger declines were observed near the 200-ZP-1 Pump-and-Treat System, especially at the single-shell T Tank Farm where additional extraction wells recently began operating. In the 200 East Area, the elevation of the water table declined only slightly by an average of 0.01 m, which was less than the decline of 0.06 m observed the previous year (DOE/RL-2008-01). In addition, the water-table elevation increased to both the north and south of the 200 East Area between March 2007 and March 2008. During late FY 2007, the water-table elevation increased over much of the 200 East Area (Figure 2.1-3), and was attributed to increased effluent discharges at the Treated Effluent Disposal Facility (DOE/RL-2008-01). The smaller decline within the 200 East Area during FY 2008

and the observed increases adjacent to the 200 East Area may be from the lingering influence of the increased effluent discharges.

2.1.3 Water-Level Monitoring in the 200 East Area

Regulations require that water-level measurements be used to determine the groundwater flow direction beneath RCRA regulated waste sites at least annually. In the 200 East Area, existing water-level measurements have not been accurate enough to determine the flow direction because of the small hydraulic gradient magnitude and large depth to water. However, progress has been made in recent years on improving the accuracy of the water-level measurements to allow for hydraulic gradient determinations.

The feasibility of collecting highly accurate water-level measurements was investigated at Low-Level Waste Management Area 1 in the northwest corner of the 200 East Area. Section 2.10 provides more information on the facility's location. Highly accurate casing elevation surveys and borehole deviation surveys were performed for a network of 14 wells at this site. The borehole deviation surveys map the position of the borehole in 3 dimensional space and enable the difference between the measured depth to water and the true vertical depth to water to be determined. Water-level measurements were collected periodically, and trend-surface analyses were performed to determine the plane that best fits the water-level elevations. The largest source of error in the water-level measurements was found to be deviation of the boreholes from true vertical. Sixteen sets of water-level measurements were collected between September 2005 and September 2008. Using the new casing elevations and correcting for borehole deviation, the trend-surface analysis results were statistically significant for 11 of the data sets at a 5% level of significance, and for 15 of the data sets at a 10% level of significance. From September 2005 through June 2008, the average groundwater flow direction was to the north-northwest (340º ± 10º azimuth). However, in August and September 2008, a southern flow direction was indicated and was likely a result of high stage in the Columbia River during June. Lower than normal effluent discharges to the Treated Effluent Disposal Facility, located east of the 200 East Area, also may have been a factor (PNNL-16346, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*, Section 2.1.3).

A similar water-level study is being performed in the southeast corner of the 200 East Area for the Integrated Disposal Facility and the RCRA PUREX Cribs (216-A-10 and 216-A-36B). Section 2.11 provides more information on the facilities' locations. Highly accurate casing elevation surveys and borehole deviation surveys were performed for a network of 11 wells at this site. Four sets of water-level measurements were collected between June 2008 and the end of the fiscal year. The data exhibited more variability than was observed at Low-Level Waste Management Area 1. Therefore, additional measurements are required before a flow direction determination can be made. Water-level measurements will continue at both Low-Level Waste Management Area 1 and the Integrated Disposal Facility/ RCRA PUREX Cribs during FY 2009. In addition, a water-level study is planned for Low-Level Waste Management Area 2 in the northeast corner of the 200 East Area during FY 2009.

2.1.4 Water-Level Monitoring in Gable Gap

Periodic collection of water-level measurements from a network of six wells within Gable Gap continued during FY 2008. These measurements were used 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. Changes in groundwater flow through Gable Gap may affect the water-table elevation within the 200 East Area (PNNL-16346). Wells 699-60-60, 699-61-62, 699-61-66, 699-64-62, 699-65-72, and 699-66-64 were used for this study (Figure 2.1-4).

The water-level elevation data were analyzed using trend-surface analysis, in which the plane that best fits the water-level elevations was determined. The direction and magnitude of the dip of the plane approximates the regional hydraulic gradient within the study area. During the initial analysis of all six wells, most of the results were not statistically significant, indicating a plane was not a good representation of the water table across all six wells. Additional analyses indicated that well 699-65-72 exerted a substantial influence on the trend surface results since it responded more quickly to river stage changes than the other wells (Figure 2.1-5). This well is located more to the west of Gable Gap and closer to the river than the other wells. After omitting well 699-65-72 from the final trend-surface analyses, 12 of 21 data set results were statistically significant for FY 2008.

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

The water-level monitoring results in Gable Gap for FY 2008 confirmed the findings presented in the previous annual report (DOE/RL-2008-01). During FY 2008, the water-table elevation within the Gable Gap area responded to seasonal changes in Columbia River stage, similar to FY 2006 and FY 2007 (Figure 2.1-5). A time lag is associated with the response. The data for well 699-65-72 exhibits an ~2-month time lag, while the remaining wells exhibit an ~3-month time lag. The magnitude and direction of the hydraulic gradient also changed in response to the seasonal fluctuation of water levels (Figure 2.1-6). The largest gradient magnitudes (~1×10^{-4}) are associated with periods of low river stage, while the smallest gradients (~4×10^{-5}) occur with periods of high river stage (following a 3-month time lag). The direction of the gradient also changed seasonally. A flow direction to the north was associated with low river stage, while a northeast flow direction was associated with high river stage. Figure 2.1-7 presents a rose diagram of groundwater flow directions in Gable Gap for FY 2008. The figure depicts the percentage of time when groundwater flowed in various directions in 10º segments. The average hydraulic gradient in Gable Gap during FY 2008 was calculated to be 8.1×10^{-5} and the average direction (time weighted) was 003º azimuth (north).

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Figure 2.1-1. Groundwater Monitoring Wells on the Hanford Site.

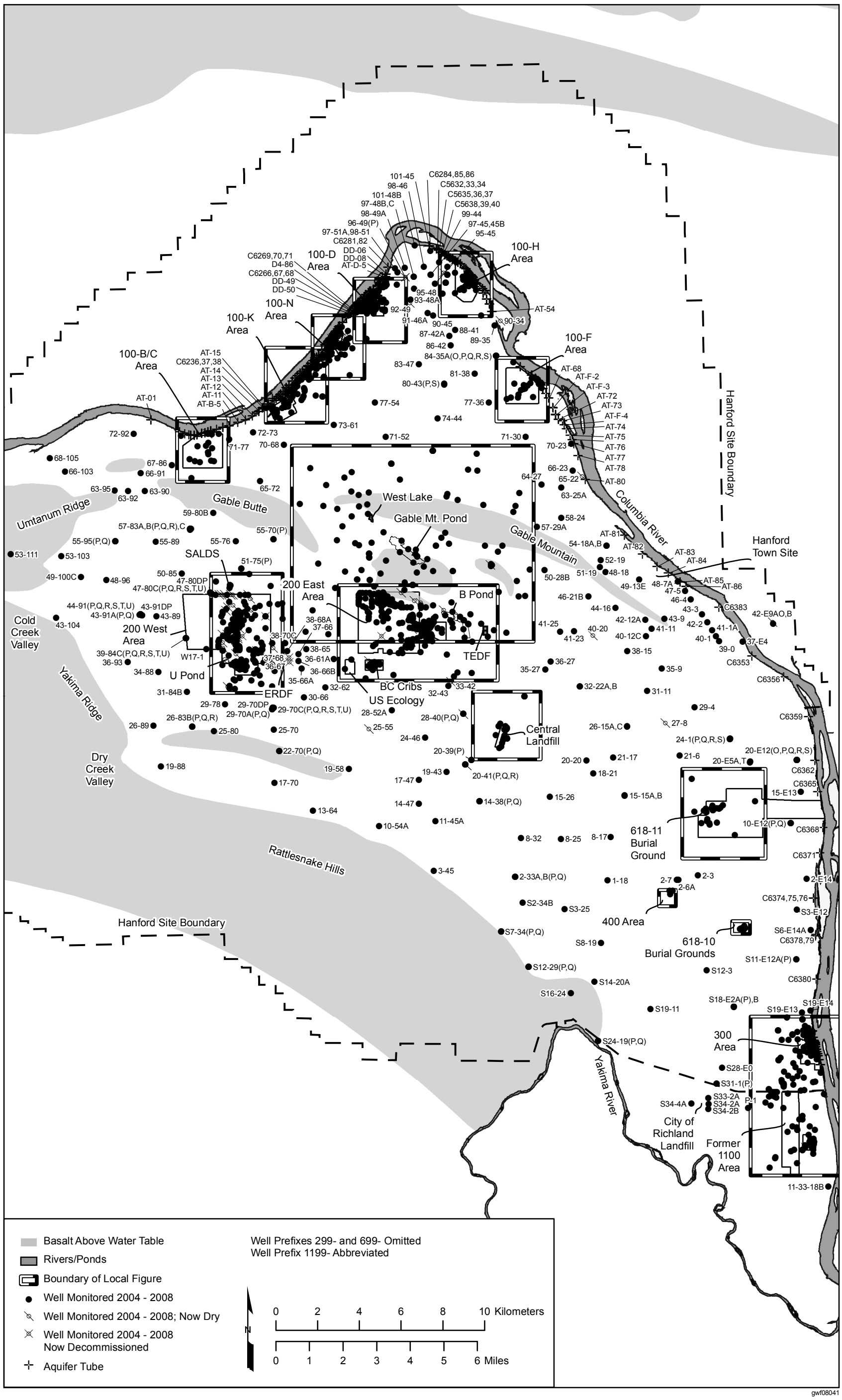

Figure 2.1-2. Hanford Site Water-Table Map, March 2008.

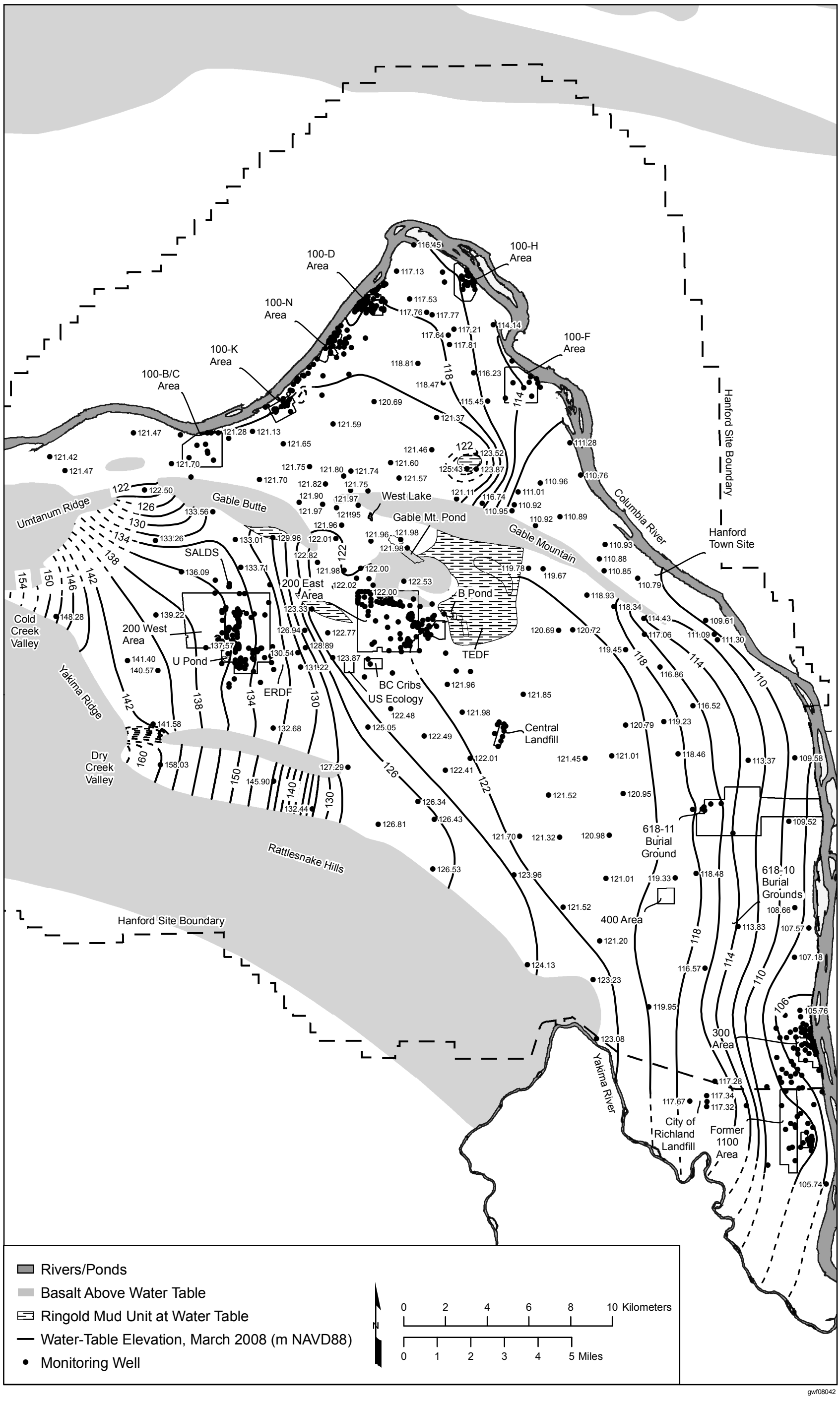

Figure 2.1-3. 200 East Area Water-Table Elevations, FY 2007 and FY 2008.

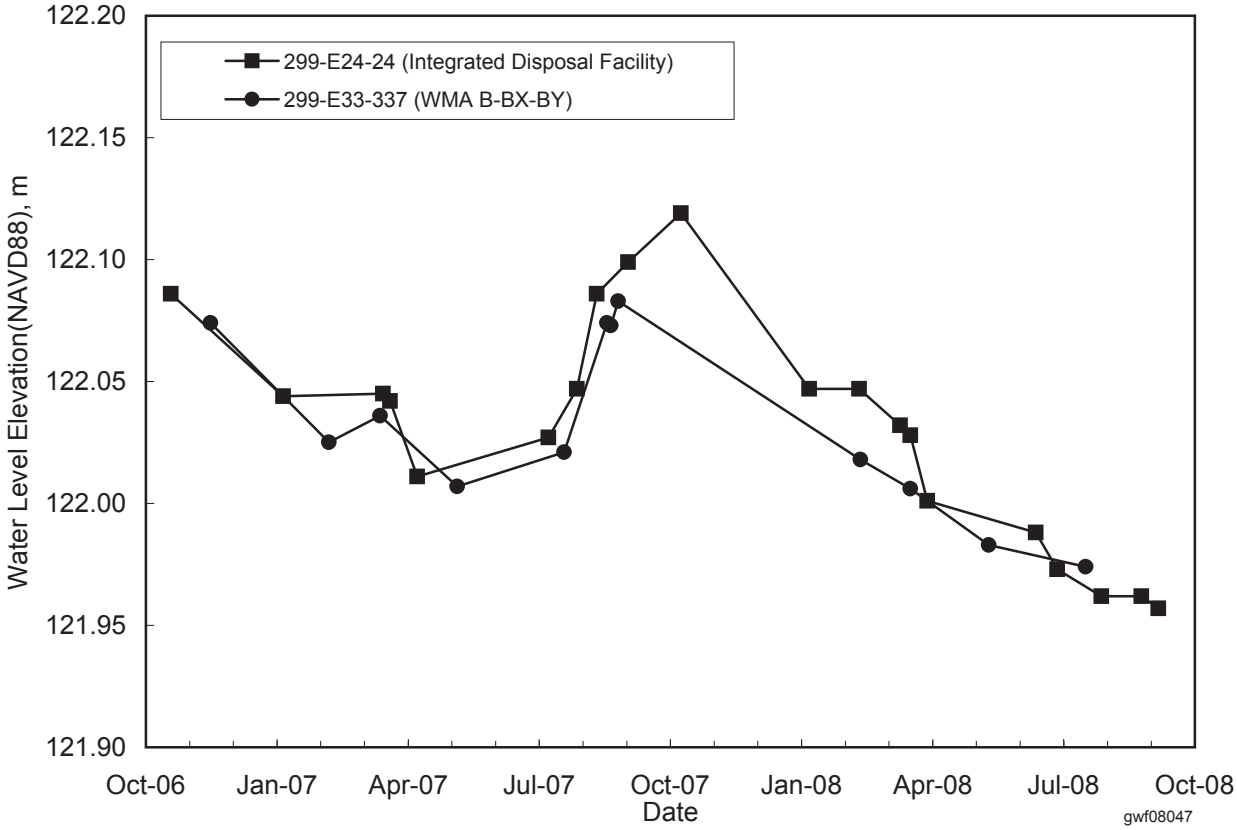

Figure 2.1-4. Locations of Wells for the Water-Level Monitoring Study in Gable Gap.

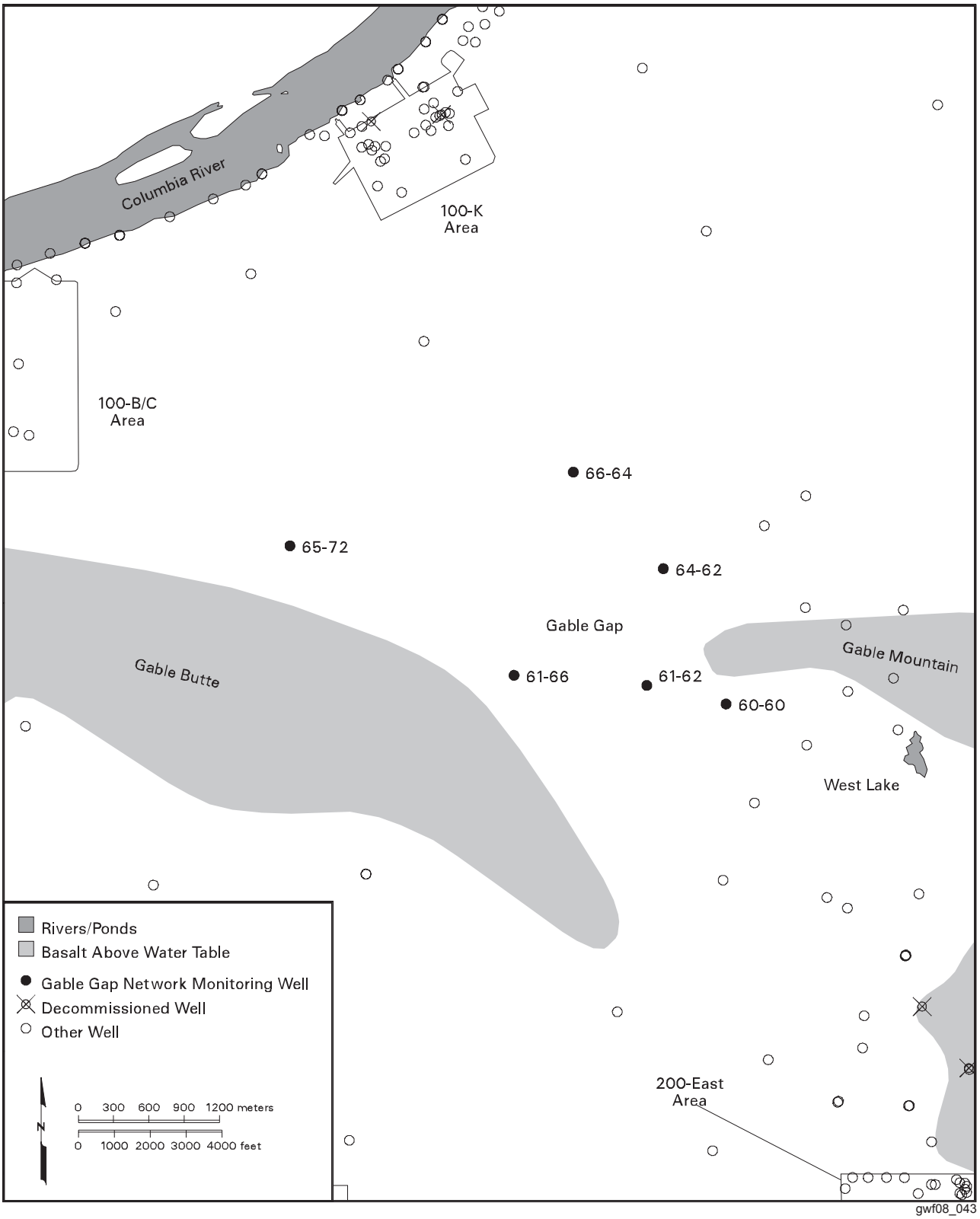

Figure 2.1-5. Correlation Between Columbia River Stage and Water-Level Elevations in Gable Gap.

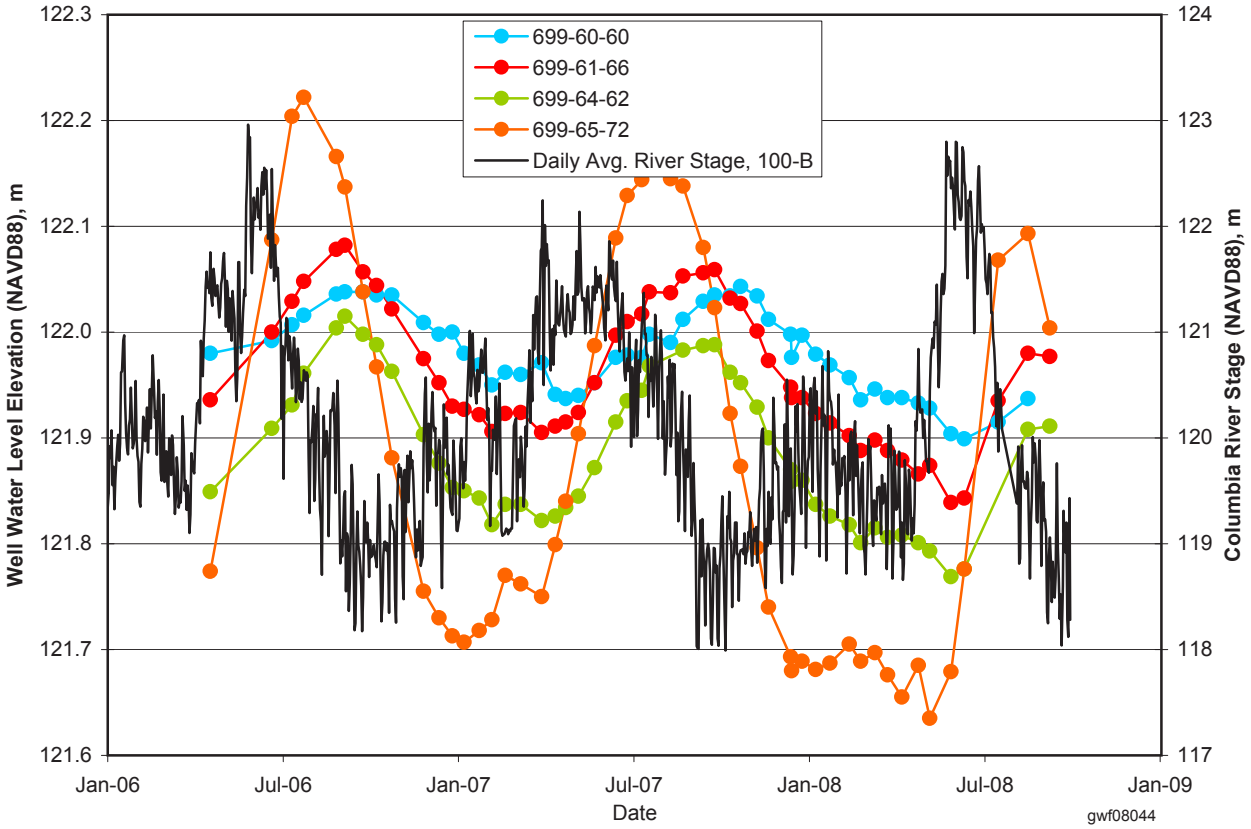

Figure 2.1-6. Variability of the Magnitude and Direction of the Hydraulic Gradient in Gable Gap.

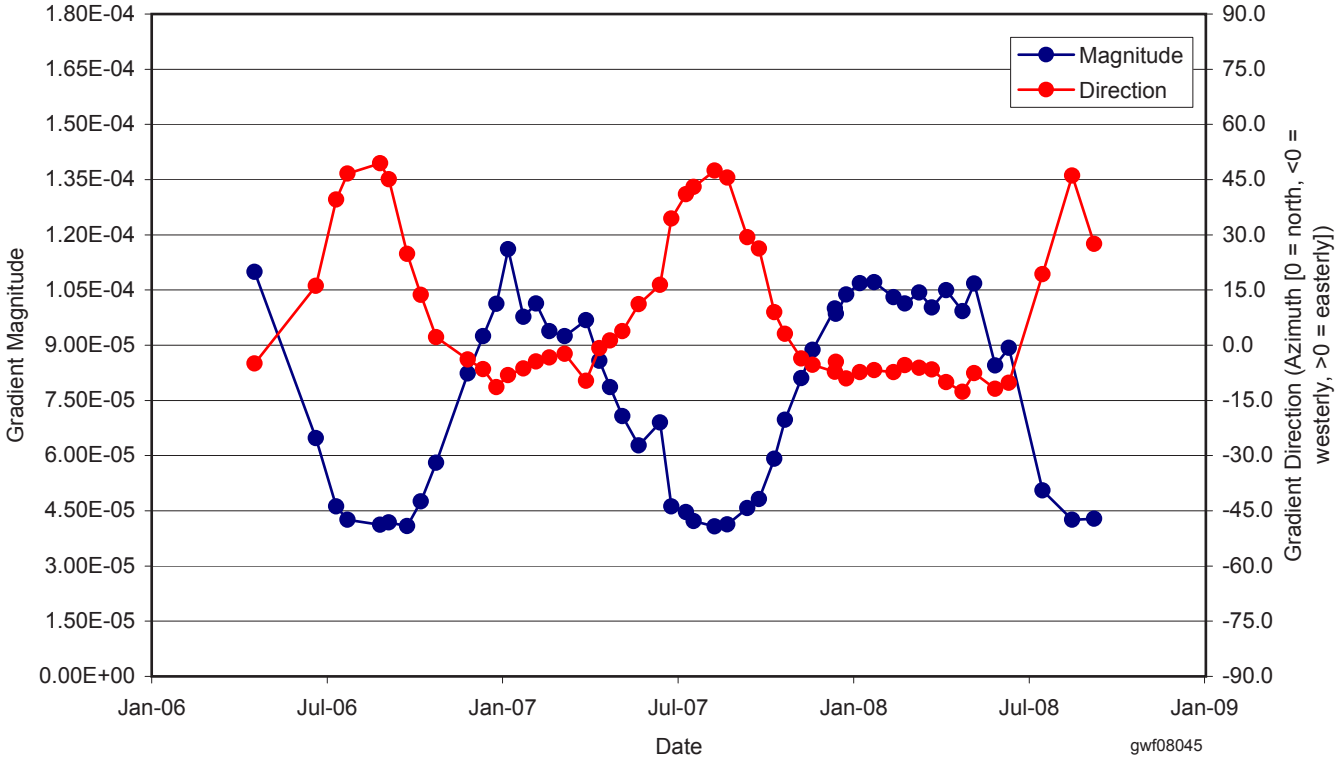
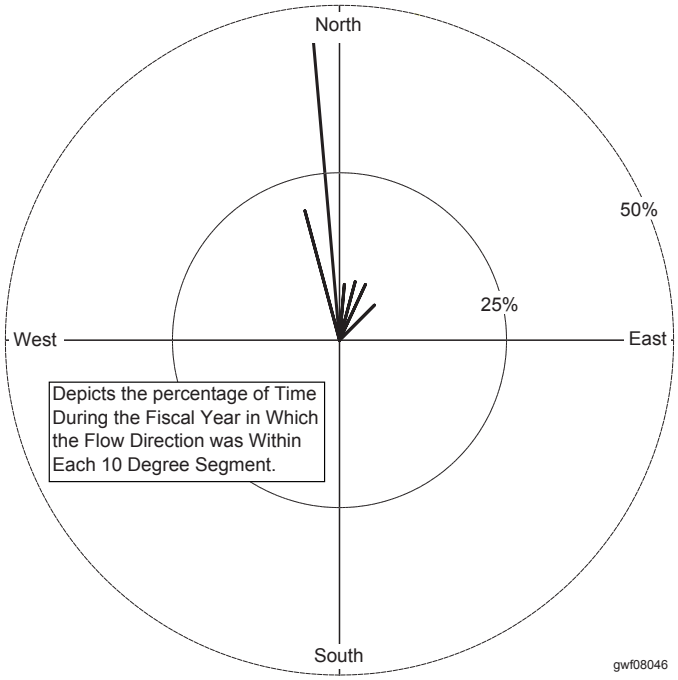
Figure 2.1-7. Histogram/Rose Diagram of Groundwater Flow Directions in Gable Gap, FY 2008.