4.8 Groundwater Protection and Monitoring Program

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The strategy for protecting groundwater at the Hanford Site is presented in the *Hanford Site Ground-Water Protection Management Plan* (DOE 1995k). Two key elements of this strategy are to 1) protect the unconfined aquifer from further contamination and 2) monitor the extent of groundwater contamination. The groundwater monitoring program at the Hanford Site documents groundwater quality to meet the needs of these elements. The monitoring program is designed to detect new contaminant plumes and to document the distribution and movement of existing groundwater contamination. Monitoring provides the historical baseline for evaluating current and future risk from exposure to groundwater contamination and for deciding on remedial options. Because the geology and hydrology of the Hanford Site control the movement of contaminants in groundwater, hydrogeologic studies are an integral part of the monitoring program.

The effort to protect groundwater quality at the Hanford Site is being implemented through programs to minimize wastes being discharged to the soil column and through site remediation activities. The Tri-Party Agreement (Ecology et al. 1989) provides a framework for remediation of the Hanford Site, including groundwater, over a 40-year period. A summary of accomplishments in waste minimization and site remediation is presented in Section 2.0, "Environmental Compliance Summary."

DOE prepared a *Plan and Schedule to Discontinue Disposal of Liquids Into the Soil Column at the Hanford Site* (DOE 1987), which presents a plan for providing alternative treatment and disposal of contaminated effluent discharged to the soil. Of the 33 major waste streams identified, the Phase I (higher priority) streams have either been eliminated or are being treated and diverted to the 200 Areas Treated Effluent Disposal Facility. In addition, process condensate from the 242-A Evaporator is treated at the 200 Areas Effluent Treatment Facility and then discharged to a state-approved facility, also called the Effluent Treatment Facility north of the 200-West Area. The location of these facilities is shown in Figures 1.0.3 and 4.8.1. They are discussed in detail in Section 2.3, "Accomplishments and Issues." Disposal of liquids to soil has been significantly reduced during the last several years. For example, in 1987, over 23 billion L (6 billion gal) of liquid effluents were discharged to the soil. This was reduced to approximately 4.9 billion L (1.3 billion gal) in 1995 and less than 1 billion L (290 million gal) in 1996. The locations and status of Phase I effluent streams are shown in Figure 4.8.1. Approximately 90% of the discharged volume goes to B Pond and approximately 9% goes to the 200 Areas Treated Effluent Disposal Facility.

Groundwater is used for drinking water and other purposes at a few locations on the Hanford Site. DE&S Hanford, Inc. and Pacific Northwest National Laboratory monitor drinking water supplies at the point of use. Results of the radiological monitoring conducted by Pacific Northwest National Laboratory are summarized in Section 4.3, "Hanford Site Drinking Water Surveillance." The locations of wells completed in the unconfined aquifer that are used for water supplies are shown in Figure 4.8.2.

Geologic Setting

The Hanford Site lies within the Pasco Basin, one of several structural basins within the Columbia Plateau. Principal geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and the Hanford formation (Figure 4.8.3).

The Columbia River basalts were formed from lava that periodically erupted from volcanic fissures starting approximately 17 million years ago and continuing until approximately 8.5 million years ago. The regional river system eroded the basalt and deposited sediments across the basalt surfaces between eruptions. Zones between the

Figure 4.8.1. Disposal Facilities for the Major Liquid Waste Streams at the Hanford Site

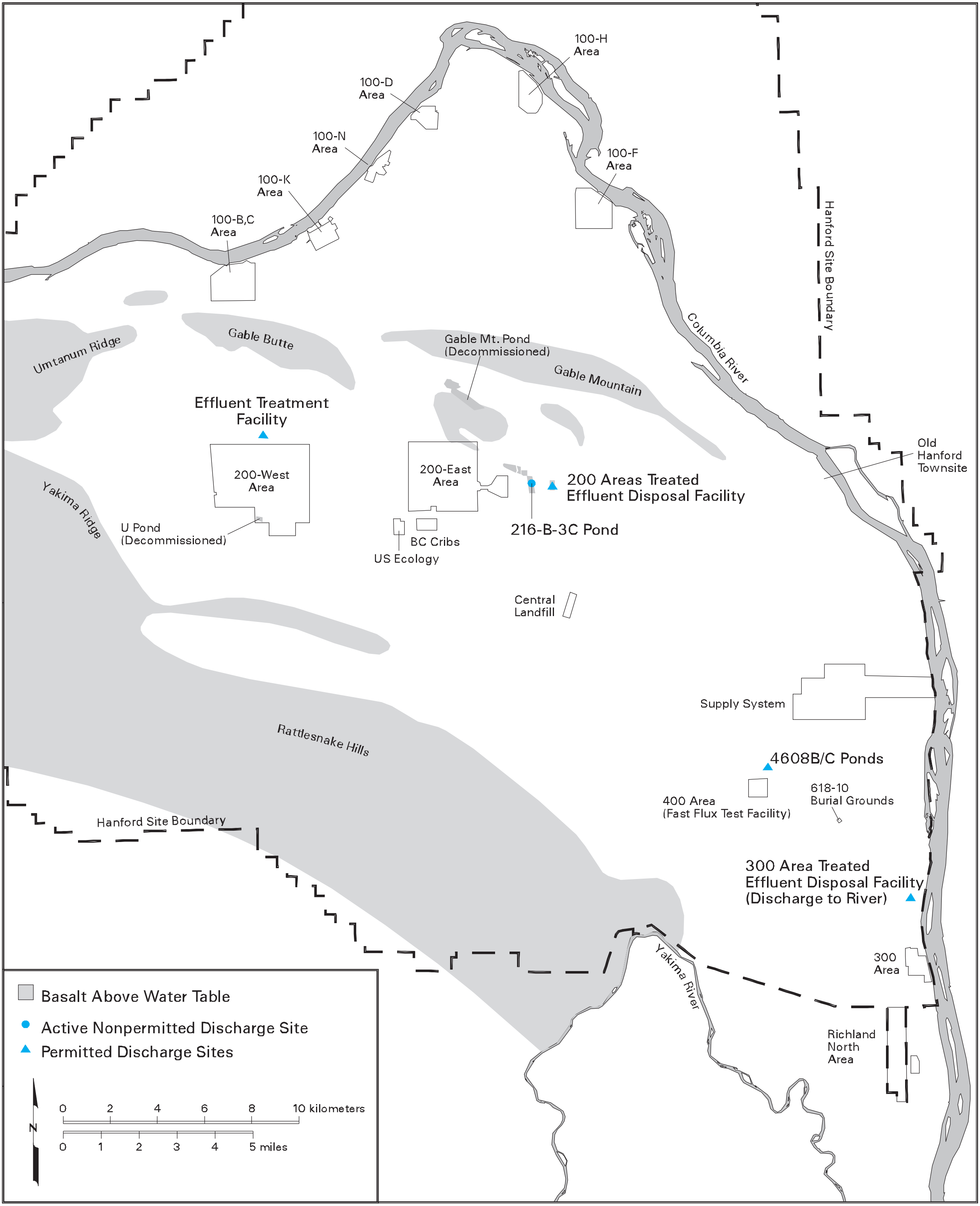

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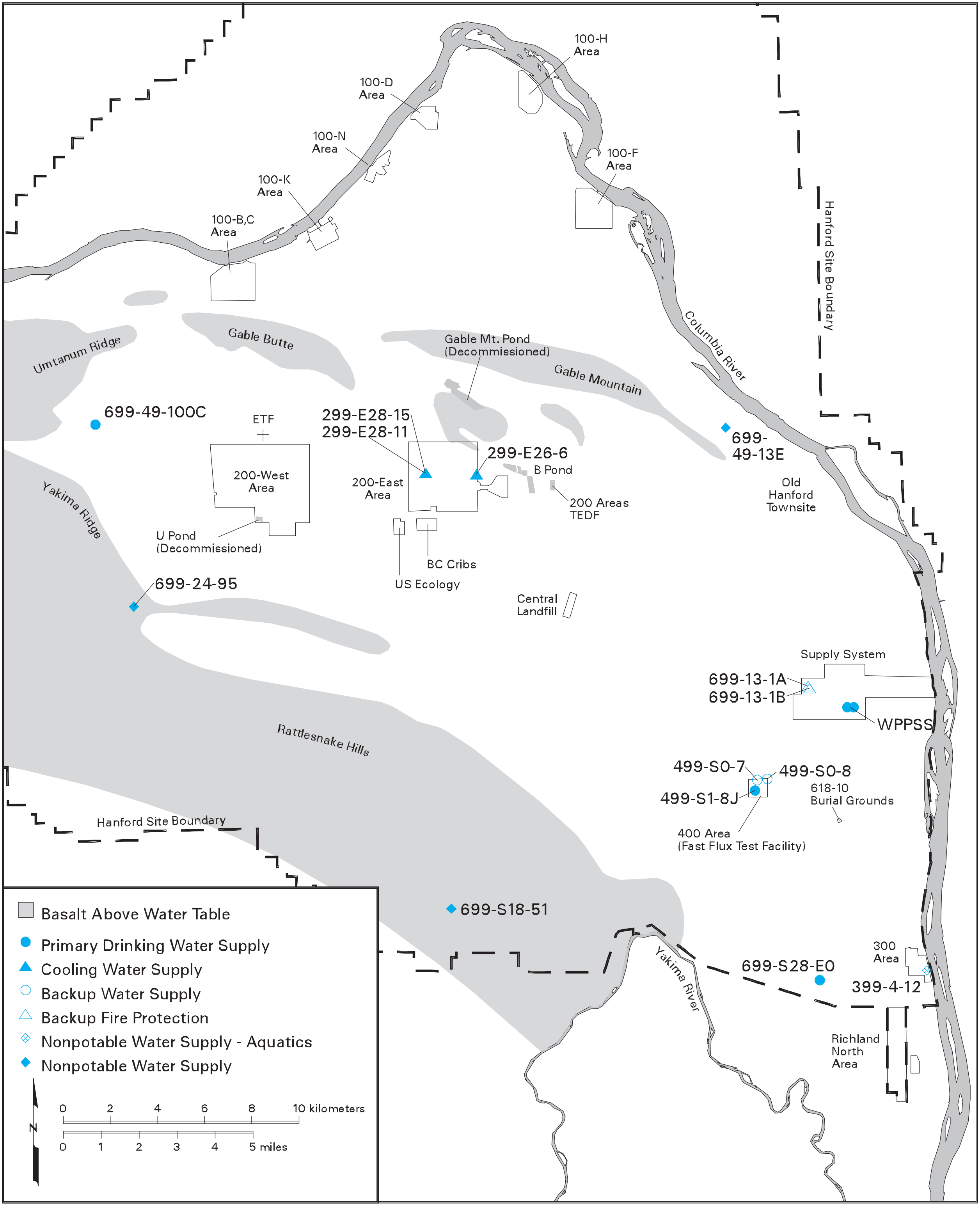
Figure 4.8.2. Water-Supply Wells in the Unconfined Aquifer at the Hanford Site



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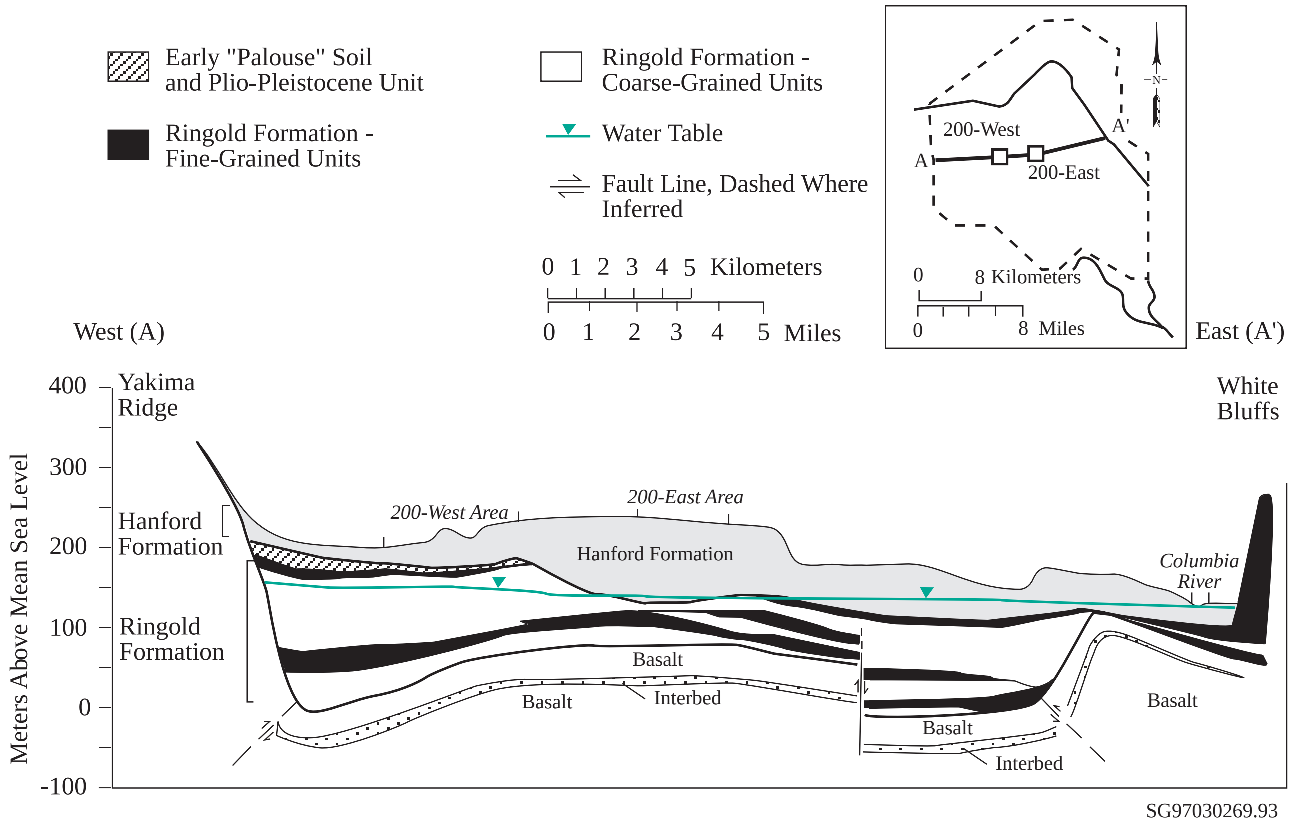

Figure 4.8.3. Geologic Cross Section of the Hanford Site

basalt flows and the sediments deposited as interbeds between basalt eruptions are frequently water-bearing zones that are used as water sources in areas around the Hanford Site.

During the period of basalt deposition, tectonic pressure was very slowly deforming the basalt flows into the generally east-west trending ridges that border the Pasco Basin today. After the last major basalt eruption, the Ringold Formation was deposited by the ancestral Columbia River as it meandered back and forth across the relatively flat basalt surface, depositing sand and gravel in the central portion of the Pasco Basin. Two major interruptions that occurred when the Columbia River was blocked downstream caused a lake to develop in the Pasco Basin. Relatively thick mud layers accumulated in the lake each time. Approximately 3.4 million years ago, the Columbia River began to erode, rather than deposit, sediments in the Pasco Basin. The uppermost mud layer was eroded from much of the Pasco Basin and a caliche layer, part of the Plio-Pleistocene unit, developed in places on the eroded surface of the Ringold Formation.

The Hanford formation sediments were deposited by catastrophic ice age floods during the past 700,000 years. Fine sands and silts were deposited in slack-water areas at the margins of the basin. However, primarily sand and gravel were deposited on the Hanford Site. In places, these sediments are covered by up to a few meters (feet) of recent stream or windblown deposits.

More detailed information on the geology of the Pasco Basin can be found in DOE (1988), Connelly et al. (1992a, 1992b), Reidel et al. (1992), Lindsey (1995), and Hartman and Dresel (1997).

Groundwater Hydrology

Both confined and unconfined aquifers are present beneath the Hanford Site. An aquifer is a water-saturated geologic interval or unit that has a high permeability, meaning it can transmit significant quantities of water. A confined aquifer is bounded above and below by low-permeability materials that restrict the vertical movement of water.

The confining layers may be dense rock such as the central parts of basalt flows, silt, clay, or well-cemented sediments. Areally extensive confined aquifers at the Hanford Site are found primarily within interflows and interbeds of the Columbia River basalts. These are referred to as basalt-confined aquifers. Locally confined aquifers are also found below the clays and silts of the Ringold Formation.

An unconfined aquifer, or water-table aquifer, is overlain by unsaturated sediments. The upper surface of the saturated zone in an unconfined aquifer, which is called the water table, rises and falls in response to changes in the volume of water stored in the aquifer. In general, the unconfined aquifer at Hanford is located in the Hanford and Ringold Formations. In some areas, the water table is below the bottom of the Hanford formation and the unconfined aquifer is entirely within the Ringold Formation. The Hanford formation sands and gravels are unconsolidated and are generally much more permeable than the compacted and silty Ringold Formation gravels. Clay and silt units and zones of natural cementation form low-permeability zones within the Ringold Formation.

The unconfined aquifer forms the uppermost groundwater zone and has been directly impacted by waste-water disposal at the Hanford Site. The unconfined aquifer discharges primarily into the Columbia River, and is the most thoroughly monitored aquifer beneath the site. The Rattlesnake Ridge interbed is the uppermost, basalt-confined aquifer within the Pasco Basin and the Hanford Site. This aquifer and other confined aquifers are generally isolated from the unconfined aquifer by dense rock that forms the interior of the basalt flows. However, interflow between the unconfined aquifer and the basalt-confined aquifer system is known to occur at faults that bring a water-bearing interbed in contact with other sediments or where the overlying basalt has been eroded to reveal an interbed (Newcomb et al. 1972, Graham et al. 1984, Reidel et al. 1992). Additional information on the basalt-confined aquifer system can be found in Spane and Vermeul (1994) and Spane and Webber (1995).

The thickness of saturated sediments above the basalt bedrock is greater than 200 m (656 ft) in some areas of the Hanford Site and thins out along the flanks of the uplifted basalt ridges (Figure 4.8.4). Depth from the ground surface to the water table ranges from <0.3 m (1 ft) near the Columbia River to >106 m (348 ft) in the center of the site. The unconfined aquifer is bounded below by either the basalt surface or, in places, by relatively impervious clays and silts within the Ringold Formation. The water table defines the upper boundary of the unconfined aquifer. Laterally, the unconfined aquifer is bounded by basalt ridges and by the Yakima and Columbia Rivers. The basalt ridges have a low permeability and act as a barrier to lateral flow of groundwater where they rise above the water table (Gephart et al. 1979).

The water-table elevation contours shown in Figure 4.8.5 indicate the direction of groundwater flow and the magnitude of the hydraulic gradient in the unconfined aquifer. Groundwater flow is generally perpendicular to the water-table contours from areas of higher elevation, or head, to areas of lower head. Areas where the contours are closer together are high-gradient areas, where the "driving force" for groundwater flow is greater. However, because sediments with low permeabilities inhibit groundwater flow and produce steeper gradients, a high gradient does not necessarily mean high groundwater velocity. The permeability of the Ringold sediments is generally lower than that of the Hanford sediments, so lower transmissivity and steeper gradients are often associated with areas where the water table is below the bottom of the Hanford formation and the aquifer is entirely within the less-permeable Ringold sediments. Figure 4.8.6 shows the generalized distribution of transmissivity as determined from aquifer pumping tests and groundwater flow model calibration. Additional information on aquifer hydraulic properties at Hanford is presented in DOE (1988) and Thorne and Newcomer (1992).

Recharge of water within the unconfined aquifer comes from several sources (Graham et al. 1981). Natural recharge occurs from infiltration of precipitation along the mountain fronts, runoff from intermittent streams such as Cold Creek and Dry Creek on the western margin of the site, and limited infiltration of precipitation on the Hanford Site. The Yakima River, where it flows along the southern boundary of the Hanford Site, also recharges the unconfined aquifer. The Columbia River is the primary discharge area for the unconfined aquifer. However, the Columbia River also recharges the unconfined aquifer for short periods during high river stage, when river water is transferred into the aquifer along the riverbank. Groundwater discharges to the surface north of the 200-East Area form West Lake, a small water body formed in a closed depression. The size of West Lake fluctuates in response to changes in the water-table elevation, which is influenced by waste-water discharge practices. Recharge from infiltration of precipitation is highly variable on the Hanford Site both spatially and from year to year. The rate of natural recharge depends primarily on soil texture, vegetation, and climate (Gee et al. 1992,

Figure 4.8.4. Saturated Thickness of the Unconfined Aquifer at the Hanford Site

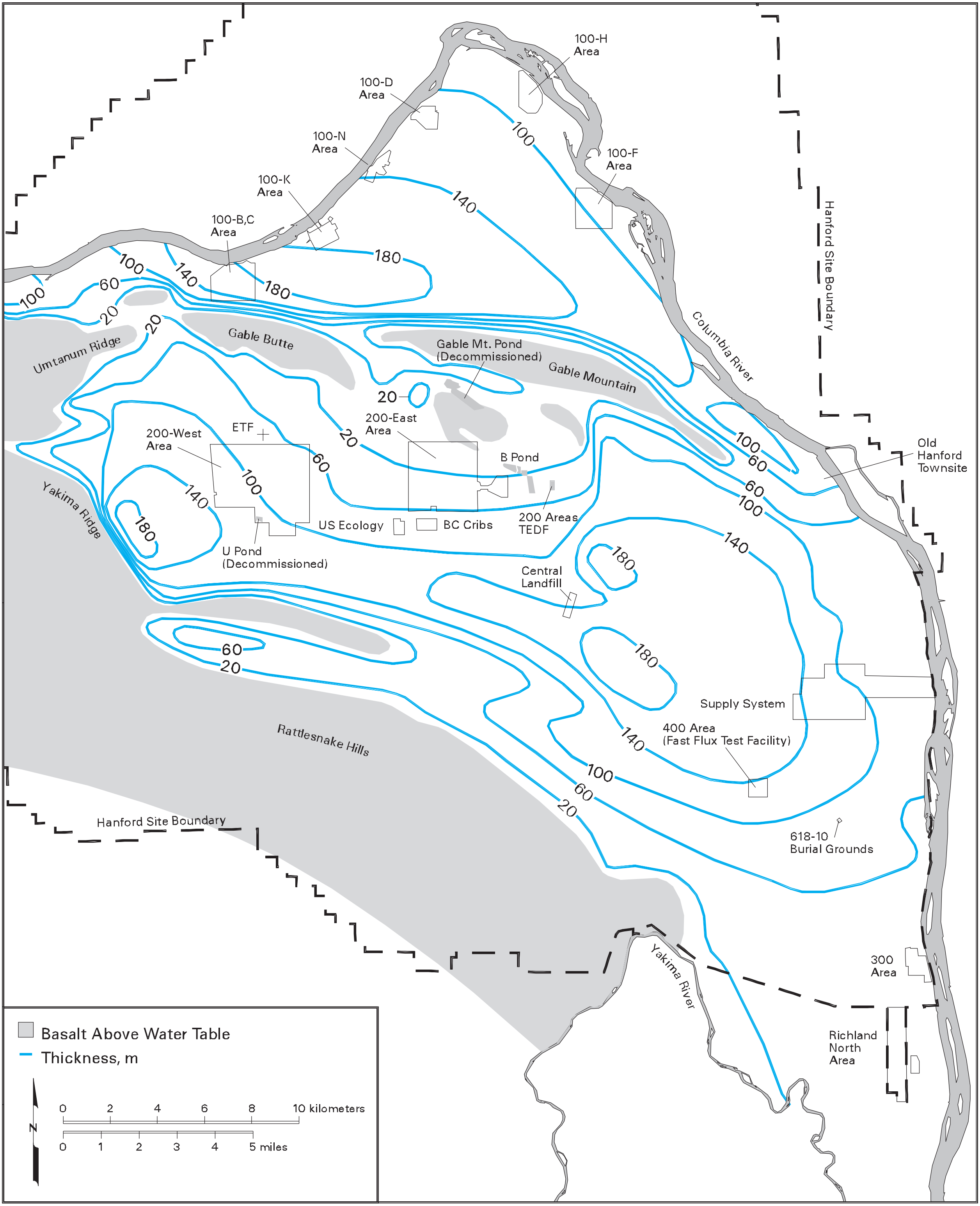

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Figure 4.8.5. Water-Table Elevations for the Unconfined Aquifer at the Hanford Site and in Adjacent Areas East and North of the Columbia River, June 1996

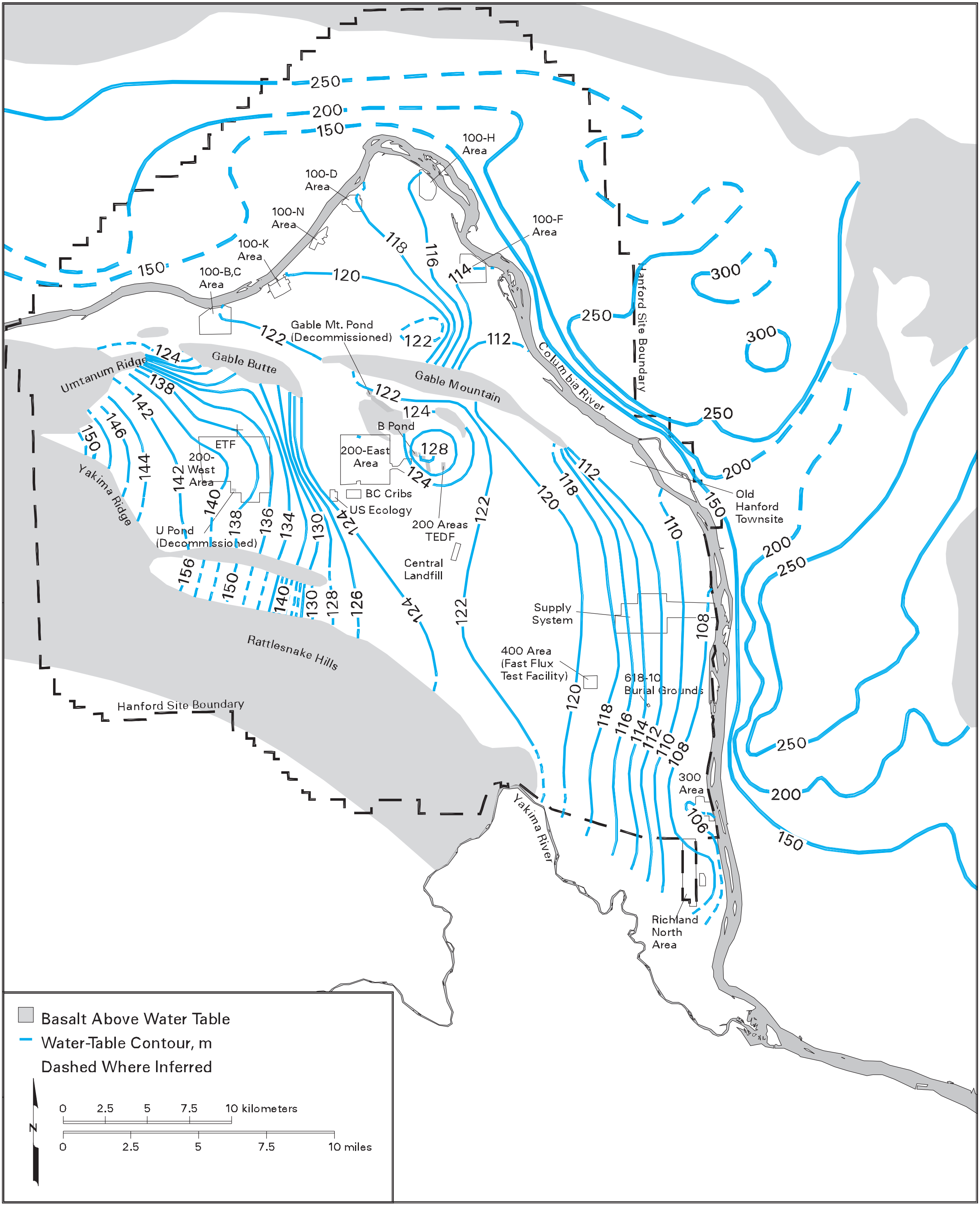

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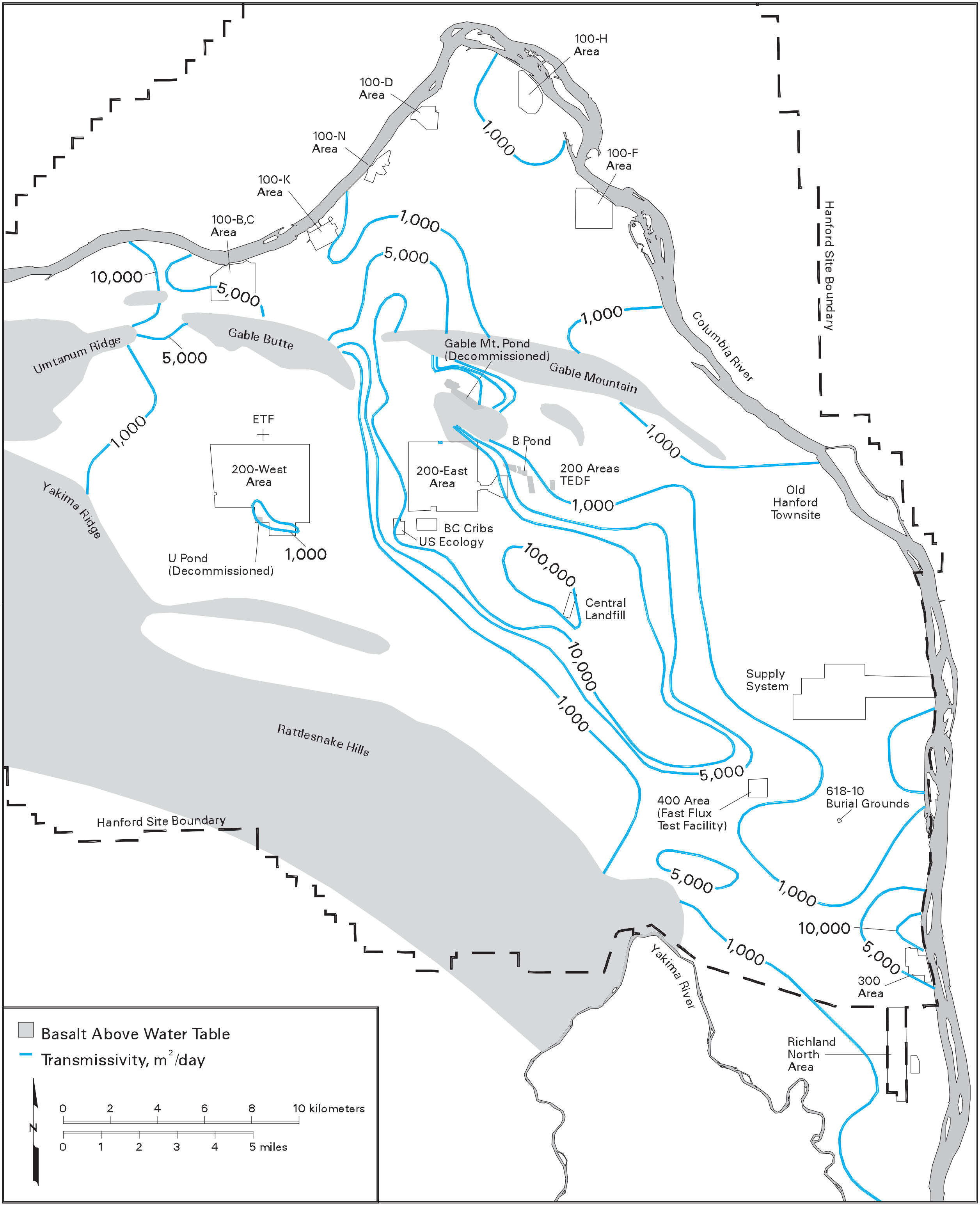
Figure 4.8.6. Distribution of Transmissivity of the Unconfined Aquifer at the Hanford Site



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Fayer and Walters 1995), and ranges from near zero, where fine-grained soils and deep-rooted vegetation are present, to >10 cm/yr (4 in./yr) in areas where soils are coarse textured and bare of vegetation.

Large-scale artificial recharge to the unconfined aquifer occurs from liquid waste disposal in the operating areas and offsite agricultural irrigation. Discharge of waste water has caused the water table to rise over most of the Hanford Site. Local areas with elevated water tables are called groundwater mounds. Figure 4.8.7 shows the change in water-table elevations between 1944 and 1979, when the water table had stabilized over most of the site. During the past 10 years, water-table elevations have declined in response to a decrease in liquid waste discharges from Hanford operations. The change in water-table elevations from 1979 to 1996 is shown in Figure 4.8.8. Irrigation in the Cold Creek Valley has increased water levels in this area west of the Hanford Site. Recharge from the Cold Creek Valley irrigation enters the Hanford Site as groundwater flow across the western boundary. Recharge from irrigation and canal leakage in agricultural areas across the Columbia River from the Hanford Site has caused larger water-table increases than those on the Hanford Site. As indicated in Figure 4.8.5, the water-table elevation to the east of the Columbia River is currently from 50 to 150 m (164 to 492 ft) higher than the water-table elevation on the Hanford Site.

Two major groundwater mounds formed in the vicinity of the 200-East and 200-West Areas in response to waste-water discharges. The first of these mounds was created by disposal at U Pond in the 200-West Area. This mound is slowly dissipating because the pond was decommissioned in 1984. The second major mound was created by discharge to B Pond, east of the 200-East Area. The water-table elevation near B Pond increased by a maximum of approximately 9 m (29 ft) before 1990 (Newcomer 1990) and has decreased slightly over the last 5 years because of reduced discharge. These mounds have altered the unconfined aquifer's natural flow pattern, which is generally from the recharge areas in the west to the discharge areas (primarily the Columbia River) in the east and north. Water levels in the unconfined aquifer have continually changed as a result of variations in the volume and location of waste-water discharge. Consequently, the movement of groundwater and its associated constituents has also changed with time. Groundwater mounding has also occurred in some of the 100 and 300 Areas. Groundwater mounding in these areas is not as great as in the 200 Areas because of lower discharge volumes.

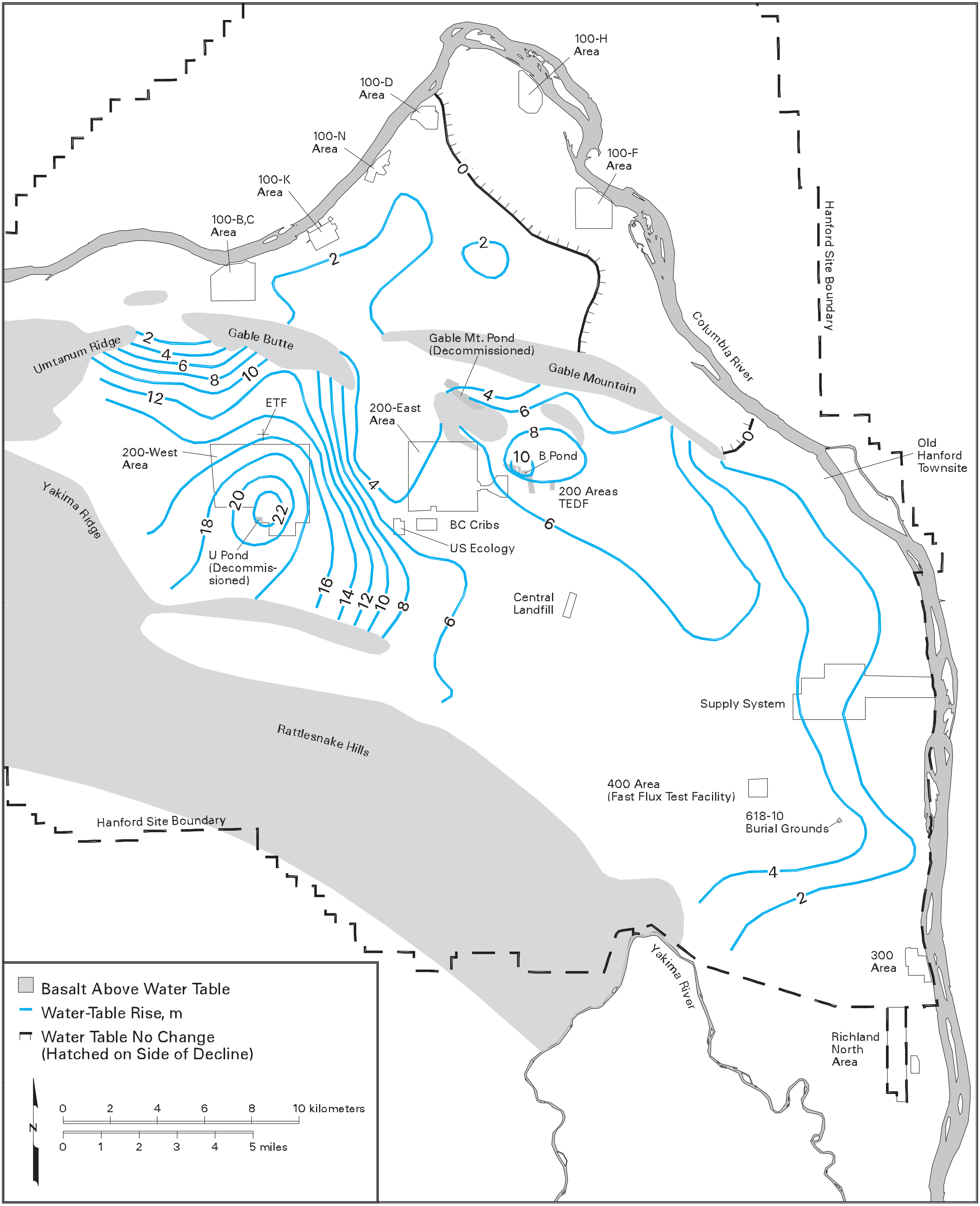
In the 100 and 300 Areas and other locations near the Columbia River, groundwater levels are influenced by river stage. Water levels in the Columbia River fluctuate on annual and daily cycles. The river level is primarily controlled by the operation of Priest Rapids Dam upstream of the Hanford Site. As the river stage rises, the increased water pressure is transmitted inland, increasing water levels in wells near the river. Very near the river, water flows from the river into the aquifer when the river stage is high and flows in the opposite direction when the river stage is low. This produces some dilution of contaminants near the river. However, the pressure effects of river-stage variation are observed much farther inland than the river water actually travels (up to 1.6 km [1 mi] in places).

Contaminant Transport

The history of contaminant releases and the physical and chemical principles of mass transport control the distribution of radionuclides and chemicals in groundwater. Processes that control the movement of these contaminants at the Hanford Site are discussed below.

Most of the groundwater contamination at Hanford resulted from discharge of waste water from reactor operations, reactor fuel fabrication, and processing of spent reactor fuel. Table 4.8.1 lists the major contaminants found in each area and the type of operation that generated them. In the 100 Areas, discharges included reactor cooling water, fuel storage basin water, filter backwash, and smaller amounts of waste from a variety of other processes. In the 200 Areas, large quantities of waste water from fuel reprocessing were discharged. Other contamination sources in the 200 Areas include plutonium purification waste and decontamination waste. The plutonium purification process resulted in the discharge of large amounts of chemicals in a liquid organic chemical form in addition to aqueous solutions. In particular, carbon tetrachloride was discharged in the 200-West Area in a nonaqueous liquid form. This organic liquid, once in contact with groundwater, slowly dissolves and produces groundwater contaminant plumes. The presence of nonaqueous liquid has a major impact on the site's groundwater remediation strategy because the organic liquid in the subsurface represents a continuing source of groundwater contamination but is very difficult to clean up. Groundwater contamination in the 300 Area resulted mainly from discharge of fuel fabrication wastes. Historically, the discharge of large volumes of water during site operations had a major impact on groundwater flow

Figure 4.8.7. Change in Water-Table Elevations Between 1944 and 1979



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