Probabilistic seismic hazard analyses have been used to determine the seismic ground motions expected from multiple earthquake sources, and these are used to design or evaluate facilities on the Hanford Site. The most recent Hanford Site-specific hazard analysis (Tallman 1994, 1996) estimated that 0.10 g (1 g is the acceleration of gravity) horizontal acceleration would be experienced on average every 500 yr (or with a 10 percent chance every 50 yr). This study also estimated that 0.2 g would be experienced on average every 2500 yr (or with a 2 percent chance in 50 yr). These estimates are in approximate agreement with the results of national seismic hazard maps produced by the U.S. Geological Survey (Frankel et al. 1996).

The Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) operate a 40-station seismic monitoring network in eastern Washington, which has been used to determine the locations and magnitudes of earthquakes since 1969. In addition, PNNL operates a network of five strong motion accelerometers near Hanford facilities to measure ground motion levels from larger earthquakes (Hartshorn et al. 2001).

4.5 Hydrology

Hydrology considerations at the Hanford Site include surface water, the vadose zone, and groundwater. The vadose zone is the unsaturated or partially saturated region between ground surface and the saturated zone. Water in the vadose zone is called soil moisture. Groundwater refers to water within the saturated zone. Permeable saturated units in the subsurface are called aquifers.

4.5.1 Surface Water

Surface water at Hanford includes the Columbia River, Columbia riverbank seepage, springs, and ponds. Intermittent surface streams, such as Cold Creek, may also contain water after large precipitation or snowmelt events. In addition, the Yakima River flows near a short section of the southern boundary of the Hanford Site (Figure 4.15).

4.5.1.1 Columbia River

In terms of total flow, the Columbia River is the second largest river in the contiguous United States and is the dominant surface-water body on the Hanford Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River.

Originating in the mountains of eastern British Columbia, Canada, the Columbia River drains an area of about 680,000 km^2 (260,000 mi^2) en route to the Pacific Ocean. The primary uses of the Columbia River include the production of hydroelectric power, irrigation of cropland in the Columbia Basin, and transportation of materials by barge. Many communities located on the Columbia River rely on the river as their source of drinking water (see Section 4.8.9). The Columbia River is also used as a source of drinking water and industrial water for several Hanford Site facilities (Dirkes 1993). In addition, the Columbia River is used extensively for recreation that includes fishing, bird hunting, boating, sail boarding, water skiing, diving, and swimming.

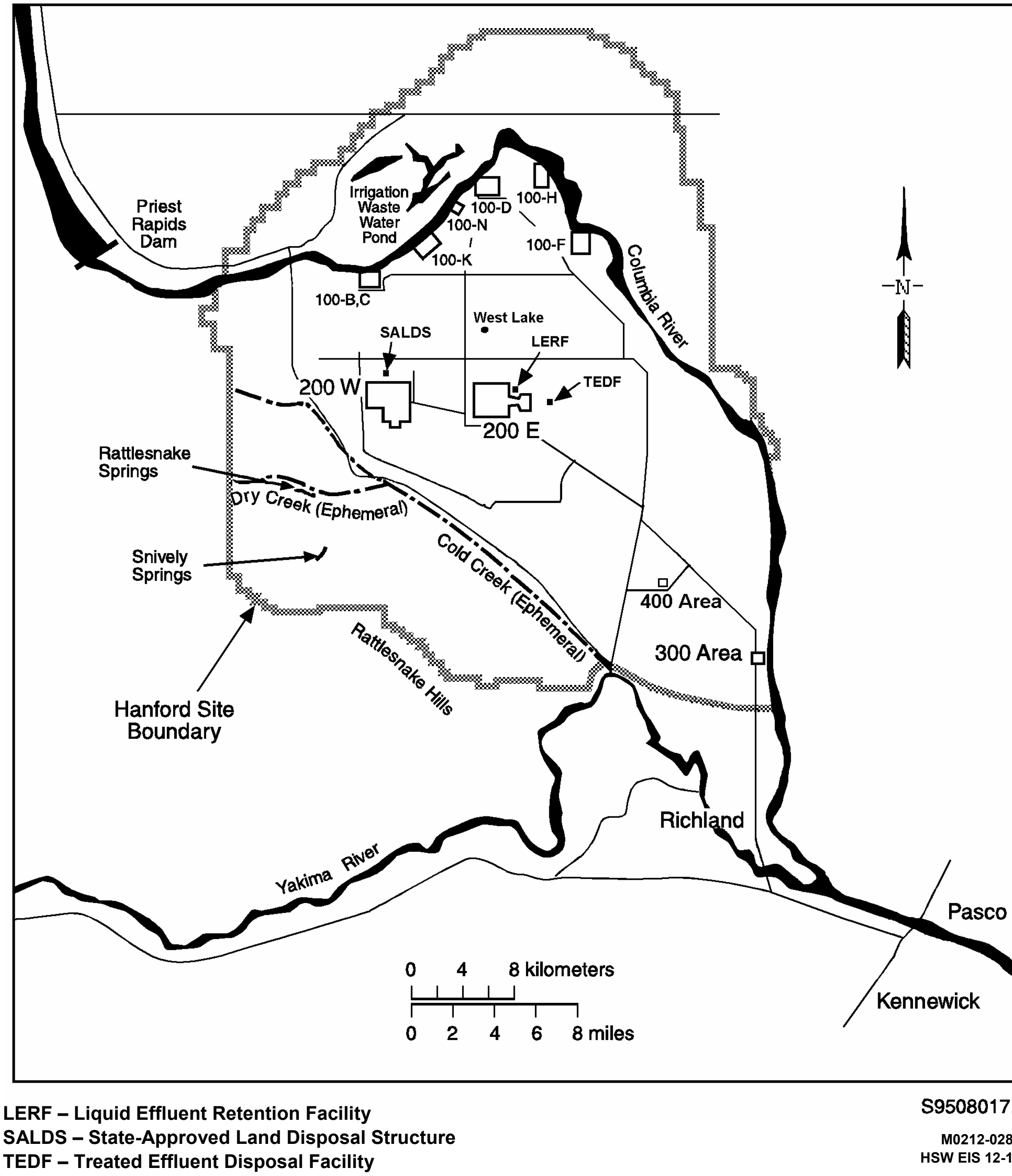


Figure 4.15. Surface Water Features Including Rivers, Ponds, Major Springs, Ephemeral Streams, and Artificial Ponds on the Hanford Site (after Neitzel 2002a)

4.5.1.2 Springs and Streams

Rattlesnake Springs and Snively Springs, two small spring-fed streams on the Fitzner/Eberhardt Arid Lands Ecology Reserve (ALE), are the only naturally occurring streams on the Hanford Site. Rattlesnake Springs, located 10 km (6 mi) west of the 200 West Area, forms a small surface stream that flows for approximately 2.5 km (1.6 mi) before it disappears into the ground as a result of seepage. Base flow of this stream is about 0.01 m^3/s (0.4 ft^3/s) (Cushing and Wolf 1982). Snively Springs is located to the west and at a higher elevation than Rattlesnake Springs.

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Hanford Site. These streams drain areas to the west of the Hanford Site and cross the southwestern part of the site toward the Yakima River. When it occurs, surface flow infiltrates rapidly and disappears into the surface sediments in the western part of the site.

4.5.1.3 Columbia Riverbank Seepage

The seepage of groundwater into the Columbia River has been known to occur for many years. Riverbank seeps were documented along the Hanford Reach long before Hanford operations began during the Second World War (Jenkins 1922). Seepage occurs below the river surface and also on the exposed riverbank, particularly noticeable at low-river stage. The seeps flow intermittently, apparently influenced primarily by changes in river level. Groundwater contaminants attributed to Hanford operations reach the Columbia River through these seeps.

4.5.1.4 Onsite Ponds and Artificial Water Bodies

West Lake is the only naturally occurring pool on the Hanford Site. West Lake is several hectares in size and is located approximately 8 km (5 mi) northeast of the 200 West Area and about 3 km (2 mi) north of the 200 East Area. It is situated in a topographically low-lying area and is sustained by groundwater inflow resulting from an intersection with the groundwater table. Water levels of West Lake fluctuate with water table elevation, which is influenced by wastewater discharge in the 200 Areas. The water level and size of the lake has been decreasing over the past several years because of reduced wastewater discharge. West Lake water quality samplings demonstrate elevated dissolved solids and nitrates. Total dissolved solids are approximately 15,000 mg/L, and pH is over 9. Nitrate concentrations are about 1.8 mg/L and ammonia concentrations are about 2.6 mg/L (Neitzel 2002a). Evaporation has also led to relatively high levels of uranium due to concentration of natural sources (Poston et al. 1991).

The Nature Conservancy (Hall 1998) has documented the existence of several naturally occurring vernal ponds near Gable Mountain and Gable Butte. These ponds appear to occur where a depression is present in a relatively shallow buried basalt surface. Water collects within the depression over the winter, resulting in a shallow pond that dries during the summer months. The formation of these ponds in any particular year depends on the amount and temporal distribution of precipitation and snowmelt events. The vernal ponds ranged in size from about 6.1 m x 6.1 m to 45.73 m x 30.5 m (20 ft x 20 ft to 150 ft x 100 ft), and were found in three clusters. Approximately ten vernal ponds were documented at the eastern end of Umtanum Ridge, six or seven were observed in the central part of Gable Butte, and three were found at the eastern end of Gable Mountain.

The 200 Area Treated Effluent Disposal Facility (TEDF) consists of two man-made disposal ponds. These ponds are each 2 ha (5 ac) in size and receive industrial wastewater permitted in accordance with the State Waste Discharge Permit Program (WAC 173-216). The treated effluent percolates into the ground from the disposal ponds.

The Liquid Effluent Retention Facility (LERF) is a wastewater holding facility consisting of three surface impoundments with a total capacity of 29.5 million L (7.8 million gal) each. The LERF provides storage until the waste is transferred to the ETF for final treatment. These ponds are equipped with double liners, a leak detection system, and floating covers (Poston et al. 2002). The LERF also includes piping and pumping systems, utilities, and a basin operations structure. Aqueous waste from the LERF is transferred to the 200 Area Effluent Treatment Facility (ETF) via pipelines.

The State-Approved Land Disposal Structure (SALDS) is located north of the 200 West Area. The SALDS is a Washington State permitted facility containing drain fields where tritium-bearing wastewater discharge is authorized as per the permit.

4.5.1.5 Floodplains and Runoff

No floodplains are found in the 200 Areas. Although floods in Cold Creek and Dry Creek have occurred historically, no historic flood events have been observed in the 200 Areas. The flooding of Cold Creek and Dry Creek infiltrated into the permeable sediments before reaching the 200 Areas.

Natural runoff generated onsite or from offsite up-gradient sources is not known to occur in the 200 Areas. Measurable runoff occurs during brief periods in two locations, Cold Creek Valley and Dry Creek Valley west and southwest of the 200 West Area (Newcomb et al. 1972). This surface runoff either infiltrates into the valley floor or evaporates. During periods of unusually rapid snowmelt or heavy rain-fall, surface runoff extends beyond Rattlesnake Springs in the upper part of Dry Creek. However, this runoff quickly infiltrates into the alluvial sediments of Cold Creek Valley.

Evaluation of flood potential is conducted in part through the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a drainage area and other hydrologic factors, such as antecedent moisture conditions, snowmelt, and tributary conditions that could result in maximum runoff. The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 m^3/s (1.4 million ft^3/s) and is greater than the 500-year flood. This flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the Central Plateau region of the Hanford Site would remain unaffected (DOE 1986).

In 1980, a flood risk analysis of Cold Creek, an ephemeral stream within the Yakima River drainage system, was conducted as part of the characterization of a basaltic geologic repository for high-level radioactive waste. Such design work is usually done according to the criteria of Standard Project Flood or probable maximum flood, rather than the worst-case or 100-year flood scenario. Therefore, in lieu of

100- and 500-year floodplain studies, a probable maximum flood evaluation was performed (Skaggs and Walters 1981). The probable maximum flood discharge rate for the lower Cold Creek Valley was 2265 m^3/s (80,000 ft/s) compared to 564 m^3/s (19,900 ft^3/s) for the 100-year flood. Modeling indicated that State Route (SR) 240 along the Hanford Site's southwestern and western areas would not be usable (Figure 4.16). Water from a probable maximum flood could potentially reach the southwest corner of the 200 West Area, but not the waste management areas.

4.5.2 Hanford Site Vadose Zone

The vadose zone is that part of the subsurface found between the ground surface and the top of the saturated zone. At the Hanford Site, the thickness of the vadose zone ranges from 0 m (0 ft) near the Columbia River to greater than 100 m (328 ft) beneath parts of the central plateau (Hartman 2000). Unconsolidated glacio-fluvial sands and gravels of the Hanford formation make up most of the vadose zone. In some areas, however, such as west and south of 200 East Area and in some of the 100 Areas, the fluvial-lacustrine sediments of the Ringold Formation make up the lower part of the vadose zone.

Moisture movement through the vadose zone is important at the Hanford Site because it is the driving force for migration of most contaminants. Radioactive and hazardous wastes in the soil column from past intentional liquid-waste disposals, unplanned leaks, solid waste disposal, and underground tanks are potential sources of future vadose zone and groundwater contamination. Contaminants may continue to move slowly downward for long periods (tens to hundreds of years depending on recharge rates) after termination of liquid waste disposal.

Except for SALDS, the 200 Area TEDF ponds, and septic drain fields, artificial recharge (the process by which excess surface water is directed into the ground) to the vadose zone ended in the mid-1990s. Natural infiltration in the vadose zone causes older preexisting water to be displaced downward by newly infiltrated water. The amount of recharge at any particular site is highly dependent on the soil type and the presence of vegetation. Usually, vegetation reduces the amount of infiltration through the biological process of evapotranspiration.

Although most natural recharge is probably uniform flow (Jones et al. 1998), the vadose zone stratigraphy influences the movement of liquid through the soil column. Where conditions are favorable, lateral spreading of liquid effluent or local perched water zones may develop. Perched water zones form where downward moving moisture accumulates on top of low-permeability soil lenses or highly cemented horizons.

Preferential flow may also occur along discontinuities, such as clastic dikes and fractures. Clastic dikes are a common geologic feature in the suprabasalt sediments at the Hanford Site. Their most important feature is their potential to either enhance or inhibit vertical and lateral movement of contaminants in the subsurface, depending on textural relationships. Preferential flow may also take place via old, abandoned, or poorly sealed vadose zone and groundwater wells.

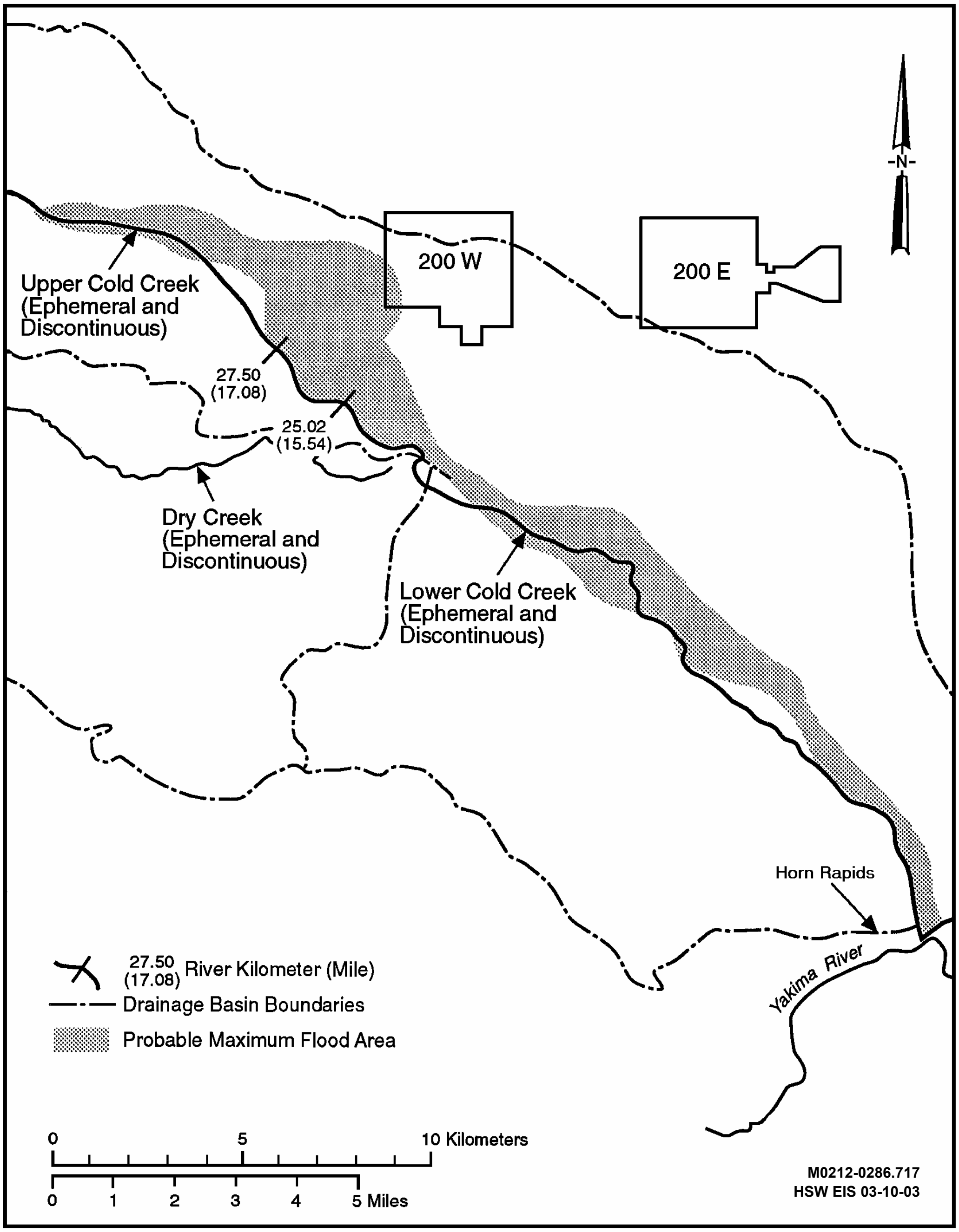


Figure 4.16. Extent of Probable Maximum Flood in Cold Creek Area (Skaggs and Walters 1981)

Subsurface source characterization, sediment sampling and characterization, and vadose zone monitoring are employed to describe the current and future configuration of contamination in the vadose zone.

4.5.2.1 Vadose Zone Contamination

The Hanford Site has more than 800 former (referred to as past-practice) liquid disposal facilities. Radioactive liquid waste was discharged to the vadose zone through reverse (injection) wells, French drains, cribs, ponds, and ditches. Over the last 56 years, 1.5 to 1.7 billion m^3 (396 to 449 billion gal) of effluent were disposed of to the soils (Gephart 1999). Most effluent was released in the 200 Areas. The major groundwater contaminant plumes emanating from the 200 Areas are tritium and nitrate. The major source for both contaminants was liquid discharges resulting from chemical processing activities. These discharges also included technetium-99 and iodine-129 which, like tritium and nitrate, are mobile in groundwater. Carbon tetrachloride was also discharged to cribs near the Plutonium Finishing Plant in the 200 West Area. Vadose zone sources for these contaminants almost certainly remain beneath many past-practice disposal facilities.

Approximately 280 unplanned releases in the 200 Areas also contributed contaminants to the vadose zone (DOE-RL 1997). Many of these were releases from underground tanks and have contributed significant contamination to the vadose zone. In addition, approximately 50 active and inactive septic tanks and drain fields and numerous radioactive and non-radioactive landfills and dumps have impacted the vadose zone (DOE-RL 1997). The landfills are and were used to dispose of solid wastes, which, in most instances, are easier to locate, retrieve, and remediate than are liquid wastes.

A total of 149 single-shell tanks and 28 double-shell tanks have been used to store high-level radioactive and mixed wastes in the 200 Areas. The wastes resulted from uranium and plutonium recovery processes and, to a lesser extent, from strontium and cesium recovery processes. Of the single-shell tanks, 67 are assumed to have leaked an estimated total of 2839 to 3975 m^3 (750,000 to 1,050,000 gal) of contaminated liquid to the vadose zone (Hanlon 2001). The three largest tank leaks were 435,320 L (115,000 gal), 37,850 to 1,048,560 L (10,000 to 277,000 gal), and 265,980 L (70,365 gal). The average tank leak was between 41,640 and 60,565 L (11,000 and 16,000 gal) (Hanlon 2001).

The amount of contamination remaining in the vadose zone is uncertain. Several compilations of vadose zone contamination have been formulated through the past years. DOE-RL (1997) and Kincaid et al. (1998) contain the most recent inventories of contaminants disposed of to past-practice liquid disposal facilities in the 200 Areas. Dorian and Richards (1978) list contaminant inventories disposed of to most 100 Area past-practice facilities. Anderson (1990) lists inventories of effluents sent to single-shell tanks. A series of reports estimate the curies of gamma-emitting radionuclides and the volumes of contaminated soil associated with each single-shell tank farm. (See the series of online reports at the Hanford Tank Farm Vadose Zone Project (http://www.gjo.doe.gov/programs/hanf/HTFVZ.html). Their estimates for all locations for the three most widespread contaminants are 8901 Ci of cesium-137 in 395,550 m^3 of soil, 0.8611 Ci of europium-154 in 30,133 m^3 of soil, and 0.7424 Ci of cobalt-60 in 74,369 m^3 of soil.

4.5.2.2 Vadose Zone Monitoring and Characterization Activities

Although disposal of untreated wastewater to the ground stopped in 1995 (Schmidt et al. 1996), contaminant movement still occurs in the soil column beneath past-practice sites. Vadose zone monitoring/characterization is one approach for evaluating the status of possible leaks or remobilization of contaminants caused by natural or artificial infiltration. The objectives of vadose-zone monitoring/ characterization are to document the location of the contamination, determine the moisture and contaminant movement in the soil column, and assess the effectiveness of remedial actions.

DOE has been conducting an expedited response action to treat carbon tetrachloride contamination since 1992 at the 200-ZP-2 Operable Unit, located in the 200 West Area, with the concurrence of the EPA and the Washington State Department of Ecology (Ecology). Soil-vapor extraction is being used to remove carbon tetrachloride from the vadose zone as part of this expedited response action (Rohay 1999; Hartman et al. 2001). To track the effectiveness of the remediation effort, measurement of soil-vapor concentrations of chlorinated hydrocarbons are made at the inlet to the soil-vapor-extraction system and at individual off-line wells and probes through the soil-vapor extract sites. As of September 2002, 84,700 kg (187,000 lb) of carbon tetrachloride had been removed from the groundwater and vadose zone beneath the 200 West Area. The soil-vapor concentrations monitored deep within the vadose zone during the past few years suggest that soil vapor-extraction remediation has removed a substantial amount of the carbon tetrachloride from the vadose zone (Hartman et al. 2003).

Baseline vadose zone characterization has been conducted at the single-shell tank farms since 1995. Spectral gamma-ray logging detectors were used in approximately 800 boreholes at the 149 single-shell tanks to locate man-made gamma-emitting radionuclides in the soil. During the initial logging of the drywells, several areas were found with levels of contamination high enough to effectively saturate the gamma-ray detectors. Those areas were relogged in 2000 with more robust systems. The maximum radionuclide concentration (cesium-137) detected was about 100 million pCi/g. In addition, during 2000, 88 boreholes that were logged previously were relogged to determine whether contamination continues to move in the vadose zone. Data acquired in 22 of the 88 boreholes showed increases in concentration, suggesting possible continued contaminant movement through the vadose zone (Poston et al. 2001).

During 1999, boreholes around 25 inactive 200 East Area facilities, termed specific retention facilities, were monitored by spectral gamma-ray and neutron moisture methods. Specific retention facilities were designed to use the moisture-retention capability of the soil to retain contaminants. Ideally, liquids disposed of to specific retention facilities would be limited to less than about 10 percent of the soil volume between the facility and the groundwater, resulting in retention of the liquid in the soils (Waite 1991). Significant quantities of radionuclides and chemicals were discharged to specific retention trenches with some trenches receiving up to 1570 Ci of cesium-137, 475 Ci of strontium-90, and 89 Ci of technetium-99. The volume of liquid discharged to each trench is thought to be insufficient to drive contaminants through the vadose zone to groundwater. Therefore, the discharged contaminants remain in the soil column and these sites represent potential sources for future groundwater contamination at the Hanford Site. Of the 29 boreholes logged, 4 had previous spectral gamma logs for comparison. Logs from two of those boreholes showed that changes in subsurface distribution of man-made radionuclides had occurred since 1992 (Horton and Randall 2000), indicating continued movement of contaminants in the vadose zone years after the facilities ceased operations.

4.5.3 Groundwater

Groundwater originates as surface water, either from natural recharge, such as rain, streams, and lakes, or from artificial recharge, such as reservoirs, excess irrigation, canal seepage, deliberate augmentation, industrial processing, and wastewater disposal.

4.5.3.1 Hanford Site Aquifer System

Groundwater beneath the Hanford Site is found in an upper unconfined aquifer system and deeper basalt-confined aquifers. The unconfined aquifer system is also referred to as the suprabasalt aquifer system because it is within the sediments that overlie the basalt bedrock. Low-permeability layers of fine-grained sediment locally confine portions of the suprabasalt aquifer system. However, because the entire suprabasalt aquifer system is interconnected on a sitewide scale, it is referred to in this report as the Hanford unconfined aquifer system.

Basalt-Confined Aquifer System. Relatively permeable sedimentary interbeds and the more porous tops and bottoms of basalt flows form the confined aquifers within the Columbia River Basalts. The horizontal hydraulic conductivities of most of these aquifers fall in the range of 10^{-10} to 10^{-4} m/s (3×10^{-10} to 3×10^{-4} ft/s). Saturated but relatively impermeable dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from 10^{-15} to 10^{-9} m/s (3×10^{-15} to 3×10^{-9} ft/s), about five orders of magnitude lower than some of the confined aquifers that lie between these basalt flows (DOE 1988). Hydraulic-head information indicates that groundwater in the basalt-confined aquifers generally flows toward the Columbia River and, in some places, toward areas of enhanced vertical communication with the unconfined aquifer system (Hartman et al. 2001; DOE 1988; Spane 1987).

Recharge to the upper basalt-confined aquifer is believed to occur along the margins of the Pasco Basin as a result of precipitation infiltration and surface water where the basalt and interbeds are exposed at ground surface. Recharge may also occur through the Hanford/Ringold aquifer system, where a downward hydraulic gradient exists between the Ringold Formation and the confined and upper basalt-confined aquifers or from deeper basalt aquifers having an upward gradient.

South of the Umtanum Ridge/Gable Mountain area, groundwater in the upper basalt-confined aquifer system generally flows from west to east across the Hanford Site toward the Columbia River. The elevated regions to the west and southwest of the site are believed to be recharge areas for the system, and the Columbia River represents a discharge area.

Unconfined Aquifer System. The unconfined aquifer is generally located in the unconsolidated to semi-consolidated Ringold and Hanford formation sediments that overlie the basalt bedrock. Where it is below the water table, the coarse-grained Hanford formation makes up the most permeable zones of the unconfined aquifer system.

The saturated thickness of the unconfined aquifer on the Hanford Site is greater than 61 m (200 ft) in some areas but pinches out along the flanks of the basalt ridges. Depth to the water table ranges from less than 0.3 m (1 ft) near the Columbia River to more than 106 m (348 ft) near the 200 Areas. Perched water-table conditions have been encountered in sediments above the unconfined aquifer in the 200 West Area (Airhart 1990; Last and Rohay 1993) and in irrigated offsite areas east of the Columbia River (Brown 1979). Because the Ringold sand and gravel sediments are more consolidated and are partially cemented, they are about 10 to 100 times less permeable than the sand and gravel sediments of the overlying Hanford formation. Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 0.27 to 2.7 m/d (0.9 to 9 ft/d), compared to 305 to 3050 m/d (1000 to 10,000 ft/d) for the Hanford formation (DOE 1988). Mud-dominated units with the Ringold Formation are relatively impermeable.

Groundwater in the unconfined aquifer at Hanford generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site, and toward the Columbia River on the eastern and northern boundaries. The Columbia River is the primary discharge area for the unconfined aquifer. A map showing water table elevations for the Hanford Site and adjacent areas across the Columbia River is displayed in Figure 4.17. Figure 4.18 details the water table elevations for the 200 Areas. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge. Along the Columbia River shoreline, daily river level fluctuations may result in water table elevation changes of up to 3 m (10 ft). As the river stage rises, a pressure wave is transmitted inland through the groundwater.

Natural area recharge from precipitation across the entire Hanford Site ranges from about 0 to 10 cm/yr (0 to 4 in./yr), but is probably less than 2.5 cm/yr (1 in./yr) over most of the site (Gee and Heller 1985; Bauer and Vaccaro 1990; Fayer and Walters 1995). Between 1944 and the mid-1990s, the volume of artificial recharge from Hanford wastewater disposal was significantly greater than the natural recharge. An estimated 1.7×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds and cribs during this period (Hartman et al. 2001). Because of the reduction in discharges, groundwater levels are falling, particularly around the operational areas (Hartman 2000).

After the beginning of Hanford operations, the water table rose about 27 m (89 ft) under the U Pond disposal area in the 200 West Area and about 9 m (30 ft) under disposal ponds near the 200 East Area. The volume of water that was discharged to the ground at the 200 West Area was actually less than that discharged at the 200 East Area. However, the lower conductivity of the aquifer near the 200 West Area inhibited groundwater movement in this area resulting in a higher groundwater mound. The presence of the groundwater mounds locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (1986) documented changes in water table elevations between 1950 and 1980. Until about 1980, the edge of the mounds migrated outward from the sources over time. Water levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (Hartman 2000). Although the reduction of wastewater discharges has caused water levels to drop significantly, a residual groundwater mound beneath the 200 West Area is still shown by the curved water table contours near this area (Figures 4.17 and 4.18).

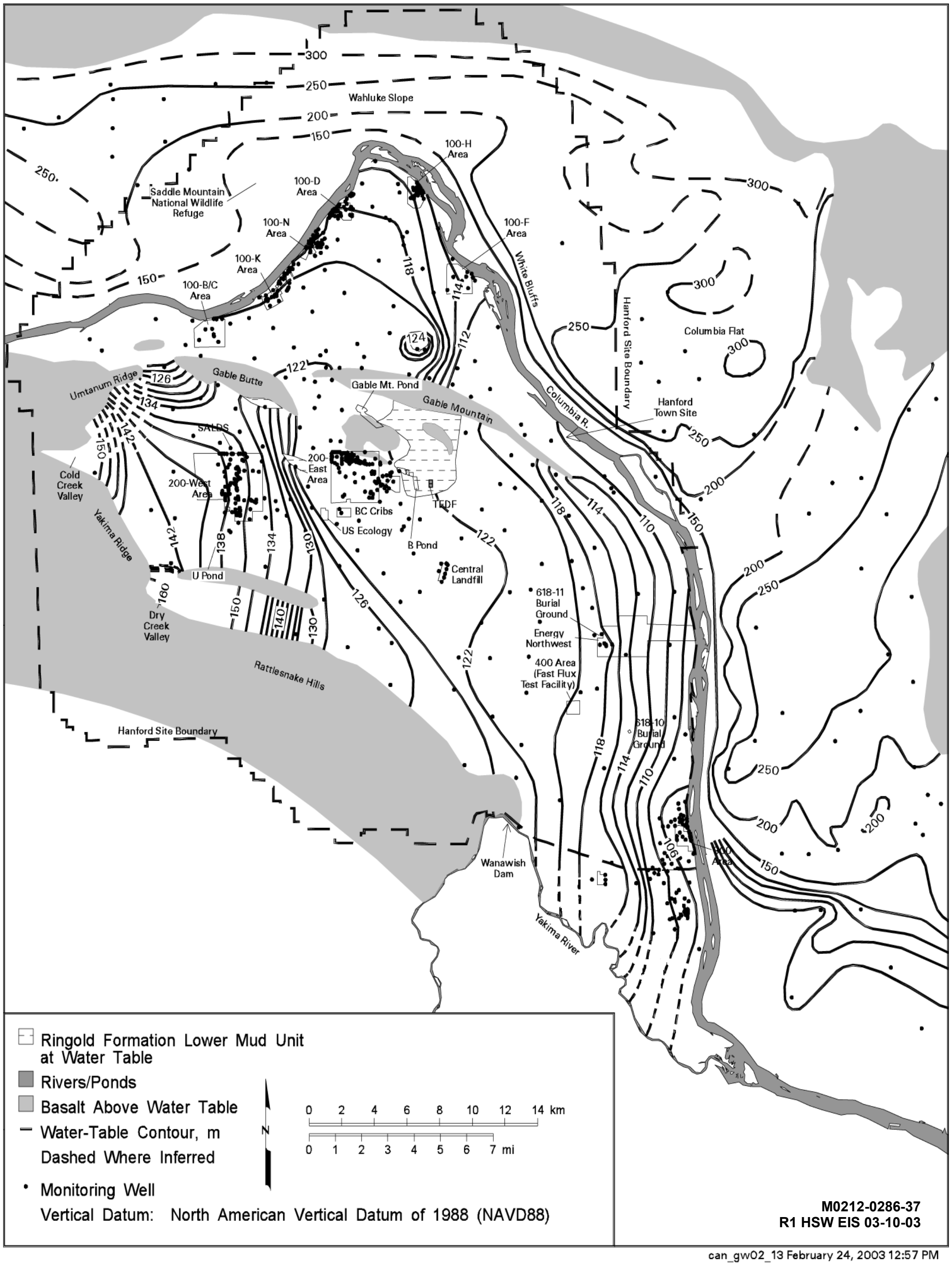


Figure 4.17. Groundwater Elevations for the Unconfined Aquifer at Hanford, March 2001 (after Hartman et al. 2002b)

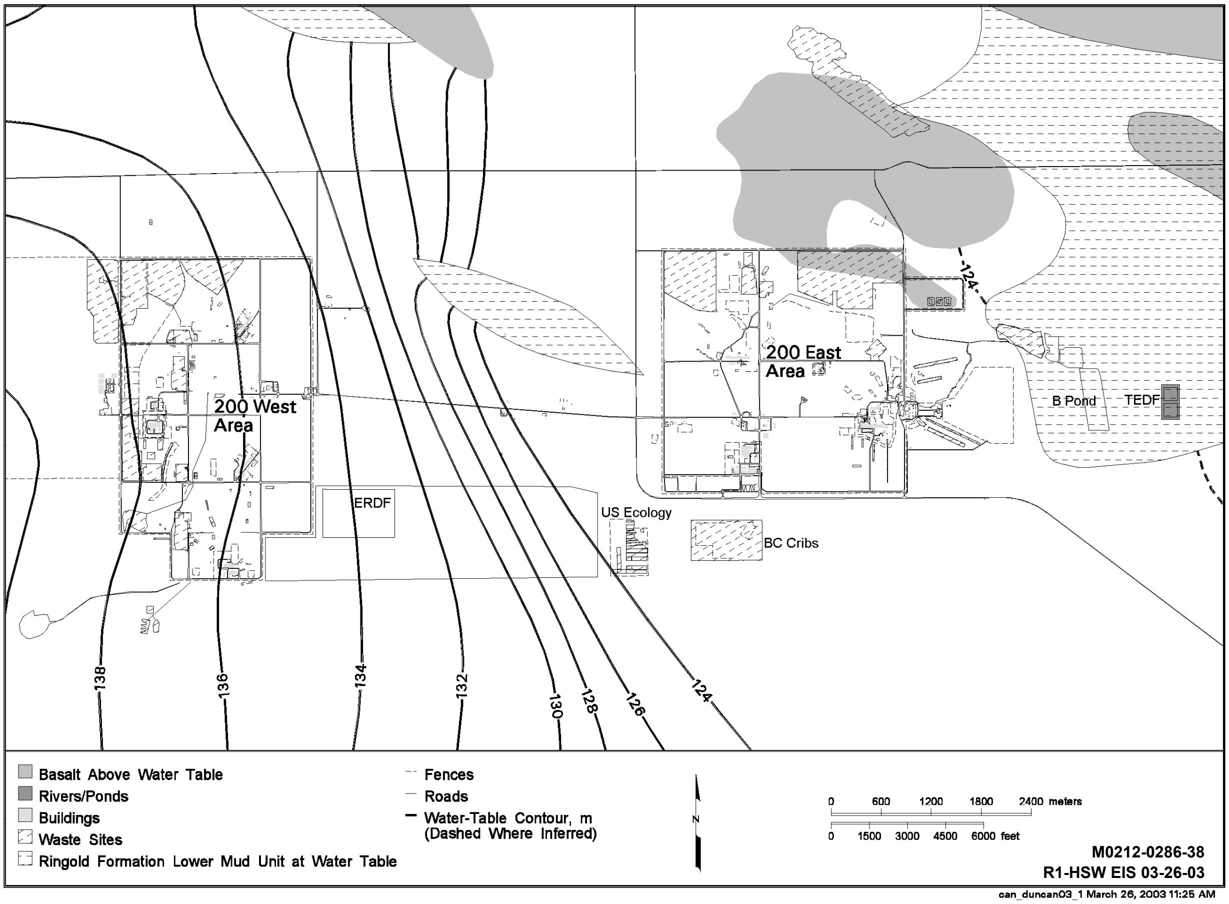


Figure 4.18. Groundwater Elevations for the Unconfined Aquifer at the 200 Areas (after Hartman et al. 2002b)

The saturated thickness and flow conditions in the unconfined aquifer are expected to return to pre-Hanford conditions with the decline and eventual cessation of artificial discharges at Hanford. Water levels have dropped in the vicinity of central areas in the site where the basalt crops out above the water table. Analyses by Cole et al. (1997) suggest the saturated thickness of the unconfined aquifer will decrease and areas of the aquifer may actually dry out. With this thinning and drying of the aquifer, which is predicted to occur in the area between Gable Butte and the outcrop south of Gable Mountain, the potential exists for the northern area of the unconfined aquifer to become hydrologically separated from the area south of Gable Mountain and Gable Butte. Therefore, flow from the 200 West Area and the northern half of the 200 East Area, that currently migrates through the gap between Gable Butte and Gable Mountain, will be effectively cut off in the next 200 to 300 years. In time, the overall water table (including groundwater mounds near the 200 East and West Areas) will decline, and groundwater movement from the 200 Area Plateau will shift to a dominantly west-to-easterly pattern of flow toward points of discharge along the Columbia River between the Old Hanford townsite and the Energy Northwest facility.

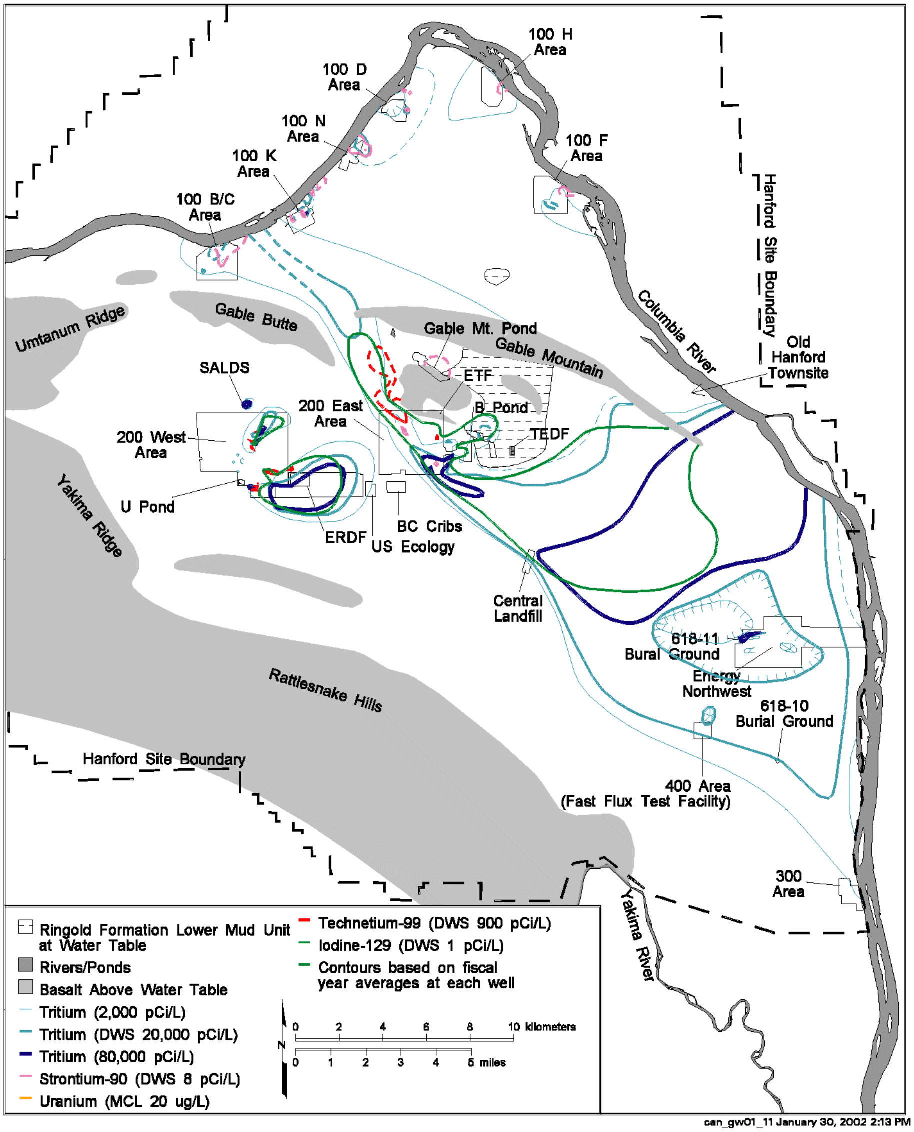
During 2000, the groundwater mounds have become less prominent. Water levels east of the 200 East Area have dropped below the top of a fine-grained confining unit, creating a barrier to movement in the surrounding unconfined aquifer (Hartman et al. 2001). Beneath this confining unit, the uppermost aquifer is a transmissive unit in the Ringold Formation. Groundwater flow in the confined aquifer is still influenced by the recharge mound.

4.5.3.2 Groundwater Quality

Groundwater beneath large areas of the Hanford Site has been impacted by radiological and chemical contaminants resulting from past Hanford Site operations. These contaminants were primarily introduced through wastewater discharged to cribs, ditches, injection wells, and ponds (Kincaid et al. 1998). Additional contaminants from spills, leaking waste tanks, and 618-10 and 618-11 Burial Grounds have also impacted groundwater in some areas. Contaminant concentrations in the existing groundwater plumes are expected to decline through radioactive decay, chemical degradation, and dispersion. However, contaminants also exist within the vadose zone beneath waste sites (see Section 4.5.2), as well as in waste storage and disposal facilities. These contaminants have a potential to continue to move downward into the aquifer. Some contaminants, such as tritium, move with the groundwater while the movement of other contaminants is slower because they react with or are sorbed on the surface of minerals within the aquifer or the vadose zone. Groundwater contamination is monitored and is being actively remediated in several areas through pump-and-treat operations.

Contaminant concentrations in groundwater were compared with established drinking water standards as a benchmark for quality of the groundwater resource. These benchmark standards include the maximum contaminant level (MCL) and drinking water standard (DWS) for specific chemicals and radionuclides, which are legally enforceable limits for public drinking water supplies set by EPA or the Washington State Department of Health (WDOH). DOE Order 5400.5 establishes a limit for dose from radionuclides in public drinking water supplies operated by DOE or its contractors (DOE 1993). The dose limit is 4 mrem/yr (as total effective dose equivalent) from consumption of water at 2 L/day, which is intended to provide protection equivalent to that of the EPA and state standards. The published DOE derived concentration guide (DCG) for a specific radionuclide in drinking water may also be used as a benchmark for groundwater quality in the same manner as the EPA and state standards. The DCG represents the concentration of each radionuclide in drinking water that would result in a dose of 100 mrem/yr at a consumption rate of 2 L/day. Therefore, the DOE standard for a given radionuclide in drinking water corresponds to 4 percent of the DCG for that radionuclide.

Radiological constituents, including carbon-14, cesium-137, iodine-129, strontium-90, technetium-99, total alpha, total beta, tritium, uranium, and plutonium-239/240, were detected at concentrations greater than the MCL in one or more onsite wells within the unconfined aquifer. Concentrations of strontium-90, tritium, uranium, and plutonium were detected at levels greater than their respective DOE DCGs. Certain non-radioactive chemicals regulated by the EPA or the State of Washington (carbon tetrachloride, chloroform, chromium, cyanide, cis-1, 2 dichloroethene, fluoride, nitrate, sulfate, and trichloroethene) were also present in Hanford Site groundwater. Figure 4.19 shows the distribution of some radiological contamination in Hanford Site groundwater and Figure 4.20 shows the distribution of some hazardous chemical



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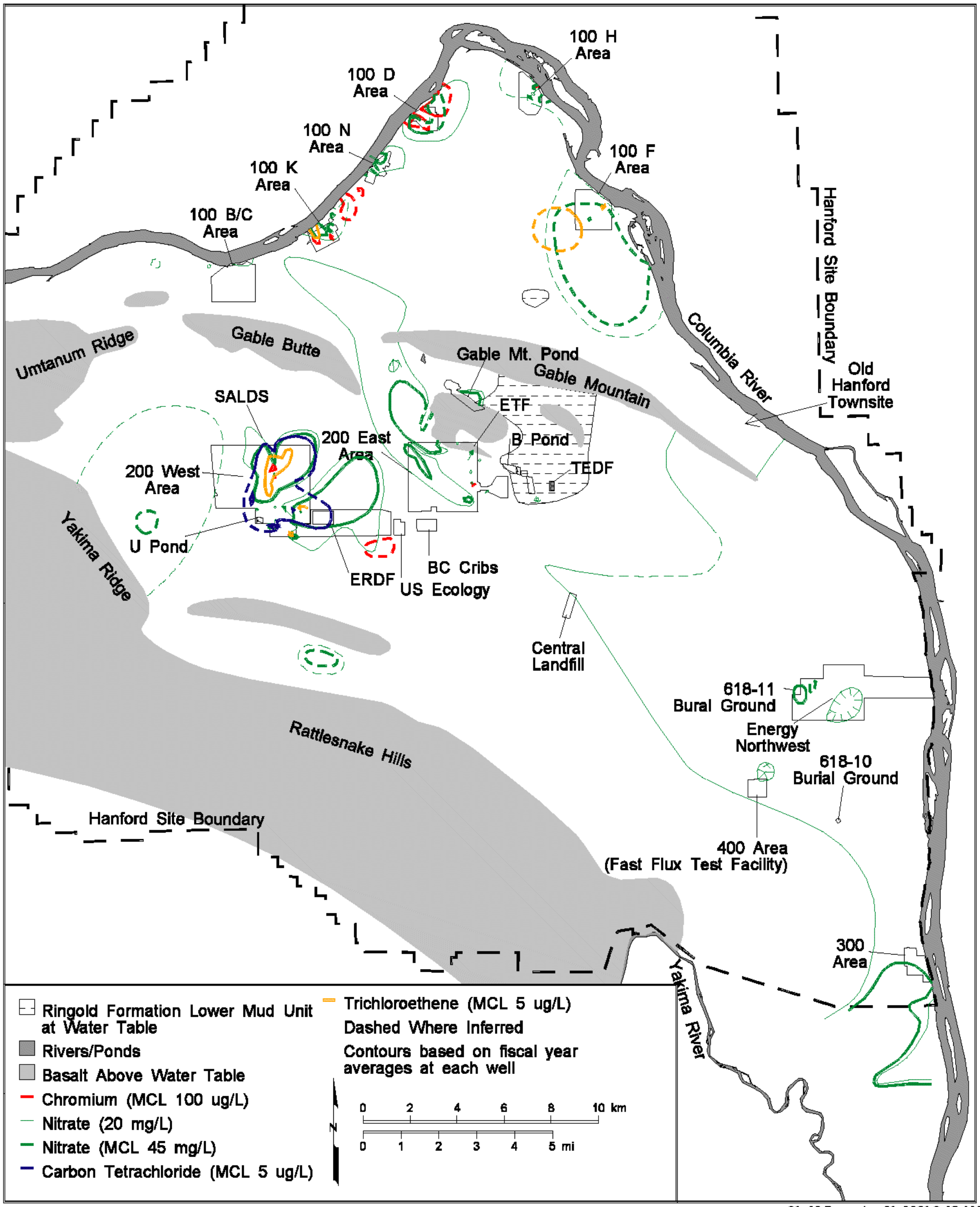
R1 HSW EIS 03-10-03

ERDF – Environmental Restoration Disposal Facility
ETF – Effluent Treatment Facility
SALDS – State-Approved Land Disposal Structure
TEDF – Treated Effluent Disposal Facility

Figure 4.19. Distribution of Major Radionuclides in Groundwater at Concentrations Above the Drinking Water Standards During FY 2001 (after Hartman et al. 2002b). Maximum concentrations are listed in Table 4.10.



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ERDF – Environmental Restoration Disposal Facility
ETF – Effluent Treatment Facility
SALDS – State-Approved Land Disposal Structure
TEDF – Treated Effluent Disposal Facility

Figure 4.20. Distribution of Major Hazardous Chemicals in Groundwater at Concentrations Above the Drinking Water Standards During FY 2001 (after Hartman et al. 2002b). Maximum concentrations are listed in Table 4.10.

Table 4.10. Maximum Concentrations of Groundwater Contaminants at Hanford in FY 2001 (Hartman et al. 2002b)

Contaminant (alphabetical order)	DWS or MCL [DCG][a]	Units	100-B/C Wells	100-B/C Shore[b]	100-K Wells	100-K Shore[b]	100-N Wells	100-N Shore[b]	100-D Wells	100-D Shore[b]	100-H Wells	100-H Shore[b]	100-F Wells	100-F Shore	200 West Wells
Carbon tetrachloride	5	µg/L													**7400**
Carbon-14	2000 [70,000]	pCi/L			**16,300**	ND									
Cesium-137	200 [3000]	pCi/L													
Chloroform	100	µg/L													160
Chromium (dissolved)	100	µg/L	86	48	**1332**	**110**	**173**	12	**4750**	**521**	**160**	88	79	19	**248**
Cobalt-60	100 [5000]	pCi/L													
Cyanide	200	µg/L													
cis-1,2 Dichloroethene	70	µg/L													
Fluoride	4	mg/L									0.32				**4.9**
Gross alpha	15	pCi/L									**33**				**18**
Gross beta	50	pCi/L	**270**	50	**8670**	**82**	**3440**	5.9	**75**	14	**278**	27	**80**	10	**28,700**
Iodine-129	1 [500]	pCi/L													**64**
Nitrate (as NO_3^-)	45	mg/L	34	**67**	**160**	**74**	**125**	22	**86**	**88**	**150**	17	**158**	(c)	**1300**
Nitrite (as NO_2)	3.3	mg/L							**8.3**						**27**
Plutonium 239/240	NA [30]	pCi/L													undetected
Strontium-90	8 [1000]	pCi/L	**135**	**15.8**	***5210***	ND	***9690***	***9690***	**12**	1.4	**38**	**14**	**38**	1.7	**69**
Technetium-99	900 [100,000]	pCi/L									471				**81,500**
Trichloroethene	5	µg/L			**19**								**16**		**21**
Tritium	20,000 [2,000,000]	pCi/L	**40,700**	**31,300**	**1,750,000**	6140	**36,900**	**29,700**	18,600	**22,100**	7740	5460	**38,600**	1380	**1,540,000**
Uranium	30 [790]	µg/L									**49**		23		***2140***

Note: Table lists highest concentration for fiscal year 2001 in each geographic region. Concentrations in **bold** exceed drinking water standards. Concentrations in ***bold italic*** exceed DOE derived concentration guides. Blank spaces indicate the constituent is not of concern in the given area. ND = not detected.

(a) DWS = drinking water standard; MCL = maximum contaminant level; DCG = derived concentration guide (based on 100 mrem/yr). See PNNL-13080 (Hartman 2000) for more information on these standards.

(b) Shoreline sampling includes aquifer sampling tubes, seeps, and shoreline wells from fall 2000. 200 East Area plumes monitored at Old Hanford Townsite.

(c) Fiscal year 2001 results appear erroneous. Past year's results up to 55 mg/L.

Table 4.10. (contd)

Contaminant (alphabetical order)	DWS or MCL [DCG][a]	Units	200 East Wells	200 East Shore[b]	400 Wells	600 Wells	300 Wells	300 Shore[b]	618-11 Wells	Richland North Wells	Basalt-Confined Wells
Carbon tetrachloride	5	μg/L				ND					
Carbon-14	2000 [70,000]	pCi/L									
Cesium-137	200 [3000]	pCi/L	**1910**								
Chloroform	100	μg/L				0.43					
Chromium (filtered)	100	μg/L	**1640**			17					
Cobalt-60	100 [5000]	pCi/L78	78								ND
Cyanide	200	μg/L	**423**								29
cis-1,2 Dichloroethene	70	μg/L					**190**				
Fluoride	4	mg/L								**15**	**8.5**
Gross alpha	15	pCi/L	**357**				**43**	**88**	8.0	10	3.5
Gross beta	50	pCi/L	**25,700**	36			**282**	33	**84**	24	**330**
Iodine-129	1 [500]	pCi/L	**10**	0.27							ND
Nitrate (as NO_3^-)	45	mg/L	**748**	**100**	**87**	22	**89**	**104**	**93**	**162**	38
Nitrite (as NO_2)	3.3	mg/L			0.36						
Plutonium 239/240	NA [30]	pCi/L	**63**								
Strontium-90	8 [1000]	pCi/L	***12,000***								ND
Technetium-99	900 [100,000]	pCi/L	**13,000**	112							**1120**
Trichloroethene	5	μg/L					**5.3**			**5.1**	
Tritium	20,000 [2,000,000]	pCi/L	***4,300,000***	**107,000**	**57,600**	**49,800**	**57,700**	11,700	***8,370,000***	551	5770
Uranium	30 [790]	μg/L	**678**				**205**	**210**	11	23	

Note: Table lists highest concentration for fiscal year 2001 in each geographic region. Concentrations in **bold** exceed drinking water standards. Concentrations in ***bold italic*** exceed DOE derived concentration guides. Blank spaces indicate the constituent is not of concern in the given area. ND = not detected.

(a) DWS = drinking water standard; MCL = maximum contaminant level; DCG = derived concentration guide (based on 100 mrem/yr). See PNNL-13080 (Hartman 2000) for more information on these standards.

(b) Shoreline sampling includes aquifer sampling tubes, seeps, and shoreline wells from fall 2000. 200 East Area plumes monitored at Old Hanford Townsite.

(c) Fiscal year 2001 results appear erroneous. Past year's results up to 55 mg/L.

constituents above the applicable DWSs. The area of contaminant plumes on the Hanford Site with concentrations exceeding drinking water standards was estimated to be 208 km^2 (80.3 mi^2) in fiscal year (FY) 2001. This estimate is 1 percent smaller than that for FY 2000. The decrease is primarily due to shrinkage of the tritium plume from 200 East Area, which was caused primarily by radioactive decay. Table 4.10 shows the maximum concentrations of groundwater contaminants observed on the Hanford Site during FY 2001, along with DWS and DCG values (Hartman et al. 2002b).

The upper basalt-confined aquifer is monitored by about 40 wells that are sampled annually to triennially. Most of these wells are located near the 200 Areas. During the year 2001, seventeen upper basalt-confined aquifer wells were sampled. Tritium, iodine-129, and nitrate were sampled in most of the wells, as they are most mobile in groundwater, the most widespread in the overlying unconfined aquifer, and provide an early warning of potential contamination in the upper basalt-confined aquifer. Results for each of these constituents were less than their respective drinking water standards for 2001. Monitoring results for the groundwater in the upper basalt-confined aquifer in 2000 indicate a tritium concentration of 5770 pCi/L beneath B Pond. Levels of tritium in this location are believed to be a result of downward migration from the overlying unconfined aquifer and have declined since 1996. The highest nitrate concentration, 38 mg/L, was found in the northern section of the 200 East Area in well 299-E33-12. Iodine-129 was not detected in 2001 (Hartman et al. 2002b).

4.5.3.3 200 Areas Hydrology

In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels. Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the Missoula floods that subsequently deposited Hanford gravels and sands on the remains of the Ringold Formation. Because the Hanford formation sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher. On the north side of the 200 East Area, evidence appears of erosional channels that may allow communication between the unconfined and uppermost basalt-confined aquifer (Graham et al. 1984; Jensen 1987).

Groundwater occurs in the 200 West Area within the Ringold Formation primarily under unconfined conditions, approximately 61 to 87 m (200 to 285 ft) beneath the surface. The saturated section is 110 m (360 ft) thick. Hydraulic conductivities measured in the 200 West Area in the Ringold Unit E aquifer range from approximately 0.02 to 60 m/day (0.06 to 200 ft/day). Hydraulic conductivities range from 0.5 to 1.2 m/day (1.6 to 4 ft/day) in the semi-confined to confined Ringold Unit A gravels. Groundwater in the 200 West Area generally flows east toward the 200 East Area. In the northwest corner of the 200 East Area, groundwater has flowed northward through the gap between Gable Butte and Gable Mountain. This northward flow appears to be diminishing (Hartman et al. 2002b).

Natural recharge from precipitation falling on the Hanford Site is highly variable spatially and temporally, ranging from near zero to more than 100 mm/yr, depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). Areas with shrubs and fine-textured soils like silt loams tend to have low recharge rates, while areas with little vegetation and coarse-textured soils, such as dune sands, tend to have high recharge rates. Recharge is also generally higher near the basalt ridges because of greater precipitation and runoff. Past estimates of recharge have been summarized in earlier status reports (Thorne and Chamness 1992; Thorne et al. 1993). Fayer and Walters (1995) developed a natural recharge map for 1979 conditions to support the Hanford Site three-dimensional groundwater and transport model. The distributions of soil and vegetation types were mapped first. A recharge rate was then assigned to each combination on the basis of data from lysimeters, tracer studies, neutron probe measurements, and computer modeling. Estimated recharge rates for 1992 were found to range from 2.6 to 127 mm/yr, and the total volume of natural recharge from precipitation over the Hanford Site was estimated at 8.47 x 10^6 m^3/yr. This value is of the same order of magnitude as the artificial recharge to the 200 Area waste disposal facilities during 1992 and is about half the volume of discharge to these facilities during 1979 (Fayer and Walters 1995).

The other source of recharge to the unconfined aquifer is artificial recharge from wastewater disposal. Over the past 50 years, the large volume of wastewater discharged to disposal facilities at the Hanford Site has significantly affected groundwater flow and contaminant transport in the unconfined aquifer. The volume of artificial recharge has decreased significantly during the past 10 years and continues to decrease. Wurstner et al. (1995) summarized the major discharge facilities incorporated in the three-dimensional model. Cole et al. (1997) summarized the major wastewater discharges from past and future sources.

Depth to groundwater in the 200 East Area ranges from 97 m (320 ft) in the southeast to 37 m (120 ft) in the vicinity of the 216-B-3C pond (B Pond mound). A downward gradient has formed in the B Pond vicinity due to groundwater mounding from discharges. Based on data collected in March 2002 for well pair 699-43-42J (water table) and 699-42-42B (7.37 m deeper), the downward gradient was 0.038. This is greater than the horizontal gradient, 0.002. Groundwater flow in the 200 East Area is to the southeast. Interconnection between the unconfined and lower confined aquifer is possible across the Central Plateau. However, except for the area near the erosional windows that occur in the basalt several kilometers north of the 200 East Area and B Pond vicinity in the 200 East Area, no indication is shown of aquifer interconnection. Several kilometers north of the 200 East Area, an absence of confining layer(s) is associated with an erosional window that has resulted in enhanced interconnection of the aquifers in this area. Hydraulic conductivities of the unconfined aquifer in the 200 East Area range from 150 to 300 m/day (500 to 1000 ft/day). Flow may split east of Gable Butte, one path heading north toward the gap between Gable Butte and Gable Mountain, and the other path east to the Columbia River.

Groundwater is monitored in the vicinity of the LLBGs as a result of interim status requirements of WAC 173-303. The LLBGs are divided into five low-level waste management areas (LLWMAs). Since 1996, groundwater has not been monitored within LLWMA-5, the location of the 218-W-6 Burial Ground, as the site has never received waste.

LLWMA-1 consists of the 218-E-10 Burial Ground. Well 299-E33-34, a downgradient monitoring well, exceeded the critical mean for specific conductance in 2000, but this was related to the nitrate plume with an upgradient source in the northern portion of this LLWMA (Poston et al. 2001).

LLWMA-2 is located in the 200 East Area and includes all of the 218-E-12B Burial Ground. Upgradient well 299-E34-7 exceeded the critical mean value for specific conductance in 2000. Sulfate and calcium are the major contributors to the increase and their source is not known. However, only 0.6 m (2 ft) of water remains in this well, which is at the top of the basalt, and the increases may be due to basalt chemistry. Well 299-E34-7 also exceeded the comparison value for total organic carbon in 2000. Results for volatile and semi-volatile organics were less than detection limits, with the exception of bis (2-ethylhexyl) phthalate at 1.7 μg/L.

LLWMA-3 includes the 218-W-3A, 218-W-3AE, and 218-W-5 Burial Grounds in the 200 West Area. Indicator parameter data from upgradient wells were statistically evaluated and values from downgradient wells were compared with established values from upgradient wells in 2000. The critical mean value for specific conductance was exceeded in an upgradient well, but is due to increases in sulfate and nitrate from upgradient sources. None of the other wells in LLWMA-3 exceeded contamination parameters during 2000. Several of the wells in LLWMA-3 have gone dry, as the water table continues to decline.

LLWMA-4 is located in the 200 West Area and includes 218-W-4B and 218-W 4C Burial Grounds. Indicator parameter data from upgradient wells were statistically evaluated and values from downgradient wells were compared with established values from upgradient wells in 2000. The critical mean value for total organic halides was exceeded in one downgradient well in 2000, caused by carbon tetrachloride from an upgradient source. Groundwater in LLWMA-4 is being actively remediated using pump-and-treat methods.

DOE has an Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project (Hartman et al. 2002a) that integrates all of the separate monitoring plans that are prepared for RCRA, CERCLA, and DOE Orders. Groundwater is a dynamic system, and the monitoring network is annually reviewed and modified to accommodate changes. Any additional wells for the LLBGs will be defined through the RCRA permit process and will be drilled under the TPA M-24 Milestone. DOE-RL has worked with EPA and Ecology to revise the M-24 Milestone as needed, and tentative agreement has been reached on a four-year schedule for drilling additional wells, including 17 proposed new wells for the LLBG waste management areas. The M-24 TPA Change Package for the new wells was issued for public comment in September 2003. A total of 1,278 wells are scheduled to be sampled in fiscal years 2003, 2004, or 2005 for all programs combined.

4.6 Biological and Ecological Resources

The Hanford Site is characterized as a shrub-steppe ecosystem (Daubenmire 1970). Such ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, the dominant plant in the area was big sagebrush underlain by perennial Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement, livestock grazing and agricultural production contributed to colonization by nonnative vegetation species that currently dominate the landscape. Although agriculture and production of livestock were the primary activities at the beginning of the twentieth century, these activities ceased when the site was established in 1943. Remnants of past agricultural practices are still evident.