DOE/RL-2010-97
Draft A

Remedial Investigation/Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

U.S. DEPARTMENT OF ENERGY | Richland Operations Office

P.O. Box 550
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Executive Summary

Introduction

This remedial investigation/feasibility study (RI/FS) document supports the remedy selection for the 100-KR-1 and 100-KR-2 Source Operable Units (OUs) and the 100-KR-4 Groundwater OU under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).[1] These operable units are part of the six geographic areas (Figure ES-1) of the Hanford Site that border the Columbia River (the River Corridor): 100-BC, 100-K, 100-D/H, 100-N, and 100-F combined with 100-IU-2/6 (100-F/IU), with an additional area defined as the 300 Area. The geographic areas include groundwater OUs, source OUs, and facilities that encompass the 100 Area National Priority List (NPL) sites.

This RI/FS will support the CERCLA Proposed Plans and, ultimately, the Records of Decisions (RODs) that address the cleanup of contaminated soil, solid waste burial grounds, groundwater, and releases from and/or due to reactor buildings associated with these OUs. The objective of these impending decisions (as well as that of past decisions) is to protect human health and the environment, based on reasonably anticipated future land use.

Hanford Site Background

The Hanford Site, managed by U.S. Department of Energy (DOE), encompasses approximately 1,517 km^2 (586 mi^2) in the Columbia Basin of south-central Washington State. In 1942, during World War II, Hanford was selected by the leaders of the Manhattan Project as the site for building the first production-scale nuclear reactors to produce plutonium for nuclear weapons. The Site was chosen because of its remoteness at the time, the availability of water from the Columbia River, and access to electricity from hydropower plants at the Bonneville and Grand Coulee Dams. The Hanford Site's plutonium production mission continued throughout the Cold War period until the early 1990s.

In July 1989, U.S. Environmental Protection Agency (EPA) placed the 100, 200, 300, and 1100 Areas of the Hanford Site on its NPL (40 CFR 300, Appendix B). Since that time, the Hanford Site's mission has focused on environmental cleanup.

[1] *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 42 USC 9601, et.seq., Pub. L. 107-377, December 31, 2002. Available at: http://epw.senate.gov/cercla.pdf.

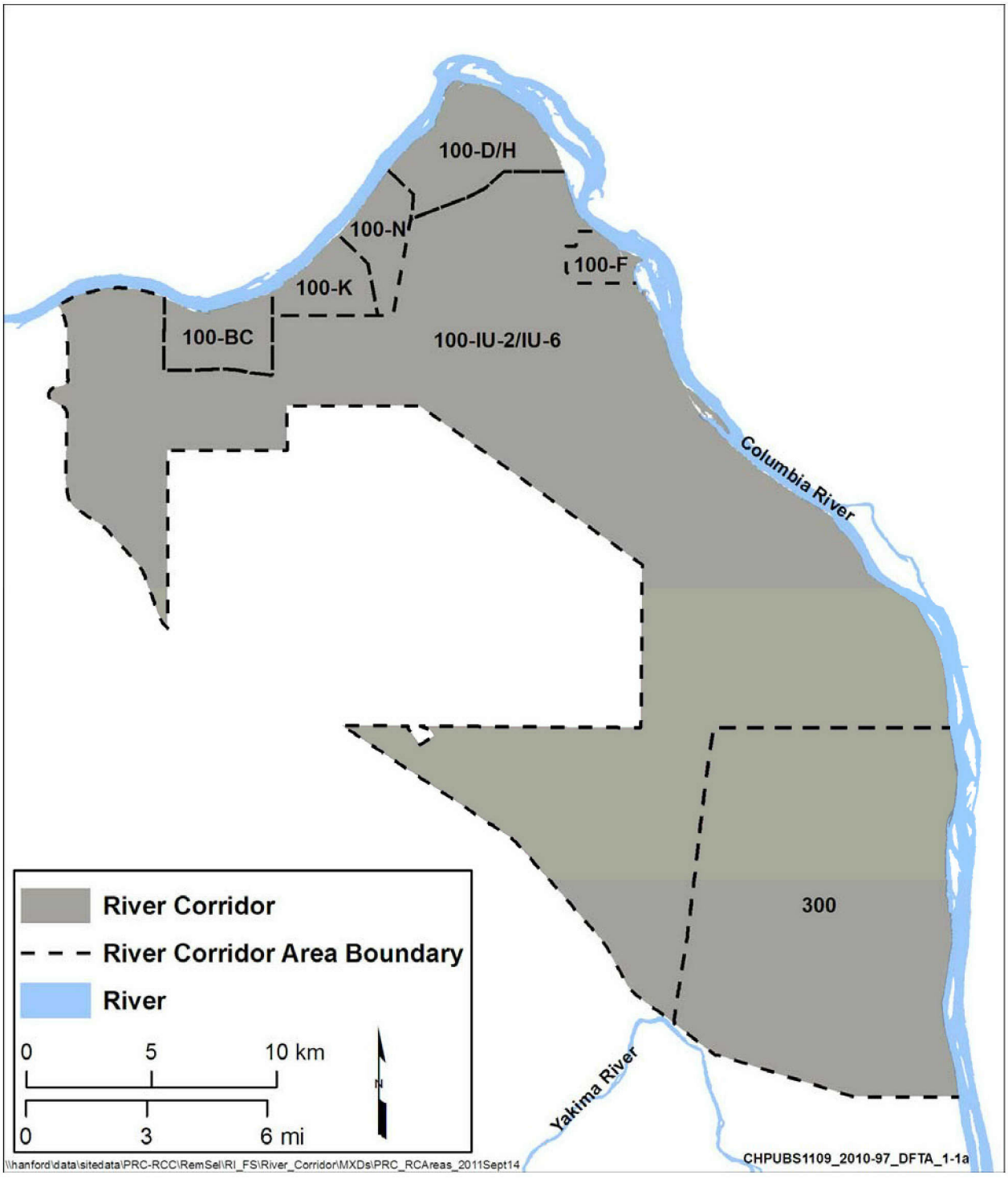

Figure ES-1. River Corridor Areas

The NPL is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States. The list is intended to guide the EPA in determining waste sites that warrant further investigation. For the Hanford Site, source waste sites and groundwater contamination

areas have been grouped into operable units to identify a portion of the site with associated actions.

Also in 1989, the EPA, DOE, and Washington State Department of Ecology (Ecology) (known as the Tri-Parties) developed a strategy to document the decisions needed to complete cleanup in the River Corridor into the *Hanford Federal Facility Agreement and Consent Order,*[2] known as the Tri-Party Agreement.

Early Cleanup Decisions

In the early 1990s, the Tri-Parties decided that sufficient information was known about contaminated soil and groundwater at the Hanford Site to begin cleanup with a focus on protecting the Columbia River. This decision led to an early start for cleanup of contaminated soil and groundwater in the River Corridor and development of *The Hanford Past-Practice Strategy.* This strategy provided the basis for prioritizing investigations and cleanup actions across the Hanford Site. This strategy emphasized the need to address waste sites and groundwater contamination that may pose a near term impact to public health and the environment. In addition, the strategy proposed a bias-for-action to cleanup waste sites and existing contamination where the need for a remedy was evident.

Limited Field Investigations were conducted to identify the nature and extent of contamination in waste sites and groundwater to provide a focus for the cleanup actions. The early cleanup decisions were documented in CERCLA interim action RODs. These early actions helped to clean up the site and provided information about where contamination exists and how it moves through soil and groundwater.

At this time, about 8 million tons of contaminated soil and debris have been removed from nearly 300 waste sites in the River Corridor and disposed at authorized facilities. Pump-and-treat systems have processed more than 12.8 billion L (3.4 billion gal) of contaminated groundwater. Observations made during these early actions helped to evaluate ongoing cleanup activities and develop future cleanup activities. Evaluation of residual soil concentrations has demonstrated that the ongoing interim action cleanups meet the goals and objectives of the interim action RODs.

[2] Ecology, EPA, and DOE, 1989a, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.hanford.gov/?page=81.

In parallel with continuing the interim actions, the Tri-Parties developed the strategy for pursuing the final cleanup decisions in 2006. This strategy involved organizing the decisions for the River Corridor operable units into six geographic areas and integrating decisions for both soil and groundwater.

100-K Site Description

The 105-KE and 105-KW Reactors were the largest production reactors at Hanford. Their size and operations produced unique features at 100-K. Figure ES-2 shows an overview of 100-K facilities. Operation of the reactors at 100-K between 1955 and 1971 used an estimated 12 trillion L of cooling water. The cooling water was piped to retention basins for thermal cooling and decay of short-lived radionuclides prior to discharge to the Columbia River. Leaks developed in the retention basins from thermal stress, which led to a saturated area between the basins and the Columbia River. Fuel cladding failures in the reactors led to radioactive contamination of the cooling water, which was diverted from the retention basins to the 116-K-2 Trench. Discharges to 116-K-2 were initially limited volumes of radioactively contaminated fluids. Infrastructure degradation, including leaks in isolation valves, resulted in additional discharges to the 116-K-2 Trench. The 116-K-2 Trench was also known as the Mile-Long Trench because of its size. The disposal volumes eventually overwhelmed the infiltration capacity of the soil beneath the trench, which resulted in overland flows from the trench toward the river.

The cooling water was treated prior to its use with sodium dichromate to introduce hexavalent chromium (Cr(VI)) as a corrosion inhibitor. This treatment used an estimated 6.3 million kg of Cr(VI) during the operating period. These reactors operated with approximately 60 percent more process tubes than the other single pass reactors at Hanford, and the amount of Cr(VI) that was discharged at 100-K was proportionally larger. Use of high volumes of dilute concentrations of Cr(VI) as cooling water and low volumes of concentrated solutions of Cr(VI) at transfer and mixing facilities resulted in releases and spills to the environment. Figure ES-3 presents a diagram of facilities where transfer, storage, and mixing of concentrated Cr(VI) solution occurred, and dilute solutions were used. Yellow stained soil observed during remedial actions at facilities south of the reactors, combined with Cr(VI) groundwater plumes, have provided evidence of both dilute and concentrated Cr(VI) releases.

Radionuclides, including carbon-14, tritium, and strontium-90 (Sr-90), solvents, including trichloroethene and chloroform, and other chemicals such as nitric and sulfuric acid, were also released with solid and liquid wastes at disposal facilities and through system leaks. Releases and potential releases of contaminants at 100-K have been identified at more than 165 waste sites and resulted in multiple groundwater contaminant plumes in the unconfined aquifer beneath the area. The largest high volume liquid waste disposal facility was the 116-K-2 Trench.

After shutdown of the reactors was completed in 1971, some of the support facilities remained in use to support other Hanford operations. Dispositioning and removal of support facilities began in the mid-1970s. Facilities at 100-K are being removed through the approach agreed upon by DOE and EPA for the conduct of decommissioning projects consistent with CERCLA requirements. The strategy for facility removal at 100-K has focused on shrinking the footprint of the site to within the fenced operational area, and then completing work within the operational area. Deactivation, decontamination, decommissioning, and demolition have been completed at 39 of 111 facilities through May 2011.

Disposition of the 105-KE and 105-KW Reactors will be conducted following procedures in the 1993 NEPA ROD (58 FR 48509).[3] This identifies DOE's decision of Interim Safe Storage (ISS) followed by one-piece removal to a Central Plateau disposal facility. The ISS period of 75 years prior to removal provides time for radioactivity in the reactor cores to decay to levels safe for handling. DOE evaluated the coordination of the final decommissioning actions with the completion of remaining actions in 100-K, including remedial alternatives for waste sites in proximity to the reactors.

[3] 58 FR 48509, "Record of Decision: Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington," *Federal Register*, Vol. 58, p. 48509, September 16, 1993.

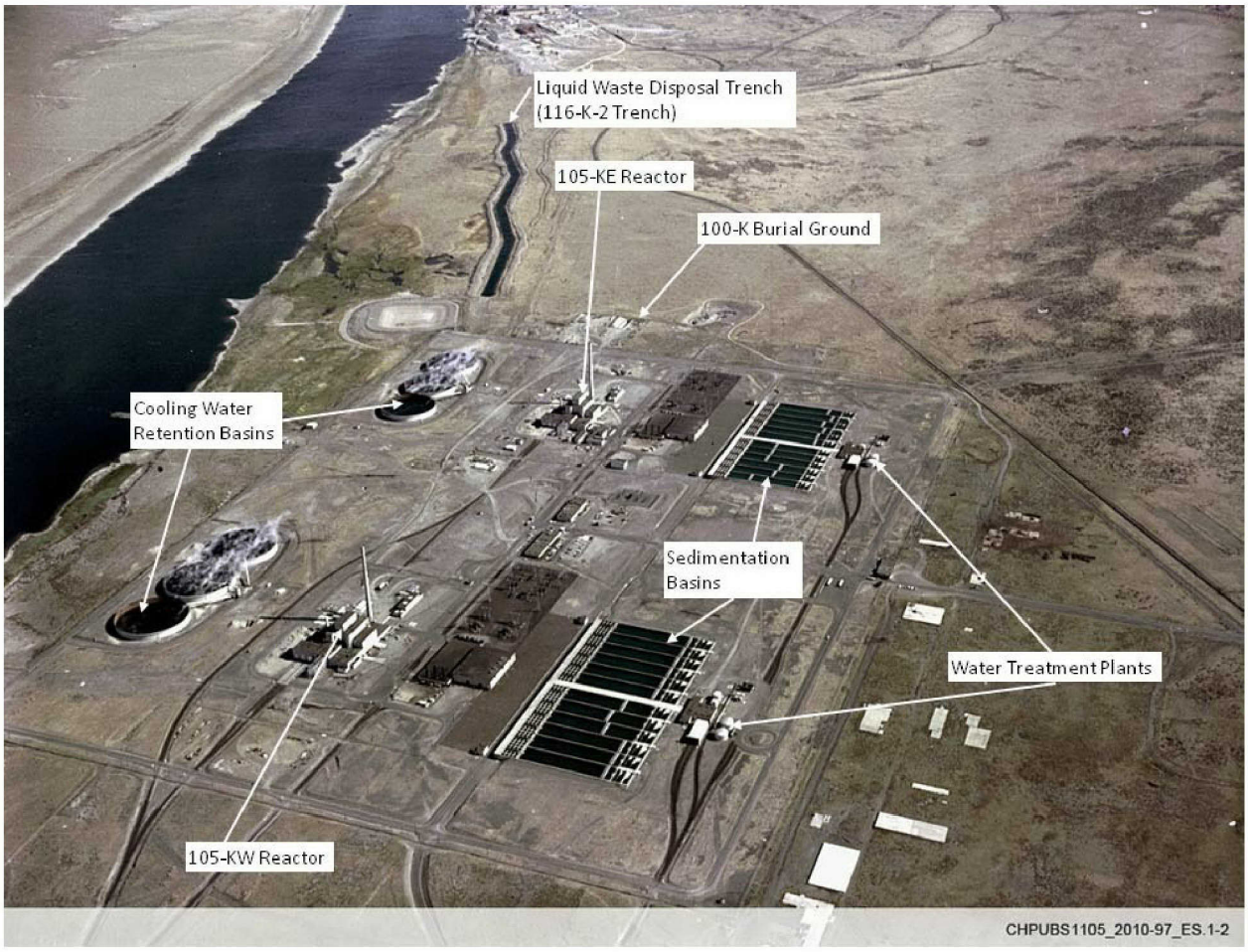

Figure ES-2. Overview of 100-K

Recently completed and ongoing interim remedial actions at 100-K include removal, treatment, and disposal (RTD) at waste sites and treatment of groundwater contaminated with Cr(VI) using three pump-and-treat systems. All the interim actions consider potential impacts to cultural resources through reviews coordinated with the tribal nations performed before the actions are initiated.

Interim action waste site remediation has been completed at 16 of the 165 total waste sites and subsites. Over a million tons of waste have been excavated and removed from the 100-K river area to authorized disposal areas. The waste site interim actions have focused on high priority sites that exhibited the greatest risks. As the interim actions progress, mobile contaminants present in deeper soil are being addressed by continuing excavation where necessary to achieve interim action cleanup objectives

All waste sites (165 total) are evaluated at various points in this report. Table ES-1 presents an overview of the process and references the chapter where the waste site evaluations occur.

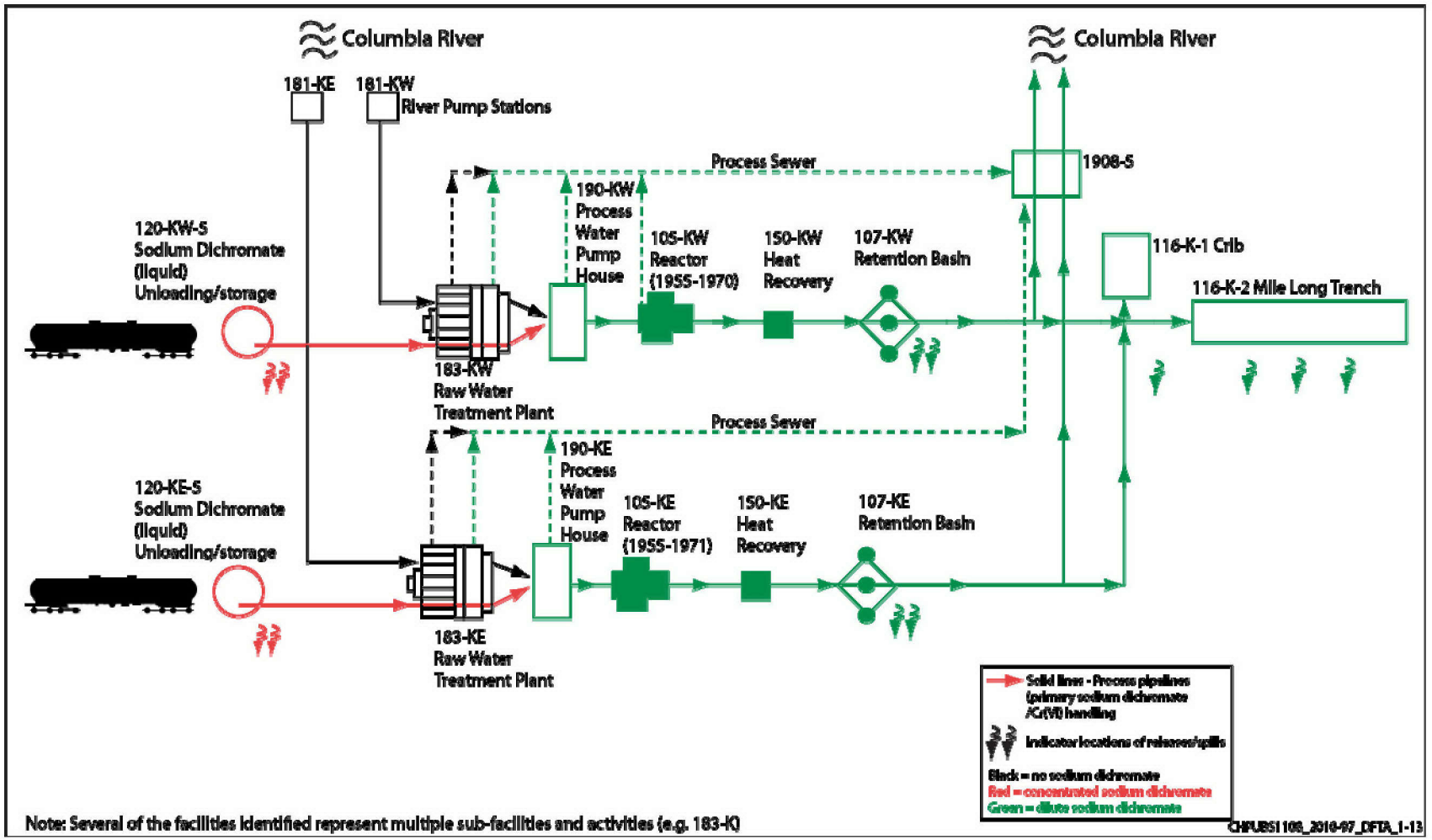

Figure ES-3. Areas Showing Sodium Dichromate Solution Releases

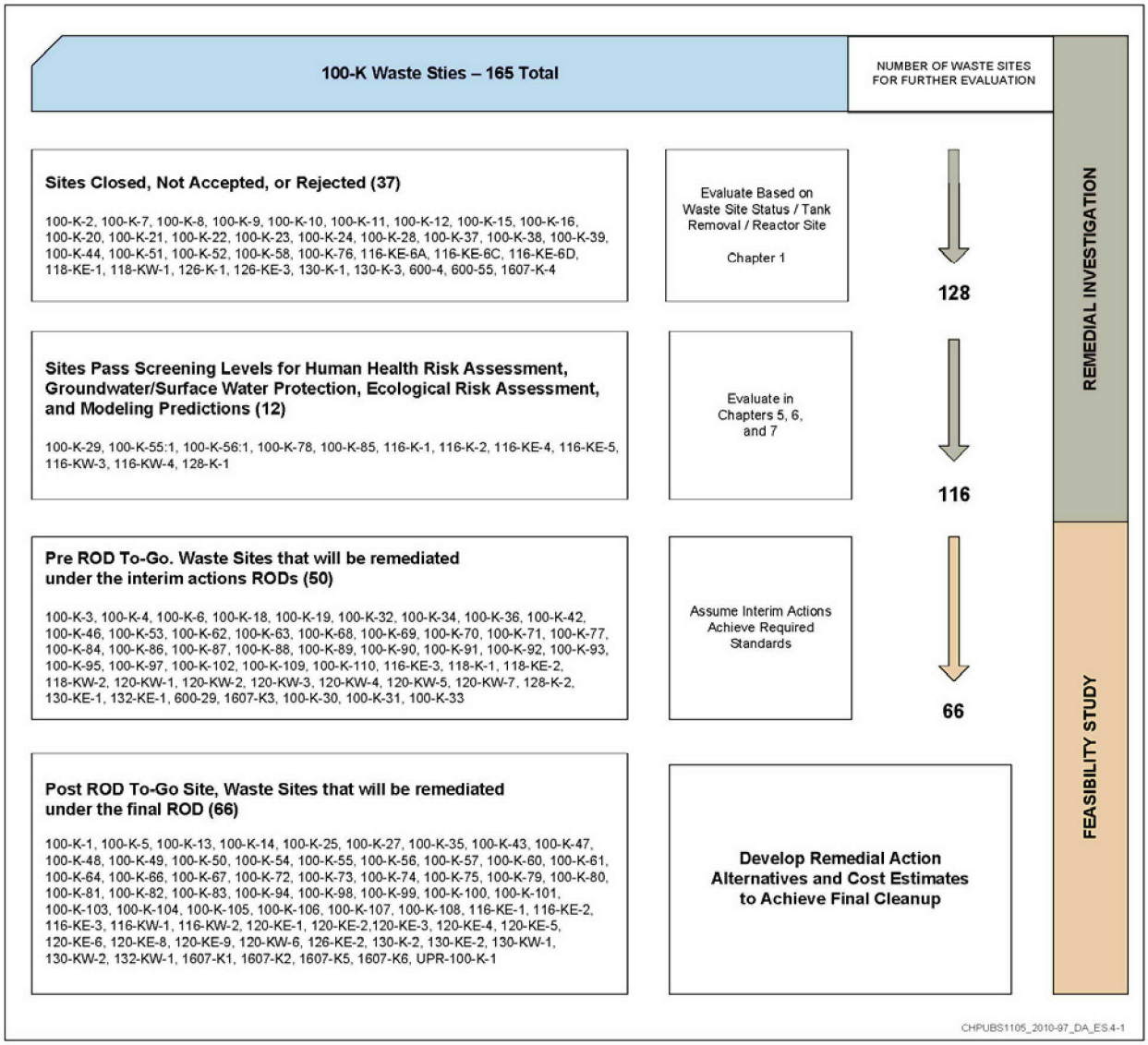

Table ES-1. Waste Site Evaluation for 100-K RI/FS

Three groundwater treatment systems have been installed and operational since 1997. The original KR system was designed to capture the Cr(VI) plume and prevent discharge to the Columbia River. The KW and KX systems became operational in 2007 and 2009, respectively, to provide additional containment and to remediate the Cr(VI) plume. These three systems have treated over 8.3 billion L (2.2 billion gal) of groundwater by removing 576 kg (1,269 lbs) of Cr(VI) through the end of 2010. These interim remedial actions provide protection to the Columbia River and mitigate threats to human health, groundwater, and ecological receptors. These systems are evaluated (including additional treatment capacity) as part of this RI/FS to achieve protectiveness under the ROD.

100-K Remedial Decision

An integrated RI/FS work plan[4] was developed for the entire 100 Area, and a 100-K specific work plan addendum,[5] to identify additional data needed to make an integrated final action decision for all contaminated soil and groundwater in the River Corridor. The 100-K work plan uses information collected over the past 20 years, including operational history, process knowledge, waste generation, waste handling, waste disposal, remedial investigations, and knowledge gained through ongoing implementation of interim actions. The 100-K work plan identified data gaps, data needs, and uncertainties, and designed a field program to address these data needs and uncertainties by collecting information to support remediation decisions. After the data are gathered (Chapter 2) and analyzed, the RI/FS report identifies contaminants and their interaction with the environment (Chapters 3 through 5), summarizes pertinent information related to human health and environmental risk (Chapters 6 and 7), and identifies and evaluates remedial alternatives to provide protection (Chapters 8 through 10). The conceptual site model (CSM) is an ongoing, refined collection and interpretation of data that supports the entire RI/FS investigative and decision process.

Conceptual Site Model

The 100-K CSM describes the features, events, and processes that resulted in environmental contamination, the fate and transport of contaminants in soil and groundwater, and the risks posed by the contaminants via exposure pathways at the site. Figure ES-4 presents a simplified depiction of CSM components.

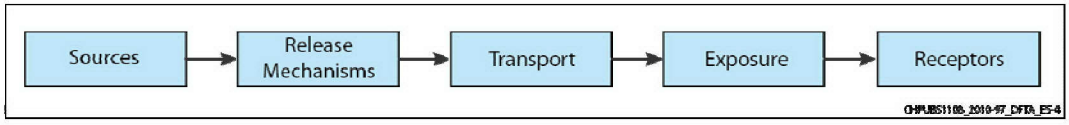

Figure ES-4. Conceptual Site Model Components

The water-cooled nuclear reactors and associated processes, structures, and effluent during production operations and Hanford site support activities led to releases to the environment. Contaminant processes at 100-K are discussed in the context of the front side of the reactors and the back side of the reactors. Front side processes occurred prior to irradiation of fuel slugs, and included mixing of chemicals in the water treatment

[4] Integrated 100 Area Remedial Investigation/ Feasibility Study Work Plan (DOE/RL-2008-46).

[5] Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 Operable Unit (DOE/RL-2010-28-ADD2).

plants headhouses to provide cooling water, and facility and reactor maintenance. Back side processes discharged variable volumes of contaminated effluent, including cooling water and airborne radionuclides. The largest discharges were cooling water with low concentrations of Cr(VI) to retention basins and the 116-K-2 Trench for thermal cooling and decay of short-lived radionuclides prior to discharge to the Columbia River. Additional back side discharges included irradiated cooling water following fuel cladding failures, irradiated fuel storage basin water discharge and leaks, and other liquid discharges to the vadose zone. Stacks at the reactors dispersed airborne radionuclides away from the operating area, and additional contaminants were transported as ambient windborne particulates or vapors.

The contamination at 100-K results from both primary and secondary sources. The primary sources of contamination included process chemicals, working solutions, and radioactive and non-radioactive wastes that were released into the environment during operations at 100-K. These sources consisted of low volume high concentration Cr(VI), widely variable volumes of liquid effluent, and solid waste. Solid wastes were intentionally disposed in burial grounds, while liquid wastes were discharged through planned releases to engineered structures or through unplanned releases to the ground surface.

Discharge of liquid effluent during operations formed groundwater mounds beneath waste sites at the back side of the reactors and directed flow radially. Mobile contaminants such as Cr(VI), trichloroethene (TCE), and tritium migrated with the flow of liquid, while less mobile contaminants such as Sr-90 migrated at slower rates. The mounds dissipated after the discharge ceased, with a portion of the contaminants dispersed inland. The primary high concentration contaminant was a solution containing 70 percent Cr(VI) that was mixed with water from the Columbia River to provide reactor cooling water. High concentration/low volume waste sites include liquid and solid waste sites and surface spills. Concentrated Cr(VI) was released and spilled at the front side of the reactors near the water treatment facilities and discharged from cleaning operations. Reactor condensate discharges resulted in the carbon-14 contaminant plume observed in groundwater. Irradiated fuel storage basin water contributed to the Sr-90 contamination, while the tritium, nitrate, and sulfate contamination observed at 100-K also appear to have originated from high concentration/low volume waste sites.

The features of the natural physical environment at 100-K influencing contaminant distribution include ground cover, net infiltration, and hydrogeology. These features dominate the infiltration, percolation, leaching, volatilization, and particulate resuspension contaminant release mechanisms. Contaminants in the vadose zone remain dissolved within pore water or sorbed to soil unless sufficient moisture is available for transport. The driving force for transport of contaminants in the vadose zone is net infiltration or anthropogenic contributions of water.

Secondary sources include environmental media, such as soil or groundwater that have been impacted by the releases from primary sources. The secondary sources retain sufficient levels of contaminants to provide continuing sources of contamination entering soil, surface water, groundwater, or air. Only secondary sources are currently found in 100-K.

The main secondary source of concern for Cr(VI) in 100-K is vadose zone soil present in unremediated waste sites and as residues in the vadose zone soil, in the periodically rewetted zone, within fine grained sediment in the unconfined aquifer, and possibly in the Ringold Upper Mud at the base of the aquifer.

The historical release of concentrated sodium dichromate solution appears to account for persistent Cr(VI) groundwater plumes near water treatment facilities. Reactor cooling gas condensate releases at cribs adjacent to the reactors appear to account for persistent plumes of carbon-14 in groundwater immediately downgradient of the reactors. The localized TCE plume is associated with the 105-KW Reactor. Unplanned releases of fuel oil and other petroleum products near the fuel oil storage tanks and boiler/generator facility likely account for the petroleum hydrocarbons found in soil near those facilities. Releases of cooling water are responsible for most of the soil and groundwater contamination observed near the cooling water retention basins, the 116-K-1 Crib, and 116-K-2 Trench. The use of 100-K fuel storage basins until 2007 resulted in additional long-lived fission product contamination of the soil and groundwater beneath the fuel storage basins from water leaks to the soil.

Contaminant characteristics and driving forces influence leaching of contaminants from secondary sources and transport through environmental media. The relative mobility of contaminants in the vadose zone is primarily determined by the ability to adsorb to soil and the amount of infiltration from natural and artificial sources. Mobile constituents have experienced sufficient downward water flux to pass through the vadose zone into

groundwater, while less mobile constituents tend to adsorb to the soil in the vadose zone. Groundwater flow and contaminant transport in the unconfined aquifer is dependent on groundwater flow velocity and contaminant retardation factors. Cr(VI), tritium, carbon-14, and nitrate are highly mobile and migrate at the same velocity as groundwater. Sr-90 is only slightly mobile, and migrates slowly in the saturated zone. Groundwater flow and contaminant transport in the unconfined aquifer is also affected by Columbia River stage fluctuations. Increases in the river stage push water inland and cause water table elevation increases throughout 100-K, altering the hydraulic gradient so less water flows into the river from the aquifer. During low river stage, groundwater flow toward the river dominates. Depending on the location within 100-K, direction variability in flow occurs because of these competing influences. Plants may absorb contaminants through their roots, and contaminants from surface deposits may accumulate in animal tissue. The risk assessment evaluated potential exposures and receptors.

Risk Assessment

The RI/FS integrates past and ongoing human health and ecological risk assessment (ERA) evaluations to support development of remedial alternatives for waste sites and contaminated groundwater in 100-K. The River Corridor Baseline Risk Assessment (RCBRA)[6] addresses the CERCLA regulatory requirement that a baseline risk assessment be performed to evaluate current and potential future risks posed by hazardous substance releases. The RCBRA human health risk assessment and the companion ecological risk assessment evaluated ecological and human health risk from residual contamination at waste sites remediated under the interim action RODs. The supplemental risk evaluations used for the RI/FS include exposure scenarios for a resident, resident-monument worker, and casual-recreational user. Assumptions for the residential scenario are the basis for narrative remedial action objective (RAO) statements that define the extent to which waste sites require cleanup to protect human health and the environment. Preliminary remediation goals (PRGs) are the numeric values that represent the RAOs. In addition to the residential scenario, PRG values were developed for the resident-monument worker and the casual user exposure scenarios. The resident-monument worker and casual recreational user scenarios incorporate assumptions that reflect reasonably anticipated future land use. Additionally, these

[6] *Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment* (DOE/RL-2007-21).

numeric values were used as risk-based screening levels (RBSLs) in the supplemental soil risk evaluation.

When remedial action goals were initially established for the River Corridor, the Tri-Party Agreement signatories agreed that it was appropriate to protect for a range of potential exposures in the future so cleanup actions did not limit future use of the site. DOE has determined that cleanup actions will support reasonably anticipated future land uses consistent with the Hanford Reach National Monument, where applicable, and the Land-Use ROD (64 FR 61615).[7] The land use at 100-K is identified as conservation/preservation. The resident-monument worker and casual-recreational user exposure scenarios reflect exposure assumptions and exposure pathways that are consistent with reasonably anticipated future land use.

The soil and groundwater risk evaluations provided in Chapter 6 and the ecological risk assessment provided in Chapter 7 are intended to supplement the RCBRA and were prepared to address differences in scope and purpose. Integration of the RCBRA, the supplemental soil and groundwater risk evaluations, and the ecological risk assessment will support the development of RODs for the River Corridor.

The results of the supplemental soil risk evaluation are used to determine whether additional response action is necessary at the site, modify preliminary remediation goals, support selection of the "no action" remedial alternative where it is appropriate, and document the magnitude of risk and primary contributors (e.g., chemicals and exposure pathways) to risk at a site. The results of the supplemental soil risk evaluation did not modify PRGs for human health. Ecological PRGs were further refined in the RI/FS (based on bioassay results). The exposure scenarios use different assumptions based on the elements of a complete exposure pathway.

The supplemental soil risk evaluation used data from previously remediated waste sites. The principal contaminants identified as contaminants of potential concern (COPCs) in vadose zone soil are waste disposal radionuclides and metals. Waste disposal radionuclides included cesium-137, cobalt-60, europium-152, europium-154, and Sr-90. The cumulative risk from waste disposal radionuclides within the shallow zone soil (top 4.6 m [15 ft]) is slightly greater than the upper EPA target risk threshold at one waste

[7] 64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)," *Federal Register*, Vol. 64, No. 218, pp. 61615-61625, November 12, 1999. Available at: http://gc.energy.gov/NEPA/nepa_documents/rods/1999/61615.pdf.

site, based on the residential scenario, but no individual radiological COPCs were reported with a risk greater than 1×10^{-4}. Under reasonably anticipated future land use, the risk to the resident monument worker and resident are similar, while the risk to the casual user is two orders of magnitude lower.

For the residential scenario, the noncancer hazard indices for noncarcinogens fell within EPA's and WAC 173-340-708)[8] target risk ranges. The noncancer hazard indices for noncarcinogens fell within EPA's target risk range for the resident-monument worker and casual user scenarios.

Residents are unlikely to be exposed to contaminants in soil located at depths greater than 4.6 m (15 ft) below ground surface through the direct contact exposure pathway. However, soil concentrations from deep zone soils were compared to residential RBSLs in order to account for residual concentrations in the environment from waste disposal practices. This evaluation provides information to risk-managers to assess the need for enhanced controls to prevent contact with this media. The FS evaluated three waste sites because concentrations of one or more radioisotopes in the deep zone are greater than the residential RBSL. The FS concluded institutional controls are needed to prevent uncontrolled drilling or excavation into the deep zone until concentrations of these isotopes have decayed to levels at or below RBSLs.

The RCBRA assessed human health risks for the Avid Angler, Casual User, and Tribal use scenarios from exposure to COPCs in upland and riparian surface soils, river water and sediment, and fish tissue.

The results from the 100-K OU for the Casual User and Avid Angler scenarios showed that lifetime cancer risks generally were near or below target thresholds and were below the noncancer hazard index for direct exposures to soil, sediment, and surface water.

The analysis from the Casual User and Avid Angler scenarios concluded there are no COPCs in riparian soils, nearshore sediments, and surface water that warrant further evaluation in the FS. However, carbon-14 was detected in one riparian soil sample at a concentration greater than the residential RBSL of 81 pCi/g. The carbon-14 concentration, analyzed using MULTI INCREMENT® sampling, reflects an average concentration of 112 pCi/g collected throughout a one hectare plot near the 116-K-2

[8] *Washington Administrative Code*, "Model Toxics Control Act—Cleanup" (WAC 173-340-708).
® MULTI-INCREMENT is a registered trademark of EnviroStat, Inc., Fort Collins, Colorado.

Trench. The results of this evaluation indicate that carbon-14 is a COPC in riparian soil that warrants further evaluation in the FS.

The Nonresident Tribal scenario risks from riparian soils were above the target cancer threshold and noncancer hazard index. Fish ingestion cancer risks exceeded thresholds for the Tribal scenarios. The Tribal scenarios assist interested parties in providing input on remedial alternatives, and are not used for development of PRGs as part of alternatives analyses in FS.

The groundwater contaminants of concern are chromium and Cr(VI), carbon-14, Sr-90, tritium, nitrate, and TCE. Concentrations in groundwater were compared with federal and state drinking water standards (DWS), federal and state surface water standards for protection of human health and aquatic organisms, and state groundwater cleanup levels.

Concentrations of nitrate and tritium in groundwater are greater than the DWS. Localized concentrations of carbon-14, Sr-90, and TCE are greater than their respective DWS. Potential remedial technologies for nitrate and tritium are evaluated in the FS, while design considerations and engineered controls are evaluated for carbon-14, Sr-90, and TCE.

Concentrations of chromium and Cr(VI) in groundwater both exceed the ambient water quality criteria for protection of aquatic receptors. In addition, concentrations of chromium are greater than the DWS. Potential remedial technologies for chromium and Cr(VI) are evaluated in the FS because their concentrations are greater than the DWS or the AWQS.

The Ecological Risk Assessment (ERA) used data from 16 previously remediated waste sites in the 100-K Source OU. Soil concentrations were compared to background and to PRGs protective of plants, invertebrates, and wildlife. Analytes with concentrations greater than background and PRGs were retained as contaminants of ecological concern (COECs). Mercury was identified as a COEC at four waste sites and warrant further evaluation in the FS.

At the scientific management decision point (SMDP), the results of the ERA were considered in the context of other factors (spatial coverage, data, chemical specifics, receptors at risk, confidence in PRGs) to reach a final decision on the COECs to be brought forward to the FS and agreement on the assessment endpoints, representative receptors, and complete exposure pathways that correspond to those COECs. The SMDP

concluded there are unacceptable risks to ecological receptors within four waste sites of the100-K Source OU. Risks at these waste sites are considered unacceptable because detected concentrations of mercury at all four waste sites are greater than PRGs for wildlife.

Feasibility Study

The RAOs present statements of protectiveness for human health and the environment from risks identified at 100-K in the baseline risk assessment. RAOs are developed to describe what the remedial actions are expected to accomplish for protecting human health and the environment. Contaminants that exceed target risk thresholds at the end of the risk assessment are identified as contaminants of concern (COCs). Waste site COCs includes radiological and nonradiological contaminants. For groundwater, contaminant concentrations were compared to EPA standards for drinking water quality, state groundwater cleanup levels, and action level criteria for water quality. This comparison identified Cr(VI), tritium, carbon-14, Sr-90, chromium, TCE, and nitrate as COCs. An evaluation of federal and state regulations was conducted in accordance with the National Contingency Plan (NCP) (40 CFR 300)[9] to define compliance requirements. Preliminary remediation goals were then established as numeric representations of RAOs to define the allowable concentrations of COCs in environmental media under specified exposure conditions, and provide area and volume estimates for remedial actions. Final RAOs will be established upon approval of the ROD.

Methods and technologies that could remove contaminants from the source or environmental transport media, and/or interrupt the exposure pathways were identified for further evaluation. A range of general response actions to meet RAOs was identified for waste sites and contaminated groundwater at 100-K. The general response actions identified for waste sites and groundwater included in situ treatment, containment, and institutional controls. RTD was also identified as a waste site-specific general response action. Pump-and-treat with collection, ex situ treatment, and discharge were groundwater-specific general response actions. Treatment technologies were identified and screened for the waste sites and groundwater contaminant plumes to select representative technologies for development of alternatives. Factors considered in the evaluation included the state of technology development, site conditions, waste

[9] 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of Federal Regulations*. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2010-title40-vol27/xml/CFR-2010-title40-vol27-part300.xml.

characteristics, nature and extent of contamination, and presence of constituents that could limit the effectiveness of the technology. A qualitative comparison of implementability, effectiveness, and cost provided additional evaluation of technologies.

The FS identified and screened technologies to determine suitability in remediating the identified sources and contaminant plumes. Three alternatives emerged from the technology evaluation.

Alternative 1—No Action. The NCP requires consideration of a No Action Alternative, which serves as a baseline for evaluating other remediation action alternatives and is retained throughout the FS process. The No Action alternative would end all site operations, including shut down of the existing groundwater pump-and-treat systems and an end to waste site remediation.

Alternative 2—RTD and Groundwater Pump-and-Treat, Optimized with Other Technologies. This alternative optimizes risk reduction and cost by combining RTD and groundwater treatment with other technologies. The actions at individual waste sites will vary, depending on the nature and extent of contamination and the results of a cost/benefit analysis. The options are to continue RTD, and employ soil flushing and bioinfiltration. Options for total petroleum hydrocarbon contaminated sites include continue RTD, bioventing, and land farming. Groundwater remediation optimizes operation of the interim action pump-and-treat systems by including biological injection and biological infiltration, with air stripping for locations where carbon-14 exceeds standards.

Alternative 3—RTD and Expanded Groundwater Treatment. RTD is used for waste site remediation. The existing pump-and-treat system for groundwater is expanded with additional extraction and injection wells and new treatment plants built to handle the additional flow. This alternative also treats carbon-14 with air stripping.

Alternatives 2 and 3 include a surface barrier around the reactor until final decommissioning. Both the alternatives allow that waste sites that cannot be remediated because of their location near reactors will be capped and/or safely contained until they can be accessed after the reactors have been dispositioned.

The alternatives are evaluated using criteria in threshold, balancing, and modifying categories based on the purpose of each category in the remedy selection process.

Protection of human health and the environment, and compliance with applicable or relevant and appropriate requirements (ARARs) are threshold criteria that must be met by the selected remedial action. The balancing criteria represent specific categories for detailed analysis and include long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost. The preferred alternative will be the alternative that is protective of human health and the environment, is ARAR-compliant, and provides the best combination of primary balancing attributes.

State and community acceptance are modifying criteria that are formally assessed during preparation of the Proposed Plan and following review of public and stakeholder comments (state and community acceptance) on the Proposed Plan. Community and state acceptance are not addressed in the FS.

Individual evaluations rated the performance of each alternative relative to threshold and balancing criteria. A comparative analysis provided an indicator of performance relative to the other alternatives. Alternative 1, which did not meet threshold criteria, was not evaluated further against balancing and modifying criteria. Table ES-2 provides a summary of the comparative analysis. Alternatives 2 and 3 meet the threshold and balancing criteria with different tradeoffs. These alternatives provide a robust approach through eliminating sources and treating existing groundwater contamination to prevent exposure. The selected alternative will be implemented in the 100-KR-1 and 100-KR-2 source OUs, and the 100-KR-4 groundwater OU. The available information is sufficient to implement a remedy that will protect human health and the environment and achieve ARARs.

Waste site remediation that is ongoing under interim action RODs will continue until the final ROD is issued, at which time the actions will be evaluated against RAOs established under the final ROD. The information used to verify interim waste site closure for previously remediated waste sites was evaluated further in this RI/FS. The human health and ecological risk evaluations showed RTD has proven effective in meeting interim action RAOs and is sufficient to meet RAOs developed for the RI/FS. Existing interim action groundwater pump-and-treat systems have proven effective in remediating groundwater contamination. Sites that do not meet the PRGs will be evaluated depending on the risk drivers that remain and a remedy will be selected from the final ROD. The selected remedial actions will be considered minor modifications to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL

fact sheet, with public notification. These waste sites will be added to the appropriate Remedial Design/Remedial Action Work Plan for implementation of the remedial action.

Table ES-2. Comparative Analysis of Alternatives

	CERCLA Criteria	Alternative 1 – No Action	Alternative 2 - RTD and Groundwater Pump-and-Treat Optimized with Other Technologies	Alternative 3 – RTD and Expanded Groundwater Treatment
Threshold	Overall Protection of Human Health and the Environment	Not Protective	Expected to be Protective	Expected to be Protective
	Compliance with ARARs	Not Compliant	Expected to be Compliant	Expected to be Compliant
Balancing	Long-Term Effectiveness and Permanence	Not Evaluated	◉	◉
	Reduction of Toxicity, Mobility, and Volume Through Treatment	Not Evaluated	◉	◉
	Short-Term Effectiveness	Not Evaluated	◉	○
	Implementability	Not Evaluated	◉	○
	Cost[1]: Net Present Value of Alternative (Discounted)/ Non Discounted	Not Evaluated	$616,808,000/ $1,030,151,000	$714,654,000/ $1,088,497,000

(1) Detailed cost estimates are presented in Appendix J

◉ Expected to perform very well against the criterion with no apparent disadvantages or uncertainty
○ Expected to perform moderately well against the criterion but with some disadvantages or uncertainty
● Expected to perform poorly against the criterion and may have disadvantages or uncertainty

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Terms

AEA	*Atomic Energy Act of 1954*
AEC	Atomic Energy Commission
AL	action level
AFD	Adjustable Frequency Drive
AMSL	above mean sea level
ARAR	applicable or relevant and appropriate requirement
ASTDR	Agency for Toxic Substances and Disease Registry
AVS/SEM	acid volatile sulfides/simultaneously extracted metals
AWQC	Ambient Water Quality Criterion
AWQS	Ambient Water Quality Standard
B.P.	before present (time)
BAF	bioaccumulation factor
BCG	Biota Concentration Guide
BDL	below detection limit
bgs	below ground surface
BV	background value
CAS	Chemical Abstract Service
CCC	criteria continuous concentration
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
CLARC	Cleanup Levels and Risk Calculations
CMC	criteria maximum concentration
COC	contaminant of concern
COEC	contaminant of ecological concern
COPC	contaminant of potential concern
COPEC	contaminant of potential environmental concern
CRBG	Columbia River Basalt Group
CRC	Columbia River Component

CSM	conceptual site model
CSS	Colorado silica sand
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CV	coefficient of variation
CVP	cleanup verification package
CWA	*Clean Water Act of 1972*
CY	calendar year
D&D	decommissioning and demolition
D4	deactivation, decontamination, decommissioning, and demolition
DAD	dermal absorbed dose
DOM	drawn over mandrel
DNE	does not exist (destroyed or unable to locate after numerous attempts)
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DPT	Direct Push Technology
DQA	data quality assessment
DWS	drinking water standard
EC	effective concentration
Ecology	Washington State Department of Ecology
EIS	environmental impact statement
ELCR	excess lifetime cancer risk
ENRE	Environmental Remediation Database
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
EPC	Engineering, Projects, and Construction
EQL	estimated quantitation limit
ERA	environmental risk assessment
ERAGS	Ecological Risk Assessment Guidance for Superfund

ERDF	environmental restoration disposal facility
ERE	ecologically relevant endpoint
FLTF	field lysimeter test facility
FS	feasibility study
FSB	fuel storage basin
FY	fiscal year
GAC	granulated activated carbon
GEA	gamma energy analysis
GHG	greenhouse gas
GRA	general response action
HCP-EIS	Hanford Comprehensive Land-Use Plan Environmental Impact Statement
HCR	horizontal control rod
HDPE	high density polypropylene
HEAST	health effects assessment summary tables
HEIS	Hanford Environmental Information System
HGP	Hanford Generating Plant
HHE	human health and the environment
HHRA	human health risk assessment
HI	hazard index
HMS	Hanford Meteorological Station
HQ	hazard quotient
HRM	Hanford River Marker (approximate miles downstream of Vernita Bridge)
HSP	health and safety plan
IAMP	Interim Action Monitoring Plan
IC	institutional control
ICP	inductively coupled plasma
IEUBK	integrated exposure uptake biokinetic
IRIS	integrated risk information system
ISCO	in situ chemical oxidation

ISGR	in situ gaseous reduction
ISRM	in situ redox manipulation
ISS	interim safe storage
IWP	integrated work plan
IWTS	integrated water treatment system
IWTS	Integrated Water treatment system
IX	ion exchange
K_d	distribution coefficient
KOP	knockout pot
KUT	potassium-40, uranium-238, and thorium-228
LDR	land disposal restriction
LFI	limited field investigation
LIDAR	light detection and ranging
LOAEC	lowest observed adverse-effect concentration
LOAEL	lowest observed adverse-effect level
LOEC	lowest observed effect concentration
LSC	liquid scintillation counting
MATC	maximum allowable toxicant concentration
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDL	method detection limit
MIS	MULTI INCREMENT® sampling
MNA	monitored natural attenuation
MRDL	maximum residual disinfectant level
MRL	minimal risk level
MS	mass spectrometry
MTCA	Model Toxic Control Act
MW	molecular weight
NAPL	non-aqueous phase liquid

NCEA	National Center for Environmental Assessment
NCP	national contingency plan
NEPA	*National Environmental Policy Act of 1969*
NFM	near-facility air sampling monitor
NHPA	*National Historic Preservation Act of 1966*
NJDEP	New Jersey Department of Environmental Protection
NOAEC	no observed adverse-effect concentration
NOAEL	no observed adverse-effect level
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NPL	National Priorities List
NTU	nephelometric turbidity unit
O&M	operations and maintenance
OEHHA	Office of Health Hazard Assessment
ORNL	Oak Ridge National Laboratory Oak Ridge, TN
ORP	oxidation-reduction potential
OSE	orphan site evaluation
OSHA	Occupational Safety and Health Administration
OU	operable units
PA	preliminary assessment
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PNNL	Pacific Northwest National Laboratory
PPE	personal protective equipment
PPRTV	Provisional Peer Reviewed Toxicity Value
PQL	practical quantitation limit
PRG	preliminary remedial goal
PUREX	plutonium uranium extraction
PVC	polyvinyl chloride

QA	quality control
QAPjP	quality assurance project plan
QC	quality control
QRA	qualitative risk assessment
RA	risk assessment
RAA	remedial action objectives
RAG	remedial action goal
RAGS	Risk Assessment Guidance for Superfund
RAIS	Risk Assessment Information Center
RAO	remedial action objective
RBSL	risk based screening level
RCBRA	River Corridor Baseline Risk Assessment
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
RD/RA	remedial design/removal action
RDR/RAWP	remedial design report/remedial action work plan
RESRAD	residual radiation
RfD	reference dose
RI	remedial investigation
RL	Richland Operations Office
RLM	Ringold lower mud
RME	reasonable maximum exposure
ROD	record of decision
RPO	remedial process optimization
RSVP	remaining site verification package
RTD	removal, treatment, and disposal
RUM	Ringold Upper Mud
SAP	sampling and analysis plan
SARA	*Superfund Amendments and Authorization Action of 1986*

SDWA	*Safe Drinking Water Act of 1974*
SESP	Surface Environmental Surveillance Program
SGBR	subgrade bioreactor
SI	site investigation
SNF	spent nuclear fuel
SSL	soil screening level
STOMP	*Subsurface Transport Over Multiple Phases*
STSC	Superfund Health Risk Technical Support Center
SVOC	semivolatile organic compound
TBC	to be considered
TCE	trichloroethylene
TEF	toxic equivalence factor
TEF	test and evaluation facility
TI	technical impracticability
TIC	total inorganic carbon
TMV	toxicity, mobility, and volume
TOC	total organic carbon
TPH	total petroleum hydrocarbons
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRU	transuranic
TRV	toxicity reference value
TSCA	*Toxic Substances Control Act of 1976*
TSD	temporary storage and disposal
UCL	upper confidence level
UPR	unplanned release
USACHPPM	United States Army Center for Health Promotion and Preventive Medicine
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UTL	upper tolerance limit

VCR	vertical control rod
VOC	volatile organic compound
WCH	Washington Closure Hanford
WIDS	Waste Information Data System
WOE	weight of evidence
XRF	X-ray fluorescence
ZVI	zero-valent iron

1

1 Introduction

In 1989, the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) (known as the Tri-Parties) signed the *Hanford Federal Facility Agreement and Consent Order* (hereinafter called Tri-Party Agreement [TPA] [Ecology et al., 1989a]) to provide a framework for the cleanup of the Hanford Site (Figure 1-1). The scope of the agreement addressed the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remediation of inactive hazardous waste sites, active waste management operations, *Resource Conservation and Recovery Act of 1976* (RCRA) corrective action for solid waste management units, and closure of RCRA treatment, storage, and/or disposal units across the Hanford Site.

For the purpose of CERCLA cleanup, four sections of the Hanford Site were placed on the National Priorities List (NPL) as separate areas: 100 Area (Reactor Operations), 200 Area (Irradiated Fuel Reprocessing and Waste Management), 300 Area (Nuclear Fuel Production and Research and Development), and 1100 Area (Equipment and Maintenance). Due to the large number of waste sites, unplanned releases, and extensive groundwater contamination, the 100 Area was further divided into source and groundwater operable units (OUs) for management of the investigation and remediation.

This document presents the results of a CERCLA Remedial Investigation (RI)/Feasibility Study (FS) undertaken for 100-K (Figure 1-1). The information contained in this RI/FS supports a Proposed Plan, which will go through a public review and provide the final basis for a Record of Decision (ROD). The ROD for 100-K will apply to the source OUs 100-KR-1 and 100-KR-2, and to the 100-KR-4 Groundwater OU (Figure 1-2).

In 1991, the Tri-Parties determined there was a need to prioritize the CERCLA investigations and identify early actions to address waste sites and groundwater contamination. *The Hanford Past-Practice Strategy* (hereinafter called Past-Practice Strategy [DOE/RL-91-40]) provided the basis for prioritizing investigations and cleanup actions across the Hanford Site. This strategy emphasized the need to address waste sites and groundwater contamination that may pose a near term impact to public health and the environment. In addition, the strategy proposed a bias-for-action to cleanup waste sites and existing contamination where the need for a remedy was evident.

Initial waste site identification for the Hanford Site, including 100-K, began when liquid and solid wastes were first disposed into the soil column. As more disposal locations were constructed and operated, documents that tracked location and content were developed. Eventually, these waste sites were assigned a standardized identification number and included for tracking purposes in a database, the Waste Information Data System (WIDS). As a result of the potential listing on the NPL, a preliminary assessment/site investigation (PA/SI) was conducted. This PA/SI identified the potential waste site by geographic area across the Hanford Site and assigned each waste site a hazard ranking. This combined hazard ranking score resulted in the four areas to be added to the NPL (100, 200, 300, and 1100). Waste sites identified within the geographic areas included 100-KE and 100-KW and the nearby environs. These waste sites were included in WIDS and formed the basis for the preliminary list of waste sites in the 100-K geographic area. Since the PA/SI, additional efforts have been conducted to ensure that all waste sites posing a threat to human health and the environment are addressed through the Nonoperational Area Evaluation process, including the Orphan Site Evaluation and Discovery Site processes. These processes help ensure that no waste sites will be missed.

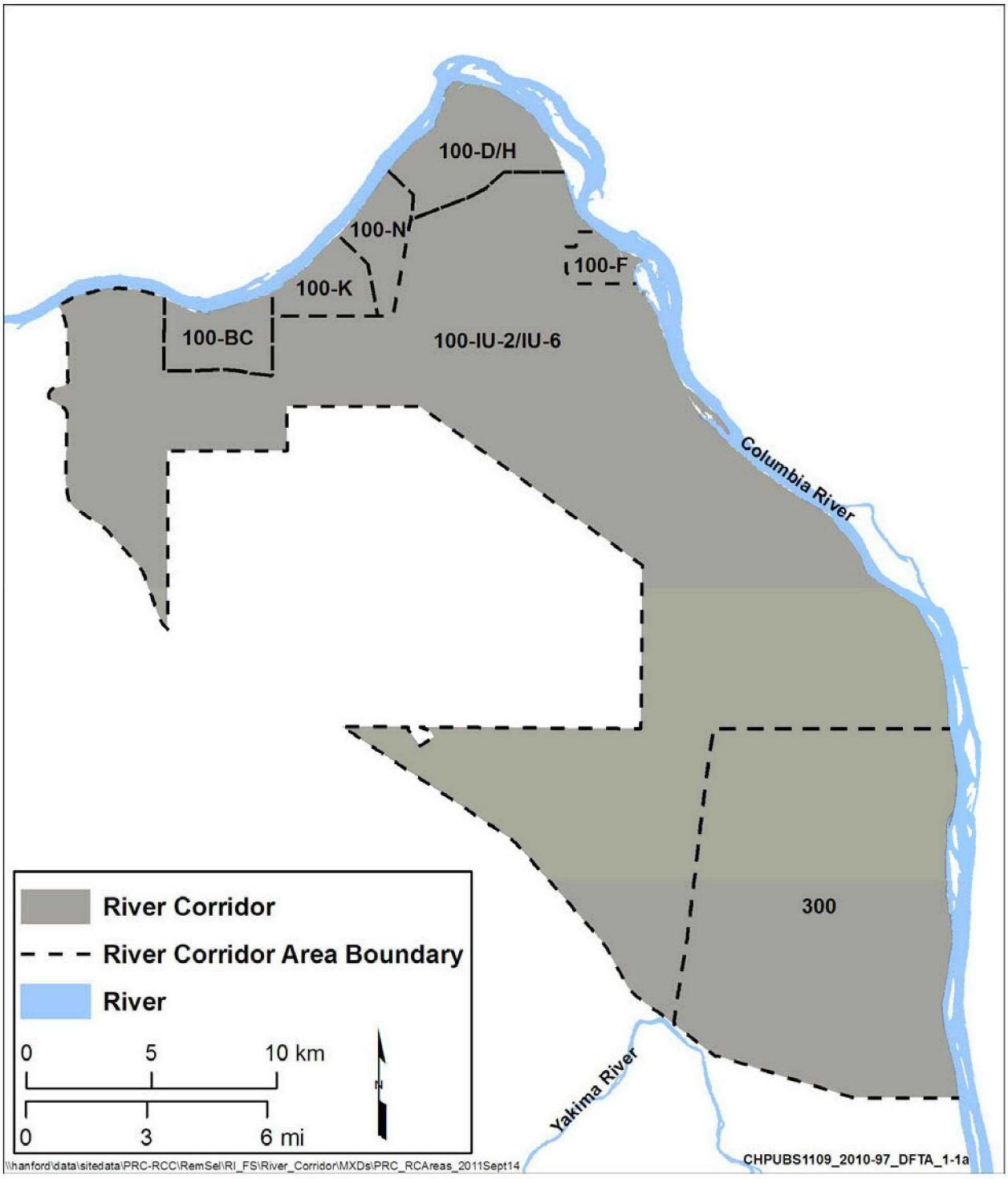


Figure 1-1. Hanford Site Map

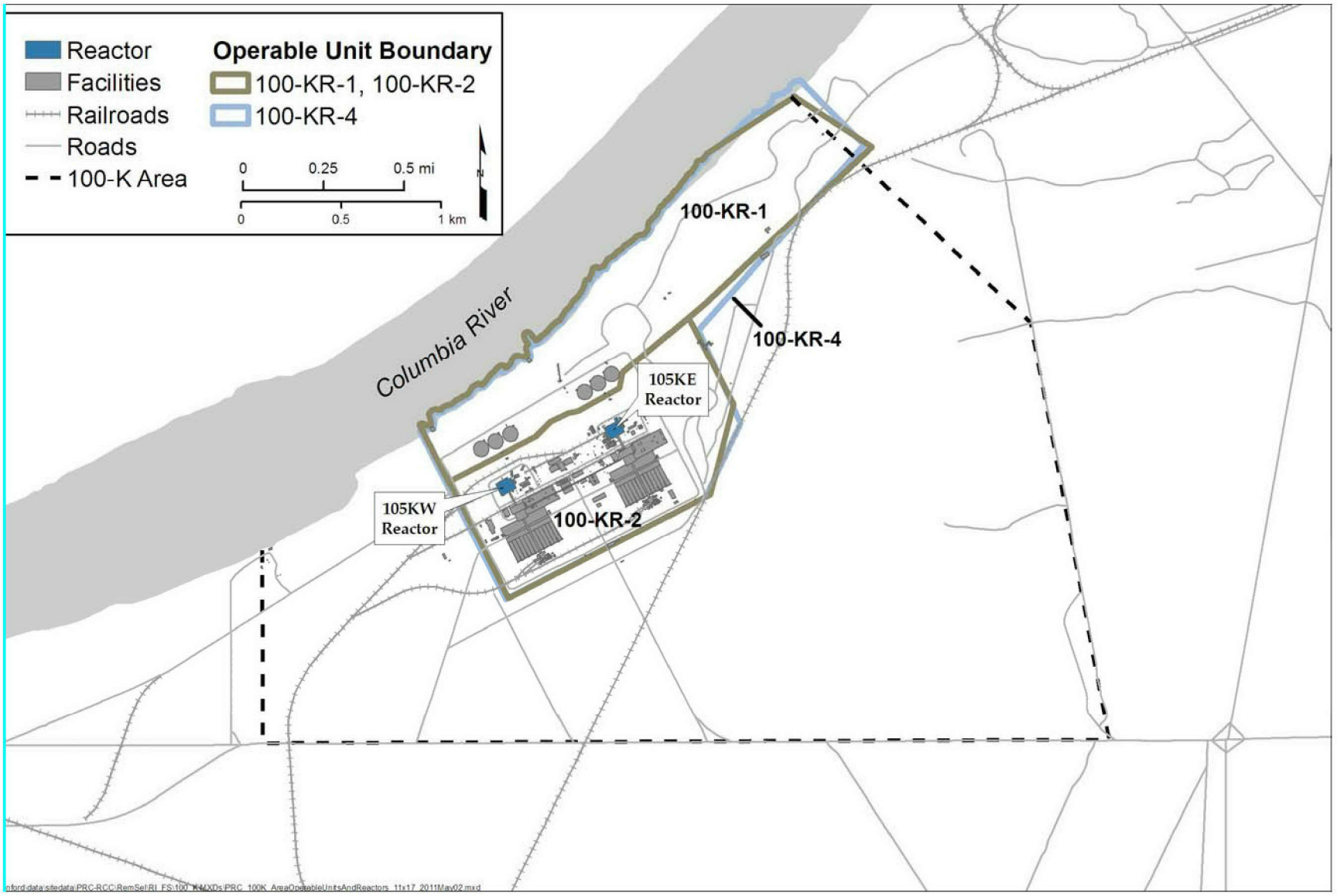


Figure 1-2. 100-K Operable Units

For 100-K, the Past-Practice Strategy (DOE/RL-91-40) translated into priority investigations. Limited Field Investigations (LFIs) (*Limited Field Investigation Report for the 100-KR-1 Operable Unit* [DOE/RL-93-78]; *Limited Field Investigation Report for the 100-KR-4 Operable Unit*, hereinafter called 100-KR-4 LFI [DOE/RL-93-79]) were initiated for the 100-KR-1 and 100-KR-2 OUs. These LFIs characterized the nature and extent of contamination in the vadose zone, structures, and debris that received radioactive liquid effluent discharges.

The LFIs indicated that sites in 100-KR-1 and 100-KR-2 were primarily responsible for the continuing release of hexavalent chromium (Cr(VI)) above established limits to the groundwater. For the 100-KR-4 OU, it was established that Cr(VI) in groundwater was entering the Columbia River at concentrations considered toxic to aquatic organisms. This led to the selection of interim actions to remediate source and groundwater contamination within the 100-KR-1, 100-KR-2, and 100-KR-4 OUs under the following interim RODs:

- EPA/ROD/R10-99/039, July 1999, *Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units, Hanford Site, Benton County, Washington (100 Area Remaining Sites)* (hereinafter called 100 Area Remaining Sites ROD)

- EPA/ROD/R10-99/059, September 1999, *Interim Remedial Action Record of Decision for the 100-KR-2 Operable Unit K Basins, Hanford Site, Benton County, Washington* (hereinafter called 100-KR-2 OU ROD)

- EPA/ROD/R10-96/134, March 1996, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington* (hereinafter called 100-HR-3 and 100-KR-4 OU ROD)

Interim Remedial Action Objectives (RAOs) for the cleanup of waste sites within the 100-KR-1 and 100-KR-2 OUs focused on protecting human health from contaminants in the soil, controlling the sources of groundwater contamination to minimize the impacts to groundwater resources, and protecting the Columbia River from further adverse impacts. For the 100-KR-4 Groundwater OU, RAOs focused on Cr(VI) as the primary impact posed by the site to groundwater and surface water. Reducing the concentrations of Cr(VI) entering the Columbia River and restoring the groundwater to beneficial use remain the primary objectives of groundwater remediation within 100-K.

DOE is the lead federal agency at Hanford, per CERCLA, *Superfund Implementation* (Executive Order 12580), and the TPA. DOE develops implementation strategies and conducts response actions in this lead federal agency role. With implementation of the Past-Practice Strategy (DOE/RL-91-40) and progress with the interim remedial actions, DOE prepared the *Hanford Site Cleanup Completion Framework* (hereinafter called Cleanup Completion Framework [DOE/RL-2009-10]) to describe the cleanup strategy (Table 1-1). One of the principal components of the framework is the River Corridor, which consists of approximately 570 km^2 (220 mi^2) of the Hanford Site along the Columbia River. It includes a contiguous area that extends from the 100 and the 300 Areas to the Central Plateau boundaries (Figure 1-1).

Table 1-1. Overarching Goals for Hanford Site Cleanup

Goal	Description
1	Protect the Columbia River.
2	Restore groundwater to its beneficial use to protect human health, the environment, and the Columbia River.

Table 1-1. Overarching Goals for Hanford Site Cleanup

Goal	Description
3	Clean up River Corridor waste sites and facilities to protect groundwater and the Columbia River, shrink the active cleanup footprint to the Central Plateau, and support anticipated future land uses.
4	Clean up Central Plateau waste sites, tank farms, and facilities to protect groundwater and the Columbia River, minimize the footprint of areas requiring long-term waste management activities, and support anticipated future land uses.
5	Safely manage and transfer legacy materials scheduled for offsite disposition, including special nuclear material (including plutonium), spent nuclear fuel, transuranic waste, and immobilized high-level waste.
6	Consolidate waste treatment, storage, and disposal operations on the Central Plateau.
7	Develop and implement institutional controls and long-term stewardship activities that ensure protection of human health and the environment after cleanup activities are completed.

Source: Cleanup Completion Framework (DOE/RL-2009-10)

Note: Status as of May 2011.

For sites in the River Corridor, final remedial actions are expected to restore groundwater to drinking water standards and protect aquatic life in the Columbia River by achieving ambient water quality standards at groundwater discharge points to the river. Unless technically impracticable, these objectives will be achieved within a reasonable period. If remedial action objectives are not achievable in a reasonable period or are determined to be technically impracticable, programs will be implemented to prevent further migration of the plume, prevent exposure to contaminated groundwater, and evaluate further risk reduction opportunities as new technologies become available.

Current River Corridor cleanup work is progressing based on interim action RODs. A primary objective of this work has been to move potential sources of contamination that are close to the Columbia River to the Central Plateau for final disposal. In addition, interim actions have been taking place to address groundwater contamination. Cleanup actions will support reasonably anticipated future land uses consistent with the Hanford Reach National Monument, where applicable, and the "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)" (64 FR 61615).

To complete final cleanup, the River Corridor has been divided into six geographic decision areas, including 100-K, to achieve final source and groundwater remedy decisions (Figure 1-1). These decisions will provide comprehensive coverage for all areas within the River Corridor and will incorporate interim action cleanup activities. Cleanup levels will be established that will protect human health and the environment under both current and reasonably anticipated future land use conditions. These levels will also comply with ARARs and consider the cleanup levels previously used in implementation of Interim Action Records of Decision for River Corridor operable units.

Much of Chapter 1 is devoted to summarizing the assessment and remediation work that was completed before preparation of this RI/FS Report. In addition to 100-K specific work, other relevant work that supports remedy selection for 100-K (such as treatability tests) and 100 Area studies that describe the nature and extent of contamination across all six River Corridor areas are described. This RI/FS Report builds on this body of previous work, including the River Corridor Baseline Risk Assessment (RCBRA) (*Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk*

Assessment [DOE/RL-2007-21, Draft B]) (discussed in Chapters 6 and 7), to provide a comprehensive picture of the current and much improved site conditions and to present a range of options for addressing the remaining contamination at 100-K.

For the purpose of this RI/FS, the following definitions are used:

- **Shallow vadose zone**—from ground surface to a depth of 4.6 m (15 ft). This depth interval must meet soil standards for direct contact exposure by humans and terrestrial ecology, and be protective of groundwater and surface water.
- **Deep vadose zone**—from a depth of 4.6 m (15 ft) to the water table. This depth interval must meet soil standards for protection of groundwater and surface water.

The RI/FS for 100-K was undertaken in accordance with *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan* (hereinafter called the Integrated Work Plan [DOE/RL-2008-46]), which contains the planning elements that are common to all the Hanford Site 100 Area source and groundwater OUs, and *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units* (hereinafter called the 100-K Work Plan [DOE/RL-2008-46-ADD2]), which is specific to 100-K. These work plans were developed to assist in reaching final decisions for the OUs within the 100 Area NPL Site.

This introductory chapter is followed by the RI portion of the report (Chapters 2 through 7), the FS portion of the report (Chapters 8 through 10), and a list of the works used in preparing this report (Chapter 11).

- Chapter 2 Study Area Investigation
- Chapter 3 Physical Characteristics of 100-K
- Chapter 4 Nature and Extent of Contamination in 100-K, including Individual Evaluations of All Waste Sites
- Chapter 5 Contaminant Fate and Transport
- Chapter 6 Human Health Risk Assessment
- Chapter 7 Ecological Risk Assessment
- Chapter 8 Identification and Screening of Remediation Technologies, including Preliminary Remediation Goals (PRGs), Applicable or Relevant and Appropriate Requirements (ARARs), and RAOs
- Chapter 9 Development and Screening of Remedial Action Alternatives (RAAs)
- Chapter 10 Detailed Analysis of Remedial Action Alternatives
- Chapter 11 References

This RI/FS Report includes extensive data used to perform calculations and assessments. Due to the volume of this information (such as laboratory analytical data and risk calculations), summaries of data are provided in this document and appendices, and electronic links are provided to direct the reader to more detailed information contained in particular studies, databases, or reports found in the Administrative Record. Appendices are as follows:

- Appendix A Site Maps

- Appendix B Annotated Bibliography and Previous Investigations Summary
- Appendix C Field Reports
- Appendix D Analytical Data
- Appendix E Waste Site Table
- Appendix F Fate and Transport Modeling Documentation
- Appendix G Human Health Risk Assessment Calculation Brief
- Appendix H Ecological Risk Assessment Calculation Brief
- Appendix I Technology Screening—Not Retained Technologies
- Appendix J Alternative Development Supporting Documentation
- Appendix K Nonoperational Area
- Appendix L Riparian/Nearshore Evaluation

1.1 Purpose and Scope of Report

The RI/FS process is outlined in EPA and DOE RI/FS guidance (*Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [EPA/540/G-89/004]; *Remedial Investigation/Feasibility Study [RI/FS] Process, Elements, and Techniques* [DOE/EH-94007658]). The RI/FS process represents the methodology established by the *Superfund Amendments and Reauthorization Act of 1986* (SARA) program for characterizing the nature and extent of risks posed by uncontrolled hazardous waste sites and for evaluating potential remedial options. This approach should be viewed as a dynamic, flexible process that can be tailored to specific circumstances of individual sites; it is not a rigid, step-by-step approach that must be conducted identically at every site.

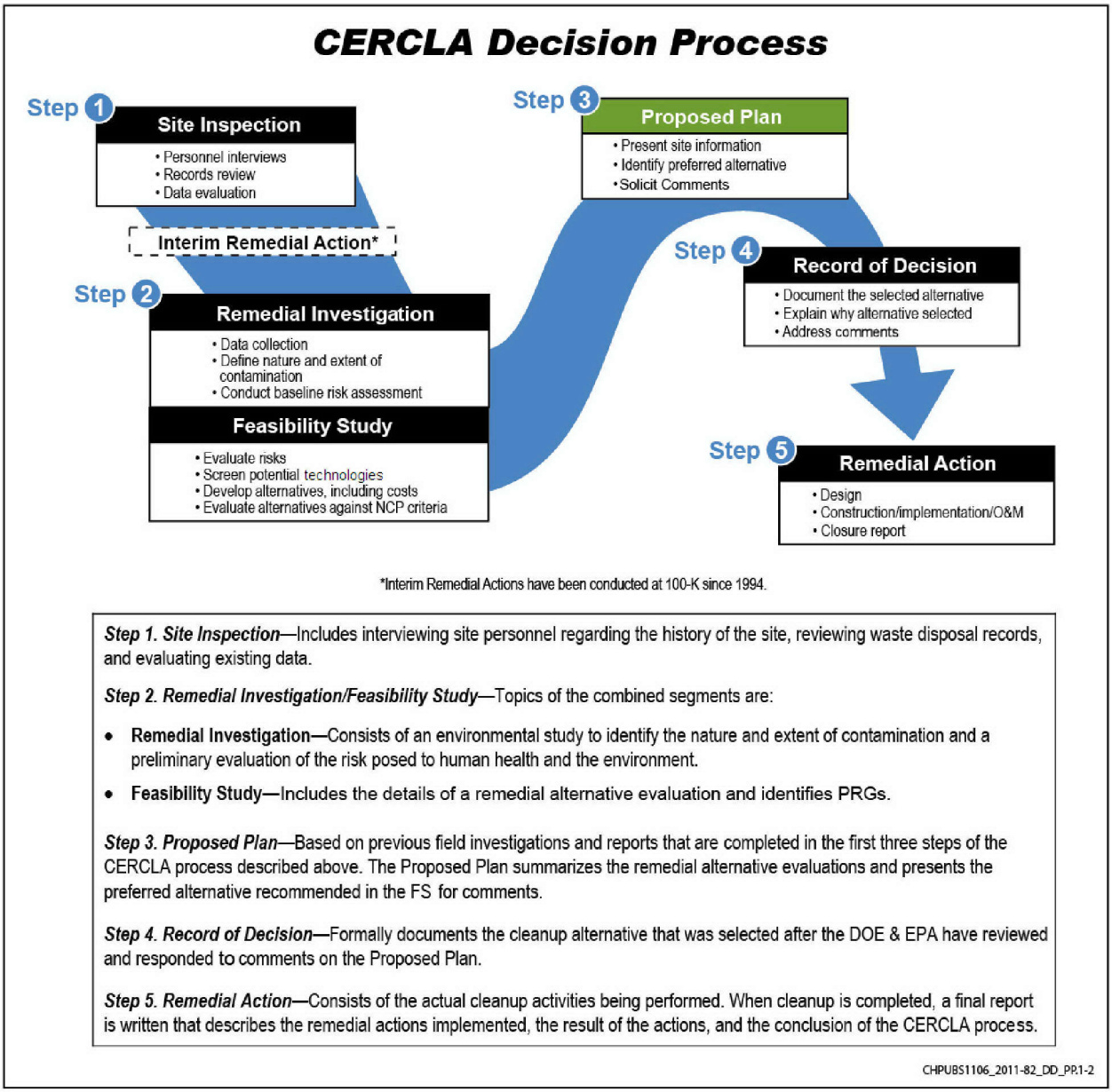
This RI/FS Report was prepared in accordance with the previously referenced guidance as well as *CERCLA Compliance with Other Laws Manual: Interim Final* (EPA/540/G-89/006) and *CERCLA Compliance with Other Laws Manual: Part I* (EPA/540/G-89/009). Figure 1-3 summarizes the CERCLA process. The guidance documents provide information on the regulations and standards that govern the RI/FS process, as well as an overview of requirements for each section of the RI/FS Report.

This RI/FS Report has the following objectives:

- Provide information concerning the physical environmental setting and site characterization.
- Draw conclusions concerning nature and extent of contamination present at the site, the potential for migration of contamination from the site, and the potential for adverse human health and environmental effects if no action is taken at the site and exposure occurs. This goal is achieved by evaluating historical and operational information about the site, contaminants of potential concern (COPCs), potential migration pathways, potential receptors, exposure (dose), and contaminant toxicity.
- Develop and evaluate an appropriate range of remedial action alternatives for the site based on unacceptable risk to human health and the environment.

EPA is the lead regulatory agency for 100-K and, as such, has the primary responsibility for overseeing all remedial action activities to ensure they meet applicable requirements. DOE, as the lead agency, is responsible for performing all 100-K remedial actions. DOE has completed its RI/FS Report for 100-K and is issuing it as a component of CERCLA and the "National Oil and Hazardous Substances Pollution Contingency Plan" (hereinafter called the National Contingency Plan or NCP [40 CFR 300]). This report also fulfills DOE's responsibility under the *National Environmental Policy Act of 1969* (NEPA) to assess NEPA values when evaluating CERCLA remedial actions. The U.S. Department of Energy, Richland

Operations Office (DOE-RL) will issue a Proposed Plan detailing the proposed final remedies for comment by the public and the Tribal Nations. EPA and DOE-RL will issue a ROD for the 100-K OUs, which will include responses to the comments received and the 100-K final remedies. After the ROD is issued, a remedial design/remedial action (RD/RA) will be developed, approved, and implemented.



Source: Modified from EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*.

Figure 1-3. The CERCLA Decision Process

The conceptual site model (CSM) will be used in this RI/FS Report to present what is known about 100-K. The American Society for Testing and Materials *Standard Guide for Developing Conceptual Site Models for Contaminated Sites* (ASTM E1689-95) defines the CSM as "a written or pictorial of an environmental system and the biological, physical, and chemical processes that determine the transport of contaminants from sources through environmental media to environmental receptors within the system."

For the 100-K RI/FS Work Plan, the CSM was used as a base to integrate relevant site information, determine whether information including data were missing (data gaps), and identify additional information to be collected. In Chapters 2 through 7 of this report, the model is refined by the additional information and then used to identify and evaluate potential risk to human health and the environment.

Figure 1-4 presents the basic activities associated with a CSM. For an exposure pathway to be complete, all the components must be present:

- "Source" is the location from which a contaminant enters the physical setting. The primary sources of contaminants were releases and effluents related to reactor operations. Primary sources are described in Chapter 1. A secondary source is created when the contaminants are mixed in the vadose zone and then the groundwater. Reactor operations at 100-K have ceased; therefore, this document focuses on secondary sources of contaminants in the vadose zone and groundwater and further potential risk to human health and the environment. These secondary sources are described in Chapter 4.

- "Release Mechanisms" are the potential to release to the environment through resuspension of contaminated particulate matter, surface runoff, leaching to the vadose zone, plant intrusion, animal burrowing, erosion, or groundwater migration. Release mechanisms and relevant 100-K physical features are introduced in Chapter 3 and discussed in Chapter 5.

- "Transport" is movement of a chemical or physical agent in the environment from a secondary source to an environmental medium, or via a food chain. Contaminants introduced into the environment can flow between different environmental media such as air, vadose zone, groundwater, and surface water due to interconnecting release mechanisms. Transport is discussed in Chapter 5.

- "Exposure" is the process by which a contaminant or physical agent in the environment comes into direct contact with the body, tissues, or exchange boundaries of an environmental receptor organism (for example, ingestion, inhalation, dermal absorption, or root uptake). The courses through which contaminants in the environment may move away from the secondary source to potential environmental receptors are called pathways. An exposure point is where a receptor could encounter a contaminant in an environmental medium. Potential exposure scenarios are discussed in Chapters 6 and 7.

- "Receptors" include humans and other organisms (e.g., plants, animals, and other species) that may come into direct contact with the contaminants. Chapters 6 and 7 evaluate exposure to receptors.

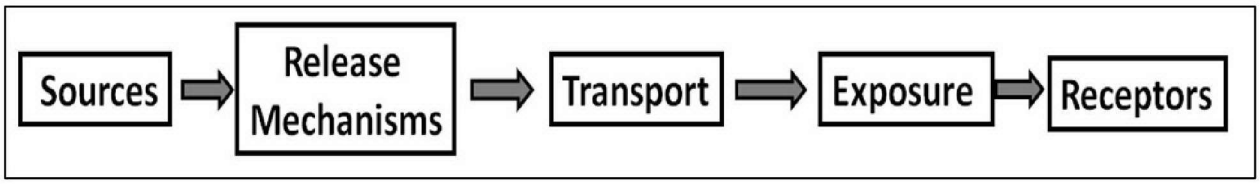


Figure 1-4. Conceptual Site Model

In Chapters 8 through 10, the refined model is used to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions in interrupting the exposure pathways of contaminants to human and environmental receptors. The CSM, as presented in this RI/FS Report, provides a basis for a follow-on proposed remedy decision, together with public participation, for DOE and EPA to make a decision to begin design and implementation of selected long-term remedial actions.

The identification of data needs in 100-K Work Plan (DOE/RL-2008-46-ADD2) led to development of a sampling and analysis plan (SAP) that established characterization activities specific to 100-K (*Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*, hereinafter called 100-K

SAP [DOE/RL-2009-41]). The 100-K SAP includes a Field Sampling Plan that provides the sampling strategy and techniques used to obtain the supplemental data required for the RI/FS. The 100-K SAP also provides a Quality Assurance Project Plan (QAPjP) to ensure that data collected meet the appropriate quality assurance (QA) and quality control (QC) requirements. Once the RI activities have filled the CSM data needs, the FS process is used to assemble various combinations of technologies into RAAs that address the contamination in the various media at 100-K (*Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [EPA 540/G-89/004]).

1.2 Site Background

The Hanford Site encompasses approximately 1,517 km^2 (586 mi^2) in Benton, Franklin, and Grant counties in south-central Washington State within the semiarid Pasco Basin of the Columbia Plateau. The site stretches approximately 50 km (30 mi) north to south and about 40 km (24 mi) east to west, immediately north-northwest of the confluence of the Yakima and Columbia Rivers; the cities of Kennewick, Pasco, and Richland (the Tri-Cities); and the City of West Richland. The Columbia River flows 80 km (50 mi) through the northern part of the Hanford Site and, turning south, forms part of the site's eastern boundary, while the Yakima River runs near the southern boundary of the Hanford Site, joining the Columbia River at the City of Richland. The central portion of the Hanford Site is punctuated by two small east-west trending ridges, Gable Butte and Gable Mountain. Lands adjoining the site to the west, north, and east are principally range and agricultural. State Routes 240 and 24 skirt the southwestern and northern portions of the site, respectively.

The Hanford Site area is culturally rich, experiencing a history of multiple occupations by both Native and non-Native Americans. For thousands of years, Native American peoples have inhabited the lands both within and around the Hanford Site (*Tribal Distribution in Washington* [Spier, 1936]; and *Handbook of North American Indians: Volume 12, Plateau* [Walker and Sturtevant, 1998]). Non-Native American presence in the mid-Columbia began in 1805 with the arrival of the Lewis and Clark Expedition along the Columbia and Snake Rivers. In the late 19th and early 20th centuries, non-Native people began intensive settlement on the Hanford Site, establishing an early settler and farming landscape. Farmstead communities existed from 1880 to 1943, located primarily in the upland environment adjacent to the Columbia River. The area became one of the premier orchard regions in the state following formation of the Hanford Irrigation and Development Company in1905. The farming life came to an abrupt halt in 1943 when the U.S. government took possession of the land to produce weapons-grade plutonium as a part of the Manhattan Project (Figure 1-5).

Figure 1-5. Historical Farm in 100-K (1943)

1.2.1 Site Description

The Hanford Site is divided into numerically designated areas. These areas served as the location for reactor, chemical separation, and related activities for the production and purification of special nuclear materials and other nuclear activities. The reactors and their ancillary/support facilities were located along the south shore of the Columbia River in the 100 Area, due to the need for large quantities of water to dissipate the heat generated during reactor operations. The 200 Area, located about 11 km (7 mi) from the Columbia River, contained all the facilities used to separate, isolate, store, and ship the plutonium from reactor operations. The 300 Area, located adjacent to and north of the City of Richland, contained the reactor fuel manufacturing plants and the research and development laboratories, while the 400 Area, located 8 km (5 mi) northwest of the 300 Area, contained the Fast Flux Test Facility designed for testing liquid metal reactor systems. The 600 Area consisted of facilities that served more than one specific area, or in some cases, the entire project.

100-K is adjacent to the Columbia River in the northern portion of the Hanford Site between 100-BC and 100-N, as shown in Figure 1-1. The section of the Columbia River along 100-K (Figure 1-6) defines a portion of the Hanford Reach, an important ecological, cultural, historical, and recreational feature that extends from the base of Priest Rapids Dam to the slack water of Lake Wallula near the southern boundary of the 300 Area.

Figure 1-6. The Columbia River along 100-K

Active facilities in 100-K include office buildings, storage buildings, a substation switch house, and pump-and-treat facilities. Inactive facilities remaining within 100-K include the 105-KE and 105-KW Reactor buildings, a water treatment plant, outfall structures, mobile office, and numerous storage buildings. Figure 1-7 shows 100-K under construction in 1954. Figure 1-2 presents the location of 100-K OUs and Appendix E includes information about active and former 100-K facilities.

Figure 1-7. 100-K Construction (1954)

1.2.2 Hanford Site and Operational History

This section provides an overview of the history of the Hanford Site as well as the operational and process histories of 100-K. It describes the 100-K Reactors and support facilities, cooling water systems, and radioactive and nonradioactive waste streams, as well as the types of waste disposal facilities that were used during site operations. It also describes the types of locations where contaminants were released, and indicates the types of contaminants that are likely to be found in various locations at 100-K.

1.2.2.1 Hanford Site History Overview

The Hanford Site was selected for plutonium production for military nuclear weapons in 1942 as part of the Manhattan Project because of the availability of water from the Columbia River, access to power from the Bonneville and Grand Coulee Dams, its remote location, and its relatively small population. Land acquisition for the Hanford Site took place in February 1943 and represented one of the largest land procurements (approximately 160,000 ha [400,000 ac]) carried out during World War II. Site construction, which began the following month, was largely completed with the first three reactors (B, D, and F) coming online by April 1945.

Between 1947 and 1955, the Atomic Energy Commission (AEC) added five new reactors (C, H, DR, KE, and KW) at the Hanford Site while at the same time boosting the output of the three Manhattan Project reactors (B, D, and F). Incremental improvements in the basic components of the World War II reactors and a construction program to build reactors that incorporated these changes accounted for doubling the plutonium output at Hanford in 1952 and 1953.

The period from 1956 through 1964 saw the most intense defense production at Hanford, including the construction of a new dual-purpose reactor for the Hanford Site capable of both generating electricity and producing plutonium. Construction of N Reactor, which featured a new closed loop, primary cooling system, was completed in 1963 with plutonium production beginning in 1964. The 800 MW steam plant began producing electricity in 1966 and was the world's largest nuclear power plant for many years.

By the 1960s, however, the nation's plutonium stockpile was much larger than deemed necessary, and plutonium production at Hanford gradually decreased. In 1964, the AEC shut down the H, DR, and F Reactors, followed by D Reactor in 1967 and B Reactor in 1968. All the remaining reactors (C, KE, and KW) at Hanford were shut down in 1969–1971 (with the exception of N Reactor), along with the fuel manufacturing and separation plants. N Reactor was shut down in 1986 following the Chernobyl explosion in the former Soviet Union, and was transitioned to cold standby in 1989 with the end of the Cold War, signaling the close of Hanford's production mission and the start of its cleanup mission. During the Manhattan Project and Cold War, more than 67,000 kg (147,000 lb) of plutonium were produced at the Hanford Site, 13,000 kg (29,000 lb) of which were fuel grade plutonium. The Hanford Site produced the entire nation's nuclear arsenal plutonium between 1945 and 1963, and accounted for more than 65 percent of all plutonium in the history of U.S. plutonium production.

Construction of the two 100-K Reactors (105-KE and 105-KW) began in tandem in September 1952 in an effort to hasten development of the nation's nuclear deterrent arsenal. Operation of the twin reactors began in early 1955 at an initial output of 1,850 MW each. However, output was gradually increased until the reactors each reached their maximum authorized power of 4,400 MW in 1961.

The 105-KW and 105-KE Reactors were shut down in 1970 and 1971, respectively. Housekeeping and decommissioning activities began at 100-K as part of a sitewide initiative in 1973. This effort progressed as resources allowed from 1974 through 1990, with buildings being demolished, surplus equipment salvaged or redeployed, and active operations maintained at a minimal level (*Summary of the Hanford Site Decontamination, Decommissioning, and Cleanup FY 1974 Through FY 1990* [WHC-EP-0478]). However, because of their proximity to the 105-N Reactor, many of the facilities at 100-K remained in service to support the 105-N Reactor's continued operation. Therefore, relatively little demolition or salvage work had been done at 100-K until 2008, when active demolition of the KE and KW Reactor support facilities began again.

The environmental impacts associated with the ultimate disposition of the reactors were evaluated in *Addendum (Final Environmental Impact Statement): Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington* (DOE/EIS-0119F). The Environmental Impact Statement (EIS) ROD ("Record of Decision: Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington," hereinafter called the NEPA ROD [58 FR 48509]) documented the selection of interim safe storage (ISS) for the reactors. (ISS is the provision of an upgraded, weather resistant shell to isolate the reactor core until remedial activities are conducted.)

1.2.2.2 100-K Operational History

The primary operational period for 100-K relates to plutonium production from the 105-KW and 105-KE Reactors starting in 1955 until 1971. During this period, all reactor systems for influent cooling

water, reactor pile, effluent waste disposal, and ancillary support services were operated. In addition to its primary operational history, 100-K had a second operational period from 1975 until 2007 when the reactor fuel storage basins were repurposed to store spent fuel from the 105-N Reactor. A discussion of these two operating periods follows.

1.2.2.3 Plutonium Production Operations (1955–1971)

In 1955, the 105-KW and 105-KE Reactors were started up (January 4 and April 17, respectively) as the seventh and eighth plutonium production reactors at the Hanford Site. Each reactor was about 60 percent larger than the older single pass reactors (B, C, D, DR, F, and H) and each had a graphite block with 3,220 process tubes compared to the 2,004 process tubes for the older production reactors (*Hazards Summary Report: Process Control and Technical Data Hanford K Production Reactors*, hereinafter called Hazards Summary Report [HW-74095]). The increased number of process tubes accounted for most of the operating history differences between the 105-KE and 105-KW Reactors and the older reactors. Each reactor operated with greater volumes of cooling water to and from the reactor pile, an increased volume of inert cover gas recirculated through the graphite moderator block within the pile, and an increased number of fuel elements in the reactor pile than the older single-pass reactors.

Production Related Materials. Materials that passed through the reactors were contaminated with generally short-lived radioisotopes and represented the majority of the wastes produced. Active physical barriers and strong administrative measures were in place to minimize radiological hazards throughout the Hanford Site production areas. These measures affected the disposal locations and waste management procedures for the various production operation waste streams.

Waste streams from the reactor production process include the following:

- Process inputs:
  - Raw materials processed through the reactor, such as uranium fuel and cooling water
  - Process chemicals for water conditioning and inhibiting corrosion (for example, sodium dichromate and sulfuric acid)
  - Materials used for reactor maintenance, such as acids and solvents
- Process outputs:
  - Isotopes and byproducts, including a host of long-lived radionuclides such as plutonium-239, strontium-90, cesium-137, tritium, and carbon-14, and numerous short-lived radionuclides
  - Radioactively and chemically contaminated materials (solid and liquid wastes)
  - Radioactively and chemically contaminated cooling water
  - Uncontaminated waste materials

Reactors generated a variety of radionuclides (*Radiological Characterization of the Retired 100 Areas* [UNI-946]; *100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]). Principal radionuclides were as follows:

- Thermal shields—cobalt-60 and nickel-63
- Reactor graphite cores—tritium and carbon-14

- Process tubes (and the film inside the process tubes)—manganese-54, cobalt-60, zinc-65, europium-154, cesium-137, and strontium-90

More detailed discussions on the nature and extent of the contaminants associated with these processes is provided in Chapter 4. Liquid wastes from reactor operations and associated facilities were released to the vadose zone and the Columbia River. Solid wastes were disposed in burial grounds associated with the facilities. Sites for wastes intentionally or unintentionally released to or buried within 100-K included trenches, cribs, French drains, retention basins, pipelines, burial grounds, and unplanned spills and releases, each of which is described in the following text.

Trenches. Shallow, narrow, unlined surface liquid waste sites of variable length that received limited quantities of sludge and/or liquid wastes (cooling water, contaminated water and sludge, sodium dichromate, fuel rupture effluent, and decontamination solutions [that is, citric acid, nitric acid, and solvents]). Trenches typically were 15 to 40 m (50 to 130 ft) long, 3 to 5 m (10 to 17 ft) wide, and 2 to 6 m (6 to 20 ft) deep. However, at 100-K, a 1,219 m (4,000 ft) trench (116-K-2) was constructed to dispose of large volumes of reactor effluent waste, as shown in Figure 1-8.

Figure 1-8. Mile Long Trench (116-K-2) Excavation in 1955

Cribs. Subsurface liquid waste disposal sites for percolating wastewater into the ground without exposure to the atmosphere. The cribs typically were 3 × 3 × 3 m (10 × 10 × 10 ft) boxes, shored with wooden railroad ties, and filled with gravel (e.g., 116-KE-1 and 116-KW-1). Early waste management practices used cribs to receive low-level radioactive waste for disposal and to provide a physical barrier against surface exposure. Cribs received contaminated water and sludge, contaminated process tube effluent, fuel

storage effluent, spent laboratory solutions, and potassium borate solutions. The 116-K-1 Crib shown in Figure 1-9 was a unique combination crib/trench design.

French Drains. Subsurface liquid waste disposal sites designed to percolate wastewater into the ground without exposure to the atmosphere (e.g., 100-K-36). These sites were usually constructed with a 1 m (3 ft) diameter, open or gravel-filled pipe placed vertically to less than 5 m (16 ft) below ground surface (bgs). French drains typically received low volumes of low-level radioactive waste for disposal.

Solid Waste Burial Grounds. Areas used for near surface disposal of solid waste containing radioactive and nonradioactive hazardous substances, construction debris (such as steel, concrete, and wood) from reactor modifications, contaminated construction equipment, contaminated vadose zone material, irradiated reactor parts, and low-level radioactive combustible material (*Estimates of Solid Waste Buried in 100 Area Burial Grounds* [WHC-EP-0087]; *Historical Events—Reactors and Fuels Fabrication* [RL-REA-2247]) (e.g., 118-K-1).

Figure 1-9. 116-K-1 Crib during Construction (1954)

Unplanned Release Sites. Sites where wastes unintentionally released to the environment created sources of contamination. Waste sites in this group typically related to liquid waste spills (e.g., UPR-100-K-1 and 100-K-48).

Retention Basins. Large, open, compartmentalized, reinforced concrete structures designed to hold temporarily cooling water from reactor operations then discharged to the Columbia River after cooling and decay of short-lived radioactive contaminants. Although retention basins are sometimes considered liquid waste sites because they leaked substantially to the surrounding vadose zone, they were not designed to percolate liquids into the vadose zone.

Pipelines. Closed transfer lines between facilities or structures that were used to transfer chemicals or waste effluents and included lines that may have leaked.

1.2.2.4 Spent Fuel Storage Operations (1975–2007)

The 105-KW Reactor was shut down on February 1, 1970 and the 105-KE Reactor was shut down on January 29, 1971. Work then followed to remove their fuel and stabilize their subsystems, including the effluent waste disposal sites (*100 K Facility Deactivation Documentation* [SNF-11168]). Beginning in 1973, the 105-KE and 105-KW Reactors fuel storage basins (FSBs) were re-purposed to temporarily store spent fuel from the 105-N Reactor. The temporary storage of spent 105-N fuel in the 105-KE and 105-KW FSBs included plans for its removal and reprocessing in the 200 Area.

The Plutonium Uranium Extraction (PUREX) reprocessing plant in the 200 East Area was restarted in 1983 and began reprocessing the spent 105-N fuel. The last shipment of 105-N spent fuel was received and stored in the FSB in 1989. However, when the decision was made in 1992 to stop spent fuel reprocessing at the Hanford Site, the PUREX plant was shut down, leaving some spent fuel, approximately 2,100 metric tons (2,300 tons), stored in the 105-KE and 105-KW FSB. The remaining spent fuel was later consolidated in the 105-KW FSB, where it remained until 2007 when it was transferred for storage in the 200 Area.

The operation of the 105-KE and 105-KW FSBs from 1975 until 2007 resulted in additional long-lived fission product contamination of the vadose zone and groundwater beneath the FSBs due to spent fuel contamination of the FSB water and leaks to the vadose zone (*Groundwater Monitoring and Assessment Plan for the 100-K Fuel Storage Basins* [PNL-14033]).

1.2.2.5 Reactor Mechanics and Layout

The 105-KW and 105-KE Reactors were installed in parallel, about 610 m (2,000 ft) apart, roughly 750 m (2,500 ft) from the Columbia River (Figure 1-7). At grade, each reactor building was 65 m (213 ft) long × 84 m (275 ft) wide × 32.6 m (107 ft) high. The lowest floor in each building was 6.3 m (20.8 ft) below grade. Each reactor building had an associated 91 m (300 ft) tall ventilation stack.

The 105-KW and 105-KE Reactors were graphite moderated, "single pass," water cooled reactors used to produce weapons grade plutonium. The reactors produced plutonium with the same operating materials and processes used at the other single pass production reactors in the 100 Area, but were larger. The 105-KW and 105-KE Reactors construction and layout were identical except for the 1706-KER Test Loop installed at the 105-KE Reactor.

Reactor Pile. A steel box with a graphite moderator block in the center surrounded by the thermal shield, which, in turn, was surrounded by the biological shields. The 105-KE and 105-KW Reactor piles had 3,220 process tubes penetrating them from front to back. Each process tube was 13 m (44 ft) long and had a 4.3 cm (1.7 in.) outer diameter (Hazards Summary Report [HW-74095]). The process tubes contained aluminum clad, uranium metal fuel elements containing uranium-235 that fissioned, releasing neutrons slowed by the graphite and absorbed by the uranium-238 to transmute to plutonium-239 (the product).

During the production of plutonium, fission neutrons captured by the reactor operating equipment and materials produced radioactive activation products. The fission products and activation products included radionuclides with very short to long half-lives. The very short half-life radionuclides were a concern during operations because they were discharged to the river. The long half-life radionuclides became COPCs for Hanford restoration activities. During 105-KE and 105-KW Reactor operations (1955 to 1971), the short-lived radioisotopes (e.g., manganese-54, iodine-131, and zinc-65) represented more than 98 percent of the radioactivity in the reactor effluents (*The Hanford Site Historic District Manhattan*

Project 1943 Thru 1946 Cold War Era 1947 Thru 1990, Table 1 [DOE/RL-97-104]). These very short half-life radionuclides have decayed since the operations period to concentrations below cleanup standards. Long-lived radioisotopes (e.g., cobalt-60, Sr-90, cesium-137, europium-152, carbon-14, and tritium) were those with a decay half-life greater than three years (*The Hanford Site Historic District Manhattan Project 1943 Thru 1946 Cold War Era 1947 Thru 1990*, Table 2 [DOE/RL-97-104]), and are historically the primary radioactive contaminants for 100-K.

Graphite Moderator. As the 105-KE and 105-KW Reactors production rates were increased after startup in 1955, the operating temperatures increased within the reactor piles. The graphite cover gas was changed from carbon dioxide-helium to nitrogen-helium for improved protection of the graphite at the higher temperatures. The use of nitrogen instead of carbon dioxide in the 105-KE Reactor began in December 1960 (*Historical Events – Reactors and Fuels Fabrication* [DUN-3232]), and the reactor was fully switched over to nitrogen by 1962, after completing an extended production test from early 1960 through early 1962. The replacement of carbon dioxide with nitrogen is cited in Hazards Summary Report (HW-74095 v3, page 70, "Description of the 100-KE and 100-KW Production Reactor Plants").

The inert cover gases were continuously recirculated over the graphite block and through a drying and filtration system (115-KE and 115-KW Buildings) that removed and disposed cooling water in-leakage to the deep below-grade 115-KE and 115-KW Condensate Cribs (116-KE-1 and 116-KW-1, respectively). Although the nitrogen-helium cover gas provided greater protection of the graphite, it also resulted in an increased release of carbon-14 and tritium, which were discharged into the below-grade cribs.

The 115-KE Crib received approximately 800,000 L (211,338 gal) of condensate and other waste from the reactor gas purification systems. At the 105-KW Reactor area, the 115-KW Condensate Crib also received approximately 800,000 L (211,338 gal) of condensate and wastewater from the reactor gas purification systems. Both waste sites operated from 1955 to 1971. The radionuclide inventory for both cribs is documented and presented in *100-K Area Technical Baseline Report* (WHC-SD-EN-TI-239).

1706-KER Test Loop. The 1706-KER Building was a process improvement laboratory. The 1706-KER test loop supported cooling water process improvements and involved 12 of the 3,220 105-KE Reactor process tubes. Of these 12 tubes, 8 processed cooling water as "once through" process tubes, while the other 4 operated in a "closed loop" configuration where the "feed-and-bleed" effluent wastes were disposed to the 1706-KER waste disposal system (116-KE-2 process trench).

Pressure drops on any process tube (including the 1706-KER Test Loop tubes) prompted defilming purges using diatomaceous earth/water slurries that discharged with the reactor effluent pipelines to the retention basins and were then diverted to the 116-K-2 process trench. Sharp increases in tube effluent radioactivity signaled a fuel failure event, which prompted collection and diversion of the reactor cooling water to a retention basin and then diversion to the 116-K-2 process trench. Reactor pile instruments were used to monitor the pile reactivity. The pile reactivity was maintained within acceptable ranges using the Horizontal Control Rods (HCR) and Shims. In the event of an emergency shutdown condition, the reactor was "scrammed" by releasing the Vertical Control Rods (VCR). The cooling water from the HCRs and the VCRs drained to the radioactive process sewer.

*Fuel Storage Basin (1955 to 2007).*The FSB at each reactor was a series of belowground, reinforced concrete, rectangular pools with dimensions of approximately 38.1 × 20.4 m (125 × 67 ft). The walls of the basin were 6.3 m (20.75 ft) high and up to 0.7 m (2.3 ft) thick. The basin floors were 0.6 m (2 ft) thick (nominal) reinforced concrete. Reinforcing steel connected the basin floor to the walls.

The FSB pool water retained radioactive particulate and soluble radionuclide materials that were released from damaged spent nuclear fuel (SNF). The FSBs contained water about 5 m (17 ft) deep to shield

workers from stored spent fuel radiation. The water clarity in the FSB was maintained by removing settled solids with a centrifugal pump and discharging the waste to the radioactive process sewers (100-K-55 and 100-K-56). The water was also maintained by a feed-and-bleed water supply that continuously overflowed at the surface of the basin to the contaminated process sewer (Hazards Summary Report [HW-74095]).

When plutonium concentrations in the fuel reached the desired product levels, the reactor was shut down and fresh fuel was used to push the spent fuel out of the reactor pile into the FSBs. The spent fuel was typically stored in the FSBs for 90 days to allow short-lived fission products to decay. The decayed spent fuel was then loaded into casks, transferred to water-filled railroad cars, and transported to the 200 Area for reprocessing.

The reactor process tubes also contained "spacers" and "dummy fuel elements" (dummies). These were used to ensure the fuel was within the moderated region of the reactor pile and to ensure uniform cooling water flow during operations. Used spacers and dummies were also stored in the FSBs to allow for activation product decay and transferred to casks for decontamination (so they could be reused) or for disposal as solid waste.

The 105-KE and 105-KW FSBs had a unique leak collection system installed beneath their concrete floors during construction. An asphaltic membrane with perforated collection pipes drained water leaks from the FSBs to cribs (116-KW-2 or 116-KE-3) with reverse/injection wells that discharged the leaks below the unconfined aquifer (in the water table) (*100-K Areas Outside Lines Details and Sections* [H-1-23207]). For these cribs, the reverse/injection well was the primary means for disposing the sub-basin leaks, while the crib structure provided surge capacity. Based on reactor operating experience, most FSB leaks occurred at the concrete joint between the FSB and the reactor wall (an area not covered by the asphaltic membrane).

There have been two periods of leakage from 105-KE FSB. The first occurred during the early phase of converting the basin from its original purpose during reactor operations to that of storage of fuel from the 105-N Reactor. The second period occurred approximately 13 years later. There are no documented occurrences of leakage from the 105-KW FSB.

105-KE FSB (1976 to 1979). Approximately 56.8 million L (15 million gal) of shielding water are estimated to have been lost to the underlying soil column during the period 1976 to 1979.

- Water loss during this period had been monitored using drawdown tests in the basin, and the leakage rate was determined to be dependent on water temperature (i.e., higher leak rates were associated with cooler temperatures). Peak water loss rate was 1,819 L (480 gal) per hour, which occurred during 1977 to 1978.
- The refurbishing of 105-KE FSB identified the construction joint between the storage basin and reactor building as the potential leakage site.
- Sealing the construction joint was competed in May 1980.

Radionuclide concentrations in the 105-KE FSB were relatively low during leakage in the late 1970s. However, approximately 2,500 Ci of radionuclides, exclusive of tritium, were estimated to have been released, with peak water loss rates occurring during 1977. This inventory, except for tritium (and possibly minor amounts of antimony-125 and technetium-99), was largely retained within the vadose zone because of adsorption onto soil particles.

105-KE FSB (1993). Leakage was first noticed in February 1993 when water balance calculations showed an increased loss rate that could not be explained by evaporation alone. Leakage was suspected to have occurred during the period January through August 1993, with an average water loss rate estimated at

95 L (25 gal) per hour. The construction joint in the pickup chute structure was the suspected leakage location and additional measures to seal it were undertaken. The moisture collection system beneath each basin does not extend to the area beneath the pickup chute, so shielding water was discharged into the vadose zone and underlying groundwater. By March 1995, the loading chute structure was physically isolated from the main storage basin and contamination removed.

A tritium plume was created by this period of leakage and was recorded as it passed by downgradient monitoring wells. Vadose zone contamination was apparently remobilized in the late 1990s by above-normal infiltration of water from the surface, which was caused by fire hydrant utility line breaks.

Beginning in 1973, the 105-KE and 105-KW FSBs were used to store spent fuel from the 105-N Reactor (*K Basins Safety Analysis Report* [WHC-SD-WM-SAR-062]). The FSBs were modified to operate in an isolated, closed loop configuration. This system recirculated the FSB water from Sump C through filters and ion exchangers, and allowed water additions to replace water lost due to leaks and evaporation to the building ventilation system. The replacement water was provided from a few of the water treatment lines at the 183-KE water treatment plant, which also provided facility services operating water (e.g., sanitary and ventilation). An important aspect of the FSB modification involved isolating the FSB process sewers from the reactor process sewers and effluent systems. The contaminated process sewer collection box was modified to drain to a new underground waste storage tank and the cribs with reverse/injection well systems were modified to be collected in a Lift Station (Sump D) and pumped to the contaminated process sewer. The Sump D design included an overflow to the abandoned 116-KW-2 and 116-KE-3 Cribs (*Structural Pump Gallery & Catch Tank Plan & Details* [H-1-34654]). Instrumentation was also installed to monitor FSB water levels, temperatures, and gamma radioactivity.

The spent fuel from 105-N was initially received and stored at the 105-KE FSB in mid-1975, and then at 105-KW FSB starting in 1981. From 1983 to 1989, 105-N spent fuel was shipped to the PUREX plant in the 200 East for reprocessing. The last shipment of spent fuel was received at 100-K in 1989, but the PUREX plant was shut down before all the spent fuel stored at 100-K was reprocessed.

After termination of reactor operations in 100-K, a number of irradiated uranium fuel elements was found in the basins during removal of FSB sludge in 1975. These fuel elements were not processed through the PUREX Plant during the final separation runs that occurred from 1983 to 1988 and in 1992. All spent fuel was removed from the basins in 2004. Contaminated sludge removal has been completed in the 105-KE FSB, basin demolition is complete, and underlying vadose zone is being remediated. Consolidation of the KE and KW Basins sludge into the KW Basin has been accomplished. The result is about 23 m^3 (30 yd^3) of sludge temporarily stored in five engineered containers in the KW Basin. About 5 m^3 (6.5 yd^3) of sludge in the settler tubes was removed in April 2010. The sludge generated from fuel packaging operations in the KW Basin resides in particulate capturing equipment, including strainers, knockout pots (KOPs), and settler tubes that are part of the KW Integrated Water Treatment System (IWTS).

Several thousand metric tons (millions of pounds) of both radioactive and nonradioactive sludge accumulated at 100-K. The radioactive sludge was generated during reactor operations in the pipes and the cooling water effluent system, in the 116-KE-4 and 116-KW-3 Retention Basins, and in the reactor FSBs. Smaller volumes of sludge also collected in water traps located in the 115-KE and 115-KW Gas Recirculation Facility and in the 117-KE and 117-KW Exhaust Air Filter Buildings. The sludge included diatomaceous earth, which was used periodically to scour internal surfaces of the reactor process tubes, and fine particulate matter, which originated from pipe slag, rust, failed fuel elements, graphite powder, dissolved and suspended solids in river water, and other undefined solids. The sludge was contaminated with radionuclides and various chemical contaminants (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]).

Process Sewers. Each reactor had two sewers—a "chemical sewer" that collected liquid wastes from nonradioactive facilities and a "contaminated sewer" that collected potentially radioactive liquid wastes.

Chemical Sewers. Sewer lines that drained to a sump, discharged to the 1908-K Outfall, and finally went to the Columbia River pipelines. These sewers received the process equipment drains from the water treatment plant, including sedimentation basin sludge and filter backwashes (*Liquid Waste Disposal Review 100-K Plant* [DUN-7238]). These sewers also received wastes from ancillary facility floor drains (e.g., 183-KE and 183-KW operating galleries, 100-K-79 pipe tunnel, and 190-KE and 190-KW Pump Houses).

The volume and disposition of chemical wastes generated after 1975 is unknown. The 183-KE water treatment plant has continued to operate and discharge to the river until the present, maintaining water levels in the FSBs and providing project water needs during waste site remediation and facility deactivation, decontamination, decommissioning, and demolition (D4) activities.

Additional discharge sources to the chemical sewer included the 150-K Heat Recovery System heat exchangers (operated with ethylene glycol), the 166-K Control Buildings (diesel fuel oil tanks for generators and steam boilers), the 1607-K Septic Systems, the 1706-KEL laboratory drains, and the 100-K support buildings (e.g., administrative offices and maintenance garage).

Contaminated Sewer. Sewer lines that drained to a collection sump (100-K-71 or 100-K-75), normally discharged to the 1908-KE radiation monitoring station, then discharged to the 1908-K Outfall, and finally to the Columbia River pipelines. The radiation monitoring station-detected radioactivity levels that required diversion of sewer flow to the 116-K-2 process trench. Decontamination solutions, which generally contained both radionuclide and chemical contaminants, were occasionally combined with reactor cooling water and discharged to the contaminated sewer. The contaminated sewer sump received liquid wastes from the FSBs overflow, the FSBs floor cleaning pump discharge, the Railroad Cask loading area floor drain, the 116-K Stack floor drain, the 117-KE and 117-KW Exhaust Air Filtration Buildings water seal overflow, and the reactor building floor drains.

From 1973 to 1975, the contaminated sewer was isolated from the reactor effluent disposal systems and 76,000 L (20,000 gal) underground waste storage tanks (100-K-70 and 100-K-74) were installed to receive and store any remaining radioactive process sewer wastes. The contaminated sewer collection Sump C piping at each reactor was modified to discharge to the waste storage tank or recycled back into the FSBs as described previously.

105-KE and 105-KW Buildings Ventilation. Prior to 1960, reactor ventilation air was released directly to the atmosphere through the 116-KE Stack. In 1960, air filtering systems were added to minimize the release of radionuclides and all building exhaust passed through particulate and activated charcoal filters before discharge to the atmosphere via a 91 m (300 ft) tall concrete stack. The 117-KE Building housed the 105-KE Building exhaust air filters and airflow control system. The 105-KE Reactor was connected to the 115-KE Building via a gas-piping tunnel and to the 117-KE Building by way of a ventilation duct. The tunnel and ducts are each about 60 m (200 ft) long. A similar system was used for the 105-KW Reactor ventilation system.

There were also ventilation systems associated with each of the reactors that circulated fresh air from the staffed areas into zones of increasing contamination levels, and upward past the reactors to overhead ducts, and exhaust stacks. Ventilation air became contaminated with radionuclides that were present as radioactive gases, entrained vapors, and particulates generated by the cascade of cooling water in the reactors.

These emissions may have resulted in surface contamination, as indicated in part by the presence of carbon-14 in vegetation. Other radionuclides included tritium and iodine-129. Two types of filter banks were used: a high efficiency particulate bank and a halogen (activated charcoal) bank. These filtering systems were placed

underground in the 117-KE and 117-KW Buildings just east of the reactor buildings (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]).

Sections of the 115-KE/KW and 117-KE/KW Buildings and associated tunnels were contaminated primarily with cobalt-60, cesium-137, carbon-14, and tritium, as well as Sr-90, cesium-134, europium-152, europium-154, and europium-155.

The seal water for the 117-KE and 117-KW Buildings drained to the contaminated sewer. Figure 1-10 provides a pictorial representation of the airflow through the structures and systems.

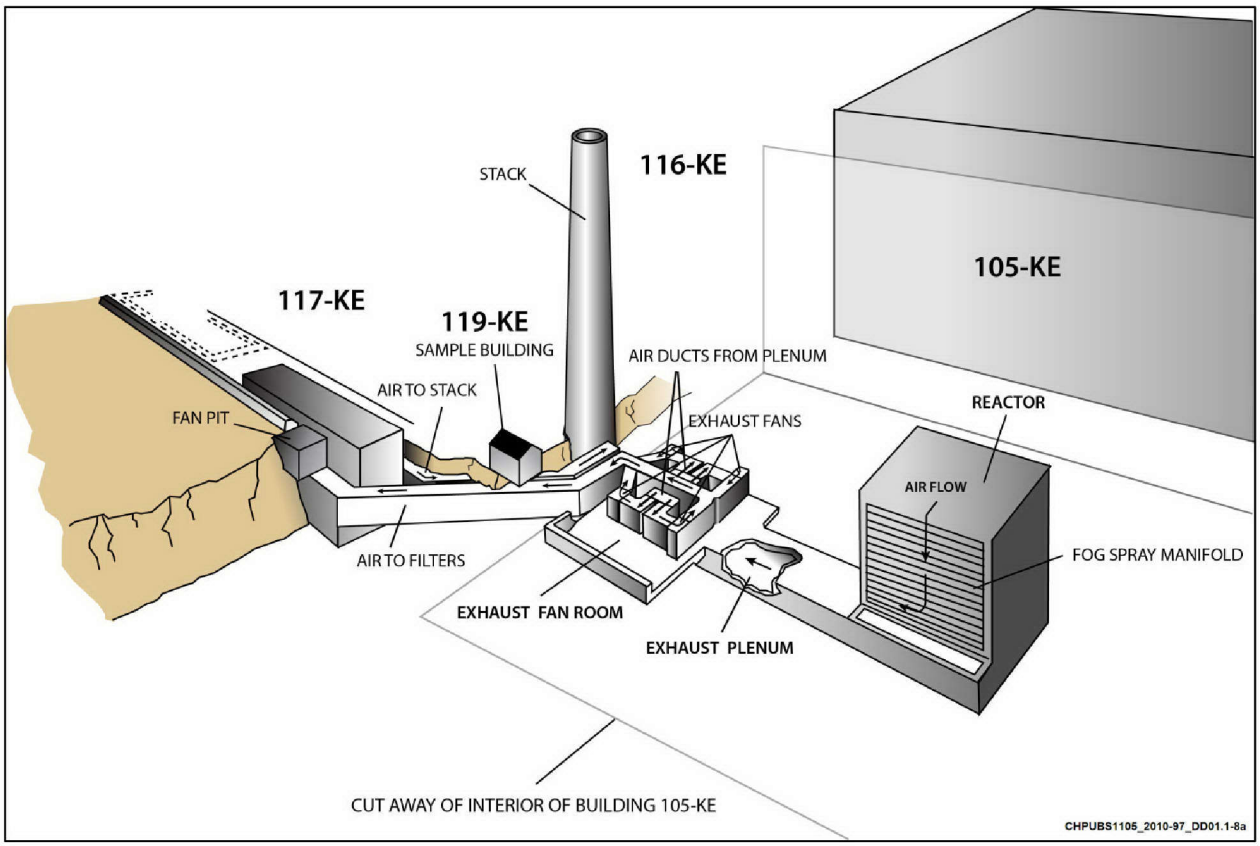


Figure 1-10. Diagram of the 105-KE Reactor Exhaust System

1.2.2.6 Cooling Water

The 105-KE and 105-KW Reactors were cooled using water from the Columbia River. Reactor operations required a continuous supply of high quality cooling water to prevent reactor core damage from heat generated by fission reactions. The 100-KE and 100-KW Reactors initially required about 570,000 L/min (150,000 gpm) of cooling water each (1955–1956). As the plutonium production requirements increased with corresponding increases in the power levels, the reactor cooling water requirements increased. Facility and pump upgrades increased cooling water flow to about 760,000 L/min (200,000 gpm) at each reactor by 1971.

Water Treatment. Figure 1-11 illustrates the cooling water treatment process for 100-K. The cooling water supply was provided from the Columbia River via river pump houses (181-KW and 181-KE), a water treatment plant (flocculation, sedimentation, and filtration) (183-KW and 183-KE) with sodium dichromate injection pumps (aluminum corrosion inhibitor), and a main pump house (190-KW and 190-KE). Figure 1-12 is a schematic depiction of facilities that stored and transferred liquid dichromate solution. Except for sodium dichromate, the water treatment chemical additives and wastes were

primarily flocculating agents to improve the sedimentation of suspended river water solids and surfactants to improve filtration. Alum, an aluminum sulfate solution, was added to the river water to enhance the settling of suspended solids and the performance of the filtration system in removing the remaining solids. These additives and the filter backwash materials were periodically flushed with the sedimentation solids to the chemical sewer that discharged to the river (*Liquid Waste Disposal Review 100-K Plant* [DUN-7238]).

Sodium dichromate, a source of Cr(VI), was added to the reactor coolant water to inhibit aluminum corrosion. More than 6 million kg (14 million lb) of sodium dichromate were used in the cooling water between 1955 and 1971 for the 105-KE and 105-KW Reactors. The increased cooling water volumes at 100-K (compared to the other 100 Area reactors) required an increase in the sodium dichromate used during operations. A concentrated sodium dichromate solution (about 70 percent by weight) was brought to the site by railcar. The solution was then transferred to two 158,987 L (42,000 gal) tanks (120-KW-5 and 120-KE-6) located adjacent to the 183.2 KW and 183.2 KE Flocculation and Sedimentation Basins and 183.3-KW and 183.3-KE Sand Filter Basins that treated and stored Columbia River water. The concentrated sodium dichromate solution had a pH of 1.5 to 2, a specific gravity of about 1.7 g/cm^3 and Cr(VI) concentrations of about 466 g/L (*Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site* [PNNL-17674]). Figure 1-13 presents the facilities and waste sites where Cr(VI) was known to be present in high (70 percent solution) and low (less than 2 ppm) concentrations.

The concentrated sodium dichromate solution was transferred from the storage tanks to metering pumps in the basement of the 183.1-KW and 183.1-KE Head Houses. The solution was then transferred via feed lines in the 183.7-KW and 183.7-KE Pipe Tunnels to the 190-KW and 190-KE Process Water Pump Houses. It was then mixed in the appropriate proportions to generate a sodium dichromate concentration of 2 mg/L (700 µg/L of Cr(VI)) in the reactor cooling water (Figure 1-12). By 1964, sodium dichromate concentrations had decreased to about 1 mg/L (350 µg/L of Cr(VI)), and then decreased further in 1968 to 0.5 mg/L (175 µg/L of Cr(VI)) (*Chemicals Discharged to the Columbia River from DUN Facilities Fiscal Year 1969* [DUN-6205]). During sodium dichromate solution transfer from the railcars to the storage tanks, some sluicing of fluids into a nearby French drain occurred, as did unintentional spills.

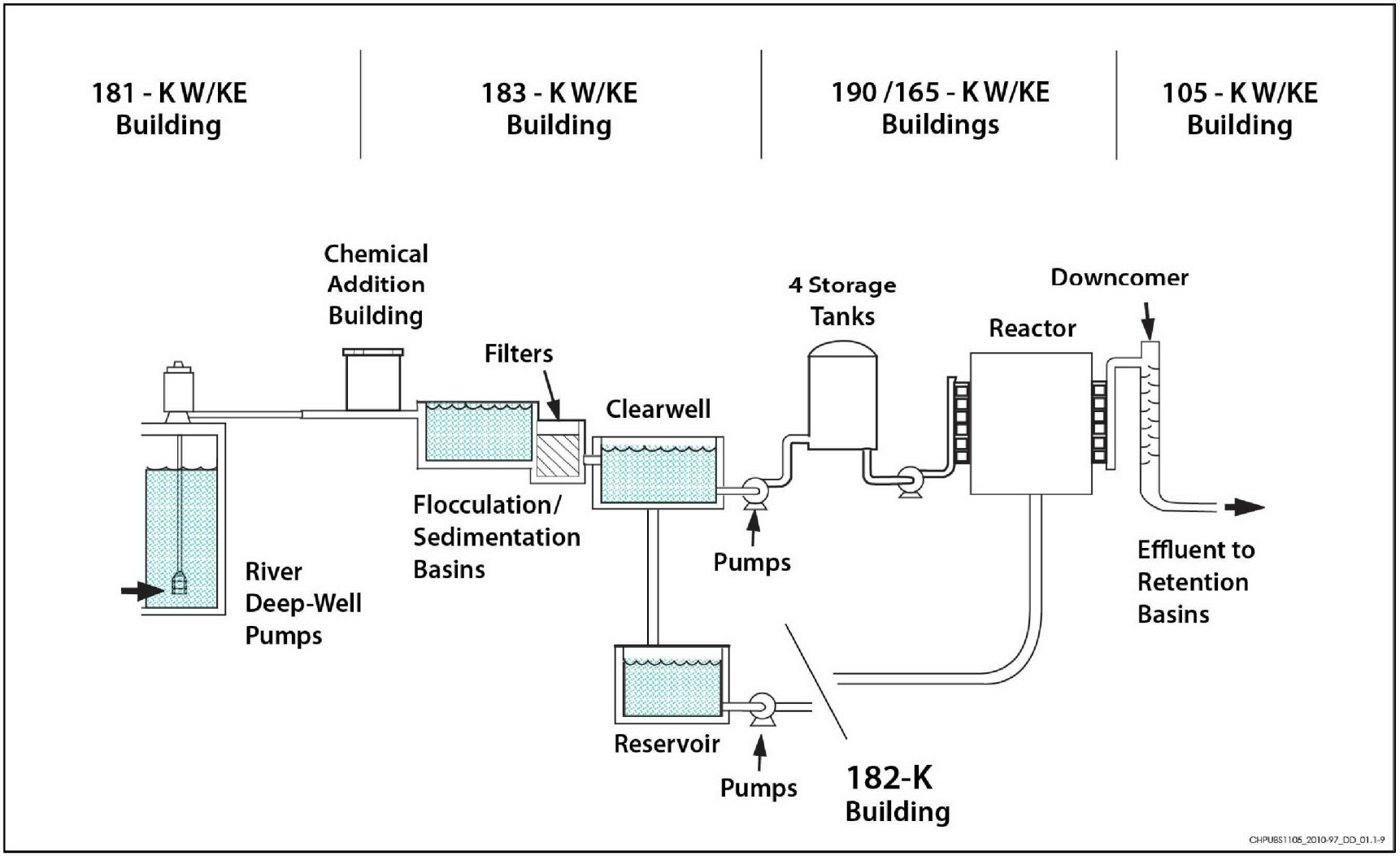


Figure 1-11. Illustration of the Cooling Water Treatment Process

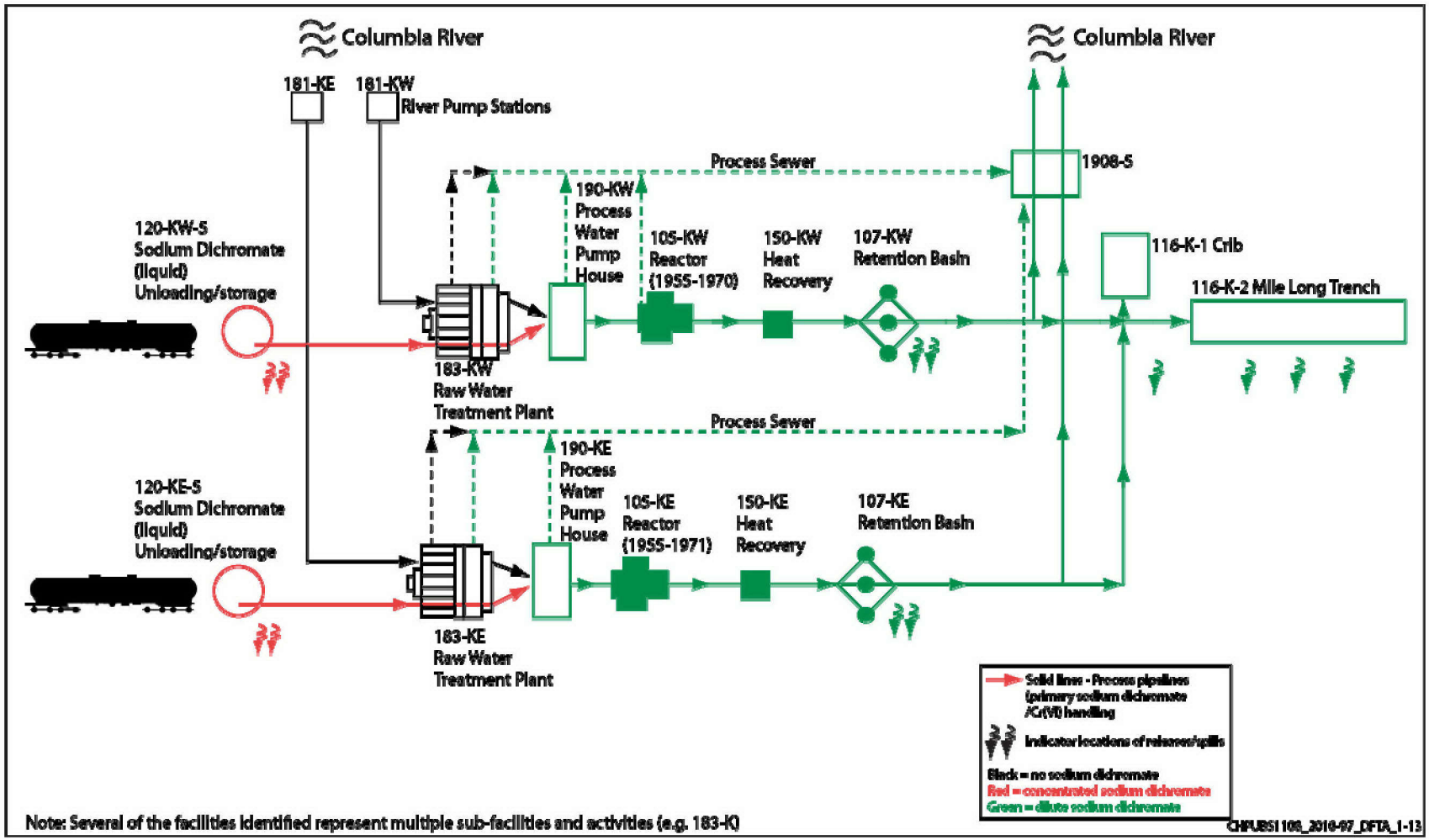


Figure 1-12. Schematic Flow Diagram of 100-K Reactor Cooling Water Upstream of the Reactor

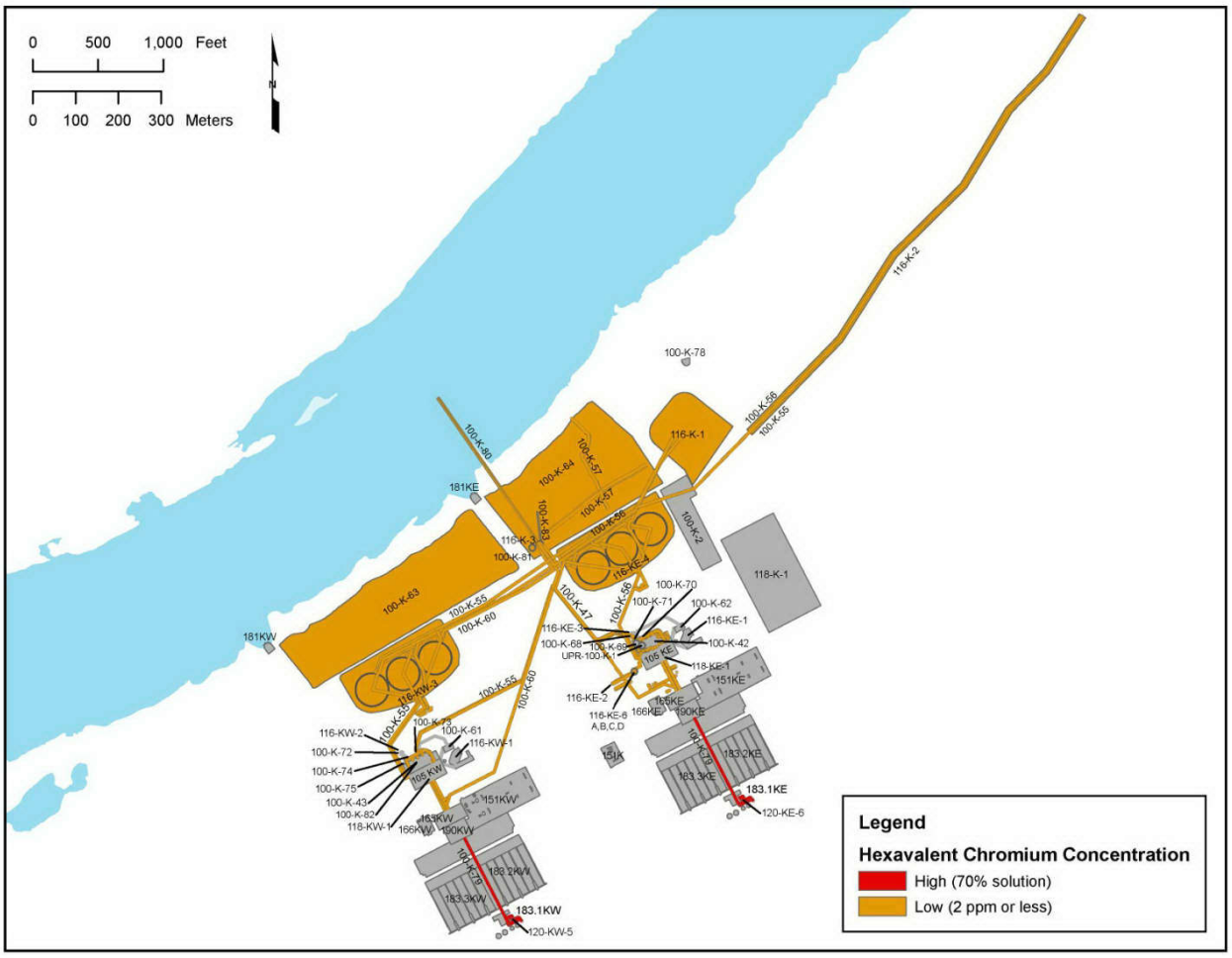


Figure 1-13. Facilities and Waste Sites Known to Have Cr(VI)

Reactor Cooling Water Effluent Disposal. After passing through the reactors, the cooling water was discharged via underground pipelines to open-topped steel retention basins (107-KW and 107-KE). The storage in the retention basins allowed for decay of short-lived radionuclides prior to discharge to the river. From the retention basins, the water was transferred through large pipes to the 116-K-3 (1904-K) Outfall and then into 84 in. pipes that discharged at the bottom center of the Columbia River. Overflow from the outfall structures could also discharge directly to the river shore through a concrete lined spillway and earthen ditch.

Of the three retention basins for each reactor, one was empty for use during fuel failure events. Fuel cladding failures occurred when corrosion or swelling of the aluminum cladding covering a uranium fuel slug caused it to break open, releasing uranium and an array of fission products into the reactor core cooling water. During a fuel failure event, the cooling water was diverted through the empty basin and then to the 116-K-2 Process Trench, rather than being discharged to the Columbia River.

The 116-K-1 Emergency Crib was originally designed to receive the diverted cooling water or chemical sewer effluent. The 116-K-1 Crib consisted of a crib with a horizontal inlet distributor pipe about 6 m (20 ft) below grade that was installed over rock/gravel fill to enhance the percolation of liquid wastes into the vadose zone (Figure 1-8). The 116-K-1 Emergency Crib had a unique large, open, above grade impoundment with soil banks to operate as a process trench during high volume waste disposals in the event of fuel failures. It flooded and overflowed in 1955, likely during initial tests with diversion flows.

The 116-K-2 Process Trench replaced the 116-K-1 Emergency Crib in 1955, before the first 100-K fuel failure (*Fuel-Element Failures in Hanford Single-Pass Reactors, 1944-1971* [PNWD-2161 HEDR]).

The 116-K-2 Process Trench (also known as the "Mile Long Trench") was 5.3 m (17.5 ft) deep, 1,250 m (4,100 ft) long, 17.2 m (56.5 ft) wide at the top, and 1.2 m (4 ft) wide at the bottom. The trench was used through the reactor operations period from 1955 until 1971. It consisted of an open surface, long ditch used to percolate liquid wastes into the vadose zone from the reactor subsystems. The 116-K-2 Process Trench received reactor cooling water diverted during fuel failure events at 100-K. The 107-KW and 107-KE Retention Basins provided the largest volumes of effluent to the 116-K-2 Process Trench.

At times, the 116-K-2 Process Trench overflowed or lost water to the surface through its sides, and occasionally into the 116-K-1 Emergency Crib area. Aerial photos after 1965 show the 116-K-1 Emergency Crib and the 116-K-2 Process Trench containing water. By 1967, leaks were also seen in the open area between the diversion valves near the 107-KW and 107-KE Retention Basins and the river shore. Losses also occurred as the retention basins piping systems degraded, causing effluent releases to the floodplain directly north of the retention basins and contaminating the surface at the 100-K-63 and 100-K-64 waste sites.

1.2.2.7 Other Waste Streams

Although cooling water may have been the primary waste stream at 100-K due to the quantities used, other radioactive waste streams (solid radioactive and nonradioactive wastes) also contributed to the contamination observed in 100-K vadose zone and groundwater. Figures 1-14 through 1-16 present the facilities and waste sites where carbon-14, strontium-90, and tritium have been known to be present.

Solid Waste Burial Grounds. Most of the radioactive solid wastes generated in 100-K were buried in the 118-K-1 Burial Grounds. Radioactive solid wastes generally consisted of reactor components, contaminated equipment, tools, and miscellaneous contaminated items (paper, rags, and structural concrete). The primary source of these wastes was reactor operations, and the most highly contaminated solid wastes were the reactor components. These included aluminum spacers, lead cadmium reactor neutron-poison pieces, boron splines, graphite, control rods, nozzles, Zircaloy 2 tubing, and cadmium sheets (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]). Other radioactive solid waste included air filters used in the 115-K Gas Recirculation Buildings and the 117-K Exhaust Air Filter Buildings, equipment used in connection with the cooling water effluent system, sludge from the retention basins, and contaminated dirt removed from near the effluent lines. Figure 1-17 shows a track-mounted probe surveying radioactive materials.

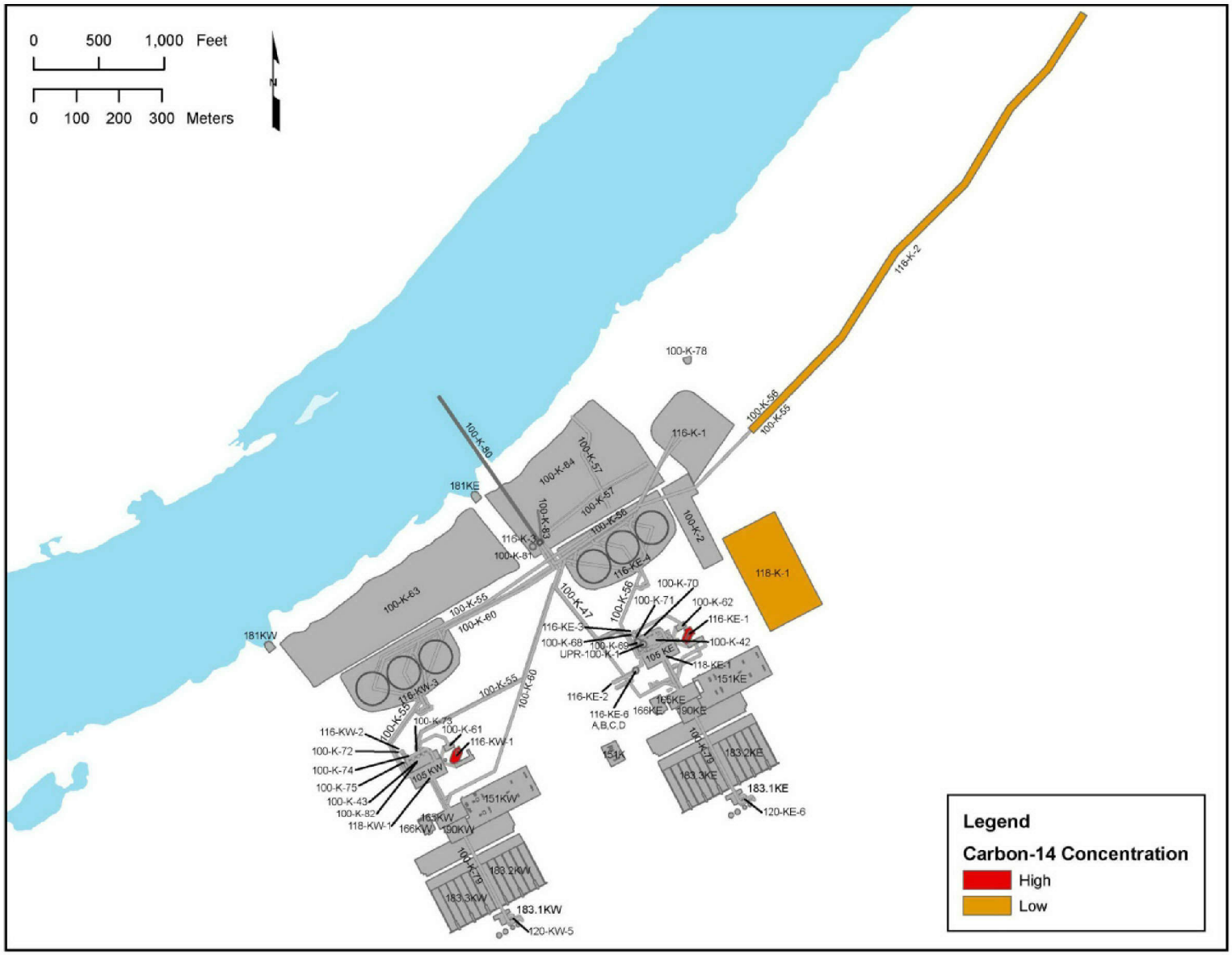


Figure 1-14. Facilities and Waste Sites Known to Have Carbon-14 Present

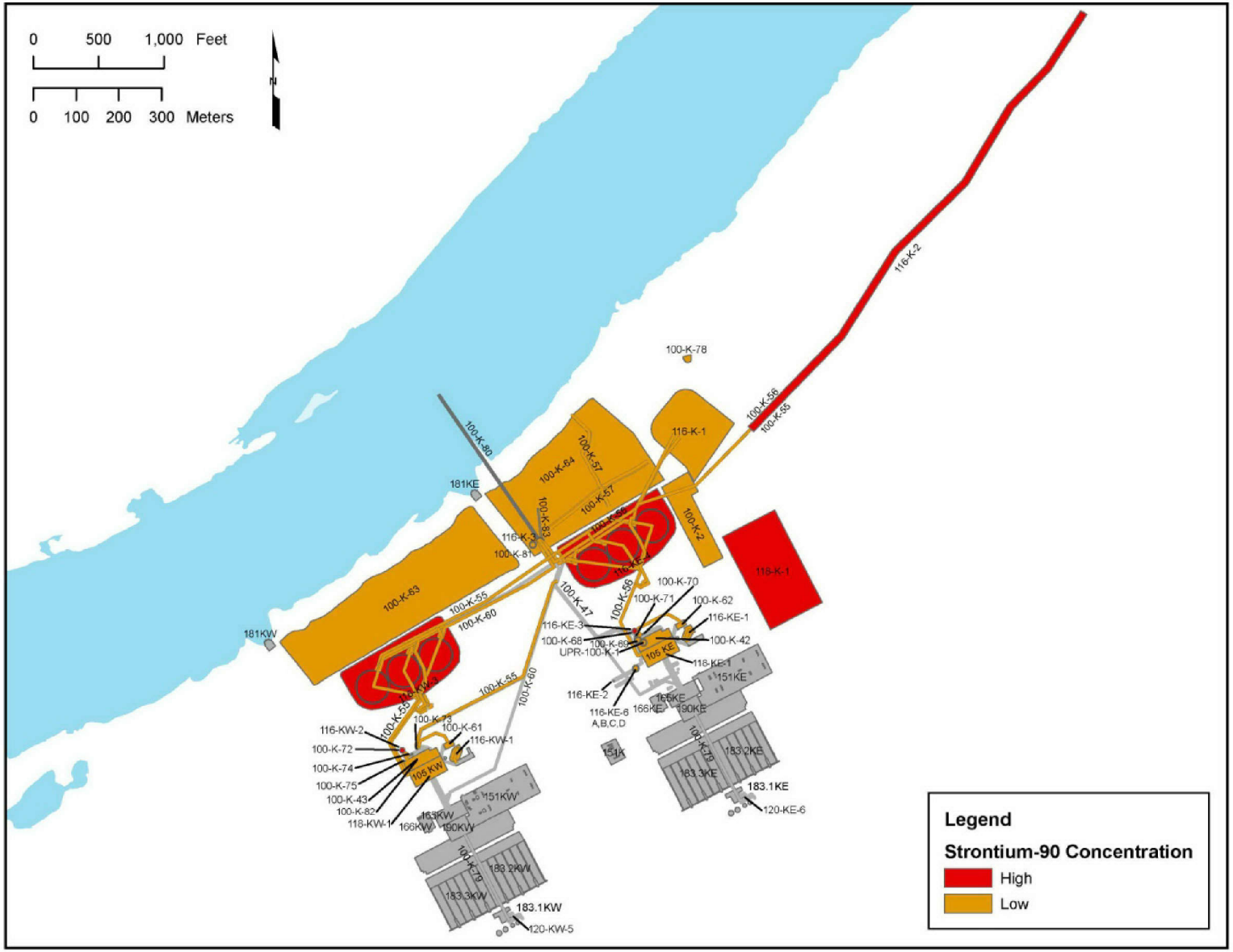


Figure 1-15. Facilities and Waste Sites Known to Have Strontium-90 Present

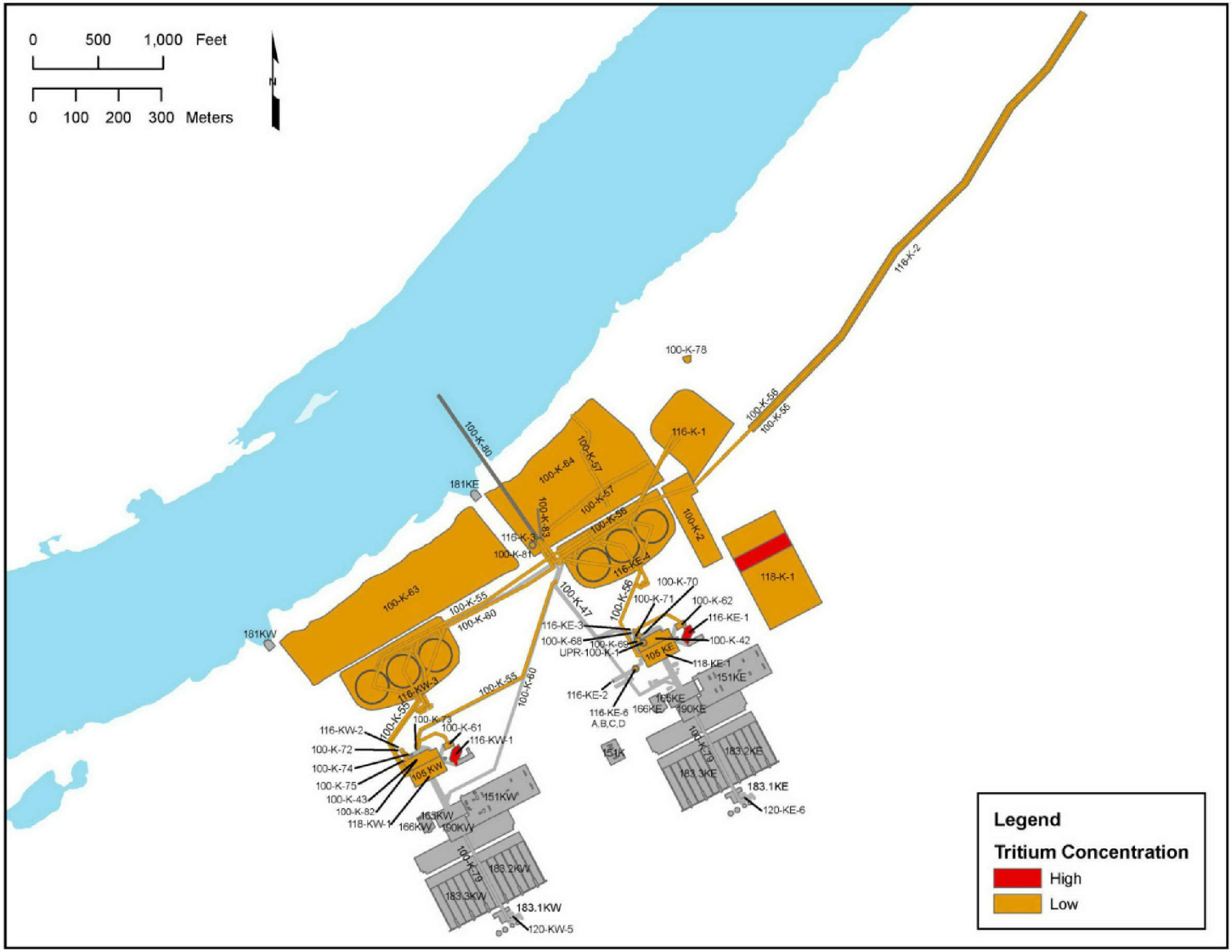


Figure 1-16. Facilities and Waste Sites Known to Have Tritium Present

Figure 1-17. Track-Mounted Probe Surveying Radioactive Materials at the 118-K-1 Burial Ground

1.2.2.8 Nonradioactive Wastes

Nonradioactive wastes generated at 100-K had the potential to contribute to vadose zone and groundwater contamination, and included septic system wastes, a variety of other liquid wastes, and solid wastes.

Sanitary liquid wastes (primarily detergents, cleaning compounds, and solvents) were routed by sewer lines to at least six known septic systems in 100-K. There are no records of radiological wastes being disposed to these systems, but leaks in the sewer lines transferring these materials may have occurred and may have contributed to discharges of contaminants to the vadose zone, particularly petroleum hydrocarbons and trichloroethylene. All six sanitary systems (1607-K1, 1607-K2, 1607-K3, 1607-K4, 1607-K5, and 1607-K6) were located in the 100-KR-2 OU and consisted of reinforced concrete septic tanks with associated drain fields.

Discharges of nonradioactive liquid wastes occurred at various buildings, and included the following hazardous substances:

- Water treatment chemicals (such as alum, sulfuric acid, chlorine, and sodium dichromate) used and stored near the 183-KE and 183-KW Buildings.
- Wet-type electrical transformers and hydraulic machinery containing oil contaminated with polychlorinated biphenyls (PCBs).
- Boiler water treatment chemicals for the 165-KE and 165-KW Power Houses (for example, sodium sulfate, tri-sodium phosphate, and dichromates) that ended up in boiler sludge. The volume of boiler sludge generated and the disposal methods are not known.

- Zeolite water softener regeneration solutions containing salt from the 165 and 183-H Power Houses. Sodium chloride solutions were used to regenerate the zeolite ion exchange (IX) beds in the water softener tanks. Disposal methods are unknown, but process knowledge suggests that these wastes (zeolite water and sodium chloride) most likely were discharged to the area process sewer.
- Diesel fuel stored in underground tanks at the 166-KE/KW Fuel Bunkers adjacent to the 165-KE/KW Power Stations, north of the 182-KE/KW Building (130 K-3A and 130-K-3B), east of the 105-KE Reactor (130-KE-1A and 130-KE-1B), and east of the 105-KW Building (130-KW-1A and 130-KW-1B).
- Gasoline fuel stored in an underground tank northwest of the 1717-K Building (130-K-1).
- Waste oil stored in an underground tank northwest of the 1717-K Building (130-K-2).
- Oil stored in underground tanks south of the 166-KE Building (130-KE-2) and 166-KW Building (130-KW-2).
- Demineralizer regeneration, research, and development wastes from the 1706-KER Building were routinely disposed in the 116-KE-2 Crib.
- Diesel and batteries for the Ball 3X systems. The diesel storage tank was located on the east side of the reactor buildings.
- Oils, paints, and solvents used and stored in the 1706-KE, 1717-K, 190-KE, 190-KW, 1713-KE, and 1713-KW Buildings.
- Herbicides were used throughout 100-K and, in the 1970s, ground and aerial applications of herbicides and ground sterilants were employed.

Nonradioactive solid waste also included miscellaneous materials such as paper, trash, pieces of metal, and plastic parts. The 128-K-1 Burn Pit is a site where combustible wastes were burned and their residue (e.g., ash and incompletely combusted materials) disposed. Other solid wastes consisted of uncontaminated concrete, metal parts, and other materials generated during decommissioning and demolition activities.

Sludge disposal from water treatment facilities, in particular, sulfuric acid sludge from the bottom of the concentrated sulfuric acid storage tanks that was periodically drained to the nearby neutralization pit (100-K-34), is of notable concern. This type of sludge was also drained to French drains and percolation trenches adjacent to the 183-KE and 183-KW Buildings. In 1971, about 5,443 kg (12,000 lb) of sulfuric acid sludge was removed from percolation trenches. Analysis indicated that approximately 14 percent of the sludge weight consisted of mercury, an impurity in the sulfuric acid purchased at the time (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]).

1.2.3 Previous and Ongoing Investigations and Remediation

Considerable environmental investigation and remediation activities have been completed at 100-K. Since the beginning of reactor operations, investigations were conducted to determine impacts to the environment, including the Columbia River. With the issuance of the Tri-Party Agreement in 1989 (Ecology, et al., 1989a), activities transitioned to cleanup activities, which have been ongoing continuously under CERCLA to determine how best to protect human health and the environment within the River Corridor. These overall River Corridor activities supplement specific activities that continued to be conducted at 100-K.

These interim investigation and remediation activities have occurred and are ongoing for facilities, vadose and waste sites, and groundwater. This subsection summarizes the most relevant investigation and remediation activities that have been performed and are occurring at 100-K. Investigations and remediation

activities were carried out pursuant to various remedial and removal action decision documents for facilities, vadose and waste sites, and groundwater, shown in Figures 1-18, 1-19, and 1-20, respectively.

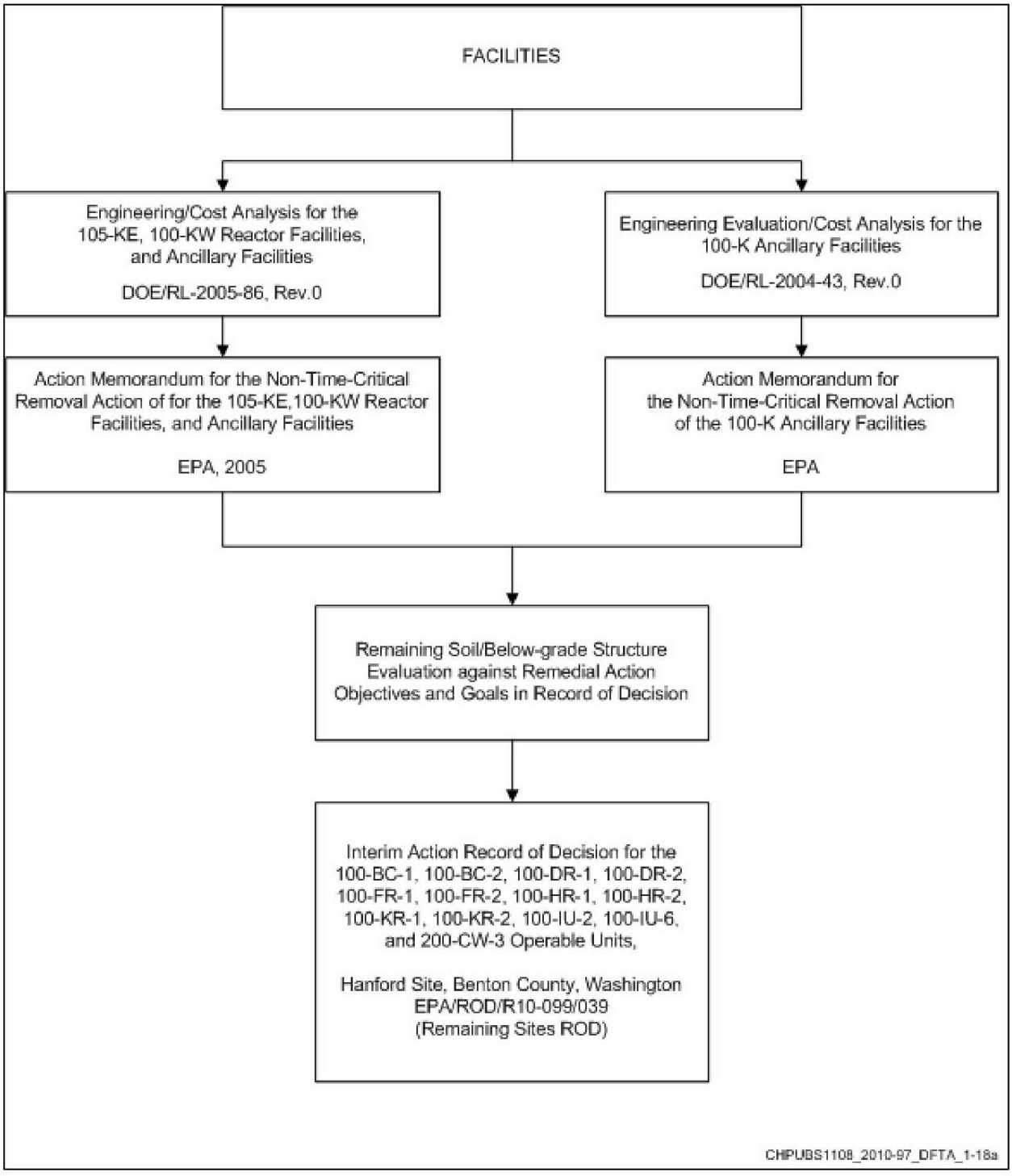


Figure 1-18. CERCLA Decision Document Flow for Facilities

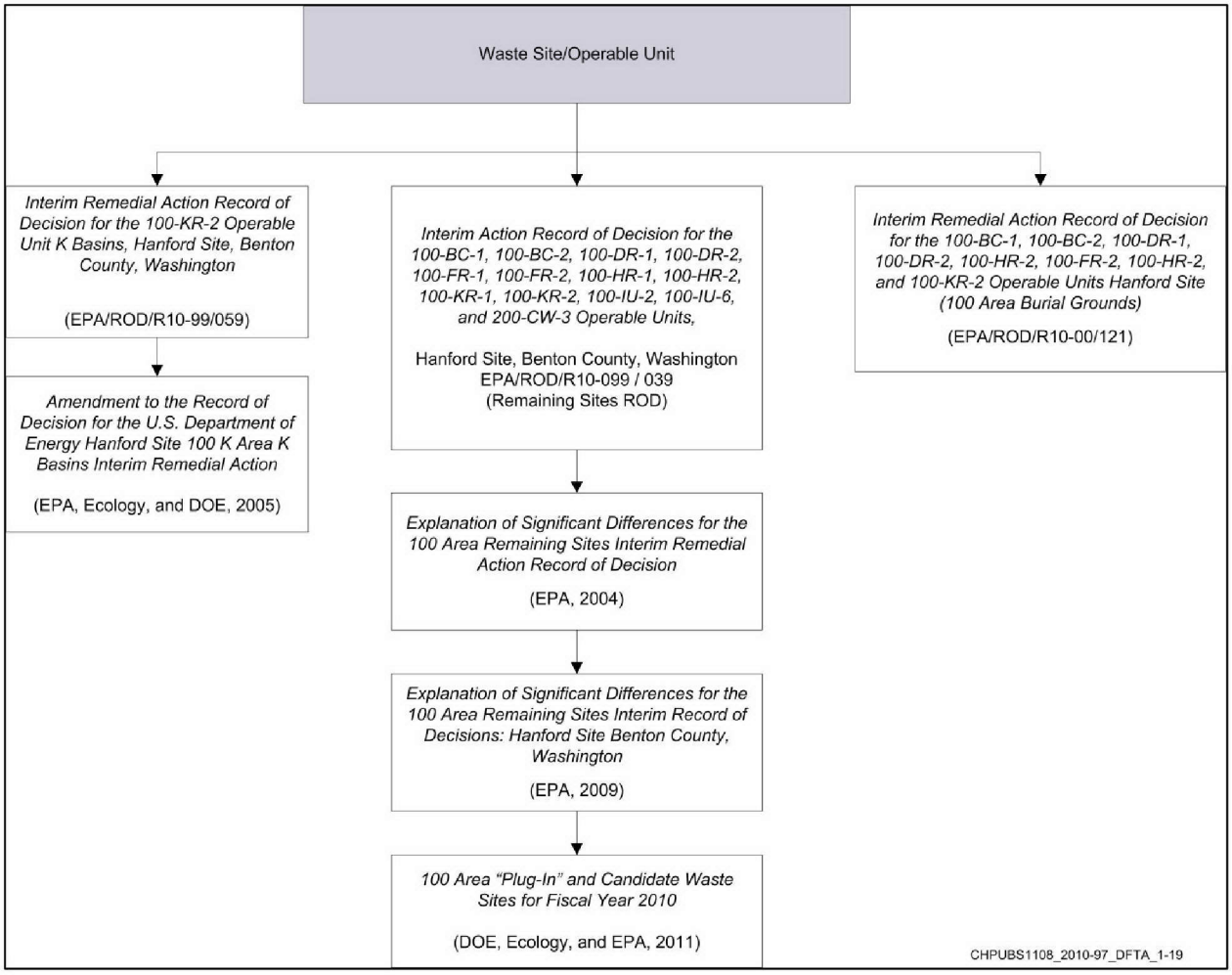


Figure 1-19. CERCLA Decision Document Flow for Vadose/Waste Site

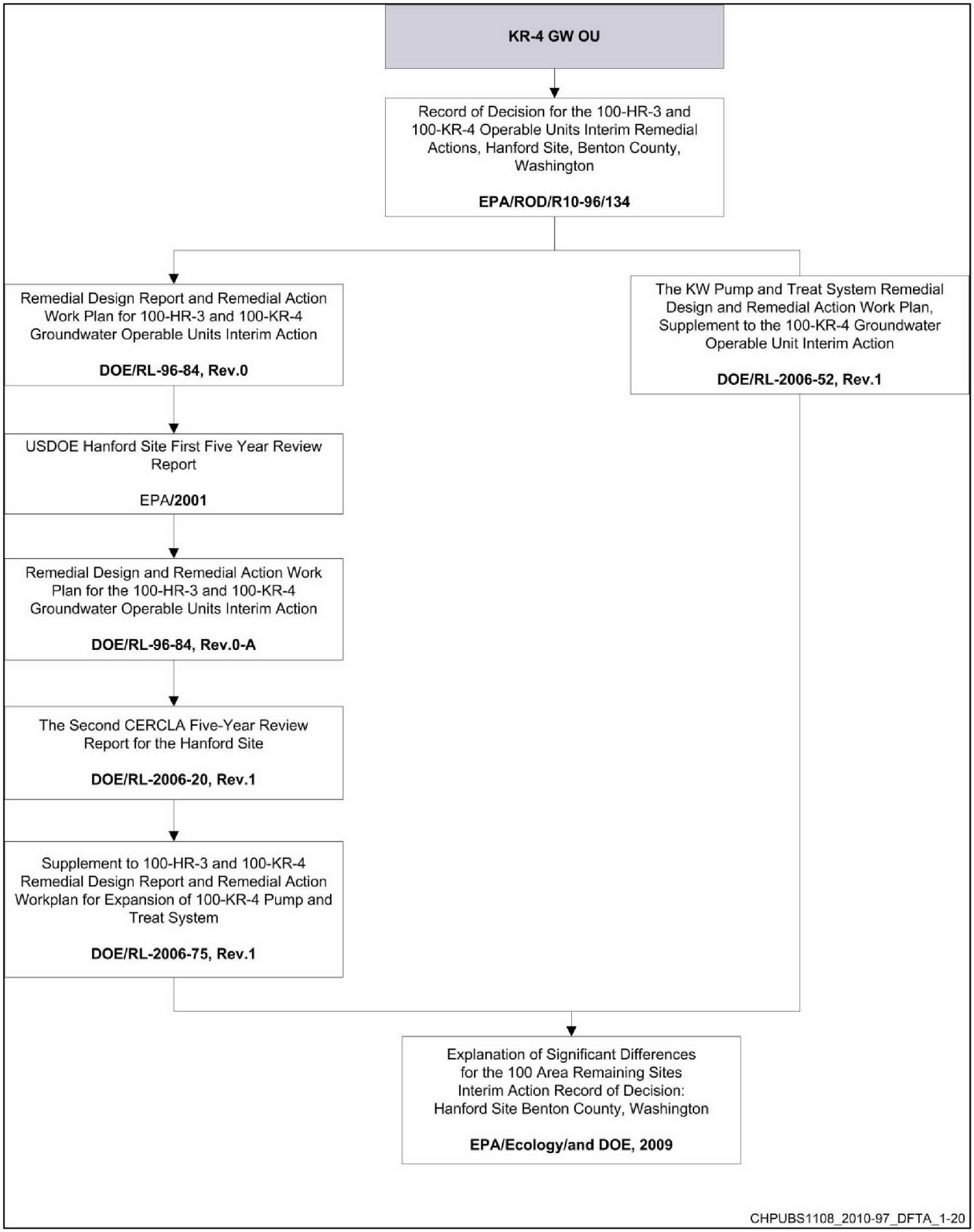


Figure 1-20. CERCLA Decision Document Flow for Groundwater

The various 100-K decision documents are summarized in Table 1-2. Appendix B presents an annotated bibliography of CERCLA documentation for the River Corridor.

Table 1-2. Summary of Decision Documents for 100-K

Decision Document	Summary
Reactors and Facilities	
EPA, 2007a, *Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities*	Calls for decontamination and demolition of the contaminated reactor buildings (except for the reactor blocks) and ancillary facilities, and disposal of the waste. Calls for interim safe storage enclosure over reactor blocks.
EPA, 2005, *Action Memorandum for the Non-Time-Critical Removal Action for the 100-K Area Ancillary Facilities*	Calls for the demolition and disposal of 27 100-K facilities.
Source Operable Units	
EPA/ROD/R10-99/039, *Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units, Hanford Site, Benton County, Washington (100 Area Remaining Sites)*	Removal, treatment, and disposal of contaminated soil, structures, and debris for sites where sufficient information exists; plug-in approach for sites with limited information that meet the waste site profile; disposal of equipment and debris from B, D, H, KE, and KW Reactor buildings consistent with previous CERCLA disposal for areas associated with the C, F, and DR Reactor buildings.
EPA/ROD/R10-99/059, *Interim Remedial Action Record of Decision for the 100-KR-2 Operable Unit K Basins, Hanford Site, Benton County, Washington*	Selected the interim remedial action to mitigate the potential to release hazardous substances from the two 100-K FSB.
EPA et al., 2005, *Amendment to the Record of Decision for the U.S. Department of Energy Hanford Site 100 K Area K Basins Interim Remedial Action* - Sludge and portion of the debris in the bottom of the K Basins	The 2005 ROD Amendment for the K Basins changes the sludge disposition and how underwater debris is retrieved, treated, and disposed from both the 105-K East and West Spent Nuclear Fuel Basins. The ROD amendment requires the sludge be treated and packaged for disposal, and shipped off Hanford to a national repository.
EPA/ROD/R10-00/121, *Interim Remedial Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2, and 100-KR-2 Operable Units (100 Area Burial Grounds), Benton County, Washington*	Selected remedies include remove contaminated soil, structures, and associated debris; treat these wastes as required to meet disposal facility requirements; dispose of contaminated materials at the ERDF; and backfill excavated areas with clean material, followed by revegetation.

Table 1-2. Summary of Decision Documents for 100-K

Decision Document	Summary
EPA et al., 2004, *Explanation of Significant Differences for the 100 Area Remaining Sites Interim Remedial Action Record of Decision* (100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6 and 200-CW-3 Operable Units)	This ESD added 28 waste sites. It also added "Compliance with Floodplain and Wetland Environmental Review Requirements" (10 CFR 1022) and "Procedures for Implementing the National Environmental Policy Act and Assessing the Environmental Effects Abroad of EPA Actions" (40 CFR 6, Subpart A—General Provisions for EPA Actions Subject to NEPA), as ARARs. Revised the annual institutional controls report submittal date to be consistent with the requirements contained in the Hanford sitewide institutional controls report, titled *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41).
EPA et al., 2009, *Explanation of Significant Differences for the 100 Area Remaining Sites Interim Record of Decision: Hanford Site Benton County, Washington* (100 Areas and 200-CW-3 Operable Units [100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units])	This ESD added additional waste sites that will be remediated under the interim ROD.
DOE et al., 2011, *100 Area "Plug-In" and Candidate Waste Sites for Fiscal Year 2010*	Annual listing of waste sites plugged into the remove, treat, and dispose remedy in the 1999 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039).
Groundwater Operable Units	
EPA/ROD/R10-96/134, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington*	Initiates the use of IX technology to remove Cr(VI) from groundwater using a system of extraction and injection wells.
EPA et al., 2009, *Explanation of Significant Differences for the 100-HR-3 and 100-KR-4 Operable Units Interim Action Record of Decision: Hanford Site Benton County, Washington*	The ESD was issued to update costs for the pump-and-treat remedial actions at 100-HR-3 and 100-KR-4 and the need to alter re-injection locations.

Note: Status as of May 2011.

Effectiveness of the above interim actions is evaluated through the CERCLA five-year review process. This review determines whether the selected remedy(ies) remain protective of human health and the environment. Since the issuance of the first interim ROD, there have been two five-year reviews for the 100 Area NPL Site. *The Second CERCLA Five-Year Review Report for the Hanford Site* (DOE/RL-2006-20) listed three issues and recommended four actions:

- **Issue 3.** The southeastern (inland) extent of the chromium groundwater plume from the 116-K-2 Trench, northeast of the current injection wells, has not been delineated.

- **Action 3-1.** Install three additional wells to further delineate the southeastern (inland) extent of the chromium groundwater plume from the 116-K-2 Trench, northeast of the current injection wells. Wells installed as part of the pump-and-treat system expansion or injection well relocation may count toward this effort if appropriately located. Wells 199-K-153, 199-K-154, and 199-K-163 were drilled in November 2008. This completed the required action.

- **Issue 4.** The small chromium plume at KW Reactor site has reached the Columbia River, as evidenced by nearshore aquifer tubes. There is currently no active remediation system in place for the small chromium plume at the KE/KW Reactor site.

  - **Action 4-1.** Implement the existing remedial action decision (pump-and-treat) at this location. An ion exchange (IX) pump-and-treat system (capacity of 379 L/min) constructed at the KW Reactor began operations in January 2007. This completed the required action. (Note that the KW system was expanded to a treatment capacity of 757 L/min in 2008 and 2009, and the expanded system became operational in April 2009.)

- **Issue 5.** Groundwater monitoring indicates that the expansion of 100-K pump-and-treat extraction system has not yet achieved the remedial action objective.

  - **Action 5−1.** Expand the 100-K pump-and-treat system by 378.5 L/min to enhance remediation of the chromium plume between the 116-K-2 Trench and the N Reactor perimeter fence. The KX IX pump-and-treat system (capacity of 2,271 L/min) began operation in February 2009 and reached full operating capacity by May 2009. This completed the required action.

  - **Action 5−2.** Add wells between the 116-K-2 Trench and the N Reactor perimeter fence for groundwater extraction and connect the additional wells to the pump-and-treat system. Wells 199-K-148, 199-K-149, and 199-K-150 were drilled in late 2007 and early 2008 and, along with existing Wells 199-K-130 and 199-K-131, were converted to extraction wells, and connected to the KX treatment system. This completed the required action.

Historical investigations and remediation activities carried out pursuant to these interim decision documents have been summarized in numerous documents. The relevant data and conclusions from these investigations and remediation activities form the basis for information analyzed and evaluated in this final RI/FS. Following are the various data sets used for evaluations in the remaining chapters of the RI/FS:

- Vadose zone contaminants
- Groundwater contaminants
- Geologic contact information, fate and transport parameters (for example, distribution coefficient [K_d] dispersivity, hydraulic conductivity, and soil bulk density)
- Well and borehole information (e.g., drill depth, screen length, and screen depth)
- Groundwater elevations and river stage
- Geographic information system shape files (e.g., aerial photography, Columbia River, and locations of wells and boreholes, salmon redds, facilities, roads, and waste sites)

Analytical data used in this RI/FS Report (provided in Appendix D) include the data reduction protocols and quality assurance reports.

Summaries of facility demolition activities, vadose zone investigation and remedial activities, and groundwater investigation and remedial activities are provided below. Information on previous risk assessments that influence 100-K activities are described as well.

1.2.3.1 Previous Facility Demolition Activities

Since its original construction, 100-K has included 111 facilities, including two reactors, storage buildings, offices, retention basins, maintenance shops, process plants, an electric substation, storage tanks, pump stations, and outfall structures. Many of these structures cover source waste sites. Until the structures over a source site have been removed, no vadose zone remediation can be completed. Therefore, the facilities[1] (including contaminated pipelines associated with them) are and have been undergoing removal to clear the way for the remedial work that focuses on contamination in the vadose zone.

105-KE and 105-KW Reactors. As stated in the 1993 NEPA ROD (58 FR 48509), DOE regards the safe storage of the reactors followed by deferred dismantlement, safe storage followed by one-piece removal, and immediate one-piece removal alternatives as equally favorable based solely on the evaluation of environmental impacts. DOE uses the CERCLA process to decommission and dismantle reactors based on the joint EPA/DOE policy on decommissioning signed in 1995 and incorporated into the TPA. Since the NEPA ROD (58 FR 48509) in 1993, documentation has been prepared and implemented under CERCLA, resulting in placement of five of the eight surplus reactors (C, D, DR, F, and H) into interim safe storage (ISS) designed to prevent deterioration and release of contamination from the reactors for up to 75 years.

DOE has decided to broaden the decommissioning approach for these eight surplus reactors including 105-KE and 105-KW Reactors. DOE is retaining the deferred one-piece removal option, as selected in the 1993 ROD and, based on a recently prepared Supplement Analysis, is modifying the deferred dismantlement option, as expressed in the Final EIS, by selecting an option for immediate dismantlement. The "Amended Record of Decision for the Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, WA" (75 FR 43158), issued on July 23, 2010, documents this decision on broadening the decommissioning approach. Activities to implement this decision will be conducted as CERCLA non-time critical removal actions. Specific details on unit operations of dismantlement will be addressed in the CERCLA documentation. All practicable means to avoid or minimize environmental harm have been incorporated in this decision.

DOE evaluated the coordination of the final decommissioning actions with the completion of remaining actions in 100-K, including remedial alternatives for waste sites in proximity to the reactors (i.e., waste sites that underlie or are so close to the reactors that they cannot be remediated by removal, treatment, and disposal [RTD] prior to final reactor decommissioning). Waste sites that cannot be remediated because of their location near reactors will be capped and/or safely contained until they can be accessed after the reactors have been dispositioned. Until reactor removal is complete, DOE will continue to conduct routine maintenance, surveillance, and radiological monitoring activities to ensure continued protection of human health and the environment during the interim storage period. Actions needed to address potential environmental releases associated with reactor footprints before the reactors are removed will be specified in the proposed plan and subsequent ROD based on this feasibility study analysis and public input.

[1] "Facility" is defined here as a freestanding building, plant, laboratory, or other enclosure or associated building that fulfills, or fulfilled a specific purpose and is owned by or otherwise under the responsibility of DOE. This usage differs substantially from that contained in CERCLA or RCRA.

100-K Fuels Storage Basins—Spent Fuel Removal and Cleanup. Spent nuclear fuel that had been stored in the 100-K Fuel Storage Basins for over 20 years has been removed. Currently, an inspection of the basin floor and pits is being conducted to identify any fuel fragments mixed in with the sludge and debris. The K Basins Interim Remedial Action includes removal of all spent nuclear fuel, sludge, debris, water, and deactivation of the basin to achieve established end point criteria (*End Point Criteria for the K Basins Interim Remedial Action* [HNF-20632]).

The 100-KR-2 OU ROD (EPA/ROD/R10-99/059) directed that sludge be removed from the basins and placed in storage pending future treatment where the storage and treatment of the sludge were outside the scope of this interim remedial action. The 100-KR-2 OU ROD Amendment expanded the scope of the ROD by eliminating the need for extended storage of the untreated sludge and requiring that the sludge be treated and packaged for disposal; interim stored pending shipment, and shipped to a national repository for disposal. The 100-KR-2 OU ROD (EPA/ROD/R10-99/059) directed that debris be removed, treated as required, and disposed onsite to ERDF, as appropriate. The 100-KR-2 OU ROD (EPA/ROD/R10-99/059) did not specify the details of debris retrieval; however, the anticipated process was to be an item-by-item removal with any treatment to be completed outside the basin. The 100-KR-2 OU ROD Amendment expanded the scope of the ROD by allowing some of the debris to remain in the basins and be encased in grout, and removed as part of the demolition and removal of the basin structure. Deactivation of the basin has not yet been initiated. Institutional controls are in place to restrict access and prevent public access until the final remedial action is completed.

Implementation of these provisions in the 100-K ROD Amendment is currently in progress. Treatment and removal of water from the 105-KE Basin was initiated in 2004 and has been completed. The remaining sludge in 105-KE Basin was transferred to 105-KW Basin. The 105-KE Basin was demolished and disposed in ERDF and soil remediation at the basin location is underway. Remedial activities have begun to support sludge removal and the eventual decontamination and demolition of the 105-KW Basins. Sludge removal from 105-KW Basin is expected to be completed by the end of 2015.

The emptied and deactivated basins resulting from this remedial action have and will be remediated under the 1999 ROD (EPA/ROD/R10-00/121, *Interim Remedial Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2, and 100-KR-2 Operable Units, Hanford Site [100 Area Burial Grounds], Benton County, Washington*) for remaining sites. Deactivation, demolition, and removal of the 105-KW FSB is expected to be completed in September 2019.

100-K Facilities—Deactivation, Decontamination, Decommissioning, and Demolition. Following the deactivation of the 105-KE and 105-KW Reactors in 1970 and 1971, respectively, many 100-K facilities have remained active due to the long-term storage of spent nuclear fuel in the 105-K Basins. Numerous 100-K facilities also provide ancillary support to 100-N operations, and the 100-KR-4 groundwater pump-and-treat system requires the use of several 100-K buildings to support the treatment centers associated with the system. Because of these ongoing activities, only 39 of 111 total facilities have been demolished or removed.

Of the remaining structures, the principal structures include the two 100-K Reactors, parts of the water treatment infrastructure, and multiple support buildings such as the 183-1-KE Head House, 165-KE Control and Power Backup, 190 Cooling Water Building, sedimentation basins, and ancillary buildings located adjacent to the reactors. Figures 1-21 and 1-22 show the 105-K East Fuel Storage Basin demolition progress. While most of these structure are planned to be removed, the two reactor buildings, 105-KE and 105-KW, will be place in safe storage up to 75 years before a remediation decision is implemented (Section 1.2.4 provides further information). Table 1-3 identifies 100-K facilities that have been removed and are pending demolition.

Table 1-3. Status of 100-K Facilities

Status	Facility
Removed	107-KE, 107-KW, 150-KE, 150-KW, 1702-KE, 1702-KW, 118-KW-2, 183-KW, 183.1-KW, 183.2-KW, 183.3-KW, 183.5-KW, 183.6-KW, 183.7-KW, 110-KE, 115-KE, 117-KE, 118-KE-2, 119-KE, 1713-KE, 1714-KE, 1724-KB, 183-KE, 185-K, MO-048, MO-054, MO-101, MO-102, MO-236, MO-237, MO-323, MO-392, MO-401, MO-402, MO-907, MO-928, MO-969, MO-286, MO-214
Pending demolition	1701-KA, 1704-K, 1733-K, MO-205-K, MO-420, MO-474-K, MO-495, MO-767-K, MO-827-K, MO-854, 110-KW, 115-KW, 116-KW, 117-KW, 119-KW, 166-KW, 183.4-KW, 190-KW, 116-KE, 166-KE, 182-K, 1614-KE, 1701-K, 1720-K, 1909-K, 105-KE, 105-KW, 142-K, 142-KA, 1506-K1, 151-K, 151-KE, 151-KW, 1605-K, 165-KE, 165-KW, 166A-KE, 166A-KW, 167-K/167-KE, 1705-KE, 1706-KE, 1706-KEL, 1706-KER, 1713-KER, 1713-KW, 1714-KW, 1717-AKE, 1717-K, 1724-K, 1724-KA, 181-KE, 181-KW, 183.1-KE, 183.2-KE, 183.3-KE, 183.4-KE, 183.5-KE, 183.6-KE, 183.7-KE, 1908-KE, 190-KE, 296-K-105, 296-K-142, MO-060, MO-293, MO-442, MO-495, MO-500, MO-506, MO-507, MO-917, MO-955

Note: Status as of May 2011.

Future 100-K D4 activities will focus on the remaining structures and ISS actions for the 105-KE and 105-KW Reactors.

Figure 1-21. 100-KE Reactor before 105-K East Fuel Storage Basin Demolition

Figure 1-22. Workers Demolishing the 105-KE Fuel Storage Basin (March 2011)

100-K River Effluent Pipeline Investigations. During operations, water used in fuel production to cool the reactors was discharged to the Columbia River via effluent pipelines. The release of this cooling water ended when the associated reactors and facilities were shut down. Today, the two inactive 100-K effluent pipelines remain in their original locations in the Columbia River channel. Past characterization efforts obtained samples of the river effluent pipelines from the 105-B, 105-C, 105-D, 105-DR, and 105-F Reactors. Characterization data collected during the river pipeline evaluations were used to evaluate risks from contaminants within the pipelines and to propose remedial action alternatives.

In 1984, the *River Discharge Lines Characterization Report* (UNI-3262) discussed samples of scale (flakes of mostly rust) from the interior surfaces and enclosed sediment of the effluent pipelines from the 105-C, 105-DR, and 105-F Reactors. The pipelines were also visually inspected underwater by a diver, and their positions and physical conditions were assessed. Samples of scale and sediment were analyzed for radionuclides. The major radionuclides detected included cobalt-60, cesium-137, europium-152, europium-154, and europium-155. Radionuclide concentrations were greater in the scale than in the sediment. Direct beta-gamma radiation measurements were also obtained for interior and exterior pipe surfaces. The dose rates measured for direct contact with the interior of the pipe surfaces were less than 1 mrem/hr, and readings on the exterior were below the instrument's detection capability.

In 1994, a comprehensive geophysical survey (*Columbia River Effluent Pipeline Survey* [WHC-SD-EN-TI-278]) located and mapped the reactor effluent pipelines. The study relied mainly on remote sensing geophysical techniques, including navigation and echo sounding, side scanning radar, sub-bottom profiling, seismic reflection profiling, and ground penetrating radar. The results indicated that

the pipelines have neither broken loose nor moved from their original locations. However, portions of some pipelines are no longer buried.

In 1995, pipe scale and sediment from the interior of the effluent pipelines from 100-B and 100-D were sampled and physically characterized using a robotic transporter (*100 Area River Effluent Pipelines Characterization Report* [BHI-00538]). Analytical data from these two pipelines were intended to complement the 1984 radionuclide data (*River Discharge Lines Characterization Report* [UNI-3262]) and were expected to represent "worst case" conditions with respect to radiological contamination. This assumption was based on the long years of pipeline service and the volume of effluent known to have been discharged from the 105-B and 105-D/DR Reactors. The samples taken in 1995 were analyzed for a larger number of radionuclides than in the 1984 study and were analyzed for metals and total organic carbon. In most cases, when the results of all radionuclide analyses are decayed to 2005, the concentrations of the samples taken in 1995 are lower than 1984 concentrations. Most metals were at concentrations below the analytical detection limits. However, the concentrations of total chromium and mercury were above detection limits.

The analytical results from the 1984 and 1995 effluent pipeline characterization studies at the 105-B, 105-C, 105-D/DR, and 105-F Reactors may reasonably be extrapolated to effluent pipelines in 100-K because operations among these reactors were similar. Evaluations of human health and ecological risk have been performed for the river effluent pipelines, as they are today, located on or beneath the river channel bottom, and for a scenario in which a pipeline section breaks away from the main pipeline and is washed onto the shore of the river. Both the 1996 risk assessment effort (BHI-00538) and the 1998 risk assessment effort (*100 Area River Effluent Pipelines Risk Assessment* [BHI-01141]) relied on data collected from the 1984 and 1995 characterization work. The evaluation of human health and ecological risk performed in 1998 (*100 Area River Effluent Pipelines Risk Assessment* [BHI-01141]), concluded that the concentrations of chromium and mercury in the scale and sediment within the pipelines pose minimal ecological risk because they have been in contact with river water without dissolving since the reactors were shut down in 1971. The 1998 risk evaluation results indicated pipelines present no unacceptable risks and, therefore, no remediation requirements under CERCLA. This is supported by the following:

- Minimal deteriorated condition of the pipelines
- Continued decrease of radionuclide concentrations due to decay
- Inaccessible location
- Unavailability of significant contaminants to affect human health or the environment

1.2.3.2 Previous Vadose and Waste Site Investigations and Remediation

The behavior of contaminants in the vadose zone has been an important consideration in Hanford plant operations since the 1940s. Some reports (e.g., *Underground Waste Disposal at Hanford Works: An Interim Report Covering the 200 West Area* [HW-9671]; *The Underground Disposal of Liquid Wastes at the Hanford Works, Washington* [HW-17088]) examined the issues related to waste disposal at injection wells, shallow burial cribs, and surface ponds. Groundwater monitoring via wells was undertaken in the late 1940s to evaluate the rate of migration through the vadose zone and in the aquifer. Although most attention was focused on radionuclides, primarily within the 200 Area, groundwater monitoring around the 107-F Waste Disposal Trench and the 108-B Crib was reported for some chemicals. Waste sites (116-KE-2 and possibly 116-KE-3 and 116-KW-2) were sometimes designed with wells that would permit geophysical logging to assess radionuclide movement through the aquifer. Continued waste site use was gauged against the vertical migration of contaminants, and was shut down when contamination reached certain concentrations in groundwater at these wells. As such, hydrologic and geochemical processes in the vadose zone were of interest, but were not well understood.

Vadose Zone Investigations. The vadose zone at the Hanford Site has been extensively studied since the 1980s. *Unsaturated Water Flow at the Hanford Site: A Review of Literature and Annotated Bibliography* (PNNL-5428) provided an overview of the status of vadose zone studies in 1985. By 1992, a significant amount of data had been collected from lysimeters at a wide range of sites at Hanford ("Variations in Recharge at the Hanford Site" [Gee et al., 1992]). This study categorized the recharge response for a variety of surface covers at Hanford for both soil type and vegetation cover. The most striking finding in this study was that recharge of 8.9 of the 16 cm (3.5 of the 6.3 in.) total annual precipitation was measured in vadose zone lysimeters with a clean gravel cover at the surface. In contrast, lysimeters under native vegetation showed no measurable recharge.

The post-remediation landscape at Hanford will largely be returned to a native vegetation cover, much as was present at the inception of the Manhattan Project. In the intervening years, a large acreage of devegetated surface at 100-K had much of the top soil scraped off (Figure 1-23). This implies a significant change in vadose zone dynamics with significant increase in vadose zone water flux since construction. Under native vegetation, the recharge flux would be expected to be zero or near zero. For a typical acre of disturbed ground experiencing 3 in. of recharge per year, an acre-foot would occur in four years, 10 ac ft in 40 years, such that since construction at 100-K approximately 60 years ago, many acres of this ground may have experienced on the order of 15 ac ft of drainage through the vadose zone to the water table solely as a result of the land use change. Locally, this value could be higher where buildings, tanks, and other structures divert precipitation to specified locations. In addition, significant volumes of water have been added to remediated acreage as part of the dust control program (a typical truck holds approximately 19,000 L [5,000 gal]), with 65 truckloads equaling an acre-foot). Once remediation is complete and native vegetation cover is reestablished, recharge flux will return to the near zero conditions prior to the Manhattan Project activities at Hanford.

Vadose zone radiological characterization started at 100-K in 1975 to evaluate radionuclide inventories, distribution, and concentrations at inactive solid and liquid waste sites, reactors, and associated facilities. In the early 1990s, LFIs were performed at 100-K to assess potential impacts associated with discharging effluent to the vadose zone at high priority waste sites. Several column leaching studies have also been performed to assess leaching of Cr(VI) from contaminated vadose zone material to groundwater. Several moisture characteristic curves have been calculated for 100-K, which are summarized in the 100-KR-4 Model Technical Memorandum (*100-KR-4 Remedial Process Optimization Modeling Data Package* [SGW-41213]). Due to the presence of Cr(VI) in the groundwater, Cr(VI) source identification investigations were performed at 100-K.

The majority of waste sites are geographically located proximate to decommissioned reactors along the Columbia River. The majority of the River Corridor area consists of land with little or no subsurface infrastructure or indication of past or present releases of hazardous constituent(s) between reactors and reaches toward the Hanford Site Central Plateau. This land is otherwise known as nonoperational areas. There is the potential for contaminant transport into the nonoperational areas through five credible mechanisms that were identified, including human disposal of materials, biological vectors (spread by animals), point source dispersal (blowing dust or vegetation from known waste sites [e.g., stack emissions]), wind dispersal, and overland flows.

Waste Site Remediation. Remediation and characterization of 100-K waste sites began in 2002 under the interim action ROD for the remaining 100 Area waste sites (100 Area Remaining Sites ROD [EPA/ROD/R10-99/039]), and will continue into the future until final remedies are selected and implemented. These interim remediation activities consist chiefly of RTD of vadose zone material, debris, and waste material, plus backfilling and revegetating the excavated area. Characterization of waste sites consists primarily of sample collection and analysis to assess the nature and extent of contamination and

verify achievement of interim remedial action objectives and remedial action goals for direct exposure, protection of groundwater, and protection of surface water.

Table 1-4 summarizes the remediation status of waste sites included in 100-K. A total of 163 sites have been identified within 100-K. These consist primarily of inactive waste sites described as trenches, ditches, cribs, ponds, French drains, burial grounds, and unplanned releases. Fifteen waste sites are within the 100-KR-1 OU (Table 1-5) and 148 waste sites are in the 100-KR-2 OU (Table 1-6).

Of the 163 waste sites, 50 have been reclassified as closed out, interim closed out, rejected, or not accepted (Table 1-4 footnotes define these terms). Only one waste site, the 1607-K4 Septic Tank, has been closed, and 21 waste sites have been remediated according to interim RODs. Tables 1-5 and 1-6 provide summary classification on waste sites in the 100-KR-1 and 100-KR-2 OUs, respectively, including the identification of Cr(VI) waste sites and orphan sites. Status descriptions are from WIDS.

Table 1-4. Summary Information on 100-K Waste Sites

Operable Unit	Total Number of Waste Sites[a]	Closed Out[b]	Interim Closed Out[c]	No Action[d]	Not Accepted[e]/ Rejected[f]	Accepted[g]	Discovery[h]
100-KR-1	15	0	4	0	0	11	0
100-KR-2	150	1	17	0	28	104	0
Total 100-K	165	1	21	0	28	115	0

Note: Status as of May 2011.

a. Total number of sites includes discovery and not accepted sites. Additional information provided in Appendix J.

b. **Closed Out**—A reclassification status indicating, due to actions taken, a waste management unit meets applicable cleanup standards or closure requirements State of Washington Septic Tank Regulations (1607-K4).

c. **Interim Closed Out**—A reclassification status indicating, due to actions taken, a waste management unit meets cleanup standards specified in an Interim Action ROD or Action Memorandum, but for which a Final ROD has not been issued. Further final actions may be necessary.

d. **No Action**—A reclassification status indicating a waste site does not require any further remedial action under RCRA Corrective Action, CERCLA, or other cleanup standards, based on an assessment of quantitative data collected for the waste site.

e. **Not Accepted**—A classification status indicating an assessment has been made that a WIDS site is not a waste management unit and is not within the scope of Tri-Party Agreement Action Plan (Ecology et al., 1989b).

f. **Rejected**—A reclassification status indicating a waste site does not require remediation under CERCLA, or other cleanup standards, based on qualitative information such as a review of historical records, photographs, drawings, walk downs, ground penetrating radar scans, and shallow test pits. Such investigations do not include quantitative measurements.

g. **Accepted**—A classification status indicating an assessment has been made that a WIDS site is a waste management unit as defined in the Tri-Party Agreement Action Plan (Ecology et al., 1989b).

h. **Discovery**—An initial classification status indicating evidence of a potential waste site; assessments not yet complete. This is the classification of a newly discovered WIDS site.

Table 1-5. Status of 100-KR-1 OU Waste Sites

Status	Waste Sites	Total
Closed Out	None	0
Interim Closed Out	116-K-1,* 116-K-2,* 166-KE-4,* 116-KW-3*	4
No Action	None	0
Not Accepted	None	0
Rejected	None	0
Accepted	100-K-100, 100-K-57, 100-K-63,* 100-K-64, 100-K-78, 100-K-80, 100-K-81, 100-K-83, 100-K-93, 100-K-99, 116-K-3*	11
Discovery	None	0

Note: Status as of May 2011.

* Sites may have received Cr(VI) waste stream.

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Table 1-6. Status of 100-KR-2 OU Waste Sites

Status	Waste Sites	Total
Closed Out	1607-K4	1
Interim Closed Out	100-K-29, 100-K-30, 100-K-31, 100-K-32, 100-K-33, 100-K-37, 100-K-38, 100-K-4, 100-K-55:1, 100-K-56:1, 116-KE-5, 116-KE-6A, 116-KE-6B, 116-KE-6C, 116-KE-6D, 116-KW-4, 128-K-1	17
No Action	None	0
Not Accepted	100-K-10, 100-K-11, 100-K-12, 100-K-15, 100-K-16, 100-K-20, 100-K-21, 100-K-22, 100-K-23, 100-K-24, 100-K-28, 100-K-39, 100-K-44, 100-K-52, 100-K-58, 100-K-59, 100-K-7, 100-K-76, 100-K-8, 100-K-9, 126-KE-3, 130-K-1, 130-K-3	23
Rejected	100-K-2, 100-K-51, 126-K-1, 600-4, 600-55	5
Accepted	100-K-1, 100-K-101, 100-K-102, 100-K-103, 100-K-104, 100-K-105, 100-K-106, 100-K-107, 100-K-108, 100-K-109, 100-K-13, 100-K-14, 100-K-18, 100-K-19, 100-K-25, 100-K-27, 100-K-3, 100-K-34, 100-K-35, 100-K-36, 100-K-42, 100-K-43, 100-K-46, 100-K-47, 100-K-48, 100-K-49, 100-K-5, 100-K-50, 100-K-53, 100-K-54, 100-K-55:2 (sub site), 100-K-56:2 (sub site), 100-K-6, 100-K-60, 100-K-61, 100-K-62, 100-K-66, 100-K-67, 100-K-68, 100-K-69, 100-K-70, 100-K-71, 100-K-72, 100-K-73, 100-K-74, 100-K-75, 100-K-77, 100-K-79,*	102 (104 including sub-sites)

Table 1-6. Status of 100-KR-2 OU Waste Sites

Status	Waste Sites	Total
	100-K-82,* 100-K-84, 100-K-85, 100-K-86, 100-K-87, 100-K-88, 100-K-89, 100-K-90, 100-K-91, 100-K-92, 100-K-94, 100-K-95, 100-K-97, 100-K-98, 100-K-110, 116-KE-1, 116-KE-2, 116-KE-3, 116-KW-1, 116-KW-2, 118-K-1, 118-KE-1, 118-KE-2, 118-KW-1, 118-KW-2, 120-KE-1, 120-KE-2, 120-KE-3, 120-KE-4,* 120-KE-5,* 120-KE-6,* 120-KE-8, 120-KE-9,* 120-KW-1,* 120-KW-2, 120-KW-3, 120-KW-4, 120-KW-5,* 120-KW-6, 120-KW-7,* 126-KE-2, 128-K-2, 130-K-2, 130-KE-1, 130-KE-2, 130-KW-1, 130-KW-2, 132-KE-1, 132-KW-1, 1607-K1, 1607-K2,* 1607-K3,* 1607-K5, 1607-K6, 600-29, UPR-100-K-1*	
Discovery		0

Note: Status as of May 2011.

* Sites may have received Cr(VI) waste.

The focus of waste site remediation was initially on former liquid effluent sites. Following the remedial action, the vadose zone material from each excavation was sampled, analyzed, and modeled (if needed) to assess the risks associated with residual contamination. Waste site sample result evaluations verified that the remediation objectives and goals were met, ensuring the protection of human health and the environment. A waste site is considered interim closed if the interim remedial action objective and goals are achieved. Subsequent interim remedial actions included solid waste burial grounds and miscellaneous waste sites. Figure 1-23 is a photograph showing excavation at 100-K.

One of the most significant interim waste site remediation achievements was the completion of the remediation of the 116-K-2 Process Trench in 2006, shown in Figure 1-24. This waste site was regarded as the most highly contaminated liquid waste disposal site in the 100 Area. It was the main liquid waste disposal site for 100-K and received a range of reactor effluents while operating from 1955 to 1971. It is estimated that about 2,100 Ci (nearly one-half of the radionuclide inventory of the 100 Area) and approximately 300,000 kg (about 661,000 lb) of sodium dichromate were discharged to this trench. In remediating the trench, an area roughly 7,845 m^2 (70,610 ft^2) was excavated, backfilled, and revegetated. The revegetation of backfilled, remediated waste sites is a very important factor in minimizing the potential for residual contamination migration from the vadose zone to the unconfined aquifer below the site.

Figure 1-23. Excavations in 100-K

Figure 1-24. 116-K-2 (Mile Long Trench)—Backfilled and Ready for Revegetation

Waste Site Cleanup Documentation. Following completion of the interim remedial actions at a waste site in accordance with the applicable interim action ROD, a cleanup document is prepared. This document contains verification information that the attainment of interim remedial action goals (RAGs) and interim RAOs have been achieved. These RAOs are contained in interim RODs that have been previously listed in Table 1-2. This documentation usually includes a description of the interim remedial action conducted, sampling results, disposal information, and a chronology of events.

The exposure factors and assumptions used in the rural residential scenario are defined in *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, hereinafter called 100 Area RDR/RAWP (DOE/RL-96-17). Soil interim RAGs for protection of groundwater also reflected unrestricted use and were intended to achieve state or federal drinking water standards. In addition, RAGs were developed to protect aquatic organisms in the Columbia River. However, RAGs were not developed for the protection of terrestrial ecological receptors due to the absence of regulatory guidance at that time. Cleanup verification packages currently consider "Model Toxics Control Act—Cleanup," (WAC 173-340) standards for terrestrial receptors.

Waste Site Consideration in the RI/FS. All 100-K waste sites were considered in this final RI/FS process to determine if the sites are protective of human health and the environment. While the unique factors of each site were considered individually, the consideration of waste sites can be described generally based on classification/reclassification status:

- Sites with a "closed out" status were reviewed to confirm that this determination has been made under appropriate regulatory authority. Where a closed out status was appropriate, no further review of site information was performed, and the site was not considered further within the RI/FS.

- Sites with a "rejected" or "not accepted" status were reviewed to determine whether new information was available that contradicts the existing documented basis for rejection or nonacceptance. Where the existing classification/reclassification was not found to be inappropriate, the site was not considered further within the RI/FS process. No rejected or not accepted sites at 100-K were found to have information that contradicted the existing determinations. The existing determinations are documented for each site in accordance with *Tri-Party Agreement Handbook Management Procedures,* Guideline Number TPA-MP-14, "Maintenance of the Waste Information Data System (WIDS)" (RL-TPA-90-0001).

- Sites with a "no action" or "interim closed out" reclassification status based on confirmatory and/or verification data are all considered within the overall RI and have been quantitatively evaluated against PRGs as described in Chapters 5 through 7. Sites with a no action or interim closed out reclassification with a basis other than direct data (for example, historical decommissioning data) were considered on a site-by-site basis.

- Sites with an "accepted" classification status fit within two broad general subcategories:

  - Sites where an interim remedial action requirement has been identified in interim decision documents, but for which interim remedial action had not been completed (via an approved waste site reclassification). These sites were considered within the RI from the standpoint that a remedial action determination has already been made. Because site-specific data were not yet available, these sites were carried into the FS.

  - Candidate sites under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) for which an interim remedial action determination has not yet been made. The 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) established a process whereby new and existing sites that did not have sufficient information to warrant either a remedial action determination or exclusion from

consideration as a waste site could be evaluated to make this determination. These sites are referred to as "candidate sites" or "confirmatory sites" under the interim action framework. The candidate process to add these waste sites will be retained under the final action ROD and these sites will continue to be dispositioned according to that process, including site-specific evaluation for protection of human health and the environment.

- Any new discovery sites that are identified as interim actions continue or under future final actions will also be addressed by an addition process established through the final action ROD, but functionally identical to that used under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039).

Waste Sites Requiring No Further Consideration at 100-K. Waste sites with a closed out, rejected, or not accepted classification/reclassification status were reconsidered to ensure there was sufficient existing basis for this determination. Those sites for which the existing basis was sufficient will not be addressed further in this RI/FS, and are identified in Table 1-7. In addition to these sites, some sites with other classification/reclassification statuses and site-specific factors will not be addressed further in this RI/FS process. These sites are also listed in Table 1-7, with additional explanation provided below. However, all waste sites identified in Appendix C of the *Hanford Federal Facility Agreement and Consent Order Action Plan*, hereinafter called the Tri-Party Agreement Action Plan or TPA Action Plan [Ecology et al., 1989b]) will be included in the ROD in order for final remedy decision to be documented, even if no further remedial activities are needed.

Table 1-7. Sites that Are Not Addressed Further in the RI/FS

Classification/ Reclassification Status	Waste Sites
Closed Out	1607-K4
Rejected	100-K-2, 100-K-51, 126-K-1, 600-4, 600-55
Not Accepted	100-K-10, 100-K-11, 100-K-12, 100-K-15, 100-K-16, 100-K-20, 100-K-21, 100-K-22, 100-K-23, 100-K-24, 100-K-28, 100-K-39, 100-K-44, 100-K-52, 100-K-58, 100-K-59, 100-K-7, 100-K-76, 100-K-8, 100-K-9, 126-KE-3, 130-K-1, 130-K-3
Interim Closed Out	100-K-37, 100-K-38, 116-KE-6A, 116-KE-6B, 116-KE-6C, 116-KE-6D

100-K-37 and 100-K-38. 100-K-37, the 1706-KE Sulfuric Acid Tank, and 100-K-38, the 1706-KE Caustic Soda Tank waste sites, were used from 1963 to 1971 to store chemicals needed to regenerate the IX columns in the 1706-KE water demineralization plant, which supplied demineralized water to the 105-KE Reactor. They were emptied of their remaining contents in the early 1990s. The tanks were designated as waste sites in the late 1990s.

Verification sampling was not required to demonstrate protectiveness for waste sites 100-K-37 and 100-K-38 since both tanks were located on the 1706-KE Building concrete slab and both tanks were tied to the 100-K-36 Waste Site dry well for discharge. The CERCLA removal action for the 1706-KE Building will address the underlying foundation authorized by the *Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities* (EPA, 2007a), *Removal Action Work Plan for the 100-K Area Ancillary Facilities* (DOE/RL-2005-26), and *100-K Area Interim Safe Storage and D4 Project Waste Sampling and Analysis*

Plan (DOE/RL-2005-33), and the remediation of 100-K-36 will address any vadose zone contamination. By removing the entire source of the hazardous substances (i.e., 100-K-37 and 100-K-38), protection of human health, and the environment have been achieved and these two waste sites will not be addressed further in the FS.

116-KE-6A, 116-KE-6B, 116-KE-6C, and 116-KE-6D. The 116-KE-6A, 116-KE-6B, 116-KE-6C, and 116-KE-6D Waste Sites were components that collectively comprised the 1706-KE IWTS RCRA temporary storage and disposal (TSD) unit, which was located in the basement of the 1706-KER Building. The individual components names and waste site identification numbers were 1706-KE Condensate Collection Tank (116-KE-6A), 1706-KE Evaporation Tank (116-KE-6B), 1706-KE Waste Accumulation Tank (116-KE-6C), and 1706-KE IX Column (116-KE-6D).

As documented in the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039), DOE-RL, EPA, and Ecology agreed to combine RCRA corrective actions and CERCLA remedial actions. The CERCLA process addresses hazardous substances, including radiological contaminants. RCRA closure of the WTS was completed in accordance with the approved closure plan (*Hanford Facility Dangerous Waste Closure/Postclosure Plan for the 1706-KE Waste Treatment System* [DOE/RL-2009-29]).

The action associated with the removal of these waste sites is focused on the equipment and associated debris. The remainder of the 1706-KER Building is being addressed under a CERCLA removal action authorized by EPA (*Action Memorandum for the Non-Time-Critical Removal Action for the 105-KE and 105-KW Reactor Facilities and Ancillary Facilities* [EPA, 2007a]), *Removal Action Work Plan for the 100-K Area Ancillary Facilities* (DOE/RL-2005-26), and *100-K Area Interim Safe Storage and D4 Project Waste Sampling and Analysis Plan* (DOE/RL-2005-33). By removing the entire source of the hazardous substances (i.e., 116-KE-6A, 116-KE-6B, 116-KE-6C, and 116-KE-6D), protection of human health and the environment have been achieved and these four waste sites will not be addressed further in the feasibility study.

Waste Sites that Need Further Consideration in RI/FS. Sites with an "accepted" classification status fit within two broad general subcategories:

- Sites where an interim remedial action requirement has been identified in interim decision documents, but for which interim remedial action had not been completed (via an approved waste site reclassification). These sites were considered within the RI from the standpoint that a remedial action determination has already been made. Because site-specific data were not yet available, these sites were carried into the FS.

- Candidate sites under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) are sites for which an interim remedial action determination has not yet been made. The Remaining Sites Interim Action ROD established a process whereby new and existing sites that did not have sufficient information to warrant either a remedial action determination or exclusion from consideration would be evaluated. These sites are referred to as "candidate sites" or "confirmatory sites" under the interim action framework. The candidate process to add these waste sites to the interim action ROD will be retained under the final action ROD. There sites will continue to be dispositioned according to that process, including site-specific evaluation for protection of human health and the environment.

- Existing sites with a "discovery" classification status have been addressed as candidate sites for which a determination has not yet been made, as described previously. Any new discovery sites that are identified as interim actions continue or under future final actions will also be addressed by an addition process established through the final action ROD, but functionally identical to that used under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039).

Nonoperational Area Evaluation. In 2011, an evaluation of the River Corridor nonoperational areas was completed. The nonoperational evaluation considered the five transport mechanisms, physical features, and climate conditions that could influence transport, and used surface and near surface information from a number of available sources:

- Orphan sites evaluations
- Air emissions reports
- Environmental monitoring programs
- Statistical modeling

Appendix K describes the nonoperational evaluation process for the River Corridor, data and information used, and conclusions and recommendations. It includes specific results and conclusions for the 100-K decision area.

Orphan Sites Evaluations. The orphan sites evaluations (OSEs) are an important component the nonoperational evaluation. The purpose of the nonoperational evaluation and the OSEs is to increase confidence that waste disposal or releases requiring characterization and cleanup within a given land parcel of the Hanford Site River Corridor have been identified. Key elements of the OSE include a comprehensive review of historical information and a field investigation. Results from these activities are reviewed with DOE-RL and the lead regulatory agency. Potential "orphan" sites are evaluated under the TPA-MP-14 discovery site process. The 100-K decision area was addressed by a combination of three separate OSE reports including all of the 100-K OSE, *100-K Area Orphan Sites Evaluation Report* (OSR-2008-0003), parts of Segment 1 OSE, *100-F/IU-2/IU-6 Area – Segment 1 Orphan Sites Evaluation Report* (OSR-2009-0002), and Segment 4 OSE, *100-F/IU-2/IU-6 Area – Segment 4 Orphan Sites Evaluation Report* (OSR-2011-0001)**.** Within the 100-K decision area, 22 orphan sites (new discovery sites) were identified through the OSEs and are addressed/evaluated in this report.

Air Emissions Reports. Two groups of sources of Hanford Site stack air emissions had the potential to impact the River Corridor by air deposition. The first source group, where most of the Hanford Site stack air emissions occurred between 1944 and 1972, were the facilities in the 200 Area that separated plutonium and uranium from irradiated reactor fuel. The second source group, the nine production nuclear reactors in the 100 Area, had stacks to exhaust ventilation air from the working areas of the reactor facilities. These were minor sources of emissions compared to the 200 Area facilities that separated plutonium and uranium from irradiated reactor fuel. There is no evidence that waste sites should exist in the River Corridor area, including 100-K, as a result of historical air emission deposition. Any hot spots existing in the River Corridor area as a result of historic stack emission deposition would have decayed or attenuated to negligible levels over the past 40 plus years since the majority of the air emissions occurred. Aerial radiation surveys of the Hanford Site and widespread sampling over many years support this conclusion (*An Aerial Radiological Survey of the Hanford Site and Surrounding Area, Richland, Washington* [EGG-10617-1062]).

Environmental Monitoring Programs. Data from ongoing monitoring programs were also used as described in Appendix K. A number of these programs are described in Chapter 2, starting in Sections 2.1.3 (Contaminate Source Investigations) and 2.1.10 (Ecological Investigations).

Statistical Modeling. Statistical modeling was used to support the data analyses and development of technical recommendations such as additional sampling for the nonoperational areas in the River Corridor. The process leveraged established approaches and data sets used in the Hanford Site Central Plateau and adapted to the River Corridor. In addition to the conceptual site models developed for the Central Plateau, the CSM for the River Corridor addressed potential for overland flow, impacts on riparian, and nearshore areas. Statistical analysis was used to represent the conceptual models and incorporate the available data to support a quantitative basis for the probability that a (undiscovered) waste site might exist in the nonoperational areas. As a result of these efforts, no additional waste sites were found in the nonoperational areas of 100-K that pose a threat to human health or the environment.

1.2.3.3 Previous Groundwater Investigations and Remediation

The behavior of waste liquids discharged to the vadose zone and contaminant migration in groundwater was important to operations and the environment. A number of wells were drilled around the 100-K Reactor area prior to or early in the operations of the two reactors (199-K-1 to 199-K-14 [UNI-946]). Many of these wells penetrated only into the vadose zone, and few of the original aquifer wells survive to the present. Other wells were added during operations downgradient of the 116-K-2 Trench. The emphasis was on detection of radionuclides (tritium), but by 1962, at least a few of the wells (e.g., 199-K-10, 199-K-11, 199-K-19, 199-K-20, and 199-K-21) were sampled for nitrate. During the 1970s, more than 50 borings were drilled around the 100-K Reactors and 100-K waste sites to support remediation planning (*Radiological Characterization of the Retired 100* [UNI-946]). Wells 199-K-32A through 199-K-37 were installed and sampled for radionuclides, anions, and cations, but Cr(VI) was not included in the sampling until 1996. A few wells were also drilled to support contamination monitoring at the KE and later the KW FSB when converted to storage of 100-N Reactor fuel rods. Two sets of four wells were drilled: Wells 199-K-27 to 199-K-30 in the late 1970s and Wells 19-K-106A to 199-K-111A in 1994.

Groundwater Investigations. Little additional drilling occurred in 100-K until the start of environmental characterization activities, when a series of wells was drilled around the 100-K Reactor areas. Broad lists of analytes were sampled for in both the new and existing wells. The results of this sampling led to a determination of Cr(VI) as a primary contaminant of concern. Only with the start of the KR-4 pump-and-treat system has additional drilling and sampling found greater extents of Cr(VI) in the aquifer.

Historical groundwater monitoring results for 100-K are presented in Chapter 4, and the locations of all 100-K groundwater monitoring wells are illustrated in Appendix A. Currently, groundwater monitoring wells in 100-K are routinely sampled for COPCs. Groundwater monitoring of specific wells is conducted every one to two years, depending on location. Groundwater data for 100-K are used to create maps and plots that illustrate groundwater flow, water table elevations, hydrogeochemistry, and contaminant concentration trends and distribution. The results have been published annually in Hanford Site Groundwater Monitoring Reports since 1980 (for example, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2* [DOE/RL-2010-11]) and are discussed in Chapter 4.

In 1959, W.H. Bierschenk (*Aquifer Characteristics and Ground-Water Movement at Hanford* [HW-60601]) described the general aquifer characteristics of the Hanford Site, including one of the first sitewide groundwater flow maps showing general directions and average rates of groundwater flow. Aquifer testing and aquifer properties were evaluated and summarized in this report. Hanford operations actively discharged a variety of water and liquid wastes to the surface at locations such as B Pond and Gable Mountain Pond in the 200 Area, as well as the 100 Area retention ponds and trenches. Groundwater mounds developed at these locations and impacted groundwater flow across much of the site, including at 100-K. Changes in the Hanford Site water table over the period from 1950 to 1980 were documented by Pacific Northwest Laboratory (now Pacific Northwest National Laboratory [PNNL]) in a 1986 report (*Hanford Site Water*

Table Changes 1950 Through 1980: Data Observations and Evaluation [PNL-5506]). This report described detailed water level changes at five-year intervals at a network of wells across the site.

In 1967, a test disposal of reactor coolant effluent to trenches was conducted for 100-F and 100-D, as well as proposed (but not performed) tests at 100-BC and 100-K (*Program Review—Ground Disposal of Reactor Effluent* [DUN-3259]). During the testing, discharges were conducted to the 116-F-14 and 116-DR-1&2 Trenches. Discharge rates to the respective waste sites were 30,280 to 60,560 L/min (8,000 to 16,000 gpm) at 100-F and 17,000 to 104,000 L/min (4,500 to 27,500 gpm) at the 100-D site. In the 1970s, concerns increased about radiological contamination of groundwater at Hanford and researchers began to investigate various groundwater issues, from the vertical distribution of radioactive contamination *Vertical Contamination in the Unconfined Groundwater at the Hanford Site, Washington* [(PNL-2724]) to general radiological groundwater contamination (*Radiological Status of the Ground Water Beneath the Hanford Site January—December 1980* [PNL-3768]). A very few wells at 100-K (Wells 199-K-11, 199-K-20, and 199-K-25) were sampled as far back as 1969 for Cr(VI), but most wells from that era have been abandoned with no record of contaminant concentrations. Above-nondetect concentrations of Cr(VI) from 5.3 to 17.5 µg/L were reported at Well 199-K-11, along with chromium concentrations ranging from nondetect to 34.3 µg/L. Well 199-K-20, which lies between the 116-K-2 Trench and the Columbia River, detected Cr(VI) at concentrations around 1 to 4 µg/L (11 sample events) to 64 µg/L (one sampling event) between 1969 and 1973. Data show that a few wells downgradient of the 116-K-2 Trench were being sampled as far back as 1962 for nitrate and tritium.

By the mid-1980s, routine sampling constituents began to include nonradiological constituents such as nitrate and chromium, but Cr(VI) was not regularly included until the early 1990s. Routine sampling for Cr(VI) began in the 1992 to 1996 time frame as part of the interim action ROD characterization. By 1988, it had become clear that action would be needed under either CERCLA or RCRA in the 100 Area. The initial study work plan was developed under the RCRA umbrella that was compatible with CERCLA (*Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington* [DOE/RL-90-21]). In 1993 to 1994, an LFI report (100-KR-4 LFI [DOE/RL-93-79]) was completed along with the qualitative risk assessment (*Qualitative Risk Assessment for the 100-KR-4 Groundwater Operable Unit* [WHC-SD-EN-RA-010]).

With the approval of the interim ROD, construction of the 100-KR-4 OU interim remedy was started. Concurrently with the startup of the KR-4 pump-and-treat system, the Interim Action Monitoring Plan (IAMP) (*Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* [DOE/RL-96-90]) was completed. This IAMP set the general monitoring plan for the pump-and-treat systems in the 100-HR-3 and the 100-KR-4 OUs. The IAMP was modified by a letter from Ecology to DOE ("Sampling Changes to the 100-HR-3 and 100-KR-4 Operable Units (OU)" [Wanek, 1998]) and was modified through the TPA Change Notice process to add wells. With these modifications, the general sampling program was developed and carried forward in the Interim ROD.

Table 1-8 summarizes the chronology of reports describing groundwater monitoring at the 100-KR-4 OU, including many documents that are valid across the Hanford Site.

Table 1-8. Chronology of Reports for Groundwater Monitoring at 100-KR-4 OU

Year	Pump-and-Treat System	Annual Groundwater Monitoring Reports	Aquifer Sampling Tube Data Reports	Annual Environmental Monitoring
1980	—	PNL-3768	—	—
1981	—	PNL-4237	—	—
1982	—	PNL-4659	—	—
1983	—	PNL-5041	—	PNL-5038, PNL-5039
1984	—	PNL-5408	—	PNL-5407
1985	—	—	—	PNL-5817
1986	—	—	—	PNL-6120
1987	—	PNL-6315-1, -2	—	PNL-6464
1988	—	PNL-6315-3, -4	—	PNL-6825
1989	—	PNL-7120	—	PNL-7346
1990	—	PNL-8073	—	PNL-7930
1991	—	PNL-8284	—	PNL-8148
1992	—	—	—	PNL-8682
1993	—	PNL-10082	—	PNL-9823
1994	—	PNL-10698	—	PNL-10574
1995	—	PNL-11141	—	PNNL-11139
1996	—	PNNL-11470	BHI-00778	PNNL-11472
1997	DOE/RL-97-96	PNNL-11793	—	PNNL-11795
1998	DOE/RL-99-13	PNNL-12086	BHI-01153	PNNL-12088
1999	DOE/RL-2000-01	PNNL-13116	—	PNNL-13230
2000	DOE/RL-2001-04	PNNL-13404		PNNL-13487
2001	DOE/RL-2002-05	PNNL-13788	BHI-01494	PNNL-13910
2002	DOE/RL-2003-09	PNNL-14187	BHI-01624	PNNL-14295
2003	DOE/RL-2004-21	PNNL-14548	PNNL-14444	PNNL-14687
2004	DOE/RL-2005-18	PNNL-15070	—	PNNL-15222
2005	DOE/RL-2006-08	PNNL-15670	—	PNNL-15892
2006	DOE/RL-2006-76	PNNL-16346	—	PNNL-16623
2007	DOE/RL-2008-05	DOE/RL-2008-01	SGW-35028	PNNL-17603

Table 1-8. Chronology of Reports for Groundwater Monitoring at 100-KR-4 OU

Year	Pump-and-Treat System	Annual Groundwater Monitoring Reports	Aquifer Sampling Tube Data Reports	Annual Environmental Monitoring
2008	DOE/RL-2009-15	DOE/RL-2008-66	—	PNNL-18427
2009	DOE/RL-2010-11	DOE/RL-2010-11	—	PNNL-19445
2010	DOE/RL-2011-25	DOE/RL-2011-001	—	—
2011	—	—	—	—

Note: Complete reference citations are provided in Chapter 11.

In addition to the groundwater investigations, several pore water, aquifer tube, and Columbia River studies have been performed that are relevant to 100-K (summarized below and in Table B-1). These tests were conducted for the entire River Corridor and have direct application to activities at 100-K.

Pore Water. The first pore water (groundwater upwelling beneath the river bottom into the space between rocks and sediment of the riverbed) study in the Hanford Reach of the Columbia River was conducted in 1994. It was designed to collect substrate water quality/contaminant data for determining the potential exposure and risk to ecological receptors from groundwater discharge to the river, particularly from Cr(VI) (*Preliminary Determination of Chromium Concentration Within Pore Water and Embryonic Chinook Salmon at Hanford Reach Spawning Area in Proximity to 100-HR-3 Operable Unit* [BHI-00156]). Cr(VI) concentrations below the former 11 µg/L Ambient Water Quality Standard (AWQS) (since lowered to 10 µg/L), as measured in the river substrate, was the proposed remediation goal. Embryonic Chinook salmon were selected as the target receptor for the study because during their early life stages (egg and sac-fry), they have limited mobility, spend most of their time within or near the river substrate, and thus could be chronically exposed to Cr(VI) from subsurface groundwater discharge. The appropriate season for pore water sampling was determined to be fall (during low river stage and relatively high groundwater discharge to the river). Salmon redds were identified by aerial surveys to establish when salmon were spawning in the Hanford Reach and to determine locations where pore water samples should be collected for Cr(VI) analysis.

More recent pore water studies were conducted by Washington Closure Hanford (WCH) in the River Corridor (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* [WCH-380]). These studies showed Cr(VI) values above the AWQS at several river sites opposite the reactor areas during very low river stage. However, the majority of the sites did not show Cr(VI) above detection limits. The sample locations and detailed results for the pore water study are provided in Chapters 2 and 4 of this RI/FS report.

Aquifer Tube. Suites of aquifer tubes were installed along the Columbia River throughout the River Corridor in 1997, 2004, and 2008. Aquifer tubes consist of small, stainless steel screens that are placed in the aquifer along the riverbank in borings advanced by a percussion method. The tubes monitor shallow groundwater of the uppermost, unconfined aquifer and typically terminate one to two meters below the water table in the unconsolidated, permeable sediments. Ringold Formation upper mud (RUM) sediments typically cannot be penetrated using the percussion method for tube installation. Sampling of these tubes is governed by a SAP (*Sampling and Analysis Plan for Aquifer Sampling Tubes*, hereinafter called the SAP for Aquifer Sampling Tubes [DOE/RL-2000-59]), revised in 2009. A polyethylene tube is attached

to the aquifer tube and a peristaltic pump is used to collect a water sample from the screened interval. Specific conductivity of the sample water varies with river stage, reflecting a mixture with either more groundwater (higher specific conductivity) or more surface water (lower specific conductivity) in the aquifer tube sample. Typically, aquifer tube samples collected during low river stage are more representative of groundwater conditions. Aquifer sampling tube data reports are summarized in the SAP.

Columbia River Studies. Studies that are pertinent to the Columbia River include the following:

- DOE/RL-92-12, *Sampling and Analysis of 100 Area Springs*
- BHI-00778, *Chromium in River Substrate Pore Water and Adjacent Groundwater: 100-D/DR Area, Hanford Site*
- WCH-380, *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling*

Additional studies relevant to 100-K are currently being performed along the Columbia River as part of the river RI. These include studies regarding groundwater upwelling and pore water evaluations. The nature and extent of contaminants in groundwater discharging to the Columbia River (in particular, within the hyporheic zone) is identified as a data gap in Chapter 2 of this RI. Another data gap addressed by this RI is the rate of chemical and hydraulic exchange between the aquifer and the river in the nearshore area. In the interim, an attenuation factor of 1:1 has been assumed for groundwater entering the river (100-HR-3 and 100-KR-4 OU ROD [EPA/ROD/R10-96/134]). These ongoing investigations are discussed further in Chapter 2. Relevant data collected from these efforts are incorporated into the evaluations presented in subsequent chapters of this RI/FS.

Aquifer Testing in 100-K. Aquifer testing has been conducted at a number of older wells in 100-K. Pumping tests were conducted in the early 1990s at wells downgradient of the 116-K-2 Trench, notably Wells 199-K-18 to 199-K-22. In addition, slug tests were performed at existing wells during the Interim ROD drilling campaign in 1992 to 1994. The results are summarized in SGW-41213 from earlier documents. Hydraulic conductivities of 0.88 to 44 m/day (3 to 145 ft/day) were measured at 17 wells spread across the 100-K Reactor and the 116-K-2 Trench.

Other Groundwater Studies. A chromium reduction test using calcium polysulfide was performed at a well cluster northeast of the 116-K-2 Trench. The test plan (*Treatability Test Plan for Fixation of Chromium in the Groundwater at 100-K* [DOE/RL-2005-05]) describes the reduction of Cr(VI) to trivalent chromium as an immobile, nonhazardous hydroxide through interaction with the polysulfide. The additional reaction of sulfate reducing bacteria with precipitated sulfate further reduces the Cr(VI), but for best effect, requires the addition of an organic food source as part of the treatment. A five well "spot test" array was used with the central well as the extraction point and the surrounding diamond pattern of injection wells used to feed the calcium polysulfide and a vegetable oil carbon food source into the aquifer. Results are presented in *Treatability Test Report for Calcium Polysulfide in the 100-K Area* (DOE/RL-2006-17). The test was successful in eliminating Cr(VI) from groundwater, as observed when sampling groundwater at the extraction well and at the injection wells. Dissolved oxygen and oxidation/reduction potential were also reduced, leading to the local formation of a persistent, permeable reactive barrier that continues to reduce Cr(VI) in the aquifer. The primary issue with the treatment method was the precipitation of chemicals in pumps, piping, and flow meters, which lowered flow rates in the system.

Based on the results of previous tests performed at the 100-D/H treatment system, a new resin has been tested at the KX and KW pump-and-treat systems. The original resin, DOWEX-21K™, has been used since the start of operations at all 100-K and 100-D/H IX systems. It is shipped offsite for regeneration or disposed onsite. New resins were tested (*Resin Evaluation and Test Report to Support DX Treatment System* [SGW-41642]) in preparation for the 100-DX system design and ResinTech® SIR-700 was found superior to others. The resin was tested again at the KX pump-and-treat system (*K Area Chromium Resin Test Report* [SGW-46070]) using a bench scale system connected to the KX water influent. Two regenerable and two single-use resins were used and follow-on testing evaluated pH adjustments to chromium uptake on the SIR-700 resin. A test plan (*Test Plan to Implement ResinTech™ SIR-700 in the 100-KW Pump and Treat* [SGW-48676]) has been developed to test the resin's performance in one of the KW vessels prior to using it in all vessels. Preliminary resin performance tests suggest significant improvement over resins currently used.

Groundwater Remediation. In 1995, the Focused Feasibility Study (*100-KR-4 Operable Unit Focused Feasibility Study* [DOE/RL-94-48]) and the Proposed Plan *Proposed Plan for Interim Remedial Measure at the 100-KR-4 Operable Unit* [(DOE/RL-94-113]) were finalized. At the end of 1995, a pilot scale treatability test summary report (*The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit* [DOE/RL-95-83]) was issued and the Interim ROD followed in April 1996. The remedial design and remedial action work plan (RD/RAWP) (*Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action* [DOE/RL-96-84]) was issued in September 1996. Construction was completed by June 30, 1997, and full-time operation of the KR-4 pump-and-treat system began September 1, 1997. The purpose of the interim remedy was to reduce the concentration of the chromium plume into the Columbia River and to provide information that will lead to a final remedy.

Since the initial pump-and-treat system was operational, two additional IX systems were brought online. The KW pump-and treat system addresses Cr(VI) around the KW reactor as described in *The KW Pump and Treat System Remedial Design and Remedial Action Work Plan, Supplement to the 100-KR-4 Groundwater Operable Unit Interim Action* (DOE/RL-2006-52). The KW Reactor area pump-and-treat system uses a series of extraction wells equipped with submersible pumps to draw groundwater from the unconfined aquifer. Extracted groundwater is conveyed through aboveground piping to a collection tank(s), where it is combined with water from the other extraction wells. From the collection tank(s), the water is pumped to an enclosed treatment system where chromium is removed by IX. Treated groundwater is transferred through an aboveground pipe to the injection well network. The KX system began operations in February 2009, as described in *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System*, hereinafter called Supplement to the 100-HR-3 and 100-KR-4 RDR/RAWP (DOE/RL-2006-75). Similar to the expansion for KW, the KX system increases amount of groundwater extracted, treated, and injected to reduce the expansion of the chromium plume. Each document describes the facility operations and analytical requirements needed to demonstrate proper operation of the system and remediation of the aquifer.

The Cr(VI) plume in the 100-KR-4 OU has been divided into four separate plume areas based on likely contaminant sources. The two larger plumes are associated with the former 116-K-2 Trench, which is being remediated by the KX and KR-4 systems. The original plume has been divided by remediation

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activities. The third plume is located around the 105-KW Reactor, which is being remediated by the KW system, and the fourth plume is located downgradient of the 105-KE Reactor, which is being remediated by the KX system. Figures 1-25 and 1-26 illustrate the plume remediation progress through calendar year (CY) 2009.

The KR-4 pump-and-treat system treated 317.5 million L (83.9 million gal) of groundwater in CY 2009, bringing the total extracted since 1997 to 5.31 billion L (1.4 billion gal). The system removed approximately 7.8 kg (17.2 lb) of Cr(VI) during CY 2009, increasing the total Cr(VI) removal to 347.5 kg (766 lb). The KR-4 pump-and-treat system began operating in 1997 with seven extraction wells, four injection wells, and an IX resin treatment train to remediate the Cr(VI) plume between the former 116-K-2 Trench and the Columbia River. As additional monitoring wells and aquifer tubes were added since 1997, the interpretations of the plume boundaries also changed and the pump-and-treat network was modified. A series of modifications was made to the KR-4 network between 1997 and 2008, as described in Supplement to the 100-HR-3 and 100-KR-4 RDR/RAWP (DOE/RL-2006-75). In addition, realignment of certain wells occurred in 2009 to control a tritium plume in 100-K. The new alignment creates a partial recirculation system that contains and localizes the tritium within a smaller area.

The KX pump-and-treat system treated 718.9 million L (190 million gal) of groundwater in CY 2009, bringing the total extracted since November 2008 to 765 million L (202 million gal). The system removed approximately 39.7 kg (87.5 lb) of Cr(VI) during CY 2009, increasing the total Cr(VI) removal to 43.6 kg (96 lb). In November 2008, the KX pump-and-treat system began treating groundwater, expanding the area of influence around the 116-K-2 Trench. This system uses the same IX process as KR-4, and with 15 extraction wells and 8 injection wells, is designed to treat groundwater at a rate of up to 2,271 L/min (600 gpm). The injection wells on the northeastern plume border were located to minimize Cr(VI) plume migration further into 100-N.

During KX well development, higher than expected levels of Cr(VI) and tritium were detected in some groundwater samples. This information required realigning the wells within the KR-4 and KX systems to maximize plume capture, minimize tritium spread, and increase the groundwater treatment volume. Figure 1-27 shows the current location of the KR-4 and KX well network.

The KW pump-and-treat system treated 269.9 million L (71.3 million gal) of groundwater in CY 2009, bringing the total extracted since January 2007 to 667 million L (176.2 million gal). The system removed approximately 49.3 kg (109 lb) of Cr(VI) during CY 2009, increasing the total Cr(VI) removal to 83.3 kg (184 lb). In January 2007, the 379 L/min (100 gpm) capacity KW pump-and-treat system began treating Cr(VI) in groundwater near and downgradient of the KW Reactor, using the same IX process employed in the KR-4 and KX systems. The original system extracted groundwater from four wells, and returned the treated groundwater to the subsurface via two wells, as shown in Figure 1-28. During the first year, the KW pump-and-treat system removed 21 kg (46 lb) of Cr(VI) and treated 170 million L (45 million gal) of groundwater.

The KW pump-and-treat system was expanded in April 2009 to double the design treatment capacity up to 757 L/min (200 gpm). As part of this expansion, the well network was modified to connect a total of eight extraction wells and four injection wells. Figure 1-29 shows the location of the KW expanded well network.

Table 1-9 summarizes the current pump-and-treat system capacities. The removal efficiency and treatment performance of the KR-4, KW, and KX systems are presented in the 2009 annual groundwater monitoring report (*Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2* [DOE/RL-2010-11]).

Table 1-9. Pump-and-Treat Systems Summary for the 100-KR-4 OU

System	Actual Start	Design Capacity (gpm)	Number of Extraction Wells	Number of Injection Wells
100-KR-4	October 1997	300	10	5
100-KX	February 2009	600	14	9
100-KW	January 2007 and expanded in May 2009	200	7	3
Totals (February 2010)		**1,100**	**31**	**17**

Notes: These values are based on information as of May 31, 2010, and may change with future system improvements.

Groundwater Ion Exchange Resin Evaluations. Several resin evaluations and process alternatives analyses have been performed to develop *100 Area Groundwater Chromium Resin Management Strategy for Ion Exchange Systems* (SGW-46621). Development of the strategy included a decision analysis workshop in May 2010 to select the optimal IX resin management process for 100-K with extension to the entire 100 Area. The following regeneration options were considered in the decision analysis process:

- Offsite—remote regeneration (current practice)
- Offsite—near-site regeneration
- Onsite—at a central regeneration facility
- Single use at pH 5.0
- Single use at pH 6.5
- In-vessel regeneration

A resin skid was located at the KX Plant to test four candidate resins (Dowex 21K, which is used currently; Purolite A500®, ResinTech SIR-700, and WBG30-B, which is a spherical form of SIR-700). The resin testing and subsequent alternatives analysis identified ResinTech SIR-700 provided significant savings in terms of life-cycle costs over the resin currently being used at 100-K pump-and-treat facilities. Implementation of SIR-700 use will be phased, beginning with the KW Pump-and-Treat Facility. The initial operation will be limited to validating predicted Cr(VI) removal, selecting the operating pH range, and confirming compatibility of the vessel lining with the reduced pH.

® Purolite A500 is a registered trademark of the Purolite Company, Bala Cynwyd, Pennsylvania.

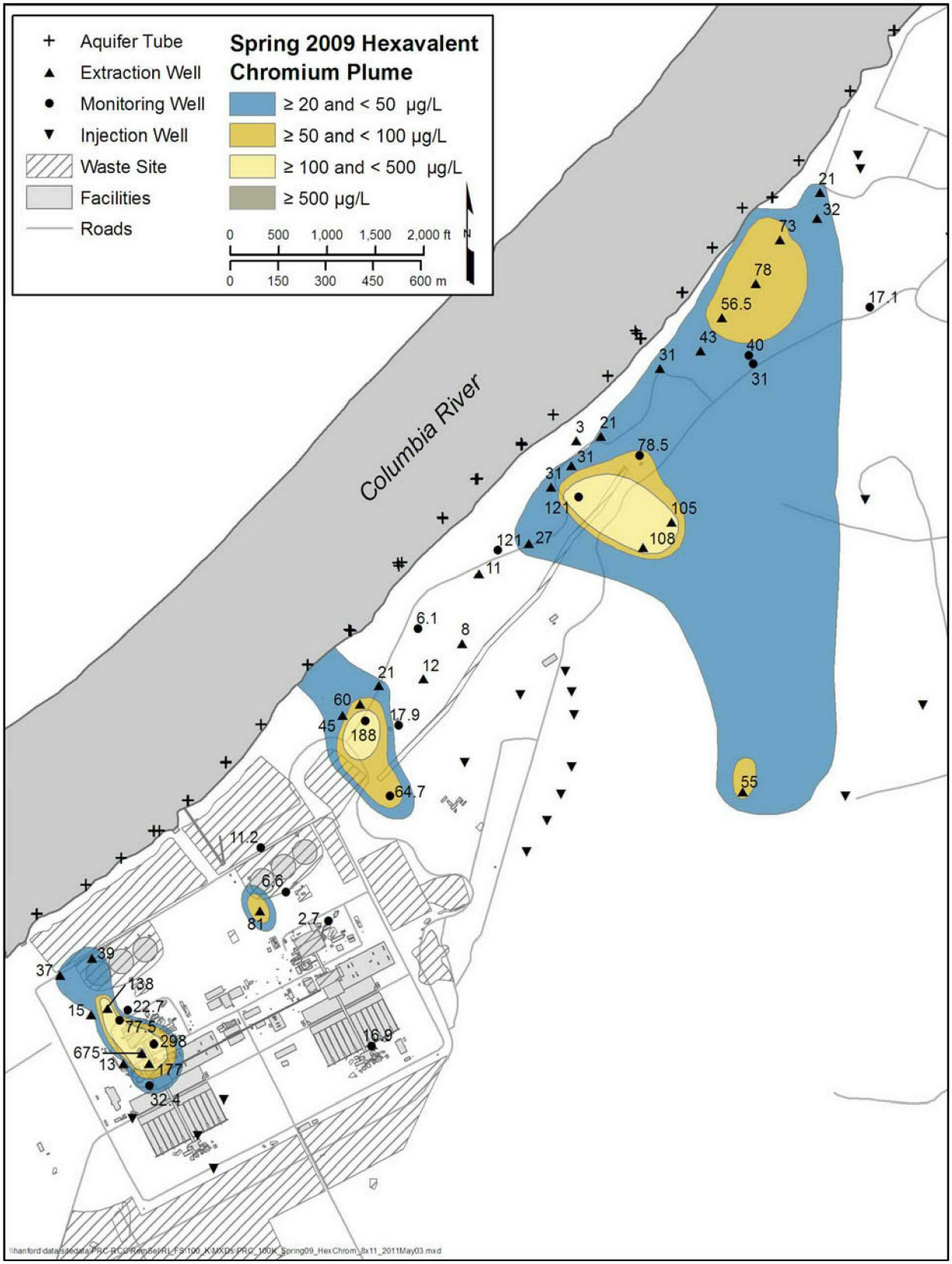


Figure 1-25. 100-K Cr(VI) Plume Remediation Progress in Spring 2009

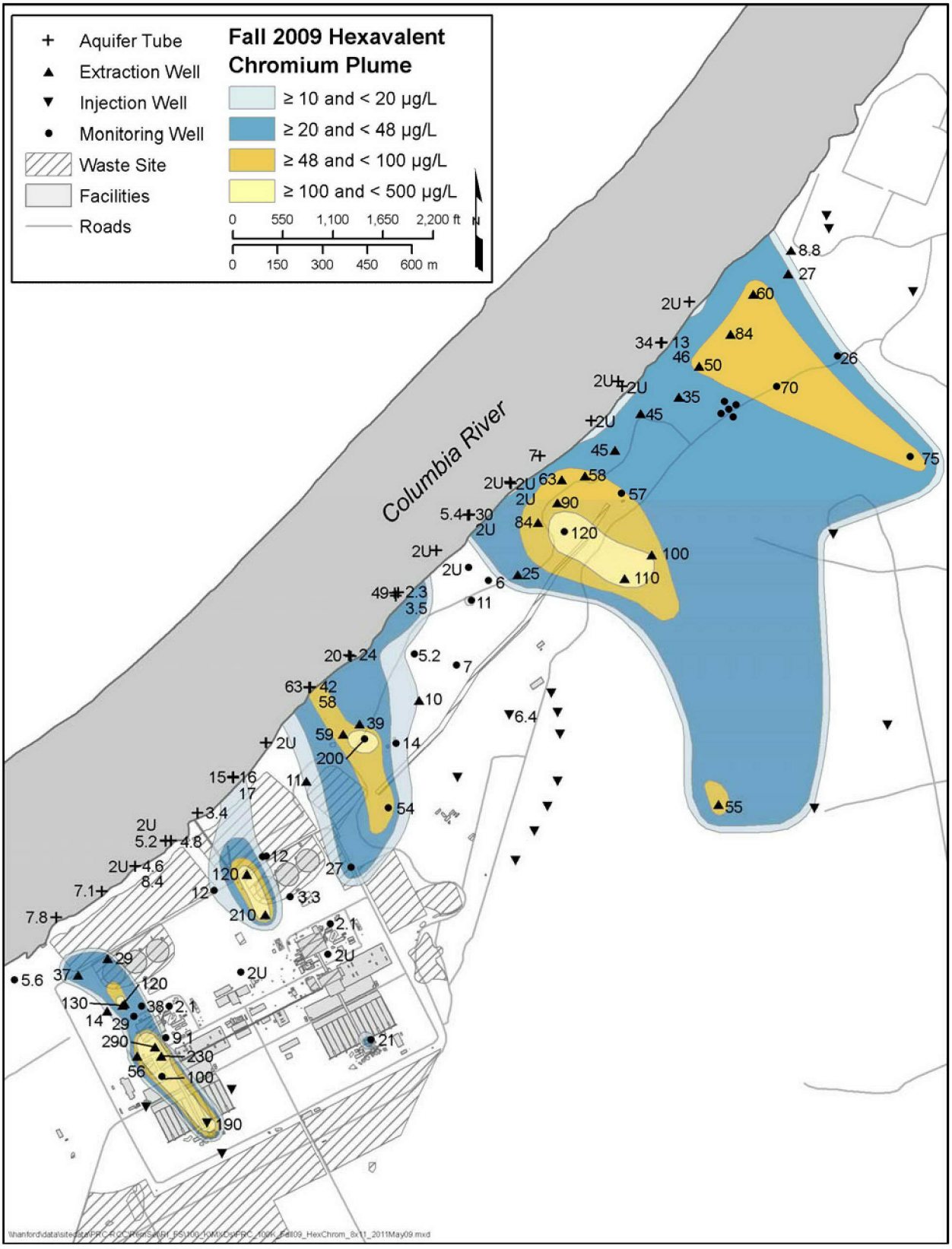


Figure 1-26. 100-K Cr(VI) Plume Remediation Progress in Fall 2009

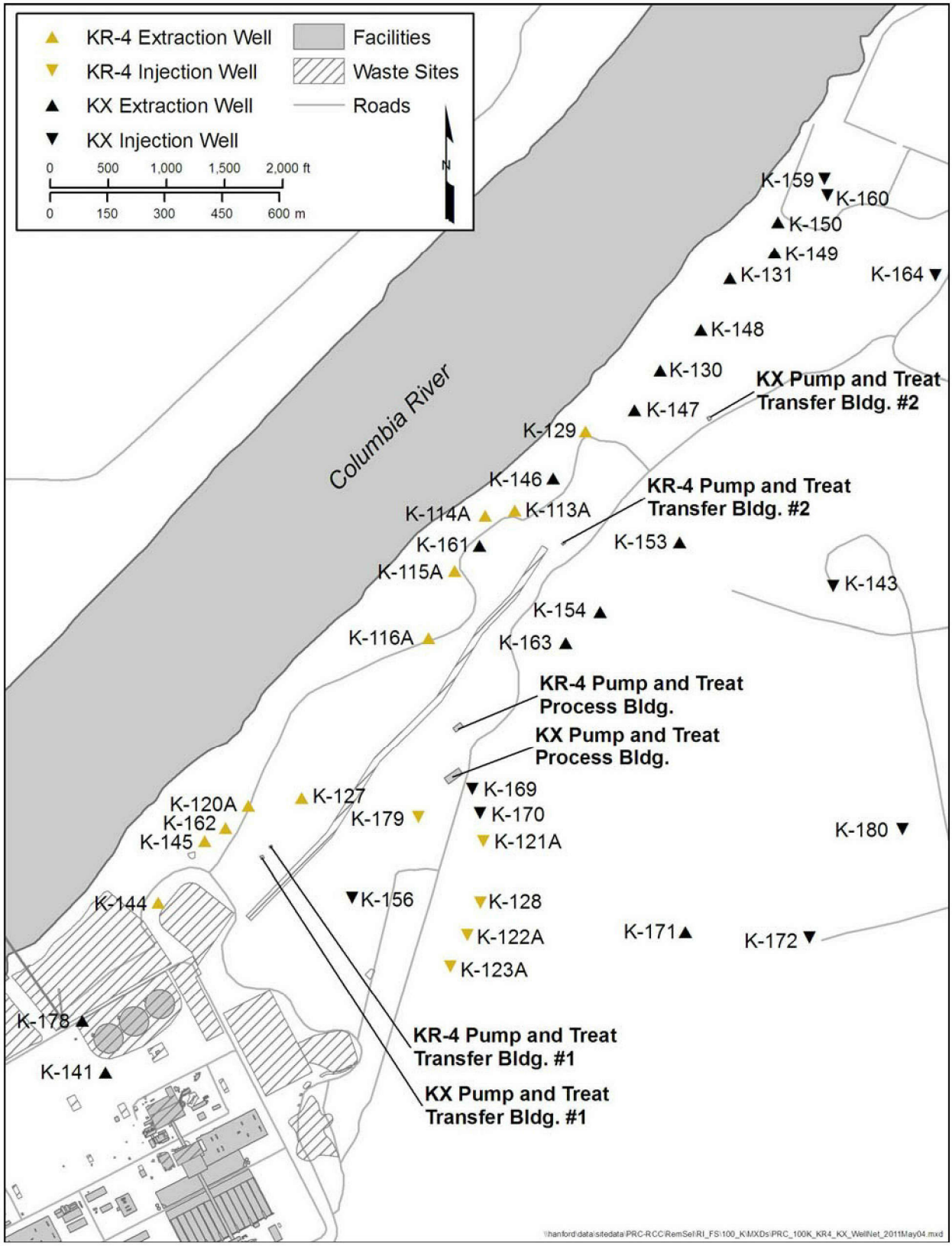


Figure 1-27. Location of the KR-4 and KX Optimized Well Network

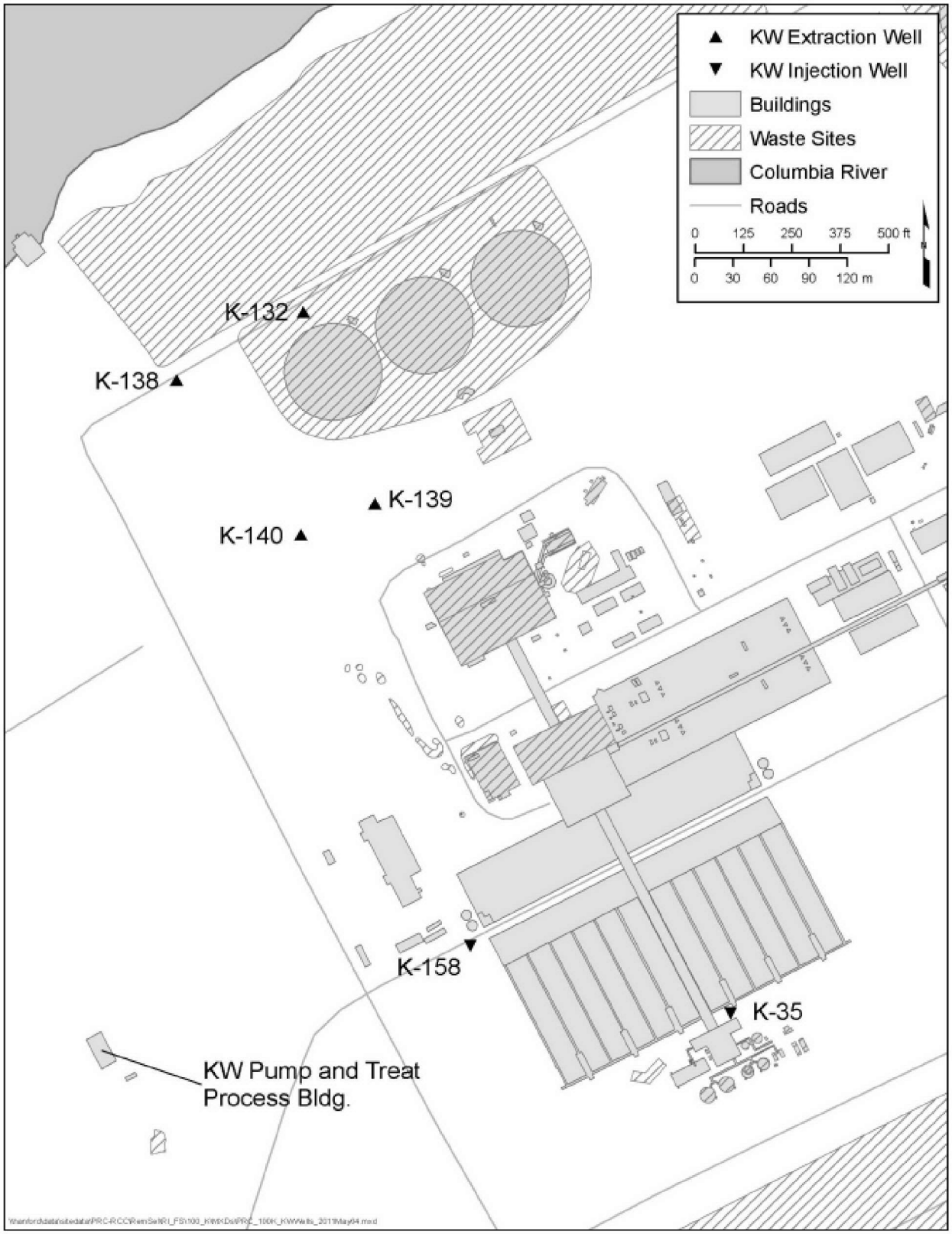


Figure 1-28. Location of KW Pump-and-Treat System Wells

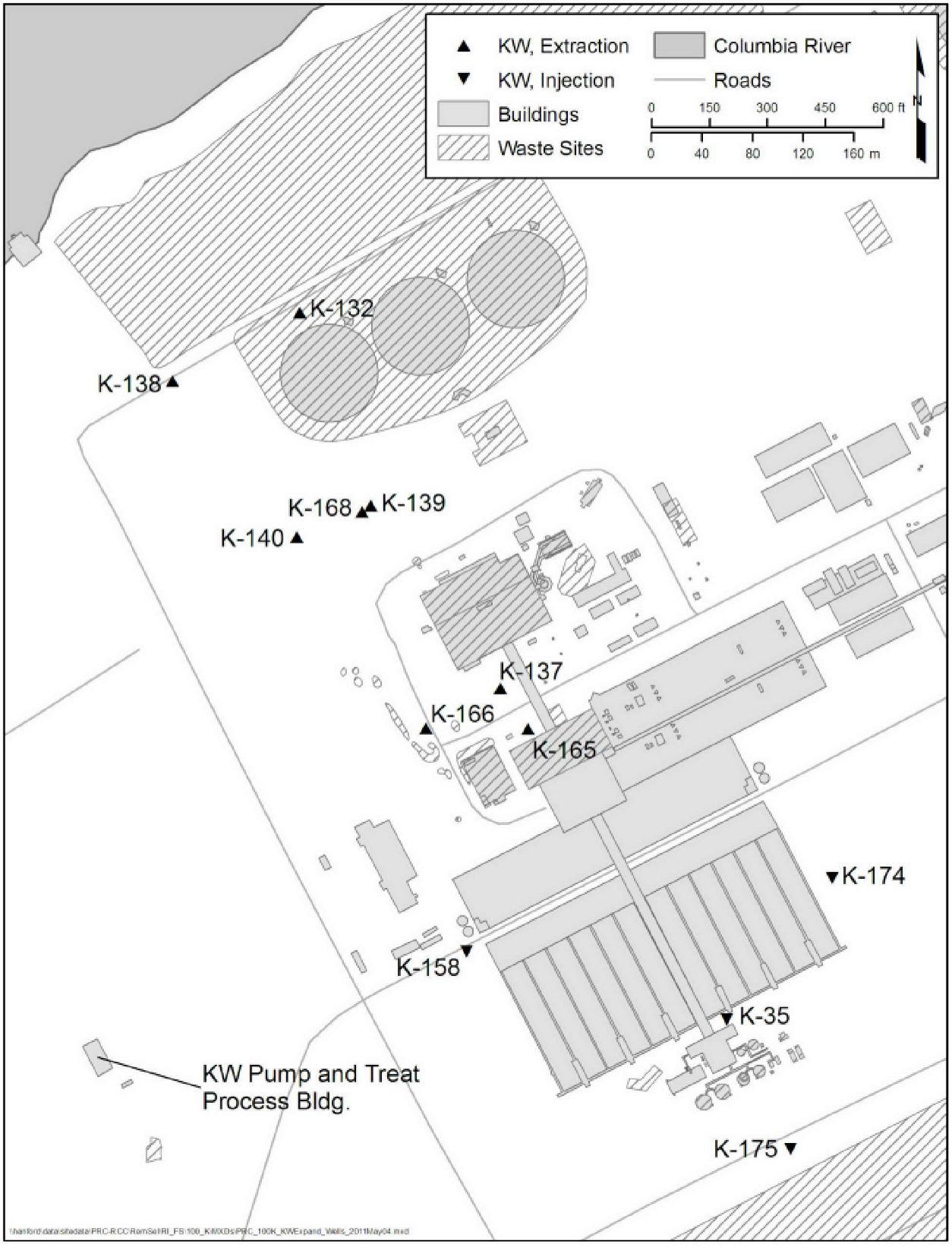


Figure 1-29. 100-KR-4 OU, Expanded KW Pump-and-Treat System

Remedial Process Optimization. Prompted by the persistence of hexavalent chromium in 100-KR-4 Groundwater OU and discovery of high concentration areas ("hot spots") in both the vadose zone and groundwater, a remedial process optimization (RPO) effort was undertaken to improve remedial performance (*Conceptual Design of Process Enhancements 100-KR-4 Groundwater Operable Unit Remedial Process Optimization* [SGW-46532]). Remedial process optimization is a continuing process to review and evaluate operating remediation systems and provide recommended alternatives to optimize system operations and potentially reduce costs. To address these issues, the following four objectives were established as part of the RPO activities for 100-KR-4:

- Develop alternatives for optimizing the existing 100-KR-4 treatment systems in both the short and the longer terms
- Present conceptual designs and cost information for enhancements to the 100-KR-4 OU systems by developing a range of alternatives that would allow the selection of the most cost-effective approach to achieve the Tri-Party Agreement goals
- Provide a basis for future analysis of the recommended 100-KR-4 OU alternative in the FS for 100-K
- Recommend additional extraction and injection well locations to be installed in fiscal year (FY) 2010 and 2011

The RPO approach involves modeling groundwater flow, determining where the hexavalent chromium plume will reach the Columbia River without any intervention, and then revising the current pump-and-treat system to determine where longer-term threats exist so more complex system changes away from the river (including alternative treatment technologies) can be applied. The work is proceeding in five phases:

- Phase 1 addressed well realignments to the KR-4/KX treatment systems to focus on tritium issues (completed in 2009).
- Phase 2 addressed the drilling of five additional wells for use at the KR-4/KX treatment systems (completed in 2010).
- Phase 3 addressed drilling four new wells for plume control, consisting of three wells at the KR-4 treatment system and one well at the KW treatment system (in progress to complete in 2012).
- Phases 4 and 5 propose drilling multiple new wells with the objective of improving hydraulic containment along the river and cleaning up the plume more effectively.

100-K RPO Modeling. Groundwater flow and contaminant transport modeling was performed to support the calculation of appropriate pumping rates for 100-KR-4 OU injection and extraction wells to achieve the RPO objectives. The objectives are to prevent the discharge of Cr(VI) to the Columbia River substrate at concentrations exceeding those considered protective of aquatic life in the river and riverbed sediments by 2012 and to restore the aquifer by attaining target cleanup levels in the 100-KR-4 OU by 2020. These objectives will be met by pumping groundwater from existing and proposed extraction wells located within and around the contaminated areas by removing Cr(VI) from the groundwater for ex situ treatment, bioinjection, and bioinfiltration at the KE and KW Head House areas (*Conceptual Design of Process Enhancements 100-KR-4 Groundwater Operable Unit Remedial Process Optimization* [SGW-46532]).

The groundwater flow model was constructed using MODFLOW, along with MODPATH, MT3DMS, and PEST add-ons. The model simulated two-dimensional groundwater flow; used spatially varying hydraulic conductivity for the Hanford formation, Ringold Formation unit E, and RUM unit; and did not

include any continuing sources of hexavalent chromium in the vadose zone or in the RUM unit (*100-KR-4 Remedial Process Optimization Modeling Data Package* [SGW-41213]).

The Base Case well field design consists of 31 existing wells, 3 new extraction wells, and 17 existing injection wells. The proposed well field design for the Recommended Alternative 1 (RPO Phase 4) consists of existing monitoring wells (Base Case) and the installation of seven new wells. Two wells are proposed for extraction purposes only, and the remaining five new wells will serve dual purposes as both extraction and injection wells. RPO Phase 4 and Phase 5 will be evaluated in conjunction with the remedial alternatives developed in this RI/FS.

1.2.3.4 Risk Assessments

Various risk assessments have been and are currently being conducted at the 100 Area, including risk assessments described in the Integrated Work Plan (DOE/RL-2008-46). The focus of initial risk assessments for human health and ecological impacts was on the near-term risks, in support of remediation of waste sites and impacts to groundwater using interim actions under the authority of interim action RODs (Past-Practice Strategy [DOE/RL-91-40]). Risk assessments types include Qualitative Risk Assessments (QRAs) and RCBRA (DOE/RL-2007-21), described in the following text:

Qualitative Risk Assessments. Qualitative risk assessments have been used to define the basis for remedial actions under interim action RODs. Assessment of human health risks in the QRAs was based on frequent-use and occasional-use scenarios, which reflected current guidance for that time. The COPCs were identified from the historical site data and data collected during the LFIs, taking into consideration Hanford Site background activity of radionuclides and inorganic concentrations in vadose zone, and risk-based screening using residential exposure parameters (*Hanford Site Risk Assessment Methodology* [DOE/RL-91-45]). Human health risks presented in the QRAs were based on the maximum concentrations detected in waste site vadose zone material and in groundwater. Human health risks were quantified for a limited set of exposure pathways (soil ingestion, fugitive dust or volatile inhalation, and external exposure). Ecological risks were estimated using a streamlined approach, focusing on a single organism, the Great Basin pocket mouse, using the assumption that the waste site was the home range.

The results of the QRAs are included in interim RODs, as detailed in Table 1-2, and will be presented in the final RCBRA. Data collection in support of the QRA process is ongoing within 100-K.

River Corridor Baseline Risk Assessment. Note: DOE has issued the Draft C version of the River Corridor Baseline Risk Assessment (RCBRA), Volume II: Human Health Risk Assessment for review by Ecology, EPA, and stakeholder groups. It is anticipated that Rev. 0 of this document will be available for incorporation into all the RI/FS Reports in 2011. The ecological risk assessment portion of the RCBRA (Volume I) is still under development.

The Human Health Risk Assessment (HHRA) estimates the potential risk to people who may work, live, or recreate in the River Corridor of the Hanford Site. Waste site and groundwater cleanup actions in the River Corridor have been implemented since 1995 through interim action RODs. During this time, about 7.2×10^9 kg (8 million tons) of contaminated vadose zone material and debris have been removed from nearly 300 waste sites and disposed at authorized facilities. In addition, more than 7.6×10^9 L (2 billion gal) of contaminated groundwater have been processed through pump-and-treat systems.

The HHRA looks at how people might be exposed to residual levels of radioactive and chemical contaminants in cleaned up waste sites and potentially affected areas near the waste sites in the River Corridor and what health risks they might face. A screening-level groundwater risk assessment was also completed to evaluate potential risks associated with groundwater exposures for impacted River Corridor areas.

The Tri-Parties looked at several ways people might be exposed to residual contamination in the River Corridor and focused on the following groups and modes of exposure to residual contaminants:

- **Recreational users that engage in day-use activities:** This included one "Casual User" group that picnics or walks in the riparian habitat along the river, one "Avid Angler" group that fishes along the river shoreline, and one "Avid Hunter" group that hunts in the upland region. Adults and children in these groups are assumed to be exposed for up to 30 years as they participate in these activities throughout the River Corridor.

- **Tribal members:** This group would use the River Corridor for traditional activities including fishing, hunting, and gathering plants but live offsite. Adults and children in this group are assumed to be exposed over their lifetime (up to 75 years) as they participate in these activities throughout the River Corridor.

- **Adults working on the site:** This group includes an "Industrial Worker" group that works at a location in the River Corridor and lives offsite, and a "Resident Monument Worker" group that both works and lives in the River Corridor. This latter group is intended to represent employees of the Hanford Reach National Monument, who may also use groundwater at onsite housing. Adults in these groups are assumed to be exposed for up to 30 years. The location of an industrial building or employee residence was assumed to be upon a remediated waste site.

- **Adults and children who live in the River Corridor:** This group would consume food grown or raised on the site and use groundwater from the site. This group includes a "Subsistence Farmer" group, and two resident Native American groups based on exposure scenarios provided by the Confederated Tribes of the Umatilla Indian Reservation and the Yakama Nation. The locations of a residence and associated garden and livestock areas are assumed to be upon a remediated waste site.

The methods used to calculate risk are designed to produce a conservative estimate. This way, cleanup and other actions to reduce risk will protect "sensitive" groups of people, like children, pregnant women, and the elderly. The results of the human health and ecological risk assessment are presented in Chapters 6 and 7 of the RI/FS Report.

1.2.3.5 Riparian and Nearshore Areas

The River Corridor has been divided in three environmental zones for purposes of investigation (RCBRA [DOE/RL-2007-21]; Integrated Work Plan [DOE/RL-2008-46]). The three zones—upland, riparian, and nearshore aquatic—are described in Section 3.9.

Riparian and nearshore environments are of specific interest in the 100 and 300 Areas. The riparian zone contains plant communities requiring more water than the shrub-steppe vegetation of the upland zone, and because of the shallow water table, is generally green throughout the year (*Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* [PNNL-SA-41467]). While the wildlife and food webs of the upland and riparian zones overlap, some wildlife species occur specifically within the riparian zone (*DQO Summary Report for the 100 Area and 300 Area Component of the RCBRA* [BHI-01757]). The nearshore zone is more frequently under water, and is capable of sustaining aquatic biota.

There are few waste sites located within the riparian zone. However, releases and contaminant transport from waste sites could have resulted in hazardous or radioactive constituents being released to riparian and nearshore media. Groundwater from the Hanford Site discharges into the Columbia River through seeps, springs, and other upwelling locations. Discharge of groundwater could also have resulted in hazardous or radioactive constituents being released to riparian or nearshore zones.

Investigations that were historically conducted in the riparian and nearshore areas of 100-K are summarized in *Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* (PNNL-SA-41467). In addition to these historical investigations, other sampling and analytical data have been collected from riparian and nearshore areas as part of the Surface Environmental Surveillance Program (SESP). The data from the SESP are summarized in the Annual Environmental Reports for the Hanford Site. Finally, investigations of riparian and nearshore areas were conducted as part of the RCBRA (DOE/RL-2007-21; *100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan*, hereinafter called RCBRA SAP [DOE/RL-2005-42]).

Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River (PNL-5289), identified riverbank springs and groundwater seeps along the length of the Hanford Site shoreline and presented for 100-K analytical results for tritium detected in groundwater, riverbank springs, and adjacent surface water. The highest concentrations of tritium were 49,000 pCi/L in groundwater, 5,500 pCi/L in springs, and 300 pCi/L in surface water.

Sampling of riverbank springs and adjacent surface water performed in 1991 detected chromium (14 to 64 µg/L in the springs; 2 to 6 µg/L in surface water), tritium (400 to 8,900 pCi/L in the springs, below detection limit in surface water), Sr-90 (one detected concentration of 8.8 pCi/L in the springs; <0.4 to 0.7 pCi/L in the surface water), technetium-99 (2 to 5.2 pCi/L in the springs; 2 to <3 pCi/L in surface water), and total uranium (0.24 to 1.1 pCi/L in the springs; 0.2 to 0.5 pCi/L in surface water). Samples of riverbank spring sediment from the 100-K had low concentrations of Sr-90, cesium-137, radium-226, thorium-228, and thorium-232 (*Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site* [WHC-EP-0609]).

Also in 1991, five sediment samples were collected from four locations near 100-K (*100 Area Columbia River Sediment Sampling* [WHC-SN-EN-TI-198]). Maximum concentrations of inorganic constituents detected in these samples included arsenic (10.7 µg/g), chromium (64.1 µg/g), lead (59.3 µg/g), and zinc (454 µg/g). Cesium-137 (0.45 pCi/g) and europium-152 (0.32 pCi/g) were detected in a single sample.

The SESP does not routinely monitor surface water near 100-K. The nearest routinely monitored locations are transects located at the Vernita Bridge and 100-N. Riverbank spring locations near 100-K have been monitored by the SESP. The trends in metals concentrations in spring samples are reported to have been consistent over the past several years. With the exception of chromium, concentrations of metals in spring samples in 100-K were below Washington State chronic ambient surface water quality criteria in "Water Quality Standards for Surface Waters of the State of Washington" (WAC 173-201A). Concentrations of radionuclides detected in springs in 2009 were reported to be similar to those in previous years. Potassium-40, cesium-137, and uranium isotopes were the only radionuclides reported above minimum detectable concentrations. Concentrations of radionuclides and metals in 100-K sediments were similar to levels detected in previous years (*Hanford Site Environmental Report for Calendar Year 2009*, hereinafter called 2009 Sitewide Environmental Report [PNNL-19455]).

Investigations of riparian and nearshore areas were conducted in support of the RCBRA. Riparian and nearshore areas were selected where affected media (seeps, springs, or runoff) may have created exposure pathways to biota (RCBRA SAP [DOE/RL-2005-42]). Riparian sampling locations also were identified based on radiation field survey results (RCBRA SAP [DOE/RL-2005-42], Appendix C; *DQO Summary Report for the 100 Area and 300 Area Component of the RCBRA* [BHI-01757], Appendix H). Radiation survey results and detection of chromium in groundwater, aquifer tube, and biota (bivalve) samples provided the primary basis for selection of riparian and nearshore study sites in the 100-K decision area (RCBRA SAP [DOE/RL-2005-42], Table C-1). Four nearshore (aquatic) study sites were located near

100-K. These were located downstream of the 100-K operational area, within the discharge zone of a Cr(VI) groundwater plume. One riparian study site was also located downstream of 100-K.

Sample collection rationale and techniques varied by area and medium. Investigation areas characterized by data collected under the RCBRA SAP (DOE/RL-2005-42) included the upland, riparian, and nearshore river zones. Sites selected for sampling were identified based on existing data demonstrating a range of contaminant concentrations. Reference sites were identified using evidence/knowledge of areas not affected by contaminant release and selected based on physical/ecological similarity to onsite investigation areas.

Media collected in the upland and riparian zones included soil, vegetation, invertebrates, small mammals, and kingbirds (kingbirds in riparian zone only). Nearshore media included sediment, interstitial pore water, surface water, benthic macroinvertebrates, clams, and sculpin. Toxicity testing was performed on soil, sediment, and water to provide Hanford Site-specific information on the ecological effects of contaminant mixtures and contaminant bioavailability. The results of these tests are used to make informed inferences on the toxicity of contaminants to Hanford Site biota. A more detailed discussion of the results from the RCBRA (DOE/RL-2007-21) in riparian and nearshore areas is presented in Chapter 4 of this RI/FS Report.

2 Study Area Investigation

Highlights

- Nine groundwater monitoring wells were installed in the unconfined aquifer. Four soil borings were drilled into the RUM; however, a water bearing unit was identified in only one of these four.
- The completion of soil borings drilled in the 116-K-2 Trench as temporary monitoring wells represents an approved deviation from the work plan.
- Monitoring Well 199-K-186 was relocated approximately 80 m (262 ft) southeast of the 105-KE Reactor building to provide additional characterization for the KE Reactor area. Monitoring Well 199-K-189 was relocated approximately 75 m (250 ft) to the north due to ongoing remediation activities.
- A subset of existing wells was sampled three times to determine spatial and temporal variations in groundwater contamination.
- Data gaps identified in the 100-K Work Plan were adequately addressed.

Document review and evaluation of existing data that occurred during development of the 100-K Work Plan (DOE/RL-2008-46-ADD2) identified data gaps. This chapter describes the data gaps, the data collected to fill them, and the corresponding scope of work (including field activities, tests, analyses, and data sources) that were designed and carried out in the RI/FS. Chapters 3, 4, and 5 present results of the RI/FS activities. The 100-K Work Plan and the 100-K SAP (DOE/RL-2009-41) detail the RI/FS scope of work. The SAP presents the sampling program, including the number of samples and analytical methods.

The following sections of this chapter describe the RI/FS field activities, as well as other investigations and ongoing activities that contributed to this RI/FS. These paragraphs summarize the scope of work, document any deviations from the work plans, and explain the rationale for the deviations. They also present details of investigation activities conducted under other scopes of work that may affect the development of RAAs, including the RCBRA Report (DOE/RL-2007-21); *Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River*, hereinafter called Columbia River RI Work Plan (DOE/RL-2008-11); and ongoing groundwater well and aquifer tube monitoring.

This chapter summarizes the field activity and subsequent chapters describe the results of this work and integrate it with the existing information (summarized in Chapter 1) to update the CSM and to identify and evaluate options for achieving RAOs.

2.1 RI Activities

The RI field effort included boreholes, test pits, groundwater monitoring well installation, spatial and temporal groundwater monitoring, and the associated sampling and analysis for each activity. Table 2-1 presents the relationship of the field efforts and the data gaps that were identified in the 100-K Work Plan (DOE/RL-2008-46-ADD2). Table 2-1 provides the scope of work that was outlined, a summary of the work conducted, and the section of this report where the information/data are evaluated. Table 2-2 includes the supplemental investigations identified in the Integrated Work Plan (DOE/RL-2008-46) and other investigations that may potentially affect feasibility decisions regarding 100-K waste site and groundwater contamination. Tables 2-3 and 2-4 summarize the field program and Figure 2-1 shows the field sampling locations. The 100-K SAP (DOE/RL-2009-41) provides additional details, such as specific sample intervals and sampling and analytical methodology, and technical memorandums that summarize each field activity.

The following sections describe the RI scope of work in detail, including deviations from the 100-K Work Plan (DOE/RL-2008-46-ADD2). Tables 2-5 and 2-6 present the details of the field effort for the soil and groundwater sampling, respectively. Soil and groundwater sample depths have some minor variability from the 100-K SAP (DOE/RL-2009-41) below the water table due to the depth where the water table was encountered and the formation conditions encountered. Some variability in sample location is expected and allowed under the 100-K SAP (DOE/RL-2009-41).

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
1. Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath unremediated waste sites.	Characterize below unremediated waste sites to assess the nature and extent of contamination in the vadose zone.	Continue contaminated soil removal and sampling at waste sites in 100-K. *Special Case: Petroleum Hydrocarbons in the 100-KW area.* There is no work scope for the unplanned release related to the 166-KW Oil Storage and Oil Pump Equipment facility. The associated waste site, 100-KW-2, is currently an accepted site and will be remediated. The plume will be chased laterally until sufficient contamination is removed.	CVP and/or RSVP data were available for 14 completed waste sites and evaluated through the risk assessment activities. Chapter 5, Fate and Transport Chapter 6, Human Health Risk Assessment Chapter 7, Ecological Risk Assessment	Yes
2. Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath remediated waste sites.	Characterize beneath remediated waste sites to assess the nature and extent of contamination in the vadose zone.	Drill two boreholes within the trench and sample according to the target analyte list provided in Table 2-11. Collect soil samples continuously from the bottom of the waste site (or the maximum depth of remedial action) to the water table. Collect groundwater samples and aquifer sediment samples for analysis.	Two borings (C7831 and C7832) were drilled adjacent to the K-116 Trench. Soil and groundwater samples were collected as shown on Tables 2-5 and 2-6. CVP and/or RSVP data were available for 14 completed waste sites and evaluated through the risk assessment activities. Section 3.4.3, Hydrogeologic Cross Sections Section 4.2.2, Vadose Zone Chapter 5, Fate and Transport	Yes

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
3. Vadose zone contaminant nature and extent needed to assess protection of human health, ecological resources, and groundwater around reactor structures.	Characterize around the reactor structures to assess the nature and extent of contamination in the vadose zone.	Continue contaminated soil removal and sampling at waste sites associated with the 105-KE and 105-KW Reactor sites. Appendix A shows the locations of these waste sites.	Remediation will continue at these sites following the observational approach. Future soil verification data will be evaluated against final remedial action goals. Access to the areas around the reactors is limited due to the on-going remediation. RI characterization wells were drilled both on the front side and on backside of both the 105-KE and 105-KW Reactors. The locations were adjusted to accommodate on-going remediation activities. This adds some uncertainty to our evaluation of the data gap. However, samples collected during remediation are being evaluated for understanding the nature and extent of contamination. This reduces the uncertainty in the data gap to a level that can be addressed through the robustness of the remedies selected. Chapter 9, Development and Screening of Remedial Action Alternatives	Yes.
4. Unidentified waste sites (orphan/discovery sites) exist in 100-K.	Identify new waste sites and additional sources of contamination.	Complete OSE process inside the fence line. The discovery site process will continue until waste site and facility removal are complete.	Completed OSEs within the 100-K decision area. The results of the OSE are documented in OSR-2008-0003. As a result of the OSE, 22 new waste sites were identified and are addressed in the RI/FS.	Yes
5. The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in select areas.	Define the extent of groundwater contamination above cleanup standards in select areas of the unconfined aquifer.	Drill nine new monitoring wells (Figure 2-1) and three aquifer tubes (Figure 2-1). Install five wells to better define the extent of Cr(VI) in groundwater. Install one well to better define a Cr(VI) hot spot. Install two wells and the aquifer tubes to better define the extent of Cr(VI), Sr-90, carbon-14, TCE, and	Nine new monitoring wells were drilled and sampled to define the extent of contamination: • 199-K-183 (C7683, R1)—Define extent of Cr (VI) in groundwater • 199-K-185 (C7685, R2)—Define extent of Cr (VI), Sr-90, carbon-14, TCE, and tritium downgradient of KE Reactor • 199-K-186 (7686. R9)—Define extent of Cr(VI) in groundwater	Yes

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
		tritium downgradient of the 105-KE Reactor area. Replace Well 199-K-109A to further monitor and define the extent of the Sr-90 hot spot. Install one well to better define the extent of Cr(VI) and tritium near the 116-K-2 Trench. Collect groundwater samples and analyze for constituents on Table 2-12.	• 199-K-187 (C7687, R3)—Define extent of Cr(VI) in groundwater • 199-K-189 (C7689, R5)—Replacement Well for 199-K-109A to further define extent of Sr-90 hot-spot. • 199-K-190 (C7690, R4)—Define Cr(VI) hot-spot • 199-K-191 (C7691, R6)—Define extent of Cr(VI) and tritium near 116-K-2 Trench. • 199-K-193 (C7693, R7)—Define extent of Cr(VI) in groundwater • 199-K-194 (C7694, R8)—Define extent of Cr(VI) in groundwater Three aquifer tubes were installed and sampled: • C7641 • C7642 • C7643 Section 4.2.3, Evaluation of Water Addition to Boreholes during Sampling Soil and groundwater samples were collected as shown on Tables 2-5 and 2-6.	
6. The level of groundwater contamination entering the Columbia River has not been defined and characterized.	Collect groundwater upwelling data and information during the RI for Hanford Site releases to the Columbia River.	Collect groundwater upwelling (pore water) samples in the Columbia River. Focus on sites where contamination was detected in previous pore water sampling and where specific conductance indicates groundwater upwelling. Continue routine sampling of existing aquifer tubes. Install and sample three new aquifer tubes to provide better coverage.	Pore water samples collected for six stations to define the extent of contamination entering the Columbia River. Installed and sampled three new aquifer tubes (C7641, C7642, and C7643). Section 2.1.6, Surface Water and Sediments Section 2.1.6.1, Groundwater Upwelling and Discharge into the Columbia River Section 4.2.3, Groundwater Nature and Extent Section 4.2.4 Surface Water and Sediments	Yes

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
7. The fate and transport of contaminants beneath the unconfined aquifer has not been evaluated.	Collect physical and hydrogeologic parameters from soil samples to further support determination of contaminant fate and transport beneath the unconfined aquifer.	Drill and sample soil and groundwater from four groundwater monitoring wells drilled through the unconfined aquifer to approximately 15 m (50 ft) within the RUM unit.	Installed and sampled four new monitoring wells into the RUM: • 199-K-184 (C7684, R1)—completed and screened in Ringold unit E • 199-K-188 (C7688, R2)—completed and screened in Ringold unit E • 199-K-192 (C7692, R3)—completed and screened in the RUM • 199-K-195 (C7695, R4)—completed and screened in Ringold unit E Locations are shown in Figure 2-1. Sampled soil and groundwater from four new wells and borehole (Tables 2-5 and 2-6). Section 2.1.8, Geological Investigation 2.1.9.2, Boreholes and Test Pits 2.1.10, Groundwater Investigation Section 3.4, Geology Section 3.6, Hydrogeology Chapter 5, Fate and Transport	Yes
8. It is unknown if contamination within the RUM unit will adversely affect aquatic receptors in the Columbia River.	Update bathymetric data for the river within 100-K to support calculations of contaminant transport to the river and ecological receptors.	Aquatic ecological receptors have been identified in the river. Updated and accurate bathymetric data for the river have been obtained to evaluate flow paths of contaminants to receptors from the RUM unit.	Evaluation of the top of the RUM unit surface using nearshore river wells indicated the top of the RUM Unit does not intersect the Columbia River. Section 2.1.7.1, Bathymetric Data	Yes
9. The hydraulic rate of exchange between the groundwater and the river is unknown.	Collect geochemical and hydrogeologic data to evaluate nearshore area groundwater contaminant fate and	The nearshore area is directly affected by river stage. Limited data are available to adequately understand groundwater flow paths, contaminant migration, and mixing	Re-evaluation of groundwater remedial activities provided additional information on the hydrologic rate of exchange between the river and groundwater. It was concluded that no additional data were needed under the RI/FS.	Yes

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
	transport.	in the nearshore area.	Section 2.1.6.1, Groundwater Upwelling and Discharge into the Columbia River Section 3.6.5, Groundwater-Surface Water Interaction Section 4, Nature and Extent Chapter 5, Fate and Transport	
10. The mechanism to explain the persistence of the Cr(VI) plume is unknown.	Collect soil and water samples from the following units: vadose zone, deep vadose zone, rewetted zone, unconfined aquifer, above the RUM unit, and within the RUM unit.	Collect groundwater and soil samples from RI borings and wells. Soil and water analyses needed to determine the potential for each unit to contain sufficient Cr(VI) contamination to be a continuing source of groundwater contamination.	Drilled and sampled soil and groundwater to evaluate Cr(VI) from each of the following: • Four groundwater wells completed within the RUM unit. • Nine groundwater wells completed within the unconfined aquifer. • Two boreholes drilled through the 116-K-2 Trench, which were subsequently converted to groundwater monitoring wells completed within the unconfined aquifer. Locations are shown in Figure 2-1. Soil and groundwater samples were collected as shown on Tables 2-5 and 2-6. Section 4.2.3, Groundwater Nature and Extent Chapter 5, Fate and Transport	Yes

Table 2-1. Data Gaps and Work Conducted per the RI/FS Work Plan for 100-K

Data Gap	Data Need	Scope of Work	Work Conducted/Section with Discussion	Data Gap Filled?
11. Potential alternative remedial technologies have not been sufficiently investigated.	Evaluate alternative potential remedial technologies.	Groundwater contamination above aquatic standards and drinking water MCLs has been detected in 100-K. Interim remedial actions are currently in operation. Additional data and information are needed to evaluate potential final remedies as part of the future project FS.	Information was collected on the potential use of additional groundwater treatments at 100-K. This information was gathered through the groundwater remedial process optimization (RPO) activity, and through further evaluation of existing technologies as part of this feasibility study. Section 1.2.4.5, Previous Groundwater Investigations and Remediation Chapter 8, Technology Screening Chapter 9, Development and Screening of Remedial Action Alternatives Appendix I, Technologies not Retained	Yes
12. Insufficient data are available to support fate and transport modeling.	Collect additional data to support future fate and transport modeling. Assess the physical and hydraulic properties of soil and estimate contaminant K_d to support modeling.	Estimate soil and hydraulic properties, determine level of contamination, confirm contaminant K_ds, and perform batch leach contacting test on selected soil samples.	Collected physical soil properties (Table 2-5) from RI borings including batch leach, soil analytical, and physical property data. Performed batch leach testing on six RI borings (C7684, C7686, C7688, C7695, C7831, and C7832) (locations are shown in Figure 2-1). Section 3.5.1, Vadose Zone Below the Soil Horizon Section 5.7.1, Factors Affecting Contaminant Migration in the Vadose Zone	Yes
13. Data are needed to define the spatial and temporal distribution of groundwater contamination.	Collect and analyze groundwater samples from select groundwater monitoring wells.	Collect and analyze groundwater samples from 18 groundwater monitoring wells at three river stages (high, low, and transitional) to characterize the spatial, temporal, and chemical extent of groundwater contamination. Wells are shown in Figure 2-1.	Sampled 18 wells three times in 2010, to be representative of high, low, and transitional river periods. These additional data were evaluated in conjunction with the historical data. Section 2.1.9.4, Spatial and Temporal Groundwater Sampling Section 4.2.3, Groundwater Nature and Extent Chapter 6, Human Health Risk Assessment	Yes

Source: OSR-2008-0003, *100-K Area Orphan Sites Evaluation Report.*

Table 2-2. Supplemental Investigations and Other Primary Investigations

Scope of Work Identified	Section with Discussion
Evaluating and developing approaches to obtain data that will demonstrate compliance with AWQSs in the river for final ROD decisions. In April 2008, a technical review panel was convened to evaluate groundwater interactions with the Columbia River (SGW-39305). The panel suggested that the current mixing/dilution conceptual model should be re-evaluated. In addition, data may be needed to show representativeness of contaminant concentrations for compliance. Therefore, evaluation will include determination of whether 1:1 dilution assumption for groundwater entering the river is valid, and may include evaluation of whether data from aquifer tube samples are representative. Data collected as part of the RI for site releases to the Columbia River may be useful in this evaluation.	Section 2.1.11, Supplemental Investigations
Collecting data and developing River Corridor background values in soil for antimony, boron, molybdenum, and selenium. Site-specific background values for these constituents may be needed to determine final soil RAG values where calculated risk-based concentrations and/or ecological protection concentrations are less than background. Interim remedial actions have used Washington State background values for antimony and selenium; interim soil RAGs for boron and molybdenum are above expected site-specific background values.	Section 2.1.11, Supplemental Investigations
Re-evaluate soil cleanup level for Cr(VI) to support the final ROD. The lowest soil RAG for Cr(VI) under the interim RODs is 2.0 mg/kg. However, the calculated WAC-173-340-747(3)(a) (2007) soil RAG value may be below the current limits of analytical quantitation in environmental samples, depending on the soil-partitioning value and groundwater-to-river dilution attenuation factor used, and final soil cleanup values may default to the limits of quantitation. Because there is uncertainty in analytical detection and quantitation of Cr(VI) near the limits of detection, it may be necessary to consider the realistic capabilities of analytical performance in determination of a final soil cleanup value.	Section 2.1.11 , Supplemental Investigations
Determining a site-specific soil-partitioning value for antimony. This value is necessary for calculation of WAC-173-340-747(3)(a) (2007) soil RAG values for antimony. Antimony is not a significant contaminant in the River Corridor, and determination will include review of scientific literature, which suggests antimony soil partitioning values in the range of 1.4 to 45 mL/g.	Section 2.1.11, Supplemental Investigations
Re-evaluate soil cleanup levels for arsenic to support the final ROD. The soil RAG for arsenic under the interim RODs is 20 mg/kg, based on the Tri-Party Agreement (Ecology et al., 1989a) to use the WAC-173-340-740(2) (1996) Method A value (DOE/RL-96-17). The WAC-173-340-740(2) (2007) Method A value is also 20 mg/kg. The WAC-173-340-740(3) (2007) Method B and WAC 173-340-747(3)(a) (2007) soil values for arsenic are below the site arsenic background of 6.5 mg/kg. Selection of a final soil cleanup level for arsenic in the River Corridor will be accomplished through development of final RODs.	Section 2.1.11, Supplemental Investigations

Table 2-2. Supplemental Investigations and Other Primary Investigations

Scope of Work Identified	Section with Discussion
Other Primary Investigations that Potentially Affect Feasibility Study Decisions for Waste Sites and Groundwater Contamination	
Columbia River Pore Water RI	Section 2.1.6, Surface Water and Sediment Investigation Section 3.6.4, Supra-Basalt Sediments and Section 4.2.4, Anomalous Metal Concentrations in Selected 100-K RI Samples
River Corridor Baseline Risk Assessment	Chapter 6 Human Health Risk Assessment Chapter 7 Ecological Risk Assessment
Annual Groundwater Monitoring	Section 2.1.9.5, Ongoing Groundwater Monitoring Section 4.2.3, Groundwater Nature and Extent
Ongoing Aquifer Tube Sampling	Section 2.1.9.5, Ongoing Groundwater Monitoring Section 4.2.3, Groundwater Nature and Extent

Sources:

DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*.

Ecology et al., 1989a, *Hanford Federal Facility Agreement and Consent Order*.

SGW-39305, *Technical Evaluation of the Interaction of Groundwater with the Columbia River at the Department of Energy Hanford Site, 100-D Area*.

WAC 173-340-740, "Model Toxics Control Act—Cleanup," "Unrestricted Land Use Soil Cleanup Standards."

WAC 173-340-747, "Deriving Soil Concentrations for Groundwater Protection."

Table 2-3. Summary of 100-K RI Field Program

Type	Number
New boreholes (converted to temporary monitoring wells in unconfined aquifer)*	2
New wells (unconfined aquifer)*	9
New wells (extending into the RUM unit)*	4
New aquifer tube locations (one location with three tubes)	1
Spatial and temporal uncertainty monitoring wells	18

* Changes to location and construction of wells and boreholes identified in the 100-K SAP (DOE/RL-2009-41) appear in *Change Notice for Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0* (TPA-CN-357); *Tri-Party Agreement Change Notice Form: Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0 (As amended by TPA-CN-257, June 1, 2010)* (TPA-CN-384); and *Tri-Party Agreement Change Notice Form: Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0 (As amended by TPA-CN-384, October 6, 2010)* (TPA-CN-405).

1

Table 2-4. Number of Field Samples Collected in 100-K

Sample Location	Soil*	Groundwater*
New boreholes (converted to temporary monitoring wells in unconfined aquifer)	29	5
New permanent and temporary wells (unconfined aquifer)	123	138
New permanent and temporary wells (extending into the RUM unit)	88	70
New aquifer tube locations (one location with three tubes)	0	12
Spatial and temporal uncertainty monitoring wells	0	54

Note: Table does not include QC or archive samples.

* The number of samples taken reflects the number of intervals sampled (100-K SAP [DOE/RL-2009-41]; *Change Notice for Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0* [TPA-CN-357]). The samples from each interval were then split amongst several laboratories for different analyses.

2

Table 2-5. Summary of Soil Samples Collected for 100-K

Well ID	Well Name	Soil Chemistry		Physical Properties		Deviations from SAP
		No. Required	No. Collected	No. Required	No. Collected	
C7683	199-K-183	7	7	5	5	None
C7684	199-K-184	20	20	5	7	Additional physical properties samples collected at approximately 7.6 and 15.2 m (25 and 50 ft) into RUM.
C7685	199-K-185	11	7	5	5	None (per TPA-CN-357)
C7686	199-K-186	21	23	5	5	Five additional samples collected based on observation of suspected petroleum hydrocarbon between approximately 12.2 and 18.3 m (40 and 60 ft) bgs.
C7687	199-K-187	7	7	5	5	None
C7688	199-K-188	25	25	5	8	Additional physical properties samples collected at approximately 1.5, 7.6, and 15.2 m (5, 25, and 50 ft) into RUM.
C7689	199-K-189	17	17	5	5	None
C7690	199-K-190	15	15	5	5	None
C7691	199-K-191	7	7	5	8	Contact between the Hanford formation and Ringold Formation was at deeper depth than estimated; therefore, additional physical property samples were collected to capture the requirements of the SAP (DOE/RL-2009-41).
C7692	199-K-192	10	12	5	7	The bottom of the unconfined aquifer was encountered deeper than estimated; therefore, two additional samples for chemical analyses were collected to satisfy the SAP requirement of a sample collected at the bottom of the unconfined aquifer. Additional physical properties samples collected at approximately 7.6 and 15.2 m (25 and 50 ft) into RUM.

Table 2-5. Summary of Soil Samples Collected for 100-K

Well ID	Well Name	Soil Chemistry		Physical Properties		Deviations from SAP
		No. Required	No. Collected	No. Required	No. Collected	
C7693	199-K-193	7	7	5	3	Contact between the Hanford formation and Ringold Formation was encountered at a depth approximately 4.6 m (15 ft) shallower than estimated; therefore, samples at approximately 3 and 1.5 m (10 and 5 ft) above the Hanford formation/Ringold Formation contact were not collected.
C7694	199-K-194	7	5	5	6	Groundwater encountered approximately 3 m (10 ft) higher than expected; therefore, two fewer samples were collected. An additional physical properties sample was collected at approximately 1.5 m (5 ft) into RUM
C7695	199-K-195	23	23	5	8	Contact between the Hanford formation and Ringold Formation was at deeper depth than estimated; therefore, additional physical property samples were collected to capture the requirements of the SAP. Additional physical properties samples collected at approximately 7.6 and 15.2 m (25 and 50 ft) into RUM.

Source: TPA-CN-357, *Change Notice for Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0*

Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, hereinafter called 100-K SAP (DOE/RL-2009-41)

1
2

Table 2-6. Summary of Water Samples Collected for 100-K

Well ID	Well Name	SAP Requirement	Approximate Depth Sampled (m/ft bgs)		No. of Intervals	Deviations from SAP
C7683	199-K-183	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	22.9, 24.4, 25.8, 27.6, 28.9, 30.3, 32, 33.5, 35.4, 36.6, 38, 39.3, 41.2, 42.8, and 44.1	75, 80.2, 84.5, 90.4, 94.8, 99.5, 105, 110, 116, 120, 124.8, 129, 135.2, 140.3, and 144.8	15	The first sample into the water table was not collected due to a cemented formation, which did not allow for adequate water production.
C7684	199-K-184	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer and from water-bearing intervals of the RUM unit	24.9, 26.4, 27.4, 29, 31.7, 32.1, 33.7, 35.2, 36.4, 38.1, 39.4, 41.1, 42.7, 44.2, 45.7, 47.3, and 48.7	81.5, 86.7, 90.0, 95.0, 104, 105.2, 110.7, 115.5, 119.4, 125.1, 129.4, 135.0, 140.0, 145, 149.8, 155.3, and 159.9	17	None
C7685	199-K-185	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	15.8, 17.4, 19.1, 20.5, 21.9, 23.5, 25, 26.5, 28, 29.6, 31.1, 32.4, 34.1, 35.7, 37.2, 38.7, and 40.2	52, 57, 62.5, 67.2, 72, 77.2, 82, 87.1, 92, 97, 102, 106.4, 112, 117, 122, 127, and 132	17	None
C7686	199-K-186	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	27.1, 28.6, 30.2, 32, 33.5, 35.1, 36.6, 38.5, 39.6, 41.1, 42.8, 44.3, 46.3, 47.2, and 48.8	89, 93.8, 99.2, 105, 110, 115.1, 120, 126.3, 130, 134.9, 140.3, 145.2, 150, 155, and 160	15	None
C7687	199-K-187	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	35.9, 36.9, 38.4, 38.7, 39.9, 43.3, 44.3, 45.9, 47.7, 49.1, 50.3, 52.1, 53.3, 55.4, 57, 58.5, and 59.6	117.7, 121.2, 126, 127, 131, 142, 145.5, 150.5, 156.5, 161, 165, 171, 175, 181.8, 187, 192, and 195.7	17	None
C7688	199-K-188	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer and from water-bearing intervals of the RUM unit	32, 33.5, 35, 36.6, 38.1, 39.8, 41.1, 42.7, 44.2, 45.7, 48.8, 50.3, 50.7, 53.3, 54.5, and 56.1	105, 109.9, 114.9, 120.2, 125, 130.5, 135, 140, 145, 150, 160, 164.9, 166.2, 172.9, 178.9, and 184	16	Sample scheduled for approximately 47.2 m (155 ft) bgs (16.8 m [55 ft] into unconfined aquifer) could not be collected due to heaving sand. A sample was attempted at 52.7 m (172.9 ft), but was not successful.

Table 2-6. Summary of Water Samples Collected for 100-K

Well ID	Well Name	SAP Requirement	Approximate Depth Sampled (m/ft bgs)		No. of Intervals	Deviations from SAP
C7689	199-K-189	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	23.5, 25, 26.7, 28, 29.6, 31.1, 32.6, 34.1, 35.7, 37.2, 38.7, 40.2, 41.8, 43.3, 44.8, and 46.3	77, 82, 87, 92, 97, 102, 107, 112, 117, 122, 127, 132, 137, 142, 147, and 152	16	None
C7690	199-K-190	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	18, 19.5, 21, 22.6, 24, 25.6, 27.1, 28.5, 30.2, 31.6, 33, 34.6, 36.2, 37.6, 39.3, and 40.8	59, 64, 69, 74, 78.6, 84, 89, 93.6, 99, 103.7, 108.3, 113.6, 118.7, 123.5, 129, and 133.7	16	None
C7691	199-K-191	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	23.8, 25.3, 26.8, 27.6, 29.7, 31.2, 32.9, 34.1, 35.8, 37.5, 39, 40.5, 42, 43.6, 45.1, and 47.2	78, 83, 88, 90.7, 97.3, 102.3, 108, 112, 117.5, 123, 128, 133, 137.7, 143, 148.1, and 155	16	None
C7692	199-K-192	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer and from water-bearing intervals of the RUM unit	16.8, 18.3, 19.8, 21.4, 22.9, 24.4, 25.8, 27.3, 28.7, 30.4, 31.9, 33.7, 35.1, 36.8, 38.1, 39.7, 41.5, 42.8, and 55.5	55, 60, 65, 70.1, 75, 80.2, 84.6, 89.7, 94.3, 99.6, 104.7, 110.6, 115.3, 120.6, 125, 130.1, 136.0, 140.5, and 182.0	19	None
C7693	199-K-193	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	25.1, 26.8, 28.3, 29.9, 31.4, 32.9, 32.9, 35.7, 37.5, 38.1, 40.5, 42.1, 43.6, 45.2, 46.6, and 48.2	82.5, 88, 93, 98, 103, 108, 113, 117, 123, 128, 133, 138, 143, 148.2, 153, and 158	16	None
C7694	199-K-194	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer	26.8, 28.4, 29.9, 31.5, 33, 34.5, 34.5, 37.7, 39.2, 40.8, 42.1, and 43.3,	88, 93, 98, 103.2, 108.2, 113.2, 117.6, 123.6, 128.6, 134, 138, and 142.2	12	None
C7695	199-K-195	Collect sample every 1.5 m (5 ft) throughout unconfined aquifer and from water-bearing intervals of the RUM unit	27.5, 29, 30.4, 31.9, 33.6, 35, 36.4, 38.2, 39.6, 41.1, 42.7, 44.2, 45.7, 47.2, 48.8, 50.3, 51.8, and 53.6,	90.1, 95.1, 99.7, 104.6, 110.3, 114.9, 119.5, 125.2, 130.0, 134.8, 140, 145, 150, 155, 160, 165, 170, and 175.8	18	None

Source: DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*, Rev. 0

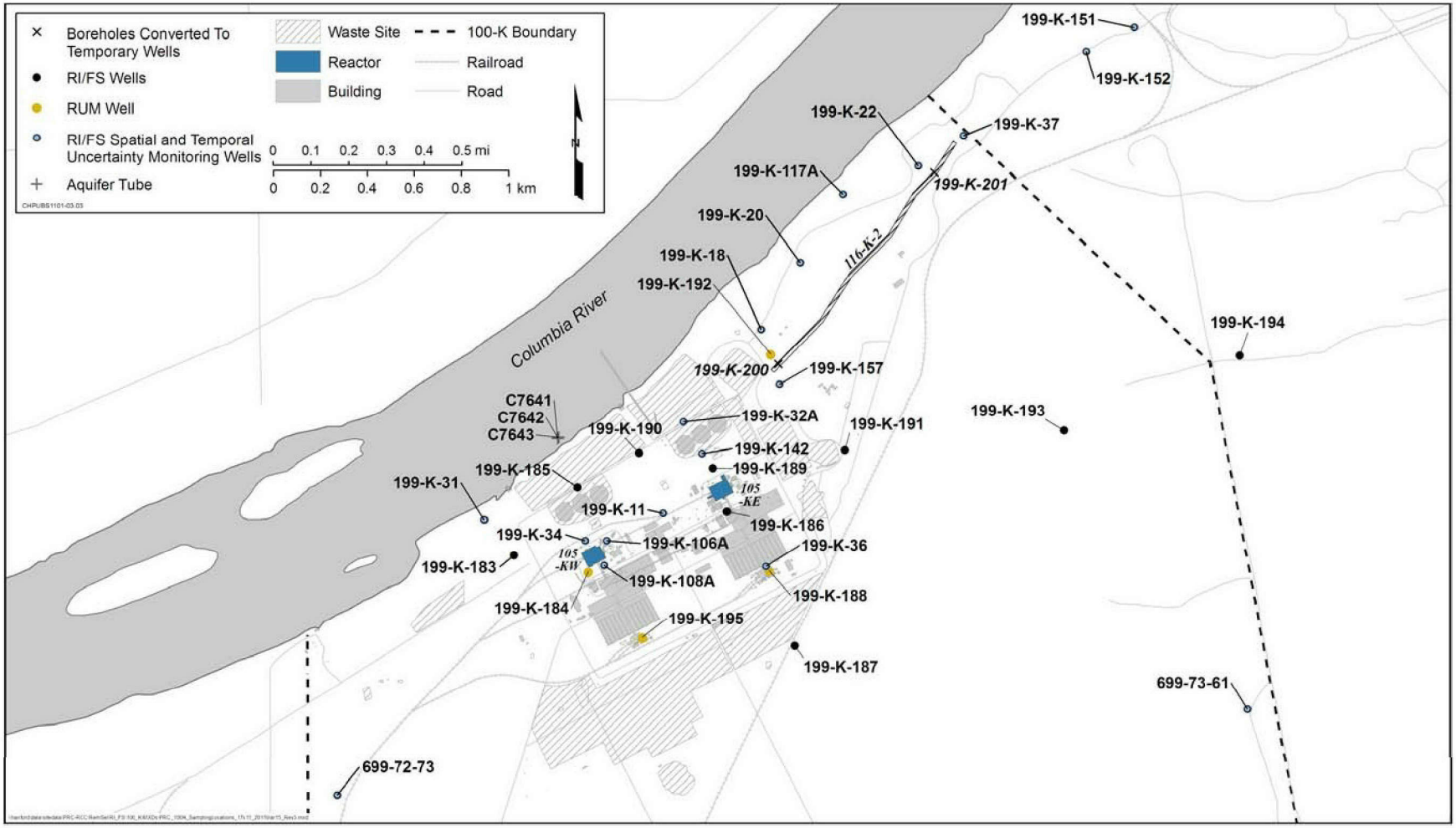


Figure 2-1. Map Showing RI Sampling Locations per 100-K SAP

Appendix C includes specific information for each borehole and sampling interval. The following sections present details of investigations conducted under the RI, as well as investigation activities conducted under other scopes of work that may affect the FS decisions including the Columbia River RI Work plan (DOE/RL-2008-11) and the RCBRA Report (DOE/RL-2007-21, Draft C).

The following lists significant work plan deviations:

- **Well 199-K-189 location.** The planned location for Well 199-K-189 interfered with the access roads for the ongoing demolition and waste site remediation activities. The well was moved approximately 75 m (250 ft) to the north to avoid this conflict.
- **Geophysical logging.** No neutron moisture log was conducted at 199-K-183.

Other approved deviations include the following:

- **Vadose zone boreholes**. The boreholes advanced into the 116-K-2 Trench were converted to temporary wells in order to obtain representative water samples from beneath the trench. Water samples were not obtained during drilling due to poor aquifer conditions, which prevented getting a representative water sample. This change was conducted per *Tri-Party Agreement Change Notice Form: Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0 (As amended by TPA-CN-257, June 1, 2010)* (hereinafter called CN for 100-K SAP June 1 Amendment [TPA-CN-384]).
- **Well completions in the RUM.** Wells 199-K-188 and 199-K-195 were constructed as temporary wells using polyvinyl chloride (PVC) piping. This change was conducted per CN for 100-K SAP June 1 Amendment (TPA-CN-384).
- **Well 199-K-186 location.** Well 199-K-186 was relocated from its planned location to provide additional characterization of the KE Reactor area. This relocation was conducted per *Change Notice for Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0* (hereinafter called CN for 100-K SAP [TPA-CN-357]).

2.1.1 RI Data Sets Used in RI/FS

Historical data as well as data collected from the RI were evaluated in this report. Appendix D provides additional details on the data set along with data. The following is a list of the available data that were compiled for the RI/FS dataset:

- Data collected as part of ongoing site sampling programs or prior to initiation of the current RI/FS field investigation activities:
  - Waste site remediation action soil analytical data (cleanup verification package [CVP] and Remaining Site Verification Packages [RSVP] data). This data set was used in the evaluation of groundwater protection (Chapter 5), human health risk assessment (Chapter 6), and ecological risk assessment (Chapter 7).
  - Field investigation soil analytical data (LFI data). This data set was used in the evaluation of nature and extent (Chapter 4).
  - Groundwater analytical data (January 1, 2006 to December 31, 2010). This data set was used in the nature and extent of groundwater (Chapter 4) and provides the basis for the initial plumes for groundwater modeling (Appendix F).

  - Well and borehole drilling and construction information. This data set was used in the development of the geologic cross-sections (Chapter 3) and groundwater model development (Chapter 5 and Appendix F).
  - Fate and transport parameters (e.g., geochemical parameters, hydrogeologic parameters, soil physical properties). Those data set was used in the development of the groundwater model and fate and transport evaluations (Chapter 5 and Appendix F).
  - Geologic information. This data set was used in the development of the geologic cross-sections (Chapter 3) and groundwater model development (Chapter 5 and Appendix F).
  - Groundwater levels and River Stage. This data set was used in the development of groundwater flow maps (Chapter 3) and groundwater model developments (Chapter 5 and Appendix F).

- Data collected as part of the ongoing interim waste site remediation (in process sampling), which is used to validate the CSM, is qualitatively discussed in Chapter 4.
- Data collected during the RI/FS field investigation activities (May 2010 to February 2011) as described in the 100-K Work Plan (DOE/RL-2008-46-ADD2), and 100-K SAP (DOE/RL-2009-41), (Table 2-1).
  - Soil analytical data. Depth specific soil samples collected during RI boring and well installation are used to evaluate contaminate distribution in the vadose zone and confirm the CSM (Chapter 4).
  - Groundwater analytical data
    - Spatial and temporal groundwater monitoring data. This data set was used in the human health risk assessment (Chapter 6) and understanding of spatial and temporal distribution of contaminants (Chapter 4).
    - Groundwater samples collected form RI borings and monitoring wells. Depth discrete groundwater samples were used in understand the vertical distribution of contaminants in groundwater (Chapter 4) and confirm the CSM.
  - Soil physical properties (grain size, moisture content, and porosity). These data were used in the groundwater model development (Chapter 3 and Appendix F).
  - Hydraulic conductivity. These data were used in the groundwater model development (Chapter 3 and Appendix F).
  - Geophysical logging. The geophysical logs from the RI borings are presented in Chapter 3. These data help with the understanding of the CSM and transport of contaminants through the vadose zone.
  - Distribution coefficient data for metals. This data set is used in the evaluation of fate and transport of metals (Chapter 5).

Analytical data used in the RI/FS were collected and analyzed in a fixed laboratory using approved methods with specific QA/QC requirements. Detection limits, precisions, accuracy, and completeness were assessed to determine whether the chemical and radiochemical data obtained were the right type, quality, and quantify to support regulatory decision-making. Data validation for the RI/FS is provided in Appendix D.

2.1.2 Historical Information Review

Historical information for 100-K was researched and considered during the work plan development and in the preparation of this report. Section 1.2.3 and Appendix B summarize those reports containing relevant or significant information, along with an annotated bibliography.

2.1.3 Surface Features

Surface feature mapping, such as high-resolution topography, was conducted using Light Detection and Ranging (LIDAR) mapping technology. LIDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

The current accuracy of the LIDAR topography is estimated at 0.011 m (4.3 in.). LIDAR mapping is used to create a topographic map for 100-K for defining surface relief/elevation differences (Section 3.1). Surface topography establishes part of the framework needed to evaluate fate and transport.

2.1.4 Contaminant Source Investigations

The OSE process in 100-K was completed in February 2008 to identify potential new (orphan) waste sites (*100-K Area Orphan Sites Evaluation Report* [OSR-2008-0003]). The OSE, as part of the nonoperational evaluation, is discussed in Chapter 1 and included in Data Gap 4. In addition, discovery sites continue to be identified during ongoing remedial actions such as RTD excavations of known waste sites.

2.1.5 Meteorological Investigations

The Hanford Meteorological Station (HMS) is operated by Mission Support Alliance for DOE (http://www.hanford.gov/hms/). HMS provides a range of Hanford Site weather forecast products and real-time meteorological data, and an extensive historical database of meteorological and climatological data. Metrological measurements have been made at HMS since late 1944. Information specific to precipitation and wind speed have the potential to affect remedial actions, as discussed in Section 3.2. No additional meteorological data were collected as part of this RI/FS.

2.1.6 Air Investigations

Hanford Site contractors monitor radionuclide airborne emissions from site facilities through several programs. The Near-Facility Environmental Monitoring Program measures concentrations of radionuclides in the ambient air on the Hanford Site in or near facilities and operations. The Hanford Site Environmental Surveillance Program measures the ambient air at sitewide locations away from facilities, offsite around the site perimeter, and in nearby and distant communities. In addition, emissions from stacks, vents, or other types of point sources are monitored individually by analyzing samples extracted from the outflow at each point of release. The data collected by each program are used to assess the effectiveness of emission treatment and control systems and pollution management practices, and determine compliance with state and federal regulatory requirements. These regulations include a radiological standard, which requires that Hanford Site emissions shall be controlled such that no member of the public in any area of unrestricted access receives greater than 10 mrem/yr total effective dose equivalent. In some cases, remedial activities are provided with project-specific point source and/or ambient air sampling to assemble project-specific data. DOE provides information to Washington State and EPA clean air offices describing the emissions and resultant maximum public dose from ongoing CERCLA activities. This information addresses contributions both from point sources and from all fugitive or diffuse sources of emissions of radionuclides.

Nonradioactive air pollutants are emitted from a variety of sources at the Hanford Site. These emissions are monitored at the source when activities are known to actually or potentially generate pollutants of concern. DOE provides information to Washington State and EPA clean air offices describing the

emissions. The following text describes the most recently published information regarding Hanford Site air monitoring activities (2009 Sitewide Environmental Report [PNNL-19455]).

2.1.6.1 Air Monitoring Near Facilities and Operations

In 2009, ambient air was monitored at locations on the Hanford Site near facilities and operations. Samplers were located primarily at or within about 500 m (1,640 ft) of sites or facilities having the potential for, or a history of, environmental radiation releases. This near-facility environmental monitoring is conducted near facilities or projects that provide the potential to disperse radioactivity. Monitoring locations are associated largely with major nuclear facilities and waste storage, disposal, or cleanup activities.

2.1.6.2 Air Monitoring at Hanford Sitewide and Offsite Locations

During 2009, as part of the Hanford Site Environmental Surveillance Program, samples were collected at 42 continuously operating sitewide and offsite locations: 23 onsite (sitewide), 11 at site perimeter locations, 7 in nearby communities, and 1 in a distant community. Samples were collected from known or expected air transport pathways, which are generally downwind of potential or actual airborne releases and downgradient of liquid discharges. Airborne particle samples were collected at each station biweekly and monitored for gross alpha and gross beta concentrations. Biweekly samples were combined into quarterly composite samples and analyzed for gamma emitting radionuclides. Samples of atmospheric water vapor were collected every four weeks and analyzed for tritium at 20 locations. All air sample results showed very low radiological concentrations in 2009, with resultant exposure to any public individual remaining well below the dose standard of 10 mrem/yr total effective dose equivalent. Ambient air sampling is the primary method used in monitoring fugitive emissions, with other media samples possibly useful as secondary indicators.

Hanford Site contractors also monitor for other impacts from airborne emissions or other releases from site facilities. This is done through sampling of various environmental media besides the air, also as part of the Surface Environmental Surveillance Program. Routine monitoring includes sampling surface contamination, external radiation doses, soil, vegetation, and animals. All doses from Hanford Site activities in 2009 were lower than EPA and DOE standards. While not a required action for the CERCLA remedial action, the State of Washington Department of Health also conducts independent sampling and analysis of various media, including ambient air, soil, and biota, both on and off the Hanford Site. This independent sampling and analysis routinely confirms little or no environmental impacts outside of Hanford's most closely controlled work areas.

No additional air monitoring, with the exception of in-process monitoring at the immediate worksite during select borehole, well, and test pit activities, was conducted as part of this RI/FS.

2.1.7 Surface Water and Sediment Investigations

An investigation of pore water, surface water, and sediment was conducted to identify the nature and extent of contaminants entering the Columbia River, specifically by groundwater upwelling. The effort was performed according to the Columbia River RI Work Plan (DOE/RL-2008-11), and activities planned prior to the RI/FS investigation as outlined in the 100-K Work Plan (DOE/RL-2008-46-ADD2). As such, Data Gaps 6 and 9 (Table 2-1) denote the importance of addressing groundwater discharge and surface water/groundwater mixing to support decision making in a ROD. Details of this investigation are presented in the Columbia River RI Work Plan.

Additional data related to groundwater discharge to surface water (Data Gap 6) and surface water/groundwater mixing (Data Gap 9) were identified as necessary to support remedy decisions. An investigation of pore water, surface water, and sediment was conducted to identify the nature and extent

of contaminants entering the Columbia River, specifically by groundwater upwelling in the Columbia River. The following sections provide details on these investigations.

2.1.7.1 *Groundwater Upwelling and Discharge into the Columbia River (Pore Water, Surface Water, and Sediment Sampling)*

The groundwater beneath the Hanford Site discharges to the Columbia River via seeps and upwelling to the riverbed. This flow path for groundwater provides a means to transport Hanford Site contaminants, which may have leached into the groundwater from the past waste disposal practices, to the Columbia River.

The availability of historical data to adequately understand preferential groundwater flow paths, contaminant migration restrictions, and groundwater and river water mixing in the nearshore area is limited. A range of mixing ratios has been observed (*Technical Evaluation of the Interaction of Groundwater with the Columbia River at the Department of Energy Hanford Site, 100-D Area* [SGW-39305]) between river water and upwelling water at the bottom of the river and between river water and groundwater at nearshore locations. Water data were collected near 100-K in 2009 and 2010 to address the uncertainty related to the level of contamination entering the Columbia River via upwelling, including the contaminant transport mechanisms. Pore water sampling in the Columbia River was conducted during three phases, as outlined in the Columbia River RI Work Plan (DOE/RL-2008-11).

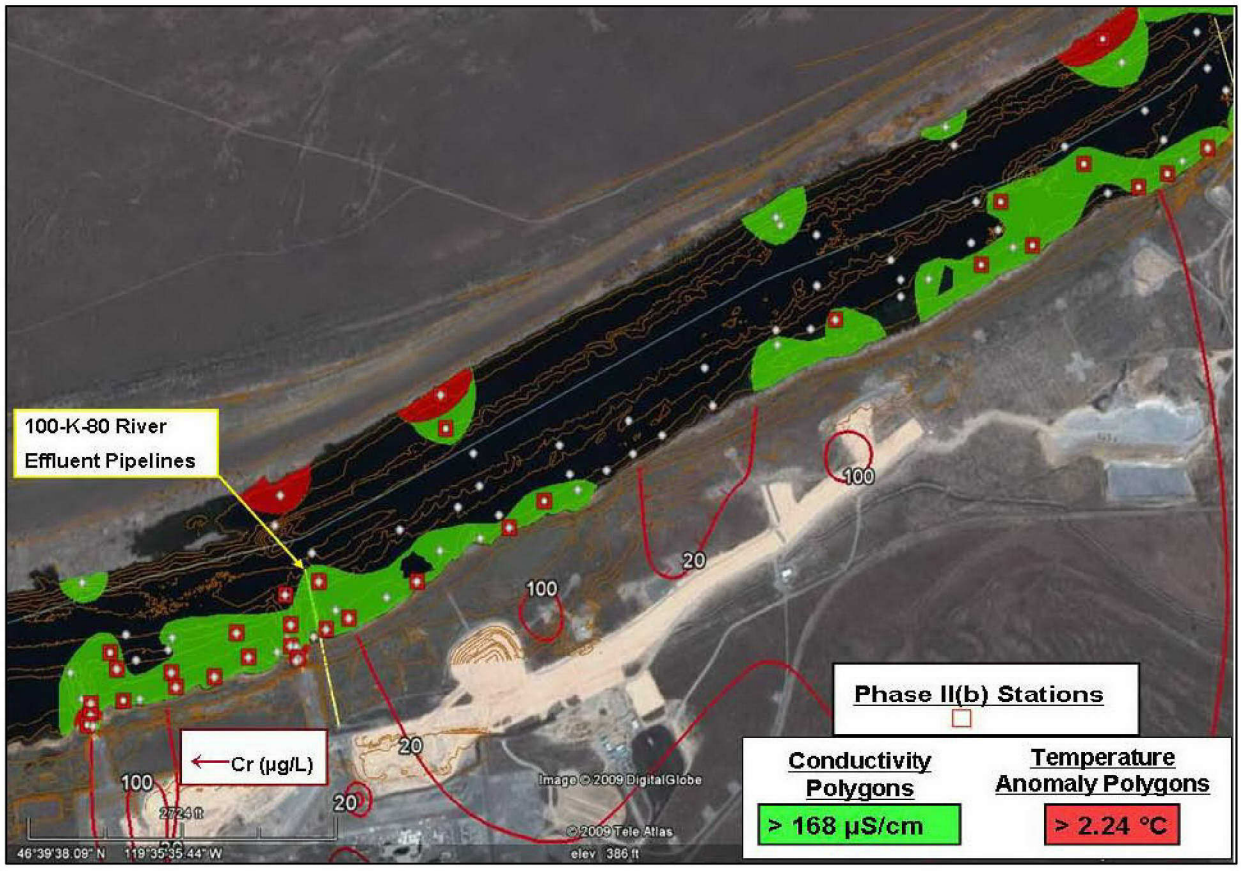
The first phase of the Columbia River RI pore water sampling was a technology demonstration to verify that the proposed equipment could be used in the variable conditions found in the Hanford Reach section of the Columbia River. The second phase, which actually consisted of two phases, was designed to delineate where groundwater upwelling was occurring. The first, termed Phase IIa, focused on identifying riverbed areas where groundwater was entering the Columbia River, based on conductivity and temperature measurements. The next phase, termed Phase IIb, returned to a subset of the Phase IIa sample locations to collect pore water samples in September and October 2009 for indicator contaminant analysis. For 100-K, the indicator contaminant for Phase IIa was temperature and conductivity; during Phase IIb, it was Cr(VI). Phase III sampling, conducted in January and February 2010, identified a subset of the previous sample locations for sampling and analysis of pore water, surface water (defined as water 0.3 m [1 ft] above the riverbed), and collocated sediment for a wide range of potential contaminants.

The objective of Phase IIa sampling was to identify and delineate groundwater upwelling in the Columbia River adjacent to Hanford Site operations areas. Pore water data were collected using a multi-sensor water sampling probe capable of being inserted approximately 30 cm (12 in.) into the riverbed and measuring conductivity and temperature in situ. Six cross-river transects were conducted near 100-K as the focus of data collection, each of which had five separate sample locations. Additionally, 10 locations surrounding the transects were sampled and, when combined, resulted in a potential of 90 sample points in 100-K. All pore water sample data collected in Phase IIa were analyzed for conductivity and temperature only.

Pore water sampling for Phase IIb was conducted at a subset of the Phase IIa locations (32 locations) that clearly showed groundwater upwelling based on conductivity and temperature variances between the river and pore water, and which were deemed most likely to show contamination. These sample locations were approved by the Tri-Parties as shown in Figure 2-2 (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington* [WCH-380]).

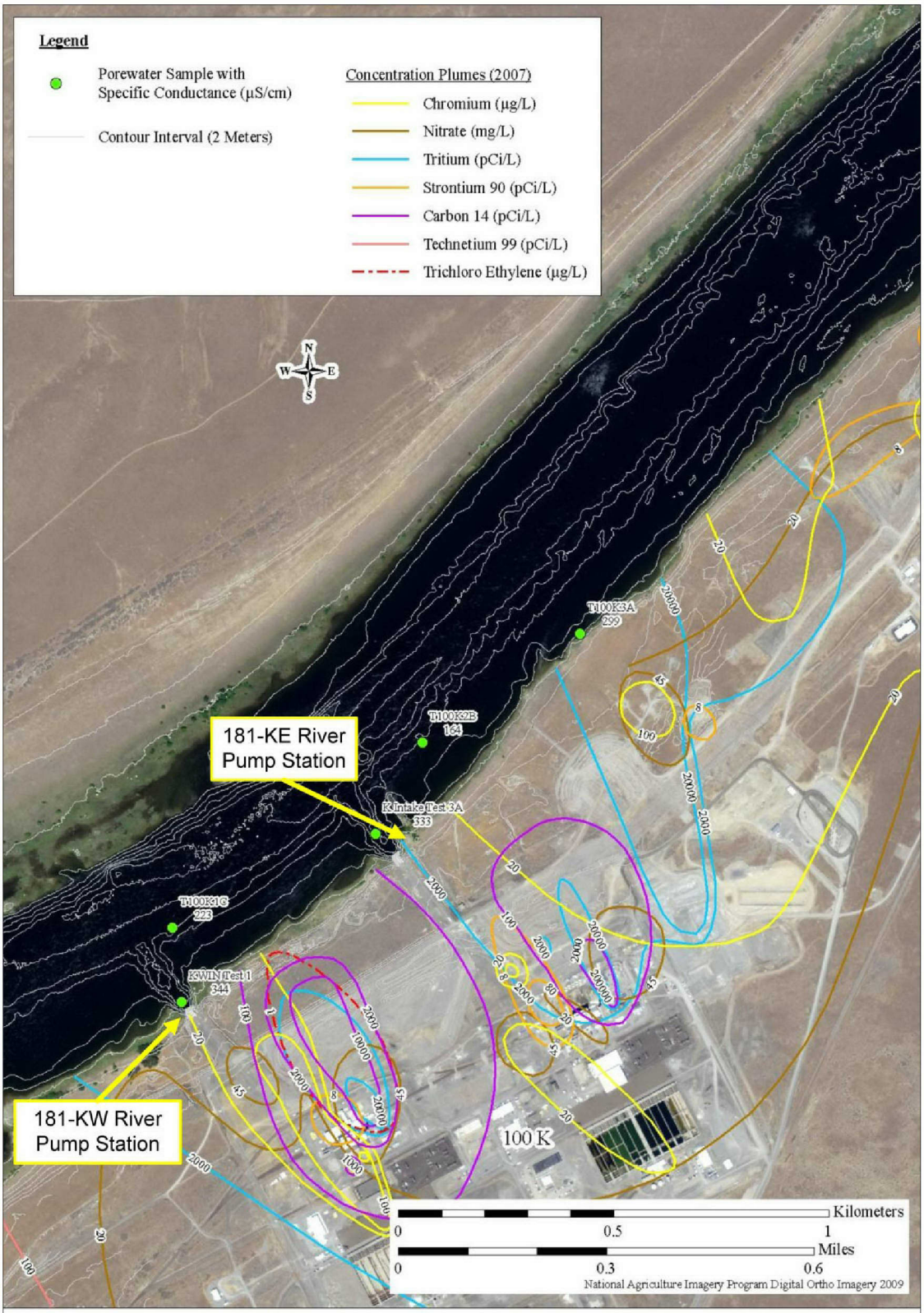
Pore water samples for Phase III were collected from established upwelling locations, with the focus on sites where the indicator contaminant (Cr(VI)) was detected in the Phase IIb pore water samples (10 sites). The Tri-Parties selected six locations near 100-K for Phase III sampling (shown in Figures 2-3 and 2-4) consisting of five primary sites and one secondary site (to be collected after primary sites had been collected).

Pore water and sediment samples were successfully obtained from these locations and analyzed for a range of radiological and nonradiological analytes (listed in Table 2-7). Chapter 4 presents the results from the sampling efforts. Table 2-8 provides information on the number of pore water samples collected during each sampling phase and the collection period.



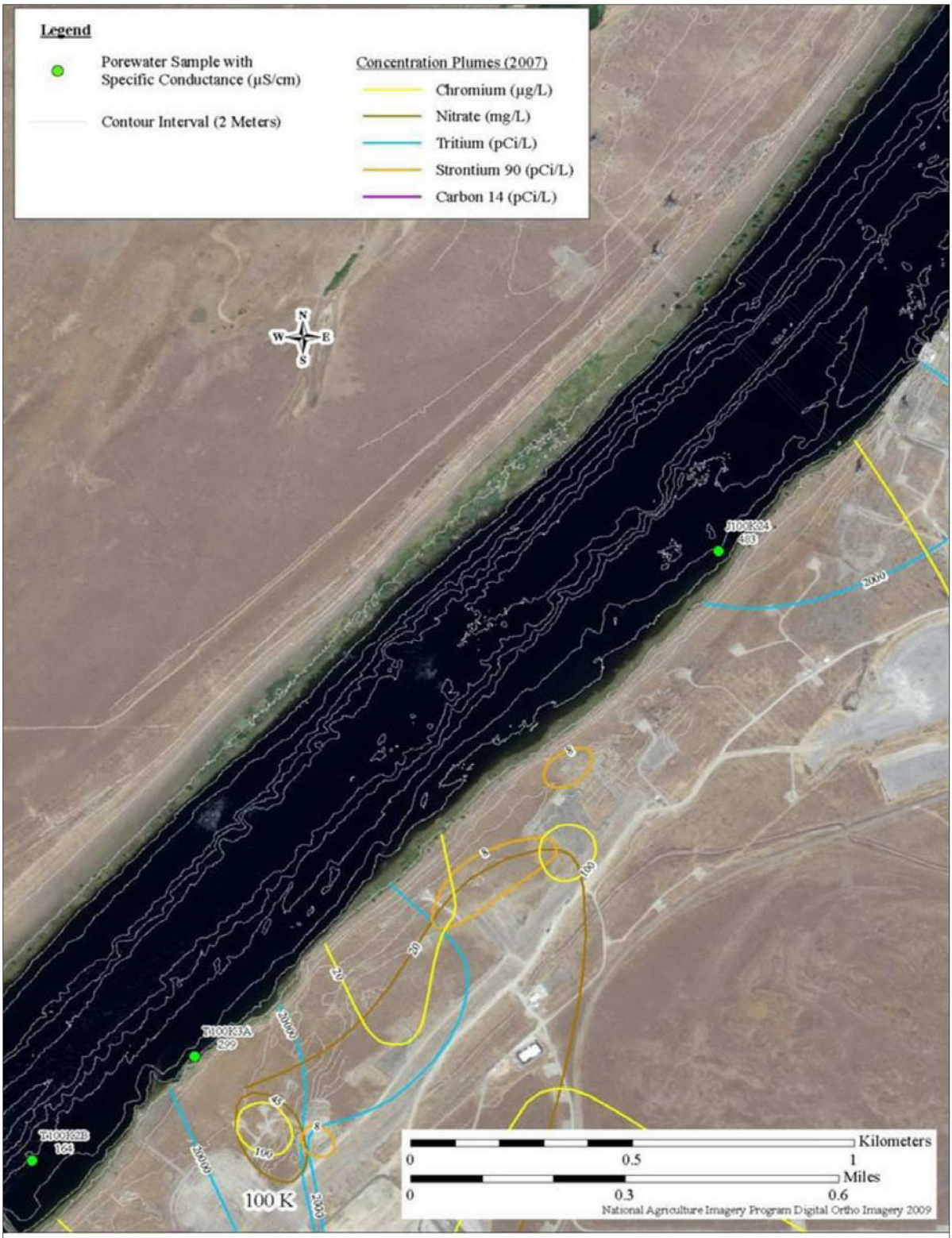
Source: WCH-380, *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling*, Figure 3-5.

Figure 2-2. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase IIb Indicator Contaminant Sample Locations at 100-K



Source: Figure 3-61, Sheet 1, WCH-380

Figure 2-3. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase III Indicator Characterization Sample Locations for 100-K



Source: Figure 3-61, Sheet 2, WCH-380

Figure 2-4. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase III Characterization Sample Locations for 100-K

2.1.7.2 Surface Water Sampling

During Phase III, the influence of contaminants on the water quality immediately above groundwater upwelling locations was determined by taking surface water column samples. River water and pore water samples were collected concurrently at approximately 0.3 m (12 in.) above the riverbed. At 100-K, surface water sample analysis at all six sample locations included the analytes listed in Table 2-7. Table 2-8 provides information on the number of surface water samples collected and the collection period.

2.1.7.3 Sediment Sampling

Sediment samples collected during Phase III of the study from the locations shown in Figures 2-3 and 2-4 were analyzed for a range of radiological and nonradiological analytes, as listed in Table 2-7. Sediment samples were obtained as close to the pore water sample locations as reasonably possible, with a preference given to locations with fine sediment deposits. Sample volume was limited in some locations due to the dominance of cobbles on the riverbed. In locations where sediment sample volume was limited, not all analyses could be performed. Table 2-8 presents information on the number of sediment samples collected and the collection period.

Table 2-7. Summary of Analyses Requested for Surface Water, Sediment, and Pore Water Sampling During Columbia River RI

Analytical Parameter	EPA Method	Surface Water	Sediment	Pore Water
VOCs	8260B	X	X	X
SVOCs	8270C	X	X	--
Metals	6010/6020/7471	X	X	X
Cr(VI) (Cr^{+6})	7196A	X	X	X
Pesticides	8081	X	X	--
PCBs	8082	X	X	--
PCB congeners	1668A	X[a]	X[a]	--
Total Organic Carbon	9060	--	X	--
Grain size	ASTM D422-63	--	X	--
TPH	8015	X	X	--
AVS/SEM[b]	N/A	--	X	--
Nitrate	300.0	X	--	X
Radionuclides	GEA/AEA/LCS	X	X	X
Hardness	130.1	X	--	--
Dissolved Organic Carbon	415.1	X	--	--
Alkalinity	310.1	X	--	--
Field parameters[c]	Field instruments	X	--	X

Sources: MSL-I-022, Determination of Elements in Aqueous and Digestate Samples by ICP/MS.

Table 2-7. Summary of Analyses Requested for Surface Water, Sediment, and Pore Water Sampling During Columbia River RI

Analytical Parameter	EPA Method	Surface Water	Sediment	Pore Water

ASTM D422-63(2007), *Standard Test Method for Particle-Size Analysis of Soils*.

Note: Analyses will be sample specific; not all samples were analyzed by all methods in this table.

a. Every 10th surface water and sediment sample analyzed for PCB Aroclors by 8082 was also analyzed for PCB congeners.

b. Sediment samples were extracted and analyzed for AVS in accordance with Battelle SOP MSL-C-001. The SEM extracts were analyzed for all other metals by ICP-MS in accordance with Battelle SOP.

c. Field parameters for surface water samples were measured in the field and consisted of temperature, specific conductivity, dissolved oxygen, and pH. Field parameters for pore water consist of temperature and conductivity.

Table 2-8. Summary of 100-K Sample Collection during Columbia River Remedial Investigation

Sample Phase	Sample Dates	Parameters of Interest	Number of Samples/ Stations
Phase IIa	January to March 2009	Temperature and conductivity	90
Phase IIb	September to November 2009	Conductivity and Cr(VI)	32
Phase III	January to February 2010	See Table 2-6	6

2.1.7.4 *Additional Surface Water, Sediment, and Island Sampling*

In addition to the sampling described in the preceding sections, supplemental samples of surface water, sediment, and island soil samples were taken during the RI at locations described in *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, River Sediments, and Island Soils* (WCH-352) and *Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington* (hereinafter called Hanford Site Releases Data Summary [WCH-398]) for the purpose of identifying the nature and extent of potential releases of contaminants associated with operations at the Hanford Site. Figure 5-8 in Hanford Site Releases Data Summary (WCH-398) shows these sample locations near 100-K. Table 2-9 provides a summary of the number of additional samples collected.

Table 2-9. Summary of Additional Samples Collected in the Vicinity of the 100-K Area

Media Collected	Number of Samples
Island Soil	0
Surface Water	1
Sediment*	13

* Includes shoreline, shallow, and core samples collected during the Columbia River Remedial Investigation.

2.1.8 Geological Investigations

The geological investigation was conducted to address the data needs listed in Table 2-1 (Data Needs 2, 5, 7, 10, and 12). Geological characterization and physical and hydraulic property data needs were identified to support development/refinement of the conceptual site model and performance of analytical and

numerical modeling within 100-K. In addition, geologic data were needed to gain a better understanding of the hydrogeologic conditions, aquifer interactions, and contaminant mobility through the vadose zone and in the unconfined and confined aquifers. To address the data needs, nine wells were installed in the unconfined aquifer. Four borings were drilled down to the deeper RUM unit with one well being installed in the RUM and the other three wells screened above the RUM in the Ringold, since a water-bearing unit was not encountered within the RUM. Two boreholes were drilled in the vadose zone and were completed as 10 cm (4 in.) temporary wells at the east and west ends of the 116-K-2 Trench (Table 2-10). The conversion of the borings advanced in the 116-K-2 Trench to temporary monitoring wells represents a deviation from the work plan. The boreholes were converted to wells in order to obtain representative water samples from beneath the trench. Water samples were unable to be obtained during drilling due to poor aquifer conditions, which prevented getting a representative water sample. Table 2-10 includes the pertinent well location information while Table 2-11 delineates the samples that were taken in accordance with the 100-K SAP (DOE/RL-2009-41). The geological investigations also focused on evaluating bathymetric data and geophysical logging, as described in the following text.

Monitoring Well 199-K-186 was relocated from the initial location presented in the 100-K Work Plan (DOE/RL-2008-46-ADD2). The initial planned location was within a defined culturally sensitive area and permission to drill the well at this location was not granted during cultural resource reviews with the local Native American Tribes. An alternative location was selected and documented via CN for 100-K SAP (TPA-CN-357) to the 100-K SAP (DOE/RL-2009-41), which relocated the well to approximately 80 m (262 ft) southeast of the former 105-KE Reactor building (Figure 2-1). The new location was selected to provide additional characterization for the KE Reactor area and was preferable to relocating the well further northeast to outside the culturally sensitive area, which may be beyond the extent of the contamination plume.

2.1.8.1 Bathymetric Data

To evaluate flow paths of contaminants to aquatic receptors, updated and accurate bathymetric data for the river were needed (Data Gap 8). Recently collected bathymetric data were combined with groundwater fate and transport analysis to evaluate contaminant risks to potential ecological receptors and related portions of the river. Preliminary evaluation of the top of the RUM unit surface using near river wells was sufficient to indicate that the top of the RUM unit intersects the Columbia River. No additional data were proposed for the area as part of the RI/FS; however, the existing data were further evaluated to better define the river bathymetry. Figure 2-5 shows the bathymetry of the Columbia River near 100-K. Coyote Rapids (Figure 2-5) is a feature that is a result of the resistant Ringold unit E cemented units occurring in the riverbed.

The development of a high-resolution bathymetry dataset for the Columbia River through the Hanford Reach was a continuation of FY 2009 work that focused on retrieving, assembling, and processing 66 km (41 mi) of existing bathymetry and terrestrial topographic data (*Development of a High-Resolution Bathymetry Dataset for the Columbia River through the Hanford Reach* [PNNL-19878]). At the conclusion of the FY 2009 work, it was determined that additional data were needed. The data would be collected over a 30 km (19 mi) section to supplement existing bathymetric and topographic data and would fill significant data gaps in the central portion of the Hanford Reach. In FY 2010, hydrographic surveys were conducted and the resulting data were incorporated into a multi-source data fusion process to produce a single high-resolution (1 m [3.3 ft]) dataset for the Hanford Reach. Chapter 4 presents a discussion of the updated bathymetric results.

Table 2-10. Summary of Well Construction Information for New RI Wells for 100-K

Well ID	Borehole ID	SAP Location ID	Northing (m)	Easting (m)	Elevation (m [ft] AMSL)	Ringold Fm. Unit E Upper Contact (m [ft] bgs)	Depth to RUM Unit (m [ft] bgs)	Total Borehole Depth (m [ft] bgs)	Depth to Static Water Level (m [ft] bgs)	Total Well Depth (m [ft] bgs)	Screened Interval (m [ft] bgs)
199-K-183	C7683	1	146439.7	568302.28	140.33 [460.39]	7.01 [23.00]	44.97 [147.50]	46.70 [153.20]	20.74 [68.04]	34.15 [112.00]	14.33 to 32.62 [47.00 to 107.00]
199-K-185	C7685	2	146726.17	568574.92	134.62 [441.65]	7.62 [25.00]	40.70 [133.50]	42.23 [138.50]	15.93 [52.26]	41.62 [136.5]	11.74 to 40.70 [38.50 to 133.50]
199-K-186	C7686	9	146625.36	569209.65	145.45 [477.20]	14.90 [49.00]	49.39 [162.00]	50.91 [167.00]	25.52 [83.70]	41.73 [136.86]	21.80 to 131.54 [71.50 to 131.54]
199-K-187	C7687	3	146054.68	569499.00	155.38 [509.76]	20.88 [68.50]	60.21 [197.50]	61.71 [202.40]	34.42 [112.90]	61.65 [202.20]	11.34 to 47.93 [97.20 to 157.20] 54.02 to 60.12 [177.2 to 197.2]
199-K-189	C7689	5	146809.68	569150.27	142.23 [466.61]	11.89 [39.00]	46.95 [154.00]	48.48 [159.00]	22.42 [73.55]	48.48 [159.00]	19.51 to 46.95 [64.00 to 154.00]
199-K-190	C7690	4	146873.27	568835.28	135.39 [444.19]	14.63 [48.00]	40.55 [133.00]	46.34 [152.00]	16.89 [55.41]	42.22 [138.47]	28.49 to 40.69 [93.44 to 133.47]
199-K-191	C7691	6	146886.65	569711.20	143.86 [471.97]	12.65 [41.50]	46.74 [153.30]	48.17 [158.00]	22.46 [73.67]	32.10 [105.30]]	15.95 to 31.19 [52.30 to 102.30]
199-K-193	C7693	7	146969.58	570641.99	144.88 [475.31]	14.02 [46.00]	49.09 [161.00]	50.61 [166.00]	23.87 [78.30]	50.70 [166.30]	18.69 to 30.88 [61.30 to 101.30] 40.03 to 49.18 [131.30 to 161.30]
199-K-194	C7694	8	147281.98	571315.65	146.48 [480.57]	19.82 [65.00]	43.11 [141.40]	44.91 [147.30]	25.29 [82.95]	33.78 [110.80]	22.20 to 32.87 [72.80 to 107.80]
RUM Wells											
199-K-184*	C7684	R1	146366.32	568618.68	142.84 [468.64]	27.44 [90.00]	49.63 [162.80]	65.88 [216.10]	23.70 [77.75]	51.16 [167.80]	35.91 to 49.63 [117.8 to 162.80]
199-K-188*	C7688	R3	146370.11	569386.80	151.07 [495.63]	18.29 [60.00]	55.79 [183.00]	71.65 [235.00]	29.79 [97.70]	40.63 [133.27]	28.29 to 38.95 [92.8 to 127.8]
199-K-192	C7692	R2	147294.32	569393.17	134.06 [439.81]	33.54 [110.00]	43.45 [142.50]	58.81 [192.90]	9.70 [31.82]	57.38 [188.20]	53.41 to 56.46 [175.20 to 185.20]
199-K-195*	C7695	R4	146086.38	568850.08	146.87 [481.84]	15.24 [50.00]	54.33 [178.20]	70.27 [230.50]	25.61 [84.00]	39.21 [128.60]	23.84 to 37.56 [78.20 to 123.20]

Table 2-10. Summary of Well Construction Information for New RI Wells for 100-K

Well ID	Borehole ID	SAP Location ID	Northing (m)	Easting (m)	Elevation (m [ft] AMSL)	Ringold Fm. Unit E Upper Contact (m [ft] bgs)	Depth to RUM Unit (m [ft] bgs)	Total Borehole Depth (m [ft] bgs)	Depth to Static Water Level (m [ft] bgs)	Total Well Depth (m [ft] bgs)	Screened Interval (m [ft] bgs)
Boreholes Converted to Temporary Wells											
199-K-200	C7831	116-K-2 West	147253.55	569426.14	135.91 [445.79]	13.72 [45.00]	N/A	18.08 [59.30]	15.39 [50.50]	18.11 [59.39]	14.40 to 17.45 [47.23 to 57.24]
199-K-201	C7832	116-K-2 East	148069.13	570092.13	133.36 [437.42]	7.93 [26.00]	N/A	18.41 [60.40]	15.36 [50.40]	17.93 [58.80]	14.20 to 17.25 [46.56 to 56.57]

Transitional gravels

Note: Depth to static water was obtained post well development.

* Drilled down to the RUM but was completed and screened in the Ringold.

AMSL = above mean sea level
bgs = below ground surface
ID = identifier
N/A = borehole not drilled deep enough to determine contact
SAP = Sampling and Analysis Plan

Table 2-11. Samples Collected for the RI/FS Wells and Boreholes

Well Name	Borehole ID	SAP Location ID	Samples Planned in SAP and Associated TCNs[a]				Samples Collected				
			Geochemical Soil Samples	Physical Soil Samples	Ground Water Samples—Unfiltered	Ground Water Samples—Filtered	Geochemical Soil Samples	Physical Soil Samples	Ground Water Samples—Unfiltered	Ground Water Samples—Filtered	Total QC Samples
199-K-183	C7683[b]	1	7	6	12	1	11	5	14	1	18
199-K-185	C7685[a,b]	2	10	6	12	1	9	5	17	1	22
199-K-186	C7686[b]	9	25	6	12	1	25	5	15	1	4
199-K-187	C7687[b]	3	7	6	12	1	11	5	16	1	19
199-K-189	C7689[b]	5	19	6	12	1	21	5	16	1	20
199-K-190	C7690[b]	4	11	6	12	1	15	5	16	1	21
199-K-191	C7691	6	7	6	12	1	14	8	16	1	19
199-K-193	C7693[b]	7	7	6	12	1	9	3	16	1	19
199-K-194	C7694	8	7	6	12	1	8	6	12	1	13
RUM Wells											
199-K-184*	C7684[a]	R1	28	6	14	1	20	7	17	1	6
199-K-188*	C7688	R3	27	6	14	1	29	7	16	1	7
199-K-192	C7692	R2	10	6	14	1	16	7	19	1	23
199-K-195*	C7695	R4	22	6	14	1	23	8	18	1	4
Boreholes Converted to Temporary Wells											
199-K-200	C7831[b]	116-K-2 West	13	2	0	1	13	1	3	3	12
199-K-201	C7832[b]	116-K-2 East	10	2	0	1	16	1	2	2	8

Note: QC requirements are per 100-K SAP (DOE/RL-2009-41).

* Drilled down to the RUM but was completed and screened in the Ringold.

a. Fewer geochemical samples were taken than required by the SAP as the bottom of the unconfined aquifer/top of the RUM was reached earlier than expected.

b. One physical soil sample was not taken, as there was insufficient soil sample in split spoon for the analysis at the assigned interval.

ID = Identifier TCN = Tri-Party Agreement Change Notice

QC = Quality Control SAP = Sampling and Analysis Plan

Geochemical Soil Samples (6 equipment blanks, 6 field blanks, 6 duplicates, 1 split) = 19

Physical Soil Samples = 0

Ground Water Samples (9 equipment blanks, 9 field blanks, 9 duplicates, 1 split) = 28

Total QC samples required by SAP: = 47

Total QC samples taken: = 215

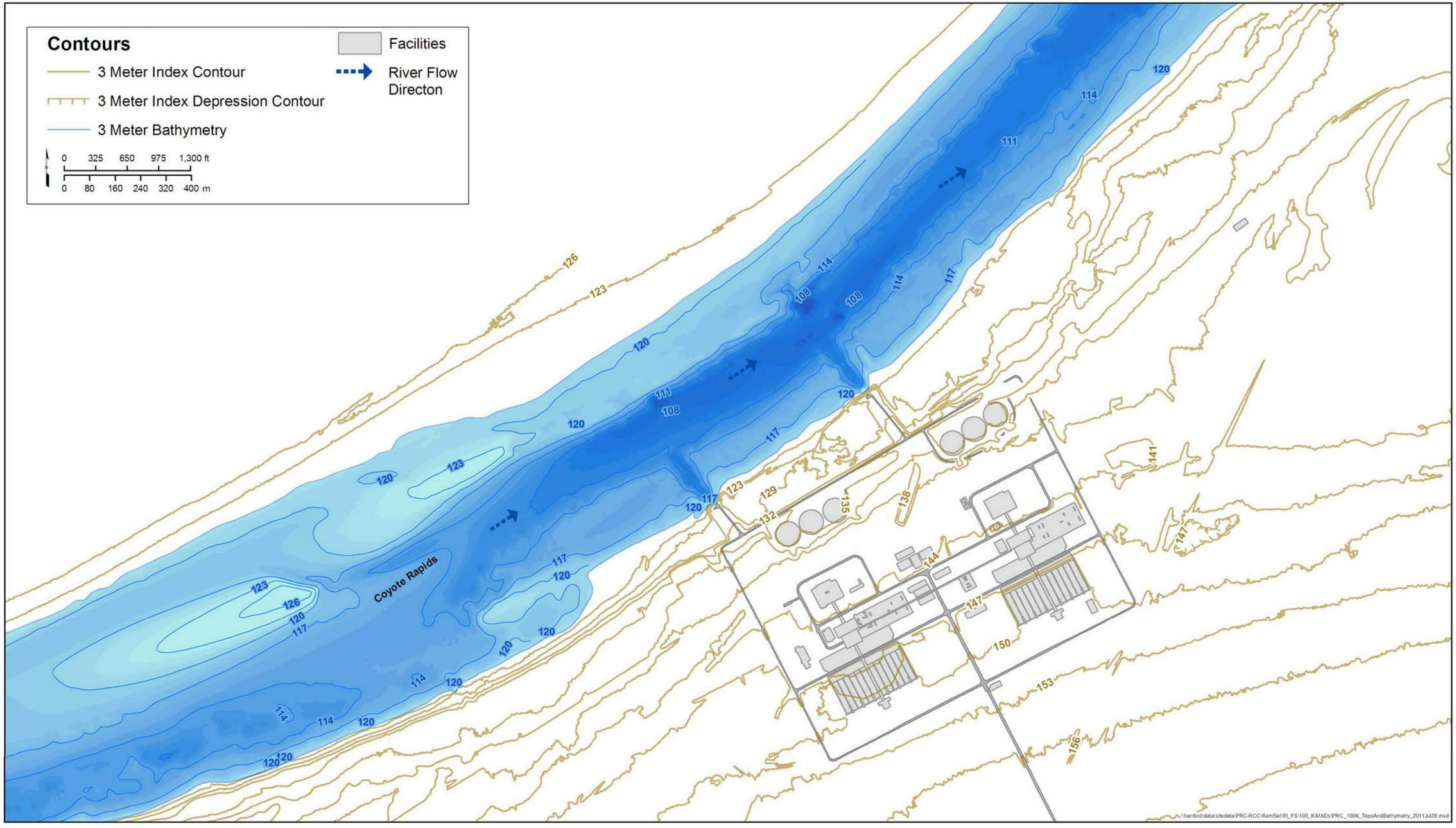


Figure 2-5. Bathymetry of the Columbia River near 100-K

2.1.8.2 Geophysical Logging

To gain a better understanding of the area geology, geophysical logging was completed at each of the soil borings conducted in this RI. Logging was conducted using S.M. Stoller Corporation's Spectral Gamma Logging System (SGLS) and Neutron Moisture Logging Systems (NMLS)™ to identify natural and manufactured gamma-emitting radionuclides and soil moisture, respectively, present near the boreholes. The starting point for logging, either the ground surface or top of the casing, was recorded for each well or borehole. Borehole logging was performed through the temporary casing to produce a geophysical log of the entire length of the borehole. The log reports are located in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760] *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]). Chapter 3 presents the results of the logging.

2.1.9 Vadose Zone Investigations

The RI work is intended to validate, confirm, and complete the CSM. One important aspect of the characterization is to confirm our understanding of the nature and extent of chromium and Cr(VI) distribution in the vadose zone. As part of this effort, characterization wells, boreholes, and test pits were constructed in the 100 Area at selected locations described in the 100-K Work Plan (DOE/RL-2008-46-ADD2) and 100-K SAP (DOE/RL-2009-41).

Data needs specific to sources are identified and described in this section. Data needs were addressed relative to unremediated and remediated waste sites and reactor areas.

2.1.9.1 Characterize Below Unremediated Waste Sites to Assess Nature and Extent of Contamination in the Vadose Zone

Characterization beneath unremediated waste sites was identified as Data Gap 1 in the 100-K Work Plan (DOE/RL-2008-46-ADD2). Interim remedial actions have been effective in documenting the remaining residual contamination following the completion of RTD activities, and are useful for assessing the nature and extent of contamination in the vadose zone. Data collected as part of the ongoing interim waste site remediation (in process sampling) is used as a component of the CSM, and the nature and extent of contamination. The data is discussed in Chapter 4.

As part of the remedy, borehole drilling was performed in conjunction with sampling and analysis to better define the nature and extent of the contamination and to identify sources within the vadose zone. Activities during excavation were guided using field instrument measurements or in process sampling employing quick turnaround laboratory analyses performed concurrently with excavation.

The observational approach based cleanup is employed to provide opportunities for the discovery of new waste sites that will be plugged into the existing remedies for cleanup. Sequencing of waste site cleanup is based on the Tri-Party Agreement (Ecology et al., 1989a) milestone framework. Within this framework, knowledge of operational processes (such as sodium dichromate use) and past releases was used to target and prioritize specific waste sites or areas with contaminants that presently exist in, or could potentially impact, groundwater. Effective implementation of waste site cleanup prevents further degradation of groundwater, thereby increasing the likelihood for success of groundwater cleanup actions (such as pump-and-treat) directed specifically at contaminated groundwater.

There are 163 waste sites in 100-K; 128 remained to be addressed according to the process outlined in the interim RODs. Data needs associated with soil remedial actions in 100-K were met by planning and

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scheduling the remedial actions, collecting data to verify interim cleanup of waste sites, and obtaining concurrence from regulators on the achievement of RAGs for direct exposure, protection of groundwater, and protection of surface waters. Data from interim remediation of 14 of the 128 remaining waste sites were incorporated into this RI/FS.

Accepted and discovery waste sites applicable to this data need are identified in Chapter 2 and Appendices B and C of the 100-K Work Plan (DOE/RL-2008-46-ADD2). Sections 2.1.8.3 and 2.1.9.1 present information for the three boreholes that were completed as monitoring wells (Wells 199-K-189, 199-K186, and 199-K184 near the 100-KE and 100-KW Reactors).

2.1.9.2 Characterize beneath Remediated Waste Sites

The need to characterize beneath 116-K-2 Trench was identified in Data Gap 2. Data Gap 2 was addressed by installing two boreholes beneath the 116-K-2 Trench to assess the vertical extent of contamination in the vadose zone. The characterization data collected were used to supplement and validate the current CSM, including modeling input parameters and assumptions addressed in Chapter 5.

The two boreholes were drilled and sampled, and 10 cm (4 in.) temporary PVC wells were installed in the 116-K-2 Trench. Tables 2-7 and 2-8 present a summary of the RI soil boring and well information. Samples were screened for radiological contamination using field instruments and visually inspected for staining as an indicator of Cr(VI). In addition, to meet the requirements of Data Need 12, batch leach testing was performed at 0.76 m (2.5 ft) intervals from the bottom of the waste site (or the maximum depth of remedial action) to the water table.

Location specific target analytes specified in the 100-K SAP (DOE/RL-2009-41) are a subset of the master list of target analytes presented in Table 2-12.

Table 2-12. Master List of Soil/Aquifer Sediment Target Analytes for 100-K

Radionuclides	Nonradionuclides		
Americium-241	1,1-Dichloroethene	Benzo(ghi)perylene	Lead
Carbon-14	1,4-Dichlorobenzene	Benzo(k)fluoranthene	Manganese
Cesium-137	Acenaphthene	Beryllium	Mercury
Cobalt-60	Aluminum	Bis (2-ethylhexyl) phthalate	Methylene chloride
Europium-152	Anthracene	Cadmium	Nickel
Europium-154	Antimony	Carbazole	Nitrate (as N)
Europium-155	Aroclor 1016 (PCB)	Carbon tetrachloride	Nitrite (as N)
Nickel-63	Aroclor 1221 (PCB)	Chloroform	Pentachlorophenol
Plutonium-238	Aroclor 1232 (PCB)	Cr(VI)	Phenanthrene
Plutonium-239/240	Aroclor 1242 (PCB)	Chromium (total)	Pyrene
Sr-90	Aroclor 1248 (PCB)	Chrysene	Selenium
Technetium-99	Aroclor 1254 (PCB)	Cobalt	Silver
Tritium	Aroclor 1260 (PCB)	Copper	Tetrachloroethene
Uranium-233/234*	Arsenic	Dibenz(a,h)anthracene	Thallium
Uranium-235	Barium	Di-n-butylphthalate	Toluene
Uranium-238	Benzene	Ethylene glycol	Total petroleum hydrocarbon
	Benzo(a)anthracene	Fluoranthene	Trichloroethylene
	Benzo(a)pyrene	Fluoride	Vanadium
	Benzo(b)fluoranthene	Indeno(1,2,3-c,d)pyrene	Zinc

* Not specified in the 100-K SAP (DOE/RL-2009-41).

At the 116-K-2 Trench, continuous sampling was performed using a split spoon sampler to the top of the unconfined water table, and an aquifer material sample and filtered water sample were collected 1.5 m (5 ft) into the unconfined aquifer. Additional samples were collected at the discretion of the geologist or sampler, based on media characteristics, visual inspection, and field screening results at the 116-K-2 Trench and remaining borings drilled for the monitoring wells. These samples were analyzed for physical properties, including grain size, porosity, moisture content, bulk density and, in the case of saturated samples, saturated hydraulic conductivity.

The two boreholes advanced within the 116-K-2 Trench (C7831 and C7832) were converted to temporary groundwater monitoring wells with concurrence from DOE and EPA. As a result, none of the borings drilled during the RI activities was abandoned. Copies of the borehole logs, detailed sampling summary, well construction summaries, well summary sheets, geophysical logs, and final surveys are located in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760] and *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY* 2010 [SGW-49459]).

2.1.9.3 Characterize beneath and around Reactor Structures

Activities associated with the D4 and ISS of the 105-KE and 105-KW Reactors are still under way. Large portions of the reactor structures and the facilities immediately adjacent to them remain in place. Access to the area has been limited due to safety concerns and, therefore, characterization immediately adjacent to the reactor buildings and associated structures has been restricted to field screening and periodic soil/building debris laboratory analyses during D4 removal actions. RI field activities, however, have been completed near both reactor buildings to address RI Data Gap 3.

Additional characterization was needed for interim closed areas adjacent to the 105-KE and 105-KW Reactor facilities and soil near these reactors to support the ROD (Data Gap 3). To fill the data gap, groundwater Monitoring Wells 199-K-184, 199-K-189, and 199-K-186 were drilled near (within 100 m [330 ft]) the 105-KE and 105-KW Reactors to provide additional characterization of the reactor area including potential tritium and Sr-90 plumes associated with the 105-KE Fuel Storage Basin. Well 199-K-186 was relocated from the original location proposed in 100-K SAP (DOE/RL-2009-41) and 100-K Work Plan (DOE/RL-2008-46ADD2) because the proposed location was in a culturally sensitive area. During RI drilling, 199-K-186 was located approximately 80 m (262 ft) southeast of the former 105-KE Reactor building (Figure 2-1). Additionally, Well 199-K-189 (a replacement well for 199-K-109A) was moved approximately 67 m (220 ft) to the north because its planned location interfered with access roads for demolition and waste site remediation activities. Soil samples were collected at each borehole before monitoring well construction and groundwater sample collection to characterize the deep vadose zone. Chapter 4 includes discussion of the soil and groundwater results.

Copies of the borehole logs, detailed sampling summaries, well construction summaries, well summary sheets, photographic logs (available only for *Borehole Summary Report for the Installation of 13 Wells in the 100-KR-4 OU in CY 2010* [SGW-49459]), geophysical logs, and final surveys are located in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760]; *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]). Appendix C, Table C-1, summarizes the slug tests. Chapter 4 presents results for soil samples collected during RI activities.

2.1.9.4 Evaluate Reasons for the Persistence of Cr(VI)

Data were needed to determine the potential for each unit to contain sufficient contamination to be a continuing source of groundwater contamination (Data Gap 10). The data developed by the sampling and

analysis activities described in Section 2.1.9.1 were evaluated in an effort to determine which geologic units contain continuing sources of Cr(VI) that account for the persistence of the Cr(VI) plumes. The sampling results are presented in Section 4.2.2.

2.1.9.5 Develop Additional Data Needed for Modeling

Insufficient data to support fate and transport modeling were identified as Data Gap 12. The fate and transport of Cr(VI), nitrate, Sr-90, tritium, C-14, chloroform, total chromium, and trichloroethylene in the environment is highly dependent on the effluent volume discharge and the contaminant specific K_d, which quantifies the partitioning of a contaminant between a solid phase and an aqueous phase. For instance, Cr(VI) typically has a very low K_d value. Thus, the contaminant typically moves in the vadose zone with the effluent discharged to the soil. However, studies also indicate that Cr(VI) movement can be retarded in the environment, depending on the contaminant source characteristics and naturally available iron. The site-specific contaminant K_d for Cr(VI) and the seven other principal COPCs (nitrate, Sr-90, tritium, C-14, chloroform, total chromium, and trichloroethylene) was needed to support assessments of contaminant fate and transport in 100-K. Information on hydraulic conductivity and soil physical properties is critical to fate and transport modeling.

Data to support contaminant fate and transport modeling were developed for selected RI samples as described further in Section 2.1.9.1, including information on physical properties, hydraulic conductivity, batch leach test results, field screening parameters, and target analyte concentrations.

2.1.10 Groundwater Investigations

Investigations were undertaken beneath the unconfined aquifer to evaluate the persistence of Cr(VI) and other COPCs. Additional data were needed from existing 100-K monitoring wells, new characterization wells, and aquifer tubes to support final remedy decision making, as described in the following text.

2.1.10.1 Characterize beneath the Unconfined Aquifer

The unconfined aquifer in 100-K is in the Ringold Formation unit E and Hanford formation. The RUM unit is considered the base of the unconfined aquifer in 100-K. Cr(VI) was detected in one well (199-K-32B) at 100-K that was completed in the RUM unit. Concentrations of Cr(VI) in this well ranged from 2.9 to 6.8 µg/L. Additional data were collected to further define the extent of contamination in the RUM unit and support evaluation of contaminant fate and transport.

Four boreholes (C7684 [R1], C7692 [R2], C7688 [R3], C7695 [R4], shown in Table 2-9) were drilled to address the need for characterization data from the RUM unit (below the unconfined aquifer) and as part of an effort to evaluate the reasons for persistence of Cr(VI), as discussed in Section 2.1.7. Borehole C7684 (R1) was drilled near the 105-KW Reactor building structure; C7692 (R2) was drilled near the 116-K-2 Liquid Disposal Trench; C7688 (R3) was drilled upgradient of the 100-KE Reactor complex and downgradient of the 120-KE-6 Head House; and C7695 (R4) was drilled upgradient of the 100-KW Reactor complex and downgradient of the 120-KW-5 Head House. Borehole C7688 (R3) was intended to be drilled near the French drain site at 100-K-98 but had to be moved because of utilities. The location was moved several hundred meters from the KE Reactor. Methods for collecting soil and groundwater samples during RUM unit drilling are as described in Section 2.1.9.2. Information on the four 100-K RUM unit wells, including data on well screen intervals and soil and groundwater samples collected during drilling, is summarized in Tables 2-6 and 2-7 and discussed further in Section 2.1.9.2.

Split spoon samples were collected from the deep unconfined aquifer at the base of the RUM unit, immediately on drilling into the RUM unit; at additional locations within the RUM unit; and within a shallow RUM sand lens. The samples were screened in the field for radiological contamination and laboratory analyzed for location specific target analytes (at Wells 199-K-184 [R1] and 199-K-192 [R2]) or radiological

constituents along with Cr(VI) and other metals (at Wells 199-K-188 [R3] and 199-K-195 [R4]). Additionally, batch leach testing for Cr(VI) and select metals was conducted. The number of samples collected per boring for these analyses can be found in Table 2-11. It should be noted that fewer geochemical samples were taken while drilling borehole C7684 (199-K-184), as the depth to the RUM was encountered earlier than expected.

Additional split-spoon samples were collected at major formation and lithology changes for analysis of physical properties (grain size, porosity, moisture content, bulk density and, in the case of saturated samples, saturated hydraulic conductivity). Table 2-11 lists the number of soil samples collected per boring under the column entitled "Physical Soil Samples." In addition, samples were collected at 1.5 m (5 ft) intervals throughout the entire boring intervals for field screening and potential placement in geologic archives.

During drilling of deep borings, unfiltered and filtered groundwater samples were collected from the unconfined aquifer and water producing portions of the RUM unit, for field screening and COPC analysis, as summarized in Tables 2-11 and 2-13.

Table 2-13. 100-K Groundwater COPCs

Radionuclides	Nonradionuclides		
Carbon-14	1,1,2-Trichloroethane	Chromium	Nitrite (as N)
Tritium	1,1-Dichloroethene	Cobalt	Selenium
Sr-90	Antimony	Copper	Sulfate
	Arsenic	Fluoride	Tetrachloroethene
	Barium	Cr(VI)	Thallium
	Benzene	Lead	Trichloroethylene
	Beryllium	Manganese	Uranium
	Cadmium	Mercury	Vanadium
	Carbon tetrachloride	Nickel	Vinyl chloride
	Chloride	Nitrate (as N)	Zinc
	Chloroform		

Groundwater samples from the boreholes were collected 1.5 m (5 ft) into the unconfined aquifer using a pump. Before sampling, the pump was operated for a period sufficient to provide stabilized field readings, but not necessarily three casing volumes. If inadequate water column and/or recharge were available for a successful pumped sample, alternative means of sampling were used. These laboratory filtered water samples were analyzed for Cr(VI) and other metals to support K_d determinations and to determine analyte distribution in the unconfined aquifer (that is, present in suspended sediments or dissolved in the water) and refine the nature and extent of Cr(VI) contamination. An analysis of groundwater containing metals with low or high K_d values will help to understand the rate of transport of contaminated groundwater with COPCs to the unconfined aquifer from the vadose zone. Historically, high mobility contaminants, such as Cr(VI) and nitrate, have migrated through the vadose zone into the groundwater when waste sites were operational. Factors affecting contaminant mobility are discussed in detail in Chapter 5.

Of the four deep boreholes drilled into the RUM, only Well 199-K192 encountered a water-bearing unit within the RUM. The other three wells did not encounter a water-bearing unit so they were screened in the unconfined aquifer. The wells were drilled approximately 15 m (50 ft) into the RUM before drilling was discontinued. All wells, except for 199-K-188 (R3), 199-K-186 (9), and 199-K-195 (R4), were constructed with 15.2 cm (6 in.) diameter, Schedule 10, Type 316L stainless steel, V-slot continuous wire wrap screen

atop a 1.5 m (5 ft) long stainless steel sump with end cap. The screen lengths vary, but generally are screened across the saturated zone in 3.05 m (10 ft) sections.

Wells 199-K-188 (R3), 199-K-186 (9), and 199-K-195 (R4) were constructed with PVC pipe instead of stainless steel in accordance with CN for 100-K SAP (TPA-CN-357), CN for 100-K SAP June 1 Amendment (TPA-CN-384), and *Tri-Party Agreement Change Notice Form: Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study, DOE/RL-2009-41, Rev. 0 (As amended by TPA-CN-384, October 6, 2010* (TPA-CN-405), to avoid costly well construction materials at the wells that were likely to be removed during demolition and waste site remediation activities.

Figure 2-6 shows the general well construction design and well construction details provided in the Well Construction Summary Reports, which are included in the borehole summary reports. (Note that Wells 199-K-187 and 199-K-193 were screened across two intervals in the unconfined aquifer.) Both wells detected Cr(VI) at concentrations above 10 ug/L near the bottom of the aquifer. The two wells were designed for sampling of the deep Cr(VI) and for possible use as injection wells in the future. A packer system will be installed to isolate the lower contaminated zone for groundwater monitoring.

In addition, copies of the borehole logs, detailed sampling summaries, photographic logs (available only for *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]), geophysical logs, and final surveys are located in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760] and *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]). The slug/aquifer test logs are located in Appendix C. Table 2-10 summarizes the well construction, the locations, and the depth to the upper contact of the Ringold Formation unit E and the RUM unit encountered during drilling of each borehole.

Following construction, each well was developed by pumping at a rate ranging from 7.6 to 379 L/min (2 to 100 gpm). Development was continued until the well produced clear water consisting of low turbidity (less than or equal to 5 nephelometric turbidity units [NTUs]) and stabilized (at least three consecutive measurements within 10 percent of each other) temperature, pH, and specific conductance measurement. Water level drawdown recovery was monitored with pressure transducer and datalogger equipment. The SAP (DOE/RL-2009-41) required slug testing at wells screened in the RUM (199-K-192). However, slug testing was conducted at all the wells except the temporary wells (199-K-200 or 199-K-201) installed in the K2 Trench, in order to provide additional information for groundwater modeling.

Following well development, slug testing was conducted in accordance with general guidelines listed in the 100-K SAP (DOE/RL-2009-41). The slug testing was performed to provide an estimate of near-well hydraulic conductivity. The resultant hydraulic conductivity values are reported in Section 3.6.7, Horizontal Hydraulic Gradients and Groundwater Velocity. The slug test data generated in the field is summarized in Appendix C, Table C-1. Table C-4 contains a list of the Slug Test Field Activity Reports that are located in Appendix C by Borehole ID. In addition to the slug testing, a pump test was conducted at Well 199-K-192 and the resultant hydraulic conductivity value is provided in Chapter 3 with the associated field data located in Appendix C, Table C-1. This well was chosen to be pump tested, in addition to being slug tested, as it was the only well that was screened in the RUM.

The new RI/FS wells have been incorporated into the monitoring well network. Initially, the new wells will be sampled quarterly and, depending upon the concentration of contaminates found, sampling will continue either semiannually or annually in accordance with the interim monitoring plan (*Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4* [DOE/RL-96-90]*Operable Units*).

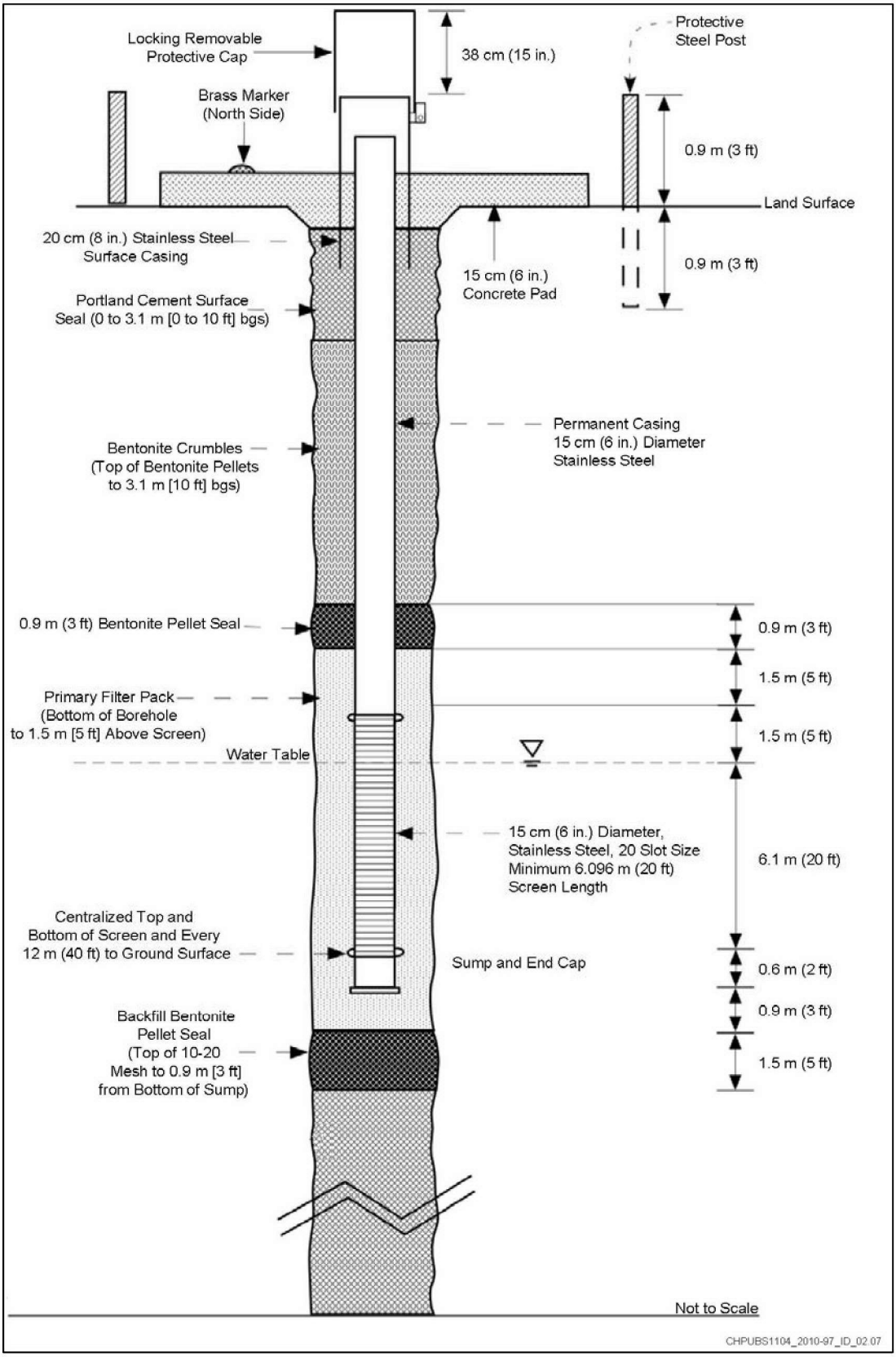


Figure 2-6. General Well Design

2.1.10.2 Refine Delineation of Nature and Extent of Groundwater Contamination in the Unconfined Aquifer

As part of the RI, it was necessary to determine the extent of select contaminants (Cr(VI), Sr-90, carbon-14, trichloroethylene, and tritium) at concentrations above standards in select locations in the unconfined aquifer in 100-K, as described in the following text. This was identified as Data Gap 5.

Nine wells were drilled to the top of the RUM and screened across the entire saturated thickness to characterize the unconfined aquifer, as summarized in Table 2-10. Soil samples were collected at 1.5 m (5 ft) intervals for geologic archive samples and field screening.

The number of samples collected per boring for these analyses can be found in Table 2-11 under the heading "Geochemical Soil Samples." It should be noted that one geochemical sample was not taken while drilling borehole C7685 (199-K-185), as the base of the unconfined aquifer was encountered earlier than expected when the SAP (DOE/RL-2009-41) was written.

To support modeling efforts, split spoon samples were also collected from each well at major formations and lithology changes to provide site-specific physical property data (grain size, porosity, moisture content, bulk density and, in the case of saturated samples, saturated hydraulic conductivity). In Table 2-11, the number of soil samples collected per boring is found under the column entitled "Physical Soil Samples." One physical sample analysis was not collected in each of the Boreholes C7683, C7685, C7686, C7687, C7689, C7690, C7693, C7831, and C7832, as there was an insufficient sample volume left for the test to be performed after a sample had been removed for the geochemical analysis.

During the drilling of each well, groundwater samples were collected at 1.5 m (5 ft) intervals throughout the unconfined aquifer beginning at approximately 1.5 m (5 ft) into the unconfined aquifer. Soil and groundwater samples were collected during drilling as described in Section 2.1.9.2. Well construction details are provided in the Well Construction Summary Reports included in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760]; *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]). Tables 2-7 and 2-8 provide a summary of the geology encountered and samples taken during drilling. Copies of the borehole logs, detailed sampling summary, photographic logs (available only for SGW-49459), geophysical logs, and final surveys are located in the borehole summary reports for April and May 2011 (*Borehole Summary Report for Two Characterization Boreholes in the K2 Trench in the 100 KR-4 OU to Support WCH in FY 2010* [SGW-48760]; *Borehole Summary Report for the Installation of 13 Wells in the 100 KR-4 OU in CY 2010* [SGW-49459]). In addition, copies of aquifer tests are located in Appendix C.

There are 28 aquifer tube locations and 70 aquifer tubes along the 100-K shoreline. An aquifer cluster consisting of three aquifer tubes was installed as part of the RI. Each of the individual tubes was driven to a different depth. Table 2-14 summarizes information on the new K-1 aquifer tube cluster installed as part of the RI. Aquifer sampling tubes are 0.64 cm (0.25 in.) diameter polyethylene tubes with 15.2 cm (6 in.) long stainless steel screens at the lower end. The main components of aquifer tube installation are shown in Figure 2-7. These aquifer tubes were added to the SAP for Aquifer Sampling Tubes (DOE/RL-2000-59) to ensure that new aquifer tubes were installed and sampled consistent with existing aquifer tubes.

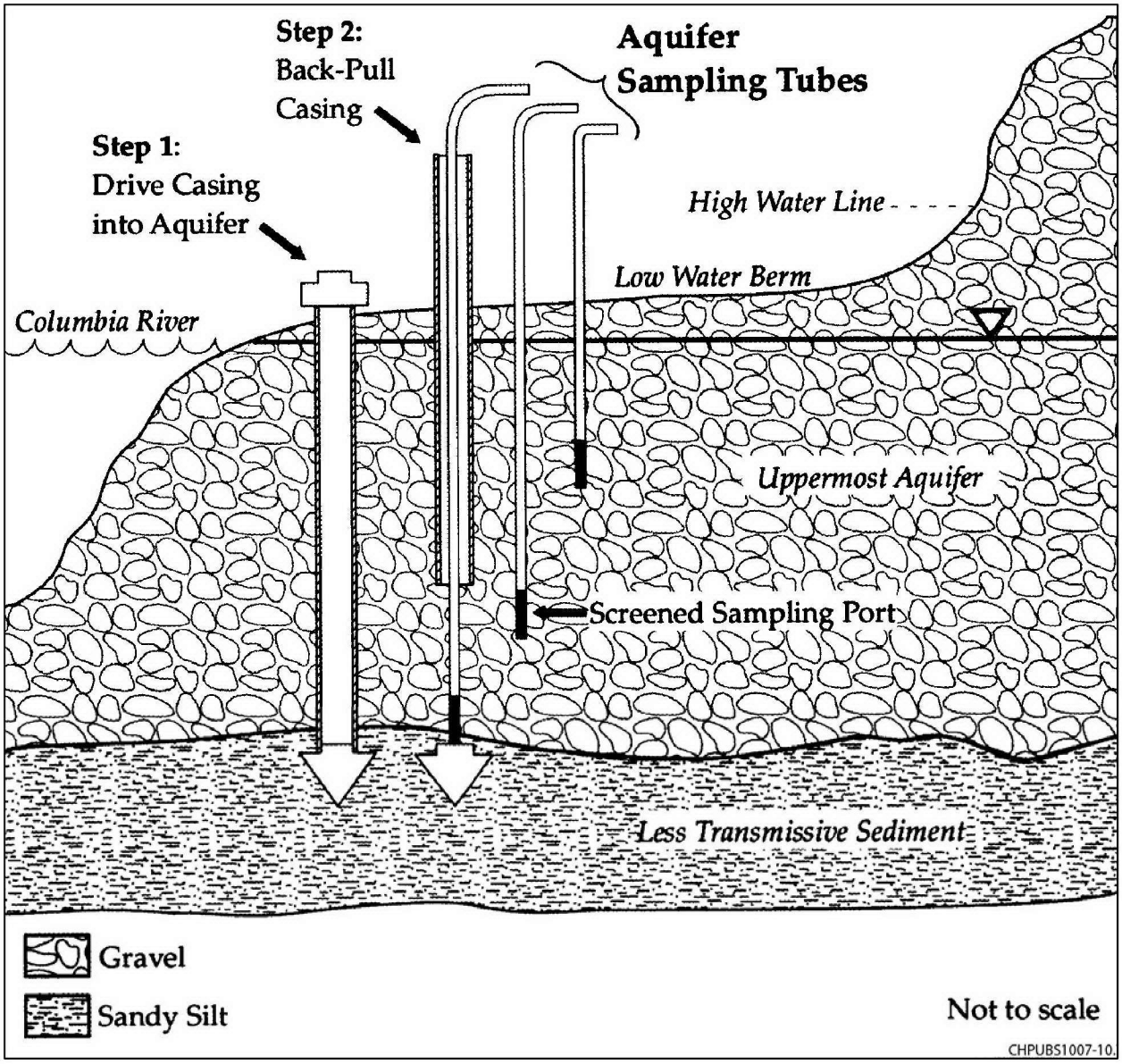


Figure 2-7. Main Components of Aquifer Tube Installation

Sampling of newly installed aquifer tubes for COPC analysis was conducted during August, November, and December 2010 during periods of "transition," "low," and "high" river stages, respectively. The sampling was conducted in concurrence with the aquifer tube-sampling program requirements established for the Hanford Site. October and November are considered the optimum time for aquifer tube sampling near low river stage.

In November, flows from Priest Rapids Dam are kept low during the daylight hours to encourage salmon spawning in deeper water. In addition, some sites are not configured to allow sampling during high river stage (SAP for Aquifer Sampling Tubes [DOE/RL-2000-59]). The aquifer tube samples were grab samples collected using a peristaltic pump. Water was first pumped from the tubes until specific conductance readings had stabilized. Samples for laboratory analysis were collected regardless whether specific conductance was greater than 160 µS/cm. The aquifer tube water quality field data, located in Appendix C, Table C-2, includes conductivity (uS/cm), temperature (° C), pH, ORP (oxygen reduction potential [mV]), DO (dissolved oxygen [mg/L]), and turbidity (NTU) measurements taken at the time of sampling. Table C-2 also

compares the initial conductivity, temperature, and pH values to the final water quality parameters taken upon completion of the sampling.

2.1.10.3 Evaluate Reasons for the Persistence of Cr(VI)

Data were needed to determine the potential for the periodically rewetted zone, unconfined aquifer, and RUM unit to contain sufficient contamination to be a continuing source of groundwater contamination (Data Gap 10). The RI data developed by the sampling and analysis activities described in Sections 2.1.9.1 and 2.1.9.2 were evaluated in an effort to determine which geologic units contain continuing sources of Cr(VI) that account for the persistence of the Cr(VI) plumes.

2.1.10.4 Define the Spatial and Temporal Distribution of Groundwater Contaminants in the Unconfined Aquifer

Additional groundwater data that are spatially representative, reflect river stage influence, and include groundwater COPCs were needed to better characterize the distribution of contamination in the unconfined aquifer and to address uncertainties associated with initial RCBRA Report (DOE/RL-2007-21) groundwater risk results (Data Gap 13).

To address this need, three rounds of groundwater samples from the 18 monitoring wells listed in Table 2-15 were collected to characterize the spatial and temporal variability in the distribution of groundwater contaminants. The wells were sampled during October 2009, and March and June 2010, with sampling rounds conducted during low, high, and transition river stages. The well locations are shown in Figure 2-1. Each round of 100-K monitoring was completed within 30 consecutive calendar days to minimize statistical variability in water levels. Field personnel measured water levels and purged each well before sampling. Groundwater samples were analyzed for COPCs, as presented in Table 2-13.

2.1.10.5 Ongoing Groundwater Monitoring

The new RI groundwater data described previously were evaluated in conjunction with groundwater data from ongoing sampling of monitoring wells and aquifer tubes. Monitoring wells in 100-K are generally sampled semiannually for Cr(VI) and annually for tritium and carbon-14. Aquifer tubes in 100-K typically are sampled annually to evaluate groundwater contaminants discharging to the Columbia River. In key areas of high Cr(VI) concentrations, aquifer tubes are sampled semiannually to quarterly as river stage allows.

Table 2-14. New Aquifer Tube Information

Tube ID	Installation Date	Hanford River Mile	Northing (m)	Easting (m)	Elevation (m [ft] AMSL)	Depth to Top of Screen (m [ft])	Depth to Bottom of Screen (m [ft])	Elevation of Top of Screen (m [ft] AMSL)	Elevation of Bottom of Screen (m [ft] AMSL)	Number of Water Samples Collected for Field Screening and COPC Analysis	Sample Dates			
											1	2	3	4
C7641	3/31/2010	6.407	146934.310	568489.160	117.87 [386.71]	2.62 [8.59]	2.77 [9.09]	115.25 [378.12]	115.40 [378.62]	4	8/15/2010	8/29/2010	11/22/2010	12/19/2010
C7642	3/31/2010	6.408	146936.420	568490.690	117.83 [386.58]	4.47 [14.66]	4.62 [15.16]	113.36 [371.92]	113.51 [372.42]	4	8/15/2010	8/29/2010	11/22/2010	12/19/2010
C7643	4/1/2010	6.412	146939.500	568494.190	117.74 [386.29]	5.25 [17.22]	5.40 [17.72]	112.49 [369.06]	112.64 [369.56]	4	8/15/2010	8/29/2010	11/22/2010	12/19/2010

Note: Hanford River Mile Marker is measured from the Vernita Bridge.

Source: DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study,* Rev. 0.

Field Quality Control Samples in the SAP:

Equipment Blank = 1
Field Blank = 1
Duplicate = 1
Split = 1
Total Field Quality Control Samples = 4

Number of Field Quality Control Samples taken:

Field Duplicate Field Quality Control Samples = 3

Table 2-15. Spatial and Temporal Uncertainty Well Information and Dates Samples Were Collected

Well Name	Northing (m)	Easting (m)	Elevation (m [ft] AMSL)	Ringold Formation Unit E Upper Contact (m [ft] bgs)	Depth to RUM Unit (m [ft] bgs)	Depth to Static Water Level (m [ft] bgs)	Screened Interval (m [ft] bgs)	Total Well Depth (m [ft] bgs)	Samples Planned (SAP)	Date Samples Collected			QC Samples Collected		
										1	2	3	1	2	3
199-K-11	146617.756	568938.002	142.70 [468.07]	unknown	51.83 [170.00]	23.02 [75.51]	21.03 to 48.78 [69.00 to 160.00]	51.83 [170.00]	3	28-Oct-09	25-Mar-10	11-Jun-10			FTB
199-K-18	147400.811	569353.687	124.68 [408.96]	unknown	unknown	6.22 [20.41]	5.48 to ND [18.00 to not documented/unknown]	18.29 [60.00]	3	22-Oct-09	05-Mar-10	11-Jun-10		DUP	
199-K-20	147687.239	569520.516	128.19 [420.47]	unknown	unknown	9.72 [31.91]	3.05 to 15.24 [10.00 to 50.00]	15.24 [50.00]	3	28-Oct-09	05-Mar-10	16-Jun-10	EBL	EBL	DUP
199-K-22	148097.376	570023.697	127.71 [418.88]	unknown	unknown	11.42 [37.46]	8.84 to 14.94 [29.00 to 49.00]	15.24 [50.00]	3	22-Oct-09	10-Mar-10	11-Jun-10			
199-K-31	146591.114	568177.564	126.73 [415.68]	unknown	unknown	7.58 [24.86]	8.53 to 15.09 [28.00 to 49.50]	15.24 [50.00]	3	22-Oct-09	25-Mar-10	11-Jun-10		DUP	FTB
199-K-32A	147006.680	569024.150	134.45 [440.99]	unknown	unknown	16.14 [52.96]	13.63 to 19.72 [44.70 to 64.70]	19.72 [64.70]	3	22-Oct-09	10-Mar-10	11-Jun-10			
199-K-34	146501.940	568605.780	141.72 [464.85]	unknown	unknown	23.53 [77.19]	20.39 to 26.49 [66.90 to 86.90]	26.49 [86.90]	3	22-Oct-09	05-Mar-10	30-Jun-10			SPLIT
199-K-36	146390.730	569373.800	149.77 [491.25]	unknown	unknown	29.86 [97.94]	27.13 to 33.23 [89.00 to 109.00]	33.23 [109.00]	3	22-Oct-09	08-Mar-10	11-Jun-10			
199-K-37	148226.542	570216.203	133.78 [438.80]	unknown	unknown	16.82 [55.19]	13.20 to 19.29 [43.30 to 63.30]	19.29 [63.30]	3	22-Oct-09	05-Mar-10	24-Jun-10			
199-K-106A	146502.390	568697.400	142.55 [467.56]	6.40 [21.0]	53.35 [175.00]	23.11 [75.80]	21.36 to 27.68 [70.06 to 90.80]	27.68 [90.80]	3	22-Oct-09	08-Mar-10	13-Jun-10			DUP
199-K-108A	146396.140	568687.200	141.78 [465.04]	9.14 [30.00]	unknown	24.46 [80.23]	21.14 to 27.34 [69.35 to 89.70]	26.62 [90.00]	3	22-Oct-09	08-Mar-10	13-Jun-10	DUP		
199-K-117A	147976.977	569702.560	127.40 [417.89]	unknown	unknown	8.82 [28.93]	8.48 to 20.70 [27.84 to 67.91]	21.63 [70.96]	3	22-Oct-09	10-Mar-10	11-Jun-10	DUP		
199-K-142	146870.940	569104.260	141.79 [465.07]	unknown	unknown	22.50 [73.80]	22.30 to 32.62 [72.00 to 107.00]	33.53 [110.00]	3	22-Oct-09	08-Mar-10	11-Jun-10		DUP	
199-K-151	148686.440	570941.320	139.81 [458.57]	unknown	35.06 [115.00]	21.75 [71.34]	13.56 to 34.91 [44.50 to 114.50]	35.28 [117.5]	3	22-Oct-09	08-Mar-10	24-Jun-10			EBL
199-K-152	148585.890	570736.250	140.24 [459.99]	unknown	35.36 [116.00]	22.38 [73.40]	12.04 to 34.91 [39.50 to 114.50]	35.28 [117.5]	3	22-Oct-09	08-Mar-10	22-Jun-10			DUP
199-K-157	147167.940	569432.180	138.83 [455.38]	unknown	42.38 [139.00]	19.09 [62.61]	11.70 to 42.19 [38.40 to 138.40]	43.11 [141.40]	3	29-Oct-09	08-Mar-10	11-Jun-10	DUP	EBL	EBL
699-72-73	145418.782	567551.544	146.54 [480.67]	unknown	50.91 [167.00]	26.22 [86.00]	18.29 to 53.66 [60.00 to 176.00]	60.97 [200.00]	3	22-Oct-09	05-Mar-10	11-Jun-10			
699-73-61	145781.525	571420.823	161.53 [529.83]	unknown	unknown	44.05 [144.49]	32.62 to 44.51 [107.00 to 146.00]	45.73 [150.00]	3	28-Oct-09	05-Mar-10	18-Jun-10	FTB		FTB

Source: DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study,* Rev. 0.

The SAP specifies:			**QC samples collected:**		
Equipment Blanks	=	3	Equipment Blanks (EBL)	=	5
Field Blanks	=	3	Field Trip Blanks (FTB)	=	4
Duplicates	=	3	Duplicates (DUP)	=	9
Split	=	1	Split	=	1
Total	=	10 QC Samples Required	QC Samples Taken	=	19

The following documents summarize information on the existing monitoring well and aquifer tube sampling sites and analytes as well as monitoring well and aquifer tube specifications:

- DOE/RL 96-84, *Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action* (KR-4 pump-and-treat)
- DOE/RL 2006-52, *The KW Pump and Treat System Remedial Design and Remedial Action Work Plan, Supplement to the 100-KR-4 Groundwater Operable Unit Interim Action* (KW pump-and-treat)
- DOE/RL-2006-75, *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System* (KX pump-and-treat)
- TPA-CN-273, *Change Notice for Modifying Approved Documents/Workplans In Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: DOE/RL-2006-75 Rev. 1, Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump and Treat System*
- TPA-CN-359, 2010, *Change Notice for Modifying Approved Documents/Workplans In Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: DOE-RL-2006-75, Rev. 1, Reissue Supplement to the 100-HR -3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump and Treat System (As amended by TPA-CN-273, May 20, 2009)*

2.1.11 Ecological Investigations

PNNL monitors and surveys Hanford plant and animal resources to establish potential radiological exposures due to site activities; assess the condition of endangered, threatened, or sensitive species; and evaluate breeding locations, habitat use, and distribution of key wildlife species. The following text describes the most recently published information regarding Hanford Site ecological monitoring activities (*Summary of the Hanford Site Environmental Report for Calendar Year 2008* [PNNL-18427-SUM]). No additional ecological investigations were conducted as part of this RI/FS effort.

Section 3.9 summarizes the ecology of the Hanford Site and Section 4.2.5 summarizes the results of the biota monitoring.

2.1.11.1 Vegetation Monitoring

In 2008, vegetation samples were collected on or adjacent to former waste disposal sites and from locations downwind and near or within the boundaries of operating facilities and remedial action sites to monitor for radioactive contaminants.

2.1.11.2 Fish and Wildlife Monitoring

Fish and wildlife on the Hanford Site are monitored for Hanford-produced contaminants. In 2008, sucker, common carp, smallmouth bass, and deer were collected at locations on and around the Hanford Site. Tissue samples were analyzed for Sr-90 and gamma emitters, including cesium-137. Since the 1990s, Sr-90 and cesium-137 have been the most frequently measured radionuclides in fish and wildlife samples. In addition, liver tissues from fish and deer were monitored for 17 trace metals.

2.1.11.3 Plant Communities and Population Surveys

Plant populations monitored on the Hanford Site include species listed by Washington State as endangered, threatened, or sensitive, and species listed as review group 1. Monitoring data are used to develop baseline

information and to monitor for changes resulting from Hanford Site operations. Surveys for rare animal species were conducted in 2008 as part of annual compliance review activities. More than 100 plants listed as endangered, threatened, sensitive or on the view or watch list are found on the Hanford Site.

2.1.11.4 Wildlife Populations Surveys

Four fish and wildlife species on the Hanford Site are surveyed annually: fall Chinook salmon, steelhead trout, bald eagle, and mule deer. The number of fall Chinook salmon spawning nests (redds) in the Hanford Reach is estimated by aerial surveys. Two aerial surveys were conducted to identify possible steelhead trout spawning areas.

During two surveys in January and February 2009, 34 eagles (18 adults and 16 juveniles) were observed along the Hanford Reach from Vernita Bridge to the City of Richland.

Roadside surveys were conducted for mule deer on the Hanford Site to assess age and sex ratios and the frequency of testicular atrophy in males. Testicular atrophy has been associated with an unusually large number of older deer residing at the site. A combined total of 566 deer observations were made over five repeated surveys during November 2008 to January 2009, which could include multiple observations of the same animal.

2.1.11.5 Habitat and Species Characterizations

Ecological monitoring on the Hanford Site includes characterizing breeding locations, habitat use, and distribution of key wildlife species. In 2008, characterization studies focused on the Woodhouse's toad and the burrowing owl, a Washington State candidate species and federal species of concern in this region. Toads were monitored using radio telemetry and found predominantly within 200 m (656 ft) of the Columbia River or the high-water channel of the 100-F slough. Burrowing owl distributions and nesting habitats were evaluated; 53 nests have been document on the site.

2.1.11.6 Contaminated Biota

Animals (including insects) must be controlled when they are contaminated with radioactivity. Biological control personnel responded to approximately 33,000 animal control requests from Hanford Site employees in 2008. A total of 33 contaminated animals or animal-related materials were discovered in 2008.

2.1.12 River Corridor Supplemental Investigations

To support information needs for the entire River Corridor, the following supplemental activities from the Integrated Work Plan (DOE/RL-2008-46) were carried out separately from the RI field investigation activities described in the 100-K SAP (DOE/RL-2009-41):

- **Evaluated groundwater and surface water interactions for the River Corridor.** Flow paths in the groundwater/river zone of interaction vary with daily and seasonal fluctuations in river stage. River water infiltrates the banks during high river stages, moves inland, and then reverses flow as the river stage subsides and moves back through the hyporheic zone and discharges to the riverbed. Monitoring and modeling studies suggest that this back-and-forth motion of groundwater and river is cyclical in response to the diurnal river stage cycle, which typically includes two high stages and two low stages in response to power peaking demands. This motion occurs as laminar flow; consequently, the water is moving back and forth along streamlines within the greater potential field that defined groundwater discharge to the regional discharge point, the Columbia River. Review of modeling suggests there is a significant back-and-forth motion in the groundwater such that an individual Cr(VI) atom experiences a significant lengthening of the flow path as it moves back and forth through the aquifer. It will experience numerous reversals in flow direction before it eventually reaches the water column in the river.

This mechanism is significant for fate and transport because it increases the length of the flow path and increases the likelihood of Cr(VI) encountering sites in the aquifer matrix where reduction can occur. The intrusion of river water that is not at equilibrium with the aquifer matrix will flush through the system and reduce passivation of the reactivity at mineral surfaces; consequently, the flushing promotes continued reduction, adsorption, and precipitation of chromium in the hyporheic zone and adjacent groundwater.

An important addition to our understanding of the fate and transport of Cr(VI) is that in addition to chemical reduction, the reduction of Cr(VI) to Cr(III) also occurs biologically, mediated by bacteria. ("A Molecular Comparison of Culturable Aerobic Heterotrophic Bacteria and 16S rDNA Clones Derived from a Deep Subsurface Sediment" [Chandler et al., 1997]) described the wide variety of microbes present in the Hanford subsurface. Their studies focused on the vadose zone. A number of studies have been conducted on deeper Hanford bacteria in the groundwater. Recent studies of 100-H groundwater microbial ecology (*Physiological and Transcriptional Studies of Cr(VI) Reduction under Anaerobic and Denitrifying Conditions by an Aquifer-Derived Pseudomonad* [Han et al., 2010]) suggest that bacteria can use multiple electron donors to reduce Cr(VI), depending on whether conditions are aerobic or anaerobic. *Hanford 100-D Area Biostimulation Treatability Test Results* (PNNL-18784) described results from biostimulation treatability tests at 100-D. Following the injection of a carbon substrate, "…microbial activity and ability to reduce the targeted species were observed throughout the monitored zone." These general mechanisms are described in the *Chromium (VI) Handbook* (Guertin et al., 2004). Consequently, the back-and-forth motion adds nutrients from the river such as organic carbon, phosphate, and other constituents that enhance bacterial reduction of Cr(VI).

- **Collected data for the determination of River Corridor background concentration values for antimony, boron, molybdenum, and selenium.** Site-specific background values for these constituents were needed to determine soil RAG values because calculated risk-based concentrations and/or ecological protection concentrations were less than Washington State or expected site-specific background values. Background values are discussed further in Section 4.1.

- **Reevaluated the soil cleanup level for Cr(VI) to support the ROD.** The lowest soil RAG for Cr(VI) under the interim RODs is 2.0 mg/kg. However, the calculated soil RAG value ("Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)]) may be below the current limits of analytical quantitation in environmental samples, depending on the contaminant K_d and groundwater to river dilution attenuation factor used.

  As with any analytical method, uncertainty in quantitation increases near the PQL, and false detections may occur, but there is not a basis for revising previously reported PQLs or raising Method 7196A PQLs in the future. The lowest soil PRG is presently expected to be sufficiently above typically achieved PQLs, such that actual cleanup criteria would not default to a PQL.

  Based on the evaluation of soil cleanup levels and analytical methods, the accepted modeling approach was used to establish PRGs for this RI/FS. The development of PRGs for groundwater and surface water protection are presented in Chapter 5.

- **Determined a site-specific contaminant K_d for antimony.** Over the past several years, different values have been identified at Hanford to serve as the K_d for antimony. This value was necessary for calculation of soil RAG values for antimony ("Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)]). Antimony is not a significant contaminant in the River Corridor, and evaluation included review of scientific literature. The literature review resulted in several different values. A summary of the literature is presented below:

- The 1.4 mL/g K_d value is based on testing of Rainier Mesa tuff and does not appear to be comparable to Hanford soil types.

- The 0 to 40 mL/g K_d range appears to be based largely on experience and general knowledge rather than on specific test results. A 1977 paper considered in establishing this range presents a K_d of approximately 65 mL/g antimony desorption from soil. This appears to be one of the few references available that presents actual K_d desorption data; the value supports the conclusion that desorption values are "much greater" than sorption values.

- The 45 mL/g K_d value is a calculated value is based on a theoretical correlation between K_d and the soil-to-plant concentration factor; it does not represent a value from experimental determination. This value is used by EPA and identified in the "Cleanup Levels and Risk Calculations" (CLARC) database (Ecology, 2003).

- The 3.76 mL/g K_d value comes from actual static batch equilibrium testing on sand/clay soil at a pH of 7.6, and appears to be a reasonable approximation of Hanford soil types. This value is based on sorption, not desorption.

- A K_d value of 3.76 mL/g was used in the groundwater modeling presented in Chapter 5. This is considered a conservative value since it assumes a higher level of mobility than suggested by the technical review of the literature. The K_d value used, while conservative, results in the maximum concentration of the analyte reaching the groundwater at a peak year much greater than 10,000 years, and an elimination of antimony as a COPC. A higher K_d value would have no effect on that result.

- **Re-evaluated soil cleanup levels for arsenic to support the ROD.** The soil RAG for arsenic under the interim RODs is 20 mg/kg, based upon the Tri-Party Agreement (Ecology et al., 1989a) stipulation to use the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(2)), 1996 Method A value (100 Area RDR/RAWP [DOE/RL-96-17]). The "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(2)), 2007, Method A, value is 20 mg/kg. The 20 mg/kg value for arsenic exceeds the 10×10^{-6} individual cancer risk based on Method B calculations. The WAC 173-340-740(3), 2007, Method B, value is 0.67 mg/kg, and the "Deriving Soil Concentrations for Groundwater Protection" (WAC 173-340-747(3)(a)) groundwater protection value is 0.00737 mg/kg for arsenic. Both of these values are below the Hanford Site arsenic background concentration of 6.5 mg/kg.

  An evaluation of the arsenic soil cleanup level was conducted to resolve the apparent contradictions. Arsenic is a statewide concern due to historic smelter operations and pesticide use. Legislative established programs to evaluate statewide arsenic contamination continue to consider the Method A soil cleanup level of 20 mg/kg as a trigger for action. Ecology has determine that cleanup of soil to the Method A level based on average concentrations is protective. Based on this evaluation, the Method A level is proposed for continued use, which is consistent with other cleanup actions throughout the State of Washington.

2.2 Field Activity Documentation

As discussed in previous sections, field investigations have been conducted in 100-K to address the concerns discussed in the Table 2-1, Data Needs, to supplement information received from the LFIs, and in response to results from ongoing remedial actions (e.g., CERCLA 5-year reviews). The results of these field investigations are summarized in a variety of documents and tables. The borehole summary reports for April and May 2011 (SGW-48760 and SGW-49459) contain the borehole logs, detailed sampling summary, well summary sheets, photographic logs (available only for SGW-49459), and the final survey data. The additional field data not contained within these reports is located in Appendix C, including Table C-1, Aquifer Slug Tests and Table C-2, Aquifer Tube Water Quality Field Data.

3 Physical Characteristics of the Study Area

This chapter describes the physical and environmental characteristics of 100-K, including the information obtained during the RI and ongoing monitoring activities. An important component of the conceptual site model is the physical characteristics of the study area in which the nature and extent of contamination exist, described in Chapter 4. In Chapter 5, key aspects of the physical setting that influence the movement of contaminants within the environment are examined. Topics of this chapter include important surface features, meteorology, hydrology, geology, soil, hydrogeology, artificial water systems, demography, and cultural resources. Some microscale topics, such as regional geology and meteorology, concern the Hanford Site as a whole, while others are more specific to 100-K.

Highlights

- The vadose zone consists of mostly Hanford formation material, which ranges in thickness from less than 1 m (3.3 ft) near the river shoreline to approximately 30 m (100 ft) near the south boundary of 100-K. Within the 100-K Area, the Hanford formation is no more than 20 m (65 ft) thick. Near the shoreline, the Ringold Formation is exposed from along the riverbank up to 366 m (1,200 ft) inland.
- Near the reactors, the aquifer is consistently within the Ringold unit E. Farther to the east, at the eastern end of the 116-K-2 Trench, the aquifer intersects the Hanford formation during periods of high water.
- Towards the eastern portion of 100-K, the aquifer thins, has low conductivity, and a lower permeability than other areas within 100-K. The tighter material has limited the rate of water exctraction, affecting the efficiency of the pump-and-treat system.
- Between the reactors and the 116-K-2 Trench, the surface of the RUM undulates and displays considerable changes in relief.
- The shoreline at 100-K has numerous culturally sensitive areas that need to be considered during any remediation activities.

3.1 Surface Features

The surface topography of 100-K near the river is generally formed upon a large-scale flood bar (Hanford formation) deposited by the late-Pleistocene cataclysmic floods. Since then, a series of step-like river channel terraces has been carved by the ancestral Columbia River, as described in *Late Pleistocene and Holocene-Age Columbia River Sediments and Bedforms: Hanford Reach Area, Washington, Part 1* (BHI-01648). Each terrace is a fragment of the channel bed and has a distinct sedimentary deposit, typically consisting of sandy pebble-to-cobble gravel. Channel beds may be armored with larger boulder-to-cobble sized material. Each terrace is defined by a low sloping to more sharply defined scarp connecting the adjacent flat areas.

Five terraces are present along the 100-K stretch of the Columbia River. The upper terrace is at an elevation of 133 to 137 m (435 to 448 ft) AMSL and displays at least two channels. One channel followed the current northeast trend of the Columbia River in this area. A second broad channel splits off to sweep south of the 100-N Reactor, and cuts through an area of irregular large-scale current ripples. The 116-K-2 Trench was dug within this first terrace. The next three terraces also follow the northeast trend of the current river channel and terminate at the 100-N Reactor, with the fifth terrace representing the lateral extent of the current Columbia River channel. Within the 100-K Reactor, construction obliterated many of the terraces while grading during construction. Fill dirt has been placed along the reactor area's northern fence line to a depth of 4.6+ m (15+ ft) and to thicknesses of 7 m (23 ft) around water basin and reactor foundations.

The topography in 100-K is relatively flat inland from the Columbia River. Topographic changes are greatest near the Columbia River. Surface elevations range from approximately 166 m (545 ft) AMSL near the southern boundary of 100-K to 119 m (390 ft) along the river. The mean elevation in 100-K is 145 m (476 ft). Figure 3-1shows 100-K topography.

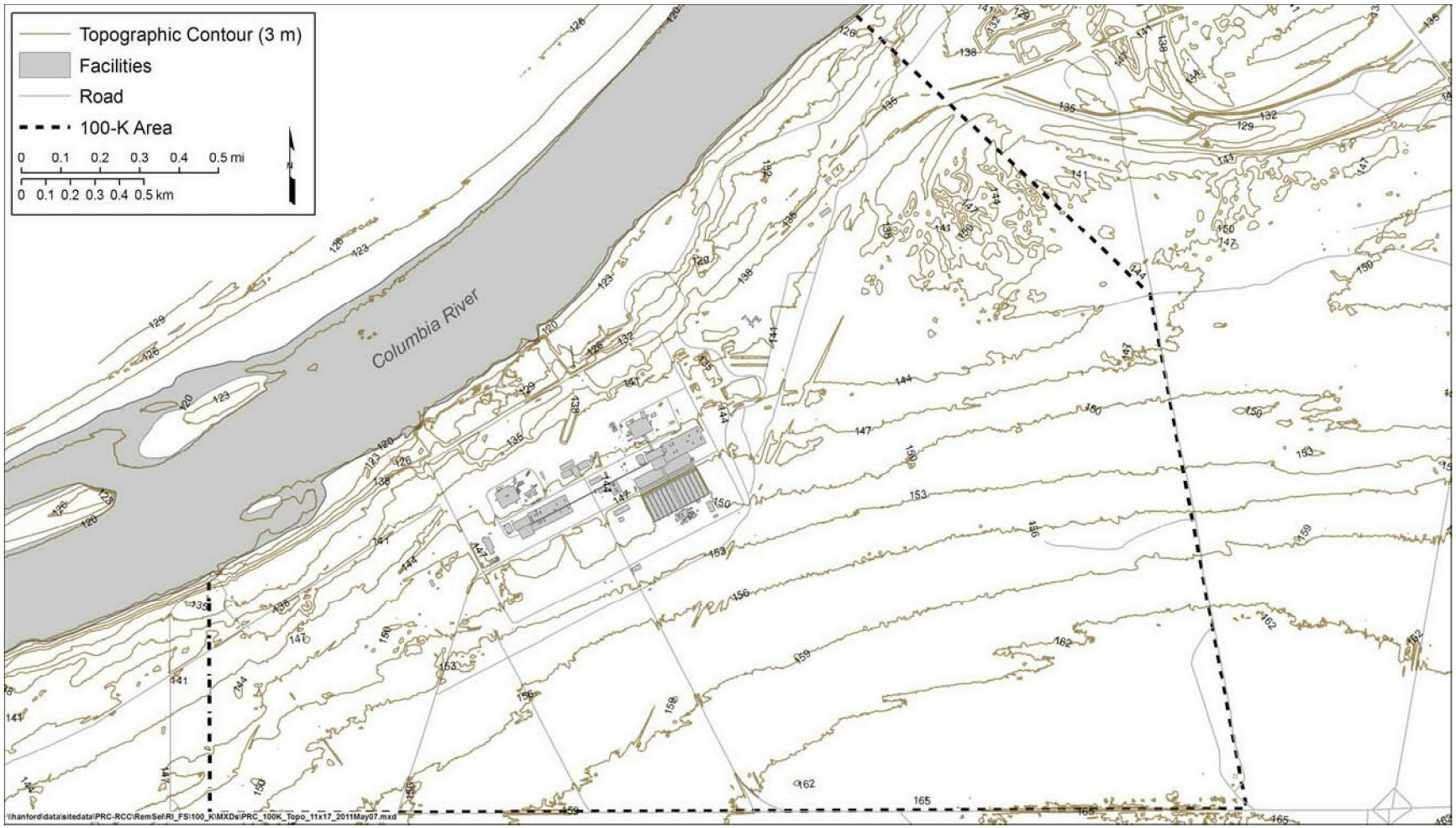


Figure 3-1. 100-K Area Topography

The land surface in and around the 100-K Reactor area has been extensively modified from its original pre-Hanford configuration (Figure 3-2) to a degree much greater than at other single-pass reactor sites. During construction in the early 1950s, the ground surface was designed to slope toward the river to facilitate flow of cooling water and other waste streams. The 100-K Reactor area was stripped of existing vegetation, which was gradually replaced by shallow-rooted grasses in areas away from operations and traffic. Areas to the south, west, and east of the reactor area were also stripped of vegetation and used for laydown yards, construction shops and other activities. Reactor and water treatment structural foundations extended to depths exceeding 7 m (23 ft), resulting in the rearrangement of significant volumes of soil.

Figure 3-2. 100-K (1951)

In areas near the river and the northern 100-K Reactor security fence, fill was added to a depth of up to 4.6 m (15 ft) (Figure 3-3). It is likely that excavated material was used with borrow pit material to build up the ground surface in areas nearer the river. The excavated material would most likely have been the coarse granular sediments of the Hanford formation (Section 3.4.2.3). In turn, when used as fill material, the sediments would have been placed on top of existing Hanford formation sediments. As a result, there is little in the way of distinguishing features between placed Hanford formation fill and in-place Hanford formation. Identifying vertical extent of fill material requires encountering artificial construction debris during drilling.

Figure 3-3. 100-K (1953)

Since 2002, demolition and waste site remediation activities have resulted in excavations to depths of 4.6 to 14 m (15 to 45 ft) bgs. Major facility demolition activities included the removal of 107-KE and -KW

Retention Basins and remediation of the subsurface soils beneath this site. In addition, the 116-K-1 Crib and 116-K-2 Trench, plus supporting pipelines, have been removed (Figure 3-4). More recently, support facilities associated with the 105-KW Reactor water treatment plant (183.1 KW Head House, 183.2 Sedimentation Basin, and 183.4 Clearwell) have been removed and adjacent waste sites have been excavated, although work is not finished as of this writing. Demolition activities at the 105-KE Reactor have removed most of the adjacent support structures (115-KE Gas Conditioning Facility, the 117-KE Filter Building, and the 105-KE Fuel Storage Basin). Significant excavations have been developed to remove basements and associated waste sites around these structures, but are being backfilled as work is completed.

Figure 3-4. 100-K (2004)

3.2 Meteorology

100-K is located in the driest and warmest portion of the Columbia Basin. The Columbia Basin's large size and complex topography contribute to substantial spatial variations in wind, temperature, precipitation, and other meteorological parameters, which are further affected by mountain barriers (*Hanford Site National Environmental Policy Act (NEPA) Characterization*, hereinafter called NEPA Characterization Report [PNNL-6415]). The Cascade Range to the west creates a rain shadow effect over 100-K, while the Rocky Mountains and ranges in southern British Columbia protect the site from the more severe Canadian polar air masses (*Hanford Site Climatological Summary 2004 with Historical Data* [PNNL-15160]).

Climatologic data are monitored at HMS and other locations throughout the Hanford Site. HMS is located approximately 9 km (5.5 mi) south of the 100-K boundary. As such, data gathered at the station are generally representative of study area conditions. From 1945 through 2009, the maximum temperature recorded at the Hanford Site was 45ºC (113ºF) in July 2002 and August 1961, and the recorded minimum temperature was -30.6ºC (-23ºF) measured twice in February 1950 (NEPA Characterization Report [PNNL-6415]). The monthly average temperature ranges from a low of 0.24ºC (31.7ºF) in January to a high of 24.6ºC (76.3ºF) in July. Annual average relative humidity at the HMS is 55 percent. It is highest during the winter months, averaging about 76 percent, and lowest during the summer, averaging approximately 36 percent (NEPA Characterization Report [PNNL-6415]).

Tables 3-1 and 3-2 present the average monthly and annual minimum and maximum temperatures, respectively, at the Hanford Site from 1945 through 2009.

Table 3-1. Monthly and Annual Minimum Temperatures from 1945 through 2009

1945–2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (°F)	6	12	21	29	35	44	49	49	39	27	18	9	0
Average (°C)	-14	-11	-6	-2	2	7	9	9	4	-3	-8	-13	-18
Lowest (°F)	-22	-23	6	21	28	37	39	41	30	7	-13	-14	-23
Lowest (°F)	-30	-31	-14	-6	-2	3	4	5	-1	-14	-25	-26	-31
Highest (°F)	24	29	32	37	48	52	58	56	48	34	28	23	20
Highest (°C)	-4	-2	0	3	9	11	14	13	9	1	-2	-5	-7

Note: Data from http://hms.pnl.gov/minmonth.htm.

Table 3-2. Monthly and Annual Maximum Temperatures from 1945 through 2009

1945–2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (°F)	57	62	70	81	93	99	105	104	95	80	65	57	107
Average (°C)	14	17	21	27	34	37	41	40	35	27	18	14	42
Lowest (°F)	36	46	63	71	81	86	96	96	86	72	54	39	100
Lowest (°C)	2	8	17	22	27	30	36	36	30	22	12	4	38
Highest (°F)	72	72	83	94	104	111	113	113	106	89	76	69	113
Highest (°C)	22	22	28	34	40	44	45	45	41	32	24	21	45

Note: Data from http://hms.pnl.gov/minmonth.htm.

Since 1947, annual precipitation at the Hanford Site has varied from approximately 7.6 to 31.3 cm (3.0 to 12.3 in.), with an annual average of 17.2 cm (6.8 in.).

As shown in Table 3-3, most precipitation occurs during late fall and winter, with more than half occurring from November through February. Snowfall accounts for approximately 38 percent of the precipitation at the Hanford Site from December through February (NEPA Characterization Report [PNNL-6415]) and for the majority of the moisture that infiltrates the ground. Average snowfall ranges from 0.25 cm (0.1 in.) during October to a maximum of 13.2 cm (5.2 in.) during December, and decreases to 1.3 cm (0.5 in.) during March. The highest monthly snowfall recorded at the HMS was 59.4 cm (23.4 in.) in January 1950.

Table 3-3. Average, Minimum, and Maximum Monthly and Annual Precipitation from 1947 through 2009

1947-2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average (in.)	0.95	0.65	0.50	0.51	0.52	0.55	0.25	0.29	0.32	0.55	0.89	1.04	6.76
Average (cm)	2.40	1.66	1.26	1.30	1.32	1.40	0.63	0.73	0.81	1.40	2.26	2.64	17.18
Minimum (in.)	0.08	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.02	0.07	2.99
Minimum (cm)	0.20	0.03	0.05	0.03	0.05	0.03	0.00	0.00	0.00	0.03	0.05	0.18	7.59
Maximum (in.)	2.47	2.10	1.86	2.23	2.03	2.92	1.76	1.36	1.34	2.72	2.67	3.69	12.31
Maximum (cm)	6.27	5.33	4.72	5.66	5.16	7.42	4.47	3.45	3.40	6.91	6.78	9.37	31.27

Note: Data from http://hms.pnl.gov/totprcp.htm.

Surface winds blow predominantly from the northwest during winter and summer months, and from the southwest during spring and fall. Local winds in the 100 Area and along the Columbia River are strongly influenced by near-river topography (NEPA Characterization Report [PNNL-6415]). Average monthly wind speeds at the Hanford Site are lowest during winter, averaging 10 to 11 kph (6 to 7 mph) (Table 3-4). The highest average wind speeds, ranging from 14 to 16 kph (8 to 10 mph), have been reported during summer. The fastest wind speeds at HMS are usually associated with flow from the southwest. However, the summertime drainage winds from the northwest frequently exceed speeds of 47 kph (30 mph).

Table 3-4. Monthly and Annual Prevailing Wind Directions, Average Speeds, and Peak Gusts at 15 m (50 ft) Level (1945 through 2004)

Month	Prevailing Direction	Average Speed (kph [mph])	Highest Average		Lowest Average		Peak Gusts		
			kph (mph)	Year	kph (mph)	Year	Speed (kph [mph])	Direction	Year
January	NW	10 (6.3)	16.6 (10.3)	1972	4.7 (2.9)	1985	129 (80)	SW	1972
February	NW	11 (7.0)	17.9 (11.1)	1999	7.4 (4.6)	1963	105 (65)	SSW	1999
March	WNW	13	17.2	1977	9.5	1958	113	SW	1956

Table 3-4. Monthly and Annual Prevailing Wind Directions, Average Speeds, and Peak Gusts at 15 m (50 ft) Level (1945 through 2004)

Month	Prevailing Direction	Average Speed (kph [mph])	Highest Average		Lowest Average		Peak Gusts		
			kph (mph)	Year	kph (mph)	Year	Speed (kph [mph])	Direction	Year
		(8.2)	(10.7)		(5.9)		(70)		
April	WNW	14 (8.8)	17.9 (11.1)	1972	12 (7.2)	2004	117 (73)	SSW	1972
May	WNW	14 (8.9)	17.2 (10.7)	1983	9.3 (5.8)	1957	114 (71)	SSW	1948
June	NW	15 (9.1)	17.2 (10.7)	1983	12 (7.3)	1982	116 (72)	SW	1957
July	NW	14 (8.6)	17.2 (10.7)	1983	11 (6.8)	1955	111 (69)	WSW	1979
August	WNW	13 (8.0)	15 (9.5)	1996	10 (6.0)	1956	106 (66)	SW	1961
September	WNW	12 (7.4)	15 (9.2)	1961	8.7 (5.4)	1957	105 (65)	SSW	1953
October	NW	11 (6.6)	15 (9.1)	1946	7.1 (4.4)	1952	116 (72)	SW	1997
November	NW	10 (6.4)	16 (10.0)	1990	4.7 (2.9)	1956	108 (67)	WSW	1993
December	NW	9.7 (6.0)	13 (8.3)	1968	5.3 (3.3)	1985	114 (71)	SW	1955
Annual	NW	12 (7.6)	14 (8.8)	1999	10 (6.2)	1989	129 (80)	SW	1972

Source: PNNL-15160, *Climatological Summary 2004 with Historical Data*, Table 5.1

Strong winds occasionally create excessive dust and contamination control problems in 100-K. Methods used to minimize wind-related concerns in 100-K include applying dust suppression water and soluble adhesives. Wind and dust can limit the progress of work, and at times, make it necessary to stop work.

The wind speed class with the highest frequency of occurrence at HMS is 6.5 to 11 kph (4 to 7 mph). Winds in that category occur 37 percent of the time. The speed class with the second highest frequency of occurrence is 13 to 19 kph (8 to 12 mph), at 25 percent. Winds averaging over 40 kph (25 mph) only occur one percent of the time on an annual basis, with the highest frequency in March (1.6 percent) (*Climatological Summary 2004 with Historical Data* [PNNL-15160]).

3.3 Surface Water Hydrology

The Columbia River forms the northern-western boundary of 100-K and is the only natural surface water feature associated with the study area.

3.3.1 Columbia River

The stretch of Columbia River along the 100 Area is referred to as the Hanford Reach. The "Reach" extends from Priest Rapids Dam, located approximately 24 km (15 mi) upstream of 100-K, to the pool headwaters near the 300 Area behind McNary Dam's Lake Wallula (Figure 1-1). In May 2000, the Hanford Reach was incorporated into the 70,820 ha (175,000 ac) ("Establishment of the Hanford Reach National Monument" [65 FR 37253]). River flows here are managed mainly for generating power, controlling floods, and promoting salmon egg and embryo survival.

The Columbia River has played a major role in the depositional and erosional processes that helped produce the sedimentary and geologic features across the Hanford Site. The river is noted for its very low suspended load, its low nutrient content, and absence of microbial contaminants (*Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164]). While the river has produced large, episodic floods in the past, the construction of multiple dams on the Columbia River has considerably reduced the likelihood of future large scale flooding (*Final Environmental Impact Statement Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes: Hanford Site, Richland, Washington* [DOE/EIS-0113]).

Columbia River flows typically peak from April through June during spring runoff from regional and high elevation snowmelt, and flows are lowest from September through October. The Columbia River has an average flow of approximately 3,250 m^3/s (115,000 ft^3/s). Flow rates range from approximately 1,020 to 10,300 m^3/s (36,000 to 362,000 ft^3/s) (*Hydrodynamic Simulation of the Columbia River, Hanford Reach, 1940-2004* [PNNL-15226]), depending on the releases from Priest Rapids Dam.

Construction of the Priest Rapids Dam began in 1956 during construction of the K Reactors, and power generation at the dam began in 1959. Priest Rapids operates as a run-of-the-river dam rather than a storage dam. Hourly to daily release rates of the Priest Rapids Dam further manage river stage to control the potential for flooding from the Columbia River at the Hanford Site. The nearest dam downstream of 100-K is McNary Dam. Construction of the McNary Dam began in 1947, before construction of the 100-K Reactors. Power generation at the dam began in 1954. The dams result in a diurnal cycle of river stage in response to power generation at the dams, in addition to the annual cycle of river stage in response to snowmelt and seasonal runoff.

The depth of the river varies significantly with changes in discharges and flow rates. Hanford Reach river width can vary from approximately 300 to 1,000 m (1,000 to 3,300 ft). Varying with flow rate, river width fluctuations cause repeated wetting and drying of the shoreline area (NEPA Characterization Report [PNNL-6415]).

The Columbia River stage is monitored on an hourly basis for 100-K. As previously discussed, the river stage fluctuates throughout the year, depending on season. The Priest Rapids Dam, which is upstream of the 100 Area, ultimately controls the volume of river water flowing through the Hanford Reach. Figure 3-5 shows the daily average and annual river discharge rates at Priest Rapids Dam from 2005 through 2009. The highest discharge rates generally occur in the spring, when snowmelt is contributing to surface runoff into the river. Figure 3-6 shows the daily average and annual average river stage for 100-K from 2008 through 2010. River stage fluctuations directly influence groundwater levels as described in Section 3.6.3.

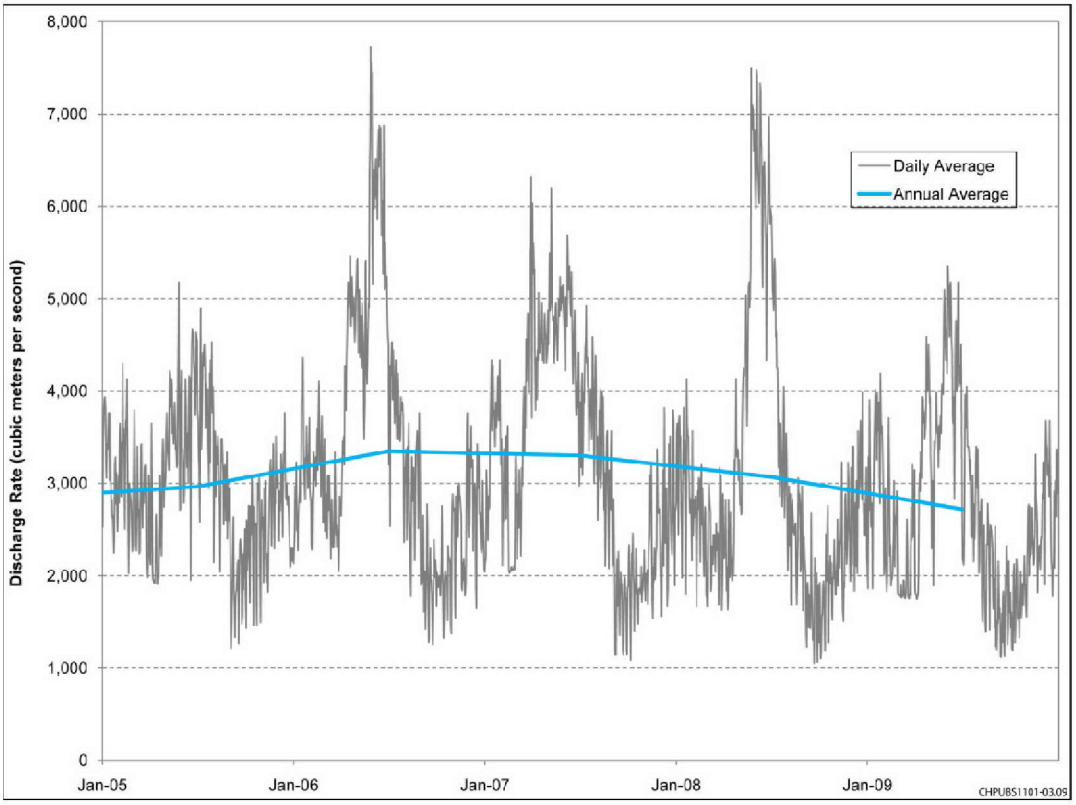


Figure 3-5. Daily Average and Annual Average Discharge Rates at Priest Rapids Dam (2005–2009)

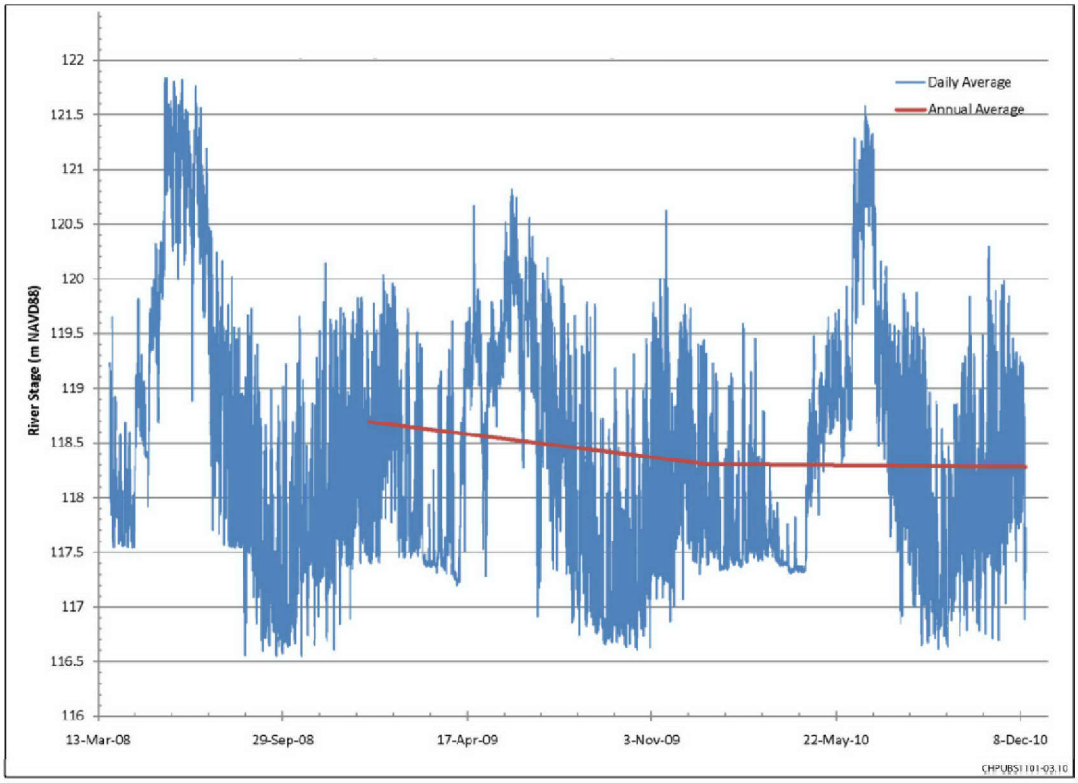


Figure 3-6. Daily Average and Annual Average River Stage at 100-K (2008–2010)

3.3.2 Surface Water Use

Water users withdraw water along the 100-K portion of the Hanford Reach for fire protection and drinking water and for Hanford Site water use (*Hanford Site Environmental Report for Calendar Year 2006* [PNNL-16623]). In addition, the Columbia River provides extensive recreation, including fishing, hunting, boating, sailing, waterskiing, diving, and swimming. The Columbia River also supplies water for public use, and wildlife habitat (*100-B/C Pilot Project Risk Assessment Report* [DOE/RL-2005-40]).

3.4 Geology

The Hanford Site and Pasco Basin lie within the Columbia Plateau of southeastern Washington State. This broad plain, situated between the Cascade Mountains to the west and the Rocky Mountains to the east, is underlain by a thick sequence of volcanic Columbia River basalt, which forms the basement rock for the region (*Hydrogeologic Model for the Gable Gap Area, Hanford Site* [PNNL-19702]). Tectonic folding and faulting, which began with extrusion of the Columbia River Basalt Group (CRBG) basalts, continues to the present. The last basalt flows to reach the Pasco Basin occurred between 8.5 and 10.5 million years ago ("The Saddle Mountains: The Evolution of an Anticline in the Yakima Fold Belt" [Reidel, 1984]; *Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164]). Sediments of the late Miocene, Pliocene, and Pleistocene ages have accumulated up to 520 m (1,700 ft) thick in the Pasco Basin, the result of ancestral Columbia and possibly Snake/Clearwater River deposition (*Geology of the 100-K Area, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-155]). During the Ice Age (Pleistocene epoch), massive cataclysmic floods repeatedly occurred, interrupted by interglacial periods of several tens of thousands of years. The oldest ice age floods were at least 780,000 years ago; however, the first floods might have occurred closer to the beginning of the Ice Age, 2.6 million years ago.

3.4.1 Geologic Setting

100-K lies on the northern flank of the Wahluke Syncline and is located adjacent the Columbia River to the west and north and east by the remaining portions of the Hanford Site footprint. The sediments above the basalts (suprabasalt sediments) below 100-K are as much as 160.7 m (527 ft) thick.

The geology of 100-K has been described in detail in numerous documents, including the following:

- DOE/RL-93-79, *Limited Field Investigation Report for the 100-KR-4 Operable Unit*
- DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for the Post-Ringold-Formation Sediments Within the Central Pasco Basin*
- WHC-SD-EN-TI-011, *Geology of the Northern Part of the Hanford Site: An outline of Data Sources and the Geologic Setting of the 100 Areas*
- BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*
- USGS Prof. Paper 717, *Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington*
- WHC-SA-0740-FP, *Sedimentology and Stratigraphy of the Miocene-Pliocene Ringold Formation, Hanford Site, South-Central Washington*
- WHC-SD-EN-DP-090, *Borehole Data Package for the 100-K Area Ground Water Wells, CY 1994*
- WHC-SD-EN-TI-155, *Geology of the 100-K Area, Hanford Site, South-Central Washington*

- WHC-SD-ER-TI-003, *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*
- DOE/RW-0164, *Site Characterization Plan: Reference Repository Location, Hanford Site, Washington*

3.4.2 Stratigraphy

Eleven stratigraphic units are recognized in 100-K. Figure 3-7 presents a generalized geologic column for 100-K. Geological cross sections are presented and discussed in Section 3.4.3. The subsections that follow provide specific stratigraphic units (from youngest to oldest) and describe the area in more detail:

- Recent eolian or backfill material (sand; sand and gravel)
- Hanford formation (gravel and sand)
- Ringold unit E (sand and gravel)
- Ringold Formation upper mud (RUM) unit (silt, fine sand, and clay—includes rare water-bearing gravely to sandy silt lenses)
- Ringold unit C (sand and gravel)
- Ringold lower mud (RLM) unit
- Ringold unit B (sand within the RLM)
- Ringold RLM (silt and clay)
- Ringold unit A (sand and gravel, includes Snipes Mountain Conglomerate)
- CRBG (basalt flows interlayered with Ellensburg Formation sediments)
- Ellensburg Formation (sedimentary interbeds [tuff, paleosols, and sand] between CRBG basalt flows)

3.4.2.1 Geologic Formations

The sediments that overlie the basalts are divided into two primary units: the Ringold Formation of late Miocene to middle Pliocene age (approximately 10.5 to 3 million before present [B.P.]) (*Sedimentology and Stratigraphy of the Miocene-Pliocene Ringold Formation, Hanford Site, South-Central Washington* [WHC-SA-0740-FP]), which is overlain by the informally named Hanford formation of Pleistocene age (approximately 1 million to 12,000 B.P.) (*Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington* [USGS Prof. Paper 717]). Holocene surficial deposits of silt, sand, and gravel form a relatively thin veneer at the surface (*Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports* [WHC-SD-ER-TI-003]; "Long History of Pre-Wisconsin, Ice Age, Cataclysmic Floods: Evidence from Southeastern Washington State" [Bjornstad et al., 2001]).

100-K is underlain by Miocene-aged (approximately 17 to 8.5 million years B.P.) basalt of the Columbia River Basalt Group and late Miocene- to Pleistocene-aged sediments (approximately 10.5 million to 12,000 B.P.) that are interbedded with the basalt flows, the Hanford formation, the Ringold Formation, and the Ellensburg Formation (*Geology of the 100-K Area, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-155]). The CRBG may exceed 3,050 m (10,000 ft) in thickness locally including the interbedded sediments of the Ellensburg Formation. The Ellensburg Formation consists of a series of sedimentary units (epiclastic and volcaniclastic) that are interbedded with many of the basalt flows of the

CRBG (*Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group* [USGS Bulletin 1457-G]).

The physical properties of these formations influence the distribution of contamination in the subsurface. The Hanford formation, two upper units of the Ringold Formation (the Ringold unit E and RUM units) and possibly backfill sediments are known to have been contacted by contaminated fluids. The rest of the Ringold Formation consists of a lower mud unit and Ringold units A, B, and C. Contaminant migration to these lower units is considered very unlikely. Chapter 4 presents a detailed discussion of the distribution of COPC contamination within the Ringold Formation.

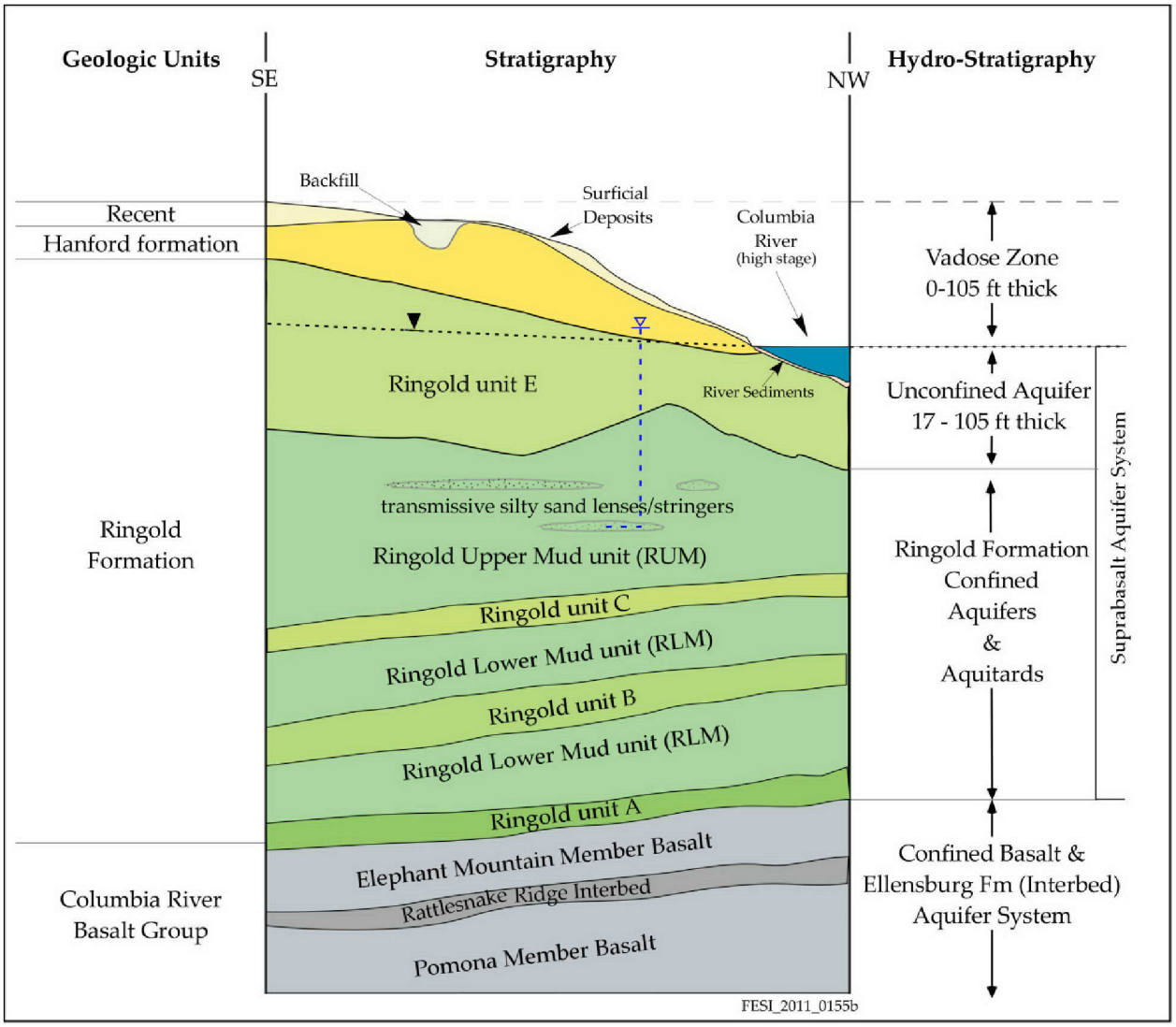


Figure 3-7. Generalized Geology and Hydrostratigraphy of 100-K

3.4.2.2 Surface Deposits

Recent backfill sand and gravel and/or Holocene (recent) deposits consisting of Columbia River terrace deposits and eolian loess, silt, sand, and gravel form the surficial deposits across 100-K, as shown in Figure 3-7. Construction backfill (Section 3.1) locally varies in depth, depending on the excavated depth of waste sites and building foundations, and backfill material may cover larger graded areas to depths of 0.3 m (1 ft) or more. Backfill deposits may be up to 8 m (26 ft) thick near reactors and clearwells, but are

generally less than 5 m (16 ft) thick in other areas. Because of anthropogenic activities associated with construction of the reactors and supporting facilities, the Holocene deposits were likely removed or altered due to extensive grading in the 1950s. Outside of those areas, the Holocene deposits are relatively thin (0.3 m [1 ft]) (*Geology of the 100-K Area, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-155]).

3.4.2.3 Hanford Formation

The Hanford formation consists of three flood-related facies: a gravel-dominated flood channel unit, a sand-dominated unit, and a silt and sand-dominated unit. Within 100-K, the gravel facies is dominant; the sand- and silt-sand facies are found to the south in the Cold Creek Basin. The gravel unit consists of loose, massive to large-scale cross-beds built of pebble-to-cobble and boulder size clasts and is dark gray in color. In general, cross-bedding indicates a water- or wind-driven depositional environment in which the steeper slope of cross-beds point to the downstream direction of movement. Silts and fine-to-coarse sands are also present, as are minor local deposits of fluvial, colluvial, and aeolian material, which occur interbedded with the flood gravels. Suspected flood-driven rip-up-clasts of RUM clays and silts have been observed on occasion in excavations around the KW Head House. Figure 3-8 shows a rip-up clast in situ at a 2011 excavation around the 183.1 KW Head House. In overall composition, gravel clasts are 50 to 75 percent or more basaltic, with lesser amounts of light-colored silicic igneous and metamorphic rock types. The Hanford sand fraction is also commonly greater than 50 percent basaltic material. Hanford gravels are typically more basalt-rich than Ringold gravels, which are composed of a wider variety of regional rock types. In addition, the Hanford gravel clasts are more angular and less rounded than Ringold gravels, as they have not been transported as far from outcrops.

The Hanford formation was deposited by cataclysmic Ice Age floodwaters that drained from glacial Lake Missoula during the Pleistocene epoch (*Draft Environmental Assessment: Reference Repository Location Hanford Site, Washington* [DOE/RW-0017]). The Hanford formation ranges in thickness from less than 1 m (3.3 ft) near the river shoreline to approximately 30 m (100 ft) near the south boundary of 100-K (*Geology of the Northern Part of the Hanford Site: An outline of Data Sources and the Geologic Setting of the 100 Areas* [WHC-SD-EN-TI-011]). Within the 100-K Reactor area, the Hanford formation is no more than 20 m (65 ft) thick. Where the Hanford formation thins near the shoreline of the Columbia River, the Ringold Formation is exposed from along the riverbank up to 366 m (1,200 ft) inland (100-HR-3 and 100-KR-4 OU ROD [EPA/ROD/R10-96/134]). The Hanford formation comprises most of the vadose zone throughout the area and, therefore, was affected by contaminated fluids where releases or leaks occurred. At one location at the northeast end of the 116-K-2 Trench, during high river stage, groundwater appears to rise into Hanford gravel sediments that locally reach to an elevation low of 116.5 m (382 ft) AMSL.

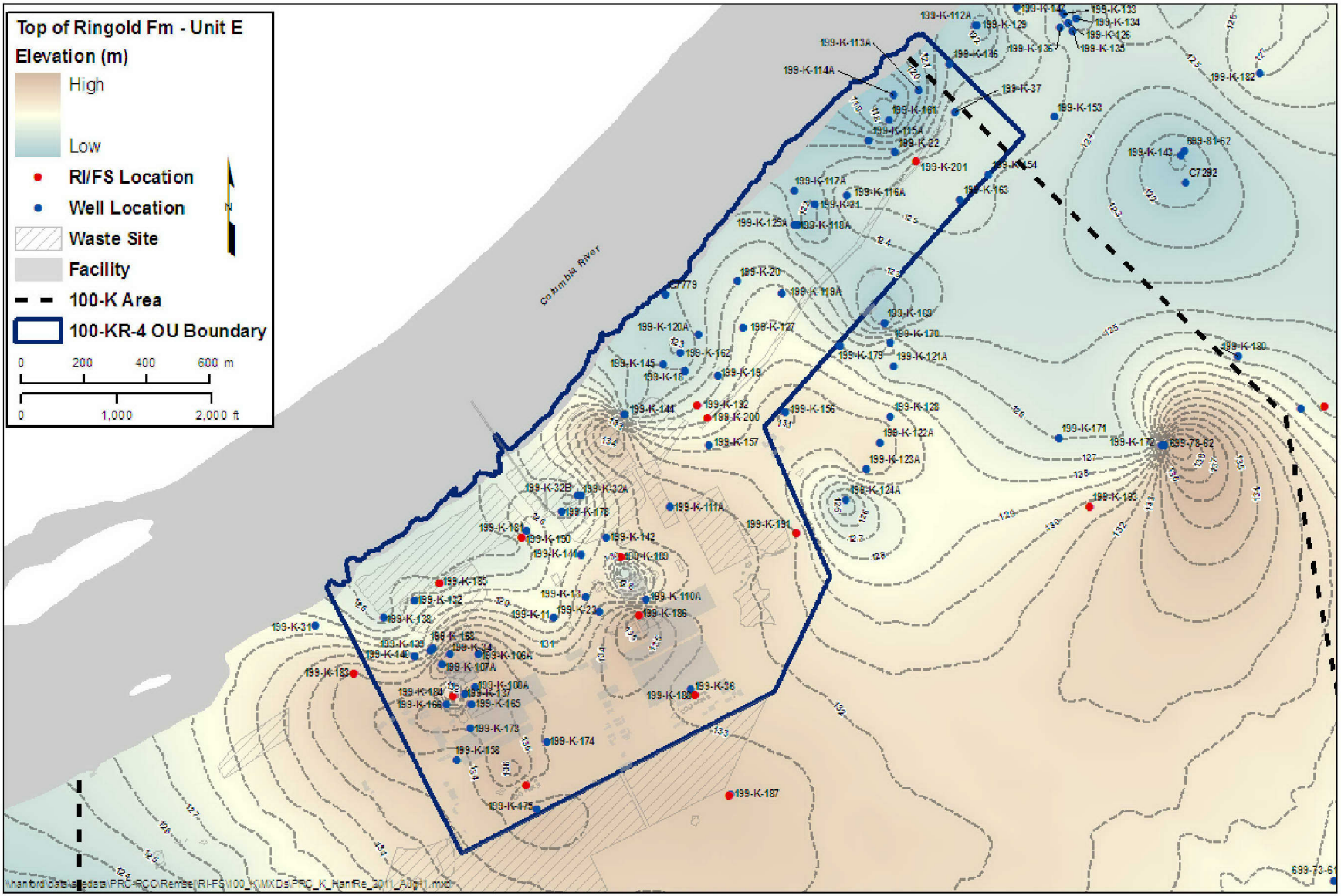
3.4.2.4 Hanford-Ringold Contact

The erosional unconformity surface between the Hanford formation sediments and the underlying Ringold Formation sediment is referred to as the "Hanford formation/Ringold Formation contact" (Figure 3-9). Hydrologic property differences exist across the Hanford-Ringold contact due to differences in the physical nature of the two units and due to actions of scouring by the paleofloods The Ringold unit E is a denser, compact and well-graded formation versus the looser, coarser-grained Hanford gravel-dominated facies. The contact may be well-defined in some wells but gradational in others, suggesting a mixing of materials near the end of a flood cycle. The pattern and flow path of these paleoflood channels are preserved in the topographic expression of the contact.

Figure 3-8. Rip-Up Clast, 120-KW-1 Excavation, 17.6 m (58 ft) bgs 2011

The contact may retard the vertical migration of wastewater and precipitation down toward the aquifer and may contribute to lateral migration. Vertical hydraulic conductivity data presented in detail in Section 3.5.1 indicate that the Hanford formation is 1 to 2 orders of magnitude more conductive than the Ringold unit E, based on small specimen testing, Also, inputs to groundwater modeling assume an order of magnitude difference between the more conductive Hanford formation and the underlying Ringold unit E, based on larger scale tests, and assume an order of magnitude difference in vertical hydraulic conductivities.

Where the Hanford formation/Ringold Formation contact occurs below the river level (approximately 120 m [394 ft] average elevation) or the water table, it may form a preferential hydrogeologic flow path. This flow path can transport groundwater to other portions of the saturated Hanford formation/Ringold Formation contact. In 100-K, the Hanford formation/Ringold Formation contact is predominantly above the water table.



Source: SGW-41213, *100-KR-4 Remedial Process Optimization Modeling Data Package*.

Figure 3-9. Structural Contour Map of the Hanford Ringold Contact (Disconformity)

3.4.2.5 Ringold Formation

The Miocene- to Pliocene-age (8.5 to 3.4 m.y. B.P.) Ringold Formation is a combination of river and lake deposits produced by the ancestral Columbia River and other regional river systems. Across the Hanford Site, the formation is as much as 185 m (606 ft) thick, but locally, within 100-K at Well 699-81-62 east of the 116-K-2 Trench, it is 159 m (520 ft) thick. The formation is divided into three informal units (*Miocene-to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington* [BHI-00184] and *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon* [Lindsey, 1996]): the Wooded Island, Taylor Flats, and Savage Island members. The Wooded Island member is a fluvial (river) to lacustrine (lake) derived unit, while the Taylor Flats and Savage Island members are primarily lake deposits. Within 100-K, the latter two members have been removed through pre-glacial and cataclysmic flood erosion, but are present in the White Bluffs area, east of the Columbia River near the 100-H and 100-F Reactors.

The Wooded Island member is composed of up to five fluvial, fine-to-coarse sandy gravel units interbedded between one or more silt/clay overbank (flood) and lacustrine deposits termed the Ringold lower and upper muds. The five coarse-grained units are informally labeled A (basal), B, C, D, and the uppermost unit E. Not all of the coarse-grained units are necessarily present in all parts of the basin. The fine-grained overbank deposits of the Wooded Island member may be one continuous unit whose depositional pattern migrated laterally with time or may represent distinctly different depositional events. The Wooded Island member appears to represent a large braided stream (ancestral Columbia River) deposit carrying sandy, coarse gravel to cobble sized clasts with contemporaneous floodplain/overbank fines deposits. The fine-grained material has paleosol (soil) features, suggesting breaks in deposition and indicating that the deposits were not always submerged.

Within 100-K at Well 699-81-62, Lindsey (1996 [*The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon*]) has identified Ringold A, B, C, and E gravels and three RUM units. For this report, the uppermost mud unit is termed the RUM unit and is considered a separate unit from the RLM. Except for the uppermost Ringold unit E gravels, the gravels are confined aquifers interbedded with aquitard muds. At the top of the basalts, a 2.1 m (7 ft) thick coarse, cemented conglomerate is found in Well 699-81-62. Elsewhere, this unit has been given the name Snipes Mountain Conglomerate and is frequently grouped within the basal Ringold unit A.

Ringold units A to E gravel consist of clast- and matrix-supported pebble to cobble gravels with a fine- to coarse-grained sand matrix (*The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon* [Lindsey, 1996]). Clasts are typically composed of a variety of source material including quartzite, intermediate to silicic volcanic, basalt, gneiss, greenstone, and granite. The degree of carbonate, iron oxide, and silica cementation within these units may vary from none to well developed. Cementation may extend laterally for several hundred meters and may be up to several meters thick. The cemented units produce little to no water. The sand and gravel units may be massively bedded or cross-bedded, indicating fluvial to aeolian deposition. The RUM units are typically plastic silts and clays, with fine sand laminations. Indications of paleosol conditions include biologic action within the sediments. The fine-grained materials occur in thick (>5 m [16 ft]) deposits as well as thin interbeds. Silty sand to fine gravely sand lenses 1 to 3 m (3 to 10 ft) thick are encountered in the RUM and may locally bear water. Individual gravel clasts tend to be more rounded to discoidal in shape.

Ringold unit A is reported to be 9 to 15 m (30 to 50 ft) thick in locations but locally within 100-K is 6 m (20 ft) thick at Well 699-81-62. It is composed of fine to coarse sands and gravels across most of the eastern Hanford Site. The RLM is 38 m (125 ft) thick and consists of overlapping lacustrine and paleosols. Ringold unit B coarse-grained is 23 m (75 ft) thick and consists of sand and gravel dominated units. In turn, a 46 m

(150 ft) thick, overbank-paleosol mud unit caps Ringold unit B. Ringold unit C gravel is separated from Ringold unit B by a thick overbank-paleosol unit, considered part of the RLM. Ringold unit C locally is 4.6 m (15 ft) thick but thickens to the west and is another sand and gravel-dominated sequence. The RUM is 30 m (100 ft) thick and displays a number of paleosol features.

The uppermost unit of the Wooded Island member is Ringold unit E, which forms the unconfined aquifer in 100-K. It is a gravel-dominated sequence comprised commonly of fine-to-coarse gravels and fine-to-coarse sands. Locally, sand-dominated units interbed with the sandy gravels. Silt and fine sand may be present as a minor (10 to 15 percent) constituent but occasionally may rise to become the dominant grain-size fraction. Rip-up clasts of RUM clays and silts are reported on rare occasion in 100-K wells. Cementing is known within Ringold unit E and it is the resistant unit forming the Columbia River's Coyote Rapids, located just upriver from the 181-KW Pump House. The relative straightness of the Columbia River between 100-K and 100-N is attributed to the river's eroding into the cemented bedrock of Ringold unit E. Ringold unit E unconformably rests on the RUM aquitard. In turn, the Hanford formation was deposited on the eroded top of Ringold unit E. Lindsey (1996 [*The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon*]) depicts Ringold unit E as absent 3.2 km (2 mi) to the southeast of 100-K and south of 100-N, beyond Well 699-77-54 in his cross section L-L'.

3.4.2.6 Columbia River Basalt Group and Ellensburg Formation

The Hanford Site and most of eastern Washington is underlain by a thick section (3,050+ m [10,000+ ft]) of Miocene to early Pliocene age basalt flows. The flows are divided into five formations: Imnaha Basalts (17.0 to 16.5 m.y. BP); Picture Gorge Basalts (16.5 to 16.0 m.y. BP); Grande Ronde Basalts (16.9 to 15.6 m.y. BP); Wanapum Basalts (15.6 to 14.5 m.y. BP); and Saddle Mountain Basalts (14.5 to 6 m.y. BP). Many individual flows make up the CRBG, and most formations are not laterally continuous across the breadth of the Columbia River Plateau. The Grande Ronde Basalt formation, which comprises an estimated 88 percent by volume of all basalt, is the dominant unit within the Plateau and beneath the Hanford Site. The CRBG has been extensively reported as part of the Basalt Waste Isolation Project (1977 to 1988). Further information is provided in *Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* (DOE/RW-0164). This project extensively characterized the upper 1,130 m (3,700 ft) of the CRBG.

Locally, flows within the Wanapum and the Saddle Mountain Basalt Formations underlie the ground surface and appear in outcrop. The Elephant Mountain, Pomona, and Esquatzel members of the Saddle Mountain Formation are exposed in the Gable Mountain-Gable Butte anticlines and immediately underlie the Ringold sediments found in the Wahluke and Cold Creek Synclines. Within 100-K, the Elephant Mountain Member is unconformably overlain by the Ringold Formation. There are no known breaks in the basalt surface within 100-K, but erosion associated with cataclysmic glacial breakout flooding at Gable Gap has stripped off the Elephant Mountain and Pomona Members, bringing interbed sediments of the Ellensburg Formation into direct contact with the suprabasalt Ringold Formations and Hanford formations.

Individual basalt flows may be as much as 70 m (225+ ft) thick but typically range between 24 to 34 m (80 to 110 ft) thick. Individual basalt flows typically consist of a chilled, porous, pillow basal contact unit and interior dense, fractured, less permeable colonnade and entablature units, which are capped by a porous, vesicular to rubbly, oxidized flow top. Fractures within the entablature and the colonnade are generally tight. Regional tectonic fracture patterns are imposed on the basalt flows, and local fold and fault structures may increase the porosity of a basalt flow.

Interbedded between the individual flows or multi-flow members are sedimentary units of the Ellensburg Formation. These units consist of fluvial to volcanic-volcaniclastic deposits, which may range up to 30 m (100 ft) in thickness. The Ellensburg Formation is more prevalent in the western part of the Columbia

Basalt Plateau and typically thickens to the west. The interbeds are generally minor units with the Grande Ronde and Wanapum Formations but become important components in the Saddle Mountain Formation basalts, comprising as much as 25 percent of the formation. The decreasing frequency of Saddle Mountain flows permitted greater periods of sediment deposition. The interbeds associated with the uppermost basalt members are the Rattlesnake Ridge and Selah Interbeds, which are directly beneath the Elephant Mountain and Pomona Basalts of the Saddle Mountain Formation.

3.4.3 Hydrogeology

Considerable information now exists for the unconfined aquifer system in 100-K, as many boreholes in 100-K reach the RUM unit. Hydrogeological cross sections, top of surface maps, and isopach maps of 100-K present detailed representations of the 100-K geology. Hydrogeologic information about the Ringold units below the RUM is far more limited than for the Hanford formation and Ringold unit E sediments.

3.4.3.1 Hydrogeology Cross Sections

A location map for 8 generalized geologic cross sections (Figure 3-10) also identifies the locations for the 15 new RI/FS wells and 3 new extraction and monitoring wells drilled in CY2011. The 8 hydrogeologic cross sections (Figures 3-11 to 3-18) show hydrologic information as well as the locations of selected waste sites located near section lines. Cross-sections A-A' to F-F' are oriented perpendicular to the river, while cross-sections G-G' and H-H' parallel the river at its shoreline.

Hydrogeologic cross section A-A' (Figure 3-11) focuses on the Cr(VI) plume around the 105-KW Reactor. It begins near the Columbia River and the 100-K-63 floodplain area and runs southeast through the 105-KW Reactor core area to beyond the 183.1 KW Head House and 183.2 KW sedimentation basin. This cross section includes three RI wells. Two of the RI wells were drilled 15.2 m (50 ft) into the RUM unit, but did not encounter water bearing sand lenses. Several existing wells upgradient of the KW reactor (e.g., 199-K-165, 199-K-173, and 199-K-35) have detected concentrations of Cr(VI) from 770 to 3,540 µg/L within the past 3 years, exceeding concentrations expected from early cooling water usage.

Figure 3-12 depicts the hydrogeologic cross section B-B' through the 107-KE Reactor area. The cross section line is aligned to examine Cr(VI) concentrations around this reactor, starting near the Columbia River and terminating southeast of the 183.1-KE Head House and the 183.2-KE sedimentation basin at Well 199-K-187. Three of the four new RI wells drilled around the KE reactor (199-K-186, 199-K-187 and 199-K-188) are included in this cross-section. Cr(VI) concentrations have been low at wells along this trend. Cr(VI) at Well 199-K-141 reached to 459 µg/L when first started as an extraction well (February 2009). The Cr(VI) trend at Well 199-K-36, near the 183.1 KE Head House, spiked to 1,320 µg/L between 1999 and 2001 but remained around 20 µg/L until June 2011, when concentrations rose to 115 µg/L.

Hydrogeologic cross section C-C' (Figure 3-13) starts near the Columbia River and runs east beneath the 116-K-1 Crib, and the southwestern end of the 116-K-2 Trench before continuing southeast past the 126-K-1 former landfill area. This cross section includes RI Monitoring Well 199-K-192, completed in the lower portion of the RUM in a confined aquifer zone, while temporary Well 199-K-200 is completed in the uppermost Ringold unit E. Sampling at the wells along this cross section has not encountered high concentrations of Cr(VI) but has detected significant concentrations of tritium and Sr-90.

Figures 3-14, 3-15, and 3-16 are hydrogeologic cross sections D-D', E-E', and F-F', respectively. These cross sections are similar in alignment to the previous sections in that they follow lower-concentration Cr(VI) plumes from inland wells to the river. Cross section D-D' (Figure 3-14) depicts an area where elevated (204 µg/L) Cr(VI) concentrations are found at the southwest end of the 116-K-2 Trench around Well 199-K-18 and toward the river at new Wells 199-K-197 and 199-K-199. Wells in this area are within a zone of low sediment hydraulic conductivity (Table 3-13). The section then crosses inland to bisect the KR-4 and KX pump-and-treat systems injection well field between Wells 199-K-169 and 199-K-124A.

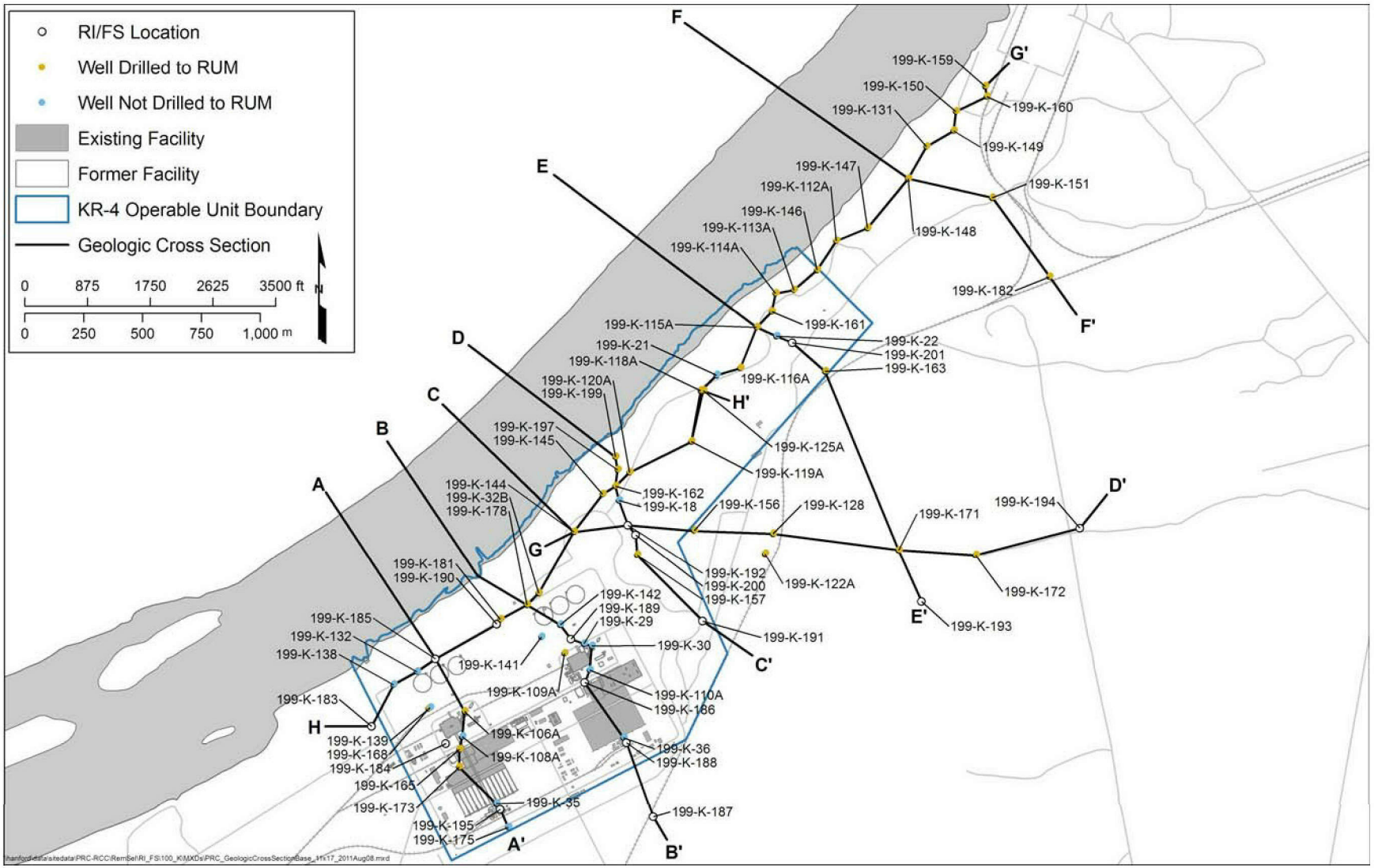


Figure 3-10. 100-K Hydrogeological Cross Section Base Map

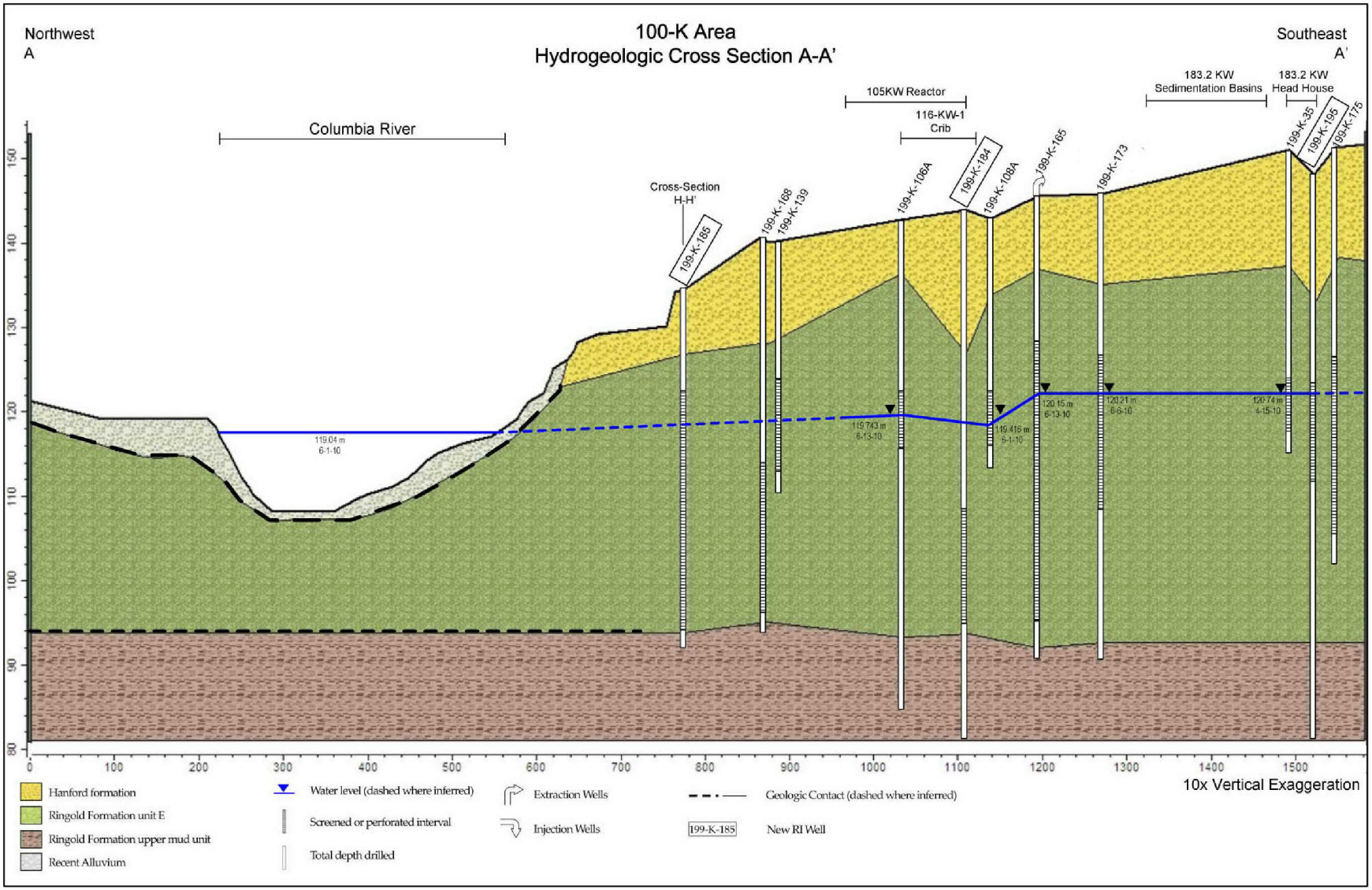


Figure 3-11. 100-K Hydrogeological Cross Section A-A'

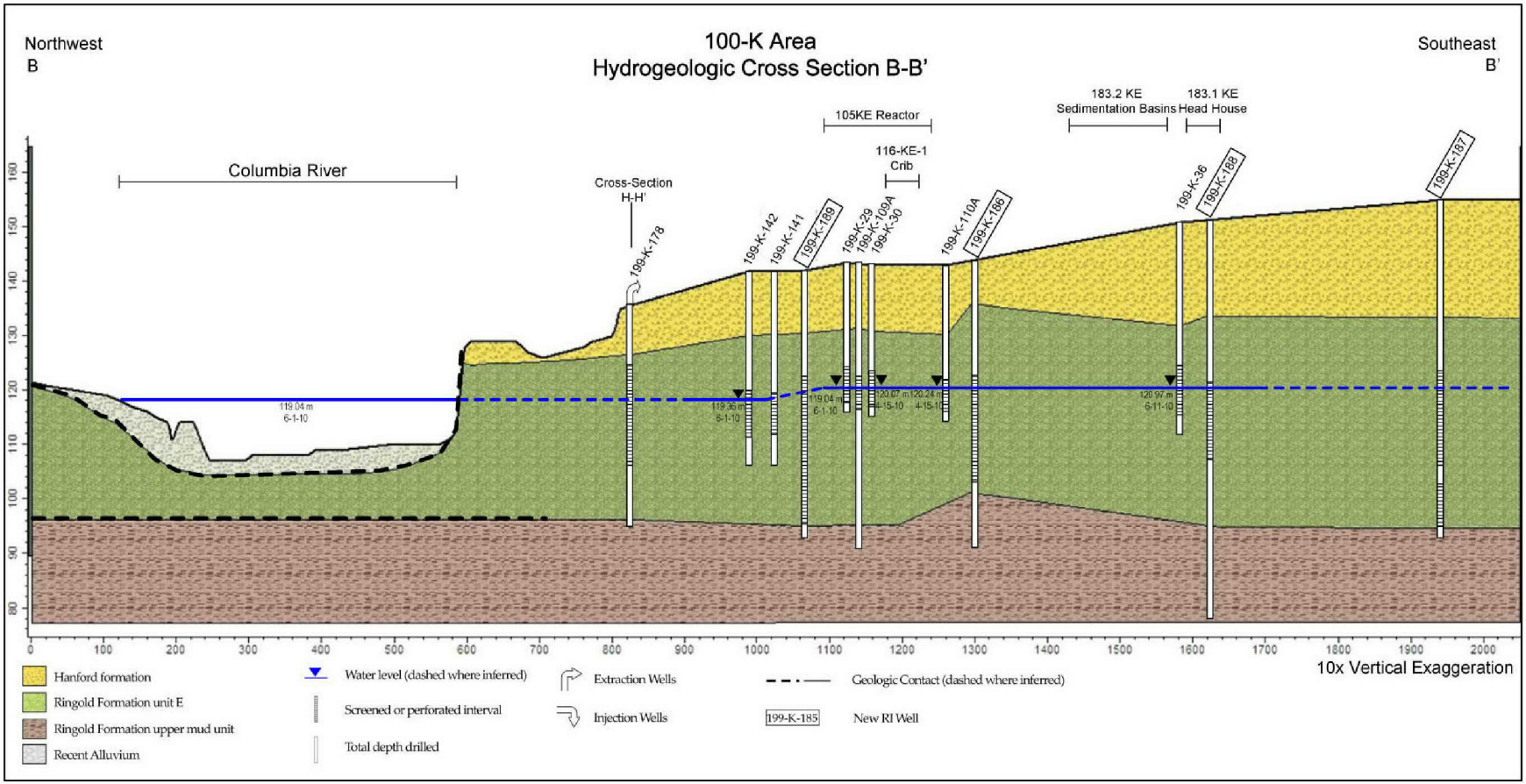


Figure 3-12. 100-K Hydrogeological Cross Section B-B'

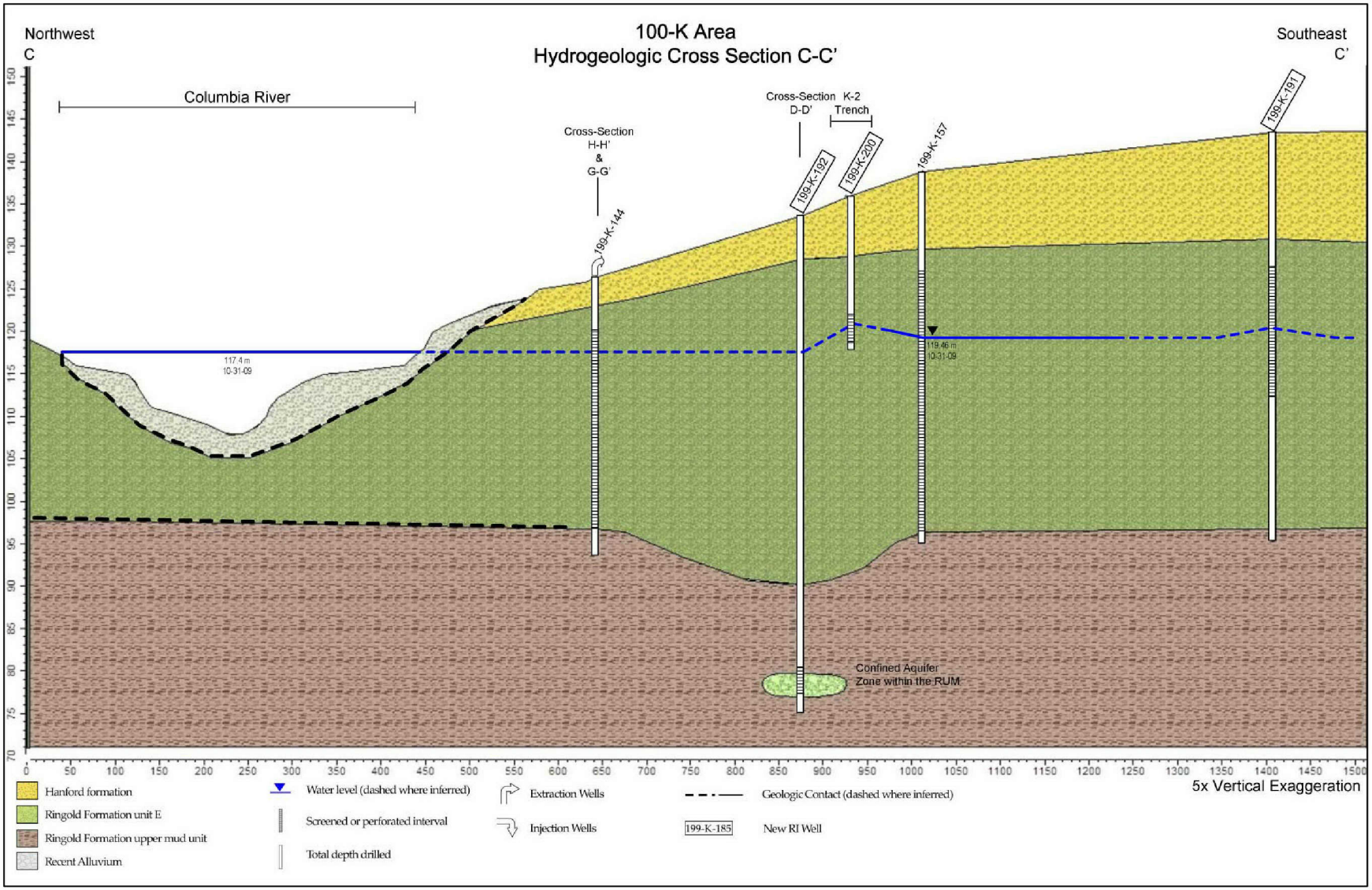


Figure 3-13. 100-K Hydrogeological Cross Section C-C'

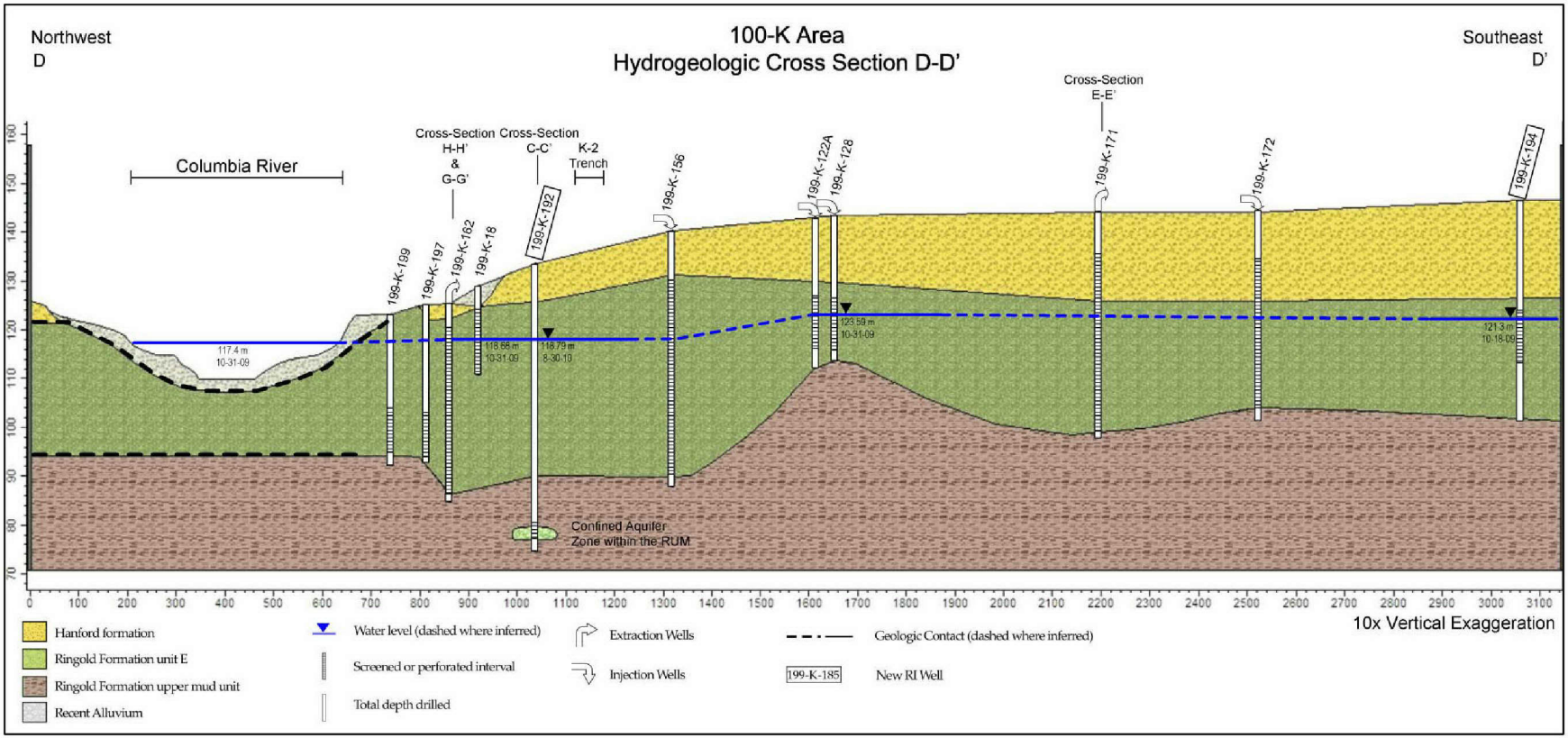


Figure 3-14. 100-K Hydrogeological Cross Section D-D'

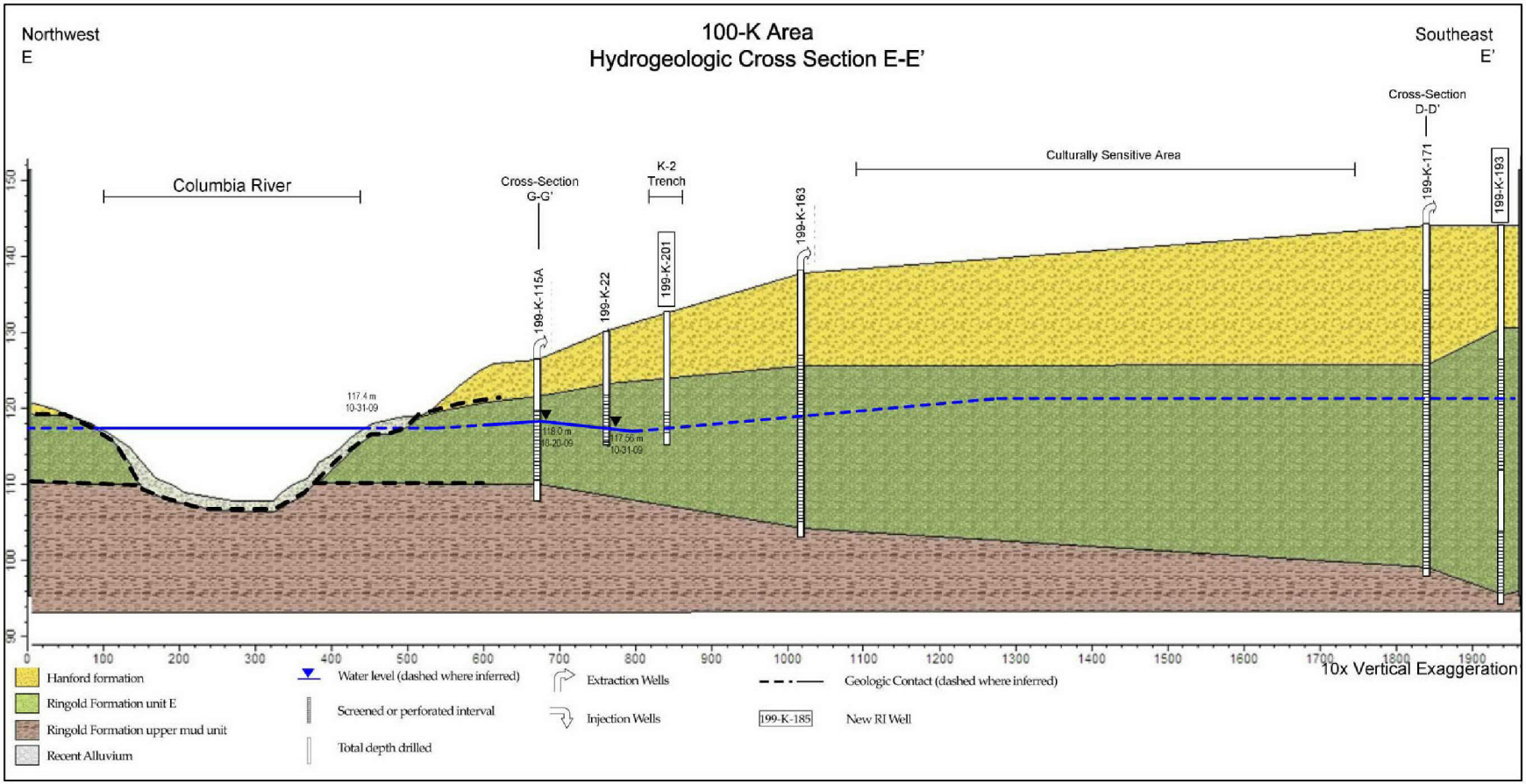


Figure 3-15. 100-K Hydrogeological Cross Section E-E'

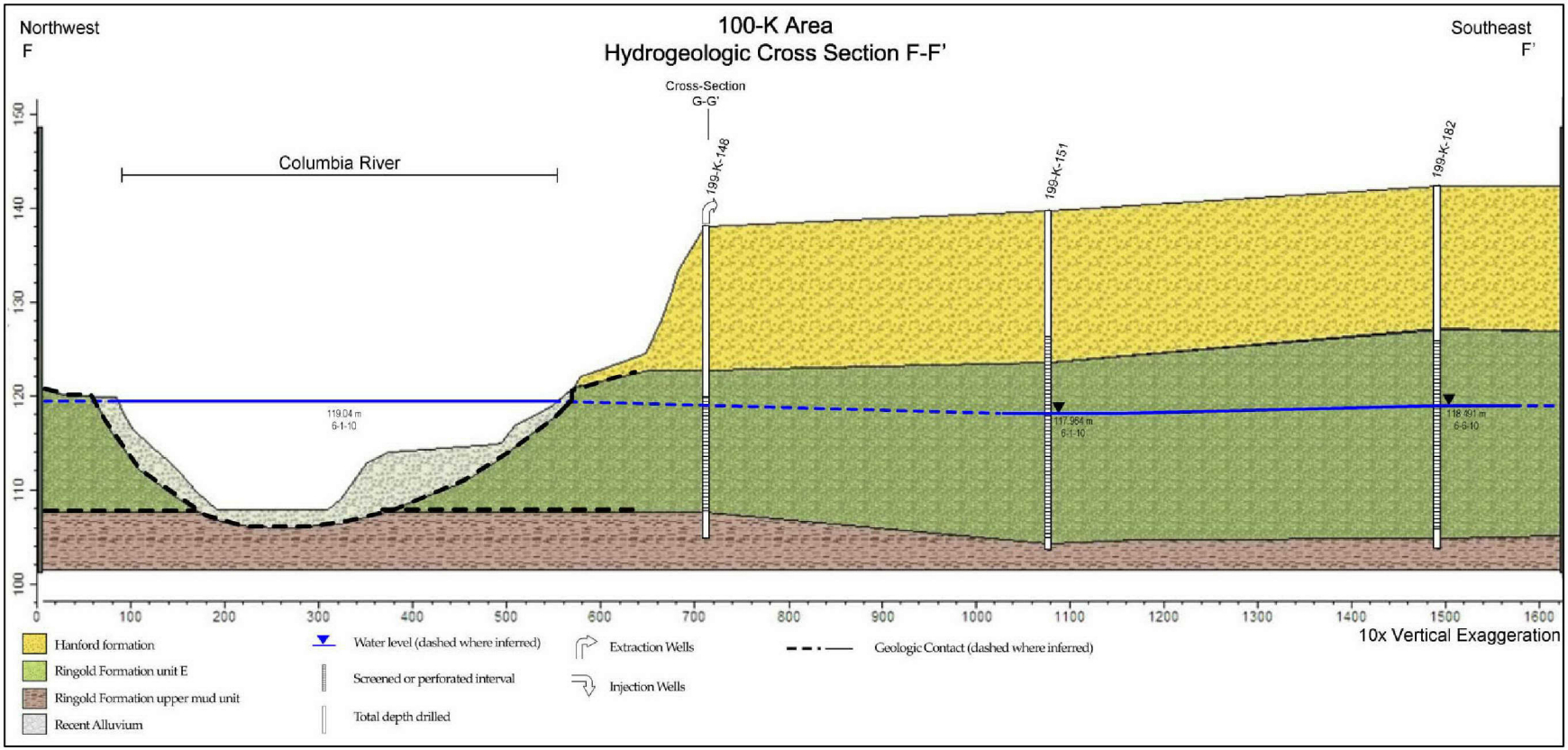


Figure 3-16. 100-K Hydrogeological Cross Section F-F'

This line depicts some of the highest as well as some of the lowest points of the RUM-Ringold unit E contact at Wells 199-K-162 and 199-K-128, respectively. Further inland, the section reaches Well 199-K-171, where initial detections of Cr(VI) at 75-80 µg/L have since slowly declined under extractive pumping.

Cross section E-E' tracks another Cr(VI) plume that extends upgradient from the river past the 116-K-2 Trench and inland again to Well 199-K-171 and new RI Well 199-K-193. Wells 199-K-22 and 199-K-201 are in another area of elevated Cr(VI) concentrations (114 µg/L at 199-K-22 in 2010 and 111 µg/L at Well 199-K-201 in 2011), and are associated with sediments with low hydraulic conductivities. The temporary RI Monitoring Well 199-K-201, completed within the 116-K-2 Trench, is screened across the upper portion of the upper Ringold unit E. Wells upgradient of the 116-K-2 Trench (199-K-163 and 199-K-154) also encountered Cr(VI) concentrations greater than 100 µg/L when drilled. Under extraction, Cr(VI) concentrations have declined to 84 and 52 µg/L, respectively. The cross sections show a steady rise in elevation from the near shore portion of the Columbia River east to the upper plateau of 100-K with proportional rises of the Hanford formation and RUM units. This cross section also depicts a rise in the RUM unit at wells around 199-K-115A. The aquifer here thins locally; nearby Wells 199-K-114A and 199-K-161 are the few wells where high river stage waters rise into the basal part of the Hanford unit. A channel eroded into the RUM appears to cross upgradient of these wells and slopes toward Wells 199-K-163 and 199-K-171.

Cross section F-F' depicts an area with moderately elevated concentrations of Cr(VI) (Figure 3-16) at the northwest end of the Cr(VI) plume, near the 100-NR-2 OU. Well 199-K-182 is the upgradient terminus for this section and has maintained a steady range of Cr(VI) concentrations between 74 and 82 µg/L. Moving along the section toward the river, concentrations drop to 52.9 µg/L near the river at Well 199-K-148.

Hydrogeologic cross sections G-G' and H-H' (Figures 3-17 and 3-18, respectively) run parallel and near to the Columbia River and cover the entire span of 100-K. Cross section G-G' profiles the area near the Columbia River, passing the 116-K-1 Crib and 116-K-2 Trench and continuing to the 100-N Reactor. Cross section H-H' extends across the northern edge of the 100-K Reactor to midway along the 116-K-2 Trench. Cross section G-G' shows the deepest (at 199-K-162) and shallowest (at 199-K-114A) locations of the RUM within 100-K. This cross section depicts some of the shallower well coverage at the downgradient edge of the KW Cr(VI) plume. An additional well to the three discussed previously is being drilled in this area to provide coverage through the full depth of the aquifer.

3.4.3.2 Well Profiles

Geological, geophysical, well completion, and contaminant data for the 13 groundwater RI wells drilled at 100-K are presented in Figures 3-19 to 3-33. Well-related information is presented in the four left columns, followed by three columns of geophysical logs. Analytical results for key chemicals and radionuclides in both sediment and groundwater are presented in the next four columns. The logs combine the geology encountered in each well, well construction attributes and a compilation of both soil and groundwater contaminant results.

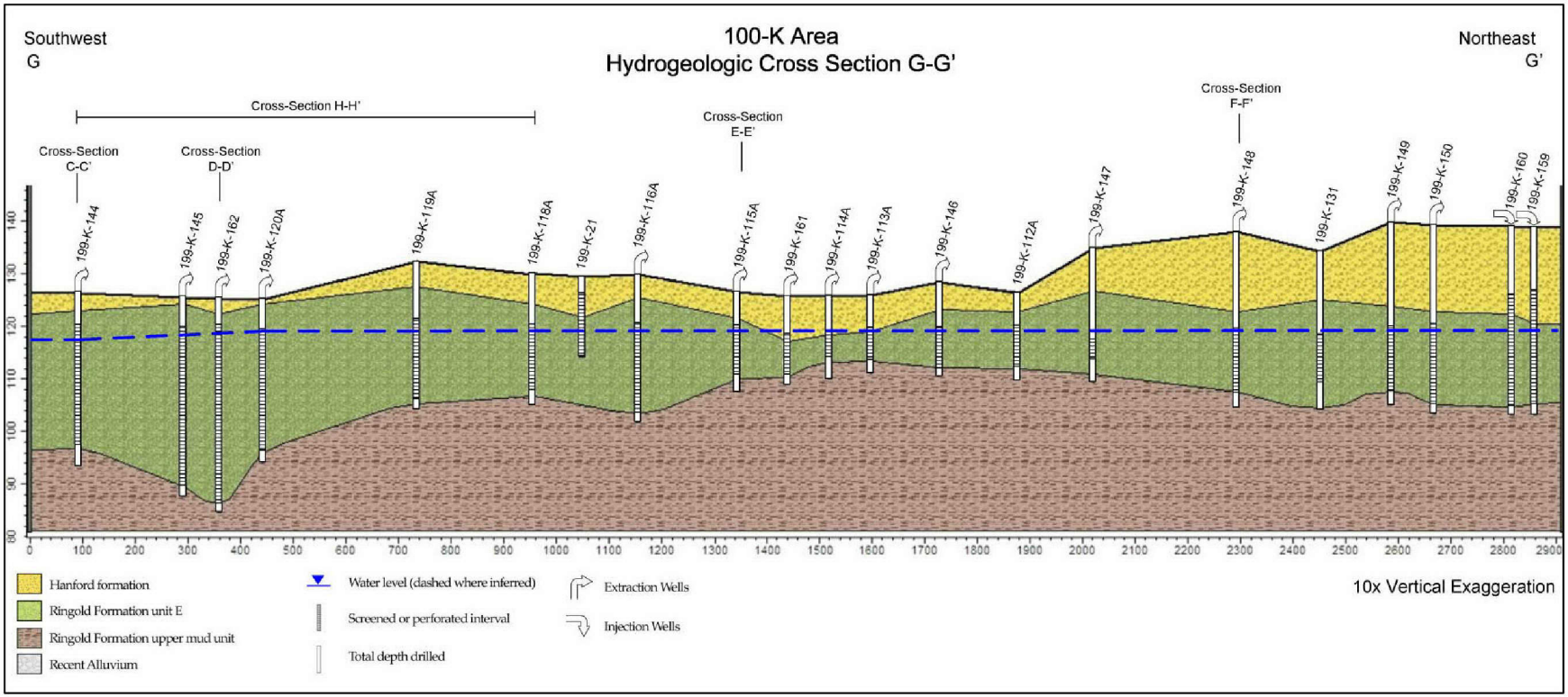


Figure 3-17. 100-K Hydrogeological Cross Section G-G'

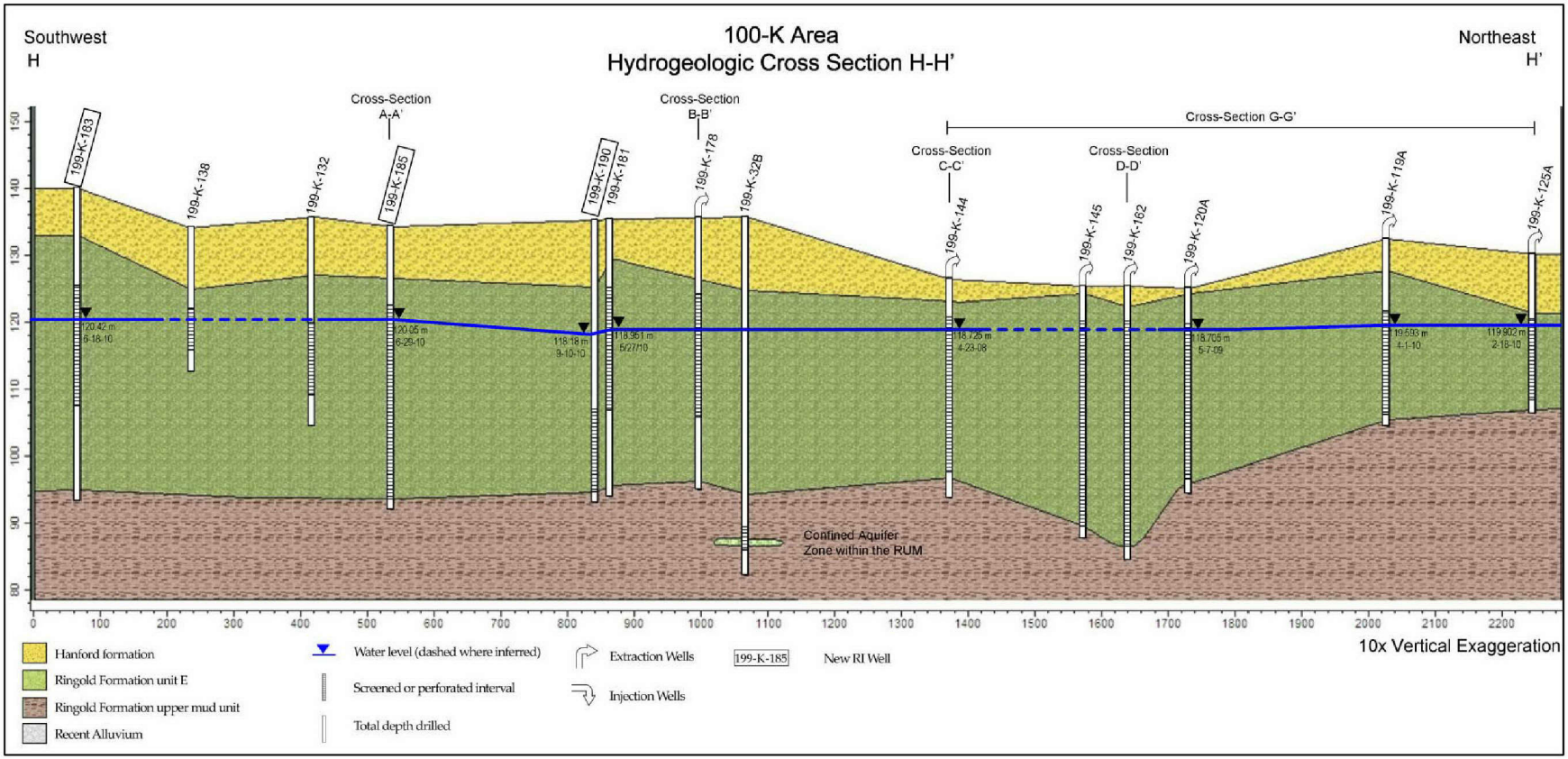
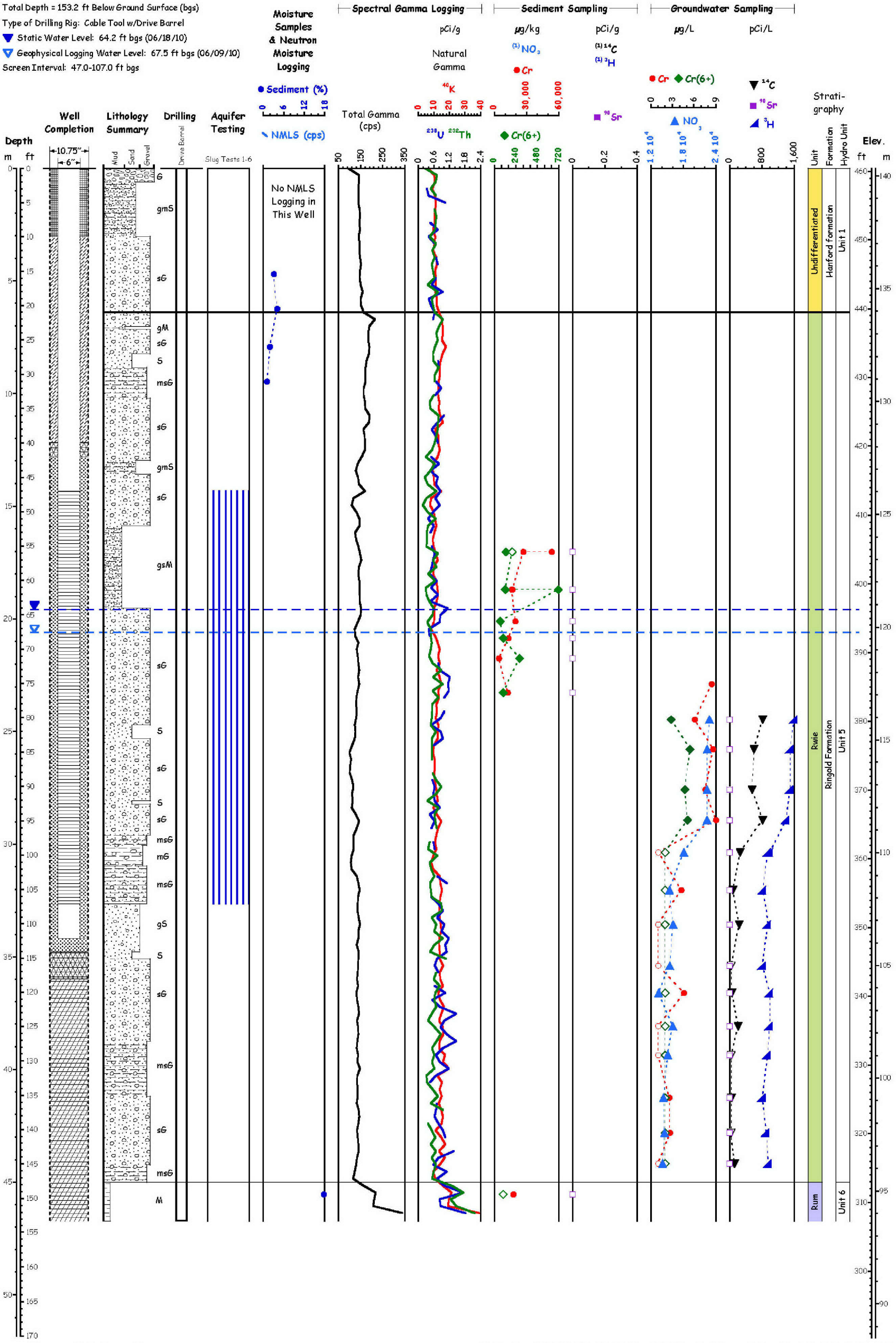


Figure 3-18. 100-K Hydrogeological Cross Section H-H'

E568,302.28 N146,439.70 NAD83(91)
Elevation: 140.329 m NAVD88
Total Depth = 153.2 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel
Static Water Level: 64.2 ft bgs (06/18/10)
Geophysical Logging Water Level: 67.5 ft bgs (06/09/10)
Screen Interval: 47.0-107.0 ft bgs

199-K-183 C7683

100-K Area



Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand
Portland Cement Grout

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7683 Well Summary Sheet.

Increasing size of dominant fraction

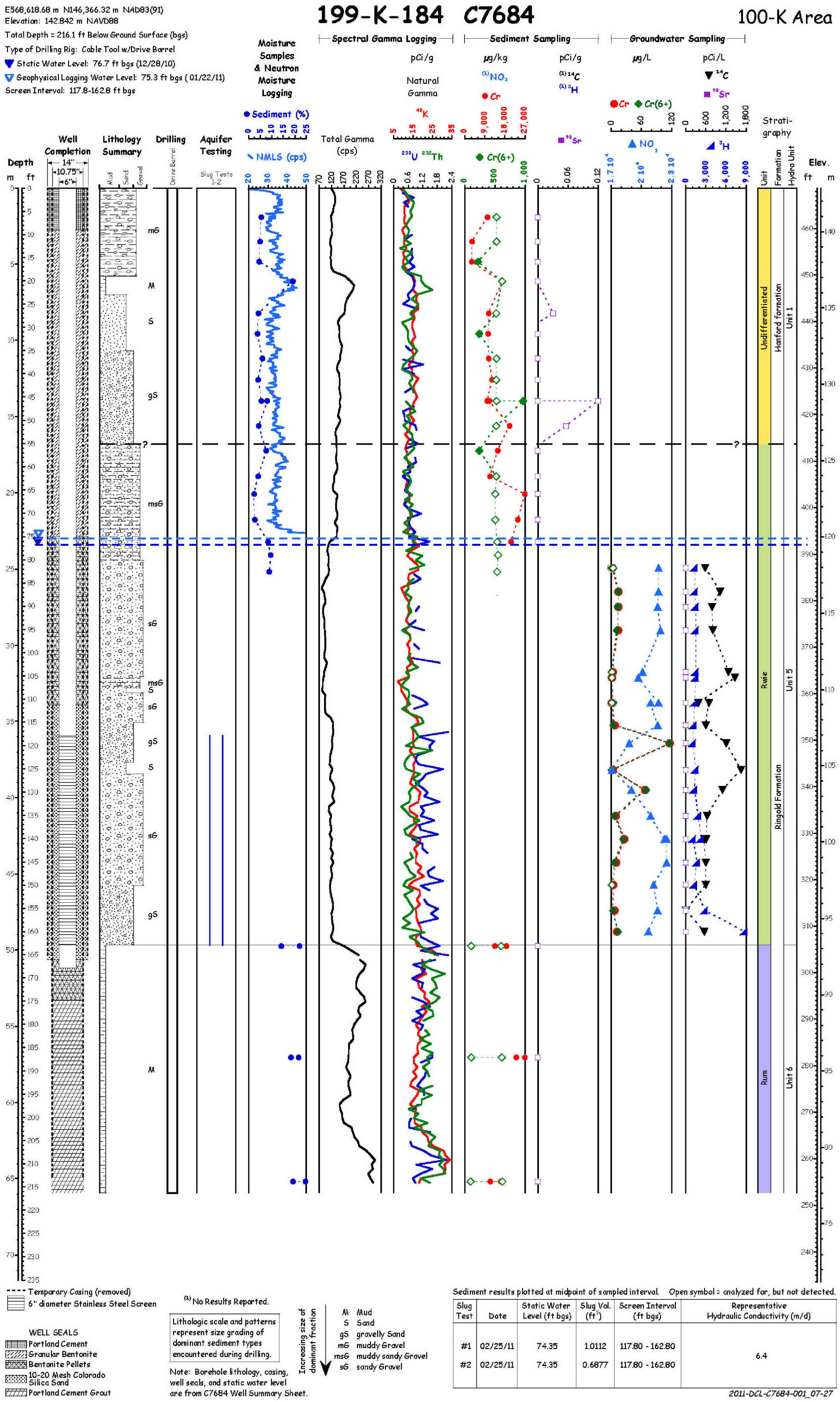
M	Mud
gsM	gravelly sandy Mud
gM	gravelly Mud
S	Sand
gmS	gravelly muddy Sand
gS	gravelly Sand
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	06/21/10	61.0	0.3276	47.0 -107.0	15
#2	06/21/10	61.0	0.3276	47.0 -107.0	
#3	06/21/10	61.0	0.6877	47.0 -107.0	
#4	06/21/10	61.0	0.6877	47.0 -107.0	
#5	06/21/10	61.0	1.0112	47.0 -107.0	
#6	06/21/10	61.0	1.0112	47.0 -107.0	

2011-DCL-C7683-001_07-27

Figure 3-19. C7683 (199-K-183)



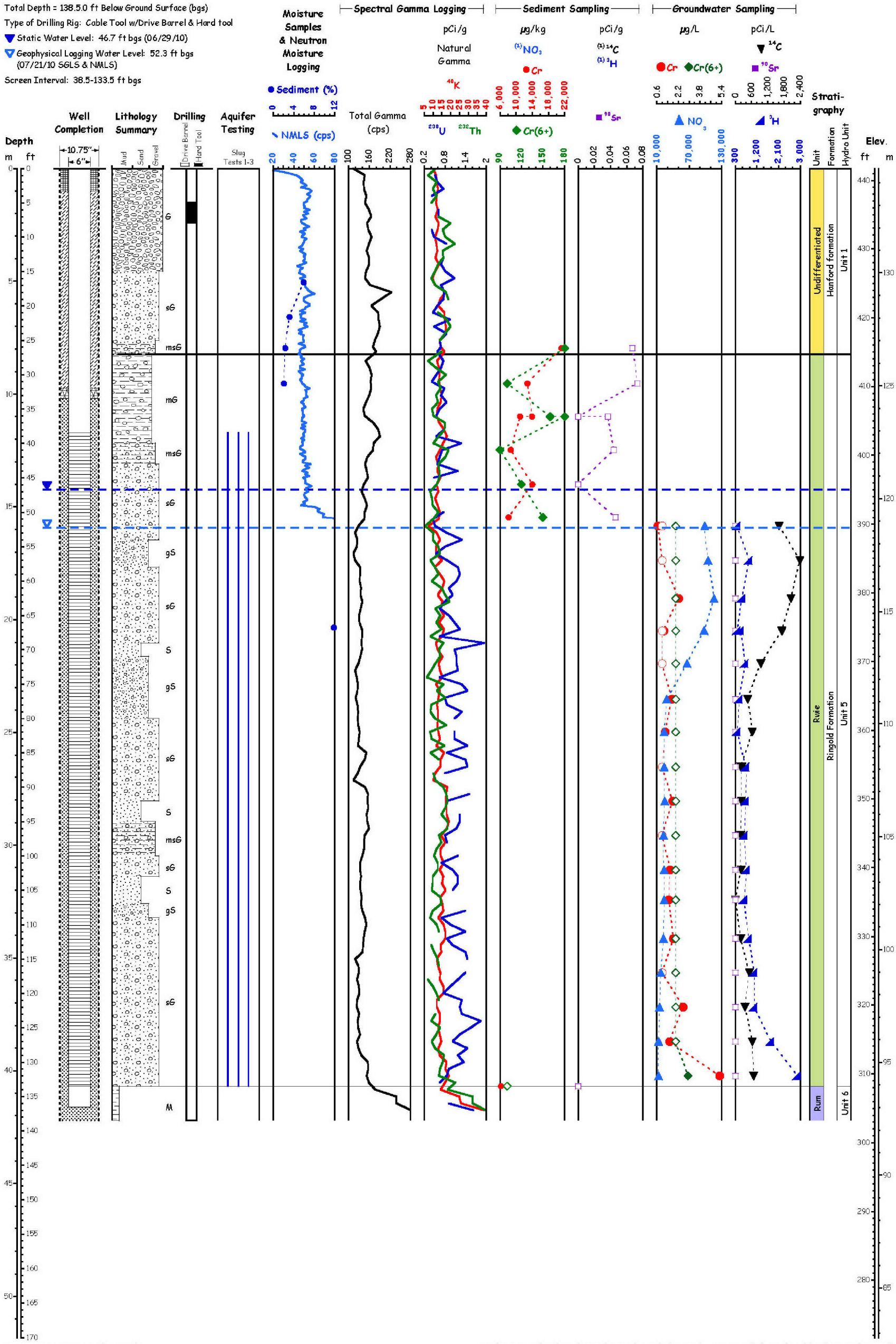
Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	02/25/11	74.35	1.0112	117.80 - 162.80	6.4
#2	02/25/11	74.35	0.6877	117.80 - 162.80	

Figure 3-20. C7684 (199-K-184)

E 568,574.92 m N 146,726.17 m NAD83(91)
Ground Surface Elevation (brass cap): 134.618 m NAVD88
Total Depth = 138.5.0 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel & Hard tool
▼ Static Water Level: 46.7 ft bgs (06/29/10)
▽ Geophysical Logging Water Level: 52.3 ft bgs (07/21/10 SGLS & NMLS)
Screen Interval: 38.5-133.5 ft bgs

199-K-185 C7685

100-K Area



Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7685 Well Summary Sheet.

Increasing size of dominant fraction

M	Mud
S	Sand
gS	gravelly Sand
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	08/16/10	52.9	Not fully submerged	38.5-133.5	
#2	08/16/10	52.9	0.6877	38.5-133.5	2.3 (Outer)
#3	08/16/10	52.9	1.0112	38.5-133.5	

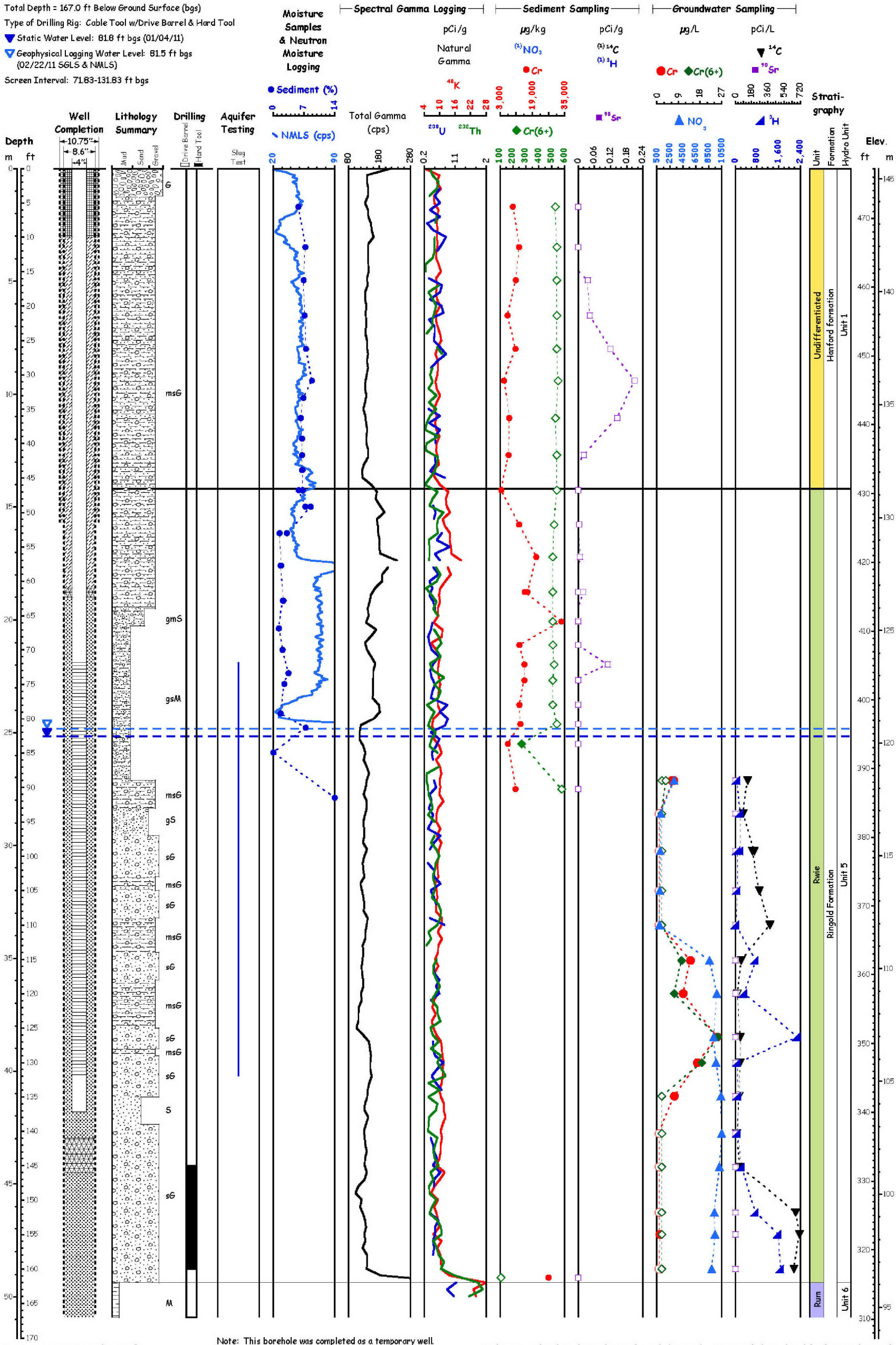
2011-DCL-C7685-001_07-27

Figure 3-21. C7685 (199-K-185)

E 569,209.65 m N 146,625.36 m NAD83(91)
Ground Surface Elevation (brass cap): 145.451 m NAVD88
Total Depth = 167.0 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel & Hard Tool
▼ Static Water Level: 81.8 ft bgs (01/04/11)
▽ Geophysical Logging Water Level: 81.5 ft bgs (02/22/11 SGLS & NMLS)
Screen Interval: 71.83-131.83 ft bgs

199-K-186 C7686

100-K Area



Temporary Casing (removed)
4" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand

Note: This borehole was completed as a temporary well.

(a) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7686 Well Summary Sheet.

Increasing size of dominant fraction

M	Mud
gsM	gravelly sandy Mud
S	Sand
gmS	gravelly muddy Sand
gS	gravelly Sand
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	03/10/11	80.66	0.3276	71.38-131.9	The well is screened in very permeable material and displacements dissipate too quickly. No values estimated.

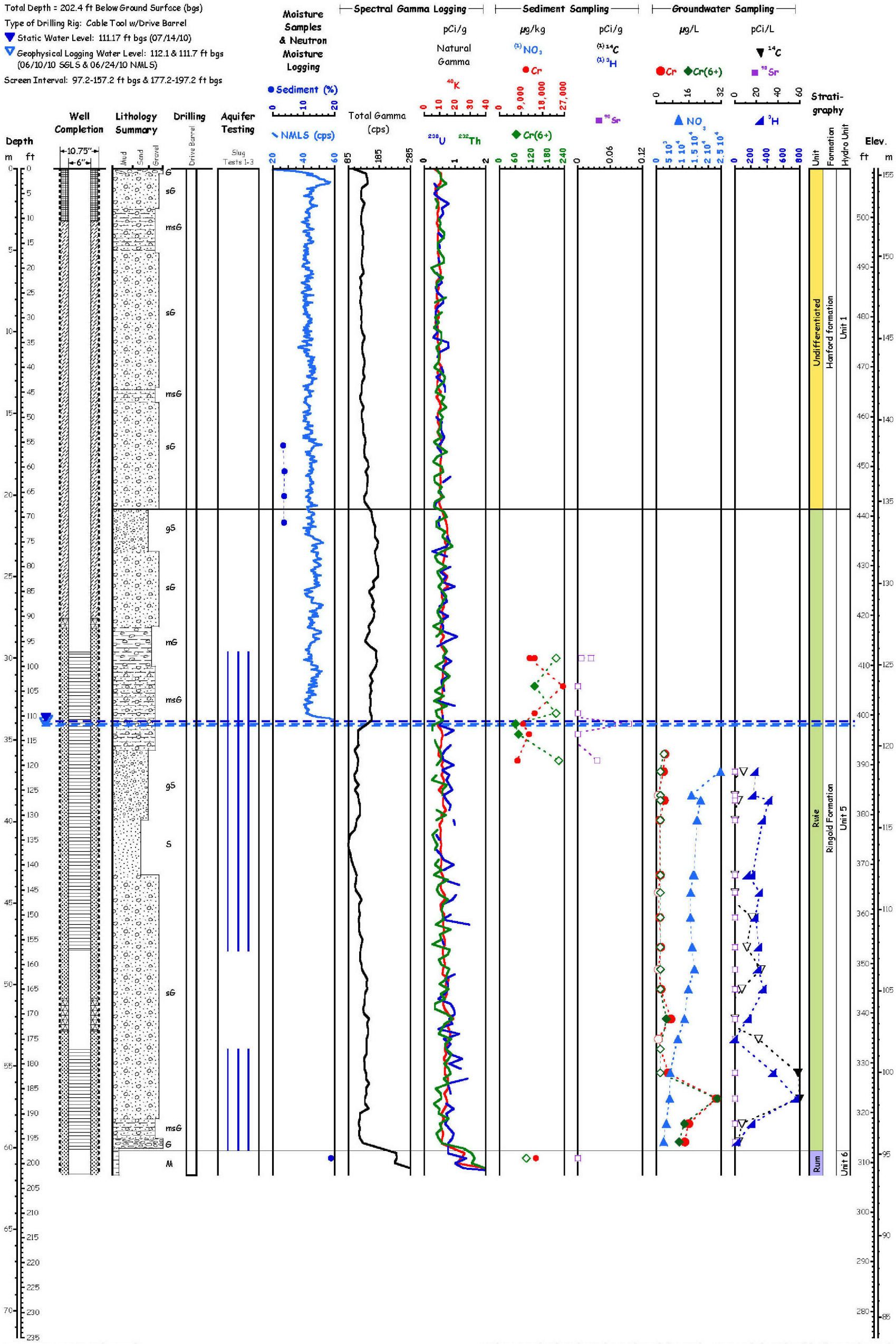
2011-DCL-C7686-001_07-27

Figure 3-22. C7686 (199-K-186)

E 569,499.00 m N 146,054.68 m NAD83(91)
Ground Surface Elevation (brass cap): 155.378 m NAVD88
Total Depth = 202.4 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel
Static Water Level: 111.17 ft bgs (07/14/10)
Geophysical Logging Water Level: 112.1 & 111.7 ft bgs (06/10/10 SGLS & 06/24/10 NMLS)
Screen Interval: 97.2-157.2 ft bgs & 177.2-197.2 ft bgs

199-K-187 C7687

100-K Area



Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand
Portland Cement Grout

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7687 Well Summary Sheet.

Increasing size of dominant fraction

M	Mud
S	Sand
gS	gravelly Sand
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	08/16/10	111.87	0.3276	97.2-157.2 177.2-197.2	27
#2	08/16/10	111.87	0.6877	97.2-157.2 177.2-197.2	
#3	08/16/10	111.87	1.0112	97.2-157.2 177.2-197.2	

2011-DCL-C7687-001_07-27

Figure 3-23. C7687 (199-K-187)

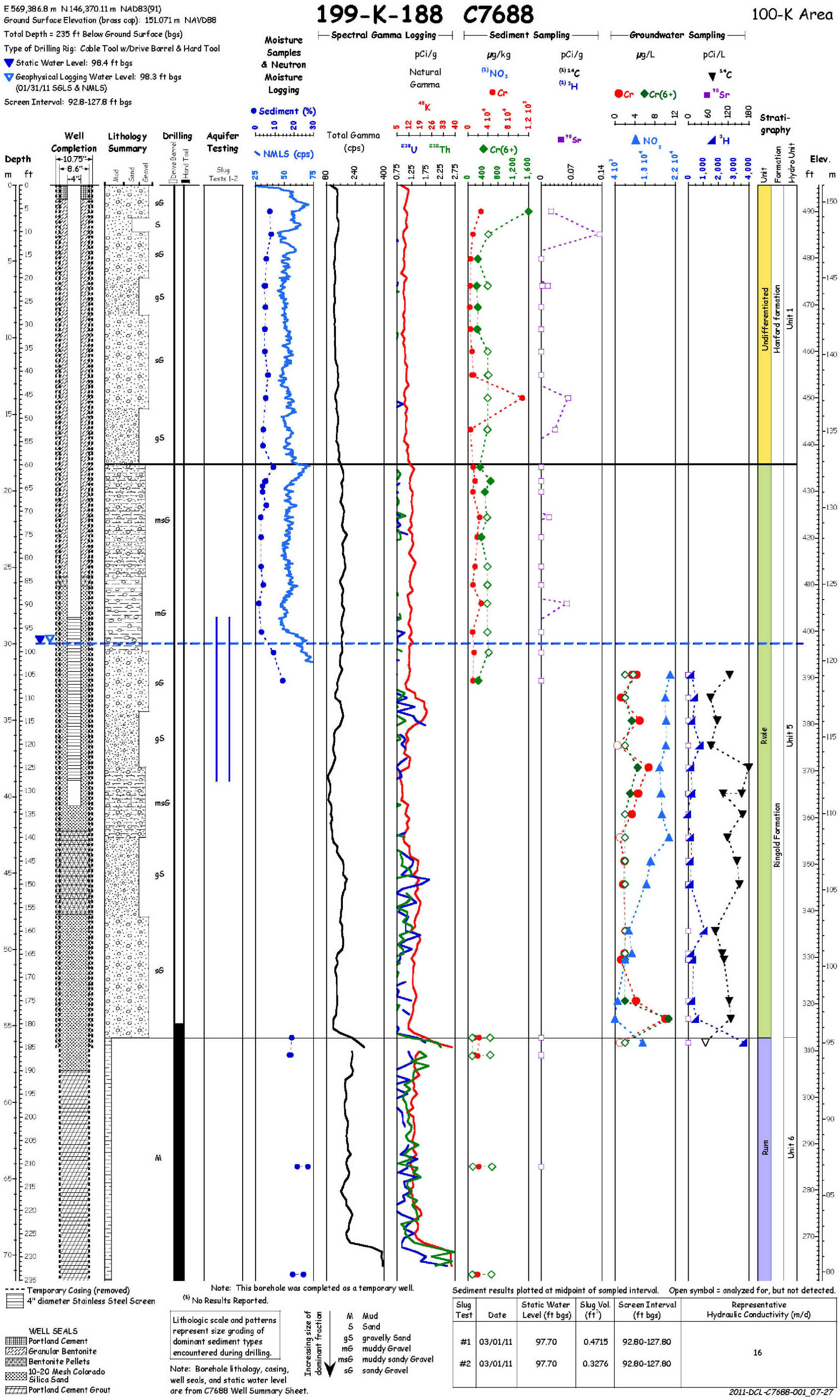
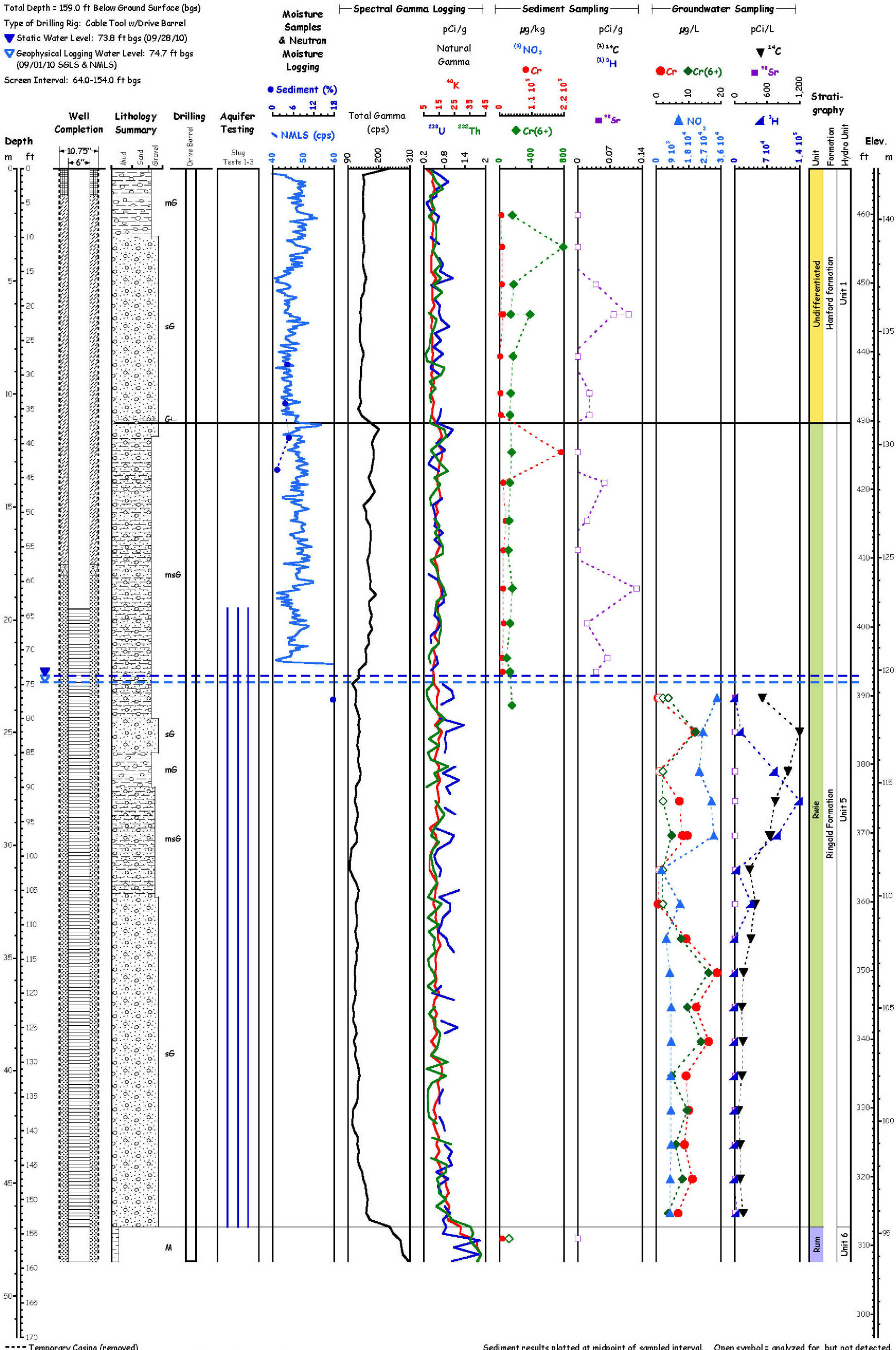


Figure 3-24. C7688 (199-K-188)

E 569,150.27 m N 146,809.68 m NAD83(91)
Ground Surface Elevation (brass cap): 142.225 m NAVD88
Total Depth = 159.0 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel
▼ Static Water Level: 73.8 ft bgs (09/28/10)
▽ Geophysical Logging Water Level: 74.7 ft bgs (09/01/10 SGLS & NMLS)
Screen Interval: 64.0-154.0 ft bgs

199-K-189 C7689

100-K Area



Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand
Portland Cement Grout

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7689 Well Summary Sheet.

Increasing size of dominant fraction

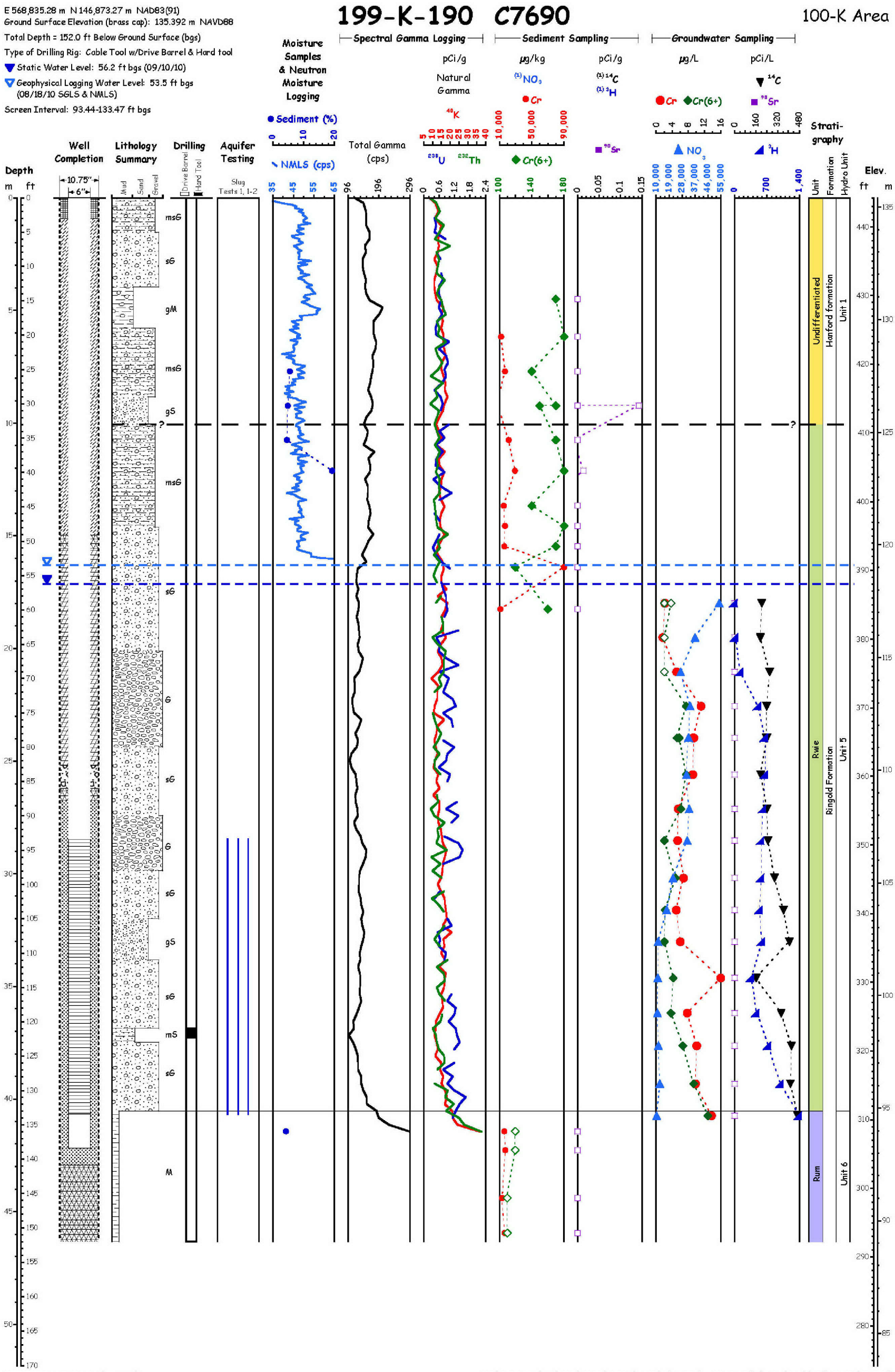
M	Mud
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
C-L	caliche - sedimentary material cemented by calcium carbonate

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft³)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	09/29/10	74.44	0.3276	64.0-154.0	
#2	09/29/10	74.44	0.6877	64.0-154.0	1.1 (Outer)
#3	09/29/10	74.44	1.0112	64.0-154.0	

2011-DCL-C7689-001_07-27

Figure 3-25. C7689 (199-K-189)



Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	09/29/10	57.10	0.3276	93.44-133.47	
#1	09/30/10	56.99	0.6877	93.44-133.47	12
#2	09/30/10	56.99	1.0112	93.44-133.47	

Figure 3-26. C7690 (199-K-190)

E 569,711.20 m N 146,886.65 m NAD83(91)
Ground Surface Elevation (brass cap): 143.859 m NAVD88
Total Depth = 158.0 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel & Hard tool
▼ Static Water Level: 72.4 ft bgs (07/14/10)
▽ Geophysical Logging Water Level: 72.2 ft bgs (07/17/10 SGLS & NMLS)
Screen Interval: 52.3-102.3 ft bgs

199-K-191 C7691

100-K Area

Spectral Gamma Logging | Sediment Sampling | Groundwater Sampling

Depth m ft | Well Completion | Lithology Summary | Drilling | Aquifer Testing | Moisture Samples & Neutron Moisture Logging | Total Gamma (cps) | Natural Gamma pCi/g | Sediment Sampling µg/kg, pCi/g | Groundwater Sampling µg/L, pCi/L | Stratigraphy | Elev. ft m

Well Completion: 10.75" / 6"

Lithology Summary: Mud, Sand, Gravel

Drilling: Drive Barrel, Hard Tool

Aquifer Testing: Slug Tests 1-3

Moisture Samples & Neutron Moisture Logging: Sediment (%) 0 7 14 21; NMLS (cps) 30 50 70

Total Gamma (cps): 75 175 275

Natural Gamma pCi/g: ^{40}K 5 15 25 35; ^{238}U ^{232}Th 0.2 0.6 1 1.8

Sediment Sampling µg/kg: (1) NO_3; Cr 7,000 23,000 39,000; Cr(6+) 50 100 150 200

Sediment Sampling pCi/g: (1) ^{14}C; (1) ^{3}H; ^{90}Sr 0 0.02 0.04 0.06

Groundwater Sampling µg/L: Cr Cr(6+) 0 10 20 30 40; NO_3 10000 45000 80000

Groundwater Sampling pCi/L: ^{14}C; ^{90}Sr 0 6 12 18 24; ^{3}H 0 1,600 3,200 4,800 6,400

Stratigraphy: Unit | Formation | Hydro Unit

Unit: Undifferentiated
Formation: Hanford formation; Ringold Formation; Rwie; Rum
Hydro Unit: Unit 1; Unit 5; Unit 6

Lithology Summary: G; msG; mG; msG; mS; sG; S; sG; gS; msG; mG; gS; msG; M

Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7691 Well Summary Sheet.

Increasing size of dominant fraction

M	Mud
mS	muddy Sand
S	Sand
gS	gravelly Sand
mG	muddy Gravel
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	08/17/10	72.85	0.3276	52.30-102.31	
#2	08/17/10	72.85	0.6877	52.30-102.31	0.5 (Outer)
#3	08/17/10	72.85	1.0112	52.30-102.31	

2011-DC1-C7691-001_07-27

Figure 3-27. C7691 (199-K-191)

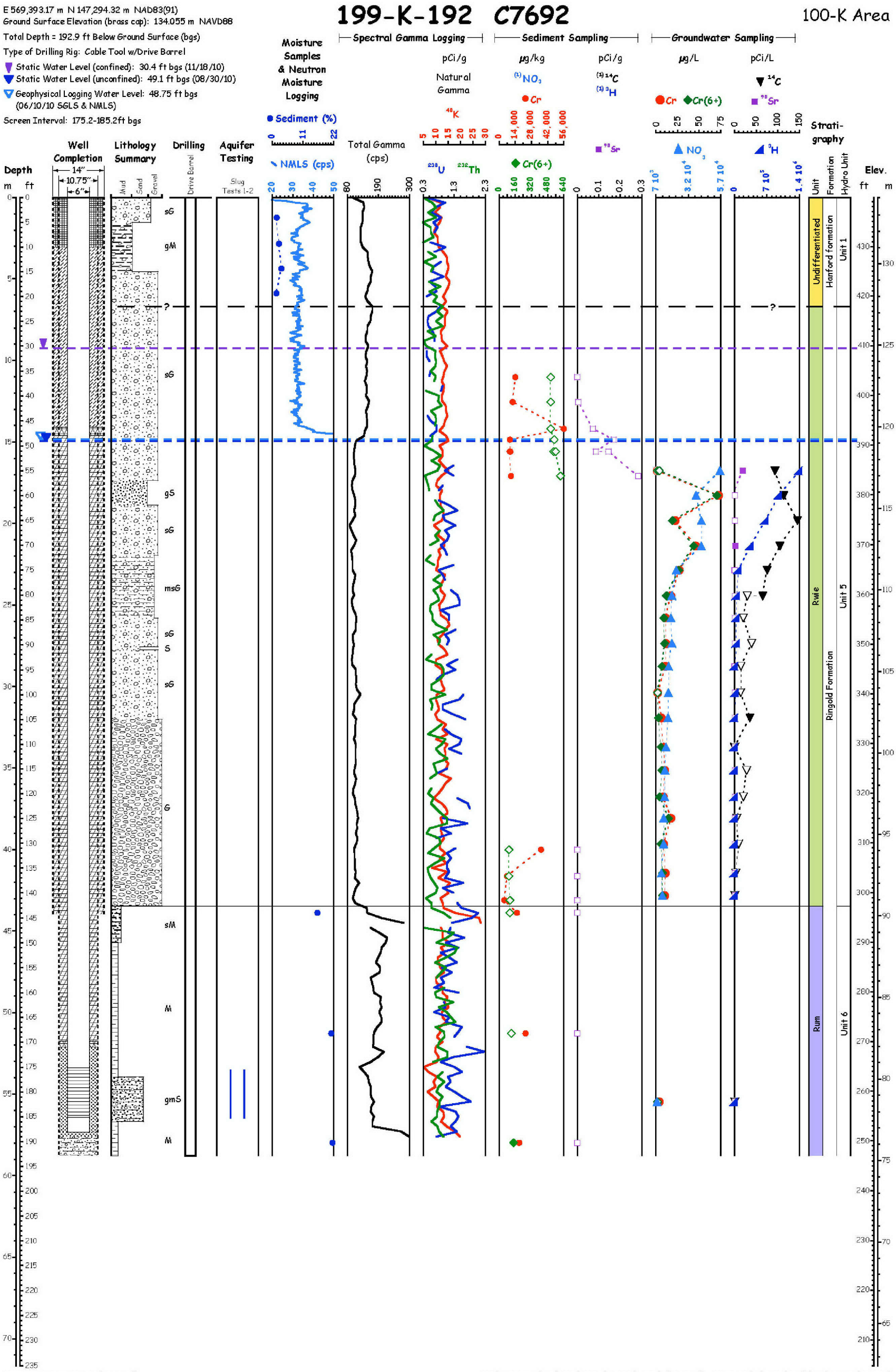


Figure 3-28. C7692 (199-K-192)

E 570,641.99 m N 146,969.58 m NAD83(91)
Ground Surface Elevation (brass cap): 144.876 m NAVD88
Total Depth = 166.0 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel & Hard tool
▼ Static Water Level: 77.2 ft bgs (09/23/10)
▽ Geophysical Logging Water Level: 88.6 ft bgs (12/01/10 SGLS & NMLS)
Screen Interval: 61.3-101.3 ft bgs

199-K-193 C7693

100-K Area

Spectral Gamma Logging | Sediment Sampling | Groundwater Sampling

Depth m ft | Well Completion | Lithology Summary | Drilling | Aquifer Testing | Moisture Samples & Neutron Moisture Logging | Total Gamma (cps) | Natural Gamma pCi/g | Sediment Sampling µg/kg | Sediment Sampling pCi/g | Groundwater Sampling µg/L | Groundwater Sampling pCi/L | Stratigraphy | Elev. ft m

Well Completion: 10.75" / 6"
Lithology Summary: Mud, Sand, Gravel
Drilling: Drive Barrel
Aquifer Testing: Slug Tests 1-3
Moisture Samples & Neutron Moisture Logging: ● Sediment (%) 0 7 14; ↘ NMLS (cps) 35 45 55 65 75 85
Total Gamma (cps): 90 200 310
Natural Gamma pCi/g: ^{40}K 5 15 25 35; ^{238}U ^{232}Th 0.1 1 1.9 2.8
Sediment Sampling µg/kg: (1) NO_3; ● Cr; ◆ Cr(6+) 10,000 20,000 30,000 40,000 50,000 60,000
Sediment Sampling pCi/g: (1) ^{14}C; (1) ^{3}H; ■ ^{90}Sr 0 0.11
Groundwater Sampling µg/L: ● Cr ◆ Cr(6+) 0 5 10 15; ▲ NO_3 0 10,000 20,000
Groundwater Sampling pCi/L: ▼ ^{14}C; ■ ^{90}Sr 0 10 20; ◢ ^{3}H 0 60 120 180 240
Stratigraphy: Unit | Formation | Hydro Unit
Undifferentiated — Hanford formation — Unit 1
Rwie — Ringold Formation — Unit 5
Rum — Unit 6

Depth ft: 0 5 10 15 20 25 30 35 40 45 50 55
Depth m: 0 5 10 15 20 25 30 35 40 45 50
Elev. ft: 470 460 450 440 430 420 410 400 390 380 370 360 350 340 330 320 310
Elev. m: 140 135 130 125 120 115 110 105 100 95

Lithology: M; msG; sG; gS; S; msG; sG; msG; mG; sG; G

Temporary Casing (removed)
6" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Note: Borehole lithology, casing, well seals, and static water level are from C7693 Well Summary Sheet.

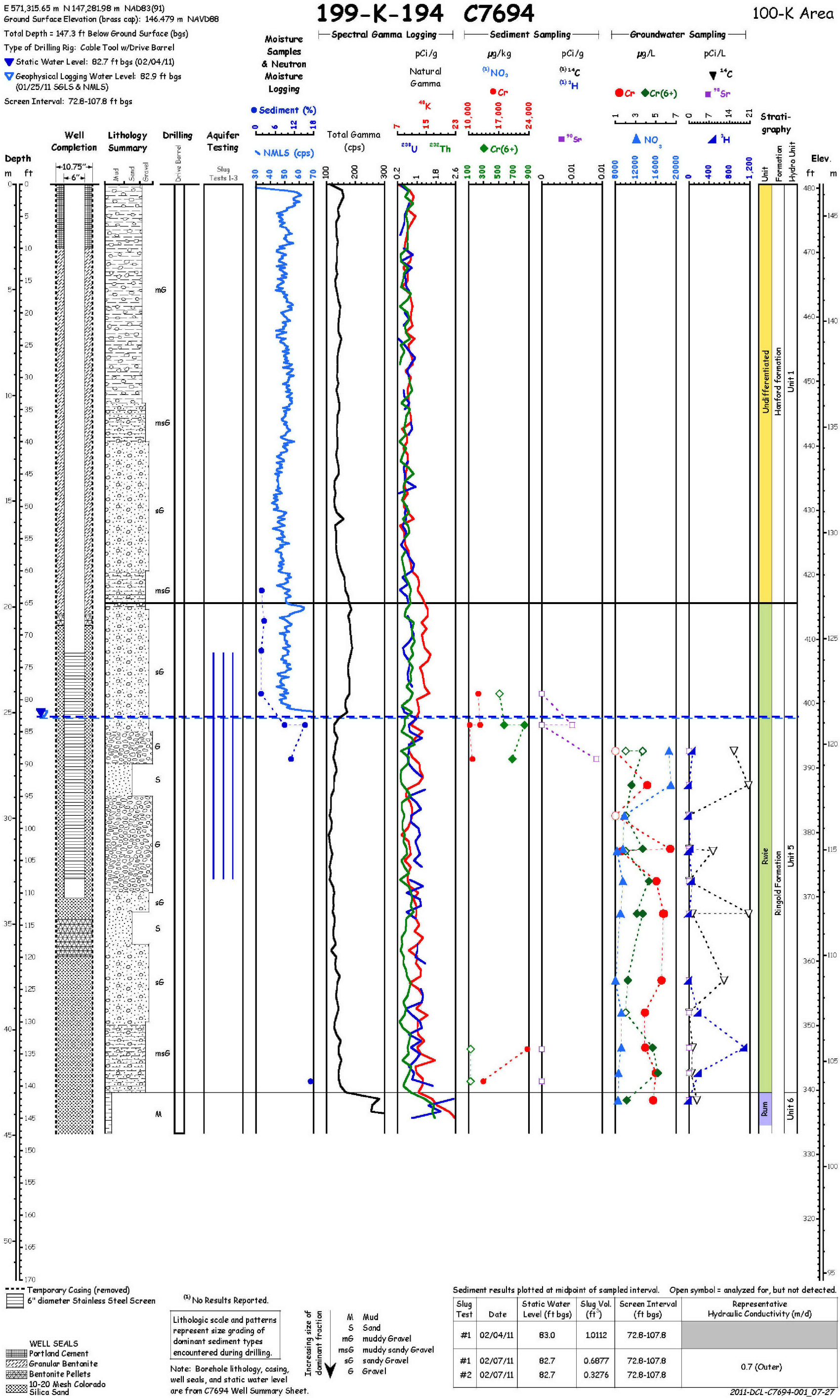
Increasing size of dominant fraction
M Mud
S Sand
gS gravelly Sand
mG muddy Gravel
msG muddy sandy Gravel
sG sandy Gravel
G Gravel

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	02/08/11	78.10	1.0112	61.30-101.30	
#2	02/08/11	78.10	0.6877	61.30-101.30	1.0 (Outer)
#3	02/08/11	78.10	0.3276	61.30-101.30	

2011-DCL-C7693-001_07-27

Figure 3-29. C7693 (199-K-193)



Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	02/04/11	83.0	1.0112	72.8-107.8	
#1	02/07/11	82.7	0.6877	72.8-107.8	0.7 (Outer)
#2	02/07/11	82.7	0.3276	72.8-107.8	

Figure 3-30. C7694 (199-K-194)

E 568,850.08 m N 146,086.38 m NAD83(91)
Ground Surface Elevation (brass cap): 146.867 m NAVD88
Total Depth = 230.5 ft Below Ground Surface (bgs)
Type of Drilling Rig: Cable Tool w/Drive Barrel & Hard Tool
▼ Static Water Level: 85.3 ft bgs (01/21/11)
▽ Geophysical Logging Water Level: 87.2 ft bgs (12/17/10 SGLS & NMLS)
Screen Interval: 78.2-123.2 ft bgs

199-K-195 C7695

100-K Area

Spectral Gamma Logging | Sediment Sampling | Groundwater Sampling

Depth m ft | Well Completion | Lithology Summary | Drilling | Aquifer Testing | Moisture Samples & Neutron Moisture Logging | Total Gamma (cps) | Natural Gamma pCi/g | Sediment Sampling µg/kg | Sediment Sampling pCi/g | Groundwater Sampling µg/L | Groundwater Sampling pCi/L | Stratigraphy | Elev. ft m

Well Completion: 10.75" / 8.6" / 4"

Lithology Summary: Mud, Sand, Gravel

Drilling: Drive Barrel, Hard Tool

Aquifer Testing: Slug Tests 1-2

Moisture Samples & Neutron Moisture Logging: Sediment (%); NMLS (cps)

Natural Gamma pCi/g: ^{40}K, ^{238}U, ^{232}Th

Sediment Sampling µg/kg: $^{(1)}NO_3$, Cr

Sediment Sampling pCi/g: $^{(1)}{}^{14}C$, $^{(1)}{}^{3}H$, ^{90}Sr

Groundwater Sampling µg/L: Cr, Cr(6+), NO_3

Groundwater Sampling pCi/L: ^{14}C, ^{90}Sr, ^{3}H

Stratigraphy: Unit, Formation, Hydro Unit

Lithologic units: sG, gS, msG, sG, G, sG, G, M

Stratigraphy: Undifferentiated; Hanford formation; Unit 1; Rwie; Ringold Formation; Unit 5; Rum; Unit 6

casing change

Note: This borehole was started at the bottom of a ~4.57 m (~15 ft deep) excavation, and was completed as a temporary well.

(1) No Results Reported.

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Increasing size of dominant fraction

M	Mud
gS	gravelly Sand
msG	muddy sandy Gravel
sG	sandy Gravel
G	Gravel

Note: Borehole lithology, casing, well seals, and static water level are from C7695 Well Summary Sheet.

Temporary Casing (removed)
4" diameter Stainless Steel Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand
Portland Cement Grout

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
#1	01/20/11	85.30	0.3276	78.2-123.2	15
#2	01/20/11	85.30	0.3276	78.2-123.2	

2011-DCL-C7695-001_07-27

Figure 3-31. C7695 (199-K-195)

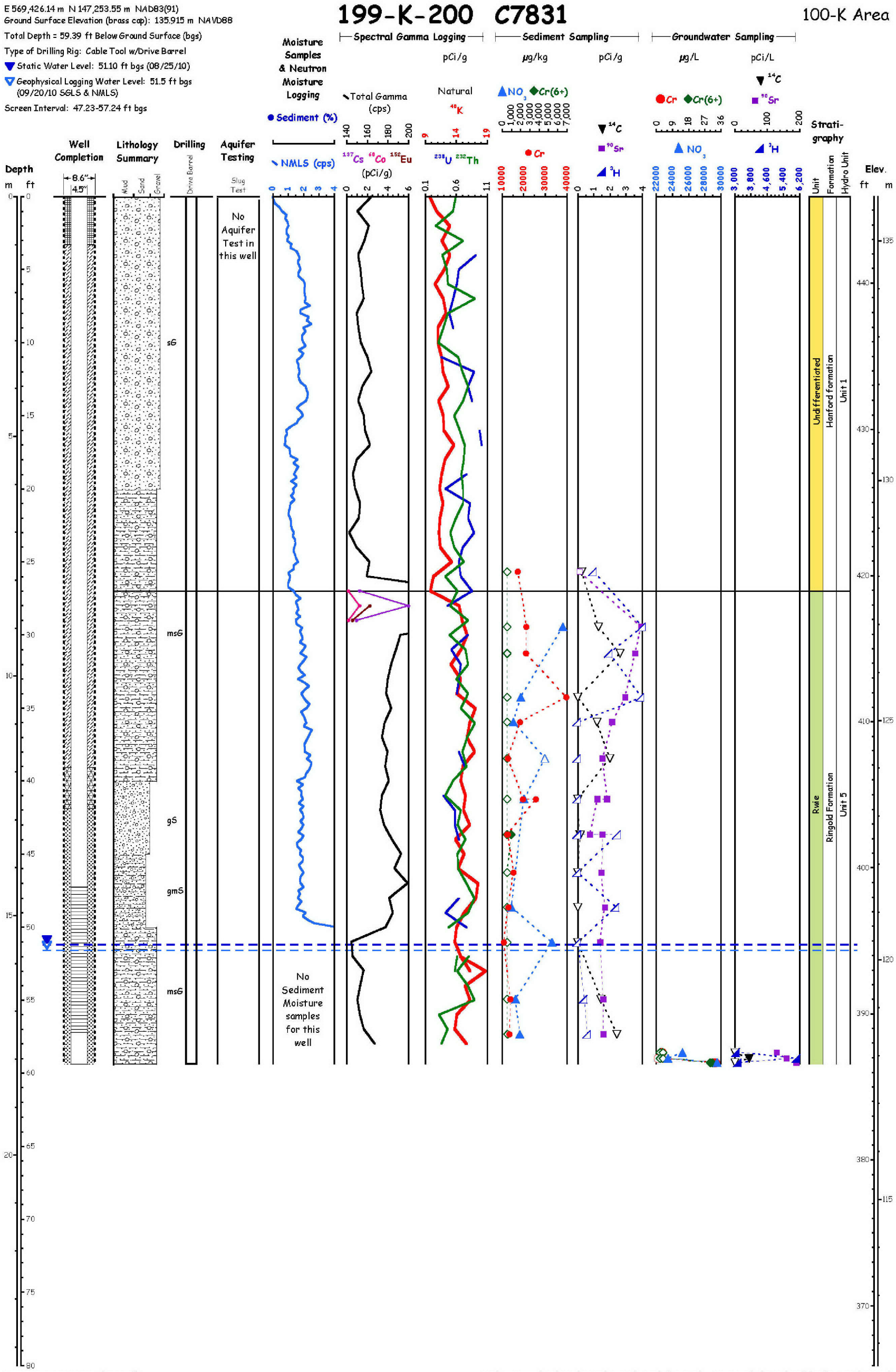


Figure 3-32. C7831 (199-K-200)

E 570,092.13 m N 148,069.02 m NAD83(91)
Ground Surface Elevation (brass cap): 133.356 m NAVD88

Total Depth = 60.4 ft Below Ground Surface (bgs)

Type of Drilling Rig: Cable Tool w/Drive Barrel

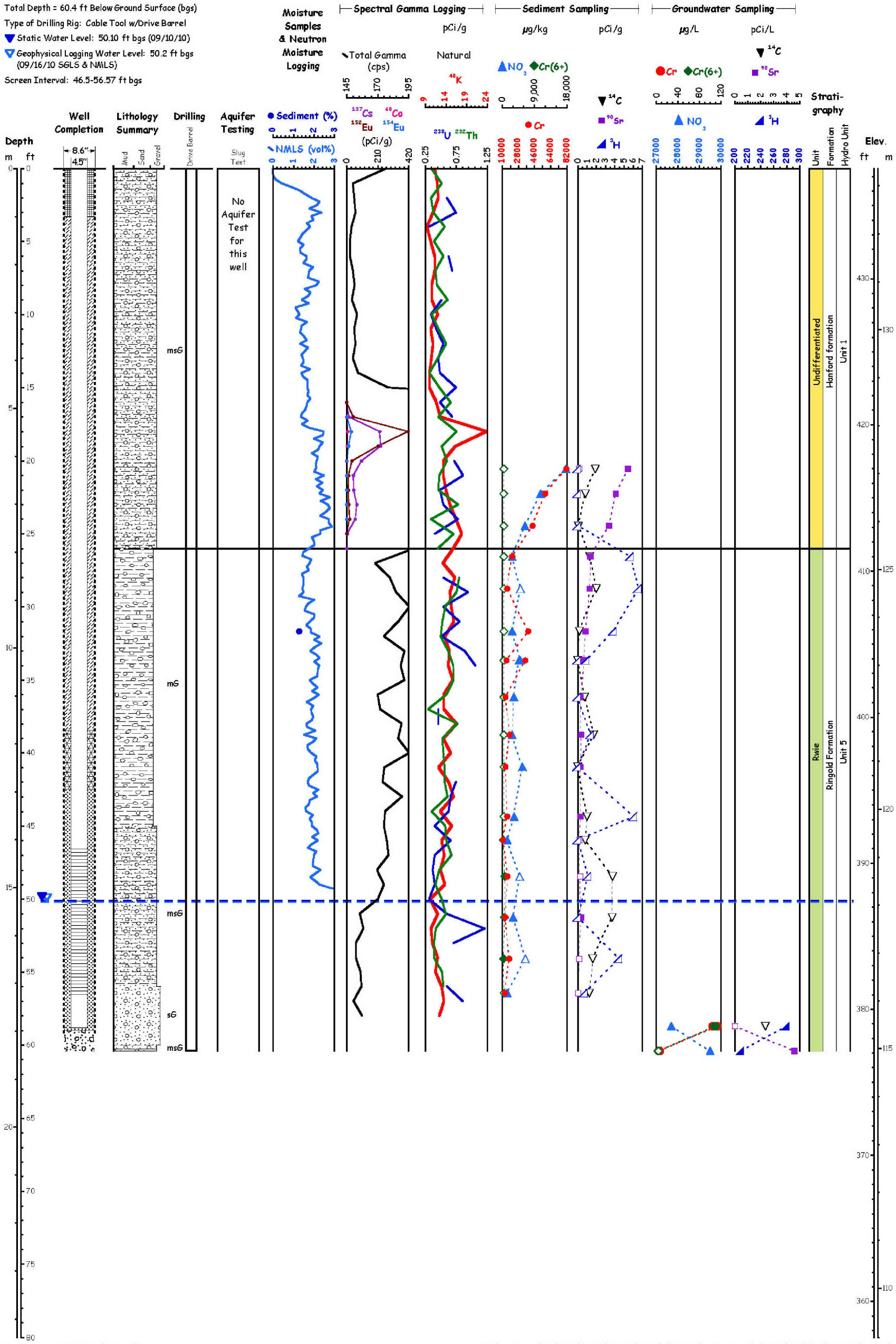
▼ Static Water Level: 50.10 ft bgs (09/10/10)

▽ Geophysical Logging Water Level: 50.2 ft bgs (09/16/10 SGLS & NMLS)

Screen Interval: 46.5-56.57 ft bgs

199-K-201 C7832

100-K Area



Temporary Casing (removed)
4.5" diameter PVC Screen

WELL SEALS
Portland Cement
Granular Bentonite
Bentonite Pellets
10-20 Mesh Colorado Silica Sand
Natural Slough

Lithologic scale and patterns represent size grading of dominant sediment types encountered during drilling.

Increasing size of dominant fraction

mG muddy Gravel
msG muddy sandy Gravel
sG sandy Gravel

Note: Borehole lithology, casing, well seals, and static water level are from C7832 Well Summary Sheet.

Sediment results plotted at midpoint of sampled interval. Open symbol = analyzed for, but not detected.

Slug Test	Date	Static Water Level (ft bgs)	Slug Vol. (ft^3)	Screen Interval (ft bgs)	Representative Hydraulic Conductivity (m/d)
					No slug testing in this well.

2011-DCL-C7832-001_07-27

Figure 3-33. C7832 (199-K-201)

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Geophysical Logs. Geophysical logging plots are also presented and require some explanation. Wells are typically logged prior to installation of the well casing, screen, grout, and bentonite, but with the drilling casing remaining in place. Total gamma and spectral gamma logs are run for the entire boring. Gross gamma logging, which reports the sum of naturally occurring radioisotopes like uranium, thorium, and potassium in counts per second, are useful in determining geologic units with greater quantities of clays and silts versus sands and gravels. The total gamma log signature increases markedly at the contact between the Ringold unit E sands and gravels with the Ringold Formation upper mud unit. Spectral gamma logging breaks out the detections of a wide band of gamma emissions, which can then be correlated to more common naturally occurring as well as artificial radioisotopes. Concentrations of uranium, thorium, and potassium are quantified and presented as concentration by volume.

Neutron logs are used to measure the moisture content of vadose zone sediments and report moisture content as a volumetric value. Neutron logs are calibrated on the Hanford Site for nominal casing diameters of 6 in. and 8 in. and report moisture as a percent-by-volume measurement. Data for Wells 199-K-200 and 199-K-201 are presented in percent moisture content by volume due to the small boring casing used. For larger diameter (10 to 14 in.) well casing used at 100-K RI Wells, absent a calibration factor, the neutron log is reported as a cps value and only shows moisture content in a relative sense. Laboratory soil moisture contents are also provided within the same column as the neutron log signature and provide specific moisture content values by weight as a percent of wet weight.

Analytical Data. Data for key analytes in both soil and groundwater have been plotted on the composite log in columns for chemical and radiological constituents. Soil samples were collected at 1.5 m (5 ft) intervals throughout the vadose zone for wells drilled inside the 100-K Reactor area. For wells outside the reactor area, samples were taken at specified intervals beginning 4.6 m (15 ft) above the estimated top of aquifer. Groundwater was sampled at 1.5 m (5 ft) intervals through the aquifer in all wells to develop a profile of the vertical distribution of contaminants. Contaminant values in vadose zone sediments plotted in the composite log are reported in concentrations of mg/kg (parts per million) or picocuries/gram; contaminant concentrations in groundwater are reported in µg/L (parts per billion) or pCi/L. Analytical results are summarized in Tables 3-5 to 3-34 for all analytes on the individual composite logs. When reviewing data for high volume concentration waste sites, it is important to recall that large fluxes have passed through these waste sites for many years. This results in the build-up of non-mobile constituents such as Sr-90 and reduced trivalent chromium.

Filled symbols on the log indicate detections during the analysis; nondetections are identified with open symbols. These symbols rely upon understanding two definitions used in addressing results where an analyte is either not detected or is detected at very low concentrations.

The Method Detection Limit (MDL) is the minimum analyte concentration that can be distinguished from the method blank with a 99 percent probability. The Estimated Quantitation Limit (EQL) (some times referred to as the Practical Quantitation Limit [PQL])is the lowest concentration that can be reliably measured within specified limits of precision and accuracy under routine laboratory operating conditions. The EQL is generally 5 to 10 times greater than the MDL. For many analytes, the EQL analytic concentration is selected as the lowest non-zero standard in the calibration curve. Sample EQLs are highly matrix dependent. It is standard industrial practice to report non-detected analytes with the laboratory-determined EQL value, also referred to as the Reporting Limit (RL). These analytes are then flagged with a "U."

There is an analytical "grey zone" below the EQL where the presence of an analyte can be detected but the analytical precision/accuracy of the values obtained will be diminished. These detects are flagged ("B" for most inorganic analytes, "J" for organics) to indicate the potential for diminished precision/accuracy.

As the reported result gets smaller (farther from the lower bound of the quantitation range), precision and accuracy become worse due primarily to two factors; extrapolation beyond determined calibration curve boundaries and increased noise-to-signal ratios from the instrument detection system.

It is important that any laboratory established detection be documented and reported to the best of the laboratory's capability. Not reporting the obtained value (even if potentially with a very large error bound) would be a functional corruption of the dataset. Requesting/requiring the laboratory to report nondetects to routine MDLs is not technically appropriate as it would negatively bias the interpretation of actual laboratory capabilities and the results thus reported. The apparent disparity in detected values reported at lower values than non-detection values (particularly when presented as plots) does not misrepresent the accuracy or usefulness of the data. If project defined EQL/RL goals are met, this facet of the data will not negatively impact decision-making activities. When doing statistical evaluation of data set with non-detected results, it is common practice at Hanford to use one-half of the EQL/RL values.

Hydrogeologic Parameters. Hydrologic conductivity tests were performed in all wells using the slug test method following well construction. Slug testing involves lowering known volumes of an inert material into the top of the aquifer, thereby displacing the water level, and monitoring water level changes in the well as the local head comes into equilibrium. Similarly, when the weight is removed, the water level drops and then recovers. The rate of recovery provides information that allows computing the local hydraulic conductivity, a measure of how fast groundwater moves through the local aquifer. Testing used slugs of increasing volumes to create increasing magnitudes of displacement.

Slug tests measure the hydrologic conductivity of the sediments in which the aquifer is located. This data is provided for the respective RI wells on the composite log and in the text for each well. Slug test calculations have been based on two more precise calculations methods—the Kansas Geological Survey ("Slug Tests in Partially Penetrating Wells" [Hyder et al., 1994]) and the Cooper-Bredehoft-Papadopulos ("Response of a Finite Diameter Well to an Instantaneous Charge of Water" [Cooper et al., 1967]) methods versus those previously used as noted in Table 3-14. Details of the calculations are provided in Appendix C. Five Wells 199-K-185, 199-K-189, 199-K-191, 199-K-193 and 199-K-194—reported dual porosity values. Where dual values are reported, the larger value is ignored as it is considered a measure of the sand pack placed around the screen rather than representing the hydrologic conductivity of the formation, which is the lower value. The text will report the lower value in instances of dual moisture measurements.

Water levels are reported as separate measured (steel tape) and logged values. Geophysical logging is usually conducted shortly after the well has been drilled to depth but before well construction. Drill crews and rigs were moved from site to site to complete the drilling and sampling program, then returned to the wells to construct them. In that time, river stage changes may have been transmitted to the nearshore wells. The longer the well is left unattended between completion of drilling and start of construction, the greater the change is likely to be. Water levels at Well 199-K-193, at completion of drilling on November 23, 2010, was determined to be 23.7 m (77.8 ft) bgs. When the well was logged on December 1, 2010, the water level had declined to 27.1 m (88.9 ft) but rebounded slightly at the start of construction to 25.9 m (85 ft). This fluctuation likely suggests a response to river stage changes, however it is not possible with this data to correlate the river stage change with the well response.

3.4.3.3 Additional Well Information

Four wells were drilled in 2011 to support containment of Cr(VI) plumes. Three of the wells (199-K-197, 199-K-198, and 199-K-199) are located downgradient of the southwest end of the 116-K-2 Trench. The locations were selected to address a lingering plume that had passed exiting extraction wells and was being detected in aquifer tubes AT-K-3-D, -M, and -S. Cr(VI) concentrations at the aquifer tubes have

ranged between 85 and 32 µg/L over the last 7 years and do not show the marked decreases in concentrations in shallower aquifer tubes observed at other tube locations. The fourth well, 199-K-196, is located at the downgradient extent of the current 105-KW Reactor plume, approximately midway between extraction wells 199-K-138 and 199-K-132 and was drilled in August 2011.

Wells 199-K-197, 199-K-198 and 199-K-199 are located downgradient of currently active Extraction Wells 199-K-162 and 199-K-120A. Two of these wells (199-K-198 and 199-K-199) were initially planned as extraction wells while 199-K-197 was planned as a monitoring well. Well 199-K-197 is closest to the existing extraction wells, lying 51 m (167 ft) crossgradient from 199-K-120A and 142 m (466 ft) from the Columbia River. Well 199-K-198 is located 100 m (328 ft) equidistant from Well 199-K-120A and the river. Well 199-K-199 is also located equidistant from the river and Well 199-K-120A and is 93 m (305 ft) from each. The three wells are located on the lowest terrace above the current river channel, and lie 4.57 to 6.2 m (15 to 20 ft) above the groundwater table. Details of the local geology, contaminant distribution, and well design for each are given below. These wells were drilled during the spring-summer 2011 high river stage with some of the greatest discharge rates observed in site history.

Well 199-K-197 was drilled to a total depth of 32.3 m (106 ft). The unconfined aquifer was encountered at a depth of 4.6 m (15 ft) bgs and the RUM was encountered at a depth of 30.8 m (101 ft) bgs. The Hanford formation was not reported in the geological log; all sediments were Ringold unit E sands and gravels. Water levels in the well later rose to 3.7 m (12 ft) bgs during high river stage.

Soil samples at all three wells were taken at 1.5 m (5 ft) intervals in the vadose zone and in the RUM unit. At 199-K-197, concentrations of total chromium ranged between 6.53 to 48.8 mg/kg while Cr(VI) concentrations ranged between 0.154 (U) to 0.914 mg/kg (N = spike sample recovery is outside control limits).

Groundwater samples at all wells were taken at 3.1 m (10 ft) intervals while drilling. Cr(VI) chromium was not detected in groundwater at 199-K-197 until a depth of 22.7 m (74.4 ft) bgs. Between that depth and 30.8 m (101.1 ft) bgs, Cr(VI) concentrations ranged between 12 and 31 µg/L, reaching the maximum value at a depth of 25 m (82 ft) bgs. The well was constructed with 15.2 cm (6 in.) diameter, 20-slot screen between depths of 21.3 to 30.5 m (70 to 100 ft) bgs. Analyses for Sr-90 were largely non-detects below 0.46 pCi/L but for one sample of 0.75 pCi/L at 4.57 m (15 ft) bgs. Radionuclide and anion concentrations were not available at the time of writing.

Well 199-K-198 is located crossgradient and downgradient from Well 199-K-120A and is 100 m (328 ft) from both that well and the river. It was drilled to a depth of 30.9 m (101.5 ft) bgs. The unconfined aquifer was encountered at a depth of 4.8 m (15.8 ft) bgs and the RUM was encountered at a depth of 28.5 m (93.6 ft) bgs. No specific contact between the Hanford formation and Ringold unit E sediments has been chosen. Shallow sediments from ground surface to 6.1 m (20 ft) bgs match descriptions of Ringold unit E but appear to be more related to Hanford formation basaltic sediments from 6.1 to 20.7 m (20 to 68 ft) bgs. Sediments below this depth appeared to be Ringold unit E felsic sands and gravels. Given the proximity to the current river channel, these sediments may be reworked Hanford formation deposited by the ancestral Columbia River. Based on the distribution of Cr(VI) in the aquifer, the well was screened with 15.2 cm (6 in.) 20-slot stainless steel casing between 4.57 to 16.8 m (15 to 55 ft) bgs.

Soil samples at 199-K-198 indicated total chromium concentrations ranging between 9.4 to 19.1 mg/kg. Cr(VI) concentrations were mostly nondetect with one detection at 0.046 (B) mg/kg. Groundwater samples returned only one detection of Cr(VI), 9.8 µg/L at 14.14 m (46.3 ft) bgs. Total chromium concentrations ranges between 9.49 and 12.1 mg/kg. The RUM sample detected Sr-90 was not detected in soil samples. A sample from the RUM detected 0.046 mg/kg Cr(VI) and 19.1 mg/kg total chromium.

Reported Cr(VI) concentrations in groundwater at Well 199-K-198 were largely nondetect; one value at 9.6 µg/L was detected at a depth of 14.1 m (46.3 ft) bgs. Total chromium was detected at concentrations just above the MDL at concentrations ranging between 2.37 to 4.04 µg/L at depths between 14.1 and 26.1 m (46 and 86 ft) bgs. Sr-90 was detected only in the deepest samples, 26.1 and 28.5 m (86 and 93 ft bgs), at concentrations of 5.1 and 3.8 pCi/L. Tritium concentrations ranged between 7,900 and 19,000 pCi/L across the unconfined aquifer with the greater concentrations near the top of the aquifer. Nitrate concentrations reached to 54,900 and 29,700 µg/L at 7.93 and 10.97 m (26 and 36 ft) below the top of the aquifer but were consistently between 12, 000 to 13,300 µg/L over the rest of the aquifer. Carbon-14 was not detected at 199-K-198.

Well 199-K-199 is located 93 m (305 ft) downgradient of Well 199-K-120A and is 93 m (305 ft) away from the Columbia River. The well was drilled to a depth of 31.4 m (103.1 ft) bgs. The top of the unconfined aquifer was encountered at 5.5 m (18 ft) bgs and the RUM was at 29.5 m (96.6 ft) bgs. In 199-K-198, after an initial 3.7 (12 ft) thickness of Ringold unit E-like sediments, Hanford formation-like basalt rich sands and gravels were encountered between 3.7 to 15.2 m (12 to 50 ft) bgs. Ringold unit E sediments were then identified to the top of the RUM. Based on the distribution of Cr(VI) in the aquifer, the well was designed with a 15.2 cm (6 in.) 20-slot stainless steel screen between 19.5 to 28.7 m (64 to 94 ft) bgs. The screened interval covers the depths at which Cr(VI) concentrations exceeded 10 µg/L.

Soil samples at 199-K-199 indicated total chromium concentrations between 6.44 to 27.7 mg/kg. Cr(VI) results were largely nondetects except for one value of 0.203 mg/kg at a depth of 4.57 m (15 ft) bgs. Sr-90 was not detected in the vadose zone.

Cr(VI) was detected in most groundwater samples at Well 199-K-199. Nondetect values were observed at depths of 12.1 and 27.3 m (40 and 89 ft) bgs. Cr(VI) detects ranged from 3.5 (B) to 38.5 µg/L, with the highest concentration at the top of the RUM. Total chromium concentrations followed the same pattern. Sr-90 and carbon-14 were not detected in this well. Tritium and nitrate showed opposite trends with depth. Nitrate concentrations decreased from 17,700 to 8,200 µg/L with depth while tritium increased from 7,100 to 17,000 pCi/L with depth.

Analytical data from the three wells indicate that Cr(VI) concentrations passing extraction wells 199-K-120A and 199-K-162 are lower than observed at downgradient aquifer tubes. The KR4 extraction wells were off-line between October 2010 and mid-January 2011. Pumping then resumed but Cr(VI) in the extraction wells, which had declined below 10 µg/L by June 2010, remained low in 2011. The distribution of Cr(VI) in the deeper part of the aquifer is unusual but may reflect the local impact of extraction in the aquifer. At present, Well 199-K-199 is planned for extraction while Wells 199-K-197 and 199-K-198 will become monitoring wells. If analytical data show increasing trends at either of the latter two, they can be converted to extraction wells.

3.4.3.4 C7683 (199-K-183)

Figure 3-19 shows the composite analytical results for Well C7683 (199-K-183). The well site is located outside and west of the security fenceline near the 105-KW Reactor and lies west of the KW plume. The well location was selected to bound the KW plume nearer to the Columbia River. It was completed in the uppermost unconfined aquifer above the top of the RUM and 6.1 m (20 ft) into the vadose zone. This design provides for possible future use during remediation as an extraction, monitoring or injection well. During the course of drilling, June 2010 water levels rose by (4 ft) in the well in a timeframe coincident with a 1.5 m (5 ft) increase in river stage.

The Hanford formation at this location consists of gravel overlying gravelly muddy sand overlying sandy gravel. The contact was selected at 8.2 m (27 ft) bgs based on geophysical logging and geological

descriptions. The Ringold Formation consists of various layers of sandy gravel, sand, and occasional muddy sandy gravel. The water table is located in Ringold unit E. A neutron moisture log was not requested for this well, but the water content measured from sediment samples indicates relatively low moisture content of only several percent by weight. The moisture data indicate a slightly higher moisture level in the Hanford sediment and slightly lower moisture below the Hanford formation/Ringold unit E contact. This profile appears to be exhibiting moisture contents below the probable background moisture levels for these sediments. Therefore, very little vertical flow would be expected under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 45 m (147 ft) bgs. A more subtle increase in total gamma also is visible at approximately 6.5 m (21 ft) bgs; this increase is associated with the Hanford formation/Ringold unit E contact.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite log (Figure 3-19). Results are provided in Tables 3-5 and 3-6. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. There is a zone of high total chromium at 55 to 56.5 ft at 53.6 mg/kg. Below that, values fall off dramatically. There appears to be a zone of high reduction within that interval. This could be due to additional iron or additional microbial activity in this area. Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. No significant contaminant spikes are observed near the periodically rewetted zone; however, the groundwater sample results from the upper 10 m (33 ft) of the 25 m (82 ft) thick unconfined aquifer are slightly elevated suggesting a shallow intrusion of contaminated groundwater within the unconfined aquifer. The initial groundwater sample at 1.5 m (5 ft) below the groundwater table was not taken due to difficulty in getting adequate quantities of groundwater. Soil was locally cemented and drilling contacted alternate wet and dry zones within a cemented layer. Cr(VI) (and total) concentrations in groundwater are less than the aquatic standard of 10 µg/L at this location, with values for Cr(VI) less than total chromium as expected. There appears to be some reduction to Cr(III) in this portion of the aquifer. Nitrate is approximately half the standard or less. Carbon-14 is less than or equal to the standard of 800 pCi/L and tritium is less than 1,600 pCi/L. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 15 m/day (49 ft/day), which is within the range of conductivity expected for the saturated Ringold unit E.

Routine groundwater sampling following well acceptance was performed at 199-K-183 in June 2011. Cr(VI) values of 2.8 (B-qualified) and 4.0 µg/L, total chrome was 7.5 and 9.0 µg/L, carbon-14 was 550 pCi/L, tritium was at 1,500 pCi/L, nitrate was 23,800 µg/L and trichloroethene was 4.6 µg/L.

Table 3-5. Analytical Results for Soil Samples 199-K-183 (C7683)

Sample Interval bgs (m [ft])	Soil–Radionuclide (pCi/g)			Soil–Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
4.5–4.9 (14.7–16.2)							3.12
5.9–6.6 (19.5–21.5)							4.19
7.6–8.2 (25–27)							2.05
9.1–9.8 (30–32)							1.15
16.8–17.2 (55–56.5)		-0.022 (U)		53.6	0.13		
16.8–17.2 (55–56.5)		0.026 (U)		27.0	0.20 (U)		
18.3–19.1 (60–62.5)		-0.00381 (U)		17.0	0.12		
18.3–19.1 (60–62.5)		-0.044 (U)		16.3	0.714		
20.–20.2 (65.5–66.3)		-0.006 (U)		19.9	0.07		
20.5–21.1 (67.4–69.3)		-0.021 (U)		13.4	0.10		
21.3–22.1 (70–72.5)		-0.032 (U)		4.57	0.28		
22.9–23.6 (75–77.5)		-0.021 (U)		12.70	0.10		
45.1–45.9 (148–150.5)		-0.66 (U)		17.80	0.10 (U)		17.7
56.6–57.3 (185.8–187.9)		-0.89 (U)		19.30	0.12 (UN)		

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

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Table 3-6. Analytical Results for Groundwater Samples 199-K-183 (C7683)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
22.9 (75)				8.47			
24.4 (80.2)	815	-4.7 (U)	1,600	6.11	2.8	22,800	
25.8 (84.5)	601	-6.1 (U)	1,500	8.63	5.4	22,400	
27.6 (90.4)	555	-5.7 (U)	1,500	7.6	4.7	22,400	
28.9 (94.8)	812	-3 (U)	1,400	9.04	5.1	22,400	
30.3 (99.5)	263	-4.4 (U)	1,000	1 (UD)	2 (U)	18,100	
30.3 (99.5)	265	-6.6 (U)	950	1 (UD)	2 (U)	18,100	
32 (105)	78.6	-3.2 (U)	830	4.22	2 (U)	15,400	
33.5 (110)	234	-2.7 (U)	950	1 (UD)	2 (U)	16,100	
35.4 (116)	39.2 (U)	-3.9 (U)	820	1 (UD)	2 (U)	15,500	
36.6 (120)	58.2	-4.6 (U)	1,000	4.6	2 (U)	13,400	
38 (124.8)	213	-3.5 (U)	990	1 (UD)	2 (U)	16,000	
39.3 (129)	43.5 (U)	-2.9 (U)	940	1 (UD)	2 (U)	15,100	
41.2 (135.2)	48.6	-1.9 (U)	820	2.54	2 (U)	14,300	
42.8 (140.3)	46.7 (U)	-9.5 (U)	910	2.66	2 (U)	14,500	
44.1 (144.8)	121	-6.3 (U)	960	1 (UD)	2 (U)	14,100	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

3.4.3.5 C7684 (199-K-184)

Figure 3-20 shows the composite analytical results for Well C7684 (199-K-184). The well site was selected to determine the extent of contamination residing in the RUM unit, physical and hydrological properties of the RUM unit, and potential transport of contamination in the RUM unit. The well is located just upgradient of the 105-KW Reactor and drilled 15.2 m (50 ft) into the RUM unit. A water-bearing unit was not found in the RUM and the well was completed in the lowermost unconfined aquifer with the base of the screen located at the top of the RUM. The water table lies within the Ringold unit E. The Hanford formation/Ringold unit E contact is at 16.8 m (55 ft) bgs, although evidence for the contact depth is not

clear cut. The well location is downgradient of a suspected Cr(VI) source in groundwater around the former 183.2 KW Head House. This well lies near three active extraction wells (199-K-137, 199-K-165, and 199-K-166). Well 199-K-184 was screened in the lower unconfined aquifer to investigate contaminant trends below the 15.4 to 30.1 m (50 to 100 ft) bgs screened interval of Extraction Well 199-K-137.

The Hanford formation at this location consists of muddy gravel overlying a thin muddy layer overlying sand, gravelly sand, and muddy sandy gravel. Ringold unit E consists predominantly of sandy gravel and gravelly sand with occasional sand or muddy sandy gravel. The water content measured from laboratory sediment samples ranged between 5 to 10 percent by weight, with one spike to 20 percent at the top of a thin mud unit 6.2 m (20 ft) bgs. Neutron moisture logging was conducted at this well. The log plot indicates reasonable consistency between volumetric water content and laboratory moisture, including the spike at 6.2 m (20 ft). The moisture profiles indicate a slightly higher moisture level in the Hanford sediment and slightly lower moisture below the Hanford formation/Ringold unit E contact. This profile appears to be exhibiting moisture content within the probable background moisture levels for these sediments under unvegetated conditions. Given typical specific retention capacities of 1 to 2 percent for these sediments, the occurrence of vertical downward flow would be expected in these sediments.

The total gamma and natural potassium-40, uranium-238, and thorium-228 (KUT) geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 50 m (168 ft) bgs. The total gamma signature is not distinct for the Hanford formation/Ringold unit E contact at 28 m (90 ft) bgs. There is one zone of higher counts at approximately 6 m (20 ft) below the surface where a fine-grained unit is able to support higher moisture contents due to the smaller pore structure. This unit may represent the top of a Hanford flood sequence that did not experience as much wind erosion of the fine-grained material from the top of the sequence.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite log plot (Figure 3-20). Analytical results in Table 3-7 and 3-8. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. The sediment sampling indicates relatively low levels of Cr(VI) in the vadose zone sediment with total chromium ranging up to 27 mg/kg at depth from 15 to 23 m (50 to 75 ft), the lowest third of the vadose zone above the aquifer. The percentage of Cr(VI) to total chromium for each sample that had detected results ranged from 1 to 8 percent, suggesting that most of the chromium has been reduced and is immobile. This is consistent with the CSM understanding of the periodically rewetted zone, which indicates that the K_d is similar on both sides of the water table; therefore, source does not accumulate preferentially in this region and periodically discharge to the water table. However, there are some cases where chromium is elevated in the periodically rewetted zone, indicating variability in this behavior that causes some uncertainty in this area. In the aquifer, chromium concentrations are below the aquatic standard over much of the thickness of the aquifer with a spike to 120 µg/L between 35 to 36 m (115 to 120 ft) in depth and 60 µg/L between 38 to 40 m (125 to 130 ft) in depth. The total chromium and Cr(VI) track closely, indicating that most of the Cr(VI) in the groundwater is in the hexavalent state. This suggests that the chromium in the aquifer is in a very mobile state; the interim remedy approach of pump-and-treat would be a good strategy near this well.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. No significant contaminant spikes are observed near the periodically rewetted zone; however, the groundwater sample results from the upper 10 m (33 ft) of the 25 m (82 ft) thick unconfined aquifer are slightly elevated, suggesting a shallow intrusion of contaminated groundwater within the unconfined aquifer. Cr(VI) (and total) concentrations in groundwater are less than the aquatic standard of 10 µg/L at

this location, with values for Cr(VI) less than total chromium as expected. There appears to be some reduction to Cr(III) in this portion of the aquifer. Nitrate is approximately half the standard or less. Carbon-14 is greater than the standard of 800 pCi/L at depths of about 30 and 36 m (100 and 120 ft) bgs, while tritium is less than 1,800 pCi/L with the greatest concentration at the base of the aquifer. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 6 m/day (20 ft/day), which is within the range of conductivity expected for the saturated Ringold unit E.

Routine water sampling was performed at this well in May 2011. The results were Cr(VI)–15.7 µg/L, Cr(total)–21 µg/L, carbon-14–211 pCi/L, Sr-90–2.1 (U) pCi/L, tritium–1,400 pCi/L, nitrate-13,800 µg/L, and TCE–3.1 (J).

Table 3-7. Analytical Results for Soil Samples 199-K-184 (C7684)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
1.5–2.3 (5–7.5)		-0.021 (U)		103.0	0.53 (U)		5.55
3.1–3.9 (10.3–12.8)		-0.057 (U)		3.42	0.53 (U)		4.93
4.5–5.2 (14.6–17.1)		-0.195 (U)		3.28	0.22		4.57
6–6.2 (19.8–20.3)		-0.002 (U)		16.8	0.62 (U)		19.2
7.8–8.6 (25.7–28.2)		0.03 (U)		10.7	0.52 (U)		4.29
9.2–9.9 (30.1–32.6)		-0.033 (U)		10.5	0.24		3.98
10.8–11.6 (35.4–37.9)		-0.034 (U)		10.9	0.53 (U)		6.1
12.2–13 (40–42.5)		-0.089 (U)		12.3	0.52 (U)		4.19
13.6–14.3 (44.5–47)		0.119 (U)		10.0	0.53 (U)		5.52
13.6–14.3 (44.5–47)		-0.031 (U)		11.1	0.97		8.11
15.2–16 (49.9–52.4)		0.056 (U)		20.1	0.52 (U)		4.43
16.8–17.6 (55.2–57.7)		-0.016 (U)		14.9	0.24		7.66
18.5–19.3 (60.7–63.2)		-0.015 (U)		11.3	0.52 (U)		4.16
19.7–20.4 (64.5–67)		-0.037 (U)		26.9	0.51 (U)		2.51
21.3–22.1		-0.024 (U)		23.7	0.51 (U)		2.73

Table 3-7. Analytical Results for Soil Samples 199-K-184 (C7684)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
(70–72.5)							
22.8–23.6 (74.8–77.3)		-0.023 (U)		20.7	0.54 (U)		8.43
23.8–24.4 (78–80)		-0.064 (U)		9.57	0.55 (U)		9.04
24.9–25.5 (81.6–83.6)		0.003 (U)		12.0	0.54 (U)		8.06
49.7 (163)		-1.1 (U)		13.5	0.605 (U)		22
49.7 (163)				18.7	0.11 (UN)		14.2
57. (186.9)		-0.29 (U)		23.0	0.11 (U)		21.7
57. (186.9)				26.9	0.615 (U)		18.3
65.1 (213.6)		-0.65 (U)		16.2	0.098 (U)		24.6
65.1 (213.6)				11.4	0.623 (U)		19.3

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

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Table 3-8. Analytical Results for Groundwater Samples 199-K-184 (C7684)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
24.9 (81.6)	582	-1.8 (U)	1,400	1 (UD)	2 (U)	21,700	
24.9 (81.6)				2.12	3.7 (U)		
26.4 (86.7)	1020	-5.3 (U)	1,400	14.8	14.4	21,700	
27.4 (90)	782	-3 (U)	1,500	14.4	13.6	21,600	
29. (95)	806	-1.5 (U)	1,500	14.2	11.6	21,900	
31.7 (104)	1,270	-1.6 (U)	1,500	3.5	2 (U)	20,100	
32.1 (105.2)	1,470	-0.59 (U)	1,500	2.03	2 (U)	19,700	
33.7 (110.7)	683	-3.7 (U)	1,400	1.31	3.7 (U)	21,700	

Table 3-8. Analytical Results for Groundwater Samples 199-K-184 (C7684)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
33.7 (110.7)	380	-0.144 (U)	1,390	3.1 (U)	2 (U)	20,900	
35.2 (115.5)	602	-6.7 (U)	1,200	7.63	5	21,600	
36.4 (119.4)	1,210	-9.1 (U)	1,100	116	116	18,800	
38.1 (125.1)	1,640	-1.4 (U)	1,500	3.43	2 (U)	17,100	
39.4 (129.4)	1,090	-7.5 (U)	1,300	67.1	68.6	19,000	
41.1 (135)	631	-1.2 (U)	1,900	9.17	7.1	20,900	
42.7 (140)	606	-3.7 (U)	2,300	26.3	24.3	22,300	
42.7 (140)	558	-3.6 (U)	1,100	25.6	24.5	22,500	
44.2 (145)	602	-3.8 (U)	1,700	9.49	6.8	22,500	
45.7 (149.8)	596	-1.6 (U)	1,300	3.7	2 (U)	21,200	
47.3 (155.3)	9.43 (U)	-5.4 (U)	2,900	6.41	3.6	21,600	
48.7 (159.9)	544	-1.8 (U)	8,800	11.6	13.5	20,700	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

3.4.3.6 C7685 (199-K-185)

Figure 3-21 shows the composite analytical results for Well C7685 (199-K-185). The well replaces well 199-K-33, which was decommissioned in 2003 to accommodate remediation actions at the 107-KW site. Well 199-K-33 had a trend of elevated carbon-14 concentrations well above the 2,000 pCi/L drinking water standard (DWS). Tritium values occasionally exceeded the 20,000 pCi/L DWS. Total chromium results at 199-K-33 ranged from 10 to 25 µg/L, Cr(VI) was not an analyte. Well 199-K-185 was intended to provide information on the extent of Cr(VI), carbon-14, TCE, and Sr-90 in the unconfined aquifer. The well is fully screened across the 26 m (85.5 ft) thick unconfined aquifer with the base of the screen located at the top of the RUM. The Hanford formation/Ringold unit E contact was selected at 7.6 m (25 ft) bgs based on the geologic log. The water table is within the Ringold unit E.

Neutron moisture logging was conducted at this well; the results show a slight relative decrease in volumetric moisture below the Hanford formation/Ringold unit E contact. Laboratory soil moisture content ranged from a high value of 7 percent in the Hanford to 2 percent in the Ringold unit E. This

profile appears to be exhibiting moisture contents within the probable background moisture levels for these sediments under unvegetated conditions. Given typical specific retention capacities of 1 to 2 percent for these sediments, vertical downward flow would be expected to be occurring in these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 41 m (133 ft) bgs. The total gamma signature is not distinct for the Hanford formation/Ringold unit E contact at 7.5 m (25 ft) bgs. There is one zone of higher counts at approximately 5 m (16 ft) below the surface, although there is no apparent change in lithology. This unit may represent the top of a Hanford flood sequence that did not experience as much wind erosion of the fine-grained material from the top of the sequence.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-21). Analytical results are presented in Tables 3-9 and 3-10. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. The sediment sampling indicates relatively low levels of Cr(VI) in the vadose zone sediment with total chromium ranging up to 22 mg/kg at depth from 7 to 15 m (25 to 50 ft), the lower half of the vadose zone above the aquifer. These results indicate that the portion of Cr(VI) is approximately 1 to 2 percent of the total in the vadose zone, suggesting that most of the chromium has been reduced and is immobile. This is consistent with the CSM understanding of the periodically rewetted zone, which indicates that the K_d is similar on both sides of the water table; therefore, source does not accumulate preferentially in this region and periodically discharge to the water table. In the aquifer, Cr(VI) concentrations are below detection over the thickness of the aquifer until the last measurement at depth close to the RUM contact. There are occasional detections of total chromium with a value of about 6 µg/L at the base of the aquifer. The total chromium and Cr(VI) track closely, indicating that most of the Cr(VI) in the groundwater is in the hexavalent state. This suggests that the chromium in the aquifer is in a very mobile state; the interim remedy approach of pump-and-treat would be a good strategy near this well.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. No significant contaminant spikes are observed near the periodically rewetted zone; however, the groundwater sample results from the upper 10 m (33 ft) of the 25 m (82 ft) thick unconfined aquifer are slightly elevated, suggesting a shallow intrusion of contaminated groundwater within the unconfined aquifer. Cr(VI) concentrations in groundwater are less than the aquatic standard of 10 µg/L at this location, with values for Cr(VI) less than total chromium, as expected. There appears to be some reduction to Cr(III) in this portion of the aquifer. Nitrate and carbon-14 above the standard are observed in the upper 6 m (20 ft) of the aquifer. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 2 m/day (6.6 ft/day), which is within the range of conductivity expected for the saturated Ringold unit E.

Routine groundwater monitoring was performed at 199-K-185 in May 2011. The results are as follows: Cr(VI)–7.0 µg/L, total chromium–5.1 µg/L, carbon-14–175 pCi/L, Sr-90–3.1 pCi/L, tritium-680 pCi/L, nitrate–20,800 µg/L, and TCE–4.9 µg/L.

Table 3-9. Analytical Results for Soil Samples 199-K-185 (C7685)

Sample Interval bgs (m [ft])	SoiL—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
4.7–5.4 (15.35–17.8)							6.02
6.2–7 (20.35–22.85)							3.22
7.6–8.4 (24.9–27.4)		0.067 (U)		21.2	0.18		2.39
9.2–9.9 (30.05–32.55)		0.073 (U)		12.8	0.10		2.13
10.6–11.4 (34.8–37.3)		0.037 (U)		13.9	0.18		
10.6–11.4 (34.8–37.3)		-0.044 (U)		11.0	0.16		
12.1–12.9 (39.7–42.2)		0.044 (U)		8.77	0.09		
13.6–14.4 (44.7–47.2)		-0.037 (U)		14.0	0.12		
15.3–15.6 (50.2–51.2)		0.046 (U)		8.16	0.15		
40.7 (133.5)		-0.55 (U)		6.27	0.10 (N,U)		11.8

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

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Table 3-10. Analytical Results for Groundwater Samples 199-K-185 (C7685)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon–14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
15.8 (52)	1,620	-0.94 (U)	390	0.68	2 (U)	99,200	
15.8 (52)				1 (UD)	2 (U)		
17.4 (57)	2,390	-1.9 (U)	890	1 (UD)	2 (U)	105,000	
19.1 (62.5)	2,070	-6 (U)	580	2.22	2 (U)	116,000	
20.5 (67.2)	1,720	0.43 (U)	390	1.13	2 (U)	97,800	
20.5 (67.2)	1,730	-1.2 (U)	520	1 (UD)	2 (U)	96,900	
21.9 (72)	958	-3.1 (U)	720	1 (UD)	2 (U)	66,000	
23.5 (77.2)	466	-4.6 (U)	480	1.73	2 (U)	28,100	
25. (82)	636	-2.6 (U)	400	1.22	2 (U)	23,600	
26.5 (87.1)	195	-4.7 (U)	740	1 (UD)	2 (U)	23,500	
26.5 (87.1)	236	-5.6 (U)	760	1 (UD)	2 (U)	23,700	
28 (92)	233	-2.2 (U)	730	1.77	2 (U)	24,700	

Table 3-10. Analytical Results for Groundwater Samples 199-K-185 (C7685)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon–14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
29.6 (97)	210	-3.6 (U)	690	1 (UD)	2 (U)	22,400	
31.1 (102)	221	-7.5 (U)	780	1.59	2 (U)	23,700	
32.4 (106.4)	-0.44 (U)	0.08 (U)	670	1.49	2 (U)	23,600	
34.1 (112)	198	-6 (U)	860	1.84	2 (U)	22,300	
35.7 (117)	530	-4.6 (U)	1,100	1 (UD)	2 (U)	17,300	
38.7 (127)	626	-3.6 (U)	1,800	1.55	2 (U)	13,200	
40.2 (132)	682	-4.5 (U)	2,900	5.27	2.9	12,700	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.7 C7686 (199-K-186)

Figure 3-22 shows the composite analytical results for Well C7686 (199-K-186). This well was originally proposed in a culturally sensitive area southeast of the 116-K-2 Trench, but was relocated to a position between the 105-KE Reactor and the 165-KE Powerhouse. This location was selected to examine the nature and extent of Cr(VI) and other contaminant distributions around the reactor structure. The area was adjacent to active building demolition at the 1706-KE complex located just northwest of the well. The well was screened in the upper two-thirds of the unconfined aquifer to interrogate the elevated Cr(VI) concentrations found in the middle of the aquifer. The well was constructed with the base of the screen about 9 m (30 ft) above the top of the RUM. The Hanford formation/Ringold unit E contact was identified at 14.9 m (49 ft) as a gradual contact by the geological log. The water table is within the Ringold unit E. A possible cement fragment was reported in the Hanford formation at 1.8 m (6 ft) bgs, suggesting fill to this depth.

Neutron moisture logging was conducted at this well, indicating volumetric water contents, although often there is more variability with depth. The water content measured from sediment samples ranged from 5 to 10 percent to 2 to 3 percent for the Ringold unit E. The relative scale of the neutron log presents a plot that is the inverse of the analytical data. This profile appears to be exhibiting moisture contents within the probable background moisture levels for these sediments under unvegetated conditions. Given typical specific retention capacities of 1 to 2 percent for these sediments, the occurrence of vertical downward flow would be expected in these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 49 m (162 ft) bgs. The total gamma signature is

reasonably distinct for the Hanford formation/Ringold unit E contact at 15 m (49 ft) bgs. There is one zone of higher counts within the upper 3 m (10 ft) of the Ringold unit E, although there is no apparent change in lithology. This unit may represent the top of a Hanford flood sequence that did not experience as much wind erosion of the fine-grained material from the top of the sequence.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-22). Tables 3-11 and 3-12 present analytical results. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. The sediment sampling indicates relatively low levels of Cr(VI) in the vadose zone sediment with total chromium ranging up to 0.5 mg/kg. These results indicate that the portion of Cr(VI) is less than 1 percent of the total in the vadose zone, suggesting that most of the chromium has been reduced and is immobile. This is consistent with the CSM understanding of the periodically rewetted zone, which indicates that the K_d is similar on both sides of the water table; therefore, source does not accumulate preferentially in this region and periodically discharge to the water table. In the aquifer, Cr(VI) concentrations are below detection over the thickness of the aquifer until the last measurement at depth close to the RUM contact. There is a zone of chromium in the aquifer from 33 to 40 m (110 to 130 ft) bgs with a maximum value of about 27 µg/L in this zone. The total chromium and Cr(VI) track closely, indicating that most of the Cr(VI) in the groundwater is in the hexavalent state. This suggests that the chromium in the aquifer is in a very mobile state; the interim remedy approach of pump-and-treat would be a good strategy near this well.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. No significant contaminant spikes are observed near the periodically rewetted zone; however, the groundwater sample results from the upper 10 m (33 ft) of the 25 m (82 ft) thick unconfined aquifer are slightly elevated, suggesting a shallow intrusion of contaminated groundwater within the unconfined aquifer. Cr(VI) (and total) concentrations in groundwater are greater than the aquatic standard of 10 µg/L at this location, with values for Cr(VI) less than or equal to total chromium, as expected. There appears to be relatively little reduction to Cr(III) in this portion of the aquifer. Nitrate and carbon-14 are below the standard and are observed primarily in the lower half of the aquifer. This well is screened in very permeable material. A slug test was attempted but the water level change dissipated too quickly to be measured, indicating that this is high hydraulic conductivity Hanford formation.

Routine groundwater sampling began in May 2011 at well 199-K-186. Analytical results are as follows: Cr(VI)–3.9 (B) µg/L, total Cr–9 (B) µg/L, carbon-14–104 pCi/L, Sr-90–0.25 (U) pCi/L, tritium–77 (U) pCi/L, and nitrate–1,650 µg/L.

Table 3-11. Analytical Results for Soil Samples 199-K-186 (C7686)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
1.5–1.8 (5–6)		-0.007 (U)		9.44	0,53 (U)		5.82
3.1–3.9 (10.2–12.7)		-0.091 (U)		12.60	0,54 (U)		7.44
4.6–5.3 (15–17.5)		0.035 (U)		11.00	0.54 (U)		6.98

Table 3-11. Analytical Results for Soil Samples 199-K-186 (C7686)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
6.1–6.9 (20.1–22.6)		0.042 (U)		6.86	0.54 (U)		7.23
7.6–8.4 (25–27.5)		0.119 (U)		10.70	0.54 (U)		7.55
9.–9.8 (29.6–32.1)		0.21 (U)		5.00	0.55 (U)		8.93
9.8–10.5 (32.1–34.6)							6.91
10.7–11.4 (35–37.5)		0.144 (U)		7.64	0.53 (U)		6.35
11.6–12.3 (38–40.5)							6.6
12.3–13.1 (40.4–42.9)		0.021 (U)		7.34	0.54 (U)		6.64
13.–13.7 (42.6–45.1)							6.66
13–13.7 (42.6–45.1)							6.76
13.9–14.6 (45.5–48)		-0.063 (U)		3.77	0.54 (U)		5.93
13.9–14.6 (45.5–48)							6.78
14.6–15.4 (47.9–50.4)							8.59
14.6–15.4 (47.9–50.4)							7.43
15.4–16.2 (50.5–53)		0.004 (U)		12.60	0,52 (U)		1.56
15.4–16.2 (50.5–53)							3.17
16.8–17.6 (55.2–57.7)		0.007 (U)		21.10	0.51 (U)		1.79
16.8–17.6 (55.2–57.7)							1.89
18.4–19.1 (60.3–62.8)		-0.009 (U)		15.3	0.51 (U)		2.42
18.4–19.1 (60.3–62.8)		0.019 (U)		16.7	0.51 (U)		2.26

Table 3-11. Analytical Results for Soil Samples 199-K-186 (C7686)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
19.8–20.4 (64.8–66.8)		-0.018 (U)		33.5	0.51 (U)		1.44
20.9–21.3 (68.5–70)		-0.002 (U)		12.8	0.51 (U)		2.23
21.6–22.3 (70.8–73.3)		0.109 (U)		15.2	0.52 (U)		3.55
22.5–22.8 (73.9–74.9)		-0.014 (U)		15.2	0.51 (U)		2.63
23.4–24.1 (76.7–79.2)		-0.09 (U)		12.8	0.51 (U)		1.72
24.4–24.8 (80.2–81.3)		-0.008 (U)		13.0	0.54 (U)		7.47
25.1–25.9 (82.4–84.9)		-0.084 (U)		7.0	0.27		0.1
27.1–27.9 (89–91.5)		-0.112 (U)		10.7	0.58 (U)		14.1
48.8–49.5 (160–162.5)		-1.2 (U)		27.0	0.11 (U)		

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

U = analyzed for by not detected above limiting criteria

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Table 3-12. Analytical Results for Groundwater Samples 199-K-186 (C7686)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
27.1 (89)	140	0.24 (U)	66 (U)	6.27	2 (U)	3,170	
27.1 (89)				7.1	3.7 (U)		
28.6 (93.8)	88	-3.6 (U)	190 (U)	1 (UD)	2 (U)	1,100	
30.2 (99.2)	214	-2.3 (U)	180 (U)	1 (UD)	2 (U)	1,020	
30.2 (99.2)	190	-4.6 (U)	91 (U)	1 (UD)	2 (U)	1,030	
32. (105)	267	-6.3 (U)	77 (U)	1 (UD)	2 (U)	965	

Table 3-12. Analytical Results for Groundwater Samples 199-K-186 (C7686)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
33.5 (110)	384	-5.9 (U)	37 (U)	1 (UD)	2 (U)	921	
35.1 (115.1)	66.6	-2.1 (U)	750	14.1	10.3	8,630	
36.6 (120)	27 (U)	-6.4 (U)	330	11	7.3	9,740	
38.5 (126.3)	55.6	-1.3 (U)	2,300	25.2	25.6	9,300	
39.6 (130)	53.8	-2.4 (U)	100 (U)	17	18.8	9,650	
41.1 (134.9)	42.6 (U)	-0.88 (U)	110 (U)	7.27	2 (U)	10,400	
42.8 (140.3)	16.6 (U)	-3.3 (U)	94 (U)	1 (UD)	2 (U)	10,500	
44.3 (145.2)	53.2	-1.8 (U)	240	1 (UD)	2 (U)	10,200	
46.3 (151.8)	668	-3.3 (U)	760	1 (UD)	2 (U)	9,380	
47.2 (155)	716	-0.017 (U)	1,600	1.17	2 (UN)	9,520	
48.8 (160)	652	-0.92 (U)	1,700	1 (UD)	2 (U)	8,990	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as Total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

3.4.3.8 C7687 (199-K-187)

Figure 3-23 shows the composite analytical results for Well C7687 (199-K-187). The well site, which was chosen to place an upgradient bound on the Cr(VI) plume, is located about 325 m (1,066 ft) upgradient of the 183.1 KE Head House site. The well is screened in two sections—in the uppermost and lowermost portions of the unconfined aquifer—with the base of the screen located at the top of the RUM. The lower screen section monitors the zone of residual Cr(VI) found just above the bottom of the aquifer. The upper screen extends 4.6 m (15 ft) above the aquifer, so it could be used as an extraction, monitoring, or injection well. An inflatable packer system isolates the two screens within the well, which is currently equipped to permit sampling from below the packer system. The Hanford formation/Ringold unit E contact was identified at 20.9 m (68.5 ft) bgs based on borehole log. The water table is within the Ringold unit E.

Soil moisture content measured from sediment samples ranges from 2 to 4 percent for the span of samples stretching across the base of the Hanford formation into the RUM. The neutron log is in general agreement with the laboratory results. The neutron log indicates a slightly lower moisture level in the Hanford sediment relative to the slightly higher moisture level below the Hanford formation/Ringold

unit E contact. Given typical specific retention capacities of 1 to 2 percent for these sediments, occurrence of vertical downward flow would be expected, based on the measured water contents.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 60 m (197 ft) bgs. The total gamma signature and KUT exhibit a slight increase in count rate at the Hanford formation/Ringold unit E contact at approximately 21 m (67 ft) bgs. There is a drop in the count rate at the water table for the total gamma log.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-23). Analytical results are presented in Tables 3-13 and 3-14. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. The sediment sampling indicates Cr(VI) in the vadose zone sediment with total chromium ranging up to 27 mg/kg in a zone 1.5 to 3 m (5 to 10 ft) above the water table. Cr(VI) concentration is about 140 µg/L. These results indicate that the portion of Cr(VI) is much less than 1 percent of the total in the vadose zone, suggesting that most of the chromium has been reduced and is immobile. This is consistent with the CSM understanding of the periodically rewetted zone, which indicates that the K_d is similar on both sides of the water table; therefore, source material leaching through the vadose zone does not accumulate preferentially in this region and periodically discharge to the water table. In the aquifer, Cr(VI) concentrations generally are below detection over the thickness of the aquifer except for a zone near the base of the aquifer from 56 to 58 m (185 to 190 ft) bgs. Concentrations in this area are about 32 µg/L; the total chromium and Cr(VI) mass are nearly equal, indicating that chromium is predominantly in the mobile hexavalent form and that little natural reduction is occurring in the aquifer at this location. This suggests that the interim remedy approach of pump-and-treat would be a good strategy near this well.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. Nitrate, carbon-14, and tritium are below the standard and are observed throughout the thickness of the aquifer. Carbon-14 and tritium are elevated at the base of the aquifer at the same location (56 to 58 m [185 to 190 ft] bgs) where elevated chromium was observed. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 27 m/day (89 ft /day), which is within the range of conductivity expected for the saturated Ringold unit E.

After well acceptance, routine well sampling occurred in April 2011. Results from sampling at the bottom of the aquifer are as follows: Cr(VI)–3 (B) µg/L, total chrome–11 µg/L, carbon-14–3.47 (U) µg/L, Sr-90–4.5 pCi/L, tritium–280 pCi/L, and nitrate–20,500 µg/L.

Table 3-13. Analytical Results for Soil Samples SAP Well #3 199-K-187 (C7687)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
18.2–18.9 (59.6–62.1)							3.8
19.7–20.5 (64.6–67.1)							3.68
21.3–22.1 (69.9–72.4)							3.71
29.6–30.4 (97.1–99.6)		0.007 (U)		12.6	0.21 (U)		

Table 3-13. Analytical Results for Soil Samples SAP Well #3 199-K-187 (C7687)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
29.6–30.4 (97.1–99.6)		0.024 (U)		14.6	0.21 (U)		
31.3–32.1 (102.8–105.3)		-0.076 (U)		26.6	0.13		
33.–33.7 (108.2–110.7)		-0.048 (U)		14.6	0.21 (U)		
33.6–34.4 (110.4–112.9)		0.094 (U)		9.79	0.06		
34.3–35.1 (112.5–115)		-0.021 (U)		12.3	0.07		
35.9–36.7 (117.8–120.3)		0.036 (U)		7.58	0.22 (U)		
60.3–61. (197.7–200.2)		-0.59 (U)		15.2	0.10 (U)		18.8

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

U = analyzed for by not detected above limiting criteria

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Table 3-14. Analytical Results for Groundwater Samples SAP Well #3 199-K-187 (C7687)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon–14	Strontium–90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
35.9 (117.7)				4.26	3.7 (U)		
36.9 (121.2)	8.23 (U)	-3.2 (U)	260	3.43	2 (U)	24,700	
38.4 (126)	-19.5 (U)	-1.6 (U)	230	1 (UD)	2 (U)	13,600	
38.7 (127)	3.38 (U)	-0.79 (U)	430	3.82	2 (U)	17,100	
39.9 (131)	-2.21 (U)	0.31 (U)	350	1.7	2 (U)	15,700	
43.3 (142)	-25.4 (U)	-2.7 (U)	160 (U)	1.72	2 (U)	14,500	
43.3 (142)	-13.1 (U)	-3.8 (U)	220	1.98	2 (U)	14,300	
44.3 (145.5)	-10.2 (U)	-3.8 (U)	310	1 (UD)	2 (U)	13,400	
45.9 (150.5)	16.2 (U)	-3.5 (U)	260	1.71	2 (U)	13,100	

Table 3-14. Analytical Results for Groundwater Samples SAP Well #3 199-K-187 (C7687)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon–14	Strontium–90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
47.7 (156.5)	11.2 (U)	0.16 (U)	300	2.12	2 (U)	13,800	
49.1 (161)	24.4 (U)	-2 (U)	290	1 (UD)	2 (U)	14,700	
50.3 (165)	6.49 (U)	-8.4 (U)	360	2.28	2 (U)	12,400	
52.1 (171)	-13.1 (U)	-6.6 (U)	170	7.09	5	10,800	
53.3 (175)	21.9 (U)	-6.1 (U)	450	1 (UD)	2 (U)	8,230	
55.4 (181.8)	58.6	-9.6 (U)	480	5.83	2 (U)	5,360	
57 (187)	60	-9.3 (U)	760	29.8	30.1	5,140	
58.5 (192)	6.75 (U)	-6.5 (U)	220	16	14	3,800	
59.6 (195.7)	3.78 (U)	-5.7 (U)	36 (U)	14.1	11.3	2,780	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.9 C7688 (199-K-188)

Figure 3-24 shows the composite analytical results for Well C7688 (199-K-188). The well site was selected to determine the extent of contamination residing in the RUM, physical and hydrological properties of the RUM, and potential transport of contamination in the RUM, The well site was initially located at the 100-K-98 Waste Site, also known as the 183-KE French drain. This French drain is believed to have received liquids that drained from hoses used to convey sodium dichromate concentrate from railcars into the 120-KE-6 Sodium Dichromate tank. Due to live utilities at the staked location, the well was relocated about 7.6 m (25 ft) northwest to just outside the foundation of the 120-KE-6 Tank. The well was drilled 15.2 m (50 ft) into the RUM to look for water-bearing lenses. When water was not encountered in the RUM, the well was completed in the upper unconfined aquifer above the top of the RUM. Although the greatest Cr(VI) concentration was detected at the bottom of the aquifer, the screen was placed to intercept possible contaminant movement at the top of the aquifer.

The well was constructed of 4 in. PVC, as it is considered a temporary installation. Demolition of the 183.1-KE Head House and associated waste site remediation around the foundations of the head house and the adjacent 183.2 KW Sedimentation Basin dictated a less expensive well construction method.

The Hanford formation/Ringold unit E contact was selected at about 18.3 m (60 ft) bgs on the geologic log. The water table is located in the Ringold unit E at about 30 m (98 ft) bgs. Neutron moisture logging was conducted at this well along with laboratory sample analysis. The laboratory moisture data indicate a

slightly higher moisture content of 3 to 6 percent in the Hanford sediment relative to the 1 to 5 percent moisture content in the Ringold unit E. The Hanford formation/Ringold unit E contact exhibits noticeable increase in moisture content as the sediments transition from a gravelly sand to a muddy sandy gravel. This profile appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. The ground surface around the 183.1-KE Head House has been devoid of significant vegetation cover since the start of construction. Therefore, vertical flow would be expected under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments. There is some discrepancy between the neutron log measurement and the laboratory analysis of water content, likely due to calibration uncertainty with respect to borehole diameter.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 66 m (183 ft) bgs. An increase in the KUT log count occurs at approximately 33 m (108 ft) bgs; this increase is associated with a change from sandy gravel to gravelly sand within the Ringold unit E.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-24). Tables 3-15 and 3-16 present analytical data. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. Cr(VI) was encountered in the first soil sample at a concentration of 1.6 mg/kg; this is likely the result of spills around the 120-KE-6 Tank. Total chromium concentrations were ~20mg/kg. In a soil sample at approximately 13 m (43 ft), the total chromium concentration spikes up to over 100 mg/kg with Cr(VI) less than 0.4 mg/kg. This suggests that most of the chromium at this location is reduced to Cr(III). No significant contaminant spikes are observed near the periodically rewetted zone. Groundwater sample results indicate that chromium values are slightly elevated in the aquifer at both 33 to 35 m (110 and 120 ft) bgs. Cr(VI) and total chromium concentrations in groundwater are less than the aquatic standard of 10 µg/L at this location, with values for Cr(VI) less than total chromium, as expected. There appears to be some reduction to Cr(III) in the upper 9 m (30 ft) of the aquifer. Groundwater samples scheduled at 47.3 m (155 ft) and 52.7 m (173 ft) bgs were skipped due to sand heaving into the drilling casing from 45.7 to 48.8 m (150 to 170 ft) bgs. Per standard drilling practice, two water additions of 950 L (250 gal) each were added at intervals between 45.7 and 51.8 m (150 and 170 ft) bgs to control the sand inflow.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. Nitrate concentration is approximately 20 mg/L in the upper half of the aquifer, with lower concentrations in the lower half of the aquifer with a slight increase to about 13 mg/L at the base of the aquifer. Carbon-14 concentration is less than 200 pCi/L, ranging from 60 to 180 pCi/L, with the highest concentrations in the middle of the aquifer. Tritium is less than 1,000 pCi/L except for a small increase at about 36 m (117 ft) bgs. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 16 m/day (53 ft/day), which is within the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, routine sampling at Well 199-K-188 was initiated in June 2011 with the following results: Cr(VI)–41.1 µg/L, total chrome–38 µg/L, carbon-14–62.3 pCi/L, Sr-90–6.6 pCi/L, tritium–130 (U) pCi/L, and nitrate–17,700 µg/L.

Table 3-15. Analytical Results for Soil Samples 199-K-188 (C7688)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon–14	Strontium–90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
1.5–1.9 (5–6.25)		0.023 (U)		25.9	1.60		7.4
2.9–3.5 (9.6–11.5)		0.135 (U)		10.1	0.54 (U)		8.21
4.5–5.1 (14.9–16.8)		-0.065 (U)		4.72	0.26		5.62
6.2–6.9 (20.5–22.7)		0.016 (U)		4.39	0.23		5.09
6.2–6.9 (20.5–22.7)		0.002 (U)		4.10	0.53 (U)		4.78
7.7–8.3 (25.1–27.3)		-0.081 (U)		3.77	0.26		5.16
9.1–9.7 (29.9–31.9)		-0.034 (U)		4.77	0.25		4.84
10.5–11.2 (34.6–36.9)		-0.049 (U)		7.93	0.53 (U)		4.81
12.1–12.7 (39.7–41.8)		-0.052 (U)		11.3	0.53 (U)		6.47
12.1–12.7 (39.7–41.8)		-0.047 (U)		8.47	0.54 (U)		6.62
13.6–14.2 (44.7–46.7)		0.062 (U)		108.0	0.53 (U)		5.27
15.6–16.4 (51.2–53.7)		0.032 (U)		5.57	0.52 (U)		4.05
16.7–17.4 (54.7–57.2)							3.88
18.1–18.8 (59.5–61.6)		-0.096 (U)		10.7	0.32		9.2
19.2–19.6 (62.9–64.2)		-0.041 (U)		14.6	0.60		5.36
19–19.8 (62.4–64.9)							4.9
19.3–20.1 (63.3–65.8)							3.85
19.8–20.3 (64.9–66.7)		-0.073 (U)		9.74	0.45		3.74
20.6–21.2 (67.7–69.7)							5.7

Table 3-15. Analytical Results for Soil Samples 199-K-188 (C7688)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon–14	Strontium–90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
21.3–22.1 (70–72.5)		0.019 (U)		23.1	0.51 (U)		2.7
22.8–23.3 (74.8–76.3)		-0.105 (U)		18.6	0.35		3.06
24.6–25.3 (80.6–83.1)		-0.059 (U)		14.8	0.52 (U)		3.05
25.9–26.4 (84.9–86.7)		-0.163 (U)		9.75	0.52 (U)		4.1
27.3–27.4 (89.5–89.9)		0.059 (U)		26.4	0.51 (U)		1.8
28.9–29.5 (94.9–96.8)		-0.048 (U)		9.49	0.52 (U)		3.12
30.2–30.9 (99–101.5)		-0.148 (U)		12.3	0.55 (U)		9.4
32.–32.8 (105–107.5)		-0.084 (U)		9.88	0.27		14.2
55.4–56.1 (181.7–184.2)		-0.87 (U)		22.2	0.59 (U)		18.9
55.4–56.1 (181.7–184.2)				13.2	0.12 (UN)		18.3
56.5–57.3 (185.4–187.9)				12.8	0.587 (U)		17.6
63.8–64.6 (209.4–211.9)		-0.73 (U)		21.9	0.639 (U)		27.1
63.8–64.6 (209.4–211.9)				10.3	0.13 (UN)		21.6
70.9–71.6 (232.5–235)		-1.9 (U)		19.4	0.624 (U)		24.9
70.9–71.6 (232.5–235)				13.3	0.12 (UN)		19.2

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

1

Table 3-16. Analytical Results for Groundwater Samples 199-K-188 (C7688)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon–14	Strontium–90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
32 (105)	124	-1.2 (U)	250 (U)	3.43	2 (U)	20,500	
32 (105)				4.32	3.7 (U)		
33.5 (109.9)	65.9	-10 (U)	460	1.26	2 (U)	19,000	
35 (114.9)	86.9	-6.1 (U)	290 (U)	4.95	3.4	19,300	
36.6 (120.2)	68.1	-3.1 (U)	820	0.5 (U)	2 (U)	19,200	
38.1 (125)	181	0.047 (U)	220	6.74	4.5	17,400	
39.8 (130.5)	160	-1.1 (U)	260	4.5	3.1	17,700	
39.8 (130.5)	104	-3.7 (U)	290	4.67	3.1	17,800	
41.1–41.1 (134.8–135)	162	-5.9 (U)	-180 (UN)	3.35	2 (U)	18,000	
42.7 (140)	117	-7.5 (U)	190	1 (UD)	2 (U)	20,100	
44.2 (145)	145	-8.6 (U)	180	1.94	2 (U)	14,700	
45.7 (150)	153	-1.3 (U)	160 (U)	1.68	2 (U)	13,400	
48.8 (160)	81.1	-4.9 (U)	1,100	2.14	2 (U)	8,100	
50.3 (164.9)	101	0.31 (U)	250 (U)	1.9	2 (U)	8,990	
50.7 (166.2)	107	-0.81 (U)	330	1.22	2 (U)	7,040	
53.3 (175)	122	-0.75 (U)	280	4.18	2	4,830	
54.5 (178.9)	127	-3 (U)	550	10	10.7	4,000	
56.1 (184)	51.5 (U)	-4.4 (U)	3,700	1 (UD)	2 (U)	12,300	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

3.4.3.10 C7689 (199-K-189)

Figure 3-25 shows the composite analytical results for Well C7689. The well was originally planned for a location just downgradient of the 116-KE-3 crib as a replacement to the 199-K-109A well decommissioned in 2008. Well 199-K-109A had a trend of high concentrations of Sr-90 (1,120 pCi.L when decommissioned) and historically elevated concentrations of tritium. Due to active waste site

remediation at the KE FSB and crib sites, the well was relocated crossgradient to the northeast 67 m (220 ft) from the crib and is downgradient of the 100-KE Reactor. The well is fully screened across the 24.4 m (80 ft) thickness of the aquifer. The Hanford formation/Ringold unit E contact was selected at 11.2 m (37 ft) bgs, just below a thin cemented clay (caliché) layer. The water table is located in the Ringold unit E at about 20.5 m (74 ft) bgs.

Neutron moisture logging was conducted at this well along with laboratory sample analysis with good agreement between the methods. The moisture data indicate a slightly higher moisture level in the Hanford sediment and slightly lower moisture below the Hanford formation/Ringold unit E contact, although there is more variability than observed at other locations. This profile appears to be exhibiting moisture content consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments. The moisture content appears to be at or near specific retention at about 4.6 m (15 ft) bgs as well as around 19 and 22 m (62 and 72 ft) bgs. These may represent traces of a dry summer season with essentially no infiltration; the wetter area below would represent the infiltration from the winter before and the area above would represent the winter after.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 47 m (154 ft) bgs. An increase in both the total gamma and KUT log count occurs at approximately 12 m (40 ft) bgs, marking the Hanford formation/Ringold unit E contact.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-25). Tables 3-17 and 3-18 present analytical results. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. There is a slight increase of Cr(VI) to about 0.8 mg/kg at depth of about 3 m (10 ft). In a soil sample at approximately 12 m (40 ft), the total chromium spikes up to approximately 200 mg/kg with Cr(VI) of about 0.2 mg/kg. This suggests that most of the chromium at this location is reduced. No significant contaminant spikes are observed near the periodically rewetted zone; groundwater sample results indicate that chromium values are slightly elevated in the aquifer at 33 to 36 m (110 and 120 ft) bgs. Cr(VI) and total chromium concentrations in groundwater range from 0 to 20 µg/L at this location, with values for Cr(VI) less than total chromium, as expected. There are two zones measured above the aquatic standard—an area at a depth between 23 m (80 to 85 ft) in a sandy gravel and a zone from 33 to 40 m (110 to 130 ft), also in a sandy gravel. A finer-grained layer separates these zones. However, the concentration in the finer-grained layer is low, suggesting there is not a secondary source in this area.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. Nitrate is approximately 30 mg/L in the upper 7.6 m (25 ft) of the aquifer, with lower concentrations in the remainder of the aquifer; no increase in concentration is observed at the base of the aquifer. Carbon-14 is less than 200 pCi/L, ranging from 60 to 180 pCi/L, with the highest concentrations in the middle of the aquifer. Tritium exceeds the 20,000 pCi/L standard in a zone 26 to 29 m (85 to 95 ft) bgs with a value of approximately 140,000 pCi/L. Slug testing indicates the hydraulic conductivity in the aquifer at this location is approximately 1 m/day (3.3 ft/day), which is within the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, routine groundwater sampling was initiated in June 2011, with the following results: Cr(VI)–32.1 µg/L, total chrome–52.4 µg/L, carbon-14–263 pCi/L, Sr-90–0.01 (U) pCi/L, tritium–10,800 pCi/L, and nitrate–9,300 µg/L.

Table 3-17. Analytical Results for Soil Samples 199-K-189 (C7689)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
1.7–2.4 (5.5–8)		-0.077 (U)		7.16	0.16		
3.1–3.9 (10.2–12.7)		-0.054 (U)		8.80	0.79		
4.8–5.5 (15.6–18.1)		0.039 (U)		8.14	0.18		
6.1–6.9 (20–22.5)		0.11 (U)		12.8	0.14		
6.1–6.9 (20–22.5)		0.078 (U)		7.11	0.38		
8.–8.7 (26.1–28.6)		-0.016 (U)		2.56	0.17		
8.4–9 (27.5–29.5)							4.29
9.6–10.3 (31.4–33.9)		0.026 (U)		3.24	0.14		
10.–10.8 (32.9–35.4)							3.64
10.5–11.3 (34.6–37.1)		0.026 (U)		5.48	0.13		
11.6–12.3 (37.9–40.4)							4.76
12.2–13 (40–42.5)		-0.101 (U)		211.0	0.15		
13.–13.7 (42.6–45.1)							1.39
13.6–14.2 (44.7–46.7)		0.058 (U)		13.8	0.13		
15.2–16 (50–52.5)		0.02 (U)		21.9	0.12		
16.6–17.2 (54.5–56.5)		-0.04 (U)		13.4	0.11		
18.3–18.9 (60.1–62.1)		0.127 (U)		12.2	0.16		
19.8–20.5 (64.9–67.4)		0.02 (U)		15.5	0.13		
21.3–22.1 (69.9–72.4)		0.064 (U)		10.2	0.09		

Table 3-17. Analytical Results for Soil Samples 199-K-189 (C7689)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
22.2–22.5 (72.7–73.7)		0.04 (U)		11.4	0.13		
23.4–24.2 (76.8–79.3)		-0.086 (U)		7.81	0.16		
47.1 (154.5)		-1.2 (U)		9.28	0.12 (UN)		17.6

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

1

Table 3-18. Analytical Results for Groundwater Samples 199-K-189 (C7689)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
23.5 (77)	514	4.1	1,600	0.521	2 (U)	33,800	
23.5 (77)				1 (UD)	3.7 (U)		
25 (82)	1,200	-7.5 (U)	13,000	11.9	12.2	26,000	
26.7 (87.7)	981	-8.5 (U)	86,000	1 (UD)	2 (U)	24,000	
28 (92)	751	-4.1 (U)	140,000	7.11	2 (U)	30,700	
29.6 (97)	639	-2.3 (U)	93,000	8.04	4.8	32,100	
29.6 (97)	666	-6.9 (U)	92,000	9.63	4.7	32,000	
31.1 (102)	275	-1.7 (U)	4,500	1 (UD)	2 (U)	2,660	
32.6 (107)	388	-7.2 (U)	36,000	0.555	2 (U)	13,300	
34.1 (112)	297	-7.2 (U)	1,700	9.24	7.6	5,530	
35.7 (117)	164	-7 (U)	210	18.8	16.1	7,530	
37.2 (122)	128	-9.7 (U)	270	12.4	9.6	8,410	
38.7 (127)	152	-10 (U)	340	16.1	13.8	8,190	
40.2 (132)	137	-1.7 (U)	400	9.12	4.8	8,100	
41.8 (137)	71.5	-8.3 (U)	110 (U)	10	9.5	8,010	

Table 3-18. Analytical Results for Groundwater Samples 199-K-189 (C7689)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
43.3 (142)	99.9	-6.4 (U)	680	8.76	6	8,320	
44.8 (147)	101	-2.5 (U)	1,100	11.2	8	7,750	
46.3 (152)	155	-1.6 (U)	4,000	6.8	3.7	7,570	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.11 C7690 (199-K-190)

Figure 3-26 shows the composite analytical results for Well C7690 (199-K-190). The well is located near the northern edge of the reactor area, downgradient of the 100-KE Reactor, and was sited to help define the northwestern extent of Cr(VI) and Sr-90 in groundwater downgradient of a known plume at Wells 199-K-141 and 199-K-178. The well location is very close to an excavation associated with the decommissioned pipeline component of the 100-K-55 waste site; however, it appears that the well is at the very margins of the site. The well is screened in the lower half of the unconfined aquifer to monitor low concentration plumes at the bottom of the aquifer. The Hanford/Ringold unit E contact was selected at 10 m (33 ft) bgs based on geophysical logging and geologic descriptions, although the pick is regarded as uncertain.

The water table is located in the Ringold unit E at about 17 m (55 ft) bgs. Moisture content in the vadose zone ranged from 6 to 8 percent, but spiked to 20 percent at a depth of 12 m (40 ft). Neutron logging shows slightly higher volumetric soil moistures in the upper 5.2 m (17 ft) of Hanford formation before declining slightly at the bottom of a gravelly MUD unit. The lower trend continues into the upper part of the Ringold unit E. The two data trends diverge at 12 m (40 ft) bgs, as the neutron log does not spike with the laboratory value. The sediment at this location is finer-grained, indicating that it could support higher moisture content. The moisture data were collected primarily in the Hanford formation at this location. This profile appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions, given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 40.5 m (133 ft) bgs. An increase in both the total gamma and KUT log count occurs at approximately 14.5 m (53 ft) bgs, marking the Hanford formation/Ringold unit E contact, although the signature is subtle.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot

(Figure 3-26). Tables 3-19 and 20 present analytical results. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In a soil sample at approximately 17.5 m (54 ft) bgs, the total chromium spikes to approximately 90 mg/kg with Cr(VI) of about 0.12 mg/kg. This value is close to the MDL for Cr(VI). This suggests that most of the chromium at this location is reduced to Cr(III). This observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring at this location. Cr(VI) concentrations in groundwater are less than the aquatic standard of 10 µg/L at this location across the full thickness of the aquifer. There is a higher total chromium measurement of about 16.1 µg/L at a depth of 35 m (115 ft) bgs, with the corresponding Cr(VI) concentration of 4.3 µg/L. Overall, there are relatively low chromium concentrations in groundwater at this location.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. Nitrate is above the standard in the upper 3 m (10 ft) of the aquifer, with concentrations decreasing significantly to near zero in the lower 12 m (40 ft) of the aquifer; no increase in concentration is observed at the base of the aquifer. Carbon-14 and tritium are well below standards at this location. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 12 m/day (39 ft /day), which is within the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, 199-K-190 was sampled in late June 2011. As of this writing, the following results have been received: Cr(VI)–17.5 µg/L and carbon-14–131 pCi/L. Other values will be compiled as they become available.

Table 3-19. Analytical Results for Soil Samples 199-K-190 (C7690)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
4.3–4.7 (14–15.5)		-0.002 (U)		8.97	0.17		
5.8–6.6 (19–21.5)		-0.011 (U)		12.3	0.18		
7.3–8.1 (24–26.5)		-0.116 (U)		16.9	0.14		1.73
8.8–9.6 (29–31.5)		0.142 (U)		8.37	0.15		2.48
8.8–9.6 (29–31.5)		-0.044 (U)		7.48	0.17		
10.4–11.1 (34–36.5)		-0.01 (U)		21.8	0.17		1.4
11.9–12.3 (39–40.5)		0.014 (U)		29.1	0.18		1.78
13.3–14.1 (43.6–46.1)		-0.091 (U)		15.6	0.14		
14.3–14.8 (47–48.5)		-0.022 (U)		17.0	0.18		
15.1–15.8 (49.5–52)		-0.001 (U)		16.3	0.17		

Table 3-19. Analytical Results for Soil Samples 199-K-190 (C7690)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
16–16.8 (52.5–55)		-0.182 (U)		90.0	0.12		
17.9–18.6 (58.6–61.1)		-0.011 (U)		11.7	0.16		
41.4–41.5 (135.7–136.2)		-1.1 (U)		16.4	0.12 (U)		18.3
41.9–42.6 (137.4–139.9)		-0.42 (U)		17.7	0.12 (U)		
44–44.8 (144.4–146.9)		-0.93 (U)		13.3	0.11 (U)		
45.6–46.3 (149.5–152)		-1 (U)		16.7	0.11 (U)		

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

U = analyzed for by not detected above limiting criteria

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Table 3-20. Analytical Results for Groundwater Samples 199-K-190 (C7690)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
18 (59)	203	-1 (U)	-9.5 (U)	2.18	2 (U)	54,000	
18 (59)				2.2	3.7 (U)		
19.5 (64)	193	-3.9 (U)	20 (U)	1.69	2 (U)	37,100	
21 (69)	260	-3.2 (U)	130 (U)	5.13	2 (U)	27,000	
22.6 (74)	239	-7.4 (U)	510	11.2	7.5	33,600	
24 (78.6)	235	-5.2 (U)	650	9.18	5.2	32,700	
24 (78.6)	242	-5.7 (U)	670	9.43	5.8	32,400	
25.6 (84)	195	-5.9 (U)	660	9.16	7.5	31,200	
27.1 (89)	243	-5.1 (U)	630	5.5	6.1	33,000	
28.5 (93.6)	248	-3 (U)	580	5.35	2.1	31,600	

Table 3-20. Analytical Results for Groundwater Samples 199-K-190 (C7690)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
30.2 (99)	298	-0.81 (U)	580	6.81	4.8	21,800	
31.6 (103.7)	364	-3.4 (U)	550	5.01	2.2	17,400	
33. (108.3)	408	-5.4 (U)	600	6.01	2	11,400	
34.6 (113.6)	161	-3.9 (U)	360	16.1	4.3	11,000	
36.2 (118.7)	346	-0.97 (U)	480	7.74	3.7	10,800	
37.6 (123.5)	421	-5.4 (U)	730	10.1	6.7	11,600	
39.3 (129)	415	-2.3 (U)	1,000	9.83	9.4	12,500	
40.8 (133.7)	469	-6.4 (U)	1,400	13.8	12.9	10,300	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

U = analyzed for by not detected above limiting criteria

3.4.3.12 C7691 (199-K-191)

Figure 3-27 shows the composite analytical results for Well C7691 (199-K-191). The well is located 523 m (1,715 ft) east-northeast of the 105 KE Reactor. The well was intended to define the upgradient extent of the Cr(VI) plume associated with the 116-K-2 Trench. The well was sited near 126-K-1, a former gravel pit and rejected inert/demolition material disposal site. This site abuts the 118-K-1 Burial Ground, which has been undergoing remediation since FY 2009. The well is screened in the uppermost portion of the unconfined aquifer but extends an additional 6.1 m (20 ft) into the vadose zone to permit future use for injection. The Hanford formation/Ringold unit E contact, which was selected in the field at a depth of 12.8 m (42 ft), is described as gradual, suggesting a mixing of eroded Ringold unit E and Hanford formation during flood-stage deposition. The water table is located in the Ringold unit E at about 22 m (72 ft) bgs.

Vadose zone soil moisture contents of 1 to 6 percent by weight were observed in laboratory tests. Neutron moisture logging was conducted at this well and detected volumetric moisture content that was relatively greater in the top 3 m (10 ft) of the well than through the rest of the vadose zone. Approaching the groundwater table, volumetric moisture content increases slightly in the Ringold unit E. Laboratory soil moisture content decreased to 1 to 2 percent below the Hanford formation/Ringold unit E contact, although the neutron log did not show this change. The sediment at this location is muddy gravel; the fine-grained material within the gravel indicates it could support higher moisture content. This profile appears to be exhibiting moisture content consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions, given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 46.5 m (153 ft) bgs. An increase in both the total gamma and KUT log count occurs at approximately 13 m (42 ft) bgs, marking the Hanford formation/Ringold unit E contact.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-27). Analytical results are presented in Tables 3-21 and 3-22. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In a soil sample at approximately 18 m (59 ft) bgs, the total chromium value is approximately 39 mg/kg with Cr(VI) of about 0.07 mg/kg. This suggests that most of the chromium at this location is reduced to Cr(III). This observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring at this location. Chromium concentrations drop and rise again just above the top of the aquifer with a total chromium concentration of 35 mg/kg and Cr(VI) concentrations of about 0.2 mg/kg. Again, much of the chromium is in a reduced state. Cr(VI) concentrations in groundwater are not detected in the upper 1.5 m (5 ft) of the aquifer, then rise above the aquatic standard of 10 µg/L about 3 m (10 ft) below the water table with a maximum value of 40 µg/L, and then are undetected in the aquifer below that. There is a higher total chromium measurement of about 18 µg/L at a depth of 35 m (115 ft) bgs, with the corresponding Cr(VI) concentration of 4 µg/L. Overall, there are relatively low chromium concentrations in groundwater at this location. Given the clean zone at the top of the aquifer, the 40 µg/L observed 3 m (10 ft) below the water table might have originated upgradient in the groundwater flow system.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location. Nitrate is above the standard in the upper 6 m (20 ft) of the aquifer, with concentrations decreasing significantly to near zero in the lower 15 to 18 m (50 to 60 ft) of the aquifer; no increase in concentration is observed at the base of the aquifer. Carbon-14 was not detected at this location and tritium is at about one-third of the standard across the lower two-thirds of the aquifer. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 0.5 m/day (1.7 ft /day), which is within the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, routine groundwater sampling was initiated in 199-K-191 with the following results: Cr(VI)–2.1 (B) µg/L, total chrome–6.0 (B) µg/L, carbon-14–1.7 (U) pCi/L, Sr-90–3.4 pCi/L, tritium–4,500 pCi/L, and nitrate–12,000 pCi/L.

Table 3-21. Analytical Results for Soil Samples 199-K-191 (C7691)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
5.4–6.2 (17.7–20.2)							4.19
6.8–7.5 (22.2–24.7)							2.73
8.4–9.2 (27.6–30.1)							3.35
10.1–10.8 (33–35.5)							4.47

Table 3-21. Analytical Results for Soil Samples 199-K-191 (C7691)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
11.6–12.4 (38.2–40.7)							2.38
12.9–13.6 (42.2–44.7)							1.49
14.2–15 (46.7–49.2)							2.19
17.7–18.5 (58.2–60.7)		-0.034 (U)		38.7	0.07		
19.4–19.7 (63.5–64.5)		-0.035 (U)		13.3	0.11		
21–21.2 (68.8–69.5)		-0.079 (U)		25.4	0.05		
21.7–21.9 (71.3–72)		-0.11 (U)		33.6	0.19		
22.5–23.3 (73.9–76.4)		-0.024 (U)		12.1	0.16		
22.5–23.3 (73.9–76.4)		-0.063 (U)		10.6	0.11		
23.8–24.5 (78–80.5)		-0.133 (U)		8.68	0.17		
46.7–47.4 (153.1–155.6)		-0.4 (U)		7.58	0.10 (NU)		20.4

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

Table 3-22. Analytical Results for Groundwater Samples 199-K-191 (C7691)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
23.8 (78)	7.5 (U)	-4.1 (U)	180	1 (UD)	2 (U)	54,000	
23.8 (78)				27.5	3.7 (U)		
25.3 (83)	21.4 (U)	-3.7 (U)	39 (U)	38.4	35.3	76,600	
26.8 (88)	0.96 (U)	-2.8 (U)	190 (U)	1 (UD)	2 (U)	73,500	
27.6 (90.7)	-19.8 (U)	-9.1 (U)	670	1 (UD)	2 (U)	59,800	
29.7 (97.3)	-3.58 (U)	-7.5 (U)	1,400	1 (UD)	2 (U)	55,800	
31.2 (102.3)					2 (U)		
32.9 (108)	-8.68 (U)	-6.1 (U)	5,500	4.15	2 (U)	12,500	
32.9 (108)	-3.22 (U)	-7.6 (U)	5,300	4.44	2 (U)	12,600	
34.1 (112)	-17.9 (U)	-6.4 (U)	6,000	1 (UD)	2 (U)	12,300	
35.8 (117.5)	1.91 (U)	-6.2 (U)	6,400	1 (UD)	2 (U)	12,200	
37.5 (123)	8.8 (U)	-3.3 (U)	5,000	1 (UD)	2 (U)	17,600	
39 (128)	2.88 (U)	-3.7 (U)	6,200	2.21	2 (U)	12,200	
40.5 (133)	14.2 (U)	-3.8 (U)	6,100	2.05	2 (U)	11,700	
42. (137.7)	-20.3 (U)	-6.6 (U)	5,000	1 (UD)	2 (U)	16,000	
43.6 (143)	-8.1 (U)	-5.7 (U)	6,200	0.5 (U)	2 (U)	11,800	
45.1 (148.1)	-18 (U)	-7.9 (U)	6,100	1.82	2 (U)	11,800	
47.2 (155)	-3.18 (U)	-2.8 (U)	5,700	4.31	2 (U)	11,400	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.13 C7692 (199-K-192)

Figure 3-28 shows the composite analytical results for Well C7692 (199-K-192). The well site was selected to determine the extent of contamination residing in the RUM, physical and hydrological properties of the RUM, and potential transport of contamination in the RUM. The well is located near the southwest, head end of the 116-K-2 Trench, and is set 55 m (180 ft) off the centerline of the trench. The well was drilled 15.2 m (50 ft) into the RUM and encountered a 2.75 m (9 ft) thick water-bearing,

coarse-grained lens at a depth of 10.7 m (35 ft) below the Ringold unit E/RUM contact. The well was screened across this permeable confined aquifer unit. The Hanford formation/Ringold unit E contact is selected at 6.7 m (22 ft) bgs, but the selection is regarded as uncertain. The water table in the unconfined aquifer is located in the Ringold unit E at a depth of about 15 m (49 ft) bgs. The water level in the RUM unit is about 9 m (30 ft) bgs. Because the hydraulic head as exhibited by the water table is higher in the RUM than in the unconfined aquifer, there is an upward gradient at this location.

Neutron moisture logging was conducted at this well in the vadose zone in the Hanford formation above the water table. The laboratory-measured water content ranges from 2 to 5 percent across the upper 6.1 m (20 ft) of Hanford formation. The relative scale of the neutron moisture logging indicates a slightly higher moisture content near the top of the well. The vadose zone sediment at this location is a sandy gravel with a layer of gravelly mud from 1.5 to 4.5 m (5 to 15 ft); the fine-grained material within the gravel indicates that it could support a higher moisture content. This profile appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions, given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 45 m (148 ft) bgs. No particular signature change is observed in either the total gamma or KUT log count near the Hanford formation/Ringold unit E contact located at approximately 6.7 m (22 ft) bgs.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-28). Analytical results are presented in Tables 3-23 and 3-24. Cr(VI) values are less than total chromium values, which is expected because the total chromium value should include all forms of chromium. In a soil sample at approximately 14 m (46 ft) bgs, the total chromium value is approximately 56 mg/kg with Cr(VI) undetected at this location; this observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring near the periodically rewetted zone at this location. During the lifecycle of the K-2 Trench, many millions of milligrams of Cr(VI) have passed through the sediment in this location. Reduction likely was able to capture a small fraction of this flux slowly over time, resulting in the 56 mg/kg value measured today. No Cr(VI) is detected in the vadose zone sediment or upper aquifer sediment in the well. This suggests that most of the chromium at this location is reduced to Cr(III). Cr(VI) concentrations in groundwater are not detected in the upper 1.5 m (5 ft) of the aquifer, then rise to about 75 µg/L 3 to 3.6 m (10 to 12 ft) below the water table and decline to low levels with depth below that. The concentrations of Cr(VI) and total chromium are nearly equal in the groundwater, suggesting that chromium in groundwater is in primarily mobile hexavalent form that can be captured easily by the interim pump-and-treat remedy. Given the clean zone at the top of the aquifer, the 75 µg/L observed 3 to 3.6 m (10 to 12 ft) below the water table might have originated upgradient in the groundwater flow system.

Sr-90 was not detected in the vadose zone sediment or aquifer sediment but was detected in groundwater in the upper 6 m (20 ft) of the aquifer. The sample taken at 16.5 m (55 ft) bgs appears to exceed the standard of 8 pCi/L. Nitrate is above the standard in the upper 6 m (20 ft) of the aquifer, with concentrations decreasing significantly to near zero in the lower 15 to 18 m (50 to 60 ft) of the aquifer; no increase in concentration is observed at the base of the aquifer. Carbon-14 and tritium were detected in groundwater in the upper 6 m (20 ft) of the aquifer with values becoming low to undetectable below that. No concentration increases were observed at the base of the aquifer. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 0.2 m/day (0.7 ft/day), which is within the range of conductivity expected for saturated zones within the RUM.

Following well acceptance, routine sampling at Well 199-K-192 began in April 2011. Because the well is screened in the water-bearing zone in the RUM, most analytes were not detected. Sr-90 was detected at a concentration of 3.8 pCi/L and nitrate was detected at 6,240 µg/L.

Table 3-23. Analytical Results for Soil Samples SAP Well 199-K-192 (C7692)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
0.9–1.5 (3–5)							1.74
2.4–3.2 (8–10.5)							2.47
4.–4.8 (13.1–15.6)							3.25
5.5–6.3 (18.1–20.6)							1.53
10.6–11.4 (34.9–37.4)		-0.033 (U)		14.1	0.51 (U)		
12.2–12.9 (39.9–42.4)		0.005 (U)		11.7	0.51 (U)		
13.8–14.6 (45.3–47.8)		0.072 (U)		56.0	0.51 (U)		
14.5–15.2 (47.5–50)		0.168 (U)		9.65	0.55 (U)		
15.2–16 (49.9–52.4)		0.143 (U)		9.22	0.54 (U)		
15.2–16 (49.9–52.4)		0.086 (U)		9.85	0.56 (U)		
16.7–17.5 (54.8–57.3)		0.282		10.3	0.61 (U)		
39.6–40.4 (130–132.5)		-0.38 (U)		36.6	0.10 (UN)		
41.2–42. (135.3–137.8)		-0.29 (U)		7.05	0.10 (UN)		
42.8–43.4 (140.4–142.4)		-1.6 (U)		4.57	0.11 (UN)		
43.5–44.3 (142.7–145.2)		-0.98 (U)		15.5	0.11(UN)		16.2
50.9–51.7 (167–169.5)		-2.5 (U)		23.0	0.12 (UN)		21.1
57.6–58.4 (189–191.5)		-1.1 (U)		17.4	0.147		21.6

Table 3-23. Analytical Results for Soil Samples SAP Well 199-K-192 (C7692)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

1

Table 3-24. Analytical Results for Groundwater Samples SAP Well 199-K-192 (C7692)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
16.8 (55)	93.7	19	1,400,000	2 (U)	2 (U)	56,200	
16.8 (55)				1 (UD)	3.7 (U)		
18.3 (60)	114	-5 (U)	960,000	72.5	70.8	38,000	
19.8 (65)	146	-5.5 (U)	670,000	22.3	18.9	41,900	
21.4 (70.1)	105	2.4	350,000	46.1	43.7	41,900	
22.9 (75)	75.6	-1.1 (U)	87,000	26.9	26.2	22,700	
24.4 (80.2)	29.6 (U)	0.37 (U)	48,000	17.2	11.9	19,200	
24.4 (80.2)	65.3	-3.6 (U)	49,000	16.9	12.8	19,000	
25.8 (84.6)	20.9 (U)	-3.4 (U)	36,000	11	9.1	18,500	
27.3 (89.7)	39.3 (U)	-2.4 (U)	51,000	11.5	9.9	19,200	
28.7 (94.3)	14.7 (U)	-1.2 (U)	14,000	11.1	7	16,600	
30.4 (99.6)	14.1 (U)	-4.4 (U)	27,000	2.21	2 (U)	16,400	
31.9 (104.7)	35.5	-4.5 (U)	13,000	6.24	3.1	16,200	
33.7 (110.6)	-0.983 (U)	-1.3 (U)	9,500	8.93	5.5	14,800	
35.1 (115.3)	28.6 (U)	0.25 (U)	7,000	10.2	7	13,900	
36.8 (120.6)	20.8 (U)	-5.1 (U)	5,600	8.53	4.2	13,600	
38.1 (125)	5.2 (U)	-7.9 (U)	3,700	17.2	14.4	12,800	
39.7 (130.1)	9.85 (U)	-2.2 (U)	3,800	8.8	5.8	12,800	
41.5 (136)	2.84 (U)	-5.4 (U)	2,300	10.7	7.8	11,200	

Table 3-24. Analytical Results for Groundwater Samples SAP Well 199-K-192 (C7692)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
42.8 (140.5)	-20.2 (U)	-3 (U)	3,300	9.98	7.5	11,700	
55.5 (182)	0 (U)	-5.6 (U)	400	3.92	2 (U)	7,750	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.14 C7693 (199-K-193)

Figure 3-29 shows the composite analytical results for Well C7693 (199-K-193). The well was sited 1.1 km (3,600 ft) upgradient of the 116-K-2 Trench and 1.4 km (4,600 ft) east of the 105-KE Reactor. The well was designed to determine the upgradient extent of the Cr(VI) plume. This well is located 241 m (790 ft) upgradient of 100-KX Extraction Well 199-K-171. The well was screened in two sections—in the upper and lower thirds of the unconfined aquifer. The base of the lower screen is located at the top of the RUM; this segment is designed to investigate deep Cr(VI) concentrations observed during drilling. The upper screen extends 4.9 m (16 ft) into the vadose zone and was designed for possible use as an injection well in future remediation activities. The Hanford/Ringold unit E contact is 14.0 m (46 ft) bgs and was identified in the field. The water table is within the Ringold Formation at a depth of 23.5 m (77.2 ft). Geophysical logging detected the water table at a depth of 27 m (88.6 ft) when the well was logged December 1, 2010. Drilling the well was completed on November 23, 2010, construction of the well began on December 15, 2010. The water level change may indicate a slow drainage of groundwater into the RUM. River stage changes over the time the well was unattended fluctuated daily, but did not show an equivalent longer-term trend in water levels to match those of the well. The RUM was encountered at a depth of 49 m (161 ft).

The water content measured from two sediment samples is between 2 and 3 percent by weight. Neutron moisture logging indicates that the Ringold unit E in the vadose zone is slightly moister on a volumetric basis than is the Hanford formation. The Hanford formation did show increased moisture near the top of the well and just above a thin sandy gravel unit. (Note that the well was logged [December 1, 2010] when the water level had dropped in the casing.) The neutron log shows a relative change in residual water content within the periodically rewetted zone. The moisture data indicate a slightly lower moisture level in the Hanford sediment and slightly higher moisture below the Hanford formation/Ringold unit E contact. Given typical specific retention capacities of 1 to 2 percent for these sediments, the occurrence of vertical downward flow would be expected, based on the measured water contents in portions of the vadose zone, although an interval near 10 m (33 ft) bgs appears to be at or near specific retention.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 49 m (160 ft) bgs. The total gamma signature and KUT

exhibit a slight increase in count rate at the Hanford formation/Ringold unit E contact at approximately 14 m (46 ft) bgs. There is a drop in the count rate at the water table for the total gamma log. There is a marked increase in both the total gamma and thorium signature at 40 m (131 ft) bgs.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-29). Analytical results are presented in Tables 3-25 and 3-26. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. The sediment sampling indicates that Cr(VI) is not detected in the vadose zone sediment with total chromium ranging up to 60 mg/kg in a zone about 20 m (66 ft) bgs, approximately 3 to 4.9 m (10 to 15 ft) above the water table. These results indicate that most of the chromium has been reduced and is immobile. The Cr(VI) may have flowed into this location during a time when the groundwater mound was active at the K-2 Trench. A small portion of the Cr(VI) flux would have been reduced over time. This is consistent with the CSM understanding of the periodically rewetted zone, which indicates that the K_d is similar on both sides of the water table; therefore, source material leaching through the vadose zone does not accumulate preferentially in this region and periodically discharge to the water table. In the aquifer, Cr(VI) (and total) concentrations generally are below detection over the upper 7.6 m (25 ft) of the aquifer underlain by a contaminated zone in the aquifer from 9 to 15 m (30 to 50 ft) below the water table. Concentrations in this area are up to 15 µg/L; the total chromium and Cr(VI) mass are nearly equal, indicating that chromium is predominantly in the mobile hexavalent form and that little natural reduction is occurring in the aquifer at this location. This suggests that the chromium in the aquifer is in a very mobile state; the interim remedy approach of pump-and-treat would be a good strategy near this well.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location and there was no carbon-14 detected in groundwater. Nitrate and tritium are below the standard and are observed in the upper and central portions of the aquifer, decreasing to near zero in the lower portion of the aquifer. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 1 m/day (3.3 ft/day), which is at the upper end of the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, routine groundwater sampling was conducted at Well 199-K-193 with the following results: Cr(VI)—31.0 µg/L, total chrome—32 µg/L, and nitrate—11,100 µg/L. None of the routine radionuclides was detected.

Table 3-25. Analytical Results for Soil Samples 199-K-193 (C7693)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
14.2–15 (46.7–49.2)							2.45
15.7–16.5 (51.5–54)							1.4
18–18.2 (59–59.8)		-0.052 (U)		12.9	0.51 (U)		
19.5–20.3 (64–66.5)				57.8	0.51 (U)		

Table 3-25. Analytical Results for Soil Samples 199-K-193 (C7693)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
20.9–21.7 (68.7–71.2)		-0.015 (U)		11.9	0.51 (U)		
20.9–21.7 (68.7–71.2)		-0.051 (U)		10.9	0.51 (U)		
22.4–23.2 (73.5–76)		0.104 (U)		33.4	0.53 (U)		
23.7–24.5 (77.8–80.3)		-0.137 (U)		20.4	0.60 (U)		
25.1–25.9 (82.5–85)		0.046 (U)		10.6	0.61 (U)		
49.2 (161.4)		0.007 (U)		10.9	0.12 (U)		13.8

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

U = analyzed for by not detected above limiting criteria

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Table 3-26. Analytical Results for Groundwater Samples 199-K-193 (C7693)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
25.1 (82.5)	2.66 (U)	-1.1 (U)	150 (U)	2 (U)	2 (U)	16,700	
25.1 (82.5)		-6.7 (U)		1 (UD)			
26.8 (88)	-16 (U)	-3 (U)	170	1 (UD)	2 (U)	8,410	
28.3 (93)	19.1 (U)	-0.45 (U)	140 (U)	1 (UD)	2 (U)	9,830	
29.9 (98)	-18.4 (U)	-8.8 (U)	2.7 (U)	1 (UD)	2 (U)	9,610	
31.4 (103)	7.36 (U)	-9.5 (U)	-54 (U)	1 (UD)	2 (U)	8,720	
32.9 (108)	-23.1 (U)	-2.5 (U)	-6.8 (U)	1 (UD)	2 (U)	8,060	
32.9 (108)	-10.6 (U)	-4.5 (U)	9.9 (U)	1 (UD)	2 (U)	18,100	
32.9 (108)	8.31 (U)	-2.2 (U)	31 (U)	1 (UD)	2 (U)	17,700	
35.7 (117)	-6.42 (U)	-2.7 (U)	74 (U)	4.82	2.5	7,570	
37.5 (123)	3.29 (U)	-5.6 (U)	-28 (U)	1 (UD)	2 (U)	8,900	

Table 3-26. Analytical Results for Groundwater Samples 199-K-193 (C7693)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
38.1 (125)	19.4 (U)	-4.8 (U)	29 (U)	4.25	2 (U)	8,280	
40.5 (133)	-22.8 (U)	0.29 (U)	230	14.9	14.2	6,640	
42.1 (138)	-14 (U)	-3.5 (U)	190	13.2	13.2	5,580	
43.6 (143)	-7.54 (U)	-0.23 (U)	-46 (U)	12	12	3,700	
45.2 (148.2)	-17.1 (U)	-0.57 (U)	0.45 (U)	1 (UD)	2 (U)	3,330	
46.6 (153)	-31.6 (U)	-4 (U)	-120 (U)	6.57	4.1	3,710	
48.2 (158)	16.7 (U)	-7.3 (U)	36 (U)	1 (UD)	2 (U)	84.1 (UD)	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.15 C7694 (199-K-194)

Figure 3-30 shows the composite analytical results for Well C7694 (199-K-194). The well was sited 1.4 km (4,600 ft) southeast of the northeast end of the 119-K-2 Trench and 2.1 km (6,900 ft) east of the 105-KE Reactor. The well was located with the intent of determining the upgradient extent of the Cr(VI) plume. The well was screened in the upper 7.6 m (25 ft) of the unconfined aquifer. The Hanford formation/Ringold unit E contact was identified in the field at 19.8 m (65 ft) bgs. The water table is located in the Ringold unit E at about 25 m (82 ft) bgs.

Water contents ranged from 1 to 3 percent by weight in laboratory testing. Neutron moisture logging at this well showed a relatively even trend in moisture contents within the vadose zone. Slightly higher moisture contents are observed on the neutron log near the ground surface and in a muddy sandy gravel. Samples from the top of the aquifer were also measured and reported at 10 to 15 percent moisture content by weight. The sediment at this well location ranges from muddy gravel to sandy gravel in the vadose zone; the fine-grained material within the gravel indicates that it could support higher moisture content. The vadose zone appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions, given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 43 m (141 ft) bgs. A slight increase in both the total gamma and KUT log count occurs at approximately 13 m (42 ft) bgs, marking the Hanford formation/Ringold unit E contact.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-30). Analytical results are presented in Tables 3-27 and 3-28. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In a soil sample at approximately 24 m (79 ft) bgs, the total chromium value is approximately 12 mg/kg with Cr(VI) undetected. This suggests that most of the chromium at this location is reduced to Cr(III). This observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring near the periodically rewetted zone at this location. For sediments below just under the water table, total chromium is about 10 to 12 mg/kg with Cr(VI) concentrations of about 0.6 to 0.9 mg/kg. Again, most of the chromium is in a reduced state. Cr(VI) concentrations in groundwater are below the aquatic standard of 10 µg/L with no detectable chromium of any form in the upper 2 m (7 ft) of the aquifer. Below that, there is a zone about 28 m (92 ft) bgs where there is a total chromium value of 4 µg/L and Cr(VI) of about 2 µg/L. Immediately below this, no chromium is detected. Then, below that, total chromium of about 7 µg/L and Cr(VI) of 3 µg/L is detected and concentrations decline with depth below that. Overall, there are relatively low chromium concentrations in groundwater at this location. Given the clean zone at the top of the aquifer, the chromium source in the aquifer appears to be upgradient.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location and carbon-14 was not detected in groundwater. Nitrate is below the standard in the aquifer at this location, with concentrations about half the standard in the upper 3 m (10 ft) of the aquifer, decreasing significantly to near zero in the remainder of the aquifer. Below that, no increase in concentration is observed at the base of the aquifer. Tritium activity is very low in this well, with a small increase to 1,200 pCi/L located about 41 m (135 ft) bgs. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 1 m/day (3.3 ft/day), which is toward the upper end of the range of conductivity expected for the saturated Ringold unit E.

Following well acceptance, routine groundwater sampling was initiated at Well 199-K-194 with the following results: Cr(VI)—5.6 µg/L, total chrome—9.0 (B) µg/L, Sr-90—1.8 pCi/L, and nitrate—9,780 µg/L. Carbon-14 and tritium were not detected at this well.

Table 3-27. Analytical Results for Soil Samples SAP Well 199-K-194 (C7694)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
18.8–19.6 (61.8–64.3)							1.9
20.3–21. (66.5–69)							2.6
21.9–22.2 (71.9–72.9)							1.7
23.7–24.5 (77.8–80.3)		-0.049 (U)		12.3	0.51 (U)		1.6
25.2–26. (82.7–85.2)		-0.013 (U)		12.7	0.84		15.3
25.2–26. (82.7–85.2)		0.005 (U)		10.3	0.57		8.98

Table 3-27. Analytical Results for Soil Samples SAP Well 199-K-194 (C7694)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
26.8–27.6 (88–90.5)		0.009 (U)		10.9	0.68		11
40.5–41.3 (133–135.5)		-2 (U)		23.6	0.13 (UN)		
42.1–42.8 (138–140.5)		-1.6 (U)		13.5	0.13 (UN)		17

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

1

Table 3-28. Analytical Results for Groundwater Samples SAP Well 199-K-194 (C7694)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide—(pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
26.8 (88)	15.6 (U)	-1.8 (U)	77 (U)	1 (UD)	2 (U)	18,600	
26.8 (88)					3.7 (U)		
28.4 (93.3)	20.6 (U)	-0.57 (U)	-94 (U)	4.16	2.6	19,000	
29.9 (98)	-13 (U)	-1.1 (U)	-100 (U)	1 (UD)	2 (U)	9,780	
31.5 (103.2)	-17.4 (U)	-3 (U)	44 (U)	6.43	3.7	9,430	
31.5 (103.5)	8.38 (U)	-3.2 (U)	-470 (UN)	1.62	2 (U)	8,280	
33. (108.2)	-13.4 (U)	0.044 (U)	66 (U)	5.04	4.3	9,430	
34.5 (113.2)	20.6 (U)	-4.4 (U)	-370 (UN)	5.82	3.1	9,070	
34.5 (113.2)	1.3 (U)	-0.54 (U)	-360 (UN)	5.7	3.7	8,900	
37.7 (123.6)	12.2 (U)	-3.6 (U)	-37 (U)	5.57	2.2	8,010	
39.2 (128.6)	-18.7 (U)	-2.6 (U)	190	3.93	2 (U)	9,160	
40.8 (134)	1.36 (U)	-5 (U)	1,100	3.94	4.7	9,160	
42.1 (138)	0.917 (U)	-1.6 (U)	200 (U)	4.99	5.2	8,590	

Table 3-28. Analytical Results for Groundwater Samples SAP Well 199-K-194 (C7694)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide—(pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
42.9–43.3 (140.8–142.2)	2.74 (U)	-3.9 (U)	-18 (U)	4.75	2.1	8,460	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

3.4.3.16 C7695 (199-K-195)

Figure 3-31 shows the composite analytical results for Well C7695 (199-K-195). This well was located on the front side of the reactor system, 372 m (1,220 ft) southeast of the 105-KW Reactor. The well was staked at the 100-K-97 French drain site at the 100-KW Head House, with the intent of determining the extent of contamination residing in the RUM, physical and hydrological properties of the RUM, and potential transport of contamination within the RUM. The well was drilled from the bottom of a waste site remediation trench approximately 4.6 m (15 ft) below the surrounding ground surface. The adjacent 183.1 KW Head House and the 183.2 KW Sedimentation Basin were demolished between July 2009 and July 2010. The area around the well site has been undergoing waste site remediation since January 2010, which continues to the present. The well was drilled 15.1 m (50 ft) into the RUM; water-bearing zones were not detected. The well was constructed of 10.1 cm (4 in.) PVC and the well is designed for temporary use only. The well was decommissioned in late April 2011 to permit continuation of waste site remediation. The well was screened in the uppermost portion of the unconfined aquifer. The Hanford/Ringold unit E contact was identified in the field at 15.1 m (50 ft) below the excavation bottom and 19.8 m (65 ft) below the original ground surface. The water table is located in the Ringold unit E at about 26 m (85 ft) below the excavation bottom or about 30.3 m (100 ft) below the original ground surface.

Soil moisture samples were taken at 1.5 m (5 ft) intervals through the vadose zone. Moisture contents range between 4 to 8 percent by weight in the Hanford formation versus 1 to 5 percent in the Ringold unit E vadose zone; one value drops almost to 0 percent moisture. Neutron moisture logging was conducted at this well and revealed reasonably consistent trends in the lower Hanford formation and Ringold unit E. The sediment at this location is gravelly sand; this coarse-grained material would tend to support low moisture content. The vadose zone appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. This is attributed to the use of dust suppression water to control airborne contaminants. Vertical flow would be expected under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show an increased count rate at depth, indicating the top of the RUM at a depth of approximately 64 m (177 ft) bgs. A slight increase in both the total

gamma and KUT log count occurs at approximately 15 m (49 ft) bgs, marking the Hanford formation/Ringold unit E contact.

Vadose zone sediment, aquifer sediment, and groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-31). Tables 3-29 and 3-30 present analytical results. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In a soil sample at approximately 23 m (76 ft) bgs, the total chromium value is approximately 3,560 mg/kg with Cr(VI) undetected. Above this, Cr(VI) is detected at about 0.4 mg/kg. This suggests that most of the chromium at this location is reduced to Cr(III). This observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring near the periodically rewetted zone at this location.

For sediments below just under the water table, total chromium is very low and Cr(VI) is undetected. Again, most of the chromium is in a reduced state. Cr(VI) concentrations in groundwater are extremely elevated in a 3 m (10) ft thick zone centered about 5 m (16 ft) below the top of the water table. Cr(VI) concentrations were 4,980 and 1,970 µg/L in this zone. This zone is overlain by a zone of groundwater where Cr(VI) is undetected. Below that the elevated zone, Cr(VI) concentrations decreased to nondetection levels over the next 7.7 m (25 ft). Cr(VI) is undetected or at concentration no higher than 10.8 µg/L for the next 9.1 m (30.5 ft) At a depth of 50.3 m (165 ft) bgs, Cr(VI) concentrations spike to 753 µg/L, but return to nondetection level over the final 3.3 m (11 ft) of the aquifer. Overall, there are relatively low chromium concentrations in groundwater at this location. Given the clean zone at the top of the aquifer, the chromium source in the aquifer appears to be upgradient.

Sr-90 was not detected in the vadose zone sediment, aquifer sediment, or groundwater at this location and carbon-14 was not detected in groundwater. Nitrate is detected above the standard in the aquifer in the same zone as the elevated chromium, with concentrations about half the standard in the remainder of the aquifer below that. No increase in concentration is observed at the base of the aquifer. Tritium activity is very low in this well, with a small increase in activity to 2,000 pCi/L located about 33 m (108 ft) bgs, vertically below the maximum chromium values in groundwater. Slug testing indicates that the hydraulic conductivity in the aquifer at this location is approximately 15 m/day, which is within the range of conductivity expected for the saturated Ringold unit E.

Following acceptance of the well, routine groundwater sampling was initiated at 199-K-195 in mid-April, 2011, with the following results: Cr(VI)—3,310 µg/L, total chrome—3,250 µg/L, carbon-14—316 pCi/L, Sr-90—2.7 pCi/L, tritium—1,300 pCi/L, nitrate—2,900 µg/L, and TCE–3.0 (J) µg/L. The 100-KW system Injection Well 199-K-175, which is located 84 m (275 ft) upgradient of Well 199-K-195, is suspected of contributing to the carbon-14, nitrate, and tritium concentrations observed here.

Table 3-29. Analytical Results for Soil Samples 199-K-195 (C7695)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
0.8–1.5 (2.5–4.8)		0.004 (U)		6.84	0.52 (U)		4.48
1.5–2.2 (4.8–7.3)		-0.131 (U)		9.49	0.52 (U)		4.47
3.4–4.1 (11–13.5)		0.023 (U)		5.82	0.52 (U)		4.61
4.6–5.3 (15–17.5)		-0.016 (U)		6.66	0.52 (U)		4.18
6.–6.8 (19.8–22.3)		0.021 (U)		7.53	0.53 (U)		4.84
7.6–8.3 (24.8–27.3)		-0.083 (U)		6.24	0.53 (U)		5.32
9.1–9.9 (30–32.5)		0.054 (U)		7.37	0.53 (U)		5.63
10.8–11.6 (35.5–38)		0.04 (U)		4.40	0.52 (U)		4.62
12.2–13. (40.1–42.6)		-0.043 (U)		6.12	0.23		5.78
13.7–14.5 (45–47.5)		0.058 (U)		21.6	0.42		3.58
15.2–15.9 (49.8–52.3)		-0.044 (U)		15.1	0.52 (U)		3.2
16.8–17.5 (55–57.5)		-0.122 (U)		13.1	0.52 (U)		4.16
18.6–19.4 (61–63.5)		-0.147 (U)		16.0	0.52 (U)		3.75
18.6–19.4 (61–63.5)		-0.019 (U)		15.7	0.52 (U)		3.27
19.7–20.5 (64.7–67.2)		0.003 (U)		14.4	0.50 (U)		0.74
21.3–21.9 (70–72)		-0.041 (U)		13.2	0.36		3.18
23.–23.6 (75.3–77.3)		0.045 (U)		3,560	0.52 (U)		2.95
24.4–25.2 (80.2–82.7)		-0.068 (U)		54.8	0.51 (U)		2.71
25.8–26.3 (84.7–86.2)		-0.037 (U)		10.8	0.55 (U)		8.54

Table 3-29. Analytical Results for Soil Samples 199-K-195 (C7695)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90*	Tritium	Chromium	Cr(VI)	Nitrate	Percent Moisture
27.4–28. (89.8–92)		-0.051 (U)		16.1	0.58 (U)		14.4
54.4–55.2 (178.6–181.1)		-0.11 (U)		21.8	0.594 (U)		20
54.4–55.2 (178.6–181.1)				21.8	0.12 (U)		
54.9–55.6 (180–182.5)		-0.22 (U)		21.0	0.58 (U)		16.7
54.9–55.6 (180–182.5)				10.9	0.11 (U)		14.3
61.9–62.6 (203–205.5)		-1.2 (U)		20.6	0.626 (U)		25
61.9–62.6 (203–205.5)				11.2	0.12 (UN)		19.5
69.5–70.3 (228–230.5)		-1.9 (U)		17.9	0.63 (U)		24.7
69.5–70.3 (228–230.5)				15.9	0.12 (UN)		19.6

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

* Analysis was reported as total beta radiostrontium (SR-RAD).

N = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for by not detected above limiting criteria

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Table 3-30. Analytical Results for Groundwater Samples 199-K-195 (C7695)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
27.5 (90.1)	899	-0.74 (U)	1,600	1.24	2 (U)	18,800	
27.5 (90.1)				1 (UD)	3.7 (U)		
29. (95.1)	867	-2.6 (U)	1,500	325	346	23,500	
30.4 (99.7)	461	-1.5 (U)	1,100	4,300	4,890	37,200	

Table 3-30. Analytical Results for Groundwater Samples 199-K-195 (C7695)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
31.9 (104.6)	375	-3.8 (U)	1,400	1,780	1,970	27,800	
33.6 (110.3)	103	-3.5 (U)	1,100	243	277	22,500	
33.6 (110.3)	95.7	2.2 (U)	1,900	248	279	22,100	
35. (114.9)	120	-11 (U)	840	488	499	84.1 (UD)	
36.4 (119.5)	85.4	-5.5 (U)	880	192	191	21,100	
38.2 (125.2)	19.7 (U)	-0.34 (U)	720	49.9	48.7	19,400	
39.6 (130)	80.2	-2.8 (U)	650	1.74	2 (U)	18,800	
41.1 (134.8)	36.5 (U)	-5.4 (U)	880	3.68	2 (U)	18,600	
42.7 (140)	36.4 (U)	-2.9 (U)	920	2.1	2 (U)	17,800	
37.5–44.2 (123–145)	197	0.37 (U)	1,000	6.99	7	18,300	
45.7 (150)	19.9 (U)	-2.4 (U)	810	1 (UD)	2 (U)	17,400	
47.2 (155)	-14.1 (U)	-2.2 (U)	190 (U)	1 (UD)	10.8 (U)		
48.8 (160)	29 (U)	-4.1 (U)	810	11.5	7	17,400	
50.3 (165)	534	-4.4 (U)	880	701	753	22,000	
51.8 (170)	40.8 (U)	-1.7 (U)	560	0.718	2 (U)	16,400	
53.6 (175.8)	68.6	-4.5 (U)	1,100	3.1	2 (U)	16,000	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.17 C7831 (199-K-200)

Figure 3-32 shows the composite analytical results for Well C7831 (199-K-200). The well, which was drilled through the southwest end of the 116-K-2 Trench, was initially intended as a characterization boring. Groundwater samples taken at the well did not return detections of Cr(VI) and the well was screened in the uppermost portion of the unconfined aquifer as a temporary well. The Hanford/Ringold unit E contact is placed at a depth of 8.2 m (27 ft) bgs in gravels transitional between Hanford and Ringold unit E. The water table is located in the Ringold unit E at about 15.5 m (51 ft) bgs. The well was constructed with 10.2 cm (4 in.) diameter PVC in a mounting flush to the ground.

Sediment samples were not collected for moisture content determinations. The neutron moisture log was conducted in well casing for which the system is calibrated and the readout is in volumetric moisture content. Water contents range from about 3 to 11 percent. The sediment at this location is gravelly sand; this coarse-grained material would tend to support low moisture content. The vadose zone appears to be exhibiting moisture contents that are consistent with an unvegetated surface at Hanford. Therefore, vertical flow would be expected under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show a slight increase at approximately 13.5 m (45 ft) bgs marking the Hanford formation/Ringold unit E contact. This temporary well was not drilled to the RUM.

Vadose zone sediment, aquifer sediment, and upper groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-32). Analytical results are presented in Tables 3-31 and 3-32. Cr(VI) values are generally less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In a soil sample at approximately 10.5 m (34 ft) bgs, the total chromium value is approximately 40 mg/kg with Cr(VI) undetected. Below this, at about 13.5 m (44 ft) bgs, the only measured Cr(VI) is detected at about 0.5 mg/kg. This suggests that most of the chromium at this location is reduced to Cr(III). This observation is located near the periodically rewetted zone, suggesting that significant reduction is occurring near the periodically rewetted zone at this location. No increases in chromium contamination were observed near the periodically rewetted zone, indicating that chromium is not being preferentially held up in this zone. For sediments below just under the water table, total chromium is very low and Cr(VI) is undetected. Again, most of the chromium is in a reduced state. Cr(VI) concentrations in the groundwater sample taken from this temporary well are about 35 µg/L, indicating that chromium in the aquifer is in the mobile hexavalent form. Overall, the chromium concentrations in groundwater at this location are below the Washington State DWS.

Sr-90 was detected in the vadose zone sediment, aquifer sediment, and groundwater at this location and carbon-14 was detected in groundwater. There is some nitrate in the vadose zone. The geologist noted that the soil turned green when examined with hydrochloric acid in a sample from a depth of approximately 10 m. This most likely resulted from reaction with copper, although a total chromium of 40 mg/kg was noted near this location. Nitrate is detected below the standard in the aquifer in the same zone as the elevated chromium. Tritium activity is very low in this well, with a small increase in activity to 2,000 pCi/L located about 33 m (108 ft) bgs, vertically below the maximum chromium values in groundwater. Slug testing was not conducted in this well.

Following well acceptance, initial routine groundwater samples were collected at Well 199-K-200 in April 2011, with the following results: Cr(VI)—28.5 µg/L, total chrome—30 (B) µg/L, carbon-14—11 pCi/L, Sr-90—240 pCi/L; tritium—3,100 pCi/L, and nitrate—31,000 µg/L. The Sr-90 value is notably high, but the well is located at what is likely the zone most enriched with radionuclides.

Table 3-31. Analytical Results for Soil Samples 199-K-200 (C7831)

Sample Interval bgs (m [ft])	Soil–Radionuclide(pCi/g)			Soil–Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
7.6–8. (24.9–26.4)	0.249 (U)	0.126 (U)	0.981 (U)	17.2	0.53 (U)		
8.6–9.4 (28.2–30.7)	1.29 (U)	3.94	4.01 (U)	21.2	0.52 (U)	6,600	
9.1–9.9 (30–32.5)	2.62 (U)	3.56	1.97 (U)	21.0	0.51 (U)	2,000	
10.1–10.8 (33–35.5)	-0.409 (U)	2.95	3.93 (U)	39.7	0.51 (U)		
10.6–11.3 (34.7–37.2)	1.18 (U)	2.12	-0.866 (U)	18.2	0.51 (U)	1,200	
11.3–12.1 (37.2–39.7)	1.98 (U)	1.52	-2.06 (U)	12.6	0.53 (U)	4,600 (U)	
12.2–13 (40–42.5)	-0.473 (U)	1.82	-6.38 (U)	25.6	0.51 (U)	2,400	
12.2 – 13 (40–42.5)	-1.46 (U)	1.23	-6.88 (U)	19.6	0.51 (U)	2,300	
12.9–13.7 (42.4–44.9)	0.12 (U)	1.54	2.48 (U)	12.6	0.51 (U)		
12.9–13.7 (42.4–44.9)	0.164 (U)	0.757	0.0334	12.2	0.982		
13.7–14.5 (45–47.5)	-0.624 (U)	1.47	-4.46 (U)	15.2	0.51 (U)		
14.4–15.2 (47.4–49.9)	-0.056 (U)	1.68	2.38 (U)	12.9	0.51 (U)	1,000	
15.2–15.9 (49.8–52.3)	-0.725 (U)	1.39	-6.93 (U)	10.8	0.55 (U)	5,400	
16.4–17.1 (53.7–56.2)	1.44 (U)	1.58	0.411 (U)	13.9	0.55 (U)	1,400	
17.1–17.9 (56.1–58.6)	2.42 (U)	1.6	0.612 (U)	13.4	0.58 (U)	1,900	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Soil—analysis was reported as Nitrate; Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

U = analyzed for by not detected above limiting criteria

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Table 3-32. Analytical Results for Groundwater Samples 199-K-200 (C7831)

Sample Interval bgs (m [ft])	Groundwater—Radionuclide (pCi/L)			Groundwater—Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
17.9 (58.6)	0 (U)	130	3,100	3.06	2 (U)	25,200	
17.9 (58.6)				3.28	3.7 (U)		
17.9 (58.6)				3.27	3.7 (U)		
18–18 (59–59)	44.4	160	6,100	2 (U)	2 (U)	23,400	
18–18 (59–59)				1 (UD)	3.7 (U)		
18.1 (59.3)	-2.72 (U)	190	3,200	32.1	31.1	29,500	
18.1 (59.3)				33.1	30		

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Soil—analysis was reported as Nitrate; Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

D = analyte was reported at a secondary dilution factor

U = analyzed for by not detected above limiting criteria

3.4.3.18 C7832 (199-K-201)

Figure 3-33 shows the composite analytical results for Well C7832 (199-K-201). The well was drilled through the north slope of the 116-K-2 Trench, 4 m (13 ft) from the centerline of the trench. The well was intended to be a characterization boring but water samples from the top of the aquifer yielded very low to nondetect values of Cr(VI). The location is upgradient of Well 199-K-22, which has had a Cr(VI) trend above 100 µg/L since the first sample in 1996. The well was screened in the uppermost portion of the unconfined aquifer as a temporary well. The Hanford formation/Ringold unit E contact was selected at 7.9 m (26 ft) and the water table is located in the Ringold unit E at about 15 m (50 ft) bgs.

Sediment samples for moisture content were not routinely collected at this well, the one sample collected returned a moisture content of 1 percent by weight. Due to the smaller well casing diameter, neutron moisture logging conducted at this well returned values in moisture content by volume. Logged water contents range from about 1 to 3 percent in this well. The sediment at this location is muddy sandy gravel that grades into muddy gravel about 2 m (25 ft) bgs; this material would tend to support low moisture content. The vadose zone appears to be exhibiting moisture contents that are consistent with a vegetated surface at Hanford. Therefore, vertical flow would be expected to be low to nonexistent under the measured conditions given typical specific retention capacities of 1 to 2 percent for these sediments.

The total gamma and natural KUT geophysical log plots show a slight increase at approximately 8 m (26 ft) bgs, marking the Hanford formation/Ringold unit E contact. This temporary well was not drilled to the RUM.

Vadose zone sediment, aquifer sediment, and upper groundwater samples were analyzed; chromium, Cr(VI), Sr-90, nitrate, carbon-14, and tritium distribution and concentration are illustrated in the composite plot (Figure 3-33). Analytical results are presented in Tables 3-33 and 3-34. Cr(VI) values are less than total chromium values, which is reasonable because the total chromium value should include all forms of chromium. In soil samples between 6 to 8 m (20 to 26 ft) bgs, the total chromium value trends from 82 mg/kg at the top of the zone to about 15 mg/kg with Cr(VI) undetected. Below this, from 14 to 17 m (46 to 55 ft) bgs, the only measured Cr(VI) is detected at about 0.5 mg/kg. This suggests that most of the chromium at this location is reduced. This interval is located near the periodically rewetted zone, suggesting that significant reduction is occurring near the periodically rewetted zone at this location. No increases in chromium contamination were observed near the periodically rewetted zone, indicating that chromium is not being preferentially held up in this zone. For sediments below just under the water table, total chromium is very low and Cr(VI) is detected at very low levels at one location. Again, most of the chromium is in a reduced state. Cr(VI) concentrations in the groundwater sample taken from this temporary well are about 100 µg/L, indicating that the chromium in the aquifer predominantly is in the mobile hexavalent form.

Sr-90 was detected in the vadose zone sediment, aquifer sediment, and groundwater at this location. Carbon-14 was undetected in groundwater. There is some nitrate in the vadose zone. Nitrate is detected below the standard in the aquifer in the same zone as the elevated chromium. Tritium activity is very low in this well, with a small activity less than 300 pCi/L in the top of the aquifer. Slug testing was not conducted in this well.

Following well acceptance, initial routine groundwater samples were collected at Well 199-K-201, with the following results: Cr(VI)—111 µg/L, total chrome—110 µg/L, carbon—14–2.4 (U) pCi/L, Sr-90—16 pCi/L, tritium—270 pCi/L, and nitrate—32,400 µg/L.

Table 3-33. Analytical Results for Soil Samples 199-K-201 (C7832)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
5.9–6.6 (19.3–21.8)	1.89 (U)	5.45	-2.22 (U)	81.6	0.53 (U)	17.7	
6.4–7.2 (21–23.5)	0.821 (U)	4.14	-0.733 (U)	58.0	0.53 (U)	10.7	
7.1–7.8 (23.2–25.7)	0.062 (U)	3.38	-4.52 (U)	43.8	0.52 (U)	6.3	
7.7–8.5 (25.3–27.8)	1.31 (U)	1.35	5.74 (U)	21.3	0.51 (U)	2.7	
8.4–9.1 (27.5–30)	2.02 (U)	1.31	6.57 (U)	15.5	0.51 (U)	5.0 (U)	
9.3–10. (30.4–32.9)	0.181 (U)	0.823	3.85 (U)	38.8	0.51 (U)	2.7	1.28
9.9–10.6 (32.4–34.9)	-0.751 (U)	0.659	0.934 (U)	35.7	0.51 (U)	5.0	

Table 3-33. Analytical Results for Soil Samples 199-K-201 (C7832)

Sample Interval bgs (m [ft])	Soil—Radionuclide (pCi/g)			Soil—Chemical (mg/kg)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
9.9–10.6 (32.4–34.9)	-0.431 (U)	0.635	-0.473 (U)	14.8	0.51 (U)	4.7	
10.6–11.4 (34.9–37.4)	0.766 (U)	0.315	-1.2 (U)	13.6	0.51 (U)	3.2	
11.4–12.2 (37.5–40)	1.72 (U)	0.35	1.4 (U)	18.5	0.51 (U)	2.8	
12.1–12.9 (39.7–42.2)	-1.32 (U)	0.306	-4.53 (U)	13.7	0.52 (U)	5.6	
13.1–13.9 (43.1–45.6)	0.983 (U)	0.282	6.1 (U)	15.8	0.51 (U)	3.3	
13.6–14.4 (44.7–47.2)	0.785 (U)	0.17 (U)	-0.605 (U)	10.8	0.29	1.4	
14.4–15.1 (47.2–49.7)	3.73 (U)	0.243 (U)	1.12 (U)	16.0	0.72	4.9 (U)	
15.2–16. (50–52.5)	3.71 (U)	0.338	-4.36 (U)	13.3	0.64 (U)	3.0	
16.1–16.9 (52.8–55.3)	1.58 (U)	0.132 (U)	4.48 (U)	17.7	0.37	6.4 (U)	
16.8–17.6 (55.2–57.7)	1.27 (U)	0.031 (U)	0.774 (U)	12.9	0.56 (U)	1.4	

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. analysis was reported as total beta radiostrontium (SR-RAD).

b. Soil—analysis was reported as Nitrate; Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

U = analyzed for by not detected above limiting criteria

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Table 3-34. Analytical Results for Groundwater Samples 199-K-201 (C7832)

Sample Interval bgs (m [ft])	Radionuclide (pCi/L)			Chemical (µg/L)			Physical (%)
	Carbon-14	Sr-90[a]	Tritium	Chromium	Cr(VI)	Nitrate[b]	Percent Moisture
17.9 (58.7)	2.35 (U)	-3.4 (U)	280	105	107	27,700	
17.9 (58.7)				113	111		
18.4 (60.4)		4.6	210	4.81	2.5	29,500	
18.4 (60.4)				4.65	3.7 (U)		
18.4 (60.4)				6.14	3.7 (U)		

Notes: Data shown excludes soil samples collected through water extraction (WE) methods due to comparability of values. WE concentrations are consistently lower the acid extraction methods. Also excluded from data set, are result reported in water units (i.e., µg/L) for soil samples and "R" and "Y" flagged data.

Blank cells indicate sample was not analyzed for that constituent.

a. Analysis was reported as total beta radiostrontium (SR-RAD).

b. Soil—analysis was reported as Nitrate; Groundwater—analysis was reported as Nitrogen in Nitrate (NO3-N).

U = analyzed for by not detected above limiting criteria

3.5 Vadose Zone

The vadose zone (i.e., unsaturated zone) extends from ground surface to the water table. Also called the zone of aeration, it includes the surface soil; the capillary fringe zone above the water table; and the combined rock, soil, air, and moisture interface linking the two. This important region is a significant buffer to the movement of liquids and contaminants released near the surface. The dominant geological formation in the vadose zone is the Hanford formation.

The upper part of the vadose zone, to depths from 0.3 to 13.7 m (1 to 45 ft) or more, have been disturbed in a nonuniform fashion by site grading and construction activities in the early 1950s, by site operations between 1955 and 1971, and by waste site remediation and facilities decommissioning activities since reactor shutdown. Much of the 100-K Reactor security area, and the immediately surrounding land, was cleared of vegetation and regraded. Areas away from the reactor area were stripped and graded to support specific facilities but, in general, the existing plant community and soil profiles were not disrupted.

Unsaturated flow of moisture/liquid in the vadose zone is highly complex and influenced by the hydraulic properties of soil, vegetation cover, and recharge. Movement of moisture in the vadose zone is mainly vertically downward under gravity drainage, controlled by the unsaturated hydraulic conductivity and the difference in hydraulic head between two points (i.e., hydraulic gradient). Typically, the moisture content in the Hanford formation sediments ranges from 5 to 15 percent in the vadose zone, largely dependent upon the grain size distribution. The flood deposits that constitute the Hanford formation tend to fine upward within each depositional sequence, resulting in alternating coarser and finer grains vertically, with the finer-grained zones able to retain more moisture due to their smaller pore size. Cross-beds found in the Hanford formation also may locally influence vertical migration of contaminated liquids, though the extent of influence is not known. However, the vertical hydraulic conductivity of even the finer-grained

layers is much greater than the annual flux from precipitation and other sources such that the vadose zone can transmit as much water as is left over after evapotranspiration at the surface.

As described in Chapter 1, much of the operational area within 100-K was denuded of the native plant and soil cover optimizing conditions for deep percolation of precipitation through the vadose zone, eventually ending up as recharge. As noted there, 50 percent or more of the approximately 16.5 cm (6.5 in.) of annual precipitation may drain through the vadose zone and leach contaminants into the groundwater.

100-K, in addition to precipitation, other sources of leaching water include remedial action (dust suppression water), pipelines (water export system, 100-K-58), and site infrastructure (181-KE River Pump House, 182-K Water Treatment Plant), which may contribute to increased soil moisture. As such, the moisture content in the vadose zone is the result of a combination of meteoric water, effluent discharge (up to the mid-1990s), artificial recharge (dust suppression water, possible leaking infrastructure), and contribution from river stage, which seasonally raises and lowers groundwater into the basal portion of the vadose zone. Fluctuations due to river stage are illustrated in Figure 3-34 (Columbia River Stage and Groundwater Well Elevations). The Columbia River gauging station at the 100-KE Pump House responds to routine daily and seasonal changes as shown. Inland groundwater wells show diminishing and time-delayed response to river level changes when moving inland from Wells 199-K-32A to 199-K-36. Groundwater levels also increase when moving from near-river to inland wells. These wells were selected to reflect the least impact from ongoing pump-and-treat actions.

If the groundwater is contaminated, mobile contaminants may be introduced into the basal vadose zone over large areas with the rising water levels. With reduction in artificial recharge, precipitation is considered the main source of recharge; however, fluctuations in river stage and the flux from artificial recharge may impact the fate of contaminants. In the vadose zone, the pressure head is negative under unsaturated conditions (*200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program* [DOE/RL-98-28]). This reflects the fact that water in the unsaturated zone is held in the soil pores under negative pressure by surface tension forces (*200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program* [DOE/RL-98-28]). If the volume of water in the vadose zone equals the volume that can be retained by surface tension forces (field capacity), no water is available to migrate. Typically, this is the condition in the vadose zone under the native shrub-steppe vegetation on a fully developed soil profile. When this vegetation/soil cover is disturbed, as observed over large portions of 100-K, evaporation is reduced and transpiration is essentially zero due to the lack of vegetation; consequently, significant portions of the annual precipitation and any anthropogenic liquid source are able to leach through to the water table. Physically, as additional liquid is added to the vadose zone, it will migrate vertically under the force of gravity. This results because an increase in water content reduces the surface tension forces holding the moisture within the pore spaces, thus increasing the moisture flux.

Given the typical range of volumetric moisture content of 5 to 15 percent, assuming an average of 10 percent, and assuming that the volumetric moisture content is approximately equal to effective porosity and a steady input of 7.6 cm (3 in.) per year, vertically downward travel times on the order of 1 m (3 ft) per year are reasonable through the Hanford formation vadose zone. Consequently, the approximate time for leaching to occur to groundwater from waste sites that are fully exposed to the elements (bare ground) can be estimated by multiplying the estimated travel time by the thickness of the vadose zone between the bottom of the waste site and the water table. For example, a waste site 50 m (160 ft) above the water table might be expected to leach to the water table in 50 years under natural conditions. Dust suppression water and other factors could speed that up. Likewise, waste sites that have been protected by concrete, other structures, or other infiltration-limiting features would have severely limited leaching profiles and be sites with the potential for significant contamination in the vadose zone.

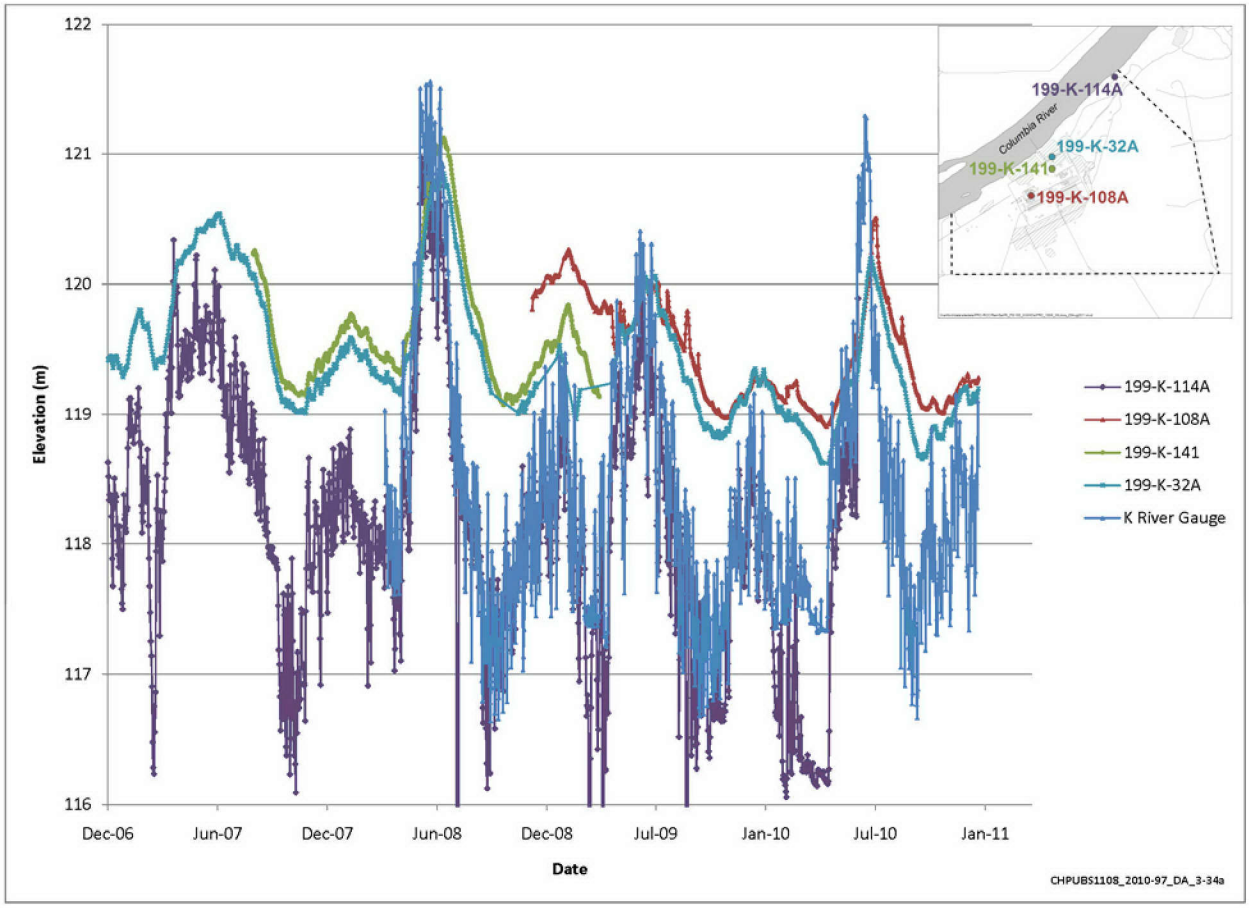


Figure 3-34. Columbia River Stage and Groundwater Well Elevations

In summary, it is useful to put the vadose zone into perspective. Under the conditions of native vegetation cover, the annual precipitation is nearly consumed by the plants over large areas, resulting in extremely dry conditions in the vadose zone sediments with very high negative pressure heads and very little water leaching to the water table. When the surface is dug up and disturbed by human activity, the vadose zone becomes very dynamic hydraulically, with over half of the natural precipitation leaching through to the water table. Dust suppression water provides additional driving force that increases the speed of leachate within the vadose zone. For a typical acre of barren ground with 7.6 cm (3 in.) per year of water introduced to the vadose zone over longer periods, the rate of water movement becomes an acre-foot in 4 years or 10 ac-ft in 40 years. Since operations at 100-K ceased in 1970 to 1971, many acres of ground have transmitted water of this magnitude to the water table.

The topsoil that has developed at the top of the vadose zone since the last Pleistocene flood provides the foundation for the plants that grow within the shrub-steppe ecosystem. Well-developed soil profiles promote water retention and plant growth within the upper few meters of the vadose zone. Soil properties such as hydraulic conductivity are important for an understanding of contaminant fate and transport. As such, this section presents a number of soil properties that are used in the fate and transport analysis of Chapter 5.

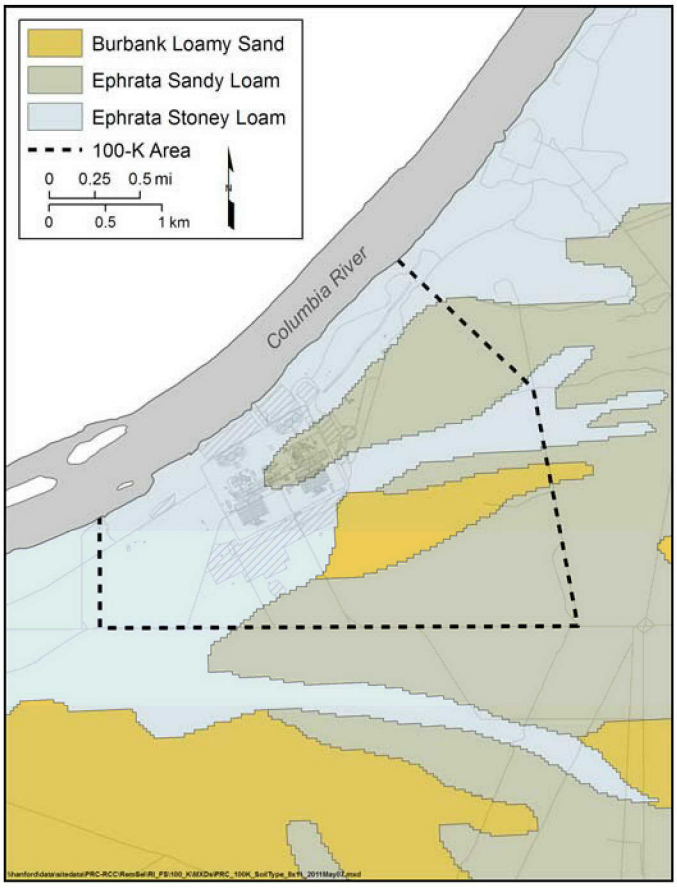
The topsoil and vegetation work together to maximize consumptive use of the annual precipitation by the ecosystem.

Soil Survey Hanford Project in Benton County Washington (BNWL-243) describes 15 soil types on the Hanford Site. The soil consists of sand, sand loams, and silty loams. Only three soil types are present within 100-K, as shown in Figure 3-35.

- **Burbank Loamy Sand.** Burbank loamy sand is a dark-colored, coarse-textured soil underlain by gravel. Its surface soil is usually about 40 cm (16 in.) thick but may be as much as 75 cm (30 in.) thick. The gravel content of its subsoil ranges from 20 to 80 percent.

- **Ephrata Sandy Loam.** Ephrata sandy loam is found on level topography on the Hanford Site. Its surface is darkly colored and its subsoil is dark grayish-brown, medium-textured soil underlain by gravelly material that may continue for many meters.

- **Ephrata Stony Loam.** Ephrata stony loan is similar to Ephrata sand loam. It differs by the presence of many large hummocky ridges that are made up of debris from melting glaciers. Areas between hummocks may contain many boulders several meters in diameter.



Source: Modified from PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization.*

Figure 3-35. Soil Types of the Hanford Site

Soil types in 100-K are dominated by the Ephrata stony and sand loams. These soil types cover over 80 percent of the area. The Burbank loamy sand is only present in the south central region of 100-K. Tables 3-35 and 3-36 present the various recharge rates for soil types in 100-K. There are also many small areas of backfill associated with construction and interim source remedial actions.

Table 3-35. Estimated Recharge Rates for 100-K—Undisturbed Conditions

	Estimated Recharge Rate			
Major Soil Type	**No Vegetation**	**Cheatgrass**	**Young Shrub-Steppe**	**Shrub-Steppe**
Ephrata sandy loam	17 mm/yr (0.7 in./yr)	8.5 mm/yr (0.3 in./yr)	3.0 mm/yr (0.1 in./yr)	1.5 mm/yr (0.06 in./yr)

Sources: PNNL-14702, *Vadose Zone Hydrogeology Data Package for the 2004 Composite Analysis.*
SGW-41213, *100-KR-4 Remedial Process Optimization Modeling Data Package*, Table 4-1.

Table 3-36. Estimated Recharge Rates and Variation for 100-K—Disturbed Conditions

Condition	Best Estimate	Estimated Standard Deviation	Minimum	Maximum
Ephrata sandy loam, disturbed and with no vegetation	17 mm/yr (0.7 in./yr)	8.5 mm/yr (0.3 in./yr)	8.5 mm/yr (0.3 in./yr)	34 mm/yr (1.3 in./yr)

Sources: PNNL-14702, *Vadose Zone Hydrogeology Data Package for the 2004 Composite Analysis*.
SGW-41213, *100-KR-4 Remedial Process Optimization Modeling Data Package*, Table 4-2.

Within 100-K, the thickness of the vadose zone varies because of natural and artificial influences, such as changes Columbia River stage. Across 100-K, the vadose zone is 10 to 32 m (32 to 105 ft) and thins to 4.6 m (15 ft) near the Columbia River. Soil types in the vadose zone include sand and loamy soil. The main geologic units in the vadose zone within 100-K include recent deposits near the surface (i.e., silt and sand, and backfill material) and the gravel dominated sequences of the Hanford formation (unit 1). As shown in Figure 3-7, the vadose zone can intersect the water table within the Hanford formation. At Wells 199-K-113A, 199-K-114A, and 199-K-161A during high river stage, the unconfined aquifer rises into basal Hanford formation sediments at depths of 5 to 6.3 m (17 to 20 ft) bgs.

Table 3-37 presents vadose zone material properties derived from laboratory specimens taken around the estimated Hanford formation/Ringold unit E contact during the RI. The data show that overall, the Ringold unit E is slightly denser and less moist, and has somewhat lower vertical saturated hydrologic conductivities than does the Hanford formation. Porosity and bulk density values cover the same general range of values, although the range of Hanford formation is slightly below that of the Ringold unit E. Table 3-38 contains van Genuchten parameters (1980) and fitted vertical saturated hydraulic conductivities applicable to the vadose zone in 100-K, and Table 3-39 presents estimated bulk density values for the Hanford formation and Ringold unit E for comparison with data presented in Table 3-37.

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Table 3-37. Hydraulic Properties of Soil—100-K

Well ID	Borehole ID and Sample Interval	Depth (m bgs)	Depth (ft bgs)	Formation	Saturated Hydraulic Conductivity (m/day)	Moisture Content (%)	Porosity (%)	Bulk Density (pcf)	Grain size		
									% Gravel	% Sand	% Silt/Clay
199-K-183	C7683-I-001	4.5 to 5.0	14.75 to 16.25	Hanford	3.90E+01	3.12	22.6	128.0	52.7	42.8	4.5
199-K-183	C7683-I-002	5.9 to 6.6	19.5 to 21.5	Hanford	1.56E+00	4.19	18.5	134.9	56.8	37.8	5.4
199-K-183	C7683-I-003	7.6 to 8.2	25 to 27	Ringold	3.72E-03	2.05	33.4	110.1	0.4	84.9	14.7
199-K-183	C7683-I-004	9.1 to 9.8	30 to 32	Ringold	1.04E-03	1.15	12.9	144.1	17.0	53.6	29.4
199-K-185	C7685–I-001	4.6 to 5.3	15 to 17.5	Hanford	2.07E-03	6.02	17.1	137.2	54.3	34.2	11.5
199-K-185	C7685–I-002	6.2 to 7.0	20.35 to 22.85	Hanford	9.68E+00	3.22	19.5	133.1	64.7	29.9	5.3
199-K-185	C7685–I-003	7.6 to 8.4	24.9 to 27.4	Ringold	3.46E-03	2.39	23.7	126.2	44.5	40.8	14.7
199-K-185	C7685–I-004	9.2 to 9.9	30.05 to 32.55	Ringold	4.15E-03	2.13	18.0	135.7	21.4	47.5	31.1
199-K-186	C7686–I-007	9.8 to 10.5	32.1 to 34.6	Hanford	7.27E+01	6.91	8,0	152.2	59.8	33.3	6.9
199-K-186	C7686–I-009	11.6 to 12.3	38.0 to 40.5	Hanford	3.00E+01	6.60	24.3	125.2	71.2	26.0	2.8
199-K-186	C7686–I-011	13.0 to 13.7	42.6 to 45.1	Hanford	3.65E+01	6.76	23.3	126.9	41.8	49.6	8.7
199-K-186	C7686–I-013	14.6 to 15.4	47.9 to 50.4	Hanford/Ringold	2.68E-03	8.59	19.8	132.6	55.5	31.8	12.7
199-K-187	C7687–I-001	16.6	54.4	Hanford	1.11E+01	3.32	9.6	149.6	41.9	51.2	6.8
199-K-187	C7687–I-002	18.2 to 18.9	59.6 to 62.1	Hanford	8.81E+00	3.80	26.9	121.0	40.4	54.7	4.9
199-K-187	C7687–I-003	19.7 to 20.5	64.6 to 67.1	Hanford	9.24E+01	3.68	20.9	130.8	37.1	59.2	3.7
199-K-187	C7687–I-004	21.3 to 22.1	69.9 to 72.4	Ringold	5.70E+01	3.71	29.8	116.1	0.8	94.1	5.1
199-K-189	C7689–I-006	8.4 to 9.0	27.5 to 29.5	Hanford	1.64E-02	4.29	21.2	130.4	44.2	47.1	8.7
199-K-189	C7689–I-008	10.0 to 10.8	32.9 to 35.4	Hanford	8.11E+00	3.64	24.5	124.9	53.1	42.1	4.7
199-K-189	C7689 I-010	11.6 to 12.3	37.9 to 40.4	Hanford/Ringold	3.54E-03	4.76	23.4	126.7	49.2	35.4	15.3
199-K-189	C7689–I-012	13.0 to 13.7	42.6 to 45.1	Ringold	1.64E-03	1.39	27.9	119.3	23.2	47.4	29.4
199-K-190	C7690–I-003	7.3 to 8.1	24.0 to 26.5	Hanford	4.84E-02	1.73	17.9	135.8	36.0	42.6	21.4
199-K-190	C7690–I-004	8.8 to 9.6	29.0 to 31.5	Hanford	3.36E+00	2.48	31.6	113.1	46.0	46.3	7.8
199-K-190	C7690–I-005	10.4 to 11.1	34.0 to 36.5	Hanford	1.21E-03	1.40	19.1	133.9	21.6	48.1	30.2
199-K-190	C7690–I-006	11.9 to 12.3	39.0 to 40.5	Hanford	6.83E-03	1.78	37.0	104.2	25.9	54.0	20.1
199-K-191	C7691–I-001	5.4 to 6.2	17.7 to 20.2	Hanford	3.11E-02	4.19	19.4	133.3	68.4	26.4	5.2
199-K-191	C7691–I-002	6.8 to 7.5	22.2 to 24.7	Hanford	3.54E-03	2.73	16.8	137.7	43.4	45.4	11.2
199-K-191	C7691–I-003	8.4 to 9.2	27.6 to 30.1	Hanford	7.78E-04	3.35	25.5	123.3	48.6	39.9	11.5
199-K-191	C7691–I-004	10.1 to 10.8	33.0 to 35.5	Hanford	3.16E+01	4.47	14.8	141.0	54.4	43.1	2.5

Table 3-37. Hydraulic Properties of Soil—100-K

Well ID	Borehole ID and Sample Interval	Depth (m bgs)	Depth (ft bgs)	Formation	Saturated Hydraulic Conductivity (m/day)	Moisture Content (%)	Porosity (%)	Bulk Density (pcf)	Grain size		
									% Gravel	% Sand	% Silt/Clay
199-K-191	C7691–Add-on 1	11.6 to 12.4	38.2 to 40.7	Hanford	1.60E+02	2.38	15.8	139.3	57.2	39.6	3.2
199-K-191	C7691–Add-on 2	12.9 to 13.6	42.2 to 44.7	Ringold	1.64E+00	2.19	17.2	137.0	72.5	24.0	3.5
199-K-191	C7691–Add-on 3	14.2 to 15.0	46.7 to 49.2	Ringold	1.81E-03	1.49	19.4	133.4	65.9	27.7	6.4
199-K-193	C7693–I-003	14.2 to 15.0	46.7 to 49.2	Ringold	4.75E-03	2.45	27.6	119.8	54.9	34.0	11.0
199-K-193	C7693–I-004	15.7 to 16.5	51.5 to 54.0	Ringold	1.56E-02	1.40	21.7	129.6	48.0	40.4	11.6
199-K-194	C7694–I-001	18.8 to 19.6	61.8 to 64.3	Hanford	1.12E-02	1.90	18.5	134.8	17.6	49.4	33.0
199-K-194	C7694–I-002	20.3 to 21.1	66.5 to 69.0	Ringold	2.94E-04	2.60	16.6	138.0	27.0	46.8	26.2
199-K-194	C7694–I-003	21.9 to 22.2	71.9 to 72.9	Ringold	1.21E-02	1.70	22.4	128.4	42.0	40.8	17.2
199-K-194	C7694–I-004	23.7 to 24.5	77.8 to 80.3	Ringold	2.76E-03	1.60	16.4	138.3	33.9	45.8	20.3
199-K-184	C7684–I-004	6.0 to 6.2	19.8 to 20.3	Hanford	3.02E-02	19.2	11.9	145.8	0.0	35.3	64.7
199-K-184	C7684–I-005	7.8 to 8.6	25.7 to 28.2	Hanford	1.41E+00	4.29	30.6	114.8	0.0	76.9	23.1
199-K-184	C7684–I-006	9.2 to 9.9	30.1 to 32.6	Hanford	3.04E+01	3.98	34.0	109.2	0.0	94.4	5.6
199-K-184	C7684–I-007	10.8 to 11.6	35.4 to 37.9	Hanford	2.94E+01	6.10	31.7	113.0	21.5	73.1	5.4
199-K-188	C7688–I-011	16.7 to 17.4	54.7 to 57.2	Hanford	2.86E+01	3.88	17.2	137.0	39.8	55.6	4.7
199-K-188	C7688–I-013	19.0 to 19.8	62.4 to 64.9	Ringold	7.17E-05	4.90	9.9	149.0	38.3	39.1	22.6
199-K-188	C7688–I-015	19.3 to 20.1	63.3 to 65.8	Ringold	4.32E-04	3.85	12.3	145.1	28.7	39.1	32.2
199-K-188	C7688–I-017	20.6 to 21.2	67.7 to 69.7	Ringold	1.73E-03	5.70	27.6	119.8	42.6	43.4	14.0
199-K-192	C7692–I-001	0.9 to 1.5	3.0 to 5.0	Hanford	1.38E-02	1.74	18.1	135.5	68.1	21.0	10.9
199-K-192	C7692–I-002	2.4 to 3.2	8.0 to 10.5	Hanford	2.25E-02	2.47	0.7	161.1	72.5	23.0	4.5
199-K-192	C7692–I-003	4.0 to 4.8	13.1 to 15.6	Hanford	2.68E-02	3.25	15.9	139.1	43.4	33.8	22.8
199-K-192	C7692–I-004	5.5 to 6.3	18.1 to 20.6	Hanford	3.28E-04	1.53	22.2	128.7	56.7	31.3	12.1
199-K-195	C7695–I-006	4.6 to 5.3	15.0 to 17.5	Hanford	3.40E+00	4.18	29.7	116.3	53.0	40.1	6.9
199-K-195	C7695–I-007	6.0 to 6.8	19.8 to 22.3	Hanford	8.90E+01	4.84	18.9	134.1	38.9	58.4	2.7
199-K-195	C7695–I-008	7.6 to 8.3	24.8 to 27.3	Hanford	4.48E+01	5.32	15.8	139.3	66.1	28.3	5.6
199-K-195	C7695–I-009	9.1 to 9.9	30.0 to 32.5	Hanford	3.54E+01	5.63	18.1	135.5	57.2	39.7	3.0
199-K-195	C7695–I-011	12.2 to 13.0	40.1 to 42.6	Hanford	3.80E+01	5.78	13.6	142.9	68.6	29.6	1.8
199-K-200	C7831–I-003	9.1 to 9.9	30.0 to 32.5	Ringold	1.07E+00	4.57	21.1	130.5	70.0	25.1	4.9
199-K-201	C7832–I-003	9.3 to 10.0	30.4 to 32.9	Ringold	2.76E-02	1.28	20.8	131	18.7	50.7	30.5

Table 3-38. van Genuchten Parameters and Fitted Saturated Hydraulic Conductivity Data for Four Sandy Gravel Samples

Sample	Operable Unit	Well Number	Depth (m [ft])	% Gravel	q_s (cm^3/cm^3)	q_r (cm^3/cm^3)	α (1/cm)	n (-)	Fitted K_s (cm/s)	Fitted K_s (ft/day)
4-1086	100-K	199-K-110A	12.77 (41.89)	65	0.137	0	0.1513	1.189	5.83E-02	1.65E+01
4-1090	100-K	199-K-111A	8.2 (26.90)	50	0.152	0.0159	0.0159	1.619	4.05E-04	1.15E+00
4-1118	100-K	199-K-109A	10.3 (33.79)	66	0.163	0	0.2481	1.183	3.89E-02	1.10E+01
4-1120	100-K	199-K-109A	18.9 (62.01)	63	0.131	0.007	0.0138	1.501	2.85E-04	8.06E-01

Source: RPP-20621, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment*.

α = a fitting parameter

K_s = saturated hydraulic conductivity

n = a fitting parameter (dimensionless)

q_r = residual moisture content (dimensionless)

q_s = saturated moisture content (dimensionless)

Table 3-39. Estimated Bulk Density Values for Hanford Formation and Ringold Unit E in 100-K

Formation	Number of Samples	Bulk Density (g/cm^3 [lb/ft^3])			
		Low	High	Mean	Standard Deviation
Hanford formation	26	1.60 (99.9)	2.30 (144)	1.91 (119)	0.21 (13)
Ringold unit E	18	1.63 (102)	2.17 (136)	1.90 (119)	0.15 (9.4)

Source: PNNL-14702, *Vadose Zone Hydrogeology Data Package for the 2004 Composite Analysis*.

3.6 Hydrogeology

The following understanding of hydrogeologic framework of 100-K is based upon past subsurface investigations and new findings from the RI. The three main hydrogeologic units include the vadose zone (discussed in Section 3.5), the suprabasalt aquifer system, and the confined CRBG aquifer system.

This section describes the saturated hydrogeology of 100-K, beginning with descriptions of the main aquifer and aquitard units of the suprabasalt aquifer system. This system includes all sediments between the water table and the top surface of the CRBG. These units are illustrated conceptually in the hydrostratigraphic column presented in Figure 3-7.

The suprabasalt aquifer system includes an unconfined aquifer consisting of relatively coarse-grained sediments with highly variable permeability, three sand-dominated confined aquifer zones, and three low-permeability units (aquitards). Table 3-40 summarizes the general sediment characteristics of the different aquifer and aquitard units. The basalt confined aquifer system includes basalts of the CRBG and interbedded sediments of the Ellensburg Formation.

Table 3-40. Summary of 100-K Aquifer and Aquitards of the Suprabasalt Aquifer System

Geologic Unit	Aquifer Type or Aquitard	Facies/Principal Sediment Types and Characteristics	Approximate Range of Thickness (m [ft])
Hanford formation	Unconfined aquifer	Cataclysmic flood deposits/sandy gravel, loose	0 to 30 (0 to 0 100) 4.6 to 20 (20 to 65) in K Reactor area
Ringold unit E		Coarse-grained fluvial deposits/sandy gravel, cobbles-to-sand, weakly to semi-consolidated, non– to well-cemented	5.2 to 27 (17 to 95)
RUM	Aquitard	Paleosol and overbank deposits/sandy silt and silty clay	30 to 60 (100 to 200)
RUM water-bearing lenses (rare)	Confined water-bearing zone	Low energy fluvial, silty gravely sand to fine silty sand	1 to 3 (3 to 10)
RUM	Aquitard	Paleosol and overbank deposits/sandy silt and clay	30 to 60 (100 to 200)
Ringold unit C	Confined water-bearing zone	Low energy fluvial deposit, sands and gravel	3 to 9 (10 to 30)
RLM	Aquitard	Overbank/Paleosol-Lacustrine deposits, sand and gravel	23 to 38 (75 to 125)
Ringold unit B	Confined water-bearing zone	Low energy alluvial and paleosols/sand, loose gravel	3 to 15 (10 to 50)
RLM	Aquitard	Overbank-Paleosol/Lacustrine deposits/silt and clay	23 to 38 (75 to 125)
Ringold unit A	Confined water-bearing zone	Low energy fluvial deposits, sand and gravel	6 to 10 (20 to33)

3.6.1 Unconfined Aquifer

The unconfined aquifer at 100-K is highly heterogeneous with respect to depth and location. The sedimentary deposits comprising the unconfined aquifer include the Hanford formation and Ringold unit E sediments. The thickness of the unconfined aquifer is determined by the difference between the water table and the top surface of the RUM, which is the base of the unconfined aquifer.

The topography at base of the unconfined aquifer is illustrated with the structure map of the RUM unit surface (Figure 3-36). This map shows 23 m (75 ft) of topographic relief on RUM unit surface in 1 m

contour intervals based on existing borehole data, including all 13 of the new RI groundwater wells. The RUM surface is the result of erosion and deposition of Ringold unit E sediments. Depressions and highs on the RUM surface are evident across 100-K. The RUM surface slopes to the west, deepens beneath 100-BC, and rises beneath 100-N. One depression is located between and northwest of the two 105-K reactors at Well 199-K-11. A second depression is defined by Wells 199-K-162 and 199-K-192, near the southwest end of the 116-K-2 Trench. The depression at Well 199-K-11 is a broader, shallower feature than the more sharply sculpted depression at Wells 199-K-162 and 199-K-192. The latter is 4 to 5 m (13 to 16 ft) lower than adjacent Well 199-K-144, which is more representative of the subsurface RUM top to the west and south.

Residual RUM highs are noted in two locations adjacent to the depression at Wells 199-K-162 and 199-K-192. Injection Wells 199-K-122A and 199-K-128 mark the drilled limits of a RUM high that rises to an elevation of 111 m (364 ft), which is 22 m (72 ft) above the erosional depression at Wells 199-K-162 and 199-K-192. Northeast from the 199-K-121A high, a second RUM high is depicted at Wells 199-K-113A and 199-K-114A. This residual high rises above 112 m (367 ft) AMSL. Between the two highs, an easterly trending channel appears to cross beneath the 116-K-2 Trench before dissipating further to the east. These depressions may have served as locations in which Cr(VI) settled during operations. Recent analyses do not show significant Cr(VI) values around Wells 199-K-162 and 199-K-192. Well 199-K-11 was screened in the upper aquifer after drilling into the RUM.

The contact between the Ringold unit E and the Hanford formation also displays considerable relief (Figure 3-9). The highest contact elevation is located adjacent to the 105-KW and is part of a broader feature beneath and southeast of the 100-K Reactor. Away from the 100-K Reactor, Ringold unit E sediments thin to the east and south and have been totally removed by Pleistocene floods east of 100-D and at a distance greater than 5 km (3 mi) to the southeast (*The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon* [Lindsey, 1996]). The deepest point for the contact is at the northeast end of the 116-K-2 Trench, at Wells 199-K-161 and 199-K-114A. These and adjacent wells define a localized depression or low in Ringold unit E. It is at this location that high-river stage water may enter into the basal Hanford sediments.

Characterization of hydrogeology at 100-K requires understanding of the properties and behavior of the vadose zone, groundwater, and surface water sources, interfaces, and interactions. The hydrogeology of the Hanford Site reflects a balance between and interdependence of surface water (Columbia River) with the unconfined and confined aquifers and the vadose zone.

Both natural and artificial hydrologic processes have influenced groundwater flow patterns and contaminant distribution in the subsurface underlying 100-K. The effects of natural processes on contaminant migration are ongoing, while the effects of artificial operations (such as the high-volume liquid discharges into the 116-K-2 Trench) have diminished over time with the end of reactor and SNF operations. However, some residual effects have not completely dissipated and other artificial processes continue to influence contaminant migration, particularly ongoing pump-and-treat operations plus facility and waste site remediation.

Figure 3-37 shows groundwater flow patterns for the unconfined aquifer. Groundwater at 100-K generally flows southeast to northwest, essentially perpendicular and toward the Columbia River. To the northwest, beyond the 116-K-2 Trench, flow has a small northeasterly flow component parallel to the river.

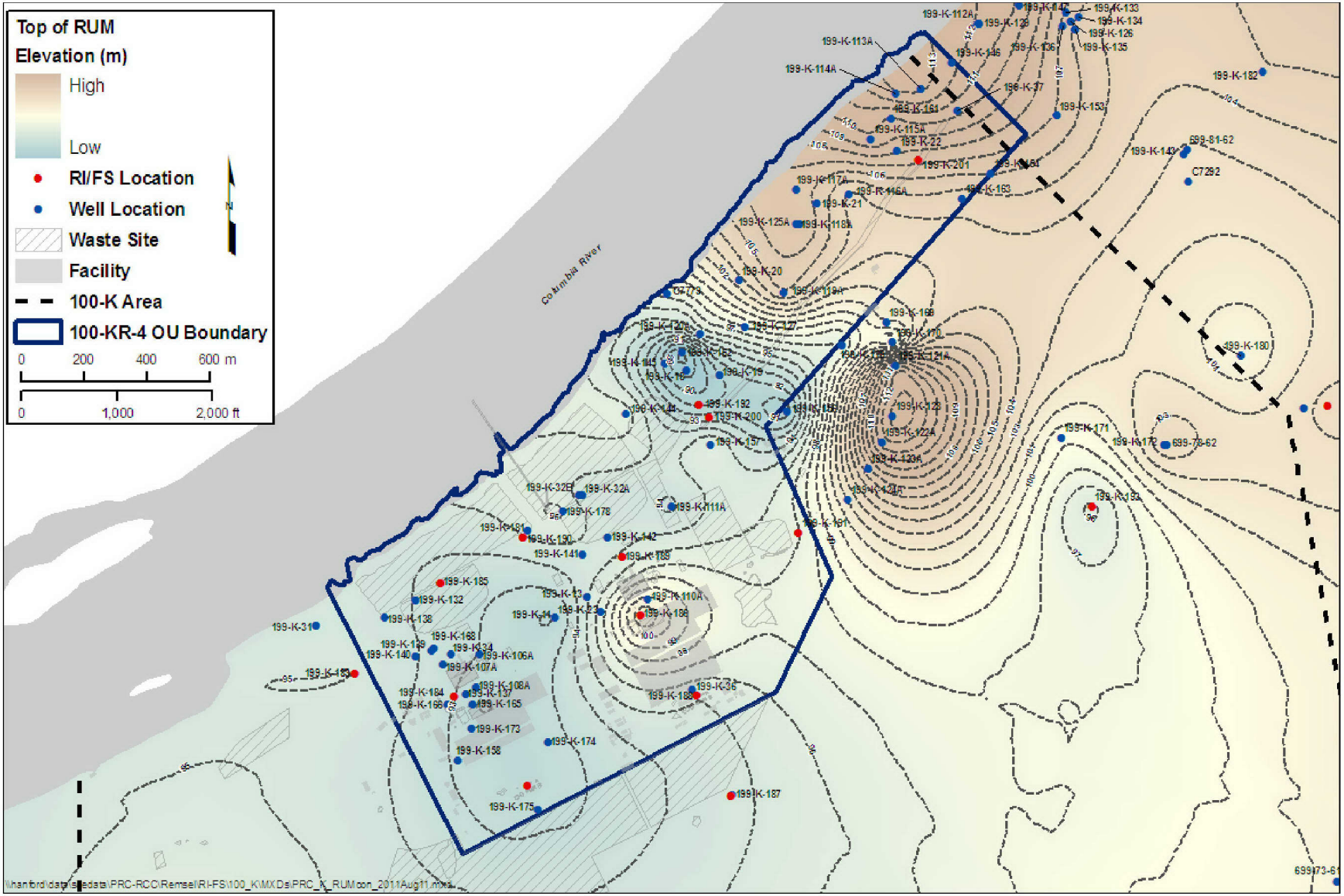


Figure 3-36. 100-K Elevation of the Top Surface of the RUM Unit

During fall, when river stage is relatively low, groundwater flow is toward the river, while in spring, when river stage is high, groundwater can flow away from or parallel to the river to the northeast. High river stages can be more than 3 m (10 ft) higher than low river stage. River stage can also fluctuate several meters over short periods (hours to days), based on operations at Priest Rapids Dam (*Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action* [DOE/RL-96-84]). Depending on the local geology, changing river stage can influence groundwater elevations up to several hundred meters inland. The groundwater level response to changes in river stage is slower and of less magnitude farther inland than near the river. However, effects have been observed as far inland as Gable Gap, approximately 3,600 m (2.2 mi) to the southeast (*Hanford Site Groundwater Monitoring for Fiscal Year 2008* [DOE/RL-2008-66]).

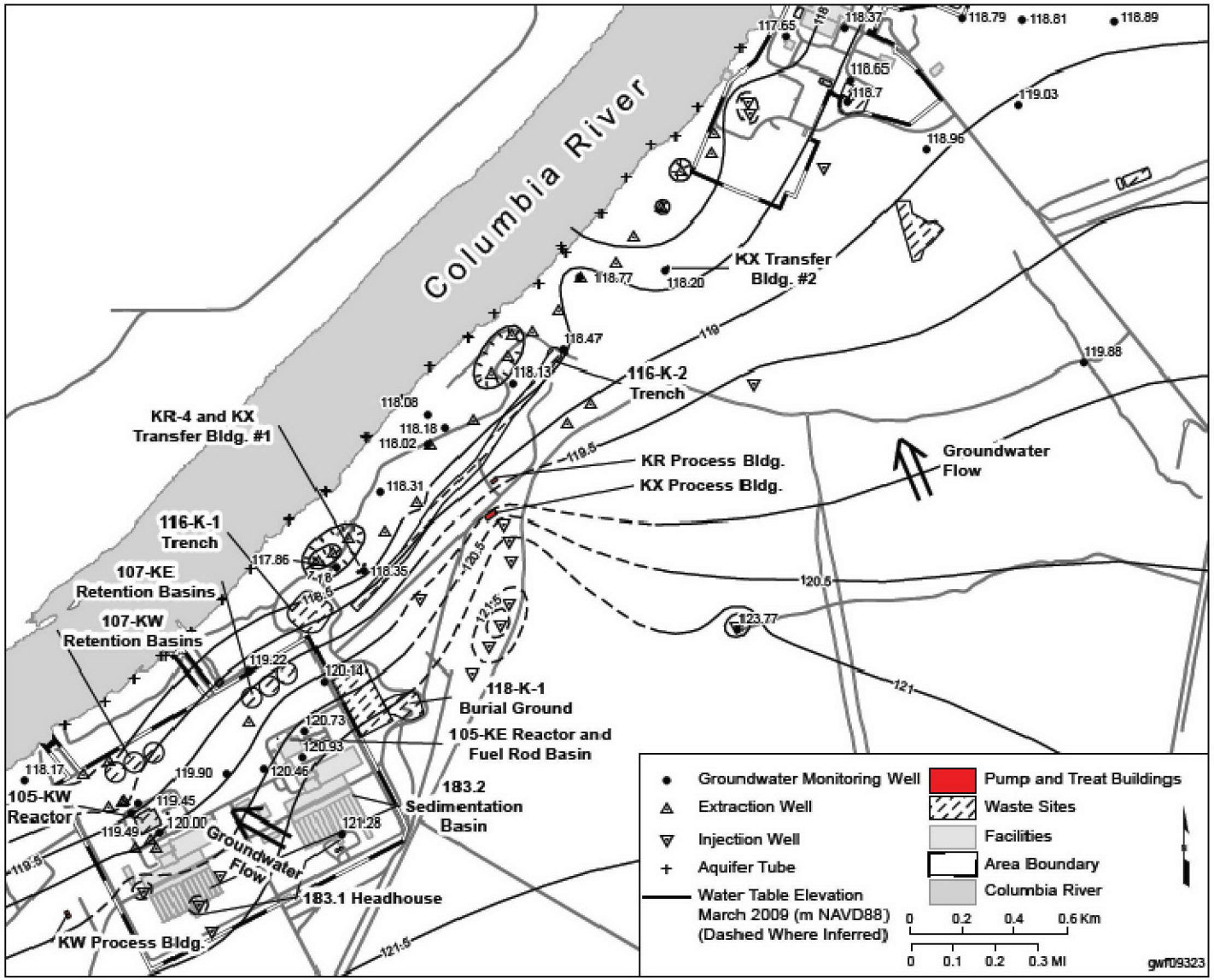
In 100-K, the primary artificial influence on groundwater flow pattern during operations was discharge of reactor cooling water to the 116-K-2 Trench, which created a large groundwater mound. Figures 3-38 and 3-39 illustrate the impact to the water table from these discharges. Figure 3-40 presents head data for three wells (located south, southwest, and west of the 116-K-2 Trench) and shows similar trends.

Of these wells, the most complete history is available for Monitoring Well 699-70-68, with records dating back to August 1955. Head elevations at this well, located about 2.4 km (1.5 mi) southwest of the 116-K-2 Trench, increased steadily to a peak of 126.04 m (413.3 ft) AMSL in April 1968, up 3.9 m (12.76 ft) from the initial measurement in August 1955, before beginning to decline. These data indicate that the groundwater mound began developing shortly after the start of discharges to the 116-K-2 Trench, and continued to expand until the late 1960s. The groundwater levels observed before and after discovery of leaks at the 183.2 Retention Basins show a steady increase in relation to historical water levels.

Head differences measured between the 116-K-2 Trench bottom and inland Well 699-78-62 best exemplify a likely inland groundwater gradient at a point 1,220 m (4,000 ft) southeast of the 116-K-2 Trench. Measurements started in June 1957 with an initial reading of 123.61 m (groundwater elevations across 100-K range from approximately 116 to 119 m [381 to 390 ft]) (*Hanford Site Groundwater Monitoring for Fiscal Year 2006* [PNNL-16346]). However, the distribution of monitoring wells is not ideal for accurately mapping the water table configuration. In addition, possible influences of discharges from the 200 Area are unknown.

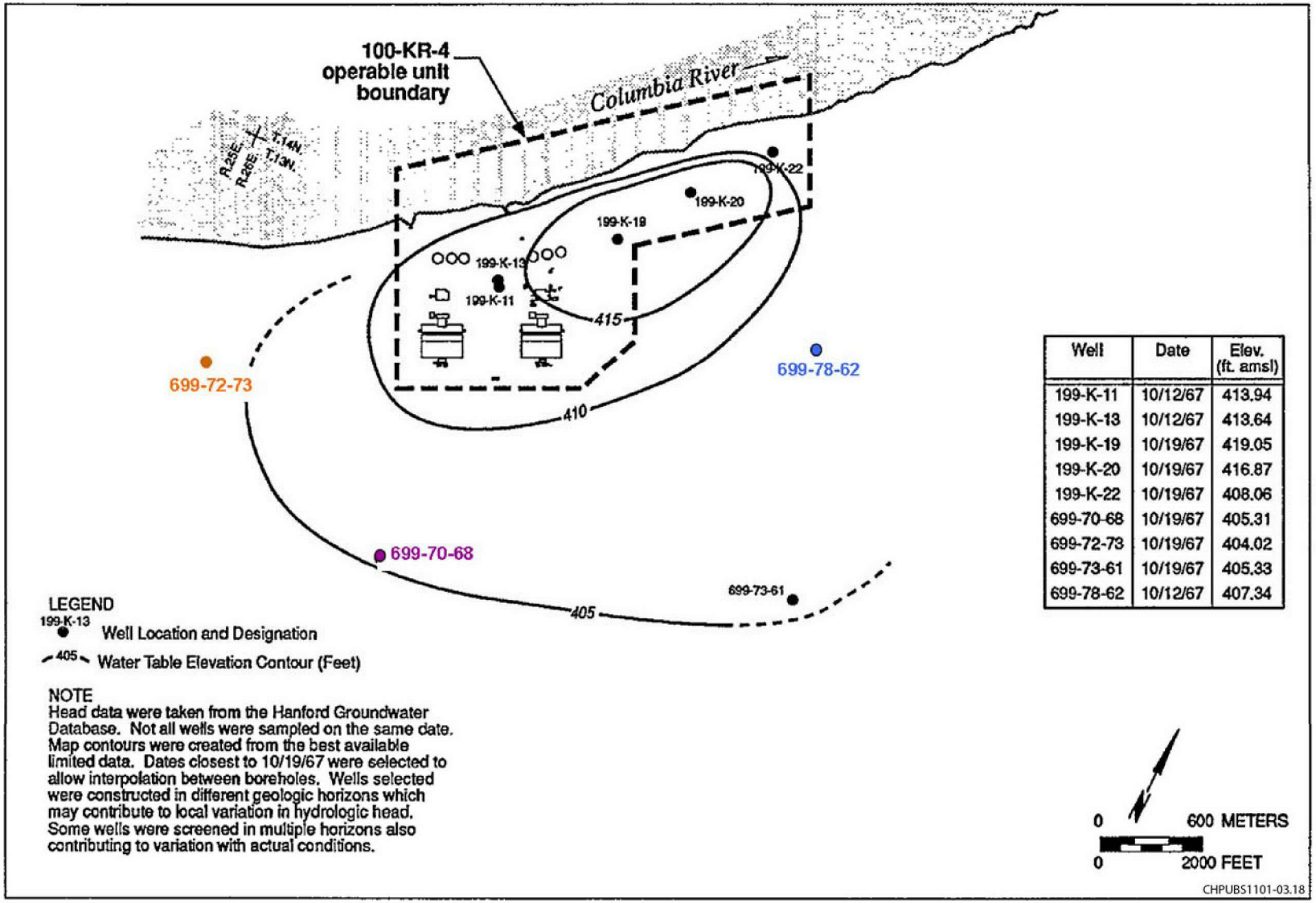
Figure 3-38 shows the groundwater mound effects on the water table in 1967. Given the head data shown in Figure 3-40, this figure demonstrates nearly the maximum areal influence of the groundwater mound at 100-K. After discharges to the trench stopped in 1971, the mound began to contract, and by the mid-1970s, the mound had greatly dissipated. The 1989 water table map, presented in Figure 3-39, shows a regional gradient rather than groundwater mound effects. Current conditions are presented in an aquifer thickness map of 100-K (Figure 3-41). This map was created by subtracting elevation of RUM contacts from unconfined monitoring well water level elevations for August to September 2010.

For most wells, a long-term trend of groundwater levels following river stage fluctuations is apparent, with amplitude greatly attenuated by pump-and-treat operations (*Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River* [PNL-9437]).



Source: DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2*, Figures 14 to 26.

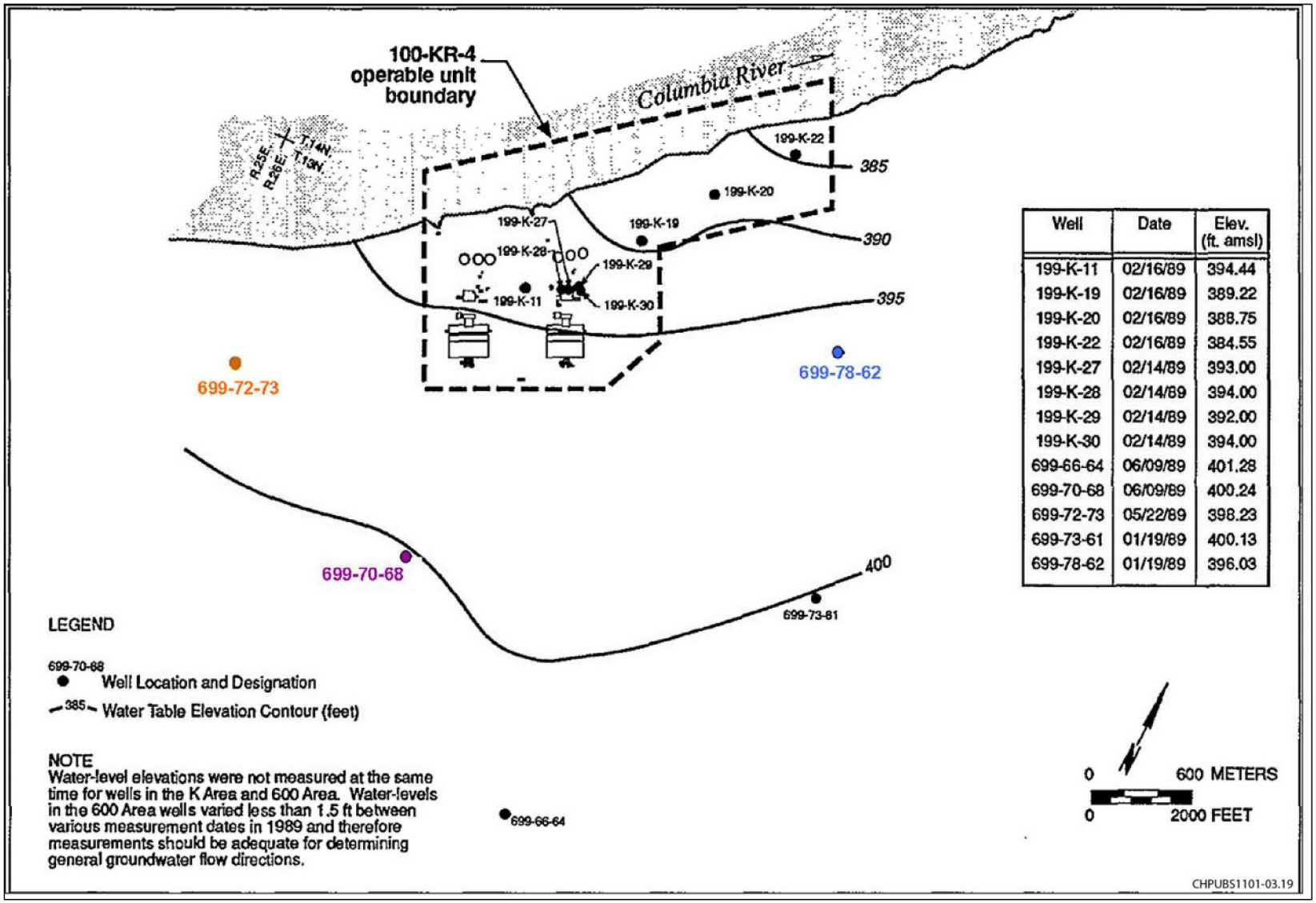
Figure 3-37. Groundwater Elevation Contours for 100-K



Well	Date	Elev. (ft. amsl)
199-K-11	10/12/67	413.94
199-K-13	10/12/67	413.64
199-K-19	10/19/67	419.05
199-K-20	10/19/67	416.87
199-K-22	10/19/67	408.06
699-70-68	10/19/67	405.31
699-72-73	10/19/67	404.02
699-73-61	10/19/67	405.33
699-78-62	10/12/67	407.34

Source: DOE/RL-90-21, *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington.*

Figure 3-38. 1967 Water Table Elevations in the 100-KR-4 OU



Well	Date	Elev. (ft. amsl)
199-K-11	02/16/89	394.44
199-K-19	02/16/89	389.22
199-K-20	02/16/89	388.75
199-K-22	02/16/89	384.55
199-K-27	02/14/89	393.00
199-K-28	02/14/89	394.00
199-K-29	02/14/89	392.00
199-K-30	02/14/89	394.00
699-66-64	06/09/89	401.28
699-70-68	06/09/89	400.24
699-72-73	05/22/89	398.23
699-73-61	01/19/89	400.13
699-78-62	01/19/89	396.03

Source: DOE/RL-90-21, *Remedial Investigation/Feasibility Study Work Plan for the 100-KR-4 Operable Unit, Hanford Site, Richland, Washington.*

Figure 3-39. 1989 Water Table Elevations in the 100 KR-4 OU

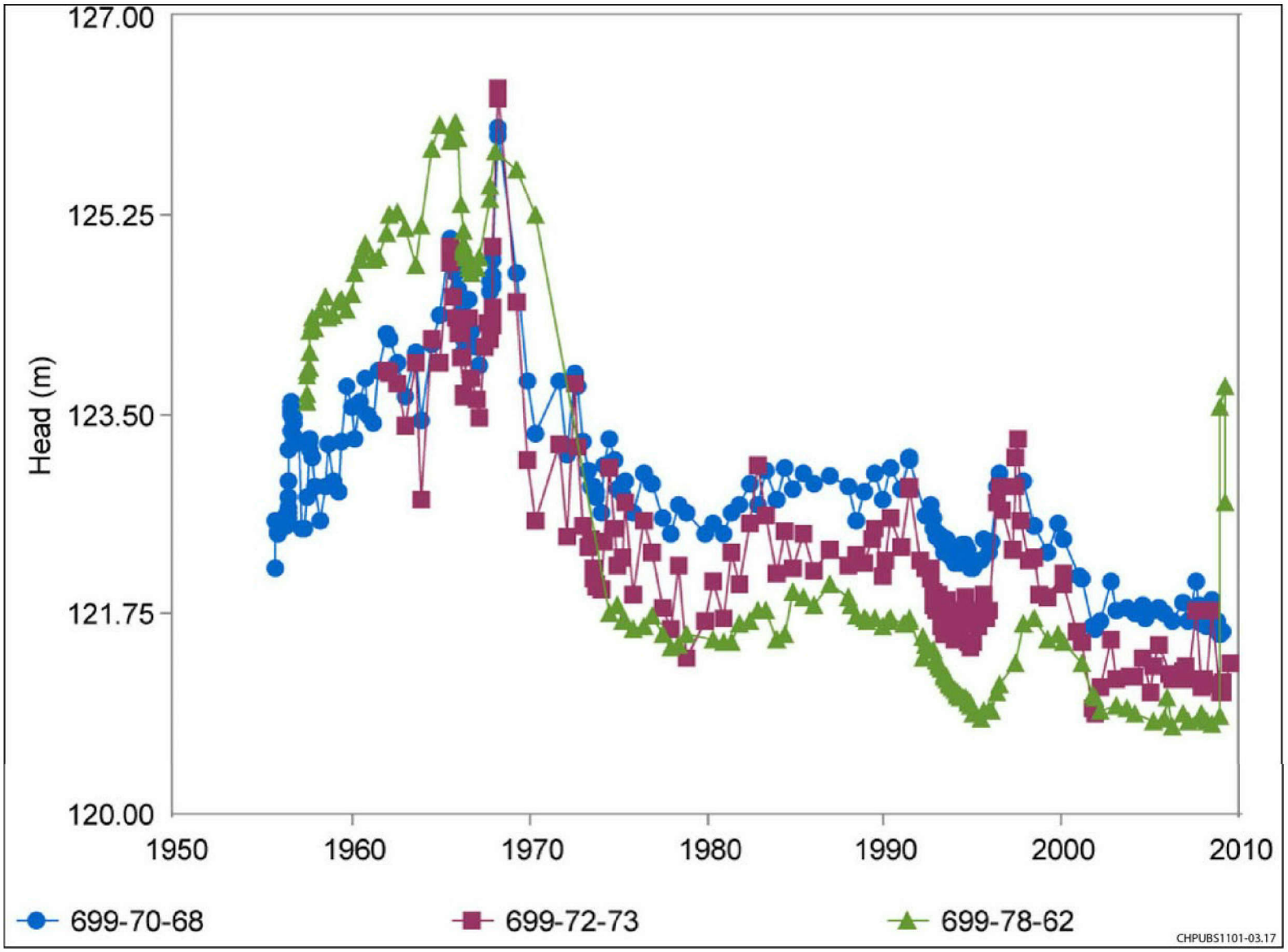


Figure 3-40. Head Level Changes in Groundwater Wells 699-78-62, 699-70-68, and 699-72-73 from the Mid-1950s to Present

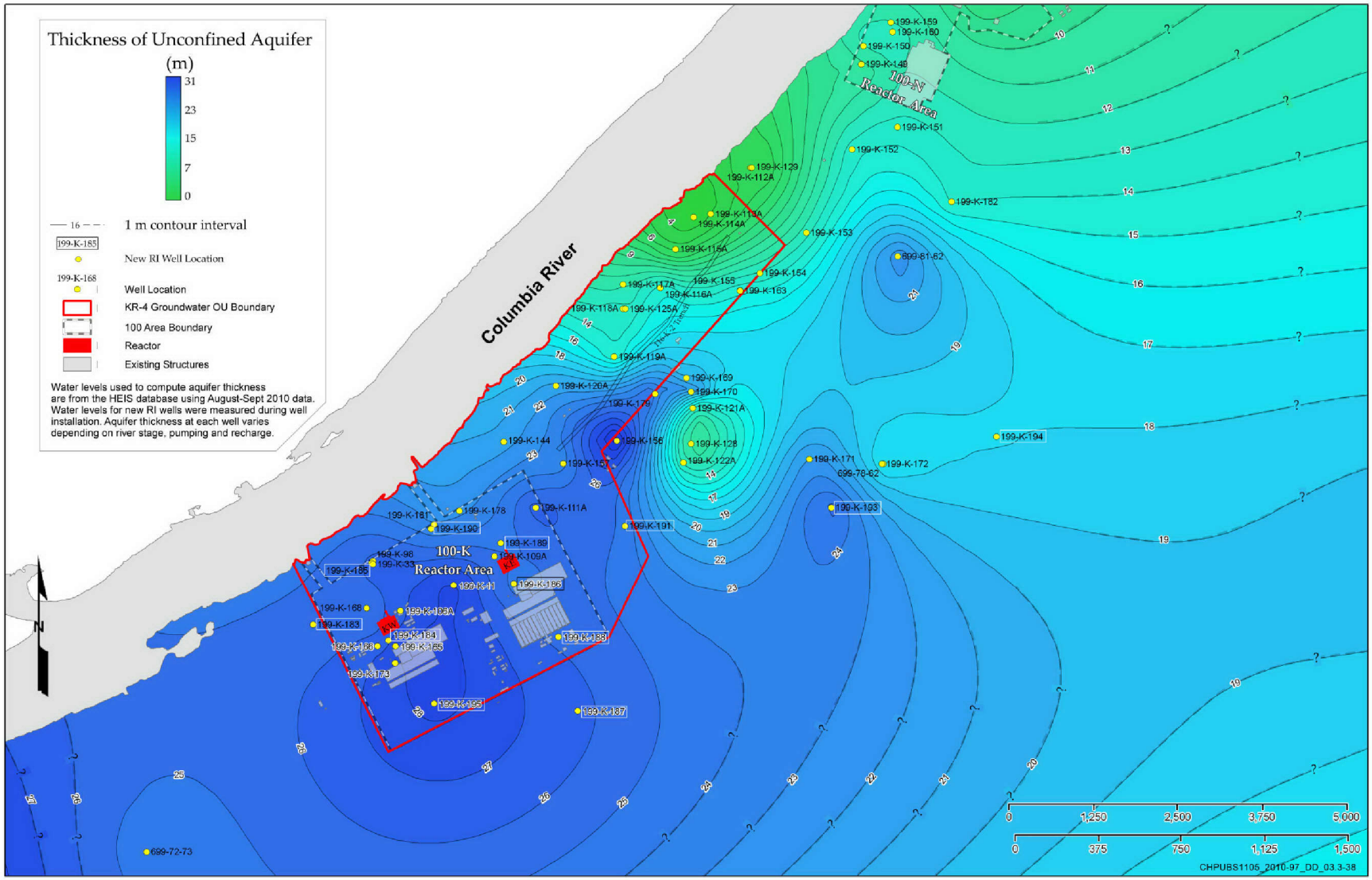


Figure 3-41. Unconfined Aquifer Thickness at 100-K for August to September 2010

Groundwater flows are driven in part by a slightly steeper gradient near the 105-KE Reactor as compared to the 105-KW Reactor. A plausible explanation is that the aquifer material is sufficiently variable and of relatively low hydraulic conductivity, and that the 100-KW Reactor was built on a more solid foundation than the 100-KE Reactor, which limited significant leaks and thus decreased downward vertical gradient. The low hydraulic conductivities found at either end of the 116-K-2 Trench are demonstrated by the comparison of conductivity values at Wells 199-K-18 (2.8 m/day) and 199-K-22 (0.88 m/day) versus high conductivity values found at Well 199-K-20 (33.8 m/day) at the center of the trench (Section 3.6.7 and Table 3-41). Water level data from nearby 100-K wells indicate that the former groundwater mounding beneath the 116-K-2 Trench was substantial during its use. Low hydraulic conductivity at 100-K is evidenced by the extensive length of the trench necessary to accommodate inflow liquid waste during operations without breaching the trench (100-KR-4 LFI [DOE/RL-93-79]).

The 100-K horizontal hydraulic conductivity is estimated at 0.5 to 44 m/day (1.6 to .4 ft/day) (Section 3.6.7 and Table 3-41), and an effective porosity range has been estimated at 10 to 20 percent. Hydraulic gradient estimates range from 0.003 to 0.006 m/day (0.0098 to 0.019 ft/day) (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]). Groundwater flows at an average rate of 0.1 to 0.3 m/day (0.024 to 0.072 ft/day), as estimated from hydraulic gradients and migration rates of plumes (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]). The best supported estimate for the groundwater flow rate between the 105-KE Reactor and the river is 0.12 m/day (0.4 ft/day), which is based on the migration of a plume created by a leak from the 105-KE Basin in 1993 (*Hanford Site Groundwater Monitoring for Fiscal Year 2001* [PNNL-13788]). An increased groundwater flow rate is observed beneath the 105-KW Reactor as compared to below the 105-KE Reactor (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]). Groundwater elevations varied by up to 0.9 m/day (3 ft/day) in some wells nearest the river and up to approximately 1.8 m (6 ft) over the season in a few wells (*Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River* [PNL-9437]). Artificially induced changes to groundwater flow have also been observed. The appearance of relatively high Sr-90 concentrations near the northwestern corner of the 105-KE Reactor building likely was caused by remobilizing a vadose zone Sr-90 source by infiltration of water from overlying fire-suppression water utility lines and hydrants (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]).

3.6.2 Confined Aquifer Zones within the Ringold Formation

A single well, 699-81-62, penetrates 160 m (527 ft) of Ringold Formation and another 288 m (945 ft) into the CRBG. Along with unpublished well logs for 699-81-62, data from wells in 100-BC and 100-N enabled Lindsay (*Geology of the Northern Part of the Hanford Site: An outline of Data Sources and the Geologic Setting of the 100 Areas* [WHC-SD-EN-TI-011]) to determine that the Ringold units A, B, and possibly C are present beneath the 100-K surface.

Limited deep drilling investigations have also shown the presence of three confined aquifer zones in the suprabasalt aquifer system: Ringold units C, B, and A.

The units comprise the bottom half of the Ringold Formation and are composed of fluvial gravels and sands, interbedded with overbank fine sand, silt, and clays. The Ringold units A, B, and C consist of clast-supported, pebble-to-gravel sized fraction particles with a fine to medium sand matrix. The overbank units are silty sands, silts, and clay size fraction deposits, which show some soil alteration/ formation and comprise the RLM and RUM.

The Ringold unit A lies on top of the CRBG. At 699-81-62, a basal 2.1 m (7 ft) thick conglomerate was noted in a log that otherwise did not describe Ringold sediments. Lindsay (*Geology of the Northern Part of the Hanford Site: An outline of Data Sources and the Geologic Setting of the 100 Areas* [WHC-SD-EN-TI-011]) interprets a total of 7.6 to 9.1 m (25 to 30 ft) of Ringold unit A material beneath the RLM. The RLM is 30 m (100 ft) thick and is separated from the RUM by the Ringold unit B gravels and sands. The Ringold unit B is reported beneath 100-BC, thinning to the east in 100-K, where it is estimated to be 18.3 m (60 ft) thick. The RUM is in excess of 61 m (200 ft) thick and is separated by a 1.5 to 3 m (5 to 10 ft) thick sand and gravel that Lindsey (1996) interprets as Ringold unit C (*Geology of the Northern Part of the Hanford Site: An outline of Data Sources and the Geologic Setting of the 100 Areas* [WHC-SD-EN-TI-011]). The Ringold unit C lies about 16.8 to 18.3 m (55 to 60 ft) below the contact with the Ringold unit E.

Of five wells drilled into the upper 15.2 m (50 ft) of the RUM at 100-K, including four drilled as part of RI characterization, water-bearing transmissive units have been found in two wells. At the two wells, 199-K-32B and recent RI Well 199-K-192, the units are found at differing elevations within the RUM. The 10.9 m (3 ft) thick lens at 199-K-32B consists of a fine sand with traces of silt and clay, while the 2.7 m (9 ft) lens at 199-K-192 consists of a gravelly, silty sand. Head measurements taken during drilling at 199-K-192 indicate a vertical upward gradient of 3.3 m (10.7 ft). Well 199-K-32B displays an average 2.8 m (9.1 ft) vertical upward head or gradient compared to adjacent Well 199-K-32A, which is screened in the upper unconfined aquifer. The static water level in Well 199-K-32B rises to within an average of 15.2 m (50 ft) of the ground surface. At 199-K-32B, the water level rises to within 9.4 m (30.4 ft) of ground surface. Hydraulic conductivity and other data have been generated from a pump test conducted in Well 199-K-192. Hydraulic testing at 199-K-32B is not known.

Available well data are inadequate to determine the extent or connection between these two units. These units may correlate with the regionally extensive Ringold unit C or may be a localized lens. The two wells are about 400 m (1,320 ft) apart.

3.6.3 Columbia River Basalt Group Hydrogeology

Based on the CRBG geology discussion in Section 3.4.2.4, the greatest porosity and permeability within a flow is usually found in the chilled basal margin and at the vesicular flow top. In addition, the interbeds usually are more permeable, although some units have reported low permeability. The dense, fractured interior of a basalt flow is typically of low permeability as the fractures usually exhibit very close spacing. Regional fracture sets and local tectonic features around folds and faults provide greater porosities. These features combine to provide generally extensive lateral flow capabilities but limited vertical migration of groundwater. Estimated effective porosities (*Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164]) have been reported as 20 percent for interbeds, 10 percent for fractured basalt zones, 5 percent for vesicular basalt zones, and 1 percent for basalt flow interiors.

The Grande Ronde, Wanapum, and Saddle Mountain basalt formations are described (*Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164]) as being confined to semiconfined aquifers. Recharge for the confined aquifers of the Grande Ronde, Wanapum, and Saddle Mountain formations comes from the western margins of the Columbia Plateau where the formations outcrop, cross stream or river outcrops, and where covered with lesser thicknesses of sediments. The Basalt Waste Isolation Project studies concluded there was also significant movement of confined groundwater between adjacent basalt flows. The Wanapum and Saddle Mountains are recharged by precipitation at outcrops and subcrops around the margins of the Pasco Basin, as at the Saddle Mountains and Rattlesnake/Horse Heaven anticlines to the south. Locally, the Gable Mountain, Gable Butte, and Umtanum Ridge may provide recharge areas.

Across the Pasco Basin, head data indicate a vertically upward gradient for confined aquifers within the Grande Ronde and Wanapum formations. For the Saddle Mountain basalts, the hydraulic head data indicate that while vertical upward gradients are generally present, they decrease with greater depth in the basalt or may exhibit a downward vertical gradient. Vertical leakage between flows is unquantified. Water levels in Well 699-81-62, screened across the Mabton Interbed (more than 406 m [1,331 ft] bgs), rose to an elevation of 125.87 m (412.9 ft) AMSL or to within 9.44 m (31 ft) of the ground surface

Basalt aquifers are characterized as low sulfate, low chloride bicarbonate water with 200 to 300 µg/L of dissolved solids and a pH ranged of 7.5 to 8.5. In total, the three basalt formations exhibit similar geochemical properties, but may differ markedly within the formations.

Transmissivity values have been estimated from data across the Columbia Plateau ((*Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164][DOE/RW-0164]). Wanapum and Saddle Mountain basalt formations fall within a range of 1 × 10E-4 to 9 × 10E-2 m^2/sec (100 to 90,000 ft^2/day) with a mean value of 2 × 10E-3 m^2/sec (2,000 $ft^{2/}$day). Storage coefficients for specific formations have not been calculated but values of 2 to 6 × 10E-3 are reported.

Groundwater conditions within the basalt flows are regarded as having none to insignificant impact to groundwater conditions and contaminant distribution in the unconfined aquifer at 100-K.

3.6.4 Supra-Basalt Sediments

Above the CRBG, a series of sedimentary units has been deposited through the actions of the ancestral Columbia River and related river systems and by cataclysmic floods. The Pasco Basin represents the lowest area both topographically and structurally in the Columbia Plateau.

3.6.5 Groundwater-Surface Water Interactions

Groundwater and surface water interactions are essential to understanding the rate and magnitude of contaminants potentially entering the Columbia River. The zone of interaction is represented by the boundary between groundwater and river water below the river and near the shoreline. Groundwater discharge into the river environment occurs across the riparian zone as seeps and via the river channel substrate. Riverbank seepage creates a potential human health risk through exposure to contaminants and the introduction of contaminants into the food chain. Upwelling of groundwater into the channel substrate also poses a potential risk to aquatic organisms and may introduce contaminants to the food chain. Section 4.2.4 discusses recent pore water, surface water, and sediment sampling results, and Figure 3-42 illustrates the zone of interaction and riverbank seepage.

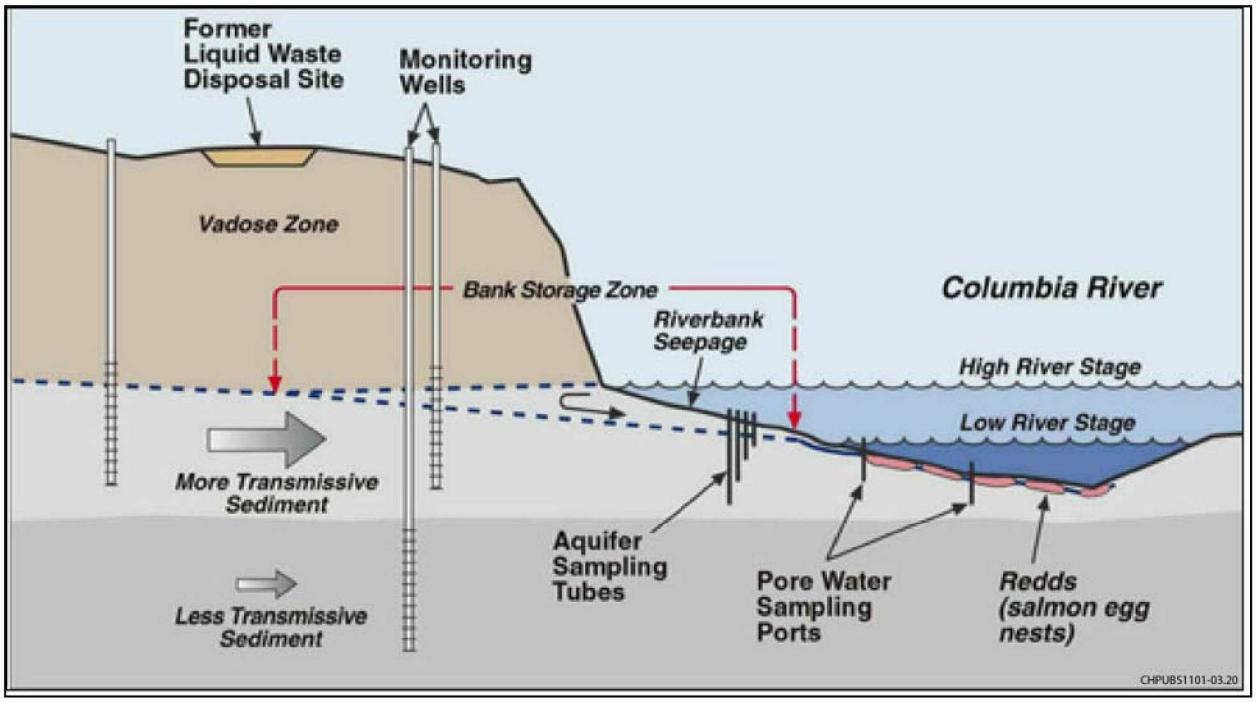
Groundwater flow, especially near the river, is strongly influenced by river stage, which is directly controlled by the upstream Priest Rapids Dam. The rise and fall of river stage create a dynamic zone of interaction between groundwater and river water, and influence flow patterns, transport rates, contaminant concentrations, and attenuation rates within the system (*Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River: Progress Report for the Groundwater/River Interface Task Science and Technology Groundwater/Vadose Zone Integration Project* [PNNL-13674]).

Physical, chemical, and biological processes that potentially alter the characteristics of approaching groundwater occur within the zone of interaction. Data suggest that physical processes are the primary influences on contaminant concentrations and fluxes where groundwater discharges into the river. Chemical processes may render contaminants less mobile as they adsorb to sediments or precipitate.

Riverbank seep discharges to the river, as shown in Figure 3-42, are visible during low river stage. Conversely, during high river stage, the seeps are submerged as river water infiltrates the riverbanks and forms either a layered system or a mixture during interaction with approaching groundwater. Data from the seeps and

along the riverbank indicate that the riverbank storage water composition oscillates dramatically from almost entirely river water during high river stage to primarily groundwater during low river stage (*Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River: Progress Report for the Groundwater/River Interface Task Science and Technology Groundwater/Vadose Zone Integration Project* [PNNL-13674]).

Along the 100 Area shoreline, riverbank seepage composed of contaminated groundwater creates potential pathways for contaminants to enter the Columbia River (*Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River* [PNNL-5289]). Potential mixing of river water with groundwater may produce lower contaminant concentrations in the seep discharges than can be found in upgradient groundwater. These lower contaminant concentrations may be attributed to the bank storage phenomenon, where infiltrated river water stored in the riverbank during high river stage returns to the river via seeps during lower river stage (*Hanford Site Environmental Report for Calendar Year 2007* [PNNL-17603]).



Note: Modified from PNNL-13674, *Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River: Progress Report for the Groundwater/River Interface Task Science and Technology Groundwater/Vadose Zone Integration Project*.

Figure 3-42. Illustration of Zone of Interaction and River Bank Seepage

3.6.6 Aquifer Intercommunication

Aquifer intercommunication occurs when groundwater moves vertically between aquifers, such as the unconfined aquifer and lower transmissive zone of the RUM, or between the RUM transmissive zone and Ringold unit B confined aquifer. There is the potential for movement of water between the Columbia River basalt confined aquifer system and Ringold unit A confined water-bearing zones. For groundwater movement to occur between different aquifers, a difference in potentiometric head must exist. The vertical hydraulic gradient has been shown to be upward at wells close to the Columbia River in 100-K (199-K-192, 199-K-32B). Intercommunication between aquifers can occur several ways:

- Natural vertical head differences between aquifers push water through the intervening aquitard

- Artificial differences in head push water through an intervening aquitard
- Erosional unconformities provide a pathway for groundwater to move between aquifers (for instance, where the RUM unit surface may have been eroded by Pleistocene floods, possibly exposing the upper transmissive zone sands to the unconfined aquifer)
- Artificial pathways along poorly constructed wells or boreholes connecting aquifers

Erosional unconformities are considered the most likely significant mechanism for direct physical interconnection between the unconfined aquifer and confined aquifer zones within the upper RUM. The potential for pathways along poorly constructed wells also exists; however, older wells suspected of having poor construction have been decommissioned.

3.6.7 Horizontal Hydraulic Gradients and Groundwater Velocity

Table 3-41 summarizes available information on horizontal saturated hydraulic conductivity (100-KR-4 RPO Mod Data Package [SGW-41213]). The hydraulic conductivity values are based on slug tests and pumping test field data developed in 100-K. As part of a modeling effort (*Conceptual Framework and Numerical Implementation of 100 Area Groundwater Flow and Transport Model* [SGW-46279]), the hydraulic conductivity data were evaluated to estimate representative values for Ringold unit E and the Hanford formation. The K_s values recorded in monitoring wells completed within the 100-KR-4 OU range from a minimum of 0.98 m/day (3 ft/day) in Monitoring Well 199-K-108A to a maximum of 44.2 m/day (145 ft/day) at Monitoring Well 199-K-37 and were estimated for the Ringold unit E portion of the Ringold Formation. Horizontal saturated hydraulic conductivity values are unavailable for the RUM unit.

3.6.8 Vertical Groundwater Gradients

Hydraulic conductivity/permeability tests were performed on undisturbed sediment samples collected in each boring, generally at the top of the RUM unit when fine-grained sediments became evident during drilling. For those wells penetrating 15.2 m (50 ft) into the RUM, samples were also taken at the midpoint and base of the borehole. Table 3-42 summarizes the coefficient of permeability data and moisture content/soil density data.

Values range from 5.4×10^{-1} to 7.9×10^{-6} m/day. (Note that these are values for groundwater flow vertically downward.) The higher values occur in sediment samples that may include a partial fraction of lower Ringold unit E, possibly mixed in during erosion of the RUM, coupled with deposition of the Ringold unit E sands and gravels. The average value for all test results is 3.22×10^{-2} m/day and for RUM only samples 6. 98×10^{-5} cm/sec. The range of vertical permeability values for RUM only specimens is 2.07×10^{-3} to 8.4×10^{-6} m/day. Data provide no conclusive evidence for permeability changes within the RUM. Data from Well 199-K-195 show decreasing permeability with depth, while Well 199-K-184 data show increasing permeability with depth. Absent vertical permeability data from overlying Ringold unit E sediments, it is difficult to state the relative differences in vertical flow for the RUM. These values agree closely with published permeability values for clays (*Applied Hydrogeology* [Fetter, 2001]) and contrast sharply for well-sorted sands (0.86 to 86.4m/day) and well-sorted gravels (8.64 to 864 m/day). Aquifer storage property data specific to 100-K are not available; however, some data are available for Ringold unit E and the Hanford formation based on field tests conducted in the 200 Area. Specific yield value for the poorly sorted sediments of Ringold unit E is estimated to range from 0.05 to 0.2.

3.6.9 Groundwater Geochemistry

The most recent major ion chemistry data available were compiled for 20 monitoring wells screened within the shallow unconfined aquifer (Ringold unit E) within or upgradient of the 100-KR-4 OU (Table 3-43 and Figure 3-43). The major element chemistry of all 20 samples was plotted on a Piper

diagram (Figure 3-44) to illustrate the general chemical characteristics of groundwater associated with the different Cr(VI) plumes (the 100-K West, 100-K East, 100-KR-4, and 100-K North plumes and associated source areas) within the 100-KR-4 OU. In addition, the nitrate, sulfate, and bicarbonate concentrations in these samples were plotted on a separate triangular diagram to illustrate the relative abundance of nitrate (Figure 3-45). Finally, individual radial diagrams for 12 of the 20 analyses are presented in Table 3-43. These Piper diagrams are associated with the monitoring well locations to better illustrate the differences in the major ion water chemistry within the 100-KR-4 OU (Figure 3-46).

Ringold Unit E. The Ringold unit E groundwater at the 100-KR-4 OU has a pH range between 7.5 and 8.3 and an average dissolved oxygen (DO) concentration of approximately 8.0 mg/L (Table 3-43). All the samples are classified as predominantly calcium bicarbonate water that also contains notable but variable concentrations of sulfate and nitrate (Figures 3-44 and 3-45). Solubility calculations indicate that all these groundwater samples were approximately saturated with respect to calcite.

Although no true background well is present in the area, Monitoring Well 699-73-61 is located several hundred meters (several thousand feet) upgradient of the 100-KR-4 OU and the groundwater from this well is nominally considered to approximate background conditions for 100-KR-4 (Figures 3-43, 3-44, and 3-45, and Table 3-43). This "background" water is dominated by calcium bicarbonate with sulfate present as the next most abundant anion (Figures 3-45 and 3-46). The presence of nitrate in this sample at a concentration of approximately 8.6 mg/L strongly suggests that some of the nitrate observed in the groundwater of the 100-KR-4 is from one or more upgradient sources.

However, most of the samples presented in Table 3-43 contain nitrate concentrations above 10 mg/L, and substantially elevated levels of nitrate (between 29 and 84 mg/L) are present in Monitoring Wells 199-K-106A, 199-K-108A, 199-K-34, and 199-K-132 in the 100-K West plume and Monitoring Well 199-K-18 in the 100-KR-4 plume (Table 3-43 and Figures 3-43, 3-45, and 3-46). The elevated levels of nitrate in the 100-KR-4 OU indicate local sources of nitrate contamination within 100-KR-4 and in the 100-K West plume. In addition, those groundwater samples containing the highest concentrations of nitrate contain elevated levels of calcium relative to those samples that have lower nitrate (Table 3-43 and Figure 3-46).

The groundwater samples showing the greatest anthropogenic effects on major ion chemistry in the 100-KR-4 OU were collected from Monitoring Wells 199-K-135 and 199-K-110A. Groundwater samples from both these wells have major ion chemistry that is notably distinct from the other samples evaluated.

Monitoring Well 199-K-135 is located near the former calcium polysulfide and vegetable oil injection treatability test that was conducted for Cr(VI) remediation. Although nitrate, sulfate, and DO concentrations are lower in this sample than in the other samples presented in Table 3-43, the alkalinity, calcium, and magnesium content of this sample are substantially higher. As a result of the geochemical processes associated with this test, the water from 199-K-135 plots much farther into the calcium-magnesium bicarbonate field of the Piper diagram presented in Figure 3-44.

Monitoring Well 199-K-110A is located in the Cr(VI) plume (Figure 3-43) immediately upgradient of the 105-KE Reactor and FSB. The DO concentration of this water is approximately 6.6, near the lower end of the range of values observed for these samples presented in Table 3-43 (except for the lower DO in the calcium polysulfide well). The anionic component of this groundwater contains a much larger fraction of chloride than any of the other samples evaluated (Table 3-43). This relative enrichment in chloride results in the separation of this sample from the general trend produced by the remaining 19 samples that are distributed along the bicarbonate-sulfate axis of the Piper diagram of Figure 3-44 (bottom right component).

Table 3-41. Horizontal Saturated Hydraulic Conductivity in 100-K

Well Number	Northing (m)	Easting (m)	K_s (ft/day)	K_s (m/day)	Formation	Test Type/ Analysis Method	Reference
199-K-10	146628.1	568912.8	52	16	Ringold unit E	Pumping/Cooper and Jacob (1946)	PNL-10886
199-K-10	146628.1	568912.8	53	16.16	Not Reported	Pumping/Cooper and Jacob (1946)	PNL-8337
199-K-106A	146502.4	568697.4	9	2.68	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-DP-090
199-K-107A	146468.8	568579.9	5	1.55	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-DP-090
199-K-108A	146396.1	568687.2	3	0.98	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-DP-090
199-K-110A	146677.9	569230	4	1.1	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-DP-090
199-K-110A	146677.9	569230	32	9.79	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-T1-221
199-K-111A	146968.9	569308.2	26	8	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-DP-090
199-K-111A	146968.9	569308.2	27	8.35	Ringold unit E	Slug/Bouwer and Rice (1976)	WHC-SD-EN-TI-221
199-K-18	147400.8	569353.7	9	2.8	Ringold unit E	Pumping/Cooper and Jacob (1946)	CCN 024566
199-K-19	147368.6	569458.5	6	1.83	Ringold unit E	Pumping/Cooper and Jacob (1946)	CCN 024566
199-K-20	147687.2	569520.5	111	33.84	Ringold unit E	Pumping/Cooper and Jacob (1946)	CCN 024566
199-K-21	147932.1	569769.9	16	5	Ringold unit E	Pumping/Cooper and Jacob (1946)	CCN 024566
199-K-22	148097.4	570023.7	3	0.88	Ringold unit E	Pumping/Cooper and Jacob (1946)	CCN 024566
199-K-32A	147006.7	569024.2	80	24.38	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79
199-K-33	146713.3	568573.7	19	5.79	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79

Table 3-41. Horizontal Saturated Hydraulic Conductivity in 100-K

Well Number	Northing (m)	Easting (m)	K_s (ft/day)	K_s (m/day)	Formation	Test Type/ Analysis Method	Reference
199-K-34	146501.9	568605.8	68	20.73	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79
199-K-35	146110.7	568832.3	124	37.8	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79
199-K-36	146390.7	569373.8	87	26.52	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79
199-K-37	148226.5	570216.2	145	44.2	Ringold unit E	Slug/Bouwer and Rice (1976)	DOE/RL-93-79
199-K-183	568,302.28	146,439.70	49	15	Ringold unit E	Slug/KGS	Appendix C
199-K-184	568,618.68	146,366.32	20	6	Ringold unit E	Slug/KGS	Appendix C
199-K-185	568,574.92	146,726.17	92	28	Ringold unit E	Slug/KGS	Appendix C
199-K-186	568,209.65	146,625.36	No Data*	No Data*	Ringold unit E	Slug/KGS	Appendix C
199-K-187	569,499.00	146,054.68	89	27	Ringold unit E	Slug/KGS	Appendix C
199-K-188	569,386.80	146,370.11	53	16	Ringold unit E	Slug/KGS	Appendix C
199-K-189	569,150.27	146,809.68	89	27	Ringold unit E	Slug/KGS	Appendix C
199-K-190	568,835.28	146,873.27	39	12	Ringold unit E	Slug/KGS	Appendix C
199-K-191	569,711.20	146,886.65	1.6	0.5	Ringold unit E	Slug/KGS	Appendix C
199-K-192	569,393.27	147,294.32	0.7	0.2	RUM/Confined Sand Lens	Slug/KGS	Appendix C
199-K-193	570,641.99	146,969.58	466	142	Ringold unit E	Slug/KGS	Appendix C
199-K-194	571,315.65	147,281.98	466	142	Ringold unit E	Slug/KGS	Appendix C
199-K-195	568,850.08	146,086.38	29	15	Ringold unit E	Slug/KGS	Appendix C

Table 3-41. Horizontal Saturated Hydraulic Conductivity in 100-K

Well Number	Northing (m)	Easting (m)	K_s (ft/day)	K_s (m/day)	Formation	Test Type/ Analysis Method	Reference

Sources: Bouwer and Rice, 1976, "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells."

CCN 024566, "Field Summary Report 100-H Area Well Production Testing."

Cooper and Jacob, 1946, "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History."

DOE/RL-93-79, *Limited Field Investigation Report for the 100-KR-4 Operable Unit.*

PNL-8337, *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System.*

PNL-10886, *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report.*

WHC-SD-EN-DP-090, *Borehole Data Package for the 100-K Area Ground Water Wells, CY 1994.*

WHC-SD-EN-TI-221, *Geology of the 100-FR-3 Operable Unit, Hanford Site South-Central Washington.*

* Water level dropped too fast during test to record data, indicates high hydrologic conductivity.

Table 3-42. Vertical Saturated Hydraulic Conductivity at 100-K RI/FS Wells

Sample Geotechnical Properties								
Well ID	Sample ID	Sample Depth/Interval (m)	Sample Depth/Interval (ft)	Log Formation/Description	Permeability, Vertical (m/day)	Wet Unit Weight (lbs)	Dry Unit Weight (lbs)	Moisture Content (%)
199-K-183	B25TX0	45.11 to 45.872	148 to 150.5	RUM, Top, Silt	1.21E-05	127.1	102	24.6
199-K-184	B27LP2	49.68	163	RUM, Top, Silt	1.47E-05	129.6	107.4	20.6
199-K-184	B29C42	56.967	186.9	RUM, Mid, Silt	1.21E-04	131.6	108.7	21.1
199-K-184	B29C43	65.105	213.6	RUM, Base, Silt	2.07E-03			
199-K-185	B25YX5	40.691	133.5	RUM, Top, Silt	3.20E-05	130.9	113	15.8
199-K-186	B29LX0	48.77 to 49.53	160 to 162.5	Ringold unit E?, Basal, Silt?	5.35E-01	123.6	116	6.5
199-K-187	B25V87	60.259 to 62.021	197.7 to 200.2	RUM, Top, Mud	8.40E-06	125.6	93.5	34.3
199-K-188	B29C45	63.825 to 64.587	209.4 to 211.9	RUM, Mid, Silt	2.40E-04			
199-K-188	B29C46	70.866 to 71.63	232.5 to 235	RUM, Base, Silt	1.04E-04	128.6	104.3	23.3
199-K-189	B26X21	47.092	154.5	RUM, Top, Clay	6.05E-04	118	97.1	21.5
199-K-190	B26VN7	41.361 to 41.514	135.7 to 136.2	RUM, Top, Silt/Mud	5.90E-04	129.4	109.5	18.2
199-K-191	B25X51	46.665 to 47.427	153.1 to 155.6	RUM, Top, Mud/Clay	7.90E-06	126.5	101.7	24.3
199-K-192	B27985	43.495 to 44.257	142.7 to 145.2	RUM. Top, Sandy Silt	5.40E-05			
199-K-193	B25YX2	49.195	161.4	RUM, Top, 85% Clay, 10% Gravel, 5% Silt	2.90E-04			
199-K-194	B260N5	40.54 to 41.3	133 to 135.5	Ringold unit E, Basal, Silty, Sandy Gravel with increasing Silt content	3.280E-02	124.6	100.4	24.1
199-K-195	B27HR8	54.86 to 55.626	180 to 182.5	RUM, Top, 85% Silt, 5% Gravel, 10% Sand	6.7E-3	146.8	133.7	24.2
199-K-195	B29BN0	61.87 to 62.636	203 to 205.5	RUM, Mid, 100% Silt/Clay	3.2E-4	126.3	101.9	24.2
199-K-195	B29BN1	69.49 to 70.256	228 to 230.5	RUM, Base, Mud/Clay, Highly plastic, moderately cemented	4.2E-5	129.2	103.9	24.4

Table 3-43. 100-KR-4 OU Major Ion Chemistry Data

Well ID	199-K-106A	199-K-107A	199-K-108A	199-K-11	199-K-110A	199-K-111A	199-K-132	199-K-135 CaS(1-X)	199-K-142	199-K-151
Sampling Date	**6/13/2010**	**10/18/2009**	**6/13/2010**	**6/11/2010**	**4/15/2010**	**6/11/2010**	**6/15/2010**	**10/18/2009**	**6/11/2010**	**6/24/2010**
Alkalinity	160	120	140	120	130	140	120	490	94	99
Ca (µg/L)	73,900	48,400	57,800	39,700	71,000	50,300	56,000	22,5000	28,000	29,900
Cl (µg/L)	26,500	14,300	10,800	8,240	51,300	7,870	13,100	18,900	6,280	9,500
DO (µg/L)	8,990	8,270	9,690	8,330	6,640	9,030	7,750	2,880	8,270	20.4
Cr(VI) (µg/L)	4.462	60.46	4.462	39.04	**2**	70.94	47.74	4.462	4.462	40.15
Mg (µg/L)	17,400	9,860	12,500	10,800	11,300	11,700	6,450	26,800	5,590	9,270
pH	7.64	7.75	7.72	7.91	7.52	7.91	7.5	7.05	8.16	8.15
K (µg/L)	7,790	5,040	6,010	5,210	3,830	5,960	3,000	5,650	3,710	4,010
Na (µg/L)	23,000	15,500	21,300	14,400	7,600	14,000	15,500	10,200	7,250	24,000
Conductivity (µmho/cm)	639	392	513	361	460	419	395	1,175	225	346
SO_4	40,700	35,700	36,200	37,700	15,900	37,000	33,600	11,800	10,400	55,700
Temperature (°C)	17	16.4	17.2	21.7	16.8	18.1	23.9	19.1	17.2	18.9
NO_3 (µg/L)	83,700	22,089.7	70,400	12,600	13,900	36,400	29,900	677	1,330	5,580
Well ID	**199-K-152**	**199-K-157**	**199-K-18**	**199-K-182**	**199-K-20**	**199-K-22**	**199-K-31**	**199-K-34**	**199-K-37**	**699-73-61**
Sampling Date	**6/22/2010**	**3/8/2010**	**6/11/2010**	**6/22/2010**	**6/16/2010**	**6/11/2010**	**6/11/2010**	**6/30/2010**	**6/24/2010**	**6/18/2010**
Alkalinity	94	110	63	91	91	91	120	140	97	110
Ca (µg/L)	35,600	67,400	71,100	39,600	42,200	60,500	46,000	59,600	38,800	34,100
Cl (µg/L)	6,530	16,200	14,000	11,200	17,500	20,400	15,000	18,200	10,500	6,620
DO (µg/L)	8,450	9,910	6,340	9,680	8,230	12,650	6,920	8,690	9970	9,160
Cr(VI) (µg/L)	139		435	181.8	4.462	261	11.38	68.04	74.73	4.462
Mg (µg/L)	10,400	10,500	11,700	12,300	9,360	10,400	10,600	10,700	8,570	9,480
pH	8.03	7.93	8.3	8.03	7.67	8.06	7.71	7.72	8.25	8.13
K (µg/L)	4280	4,800	4,180	4,390	4,330	2,770	5,220	2,180	3,700	4,930
Na (µg/L)	9,600	15,500	4,680	10,500	7,620	8,470	15,400	17,300	9,370	15,000
Conductivity (µmho/cm)	285	492	496	337	345	435	389	435	330	327
SO_4	36,600	80,100	94,800	45,300	37,700	74,500	37,000	20,000	42,100	34,900
Temp (°C)	21.1	19.4	18.8	19.9	19.8	19.7	17.1	16.8	20.2	19.1
NO_3 (µg/L)	7,480	31,600	65,500	17,600	12,000	20,500	23,400	39,700	8,320	8,680

Note: Alkalinity = mg/L as CaCO3; for 199-K-110A, Cr(VI) data from 10/2009, Cr(VI) not collected in 2010.

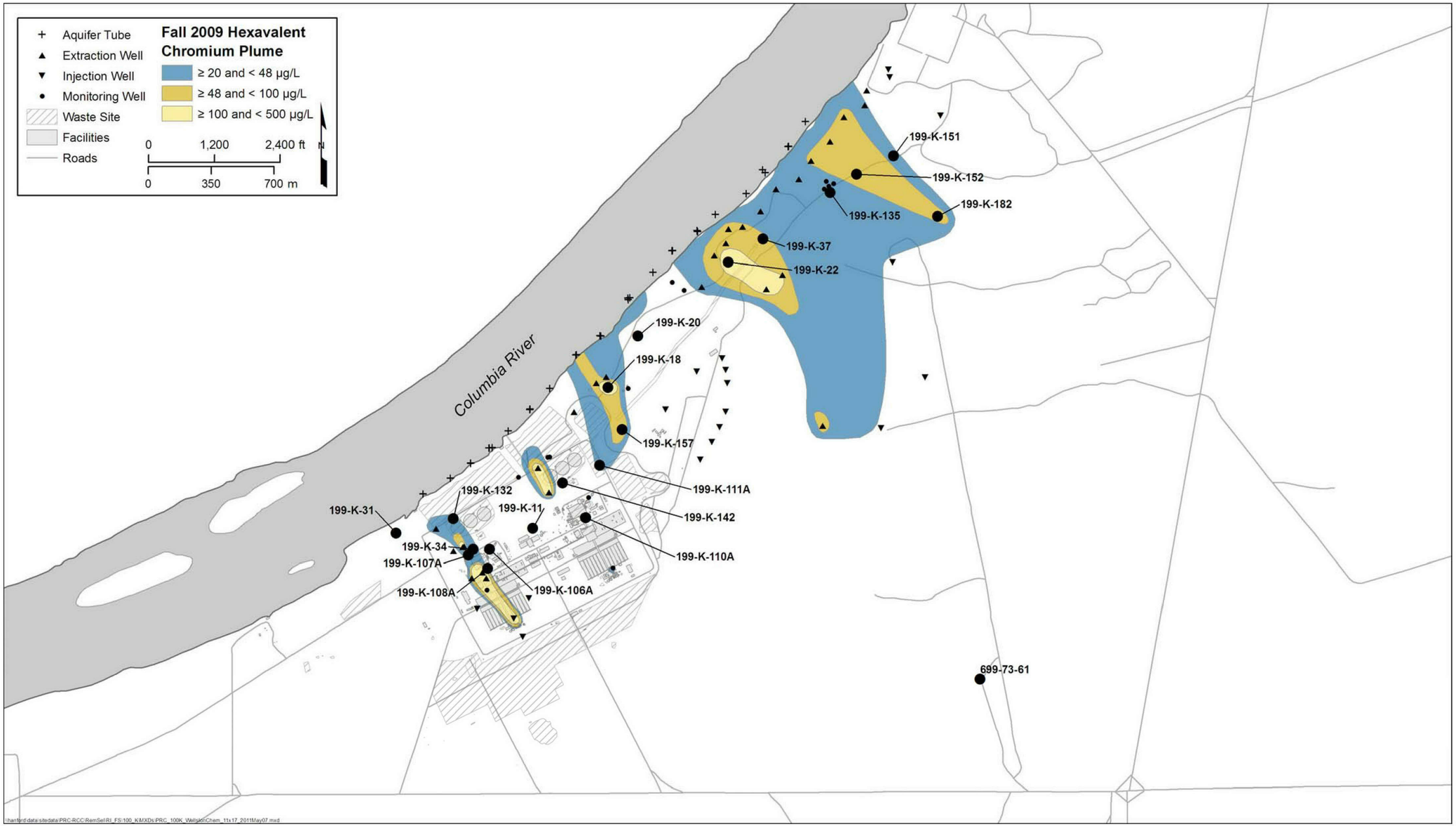


Figure 3-43. Monitoring Well Locations Selected for Major Ion Chemistry Evaluation in the 100-KR-4 OU

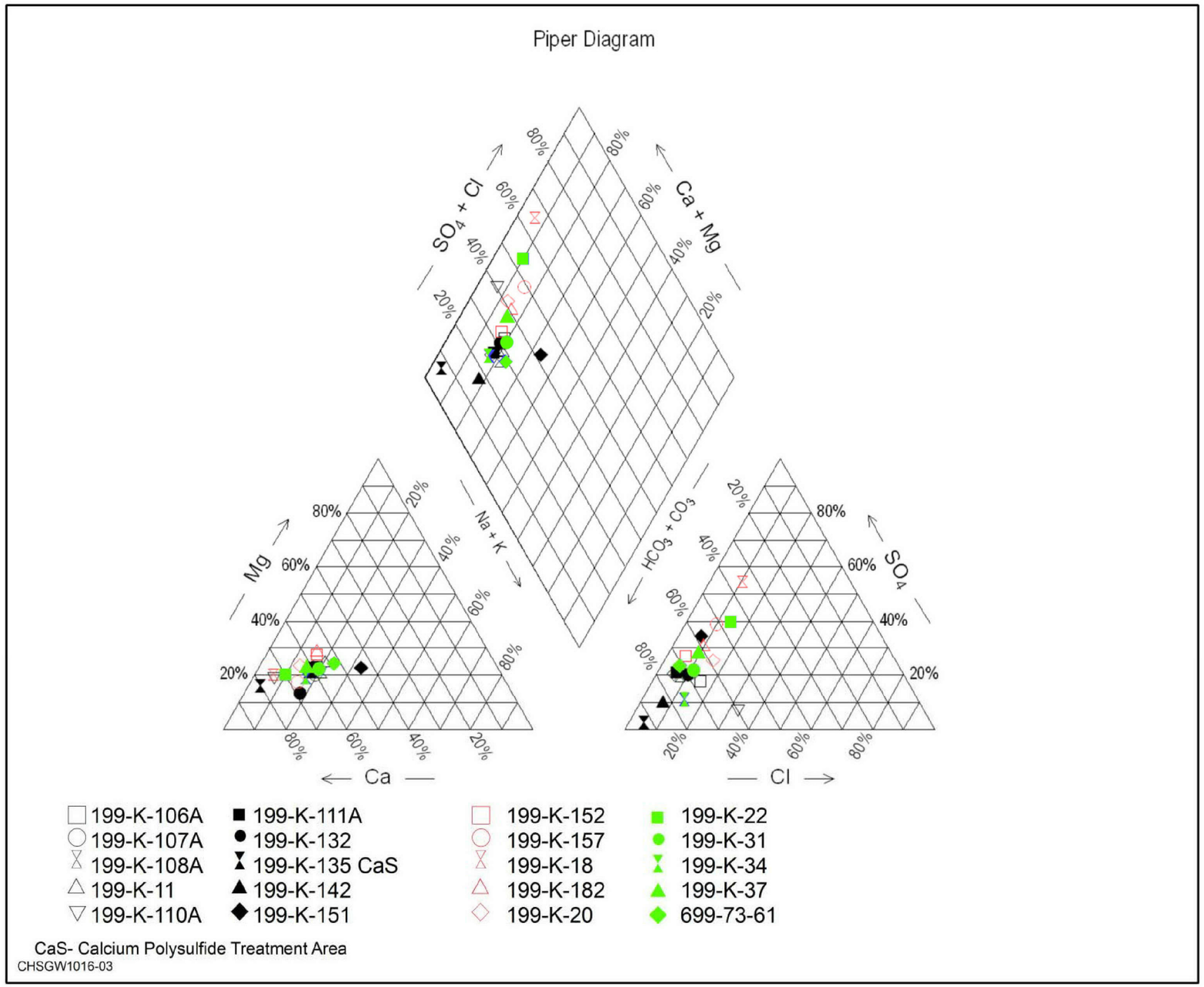


Figure 3-44. Major Ion Chemistry of Groundwater from Selected Monitoring Wells within the 100-KR-4 OU

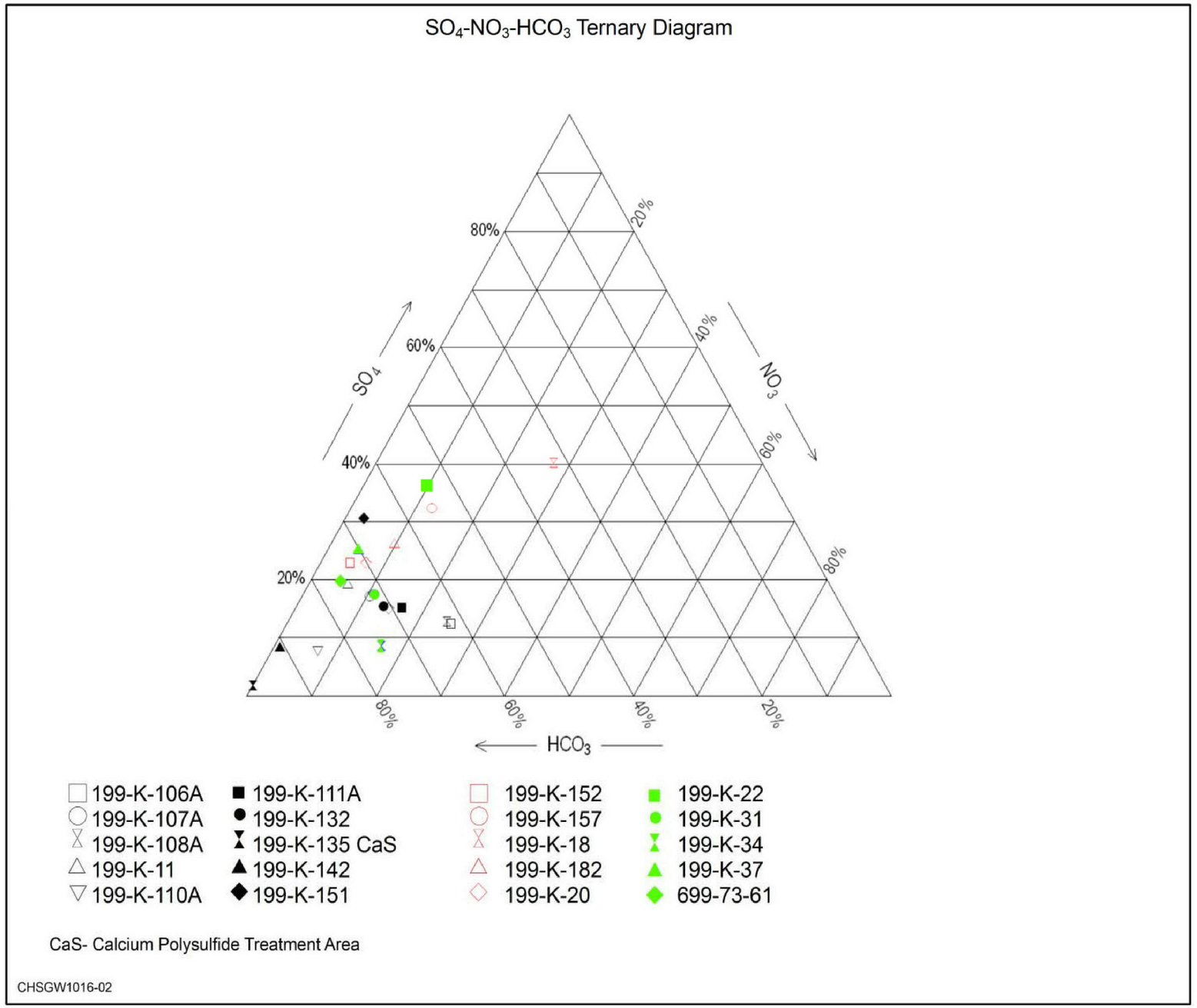


Figure 3-45. Relative Abundances of Sulfate, Nitrate, and Bicarbonate in the Groundwater of the 100-KR-4 OU

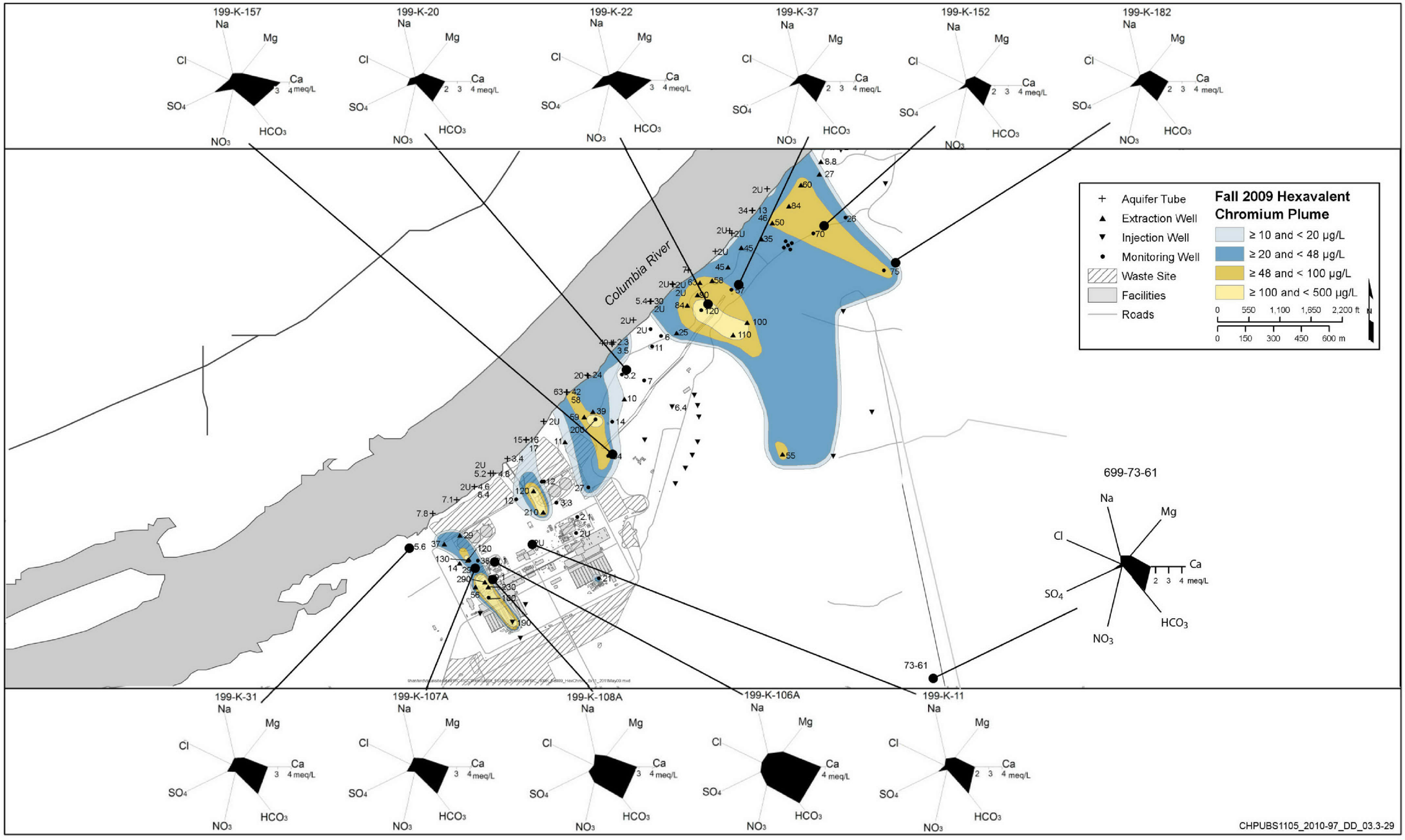


Figure 3-46. Major Ion Chemistry of the 100-KR-4 OU by Geographic Area and Plume Association

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3.6.10 Conclusions

- This association between groundwater samples containing the highest concentrations of nitrate and elevated levels of calcium suggests that the nitrate may have been introduced into Ringold unit E as nitric acid that had been leaked, spilled, or disposed in the area and subsequently neutralized by the dissolution of calcium carbonate in the vadose zone.
- These chemical characteristics of groundwater samples from Monitoring Well 199-K-135, such as elevated calcium and alkalinity, low DO, and low nitrate, are consistent with the residual effects of the calcium polysulfide and vegetable oil treatability test.
- The origin of the high chloride component and the lower DO of groundwater sampled at Monitoring Well 199-K-110A is uncertain but may reflect disposal activities at the 105-KE Reactor and FSB.

3.6.11 Groundwater Use

Currently, 100-K groundwater is extracted only for remediation and monitoring. No water supply wells are located in 100-K.

3.7 Artificial Water Systems

Artificial water systems at 100-K are the river water intake and filtration system, fire suppression lines, and the groundwater pump-and-treat system. The pump-and-treat systems are currently the only systems that affect the groundwater system. Since 1997, pump-and-treat system extraction and injection wells have contributed to localized groundwater depression and groundwater mounding, respectively, at 100-K. As a result, the groundwater flow regime in 100-K has varied significantly as extraction and injection wells are turned off and on, in addition to the seasonal variability discussed in Section 3.6.

3.8 Demography and Land Use

A detailed discussion of the population surrounding the Hanford Site, including adjacent counties and cities, is presented in the NEPA Characterization Report (PNNL-6415). The 2009 population estimate from the U.S. Census Bureau was that 47,530 people lived in the City of Richland, the closest population center to the Hanford Site. An estimated 58,650 people lived in Pasco and 67,810 people lived in Kennewick. Population groups near the Hanford Site include Native Americans and various minorities. Native American descendants living near the Hanford Site include members of the following federally recognized groups: the Confederated Tribes and Bands of the Yakama Nations, the Confederated Tribes of the Umatilla Indian Reservation, the Nez Perce Tribe, and the Confederated Tribes of the Colville Reservation. Other unrecognized Tribe members may also be living in the area. There is no continuous human inhabitation immediately adjacent to 100-K. The last human habitation in 100-K was in 1945 at a farm located near the KW Pump House.

The local economy is driven by three major sectors: DOE and its contractors operating the Hanford Site; Energy Northwest (formerly the Washington Public Power Supply System), which operates the nuclear powered Columbia Generating Station near Richland; and the agricultural community, including a substantial food processing component. Additional employment sectors driving the local economy include other major employers, such as non-DOE contractor employers in the region and the tourism industry.

DOE was assigned the authority to establish future land use for the Hanford Site in "Requirement to Develop Future Use Plans for Environmental Management Programs" (50 USC 2582). DOE worked for seven years during the 1990s using the NEPA EIS process to evaluate future land use alternatives. This process was conducted in coordination with nine cooperating agencies and consulting Tribal governments, including the U.S. Department of the Interior (Bureau of Land Management, Bureau of

Reclamation, and the U.S. Fish and Wildlife Service [USFWS]); the City of Richland; Benton, Franklin, and Grant Counties; the Nez Perce Tribe; and the Confederated Tribes of the Umatilla Indian Reservation. Although not a cooperating agency, the Yakama Nation participated at points throughout the EIS process. This effort resulted in the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (hereinafter called Hanford CLUP [DOE/EIS-0222-F]), which DOE adopted and implemented in "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)" (64 FR 61615). The intent of the Hanford CLUP (DOE/EIS-0222-F) is to provide a land-use plan for DOE's Hanford Site for at least the next 50-year planning period and lasting as long as DOE retains legal control of some portion of the real estate (*Supplement Analysis: Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, hereinafter called CLUP: Supplemental Analysis [DOE/EIS-0222-SA-01]). An amendment to this ROD clarifying the plan's implementing procedures, "Amended Record of Decision for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement" (73 FR 55824), was issued in September 2008. Hanford CLUP (DOE/EIS-0222-F) and CLUP: Supplemental Analysis (DOE/EIS-0222-SA-01) present a land-use map, the full set of nine land-use designations that define the permissible uses for each area of the site, and the implementing procedures that govern the review and approval of future land uses. The general objectives for groundwater and vadose zone cleanup are consistent with the intended use of the land.

These documents established long-term goals for use of the Hanford Site. The reasonably anticipated future land use for the 100 Area is Conservation-Mining, in which limited mining may occur for governmental purposes only. Remediation activities in the 100 Area (i.e., 100-BC, 100-K, 100-N, 100-D, 100-H, and 100-F) are considered pre-existing land use in the preservation land-use designation. Management within 100-K would allow recreational use (such as hiking, biking, hunting, and bird watching) of the surface areas but would include restrictions on intrusive human activities. Subsurface activities (e.g., excavation) would be restricted to preclude contact with or disturbance of contaminated soil. These activities could occur around, but not on, the waste sites.

Table 3-44 presents the current and potential land uses for the River Corridor, and Figure 3-47 represents the Hanford Site showing the land-use designations including the Hanford Reach National Monument.

Table 3-44. Current and Potential Future Land Use

Zone	Current Land Use	Potential Future Land Use
River Corridor	Former reactor operations and waste cleanup	High and low intensity recreation and conservation (mining) reserved for management and protection of archaeological, cultural, ecological, and natural resources. Must be consistent with the River Corridor land-use risk assessment.

Source: 64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)"

The stretch of the Columbia River flowing through the Hanford Site is referred to as the Hanford Reach. It is a major nontidal, free-flowing stretch of the Columbia River. The river, islands, gravel bars, sloughs, riparian areas, and dune field of the Hanford Reach provide a variety of habitats that are now rare along the Columbia River due to the extensive reservoir system, development, and agriculture. Since 1943, DOE (or its predecessor federal entities) has held title to the lands that make up the Hanford Reach. Administration of this unit is multi-jurisdictional and complex, with USFWS, Bureau of Land Management, DOE, and various state and local agencies each playing specific roles.

In 1994, the National Park Service completed the *Hanford Reach of the Columbia River: Comprehensive River Conservation Study and Environmental Impact Statement – Final* (DOI, 1994). This study evaluated outstanding features of the Hanford Reach and provided recommendations on alternatives for protecting the features. The associated ROD recommended designating the Hanford Reach and approximately 41,279 ha (102,000 ac) of adjacent lands as a National Wild and Scenic River and a National Wildlife Refuge, respectively (*United States Department of the Interior Record of Decision – Hanford Reach of the Columbia River: Final Environmental Impact Statement for Comprehensive River Conservation Studies* [DOI, 1996]). In 2000, Presidential Proclamation 7319 was signed, creating the Hanford Reach National Monument to be managed by USFWS and DOE ("Establishment of the Hanford Reach National Monument" [65 FR 37253]). The Monument was established for the purpose of protecting the biological, historic, and scientific objects contained within.

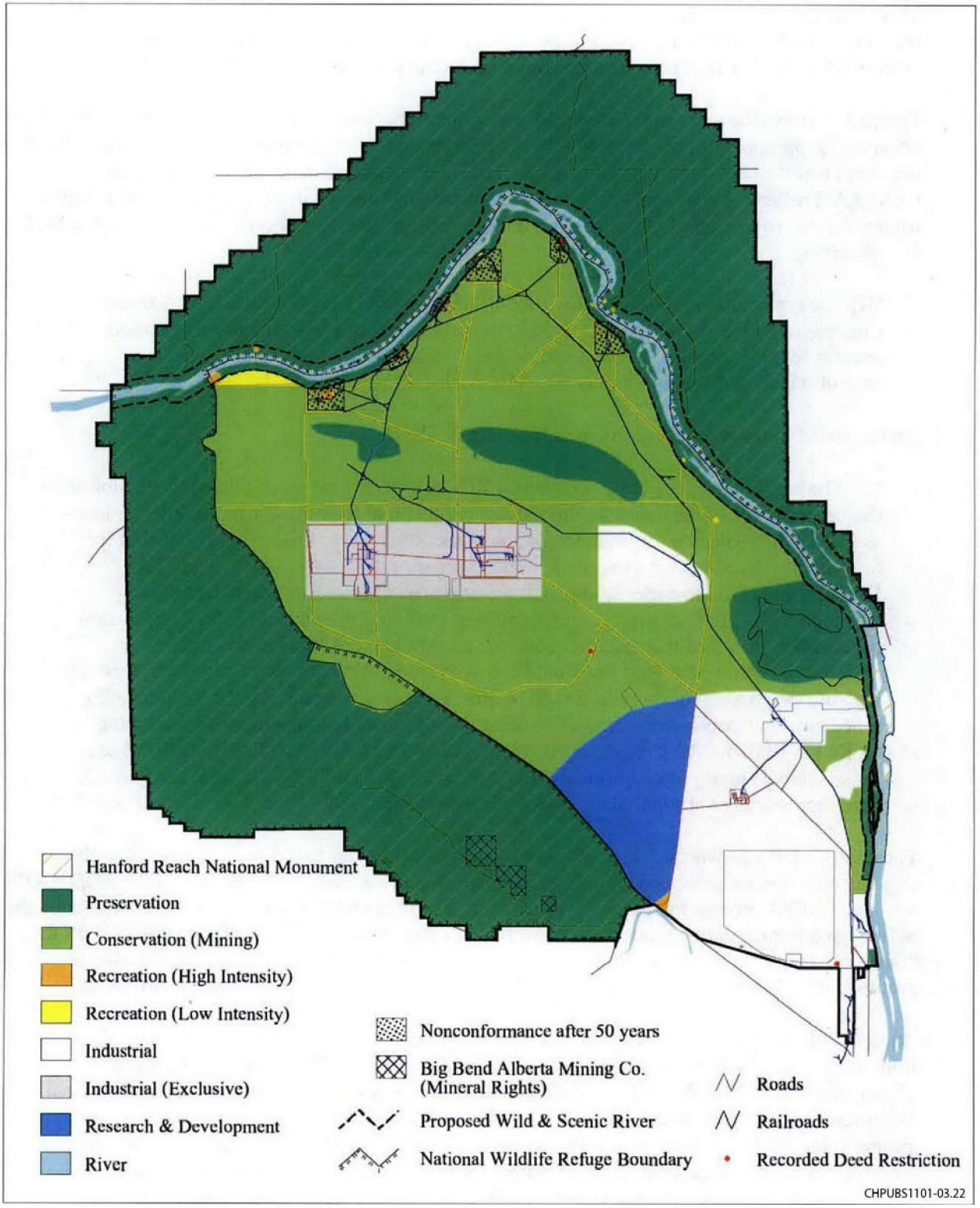
The Hanford Reach National Monument consists of an 82.1 km (51 m) long unimpounded stretch of the Columbia River and federally owned land on either side of the river with an average width of 402 m (1,320 ft). The Monument also encompasses approximately 793 km^2 (306 mi^2) of lands already owned by the federal government that had previously been designated for preservation or conservation under the Hanford CLUP (DOE/EIS-0222-F). To support continued protection of natural and cultural resources, the proclamation stated that the Monument would not be developed for residential or commercial use in the future ("Establishment of the Hanford Reach National Monument" [65 FR 37253]).

The majority of the Monument is managed by the USFWS through a Permit and Memorandum of Understanding granted by DOE in 2001. The portion of Monument lands that are managed by the USFWS are included in the *Hanford Reach National Monument: Final Comprehensive Conservation Plan and Environmental Impact Statement Adams, Benton, Grant and Franklin Counties, Washington* (USFWS, 2008). The remaining Monument lands that are managed by DOE are undergoing or supporting environmental cleanup. In a memorandum to the Secretary of Energy dated June 9, 2000, the President directed the Secretary of Energy to consult with the Secretary of the Interior on how best to permanently protect the lands around the Hanford Reach National Monument. Much of the area contains shrub-steppe habitat and other objects of scientific and historic interests that are protected within Monument lands. The President specifically included the possibility of adding lands to the monument as they are remediated.

Tribal fishing rights are recognized on rivers within the ceded lands, including the Columbia River, which flows through Hanford. In addition to fishing rights, the Tribes retained the privilege to hunt, gather roots and berries, and pasture horses and cattle on open and unclaimed lands. It is the position of DOE that Hanford, like other ceded lands that were settled or used for specific purposes, is not open and unclaimed land. While reserving all rights to assert their respective positions, the Tribes are participants in DOE's land-use planning process, and DOE considers Tribal Nation concerns in that process. Cleanup actions will support anticipated future land uses. DOE is committed to establishing cleanup goals that are at least as protective as the interim action RODs.

3.9 Ecology

The unique habitat of the Hanford Site is located in the mid-latitude, semi-arid climate of the Columbia Plateau with the last free-flowing section of the Columbia River flowing through it, supporting a rich diversity of plant and animal species (2009 Sitewide Environmental Report [PNNL-19455]). Species diversity is maintained through the long-standing management practices of DOE, which leaves most of the land area relatively undisturbed. Only about 6 percent of Hanford Site land has been disturbed or is actively used by DOE for waste disposal and storage. Thus, the native terrestrial and aquatic ecological resources found on the Hanford Site are becoming increasingly rare and highly valuable as agricultural, industrial, and residential development continues to grow throughout the region.



Source: DOE/EIS-0222-SA-01, *Supplement Analysis: Hanford Comprehensive Land-Use Plan Environmental Impact Statement.*

Figure 3-47. Hanford Site, Showing Land-Use Designations Including the Hanford Reach National Monument

The Hanford Reach National Monument was established by presidential proclamation in 2000 to place high priority on shrub-steppe community habitat maintenance and enhancement for native species. Washington State has designated shrub-steppe communities as priority habitat because of their significance to a number of wildlife species and the scarcity of this habitat type. In addition, the U.S. Department of the Interior has identified native shrub and grassland steppe in Washington and Oregon as an endangered ecosystem.

Three key ecological study zones have been identified for purposes of investigation in the River Corridor—upland, riparian, and nearshore river (*Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* [PNNL-SA-41467]; RCBRA [DOE/RL-2007-21]).

Upland Zone. The upland zone is the largest zone and consists of land adjacent to the main channel of the Columbia River above the river high-water mark that extends inland from the Columbia River. Terrestrial and generally dry, the upland zone is not influenced by river flow and depends on precipitation for its water supply. It is dominated by shrub-steppe vegetation.

Within the operational areas, most of the upland zone is highly disturbed or consists of barren or graveled areas adjacent to reactor facilities. Vegetation is dominated by non-native annual species. Most operational areas, including waste sites, were maintained free of vegetation for contamination control, fire prevention, and housekeeping purposes. Some of the areas no longer used have begun to revegetate naturally, and remediated upland CERCLA waste sites are being revegetated to promote the colonization by native species. The upland environment outside the operational areas is relatively undisturbed and consists of large areas of undisturbed, relatively native habitat.

Riparian Zone. The riparian zone extends from the point on the riverbank where upland vegetation is no longer dominant to the shoreline of the Columbia River. Typically narrow, the riparian zone varies in width, depending on the slope of the riverbank. The transition from the upland zone vegetation to riparian vegetation is generally abrupt. The vegetation that grows in the riparian zone along the river shoreline is thicker and taller than that in the upland area, attracting a broader range of wildlife species. The small mammals, birds, and reptiles common to the upland environment are also likely to inhabit the riparian environment (RCBRA [DOE/RL-2007-21]). The riparian environment adjacent to 100-K extends in a strip along the Columbia River to the north and slightly west of the facility. The strip varies in width from a narrow zone 50 to 75 m (160 to 240 ft) toward the eastern end to a wider zone 150 to 200 m (490 to 650 ft) at the westernmost portion of the facility. The riparian vegetation found near 100-K is characterized by areas of wormwood (Artemisia species)/riparian wheatgrass and wormwood/perennial grass adjacent to the upland communities. The wormwood vegetation cover types grade into a low shrub/forb/cobble association that continues to the river edge. A more detailed description of the plant and wildlife species found in the riparian zone in 100-K is presented in *Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* (PNNL-SA-41467).

Nearshore Aquatic Zone. The nearshore aquatic zone consists of a narrow band of the Columbia River adjacent to the shoreline. The nearshore aquatic zone evaluated in this report extends from the low water mark on the shoreline to roughly 1.8 m (6 ft) in depth. The aquatic vegetation found in the nearshore zone supports aquatic insect populations, benthic taxa (species and organisms that live in or on the bottom of the river), birds, and fish. At least 44 species of fish live in the Columbia River adjacent to the Hanford Site, and some use the river as a migration route to and from upstream spawning areas. The shoreline areas provide rearing habitat for many fish species including spawning habitat for threatened and endangered fish species (RCBRA [DOE/RL-2007-21]).

Knowledge of the ecological setting is a compilation of ecological data obtained from multiple biological inventories of plant and wildlife species and ecological characterizations from the following reports:

- A detailed summary of the ecology, biological resources, and hydrology for the entire Hanford Site, with selected information grouped by major operational areas, is provided in the NEPA Characterization Report (PNNL-6415).
- General information on the riparian and aquatic environments found within the Hanford Reach is provided in *United States Department of the Interior Record of Decision – Hanford Reach of the Columbia River: Final Environmental Impact Statement for Comprehensive River Conservation Studies* (DOI, 1996).
- A detailed characterization data for the 100 and 300 Areas, including comprehensive lists of plant and wildlife species occurring in or near the study area, is provided in *Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* (PNNL-SA-41467).

PNNL has been conducting ecological characterization on the Hanford Site since the early 1970s. The most recent report, 2009 Sitewide Environmental Report (PNNL-19455), provides a summary of environmental data that characterize site environmental management performance. Other ecological reports pertaining to the River Corridor include Nature Conservancy surveys (*Biodiversity Inventory and Analysis of the Hanford Site: 1997 Annual Report* [Hall, 1998]; *Biodiversity Inventory and Analysis of the Hanford Site: 1994 Annual Report* [Pabst, 1995]; *Biodiversity Inventory and Analysis of the Hanford Site Final Report 1994-1999* [Soll et al., 1999]; and *Biodiversity Inventory and Analysis of the Hanford Site: 1995 Annual Report* [Soll and Soper, 1996]); *Vascular Plants of the Hanford Site* (PNNL-13688); and the following PNNL Hanford Site Environmental Reports:

- PNNL-11795, *Hanford Site Environmental Report for Calendar Year 1997*
- PNNL-12088, *Hanford Site Environmental Report for Calendar Year 1998*
- PNNL-13487, *Hanford Site Environmental Report for Calendar Year 2000*
- PNNL-13910, *Hanford Site Environmental Report for Calendar Year 2001*
- PNNL-14295, *Hanford Site Environmental Report for Calendar Year 2002*
- PNNL-14687, *Hanford Site Environmental Report for Calendar Year 2003*
- PNNL-15222, *Hanford Site Environmental Report for Calendar Year 2004*
- PNNL-16623, *Hanford Site Environmental Report for Calendar Year 2006*
- PNNL-17603, *Hanford Site Environmental Report for Calendar Year 2007*
- PNNL-18427, *Hanford Site Environmental Report for Calendar Year 2008*

3.9.1 River Corridor Flora

Historically, much of the River Corridor upland zone was a native shrub-steppe habitat. The most prevalent shrub was big sagebrush (*Artemisia tridentata*), with smaller quantities of rabbitbrush (*Chrysothamnus* sp. and *Ericameria* sp.), and an understory dominated by Sandberg's bluegrass (*Poa secunda*, formerly *sandbergii*). During the Euro-American settlement of the area, a large portion of the reactor area was disturbed by farming. Construction activities for the reactor projects further disturbed the vegetation and soils in the area. These two major changes in land use resulted in changes to the native plant community, creating areas that have been kept free of vegetation and areas that have partially recovered to various levels of plant succession (RCBRA [DOE/RL-2007-21], Draft B).

The vegetation in the River Corridor upland zone operating areas is typically sparse and consists of early successional species such as cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola kali*), tumblemustard (*Sisymbrium altissimum*), and bur ragweed (*Ambrosia acanthicarpa*). Most operating areas, including waste sites, were historically maintained free of vegetation for contamination control, fire prevention, and maintenance purposes. Large areas of cheatgrass and exotic annual species present in the 100-D, 100-F, White Bluffs, and Hanford townsite areas that resulted from pre-Hanford farming and homesteading are described as "abandoned old fields." More detailed descriptions of vegetation by reactor area can be found in *Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessment* (PNNL-SA-41467). The 100-IU-2 and 100-IU-6 OUs consist of large areas of undisturbed native habit. Large-scale distribution of vegetation types before the 2000 wildfire, and the burn area after the wildfire, are presented in Figures 3-48 and 3-49, respectively.

Vegetation found in riparian zones reflects the transition between aquatic and upland ecosystems. Changes to the composition of shoreline vegetation over time have been influenced by moderation in the river elevation changes controlled by the Priest Rapids Dam. Due to steepness of the shoreline, the transition from riparian to upland vegetation is abrupt. Dominant vegetation within the riparian zone includes mulberry (*Morus alba*), willow (*Salix* sp.), Siberian elm (*Ulmus pumila*), northern wormwood (*Artemisia campestris*), sweet clover (*Melilotus alba* or *M. officinalis*), and reed canarygrass (*Phalaris arundinacea*) (RCBRA [DOE/RL-2007-21], Draft B).

Vegetation in the nearshore river zone consists of macrophytes and periphyton. Macrophytes are sparse in the Columbia River due to strong currents, rocky bottom, and frequently fluctuating water levels. Where macrophytes are found, they commonly include duckweed (*Lemna* sp.) and the native rooted pondweeds *(Potamogeton* spp. and *Elodea canadensis*). Macrophytes provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. Since the late 1980s, Eurasian milfoil (*Myriophyllum spicatum*), an introduced macrophyte, has increased to nuisance levels and may encourage increased sedimentation of fine particulate matter. Periphyton communities develop on suitable solid substrate wherever there is sufficient light for photosynthesis and adequate currents to prevent sediment from covering the colonies.

Up-to-date and comprehensive lists of plants found on the Hanford Site can be found in the NEPA Characterization Report (PNNL-6415) and *Vascular Plants of the Hanford Site* (PNNL-13688), respectively.

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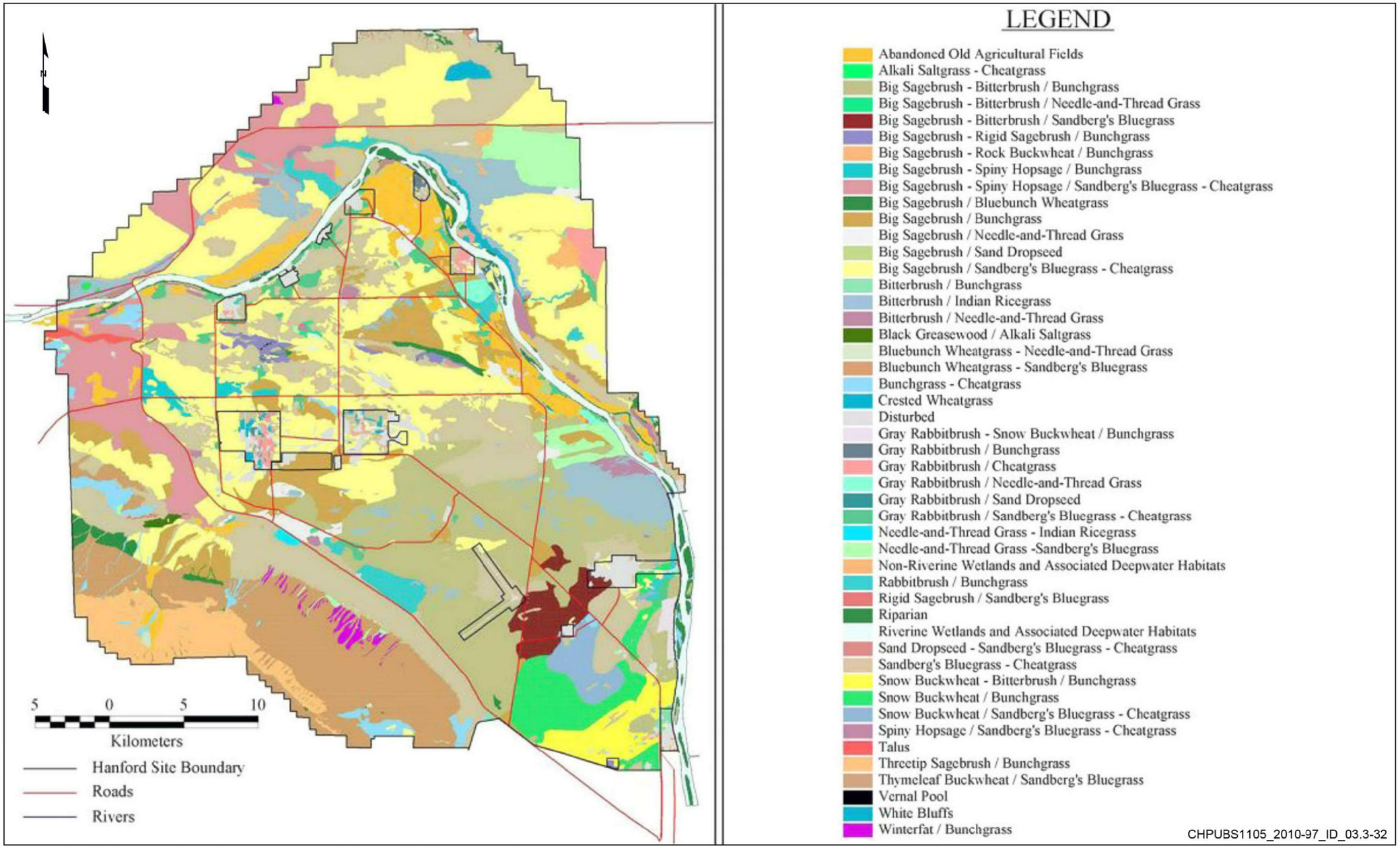

Source: PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*.

Figure 3-48. Distribution of Vegetation Types and Area before the 2000 Fire

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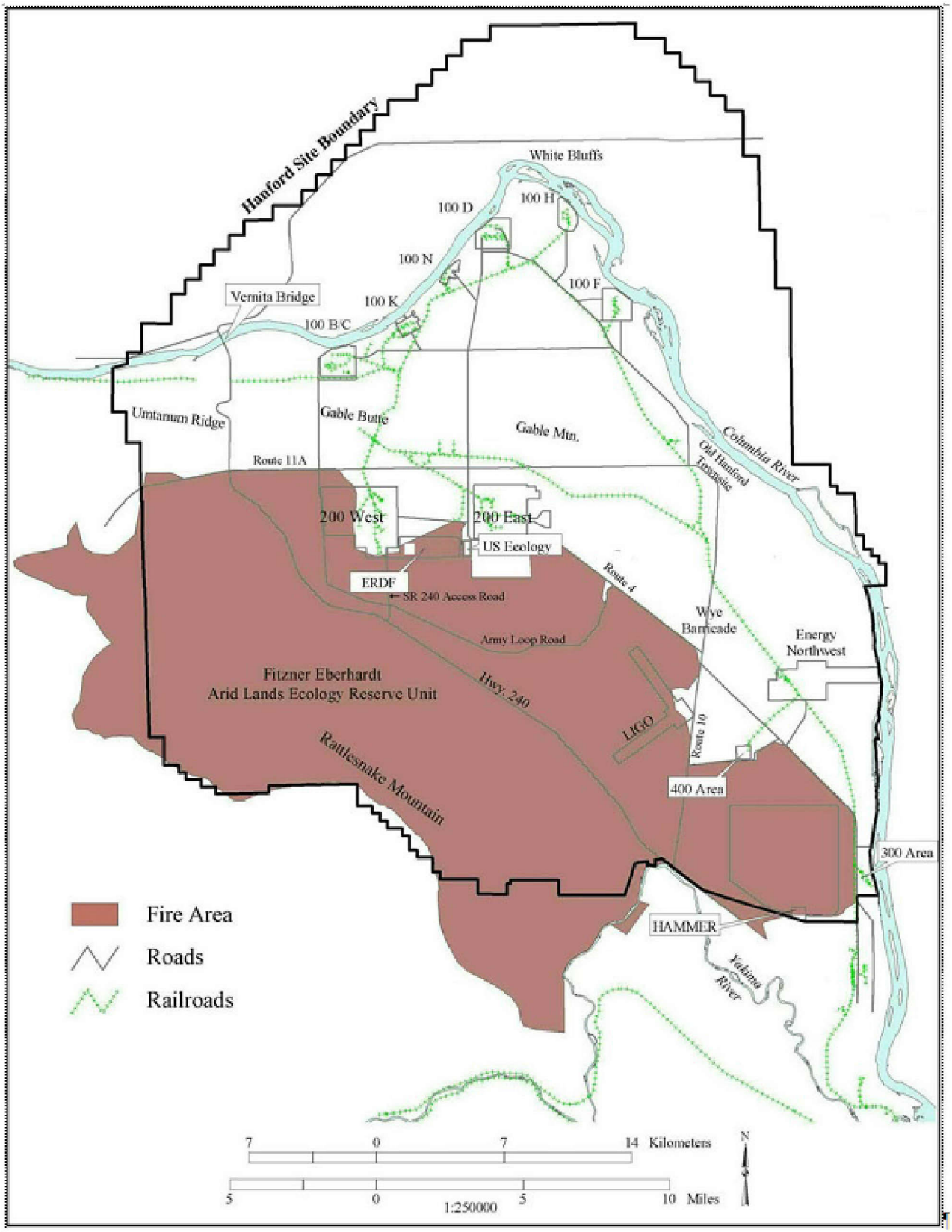

Source: PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*.

Figure 3-49. Burned Area after June 27 to July 2, 2000 Fire

3.9.2 River Corridor Fauna

Wildlife use of habitat overlaps considerably between the riparian and upland zones. Use of the riparian zone is likely higher than that of the upland zone associated with the CERCLA waste sites due to its proximity to the Columbia River. River access results in greater species diversity and the presence of higher density and higher stature vegetation that remains productive over a longer period (RCBRA [DOE/RL-2007-21], Draft B). Species lists have been compiled for the major classes of vertebrates that have been observed on the Hanford Site or within the Hanford Reach of the Columbia River and include 46 species of mammals, 145 species of birds, 10 species of reptiles, 5 species of amphibians, and more than 45 species of fish (NEPA Characterization Report [PNNL-6415]). As invertebrates are concerned, a total of 1,509 species-level identifications have been completed, and the collection of 40,000 specimens has resulted in the identification of 43 new taxa and 142 new findings in the State of Washington (*Biodiversity Inventory and Analysis of the Hanford Site Final Report 1994*-1999 [Soll et al., 1999]). The high diversity of insect species on the Hanford Site reflects the size, complexity, and relatively undisturbed quality of the shrub-steppe habitat. Table 3-45 presents an extensive list of species known or potentially occurring on the Hanford Site classified by habitat type.

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Herbivore	*Callipepla californica*	California quail	x	x		x
	Branta canadensis moffitti	Canada goose	x	x	x	
	Eremophila alpestris	Horned lark				x
	Anas platyrhynchos	Mallard	x	x	x	
	Zenaida macroura	Mourning dove	x	x		x
	Melospiza melodia	Song sparrow	x	x		x
Avian Predator	*Recurvirostra americana*	American avocet	x	x		
	Fulica americana	American coot	x		x	
	Corvus brachyrhynchos	American crow	x	x		x
	Carduelis tristis	American goldfinch	x	x		x
	Falco sparverius	American kestrel	x	x		x
	Anthus rubescens	American pipit	x			x
	Turdus migratorius	American robin	x	x		x
	Spizella arborea	American tree sparrow	x	x		x
	Pelecanus erythrorhynchos	American white pelican	x	x	x	
	Anas americana	American wigeon	x		x	
	Haliaeetus leucocephalus	Bald eagle	x	x		x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Riparia riparia*	Bank swallow	x	x		x
	Tyto alba	Barn owl	x	x		x
	Hirundo rustica	Barn swallow	x	x		x
	Bucephala islandica	Barrow's goldeneye	x		x	
	Ceryle alcyon	Belted kingfisher	x	x	x	
	Thryomanes bewickii	Bewick's wren	x	x		
	Sayomis nigricans	Black phoebe	x			x
	Pica pica	Black-billed magpie	x	x		x
	Nycticorax nycticorax	Black-crowned night heron	x	x	x	
	Pheucticus melanocephalus	Black-headed grosbeak	x	x		x
	Amphispiza bilineata	Black-throated sparrow	x			x
	Anas discors	Blue-winged teal	x		x	
	Vireo solitarius	Blue-headed vireo	x	x		
	Euphagus cyanocephalus	Brewer's blackbird	x	x		x
	Spizella breweri	Brewer's sparrow	x			x
	Molothrus ater	Brown-headed cowbird	x	x		x
	Bucephala albeola	Bufflehead	x		x	
	Icterus galbula	Bullock's oriole	x	x		x
	Athene cunicularia hypugea	Burrowing owl	x			x
	Larus californicus	California gull	x		x	
	Aythya valisineria	Canvasback	x		x	
	Catherpes mexicanus	Canyon wren	x			x
	Sterna caspia	Caspian tern	x		x	
	Carpodacus cassinii	Cassin's finch	x			x
	Bombycilla cedrorum	Cedar waxwing	x	x		x
	Spizella passerina	Chipping sparrow	x	x		x
	Alectoris chukar	Chukar	x			x
	Anas cyanoptera	Cinnamon teal	x		x	
	Hirundo pyrrhonota	Cliff swallow	x	x		x
	Bucephala clangula	Common goldeneye	x		x	

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Gavia immer*	Common loon	x		x	
	Mergus merganser	Common merganser	x		x	
	Chordeiles minor	Common nighthawk	x	x		x
	Phalaenoptilus nuttallii	Common poorwill	x	x		
	Corvus corax	Common raven	x	x		x
	Carduelis flammea	Common redpoll	x			x
	Gallinago gallinago	Common snipe	x	x		
	Accipiter cooperii	Cooper's hawk	x	x		x
	Junco hyemalis	Dark-eyed junco	x	x		x
	Phalacrocorax auritus	Double-crested cormorant	x		x	
	Picoides pubescens	Downy woodpecker	x	x		x
	Calidris alpina	Dunlin	x	x		
	Podiceps nigricollis	Eared grebe	x		x	
	Tyrannus tyrannus	Eastern kingbird	x	x		x
	Empidonax spp.	Empidonax flycatcher	x	x		x
	Sturnus vulgaris	European starling	x			x
	Coccothraustes vespertinus	Evening grosbeak	x			x
	Buteo regalis	Ferruginous hawk	x			x
	Sterna forsteri	Forster's tern	x		x	
	Passerella iliaca	Fox sparrow	x	x		x
	Anas strepera	Gadwall	x		x	
	Larus glaucescens	Glaucous-winged gull	x		x	
	Aquila chrysaetos	Golden eagle	x			x
	Regulus satrapa	Golden-crowned kinglet	x	x		x
	Zonotrichia atricapilla	Golden-crowned sparrow	x	x		x
	Ammodramus savannarum	Grasshopper sparrow	x			x
	Perdix perdix	Gray partridge	x			x
	Leucosticte tephrocotis	Gray-crowned Rosy-Finch	x			x
	Ardea herodias	Great blue heron	x	x	x	
	Casmerodius albus	Great egret	x	x	x	

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Bubo virginianus*	Great horned owl	x	x		x
	Aythya marila	Greater scaup	x		x	
	Tringa melanoleuca	Greater yellowlegs	x		x	
	Anas crecca	Green-winged teal	x		x	
	Empidonax hammondii	Hammond's flycatcher	x	x		x
	Larus argentatus	Herring gull	x		x	x
	Catharus guttatus	Hermit thrush	x	x		x
	Lophodytes cucullatus	Hooded merganser	x		x	
	Podiceps auritus	Horned grebe	x		x	
	Carpodacus mexicanus	House finch	x	x		x
	Passer domesticus	House sparrow	x	x		x
	Troglodytes aedon	House wren	x	x		x
	Charadrius vociferus	Killdeer	x	x		x
	Calcarius lapponicus	Lapland longspur	x			x
	Chondestes grammacus	Lark sparrow	x			x
	Passerina amoena	Lazuli bunting	x			x
	Aythya affinis	Lesser scaup	x		x	
	Tringa flavipes	Lesser yellowlegs	x		x	
	Melanerpes lewis	Lewis's woodpecker	x	x		x
	Melospiza lincolnii	Lincoln's sparrow	x	x		x
	Lanius ludovicianus	Loggerhead shrike	x			x
	Numenius americanus	Long-billed curlew	x			x
	Limnodromus scolopaceus	Long-billed dowitcher	x		x	
	Asio otus	Long-eared owl	x	x		x
	Oporornis tolmiei	MacGillivray's warbler	x	x		x
	Cistothorus palustris	Marsh wren	x	x		x
	Falco columbarius	Merlin	x			x
	Sialia currucoides	Mountain bluebird	x			x
	Vermivora ruficapilla	Nashville warbler	x	x		x
	Colaptes auratus	Northern flicker	x	x		x
	Accipiter gentilis	Northern goshawk	x			x
	Circus cyaneus	Northern harrier	x			x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Mimus polyglottos*	Northern mockingbird	x			x
	Anas acuta	Northern pintail duck	x		x	
	Stelgidopteryx serripennis	Northern rough-winged swallow	x	x		x
	Anas clypeata	Northern shoveler	x		x	
	Lanius excubitor	Northern shrike	x			x
	Contopus borealis	Olive-sided flycatcher	x	x		x
	Vermivora celata	Orange-crowned warbler	x	x		x
	Pandion haliaetus	Osprey	x	x	x	
	Empidonax difficilis	Pacific-slope flycatcher	x	x		
	Falco peregrinus anatum	Peregrine falcon	x		x	x
	Podilymbus podiceps	Pied-billed grebe	x		x	
	Falco mexicanus	Prairie falcon	x			x
	Mergus serrator	Red-breasted merganser	x		x	
	Sitta canadensis	Red-breasted nuthatch	x			x
	Aythya americana	Redhead	x		x	
	Sphyrapicus nuchalis	Red-naped sapsucker	x	x		x
	Podiceps grisegena	Red-necked grebe	x		x	
	Phalaropus lobatus	Red-necked phalarope	x			
	Buteo jamaicensis	Red-tailed hawk	x			x
	Agelaius phoeniceus	Red-winged blackbird	x	x		x
	Larus delawarensis	Ring-billed gull	x	x		
	Aythya collaris	Ring-necked duck	x		x	
	Phasianus colchicus	Ring-necked pheasant	x	x		x
	Columba livia	Rock dove	x			x
	Salpinctes obsoletus	Rock wren	x			x
	Buteo lagopus	Rough-legged hawk	x			x
	Regulus calendula	Ruby-crowned kinglet	x	x		x
	Oxyura jamaicensis	Ruddy duck	x		x	
	Selasphorus rufus	Rufous hummingbird	x	x		x
	Amphispiza belli	Sage sparrow	x			x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Oreoscoptes montanus*	Sage thrasher	x			x
	Grus canadensis	Sandhill crane	x	x		
	Passerculus sandwichensis	Savannah sparrow	x			x
	Sayornis saya	Say's phoebe	x			x
	Accipiter striatus	Sharp-shinned hawk	x	x		x
	Asio flammeus	Short-eared owl	x			x
	Tringa solitaria	Solitary sandpiper	x		x	
	Porzana carolina	Sora	x	x	x	
	Pipilo erythrophthalmus	Spotted towhee	x	x		x
	Actitis macularia	Spotted sandpiper	x		x	
	Buteo swainsoni	Swainson's hawk	x			x
	Myadestes townsendi	Townsend's solitaire	x	x		x
	Dendroica townsendi	Townsend's warbler	x	x		
	Tachycineta bicolor	Tree swallow	x	x	x	
	Cygnus columbianus	Tundra (Whistling) swan	x		x	
	Ixoreus naevius	Varied thrush	x	x		x
	Pooecetes gramineus affinis	Vesper sparrow	x			x
	Tachycineta thalassina	Violet-green swallow	x	x		x
	Rallus limicola	Virginia rail	x	x	x	
	Vireo gilvus	Warbling vireo	x	x		x
	Sialia mexicana	Western bluebird	x			x
	Aechmophorus occidentalis	Western grebe	x		x	
	Tyrannus verticalis	Western kingbird	x	x		x
	Sturnella neglecta	Western meadowlark	x	x		x
	Calidris mauri	Western sandpiper	x		x	
	Piranga ludoviciana	Western tanager	x	x		x
	Contopus sordidulus	Western wood-pewee	x	x		x
	Zonotrichia leucophrys	White-crowned sparrow	x	x		x
	Wilsonia pusilla	Wilson's warbler	x	x		x
	Troglodytes troglodytes	Winter wren	x	x		x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Avian Predator (cont.)	*Aix sponsa*	Wood duck	x		x	
	Dendroica petechia	Yellow warbler	x	x		x
	Icteria virens	Yellow-breasted chat	x	x		
	Xanthocephalus xanthocephalus	Yellow-headed blackbird	x	x		x
	Dendroica coronata	Yellow-rumped warbler	x	x		x
Benthic Biota	*Pacifasticus leniusculus*	Crayfish	x		x	
	Anodonta californiensis	California floater (mussel)			x	
	Anodonta kennerlyi	Western floater (mussel)			x	
	Anodonta nuttalliana	Winged floater (mussel)			x	
	Anodonta oregonensis	Oregon floater (mussel)			x	
	Corbicula fluminea	Asiatic clam	x		x	
	Gonidea angulata	Western ridged mussel			x	
	Margaritifera falcata	Western pearlshell mussel			x	
	Fisherola nuttalli	Shortface lanx			x	
	Fulminicola columbianus	Columbia pebblesnail			x	
	Pisidium sp.	Peaclam			x	
	Gyraulus sp.	Snail			x	
	Limnaea sp.	Snail			x	
	Physa sp.	Snail			x	
	Radix sp.	Snail			x	
	Stagnicola sp.	Pondsnail			x	
	Rana catesbeiana	Bullfrog	x	x		x
	Pituophis catenifer deserticola	Great Basin gopher snake	x	x		x
	Scaphiopus intermontanus	Great Basin spadefoot toad	x			x
	Hypsiglena torquata	Night snake				x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Carnivorous Reptiles and Amphibians	*Sceloporus graciosus*	Northern sagebrush lizard	x			x
	Hyla regilla	Pacific tree frog		x		
	Chrysemys picta	Painted turtle		x	x	
	Pseudacris regilla	Pacific Treefrog		x		
	Phrynosoma douglassii	Short-horned lizard				x
	Uta stansburiana	Side-blotched lizard	x			X
	Charina bottae	Rocky Mountain rubber boa		x		
	Ambystoma tigrinum	Tiger salamander			x	
	Crotalus viridis	Western rattlesnake	x			x
	Thamnophis sirtalis	Western terrestrial garter snake		x	x	
	Coluber constrictor	Western yellow-bellied racer	x	x		x
	Bufo woodhousei	Woodhouse's toad	x	x		x
Fish Herbivore	*Cyprinus carpio*	Common carp	x		x	
	Catostomus columbianus	Bridgelip sucker			x	
	Catostomus macrocheilus	Largescale sucker			x	
Fish Predator	*Alosa sapidissima*	American shad			x	
	Ameiurus melas	Black bullhead			x	
	Pomoxis nigromaculatus	Black crappie			x	
	Ictalurus furcatus	Blue catfish			x	
	Lepomis macrochirus	Bluegill	x		x	
	Ameiurus nebulosus	Brown bullhead	x		x	
	Salvelinus confluentus	Bull trout			x	
	Lota lota	Burbot			x	
	Ictalurus punctatus	Channel catfish			x	
	Oncorhynchus tshawytscha	Chinook salmon	x		x	
	Acrocheilus alutaceus	Chiselmouth	x		x	
	Oncorhynchus kisutch	Coho salmon	x		x	
	Oncorhynchus clarkii	Cutthroat trout			x	

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Fish Predator (cont.)	*Salvelinus malma*	Dolly Varden			x	
	Coregonus clupeaformis	Lake whitefish			x	
	Micropterus salmoides	Largemouth bass			x	
	Rhinichthys falcatus	Leopard dace			x	
	Rhinichthys cataractae	Longnose dace			x	
	Gambusia affinis	Western mosquitofish			x	
	Cottus bairdii	Mottled sculpin			x	
	Prosopium williamsoni	Mountain whitefish	x		x	
	Catostomus platyrhynchus	Mountain sucker			x	
	Pungitius pungitius	Nine spine stickleback			x	
	Ptychocheilus oregonensis	Northern pikeminnow	x		x	
	Lampetra tridentata	Pacific lamprey	x		x	
	Mylocheilus caurinus	Peamouth	x		x	
	Cottus beldingii	Piute sculpin			x	
	Cottus asper	Prickly sculpin	x		x	
	Lepomis gibbosus	Pumpkinseed	x		x	
	Oncorhynchus mykiss	Rainbow trout (steelhead)			x	
	Richardsonius balteatus	Redside shiner	x		x	
	Cottus perplexus	Reticulate sculpin			x	
	Lampetra ayresii	River lamprey			x	
	Percopsis transmontana	Sand roller			x	
	Micropterus dolomieu	Smallmouth bass	x		x	
	Oncorhynchus nerka	Sockeye salmon	x		x	
	Rhinichthys osculus	Speckled (spotted) dace	x		x	
	Gasterosteus aculeatus	Threespine stickleback	x		x	
	Cottus rhotheus	Torrent sculpin			x	
	Sander vitreus	Walleye	x		x	
	Pomoxis annularis	White crappie			x	

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Fish Predator (cont.)	*Acipenser transmontanus*	White sturgeon			x	
	Ameiurus natalis	Yellow bullhead			x	
	Perca flavescens	Yellow perch	x		x	
Mammal Herbivore	*Castor canadensis*	Beaver		x	x	
	Lepus californicus	Black-tailed jackrabbit	x			x
	Neotoma cinerea	Bushy-tailed woodrat	x			x
	Cervus elaphus	Rocky Mountain elk	x	x		x
	Perognathus parvus	Great Basin pocket mouse	x	x		x
	Tamias minimus	Least chipmunk				x
	Microtus montanus	Montane vole	x			x
	Odocoileus hemionus	Mule deer	x	x		x
	Ondatra zibethica	Muskrat		x	x	
	Thomomys talpoides	Northern pocket gopher	x			x
	Sylvilagus nuttallii	Nuttall's (or mountain) cottontail	x			x
	Erethizon dorsatum	Porcupine		x		
	Lemmiscus curtatus	Sagebrush vole	x			x
Mammal Herbivore (cont.)	*Urocitellus townsendii (formally Spermophilus townsendii)*	Townsend's ground squirrel	x			x
	Urocitellus washingtoni (Formally Spermophilus washingtoni)	Washington ground squirrel				x
	Reithrodontomys megalotis	Western harvest mouse	x	x		x
	Odocoileus virginianus	White-tailed deer		x		
	Lepus townsendii	White-tailed jackrabbit				x
	Marmota flaviventris	Yellow-bellied marmot				x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland
Mammal Predator	*Taxidea taxus*	Badger				x
	Eptesicus fuscus	Big brown bat	x	x		x
	Lynx rufus	Bobcat		x		x
	Canis latrans	Coyote	x			x
	Peromyscus maniculatus	Deer mouse	x	x		x
	Lasiurus cinereus	Hoary bat	x	x		x
	Mus musculus	House mouse	x	x		
	Myotis rolans	Long-legged myotis (bat)	x	x		x
	Myotis lucifugus	Little brown myotis (bat)	x	x		x
	Mustela frenata	Long-tailed weasel		x		
	Sorex merriami	Merriam's shrew				x
	Mustela vison	Mink		x		
	Puma concolor concolor	Mountain lion				x
	Onychomys leucogaster	Northern grasshopper mouse	x			x
	Rattus norvegicus	Norway rat		x		x
	Antrozous pallidus	Pallid bat	x	x		x
	Procyon lotor	Raccoon		x		
	Lutra canadensis	River otter		x	x	
	Mustela erminea	Short-tail weasel		x		
	Lasionycteris noctivagans	Silver-haired bat	x	x		x
	Mephitis mephitis	Striped skunk		x		
	Sorex vagrans	Vagrant shrew		x		
	Pipistrellus hesperus	Western pipistrelle (bat)	x	x		x
	Myotis leibii	Western small-footed myotis (bat)	x			x
	Myotis yumanensis	Yuma myotis (bat)	x	x		x

Table 3-45. Species Known or Potentially Occurring on the Hanford Site Classified by Primary Functional and Habitat Type

Functional Type	Scientific Name	Common Name	Hanford Location Data	Habitat Type		
				Riparian	Aquatic	Upland

Note: Species listed in this table are from the following sources: locational data from the Environmental Monitoring and Compliance and Site Environmental Surveillance Program (SESP) Project databases; The Nature Conservancy (TNC) (Soll et al., 1999, *Biodiversity Inventory and Analysis of the Hanford Site Final Report 1994-1999*, and Evans et al., 2003, *Biodiversity Studies of the Hanford Site: Final Report August 2003*); Fitzner and Gray, 1991, "The Status, Distribution and Ecology of Wildlife on the U.S. DOE Hanford Site: A Historical Overview of Research Activities"; PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*; and a working list of species developed by B.L. Tiller under EMC Project.

Mammals of the upland environment that might be found in and adjacent to the 100 and 300 Areas include the mule deer (*Odocoileus hemionus*), badger (*Taxidea taxus*), coyote (*Canis latrans*), Great Basin pocket mouse (*Perognathus parvus*), northern pocket gopher (*Thomomys talpoides*), black-tailed jackrabbit (*Lepus californicus*), and cottontail rabbit (*Sylvilagus nuttalii*) (*100 Areas CERCLA Ecological Investigations* [WHC-EP-0620]). The abundance of these species and the occurrence of others vary according to the soil type and vegetative community. While other large mammals, such as elk (*Cervus elaphus*), are infrequently observed in the 100 and 300 Areas upland reactor areas, the number of individual large mammals present per unit area may increase as habitat quality and shrub cover improve through natural recovery and waste site restoration. Some mammals common to the upland environment are also likely to use and inhabit the riparian environment, including the western harvest mouse (*Reithrodontomys megalotis*), the Great Basin pocket mouse (*Perognathus parvus*), and the deer mouse (*Peromyscus maniculatus*) (*Synthesis of Ecological Data Collected in the Riparian and Riverine Environments of the Hanford Reach* [PNNL-14516]). A complete list of mammals observed and expected in all habitats of the 100 Area is provided in *100 Areas CERCLA Ecological Investigations* (WHC-EP-0620), and a complete listing of Hanford Site wildlife species is in the NEPA Characterization Report (PNNL-6415).

Several species of birds present in the upland zone rely on structures such as buildings, fences, and utility poles for some of their habitat needs. Raptors, such as red-tailed hawks (*Buteo jamaicensis*), are present and frequently nest on buildings, utility poles and towers, and trees along the river. Nonvegetated areas provide nesting habitat for nighthawks (*Chordeiles minor*) and killdeer (*Charadrius vociferus*). Canada geese (*Branta canadensis*) use open cheatgrass areas for winter grazing. Following restoration, improvements in shrub coverage will provide important habitat for native shrub-steppe bird species such as the horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), savannah sparrow (*Passerculus sandwichensis*), loggerhead shrike (*Lanius ludovicianus*), and possibly sage sparrow (*Amphispiza belli*). Raptors will continue to be present, but as the shrubs develop and the open grassy areas shrink in size, wintering geese will likely avoid the area, preferring the cheatgrass areas associated with nearby abandoned farm fields and orchards. A list of bird species observed in the 100 Area is available in *100 Areas CERCLA Ecological Investigations* [WHC-EP-0620]. A catalogue of Hanford Site avian species is presented in the NEPA Characterization Report (PNNL-6415).

Synthesis of Ecological Data Collected in the Riparian and Riverine Environments of the Hanford Reach (PNNL-14516) provides information on bird populations with respect to riparian vegetation. Location data is available in the electronic Environmental Monitoring and Compliance Project database managed by PNNL. Research efforts have assessed winter bird populations in cottonwood/willow (*Populus*/*Salix*) communities of the Columbia River shoreline ("A Vagrant Occurrence of the Black Phoebe in Southeastern Washington" [Rickard, 1964]; "Comparison of Winter Bird Populations After a Decade" [Rickard and Rickard, 1972]), quantified shorebird response to water fluctuations in the Columbia River

nearshore environment ("Avian Interactions with Mid-Columbia River Water Level Fluctuations" [Books, 1985]), and evaluated habitat selection and use by spring migrant passerines ("Riparian Stopover Habitat Selection by Spring Transient Landbirds of South-Central Washington" [Duberstein, 1997]). The information gathered during these research efforts has been used to document the status and ecology of the Hanford Site's avian wildlife.

Common reptiles found in upland environments at the Hanford Site include the rattlesnake (*Crotalus viridis*), gopher snake (*Pituophis melanoleucus*), yellow-bellied racer (*Coluber constrictor*), and side blotch lizard (*Uta stansburiana*) (*Habitat Types on the Hanford Site: Wildlife and Plant Species of Concern* [PNL-8942]; *A Synthesis of Ecological Data from the 100 Areas of the Hanford Site* [WHC-EP-0601]). A variety of snakes common to the upland areas may also use the riparian habitat. Other reptiles that may be found in the riparian zone include the western terrestrial garter snake (*Thamnophis sirtalis*) and the painted turtle (*Chrysemys picta*) (*Herpetofauna of the Hanford Nuclear Reservation, Grant, Franklin and Benton Counties, Washington* [Hallock, 1998]; *Synthesis of Ecological Data Collected in the Riparian and Riverine Environments of the Hanford Reach* [PNNL-14516]). Amphibians in the riparian and nearshore environments of the Hanford Reach include mostly Woodhouse's toads (*Bufo woodhousii*), but bullfrogs (*Rana catesbeiana*) and Great Basin spadefoot toads (*Scaphiopus intermontanus*) may also be present (*Synthesis of Ecological Data Collected in the Riparian and Riverine Environments of the Hanford Reach* [PNNL-14516]).

The dominant ground-dwelling invertebrate species in the upland environment are harvester ants (*Pogonomyrmex owyheei*) and darkling beetles (family *Tenebrionidae*). Harvester ants can exist on vegetated and nonvegetated soils and have been documented on waste sites (*Characterization of the Hanford 300 Area Burial Grounds: Task IV – Biological Transport* [PNL-2774]). Darkling beetles, however, rely on vegetative matter in the soil during their larval stage and therefore are not expected to occur in areas void of vegetation (*Darkling Beetle Populations (Tenebrionidae) of the Hanford Site in Southcentral Washington* [PNL-2465]). Areas that were not used as waste sites or have not been affected by Hanford Site operations likely have less soil disturbance and may support a more robust and diverse community of soil-dwelling fauna than previously disturbed or remediated sites.

More than 45 species of fish have been identified in the Hanford Reach of the Columbia River. Of these species, Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus nerka*), Coho salmon (*Oncorhynchus kisutch*), and steelhead (*Oncorhynchus mykiss*) use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Other fish of importance to sport anglers are the native mountain whitefish (*Prosopium williamsoni*) and white sturgeon (*Acipenser transmontanus*). Introduced species like smallmouth bass (*Micropterus dolomieui*), black crappie (*Pomoxis nigromaculatus*), channel catfish (*Ictalurus punctatus*), and walleye (*Stizostedion vitreum*) are also popular. Other large fish populations include introduced common carp (*Cyprinus carpio*) and native species such as redside shiner (*Richardsonius balteatus*) and largescale suckers (*Catostomus macrocheilus*). Smaller fish, such as sculpin (*Cottus* sp.), are associated with shoreline habitats and have small home ranges (RCBRA [DOE/RL-2007-21], Draft B).

3.9.3 Threatened and Endangered Species

A variety of species are recognized by state or federal agencies as having special status based on the species' risk of extinction. Threatened and endangered species are considered at risk and, as such, these species were not identified for sacrificial sampling and subsequent analyses for the risk assessment effort. Data for selected surrogate species were required for contaminant or biological characterization based on the guild in which the special status species were identified (*Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* [DOE/RL-2004-37], Table 5-1). The list of state and federally listed species of concern, including candidate, sensitive, and monitored species thought or known to occur

on the Hanford Site, is updated regularly in the NEPA Characterization Report (PNNL-6415). No plants, invertebrates, reptiles, amphibians, or mammals on the federal list of threatened and endangered wildlife and plants are known to occur on the Hanford Site (*Literature Review of Environmental Documents in Support of the 100 and 300 Area River Corridor Baseline Risk Assessmen* [PNNL-SA-41467]).

Two species of federally listed endangered fish—the Upper Columbia River spring-run Chinook salmon and the steelhead—occur in the Hanford Reach. The spring-run Chinook salmon do not spawn in the Hanford Reach, but use it as a migration corridor. Steelhead spawning has been observed in the Hanford Reach. The bull trout is listed as threatened by the National Marine Fisheries Service, but is not considered a resident species and is rarely observed in the Hanford Reach (*100-B/C Pilot Project Risk Assessment Report* [DOE/RL-2005-40]).

DOE employs the following protective measures for endangered salmon and steelhead:

- Water diversions meet state screening criteria or appropriate administrative controls, including discharges that meet National Pollutant Discharge Elimination System (NPDES) permit requirements. Removal of native riparian or emergent vegetation is minimized. Where possible, construction projects do not simplify shoreline structures and final construction produces banks at a 3:1 slope.

- Silt-loaded surface runoff is minimized along the shoreline, and disruptive activities in the river or on the shoreline are avoided from April to November.

Although the bald eagle has been removed from the list of federally endangered species, it is still protected under the *Bald and Golden Eagle Protection Act of 1940*. In addition, DOE has decided to continue to protect nest and roost sites on the Hanford Site under *Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington* (DOE/RL-94-150). This plan is currently under revision to account for the delisting of the bald eagle. Changes have been made to reduce the buffer zones surrounding winter night roosts and nest sites from 800 to 400 m (2,600 to 2,400 ft). The Washington State Department of Fish and Wildlife requires protection of roosting trees for bald eagle habitat and foraging areas (“Permanent Regulations,” “Bald Eagle Protection Rules” [WAC 232-12-292]).

Tables 3-46 and 3-47 provide those flora and fauna species that are listed by the State of Washington as being threatened or endangered including candidate, sensitive, and monitored species thought or known to occur on the Hanford Site.

Table 3-46. Flora Threatened and Endangered Species List

Scientific Name	Common Name	State Status	Federal Status
Upland			
Oenothera caespitosa ssp. *caespitosa*	caespitose evening-primrose	SS	
Orobanche californica	California broomrape	SX	
Astragalus columbianus	Columbia milk-vetch	SS	FCo
Nicotiana attenuata	coyote tobacco	SS	
Cuscuta denticulata	desert dodder	ST	
Camissonia pygmaea	dwarf evening-primrose	SS	
Astragalus geyeri	Geyer’s milk-vetch	ST	

Table 3-46. Flora Threatened and Endangered Species List

Scientific Name	Common Name	State Status	Federal Status
Cryptantha leucophaea	gray cryptantha	SS	FCo
Aliciella leptomeria	Great Basin gilia	ST	
Lomatium tuberosum	Hoover's desert parsley	SS	FCo
Loeflingia squarrosa var. *squarrosa*	loeflingia	ST	
Cryptantha scoparia	miner's candle	SS	
Erigeron piperianus	Piper's daisy	SS	
Cistanthe rosea	rosy pussypaws	ST	
Calochortus macrocarpus	sagebrush-mariposa lily	SE	
Camissonia minor	small-flower evening primrose	SS	
Cryptantha spiculifera	Snake River cryptantha	SS	
Ribes cereum	squaw currant	SE	
Mimulus suksdorfii	Suksdorf's monkey-flower	SS	
Eriogonum codium	Umtanum desert buckwheat	SE	FC
Eatonella nivea	white etonella	ST	
Riparian			
Lipocarpha aristulata	awned halfchaff sedge	ST	
Eleocharis rostellata	beaked spike-rush	SS	
Hypericum majus	Canadian St. John's-wort	SS	
Anagallis minima	chaffweed	ST	
Ammannia robusta	grand redstem	ST	
Rotala ramosior	lowland toothcup	ST	
Rorippa columbiae	persistantsepal yellowcress	SE	FCo

Source: WNHP, 2011, "List of Plants Tracked by the Washington Natural Heritage Program."

FC = Federal Candidate
FCo = Federal Species of Concern
SE = State Endangered
SS = State Sensitive
ST = State Threatened
SX = possibly extinct or extirpated from Washington

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Table 3-47. Fauna Threatened and Endangered Species List

Scientific Name	Common Name	State Status	Federal Status
Birds			
Pelecanus erythrorhynchos	American white pelican	SE	
Haliaeetus leucocephalus	bald eagle	SS	FCo
Athene cunicularia	burrowing owl	SC	FCo
Gavia immer	common loon	SS	
Buteo regalis	ferruginous hawk	ST	FCo
Otus flammeolus	flammulated owl	SC	
Aquila chrysaetos	golden eagle	SC	
Centrocercus urophasianus	greater sage grouse	ST	FC
Melanerpes lewis	Lewis' woodpecker	SC	
Lanius ludovicianus	loggerhead shrike	SC	FCo
Accipiter gentilis	northern goshawk	SC	FCo
Falco peregrinus	peregrine falcon	SS	FCo
Amphispiza belli	sage sparrow	SC	
Oreoscoptes montanus	sage thrasher	SC	
Grus canadensis	sandhill crane	SE	
Aechmophorus occidenalis	western grebe	SC	
Mammals			
Lepus californicus	black-tailed jackrabbit	SC	
Sorex merriami	Merriam's shrew	SC	
Urocitellus townsendii (formerly *Spermophilus townsendii*)	Townsend's ground squirrel	SC	FCo
Urocitellus washingtoni (formerly *Spermophilus washingtoni*)	Washington ground squirrel	SC	FC
Lepus townsendii	white-tailed jackrabbit	SC	
Reptiles/Amphibians			
Sceloporus graciosus	northern sagebrush lizard	SC	FCo
Masticophis taeniatus	striped whipsnake	SC	

Table 3-47. Fauna Threatened and Endangered Species List

Scientific Name	Common Name	State Status	Federal Status
Aquatics			
Salvelinus confluentus	bull trout	SC	FT
Anodonta californiensis	California floater (mussel)	SC	FCo
Oncorhynchus tshawytscha	chinook salmon	SC	FE
Rhinichthys falcatus	leopard dace	SC	
Catostormus platyrhynchus	mountain sucker	SC	
Lampetra tridentata	Pacific lamprey	SM	FCo
Oncorhynchus mykiss	rainbow trout (steelhead)	SC	FT
Lampetra ayresi	river lamprey	SC	FCo
Fisherola nuttalli	Giant Columbia River limpet	SC	

Source: WDFW, 2011, "Species of Concern."

FC = Federal Candidate
FCo = Federal Species of Concern
FE = Federal Endangered
FT = Federal Threatened
SC = State Candidate
SE = State Endangered
SM = State Monitored
SS = State Sensitive
ST = State Threatened

3.9.4 River Corridor Food Web and Receptors

Consideration of ecological receptors in the risk assessment requires an understanding of relationships among biotic community members. One such relationship, trophic transfer of contaminants, is an important element in ecological risk assessments. To develop a conceptual model based on trophic guilds, EPA (*Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments: Interim Final* [EPA 540-R-97-006]) recommends defining the functional ecosystem components with regard to their role in the food web. Given the complexity of trophic interactions, food webs are a simplification of the ecosystem showing broad relationships limited to trophic transfer. At a base level, some organisms prey on plants (herbivores), plants and animals (omnivores), or just animals (carnivores). More specific feeding classes exist with a particular trophic category. Considering the terrestrial environment, for example, herbivores are pollen-feeding animals that may be relatively unimportant in terms of nutrient and energy transfer through the food web, but are important as plant pollinators. The same generalities are applicable to considerations of trophic linkages in the aquatic environment (e.g., many aquatic invertebrates consume periphyton and use this autotrophic component of the aquatic food web as a refuge from predation). Ultimately, depiction of trophic-level

relationships from a functional perspective allows for ready identification of the feeding guilds most at risk from ingestion of contaminated plant and animal materials (RCBRA [DOE/RL-2007-21], Draft B).

This framework is used to describe a simplified trophic structure for the ecological community of the RCBRA (Figure 3-50). For the most part, trophic linkages among aquatic and terrestrial biota are stronger within habitats than between habitats. In recognition of this, receptors are delineated into aquatic nearshore and terrestrial food webs. Some organisms can use both aquatic and terrestrial habitat. For example, bats and kingbirds are aerial insectivores that live on land and meet their dietary demands primarily through the consumption of emergent aquatic insects. The highest trophic level consists of avian predators that can traverse all environments.

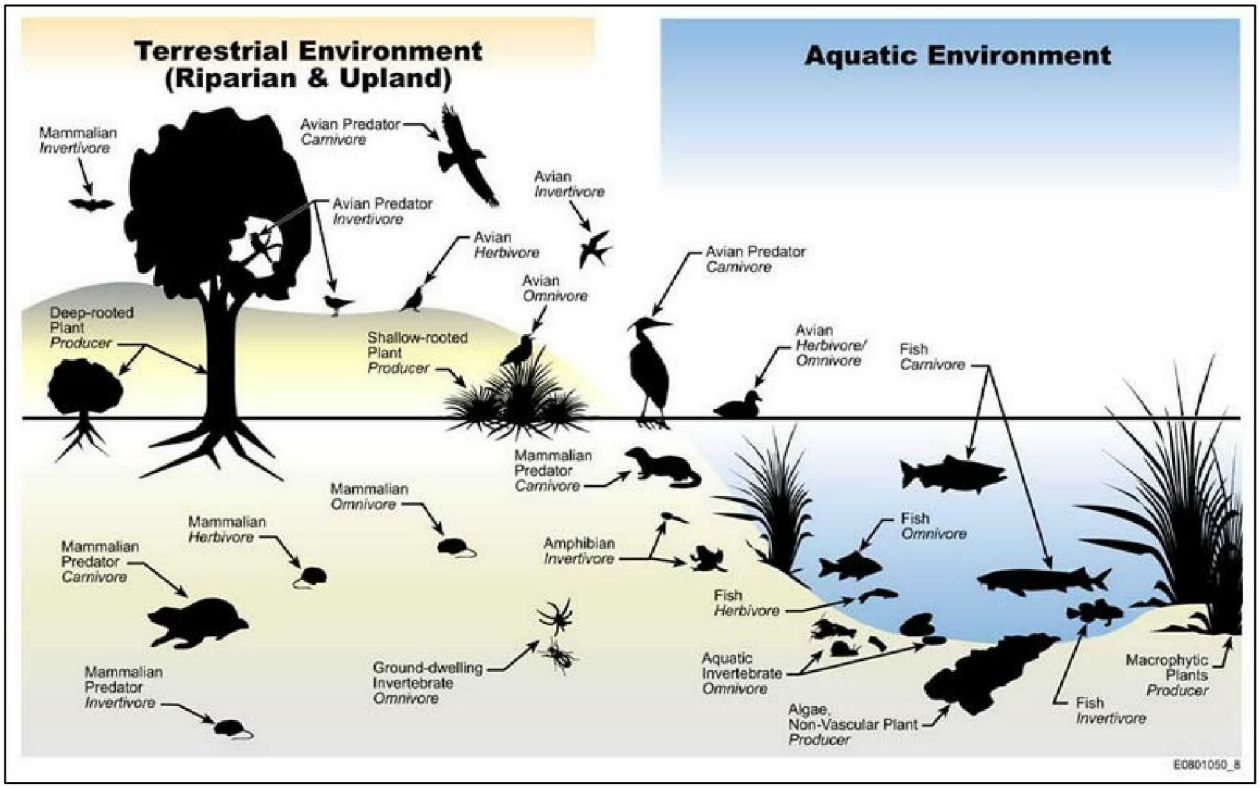


Figure 3-50. Ecological Food Web Represented by Simplified Feeding Guilds in the River Corridor

Hanford Site-specific receptors are recommended as surrogates for the "Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7490), feeding guilds because they represent relevant ecological and societal endpoints that also address management goals (*DQO Summary Report for the 100 Area and 300 Area Component of the RCBRA* [BHI-01757]). Receptor trophic-based guilds are representative of the upland, riparian, and nearshore environments and include decomposers, producers, and consumers (herbivores, omnivores, insectivores, and carnivores). While categories such as omnivory and herbivory are useful constructs to simplify a complex ecosystem, it is important to note that animals do not typically restrict themselves to narrow food sources. Considerable dietary overlap exists among the middle trophic levels, because all species are, to some degree, opportunists. Other species are primarily insectivorous only at times when insects are abundant (*Washington Department of Fish and Wildlife's Priority Habitat and Species Management Recommendations, Vol. IV: Birds – Sage Sparrow*, Amphispiza belli [WDFW, 2003]). Given the dietary overlap, it would be an artificial distinction to focus on a specific category; modeling specific diets (e.g., strict herbivory) is done to set the exposure bounds in trophic-transfer analyses.

3.10 Cultural Resources

The Hanford Site contains some of the most important archaeological sites in the region. Most of these sites are eligible to be listed on "National Register of Historic Places" (36 CFR 60). In addition, other natural resources and sacred sites important to the present cultures of the regional Tribal Nations are preserved at the Hanford Site (*Data Compendium for the Columbia River Comprehensive Impact Agreement* [PNL-9785,]). Long-term (more than 50 years) restricted access has minimized looting and vandalism of historic, cultural, and archaeological sites. Furthermore, hydroelectric and agricultural developments have not destroyed these culturally significant sites, as has been experienced elsewhere in the Columbia River Basin.

While rapid development of the Hanford Site did not accommodate protection of important Native American locations, current (and future) Hanford Site planners, directors of onsite construction activity, and Tribal Nations leaders work together for the protection of important Native American locations. The cultural resources of the Hanford Site area are important to many people interested in their historic preservation. The National Register of Historic Places criteria (*National Register of Historic Places Multiple Property Documentation Form—Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington* [DOE/RL-97-02]) offer the following three suitable categories for chronicling the historic, archaeological, and traditional cultural properties of the Hanford Site:

- Prehistoric era (10,000 B.P. to 1805)
- Homestead and townsite era (1805 to 1945)
- Manhattan Project and Cold War era (post-1945 to 1990)

DOE has undertaken an ongoing comprehensive preservation planning effort for the Hanford Site. The results of these efforts have implemented protective programs for conserving cultural resources (*National Register of Historic Places Multiple Property Documentation Form—Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington* [DOE/RL-97-02]; *Programmatic Agreement Among the U.S. Department of Energy, Richland Operations Office, The Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration, and Demolition of the Built Environment on the Hanford Site, Washington* [DOE/RL-96-77]; and *Hanford Cultural Resources Management Plan* [DOE/RL-98-10]). Cultural resource surveys are routinely conducted as part of site evaluation and preparation prior to excavation to protect culturally sensitive areas. The results of these surveys are used in the site selection process and applied in the various sampling and analysis plans. Additionally, the creation of the Hanford Reach National Monument (*Hanford Reach National Monument: Final Comprehensive Conservation Plan and Environmental Impact Statement Adams, Benton, Grant and Franklin Counties,* Washington [USFWS, 2008]; and "Hanford Reach National Monument; Adams, Benton, Franklin and Grant Counties, WA" [73 FR 72519]) provides an additional means for the preservation and maintenance of the wide range of cultural resources present along the river.

Artifacts discovered across the Hanford Site provide evidence of the site's occupational characteristics, use durations and periods, and multiple land use (for example, ceremonial and religious sites, and burial grounds). Hanford Site cultural resources are diverse, ranging from early prehistoric times to the Atomic Age. Native American archaeological sites are associated with prehistoric and ethnographic villages and activities, as well as sacred and ceremonial areas such as mountains and rivers, where food and medicinal plants were gathered and are dispersed across the landscape (*U.S. Department of Energy's Hanford Cultural Resources Laboratory Oral History and Ethnography Task Annual Report* [PNNL-14237]). Many sites and natural features along the Columbia River are regarded as sacred or important to the cultural heritage of members of the Confederated Tribes of the Umatilla Indian Reservation, Yakama

Indian Nation, the Nez Perce Tribe, and the Wanapum People. Cultural resources review process was followed for any data collection activities. Similar to other areas across the Hanford Site, disturbance maps and reports have been prepared for many areas. Tribal Nations leaders review the locations and potential impacts to these resources before site activities begin (*Hanford Cultural Resources Management Plan* [DOE/RL-98-10]).

3.10.1 Prehistoric Era

Seven prehistoric sites have been identified in 100-K, all of which are located on terraces along the Columbia River. In addition, there are numerous historic sites associated with the pre-Hanford agricultural period. In general, archaeological sites on the Hanford Reach, including 100-K, tend to be on the alluvial flats and lower terraces near the shorelines and islands of the Columbia River. Shoreline sites are generally long and narrow, and run parallel to the river. Inland prehistoric sites have been discovered on Gable Butte, Rattlesnake Mountain, and near the few isolated seeps. Prehistoric settlement patterns and seasonal rounds in this section of the Columbia Basin were associated with nonagricultural practices that included fishing, upland root gathering, and hunting. Archaeological evidence suggests that precontact settlement patterns consisted of consolidated winter villages and dispersed summer camps. Winter villages consisted of long tule mat lodges placed in shallow, bermed pits. Summer camps were associated with seasonal procurement strategies. Long-term prehistoric settlement sites (winter) tend to have pithouses and tool assemblages used for stone tool manufacture and plant and animal preparation. In contrast, short-term seasonal use sites have no pithouses, although they contain artifacts similar to long-term use sites. Seasonal use of the area centered on the fall fish migrations and consolidated winter villages. Seasonal rounds began in spring with the maturing of plants in the lowland areas and gradually moved to the higher elevations as plant maturation continued into early fall. Fishing occurred from April until September, and hunting was undertaken in the winter months. Collected food reserves were stored for later winter consumption when plant and fish supplies were the lowest of the year. Archaeological investigations conducted in the Columbia Plateau have enabled the creation of a cultural chronology dating back to the end of the Pleistocene, which is summarized in the following paragraphs (*Cultural Resources Report for the 100-HR-3 Resource Process Optimization Wells Project, Benton County, Washington* [SGW-44410]).

The Windust Phase (11,000 to 8,000 B.P.) represents the oldest known Paleo-Indian culture in the Columbia Plateau region. Although archaeological evidence is limited, it is believed the people of this period were highly mobile hunters and foragers. The food source was primarily large mammals, supplemented with small mammals and fish. Population numbers were low, and living areas are believed to have been in rock shelters and caves. No evidence of constructed dwellings or storage features exists to further support the theory of a highly mobile culture. Artifacts from this phase include projectile points, cobble tools, scrapers, gravers and burins, hammerstones, grooved stones, utilized flakes, bone awls, ocher beads, and antler wedges. Supporting evidence of a Paleo-Indian culture on the Hanford Reach was discovered in 2001 when a Windust-style projectile point was discovered near 100-K. This projectile point is the oldest known Paleo-Indian point discovered to date at the Hanford Site.

The Cascade/Vantage Phase (8,000 to 4,500 B.P.) sites include leaf-shaped Cascade projectile points, stemmed projectile points, ovate knives, edge ground cobble tools, microblades, hammerstones, core tools, and scrapers. It is believed that people of this period were mobile foragers who relied in part on fish, mussel shell, seeds, and animals. Generally, Vantage Phase sites are located at the confluence of major rivers and their tributaries, near intersections of larger side canyons, and along rapids.

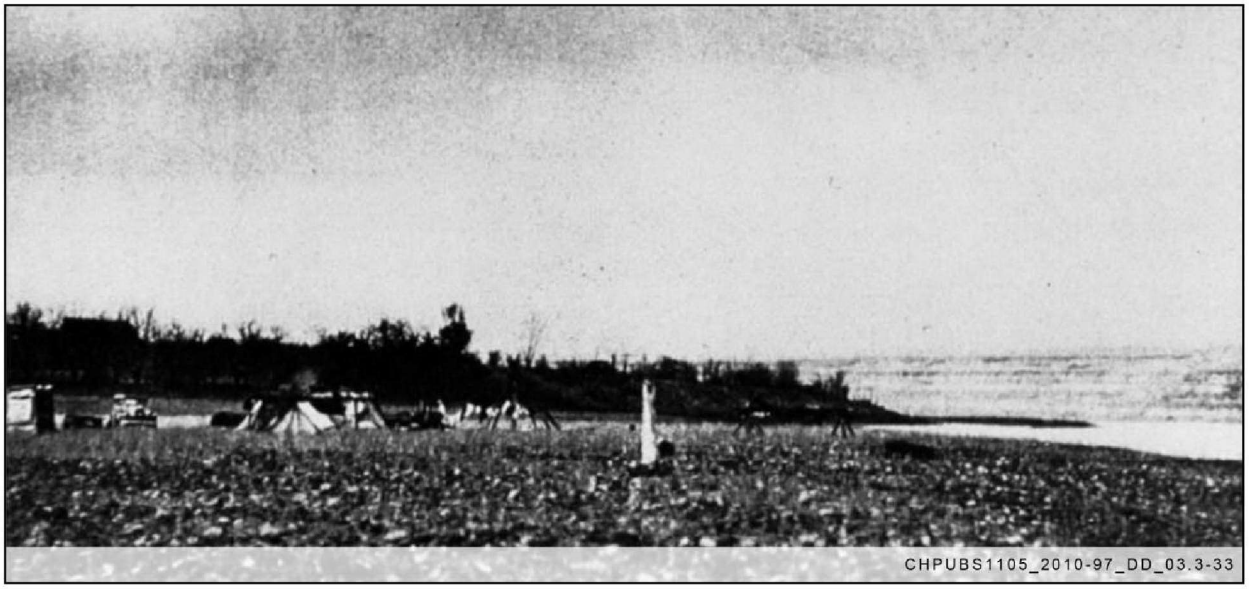
People of the Frenchman Springs Phase (4,500 to 2,500 B.P.) are believed to have been more dependent than were their predecessors on the use of natural resources from upland areas. The people from this period also shifted from tools manufactured from fine-grained basalt to cryptocrystalline silicas and petrified wood, probably the result of increased upland exploitation. It was during this period that a shift

from chipped stone to ground stone and cobble implements occurred. Mortars and pestles were first used during this period, suggesting increased reliance on seeds and roots. Semi-subterranean house pits were in use during this period, although not at every location. Research suggests there were both mobile and sedentary foragers with an increased reliance on upland resources.

The Cayuse I Phase (2,500 to 1,200 B.P.) is characterized by the use of pithouses. The pithouses had level floors and vertical walls with step-like benches, and basal-notched and corner-notched projectile points were used. The majority of the projectile points are corner notched. The Cayuse II Phase (1,200 to 900 B.P.) differs only slightly from the earlier phase in that it contains a different pithouse design. These pithouses lack the wall benches that characterize the previous phase. Projectile points remain very similar. In the Cayuse III Phase (900 to 250 B.P.), there is a decrease in the number of corner-notched projectile points and an increase in stemmed and side-notched points. An increase in the number of trade goods is also present during this period. In general, the Cayuse Phase contained well-developed ground stone technologies, small corner-notched and side-notched projectile points, scrapers, lanceolate and pentagonal knives, net weights, pestles, grinding stones, hopper mortars, and cobble implements. It was during the Cayuse period that populations increased their reliance on fish and root collecting, and reduced their reliance on hunting. Horses were introduced about 1730, increasing the hunting and transportation capabilities. The Cayuse III Phase was also the period with the largest precontact populations.

Sahaptin-speaking Wanapum people occupied the region of the Columbia River between the Wenatchee and Snake Rivers. Precontact population numbers were estimated to be as high as 10,000 before the beginning of the 19th century. By the early to mid-1800s, several epidemics reduced the population to a fraction of its original size. In the mid-1800s, a large group of indigenous people lived at Priest Rapids, referred to by early traders as Priest's Rapids People. Below Priest Rapids, the Wanapum resided at 15 different village locations. Randomly scattered between these village sites along this portion of the Columbia River were areas where small family groups also resided and places where food was cached.

Generally, the Wanapums wintered along the shoreline of the Columbia River, relying on stored foods collected during the yearly seasonal rounds. Plant collecting began in the low elevations in the spring and culminated each year in the upland areas near the end of the summer and early fall months. Midsummer was a time of hunting large and small game with seasonal camps near the foothills. By fall, the Wanapums would return to the river to pursue the fall fish migrations and prepare for the upcoming winter. Figure 3-51 shows a temporary Native American camp and Figure 3-52 shows a dugout canoe.



Note: Building in background and automobile to the left.

Figure 3-51. Native American Temporary Camp in 1945

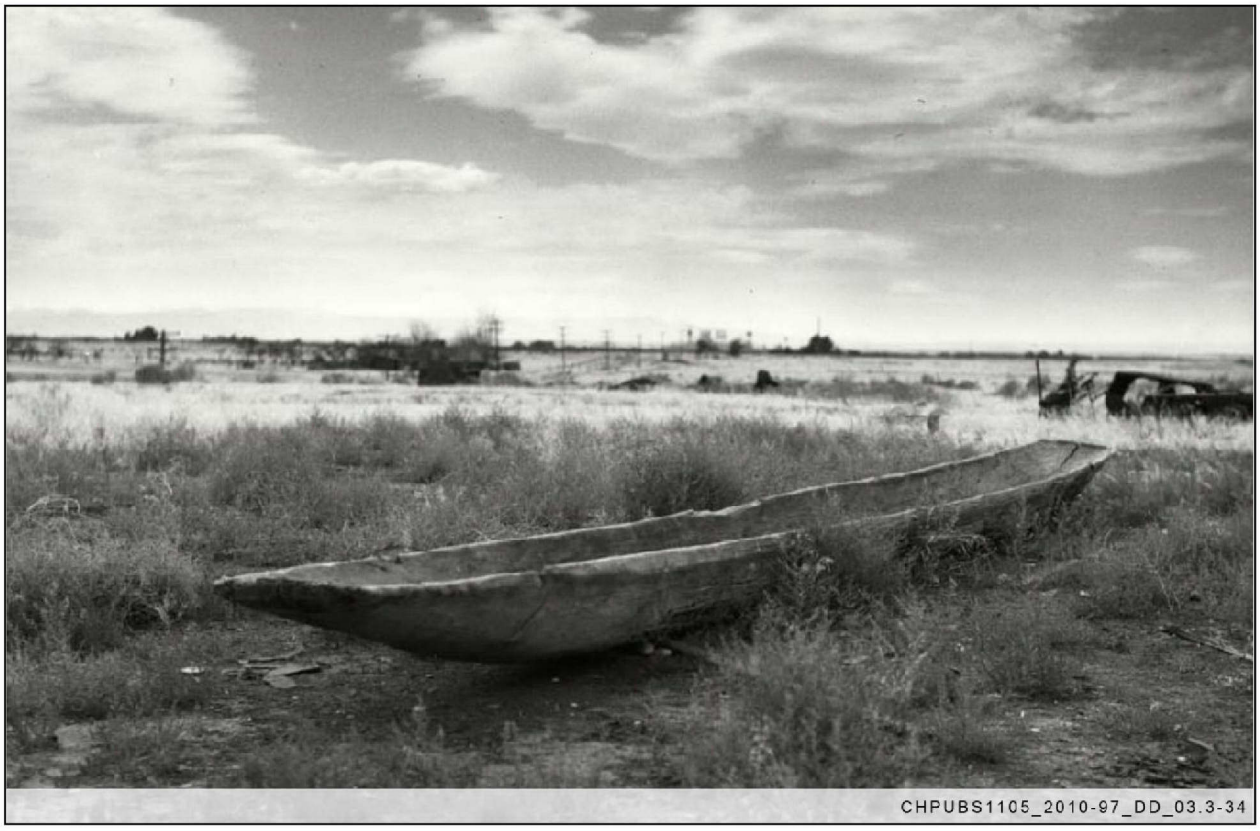


Figure 3-52. Dugout Canoe in 1945

3.10.2 Homestead and Townsite Era

The Lewis and Clark expedition of 1805 was the initial group of explorers/traders into the lower portion of the Hanford Reach. Their travels began the exploration and subsequent settlement of the region.

The explorers sought trade items from the Native Americans and trade routes for traded goods. They were later followed by gold miners, livestock producers, and homesteaders.

By the 1860s, the discovery of gold in the region resulted in a large influx of miners traveling on their way to the gold fields. Several locations along the Hanford Reach, such as Ringold, White Bluffs, and Wahluke, were part of the transportation routes used by miners and support industry. Numerous locations believed to be gold mining features created by Euro-Americans and Chinese remain along the shoreline of the Hanford Reach. The mining industry created a demand for beef, and the Columbia Basin was quickly discovered to be the ideal location for livestock production.

A noticeable increase in Euro-American settlement began in eastern Washington in the late 1800s. The initial permanent settlement of non-Indians into the area began slowly with livestock producers to support gold miners in Alaska and Idaho. Pasture was free for the taking and very abundant. Ranchers relied on the bountiful supply of bunch grass and open rangeland to graze thousands of cattle and, later, sheep and horses. The open range was also an ideal winter pasture. It lasted from the 1880s to about 1910, as homesteaders settled into the area and began to plow up the rangeland to plant crops. Even though the open rangeland was no longer available, livestock remained an important economic commodity to agricultural producers. Agricultural producers gradually replaced the open-range livestock operations that had dominated the area during the latter part of the 1800s and early 1900s.

Homesteaders developed the agricultural landscape in the Columbia Basin by removing unwanted sagebrush and bunchgrass, and plowing the land. The opportunity was brought about by the *Homestead Act of 1862*, which declared that anyone 21 years of age or older who was willing to live on and develop 65 ha (160 ac) of public land for five years was the legal owner. Near the turn of the century, many would-be homesteaders moved west to begin a new life. Many of the homesteaders traveled by one of the three transcontinental railroads (Northern Pacific, Great Northern, or Chicago, Milwaukee, St. Paul and Pacific Railroad) to the Columbia Basin area. Local transportation systems in the Columbia Valley were very limited at that time and, as a result, many of the new settlers arrived by river transportation.

Steamboat and ferry service were the primary transportation systems on the Columbia River in the early non-Indian settlement of the area. New agricultural towns of Hanford and White Bluffs, as well as small communities of Allard-Vernita, Wahluke, and Fruitvale, in addition to local rural residents, relied almost exclusively on river transportation during the early development of the area. Initially, when population numbers were low, canoes and ferry operations met the demand. However, as the population increased, steamboat owners took advantage of the opportunity to earn large profits. Many steamboats operated on the Hanford Reach carrying the larger cargoes, while canoes and ferries carried small cargoes of people, animals, and equipment primarily from one shore to the other. At least 10 ferry services operated on the Hanford Reach during their peak. As increasing numbers of farmers moved into the region, it became apparent that more water, other than small amounts of rain, was needed to produce higher agricultural yields. Irrigation projects were under construction throughout eastern Washington shortly after the turn of the 20th century.

Many irrigation projects began as small-scale, privately funded projects usually with insufficient funding, and the Hanford area was no exception. The Hanford area was sought after by developers and producers for its unique geographical ability to produce agricultural crops, especially fruit, two to three weeks ahead of harvests in surrounding areas. In the early 1900s, wheat and livestock were the primary agricultural commodities produced in Benton County.

By the early 1900s, land speculators began constructing large-scale, privately funded irrigation canals to supply water to thousands of acres in the White Bluffs, Hanford, Fruitvale, Vernita, and Richland areas. A variety of irrigation techniques were introduced to produce the most affordable irrigation system, which included pumping from wells, canals, and directly from the Columbia River. Poor economic conditions

brought about by weak commodity prices and the Depression of the 1930s created economic hardships on most local residents that continued until the area was acquired by the government under the *War Powers Act of 1941* for the Manhattan Project.

3.10.3 Manhattan Project and Cold War Era

The federal government selected the Hanford Site for the location of the Manhattan Project in 1942, and in 1943, approximately 1,500 local residents were relocated from their lands for the war effort. The following year, the Hanford Site was created to support the nation's production of plutonium during World War II. Plutonium production at the Hanford Site continued until 1965, when President Lyndon Johnson declared the nation's plutonium stockpile had exceeded its needs, and the production of plutonium was gradually decreased. The shutdown of N Reactor in 1986 and its transition to cold standby in 1989 with the end of the Cold War signaled the close of the production mission at the Hanford Site and the start of its environmental cleanup mission, which continues in earnest today. Section 1.2.2 presents additional information on the Manhattan Project and the Cold War Era.

3.11 Summary of Physical Setting

The 100-K study encompasses 3.1 km^2 (1.2 mi^2) on the south bank of the Columbia River in the northern portion of the Hanford Site between 100-BC and 100-N. The section of the Columbia River along 100-K defines a portion of the Hanford Reach, an important ecological, cultural, historical, and recreational feature that extends upstream from the base of Priest Rapids Dam to the slack water of McNary Dam, located near the southern boundary of the 300 Area. 100-K has two production reactors, 105-KE and its twin, 105-KW, located approximately 360 m (1,200 ft) to the west. 100-K is subdivided into three OUs to address cleanup of the soil and groundwater contamination: the 100-KR-1 and 100-KR-2 source OUs, which encompass liquid waste disposal sites, burial grounds, and soil waste sites; and the 100-KR-4 groundwater OU, which addresses groundwater contamination underlying 100-K.

The Columbia River discharge and resultant river stage in the Hanford Reach vary substantially, depending on the operations of Priest Rapids Dam, which ultimately controls the volume of river water flowing through the Hanford Reach. The highest discharge rates generally occur in the spring, from April through June, when snowmelt is contributing to surface runoff into the river.

The topography in 100-K is relatively flat inland from the Columbia River. Topography changes are greatest near the Columbia River where the riverbank slopes steeply. Surface elevations range from approximately 166 m (545 ft) AMSL near the southern boundary of 100-K to 119 m (390 ft) AMSL along the river. The mean elevation in 100-K is 145 m (476 ft).

The Hanford Site, including 100-K, is characterized by a semiarid, shrub-steppe climate in the driest and warmest portion of the Columbia Basin. The monthly average temperature ranges from a low of-0.24°C (31.7°F) in January to a high of 24.6°C (76.3°F) in July. Annual average relative humidity is 55 percent. Annual precipitation varies from approximately 7.6 to 31.3 cm (3.0 to 12.3 in.), with an annual average of 17.2 cm (6.8 in.). Most precipitation occurs during late fall and winter, with more than half occurring from November through February. Snowfall accounts for approximately 38 percent of the precipitation at the Hanford Site from December through February. Surface winds blow predominantly from the northwest during winter and summer months, and from the southwest during spring and fall. Local winds in the 100 Area and along the Columbia River are strongly influenced by near-river topography. Average monthly wind speeds at the Hanford Site are lowest during winter, averaging 10 to 11 kph (6 to 7 mph). The highest average wind speeds, ranging from 14 to 16 kph (8 to 10 mph), have been reported during summer.

100-K is underlain by Miocene-aged basalt of the CRBG, which is interbedded with or overlain by late Miocene– to Pleistocene-aged sediments comprising the Ellensburg Formation, the Ringold Formation,

and the Hanford formation. The Ellensburg Formation consists of a series of sedimentary units (epiclastic and volcaniclastic) that are interbedded with and overlie many of the basalt flows of the CRBG.

The Ringold Formation lies directly above the CRBG. Within 100-K, the top of the formation ranges from as shallow as 86.4 m (284 ft) bgs to approximately 110 m (370.8 ft) bgs in contact with the basalt group. The Ringold Formation is composed of nonindurated and semi-indurated (loose to semihardened) clay, silt, fine- to coarse-grained sand, or granule- to cobble-sized gravel that are grouped into five sediment layers. One of those layers, the Ringold unit E, which typically consists of fluvial gravels with lesser amounts of sand, silt, and clay as well as areas of local cementation, comprises most of the unconfined aquifer unit at 100-K. Ringold unit E is the most important Ringold unit when evaluating the nature and extent of groundwater contamination.

The Hanford formation overlies the Ringold Formation in 100-K, and consists of boulders, gravel, sand, and silt deposited by cataclysmic Ice Age flood waters that drained out of glacial Lake Missoula during the Pleistocene epoch. The Hanford formation is the dominant material in the 100 Area vadose zone (unsaturated zone), which ranges in thickness from less than 1 m (3.3 ft) near the river shoreline to approximately 30 m (100 ft) near the southeastern boundary of 100-K. The Hanford formation underlying 100-K is essentially a sand and gravel wedge that increases in thickness away from the river.

Both natural and artificial hydrologic processes have influenced groundwater flow patterns and contaminant distribution in the subsurface underlying 100-K. The effects of natural processes on contaminant migration are ongoing, while the effects of artificial operations have diminished over time with the end of reactor operations. However, some residual effects have not completely dissipated and other artificial processes continue to influence contaminant migration, particularly ongoing pump-and-treat operations.

Groundwater at 100-K generally flows southeast to northwest, essentially perpendicular and toward the Columbia River. To the northeast, beyond the 116-K-2 Trench, flow transitions to a more northeasterly direction parallel to the river. During fall, when river stage is relatively low, groundwater flow is toward the river, while in spring, when river stage is high, groundwater can flow away from or parallel to the river to the northeast. High river stages can be more than 3 m (10 ft) higher than low river stage. River stage can also fluctuate several meters over short periods (hours to days), based on operations at Priest Rapids Dam, and the changing river stage influences groundwater elevations several hundred meters inland.

Natural recharge to the aquifer is low because of the Hanford Site's hot, arid climate. In 100-K, the unsaturated conditions predominate in the vadose zone, although remedial action, pipelines, and site infrastructure contribute to increased soil moisture. As such, the moisture content in the vadose zone is the result of effluent discharge to the soil column, which ended in the mid-1990s, natural and artificial (dust suppression water, possible leaking infrastructure) recharge, and contribution from river stage. With reduction in artificial recharge, precipitation is considered the main source of recharge in 100-K.

Current land use in the Hanford Site River Corridor, including 100-K, consists of waste management, environmental monitoring, soil remediation, and conservation and restoration activities. Access is typically restricted to Hanford Site employees and contractors.

100-K is located in the Hanford Reach National Monument, which was created in 2000 to place high priority on the habitat maintenance and enhancement of shrub-steppe community native species throughout the Monument. The predominant plant community in the 100 Area is sagebrush/Sandberg's bluegrass/cheatgrass. Other shrub communities are dominated by bitterbrush, hopsage, and rabbitbrush. A relatively narrow riparian zone supports grasses, sedges, and scattered deciduous shrubs and trees such as willow, mulberry, and Siberian elm along the banks of the river. No plant species exists on the Hanford Site that is currently listed as threatened or endangered. However, two species of plants—Umtanum

desert buckwheat and White Bluffs bladderpod—are candidates for federal protection, and both are known only from the Monument.

Two species of federal-listed endangered fish—the Upper Columbia River spring-run Chinook salmon and the steelhead—occur in the Hanford Reach. The spring-run Chinook salmon do not spawn in the Hanford Reach, but use it as a migration corridor. Steelhead spawning has been observed in the Hanford Reach.

Seven prehistoric sites have been identified in 100-K, all of which are located on terraces along the Columbia River. In addition, numerous historic sites are associated with the pre-Hanford agricultural period. In general, archaeological sites on the Hanford Reach, including 100-K, tend to be on the alluvial flats and lower terraces near the shorelines and islands of the Columbia River. Shoreline sites are generally long and narrow, and run parallel to the river. Inland prehistoric sites have been discovered on Gable Butte, Rattlesnake Mountain, and near the few isolated seeps. Cultural resource surveys are routinely conducted as part of site evaluation and preparation prior to excavation to protect culturally sensitive areas. The results of these surveys are used in the site selection process and applied in the various sampling and analysis plans.

This chapter has described the setting and provided information regarding the area of interest, 100-K, the makeup of vadose materials the groundwater, and the Columbia River. Chapter 4 describes the contaminants resulting from Hanford operations and how and where they have interacted with and are now present in the setting. Contaminants can be harmful to human health and the environment if there is contact with sufficient concentrations, mass, and/or radioactive activity. Chapter 5 describes and predicts how quickly or slowly these contaminants will migrate through the setting, called fate and transport and, most importantly, the potential to enter the Columbia River. The potential to be harmful depends on specific human and environmental receptors as well as exposure times and patterns that might bring receptors and contaminants into contact. The ways that the contaminants could come into contact with and impact HHE are called pathways. Chapter 6 addresses the human health pathway. Scenarios of how humans might come into contact with contaminants in the setting with resultant health impacts are evaluated. Chapter 7 addresses the biological receptor pathway. Scenarios of how plant, animal, bird, or invertebrate species might come into contact with contaminants in the setting and be impacted are evaluated.

Chapters 3 through 7 present the setting, the contaminants, and the pathways for HHE contact and potential harm though relevant exposure scenarios. In Chapters 8 and 9, methods or technologies that could remove contaminants from the setting and/or interrupt these pathways are indentified and developed. Those methods or technologies that can best address the problem are compared and evaluated. This evaluation will support a remedial decision to implement actions to protect HHE.

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4 Nature and Extent of Contamination

The nature and extent evaluation describes the contaminant levels found in the environmental media in the study area. Contamination is determined from newly collected RI data, data from RI of the Columbia River, data available from previous field investigations, completed interim remediation, interim action ongoing remediation, and operational process information. This chapter focuses principally on the COPCs that were identified in the 100-K Work Plan (DOE/RL-2008-46-ADD2). This chapter continues to build on the CSM by adding information on contaminants into the physical setting.

This chapter also describes uncertainties associated with the data, as they relate to the nature and extent. The intent of this chapter is to provide information for determining a remedy(s) and identifying locations where the remedy(s) should be applied based on the long history of information for 100-K and the new information collected during the RI to meet the DQOs outlined in the 100-K Work Plan (DOE/RL-2008-46-ADD2) and 100-K SAP (DOE/RL-2009-41). Much of the data collected during remediation that has been documented in CVPs and LFIs also is incorporated into the discussion of nature and extent with the understanding that DQOs for these data generally are insufficient for risk assessment purposes.

Highlights

- The contaminants of potential concern are Cr(VI), Sr-90, carbon-14, tritium, and nitrate.
- Analytical results from the RI characterization wells indicated the presence of Cr(VI) in the deep vadose zone/periodically rewetted zone only at the northeast end of the K-2 Trench and suggests a potential continuing source in this area that should be monitored; Cr(VI) contamination in groundwater continues to be associated with the 100-KW Reactor, 100-KE Reactor, and the K-2 Trench with most of the contamination within and below the 3 to 4.6 m (10 to 15 ft) interval below the top of the water table.
- Both carbon-14 and Sr-90 are present in the groundwater in localized areas associated with selected cribs and trenches with vadose zone contamination near the source locations.
- Nitrate and tritium are present in large diffuse plumes.
- Pump-and-treat remediation efforts have been largely successful, especially in areas with higher transmissivity, such as the middle portion of the 116-K-2 Trench.

Information is also presented to describe the current understanding of contamination on the Columbia River, biota, and air; summarized from Hanford Site Releases Data Summary (WCH-398), the RCBRA Report (DOE/RL-2007-21), and *Hanford Site Environmental Report for Calendar Year 2008* (PNNL-18427). Section 4.2.2 describes vadose contamination associated with the 116-K-2 Trench and the 13 locations selected for new wells under the RI investigation. Section 4.2.3 describes groundwater contamination. Sections 44.3.1, 4.3.4, and 4.3.5 discuss Columbia River surface water/sediments, biota, and air, respectively.

4.1 Background Concentrations

Background refers to substances or locations that are not influenced by the releases from a site, and are usually described as naturally occurring (present in the environment in forms that have not been influenced by human activity) or anthropogenic (natural and artificial) substances present in the environment as a result of human activities not specifically related to the CERCLA site in question. Some chemicals may be present in background because of both natural and artificial conditions, such as naturally occurring arsenic and arsenic from pesticide applications (*Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* [EPA 540-R-01-003]).

The identification of background concentrations of constituents in the soil and groundwater is important in determining which waste sites may require remedial action. These concentrations are also important because calculated risk-based benchmarks (i.e., human health and ecological), in some instances, are less

than background levels. Where such benchmarks are less than background levels, RAGs default to background concentrations rather than the calculated values. CERCLA typically does not require cleanup to concentrations below background levels. Background soil and groundwater concentrations derived for the Hanford Site are presented in Tables 4-1 and 4-2, respectively, and are used as benchmarks to define contamination, as well as contaminants of potential concern.

As such, a constituent detected below background (i.e., 90th percentile in *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, hereinafter called Non-Rad Soil Background document [DOE/RL-92-24], and *Hanford Site Background: Part 2, Soil Background for Radionuclides*, hereinafter called Rad Soil Background document [DOE/RL-96-12]) is not considered a contaminant.

As part the RI, supplemental investigations for collecting data and developing River Corridor background values in soil for antimony, boron, molybdenum, and selenium were performed. Provisional data have been calculated.

Table 4-1. Background Concentrations in Hanford Site Soil

CAS Number	Analyte	Abbreviation	90th Percentile[a]	Reference
Radionuclides (pCi/g)				
14596-10-2	Americiuim-241	Am-241	--	--
14762-75-5	Carbon-14	C-14	--	--
10045-97-3	Cesium-137[b]	Cs-137	1.05	DOE/RL-96-12, Rev. 0
10198-40-0	Cobalt-60	Co-60	0.00842	DOE/RL-96-12, Rev. 0
14683-23-9	Europium-152	Eu-152	--	
15585-10-1	Europium-154	Eu-154	0.0334	DOE/RL-96-12, Rev. 0
14391-16-3	Europium-155	Eu-155	0.0539	DOE/RL-96-12, Rev. 0
13981-37-8	Nickel-63	Ni-63	--	--
13981-16-3	Plutonium-238	Pu-238	0.00378	DOE/RL-96-12, Rev. 0
15117-48-3	Plutonium-239/240[b]	Pu-239/240	0.0248	DOE/RL-96-12, Rev. 0
10098-97-2	Sr-90[b]	Sr-90	0.178	DOE/RL-96-12, Rev. 0
14133-76-7	Technetium-99	Tc-99	--	--
10028-17-8	Tritium	H-3	--	--
13966-29-5	Uranium-233/234	U-233/234	1.10	DOE/RL-96-12, Rev. 0
15117-96-1	Uranium-235	U-235	0.109	DOE/RL-96-12, Rev. 0
7440-61-1	Uranium-238	U-238	1.06	DOE/RL-96-12, Rev. 0
Nonradionuclides (mg/kg)				
7429-90-5	Aluminum	Al	11,800	DOE/RL-92-24, Rev. 4
7440-36-0	Antimony	Sb	0.13	ECF-HANFORD-11-0038
7440-38-2	Arsenic	As	6.47	DOE/RL-92-24, Rev. 4

Table 4-1. Background Concentrations in Hanford Site Soil

CAS Number	Analyte	Abbreviation	90th Percentile[a]	Reference
7440-39-3	Barium	Ba	132	DOE/RL-92-24, Rev. 4
7440-41-7	Beryllium	Be	1.51	DOE/RL-92-24, Rev. 4
7440-43-9	Cadmium	Cd	0.56	ECF-HANFORD-11-0038
7440-47-3	Chromium (Total)	Cr	18.5	DOE/RL-92-24, Rev. 4
18540-29-9	Chromium (Hexavalent)	Cr-VI	--	--
7440-48-4	Cobalt	Co	15.7	DOE/RL-92-24, Rev. 4
7440-50-8	Copper	Cu	22.0	DOE/RL-92-24, Rev. 4
7439-92-1	Lead	Pb	10.2	DOE/RL-92-24, Rev. 4
7439-96-5	Manganese	Mn	512	DOE/RL-92-24, Rev. 4
7439-97-6	Mercury	Hg	0.01	ECF-HANFORD-11-0038
7440-02-0	Nickel	Ni	19.1	DOE/RL-92-24, Rev. 4
7782-49-2	Selenium[a]	Se	0.78	ECF-HANFORD-11-0038
7440-22-4	Silver	Ag	0..17	ECF-HANFORD-11-0038
7440-28-0	Thallium	Tl	0.18	ECF-HANFORD-11-0038
7440-62-2	Vanadium	V	85.1	DOE/RL-92-24, Rev. 4
7440-66-6	Zinc	Zn	67.8	DOE/RL-92-24, Rev. 4
16984-48-8	Fluoride	F^-	2.81	DOE/RL-92-24, Rev. 4
14797-55-8	Nitrate	NO_3^-	52	DOE/RL-92-24, Rev. 4
14797-65-0	Nitrite	NO_2^-	[c]	DOE/RL-92-24, Rev. 4
75-35-4	1,1-Dichloroethene	--	--	--
106-46-7	1,4-Dichlorobenzene	--	--	--
83-32-9	Acenaphthene	--	--	--
120-12-7	Anthracene	--	--	--
12674-11-2	Aroclor 1016	--	--	--
11104-28-2	Aroclor 1221	--	--	--
11141-16-5	Aroclor 1232	--	--	--
53469-21-9	Aroclor 1242	--	--	--
12672-29-6	Aroclor 1248	--	--	--
11097-69-1	Aroclor 1254	--	--	--
11096-82-5	Aroclor 1260	--	--	--
71-43-2	Benzene	--	--	--

Table 4-1. Background Concentrations in Hanford Site Soil

CAS Number	Analyte	Abbreviation	90th Percentile[a]	Reference
56-55-3	Benzo(a)anthracene	--	--	--
50-32-8	Benzo(a)pyrene	--	--	--
205-99-2	Benzo(b)fluoranthene	--	--	--
207-08-9	Benzo(k)fluoranthene	--	--	--
191-24-2	Benzo(ghi)perylene	--	--	--
117-81-7	Bis(2-ethylhexyl)phthalate	--	--	--
86-74-8	Carbazole	--	--	--
56-23-5	Carbon tetrachloride	CCl_4	--	--
67-66-3	Chloroform	$CHCl_3$	--	--
218-01-9	Chrysene	--	--	--
53-70-3	Dibenz[a,h]anthracene	--	--	--
84-74-2	Di-n-butylphthalate	--	--	--
107-21-1	Ethylene Glycol	--	--	--
206-44-0	Fluoranthene	--	--	--
193-39-5	Indeno(1,2,3-cd)pyrene	--	--	--
75-09-2	Methylene Chloride	CH_2Cl_2	--	--
87-86-5	Pentachlorophenol	--	--	--
85-01-8	Phenanthrene	--	--	--
129-00-0	Pyrene	--	--	--
127-18-4	Tetrachloroethene	PCE	--	--
79-01-6	TCE	TCE	--	--
108-88-3	Toluene	--	--	--
68334-30-5	Total Petroleum Hydrocarbons	--	--	--

Sources: DOE/RL-92-24, Rev. 4, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*.

DOE/RL-96-12, Rev. 0, *Hanford Site Background: Part 2, Soil Background for Radionuclides*.

ECF-HANFORD-11-0038 is provided in Appendix G.

a. The 90th percentile value for Se is estimated because the majority of detections were below the minimum quantitation limit.

b. Cs-137, Sr-90, and Pu-239/240 are anthropogenic radionuclides whose background values only apply to surface soil samples.

c. Insufficient data above the reporting limit to provide for a distribution fit—either a background study has not been performed for this analyte (i.e., boron, strontium, tin) or the constituent does not occur naturally in the environment (i.e., the organic constituents).

CAS = Chemical Abstract Service

1

Table 4-2. Hanford Site Groundwater Background Concentrations for Contaminants of Potential Concern in 100-K Groundwater

Constituent	Units	90th Percentile
Nonradionuclides		
Antimony (filtered)	µg/L	55.1
Arsenic (filtered)	µg/L	7.85
Barium (filtered)	µg/L	105
Beryllium (filtered)	µg/L	2.29
Cadmium (filtered)	µg/L	0.916
Chloride (unfiltered)	mg/L	15.630
Chromium (total, filtered)	µg/L	2.4
Cobalt (filtered)	µg/L	0.916
Copper (filtered)	µg/L	0.81
Cyanide	µg/L	8.41
Fluoride	mg/L	1.047
Lead (filtered)	µg/L	0.917
Manganese (filtered)	µg/L	38.5
Mercury (filtered)	µg/L	0.003
Nickel (filtered)	µg/L	1.56
Nitrate (unfiltered)	mg/L	26.871
Nitrite (unfiltered)	mg/L	0.0937
Selenium (filtered)	µg/L	10.5
Sulfate (unfiltered)	µg/L	47014
Thallium (filtered)	µg/L	1.67
Uranium	µg/L	9.85
Vanadium (filtered)	µg/L	11.5
Zinc (filtered)	µg/L	21.8
Radionuclides		
Sr-90	pCi/L	0.0146
Tritium	pCi/L	119

Source: DOE/RL-96-61, *Hanford Site Background: Part 3, Groundwater Background*.

Note: The organic COPCs 1,1-dichloroethene, 1,1,2-trichloroethane, benzene, carbon tetrachloride, chloroform, tetrachloroethene, TCE, and vinyl chloride are assumed to have natural background concentrations of zero.

4.2 Nature and Extent

This section presents an analysis of the data collected to describe contaminant concentrations found in environmental media in 100-K. The analysis included data obtained from previous investigations as well as data collected during the RI. Analyses that are important to the risk assessment and subsequent development of remedial action alternatives include the horizontal and vertical extent of contamination in soil, groundwater, surface water, sediment, air, biota, and facilities. The ranges of contaminant concentrations in each medium, as well as the estimated maximum concentrations, are presented. The general movement of contaminants is from the vadose zone into the groundwater. Details of contaminant movement are described in Section 4.4. Likewise, contaminated groundwater can introduce contamination into the periodically rewetted zone when groundwater levels rise in response to rises in river stage. However, mobile contaminants will quickly migrate from the periodically rewetted zone back into the groundwater. In addition to spatial information, temporal trends in contamination are important in clarifying whether primary and secondary sources of contamination have been identified and are being effectively remediated. Several waste sites are located in proximity to the 105KE and 105KW Reactor buildings; for those locations that ultimately require remediation near the reactors, capping and/or other safe containment may be required until they can be accessed after the reactors have been dispositioned.

The major features of the CSM were described in Chapter 4 of the 100-K Work Plan, (DOE/RL-2008-46-ADD2). These concepts provide the basic framework for interpreting the data collected under the RI to fulfill the data gaps and data needs developed in the Work Plan. Refinement and discussion of the CSM in the context of the results presented in Chapter 4 is located in Section 4.4.

4.2.1 Sources

The primary sources of contamination in 100-K are liquid, slurry, and solid wastes generated during the operation of the reactors and support facilities, and from unplanned releases of both liquid and solid wastes. The secondary sources are contaminants remaining in the vadose zone or within the aquifer material. This section discusses what is considered a primary source and what is considered a secondary source, and highlights certain COPCs because of their extent or persistence.

4.2.1.1 Primary Sources

The primary sources of contamination in 100 K are two water-cooled nuclear reactors (105-KE and 105-KW) and the structures (e.g., fuel storage basins) and processes (e.g., sodium dichromate process) associated with reactor operations (Figures 1-12 and 1-13). The reactors were built to irradiate uranium-enriched fuel rods from which plutonium and other special nuclear materials could be extracted. The reactors and processes associated with operations generated large quantities of liquid and solid wastes. Effluent generated during operations consisted primarily of contaminated reactor cooling water, fuel storage basin water, and decontamination solutions. Cooling water consisted of river water treated to remove dissolved solids and enhanced with chemicals to reduce corrosion. Cooling water contaminants consisted of fuel materials, fission and irradiation byproducts, and CrVI (used as a corrosion inhibitor). CrVI is recognized as a primary contaminant of concern (COC) in groundwater because of its mobility, widespread presence, and potential impact to human health and the environment. Solid wastes consisted of sludge, reactor components, and various other contaminated items. Waste generated from reactor operations was contaminated with radionuclides, hazardous chemicals, or both. The 100-K SAP (DOE/RL-2009-41) provides a complete description of the chemical and radionuclides associated with area operations.

The primary release mechanisms are planned and unplanned releases. Liquid contaminants were released to the environment by discharging effluent to temporary surface impoundments, cribs, ditches, and the Columbia River. Solid waste was placed in burial grounds.

There are 163 waste sites (165 including subsites) in 100-K that consist of storage tanks, ponds, trenches, cribs, French drains, solid waste burial grounds, retention basins, pipelines, and spills/leaks. Approximately 30 percent of the waste sites have been partially or completely remediated and the remaining 70 percent are scheduled for future remediation. Appendix E contains a list of the waste sites that describes the site status with regard to assessment and remediation and includes information on site history and remaining analyte concentrations for remediated sites.

Liquid Effluent Waste Sources. The volumes of liquid effluent waste streams varied over several orders of magnitude. The largest volume streams were generated as steam condensate, cooling water, and unplanned releases. The primary contaminants related to the cooling water, as discussed in Chapter 1, include Cr(VI), carbon-14, tritium, Sr-90, and various radionuclides.

Concentrated Sodium Dichromate Waste Sources. The primary sources consisted of low volume highly concentrated sodium dichromate and variable volumes of low concentration in liquid effluent. To generate the cooling water solutions for the 105-KW and 105-KE Reactors, concentrated sodium dichromate feed solutions were processed through an infrastructure system that diluted the higher-strength source materials to achieve the required coolant composition.

Solid Waste Primary Sources. The primary solid waste source area types are buildings, burial sites, and solid waste sites. According to WIDS, the burial ground waste consists of numerous trenches and vertical steel pipes of various sizes that contain radioactive solid waste from 105-KE, 105-KW, and 105-N Reactors. The burial ground waste also includes zirconium cladding hulls and basin sludge from 105-N Reactor.

Coal-fired power plants were associated with the older reactors but were not installed at 100-K. There is no record of coal ash being disposed at 100-K from other reactor areas. Therefore, coal ash is not considered a solid-waste issue at 100-K. Incinerators operated onsite for several years burning low-level contaminated combustible material with ash being disposed as contaminated solid waste. All contaminated burning was halted in October 1960. Solid wastes were also disposed to burn pits, dumping areas, and as unplanned releases. These wastes consist of asbestos, wood, and concrete debris from building and demolition activities, garnet sand, and railroad ties.

Nonoperational Areas. The nonoperational areas at 100-K have been evaluated through the OSE process as described in Appendix K. This evaluation includes not only the potential for anthropogenic disposal activities but also considers windblown dust emissions, stack emissions, overland flow, and possible contaminant placement as a result of biointrusion by potential carriers such as wasps. Work at 100-K has been coordinated with the two contractors working on the source area remediation-inside the exclusion area and outside the exclusion area. An historical evaluation was performed inside the exclusion area and walkdowns conducted outside the exclusion area. The opportunity for additional discoveries will continue throughout cleanup of 100-K.

4.2.1.2 Secondary Sources

The releases of primary contaminant sources to the environment resulted in contaminated vadose zone material beneath facilities and waste sites. The contaminated vadose zone impacted by disposal practices and release forms the secondary sources, and has the potential to further spread contaminants through the environment. Other potential secondary sources evaluated for the current investigation included contaminated material in the periodically rewetted zone and in the top layers of the RUM, as discussed later in this chapter.

Chapter 1 presents the operational periods of the facilities. The reactor processes responsible for generating and releasing the primary sources to the environment have all been discontinued. Contaminants remaining as secondary sources may continue to migrate through the environment, depending on the individual constituent properties. The constituents detected in 100-K groundwater samples collected since 2005 are presented in Section 4.2.3.

The evaluation of risks posed by the identified secondary sources to human health and the environment through direct exposure are discussed in Chapters 6 and 7, respectively. The potential for secondary sources to provide a significant ongoing source of contamination to groundwater is evaluated through the comparison of contaminant concentrations in vadose zone material to the screening levels for groundwater and surface water protection in Section 5.1.2.

The COPCs seen in the vadose zone and groundwater are briefly discussed in the following sections. The RI results and pertinent historical data for the vadose zone and groundwater are presented in more detail in Sections 4.2.2 and 4.2.3, respectively.

4.2.1.3 Cr(VI)

In 100-K, Cr(VI) is a principal COPC, due to its mobility, widespread presence, and potential impact to human health and the environment (100-HR-3 and 100-KR-4 OU ROD [EPA/ROD/R10-96/134] and 100-K Work Plan [DOE/RL-2008-46-ADD2]). Cr(VI) is present in the groundwater at 100-K at concentrations exceeding aquatic and drinking water standards (DWSs). Sodium dichromate dihydrate ($Na_2Cr_2O_7$-$2H_2O$), the chemical form of the treatment product containing Cr(VI), was delivered as a concentrated liquid. It was added to the reactor cooling water to inhibit corrosion of the aluminum process tubes reactors (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]). The general flow path of the sodium dichromate is shown in Figure 1-12. The concentrated solution arrived at the upstream end of the reactors via rail tanker cars. The concentrated solution was diluted from 700 g/L to 2 mg/L. By 1964, that amount was reduced to 1 mg/L.

The quantities of sodium dichromate received, handled, and processed each month in 100-K were essentially the amount needed to provide the 2 mg/L (ppm) concentration of sodium dichromate in the reactor cooling water. At an average cooling water usage rate of approximately 100,000 gpm at each at the 100-K Reactors, each reactor would consume approximately 0.75 kg of sodium dichromate dihydrate from 1.081 L of stock solution per minute. This would lead to approximately 1,557 L per day of stock solution, which would require a 19,000 L (5,000 gal) railcar every 12 days per reactor. Consequently, at least a railcar per week was required at 100-K to feed both reactors. Therefore, spills of concentrated liquid solutions of sodium dichromate materials during receiving, handling, and processing activities upstream of the 190 Building was the most likely source of observed groundwater concentrations greater than 2.0 mg/L (0.7 mg/L of Cr(VI) [*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]]). In particular, the spills of sodium dichromate materials at cooling water support facilities had the greatest potential for environmental contamination. Most of the nuclear production facilities were designed so potential spills would be confined to interior surfaces and/or process equipment that drained to the process sewer and then to the Columbia River, while spills outside the facilities went to the ground and were not contained. Decontamination wastes produced in 100-K from reactor decontamination were commingled with other liquids and were routed for disposal in 116-K-2 Trench.

During the operation of the 100-KE and 100-KW Reactors and associated facilities, more than 20 locations received sodium dichromate dihydrate high concentration solutions. After operations, reactor decontamination wastes were discharged to the 116-K-2 Trench.

4.2.1.4 Tritium

Tritium was formed by neutron activation during reactor operations and in FSBs by fission of fuel rod material. Tritium was discharged at elevated concentrations to the vadose zone at the 116-KE-1 and 116-KW-1 Gas Condensate Cribs (BHI-01737) and at the 105-KE and 105-KW Fuel Rod Storage Basins and their respective cribs, 116-KE-3 and 116-KW-2. Tritium has also been found in groundwater at wells downgradient of the 118-K-1 Burial Ground. A set of six caissons at the 118-K-1 Burial Ground are linked to tritium in the soil column and groundwater (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]).

An estimated 58.5 Ci of tritium (decayed through 1986) was discharged to each of the two gas condensate cribs. Residual tritium concentrations were reported at the bottom of the gas condensate crib excavations (BHI-01737) at 465 to 851 pCi/L for 116-KE-1 and 35.5 to 162 pCi/L for 116-KW-1. It was determined that tritium would impact groundwater at concentrations greater than 20,000 pCi/L at both cribs. Tritium was also a low-level contaminant in water discharged to the Columbia River and to the 116-K-2 Trench (*Cleanup Verification Package for the 116-K-2 Effluent Trench* [CVP-2006-00001]). The tritium inventory discharged to the 116-K-2 Trench is reported as 25 Ci (*Radiological Characterization of the Retired 100 Areas* [UNI-946]). Other inventories have not been reported.

Tritium exceeds the 20,000 pCi/L DWS in groundwater near the southwestern portion of the 116-K-2 Trench and near the northern edge of the 100-KW Reactor area. Additional detail on groundwater extent is presented in Section 4.2.3. Tritium's DWS is the basis for the division between high and low waste sites.

4.2.1.5 Carbon-14

Carbon-14 was formed at the 105-K Reactor when the cover gas system was converted from a helium-carbon dioxide blend to nitrogen. The cover gas system helped cool the reactor and removed moisture vapor. The carbon was activated in the graphite blocks in the core and most likely formed CO_2 gas. The gases were condensed in the 115-KE and 115-KW Facilities, and the residual liquids were discharged to the 116-KE-1 and 116-KW-1 Cribs. As reported in BHI-01737 (2004), the cribs were partially excavated to a depth of 9 m (30 ft), removing underground piping, and up to 2,519 m^3 of contaminated soil. The excavations were not continued, as the laybacks would have undercut adjacent buildings, and were then backfilled. Residual carbon-14 concentrations remaining in the soil were as high as 7,600 pCi/g at 116-KE-1 and 45,000 pCi/g at 116-KW-1. These concentrations were indeterminate for assessing impacts of carbon-14 to groundwater. An estimated 110 Ci of carbon-14 was sent to the two cribs in 800,000 L (211,300 gal) of condensate. Carbon-14 typically would be expected to occur as calcium carbonate within the soil and aquifer matrix and as the bicarbonate ion in groundwater.

Carbon-14 is found in groundwater associated with the 115-KE and 115-KW gas condensate facilities. The DWS of 2,000 pCi/L distinguishes between high- and low-concentration carbon-14 facilities. A liquid condensate waste stream containing both carbon-14 and tritium was discharged to the two cribs during reactor operations. The contaminants appear to remain in the soil column in significant quantities, probably as insoluble calcium carbonate, and slowly leach into the aquifer, most likely as soluble bicarbonate.

4.2.1.6 Sr-90

Sr-90 is a fission product associated with plutonium formation within the reactors. It most commonly entered the environment through fuel rod ruptures in the reactors. The post reactor cooling water system was monitored for fuel rod failures and the contaminated cooling water was automatically valved directly to one of the 107-KE or 107-KW Retention Basins reserved for fuel rod rupture. During routine reactor

operations, no single basin was designated to receive the contaminated cooling water, so all three basins at both 107-KE and 107-KW received this waste stream. After the ruptured fuel rod was replaced, the collected liquid was discharged to the 116-K-2 Trench. A calculated total inventory of 2,100 Ci of radionuclides was sent to the 116-K-2 Trench, including a small Sr-90 fraction of 9 Ci (*100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]). The 116-K-2 Trench was cleaned up in 2004 to 2005 and documented in *Cleanup Verification Package for the 116-K-2 Effluent Trench* (CVP-2006-00001). Although 116-K-1 Crib never formally received cooling water contaminated by fuel rod ruptures, the facility did receive cooling water between 1965 and 1968. No inventory is known. Sr-90 was identified as a COPC in *Cleanup Verification Package for the 116-K-1 Crib* (CVP-2003-00024) for 116-K-1.

Sr-90 was also discharged to the vadose zone at the 105-KE and 105-KW FSBs and related 116-KW-2 and 116-KE-3 Cribs, both during reactor operations and as part of the N Reactor fuel storage program at the KE and KW FSBs. Again, there is no known inventory for the crib sites or for leaks at the 105-KE and 105-KW basins; however, groundwater concentrations at KE downgradient Monitoring Well 199-K-109A have reached to 18,600 pCi/L. The 107-KE and 107-KW Retention Basins also received quantities of Sr-90 through the discharge of cooling water contaminated by ruptured fuel rods (*Cleanup Verification Package for the 116-KE-4 Crib* [CVP-2005-00002], and *Attachment ES-1 Waste Site Reclassification Form* [CVP-2004-00001], respectively).

High- and low-waste sites are divided based on the Sr-90 DWS of 8 pCi/L. The contaminants may have been driven deeper into the vadose zone and possibly to groundwater by the use of dust suppression water.

4.2.1.7 Other Contaminants

Other contaminants have been identified in 100-K. These contaminants include nitrate, trichloroethene (TCE), total chromium, chloroform, technetium-99, four minor metals, and nitrite. Due to the unknown sources for the contaminants, limited data sets, and few wells where these analytes have been encountered, waste site maps have not been generated. Figure 2-1 and Appendix A provide well locations discussed in the following text.

Nitrate. Nitrate has been observed in groundwater samples taken across 100-K. It may be associated with discharge of nitric acid washes/rinses during reactor and support facility decontamination, human waste discharged to septic systems, a result of pre-Hanford agricultural activities, or some other source. Most concentrations are below the 45 mg/L DWS at 100-K Wells, but results above the DWS are found at Wells 199-K-11, 199-K-18, 199-K-30, 199-K-106A, 199-K-108A, and 199-K-111A. Levels of nitrate above the DWS at Wells 199-K-30 and 199-K-106A indicate releases to the 116-KE-1/116-KW-1 Cribs, potentially from decontamination activities. Nitrate in the 105-KW Reactor area, along with technetium-99, may be related to discharges from the 200 Area moving through Gable Gap (*Hanford Site Groundwater Monitoring for Fiscal Year 2008* [DOE/RL-2008-66]). Wastes at 199-K-18 and 199-K-111A may be attributed to decontamination waste discharges to the 116-K-2 Crib or, less likely, leakage of liquids from the 118-K-1 Burial Ground.

Trichloroethene. TCE has been observed at several wells within the 100-KW Reactor area. It may have been used as a solvent or cleaner, but its use has not been documented at facilities discharging to waste sites. The highest concentrations have been observed at Well 199-K-106A (35 µg/L, 1995) and a decommissioned (2003) downgradient Well 199-K-33 (20 µg/L, 1994). These data suggest that the source is the 116-KW-1 Gas Condensate Crib. Results at Well 199-K-185 (which replaced Well 199-K-33), other downgradient wells (199-K-132 and 199-K-34), and cross-gradient wells (199-K-34, 199-K-139, and 199-K-168) indicate that the plume has decreased from the earliest values and is being pulled by

extraction pumping at Well 199-K-132. TCE was not an analyte at Well 199-K-30, which is the equivalent well at 116-KE-1 Gas Condensate Crib.

Total Chromium. Total chromium is usually analyzed in concert with and as a backup analysis to Cr(VI) in groundwater samples. Total chromium values should be similar to and, ideally, slightly greater than the Cr(VI) in groundwater. In soil, the concentration of total chromium should be significantly greater than Cr(VI) unless significant Cr(VI) contamination is present.

Chloroform. Chloroform was detected during 1992 and 1993 analyses at Wells 199-K-29 and 199-K-32A at concentrations of 15 to 17 µg/L. This well association suggests releases from the 105-KE Reactor and/or supporting facilities at the 115-KE and 117-KE Buildings. No other more recently drilled wells in this area have encountered elevated levels of chloroform. Upgradient Well 199-K-36 detected chloroform in 1992 through 1993 to concentrations of 6 µg/L, but these concentrations have declined below 1 µg/L in recent sampling. Chloroform at Well 199-K-151 has ranged between 5.6 and 7.1 µg/L, but there are no known waste sites nearby to explain its presence.

Technetium-99. There is no obvious source for technetium-99 detected at wells around the 105-KW Reactor. Concentrations have reached 376 pCi/L (in 2003) at Well 199-K-106A, but all values reported since 1992 at other wells around the reactor are below 100 pCi/L. The elevated detection at 199-K-106A may indicate the 116-KW-1 Crib as the source, but there are no similar detections at Well 199-K-30 downgradient of the 116-KE-1 Crib. Technetium-99 in the 105-KW Reactor area may also be related to 200 Area discharges from past operations that have migrated through Gable Gap (*Hanford Site Groundwater Monitoring for Fiscal Year 2008* [DOE/RL-2008-66]).

Total Petroleum Hydrocarbons. During reactor operations, the 165-KE and 165-KW Powerhouses provided emergency backup power generation capabilities in the event of a failure on the regional electrical grid. The backup capability came from diesel powered generating equipment. The 166-KE and 166-KW diesel fuel storage facilities were buried just west of the 165-K Powerhouses. Leaks during the unloading process are known and visible as soil stains in the railcar unloading area. Total petroleum hydrocarbons (TPH)-diesel was first detected at Well 199-K-167, which was drilled in 2008. Diesel product was observed in soil samples taken at this and replacement Well 199-K-173 at a depth of 8.5 m (28 ft) bgs. These wells lie south of the 165 and 166-KW facilities. Groundwater samples taken while drilling at Wells 199-K-165 and 199-K-168 revealed initial low diesel detections in the first aquifer sample. More recent groundwater sampling has not detected diesel at any of the extraction wells (199-K-137, 199-K-165, 199-K-166, 199-K-168) in the 100-KW treatment system. New RI Well 199-K-186 encountered TPH-diesel in soil samples at a depth of 13.1 to 14.9 m (43 to 49 ft) bgs. However, TPH-diesel was not detected in groundwater samples added after the soil detection.

Minor Constituents. Antimony, lead, manganese, zinc, and nitrite were detected in groundwater samples collected while drilling. These contaminants were reported at one well (nitrite and zinc at Well 199-K-191), several wells (lead), or many (antimony and manganese) RI wells. The well distribution does not support any particular source for these contaminants. Well 199-K-191 is close to the 126-K-1 Landfill site.

COPCs Based on Process Knowledge. Appendix E presents information on all the wastes sites at 100-K and includes information on site type, site dimensions, dates of operation, site history, and COPCs.

Orchard Lands. Farmstead communities existed in the upland environment adjacent to the Columbia River from 1880 to 1943. The area became one of the premier orchard regions in the state following formation of the Hanford Irrigation and Development Company in 1905. Farms were primarily family-operated and ranged in size from under 2 ha (5 ac) to over 16 ha (40 ac). In 1913, development was bolstered by the

construction of rail lines. Farming near the towns of Hanford and White Bluffs came to an abrupt halt in 1943 when the U.S. government took possession of the land to produce weapons grade plutonium as a part of the Manhattan Project.

The River Corridor includes approximately 3,359 ha (8,300 ac) of historical farmsteads of which approximately 2,023 ha (5,000 ac) are historical orchard lands. Farmstead and orchard locations within the River Corridor were developed by analyzing historical aerial photography (1941 and 1943; pre-Hanford construction). The vertical aerial photographs were georectified to generate polygon areas for evaluation using the GIS database. Farmstead and orchard lands information was overlaid onto aerial photographs for evaluation. Other geographic data sources were used to validate the information, including the 1943 pre-Hanford Benton County Platted Ownership Lands map, county boundaries, and highways maps. Information from OSE field walk downs and 2008 high-resolution aerial photography were also used. At 100-K, an orchard was located in the area between the KW retention basins and the river and farmland was located upstream of the orchard to the southwest (Figure 4-1).

Arsenic and lead concentrations in orchard land soil are a function of the natural background (arsenic 5 to 9 ppm and lead at 11 to 24 ppm) plus the contribution from lead arsenate pesticide application prior to the advent of DDT. Lead arsenate applied in foliar sprays adhered well to the surfaces of plants, so its pesticidal effect was longer lasting. Initially, farmers prepared lead arsenate at home by reacting soluble lead salts with sodium arsenate, a practice that continued in some countries through the 1930s and likely 1940s. Lead arsenate pastes and powders also were sold commercially. Lead arsenate use in Washington State effectively terminated in 1948, when DDT became widely available to the public (*Re-establishing Apples Orchards in the Chelan-Manson Area* [Benson et al., 1969]).

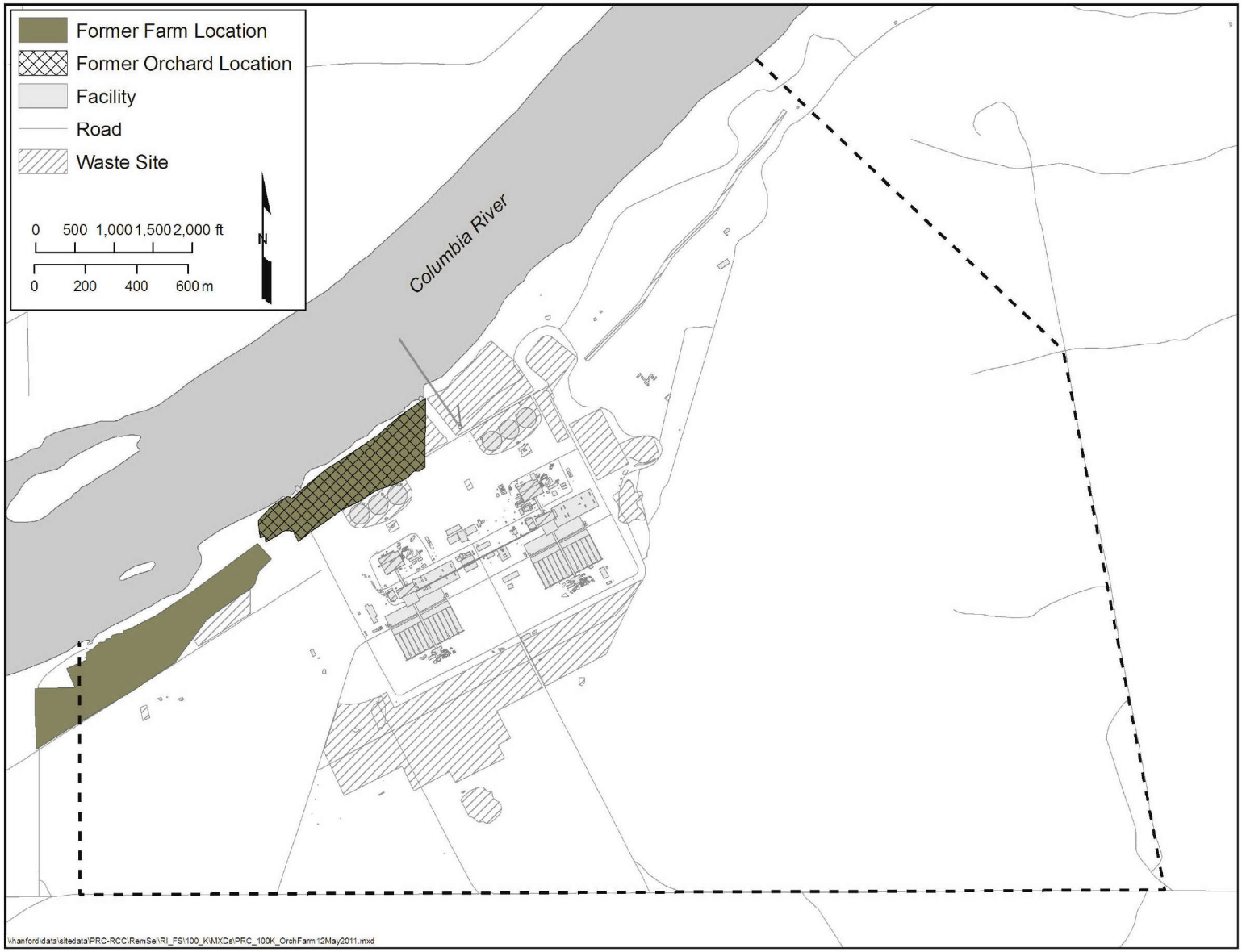

Figure 4-1. Locations of Former Orchards and Farms in the 100-K Area

Limited soil data are available for arsenic and lead concentrations within the River Corridor orchard lands.

- In 2001 to 2002, Ecology collected and analyzed surficial soil samples from six orchard areas in the River Corridor to characterize residual arsenic and lead. Concentrations for arsenic and lead were up to 270 and 1900 ppm, respectively, with an overall strong correlation between lead and arsenic results. Additional subsurface sampling up to approximately 0.46 m (1.5 ft) bgs was performed at the locations of the highest concentrations. Results for the subsurface samples generally declined with depth, though significantly more so for lead than for arsenic. Arsenic concentrations at the maximum depth sampled remained above 20 ppm, while lead concentrations were only slightly above background levels. The study also noted that the observed lead and arsenic concentrations were generally similar to other former orchard areas within Washington and elsewhere in the United States.
- WCH recently collected surficial X-ray fluorescence (XRF) data within the former orchard area surrounding the 600-151 waste site. Outside the waste site boundaries, arsenic and lead concentrations were measured up to 67 and 489 ppm, respectively.
- Ecology recently collected XRF data within former orchard areas near 100-H. Arsenic and lead concentration were measured up to 311 and 804 ppm, respectively.

Legislative established programs to evaluate statewide arsenic contamination consider the Method A soil cleanup level as a trigger for action. Cleanup actions within Washington State have and continue to be approved using the 20 mg/kg Method A value as the cleanup level—including cleanup actions at schools, childcare facilities, and residential properties. Additional information is available from Department of Ecology State of Washington web site: http://www.ecy.wa.gov/programs/tcp/area_wide/area_wide_hp.html.

Where historical orchard lands exist within the River Corridor that are not otherwise impacted by waste disposal activities or releases related to Hanford Site operations, they will be managed and addressed consistent with area wide soil contamination practices in other parts of Washington State (e.g., *Area-Wide Task Force Report*, June 30, 2003 [Ecology, 2003]). Where waste sites are collocated with former orchard areas, the waste sites are addressed normally. However, investigation and/or remediation of the waste site do not extend into surrounding or underlying soil contamination resulting from former orchard use. Solid lead was used extensively in Hanford site processes, resulting in lead-soil contamination at some waste sites. However, arsenic was not significant in Hanford processes except as a co-contaminant or impurity in other materials. It is reasonable to conclude that elevated lead and arsenic at waste sites within former orchard areas is attributable to former orchard use.

In 100 Area groundwater, arsenic is not detected above naturally occurring concentrations and detected lead concentrations are below the maximum contaminant level (MCL) of 15 µg/L. Arsenic is somewhat more mobile than lead in the subsurface, but these constituents do not exceed the MCL in groundwater. Consequently, the risk from these constituents would be expected to be minor, as detailed in Chapter 6.

4.2.2 Vadose Zone

This section describes the nature and extent of existing contamination in the vadose zone. The description of soil contamination is based upon data collected during previous field investigations, site closeout sampling, ongoing interim waste site remediation, and the current RI for constituents with concentrations that exceeded background soil concentrations (Non-Rad Soil Background document [DOE/RL-92-24], Rad Soil Background document [DOE/RL-96-12], and *Natural Background Soil Metals Concentrations in Washington State* [Ecology Publication 94-115]). Analytes detected above background in verification sampling at closed out, interim closed, and no action waste sites are summarized. Data generated from

this investigation were integrated with analytical results from *Limited Field Investigation Report for the 100-KR-1 Operable Unit* (DOE/RL-93-78).

The soil analytical data sets applicable to RI sampling include constituents characterized as having short half-lives (e.g., <3 years), common laboratory contaminants, essential nutrients, and essentially nontoxic substances. These constituents are commonly not discussed as detections and are primarily an artifact of the sampling and analysis process, not observed above background concentrations, or not a human health concern (i.e., nontoxic) per the *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A): Interim Final* (EPA/540/1-89/002). The list of constituents commonly includes aluminum, benzoic acid, bismuth, calcium, iron, magnesium, phosphate, phosphorous, potassium, silicon, sodium, tin, titanium, zirconium, cobalt-58, potassium-40, radium-226, sodium-22, thorium-228, acetone, bis(2-ethylhexyl)phthalate, diethyl phthalate, di-n-butylphthalate, toluene, and methylene chloride. Table 4-3 lists 100-K soil target analytes excluded from consideration.

Table 4-3. 100-K Soil Analytes Excluded from Further Consideration

Analyte	Exclusion Rationale	Daughters	Half-Life
	Radionuclides		
Actinium-228	Decayed daughter of Th-232/Ra-228; in equilibrium with parent; half-life less than three years	--	6.15 hrs
Cerium-144	Half-life less than three years	Pr-144m (1.2 m), Pr-144 (17.28 m), and Nd-144 (stable)	284.6 days
Cesium-134	Half-life less than three years	Ba-134 (stable)	2.065 yrs
Cobalt-58	Half-life less than three years	Ni-58 (stable)	70.88 days
Iron-59	Half-life less than three years	Co-59 (stable)	44.51 days
Lead-212	Decayed daughter of Th-232/Ra-228; in equilibrium with parent; half-life less than three years	--	10.6 hrs
Lead-214	Decayed daughter of Ra-226; in equilibrium with parent; half-life less than three years	--	26.8 min
Magnesium-54	Half-life less than three years	Fe-54 (stable)	612.2 days
Potassium-40	Naturally occurring background radiation	--	1.28 billion yrs
Radium-224	Decayed daughter of Th-232/Ra-228; in equilibrium with parent; half-life less than three years	--	3.66 days
Radium-226	Only potential source from naturally occurring background radiation (insufficient in growth time for Hanford introduced U as decay daughter of U-234/Th-230)	--	1,600 yrs
Radium-228	Naturally occurring background radiation	--	5.76 yrs
Ruthenium-103	Half-life less than three years	Rh-103m (56.12 m) and Rh-103 (stable)	39.27 days
Ruthenium-106	Half-life less than three years	Rh-106 (29.9 s) and Pd-106	1.020 yrs

Table 4-3. 100-K Soil Analytes Excluded from Further Consideration

Analyte	Exclusion Rationale	Daughters	Half-Life
		(stable)	
Sodium-22	Half-life less than three years	Ne-22 (stable)	2.605 yrs
Thorium-228	Naturally occurring background radiation (present in secular equilibrium with parent radium-228 isotope); half-life less than three years	--	1.91 yrs
Thorium-230	Only potential source from naturally occurring background radiation (insufficient in growth time for Hanford introduced U as decay daughter of U-234)	--	77,000 yrs
Thorium-232	Naturally occurring background radiation	--	14 billion yrs
Thorium-234	Decayed daughter of U-238; in equilibrium with parent; half-life less than three years	--	2.41 days
Tin-113	Half-life less than three years	In-113m (1.658 hrs) and In-113 (stable)	115.1 days
Uranium-240	Half-life less than three years	--	14.1 hrs
	Nonradionuclides		
Bismuth	No soil toxicity information available	--	--
Calcium	Essential nutrient	--	--
Chloride	Essential nutrient	--	--
Iron	Essential nutrient	--	--
Magnesium	Essential nutrient	--	--
Sodium	Essential nutrient	--	--
Potassium	Essential nutrient	--	--
Phosphate	Essential nutrient	--	--
Ammonia	No soil toxicity information available	--	--
Zirconium	No soil toxicity information available	--	--
Acetone	Laboratory contaminant	--	--
Bis(2-ethylhexyl) phthalate	Laboratory contaminant	--	--
Diethyl phthalate	Laboratory contaminant	--	--
Di-n-butylphthalate	Laboratory contaminant	--	--
Methylene chloride	Laboratory contaminant	--	--
Toluene	Laboratory contaminant	--	--

4.2.2.1 RI Sampling Locations

For the 100-K RI, nine new wells into the unconfined aquifer, four new wells into the RUM, and two boreholes beneath the 116-K-2 waste site to groundwater were completed, as described in the associated 100-K Work Plan (DOE/RL-2008-46-ADD2) and 100-K SAP (DOE/RL-2009-41). Wells 1 through 9 were installed to characterize contamination in the unconfined aquifer and RUM wells 1 through 4 were installed to characterize contaminants beneath the unconfined aquifer in the RUM. Per the SAP, all wells collected soil/sediment samples at 4.6, 3.0, 1.5, and 0.61 m (15, 10, 5, and 2 ft) above the water table, at the water table, and 1.5 m (5 ft) below the water table. Additional vadose samples were added for 100-K Wells 2, 4, 5, and 9, and RUM Wells 1, 3, and 4. RUM Well 3 is located in proximity to the 120-KE-6, 183-KE Sodium Dichromate Tank waste site and RUM Well 4 was placed within the current 100-K-97, 183-KW French Drain and Rail Spur Unplanned Release waste site excavation. Two boreholes to groundwater at the 116-K-2 Trench were sampled to characterize residual contamination beneath the remediated waste site. Table 4-4 identifies the boreholes and wells from which soil and sediment samples were collected. Figure 2-1 presents locations for 100-K RI sampling.

Table 4-4. Identification of 100-K Boreholes/Wells with Vadose Zone Samples

Borehole Identification	Well Identification	Associated Waste Site/RI Well ID[a]
A5748[b]	199-K-41	116-K-2
C7683	199-K-183	K Well 1
C7684	199-K-184	K RUM Well 1
C7685	199-K-185	K Well 2
C7686	199-K-186	K Well 9
C7687	199-K-187	K Well 3
C7688	199-K-188	K RUM Well 3 (120-KE-6)
C7689	199-K-189	K Well 5
C7690	199-K-190	K Well 4
C7691	199-K-191	K Well 6
C7692	199-K-192	K RUM Well 2
C7693	199-K-193	K Well 7
C7694	199-K-194	K Well 8
C7695	199-K-195	K RUM Well 4 (100-K-97)
C7831	199-K-200	116-K-2
C7832	199-K-201	116-K-2

a. Wells for 100-K RI are identified and described in the 100-K Work Plan (DOE/RL-2008-46-ADD2, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*).

b. Borehole A5748/Well 199-K-41 was sampled as part of the 1992 LFI activities at 116-K-2.

Samples from wells that were identified in the 100-K SAP (DOE/RL-2009-41) had the identical analytical requirements for radionuclide analyses (cesium-137, cobalt-60, europium-152, europium-154, and Sr-90),

Cr(VI), and metals. Additional analyses were performed if conditions during drilling indicated other contamination was encountered (e.g., TPHs). Analytes for the 116-K-2 RI boreholes included additional radionuclides, anions, and volatile organic compounds (VOCs) as described in the SAP.

Soil and sediment data from the 116-K-2 boreholes and related data, which underwent the most extensive characterization, are presented first. These are followed by soil data from wells that had additional vadose zone samples collected. Wells with soil/sediment data from the rewetted zone and aquifer only (K wells 1, 3, 6, 7, 8 and K RUM well 2) are presented last.

4.2.2.2 Vadose Zone Data

Vertical profiles are used to show the distribution of contamination in the vadose zone. The profiles provide, as applicable, a visual depiction of analytes above background, sample depth, the waste site structure, depth of remedial action, stratigraphy, and the water table depth encountered at sampling. As such, the profiles show those analytes detected in borehole soil/sediment above background. Reported depths from borehole sampling conservatively represent the lower end of the sample intervals rather than the entire range of the sample interval. Note that boron, molybdenum, strontium, and tin do not have established background values and are therefore reported wherever detections occurred. Closeout verification data are presented for boreholes that were sited on waste sites and reflect soil concentrations determined from closeout samples. The data presented are the closeout values for the site shallow zone [0 to 4.6 m (0 to 15 ft)] and/or deep zone >4.6 m (>15 ft) bgs soil concentrations from the CVPs or RSVPs. The concentrations represent the 95 percent upper confidence limit (UCL) based on the arithmetic mean of the data obtained from statistical sampling, unless otherwise noted. The shallow zone data provide the main indicator of contamination nearest the surface as these samples are collected at or less than 4.6 m (15 ft), depending on the depth of remedial action. The deep zone data represent samples collected at greater than 4.6 m (15 ft) bgs. For radiological data, both original results and results with decay correction to year 2012 are presented. The decay correction enables a more direct comparison to data obtained at multiple sampling times.

4.2.2.3 116-K-2 Trench

The 116-K-2 Trench is a significant waste site in 100-K due to its size, the amount of contamination it received, and its proximity to the Columbia River. The trench was excavated in 1955 and measured 1,219 × 13.7 m (4,000 × 45 ft), with a depth of 7.6 m (25 ft). The site received discharges from contaminated reactor floor drains, decontamination solutions, and approximately 500 g/min retention basis overflows containing sodium dichromate. It also received cooling water contaminated with ruptured fuel elements (*Radiological Characterization of the Retired 100 Areas* [UNI-946]). The trench was in use through the operational period of the 100-K Reactors.

Contamination associated with the 116-K-2 Trench is represented by soil samples from the three sampling events: the 1992 LFI for 100-KR-1 OU (*Limited Field Investigation Report for the 100-KR-1 Operable Unit* [DOE/RL-93-78]) borehole (pre-remediation), closeout verification samples collected in 2005 (post-remediation) (*Cleanup Verification Package for the 116-K-2 Effluent Trench* [CVP-2006-00001]), and 2010 RI boreholes. Figure 4-2 shows the location of the boreholes as well as the footprint of the original trench structure overlain with the boundary of remediation.

The 116-K-2 Trench was remediated from February 17, 2004 to October 27, 2005. Activities included removal of uncontaminated overburden and excavation and disposal of contaminated soil to a maximum depth of 7.6 m (25 ft) bgs. Following the remediation, cleanup verification samples were collected from both the shallow zone and deep zone excavation surfaces. The waste site excavation was separated into west and east ends for closeout sampling, each with a separate sampling plan. Contaminants of concern (COCs) included carbon-14, cesium-137, cobalt-60, europium-152, europium-154, nickel-63,

plutonium-239/240, Sr-90, and Cr(VI). Within the excavated area, the shallow zone consisted of the excavation sidewalls and floor that were less than 4.6 m (15 ft) bgs. Overburden was a separate sampling area with sampling results compared to shallow zone cleanup goals and is considered within the shallow zone decision unit. The remaining trench excavation greater than 4.6 m (15 ft) bgs was considered the deep zone and generally corresponds to the footprint of the engineered structure. Based on evaluation of the analytical results for shallow and deep zone closure verification samples, the site was determined to meet interim closure requirements.

The 116-K-2 waste site was selected for additional RI characterization in the 100-K Work Plan (DOE/RL-2008-46-ADD2) to address CSM uncertainties regarding contaminant distribution in the vadose zone. In addition, characterization was performed because residual contaminants had the potential to affect groundwater quality and contribute to localized Cr(VI) and tritium groundwater plumes. For the RI, two boreholes were sampled, one on the west end and the other on the east end of the trench. The original locations were mid-trench at the high concentration points of the Cr(VI) groundwater plumes. These original locations were shifted northwest approximately 2.1 m (7 ft) in an attempt to sample additional vadose zone soil above the excavation floor at 7.6 ft (25 ft) bgs. Figure 4-2 shows the location of the boreholes.

4.2.2.4 116-K-2 Trench—West Side

Table 4-5 presents data from the sampling events on the west end of the trench, including LFI borehole, cleanup verification sampling, and RI borehole results that are above established background concentrations. Figures 4-3 and 4-4 present vertical profiles of analytes detected above background in the LFI and RI boreholes.

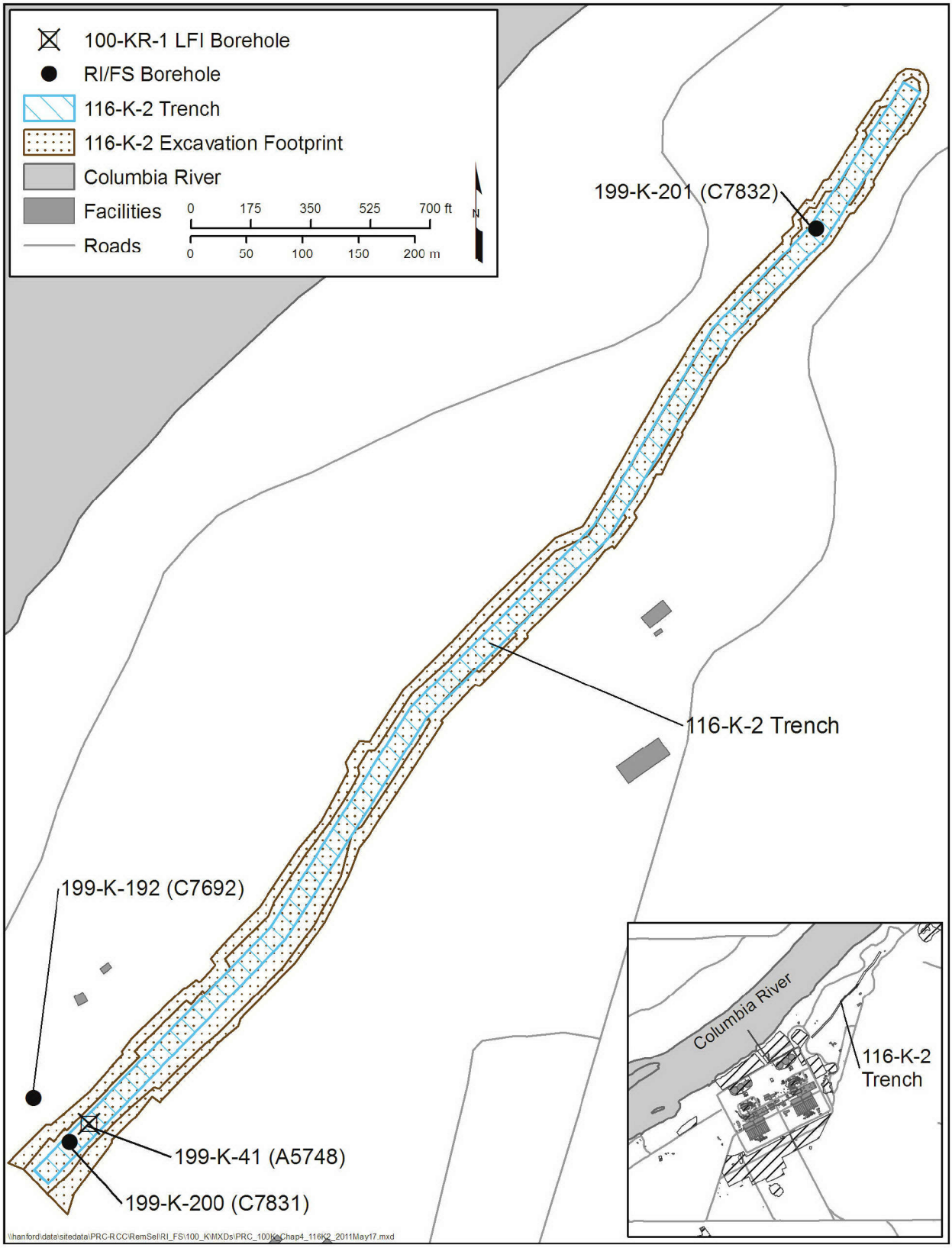

Figure 4-2. 116-K-2 Trench Location Map of LFI Borehole A5748 and RI Boreholes C7831 and C7832

Table 4-5. 116-K-2 Trench (West End)—Summary of Contaminant Soil Data

Analyte	Background	Concentration and Distribution													
		Cleanup Verification Data[a]				1992 LFI Borehole[b]					Remedial Investigation Borehole C7831[c]				
		Shallow Zone[d]		Deep Zone		Maximum Result with Corresponding Depth (m/ft bgs)		Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (6.1m/20 ft bgs)		Maximum Result with Corresponding Depth (m/ft ft bgs)		Extent of Detection above BG (m/ft ft bgs)	Result at Maximum Sample Depth (17.9 m/58.6 ft bgs)[e]	
Radionuclides (Original and Decayed Concentrations) (pCi/g)[f]															
		Original	Decayed	Original	Decayed	Original	Decayed		Original	Decayed	Original	Decayed		Original	Decayed
Americium-241	NA	ND	ND	ND	ND	13 (6.1/20)	13	7.4/24.3	U	NA	U	NA	NA	U	NA
Carbon-14	NA	0.29	0.29	1.44	1.44	11 (6.1/20)	11	6.1/20	U	NA	U	NA	NA	U	NA
Cesium-137	NA	1.10	0.92	117	97.4	1900 (6.1/20)	1173	8.4/27.5	U	NA	1.04 (9.4/30.7)	0.97	9.9/32.5	U	NA
Cobalt-60	NA	0.023 (U)	NA	4.23	1.48	370 (6.1/20)	23	9.1/30	0.077	0	0.299 (9.4/30.7)	0.20	9.4/30.7	U	NA
Europium-152	NA	0.626	0.42	76	50.4	1600 (6.1/20)	544	8.4/27.5	U	NA	0.625 (9.4/30.7)	0.54	9.4/30.7	U	NA
Europium-154	NA	0.129	0.07	7.2	3.8	250 (6.1/20)	46	7.4/24.3	U	NA	U	NA	NA	U	NA
Europium-155	NA	ND	ND	ND	ND	15 (6.1/20)	0.7	6.1/20	U	NA	U	NA	NA	U	NA
Nickel-63	NA	1.77	0.62	650	227	ND	ND	ND	ND	ND	112 (9.4/30.7)	110	9.9/32.5	U	NA
Plutonium-238	NA	ND	ND	ND	ND	2.1 (6.1/20)	1.8	6.1/20	U	NA	U	NA	NA	U	NA
Plutonium-239/240	NA	0.024 (U)	NA	4.7	4.7	44 (6.1/20)	44	7.4/24.3	U	NA	0.042 (9.4/30.7)	0.04	9.4/30.7	U	NA
Sr-90	NA	0.201	0.17	6.3	5.2	15 (6.1/20)	9.1	9.1/30	2.5	1.51	3.94 (9.4/30.7)	3.67	17.9/58.6	1.60	1.49
Nonradionuclides (mg/kg)															
Barium	132	ND		ND		122 (<BG) (9.1/30)		NA	122 (<BG)		160 (13.0/42.5)		13.0/42.5	26.9 (<BG)	
Boron	NA	ND		ND		ND		ND	ND		0.953 (13.0/42.5)		17.9/58.6	0.733 (<BG)	
Chromium	18.5	ND		ND		153 (6.1/20)		7.4/24.3	14.9 (<BG)		39.7 (10.8/35.5)		13.0/42.5	13.4 (<BG)	
Copper	22	ND		ND		44.9 (6.1/20)		9.1/30	30.7		23.4 (13.0/42.5)		13.0/42.5	15.4 (<BG)	
Cr(VI)	0	0.27[g]		2.4		ND		ND	ND		U[h]		NA	U	
Mercury	0.33	ND		ND		3.9 (6.1/20)		6.1/20	U		0.079 (<BG) (9.4/30.7)		NA	U	
Molybdenum	NA	ND		ND		ND		ND	ND		3.38 (13.0/42.5)		17.9/58.6	0.864	
Nickel	19.1	ND		ND		14 (<BG) (6.1/20)		NA	10.1 (<BG)		24.5 (10.8/35.5)		10.8/35.5	10.5 (<BG)	
Silver	0.78	ND		ND		1.5 (9.1/30)		9.1/30	1.5		U		NA	U	
Strontium	NA	ND		ND		ND		ND	ND		34.4 (13.0/42.5)		17.9/58.6	22.1	
Thallium	NA	ND		ND		U		NA	U		U		NA	U	
Tin	NA	ND		ND		ND		ND	ND		1.09 (11.3/37.2)		15.2/49.9	U	
Zinc	67.8	ND		ND		143 (6.1/20)		6.1/20	35.5 (<BG)		42.7 (<BG) (7.6/24.9)		NA	21.2 (<BG)	
Tetrachloroethene[i]	NA	ND		ND		0.004 (6.1/20)		7.4/24.3	U		U		NA	U	

Table 4-5. 116-K-2 Trench (West End)—Summary of Contaminant Soil Data

		Concentration and Distribution							
		Cleanup Verification Data[a]		1992 LFI Borehole[b]			Remedial Investigation Borehole C7831[c]		
Analyte	Background	Shallow Zone[d]	Deep Zone	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (6.1m/20 ft bgs)	Maximum Result with Corresponding Depth (m/ft ft bgs)	Extent of Detection above BG (m/ft ft bgs)	Result at Maximum Sample Depth (17.9 m/58.6 ft bgs)[e]
TCE[i]	NA	ND	ND	0.002 (6.1/20)	6.1/20	U	U	NA	U

a. Verification sample results represent the maximum 95% UCL concentration from the given decision unit(s). Values that are followed by (U) indicate that none of the data used for 95% UCL calculation were detected above the sample minimum detectable activity. Verification 95% UCL values were obtained from CVP-2006-00001, *Cleanup Verification Package for the 116-K-2 Effluent Trench*. The maximum depth of interim remedial action at 116-K-2 was 25 ft bgs.

b. LFI borehole data obtained from DOE/RL-93-78, *Limited Field Investigation Report for the 100-KR-1 Operable Unit*, and HEIS. Soil samples taken in 1992 for LFI investigation at 1, 20, 24.3, 27.5, and 30 ft bgs (deeper end of interval reported). Total borehole depth was 30 ft bgs.

c. Data obtained from HEIS The water table was encountered at 15.6 m (51.2 ft) bgs. Well was drilled to 18.1 m (59.3 ft) bgs.

d. Shallow zone value represents the excavation area unless otherwise noted.

e. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

f. Original radiological data presented in left column with decay corrected value to year 2012 in right column. Data from closeout sampling 95% UCL values obtained using U-flagged data sets is not decayed.

g. Result is from overburden.

h. None of the 13 vadose/sediment samples collected to characterize contamination in borehole C7831 detected CrVI. However, a field split sample, collected for QA/QC purposes, at 44.9 ft bgs reported CrVI at 0.982 mg/kg.

i. Result is estimated value from detection(s) near the method detection limit. Data is not presented in profiles.

BG = background
bgs = below ground surface
HEIS = Hanford Environmental Information System
LFI = Limited Field Investigation
NA = not applicable
ND = no data, not a contaminant of concern/contaminant of potential concern
U = undetected
UCL = upper confidence limit

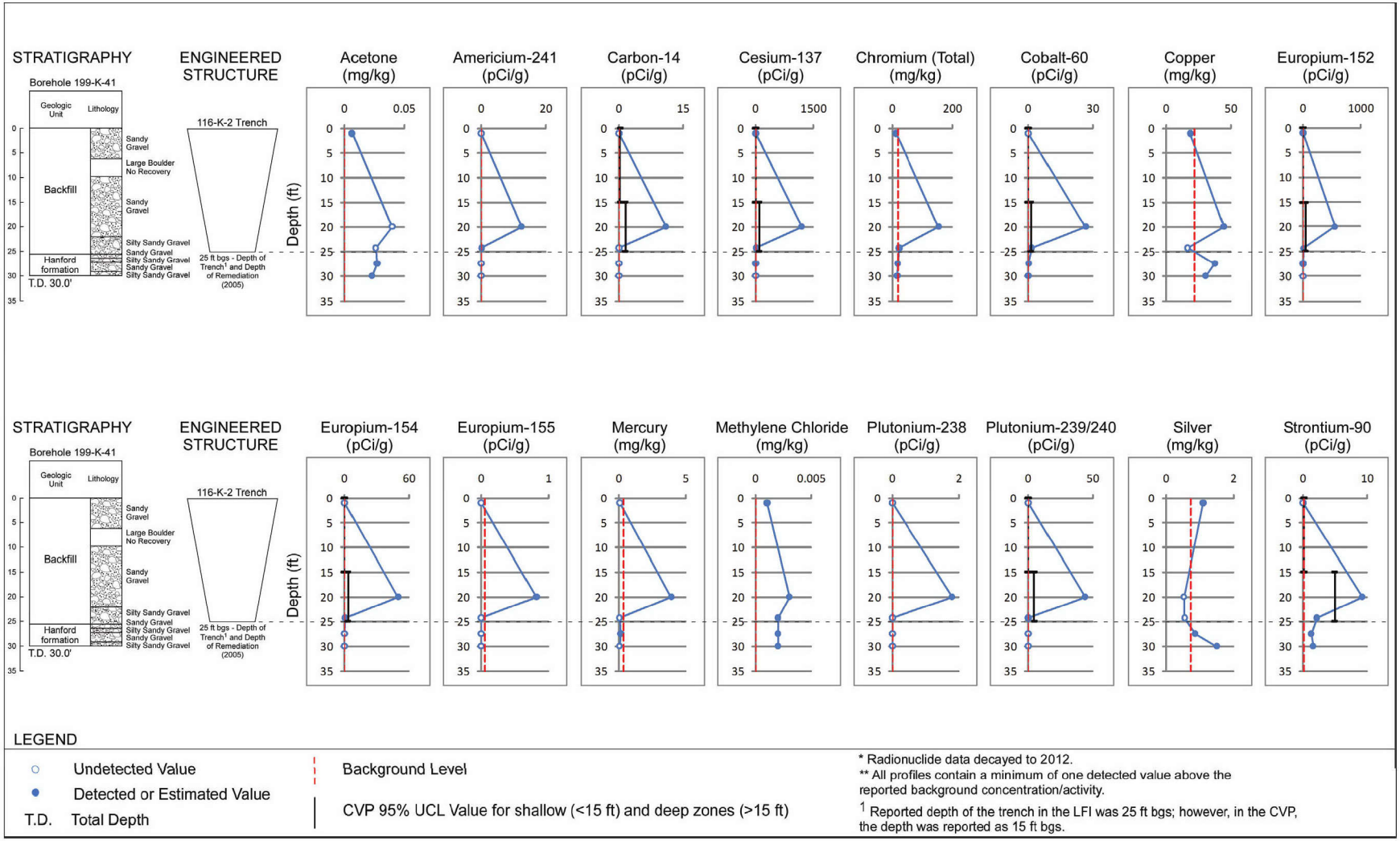

Figure 4-3. Vertical Profile from 116-K-2 LFI Borehole 199-K-41 (1992)

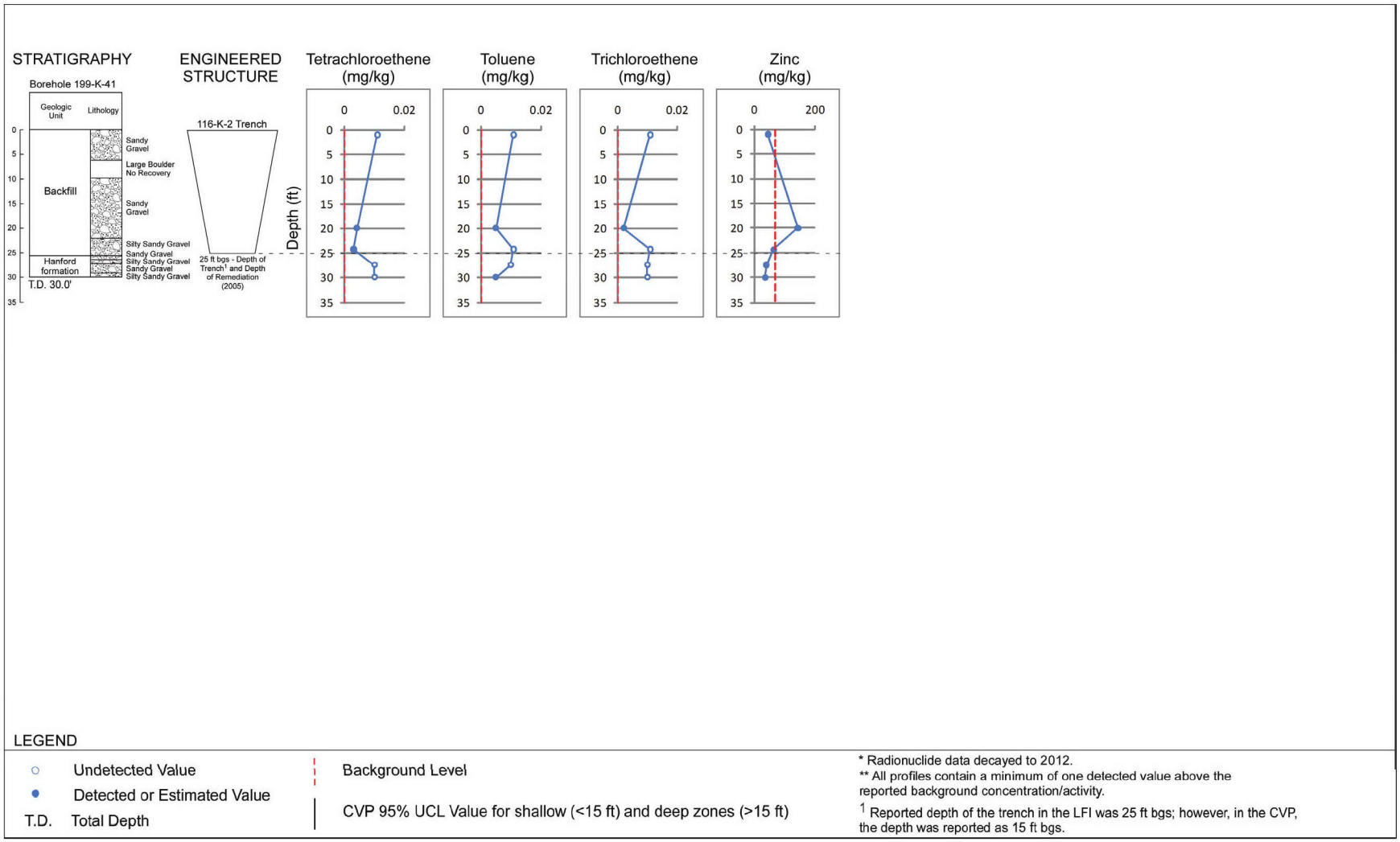

Figure 4-3. Vertical Profile from 116-K-2 LFI Borehole 199-K-41 (1992) (Cont.)

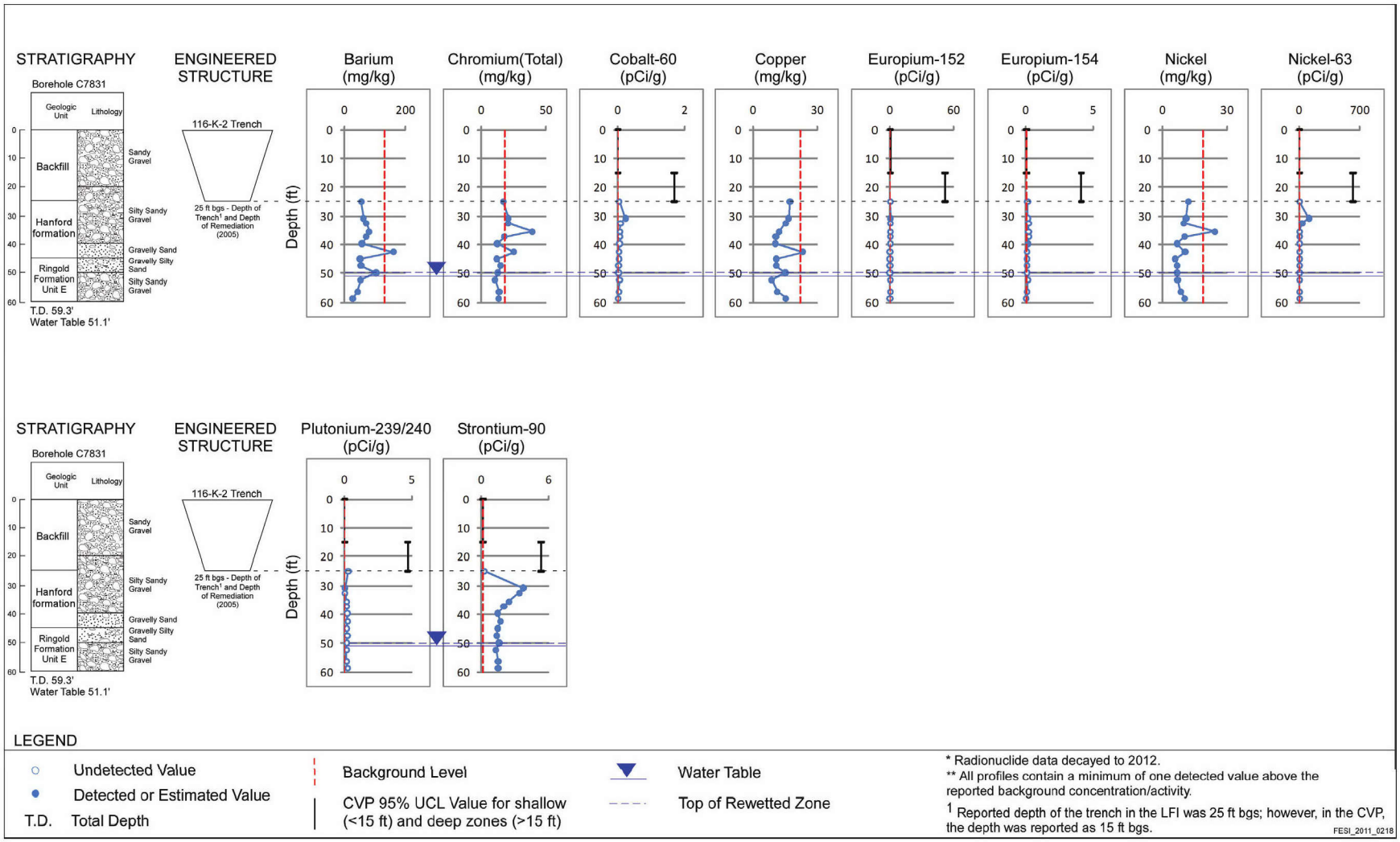

Figure 4-4. Vertical Profile from 116-K-2 Borehole C7831

Soil samples were collected during the 1992 LFI from borehole (199-K-41) sited within the trench structure on the influent (west) end of trench. Soil samples were collected from five soil intervals (0.3, 6.1, 7.4, 8.4, and 9.1 m [1, 20, 24.3, 27.5, and 30 ft] bgs). Sample results indicated significant radiological contamination in sample interval extending to 6.1 m (20 ft) bgs (Figure 4-3). Radionuclide concentrations decreased significantly with increasing depth, although the concentrations of Sr-90 were relatively constant in the three deepest intervals. Soil data from the LFI borehole samples between 0 to 7.6 m (0 to 25 ft) bgs represent material that was excavated from the trench and disposed during remedial action.

Table 4-5 summarizes analytical results for shallow and deep zone closure verification samples at west side of 116-K-2. Deep zone results were obtained from the floor of the trench excavation at a maximum depth of 7.6 m (25 ft) bgs. All site COCs were detected in the deep zone closeout samples. Based on comparison of verification sampling results to RAGs and site risk calculations, the site was determined to meet interim closure requirements.

The 2010 RI borehole for the west end of the 116-K-2 waste site (C7831) was located approximately 24 m (78 ft) southwest of 1992 LFI borehole (199-K-41). Borehole C7831 extended to total depth of 18.1 m (59.3 ft) bgs and the water table was encountered at 15.6 m (51.2 ft) bgs.

No radionuclides were detected from the uppermost sample interval at about 7.9 m (26 ft) bgs, indicating that this material was backfill placed after remediation. Sr-90 was detected in all borehole samples below the uppermost interval with a maximum concentration of 3.94 pCi/g at about 9.4 m (31 ft) bgs. Low cobalt-60, europium-152, and plutonium-239/240 activities were detected in the sample collected at about 9.4 m (31 ft) bgs. Cesium-137 and nickel-63 were elevated in the sample collected at 9.4 m (31 ft) at maximum activities of 1.04 and 112 pCi/g, respectively. The activities decreased to 0.313 and 33.1 pCi/g, respectively, in the next sample collected at 10 m (33 ft) bgs and were undetected in all other samples. Carbon-14 and tritium were undetected in all samples. In summary, with the exception of Sr-90, sample results indicate residual radiological contamination in the borehole below the west end of the trench is contained just below the depth of remediation. Residual Sr-90 concentrations are low and decrease with depth, but are present through the vadose and into the water table.

Cr(VI) was not detected in any of the samples while total chromium above background was detected in several samples between about 9.4 and 13.7 m (31 and 45 ft) bgs. The maximum concentration of total chromium, 39.7 mg/kg, was found at about 11 m (36 ft) bgs. Nickel was also elevated at 24.5 mg/kg in this sample interval. A single detection of barium above background at 160 mg/kg was found at 13.1 m (43 ft) bgs. However, the duplicate sample collected at this interval measured barium at 78.2 mg/kg, which is well under background concentration. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples. All nitrate results are below background. Both TCE and tetrachloroethene were undetected in all samples.

116-K-2 Trench—East Side. Table 4-6 presents data from closeout sampling and the RI borehole at the east end of the trench. The table presents analytical results from the cleanup verification sampling and RI borehole samples that are above established background concentrations. Figures 4-5 shows vertical profiles of analytes detected above background in the RI borehole.

Analytical results for shallow and deep zone closure verification samples at east side of 116-K-2 are summarized in Table 4-6. Deep zone results were obtained from the floor of the trench excavation at a maximum depth of 7.6 m (25 ft) bgs.

Table 4-6. 116-K-2 Trench (East End)—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution								
		Cleanup Verification Data[a]				Remedial Investigation Borehole C7832[b]			
	Back-ground	Shallow Zone[c]		Deep Zone		Maximum Result with Corresponding Depth (m/ft bgs)		Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (17.5 m/57.7 ft bgs Unless Otherwise Noted)[d]	
Radionuclides (Original and Decayed Concentrations) (pCi/g)[e]										
		Original	Decayed	Original	Decayed	Original	Decayed		Original	Decayed
Carbon-14	NA	0.70	0.70	1.26	1.26	U	NA	NA	U	NA
Cesium-137	NA	0.56	0.47	130	108	177 (6.6/21.8)	165	8.5/27.8	U	NA
Cobalt-60	NA	0.018 (U)	NA	2.48	0.87	1.71 (6.6/21.8)	1.15	8.5/27.8	U	NA
Europium-152	NA	0.17[f]	0.11	62.7	41.6	57.5 (7.8/25.7)	49.3	8.5/27.8	U	NA
Europium-154	NA	0.056 (U)	NA	5.4	2.8	4.78 (7.2/23.5)	3.75	7.8/25.7	U	NA
Nickel-63	NA	3.56	1.24	880	308	422 (6.6/21.8)	413	8.5/27.8	U	NA
Plutonium-239/240	NA	0.023 (U)	NA	6.9	6.9	3.59 (6.6/21.8)	3.59	7.8/25.7	U	NA
Sr-90	NA	0.143	0.12	7.12	5.87	5.45 (6.6/21.8)	5.07	16.0/52.5	U	NA
Nonradionuclides (mg/kg)										
Boron	NA	ND		ND		1.07 (12.2/40.0)		17.5/57.7	0.616	
Cadmium	0.81	ND		ND		1.85 (6.6/21.8)		7.8/25.7	0.072 (<BG)	
Chromium	18.5	ND		ND		81.6 (6.6/21.8)		12.2/40.0	12.9 (<BG)	

Table 4-6. 116-K-2 Trench (East End)—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution					
		Cleanup Verification Data[a]		Remedial Investigation Borehole C7832[b]		
	Back-ground	Shallow Zone[c]	Deep Zone	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (17.5 m/57.7 ft bgs Unless Otherwise Noted)[d]
Copper	22	ND	ND	23.8 (6.6/21.8)	6.6/21.8	9.0 (<BG)
Cr(VI)	NA	0.39	5.3	0.72 (15.1/49.7)	16.9/55.3	U
Mercury	0.33	ND	ND	0.745 (7.2/23.5)	7.8/25.7	U
Molybdenum	NA	ND	ND	2.82 (12.9/42.2)	17.6/57.7	1.39
Nickel	19.1	ND	ND	21.3 (10.0/32.9)	10.0/32.9	9.06 (<BG)
Strontium	NA	ND	ND	51.3 (15.1/49.7)	17.6/57.7	21.9
Tin	NA	ND	ND	2.87 (6.6/21.8)	17.6/57.7	1.03
Zinc	67.8	ND	ND	209 (6.6/21.8)	7.8/25.7	20.4 (<BG)
Styrene	NA	ND	ND	0.00992 (12.9/42.2)[g]	12.9/42.2	U

a. Verification sample results represent the maximum 95% UCL concentration from the given decision unit(s). Values that are followed by (U) indicate that none of the data used for 95% UCL calculation were detected above the sample minimum detectable activity. Verification 95% UCL values were obtained from CVP-2006-00001, *Cleanup Verification Package for the 116-K-2 Effluent Trench*. The maximum depth of interim remedial action at 116-K-2 was 25 ft bgs.

b. Data obtained from HEIS, The water table was encountered at 15.3 m (50.1 ft) bgs. Borehole was drilled to 18.4 m (60.4 ft) bgs.

c. Shallow zone value represents the excavation area unless otherwise noted.

d. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

e. Original radiological data presented in left column with decay corrected value to year 2012 in right column. Data from closeout sampling 95% UCL values obtained using U-flagged data sets is not decayed.

f. Result is from overburden.

g. Result is from single estimated detection near the method detection limit and is not presented in profiles.

BG = background

bgs = below ground surface

Table 4-6. 116-K-2 Trench (East End)—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution					
		Cleanup Verification Data[a]		Remedial Investigation Borehole C7832[b]		
	Back-ground	Shallow Zone[c]	Deep Zone	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (17.5 m/57.7 ft bgs Unless Otherwise Noted)[d]

HEIS = Hanford Environmental Information System

NA = not applicable

ND = no data, not a contaminant of concern/contaminant of potential concern

U = undetected

UCL = upper confidence limit

All site COCs were detected in the deep zone closeout samples. Radionuclide concentrations were similar to the west side closeout concentrations; however, Cr(VI) was twice the concentration in the east end deep zone (5.3 mg/kg) relative to the west end deep zone (2.4 mg/kg). Based on comparison of verification sampling results to RAGs and site risk calculations, the site was determined to meet interim closure requirements.

The 2010 RI borehole for the east end of the 116-K-2 waste site (C7832) was located in the far end of the east side of the trench in an area with the most elevated portion of the Cr(VI) groundwater plume. Borehole C7832 extended to total depth of 18.4 m (60.4 ft) bgs and the water table was encountered at 15.3 m (50.1 ft) bgs. Figure 4-5 shows vertical profiles of analytes detected above background.

As discussed in Section 4.2.2.3, the borehole location was shifted from the middle of the former trench structure to a location more likely to encounter unremediated soils shallower than the remediation depth of 7.6 m (25 ft) bgs. Due to this shift, contaminated soils were encountered above the depth of remediation. Significant concentrations of radionuclides were detected in the first sample collected at about 6.6 m (22 ft) bgs, indicating that unremediated material above 7.6 m (25 ft) was found (Figure 4-5). Sr-90 was detected at maximum concentration of 5.45 pCi/g in the upper interval. As seen in Table 4-6, the maximum concentration of Sr-90 (5.07 pCi/g with 2012 decay correction), obtained from the uppermost borehole sample, is nearly the same as the deep zone closeout value from the east end of 116-K-2 (5.87 pCi/g with 2012 decay correction). Sr-90 was detected in all samples between 6.6 m (22 ft) and 14.0 m (46 ft) with concentrations decreasing by an order of magnitude with increasing depth. Sr-90 was again detected in the sample collected from the aquifer at 16.2 m (53 ft).

Elevated cesium-137, cobalt-60, europium-152, europium-154, nickel-63, and plutonium-239/240 were consistent in samples collected between about 6.6 m (22 ft) and 7.8 m (26 ft) bgs. However, europium-154 and plutonium-239/240 are not detected, while concentrations of the remaining radionuclides decrease by an order of magnitude, in the next sample interval at 8.5 m (28 ft). The activities of these radionuclides in the upper borehole sample intervals, which are at and above the depth of remediation, are consistent with cleanup verification values from the deep zone. None of the subject radionuclides was detected in further borehole samples. Carbon-14 and tritium were undetected in all samples. In summary, with the exception of Sr-90, residual radionuclide contamination below the east end of the trench was not detected below 8.5 m (28 ft) bgs. Residual Sr-90 concentrations below this depth are similar to the low concentrations observed in the west end borehole and decrease with increasing depth. However, Sr-90 was detected through the vadose zone to a depth within the periodically rewetted zone (approximately 1.5 m [5 ft] above the water table) and below the water table.

Similar to the radionuclides, several metals were detected at elevated concentrations in upper borehole samples. Total chromium above background was detected between about 6.6 and 8.5 m (22 and 28 ft) bgs with additional elevated results at about 10.1 and 10.7 m (33 and 35 ft) bgs. The maximum result (81.6 mg/kg) was detected in the shallowest sample and concentrations were at or below background at depths greater than about 10.7 m (35 ft bgs). Elevated cadmium, copper, mercury, nickel, and zinc concentrations were measured in the uppermost one to three samples.

Concentrations of all subject metals were not detected above background below a depth of about 7.8 m (26 ft). Cr(VI) was not detected in the upper portion of the borehole but was detected in three of four samples collected in the rewetted zone and below the water table, between about 14.3 to 16.8 m (47 to 55 ft) bgs. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples. Nitrate concentrations were all below background values. The single detection of styrene at 0.00992 mg/kg at 12.9 m (42.2 ft) was reported. However, the styrene result showed contamination in the method blank and the validity of this detection is questionable. Both TCE and tetrachloroethene were undetected in all samples.

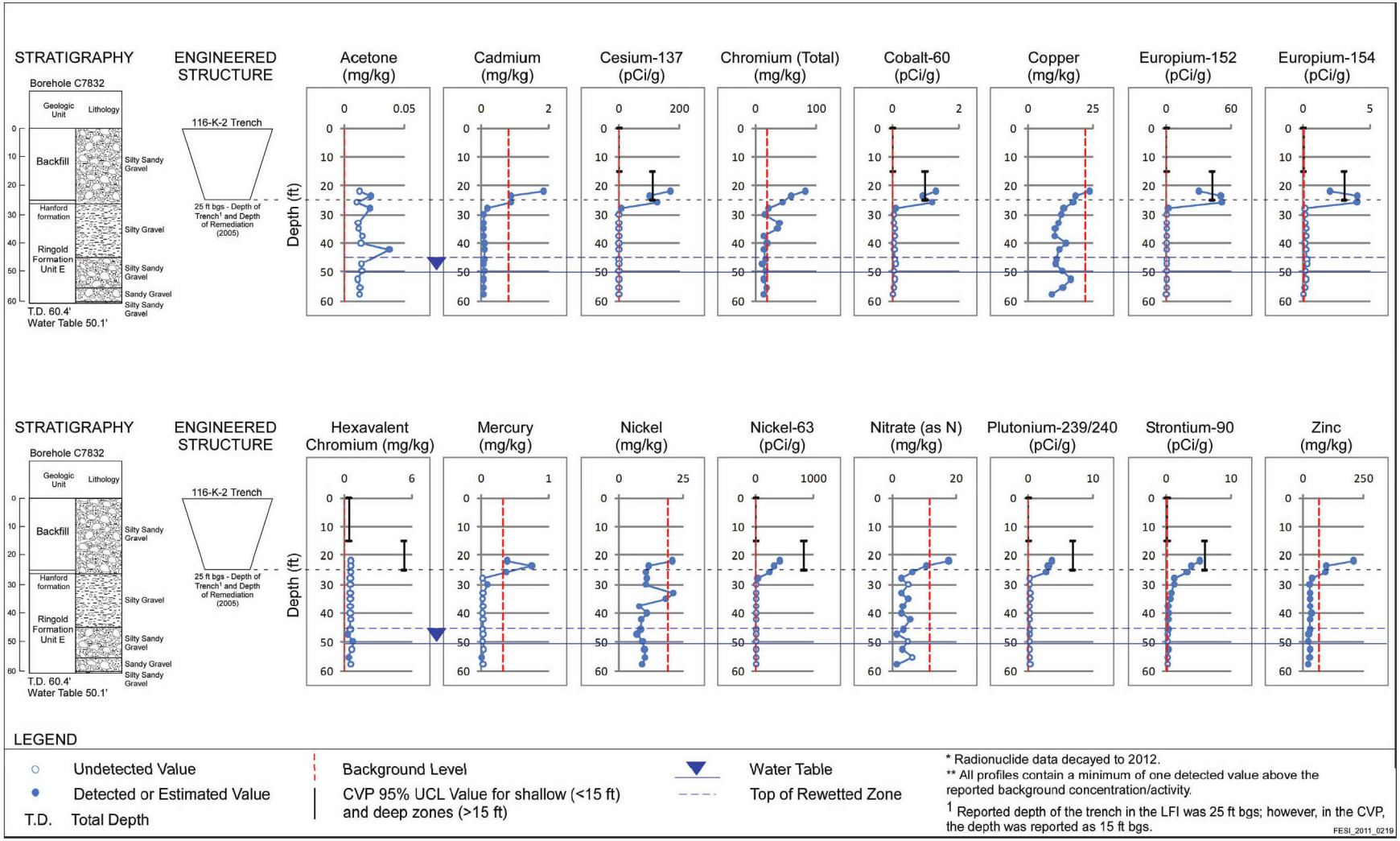

Figure 4-5. Vertical Profile from 116-K-2 Borehole C7832

4.2.2.5 Summary of Vadose Zone Contamination beneath the 116-K-2 Trench

Sr-90. Residual Sr-90 was measured below about 7.8 m (26 ft) bgs in the west borehole with a maximum value of 3.94 pCi/g in the interval extending to 9.4 m (30.7 ft) bgs. This maximum value of 3.67 (2012 decayed) compares well with the cleanup verification value of 5.2 pCi/g (2012 decayed). Sr-90 decreased with depth in the borehole but is present in all the west side vadose samples and into the water table.

In the east borehole, the maximum Sr-90 result was measured in the uppermost interval at about 6.6 m (22 ft) bgs at 5.45 pCi/g. This location corresponds to an unremediated area along the side slope of the deep zone excavation. As in the west borehole, this maximum value of 5.07 (2012 decayed) compares well with the deep zone cleanup verification value of 5.87 pCi/g (2012 decayed). Sr-90 levels decreased with depth but were detected continuously in borehole samples extending into the rewetted zone. Activities measured in the east trench borehole below 7.8 m (26 ft) were lower than those measured in the west trench borehole.

Other Radionuclides. Residual radionuclides were measured within similar sample intervals in RI boreholes and are therefore discussed together.

- In the west RI borehole, no radionuclides were detected the uppermost sample interval extending to 8 m (26 ft) bgs, indicating this sample was from backfill placed above the remediated floor of the trench. Peak residual contamination of cesium-137 (1.04 pCi/g), cobalt-60 (0.299 pCi/g), europium-152 (0.625 pCi/g), nickel-63 (112 pCi/g), and plutonium-239/240 (0.042 pCi/g) below the west end of the trench is contained in borehole intervals extending between about 9.4 × 9.9 m (31 ft × 33 ft) bgs, which is immediately below the depth of remediation. None of the subject radionuclides was detected in further borehole samples. All maximum radionuclide results from borehole are lower than that quantified for cleanup verification.

- Radiologically contaminated soil was encountered in the borehole on the east side of the trench in samples collected below 4.6 m (15 ft) bgs within an area just above depth of remedial action 7.6 m (25 ft). The most elevated results originated from an unremediated area along the side slope of the deep zone excavation. The concentrations of cesium-137, cobalt-60, europium-152, europium-154, nickel-63, and plutonium-239/240 from these upper east borehole sample intervals, which are at and above the depth of remediation, are consistent with cleanup verification values from the deep zone. The peak activities for cesium-137 (177 pCi/g), cobalt-60 (1.71 pCi/g), nickel-63 (422 pCi/g), and plutonium-239/240 (3.59 pCi/g) were observed in the interval extending to 6.6 m (22 ft) bgs above the final depth of remediation. The peak activities for europium-152 (57.5 pCi/g) and europium-154 (4.78 pCi/g) were measured at about 7.8 × 7.2 m (26 × 24 ft) bgs, respectively. Activities decreased with several feet and none of the subject radionuclides were detected below about 8.5 m (28 ft) bgs.

- Carbon-14, which was evaluated in cleanup verification samples, was undetected in all samples from both 116-K-2 RI boreholes. The highest cleanup verification value for carbon-14 was 1.44 pCi/g in the west end deep zone. Technetium-99 and tritium, which were not analyzed in verification sampling, were also undetected in all borehole samples.

- ***Cr(VI).*** Cr(VI) was not detected in the west side trench borehole. Cr(VI) was detected only just above and below the water table on the east end borehole with a maximum concentration of 0.72 mg/kg. This amount of Cr(VI) may be a source to concentrations observed in the underlying groundwater in the vicinity; therefore, additional groundwater monitoring is warranted in this area at the east end of the trench. Cr(VI) was not detected in the samples from unremediated material between about 6.6 and

7.8 m (22 and 26 ft) bgs in the east borehole. The 2005 cleanup verification sampling results for Cr(VI) in the deep zone on the west and east sides of the trench were 2.4 and 5.3 mg/kg, respectively.

- ***Total Chromium.*** Total chromium in the west trench borehole was elevated above background in most samples collected above 13.0 (43 ft) with a maximum concentration of 39.7 mg/kg. Total chromium in samples below this depth was below background. In the east trench borehole, concentrations of total chromium were highest (maximum 81.6 mg/kg) in samples extending between about 6.6 and 7.8 m (22 and 26 ft) bgs. This location corresponds to an unremediated area along the side slope of the deep zone excavation. Below this depth, total chromium was measured above background intermittently to a depth of 12.2 m (40 ft) bgs, and was below background in deeper samples.

- ***Other metals.*** Single detections of barium (160 mg/kg), copper (23.4 mg/kg), and nickel (24.5 mg/kg) above background were observed in the west end borehole. In the east trench borehole, concentrations of cadmium (maximum 1.85 mg/kg), copper (maximum 23.8 mg/kg), mercury (maximum 0.745 mg/kg), nickel (maximum 20.9 mg/kg), and zinc (maximum 209 mg/kg) were elevated above background only in samples between about 6.6 and 7.8 m (22 and 26 ft) bgs. This location corresponds to an unremediated area along the side slope of the deep zone excavation. As seen with the nonmobile radionuclides, these elevated concentrations are contained within an area just above depth of remedial action (7.6 m [25 ft]).

4.2.2.6 K Well 2

Borehole C7685 (K Well 2) was sited downgradient of the 116-KW-3 Retention Basin and 105-KW Reactor area to define the extent of Cr(VI), carbon-14, TCE, and Sr-90 in groundwater. Soil and sediment samples were collected from about 8.2 to 15.5 m (27 to 51 ft) bgs. During drilling, the water table was encountered at 14.3 m (46.7 ft) bgs. Analytes detected above background in borehole C7685 are summarized in Table 4-7, and vertical profiles of the contamination are shown in Figure 4-6.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected at very low concentrations (maximum concentration of 0.018 mg/kg) in all samples. Total chromium (21.2 mg/kg) and copper (23.6 mg/kg) were detected slightly above background in single intervals. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-7. Well K 2—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation Borehole C7685[a]		
Analyte	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (15.6 m/51.2 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	1.01 (8.4/27.4)	15.6/51.2	0.563
Chromium	18.5	21.2 (8.4/27.4)	8.4/27.4	8.16 (<BG)
Copper	22	23.6 (15.6/51.2)	15.6/51.2	23.6
Cr(VI)	NA	0.18 (11.4/37.3)	15.6/51.2	0.15
Molybdenum	NA	3.98 (11.4/37.3)	15.6/51.2	1.19
Strontium	NA	34.6 (11.4/37.3)	15.6/51.2	26.0

Table 4-7. Well K 2—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation Borehole C7685[a]		
Analyte	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (15.6 m/51.2 ft bgs)[b]
Tin	NA	2.12 (11.4/37.3)	15.6/51.2	1.68

a. Data obtained from HEIS The water table was encountered at 14.3 m (46.7 ft) bgs. Borehole was drilled to a total depth of 42.2 m (138.5 ft) bgs.
b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

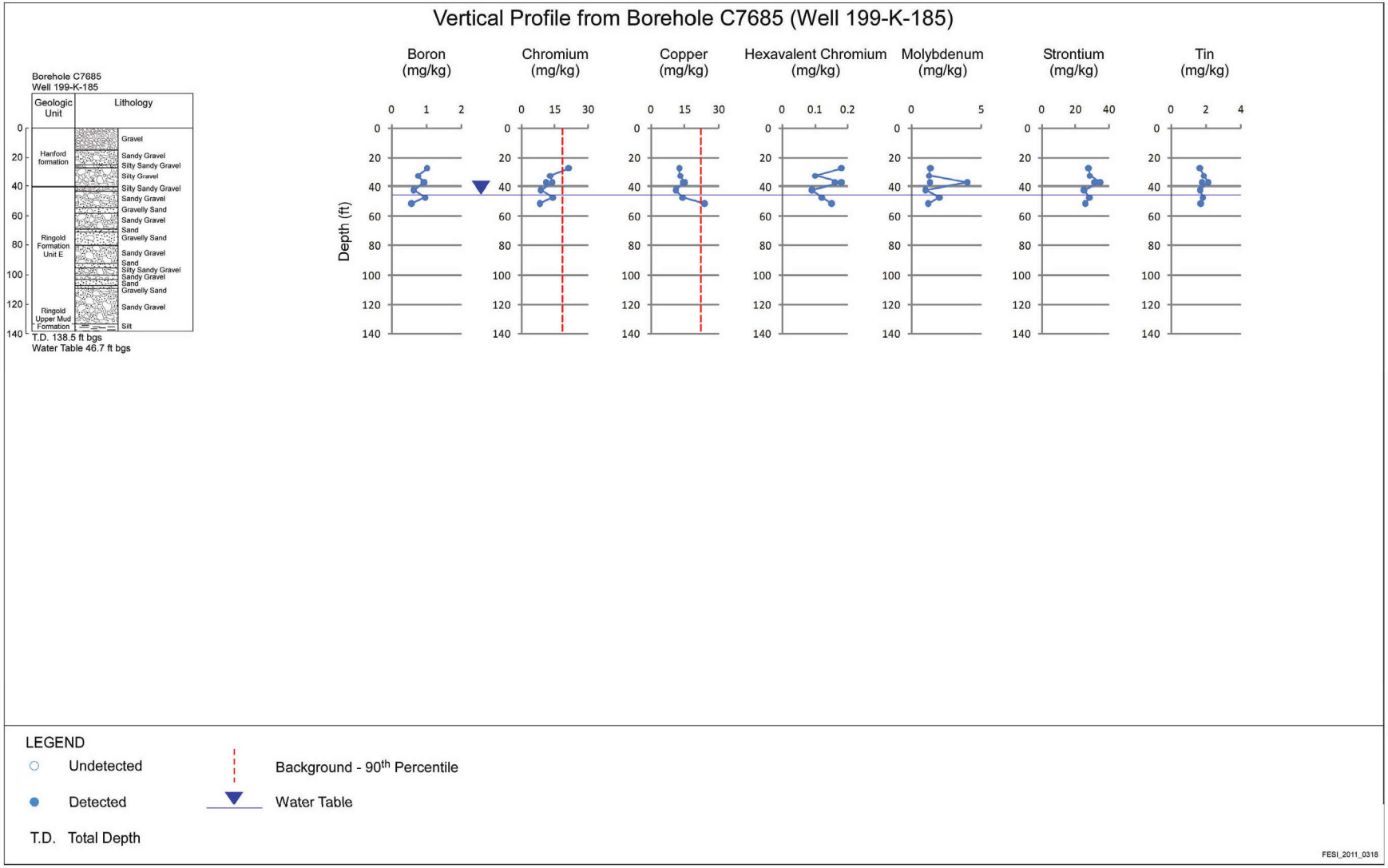

Figure 4-6. Vertical Profile from Borehole C7685 (K Well 2)

4.2.2.7 K Well 4

Borehole C7690 (K Well 4) was sited to define the extent of anomalous elevated Cr(VI) and Sr-90 in groundwater. Samples were collected from about 4.9 to 18.6 m (16 to 61 ft) bgs. During drilling, the water table was encountered at 16.6 m (54.5 ft) bgs. Analytes detected above background in borehole C7690 are summarized in Table 4-8, and vertical profiles of the contamination are shown in Figure 4-7.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected at very low concentrations (maximum concentration of 0.18 mg/kg) in all borehole samples including those from the aquifer. Total chromium was detected above background (21.8 and 29.1 mg/kg) at about 11.1 and 12.3 m (37 and 41 ft) bgs. Elevated total chromium and nickel concentrations (90.0 and 45.7 mg/kg, respectively) are observed in the sample collected at about 16.8 m (55 ft) bgs. These results are discussed further in Section 4.2.2. Total chromium or nickel above background was not measured in any other samples. A single detection of lead above background (15.7 mg/kg) was reported at about 15.8 m (52 ft) bgs. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-8. Well K 4—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
	Background	Remedial Investigation Borehole C7690[a]		
		Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (18.6 m/61.1 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	1.16 (12.3/40.5)	18.6/61.1	0.711
Chromium	18.5	90.0 (16.8/55.0)[c]	16.8/55.0	11.7 (<BG)
Cr(VI)	NA	0.18 (14.8/48.5)	18.6/61.1	0.16
Lead	10.2	15.7 (15.8/52.0)	15.8/52.0	3.60 (<BG)
Molybdenum	NA	1.94 (11.1/36.5)	18.6/61.1	1.77
Nickel	19.1	45.7 (15.8/55.0)[c]	16.8/55.0	9.00 (<BG)
Strontium	NA	30.6 (6.6/21.5)	18.6/61.1	16.0

a. Data obtained from HEIS. The water table was encountered at 16.6 m (54.5 ft) bgs. Well was drilled to a total depth of 42 m (137.7 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Results of chromium and nickel in B26VB7 collected at 16.8 m (55.0 ft) bgs are elevated. The maximum values of chromium and nickel from the well excluding this sample are 29.1 and 19.0 mg/kg, respectively, at 12.3 m (40.5 ft) bgs. Concentrations of chromium and nickel are less than background in the sample intervals above and below B26VB7 collected at 15.9 × 18.2 m (52.0 × 61.1 ft) bgs, respectively

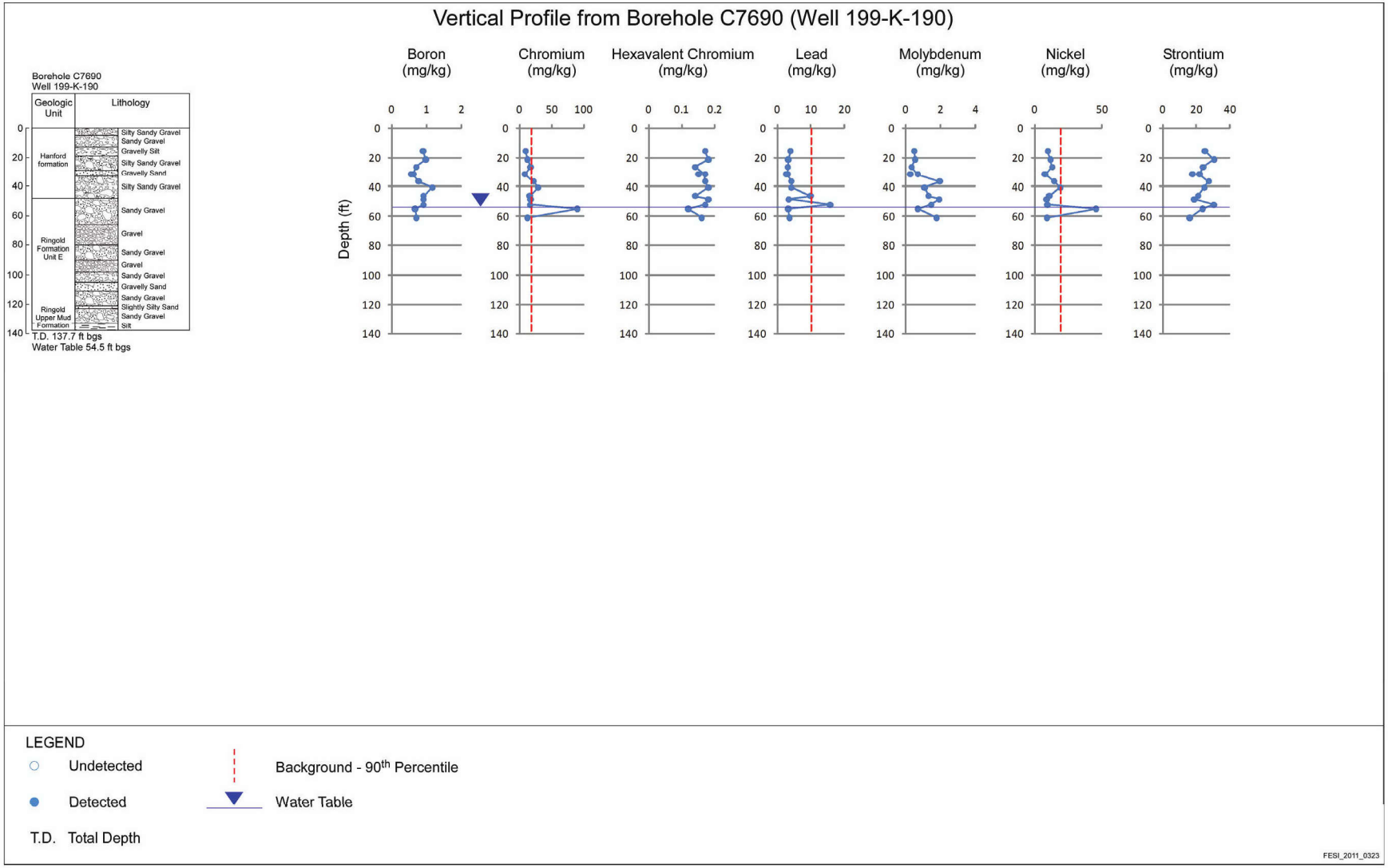

Figure 4-7. Vertical Profile from Borehole C7690 (K Well 4)

4.2.2.8 K Well 5

Borehole C7689 (K Well 5) was drilled as replacement for a previous Sr-90 Monitoring Well. C7689 was located downgradient of 105-KE Reactor. Samples were collected from about 2.4 to 24.1 m (8 to 79 ft) bgs. During drilling, the water table was encountered at 22.1 m (72.6 ft) bgs. Table 4-9 summarizes analytes detected above background in borehole C7689 and Figure 4-8 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected in all borehole samples. The maximum concentration of 0.79 mg/kg was detected at 3.9 m (13 ft) bgs. All Cr(VI) detections below about 7 m (23 ft) bgs are very low (less than 0.20 mg/kg). Concentrations of lead were above background concentration in samples collected from about 12.9 × 22.1 m (43 × 72 ft) bgs and again in the deepest sample collected beneath the water table at 24.2 m (79 ft) bgs. The highest concentration (182 mg/kg) was measured in the upper end of the detections. Lead in the sample from beneath the water table was slightly above background at 17.4 mg/kg. Total chromium was detected slightly above background (21.9 mg/kg) at about 16.0 m (53 ft) bgs. Elevated total chromium and nickel concentrations (211 and 110 mg/kg, respectively) are observed in the sample collected at about 13 m (43 ft) bgs. These results are discussed further in Section 4.2.2. Total chromium or nickel above background was not measured in any other samples. A single detection of arsenic above background (14.3 mg/kg) occurred in the sample collected at the water table. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-9. Well K 5—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7689[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (24.2 m/79.3 ft bgs)[b]
Nonradionuclides (mg/kg)				
Arsenic	6.5	14.3 (22.5/73.7)	22.5/73.7	1.33 (<BG)
Boron	NA	1.02 (20.5/67.4)	24.2/79.3	0.718
Chromium	18.5	211 (13.0/42.5)[c]	16.0/52.5	7.87 (<BG)
Cr(VI)	NA	0.79 (3.9/12.7)	24.2/79.3	0.16
Lead	10.2	182 (13.0/42.5)	24.2/79.3	17.4
Molybdenum	NA	7.04 (6.9/22.0)	24.2/79.3	0.504
Nickel	19.1	110 (13.0/42.5) [c]	13.0/42.5	8.17 (<BG)
Strontium	NA	51.1 (16.0/52.5)	24.2/79.3	26.6
Tin	NA	1.45 (22.1/72.4)	22.5/73.7	U

Table 4-9. Well K 5—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation Borehole C7689[a]		
Analyte	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (24.2 m/79.3 ft bgs)[b]

a. Data obtained from HEIS. The water table was encountered at 22.1 m (72.6 ft) bgs. Well was drilled to a total depth of 48.5 m (159 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Results of chromium and nickel in B26WF5 collected at 13.0 m (42.5 ft) bgs show elevated concentrations. The maximum values of chromium and nickel from the well excluding this sample are 21.9 and 14.5 mg/kg, respectively, at 16 m (52.5 ft) bgs. Concentrations of chromium and nickel are less than background in the sample intervals above and below B26WF5 collected at 11.3 × 14.2 m (37.1 × 46.7 ft) bgs, respectively.

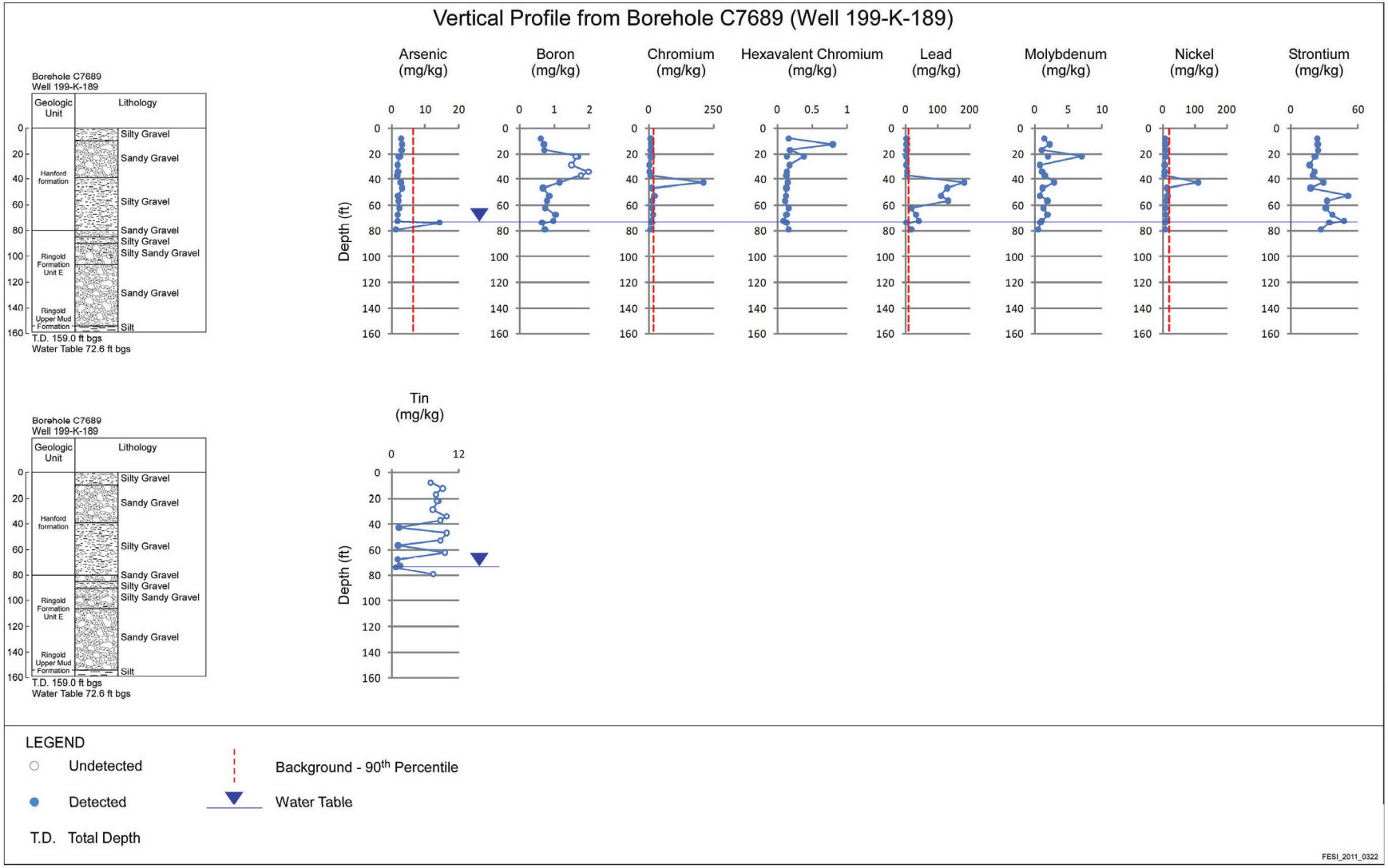

Figure 4-8. Vertical Profile from Borehole C7689 (K Well 5)

4.2.2.9 K Well 9

Borehole C7686 (K Well 9) was sited just downgradient the 183-KE water treatment facility. Samples were collected from about 1.8 to 27.9 m (6 to 92 ft) bgs. During drilling, the water table was encountered at 24.9 m (81.8 ft) bgs. Table 4-10 summarizes analytes detected above background in borehole C7686 and Figure 4-9 shows vertical profiles of the contamination.

No radionuclides including Sr-90 were detected in the borehole samples. Cr(VI) was detected only once at 0.27 mg/kg in a sample collected at the water table. Total chromium was measured above background at 21.1 × 33.5 mg/kg from samples collected at about 17.6 × 20.4 m (58 × 67 ft) bgs, respectively. Nickel was slightly above background at 20.7 × 19.4 mg/kg in samples collected from 1.8 × 20.4 m (6 × 67 ft) bgs. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

At about 13.7 m (45 ft) bgs, vadose soil from the borehole appeared to be contaminated with fuel oil. Additional samples for TPH and semivolatile organic compounds (SVOCs) were collected between 13.7 × 17.6 m (45 × 58 ft) bgs. Elevated concentrations of both diesel and motor oil range TPH were measured in most of these samples from this depth, with the highest concentrations, 22,600 × 22,500 mg/kg, respectively, from samples at the 14.6 m (48 ft) bgs. Concentrations decreased to 1.55 × 5.10 mg/kg, diesel and motor oil range, in the final TPH sample collected at 17.6 m (58 ft). Multiple polynuclear aromatic hydrocarbons (PAHs) were also measured in these samples. Benzo(a)pyrene was detected at 0.579 × 0.154 mg/kg in two samples collected at 14.6 × 15.2 m (48 × 50 ft) bgs. The borehole was approximately 24.7 m (81 ft) northeast of the 166-KE Oil Storage Tank, an underground fuel oil storage tank. It is probable that the oil-related contamination discovered at C7686 is the result of leaks from this underground tank.

Table 4-10. Well K 9—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7686[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (27.9 m/91.5 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	1.84 (20.4/66.8)	27.9/91.5	0.658
Chromium	18.5	33.5 (20.4/66.8)	20.4/66.8	10.7 (<BG)
Cr(VI)	NA	0.27 (25.9/84.9)	25.9/84.9	U
Molybdenum	NA	2.28 (20.4/66.8)	27.9/91.5	0.795
Nickel	19.1	20.7 (1.8/6.0)	20.4/66.8	8.18 (<BG)
Strontium	NA	75.8 (24.8/81.3)	27.9/91.5	24.5
Tin	NA	4.10 (1.8/6.0)	27.9/91.5	2.08
Vanadium	85.1	90.4 (1.8/6)	11.4/37.5	24.8 (<BG)
TPH—Diesel range	NA	22600 (14.6/48.0)[c]	17.6/57.7	1.55 (17.6/57.7)

Table 4-10. Well K 9—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7686[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (27.9 m/91.5 ft bgs)[b]
TPH—motor oil (high boiling)	NA	22500 (14.6/48.0)[c]	17.6/57.7	5.10 (17.6/57.7)
Acenaphthene	NA	0.599 (14.6/48.0)	16.2/53.0	U (17.6/57.7)
Acenaphthylene	NA	5.07 (14.6/48.0)	15.4/50.4	U (17.6/57.7)
Anthracene	NA	5.81 (14.6/48.0)	16.2/53.0	U (17.6/57.7)
Benzo(a)anthracene	NA	1.42 (14.6/48.0)	14.6/48.0	U (17.6/57.7)
Benzo(a)pyrene	NA	0.579 (14.6/48.0)	15.4/50.4	U (17.6/57.7)
Benzo(b)fluoranthene	NA	3.77 (13.7/45.1)	15.4/50.4	U (17.6/57.7)
Benzo(ghi)perylene	NA	0.690 (13.7/45.1)	14.6/48.0	U (17.6/57.7)
Benzo(k)fluoranthene	NA	0.316 (14.6/48.0)	14.6/48.0	U (17.6/57.7)
Chrysene	NA	10.2 (13.7/45.1)	16.2/53.0	U (17.6/57.7)
Dibenz[a,h]anthracene	NA	0.280 (14.6/48.0)	14.6/48.0	U (17.6/57.7)
Fluoranthene	NA	28.7 (14.6/48.0)	17.6/57.7	0.00327 (17.6/57.7)
Fluorene	NA	7.17 (14.6/48.0)	16.2/53.0	U (17.6/57.7)
Indeno(1,2,3-cd)pyrene	NA	0.370 (14.6/48.0)	15.4/50.4	U (17.6/57.7)
Naphthalene	NA	4.92 (14.6/48.0)	15.4/50.4	U (17.6/57.7)
Phenanthrene	NA	21.5 (14.6/48.0)	17.6/57.7	0.00261 (17.6/57.7)
Pyrene	NA	8.72 (14.6/48.0)	16.2/53.0	U (17.6/57.7)

a. Data obtained from HEIS. The water table was encountered at 24.9 m (81.8 ft). Well was drilled to a total depth of 50.9 m (167 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Samples for TPHs and SVOC analyses were collected for samples collected between 13.8 × 17.6 m (45.1 × 57.7 ft) bgs. Maximum depth for organic sample results is 17.6 m (57.7) ft bgs.

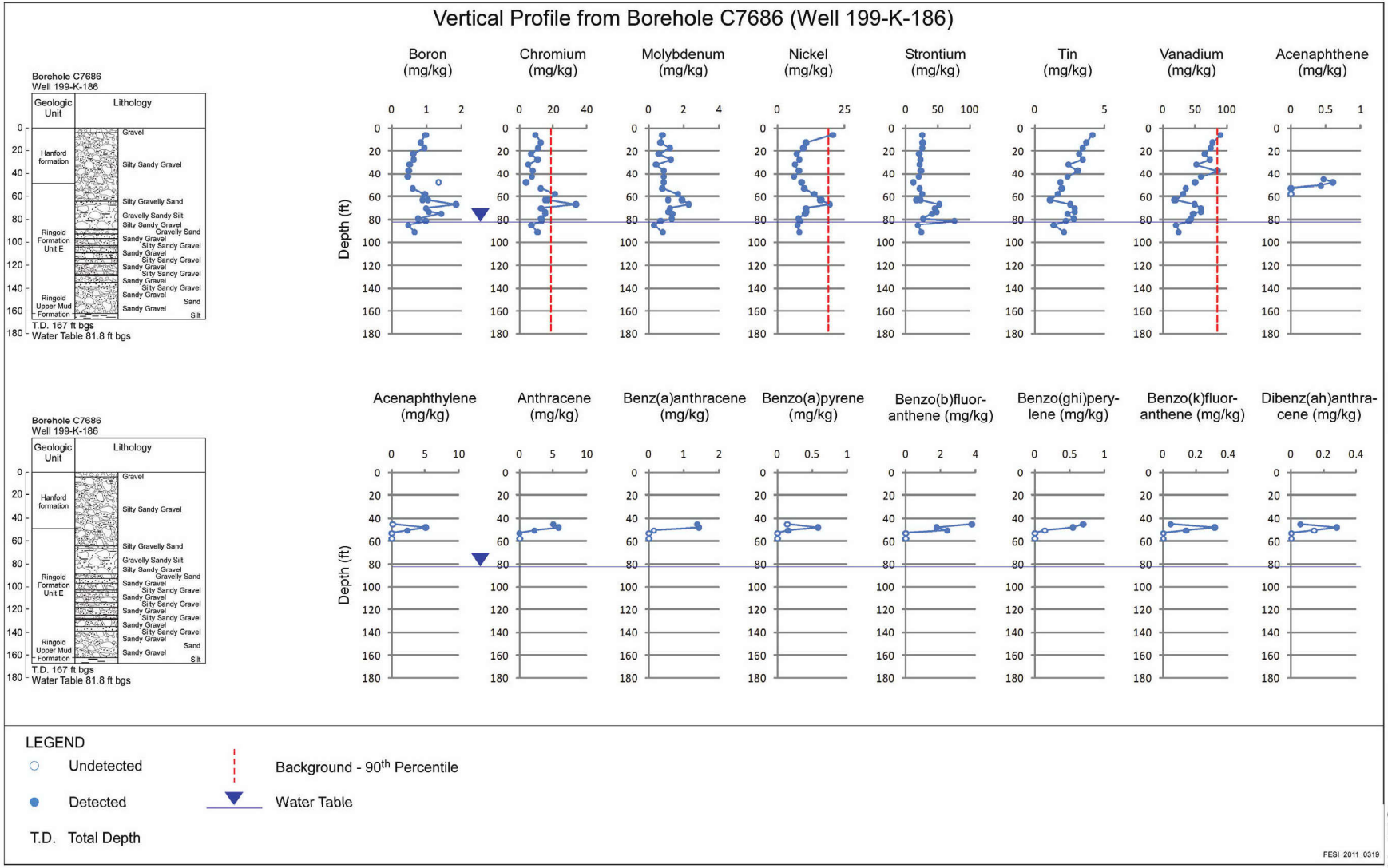

Figure 4-9. Vertical Profile from Borehole C7686 (K Well 9)

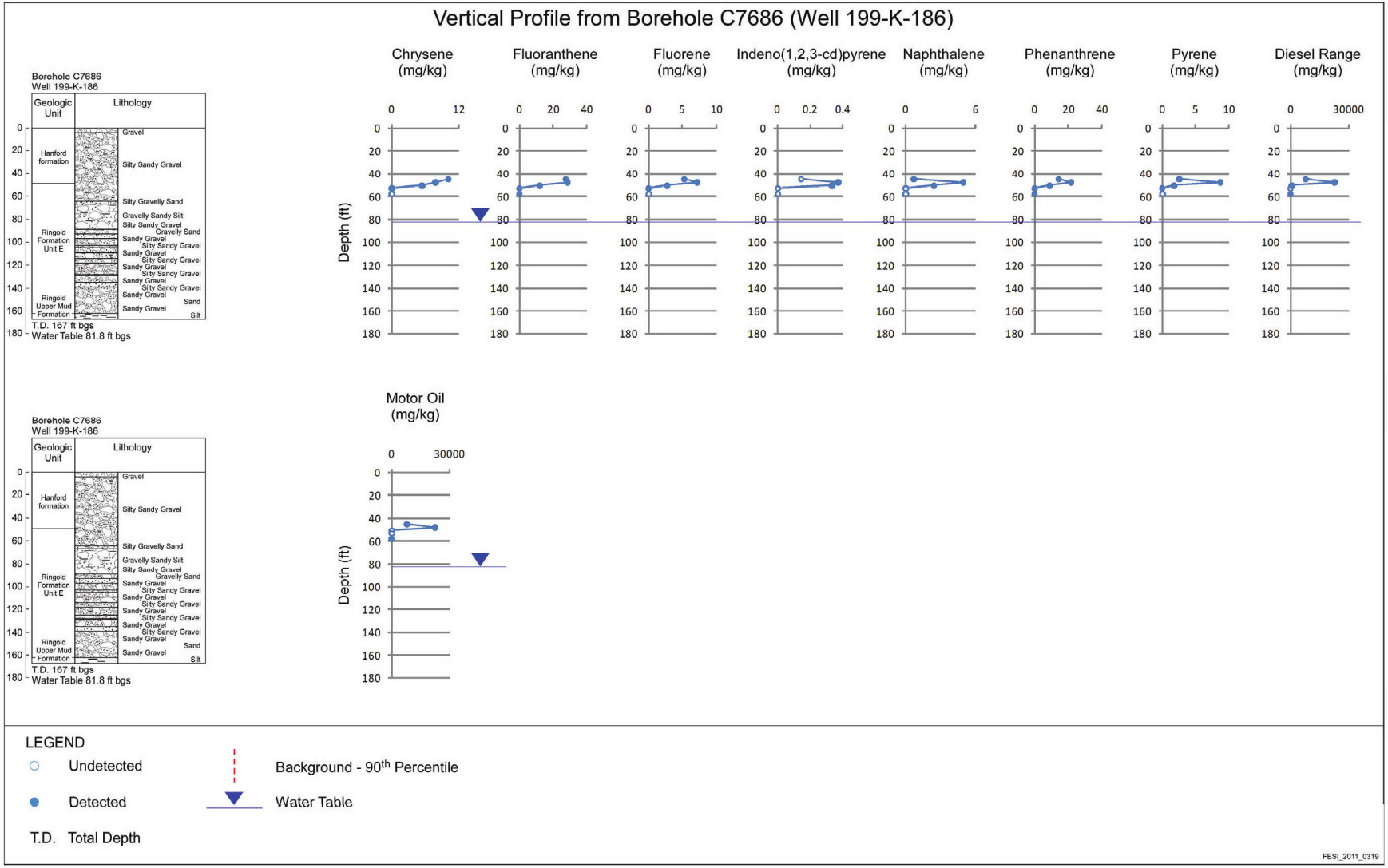

Figure 4-9. **Vertical Profile from** Borehole C7686 (K Well 9) (Cont.)

4.2.2.10 K RUM Well 1

Borehole C7684 (K RUM well 1) was sited downgradient the 183-KW water treatment facility and upgradient of 105-KW Reactor. Samples were collected from about 2.4 to 25.6 m (8 to 84 ft) bgs. During drilling, the water table was encountered at 23.4 m (76.7 ft) bgs. Table 4-11 summarizes analytes detected above background in borehole C7684 and Figure 4-10 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected in four of the sample intervals. The highest detection, 0.97 mg/kg, occurred in a duplicate sample collected at about 14.3 m (47 ft) bgs. Cr(VI) was not detected in the primary sample from this interval. Three other Cr(VI) detections at very low concentrations (maximum detection of 0.24 mg/kg) occurred in C7684. Total chromium was slightly above background in samples collect at about 16.0 m (52 ft) bgs and above the water table (20.4 to 23.6 m [67 to 77 ft] bgs). Single detections of lead and copper slightly above background and an isolated detection of arsenic (11.5 mg/kg) at 6.2 m (20 ft) were measured. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-11. K RUM Well 1—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7684[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (25.5 m/83.6 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	1.20 (6.2/20.3)	23.6/77.3	U
Chromium	18.5	26.9 (20.4/67.0)	23.6/77.3	12.0 (<BG)
Copper	22	24.5 (20.4/67.0)	20.4/67.0	9.07 (<BG)
Cr(VI)	NA	0.97 (14.3/47.0)	17.6/57.7	U
Lead	10.2	12.7 (6.2/20.3)	6.2/20.3	2.76 (<BG)
Molybdenum	NA	4.13 (20.4/67.0)	25.5/83.6	1.30
Strontium	NA	47.5 (14.3/47.0)	25.5/83.6	11.9
Tin	NA	2.32 (23.6/77.3)	25.5/83.6	1.43

a. Data obtained from HEIS. The water table was encountered at 23.4 m (76.7 ft) bgs. Borehole was drilled to a total depth of 65.9 m (216.1 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

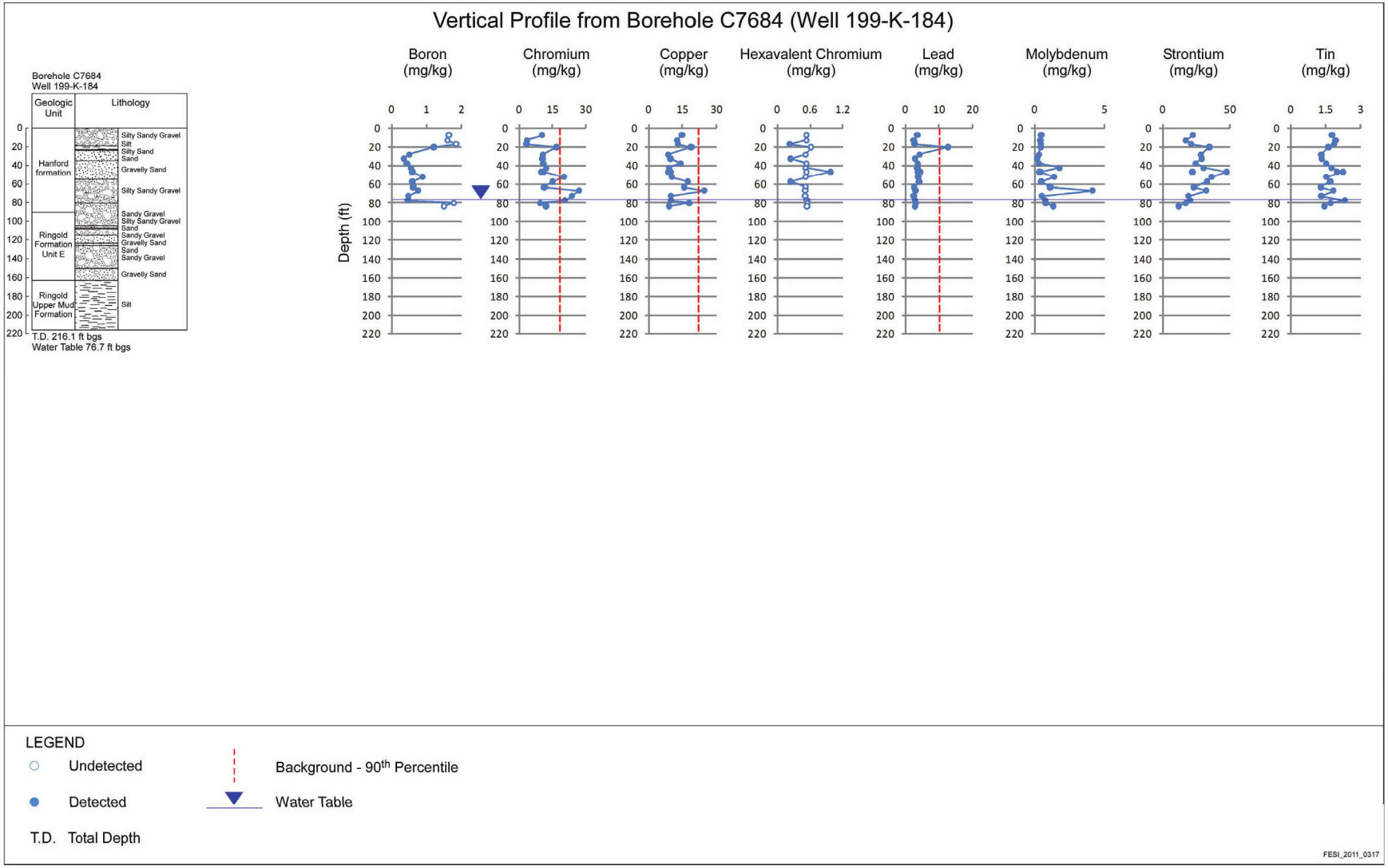

Figure 4-10. Vertical Profile from Borehole C7684 (K RUM Well 1)

4.2.2.11 K RUM Well 3 at 120-KE-6

Borehole C7688 (K RUM well 3) was sited near the location of the former 120-KE-6 Sodium Dichromate Storage Tank (Figure 4-11). Soil and sediment samples were collected from about 1.8 × 32.8 m (6 × 108 ft) bgs to evaluate contamination through the vadose zone to the water table. During drilling, the water table was encountered at 30.0 m (52.8 ft) bgs. Table 4-12 summarizes analytes detected above background in borehole C7688 and Figure 4-12 shows vertical profiles of the contamination.

Cesium-137 was detected at 0.116 pCi/g in the uppermost sample at 1.8 m (6 ft) bgs. No other radionuclides were detected throughout the borehole. This uppermost sample interval also contained chromium, lead, mercury, and thallium above background levels as well as Cr(VI) at 1.6 mg/kg. No other detections above background were reported for lead, mercury, and thallium in the borehole. Cr(VI) was detected at lower concentrations (maximum of 0.60 mg/kg) in several intervals through the upper and mid levels of the vadose zone and below the water table. Total chromium was detected slightly above background (maximum concentration of 26.4 mg/kg) at about 22.3, 23.2, and 27.4 m (73, 76, and 90 ft). Elevated total chromium and nickel concentrations are observed in the sample collected approximately 14.2 m (47 ft) bgs. These results are discussed further in Section 4.2.2. The concentration of selenium was detected at 1.1 mg/kg in this sample, but not detected elsewhere in C7688. Vanadium above background levels (maximum concentration of 107 mg/kg) was measured in multiple intervals between 5.1 and 14.2 m (17 and 47 ft) bgs. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-12. K RUM Well 3—Summary of Contaminant Soil Data

	Concentration and Distribution					
		Remedial Investigation C7688[a]				
Contaminants	Background	Maximum Result with Corresponding Depth (m/ft bgs)		Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (32.8 m/107.5 ft bgs)[b]	
Radionuclides (Original and Decayed Concentrations) (pCi/g)[c]						
		Original	Decayed		Original	Decayed
Cesium-137	NA	0.116 (1.9/6.3)	0.111	1.9/6.3	U	NA
Nonradionuclides (mg/kg)						
Boron	NA	0.808 (19.6/64.2)		32.8/107.5	0.505	
Chromium	18.5	108 (14.2/46.7)[d]		27.4/89.9	9.88 (<BG)	
Cr(VI)	NA	1.6 (1.9/6.3)		32.8/107.5	0.27	
Lead	10.2	37.7 (1.9/6.3)		1.9/6.3	2.06 (<BG)	
Mercury	0.33	0.628 (1.9/6.3)		1.9/6.3	U	
Molybdenum	NA	2.74 (19.6/64.2)		32.8/107.5	1.42	
Nickel	19.1	64.6 (14.2/46.7)[d]		14.2/46.7	6.95 (<BG)	
Selenium	0.78	1.1 (14.2/46.7)		14.2/46.7	U	
Strontium	NA	93.2 (30.9/101.5)		32.8/107.5	17.9	

Table 4-12. K RUM Well 3—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation C7688[a]		
Contaminants	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (32.8 m/107.5 ft bgs)[b]
Thallium	NA	0.213 (1.9/6.3)	1.9/6.3	U
Tin	NA	5.21 (6.9/22.7)	32.8/107.5	1.63
Vanadium	85.1	107 (14.2/46.7)	14.2/46.7	19.7 (<BG)

a. Data obtained from HEIS. The water table was encountered at 30 m (98.4 ft) bgs. Well was drilled to a total depth of 71.8 m (235.5 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Original radiological data presented in left column with decay corrected value to year 2012 in right column.

d. Results of chromium and nickel in B28F29 collected at 14.2 m (46.7 ft) bgs appear to be elevated. The maximum values of chromium and nickel from the borehole excluding this sample are 26.4 × 16.2 mg/kg, respectively, at 27.4 m (89.9 ft) bgs. Concentrations of chromium and nickel are less than background in the sample intervals above and below B28F29 collected at 12.7 m × 16.4 m (41.8 ft ×53.7 ft) bgs, respectively.

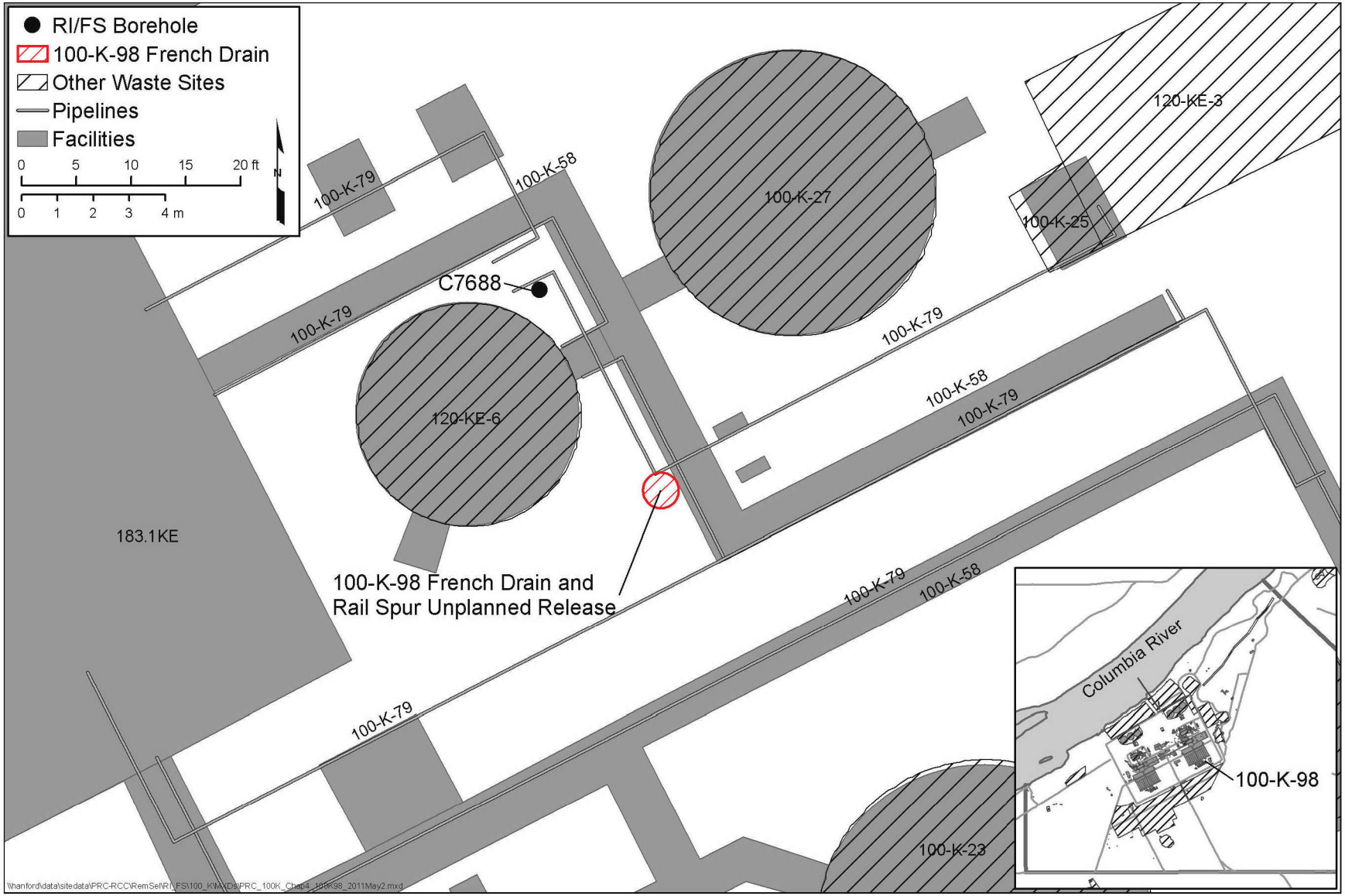

Figure 4-11. Location of Borehole C7688 (K RUM Well 3) 7688 near 120-KE-6

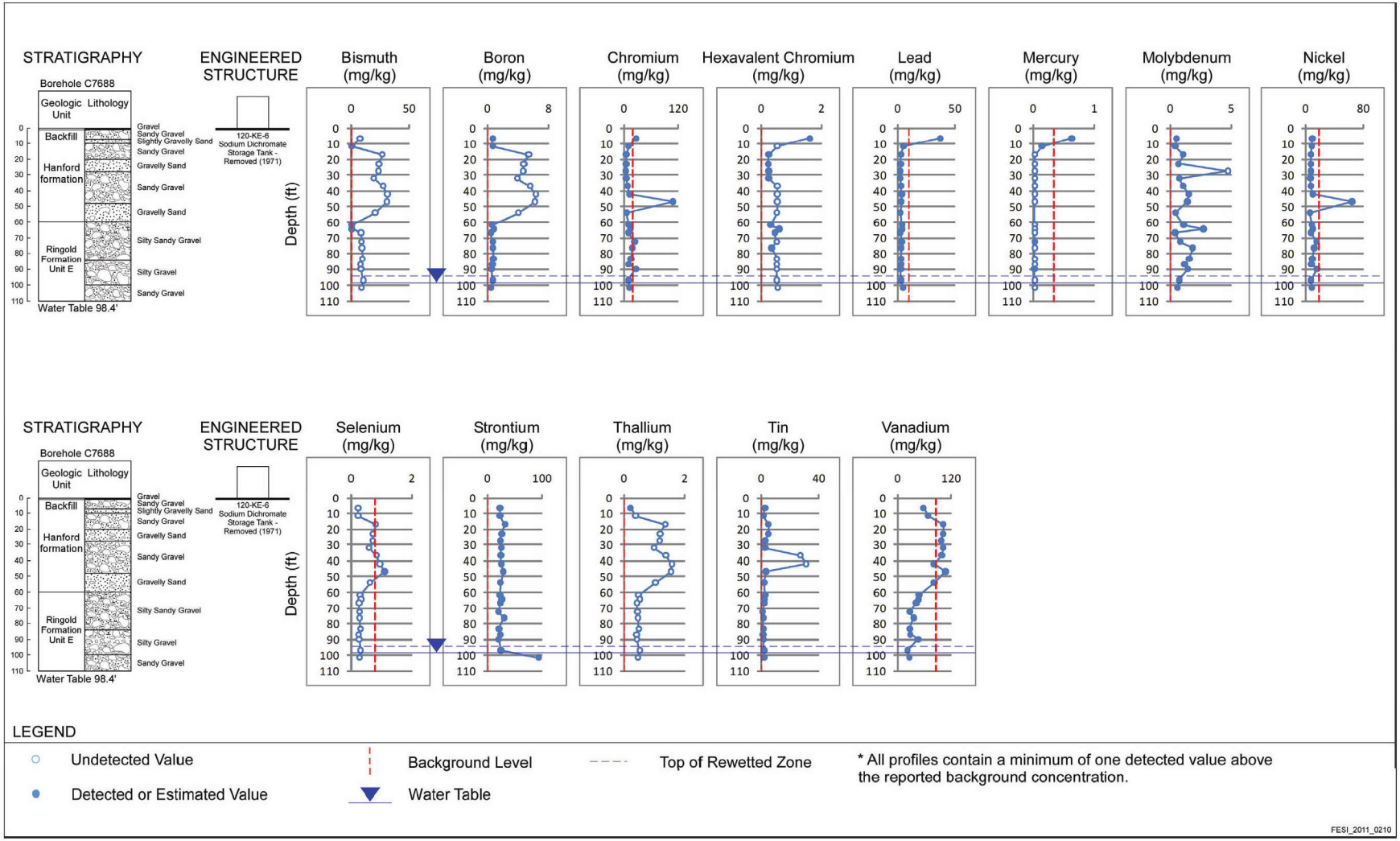

Figure 4-12. Vertical Profile from Borehole C7688 (K RUM Well 3)

4.2.2.12 K RUM Well 4 at 100-K-97

Borehole C7695 (K RUM well 4) was drilled through the 100-K-97 French Drain and Rail Spur Unplanned Release waste site (Figure 4-13), located near the former 120-KW-5 Sodium Dichromate Storage Tank, to evaluate contamination through the vadose zone to the water table. Before the RI sampling, the 100-K-97 waste site had been excavated to a depth of 4.5 m (14.8 ft) bgs and drilling was conducted at the bottom of the excavation. This depth has been accounted for in the discussion of data from the site such as reported depths represent depth below the original ground surface.

Samples were collected from about 6.0 to 32.6 m (20 to 107 ft) bgs. During drilling, the water table was encountered at 30.3 m (99.3 ft) bgs. Table 4-13 summarizes analytes detected above background in borehole C7695 and Figure 4-14 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, the most elevated concentrations of several metals are observed in samples collected at about 28.1 and 29.7 m (92 and 98 ft) bgs. Both samples show increased concentrations of chromium and nickel, as well as anomalous increases in cobalt, copper, manganese, and molybdenum in the sample from 28.1 m (92 ft) bgs (Section 4.2.2 provides discussion). Other than the analytes in these two samples, only total chromium was detected in other C7695 samples. Low concentrations of Cr(VI) were detected only in samples collected between 17.5 and 20.0 m (57 and 62 ft) and again at 26.5 m (87 ft) bgs, with a maximum concentration of 0.42 mg/kg. Except for the previously mentioned samples, concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-13. K RUM Well 4—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7695[a, b]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (32.6 m/106.8 ft bgs)[c]
Nonradionuclides (mg/kg)				
Boron	NA	1.09 (29.7/97.5)	32.6/106.8	0.584
Chromium	18.5	3560 (28.1/92.1)[d]	29.7/97.5	16.1 (<BG)
Cobalt	15.7	20.4 (28.1/92.1)[d]	28.1/92.1	3.94 (<BG)
Copper	22	44.1 (28.1/92.1)[d]	28.1/92.1	9.81 (<BG)
Cr(VI)	NA	0.42 (19.0/62.3)	26.5/86.8	U
Manganese	512	603 (28.1/92.1)[d]	28.1/92.1	226 (<BG)
Molybdenum	NA	36.6 (28.1/92.1)[d]	32.6/106.8	1.32
Nickel	19.1	2100 (28.1/92.1)[d]	29.7/97.5	6.15 (<BG)
Strontium	NA	29.3 (28.1/92.1)	32.6/106.8	19.9
Tin	NA	3.36 (28.1/92.1)	32.6/106.8	1.72

a. Data obtained from HEIS. The water table was encountered at 30.3 m (99.3 ft) bgs. Well was drilled to a total

Table 4-13. K RUM Well 4—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation Borehole C7695[a, b]		
Analyte	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (32.6 m/106.8 ft bgs)[c]

depth of 74.8 m (245.3 ft) bgs.

c. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

b. Borehole C7695 was sited within the 100-K-97 excavation at approximately 4.5 m (15 ft) bgs. Depths for this table represent total depth below original ground surface (borehole sample depth plus remediation depth of 4.5 m [15 ft]).

d. Results from samples collected at 28.1 × 29.7 m (92.1 × 97.5 ft) bgs (samples B27H40 and B27H41, respectively) indicate several elevated metals concentrations in the samples. Sample B27H40 shows significantly elevated chromium, nickel, and molybdenum, as well as cobalt, copper, and manganese all above background. The latter metals are less than background in all other C7695 well samples. Concentrations of chromium, cobalt, copper, manganese, and nickel are below background in the sample intervals above and below B27H40 and B27H41 collected at 26.5 × 30.8 m (86.8 × 101 ft) bgs, respectively.

1

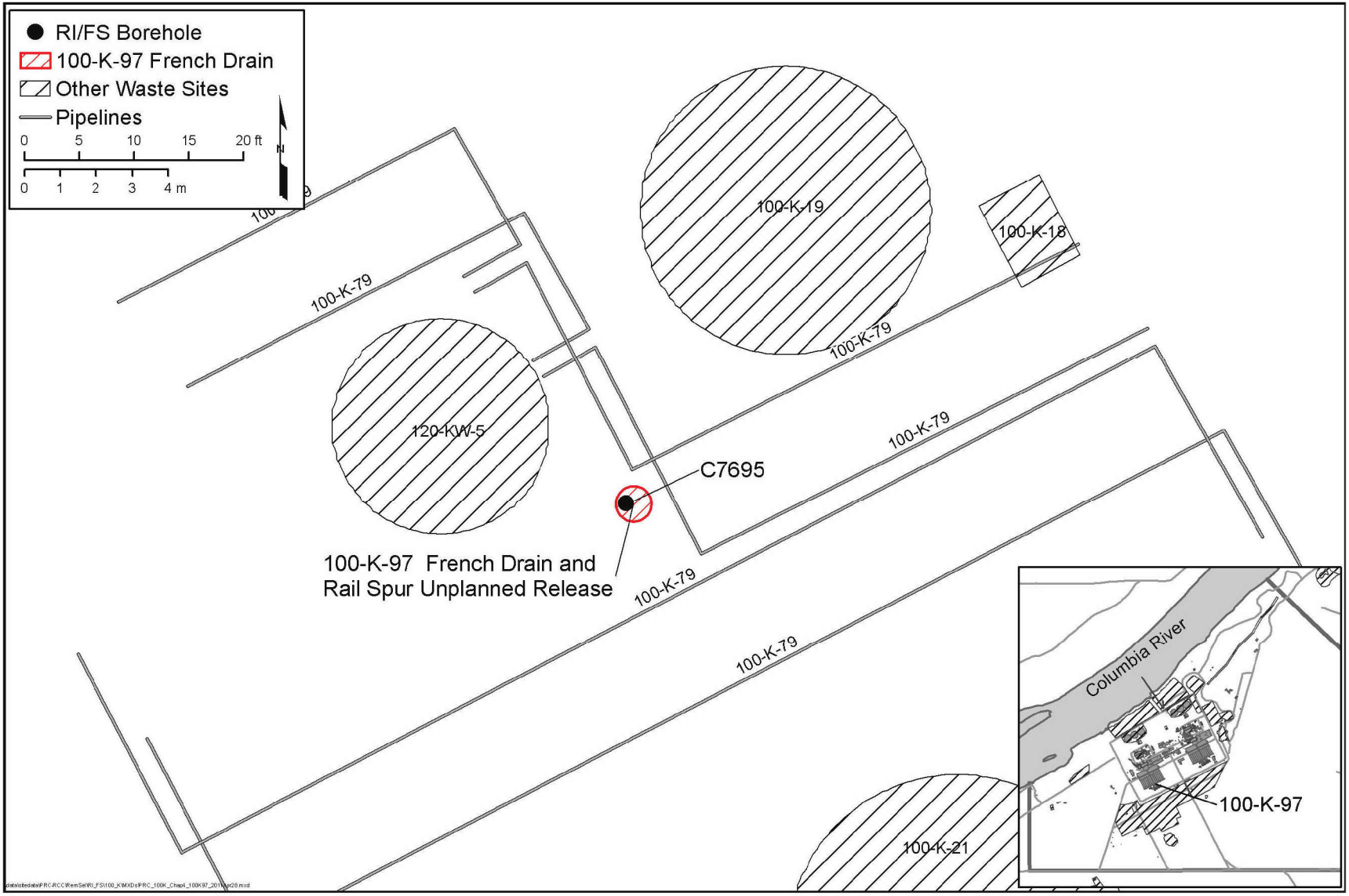

Figure 4-13. Location of Borehole C7695 (K RUM Well 4) at 100-K-97 French Drain Waste Site

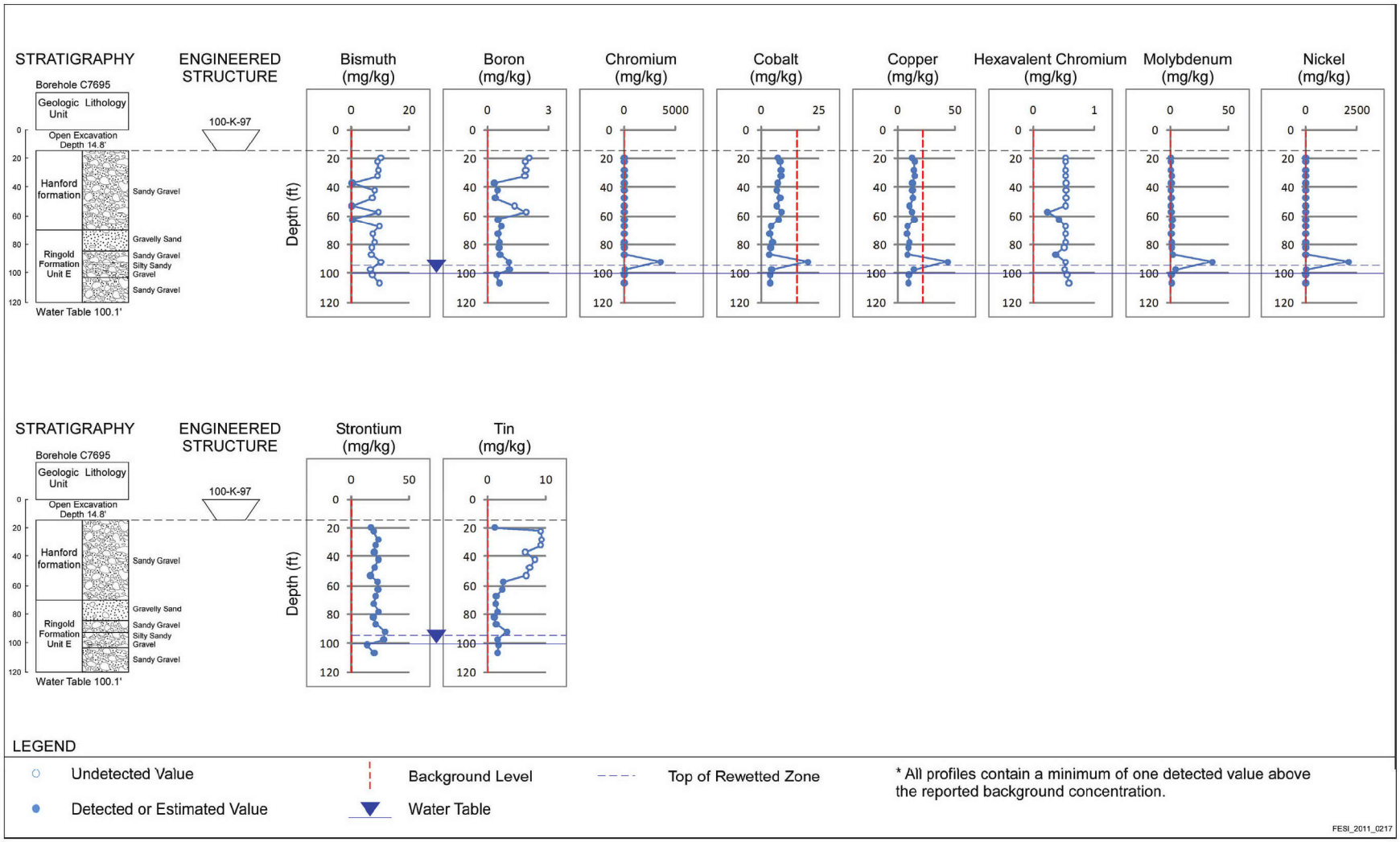

Figure 4-14. **Vertical Profile from** Borehole C7695 (K RUM Well 4)

4.2.2.13 K Well 1

Borehole C7683 (K well 1) was located approximately 290 m (940 ft) west of the 105-KW Reactor to define the upgradient extent of Cr(VI) in groundwater. Samples were collected from about 16.8 × 23.6 m (55 × 78 ft) bgs. During drilling, the water table was encountered at 20.5 m (67.3 ft) bgs. Table 4-14 summarizes analytes detected above background in borehole C7683 and Figure 4-15 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected at low concentrations (maximum result of 0.28 mg/kg) in at least one sample from all samples intervals. Total chromium above background was measured at 16.8 m (55 ft) (27.0 × 53.6 mg/kg for primary and duplicate samples) and again at slightly above background at 20.0 m (66 ft) bgs. Elevated nickel (30.4 mg/kg) was also measured in the duplicated sample from this same interval. These results are discussed further in Section 4.2.2. Concentrations of lead greater than background are measured in nearly all samples with a maximum concentration of 185 mg/kg in the primary sample collected at 16.8 m (55 ft). Lead was elevated in the duplicate sample but the concentration was significantly lower (34.2 mg/kg). Subsequent samples at 18.2 × 23.8 m (60 × 78 ft) have similar concentrations of lead 47.6 × 38.7 mg/kg, respectively. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-14. Well K 1—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7683[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (23.6 m /77.5 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	0.976 (19.1/62.5)	21.1/69.3	U
Chromium	18.5	53.6 (17.2/56.5)[c]	20.0/65.5	12.7 (<BG)
Cr(VI)	NA	0.28 (22.1/72.5)	23.6/77.5	0.10
Lead	10.2	185 (17.2/56.5)	23.6/77.5	38.7
Molybdenum	NA	5.06 (17.2/56.5)	17.2/56.5	2.24
Nickel	19.1	30.4 (17.2/56.5)[c]	21.3/55.0	7.2 (<BG)
Strontium	NA	31.4 (17.2/56.5)	23.6/77.5	13.0

a. Data obtained from HEIS. The water table was encountered at 20.5 m (67.3 ft). Well was drilled to a total depth of 46.5 m (152.5 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Results of chromium and nickel in duplicate sample B27FF5 collected at 16.1 m (52.8 ft) bgs are elevated. Results in this duplicate sample are approximately two times that measured in the primary sample B25L27 for chromium and nickel (27.0 × 18.2 mg/kg, respectively). Nickel results did not exceed background in any other samples from this borehole.

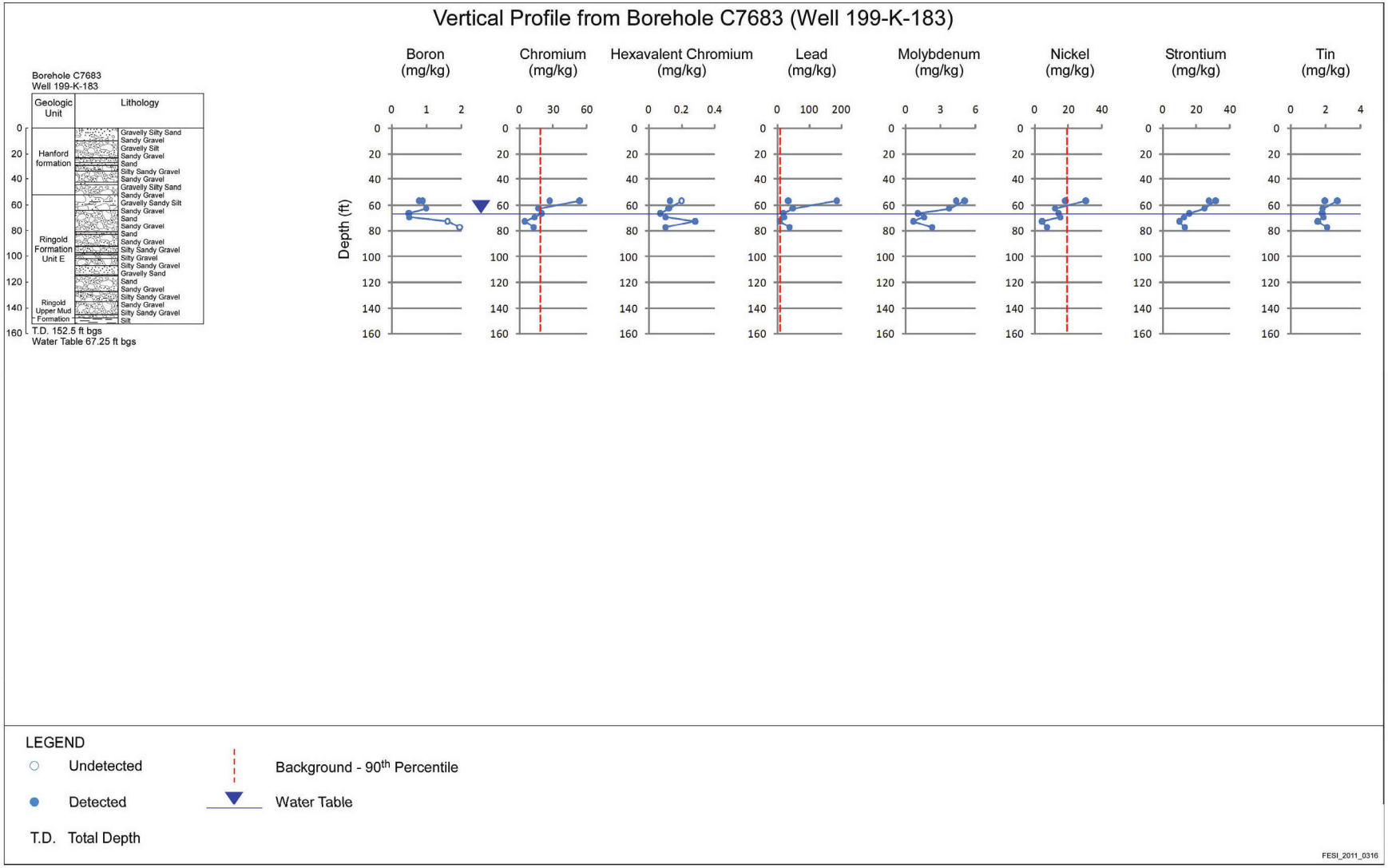

Figure 4-15. **Vertical Profile from** Borehole C7683 (K Well 1)

4.2.2.14 K Well 3

Borehole C7687 (K well 3) was located approximately 325 m (1,070 ft) west of the 105-KE reactor to define the upgradient extent of Cr(VI) in groundwater. Samples were collected from about 30.5 to 36.6 m (100 to 120 ft) bgs. During drilling, the water table was encountered at 34.2 m (112 ft) bgs. Table 4-15 summarizes analytes detected above background in borehole C7687 and Figure 4-16 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, very low concentrations of Cr(VI) (maximum of 0.13 mg/kg) were detected in samples collected just above and at the water table. Total chromium was slightly above background (26.6 mg/kg) in a sample collected at about 32.1 m (105 ft) bgs. A single detection of copper slightly above background was measured in the shallowest sample. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-15. Well K 3—Summary of Contaminant Soil Data

	Concentration and Distribution			
		Remedial Investigation Borehole C7687[a]		
Analyte	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (36.7 m/120.3 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	0.910 (32.1/105.3)	36.7/120.3	0.646
Chromium	18.5	26.6 (32.1/105.3)	32.1/105.3	7.58 (<BG)
Copper	22	24.9 (30.4/99.6)	30.4/99.6	7.93 (<BG)
Cr(VI)	NA	0.13 (32.1/105.3)	35.1/115	U
Molybdenum	NA	4.92 (32.1/105.3)	36.7/120.3	0.632
Strontium	NA	25.3 (32.1/105.3)	36.7/120.3	17.1
Tin	NA	1.77 (32.1/105.3)	36.7/120.3	1.54

a. Data obtained from HEIS. The water table was encountered at 34.2 m (112 ft). Well was drilled to a total depth of 61.7 m (202 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

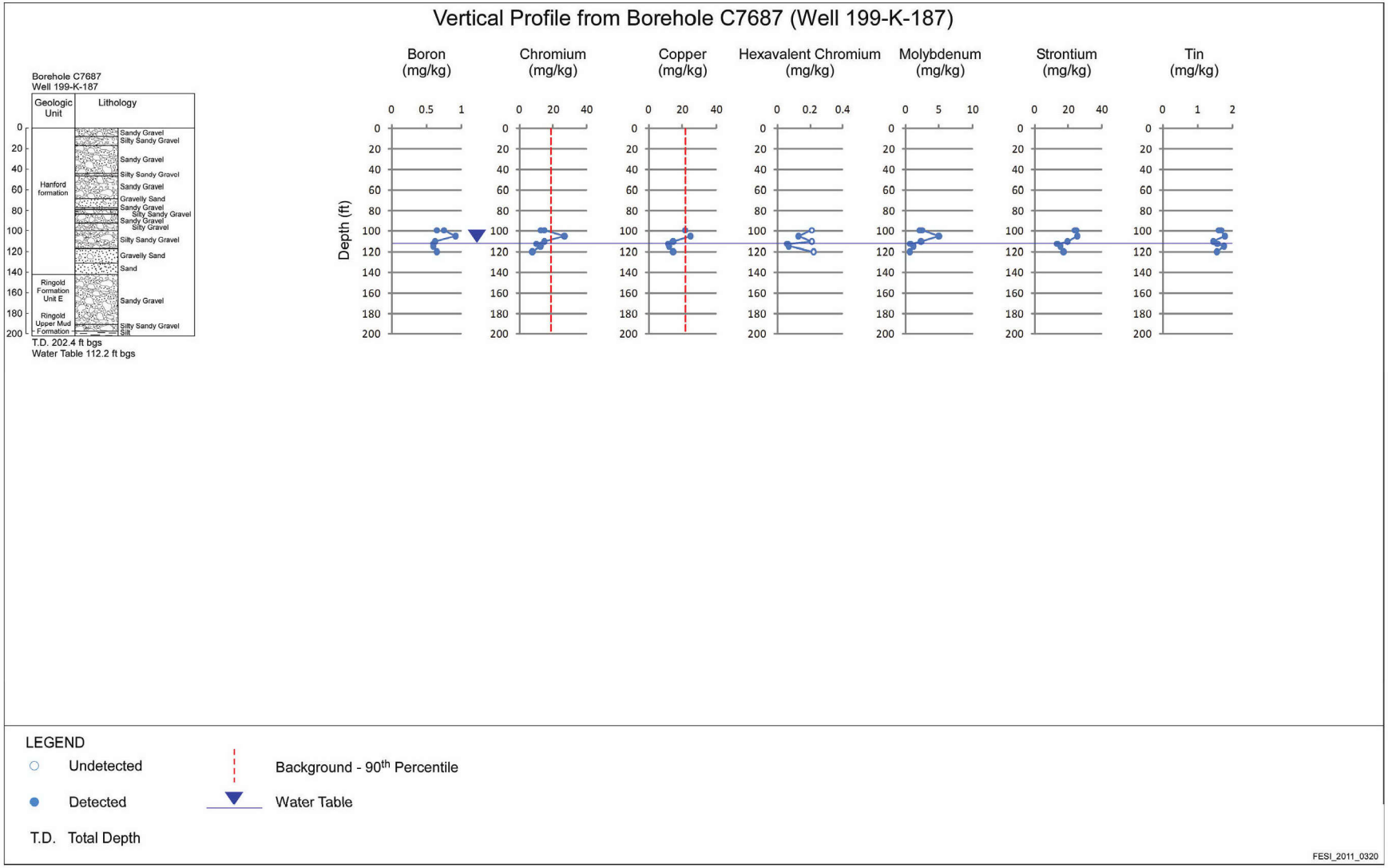

Figure 4-16. **Vertical Profile from** Borehole C7687 (K Well 3)

4.2.2.15 K Well 6

Borehole C7691 (K Well 6) was one of three wells drilled to define the Cr(VI) groundwater plume upgradient of the 116-K-2 trench. Samples were collected from about 18.5 × 24.5 m (61 × 81 ft) bgs. During drilling, the water table was encountered at 22.1 m (72.5 ft) bgs. Table 4-16 summarizes analytes detected above background in borehole C7691 and Figure 4-17 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. For nonradionuclides, Cr(VI) was detected at very low concentrations (maximum concentration of 0.19 mg/kg) in all borehole samples including that from the aquifer. Total chromium was detected above background (maximum concentration of 38.7 mg/kg) between about 18.8 × 24.5 m (61 × 72 ft) bgs. Concentrations of lead were above background in all samples between 18.8 × 23.3 m (61 × 76 ft) bgs. The highest concentration was measured just above the water table at 229 mg/kg. Lead in the samples immediately above and below this sample are an order of magnitude lower at 28.7 × 26.9 mg/kg, respectively. A single detection of copper slightly above background (23.6 mg/kg) was measured at 21.9 m (72 ft) while nickel above background (25.8 mg/kg) was measured at 18.8 m (61 ft) bgs. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-16. Well K 6—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7691[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (24.5 m/80.5 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	2.07 (21.9/72.0)	24.5/80.5	0.643
Chromium	18.5	38.7 (18.5/60.7)	21.9/72.0	8.68 (<BG)
Copper	22	23.6 (21.9/72.0)	21.9/72.0	8.66 (<BG)
Cr(VI)	NA	0.19 (21.9/72.0)	24.5/80.5	0.17
Lead	10.2	229 (21.9/72.0)	24.5/80.5	10.9 (<BG)
Molybdenum	NA	7.34 (21.9/72.0)	24.5/80.5	1.65
Nickel	19.1	25.8 (18.5/60.7)	18.5/60.6	6.39 (<BG)
Strontium	NA	39.9 (21.9/72.0)	24.5/80.5	22.8
Tin	NA	2.98 (21.2/69.5)	24.5/80.5	1.67

a. Data obtained from HEIS The water table was encountered at 22.1 m (72.5 ft) bgs. Well was drilled to a total depth of 48.2 m (158 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

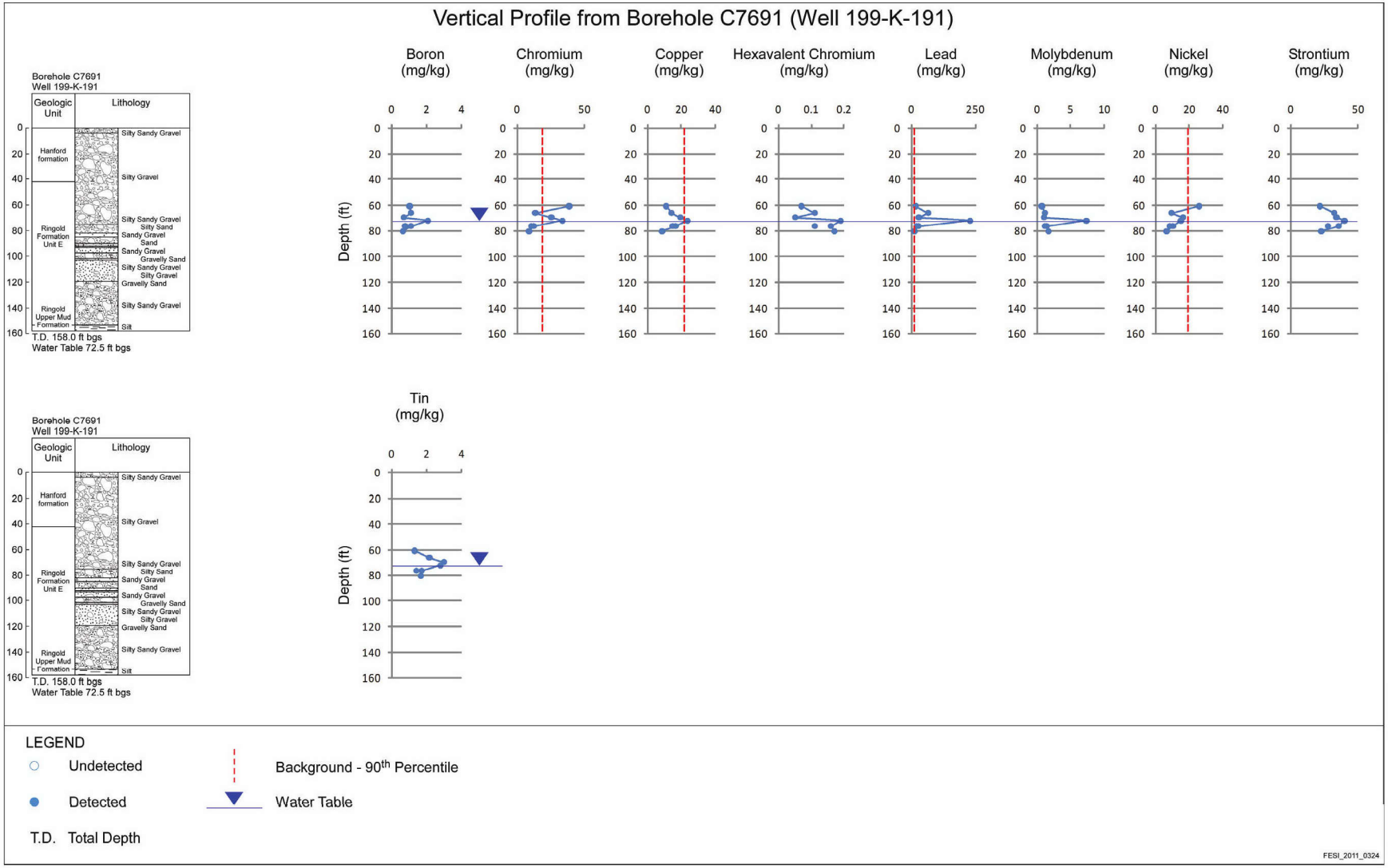

Figure 4-17. **Vertical Profile from** Borehole C7691 (K Well 6)

4.2.2.16 K Well 7

Borehole C7693 (K Well 7) was one of three wells drilled to define the Cr(VI) groundwater plume upgradient of the 116-K-2 Trench. Samples were collected from about 18.2 to 25.9 m (60 to 85 ft) bgs. During drilling, the water table was encountered at 23.7 m (77.8 ft) bgs. Table 4-17 summarizes analytes detected above background in borehole C7693 and Figure 4-18 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. Cr(VI) was also undetected in all samples. Total chromium was measured above background at 33.4 and 20.4 mg/kg from samples collected just above and at the water table (about 23.2 and 24.5 m (76 and 80 ft) bgs). Elevated total chromium and nickel concentrations (57.8 and 32.1 mg/kg, respectively) observed in the sample collected at about 20.3 m (67 ft) bgs. These results are further discussed in Section 4.2.2.

Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-17. Well K 7—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
	Background	Remedial Investigation Borehole C7693[a]		
		Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (20.3 m/66.5 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	0.781 (18.2/59.8)	25.9/85.0	0.640
Chromium	18.5	57.8 (20.3/66.5)[c]	24.5/80.3	10.6 (<BG)
Molybdenum	NA	2.90 (18.2/59.8)	25.9/85.0	2.01
Nickel	19.1	32.1 (20.3/66.5)[c]	20.3/66.5	7.96 (<BG)
Strontium	NA	79.7 (23.2/76.0)	25.9/85.0	25.8
Tin	NA	3.70 (20.3/66.5)	25.9/85.0	1.02

a. Data obtained from HEIS. The water table was encountered at 23.7 m (77.8 ft) bgs. Well was drilled to a total depth of 50.6 m (166 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Results of chromium and nickel in B25YL6 collected at 20.3 m (66.5 ft) bgs are elevated. The maximum values of chromium and nickel from the borehole excluding this sample are 33.4 and 18.5 mg/kg, respectively, at 23.2 m (76.0 ft) bgs. Concentrations of chromium and nickel are below background in the sample interval above B25YL6 collected at 18.2 m (59.8 ft) bgs.

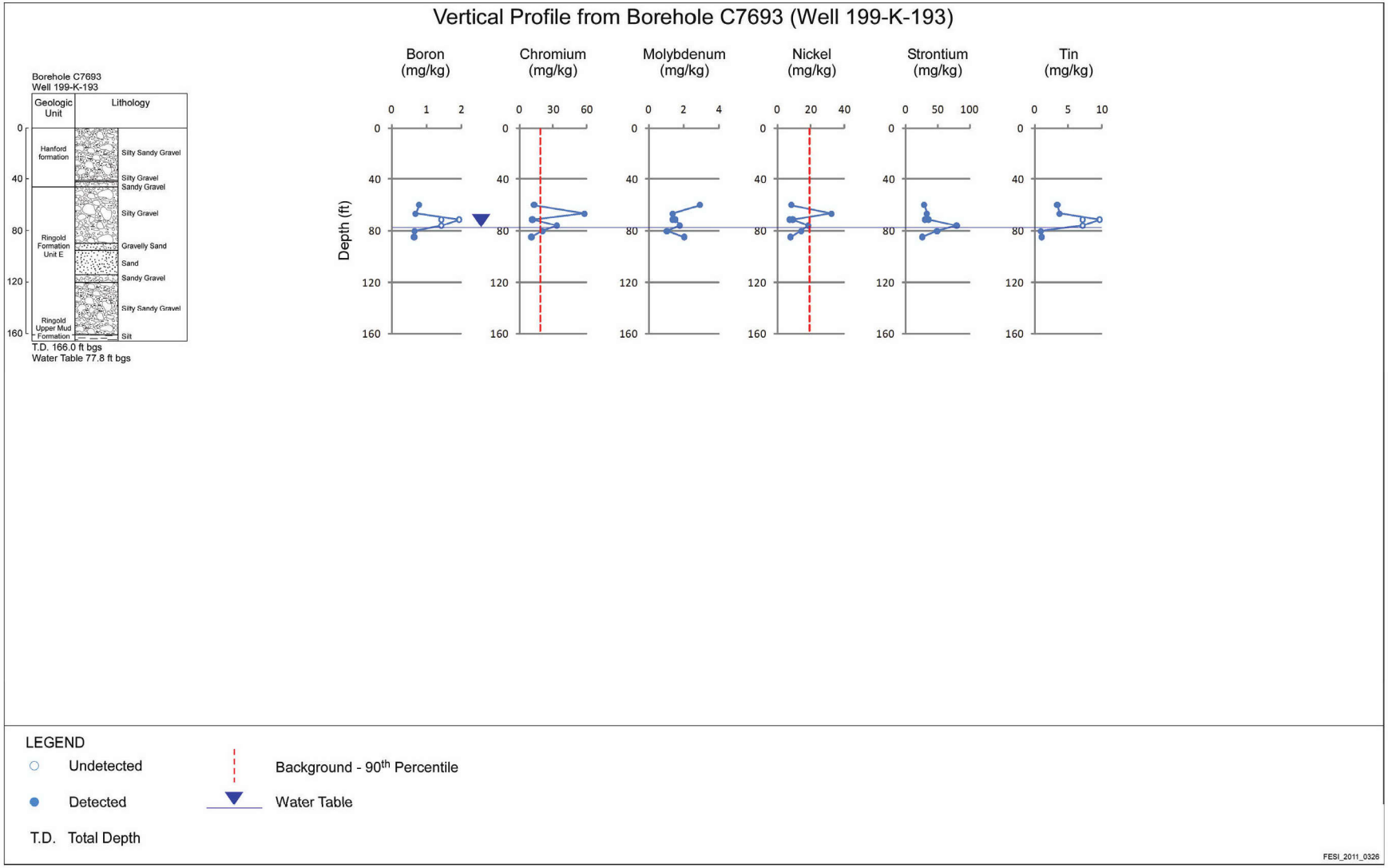

Figure 4-18. **Vertical Profile from** Borehole C7693 (K Well 7)

4.2.2.17 K Well 8

Borehole C7694 (K Well 8) was one of three wells drilled to define the Cr(VI) groundwater plume upgradient of the 116-K-2 Trench. Samples were collected from about 24.5 to 27.6 m (80 to 91 ft) bgs. During drilling, the water table was encountered at 25.2 m (82.7 ft) bgs. Table 4-18 summarizes analytes detected above background in borehole C7694 and Figure 4-19 shows vertical profiles of the contamination.

No radionuclides, including Sr-90, were detected in the borehole samples. Cr(VI) was detected in samples collected at and below the water table between 0.57 and 0.68 mg/kg. No other metals with an established background value were detected above background. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-18. Well K 8—Summary of Contaminant Soil Data

Analyte	Concentration and Distribution			
		Remedial Investigation Borehole C7694[a]		
	Background	Maximum Result with Corresponding Depth (m/ft bgs)	Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (27.6 m/90.5 ft bgs)[b]
Nonradionuclides (mg/kg)				
Boron	NA	0.588 (24.5/80.3)	27.6/90.5	0.429
Cr(VI)	NA	0.84 (26.0/85.2)	27.6/90.5	0.68
Molybdenum	NA	1.63 (27.6/90.5)	27.6/90.5	1.63
Strontium	NA	35.3 (26.0/85.2)	27.6/90.5	29.5
Tin	NA	1.99 (26.0/85.2)	927.6/0.5	1.38

a. Data obtained from HEIS. The water table was encountered at 25.2 m (82.7 ft) bgs. Well was drilled to a total depth of 44.9 m (147.3 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

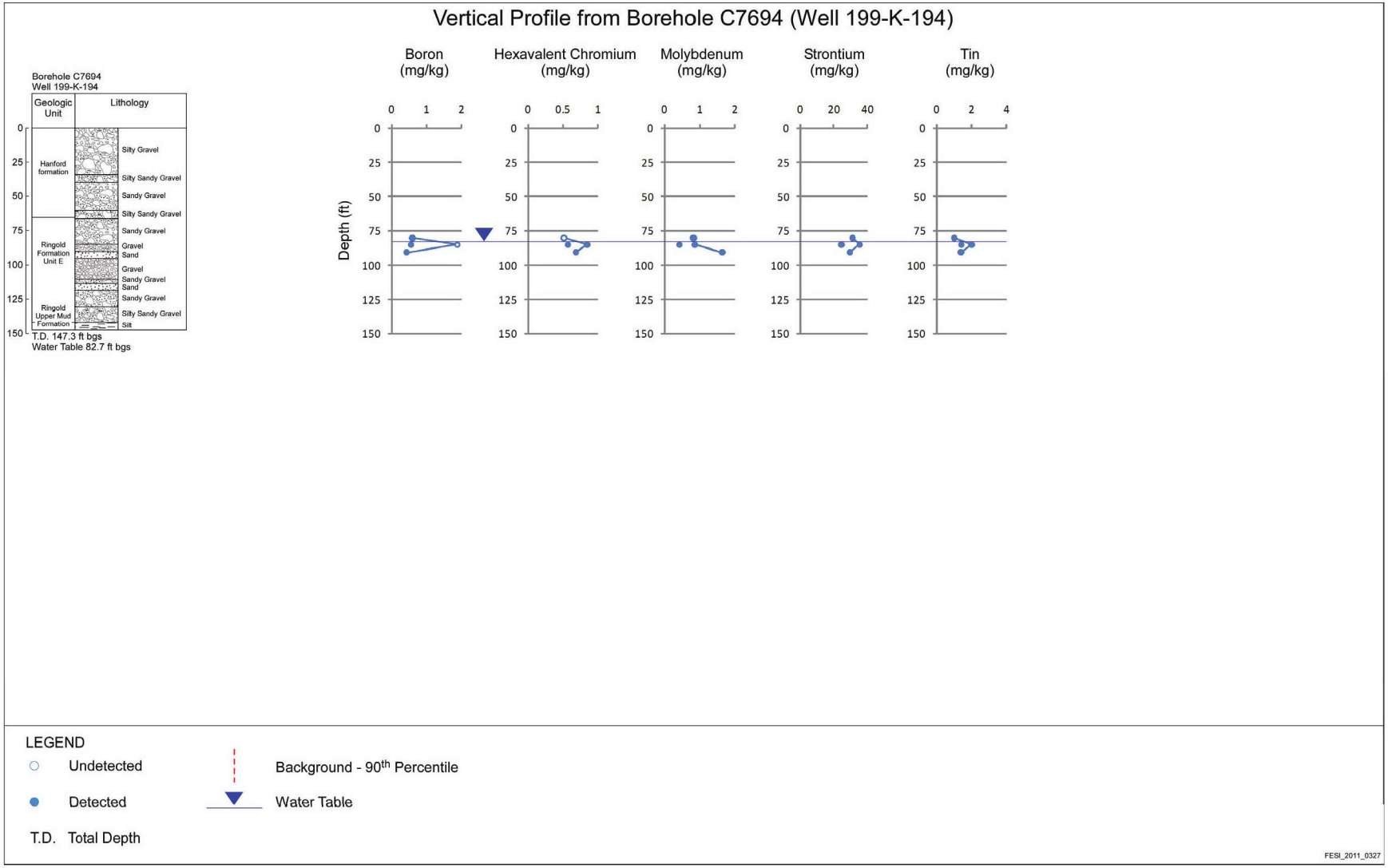

Figure 4-19. **Vertical Profile from** Borehole C7694 (K Well 8)

4.2.2.18 K RUM Well 2

Borehole C7692 (K RUM well 2) was sited downgradient from the from the inlet end of the 116-K-2 Trench. Soil and sediment samples were collected from about 11.4 to 17.5 m (37 to 57 ft) bgs. During drilling, the water table was encountered at 15.0 m (49.1 ft) bgs. Table 4-19 summarizes analytes detected above background in borehole C7692 and Figure 4-20 shows vertical profiles of the contamination.

Sr-90 was detected at 0.282 pCi/g in the deepest sample, collected below the water table. No other radionuclides were detected in the borehole. Cr(VI) was not detected in any borehole samples. Elevated total chromium and nickel concentrations (56.0 and 28.9 mg/kg, respectively) are measured in the sample collected at about 14.6 m (48 ft) bgs. These results are discussed further in Section 4.2.2. These are the only concentrations of chromium and nickel above background in the borehole samples. Lead was measured above background at 11.4 and 12.9 m (37 and 42 ft) bgs at concentrations of 23.3 and 10.9 mg/kg, respectively. Concentrations of nonradiological analytes for which a background value is not available (e.g., boron, tin) are consistent with concentrations measured in other 100-K RI samples.

Table 4-19. K RUM Well 2—Summary of Contaminant Soil Data

Analyte	Background	Concentration and Distribution				
		Remedial Investigation Borehole C7692[a]				
		Maximum Result with Corresponding Depth (m/ft bgs)		Extent of Detection above BG (m/ft bgs)	Result at Maximum Sample Depth (17.5 m/57.3 ft bgs)[b]	
Radionuclides (Original and Decayed Concentrations) (pCi/g)[c]						
		Original	Decayed		Original	Decayed
Sr-90	NA	0.282 (17.5/57.3)	0.267	17.5/57.3	0.282 (17.5/57.3)	0.267
Nonradionuclides (mg/kg)						
Boron	NA	0.699 (15.2/50.0)		16.0/52.4	U	
Chromium	18.5	56.0 (14.6/47.8)[d]		14.6/47.8	10.3 (<BG)	
Lead	10.2	23.3 (11.4/37.4)		12.9/42.4	5.4 (<BG)	
Molybdenum	NA	1.31 (11.4/37.4)		17.5/57.3	0.327	
Nickel	19.1	28.9 (14.6/47.8) [d]		14.6/47.8	8.91 (<BG)	
Strontium	NA	27.1 (12.9/42.4)		17.5/57.3	25.6	
Tin	NA	0.882 (15.2/50.0)		15.2/50.0	U	

a. Data obtained from HEIS. The water table was encountered at 15.0 m (49.1 ft) bgs. Well was drilled to a total depth of 58.8 m (192.9 ft) bgs.

b. The maximum depth from which samples were collected is in the rewetted zone/aquifer.

c. Original radiological data presented in left column with decay corrected value to year 2012 in right column.

d. Results of chromium and nickel in B276W2 collected at 47.8 ft bgs are elevated. The maximum values of chromium and nickel from the borehole excluding this sample are below background concentrations at 14.1 and 8.46 mg/kg, respectively, at 23.3 m (37.4) ft bgs. Concentrations of chromium and nickel are less than background in the sample intervals above and below B276W2 collected at 12.9 and 15.2 m (42.4 and 50.0 ft) bgs, respectively.

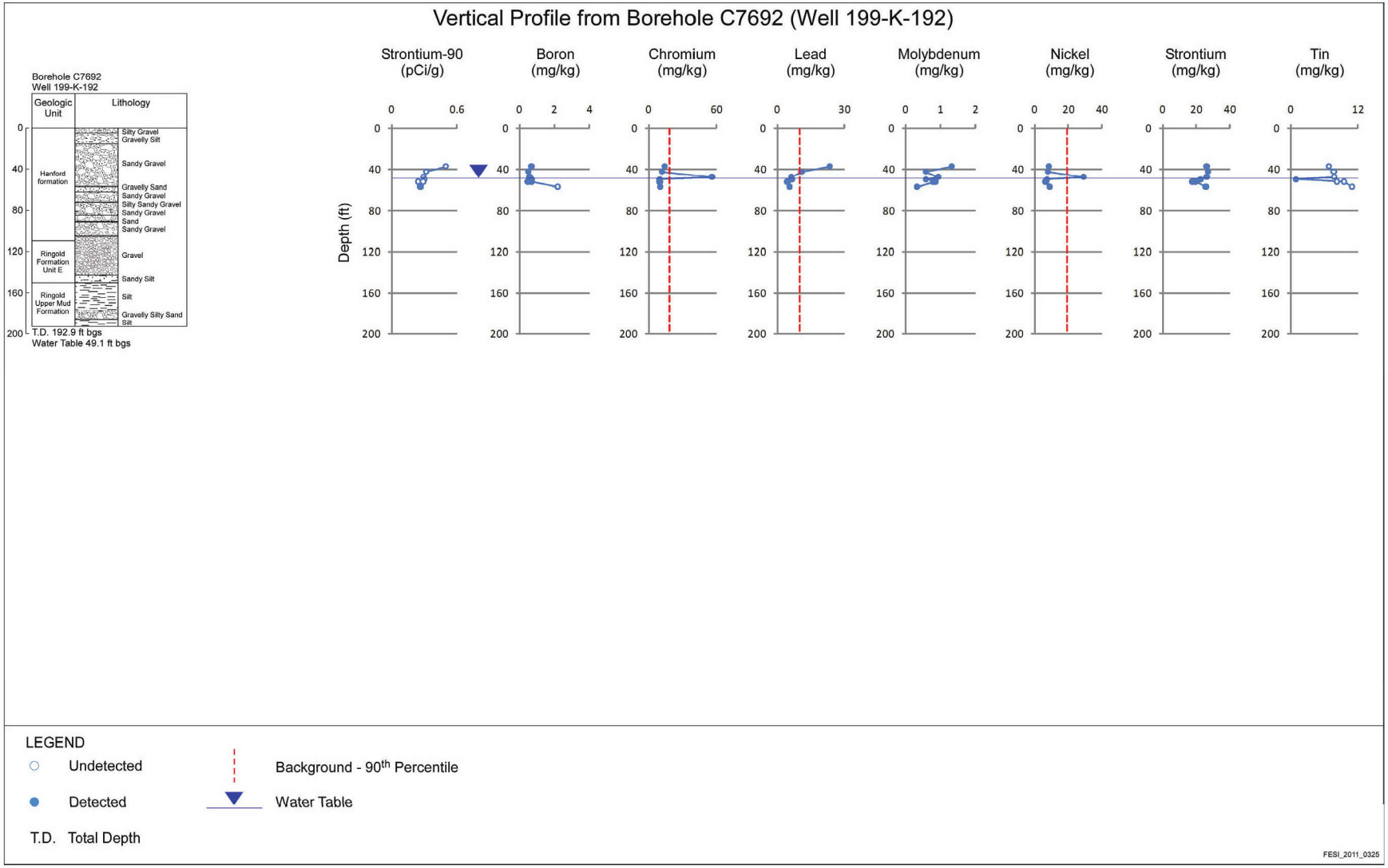

Figure 4-20. **Vertical Profile from** Borehole C7692 (K RUM Well 2)

4.2.2.19 Summary of Significant Soil/Sediment Results from 100-K RI Wells

Nine new wells into the unconfined aquifer and four new wells into the RUM were drilled for the 100-K RI. Soil/sediment samples were collected during drilling at 4.6, 3.0, 1.5, and 0.61 m (15, 10, 5, and 2 ft) above the water table, at the water table, and 1.5 m (5 ft) below the water table. Additional vadose samples were added for 100-K Wells 2, 4, 5, and 9, and RUM Wells 1, 3, and 4.

Radionuclides. From amongst the soil and sediment samples collected at the 13 wells, only 2 samples had radionuclide detections. A sample collected at 1.5 m (5 ft) into the water table (17.5 m [57.3 ft] bgs) at 100-K RUM Well 2 (C7692) had a detection of Sr-90 at 0.282 pCi/g. 100-K RUM Well 2 was located downgradient of the inlet end of the 116-K-2 Trench. At K RUM well 3 (C7688), near the former 120-KE-6 Sodium Dichromate Storage Tank, a single detection of cesium-137 at 0.116 pCi/g was measured in the sample collected closest to the surface at 1.9 m (6.25 ft) bgs. This result indicates low-level near surface contamination is present in this location.

Cr(VI). The highest concentration of Cr(VI) from amongst all the RI boreholes (1.6 mg/kg) was measured in the uppermost interval (1.9 m [6 ft]) bgs at K RUM well 3 (C7688) sited near the former 120-KE-6 Sodium Dichromate Storage Tank. Cesium-137, total chromium, lead, and mercury were also detected above background here, indicating that some shallow zone contamination is present in this location. Elevated Cr(VI) detections were seen intermittently through the remainder of C7688 but at significantly lower concentrations.

A single elevated Cr(VI) detection (0.97 mg/kg) was observed in a duplicate sample from 100-K RUM Well 1 (C7684) at about 14.3 m (47 ft). Cr(VI) was detected in all samples at 100-K Well 5 (C7689) with a maximum concentration of 0.79 mg/kg at 3.9 m (13 ft) bgs. All but one of the remaining detections was less than 0.20 mg/kg. Cr(VI) was detected in all sample intervals covering a distance of about 6.0 to 13.7 m (20 to 45 ft), including rewetted zone and aquifer samples, but at low concentrations (less than 0.20 mg/kg) at 100-K Wells 2, 4, and 6, which were sited to define extent of current Cr(VI) groundwater plumes.

Total Chromium. Most total chromium results from borehole samples were below background. Results above background were generally low (less than 40 mg/kg) with the exception of samples showing elevated chromium and nickel results. Section 4.2.4 provides additional discussion.

Lead. Elevated lead concentrations (182 to 229 mg/kg) over multiple sample intervals were measured in K wells 1, 5, and 6 (C7683, C7689, and C7691). All detections were from samples collected below 12.2 m (40 ft) bgs. One of the most notable is seen in 100-K Well 6 results, which showed lead above background in samples from about 18.5 to 23.2 m (61 to 76 ft) bgs. The concentrations increase from just above background to 229 mg/kg and then decrease just above the water table. In 100-K RUM Well 2 (C7692), lead above background (maximum 23.3 mg/kg) was measured in upper intervals extending to 11.4 and 12.9 m (37 and 42 ft) bgs. Single detections of lead slightly above background were measured in 1000-K RUM Well 1 (C7684) and 100-K Well 4 (C7690). The source of the deep vadose lead detections is unknown but there is no evidence that they are related to Hanford Site operations.

Lead above background (37.7 mg/kg) was detected above background in the uppermost interval (1.9 m [6 ft]) bgs at 100-K RUM Well 3 (C7688) sited near the former 120-KE-6 Sodium Dichromate Storage Tank, indicating that some shallow zone contamination is present in this location.

Other Metals. Two isolated detections of arsenic above background were measured from amongst all borehole samples. The maximum concentration was 14.3 mg/kg in the water table sample from 100-K Well 5 (C7689). Selenium was measured above background (1.01 mg/kg) in one sample at 14.3 m (47 ft)

from 100-K RUM Well 3 (C7688). Vanadium above background was measured in several sample intervals below 4.6 m (15 ft bgs) from this same borehole.

Elevated cobalt, manganese, and molybdenum were measured in a sample from 100-K RUM Well 4 (C7695) as well as elevated chromium and nickel results. Section 4.2.4 provides additional discussion of this sample result.

Total Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons. Significant TPH contamination was observed in several sample intervals in 100-K Well 9 (C7686) from about 13.7 to 17.6 m (45 to 60 ft) bgs. Concentrations of diesel and motor oil range hydrocarbons peaked at 22,600 and 22,500 mg/kg, respectively, within this range. Multiple PAHs were also elevated with a maximum benzo(a)pyrene detection of 0.579 mg/kg. The source of this contamination is most likely a nearby underground fuel oil tank, the 166-KE Oil Storage Tank.

4.2.2.20 Ongoing Interim Remediation

Information being gathered by ongoing interim remediation allows us to understand the movement of contaminants through the soil and its affect on groundwater. Three areas are described to assist in the understanding of high concentrations of sodium dichromate, Sr-90, and carbon-14. Each of these areas is a suspected source for continuing groundwater contamination. Data from this ongoing interim remediation will continue to be evaluated.

183-KW Water Treatment Area. The south end of the 183-KW Water Treatment Area includes 14 waste sites (1607-K3, 100-K-79 Subsites 1a and 2a, 100-K-18, 100-K-19, 100-K-34, 120-KW-1, 120-KW-2, 120-KW-3, 120-KW-4, 120-KW-5, 120-KW-7, 100-K-97, 100-K-102, and 100-K-109), which are presently undergoing remediation. The waste sites resulted from water influent treatment chemicals on the front side of the reactor that were introduced to support operation of the 105-KW and 105-KE Reactors.

From 1968 to 1971, commercial grade sulfuric acid was obtained from the Bunker Hill Company in Kellogg, Idaho. The sulfuric acid was used in the water treatment system and large amounts were discharged into surrounding waste sites. The acid was contaminated with high levels of mercury and lesser amounts of barium, total chromium, lead, and selenium.

In addition to sulfuric acid, large quantities of sodium dichromate were used in the water treatment system. As a result, minor amounts of Cr(VI) where detected on the soil surface at the beginning of remediation; however, no Cr(VI) above the remedial action goals has been found past the 1.83 m (6 ft) level.

Between April 2010 and March 2011, the waste sites were excavated to remove the structures and contaminated soil. Initially, the majority of the remediation was limited to a depth of 1.83 m (6 ft). High levels of mercury contamination in soils continued to be detected due to the contaminated sulfuric acid. Soil remediation then continued to a depth of 4.6 m (15 ft); however, mercury contamination continued to be detected and excavation continued to a maximum depth of 14.2 m (46.6 ft). A borehole (199-K-195) to groundwater was installed in spring 2011, through the 100-K-97 Waste Site. Results from the borehole analyses are discussed in Section 3.4.3.16. Final verification sampling of the 14 remediated waste sites and the area as a whole is ongoing at this time.

It is anticipated that the south end of the 183-KE Water Treatment Area, which also includes 14 waste sites (1607-K2, 100-K-79 Subsite 1b and 2b, 120-KE-1, 120-KE-2, 120-KE-3, 120-KE-4, 120-KE-5, 120-KE-6, 120-KE-9, 100-K-25, 100-K-27, 100-K-35, 100-K-98, and 100-K-101) and supported an identical function, will require the same amount of remediation. A borehole (199-K-188) to groundwater was installed in spring 2011 near the 100-K-98 and 120-KE-6 Waste Sites. Results from the borehole analyses are discussed in Section 3.4.3.5.

115-KE and 115-KW Condensate Cribs. The 115-KE and 115-KW Condensate Cribs are designated as the 116-KE-1 and 116-KW-1 Waste Sites, respectively. The condensate cribs received recirculated reactor blanket gases from the 105-KE and 105-KW Reactors. The primary COCs associated with the cribs are cesium-137, cobalt-60, europium-154, Sr-90, and tritium, with the key COC being carbon-14.

The 105-KE and 105-KW Reactors used nitrogen, which created an abundance of carbon-14 by the conversion of nitrogen-14 to carbon-14. The carbon-14 was then released into the atmosphere and into the air filtration condensate cribs (116-KE-1 and 116-KW-1) in an aqueous and gaseous form, causing the carbon-14 groundwater plumes associated with both cribs, which has led to the assumption that carbon-14 within 100-K has greater mobility than at other reactors and areas.

Since a more mobile form of carbon-14 has been detected in 100-K vadose zone, both soil and groundwater samples were collected and analyzed to estimate the potential for distribution of carbon-14 between the soil and the groundwater.

As water flows through the ground, chemical reactions interchange compounds between the water and the soil. These reactions affect the rate at which contaminants may be transported through the aquifer or deposited into the soil. An empirical relationship known as the K_d is used to describe the equilibrium relationship between a component's concentration in the soil and that component's concentration in the groundwater in contact with the soil. Leachability testing was conducted in spring 2011. The soil samples were collected at about 10 m (30 ft) below grade at the 116-KE-1 Waste Site. The results showed that a low percentage (7 percent) of mobile carbon-14 on the soil particles was easily washed off; however, the majority of the carbon-14 (> 90 percent) was strongly adsorbed or chemically reacted with the soil and not readily removed by leaching with water. The calculated K_d values ranged from 13 to 363 mL/g.

Waste Site 100-K-42. The FSB for the 105-KE Reactor, Waste Site 100-K-42, is located at the north end of the reactor. The concrete basin area served as a collection, storage, and transfer facility for the irradiated fuel elements discharged from the reactor. During the FSB operation, it developed leaks from the discharge chute into the soil beneath the basin and the reactor. This leak was identified as Waste Site UPR-100-K-1. Water in the FSB likely contained the following contaminants: americuim-241, cesium-137, cobalt-60, europium-152, europium-154, europium-155, plutonium-238, plutonium-239/240, Sr-90, uranium-234, uranium-235, and uranium-238. In an attempt to characterize the leak below the FSB, wells were drilled using Direct Push Technology (DPT) and logged using gamma logging to determine the relative levels of cesium-137.

Ten DPT wells were logged, four of which went diagonally under the reactor wall and six went straight down surrounding the former location of the discharge chute. The ten DPT wells indicate contamination present under the reactor and within the former location of the FSB. The highest reading detected during the gamma logging was approximately 4 million pCi/g cesium-137. Relative concentrations of the other contaminants will be determined from additional soil samples including Sr-90.

The DPTs conducted provided enough information to determine that contamination exists very close to and underneath the 105-KE Reactor; however, a clear picture of the nature and extent of contamination and enough information to characterize the entire fuel storage basin leak has not yet been developed. Additional activities to characterization the leak are currently planned, including additional DPTs and soil samples. More information is necessary to understand the complex leak that occurred from the 105-KE FSB. Similar sites may be present at the 105-KW Reactor and Fuel Storage Basin, which are also identified and Waste Sites 100-K-43 and 100-K-82, respectively; however, no characterization data are available for these sites.

4.2.3 Evaluation of Water Addition to Boreholes during Sampling

Most of these areas have been subject to precipitation and the corresponding deep infiltration of approximately 0.25 ft per year due to the lack of vegetation in areas undergoing remedial actions. In addition, dust suppression water has been applied during vadose zone remediation since operation of the reactors ceased in the late 1960s and early 1970s (at 100-K). It is assumed that no unplanned releases of Cr(VI) have occurred since operations ceased. Due to the bare ground conditions, more infiltration than would occur under natural conditions would take place and much of the vadose zone will have experienced significant leaching during the forty years since operations ceased, except for those areas protected by concrete or other structures.

The wells and boreholes installed during the RI field activities were drilled using the cable tool method, which is standard practice at Hanford. Periodically, water was added to the hole to allow removal of drill cuttings from the dry, unconsolidated sediments of the Hanford formation and Ringold Formation unit E. The intent is to provide sufficient water for removing cuttings and advancing the borehole without disturbing the underlying material, which is being tested for a variety of mobile and immobile contaminants. An analysis was conducted of the impacts to the representativeness of the RI characterization samples (*Data Quality Evaluation of Vadose Zone Soil Sampling Data Collection During RI Drilling for the 100 Area Operable Units* [ECF-100KR4-11-0166]). Typically, one gallon (0.13 ft^3) of water was sufficient to provide some cohesion to the cuttings, allowing the sample to be retrieved. However, occasionally 5 to 15 gal (0.67 to 2.01 ft^3) were used. Most of the additions were completed at least 0.6 m (2 ft) above the planned split-spoon sample interval.

The hydraulic evidence indicates that the large majority of the samples are unlikely to be significantly disturbed. For scale, one gallon (0.13 ft^3) of added water would fill a sphere of approximately 0.3 m (1 ft) in diameter assuming 20 percent porosity. Fifteen gallons (2.01 ft^3) would fill a sphere of 0.8 m (2.7 ft) in diameter. The high matric potential combined with the higher horizontal conductivity would tend to flatten the sphere as water preferentially wets in the horizontal direction. This is generally confirmed by the results of neutron logging in the wells and boreholes that show close correlation between the depth of water addition and the presence of elevated water in the adjacent formation, indicating water has moved laterally away from the borehole and away from the target split-spoon sample interval vertically below.

Evaluation of the Cr(VI) data from a large number of boreholes does not reveal any particular trends. There are occasional changes up to plus or minus 0.5 mg/kg, which may be a result of some redistribution during drilling or more likely reflects the actual distribution with depth. Some of the differences appear to be within the bounds of measurement error. The data from sample intervals with added water were consistent with data from internals above and/or below the interval. These observations suggest that the samples do provide us with a reasonable and representative estimate of subsurface conditions that can be added to our extensive body of knowledge to reach reasonable remediation decisions.

In conclusion, the intent of the drilling was to provide representative samples for physical property and contaminant analysis. Occasionally, the addition of water was required to provide some cohesion to remove the cuttings so the drilling could progress. Review of the vadose zone conditions indicates that the large matric potentials will tend to wick water preferentially in the lateral direction. This was confirmed in many instances by the neutron logs that measured the presence of higher water content at the depth where water was added. Consequently, it does not appear that the additional water would have significantly contacted the zone of the split spoon in a large majority of the split spoon samples collected. While there are samples impacted, there does not appear to be a bias introduced to these data that would cause significant impact to the selection of remedies and combination of remedies that are described in the Proposed Plan.

4.2.4 Anomalous Metal Concentrations in Selected 100-K RI Samples

Upon review of the analytical data from the vadose zone soil samples, some of the chromium and nickel results appear anomalous when compared to other results from neighboring intervals in the same boring, duplicate sample results, and analyses performed in support of the batch leach tests. This trend of elevated chromium and nickel results occur primarily in a ratio of 1.5 to 2.2, chromium: nickel. The ratio between the metals generally decreases as the analytical result approaches background values of chromium (18.2 mg/kg) and nickel (19.1 mg/kg). In some cases, concentration of other metals, such as molybdenum, are also anomalous. Table 4-20 presents data for the corresponding wells and intervals in 100-K Boreholes that show the elevated chromium and nickel results and the relative ratios of chromium: nickel in these samples.

Table 4-20. Borehole Samples with Chromium and Nickel Anomalies

Well ID	Interval	Sample	Chromium (mg/kg)	Nickel (mg/kg)	Ratio Chromium:Nickel
C7683	I-005	B25L28	53.6	30.4	1.76
C7688	I-009	B28F29	108	64.6	1.67
C7689	I-011	B26WF5	211	110	1.92
C7690	I-010	B26VB7	90.0	45.7	1.97
C7692	I-007	B276W2	56.0	28.9	1.94
C7693	I-012	B25YL6	57.8	32.1	1.80
C7695	I-018	B27H40	3560	2100	1.70
C7695	I-019	B27H41	54.8	25.2	2.17

Results from C7683, Interval I-005 duplicate sample B25L28 shows elevated chromium (53.6 mg/kg) and nickel (30.4 mg/kg) (Table 4-21). Molybdenum is relatively high in both samples and concentrations decrease in samples collected at greater depths. Results in this duplicate are approximately two times that measured in the primary sample B25L27 for chromium and nickel (27.0 and 18.2 mg/kg, respectively). No other samples from this borehole show nickel to exceed background.

Table 4-21. Borehole C7683, Interval 5 (Samples B27L27 and B27L28) Chromium, Nickel, and Molybdenum Results Relative to Neighboring Interval Sample Results

Interval	Sample	Sample Depth (ft)	Chromium (Total)		Nickel		Molybdenum	
			mg/kg	Q	mg/kg	Q	mg/kg	Q
C7683; I-005	B25L27	55.0	27.0		18.2		5.06	
Duplicate of B25L27	B25L28	55.0	53.6		30.4		4.33	
C7683; I-006	B25L29	60.0	17.0		11.9		3.72	
C7683; I-007	B25L30	65.5	19.9		14.2		1.06	B

Note: Interval 5 was the uppermost sample collected in borehole C7683.

B = analyte detected at less than the contract required detect limit, but greater than the detection limit

Q = qualifer

Results from C7695, Intervals I-018 and I-019 also show an unexpected increase in chromium, nickel, molybdenum, and other metal concentrations (Table 4-22). Samples B27H40 and B27H41 (Intervals I-018 and I-019) are the only samples from the borehole with cobalt, copper, manganese, and nickel above background (18.5 and 19.1 mg/kg, respectively). B27H40 has concentrations of total chromium and nickel over 2 orders of magnitude greater than nonsuspect samples, while the subject concentrations in B27H41 are over 2 times that of any of the nonsuspect samples. The concentrations of cobalt, copper, manganese, and molybdenum also show a significant and unexpected increase in sample B27H40. Molybdenum in sample B27H41 decreased significantly, but is still elevated with chromium and nickel. Concentrations of the other metals (cobalt, copper, and manganese) are also approximately 2 to 3 times higher in sample B27H39 relative to other borehole samples. The results from Intervals I-018 and I-019 exhibit some anomalies in metal concentrations.

In summary, the analyses from several soil samples exhibit some anomalous metals concentrations. Total chromium and nickel tend to be higher at these locations along with selected other metals. In general, these metals tend to be relatively immobile constituents. Therefore, these results do add some uncertainty to the assessment of nature and extent; the immobility of the constituents together with the relatively small number of samples exhibiting these characteristics indicates that this uncertainty is manageable.

4.2.5 Contaminants above Background at Remediated Waste Sites

Analytical data used to reclassify waste sites in 100-K to “Closed Out,” “Interim Closed Out,” and “No Action” was evaluated to document the occurrence of analytes detected above background. Analytes detected above background at each reclassified waste site are identified in Table 4-23. Data from 116-K-2 are not included in the table as they were previously evaluated in this chapter.

The sites listed in Table 4-23 are evaluated against human health and ecological risk in Chapters 6 and 7. Several sites stand out as key locations based on the presence of both shallow and deep contamination with radionuclides. These include 100-K-55:1, 100-K-56:1, and 116-K-1. In addition to 116-K-2, these sites are potential candidates for future risk that will be carried into the risk assessment.

Table 4-22. Borehole C7695, Intervals 18 and 19 (Samples B27H40 and B27H41) Elevated Metals Results Relative to Neighboring Interval Sample Results

Interval	Sample	Sample depth (ft)	Chromium		Cobalt		Copper		Manganese		Molybdenum		Nickel	
			mg/kg	Q	mg/kg	Q	mg/kg	Q	mg/kg	Q	mg/kg	Q	mg/kg	Q
C7695 (199-K-195); I-017	B27H39	72.0	13.2		3.69		8.97		278		2.03		7.24	
C7695 (199-K-195); I-018	B27H40	77.3	3560		20.4		44.1		603		36.6		2100	
C7695 (199-K-195); I-019	B27H41	82.7	54.8		4.65		14.6		278		4.79		25.2	
C7695 (199-K-195); I-020	B27H42	86.2	10.8		4.04		10.1		247		0.913	B	7.46	

B = analyte detected at less than the contract required detect limit, but greater than the method detection limit

Q = qualifer

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Table 4-23. Analytes Detected above Background in Soil Samples Used for Waste Site Reclassification in 100-K Area

Waste Site(s)	CVP/WSRF Number	Waste Site-Specific Decision Unit Sampled for Reclassification[a]		100-K Target Analytes Detected[b]																										Other Analytes				
		Shallow Zone	Deep Zone	Cs-137	Co-60	Eu-152	Eu-154	Pu-239/2404.5	Sr-90	U-233/234	Barium	Chromium (total)	Cr(VI)	Lead	Selenium	Mercury	TPH	Aroclor 1254	Ethylene glycol	Bis(2-ethylhexyl) phthalate	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(ghi)perylene	Benzo(k)fluoranthene	Chrysene	Fluoranthene	Indeno(1,2,3-cd)pyrene	Phenanthrene	Pyrene	Boron	Molybdenum	Strontium	Tin	Sulfate
100-K-29	WSRF 2004-040	Yes	No									S	S	S				S																
100-K-30	WSRF 2003-036	Yes	No										S	S		S																		S
100-K-31	WSRF 2004-038	Yes	No								S		S	S		S																		S
100-K-32	WSRF 2004-039	Yes	No										S			S																		S
100-K-33	WSRF 2004-041	Yes	No									S	S			S																		S
100-K-37 100-K-38	DOE/RL-2010-44	--[c]	--[c]																															
100-K-4	DOE/RL-2010-43	Yes	Yes	S, D							D			S	S, D																S, D	S, D	S, D	S, D	
100-K-55:1 100-K-56:1	CVP-2005-00006	Yes	Yes	S, D	S	S, D	S, D		S																									
116-KW-4 116-KE-5		Yes	No									S	S	S					S															
116-K-1	CVP-2003-00024	Yes	Yes	S, D	S, D	S, D	D		S, D				S, D																					
116-K-2	CVP-2006-00001	Not evaluated	Not evaluated																															
116-KE-4	CVP-2005-00002	Yes	No	S	S	S	S		S	S			S																					
116-KE-6A 116-KE-6B 116-KE-6C 116-KE-6D	DOE/RL-2010-42	--[c]	--[c]																															
116-KW-3	CVP-2004-00001	Yes	No	S	S	S	S	S					S																					
128-K-1	WSRF 2004-042	Yes	No										S	S	S		S			S	S	S	S	S	S	S	S	S	S					
1607-K4	WSRF 99-103	--[c]	--[c]																															

1

Note: Complete reference citations are provided in Chapter 11.

a. Shallow zone operable units sampled for reclassification include excavated areas generally 4.5 (15 ft) or less bgs, overburden or below cleanup level soil stockpile, and/or waste staging area footprints, as needed for specific remediation area. For No Action reclassification, data from confirmatory samples collected less than 4.5 m (15 ft) bgs are considered shallow zone. Deep zone operable units are always located greater than 4.5 (15 ft) bgs.

b. Radiological results evaluated based on original data without accounting for subsequent decay.

c. No soil samples were obtained for waste site reclassification.

D = analyte detected or detected above background in soil data from deep zone decision unit(s) used to support site reclassification

S = analyte detected or detected above background in soil data from shallow zone decision unit(s) used to support site reclassification

The 100-K-56:1 Reactor Process Effluent Pipelines subsite was an extensive system of underground pipelines that transported process cooling water effluent from the 105-KE Reactor to the 116-K-1 Crib, 116-K-2 Trench, and 116-KE-4 Retention Basins. This subsite includes pipeline sections downstream of the reactor and outside of the 105-KE Reactor security fence. Remediation of the pipelines was completed in 2005 and extended to a maximum depth of 8.8 m (29 ft) bgs (*Cleanup Verification Package for the 100-K-55:1 and 100-K-56:1 Pipelines and the 116-KE-5 Heat Recovery Stations* [CVP-2005-00006]). Cleanup verification sampling for cesium-137, europium-152, and europium-154 was conducted for both shallow and deep zone excavation areas and overburden stockpiles. The sampling areas for the 100-K-56:1 shallow and deep zones encompassed areas of 19,840 and 11,130 m^2 (213,600 and 119,810 ft^2), respectively. Cesium-137 values determined from the 2005 sampling were low with 95 percent UCL values of 0.61 and 1.32 pCi/g in the shallow and deep zones, respectively. Interim closeout values for europium-152 were 1.7 and 13.7 pCi/g, while europium-154 values were 0.14 and 1.87 pCi/g, in the shallow and deep zones, respectively. Overburden values were very low with cesium-137 below background and europium-152 and europium-154 at 0.30 and 0.053 pCi/g, respectively. Site-specific evaluation of these values showed the residual radionuclide concentrations achieved the applicable remedial action goals for reclassification.

4.2.6 Groundwater

This section presents a comprehensive interpretation of the results of sampling conducted to address additional data needs for spatial and temporal distribution of contaminants as identified in the 100-K Work Plan (DOE/RL-2008-46-ADD2). Concentration trends over time and summary statistics for groundwater COPCs are based on groundwater data from wells sampled over a five-year period (from January 2006 through December 2010). Figure 4-21 presents the location of the groundwater monitoring wells and the aquifer tubes in 100-K. Effects on contaminant concentrations and distributions from changes in Columbia River stage are discussed.

The 100-K Work Plan (DOE/RL-2008-46-ADD2), Table 4-5, identified the following two data needs associated with obtaining a better understanding of the nature and extent of contamination in groundwater.

Data Need No. 10: The Mechanisms to Explain the Persistence of the CrVI Plume are Unknown. These data are needed to evaluate alternative CSM components regarding whether groundwater contamination is from vadose zone sources (in areas of past handling and storage of high concentration sodium dichromate and in the periodically wetted zone), within the unconfined aquifer, above the RUM Unit, or within the RUM Unit and diffusing to the unconfined aquifer.

Data Need No. 13: Data are Needed to Better Define the Spatial and Temporal Distribution of Groundwater Contamination. As a result of the uncertainties identified in the RCBRA Report (DOE/RL-2007-21), the Integrated Work Plan (DOE/RL-2008-46) added activities that would help reduce uncertainties, verify conclusions of the HHRA presented in the RCBRA Report (DOE/RL-2007-21), and ensure that contaminants were not inadvertently overlooked based on the use of the existing groundwater data set. Section 3.6.5.1 of the Integrated Work Plan (DOE/RL-2008-46) identifies the following activities to reduce uncertainties:

- Identify existing and/or install new monitoring wells that are spatially representative of the groundwater. This set of wells will represent locations where a receptor potentially could contact groundwater.
- Conduct multiple rounds of sampling to obtain temporal representation of the unconfined aquifer from influence of river stage. Additional rounds of sampling at spatially representative monitoring

wells will represent current groundwater conditions and capture the influence of river fluctuations on COPC concentrations.

- Analyze all spatially representative monitoring wells for a focused list of groundwater COPCs identified for each round of sampling. Analyzing each of the monitoring wells for COPCs will provide a data set that is representative of potential releases to the groundwater.

- Evaluate sample results from characterization activities to support final remedial action decisions for groundwater.

The maximum concentrations of Cr(VI) measured in groundwater sampling, conducted in fall 2009 and spring 2010, were used to provide conservative assumptions for discussing contaminant distribution. This approach resulted in discussion of three plumes, as opposed to four, as typically reported in the annual groundwater monitoring report. Based upon the groundwater distribution of Cr(VI) (Figure 4-22), the 100-K plume areas have been designated as 100-K West, 100-K East, and 100-K North for the purpose of presenting the nature and extent of groundwater contamination. In general, the 100-K West plume originates around the 183.1-KW Head House, extends beneath the reactor footprint, and stretches downgradient toward the Columbia River. The 100-K East plume originated around the 183.1 KE Head House and now stretches downgradient toward the Columbia River. One part of the 100-K East plume is found downgradient and west of the process facilities centerline, while another portion of the 100-K East Plume merges to the northeast and combines with the Cr(VI) found at the southwestern end of the 116-K-2 Trench. The100-K North plume encompasses the northern portion of the 116-K-2 Trench and extends northeast to the 100-N Reactor fence line.

Three pump-and-treat systems currently operate in 100-K, with pump-and-treat operations conducted under the 1996 interim ROD (100-HR-3 and 100-KR-4 OU ROD [EPA/ROD/R10-96/134]). The original KR-4 system focused on the 116-K-2 Trench plume and began operations in 1997. The new KX system, which became fully operational in February 2009, treats groundwater contaminated by the 116-K-2 Trench that has migrated to the east. The KW pump-and-treat system began operations in January 2007 and treats groundwater in the KW Reactor area. The KW, KX, and KR-4 treatment systems currently provide a total combined capacity of 4,164 L/min (1,100 gpm).

For COPCs that have shown consistent detections above action levels (ALs), plume maps were developed to show the spatial extent of contamination in the unconfined aquifer at 100-K. Plume maps were created for Cr(VI), nitrate, carbon-14, Sr-90, and tritium. Historical summary statistics are based on groundwater data from 2006 through 2010.

4.2.6.1 Groundwater Data Collected during the Remedial Investigation

The groundwater-monitoring program for the 100-K RI/FS analyzed 34 COPCs identified in the 100-K SAP (DOE/RL-2009-41). The COPCs were analyzed in samples collected from newly installed groundwater monitoring wells and selected pre-existing wells. Wells locations are shown in Figure 4-21. Results are presented in this section in both map view and cross section.

Groundwater data were collected from 12 new unconfined aquifer wells, 2 boreholes, 1 well drilled into the RUM, 1 new three-tube aquifer tube cluster, and 18 existing monitoring wells (Figure 2-1). Monitoring wells (199-K-183, 199-K-184,199-K-185, 199-K-186, 199-K-187, 199-K-188,199-K-189, 199-K-190, 199-K-191, 199-K-193, 199-K-194, 199-K-195, 199-K-200, and 199-K-201) were installed in the unconfined aquifer to obtain additional data to address Data Needs 5, 10, and 12 (Chapter 2). Boreholes C7831 and C7832 were originally intended as temporary borings to collect soil samples and grab groundwater samples below the remediated 116-K-2 Trench. During drilling, however, lithologic

conditions prohibited collection of grab groundwater samples and the borings were converted to temporary Monitoring Wells 199-K-200 and 199-K-201.

Four wells were drilled into the RUM (Wells 199-K-184, 199-K-192, 199-K-188, and 199-K-195); only Well 199-K-192 encountered a water-bearing unit and was screened across it to assess fate and transport of contaminants beneath the unconfined aquifer. The other three wells were constructed within the unconfined aquifer. One new aquifer tube cluster (C7641, C7642, and C7643) was installed downgradient of the KW groundwater plume to address Data Needs 5 and 6 (Chapter 2). Data from adjacent aquifer tubes are included.

Water quality data including conductivity, temperature, pH, oxidation-reduction potential, dissolved oxygen, and turbidity were collected during sampling, well development, and pump tests.

Eighteen wells were sampled in October 2009 (low river stage), January 2010 (intermediate river stage), and June 2010 (high river stage) to define spatial and temporal distribution of groundwater contamination to address Data Gap 13. These sampling intervals are evaluated with respect to the temporal changes in the aquifer and the degree to which the intervals capture varying aquifer conditions related to fluctuations in the Columbia River elevations.

Because of the 100-K proximity to the Columbia River, seasonal variations in the river's elevation affect aquifer conditions by causing temporary changes in the water table. These elevation changes affect flow directions and rates, causing local changes in contaminant concentrations. For example, high river elevations may cause an influx of clean water from the river, lowering contaminant levels. When the aquifer further inland experiences the high river elevation as a pressure pulse, the higher water table may impact a contaminated section of unsaturated sediments, causing contaminant levels to rise. Conversely, when the river stage is at the lowest levels, the flow direction near the river is approximately toward the river, causing contaminant plumes to migrate toward the river. Further inland contaminant levels in the aquifer may decrease since contaminated soils are above the water table and not contributing to groundwater chemistry. To adequately characterize the dynamic groundwater conditions and associated contaminant levels, sampling was conducted during periods when the river elevation and water table are high, when both are low, and at some interval between or transitional to the extreme conditions.

River elevation variations from the lowest to highest levels are 3 to 4 meters, resulting in aquifer fluctuations of several meters, depending on the nature of the local sediments and the distance of the observation point from the river. Examples of the seasonal river elevation changes are shown in Figure 4-23. The daily averaged elevations depict a cyclic pattern of maximum to minimum river stage from year to year. These periodic or cyclic changes are engineered by upstream dams and reservoirs used for flood control, hydroelectric production, and salmon spawning programs. For any given year, the highest river elevations occur from May through June while the lowest levels occur from September through October, possibly to mid November. The intervals between the maximum and minimum river elevations from approximately December through April and July through August are periods when the aquifer is in transition. The change from low to high elevations occurs gradually over about four months, when levels are increasing from the low in the fall of the year to the May to June maximum. The change from high to low levels is sharp, occurring over a two-month interval through July and August.

To illustrate that the maximum and minimum river elevations are predictable and therefore useful for setting the 100-KR4-OU risk assessment sampling schedule, trends of daily averaged elevation measurements covering the same 360-day period from September through August of the following year are superimposed in Figure 4-24. For example, data from September 1, 2005 is overlain on data from September 1, 2006 and September 1, 2007. Such a comparison illustrates the repeatable cycle of seasonal variations allowing the timing of river fluctuations to set the schedule for the 100-KR4 OU remedial

investigation groundwater sampling. This schedule, as discussed in the Integrated Work Plan (DOE/RL-2008-46), began in October 2009 and was completed in June 2010.

With this prescribed period over which the groundwater samples could be collected, the water table was low in October 2009, and at or near a maximum in June 2010. The transitional period occurred during the winter of 2009 to 2010 through the early spring of 2010. Thus, sampling of the groundwater network was scheduled in October 2009, March 2010, and June 2010. The final sampling intervals based on actual sampling dates are compared to a trend line of the river elevation data in Figure 4-25. First, each sampling event was completed within the pre-determined periods for low water table from mid-September to mid-November, transitional aquifer conditions occurring from December 2009 through April 2010, and maximum aquifer levels from May through June 2010. Second, each sampling event was completed within 30 days, thus minimizing effects from dynamic river fluctuations. Based on the previous discussion, the chemistry data from groundwater samples collected during these three sampling event are fully representative of the dynamic groundwater conditions at the 100-KR4-OU.

The analytical data are presented in Appendix D, incorporated into the historical summary statistics, and included in the contaminant distribution discussions. Further evaluations of this data set, including the evaluations of COPCs, are presented in Chapter 6, Human Health Risk Assessment.

Appendix D of this RI/FS report contains the analytical data. The analytical results for the new RI aquifer tube cluster installed downgradient of the 100-KE and 100-KW Reactor areas are presented in Table 4-25. Analytical results for other aquifer tubes located in 100-K are presented in previous groundwater annual reports. Groundwater analytical results for eight COPCs (Cr(VI), nitrate, chloroform, tritium, carbon-14, Sr-90, TCE, and total chromium) are presented in each constituent section.

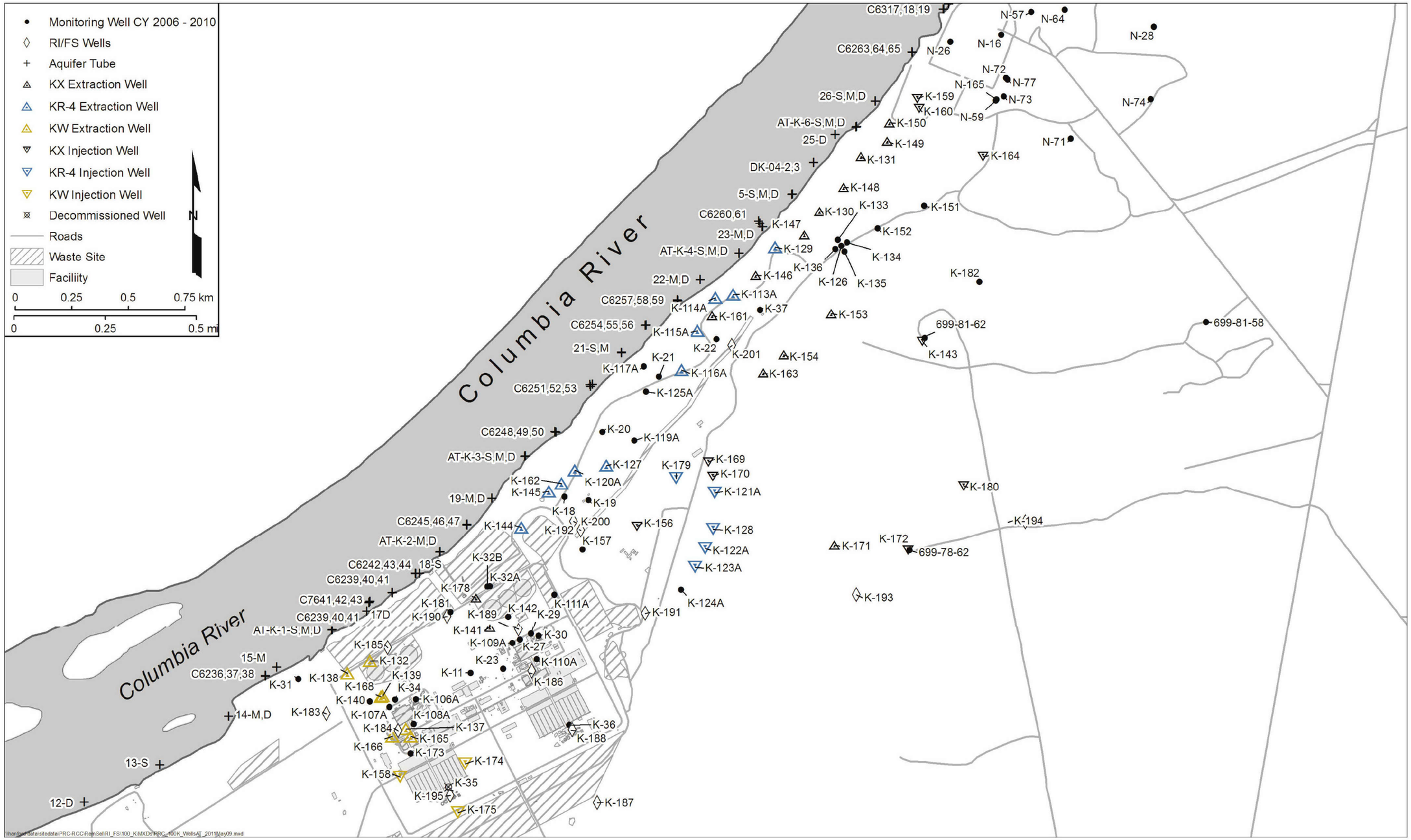

Figure 4-21. Groundwater Wells and Aquifer Tube Location Map

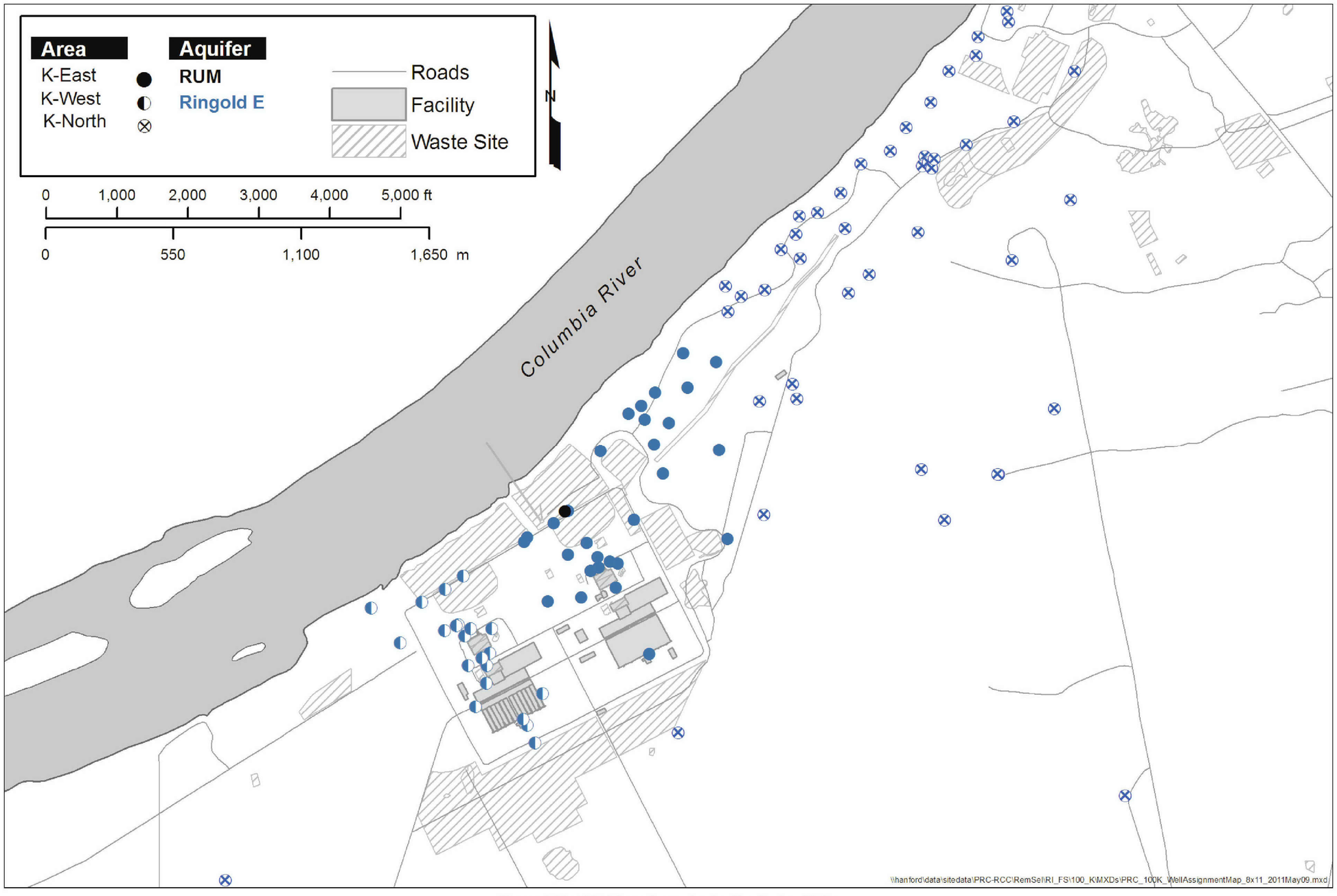

Figure 4-22. 100-K Area Groundwater Monitoring Wells

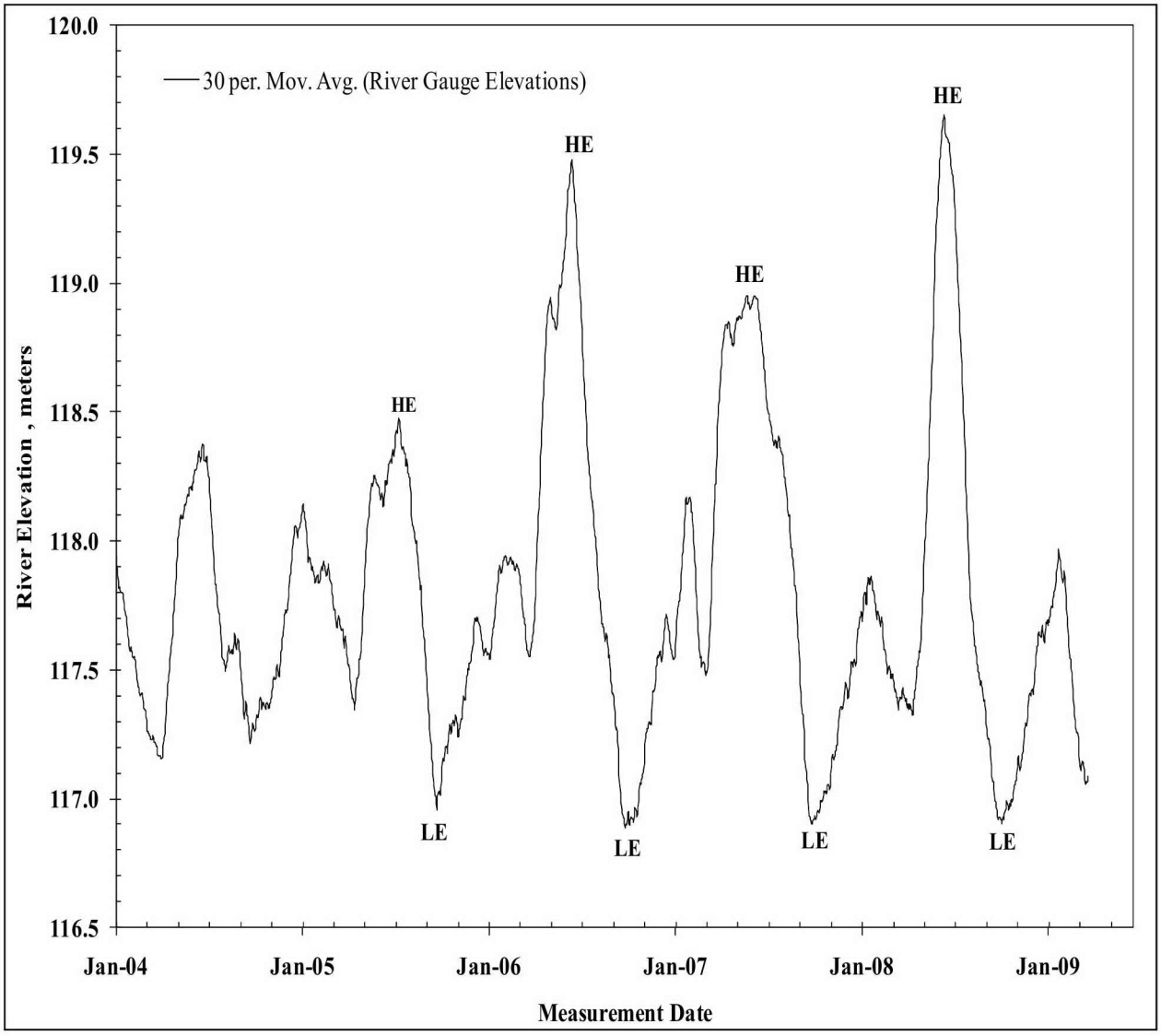

Figure 4-23. Seasonal Fluctuations in River Elevations Illustrating the Cyclic Nature of Maximum High (HE) and Low Elevations (LE) Over Multiple Years

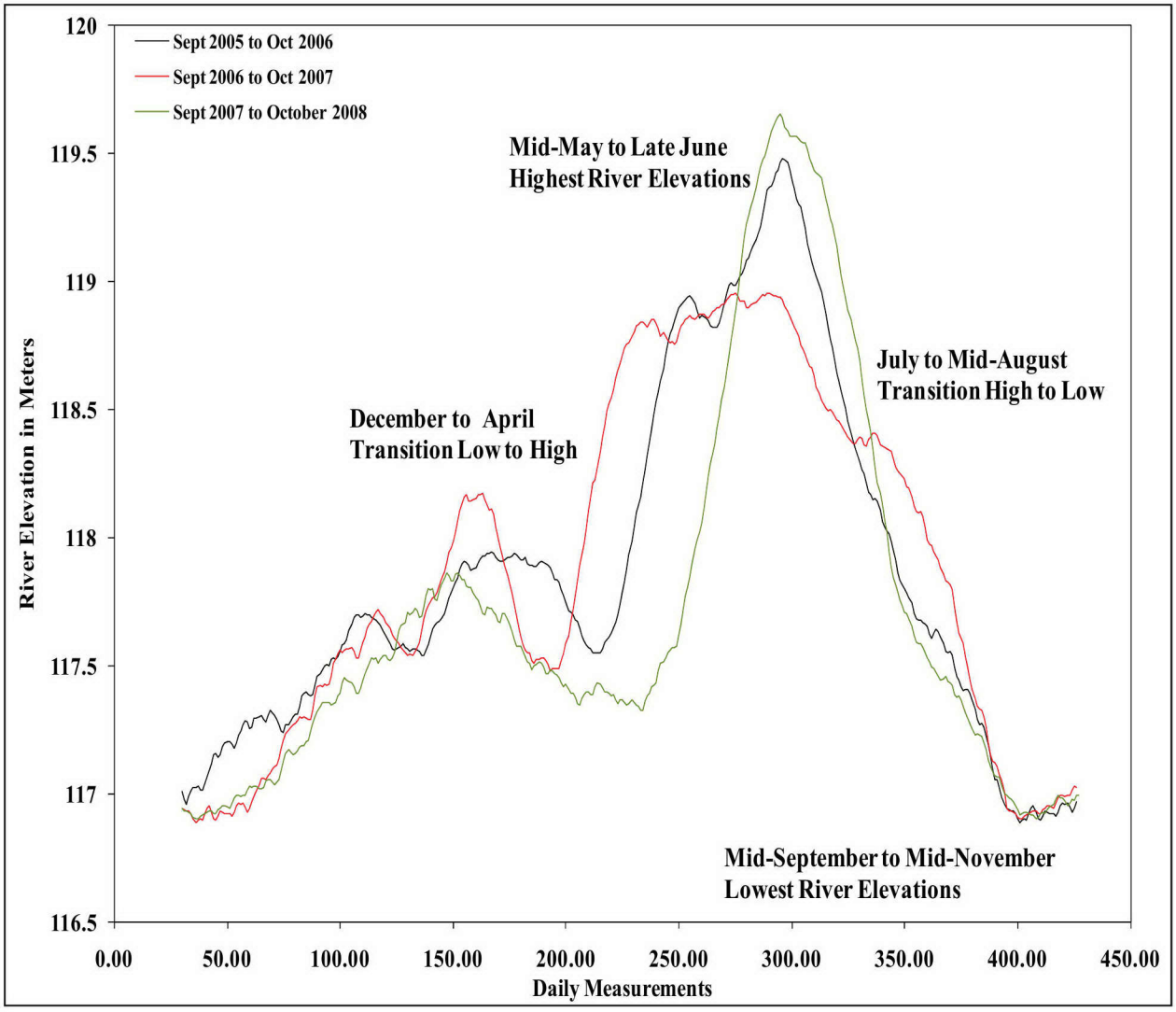

Figure 4-24. Annual Trends in River Elevations Measured at One Location for Three Years are Superimposed for a 360-Day Period to Illustrate That High, Low and Transitional Intervals are Cyclic and Repeatable from Year to Year

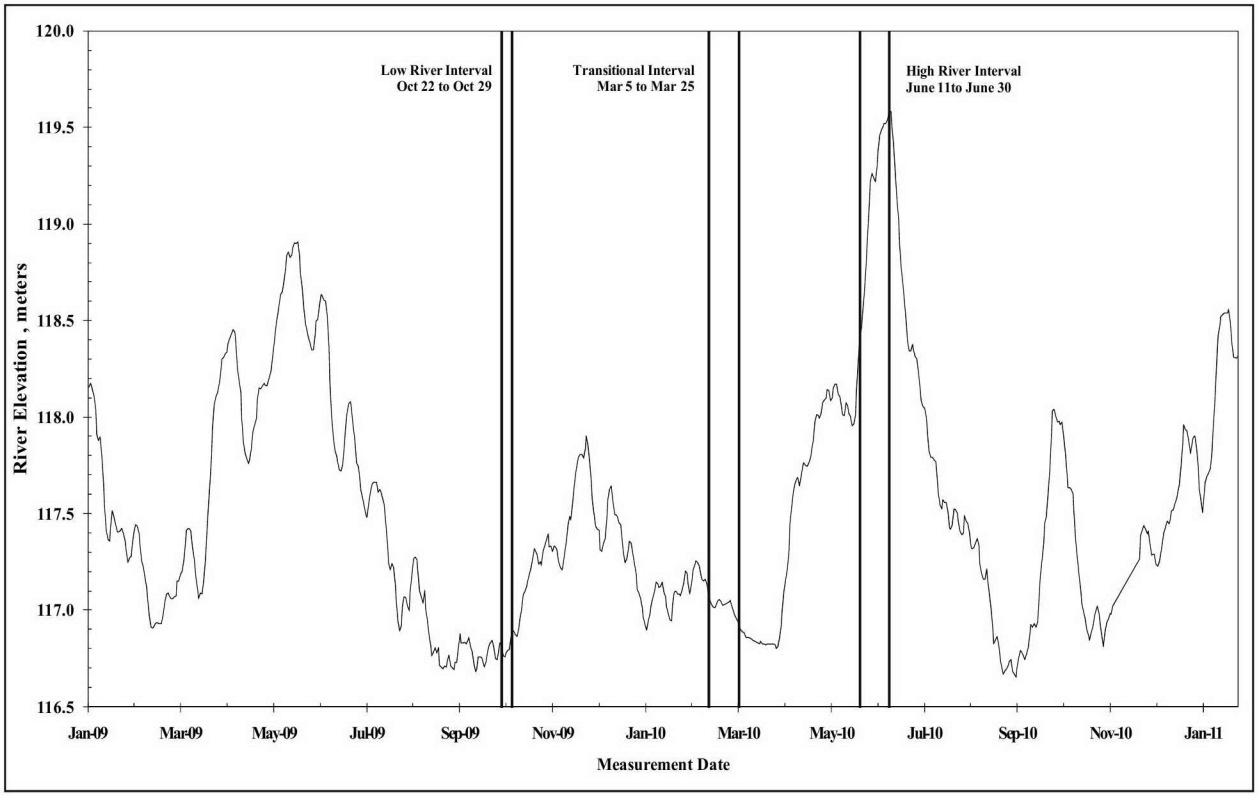

Figure 4-25. The Three Groundwater Sampling Intervals during Low, Transitional, and High River Stages Compared to a Trendline of Daily Averaged River Elevations

4.2.6.2 Historical Groundwater Evaluation

Uncertainties associated with the groundwater data set were identified in the RCBRA. These uncertainties relate to the ability of the groundwater data set collected from 1998 to 2008 to represent current baseline conditions and potential exposure within each groundwater OU. Analytical data used for the screening level assessment were collected to fulfill a variety of state and federal regulations, including the *Atomic Energy Act of 1954*; the RCRA, CERCLA, and Section 173 of the *Washington Administrative Code*. While the monitoring data can be used for risk assessment purposes, there are uncertainties associated with its use. Specifically, target analytes, sampling frequencies, and method detection limits (or reporting limits) are different between programs because the information is used to meet different requirements.

As a result of the uncertainties identified in the RCBRA (DOE/RL-2007-21), 100-K Work Plan (DOE/RL-2008-46-ADD2) performed a rigorous analysis of groundwater data for the purpose of identifying COPCs. The groundwater data set used for COPC identification consisted of sampling and analysis data collected from 57 monitoring wells from the 100-KR-4 Groundwater OU. The sampling and analysis data were collected between January 23, 1992, and December 8, 2008 and include four consecutive quarterly rounds collected during 1992 and 1993 and reported in 100-KR-4 LFI (DOE/RL-93-79), which were also used for the ecological component of the qualitative risk assessment (*Qualitative Risk Assessment for the 100-KR-4 Groundwater Operable Unit* [WHC-SD-EN-RA-010]).

A total of 34 groundwater COPCs were identified through the activities of the 100-K Work Plan (DOE/RL-2008-46-ADD2) and are listed in the 100-K SAP (DOE/RL-2009-41), Table 1-3. The analytical performance requirements (required analytical method) and the lowest chemical-specific ARAR (the action level) listed in the 100-K SAP (DOE/RL-2009-41), Table 2-4 were intended to meet

data need No. 13. The action level is listed to ensure that the estimated quantitation limit (EQL) is adequate for confirming the presence or absence of the COPC at the corresponding level. A total of 18 monitoring wells were selected to spatially represent the 100-KR-4 Groundwater OU, three sampling rounds were collected from each location. This data set was used to perform the supplemental risk evaluation that is presented in Section 6.3.

4.2.6.3 Current Groundwater Evaluation for the Unconfined Aquifer

The nature and extent of contamination in groundwater was based on the last five years of data, which were considered representative of current groundwater conditions (i.e., samples collected between January 1, 2006 and December 31, 2010). The nature and extent evaluation uses a subset of data from the work plan for wells screened in the unconfined aquifer and includes all groundwater data collected to fulfill data need No. 13.

Groundwater data for 100-K were compiled and statistically analyzed and the results are presented in Table 4-24. This table presents the summary statistics for each analyte identified as a COPC in the work plan and the SAP and lists the background concentrations in Hanford Site groundwater (*Hanford Site Background: Part 3, Groundwater Background* [DOE/RL-96-61]) where available, and the lowest chemical-specific ARAR for each analyte.

The evaluation presented in this section focuses on the following:

- Analytes that are identified as COPCs in the supplemental groundwater evaluation provided in Section 6.3 that warrant further evaluation in the FS
- Analytes of interest that were identified as COPCs in the work plan as a result of uncertainties due to limitations in the analytical data (inadequate method detection limits or anomalous results) and do not warrant further evaluation in the FS

4.2.6.4 Final COPCs Warranting Further Evaluation in FS

Section 6.3 identifies Cr(VI), nitrate, carbon-14, Sr-90, tritium, and trichloroethene as COPCs that warrant further evaluation in the FS. Generally, concentrations of Cr(VI), nitrate, and tritium are widely distributed and consistently present at concentrations above the DWS (nitrate and tritium) or the ambient water quality criteria (Cr(VI)). Carbon-14, Sr-90, and trichloroethene are not widely distributed but are present at concentrations above the DWS in localized areas. The distribution of each of these six analytes statistics are shown in Table 4-26.

Cr(VI) was detected in 88 percent of the unfiltered and 83 percent of the filtered groundwater samples. Cr(VI) was reported above the action level of 10 µg/L in 87 percent of the detected unfiltered results and 79 percent of the detected filtered results. Concentrations of filtered Cr(VI) ranged between 2 and 2,300 µg/L. With the exception of one nondetected result (both filtered and filtered), all method detection limits were less than or equal to the action level of 10 µg/L.

Nitrate was detected in 82 percent of the unfiltered and 67 percent of the detected filtered groundwater samples. Nitrate was reported above the DWS of 45,000 µg/L in 24 percent of the detected unfiltered results and no detected filtered results were above the DWS. Concentrations of unfiltered nitrate ranged between 53 and 2,250,000 µg/L. All method detection limits were less than the DWS of 45,000 µg/L.

Tritium was detected in 85 percent of the unfiltered and 100 percent of the filtered groundwater samples. Tritium was reported above the DWS of 20,000 pCi/L in 17 percent of the detected unfiltered results and no detected filtered results were above the DWS. Concentrations of unfiltered tritium ranged between 59 and 669,000 pCi/L. All method detection limits were less than the DWS of 20,000 pCi/L.

Carbon-14 was detected in 77 percent of the unfiltered and filtered groundwater samples were not analyzed. Carbon-14 was reported above the DWS of 2,000 pCi/L in 21 percent of the detected unfiltered results. Concentrations of unfiltered carbon-14 ranged between 8.6 and 13,500 pCi/L. All method detection limits were less than the DWS of 2,000 pCi/L.

Sr-90 was detected in 27 percent of the unfiltered and zero percent of the filtered groundwater samples. Sr-90 was reported above the DWS of 8 pCi/L in 48 percent of the detected unfiltered results. Concentrations of unfiltered Sr-90 ranged between 0.15 and 1,610 pCi/L. All method detection limits were less than the DWS of 20,000 pCi/L.

Trichloroethene was detected in 57 percent of the unfiltered samples and in the only filtered sample. The action level for trichloroethene is 0.49 µg/L based on the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level; however, it defaults to the EQL of 1 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. Trichloroethene was reported above the action level of 1 µg/L in 90 percent of the detected results. Trichlorothene was reported above the DWS of 5 µg/L in 7 percent of the detected results. Concentrations of unfiltered trichloroethene ranged between 0.22 and 7.4 µ/L. All method detection limits were less than the EQL of 1 µg/L.

4.2.6.5 Analytes of Interest

The following descriptions of analytes of interest include metals, anions, and VOCs.

Metals. Antimony was identified as a COPC in the work plan because it was detected above the action level and most MDLs were greater than the action level. MDLs were not adequate for determining the presence of antimony at or below the action level of 5.6 µg/L. Antimony was detected in 10 of 316 unfiltered samples (3 percent) and seven of 348 (2 percent) of the filtered groundwater samples. Antimony concentrations in unfiltered and filtered groundwater samples range between 0.5 and 68 µg/L. Unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for these results range between 3.6 and 72 µg/L and detected concentrations range between 7.2 and 68 µg/L. All antimony results reported by Method 6010 were flagged with a "B" qualifier, flagged with "C" qualifier, or flagged with both a "B" and a "C" qualifier. The "B" qualifier indicates the analyte was detected at a value less than the required detection limit, but greater than or equal to the MDL. The "C" qualifier indicates that the analyte was detected in both the sample and the associated QC blank, and the sample concentration was less than or equal to five times the blank concentration. Antimony concentrations for unfiltered and filtered samples flagged with a "B" ranged between 7.1 and 42 µg/L. Antimony concentrations for unfiltered and filtered samples flagged with a "C" or "BC" ranged between 8.6 and 68 µg/L. Samples collected for the RI were analyzed using trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.3 and 4 and detected concentrations range between 0.54 and 0.89 µg/L. The results of this evaluation indicate that antimony has historically been detected in groundwater samples at a low frequency of detection (3 percent in unfiltered samples and 2 percent in filtered samples) with concentrations up to 8 times greater than the action level. All historic detections of antimony are flagged with a combination of "B" and "C" qualifiers. Antimony concentrations are not associated with a specific locationor a trend. Antimony concentrations associated with samples collected for the RI are not above the action level of 5.6 µg/L. With the exception of two sample results flagged with a "C" qualifier, all antimony concentrations are below the 90th percentile Hanford Site background level of 55 µg/L.

Arsenic was identified as a COPC in the work plan because it was detected above the action level and all MDLs were greater than the action level. MDLs were not adequate for determining the presence of arsenic at or below the action level of 0.018 µg/L. The action level for arsenic is 0.018 µg/L based on the

"Groundwater Cleanup Standards (WAC 173-340-720) groundwater cleanup level; however, the action level defaults to the EQL of 4 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. Arsenic was detected in 149 of 158 (94 percent) of the unfiltered and 66 and 71 (93 percent) of the filtered groundwater samples. Arsenic concentrations in unfiltered groundwater range between 0.5 and 33 and range between 0.8 and 14 µg/L in filtered samples. Many arsenic results were flagged with a "B" qualifier or a "C" qualifier. Arsenic concentrations for unfiltered and filtered samples flagged with a "B" ranged between 0.81 and 7.9 µg/L. Concentrations of arsenic for unfiltered and filtered samples flagged with a "C" ranged between 4.4 and 17 µg/L. Samples collected prior to and for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples are 0.8 µg/L. Minimum, maximum, and 90th percentile concentrations for (filtered) background concentrations of arsenic are 0.5, 8.8, and 7.85 µg/L, respectively. Arsenic concentrations in filtered samples were within the range of background concentrations except for 2 of 71 sample results. Arsenic was measured at a concentration of 14 µg/L at 199-K-136 and at a concentration of 9.6 µg/L at 199-N-72. Although two filtered results were greater than background, the presence of arsenic is consistent with background and not related to a site-release. Samples evaluated for the RI indicate that arsenic is present at concentrations above the action level of 4 µg/L. Arsenic concentrations in filtered samples are generally within the range of naturally occurring levels at the Hanford Site. Arsenic concentrations above background are at a low frequency (2 of 76 samples), are not associated with a specific location or a trend, and the highest concentration of 14 µg/L was flagged with a "C" qualifier.

Barium was identified as a COPC in the work plan because it was detected above the action level of 1,000 µg/L. Barium was detected in 100 percent of the unfiltered and filtered groundwater samples. Concentrations of unfiltered barium results ranged between 9.9 and 233 and filtered concentrations ranged between 9.4 and 213 µg/L. Samples collected within the last 5 years and those evaluated for the RI indicate that barium concentrations are not above the action level of 1,000 µg/L.

Beryllium was identified as a COPC in the work plan because it was detected above the action level and most MDLs were greater than the action level of 4 µg/L. Beryllium was detected in 4 of 316 samples (1.3 percent) of the unfiltered samples and in 3 of 348 (0.86 percent) of the filtered groundwater samples. Beryllium concentrations in unfiltered and filtered groundwater samples range between 0.11 and 6.8 µg/L. Unfiltered and filtered groundwater samples collected prior to the RI were analyzed by Method 6010, MDLs for these results range between 0.1 and 8 and detected concentrations range between 0.5 and 6.8 µg/L. All beryllium results reported by Method 6010 were flagged with a "B" qualifier. Samples collected for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.05 and 0.5 and detected concentrations for both unfiltered and filtered results range between 0.11 and 0.24 µg/L.The results of this evaluation indicate that beryllium has historically been detected in groundwater samples at a low frequency of detection (1 percent in unfiltered samples and 0.7 percent in filtered samples) with concentrations up to 2 times greater than the action level. All historic detections of beryllium are flagged with a "B" qualifier. Beryllium concentrations above the action level are not associated with a specific location or with a trend. Beryllium concentrations associated with samples collected for the RI are not above the action level of 4 µg/L. With the exception of one beryllium result flagged with a "B" qualifier, all filtered samples are below the 90th percentile Hanford Site background level of 2.3 µg/L.

Cadmium was identified as a COPC in the work plan because it was detected above the action level and most MDLs were greater than the action level of 0.25 µg/L. Cadmium was detected in 6 of 316 (1.9 percent) of the unfiltered samples and in 6 of 348 (1.7 percent) of the filtered groundwater samples. Cadmium concentrations in unfiltered and filtered groundwater samples range between 0.06 and 15 µg/L. Unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for these results range between 0.3 and 8 µg/L, unfiltered concentrations ranged between 4.2 and 5.9 µg/L, and

filtered concentrations ranged between 0.4 and 15 µg/L. All cadmium results reported by Method 6010 were flagged with a "B" qualifier. Samples collected for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.06 and 0.45 and detected concentrations for both unfiltered and filtered results range between 0.06 and 0.31 µg/L. Cadmium was detected above the action level in six wells (199-K-32B, 199-K-107A, 199-K-133, 199-K-135, 199-K-137, and 699-73-61). Cadmium was detected in a filtered groundwater sample from Monitoring Well 199-K-32B at a concentration of 15 µg/L, and the corresponding unfiltered sample collected from this well was 4 µg/L. Cadmium was detected in a filtered groundwater sample from Monitoring Well 199-K-107A at a concentration of 4.9 µg/L, and the corresponding unfiltered sample collected from this well was 5.9 µg/L. Cadmium was detected once above the action level at 199-K-133 (4.1 µg/L), 199-K-135 (4.7 µg/L), 199-K-137 (0.39 µg/L), and 699-73-61(0.31 µg/L). Additional rounds of samples were collected from each of the six wells with cadmium concentrations less than the action level or reported as nondetected concentrations with MDLs ranging between 3 and 4 µg/L. The results of this evaluation indicate that cadmium has historically been detected in groundwater samples at a low frequency of detection (2 percent in unfiltered samples and 1.6 percent in filtered samples) with concentrations up to 60 times greater than the AL. The highest historic cadmium concentrations are flagged with a "B" qualifier. Cadmium concentrations above the action level are not associated with a specific location or with a trend. Cadmium concentrations associated with samples collected for the RI are not above the action level of 0.25 µg/L. Cadmium concentrations in filtered samples collected for the RI are below the 90th percentile Hanford Site background level of 0.96 µg/L.

Total chromium was identified as a COPC in the work plan because it was detected above the action level of 65 and some MDLs were greater than the action level. Chromium was detected in 330 of 408 (81 percent) of unfiltered samples and 259 of 351 (74 percent) of the filtered groundwater samples. Total chromium was reported above the AWQC of 65 µg/L for 28 percent of the unfiltered results and above the AWQS in 27 percent of the filtered chromium results. All method detection limits were less than the AWQS of 65 µg/L. Although total chromium concentrations in groundwater are greater than the AWQS, it is assumed that a portion of dissolved concentrations of total chromium are present in the form of Cr(VI). Cr(IV) was previously evaluated and identified as a COPC warranting further evaluation in the FS.

Cobalt was identified as a COPC in the work plan because it was detected above the action level and some MDLS were greater than the action level of 2.6 µg/L. Cobalt was detected in 40 of 316 (13 percent) of unfiltered samples and 60 of 348 (17 percent) of filtered groundwater samples. Cobalt concentrations in unfiltered and filtered groundwater samples range between 0.09 and 21 µg/L. Unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010, MDLs for these results range between 0.5 and 8 µg/L, unfiltered concentrations ranged between 0.5 and 20 µg/L, and filtered concentrations ranged between 0.8 and 21 µg/L. All cobalt results reported by Method 6010 were flagged with a "B" qualifier, flagged with "C" qualifier, or flagged with both a "B" and "C" qualifier. Cobalt concentrations for unfiltered and filtered samples flagged with a "B" ranged between 4 and 16 µg/L (all results above action level). Cobalt concentrations for unfiltered and filtered samples flagged with a "C" or "BC" ranged between 0.5 and 21 µg/L (21 of 25 results above action level). Samples collected for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.1 and 0.22 µg/L, detected concentrations for unfiltered samples ranged between 0.1 and 3.0 µg/L, and ranged between 0.09 and 1.6 µg/L for filtered samples. The results of this evaluation indicate that cobalt has historically been detected in groundwater samples (15 percent of unfiltered samples and 16 percent of filtered samples) at concentrations up to 8 times greater than the action level; however, all cobalt results are flagged with either a "B" or C" qualifier. Cobalt concentrations above the action level are not associated with a specific location or with a trend. Cobalt concentrations associated with samples

collected for the RI are not above the action level of 2.6 µg/L. Cobalt concentrations in filtered samples are above the 90th percentile Hanford Site background level of 0.92 µg/L.

Copper was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 9.0 µg/L. Copper was detected in 59 of 316 (19 percent) unfiltered samples and 47 of 348 (14 percent) of filtered groundwater samples. Unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for these results range between 0.8 and 8 µg/L, unfiltered concentrations ranged between 1.5, and 33 and filtered concentrations ranged between 1 and 14 µg/L. Many copper results reported by Method 6010 were flagged with a "B" qualifier, flagged with "C" qualifier, or flagged with both a "B" and a "C" qualifier. Copper concentrations for unfiltered and filtered samples flagged with a "B" ranged between 2.8 and 14 µg/L (4 of 22 results above action level). Copper concentrations for unfiltered and filtered samples flagged with a "C" or "BC" ranged between 4.4 and 14 µg/L (16 of 34 results above action level). Samples collected for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.1 and 0.45 µg/L, detected concentrations for unfiltered samples ranged between 0.2 and 4 and ranged between 0.2 and 3.6 µg/L for filtered samples. Many copper results reported by trace methods were flagged with a "B" qualifier, or flagged with both a "B" and a "C" qualifier. Copper concentrations for unfiltered and filtered samples flagged with a "B" ranged between 0.20 and 1.6 µg/L (no results above action level). Copper concentrations for unfiltered and filtered samples flagged with a "BC" ranged between 0.4 and 1.7 µg/L (no results above action level). The results of this evaluation indicate that copper has historically been detected in groundwater samples (20 percent of unfiltered samples and 14 percent of filtered samples) at concentrations up to 1.5 times greater than the action level, and many copper results are flagged with either a "B" or C" qualifier. Copper concentrations above the action level are not associated with a specific location or with a trend. Copper concentrations associated with samples collected for the RI are not above the action level of 9 µg/L. Copper concentrations in filtered samples are above the 90th percentile Hanford Site background level of 0.81 µg/L.

Iron was detected above the action level of 300 µg/L in samples collected for the RI and is included in the nature and extent evaluation. The action level for iron is based on the secondary MCL. Iron affects aesthetic qualities relating to public acceptance of drinking water. These regulations are not federally enforceable, but are intended as guidelines for states. Because the action level is based on a secondary MCL, iron concentrations in groundwater are compared to the AWQC of 1,000 µg/L. Iron was detected in 308 of 399 (77 percent) of unfiltered and 148 of 347 (43 percent) of filtered groundwater samples. All samples collected prior to the RI and for the RI were analyzed by Method 6010. MDLs for these samples ranged between 9 and 330 µg/L, detected concentrations for unfiltered samples ranged between 11 and 7,890 and ranged between 10 and 1,760 µg/L concentrations for filtered samples. A total of 241 iron results were flagged with a "C" or a "BC" qualifier with concentrations ranging between 9.6 and 7,890 µg/L. Iron was detected in 12 wells (199-K-20, 199-K-23, 199-107A, 199-K-110A, 199-K-126, 199-K-133, 199-K-134, 199-K-135, 199-K-136, 199-K-165, 199-K-168, and 699-73-61) with concentrations greater than 1,000 µg/L. Iron was detected at concentrations greater than 1,000 µg/L in filtered samples collected from 199-K-134 (1,140 and 1,760 µg/L). Six additional filtered samples were collected from 199-K-134 with concentrations ranging between 35 and 271 µg/L. The results of this evaluation indicate that iron concentrations have historically been detected in groundwater. Iron concentrations above the AWQC of 1,000 µg/L are at a low frequency in unfiltered samples (26 of 399 samples; 6.5 percent and filtered samples (2 of 347 samples; 0.6 percent) at concentrations up to 7 times greater than the AWQC. Iron present in Wells 199-K-133, 199-K-134, 199-K-135, and 199-K-136 is likely due the calcium polysulfide treatment test conducted at the OU. Iron concentrations in filtered water samples have historically been detected above the background level of 760 µg/L at a low frequency (4 of 347 samples).

Lead was identified as a COPC in the work plan because it was detected above the action level and some MDLS were greater than the action level of 2.1 µg/L. Lead was detected in 43 of 148 (29 percent) of unfiltered and seven of 74 (10 percent) of filtered groundwater samples. Most of the samples collected prior to the RI and all of the RI were analyzed by trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.05 and 0.2 µg/L, detected concentrations for unfiltered samples ranged between 0.06 and 16 µg/L, and ranged between 0.25 and 17 µg/L for filtered samples. Lead was detected at a concentration of 16 µg/L in the unfiltered sample and at a concentration of 17 µg/L in the filtered sample from Well 699-73-71. However, the duplicate filtered sample collected at the same time was reported with a lead concentration of 2.3 µg/L. Three other sampling rounds were collected from this location with concentrations in unfiltered samples ranging between 0.4 and 1.1 and between 0.2 and 0.6 µg/L in filtered samples. Lead was detected in the filtered sample from 199-K-32A at a concentration of 2.8 µg/L. This is the only lead analysis performed at this well. The results of this evaluation indicate that lead has historically been detected in groundwater samples. Lead concentrations above the action level are detected at a low frequency in unfiltered samples (7 of 148; 4.7 percent) and filtered samples (2 of 74 samples; 2.7 percent) with concentrations up to 8 times greater than the action level. Lead concentrations are not associated with a specific location or with a trend. Continued monitoring at these wells with an appropriate analytical method would help resolve uncertainties associated with infrequent detections. Lead concentrations in filtered samples are above the 90th percentile Hanford Site background level of 0.91 µg/L.

Manganese was identified as a COPC in the work plan because it was detected above the action level of 50 µg/L. Manganese was detected in 198 of 401 (49 percent) of unfiltered and 108 of 348 samples (31 percent) of filtered groundwater samples. The action level for manganese is based on the secondary MCL. Manganese affects aesthetic qualities relating to public acceptance of drinking water. These regulations are not federally enforceable, but are intended as guidelines for states. Because the action level is based on a secondary MCL, manganese concentrations in groundwater are compared to the "Surface Water Cleanup Standards" (WAC 173-340-730) surface water cleanup level of 907 µg/L. All samples collected prior to the RI and for the RI were analyzed by Method 6010. MDLs for these samples ranged between 0.24 and 8 µg/L, detected concentrations for unfiltered samples ranged between 0.32 and 6,480 µg/L, and filtered samples ranged between 0.23 and 6,330 µg/L concentrations. A total of 80 manganese results were flagged with a "C" or a "BC" qualifier with concentrations ranging between 0.23 and 100 µg/L. Manganese concentrations above the action level are reported in 199-K-133, 199-K-34, 199-K-135, and 199-K-136. The results of this evaluation indicate that manganese has historically been detected in groundwater samples. Manganese concentrations above the action level are associated with a trend at 199-K-133, 199-K-34, 199-K-135, and 199-K-136 where concentrations in filtered samples range between 1.3 and 7 times greater than the action level of 907 µg/L. The presence of manganese in these wells is associated with the calcium polysulfide treatment test conducted at the OU and is not the result of a site-release. Manganese concentrations in all remaining wells are less than the action level. Manganese concentrations in filtered samples are above the 90th percentile Hanford Site background level of 39 µg/L.

Mercury was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 0.012 µg/L. Mercury was detected in two of 76 (2.6 percent) of unfiltered and three of 72 (4.2 percent) of filtered groundwater samples. The action level for mercury is 0.012 µg/L based on the AWQC; however, it defaults to the EQL of 0.5 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All samples collected prior to the RI and for the RI were analyzed by Method 7470 or trace methods. MDLs for these samples ranged between 0.016 and 0.1 µg/L, a single detection of was reported in an unfiltered sample at 199-K-142 (0.042 µg/L) and at 199-K-36 (0.08 µg/L) and single occurrences of mercury were

measured in filtered samples collected from 199-K-34 (0.11 µg/L), 199-K-117A (0.075 µg/L), and 199-K-142 (0.11 µg/L). Samples evaluated for the RI indicate that mercury is not present at concentrations above the action level of 0.5 µg/L. Mercury concentrations in filtered samples are above the 90th percentile Hanford Site background level of 0.003 µg/L.

Nickel was identified as a COPC in the work plan because it was detected above the action level of 52 µg/L. Nickel was detected in 78 of 313 (25 percent) of unfiltered and 66 of 345 (19 percent) of filtered groundwater samples. All samples collected prior to the RI and for the RI were analyzed by Method 6010. MDLs for these samples ranged between 0.2 and 13 µg/L, detected concentrations for unfiltered samples ranged between 0.46 and 118 µg/L, and concentrations ranged between 0.42 and 106 µg/L for filtered samples. Some sample results reported by Method 6010 were flagged with a "B" qualifier, with a "C" qualifier, or flagged with both a "B" and a "C" qualifier. Nickel concentrations for unfiltered and filtered samples flagged with a "B" ranged between 0.42 and 40 µg/L. Nickel concentrations for unfiltered and filtered samples flagged with a "C" or "BC" ranged between 4 and 52 µg/L. Nickel concentrations in filtered samples were greater than 52 µg/L in three wells (199-K-36, 199-K-110A, and 199-K-137). A total of 13 samples were collected from 199-K-36 with nickel concentrations in filtered samples at ranging from 14 to 98 µg/L (five of 13 samples was greater than 52 µg/L). A total of nine samples were collected from 199-K-110A with nickel concentrations in filtered samples ranging from 18 to 94 µg/L (four of nine samples were greater than 52 µg/L). A total of five samples were collected from 199-K-137 with nickel concentrations in filtered samples ranging from 1.8 to 106 µg/L (one of five samples were greater than 52 µg/L). The results of this evaluation indicate that nickel has historically been detected in groundwater samples. Nickel concentrations above the action level are at a low frequency in unfiltered samples (13 of 313; 4.1 percent) and filtered samples (10 of 345 samples; 2.9 percent). Nickel concentrations are associated with a trend at 199-K-36 and 199-K-110A where concentrations have ranged been 1.2 to 1.9 times greater than the action level of 52 µg/L. The presence of nickel is potentially associated with corrosion of the well casing as 199-K-36 and 199-K-110A, which were installed in 1992 and 1994, respectively. Nickel concentrations in filtered samples are above the 90th percentile Hanford Site background level of 1.6 µg/L.

Selenium was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 5 µg/L. Selenium was detected in 56 of 77 (73 percent) of unfiltered and 58 of 72 (81 percent) of filtered groundwater samples. Some unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for this method were reported at 3.6 and 4.8 µg/L. Most of the samples collected prior to the RI and all of the RI were analyzed by trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.6 and 1.3 µg/L, detected concentrations for unfiltered samples ranged between 0.7 and 3 µg/L, and ranged between 0.6 and 3.3 µg/L for filtered samples. Many of the results were flagged with a "B" qualifier or with a "BC" qualifier. Selenium concentrations for unfiltered and filtered samples flagged with a 'B" range between 0.61 and 3.3 µg/L. Selenium concentrations for unfiltered and filtered samples flagged with a "BC" range between 0.89 and 1.6 µg/L. Samples evaluated for the RI indicate that selenium concentrations are not above the action level of 5 µg/L. Selenium concentrations in filtered samples are below the 90th percentile Hanford Site background level of 11 µg/L.

Thallium was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 0.24 µg/L. The action level for thallium is 0.24 µg/L based on the AWQS; however, it defaults to the EQL of 2 µg/L identified in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. Thallium was detected in 3 of 77 (3.9 percent) of unfiltered and 4 of 72 (5.6 percent) of filtered groundwater samples. Some unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for this method ranged between 6.4 and 7 µg/L (no detected concentrations associated with this method). Most of

the samples collected prior to the RI and all of the RI were analyzed by trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples range between 0.05 and 0.1 µg/L, detected concentrations for unfiltered samples ranged between 0.9 and 1.7 µg/L, and ranged between 0.06 and 1.2 µg/L for filtered samples. The results of this evaluation indicate that thallium has historically been detected in groundwater samples at a low frequency of detection (4 percent of unfiltered samples and 6 percent of filtered samples) and thallium concentrations are not above the action level of 2 µg/L. Thallium concentrations in filtered samples are below the 90th percentile Hanford Site background level of 1.7 µg/L.

Uranium was identified as a COPC in the work plan to determine whether it is present in groundwater above the DWS of 30 µg/L. Uranium was detected in 75 of 79 (95 percent) of unfiltered and all 17 of the filtered groundwater samples. Uranium concentrations in unfiltered groundwater range between 0.38 and 11 and between 0.56 and 11 µg/L in filtered samples. All method detection limits and all detected concentrations were less than the DWS of 30 µg/L. The results of this evaluation indicate that uranium has historically been detected in groundwater samples at concentrations less than the action level of 30 µg/L. Uranium concentrations in filtered samples are above the 90th percentile Hanford Site background level of 10 µg/L.

Vanadium was identified as a COPC in the work plan because it was detected above the action level of 80 µg/L. Vanadium was detected in 143 of 313 (46 percent) of unfiltered and 156 of 345 (45 percent) of filtered groundwater samples. Unfiltered and filtered samples collected prior to the RI were analyzed by Method 6010. MDLs for these results range between 4 and 17 µg/L, unfiltered concentrations ranged between 1.8 and 34 µg/L, and filtered concentrations ranged between 2 and 28 µg/L. Some vanadium results reported by Method 6010 were flagged with a "B" qualifier, with a "C" qualifier, or with both a "B" and a "C" qualifier. Vanadium concentrations in unfiltered and filtered samples flagged with a "B" ranged between 2 and 34 µg/L. Vanadium concentrations in unfiltered and filtered samples flagged with a "C" or with a "BC" ranged between 8.5 and 27 µg/L. Some samples collected for the RI used trace methods identified in the 100-K SAP (DOE/RL-2009-41). MDLs for these samples were not reported as all were detected concentrations. Detected concentrations for unfiltered samples ranged between 1.5 and 25 µg/L, and ranged between 1 and 18 µg/L for filtered samples. Most of these sample results were also flagged with a "B" or a "C." The results of this evaluation indicate that vanadium has historically been detected in groundwater samples. Vanadium concentrations are less than the action level of 80 µg/L. Vanadium concentrations in filtered samples are above the 90th percentile Hanford Site background level of 12 µg/L.

Zinc was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 91 µg/L. Zinc was detected in 119 of 313 (38 percent) of unfiltered and 127 of 345 (37 percent) of filtered groundwater samples. Most samples collected prior to the RI and for the RI were analyzed by Method 6010; however, some were analyzed by trace methods. MDLs for samples analyzed by Method 6010 ranged between 2 and 9.6 µg/L, detected concentrations for unfiltered samples ranged between 1.9 and 1,260 µg/L, and ranged between 2 and 477 µg/L for filtered samples. MDLs for samples analyzed by trace methods ranged between 1.6 and 8.3 µg/L, detected concentrations for unfiltered samples ranged between 2 and 216 µg/L, and ranged from 2 to 168 µg/L for filtered samples. Some zinc results reported by all methods were flagged with a "B" qualifier, with a "C" qualifier, or with both a "B" and a "C" qualifier. Zinc concentrations in unfiltered and filtered samples flagged with a "B" ranged between 2 and 29 µg/L. Zinc concentrations in unfiltered and filtered samples flagged with a "C" or with a "BC" ranged between 1.9 and 316 µg/L. Zinc concentrations above 91 µg/L in filtered samples were reported in six wells (199-K-19, 199-K-22, 199-K-27, 199-K-108A, 199-K-152, and 699-73-61). Five samples were collected from 199-K-19 with zinc concentrations in filtered samples ranging from 168 to 257 µg/L (all samples greater than 91 µg/L). Six samples were collected from

199-K-22 with zinc concentrations in filtered samples ranging from 179 to 336 µg/L (all samples greater than 91 µg/L). Five samples were collected from 199-K-27 with zinc concentration in filtered samples ranging from 4 and 108 µg/L (one of five samples greater than 91 µg/L). Twelve samples were collected from 199-K-108A with zinc concentrations in filtered samples ranging from 5.6 to 151 µg/L (2 of 12 samples greater than 91 µg/L). Four samples were collected from 199-K-152 with zinc concentrations in filtered samples ranging from 6 to 477 µg/L (one of four samples greater than 91 µg/L). Five samples were collected from 699-73-61 with zinc concentrations in filtered samples ranging from 224 to 281 µg/L (all samples greater than 91 µg/L). The results of this evaluation indicate that zinc has historically been detected in groundwater samples. Zinc concentrations above the action level are associated with a trend at 199-K-19, 199-K-22, 199-K-108A, and 699-73-61 where concentrations have ranged been 1.1 to 3.7 times greater than the action level of 91 µg/L. The presence of zinc is potentially associated with corrosion of the well casings at 199-K-19, 199-K-22, 199-K-108A, and 699-73-61, which were installed between 1955 and 1994. Zinc concentrations in filtered samples are above the 90th percentile Hanford Site background level of 12 µg/L.

Anions. Chloride was identified as a COPC in the work plan because it was detected above the State AWQC of 230,000 µg/L. Chloride was detected in 100 percent of unfiltered (472 samples) and filtered (two samples) groundwater samples. Chloride concentrations in unfiltered groundwater samples range between 1,090 and 288,000 and chloride concentrations range between 8,310 and 9,450 µg/L in filtered samples. Chloride concentrations above the action level were reported at 199-K-137 with concentrations ranging between 258,000 and 288,000 µg/L. The results of this evaluation indicate that chloride has historically been detected in groundwater. Concentrations of chloride above the action level are infrequent (2 of 474 samples; 0.4 percent). Chloride concentrations above the action level are associated with a trend at 199-K-137; however, this well is associated with the calcium polysulfide treatment test and is not the result of a site release. Chloride concentrations in unfiltered samples are above the 90th percentile Hanford Site background level of 184 µg/L.

Fluoride was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 960 µg/L. Fluoride was detected in 313 of 401 (78 percent) of unfiltered groundwater samples, filtered samples were not analyzed for fluoride. Fluoride concentrations in unfiltered groundwater ranged between 13 and 760 µg/L. All method detection limits were less than the action level of 960 µg/L. Samples evaluated for the RI indicate that fluoride is not present at concentrations above the action level of 960 µg/L. Fluoride concentrations in unfiltered samples are below the 90th percentile Hanford Site background level of 1,047 µg/L.

Nitrite was identified as a COPC in the work plan because it was detected above the action level and some MDLs were greater than the action level of 3,300 µg/L. Nitrite was detected in 29 of 471 (6 percent) of unfiltered samples and was not detected in the filtered samples (two samples). Nitrite concentrations in unfiltered groundwater ranged between 29 and 6,540 µg/L. All MDLs were less than the action level of 3,300 µg/L. Nitrite concentrations above the action level were reported in wells 199-K-133 (4,070 µg/L) and 199-K-134 (4,370 and 6,540 µg/L). Twenty-two additional samples were collected and analyzed for nitrite at 199-K-133 with concentrations that range between 10 and 4,070 µg/L; all but one round were less than the action level. Twenty-two additional samples were collected and analyzed for nitrite at 199-K-134 with concentrations that range between 43 and 4,070 µg/L; all but two rounds were less than the action level. The results of this evaluation indicate that nitrite has historically been detected in groundwater. Concentrations of nitrite above the action level are infrequent (3 of 473 samples; 0.6 percent) with concentrations ranging between 1.3 and 2 times greater than the action level. Nitrite concentrations are not associated with a specific location or with a trend. Nitrite concentrations in unfiltered samples are above the 90th percentile Hanford Site background level of 1,047 µg/L.

Sulfate was identified as a COPC in the work plan because it was detected above the action level of 250,000 µg/L. Sulfate was detected in 100 percent of unfiltered (472 samples) and unfiltered (2 samples) groundwater samples. Concentrations of unfiltered sulfate ranged between 1,530 and 433,000 and ranged between 69,200 and 73,400 µg/L. Sulfate concentrations above the action level were reported in 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136. The results of this evaluation indicate that sulfate has historically been detected in groundwater samples. Sulfate concentrations above the action level are associated with a trend at 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136 where concentrations have ranged been 1.1 to 3.7 times greater than the action level of 91 µg/L. The presence of sulfate in these wells is associated with the calcium polysulfide treatment test conducted at the OU and is not the result of a site-release Sulfate concentrations in unfiltered samples are below the 90thpercentile Hanford Site background level of 47,000 µg/L.

Volatile Organic Compounds. VOCs were identified as COPCs in the work plan when the VOC was not detected but the MDL was not adequate for determining its presence at or below their respective action level or the VOCs had detections and the MDL was not adequate for determining its presence at or below their respective action level. The following discussion addresses both categories of uncertainties.

4.2.6.6 Method Detection Limits above Action Levels

Benzene, 1,1-dichloroethene, 1,1,2-trichloroethane, tetrachloroethene, and vinyl chloride were identified as a COPCs in the work plan because most of the method detection limits were not adequate for determining their presence at or below their action level.

Benzene was not detected in any unfiltered or filtered groundwater sample. MDLs for groundwater samples analyzed prior to the RI were less than or equal to 1 µg/L. MDLs for groundwater samples analyzed for the RI ranged between 0.045 and 1 µg/L. The action level for benzene is 0.8 µg/L based on the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level; however, it defaults to the EQL of 1.5 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All MDLs are less than the EQL listed in the 100-K SAP (DOE/RL-2009-41).

1,1-Dichloroethene was not detected in any unfiltered or filtered groundwater sample. MDLs for groundwater samples analyzed prior to the RI were less than or equal to 1 µg/L. MDLs for groundwater samples analyzed for the RI ranged between 0.05 and 1 µg/L. The action level for 1,1-dichloreothene is 0.073 µg/L based on the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level; however, it defaults to the EQL of 2 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All MDLs are less than the EQL listed in the 100-K SAP (DOE/RL-2009-41).

1,1,2-Trichloroethane was not detected in any unfiltered groundwater sample and was not analyzed in filtered groundwater samples. MDLs for groundwater samples analyzed prior to the RI were less than or equal to 1 µg/L. MDLs for groundwater samples analyzed for the RI ranged between 0.063 and 1 µg/L. The action level for 1,1,2-trichloroethane is 0.59 µg/L based on the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level; however, it defaults to the EQL of 2 µg/L reported in the 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All MDLs are less than the EQL listed in 100-K SAP (DOE/RL-2009-41).

Tetrachloroethene was not detected in any unfiltered groundwater sample and filtered samples were not analyzed. MDLs for groundwater samples analyzed prior to the RI were less than or equal to 1 µg/L. MDLs for groundwater samples analyzed for the RI ranged between 0.088 and 1 µg/L. The action level for tetrachloroethene is 0.081 µg/L based on the "Groundwater Cleanup Standards" (WAC 173-340-720)

groundwater cleanup level; however, it defaults to the EQL of 5 µg/L reported in 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All MDLs are less than the EQL listed in 100-K SAP (DOE/RL-2009-41).

Vinyl chloride was not detected in any unfiltered groundwater sample and filtered samples were not analyzed. MDLs for groundwater samples analyzed prior to the RI were less than or equal to 1 µg/L. MDLs for groundwater samples analyzed for the RI ranged between 0.032 and 1 µg/L. The action level for vinyl chloride is 0.025 µg/L based on the "Groundwater Cleanup Standards (WAC 173-340-720) groundwater cleanup level; however, it defaults to the EQL of 5 µg/L reported in 100-K SAP (DOE/RL-2009-41) when the analytical method cannot achieve the action level. All MDLs are less than the EQL listed in 100-K SAP (DOE/RL-2009-41).

4.2.6.7 Analytes with Detections and Method Detection Limits above Action Levels

Carbon tetrachloride was identified as a COPC in the work plan because it was detected above the action level and most MDLs were greater than the action level. MDLs were not adequate for determining the presence of carbon tetrachloride at or below the action level of 0.23 µg/L. The action level for carbon tetrachloride defaults to the EQL of 1 µg/L reported in 100-K SAP (DOE/RL-2009-41)when the analytical method cannot achieve the action level. Carbon tetrachloride was detected in 2 of 88 unfiltered groundwater samples (2.3 percent) and filtered samples were not analyzed for carbon tetrachloride. Carbon tetrachloride was detected once in 199-K-165 (1.7 µg/L) at a concentration greater than the action level of 1 µg/L. Carbon tetrachloride was detected once in 199-K-168 (3.3 µg/L) at a concentration greater than the action level of 1 µg/L. Carbon tetrachloride was analyzed in two subsequent sampling rounds at both wells and reported at nondetected concentrations. Wells 199-K-165 and 199-K-168 were not part of the monitoring well network of the RI sampling program. All MDLs are less than the EQL listed in 100-K SAP (DOE/RL-2009-41). The results of this evaluation indicate that carbon tetrachloride has historically been detected in groundwater samples at a low frequency (2 of 88 samples; 2.3 percent). Carbon tetrachloride concentrations above the action level are infrequent (2 of 88 samples; 2.3 percent) and are not associated with a specific location or a trend.

Chloroform was identified as a COPC in the work plan because it was detected above the action level and most MDLs were greater than the action level. MDLs were not adequate for determining the presence of chloroform at or below the action level of 1.4 µg/L. Chloroform was detected in 49 of 86 (57 percent) unfiltered groundwater samples and chloroform was not analyzed in filtered samples. Chloroform concentrations above 1.4 µg/L were reported in five wells (199-K-18, 199-K-32A, 199-K-151, 199-N-71, and 199-N-72). Three samples were collected from 199-K-18 with chloroform concentrations ranging from 2 to 2.1 µg/L (all samples greater than 1.4 µg/L). Three samples were collected from 199-K-32A with chloroform concentrations ranging from 2.1 to 2.3 µg/L (all samples greater than 1.4 µg/L). Four samples were collected from 199-K-151 with chloroform concentrations ranging from 5.6 to 7.1 µg/L (all samples greater than 1.4 µg/L). Two samples were collected from 199-N-71 with chloroform concentrations ranging from 1.2 to 1.5 µg/L (one of two samples greater than 1.4 µg/L). Three samples were collected from 199-N-72 with chloroform concentrations ranging from 3.6 to 4.7 µg/L (all samples greater than 1.4 µg/L). The results of this evaluation indicate that chloroform has historically been detected in groundwater samples (57 percent). Chloform concentrations above the action level are associated with a trend at 199-K-18, 199-K-32A, 199-K-151, and 199-N-72 where concentrations have ranged been 1.1 to 5.1 times greater than the action level of 1.4 µg/L.

4.2.6.8 The 100-K SAP Conclusions from Analysis

Uncertainties identified for the COPCs in the work plan were generally associated with limitations in the analytical methods selected for analysis. Action levels for many of the metals and VOCs require methods

that can measure the analyte at low levels and require the use of analytical methods that can detect analytes at trace levels. The analytical data set evaluated for this evaluation represented five years of data from all of the monitoring and compliance wells that are currently in use. The analysis provided above identified when uncertainties were associated with data quality issues or limitations associated with the analytical method used. The following summarizes the outcome of the analysis and if uncertainties continue to persist for the analytes of interest.

Use of Method 6010 resulted in the introduction of uncertainties for nine metals because it cannot measure these analytes at low levels. Analytical results from Method 6010 are not adequate for determining the presence at or near the action level for the following metals:

Antimony, Beryllium, Cadmium, Cobalt, Copper, Lead, Selenium, Thallium, and Vanadium. The following summarizes the conclusions that can be made from the evaluation presented above and identifies uncertainties associated with the results of the evaluation:

- Barium, mercury, selenium, thallium, uranium, vanadium, chloride, and fluoride are present in groundwater but detected concentrations and MDLs that are less than their respective action level.
- Cadmium, selenium, thallium, and fluoride concentrations are considered naturally occurring because filtered sample results are below the 90thpercentile Hanford Site background concentration.
- Antimony, beryllium, and cadmium are detected historically in groundwater at a low frequency (less than 2 percent). Historic concentrations of antimony, beryllium, and cadmium are above the action level are at a low frequency (less than 2 percent). These concentrations are up to 20 times greater than the action level and are flagged with a combination of "B" and "C" qualifiers; associated MDLs are greater than the action level. Historic concentrations of antimony, beryllium, and cadmium are not associated with a specific location or a trend. Concentrations and MDLs for antimony, beryllium, and cadmium in samples collected for the RI are below the action level.
- Cobalt, copper, lead, and nitrite are detected historically in groundwater at a frequency of less than 20 percent. Historic concentrations of cobalt, copper, lead, and nitrite are above the action level at a low frequency (less than 6 percent). These concentrations are up to 8 times greater the action level and are flagged with a combination of "B" and "C" qualifiers; associated MDLs are greater than the action level. Historic concentrations of cobalt, copper, and nitrite are not associated with a specific location or a trend. Except for two low-level concentrations of lead, concentrations and MDLs for cobalt, copper, lead, and nitrite in samples collected for the RI are below the action level.
- Arsenic is present in groundwater at concentrations above the action level. Arsenic concentrations in filtered samples are within the range of background concentrations except for 2 of 71 sample results. Arsenic concentrations are not associated with a specific location or a trend, and the highest concentration of 14 µg/L is flagged with a "C" qualifier; indicating the potential for laboratory contamination.
- Beryllium in filtered samples are within the range of background concentrations except for 1 of 3 results. Beryllium concentrations are not associated with a specific location or a trend, and the single concentration of 6.8 µg/L is flagged with a "B" qualifier, indicating that the sample concentration is outside the calibration range of the instrument.
- Total chromium concentrations in groundwater are greater than the AWQS. It is assumed that dissolved concentrations of total chromium are present in the form of Cr(VI) and total chromium is not presented separately from Cr(VI) in the nature and extent evaluation.

- Iron has historically been detected in groundwater. Iron concentrations above the AWQC of 1,000 µg/L are at a low frequency in unfiltered samples (26 of 399 samples; 6.5 percent and filtered samples (2 of 347 samples; 0.6 percent) at concentrations up to 7 times greater than the AWQC. With the exception of the wells associated with the calcium polysulfide treatment test (discussed below), iron concentrations in filtered samples are below the action level.

- Nickel has historically been detected in groundwater. Nickel concentrations above the AWQC of 52 µg/L are at a low frequency in unfiltered samples (13 of 313; 4.1 percent) and filtered samples (10 of 345 samples; 2.9 percent). Nickel concentrations are associated with a trend at 199-K-36 and 199-K-110A where concentrations have ranged between 1.2 to 1.9 times greater than the action level of 52 µg/L. The presence of nickel in 199-K-36 and 199-K-110A is potentially associated with corrosion of the well casing, these wells were installed in 1992 and 1994, respectively. With the exception of these two wells, nickel concentrations in filtered samples are less than the AWQC.

- Zinc has historically been detected in groundwater samples. Zinc concentrations above the AWQC of 91 µg/L are associated with a trend at 199-K-19, 199-K-22, 199-K-108A, and 699-73-61 where concentrations have ranged been 1.1 to 3.7 times greater than the AWQC of 91 µg/L. The presence of zinc is potentially associated with corrosion of the well casing at 199-K-19, 199-K-22, 199-K-108A, and 699-73-61, which were installed between 1955 and 1994. With the exception of these four wells, zinc concentrations in filtered samples are less than the AWQC.

- Iron, manganese, and sulfate concentrations above their action levels were reported in 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136. The presence of iron, manganese, and sulfate in these wells is associated with the calcium polysulfide treatment test conducted at the OU and is not the result of a site-release. With the exception of the above wells, iron, manganese, and sulfate concentrations in filtered samples are less than their respective action levels.

- Benzene, 1,1-dichloroethene 1,1,2-trichloroethane, tetrachloroethene, and vinyl chloride were not detected in any unfiltered or filtered groundwater sample. All MDLs were less than the EQL listed in 100-K SAP (DOE/RL-2009-41).

- Carbon tetrachloride has historically been detected in groundwater samples at a low frequency (2 of 88 samples; 2.3 percent). Carbon tetrachloride concentrations above the action level are infrequent (2 of 88 samples; 2.3 percent) and are not associated with a specific location or a trend.

- Chloroform has historically been detected in groundwater samples (57 percent). Chloform concentrations above the action level are associated with a trend at 199-K-18, 199-K-32A, 199-K-151, and 199-N-72 where concentrations have ranged been 1.1 to 5.1 times greater than the action level of 1.4 µg/L.

Table 4-24. Groundwater Summary Statistics for 100-K—Unconfined Aquifer

Analyte Name	Filtered	Units	Number of Results	Number of Detects	Frequency of Detects (%)	Min. Non-Detect	Max. Non-Detect	Min Detect	Max Detect	Mean Detect	Median Detect	Background 90th Percentile	No. of Detects >Background	Action Level	No. of Detects > Action Level	Action Level Basis
Anion																
Chloride	N	µg/L	472	472	100	0	0	1,090	288,000	18,570	13,050	15,630	184	230,000	2	Clean Water Act -- Freshwater CCC
Chloride	Y	µg/L	2	2	100	0	0	8,310	9,450	8,880	8,880	15,630	0	230,000	0	Clean Water Act -- Freshwater CCC
Fluoride	N	µg/L	401	313	78	12	300	13	760	195	187	1,047	0	960	0	WAC 173-340-720(4)(b)(iii)(A) and (B)
Nitrate	N	µg/L	488	402	82	22	2,570	53	2.25E+06	36,940	22,100	26,871	162	45,000	76	40 CFR 141 - Federal MCL
Nitrate	Y	µg/L	3	2	67	398	398	6,770	18,600	12,690	12,685	26,871	0	45,000	0	40 CFR 141 - Federal MCL
Nitrite	N	µg/L	471	29	6.2	9.9	2,500	29	6,540	1,362	916	94	26	3,300	3	40 CFR 141 - Federal MCL
Nitrite	Y	µg/L	2	0	0	161	161	0	0	0	0	94	0	3,300	0	40 CFR 141 - Federal MCL
Sulfate	N	µg/L	472	472	100	0	0	1,530	433,000	62,150	36,400	47,014	174	250,000	15	40 CFR 141 - Federal MCL
Sulfate	Y	µg/L	2	2	100	0	0	69,200	73,400	71,300	71,300	47,014	2	250,000	0	40 CFR 141 - Federal MCL
Metals																
Antimony	N	µg/L	316	10	3.2	0.60	72	0.54	58	29	37	55	1	5.6	8	Clean Water Act -- Human Health Water + Organism
Antimony	Y	µg/L	348	7	2.0	0.30	72	0.69	68	28	33	55	1	5.6	6	Clean Water Act -- Human Health Water + Organism
Arsenic	N	µg/L	158	149	94	0.40	6.1	0.51	33	5.7	4.0	7.9	34	0.018	149	Clean Water Act -- Human Health Water + Organism
Arsenic	Y	µg/L	71	66	93	0.80	0.80	0.81	14	3.5	3.2	7.9	4	0.018	66	Clean Water Act -- Human Health Water + Organism
Barium	N	µg/L	316	316	100	0	0	9.9	233	41	33	105	14	1,000	0	Clean Water Act -- Human Health Water + Organism
Barium	Y	µg/L	348	348	100	0	0	9.4	213	40	33	105	12	1,000	0	Clean Water Act -- Human Health Water + Organism
Beryllium	N	µg/L	316	4	1.3	0.10	4.0	0.23	0.88	0.47	0.39	2.3	0	4.0	0	40 CFR 141 - Federal MCL
Beryllium	Y	µg/L	348	3	0.86	0.050	8.0	0.11	6.8	2.4	0.19	2.3	1	4.0	1	40 CFR 141 - Federal MCL
Cadmium	N	µg/L	316	6	1.9	0.055	4.0	0.072	5.9	2.6	2.3	0.92	3	0.25	4	Clean Water Act -- Freshwater CCC
Cadmium	Y	µg/L	348	6	1.7	0.055	8.0	0.057	15	4.1	2.2	0.92	3	0.25	4	Clean Water Act -- Freshwater CCC
Chromium	N	µg/L	408	330	81	0.50	14	0.52	12,100	156	31	2.4	303	65	94	Clean Water Act -- Freshwater CCC
Chromium	Y	µg/L	351	259	74	0.70	14	1.0	3,350	115	30	2.4	251	65	69	Clean Water Act -- Freshwater CCC

Table 4-24. Groundwater Summary Statistics for 100-K—Unconfined Aquifer

Analyte Name	Filtered	Units	Number of Results	Number of Detects	Frequency of Detects (%)	Min. Non-Detect	Max. Non-Detect	Min Detect	Max Detect	Mean Detect	Median Detect	Background 90th Percentile	No. of Detects >Background	Action Level	No. of Detects > Action Level	Action Level Basis
Cobalt	N	µg/L	316	40	13	0.10	7.0	0.10	20	4.4	0.57	0.92	18	2.6	17	WAC 173-340-730(3)(b)(iii)(A) and (B)
Cobalt	Y	µg/L	348	60	17	0.10	8.0	0.087	21	4.1	0.40	0.92	24	2.6	23	WAC 173-340-730(3)(b)(iii)(A) and (B)
Copper	N	µg/L	316	59	19	0.20	7.0	0.23	33	5.8	4.8	0.81	46	9.0	12	Clean Water Act -- Freshwater CCC
Copper	Y	µg/L	348	47	14	0.10	8.0	0.20	14	5.6	5.3	0.81	36	9.0	11	Clean Water Act -- Freshwater CCC
Cr(VI)	N	µg/L	1019	901	88	1.8	40	1.01E-04	3,540	178	76	Not Available	Not Available	10	784	40 CFR 131 -- Freshwater CCC
Cr(VI)	Y	µg/L	376	311	83	2.0	40	2.0	2,288	112	38	Not Available	Not Available	10	246	40 CFR 131 -- Freshwater CCC
Iron	N	µg/L	399	308	77	9.0	330	10.7	7,890	314	93	570	41	300	72	40 CFR 141 - Federal MCL
Iron	Y	µg/L	347	148	43	9.0	44	9.6	1,760	83	32	570	4	300	7	40 CFR 141 - Federal MCL
Lead	N	µg/L	148	43	29	0.050	3.1	0.059	16	1.0	0.36	0.92	13	2.1	3	WAC 173-201A
Lead	Y	µg/L	74	7	9.5	0.050	0.20	0.25	17	3.2	0.67	0.92	2	2.1	2	WAC 173-201A
Manganese	N	µg/L	401	198	49	0.96	6.0	0.32	6,480	421	53	39	108	50	99	40 CFR 141 - Federal MCL
Manganese	Y	µg/L	348	108	31	0.24	8.0	0.23	6,330	533	13	39	43	50	42	40 CFR 141 - Federal MCL
Mercury	N	µg/L	76	2	2.6	0.016	0.10	0.042	0.080	0.061	0.061	0.0030	2	0.012	2	40 CFR 131 -- Freshwater CCC
Mercury	Y	µg/L	72	3	4.2	0.045	0.10	0.075	0.11	0.098	0.11	0.0030	3	0.012	3	40 CFR 131 -- Freshwater CCC
Nickel	N	µg/L	313	78	25	0.40	13	0.46	118	27	13	1.6	77	52	13	Clean Water Act -- Freshwater CCC
Nickel	Y	µg/L	345	66	19	0.20	13	0.42	106	26	17	1.6	65	52	10	Clean Water Act -- Freshwater CCC
Selenium	N	µg/L	77	56	73	0.60	3.6	0.72	4.8	1.5	1.4	11	0	5.0	0	Clean Water Act -- Freshwater CCC
Selenium	Y	µg/L	72	58	81	0.60	1.3	0.61	3.3	1.4	1.4	11	0	5.0	0	Clean Water Act -- Freshwater CCC
Thallium	N	µg/L	77	3	3.9	0.10	7.0	0.91	1.7	1.4	1.5	1.7	1	0.24	3	Clean Water Act -- Human Health Water + Organism
Thallium	Y	µg/L	72	4	5.6	0.050	0.10	0.055	1.2	0.62	0.62	1.7	0	0.24	2	Clean Water Act -- Human Health Water + Organism
Uranium	N	µg/L	79	75	95	21	24	0.38	23	3.7	2.8	9.9	2	30	0	40 CFR 141 - Federal MCL
Uranium	Y	µg/L	17	17	100	0	0	0.56	11	3.5	2.3	9.9	1	30	0	40 CFR 141 - Federal MCL
Vanadium	N	µg/L	313	143	46	4.1	17	1.5	34	16	16	12	112	80	0	WAC 173-340-720(4)(b)(iii)(A)

Table 4-24. Groundwater Summary Statistics for 100-K—Unconfined Aquifer

Analyte Name	Filtered	Units	Number of Results	Number of Detects	Frequency of Detects (%)	Min. Non-Detect	Max. Non-Detect	Min Detect	Max Detect	Mean Detect	Median Detect	Background 90th Percentile	No. of Detects >Background	Action Level	No. of Detects > Action Level	Action Level Basis
																and (B)
Vanadium	Y	µg/L	345	156	45	4.1	17	1.0	28	15	16	12	114	80	0	WAC 173-340-720(4)(b)(iii)(A) and (B)
Zinc	N	µg/L	313	119	38	1.6	9.0	1.9	1,270	70	14	22	48	91	21	WAC 173-201A
Zinc	Y	µg/L	345	127	37	1.6	9.6	1.9	477	51	12	22	49	91	20	WAC 173-201A
Radionuclides																
Carbon-14	N	pCi/L	227	174	77	-5.71E+00	7.8	8.6	13,500	1,365	251	Not Available	Not Available	2,000	37	40 CFR 141 - Federal MCL
Strontium-90	N	pCi/L	247	66	27	-1.40E+01	1.2	0.15	1,610	123	7.4	0.0010	66	8.0	32	40 CFR 141 - Federal MCL
Strontium-90	Y	pCi/L	1	0	0	-6.80E-01	-6.80E-01	0	0	0	0	0.0010	0	8.0	0	40 CFR 141 - Federal MCL
Tritium	N	pCi/L	465	393	85	-2.40E+02	306	59	669,000	38,220	3,900	119	392	20,000	68	40 CFR 141 - Federal MCL
Tritium	Y	pCi/L	1	1	100	0	0	960	960	960	960	119	1	20,000	0	40 CFR 141 - Federal MCL
Organics																
1,1,2-Trichloroethane	N	µg/L	86	0	0	0.063	1.0	0	0	0	0	Not Available	Not Available	0.59	0	Clean Water Act -- Human Health Water + Organism
1,1-Dichloroethene	N	µg/L	103	0	0	0.045	1.0	0	0	0	0	Not Available	Not Available	0.057	0	40 CFR 131 -- Human Health Water + Organism
1,1-Dichloroethene	Y	µg/L	1	0	0	1.0	1.0	0	0	0	0	Not Available	Not Available	0.057	0	40 CFR 131 -- Human Health Water + Organism
Benzene	N	µg/L	103	0	0	0.032	1.0	0	0	0	0	Not Available	Not Available	0.80	0	WAC 173-340-720(4)(b)(iii)(A) and (B)
Benzene	Y	µg/L	1	0	0	1.0	1.0	0	0	0	0	Not Available	Not Available	0.80	0	WAC 173-340-720(4)(b)(iii)(A) and (B)
Carbon tetrachloride	N	µg/L	88	2	2.3	0.039	1.0	1.7	3.3	2.5	2.5	Not Available	Not Available	0.23	2	Clean Water Act -- Human Health Water + Organism
Chloroform	N	µg/L	86	49	57	0.10	1.0	0.11	7.1	1.5	0.76	Not Available	Not Available	1.4	14	WAC 173-340-720(4)(b)(iii)(A) and (B)
Tetrachloroethene	N	µg/L	86	0	0	0.087	1.0	0	0	0	0	Not Available	Not Available	0.081	0	WAC 173-340-720(4)(b)(iii)(A) and (B)
Trichloroethene	N	µg/L	103	59	57	0.11	1.0	0.22	7.4	3.2	3.4	Not Available	Not Available	0.49	55	WAC 173-340-720(4)(b)(iii)(A) and (B)
Trichloroethene	Y	µg/L	1	1	100	0	0	2.4	2.4	2.4	2.4	Not Available	Not Available	0.49	1	WAC 173-340-720(4)(b)(iii)(A) and (B)
Vinyl chloride	N	µg/L	86	0	0	0.032	1.0	0	0	0	0	Not Available	Not Available	0.025	0	Clean Water Act -- Human Health Water + Organism

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Table 4-25. Analytical Results Collected from the New Aquifer Tube Cluster (C7641, C7642, and C7643)

Aquifer Tube Name	Date	Specific Conductivity (µS/cm)	Carbon-14 (pCi/L)	Chloroform (µg/L)	Chromium Total (µg/L)	Cr(VI) (µg/L)	Nitrate (µg/L)	Trichloroethene (TCE) (µg/L)	Tritium (pCi/L)
Constituent Action Level			**2,000**	**5.7**	**65**	**10**	**45,000**	**0.49**	**20,000**
C7641	8/15/10	167	3.08	0.1	3.1	3.7	2,260	0.25	-20.4
C7641	8/15/10	167	24.1	1	3.3	13	2,240	1	-100
C7641	8/15/10	167	na	na	3.1	2	na	na	na
C7641	8/15/10	167	na	na	3.3	2	na	na	na
C7641	8/15/10	167	na	na	1.78	na	na	na	na
C7641	8/15/10	167	na	na	14	na	na	na	na
C7641	8/15/10	167	na	na	2.95	na	na	na	na
C7641	8/15/10	167	na	na	14	na	na	na	na
C7641	8/29/10	186	13.6	na	3.08	2	1,090	1	77
C7641	11/22/10	132	-1.33	1	1	2	174	1	74
C7641	11/22/10	132	na	na	14	2	na	na	na
C7641	11/22/10	132	na	na	2.99	na	na	na	na
C7641	11/22/10	132	na	na	14	na	na	na	na
C7641	12/19/10	132	na	1	1	2	145	1	210
C7641	12/19/10	132	na	na	14	2	na	na	na
C7641	12/19/10	132	na	na	1	na	na	na	na
C7641	12/19/10	132	na	na	14	na	na	na	na
C7642	8/15/10	342	53.4	1	1.06	2	6,600	1	70
C7642	8/15/10	342	na	na	14	2	na	na	na
C7642	8/15/10	342	na	na	2.78	na	na	na	na

Table 4-25. Analytical Results Collected from the New Aquifer Tube Cluster (C7641, C7642, and C7643)

Aquifer Tube Name	Date	Specific Conductivity (µS/cm)	Carbon-14 (pCi/L)	Chloroform (µg/L)	Chromium Total (µg/L)	Cr(VI) (µg/L)	Nitrate (µg/L)	Trichloroethene (TCE) (µg/L)	Tritium (pCi/L)
C7642	8/15/10	342	na	na	14	na	na	na	na
C7642	8/29/10	313	92.2	na	5.1	2	6,910	1	49
C7642	11/22/10	236	23.3	1	1.42	2	6,150	1	83
C7642	11/22/10	236	27.5	1	14	2	84.1	1	180
C7642	11/22/10	236	na	na	1.03	2	na	na	na
C7642	11/22/10	236	na	na	14	2	na	na	na
C7642	11/22/10	236	na	na	1	na	na	na	na
C7642	11/22/10	236	na	na	14	na	na	na	na
C7642	11/22/10	236	na	na	1	na	na	na	na
C7642	11/22/10	236	na	na	14	na	na	na	na
C7642	12/19/10	234	na	1	1	2	5,440	1	150
C7642	12/19/10	234	na	na	14	2	na	na	na
C7642	12/19/10	234	na	na	1	na	na	na	na
C7642	12/19/10	234	na	na	14	na	na	na	na
C7643	8/15/10	249	35	1	1	2	3,170	1	60
C7643	8/15/10	249	na	na	14	2	na	na	na
C7643	8/15/10	249	na	na	1.74	na	na	na	na
C7643	8/15/10	249	na	na	14	na	na	na	na
C7643	8/29/10	217	27.5	na	3.17	2	2,300	1	120
C7643	11/22/10	155	9.07	1	1	2	540	1	38
C7643	11/22/10	155	na	na	14	2	na	na	na

Table 4-25. Analytical Results Collected from the New Aquifer Tube Cluster (C7641, C7642, and C7643)

Aquifer Tube Name	Date	Specific Conductivity (µS/cm)	Carbon-14 (pCi/L)	Chloroform (µg/L)	Chromium Total (µg/L)	Cr(VI) (µg/L)	Nitrate (µg/L)	Trichloroethene (TCE) (µg/L)	Tritium (pCi/L)
C7643	11/22/10	155	na	na	1.57	na	na	na	na
C7643	11/22/10	155	na	na	14	na	na	na	na
C7643	12/19/10	167	na	1	0.506	2	1,480	1	110
C7643	12/19/10	167	na	1	14	2	1,410	1	150
C7643	12/19/10	167	na	na	1	2	na	na	na
C7643	12/19/10	167	na	na	14	2	na	na	na
C7643	12/19/10	167	na	na	1	na	na	na	na
C7643	12/19/10	167	na	na	14	na	na	na	na
C7643	12/19/10	167	na	na	1	na	na	na	na
C7643	12/19/10	167	na	na	14	na	na	na	na

na = not analyzed

4.2.6.9 Distribution of Contaminants

Five groundwater contaminants are identified as COPCs in Chapter 6 of this RI/FS report through comparison of the spatial and temporal investigation data to groundwater and surface water ALs (100-K SAP [DOE/RL-2009-41]). The five COPCs are total chromium, Cr(VI), nitrate, tritium, carbon-14, and Sr-90. Groundwater plume maps, concentration trends, bar charts, and cross-sectional diagrams have been prepared for the COPCs and are discussed in the following sections. The depth discrete data from the RI wells are also presented and discussed. Unless otherwise noted, the groundwater plume maps represent constituent concentrations in the upper part of the unconfined aquifer, and are based on recent sampling events (fall 2009 and spring 2010). The wells used are existing monitoring or extraction wells, and do not include data from the 15 wells drilled for this RI report. This data set is presented in Sections 3.4.3.4 through 3.4.3.18. These two data sets provide a depiction of contaminant concentrations over an entire year. Contaminant concentration isopleth maps were constructed for Cr(VI), Sr-90, tritium, nitrate, and carbon-14. Figures were also prepared for TCE and chloroform, but concentration isopleths were not constructed due to the sparse nature of detections. Contaminant trends at selected wells associated with the plume maps are displayed to depict changes in response to treatment.

Bar charts were constructed to compare fall 2009 and spring 2010 concentrations in wells (monitoring, injection, and extraction wells) and aquifer tubes. Wells and aquifer tubes were included in the bar charts if they had data for both sampling rounds and if at least one result was a detectable concentration. If the other result was nondetect, it is shown having a concentration equal to the detection limit. Applicable standards are presented on the bar charts for comparison; however, it is important to bear in mind that aquifer tubes are not compliance points.

Cross sectional plume interpretations are based on concentrations from the recent sampling events (fall 2009 and spring 2010). As with the plume maps, depth discrete data from the RI wells were not used in these figures. However, depth discrete data from the RI wells are discussed with each COPC. The process for selecting the sample data set and generating plume maps, bar charts, and trend graphs is explained in more detail in Appendix E.

In addition to the COPCs, TPHs and Tc-99 are discussed in detail because these constituents are discussed in the annual groundwater monitoring reports (such as *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2* [DOE/RL-2010-11]).

Table 4-26 summarizes the approximate areal extent of plume areas exceeding standards.

Table 4-26. Approximate Areal Extent of 100-K Plumes

Contaminant	Standard	100-K West (km^2 [mi^2])	100-K East (km^2 [mi^2])	100-K North (km^2 [mi^2])	Total (km^2 [mi^2])
Cr(VI)	10[a] µg/L	0.10 (0.04)	0.35 (0.14)	1.9 (0.74)	2.4 (0.9)
Cr(VI)	48[b] µg/L	0.04 (0.02)	0.07 (0.03)	0.34 (0.13)	0.45 (0.17)
Nitrate	45[c] mg/L	0.09 (0.03)	0.04 (0.02)	_	0.13 (0.05)
Tritium	20,000[d] pCi/L	_	0.08 (0.03)	_	0.08 (0.03)

Table 4-26. Approximate Areal Extent of 100-K Plumes

Contaminant	Standard	100-K West (km^2 [mi^2])	100-K East (km^2 [mi^2])	100-K North (km^2 [mi^2])	Total (km^2 [mi^2])
Carbon-14	2,000[e] pCi/L	_	0.06 (0.02)	_	0.06 (0.02)
Sr-90	8[d] pCi/L	0.01 (0.01)	0.01 (0.01)	0.02 (0.01)	0.03 (0.01)

a. WAC 173-201A, "Water Quality Standards for Surface Waters of the State of Washington."

b. WAC 173-340-720(4)(b)(iii), "Model Toxics Control Act—Cleanup," "Groundwater Cleanup Standards."

c. 40 CFR 141.62, "National Primary Drinking Water Regulations," "Maximum Contaminant Levels for Inorganic Contaminants" (modified, 10,000 µg/L × 1/0.226).

d. 40 CFR 141.66, "National Primary Drinking Water Regulations," "Maximum Contaminant Levels for Radionuclides."

Cr(VI). Cr(VI) is present in groundwater in 100-K and into the southwestern portion of the 100-NR-2 Groundwater OU, to the N Reactor fence line. The total footprint of the plume areas exceeding the 10 µg/L AWQS, the AL for Cr(VI), is approximately 2.4 km^2 (0.9 mi^2), and the total footprint of the plume areas exceeding the 48 µg/L MTCA DWS is approximately 0.45 km^2 (0.2 mi^2). The highest concentrations occur around the 183.1 KW Head House, and at the southwestern and northeastern ends of the 116-K-2 Trench. Figures 4-26 through 4-28 illustrate the Cr(VI) plumes in the K-West (KW), K-East (KR-4 and KX), and K-North (KX) areas for the fall 2009 sampling event along with Cr(VI) concentration trends in selected wells.

Figure 4-29 shows bar charts of Cr(VI) fall 2009 and spring 2010 concentrations for 100-K wells, and Figure 4-30 shows bar charts of Cr(VI) concentrations for 100-K aquifer tubes. Forty-seven groundwater wells were sampled for Cr(VI) in fall 2009 and spring 2010. Concentrations greater than the AL were measured in 38 wells (81 percent) in fall 2009 and 33 wells (70 percent) in spring 2010. Concentrations greater than the 48 µg/L MTCA standard were measured in 21 wells (45 percent) of the fall 2009 well samples and 16 wells (34 percent) in spring 2010.

Only two aquifer tubes (C6241 and C6250) were sampled for Cr(VI) for fall 2009 and spring 2010. One of the aquifer tubes (C6250) detected concentrations greater than the 10 µg/L AWQS for both the fall and spring sampling events (Figure 4-30). Neither of the aquifer tubes exceeded the 48 µg/L MTCA standard. Fall 2009 concentrations were higher than spring 2010 concentrations in 37 (79 percent) of the monitoring wells.

Analytical results for one new aquifer tube cluster are presented in Table 4-24. Cr(VI) was detected above the AL in one of the aquifer tubes, C7641, at a concentration of 13.1 µg/L. The remaining tubes (C7642 and C7643) were either nondetected or below the AL. Historical results from aquifer tubes located immediately to the northeast—17-D and cluster C6239, C6240, and C6241—show detections above the AL measured in December 2007 (24.3 µg/L) and September 2008 (11.4, 16.6, and 32.1 µg/L), respectively. However, Cr(VI) was not detected when these tubes were sampled in 2009 and 2010. Southwest of the new RI aquifer tube cluster, tubes AT-K-1-D and AT-K-1-M detections above the AL, at concentrations of 21.8 and 41.9 µg/L, respectively, were measured in December 2007. The concentration of Cr(VI) at AT-K-1-D was below the AL in 2009 and 2010.

The Cr(VI) concentrations vary seasonally for wells closer to the river, as shown by the bar charts. The variation is greatest adjacent to the river, with lower seasonal variation observed in inland areas. For

example, Wells 199-K-20, K-114A, K-115A, K-129, K-144, K-146, and K-149 in the 100-K East and 100-K North plumes show cyclic seasonal variations with elevated concentrations in the fall low-river stage and low concentrations in the spring/early summer high-river stage. Wells located in K-West are not as close to the river and variations are not as apparent. As explained in Section 3.6.1, when river stage is high (in the spring), head in the river is greater than groundwater head and, as a result, the river becomes a "losing" stream. When river stage is low, the river becomes a "gaining" stream. Thus, in the spring, a hydrologic barrier in groundwater is formed near the river with relatively clean river water moving inland. As a result, measured Cr(VI) concentrations are lower than in the fall when the hydrologic barrier is not active. This seasonal variation holds true for other contaminants as well.

Maximum detected concentrations of Cr(VI) for RI monitoring wells are shown in Figure 4-31. Table 4-29 presents detected concentrations of Cr(VI) above the AL measured in groundwater samples collected from all RI borings and monitoring wells. For RI wells completed in the unconfined aquifer, detected concentrations above the AL ranged from 10.3 µg/L in 199-K-186 at a depth of 35 m (115 ft bgs, to 4,890 µg/L in 199-K-195 at a depth of 30 m (99 ft) bgs, located immediately adjacent the KW Head House. Note that 199-K-195 was started in a 4.6 m (15 ft) deep excavation.

100-K West Plume. The 100-K West plume has the highest concentrations of Cr(VI). The frequency of detections above the AL in monitoring wells at the K-West plume was 84 percent over a five-year period, with median and maximum detection values of 107 and 3,540 µg/L, respectively (Table 4-24). Consistent with generally higher concentrations of Cr(VI), the 100-K West plume contains the highest frequency of detections above the groundwater AL in any of the three plume areas. The K-West plume covers less surface area than the 100-K East and 100-K North plumes. The highest spring 2010 concentration of Cr(VI) in a monitoring well for the 100-K West plume is 920 µg/L at Well 199-K-173 (Figure 4-32).

Initial Cr(VI) concentrations in the K-West plume have increased as drilling activities moved inland from the initial four extraction wells (199-K-132, 199-K-138, 199-K-139, and 199-K-140). At the start of treatment, 199-K-107A ranged between 394 and 614 µg/L. Wells drilled farther upgradient encountered Cr(VI) in concentrations as high as 3,540 µg/L at 199-K-137 and 3,020 µg/L at 199-K-165. Extraction at these wells began in April 2009 and concentrations dropped quickly from 1,000 µg/L in April 2009 to 104 µg/L in August 2010 at 199-K-137, and from 480 µg/L in April 2009 to 247 µg/L in January 2011 at 199-K-165.

Two other monitoring wells have spiked in 2010 to concentrations above 700 µg/L. Well 199-K-35, a former injection well near the 183.1-KW Head House, was shut down in preparation for the demolition of that building. Weekly sampling began when the first post-injection sample was 188 µg/L. Cr(VI) concentrations increased to 771 µg/L, declined to 252 µg/L a month later, and ranged between 409 and 263 µg/L when the well was decommissioned. Well 199-K-173 increased from 104 µg/L in October 2009 to 974 µg/L in March 2010. Weekly sampling began in May 2010 and concentrations dropped to 216 µg/L in June followed by a rebound to 968 µg/L in August 2010. The mechanism driving spikes in Cr(VI) concentrations at these two wells is not known. Dust suppression water and drainage from the deep vadose zone around the 199-K-35 injection well are potential mechanisms.

Within the K-West plume area, two RI wells were installed within the unconfined aquifer (199-K-183 and 199-K-185). Cr(VI) concentrations in those two wells did not exceed the AL or MTCA standards. These additional data suggest that the west-southwest portion of the plume is bounded below the AL between 199-K-140, 199-K-183, and 199-K-31.

Three RUM wells drilled 15.2 m (50 ft) into the mud unit (199-K-184, 199-K-188, and 199-K-195 [Figure 4-21]) did not encounter water-bearing zones and were screened in the unconfined aquifer. Cr(VI)

was detected above the AL in groundwater samples collected from borings and monitoring wells, as shown in Table 4-27.

Cr(VI) concentrations detected above the AL in grab groundwater samples at Monitoring Well 199-K-184 ranged from 116 µg/L at a depth of 36 m (119 ft) bgs to 13.5 µg/L at a depth of 48 m (159 ft) bgs. At 199-K-195, concentrations ranged from a maximum of 4,890 µg/L at a depth of 30 m (99 ft) bgs to 10.8 µg/L at a depth of 47 m (159 ft) bgs (Figure 4-41). Cr(VI) was detected at a concentration of 753 µg/L at one of the deepest sample intervals (50 m [165 ft]) at Well 199-K-195. Well 199-K-195 was temporarily installed immediately upgradient of the KW Head House, and approximately 100 m (330 ft) from 199-K-35. Before Well 199-K-195 was decommissioned, groundwater samples indicated a Cr(VI) concentration of 3,310 µg/L. Well 199-K-184 was installed adjacent to 199-K-137, approximately 20 m (65.6 ft) southeast of the 105-KW Reactor building. Well 199-K-184 is also located near the central axis of the 100-K West plume.

Summary. The 100-K West plume contains the highest frequency of detections above the groundwater AL in any of the three plume areas. Concentrations of Cr(VI) upgradient of the KW Reactor indicate that the plume source is from past upgradient leaks or spills of concentrated sodium dichromate solution near the 183-KW Head House. The K-West plume footprint has been reduced by the pump-and-treat system. Figure 4-33 shows changes in the K-West plume configuration between 1997 and 2010.

100-K East and 100-K-North Plumes. Groundwater extracted from the active pumping wells is currently being treated at the KR-4 and KX treatment systems. Figures 4-34 and 4-35 show 100-K Cr(VI) concentrations for K-East and K-North plumes for the fall 2009 and spring 2010 sampling events. The frequency of detections above the AL in the K-East plume was 61 percent over a five-year period, with median and maximum detections of 18.9 and 421 µg/L, respectively (Table 4-27). Cr(VI) was detected above the AL in the K-North plume 66 percent of the time over a five-year period, with median and maximum detections of 46.5 and 137 µg/L, respectively (Table 4-27).

The K-East plume combines two Cr(VI) plumes from different sources. A residual plume associated with the 105-KE Reactor water treatment facilities appears to have split. One part of it is being treated at KX Extraction Wells 199-K-141 and 199-K-178. The other part of this plume appears to have merged with the southwestern remnant of the residual 116-K-2 chromium plume and is being contained by three KR-4 treatment system extraction wells (199-K120A, 199-K-162, and 199-K-145). The 116-K-2 plume has been split by injection of treated water from the KR-4 treatment systems and more recently the KX systems along the middle of the trench. A small plume has been identified at upgradient Well 199-K-36, adjacent to the 183.1 Head House, where the Cr(VI) concentration increased to 34.2 µg/L in fall 2010. This well was the site of significant chromium spikes in the 1998 to 2001 period when concentrations reached 1,330 µg/L.

The recent Cr(VI) concentrations are similar in both plumes and range from 10 to 210 µg/L. The Cr(VI) concentration detected in Well 199- K-18, located at the southwestern end of the trench, was 200 µg/L in both fall 2009 and spring 2010. Concentrations at 199-K-18 began declining in December 2010 and dropped by 30 percent. The smaller plume, adjacent to the 107-KE Retention Basins footprint, had slightly higher concentrations during the fall sampling event. Primary historical source of Cr(VI) for the 100-K East plumes include the 116-K-2 Trench, 116-K-1 Trench, and over ground flow from leaks at the 107-KE Retention Basin (Figure 4-2).

Concentration trends in plumes being treated by the KX and KR-4 extraction wells vary (Figures 4-34 and 4-35). In the K-North plume, Cr(VI) concentrations have generally been decreasing (199-K-114A, 199-K-37, 199-K-151, 199-K-130, and 199-K-152), while 199-K-18 and 199-K-145, located at the southwestern end of 116-K-2 Trench (K-East plume) have generally been increasing. Concentrations at 199-K-145 began decreasing in early 2011. Concentrations for wells located between the K-North and

K-East plumes (199-K-119A, 199-K-125A, and 199-K-20) show decreasing trends. The concentrations in monitoring wells downgradient of the 100-KE Reactor (199-K-32A and 199-K-178) show steady to slightly increasing trends. The well with the highest historical Cr(VI) concentrations (199-K-141) shows a decreasing to stable trend. The concentration trends in 199-K-18 and 199-K-145 indicate that the plume core located at the southwestern end of the 116-K-2 Trench was growing but is now beginning to shrink. The continuing persistence of elevated Cr(VI) is attributed to the lower hydraulic conductivity measured in the Ringold unit E, although sources in the lower vadose zone may also produce this observation.

The majority of the Cr(VI) concentrations within the 100-K North plume range from 25 to 50 µg/L. Higher concentrations exist on the eastern and western fringes of the plume. The highest concentrations range from 84 to 110 µg/L and were detected at the northeastern end of the 116-K-2 Trench. Cr(VI) concentrations at 199-K-22 have slowly declined under the influence of downgradient extraction wells (199-K-161, 199-K-115A, and 199-K-114A). The aquifer at this location is thin due to a high in the underlying RUM, and the Ringold unit E aquifer is known to have a low hydraulic conductivity. The Cr(VI) concentration detected in Well 199- K-163, located inland from the end of the 116-K-2 Trench, was 110 µg/L. The primary historical source of Cr(VI) for the 100-K North plume is the 116-K-2 Trench (Figure 4-2).

Well 199-N-189 was drilled and completed in the summer of 2011. This well is located about 250 m (820 ft) east of well 199-K-182. Groundwater samples collected and analyzed for Cr(VI) during drilling had a concentration at the water table of 35 µg/L. This data point is not directly comparable to the chromium plume for fall 2009 (Figure 4-28) because of the seasonal differences of when the sample was taken. However, the isopleths for the 100-K North plume will likely move to the east when data from this well are considered.

1

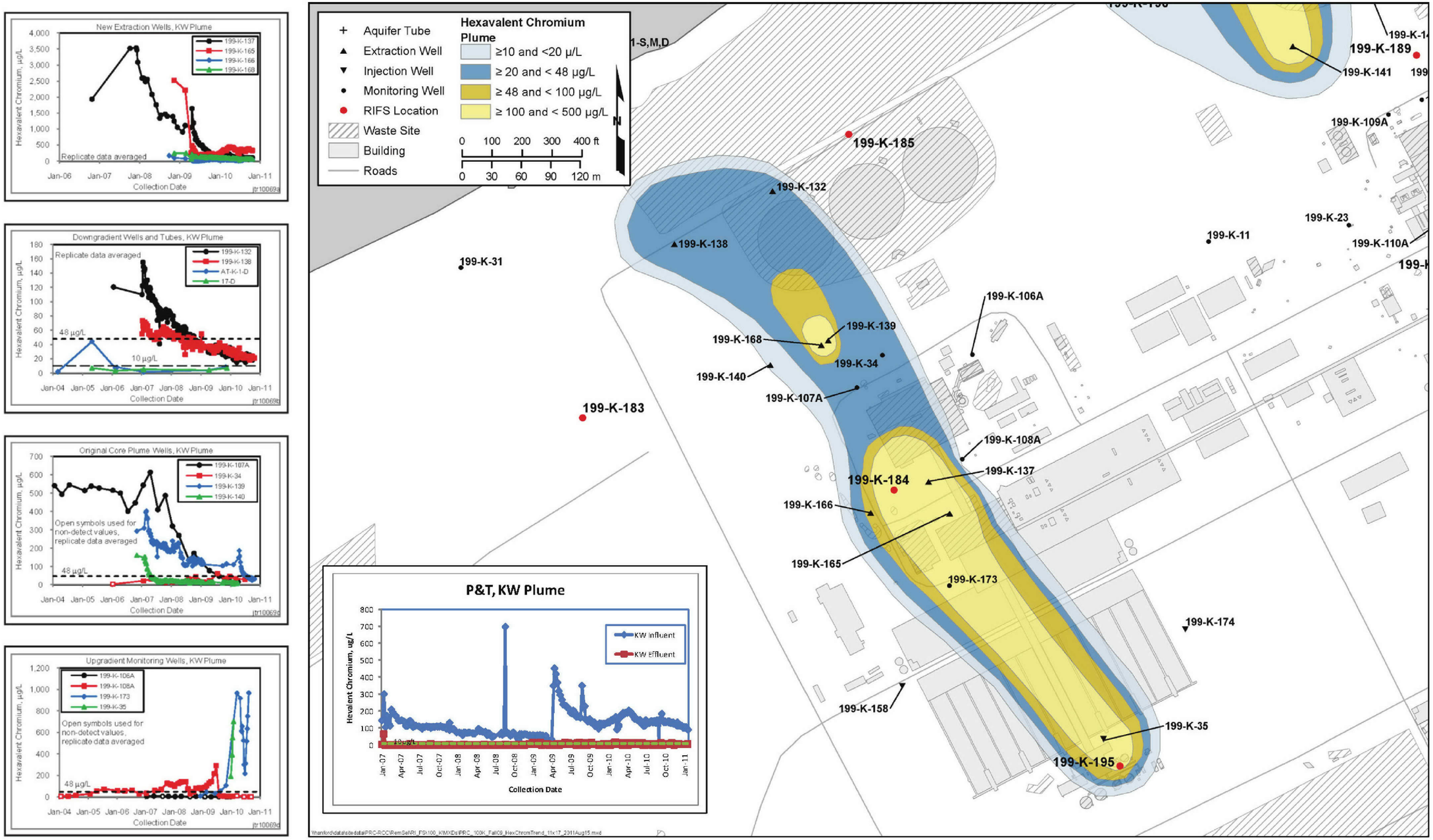

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Figure 4-26. 100-K Groundwater Cr(VI) Plume and Trend Plots for 100-K West (Fall 2009)

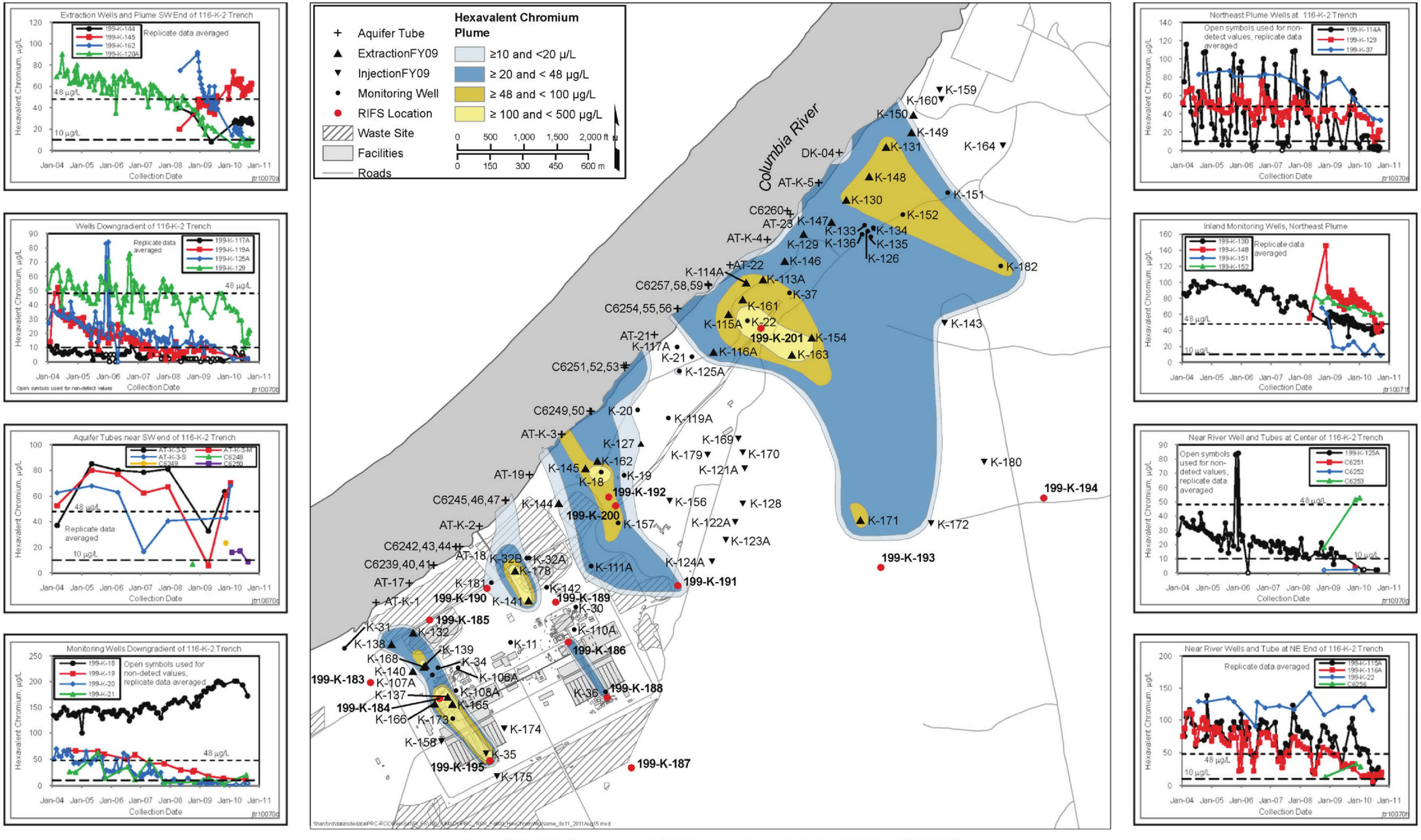
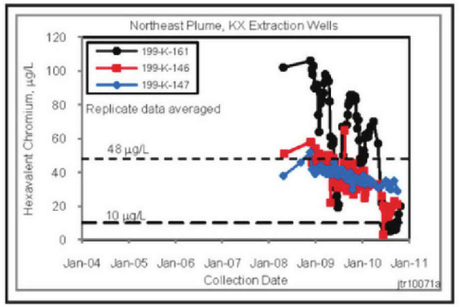
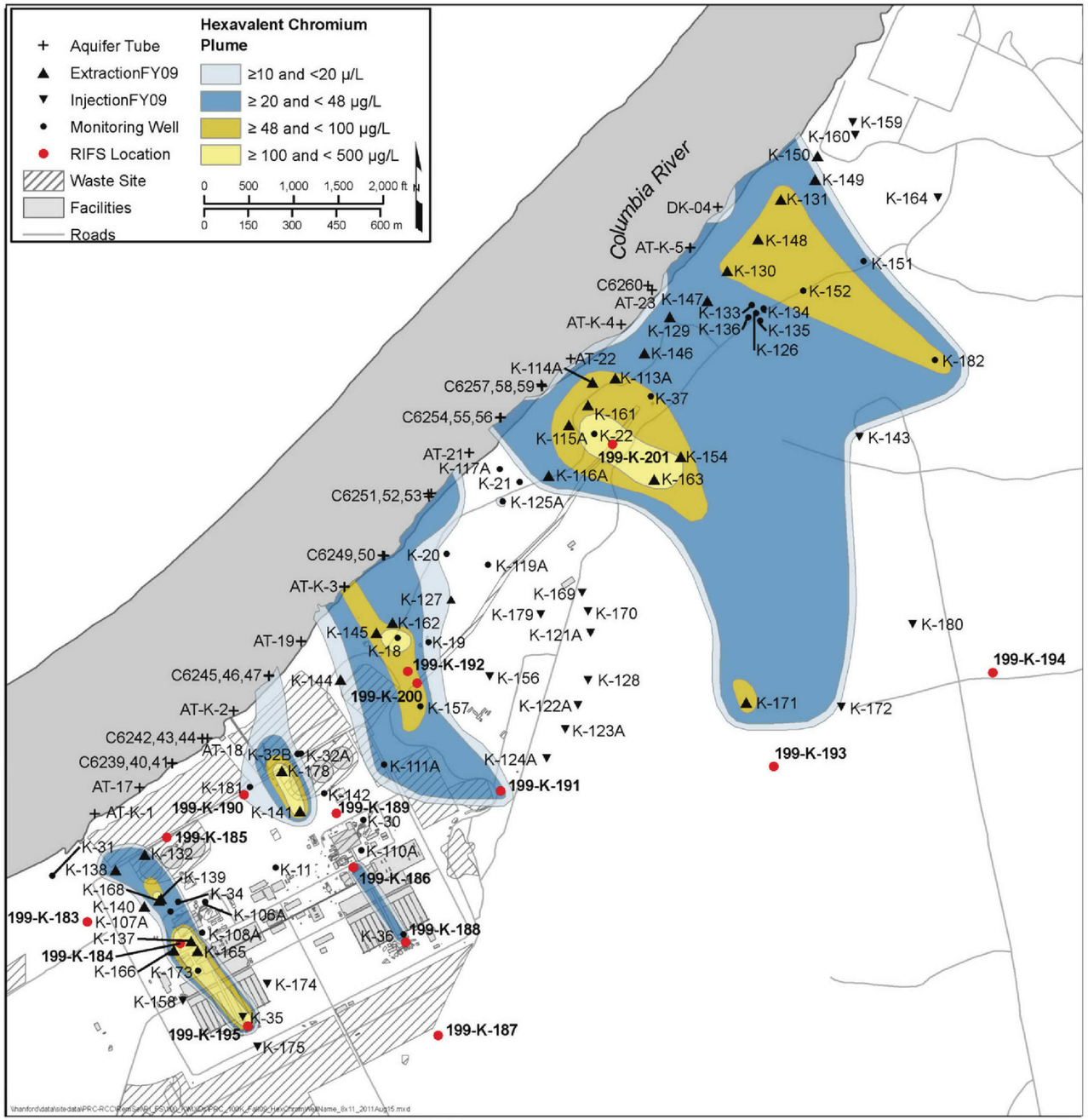
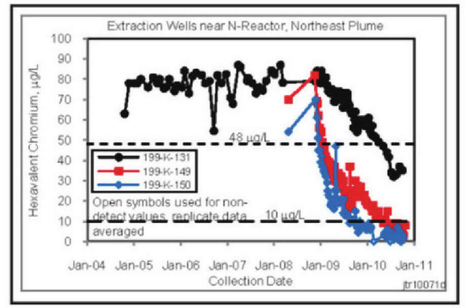
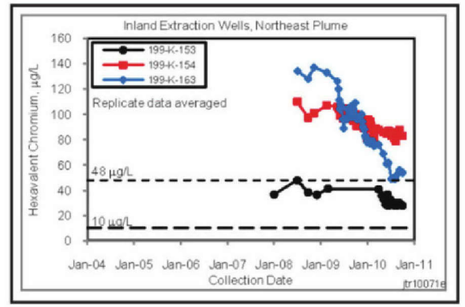


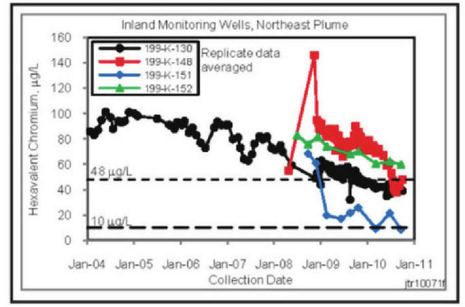
Figure 4-27. 100-K Groundwater Cr(VI) Plume and Trend Plots for 100-K East (Fall 2009)











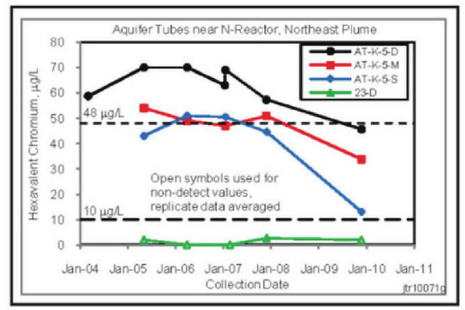


Figure 4-28. 100-K Groundwater Cr(VI) Plume and Trend Plots for 100-K North (Fall 2009).

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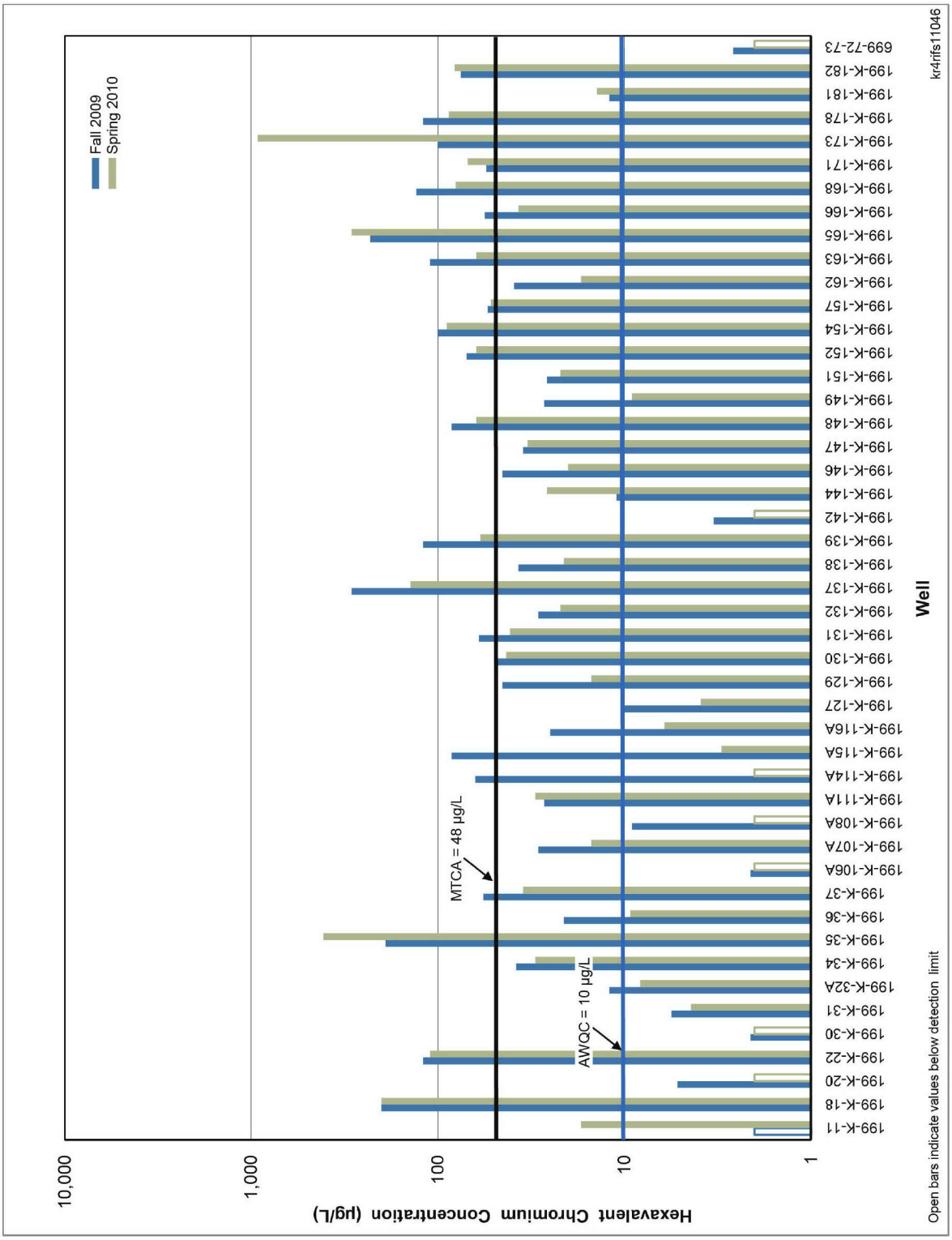

Figure 4-29. 100-K Bar Charts of Cr(VI) Concentration in Wells, Fall 2009 and Spring 2010

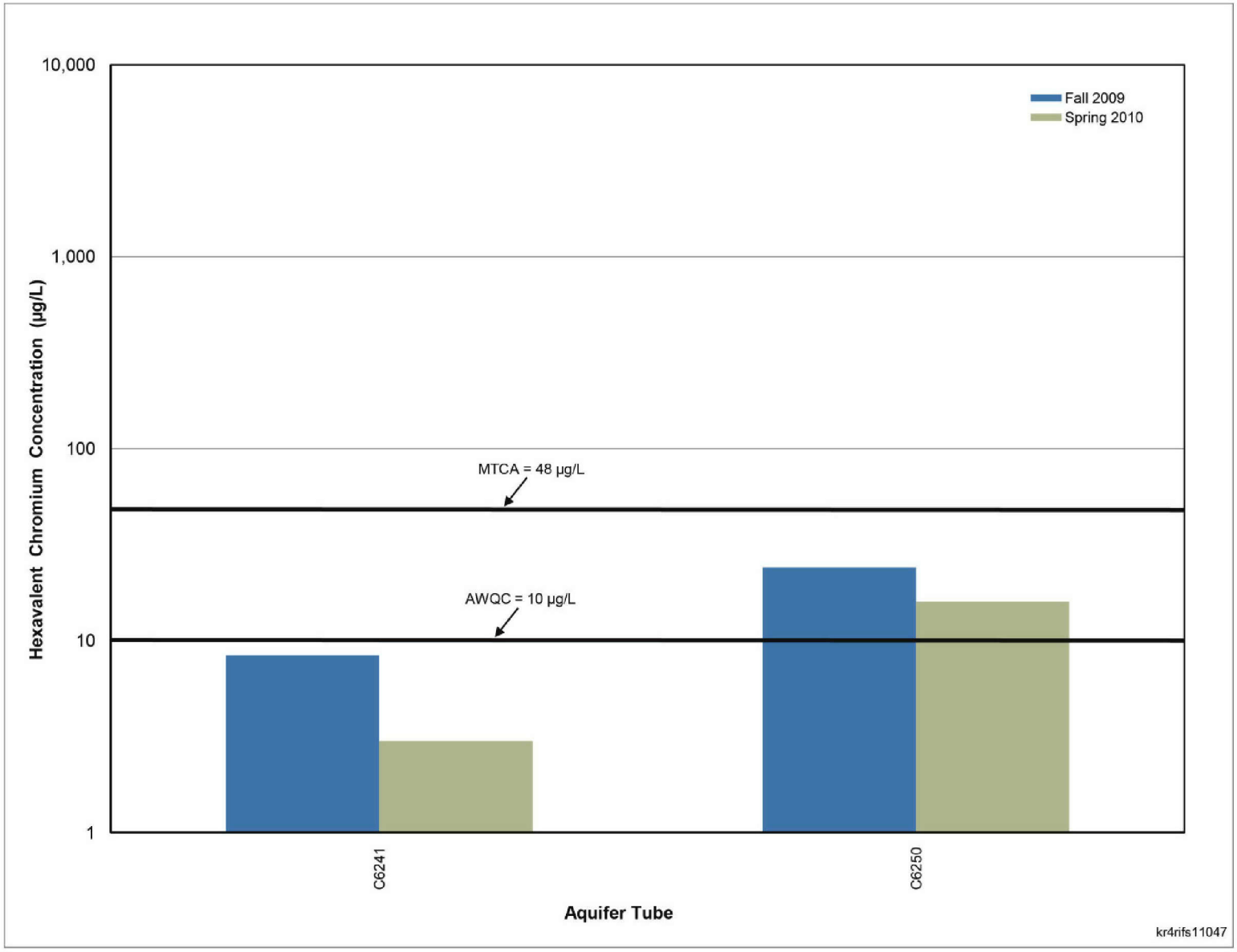

Figure 4-30. 100-K Bar Charts of Cr(VI) in Aquifer Tubes, Fall 2009 and Spring 2010

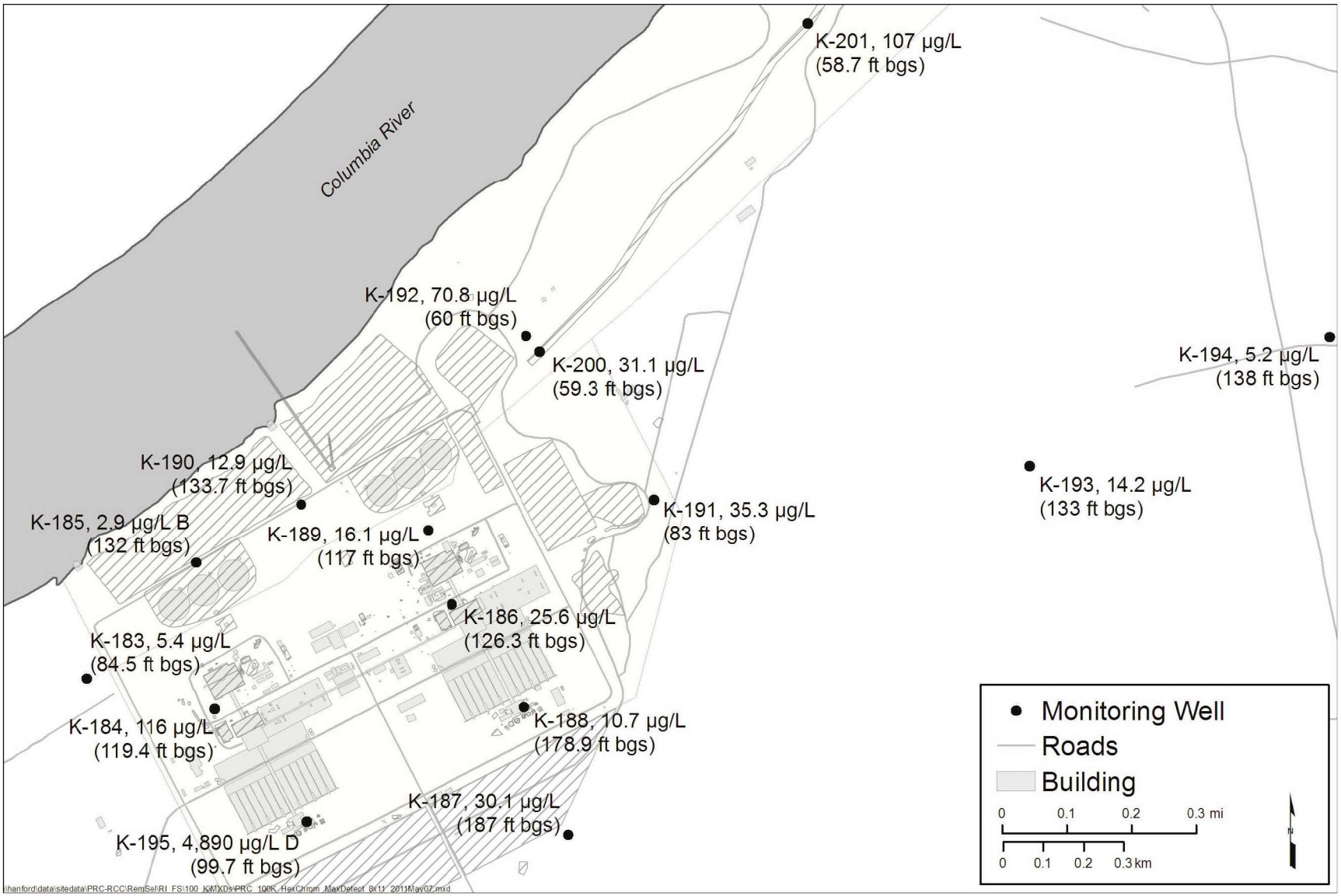

Figure 4-31. Maximum Cr(VI) Concentrations in Discrete Samples from RI Wells

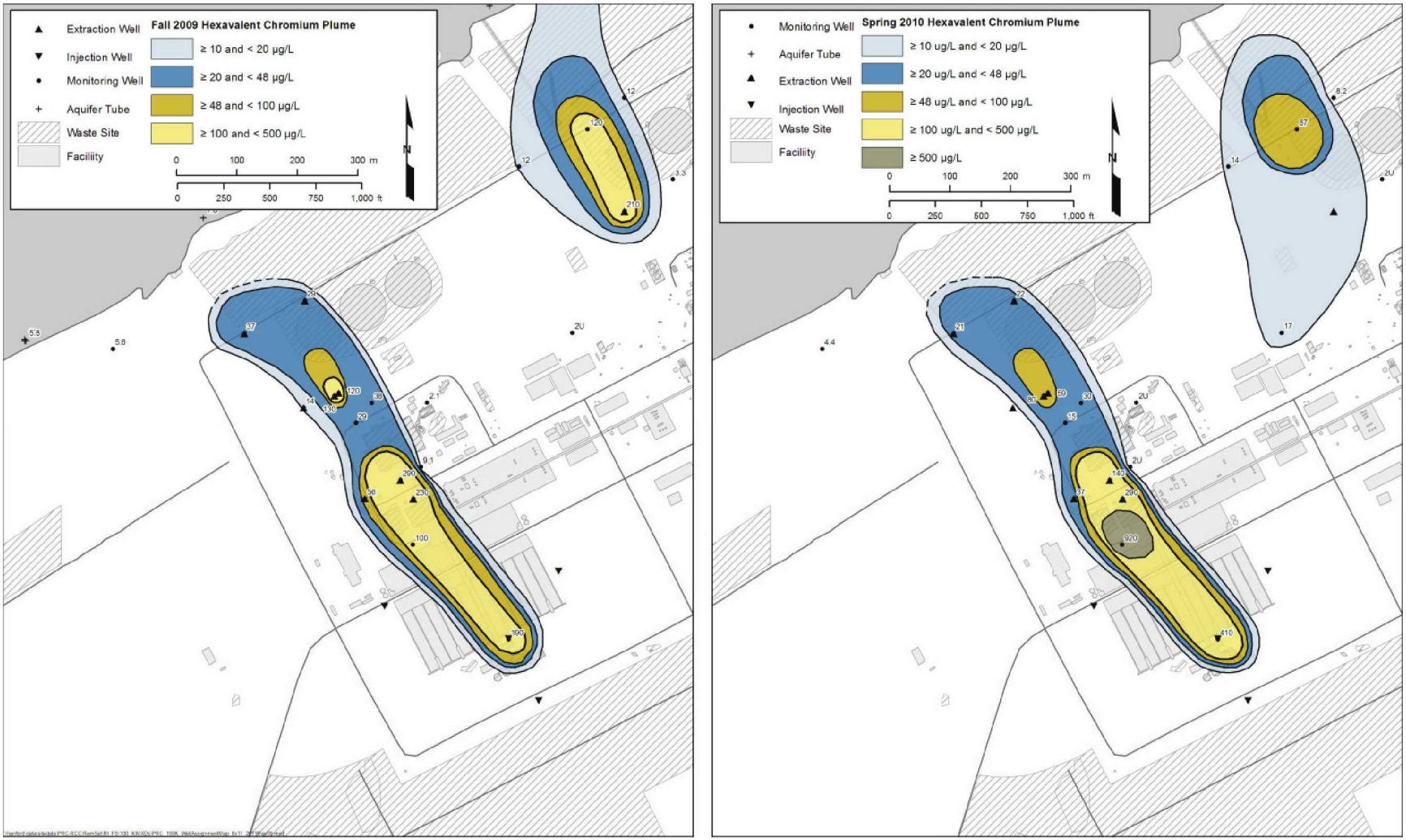

Figure 4-32. Fall 2009 and Spring 2010 Cr(VI) Plume in 100-K West

Table 4-27. Detected Concentration of Cr(VI) above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells 100-K

Well ID	Borehole ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth Below Top of WL (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Cr(VI) Concentration (µg/L)
Constituent Action Level 10 (µg/L)							
199-K-184	C7684	12/29/2010	26.43	86.70	24.7 [78.75] to 49.63 [162.80]	B27LH5	14.4
199-K-184	C7684	12/30/2010	27.43	90.00		B27LH6	13.6
199-K-184	C7684	12/30/2010	28.96	95.00		B27LH7	11.6
199-K-184	C7684	1/10/2011	36.39	119.40		B27LJ2	116
199-K-184	C7684	1/13/2011	39.44	129.40		B27LJ4	68.6
199-K-184	C7684	1/15/2011	42.67	140.00		B28374	24.3
199-K-184	C7684	1/15/2011	42.67	140.00		B27LJ6 (DUPLICATE)	24.5
199-K-184	C7684	1/21/2011	48.74	159.90		B27LK0	13.5
199-K-186	C7686	1/10/2011	35.08	115.10	TBD to 49.39 [162.00]	B29LP3	10.3
199-K-186	C7686	1/14/2011	38.50	126.30		B29LP9	25.6
199-K-186	C7686	1/14/2011	39.62	130.00		B29LR2	18.8
199-K-187	C7687	6/7/2010	57.00	187.00	35.42 [113.90] to 60.21 [197.50]	B25V28	30.1
199-K-187	C7687	6/7/2010	58.52	192.00		B25V29	14
199-K-187	C7687	6/8/2010	59.65	195.70		B25V30	11.3
199-K-188	C7688	1/28/2011	54.53	178.90	30.79 [98.70] to 55.79 [183.00]	B28FJ8	10.7
199-K-189	C7689	8/18/2010	24.99	82.00	23.42 [74.55] to 46.95 [154.00]	B26WW0	12.2
199-K-189	C7689	8/26/2010	35.66	117.00		B26WW9	16.1
199-K-189	C7689	8/27/2010	38.71	127.00		B26WX1	13.8
199-K-190	C7690	8/17/2010	40.75	133.70	17.89 [56.41] to 40.55 [133.00]	B26VL2	12.9
199-K-191	C7691	6/25/2010	25.30	83	23.46 [74.67] to 46.74 [153.30]	B25X09	35.3
199-K-192	C7692	8/31/2010	18.29	60	10.70 [32.82] to 43.45 [142.50]	B27745	70.8
199-K-192	C7692	9/1/2010	19.81	65		B27746	18.9
199-K-192	C7692	9/2/2010	21.37	70.1		B27747	43.7
199-K-192	C7692	9/3/2010	22.86	75		B27748	26.2
199-K-192	C7692	9/7/2010	24.44	80.2		B27749	11.9
199-K-192	C7692	9/7/2010	24.44	80.2		B27750 (DUPLICATE)	12.8
199-K-192	C7692	11/4/2010	38.10	125		B27796	14.4
199-K-193	C7693	11/15/2010	40.54	133	24.87 [79.30] to 49.09 [161.00]	B25YR5	14.2
199-K-193	C7693	11/15/2010	42.06	138		B25YR6	13.2

Table 4-27. Detected Concentration of Cr(VI) above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells 100-K

Well ID	Borehole ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth Below Top of WL (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Cr(VI) Concentration (µg/L)
199-K-193	C7693	11/16/2010	43.59	143		B25YR7	12
199-K-195	C7695	11/16/2010	28.99	95.1		B27HF2	346
199-K-195	C7695	11/17/2010	30.39	99.7	26.61 [85.00] to 54.33 [178.20]	B27HF3	4890
199-K-195	C7695	11/18/2010	31.88	104.6		B27HF4	1970
199-K-195	C7695	11/19/2010	33.62	110.3		B27HF5	277
199-K-195	C7695	11/19/2010	33.62	110.3		B27RD0 (DUPLICATE)	279
199-K-195	C7695	11/23/2010	35.02	114.9		B27HF6	499
199-K-195	C7695	11/29/2010	36.42	119.5		B27HF7	191
199-K-195	C7695	11/30/2010	38.16	125.2		B27HF8	48.7
199-K-195	C7695	12/10/2010	47.24	155		B27HH4	10.8
199-K-195	C7695	12/14/2010	50.29	165		B27HH6	753
199-K-200	C7831	1/31/2011	18.07	59.3		B2BHJ4	31.1
199-K-201	C7832	1/31/2011	17.89	58.7		B2BHK2	107

TBD = to be determined
WL = water level

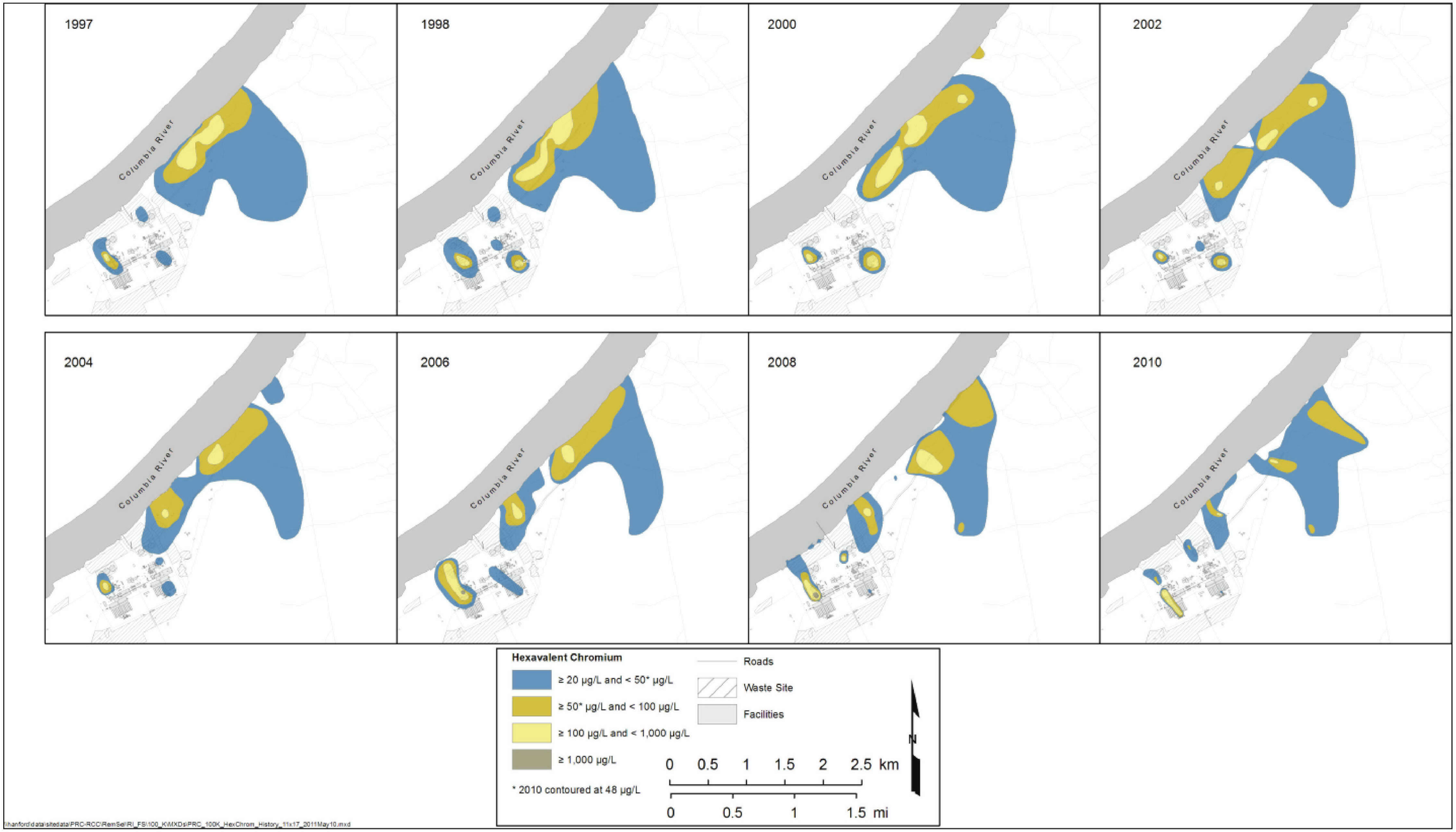

Figure 4-33. Historical Cr(VI) Map Showing Plume from 1997 to 2010

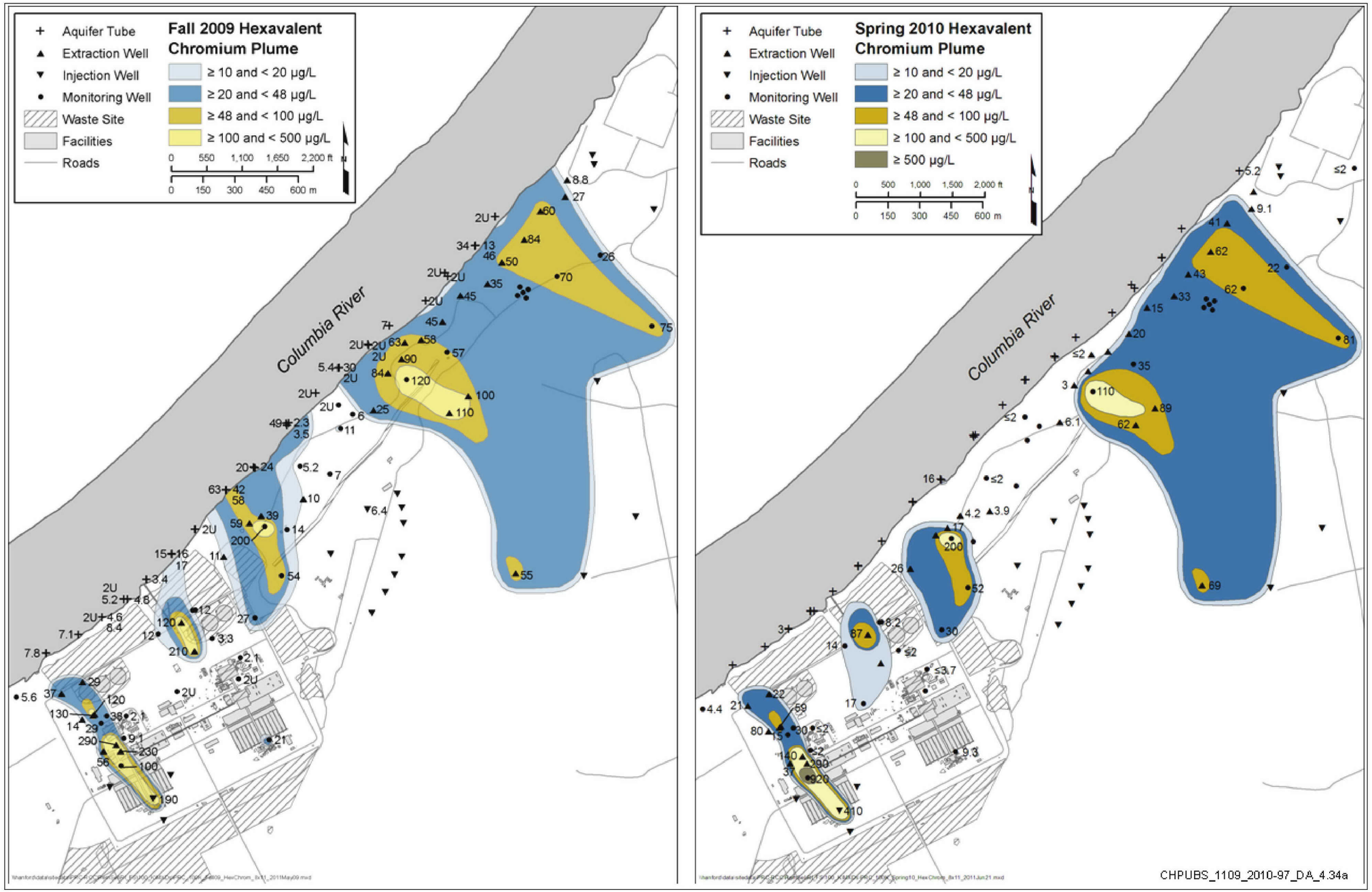

Figure 4-34. Fall 2009 and Spring 2010 Hexavalent Plume of K-East (KR4)

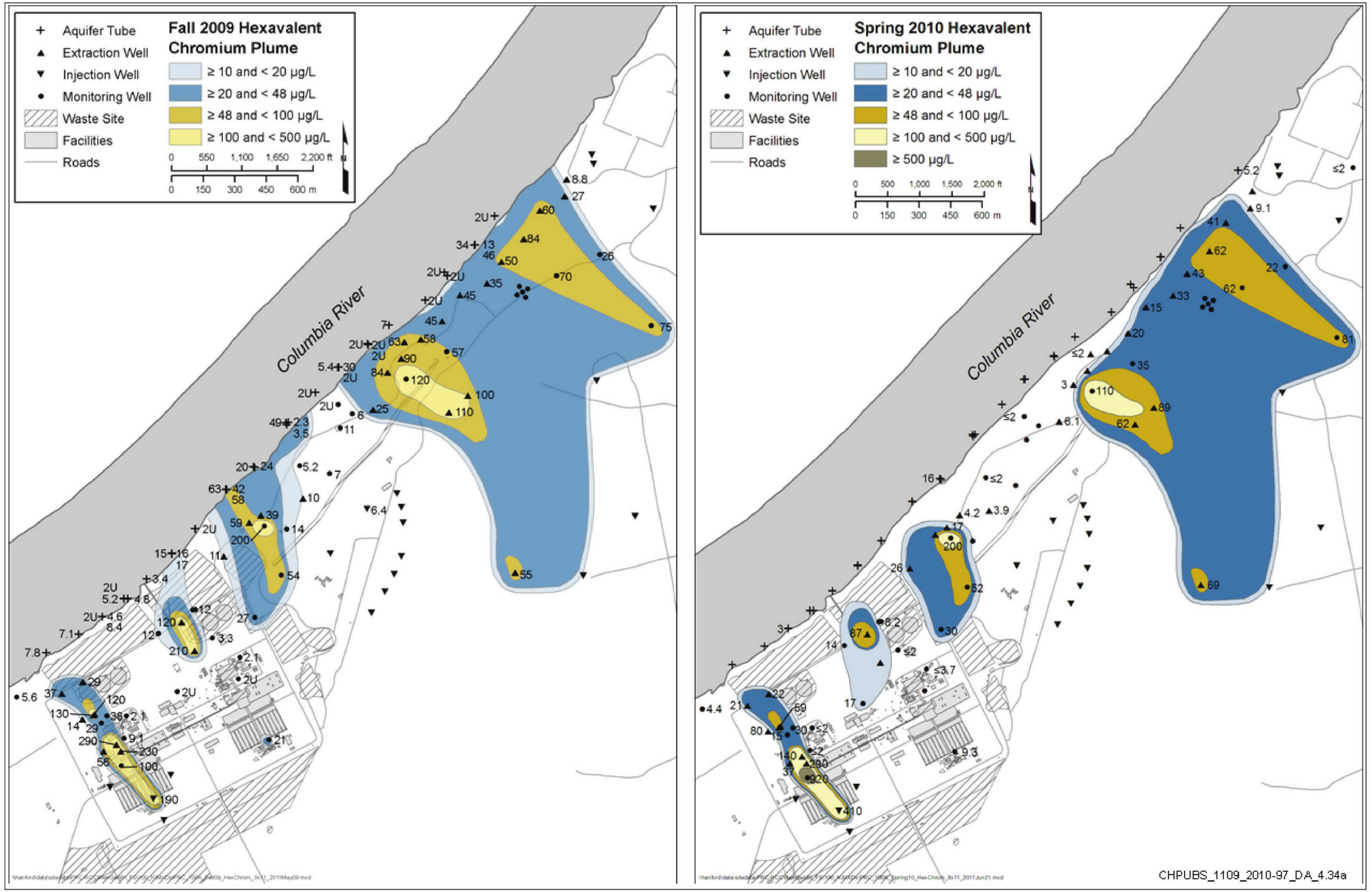

Figure 4-35. Fall 2009 and Spring 2010 Hexavalent Plume of K-North (KX).

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Nine RI monitoring wells and two temporary wells (199-K-186, 199-K-187, 199-K-188, 199-K-189, 199-K-190, 199-K-191, 199-K-192, 199-K-193, 199-K-194, 199-K-200, and 199-K-201) were installed in or adjacent to the 100-K East and 100-K North plumes and provide additional data to further delineate the extent. Four of the 15 boreholes were drilled 15.2 m (50 ft) into the RUM unit. One location, 199-K-192, encountered a water-bearing zone in the RUM, and was screened across this zone. The remaining wells were installed within the unconfined aquifer in the upper Ringold unit E (Figures 3-8 and 3-9). Cr(VI) was detected above the AL in 199-K-186 through 199-K-193 while drilling during vertical profile sampling. Temporary Wells 199-K-200 and 199-K-201 did not encounter chromium at detectable concentrations, but Cr(VI) was detected at both wells above the AL (31.1 and 111 μg/L, respectively) when sampled in January 2011. Concentrations in the RI groundwater samples ranged from 10.3 μg/L in 199-K-186 at a depth of 35 m (115 ft) bgs to a maximum of 70.8 μg/L in 199-K-192. Well 199-K-186 is located approximately 80 m (262 ft) southeast of the former 105-KE Reactor building, while 199-K-201 is located in the eastern end of the 116-K-2 Trench within the 100-K North plume.

The Cr(VI) observed at 199-K-191 (maximum concentration of 35.3 μg/L) is above the AL and is consistent with the concentrations observed in wells located in the eastern portions of the 100-K-East/North plume, such as 199-K-171 (55 μg/L) and 199-K-36 (21 μg/L). RI Monitoring Well 199-K-190, which was installed near the southwestern edge of the 100-K East plume area near the 107-KE Retention Basin site, is screened within the unconfined aquifer. The maximum detected concentration measured in 199-K-190 was 12.9 μg/L at a depth of 40 m (133 ft) bgs, which is consistent with concentrations observed in nearby Monitoring Well 199-K-181.

The Cr(VI) detected in 199-K-193 and 199-K-194 indicates that the southern and southeastern boundary of the 100-K North plume lies between these wells and the river. Chromium in 199-K-193 was found in the bottom half of the well at concentrations slightly above the AL. At 199-K-194, the Cr(VI) concentrations were below the AL and were observed across the aquifer's thickness. The maximum detection of Cr(VI) in grab groundwater samples from 199-K-187 and 199-K-188 was 30.1 μg/L at a depth of 57 m (187 ft) bgs and 10.7 μg/L at a depth of 54 m (179 ft) bgs, respectively. The K-North plume remains unbounded south and east of 199-K-182, where Cr(VI) concentrations are between 75 and 81 μg/L. The presence of Cr(VI) east of the 183.1 KE Head House indicates possible migration toward the 116-K-2 Trench plume.

Summary. The original Cr(VI) plume associated with the 116-K-2 Trench was one larger plume in the past; however, the row of current and former injection wells extending from K-124A to K-169 has separated it into two distinct plumes. The split appears to have been helped by the presence of a higher hydraulic conductivity in sediments within the middle of the 116-K-2 Trench, as discussed in detail in Chapter 3. A historical plume associated with releases from the 183.1 KE Head House has likely been fragmented, possibly by leaks from the 183.2-KE Sedimentation Basin and the 185.4-KE Clearwells. The interpretation of the 100-K East and 100-K North plumes has changed over the years as additional wells have been drilled. The overall size of the two plume components appears to be decreasing with treatment. The plume extent has increased in the last five years as further investigations have led to better refinement of the plume extent. The areas of higher concentrations have decreased over time. The aquifer between 199-K-171 and 199-K-163 lies beneath a culturally sensitive feature. The elevated concentrations at these two wells (52.2 and 53 μg/L, respectively in November 2010) suggest the presence of a plume above the 48 μg/L MTCA standard.

The concentration trends in 199-K-18 and 199-K-145 indicate that the plume core located at the southwestern end of the 116-K-2 Trench is beginning to shrink, although local aquifer conditions may be retarding the remediation of Cr(VI). Figure 4-33 shows changes in configuration of the K-East and K-North plumes between 1997 and 2010. The results from RI wells drilled within the unconfined

Ringold unit E aquifer suggest that Cr(VI) was driven upgradient from and deeper into the aquifer by operational discharges to the 116-K-2 Trench. Northward migration of the K-North plume is attributed to the combined effects of discharges to the 116-K-2 Trench, river stage fluctuations, and injection of groundwater by the KR-4 and KX treatment systems at the trench. Much of the plume observed in this area may be old cooling water forced upgradient by the 116-K-2 groundwater mound. Current injection upgradient of the trench may be diluting and forcing contaminated water flowing downgradient around the ends of the trench. RI data from boreholes collected at either end of the trench also indicate the possibility of elevated concentrations in the lower most vadose zone that could be slowly bleeding additional Cr(VI) into the water.

Vertical Distribution of Cr(VI). Cross sections across 100-K have been developed to show the general geology, depth of wells, well screen length, and Cr(VI) concentrations that have been detected in both fall 2009 and spring 2010. Figure 4-36 illustrates the cross section locations for 100-K.

Figures 4-37 through 4-47 are cross-sectional plume interpretations depicting the extent of Cr(VI) contamination in the aquifer.

At RI Monitoring Well 199-K-192, the maximum detected concentration of Cr(VI) in a grab groundwater sample collected during drilling at approximately 18 m (60 ft) bgs within the unconfined aquifer was 70.8 µg/L, above the AL and MTCA standard. Well 199-K-192 was installed downgradient of and near the southwestern end of the 116-K-2 Trench within the lower RUM unit and the well was screened at a depth of 53 to 56 m (175 to 185 ft) bgs, approximately 10 m (32 ft) below the unconfined RUM unit E aquifer. Subsequent grab groundwater samples collected while drilling 199-K-192 show no evidence of Cr(VI) above the AL at depths below the unconfined aquifer. For samples within the unconfined aquifer, the concentration of Cr(VI) in grab groundwater samples ranged above the AL—between 70.8 µg/L at 18.3 m (60 ft) bgs to 14.4 µg/L collected at approximately 38 m (125 ft) bgs. Monitoring Well 199-K-200 was completed less than 91 m (300 ft) to the east of Well 199-K-192. In comparison, the concentration of Cr(VI) observed in 199-K-200 at a depth of 18 m (60 ft) bgs was 31.1 µg/L (January 2011), also above the AL. The absence of detectable Cr(VI) within the RUM water-bearing unit at 199-K-192 suggests no vertical connection to Cr(VI) plumes in the unconfined aquifer (Figure 4-39). Hydraulic head gradients are upward in the RUM wells.

Between RI Wells 199-K-184 and 199-K-195, and other active extraction wells located at the 100-K West plume, a downward movement of Cr(VI) appears to exist. At Well 199-K-195, a Cr(VI) peak concentration of 4,890 µg/L 30.4 m (99 ft) bgs and 3.7 m (12 ft) below the aquifer decreases to nondetect levels within the next 9.2 m (30 ft). At 50. 3 m (165 ft) bgs, a secondary peak of 753 µg/L is found in 199-K-195. At Well 199-K-184, most of the Cr(VI) detected in groundwater samples came from the lower half of the unconfined aquifer. The maximum Cr(VI) concentration in 199-K-184 was 116 µg/L at 36.4 m (119 ft) bgs. Groundwater grab samples at extraction well 199-K-165 were taken at 6 m (20 ft) intervals and revealed Cr(VI) concentrations across the unconfined aquifer between 2,810 µg/L at the top of the aquifer to 286 µg/L at the base of the aquifer. Nearby Extraction Wells 199-K-166 and 199-K-168 have vertical profiles of Cr(VI) concentrations that decline with depth but are greater than AL concentrations throughout the aquifer. The well data indicate vertical dispersion and migration through the unconfined aquifer as one moves away from the presumed source area around the 183.1 KW Head House. The active KW pump-and-treat system may account for some of this dispersion. The secondary increase of Cr(VI) concentrations toward the base of the aquifer, as at 199-K-195 and at downgradient Well 199-K-173 and Extraction Well 199-K-168, hint at the vertical migration of Cr(VI) through the unconfined aquifer during water system operations. With a residence time of over 40 years, only residual amounts of this mass appear to remain. However, the observation also could be explained by contaminated water moving in from upgradient. Concentrations greater than 700 µg/L indicate a higher concentration source than the cooling water.

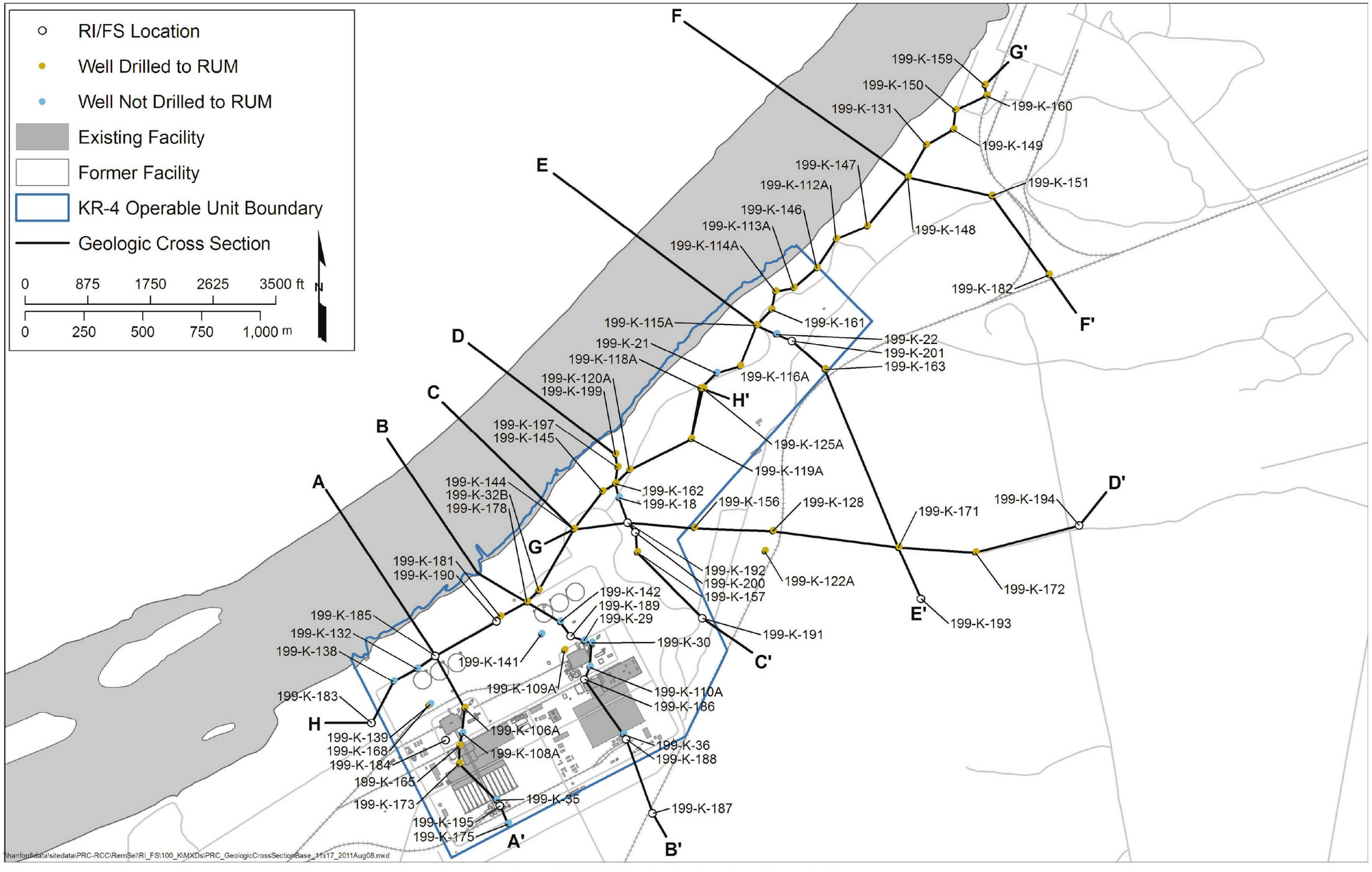

Figure 4-36. Plan View Showing Location of Cross Sections

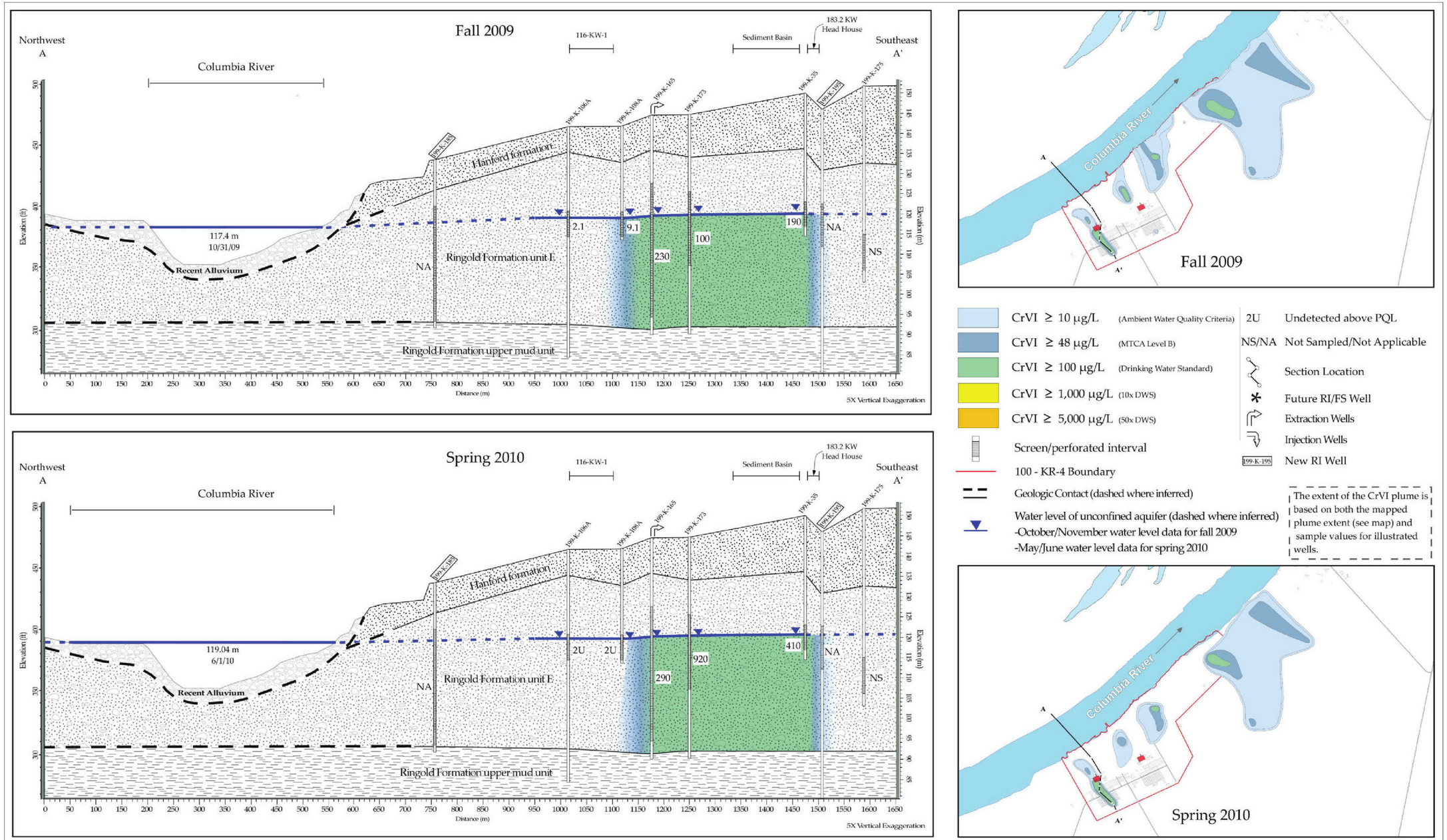

Figure 4-37. Cr(VI) Concentration on Cross Section A-A'

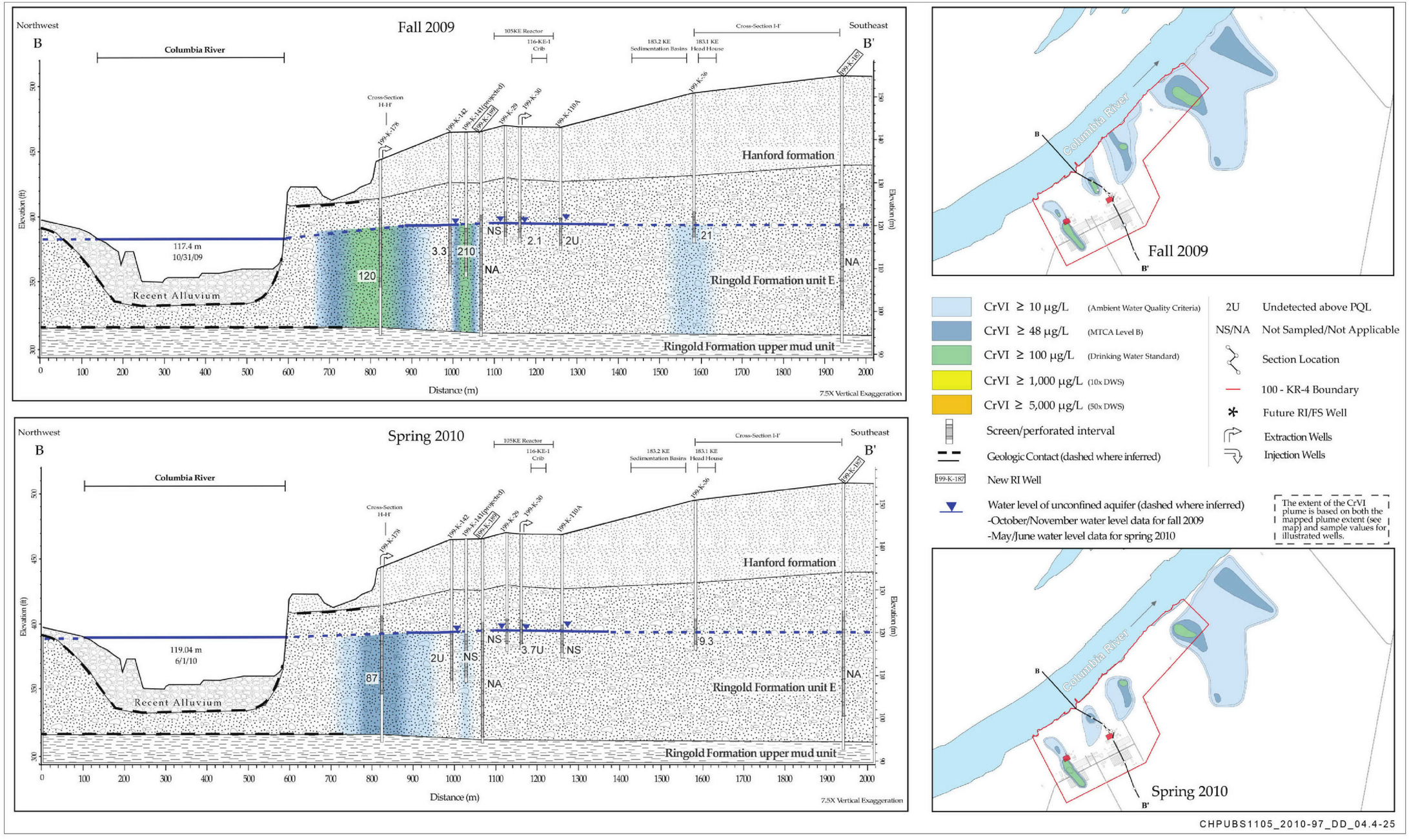

Figure 4-38. Cr(VI) Concentration on Cross Section B-B'

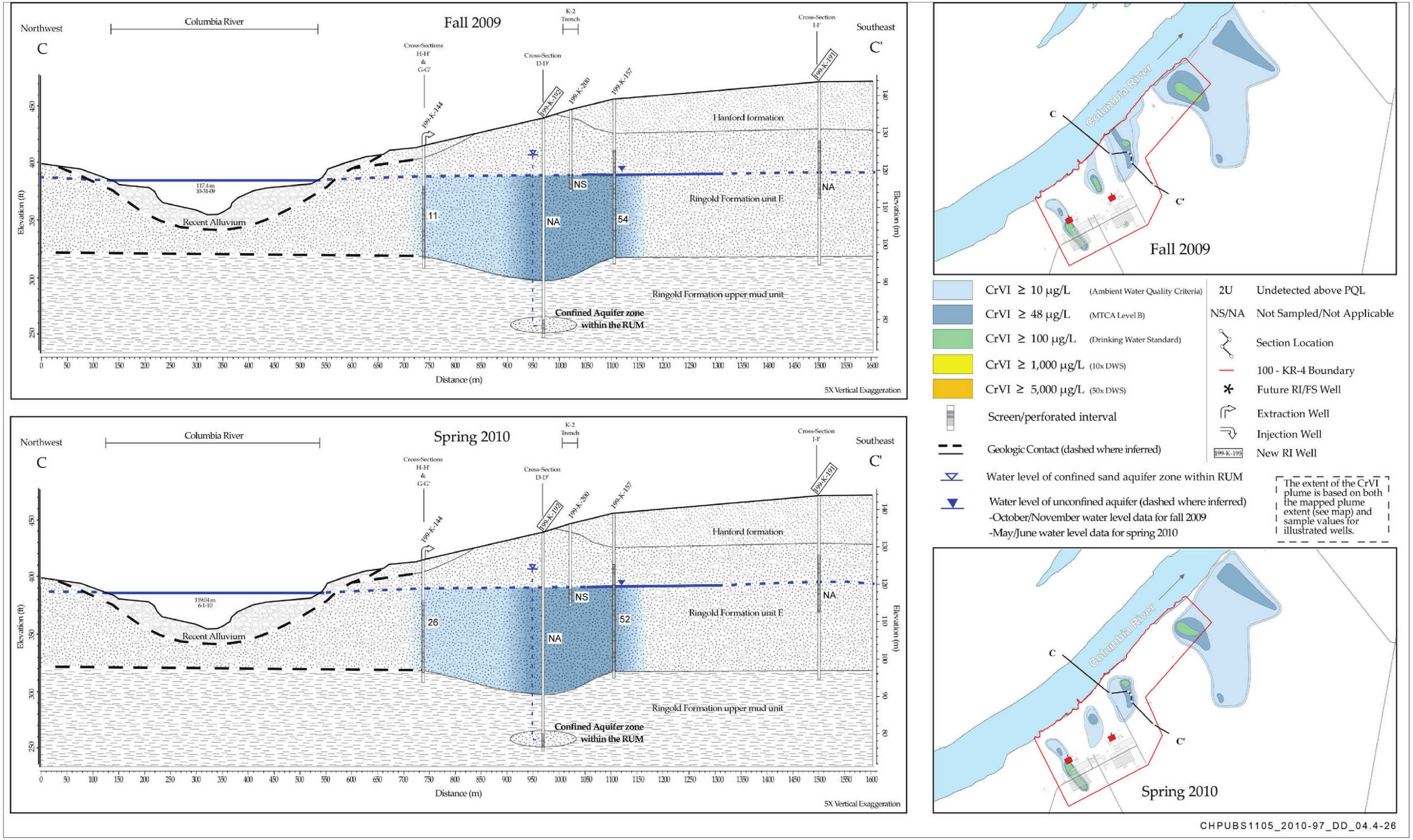

Figure 4-39. Cr(VI) Concentration on Cross Section C-C'

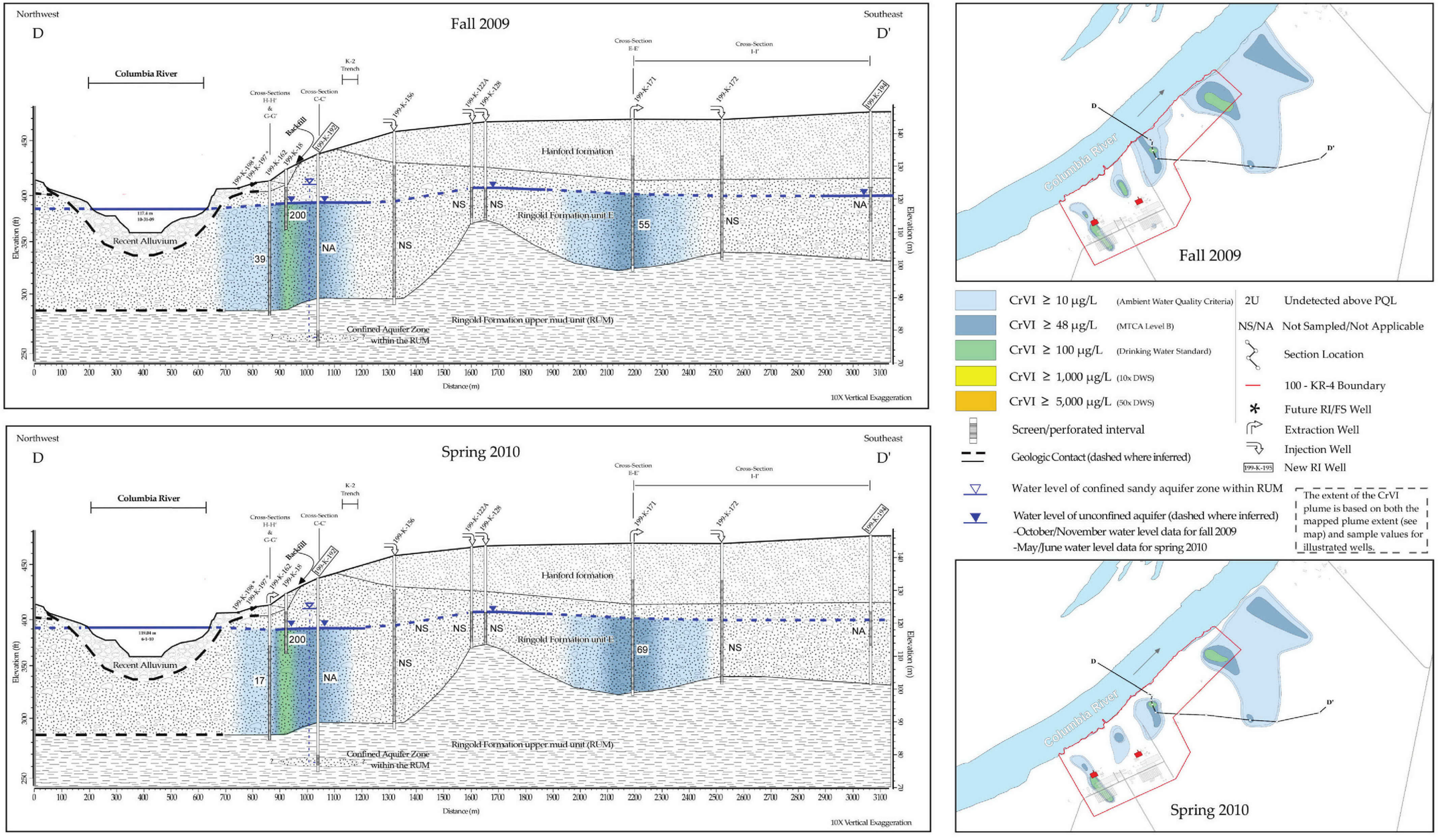

Figure 4-40. Cr(VI) Concentration on Cross Section D-D'

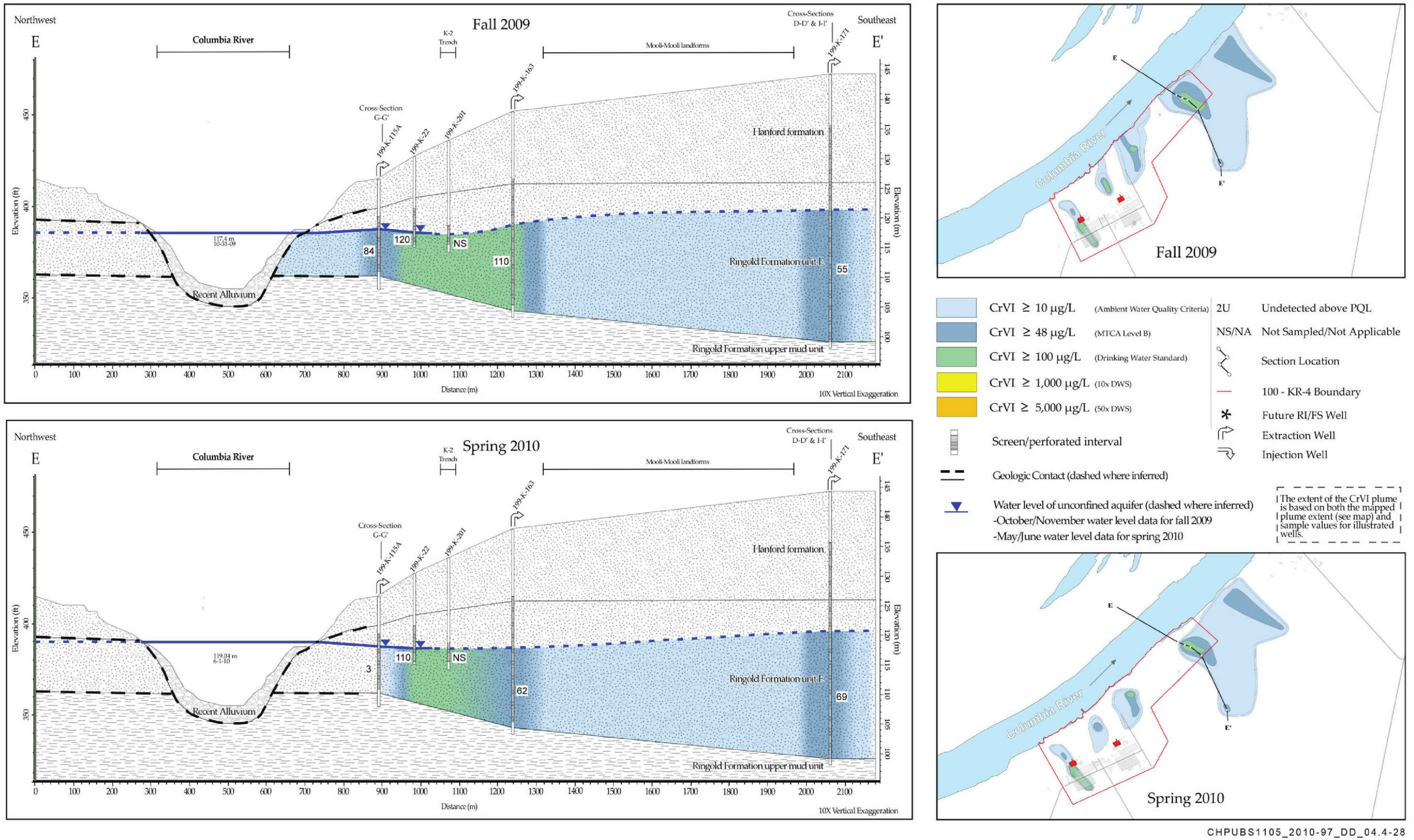

Figure 4-41. Cr(VI) Concentration on Cross Section E-E'

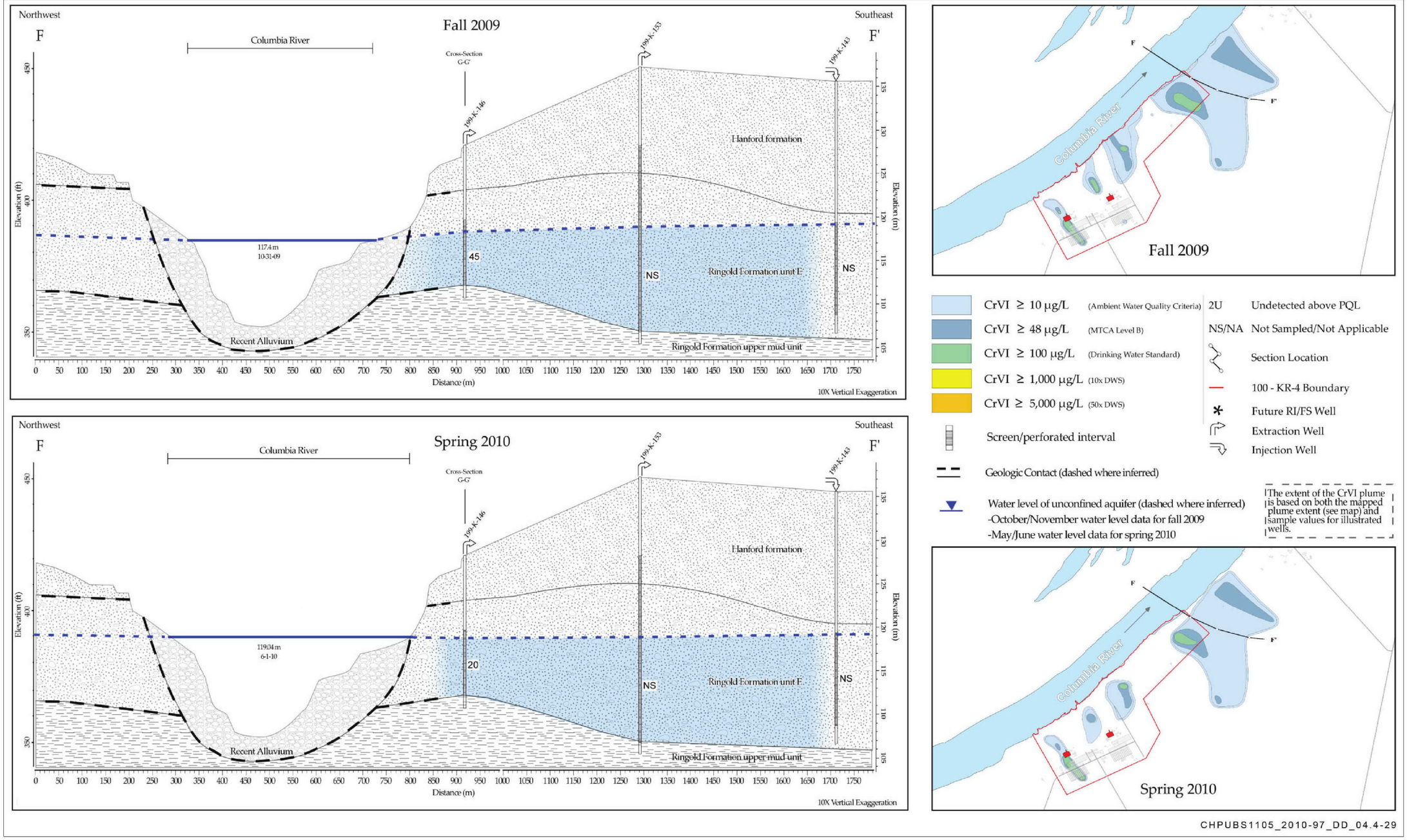

Figure 4-42. Cr(VI) Concentration on Cross Section F-F'

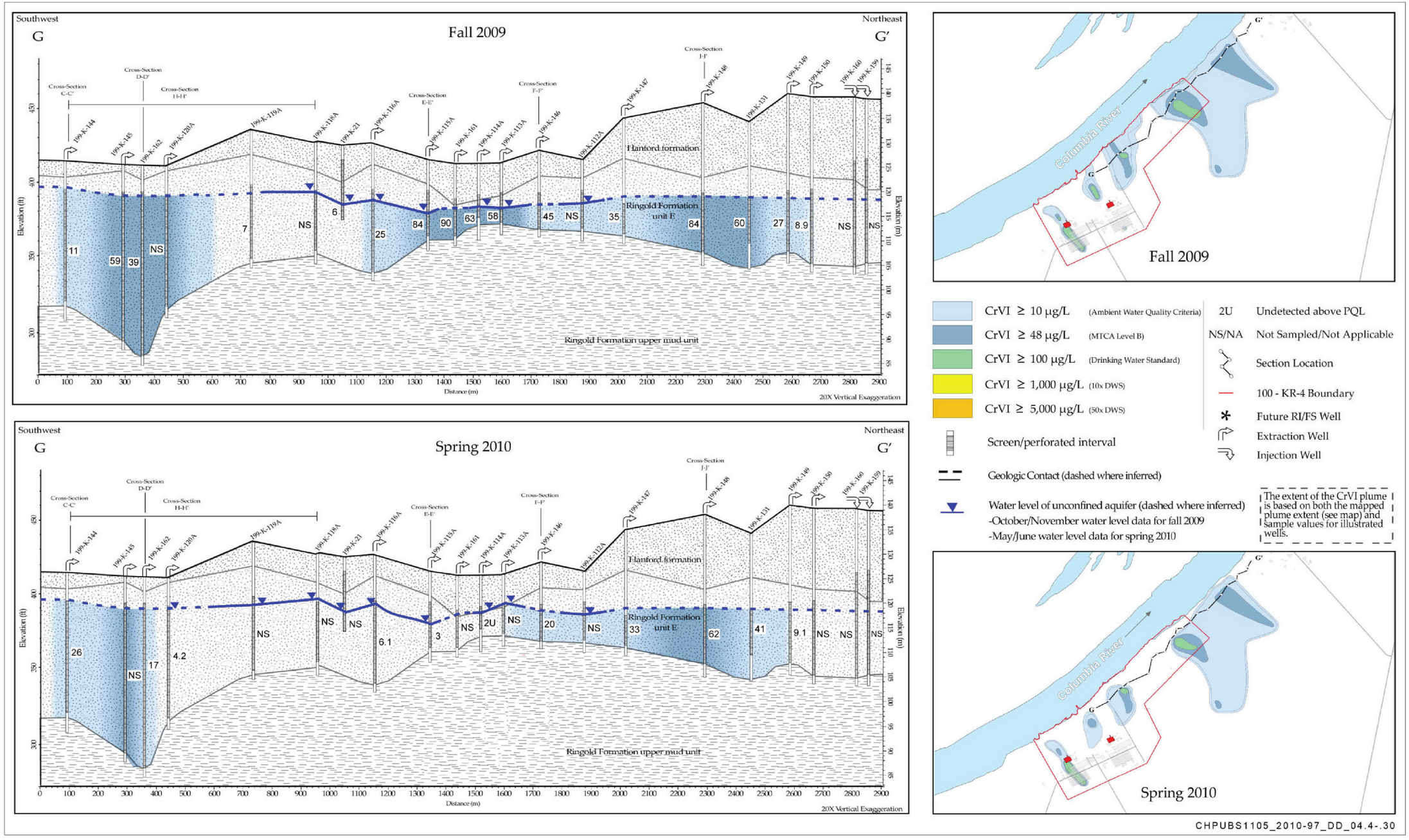

Figure 4-43. Cr(VI) Concentration on Cross Section G-G'

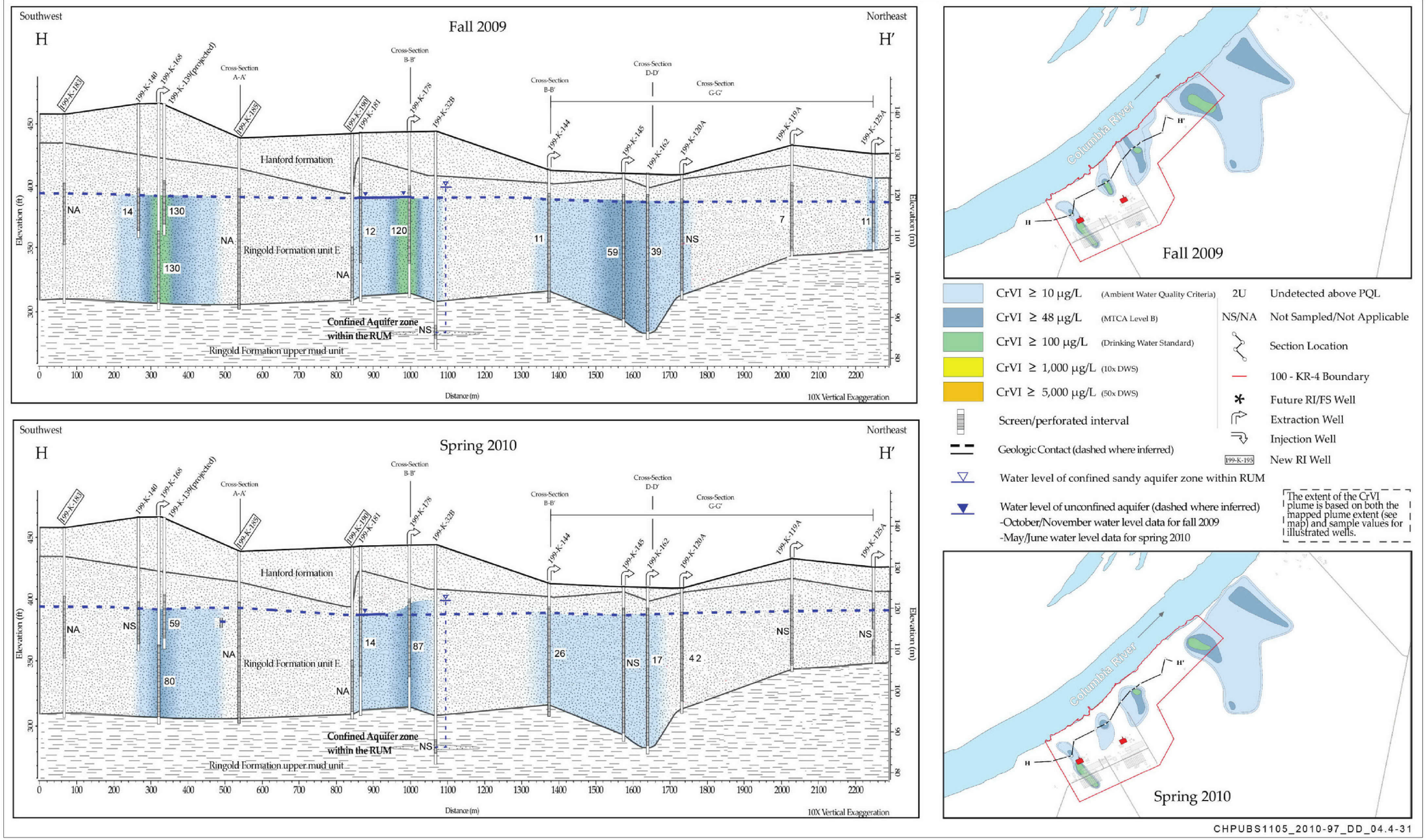

Figure 4-44. Cr(VI) Concentration on Cross Section H-H'

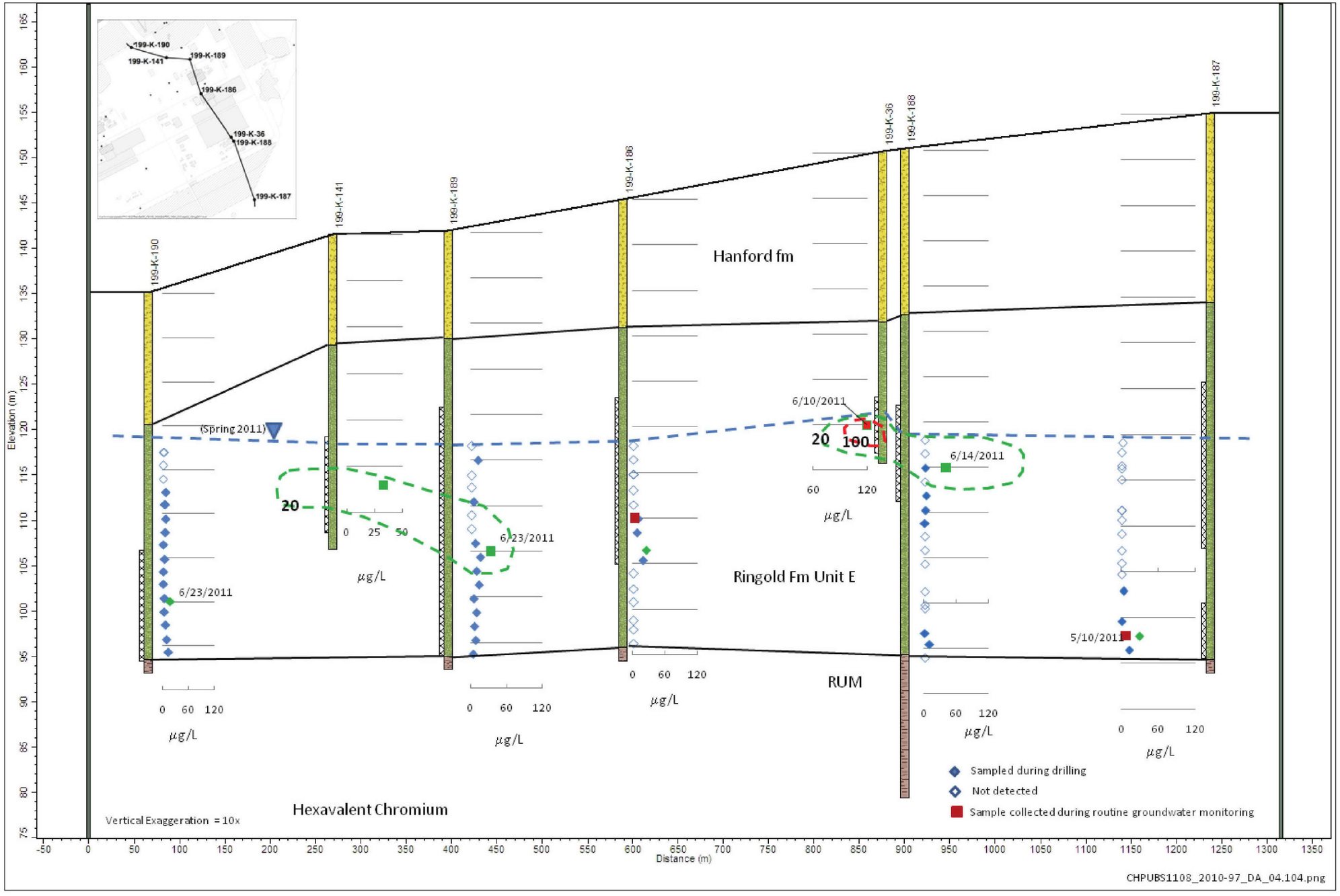

Figure 4-45. Vertical Distribution of Cr(VI)

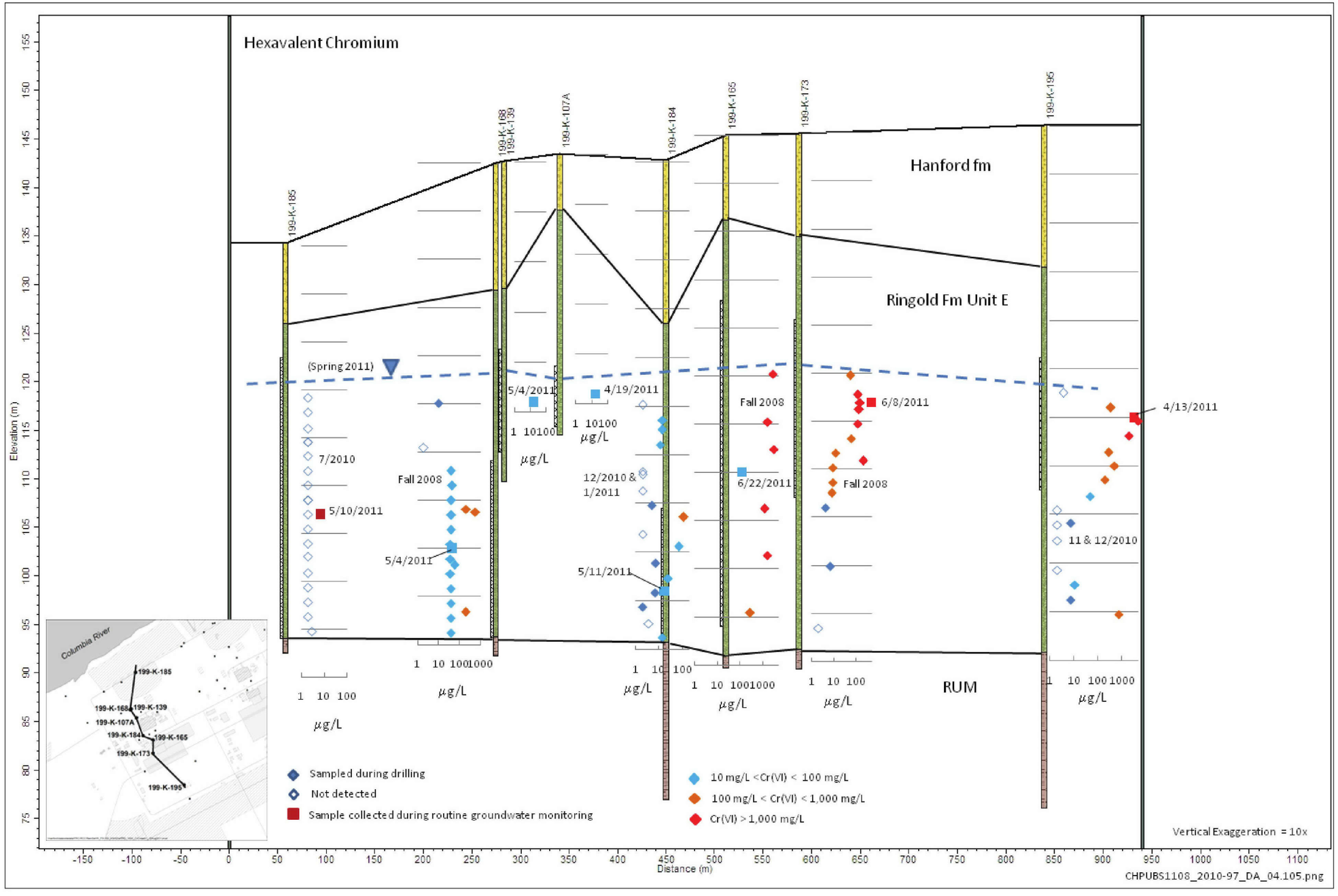

Figure 4-46. Vertical Distribution of Cr(VI)

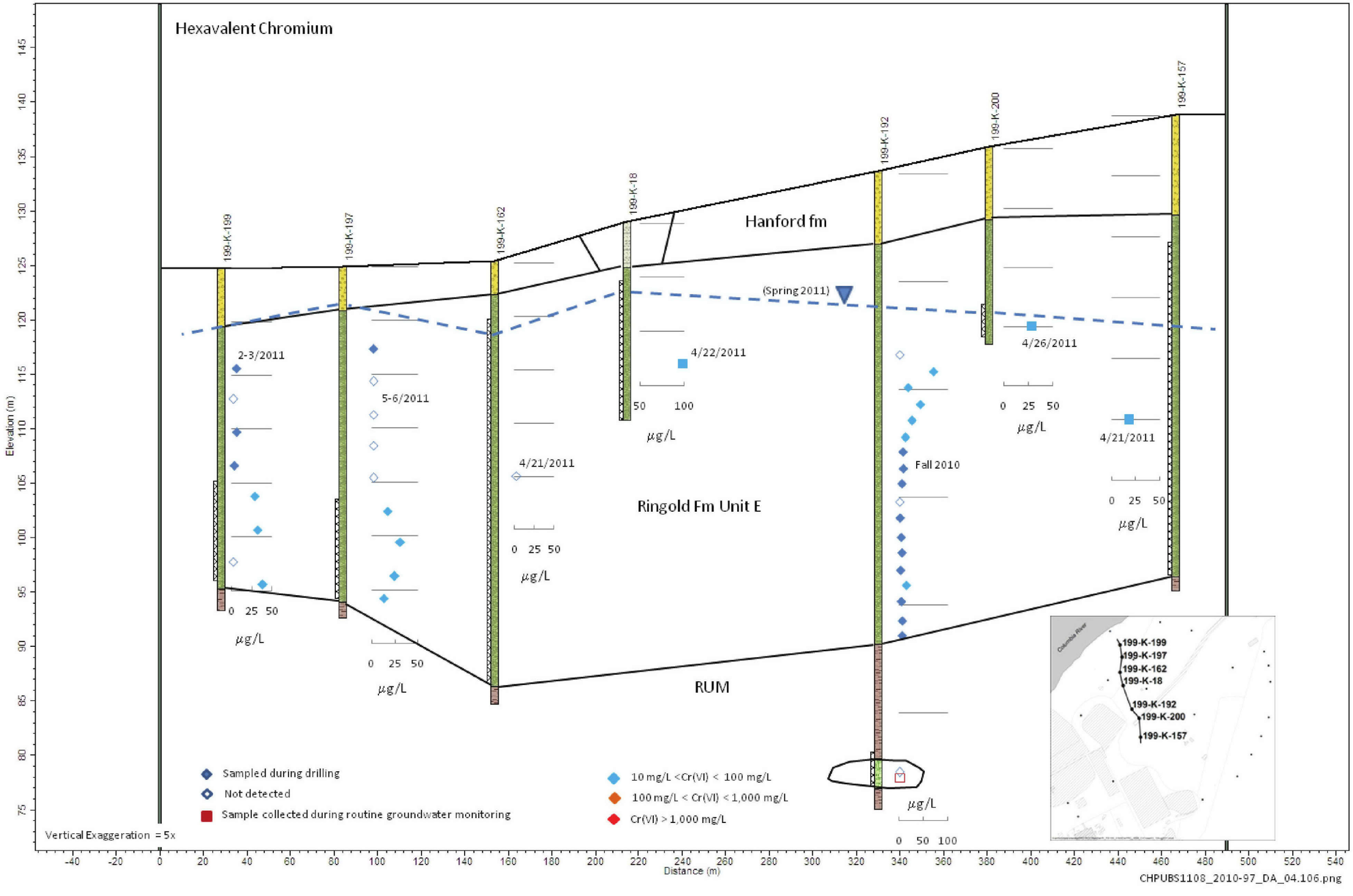

Figure 4-47. Vertical Distribution of Cr(VI)

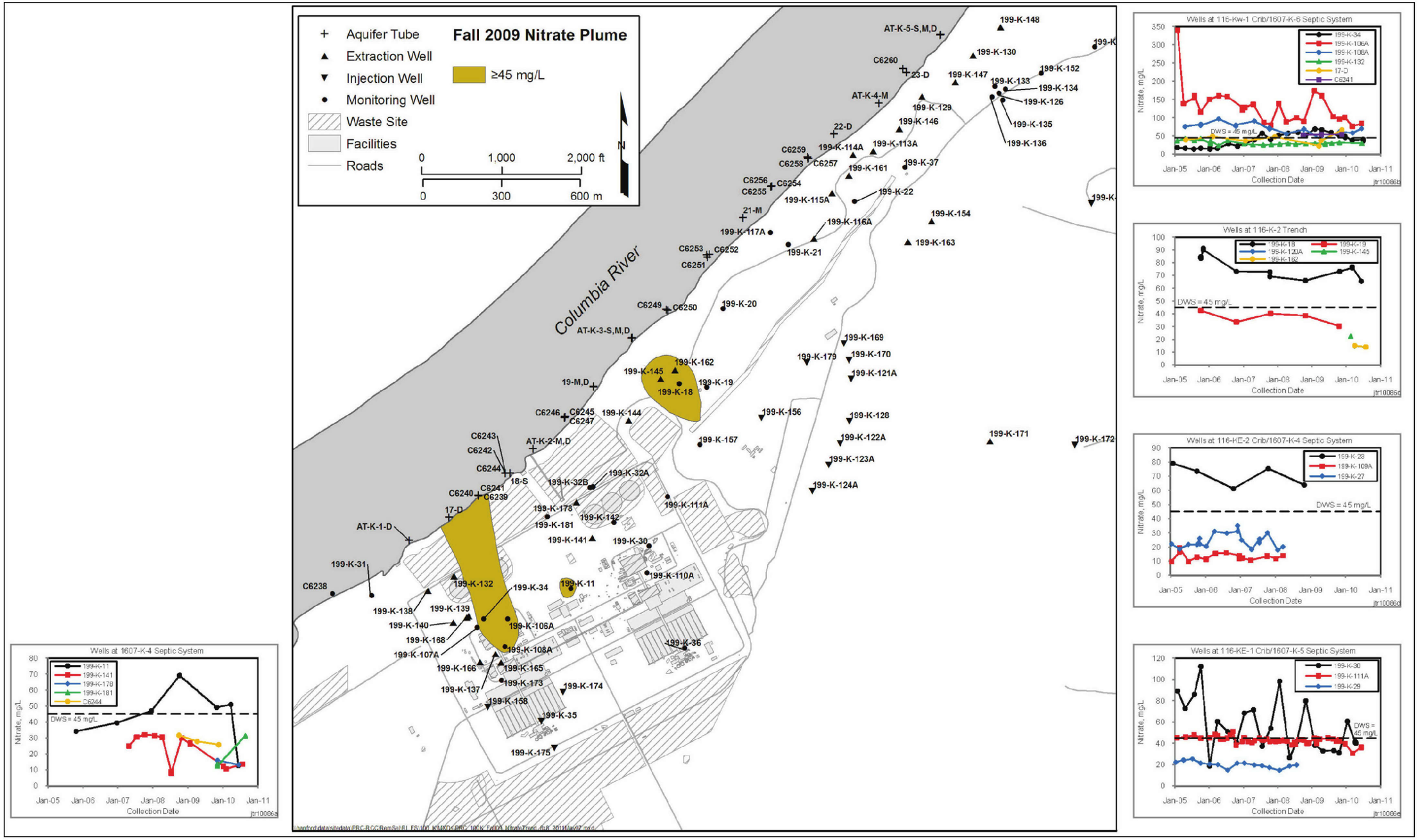

Figure 4-48. 100-K Area Nitrate Plume and Trend Plots

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Nitrate. Nitrate has been monitored at 100-K historically for many years. Nitrate was not designated as a co-contaminant at 100-K in the 1996 ROD. As part of the RI activities, extensive groundwater sampling was performed to update the assessment of nitrate throughout 100-K. Nitrate is present in groundwater in 100-K in most wells at or below the MCL, which is the AL at a concentration of 45 mg/L. The total footprint of the plume areas exceeding 45 mg/L is approximately 0.13 km^2 (0.05 mi^2) and is present predominantly in the 100-K West and 100-K East plumes. Potential sources of nitrate include 105-KE and 105-KW Reactor decontamination activities, septic systems, or pre-Hanford agricultural activities. Nitric acid was not known to be routinely used during reactor operations. Trend plots in Figure 4-48 show that nitrate concentrations in 100-K exhibit stable to decreasing trends in Wells 199-K-19, 199-K-27, 199-K-111A, 199-K-141, and 199-K-132 located in both the 100-K North and 100-K East plumes. Within the 100-K West plume, the frequency of detections above the AL (26 percent) is almost double that observed at 100-K East (15 percent), and indicates a higher magnitude of residual nitrate infiltration to groundwater from former waste sites located near the 100-K West Reactor area (116-KW-1, 1607-K6).

Within the 100-K East plume area, nitrate has exceeded the AL at Wells 199-K-29 and 199-K-30. Well 199-K-30 has trended well above the AL for the past 19 years, and has cycled between above- and below-AL values from 2006 to 2010. Well 199-K-29 has remained below the AL until the last sample drawn in December 2010, in which nitrate exceeded the AL. It is suspected but not verified that the sample results were mislabeled. The trend at 199-K-30 suggests that 116-KE-1 Crib may be a source for a small historical nitrate plume in this area.

Nitrate exceeded the AL in fall 2009 sampling in 199-K-18, 199-K-106A, and 199-K-108A. Increasing but below-AL trends were observed in 199-K-132 and 199-K-181. Nitrate concentrations in the other wells are below the AL in all recent sampling.

Upward gradients were observed in the deep RUM wells in 100-K. Combined with the low hydraulic conductivity of the RUM, there are no physical mechanisms for water to migrate below the base of the unconfined aquifer in 100-K.

Figure 4-49 shows fall 2009 and spring 2010 nitrate concentrations for 100-K wells. (Aquifer tubes were not sampled for nitrate in these areas in spring 2010; therefore, no bar charts comparing fall 2009 and spring 2010 were prepared.) Forty-one groundwater wells were sampled for nitrate in fall 2009 and spring 2010. In the 100-K East plume, concentrations greater than the 45 mg/L AL in groundwater samples collected were measured in five wells (12 percent) during the fall 2009 event and three wells (7 percent) during the spring 2010 event. Nitrate concentrations were greater in fall 2009 than in spring 2010 in 29 (71 percent) of the wells.

The nitrate plume extent varies seasonally, as suggested by the bar charts. The seasonal variation of 100-K nitrate plume extent is shown in plan view in Figure 4-50. The typical concentrations observed in the plumes during fall 2009 and spring 2010 is similar, with the fall being slightly higher. In approximately 50 percent of the wells, the fall sample concentration is considerably higher than the spring. During the spring when the Columbia River is a losing stream (diluting the groundwater near the river), both plumes are smaller.

Two aquifer tubes (17-D and C6241) located downgradient of 116-KW-1 Crib/1607K-6 Septic System and north of the new RI aquifer cluster detected nitrate concentrations that exceed the AL of 45 mg/L (fall 2009). None of the other 11 aquifer tubes located along the Columbia River shoreline in the 100-KE Reactor, 100-KW Reactor, or downgradient of the 116-K-2 Trench area detected nitrate above the AL. Nitrate concentrations measured in the new aquifer tube cluster were below the AL (Table 4-25).

All 15 RI monitoring wells were sampled between May 2010 and March 2011 for the presence of nitrate. Nitrate was detected above the AL at Wells 199-K-185, 199-K-190, 199-K-191, and 199-K-192 (Figure 4-51). The maximum detected concentration of nitrate measured in groundwater samples collected from all RI borings and monitoring wells is presented in Table 4-28. The concentration of nitrate was below the AL in the remaining RI monitoring wells. The two main plumes of nitrate contamination evident in 2009 data at 100-K are located near the 116-KW-1 Crib and immediately downgradient of the 116-K-1 Crib and the southwestern end of the 116-K-2 Trench. A third plume is associated with the 116-KE-1 Crib. The maximum detected nitrate concentration at 199-K-185 was 116 mg/L, consistent with the average detections observed in the K-West plume. The frequency of detections above the AL in the K-West plume was 26 percent over a five-year period, with median and maximum detections of 28.3 and 174 mg/L, respectively. Similar to the trend observed for higher concentrations of Cr(VI), the 100-K West plume contains the highest frequency of detections above the groundwater AL in any of the three plume areas.

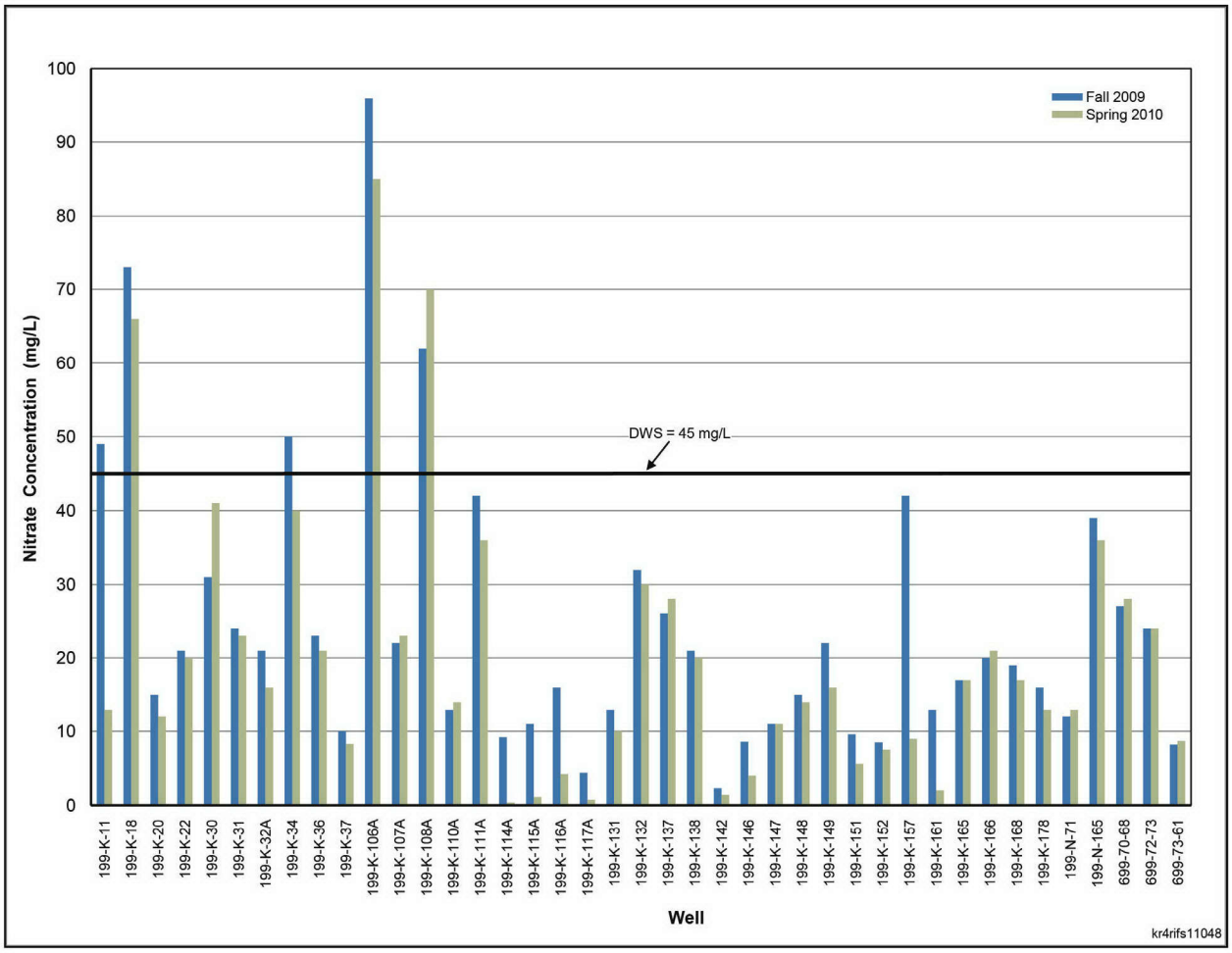
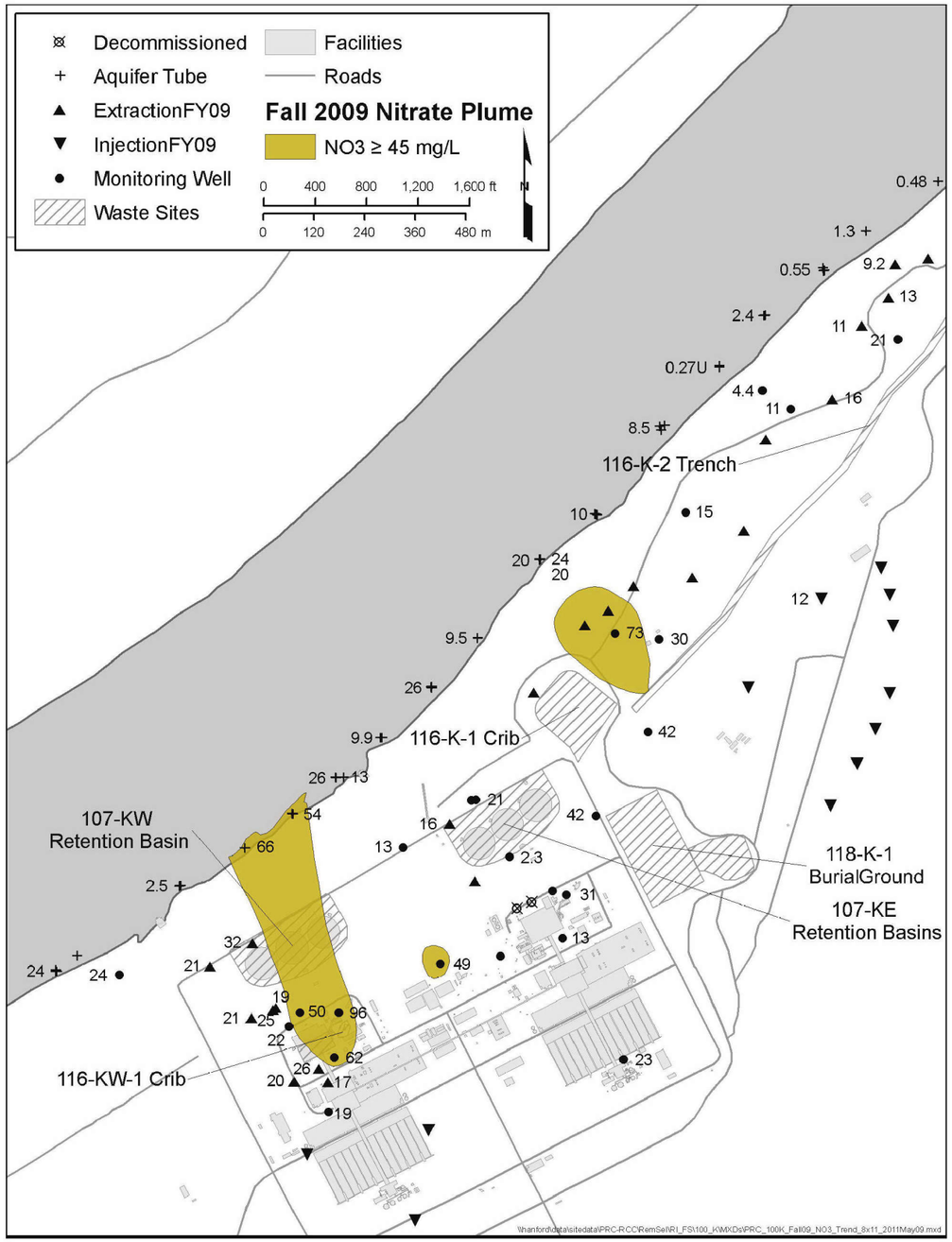


Figure 4-49. 100-K Area Bar Charts of Nitrate Concentrations in Wells, Fall 2009 and Spring 2010



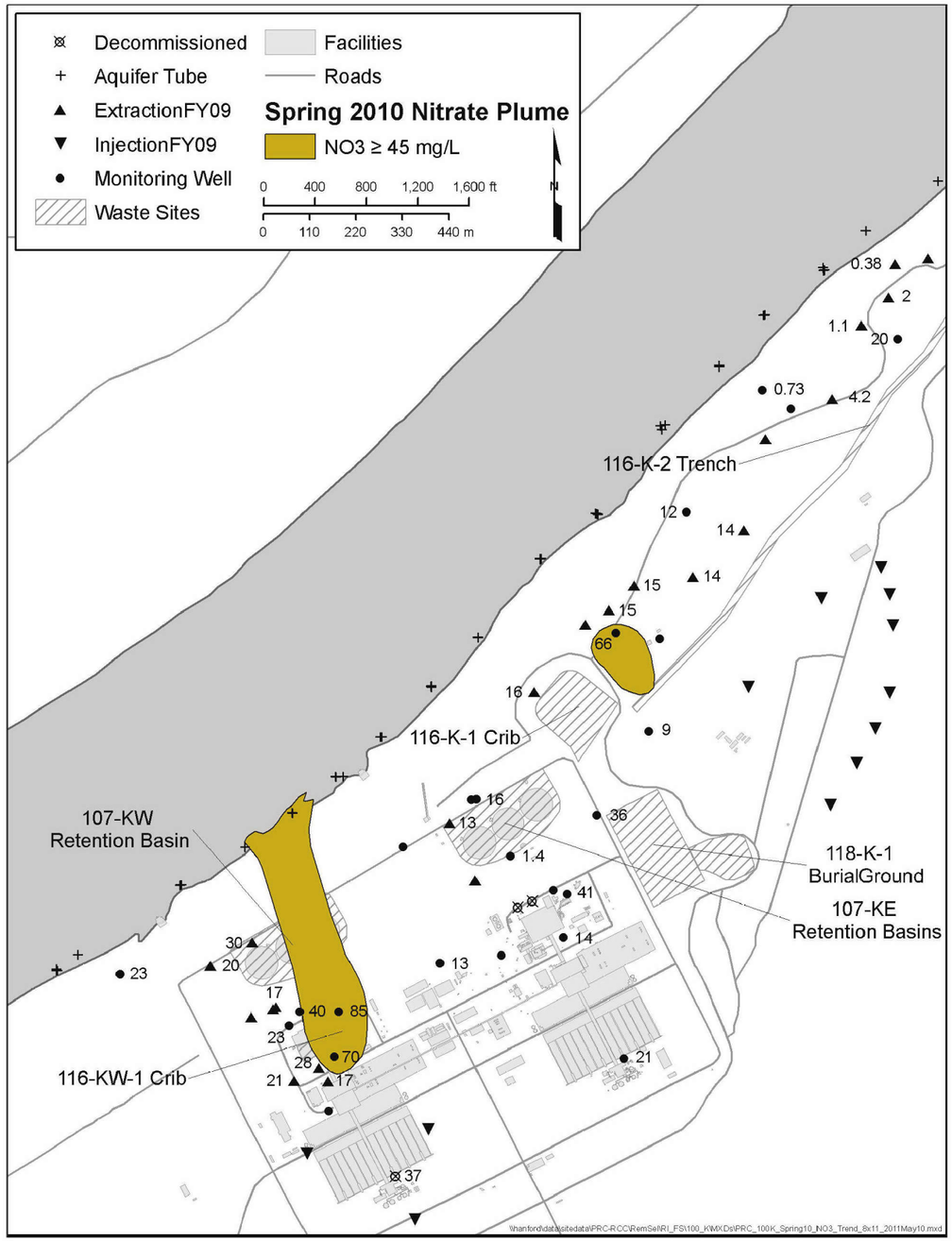


Figure 4-50. Fall 2009 and Spring 2010 Nitrate Plumes in 100-K

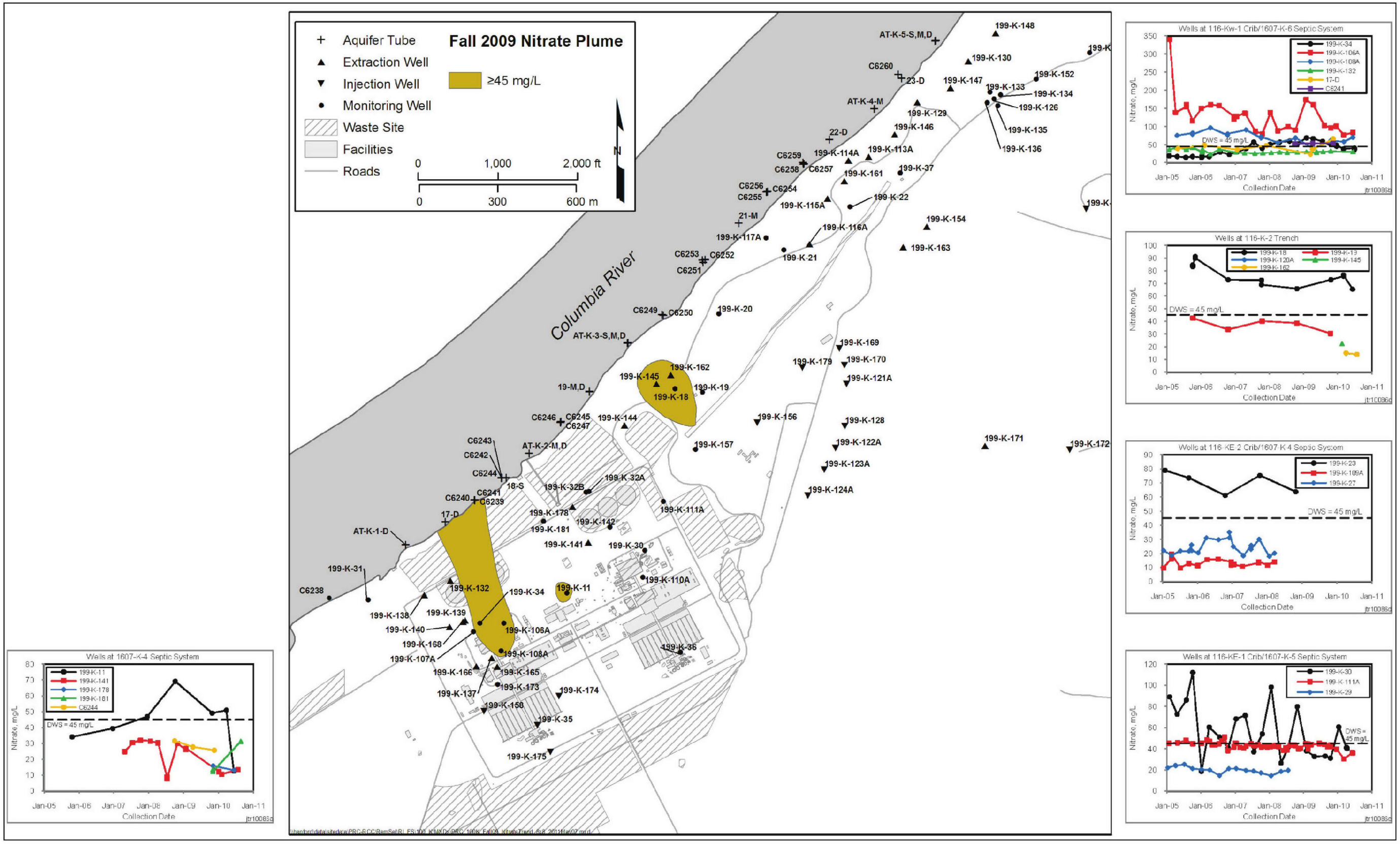


Figure 4-51. Maximum Concentration of Nitrate from Discrete RI Well Samples

Table 4-28. Detected Concentration of Nitrate above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below top of WL (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Nitrate Grab Groundwater Concentration (µg/L)
Constituent Action Level								**45,000**
199-K-185	C7685	2	7/2/2010	15.85	52.00	16.93 [53.26] to 40.70 [133.50]	B26507	99,200
199-K-185	C7685	2	7/6/2010	17.37	57.00		B264P0	105,000
199-K-185	C7685	2	7/6/2010	19.05	62.50		B264P1	116,000
199-K-185	C7685	2	7/8/2010	20.48	67.20		B264P3	96,900
199-K-185	C7685	2	7/8/2010	20.48	67.20		B264P2 (DUPLICATE)	97,800
199-K-185	C7685	2	7/8/2010	21.95	72.00		B264P4	66,000
199-K-190	C7690	4	8/3/2010	17.98	59.00	17.89 [56.41] to 40.55 [133.00]	B26VD5	54,000
199-K-191	C7691	6	6/24/2010	23.77	78	23.46 [74.67] to 46.74 [153.30]	B262V3	54,000
199-K-191	C7691	6	6/25/2010	25.30	83		B25WX5	76,600
199-K-191	C7691	6	6/28/2010	26.82	88		B25WX6	73,500
199-K-191	C7691	6	6/29/2010	27.65	90.7		B25WX1	59,800
199-K-191	C7691	6	6/29/2010	29.66	97.3		B25WX2	55,800
199-K-192	C7692	R2	8/31/2010	16.76	55	10.70 [32.82] to 43.45 [142.50]	B277B3	56,200

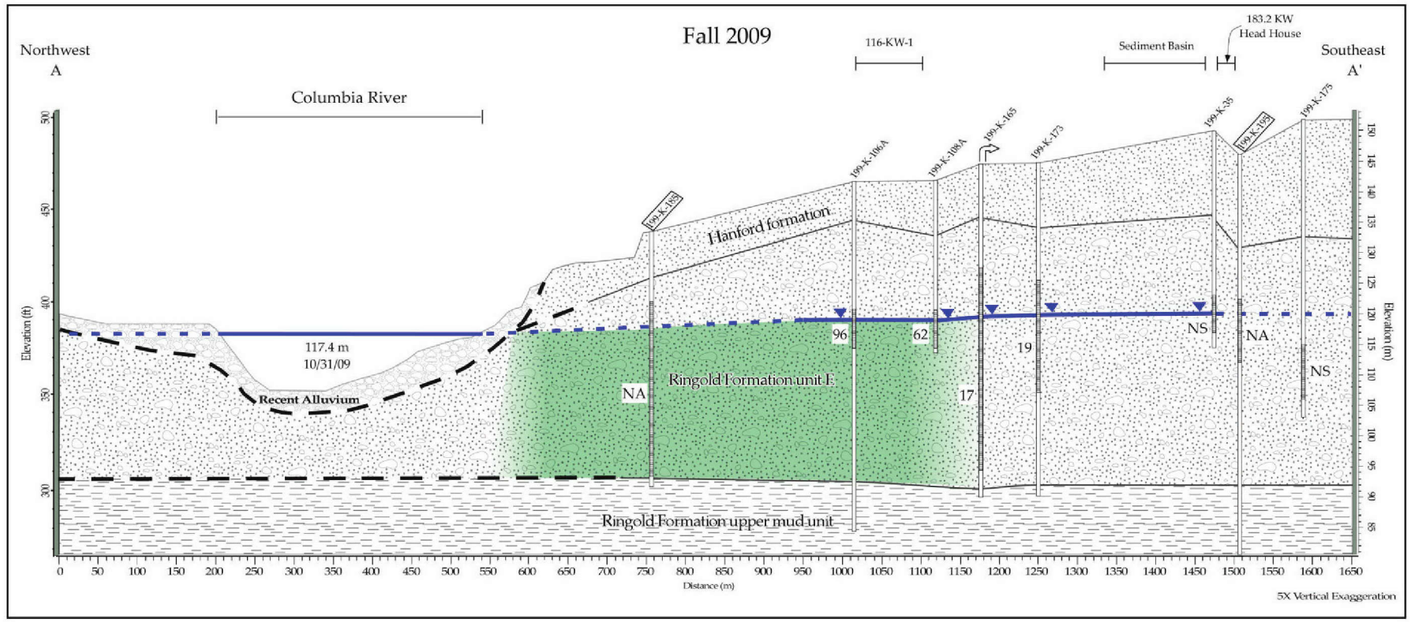
The frequency of detections above the AL in the 100-K East plume was 15 percent over a five-year period, with median and maximum detections of 24.8 and 98.3 mg/L, respectively. The frequency of detections above the AL in the 100-K North plume was 2 percent over a five-year period, with median and maximum detections of 10.8 and 58.8 mg/L, respectively.

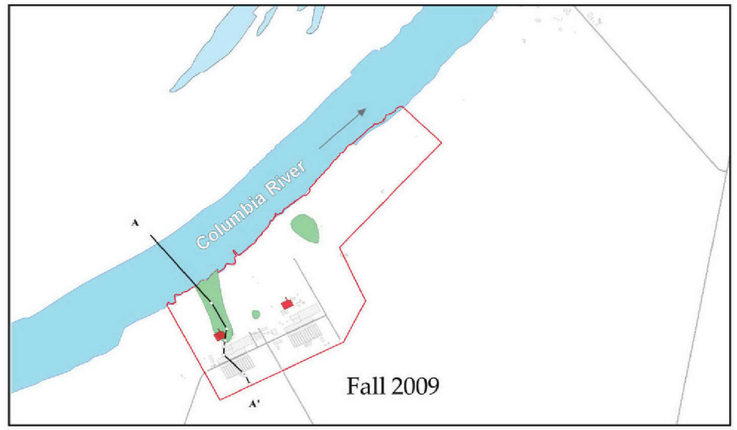
The maximum detected concentrations observed in samples collected from 199-K-190 and 199-K-191 were 54 and 76 mg/L at depths of 18 m (59 ft) bgs and 25 m (83 ft) bgs, respectively. The detection of nitrate in both wells was slightly above the AL. The RI data collected from 199-K-190 shows nitrate concentrations elevated at the top of the aquifer and diminishing rapidly with aquifer depth. This data may be related to recent elevated nitrate concentrations observed at 199-K-11. Elevated nitrate levels at 199-K-191 are not observed at downgradient wells. This well is close to the 126-K-1 Landfill site and may be tied to wastes disposed within it (Figure 4-51).

Nitrate was detected at one concentration above the AL in the uppermost grab groundwater sample collected at 199-K-192 (56 mg/L) at a depth of 17 m (55 ft) bgs. The concentration measured in 199-K-192 is slightly above the AL but consistent with the concentrations measured in 199-K-18 (66 mg/L in spring 2010) screened within the upper unconfined aquifer and located within the nitrate plume immediately northeast of the 116-K-1 Crib waste site.

Figures 4-52 through 4-56 show 100-K cross sections depicting the vertical extent of nitrate contamination.

Summary. Nitrate concentrations in 100-K show stable to decreasing trends in wells located in both the 100-K West and East plumes, which appear to be related to the Gas Condensate Cribs. The frequency of detections in 100-K West above the AL is almost double that observed the 100-K East plume and indicates a higher magnitude of residual nitrate infiltration to groundwater from former waste sites located near the K-West Reactor area. A new plume may exist around 199-K-191 and may be associated with the 126-K-1 Landfill. A plume at the southwest end of the 116-K-2 Trench may be related to decontamination wastes discharged following reactor operations at 100-K. There is no evidence of nitrate migration between the unconfined and the water-bearing zone encountered in the RUM. Hydraulic gradients in the RUM are upward, the hydraulic conductivity of the unit is low, and no nitrate was observed in sampling of the unit for this report.





Nitrate ≥ 45 mg/L (Drinking Water Standard)

0.27U Nitrate ≥ PQL

NS/NA Not Sampled/Not Applicable

Section Location

100 - KR-4 Boundary

Geologic Contact (dashed where inferred)

Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010

The extent of the Nitrate plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.

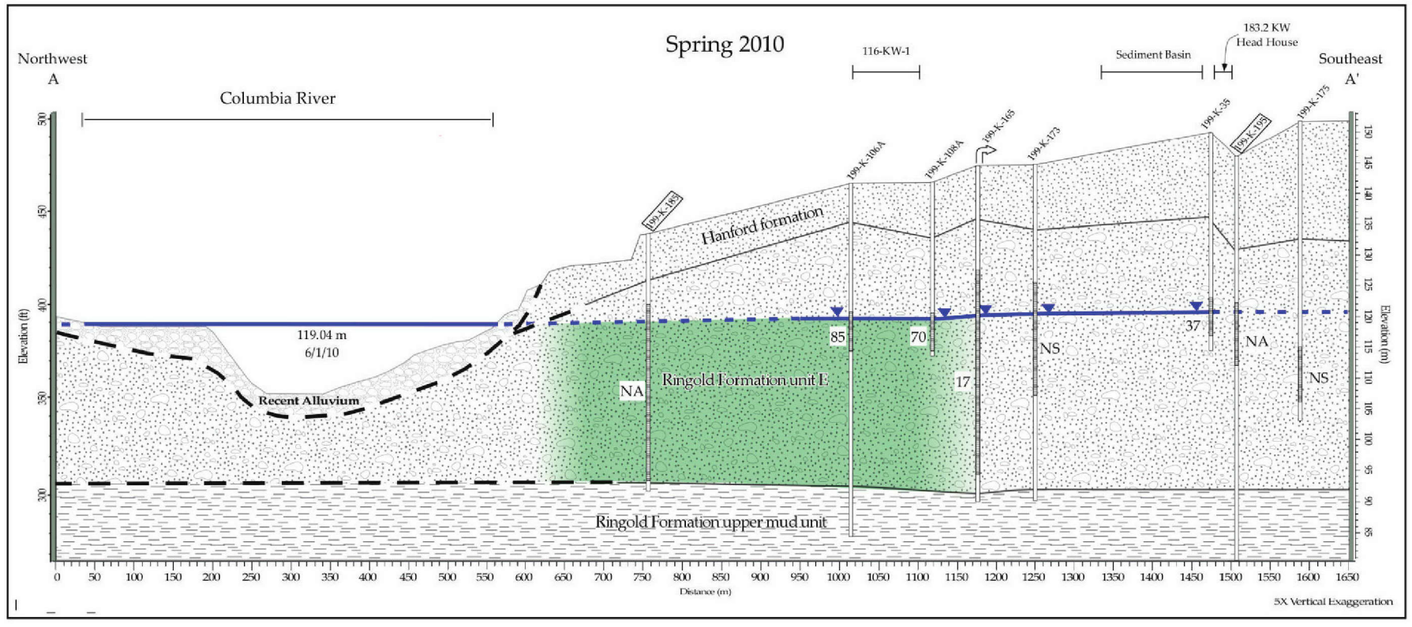
Future RI/FS Well

Extraction Well

Injection Well

Screen/perforated interval

199-K-195 New RI Well



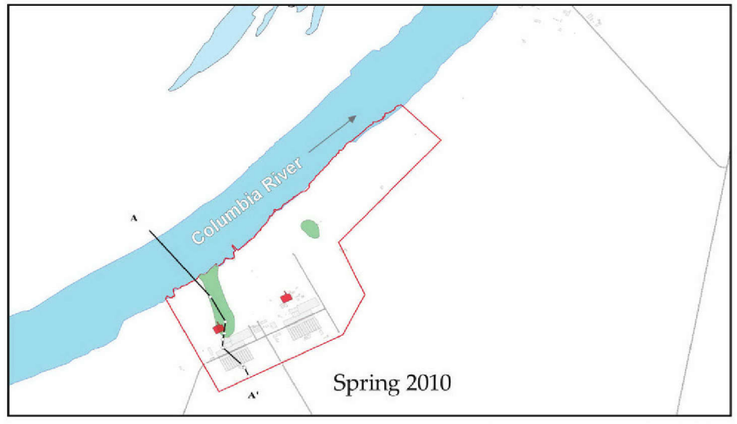


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Figure 4-52. Nitrate Concentration on Cross Section A-A'

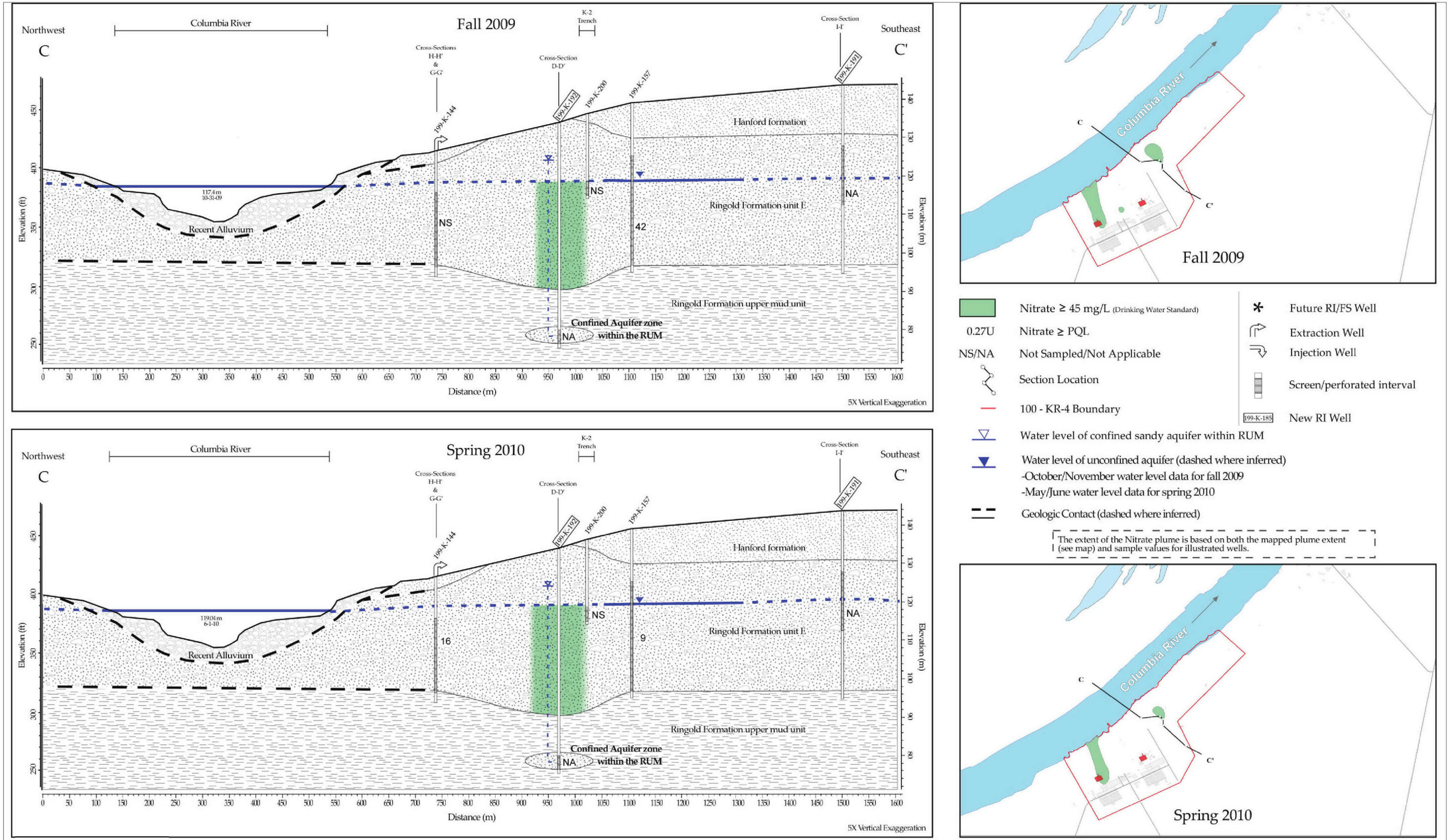
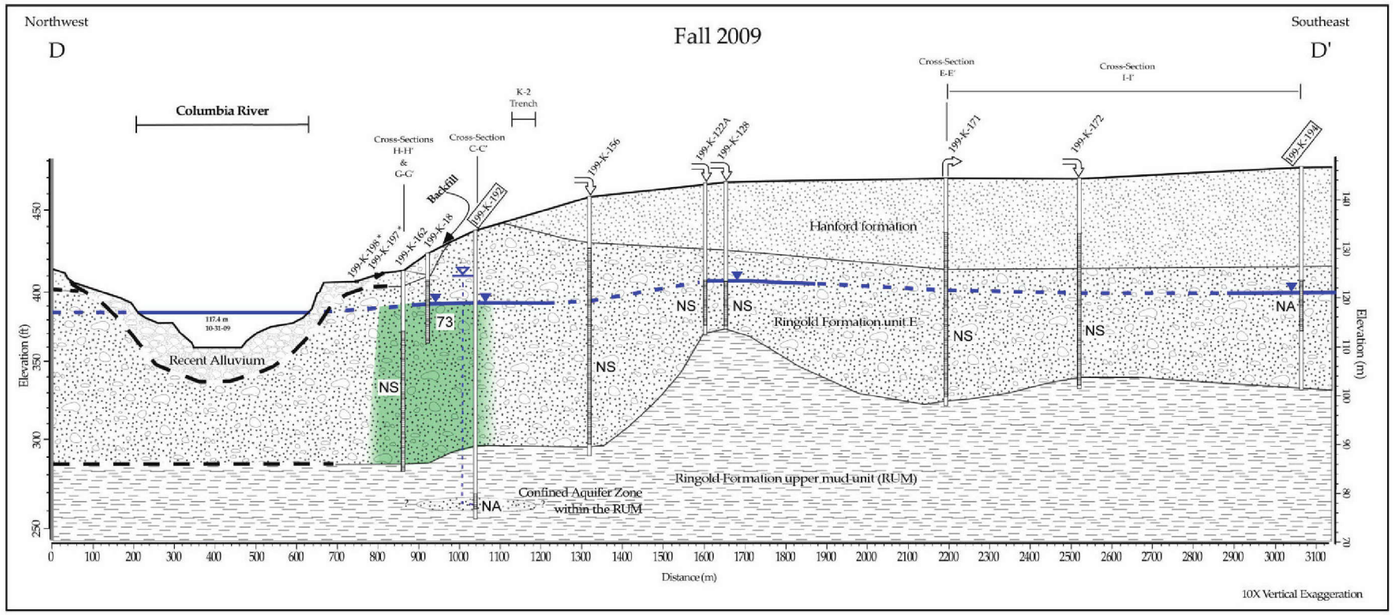
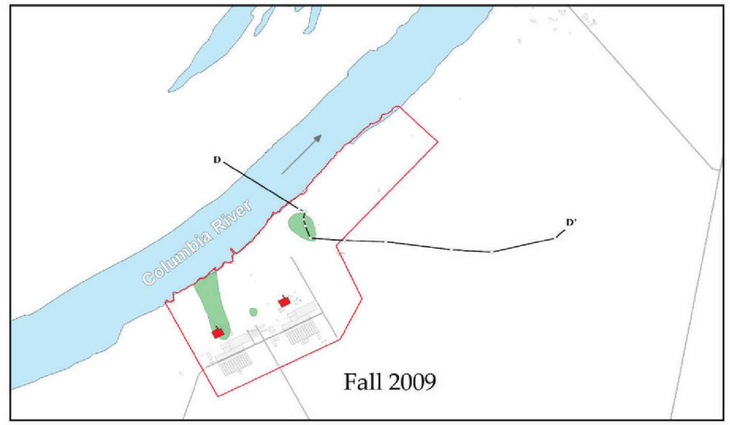


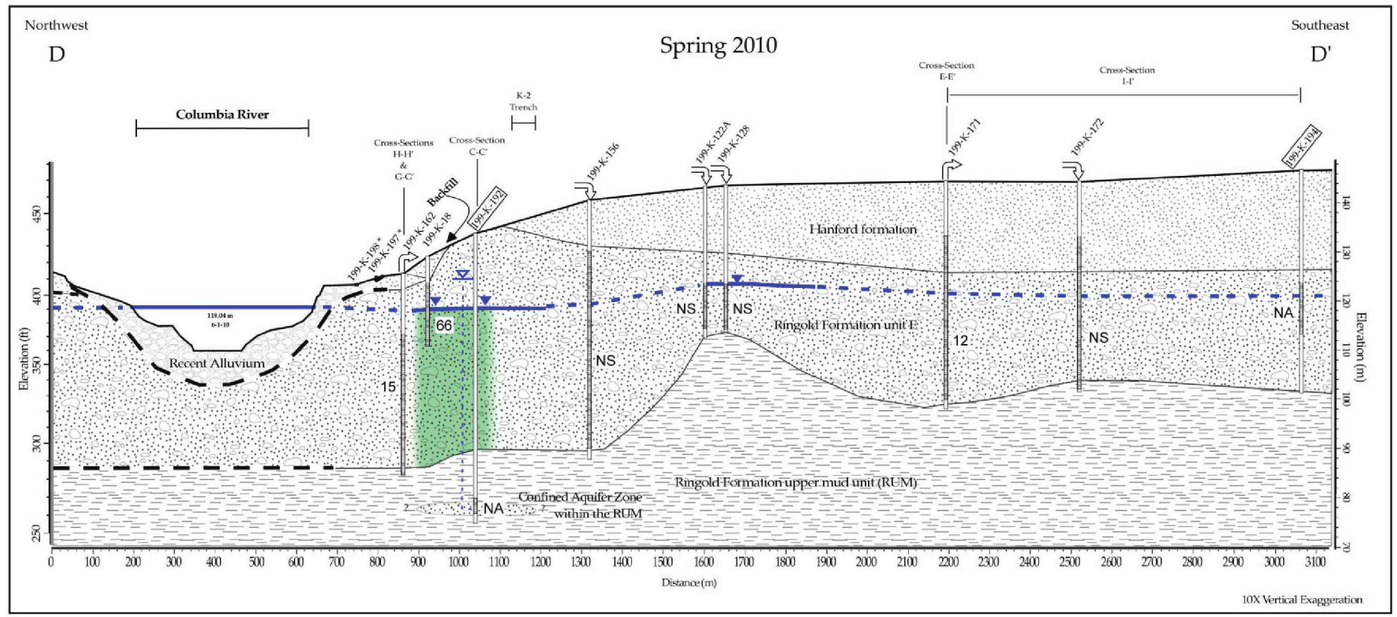
Figure 4-53. Nitrate Concentration on Cross Section C-C'





Nitrate ≥ 45 mg/L (Drinking Water Standard)
0.27U Nitrate ≥ PQL
NS/NA Not Sampled/Not Applicable
Section Location
100 - KR-4 Boundary
Geologic Contact (dashed where inferred)
Water level of confined sandy aquifer within RUM
Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010
Future RI/FS Well
Extraction Well
Injection Well
Screen/perforated interval
199-K-185 New RI Well

The extent of the Nitrate plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.



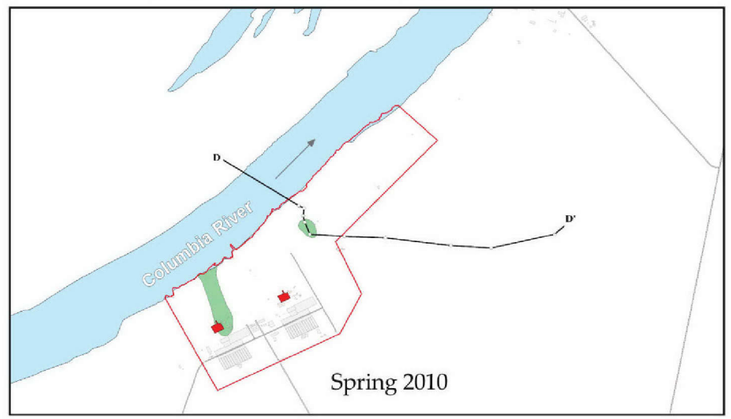


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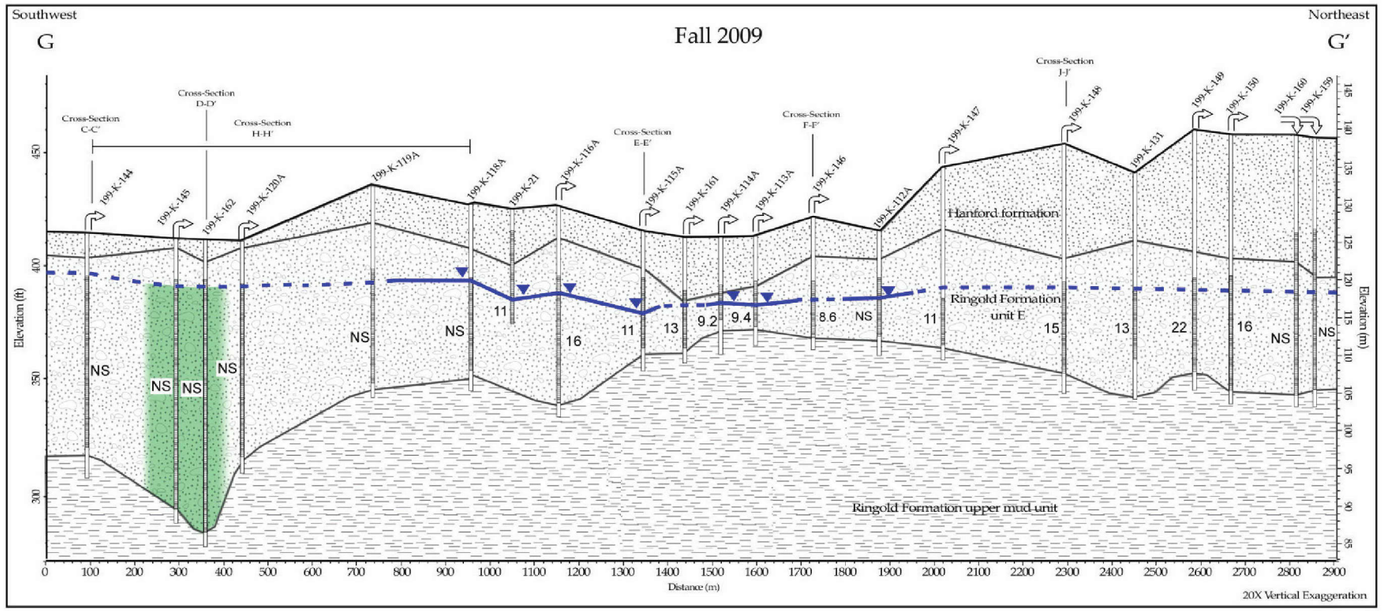
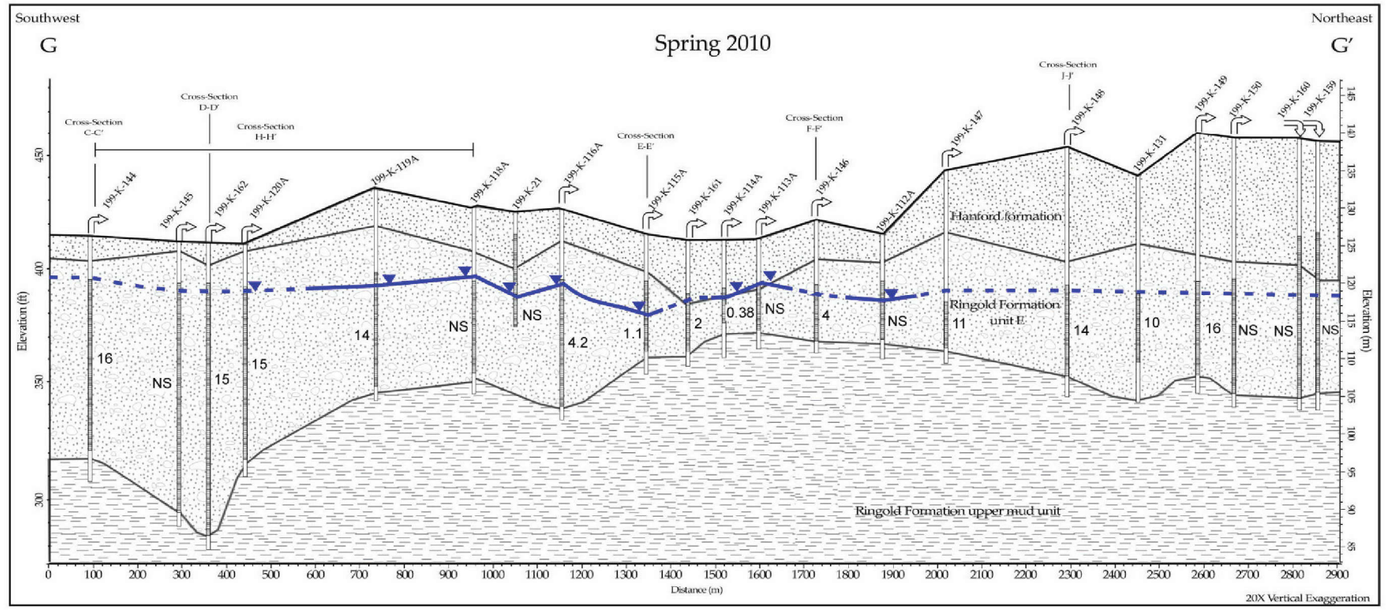
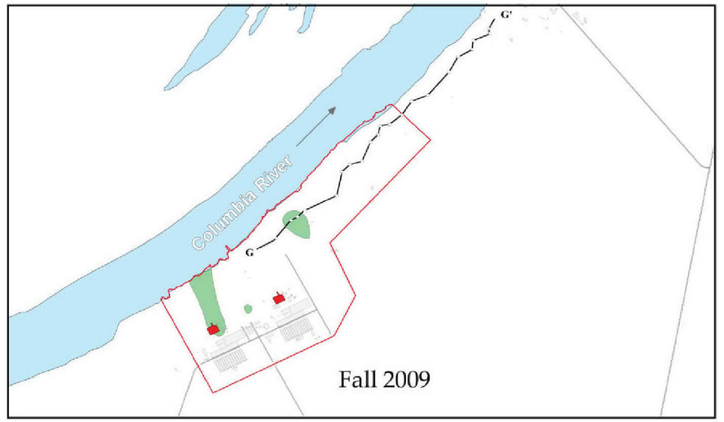
Figure 4-54. Nitrate Concentration on Cross Section D-D'







Nitrate ≥ 45 mg/L (Drinking Water Standard)

0.27U Nitrate ≥ PQL

NS/NA Not Sampled/Not Applicable

Section Location

100 - KR-4 Boundary

Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010

Future RI/FS Well

Extraction Well

Injection Well

Screen/perforated interval

The extent of the Nitrate plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.

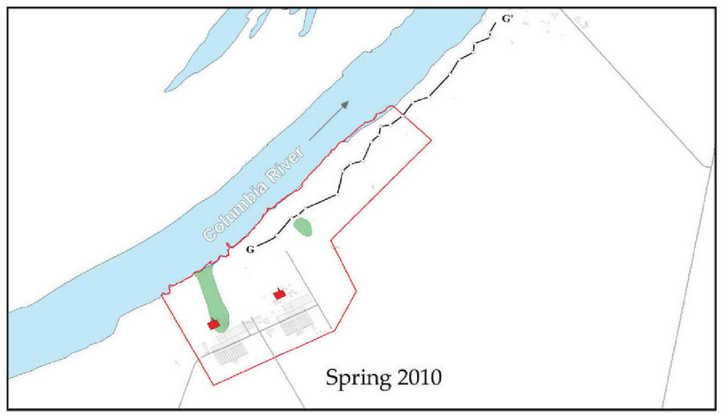


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Figure 4-55. Nitrate Concentration on Cross Section G-G'

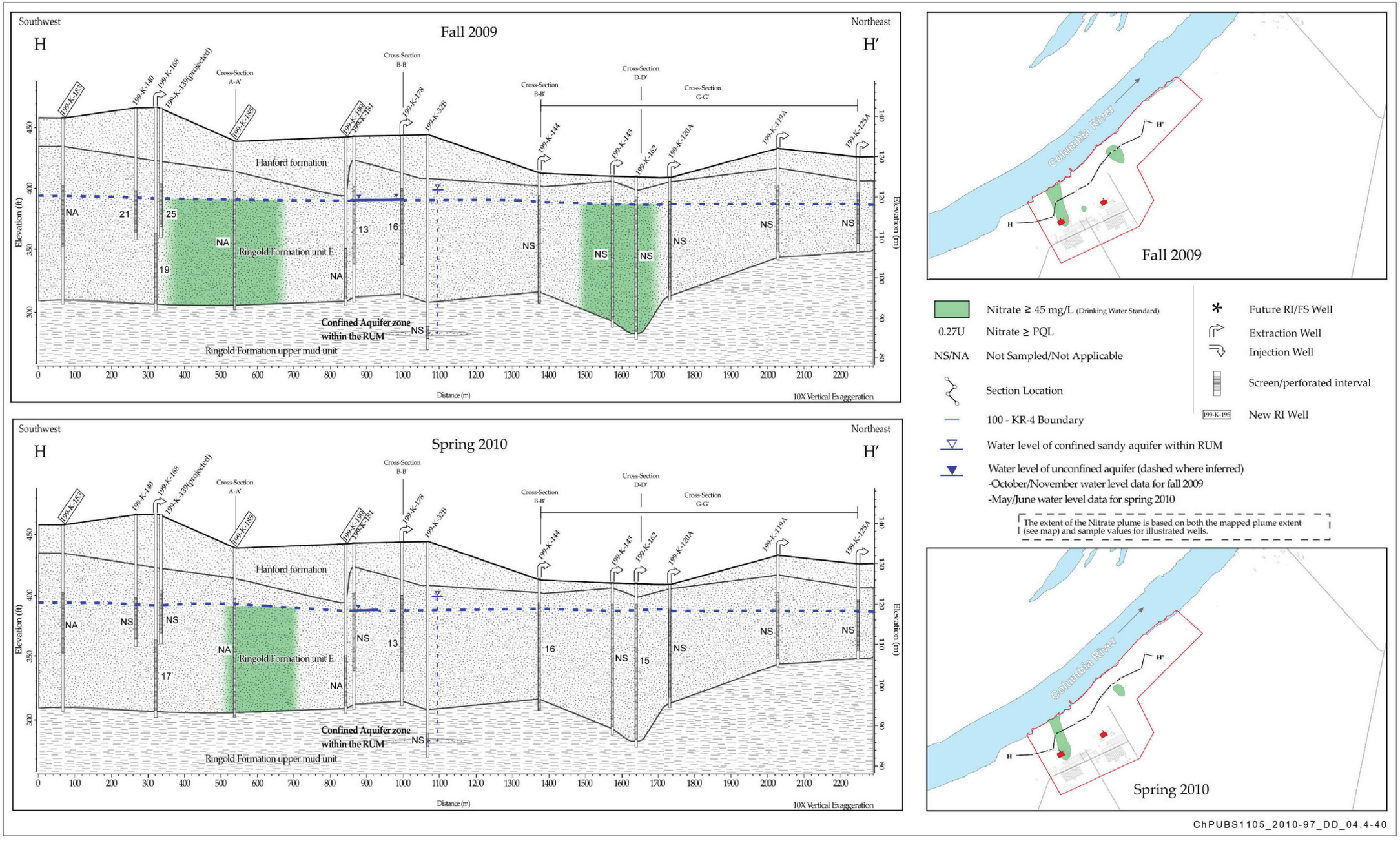

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Figure 4-56. Nitrate Concentration on Cross Section H-H'

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Tritium. Extensive groundwater sampling for tritium was performed prior to RI activities as part of ongoing monitoring throughout 100-K. Tritium is found in groundwater within the northwestern portion of the 100-K East plume and is also in the 100-K East plume centrally located in 100-K.

The total footprint of the plume areas exceeding 20,000 pCi/L (the AL for tritium) is approximately 0.08 km^2 (0.03 mi^2). Potential sources of tritium plume include 116-KW-1 and 116-KE-1 Gas Condensate Cribs, the 105-KE FSB and associated 116-KE-3 Crib, and the 118-K-1 Burial Ground (Figure 4-2). Tritium plumes with activities above the AL are present in two areas within the 100-K East plume—located downgradient of the 118-K-1 Burial Ground and the 116-KE-1 Gas Condensate Crib. The highest activity (350,000 pCi/L) occurs downgradient of 118-K-1 Burial Ground. The frequency of detection above the AL within the 100-K East plume is 24 percent with a median detection of 8,300 pCi/L and a maximum detected activity of 621,000 pCi/L in 2008. Elevated tritium concentrations observed at 199-K-109A are noted before 2006 but have declined since. The tritium trend for 199-K-107A at the 105-KW FSB and the 116-KW-2 Crib, the equivalent to 199-K-109A at KE FSB, does not show above-AL values since drilled in 1992.

Figure 4-57 shows tritium activity and trend plots for 100-K. Tritium activity is generally decreasing in 100-K. Wells 199-K-18, 199-111A, and 199-K-141 show slightly increasing to increasing trends. In fall 2009, four wells (199-K-18, 199-K-157, 199-K-30, and 199-K-29) exceeded the AL. Well 199-K-192 encountered high levels of tritium in the uppermost aquifer, reaching 1,400,000 and 970,000 pCi/L in the first two samples 1.5 to 3.1 m (5 to 10 ft) below the top of the aquifer. The current elevated levels of tritium at 199-K-18 and 199-K-192, plus declining concentrations at 199-K-157, may be attributed to remediation activities at the 118-K-1 Burial Ground.

Wells 199-K-199 and 199-K-198 were drilled in March and April 2011 as part of Phase 3 RPO activities at 100-K. These two wells are downgradient of 199-K-18, 199-K-120A, 199-K-162, 199-K-145, and 199-K-144. These wells did not exceed the AL for tritium. The four extraction wells have been above the AL at some point between 2006 and 2010.

The maximum detected activity of tritium within the K-East plume area 199-K-189 was measured at 140,000 pCi/L during the RI field activities. This was consistent with activity measured in 199-K-30 during the fall 2009 and spring 2010 periods at 140,000 and 190,000 pCi/L, respectively. The consistent activity measured in 199-K-30, 199-K-27, and 199-K-32A, and the RI 199-K-189 shows further evidence of the tritium plume extent near the KE Reactor complex and in the downgradient portion of the 100-K East plume.

Figure 4-58 shows tritium fall 2009 and spring 2010 activities for 100-K wells. No 100-K aquifer tubes were sampled for tritium in spring 2010. Therefore, bar charts were not constructed for aquifer tubes. In fall 2009 and spring 2010, 21 groundwater wells were sampled for tritium. Activities greater than the AL were measured in three wells (13 percent) of the fall 2009 well samples and in four wells (17 percent) of the spring 2010 well samples. Tritium activity was higher in fall 2009 than in spring 2010 in nine (38 percent) of the wells.

There are no near-river plume tritium activities that exceed the AL in 100-K. None of the aquifer tubes, including the new RI aquifer tube cluster, located along the Columbia River shoreline in the 100-KE Reactor, KW Reactor, or downgradient of the 116-K-2 Trench areas, detected tritium above the AL.

The seasonal variation of 100-K tritium plume extent is shown in plain view in Figure 4-59. There is a slight variation in plume sizes between fall 2009 and spring 2010, but the plume extents are very similar. In general, the tritium concentrations in spring 2010 are similar (some slightly higher and some slightly

lower) than fall 2009. Locally at the southwest end of the 116-K-2 Trench, tritium concentrations appear to be increasing as less tritium-rich groundwater from around the 118-K-1 Burial Ground moves downgradient. Extraction wells from the KR-4 pump-and-treat system (199-K-144, 199-K-145, 199-K-162, and 199-K-120A) are located within the areas identified with tritium. IX systems at 100-K do not treat tritium. Monitoring wells downgradient of the 116-K-2 Trench and the KR-4 injection field have detected increasing but below-AL tritium levels. Tritium concentrations at 199-K-20, 199-K-119A, and 199-K-125A have increased since start of pump-and-treat operations in 1997, to concentrations between 7,900 and 8,300 pCi/L.

Wells 199-K-200 and K-201 were sampled in January 2011; tritium was detected at concentrations of 3,200 and 280 pCi/L, respectively. Maximum detections of tritium above the action level are shown in Figure 4-60, and the detected activities of tritium above the action level measured in groundwater samples collected from all RI borings and monitoring wells are presented in Table 4-29. The distribution of tritium concentrations in 199-K-189 and 199-K-192 is consistent with the historical plume (100-K East) distribution as shown in Figure 4-59. Figures 4-61 through 4-65 show 100-K cross sections depicting tritium contamination. Vertical profiles of tritium at the RI wells shown in Figure 4-66 are near the 100-KW area and the profiles in Figure 4-67 are in 100-KE area. Well 199-K-189 is within the tritium plume (Figure 4-59).

Summary. In general, tritium concentrations are generally decreasing at the majority of 100-K wells. Wells at the southwest end of the 116-K-2 Trench are undergoing significant changes, possibly linked to remediation activities at 118-K-1 Burial Grounds. Based on grab groundwater samples collected from Well 199-K-192, tritium does not seem to have migrated to the confined portion of the lower RUM unit.

Carbon-14. Before and during the RI activities, extensive groundwater sampling was performed for carbon-14 throughout 100-K. Carbon-14 is present in groundwater in 100-K in two locations—the 100-K East and West plumes. The highest activities are found in wells located near the former 116-KW-1 and 116-KE-1 Cribs. The total footprint of the plume areas exceeding 2,000 pCi/L, the AL for carbon-14, is approximately 0.06 km^2 (0.02 mi^2). Potential sources of carbon-14 plumes include the 116-KW-2 and 116-KE-1 Gas Condensate Cribs and, to a lesser degree, the 116-K-2 Trench (Figure 4-2). The 100-K carbon-14 activity above the AL is present in two plume areas, one immediately downgradient of the 116-KE-1 Crib and 100-KE Reactor within the 100-K East plume and one immediately downgradient of the 116-KW-1 Crib. The 100-K West plume is being pulled to the west beneath the former 107-KW Retention Basins by pumping at 100-KW Extraction Well 199-K-132 (Figure 4-68).

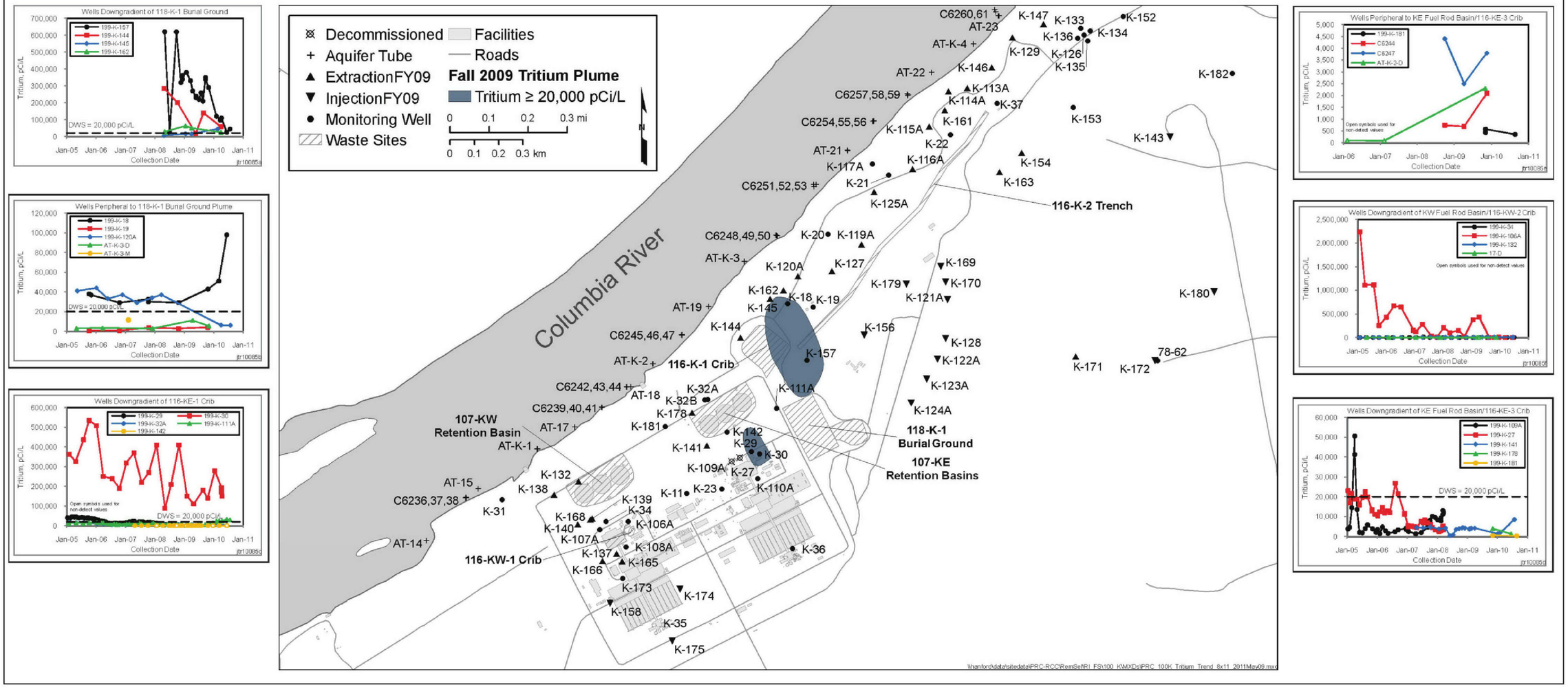


Figure 4-57. 100-K Area Tritium Plume and Trend Plots

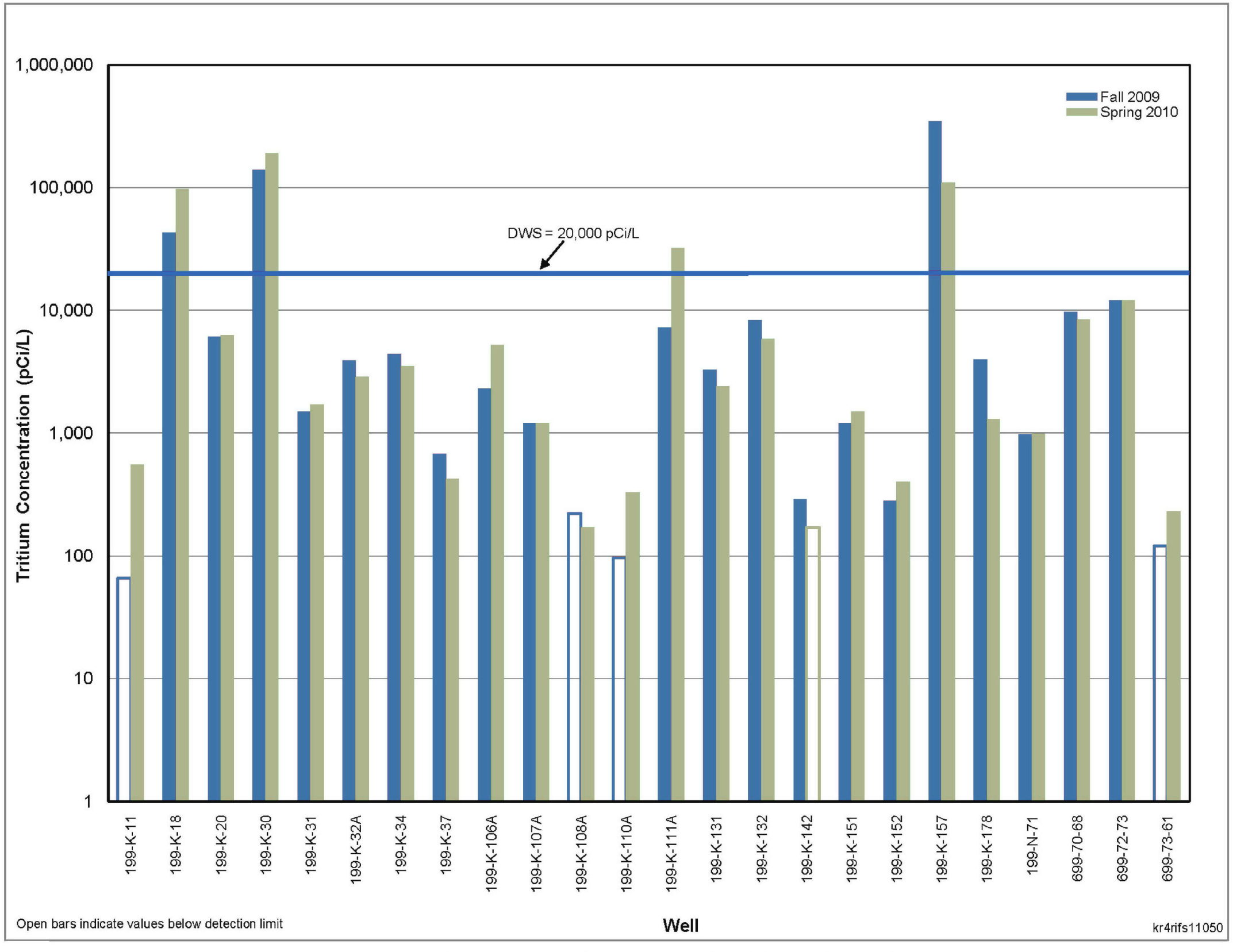


Figure 4-58. 100-K Area Bar Charts of Tritium Activity in Wells, Fall 2009 and Spring 2010

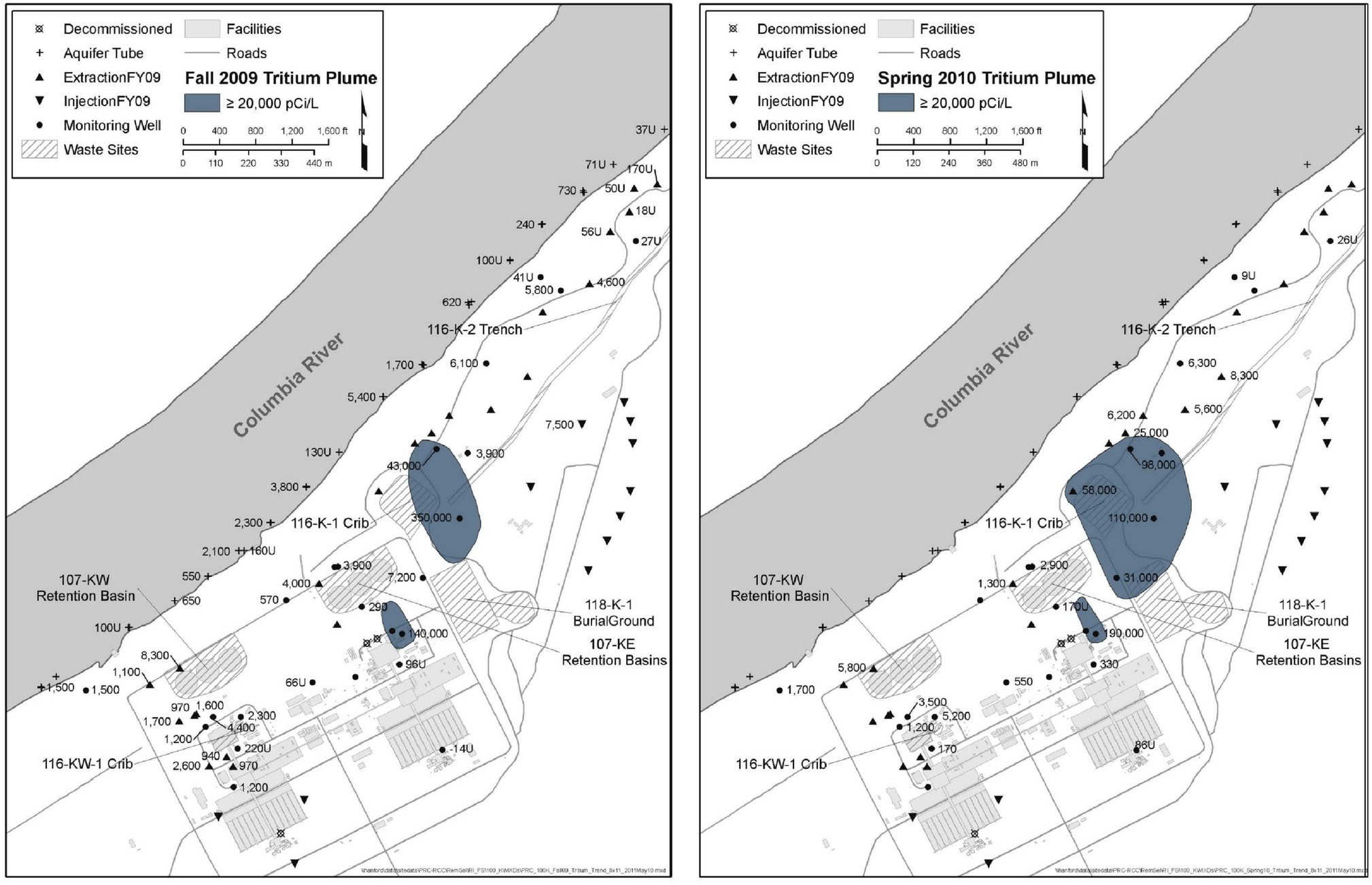


Figure 4-59. Fall 2009 and Spring 2010 Tritium Plumes in 100-K

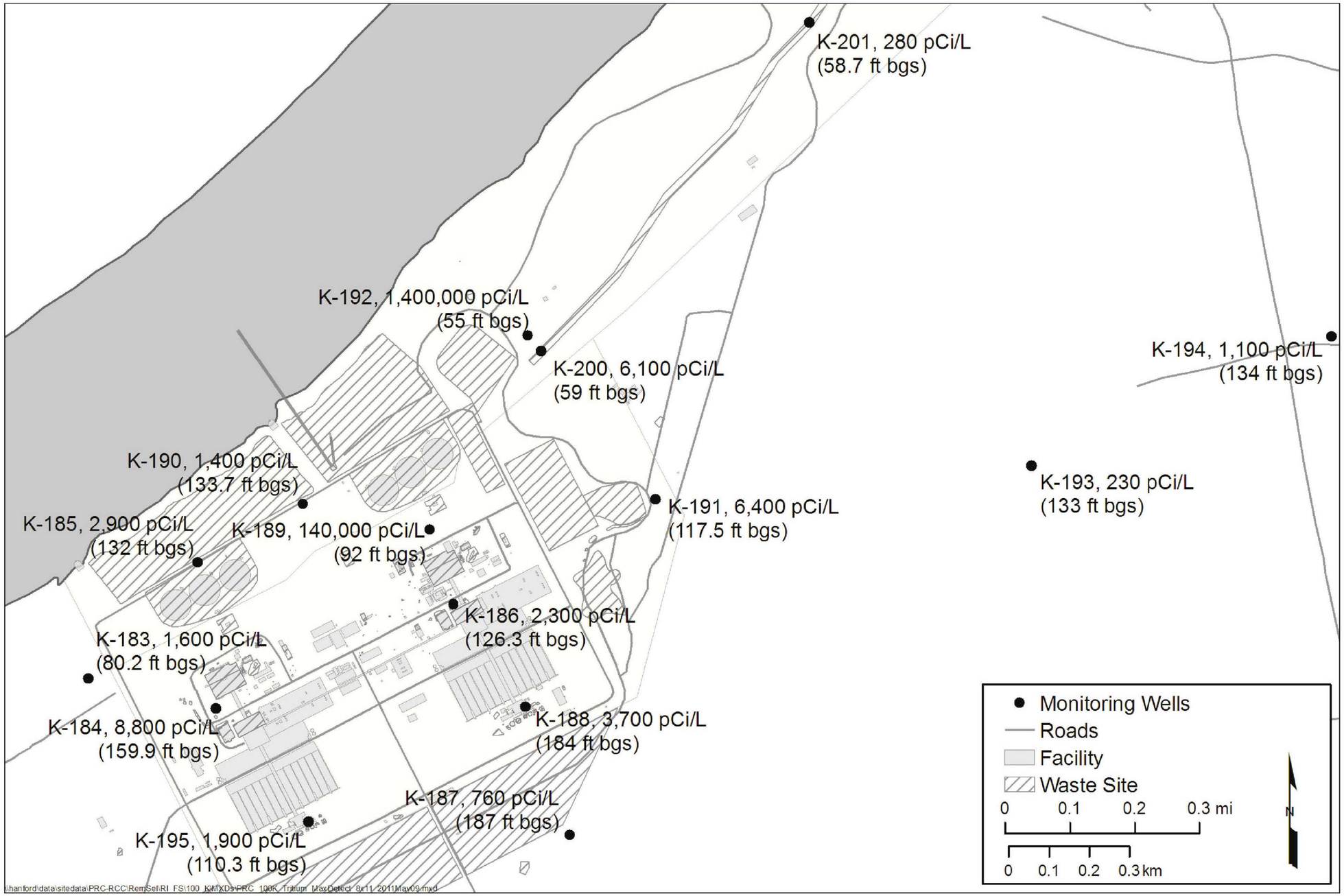


Figure 4-60. Maximum Activity of Tritium from Discrete RI Well Samples

Table 4-29. Detected Activity of Tritium in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of WL (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Tritium Grab Groundwater (pCi/L)
Constituent Action Level								**20,000**
199-K-189	C7689	5	8/19/2010	26.73	87.70	23.42 [74.55] to 46.95 [154.00]	B26WR7	86000
199-K-189	C7689	5	8/20/2010	28.04	92.00		B26WR8	140000
199-K-189	C7689	5	8/23/2010	29.57	97.00		B26WR9	92000
199-K-189	C7689	5	8/23/2010	29.57	97.00		B26WT0 - DUPLICATE	93000
199-K-189	C7689	5	8/25/2010	32.61	107.00		B26WT2	36000
199-K-192	C7692	R2	8/31/2010	16.76	55	10.70 [32.82] to 43.45 [142.50]	B277B3	1400000
199-K-192	C7692	R2	8/31/2010	18.29	60		B277B4	960000
199-K-192	C7692	R2	9/1/2010	19.81	65		B277B5	670000
199-K-192	C7692	R2	9/2/2010	21.37	70.1		B277B6	350000
199-K-192	C7692	R2	9/3/2010	22.86	75		B277B7	87000
199-K-192	C7692	R2	9/7/2010	24.44	80.2		B277B8	48000
199-K-192	C7692	R2	9/7/2010	24.44	80.2		B277B9 - DUPLICATE	49000
199-K-192	C7692	R2	9/8/2010	25.79	84.6		B277C0	36000
199-K-192	C7692	R2	9/10/2010	27.34	89.7		B277C1	51000
199-K-192	C7692	R2	9/14/2010	30.36	99.6		B277C3	27000

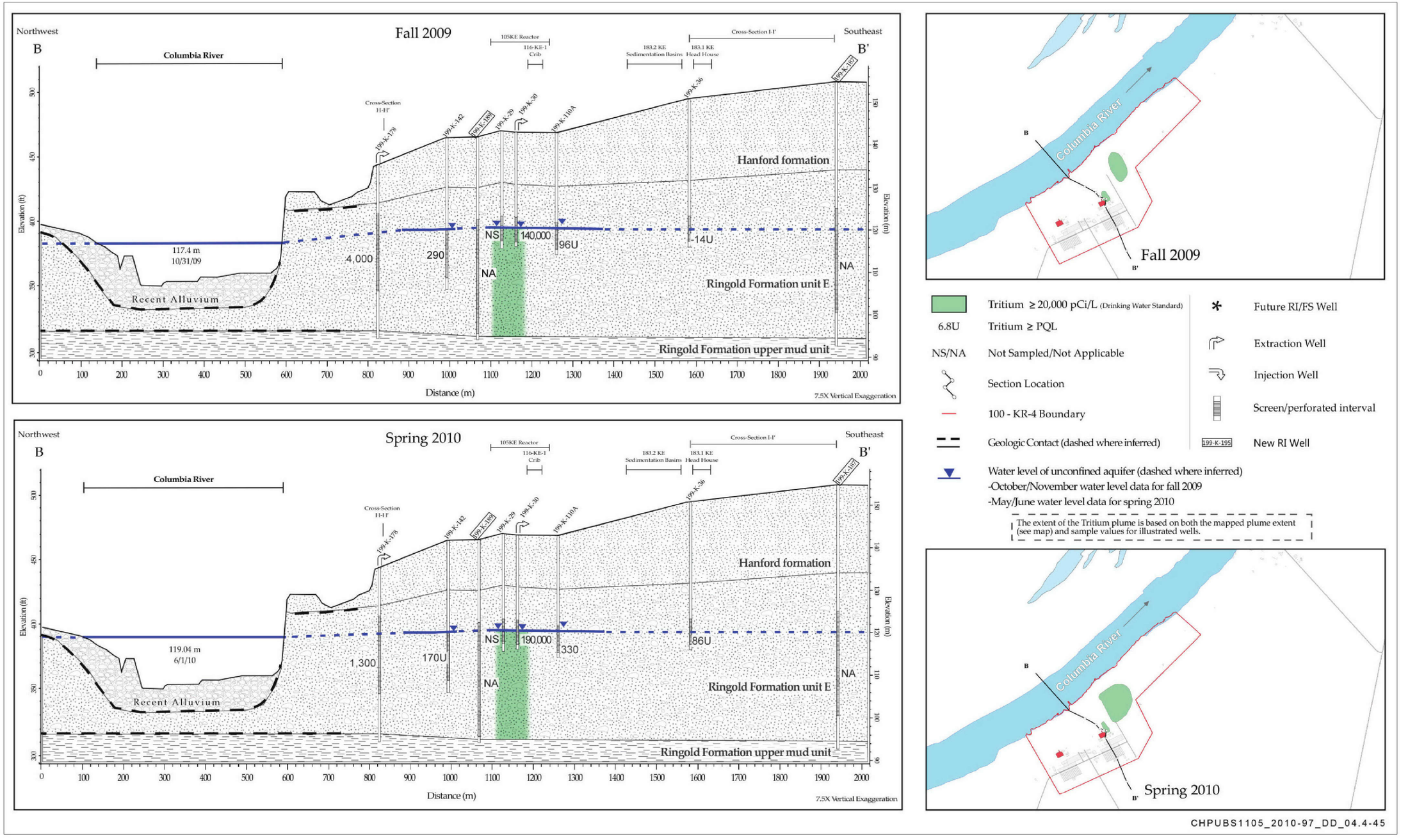


Figure 4-61. Tritium Activity Concentration on Cross Section B-B'

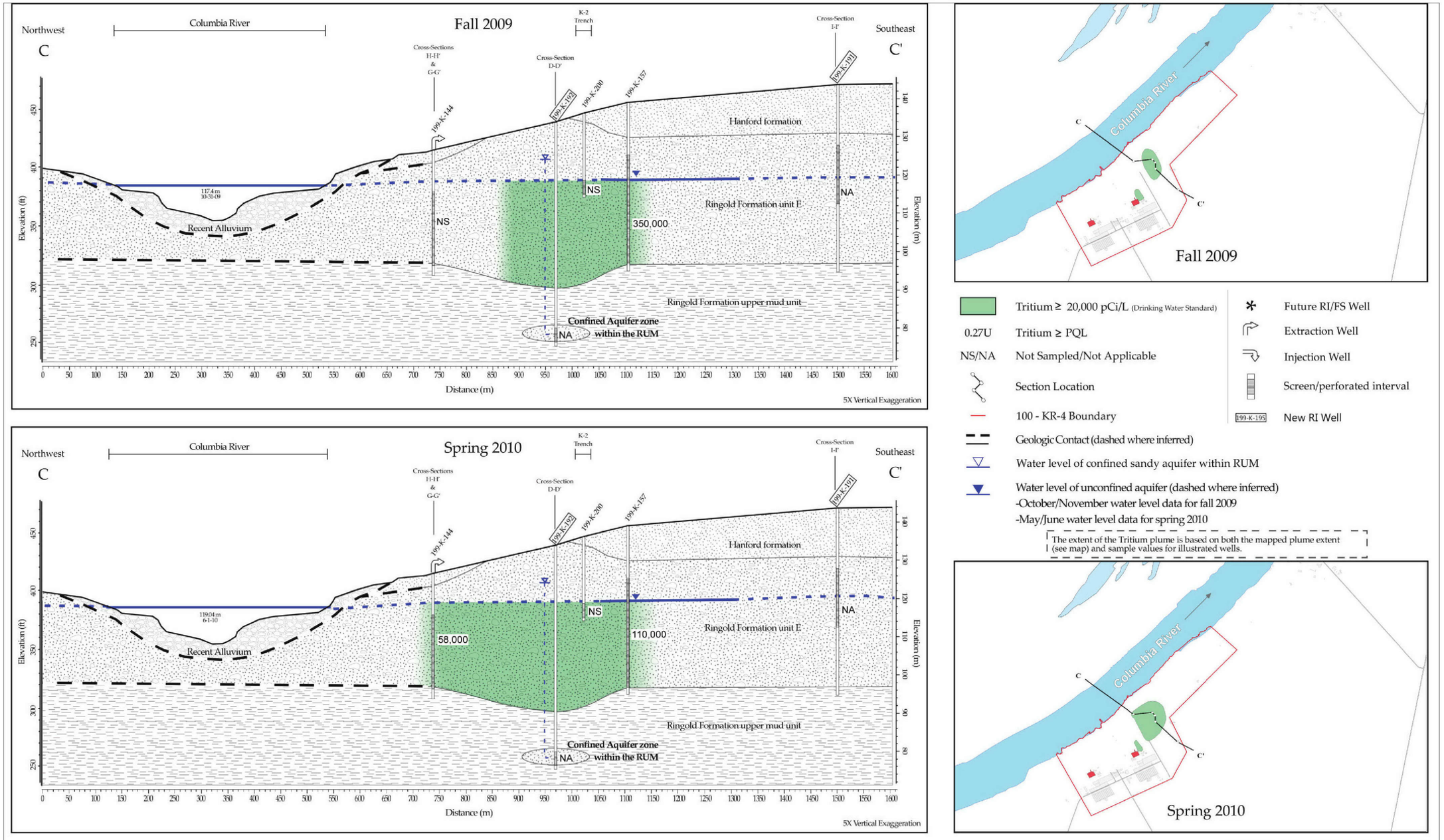


Figure 4-62. Tritium Activity Concentration on Cross Section C-C'

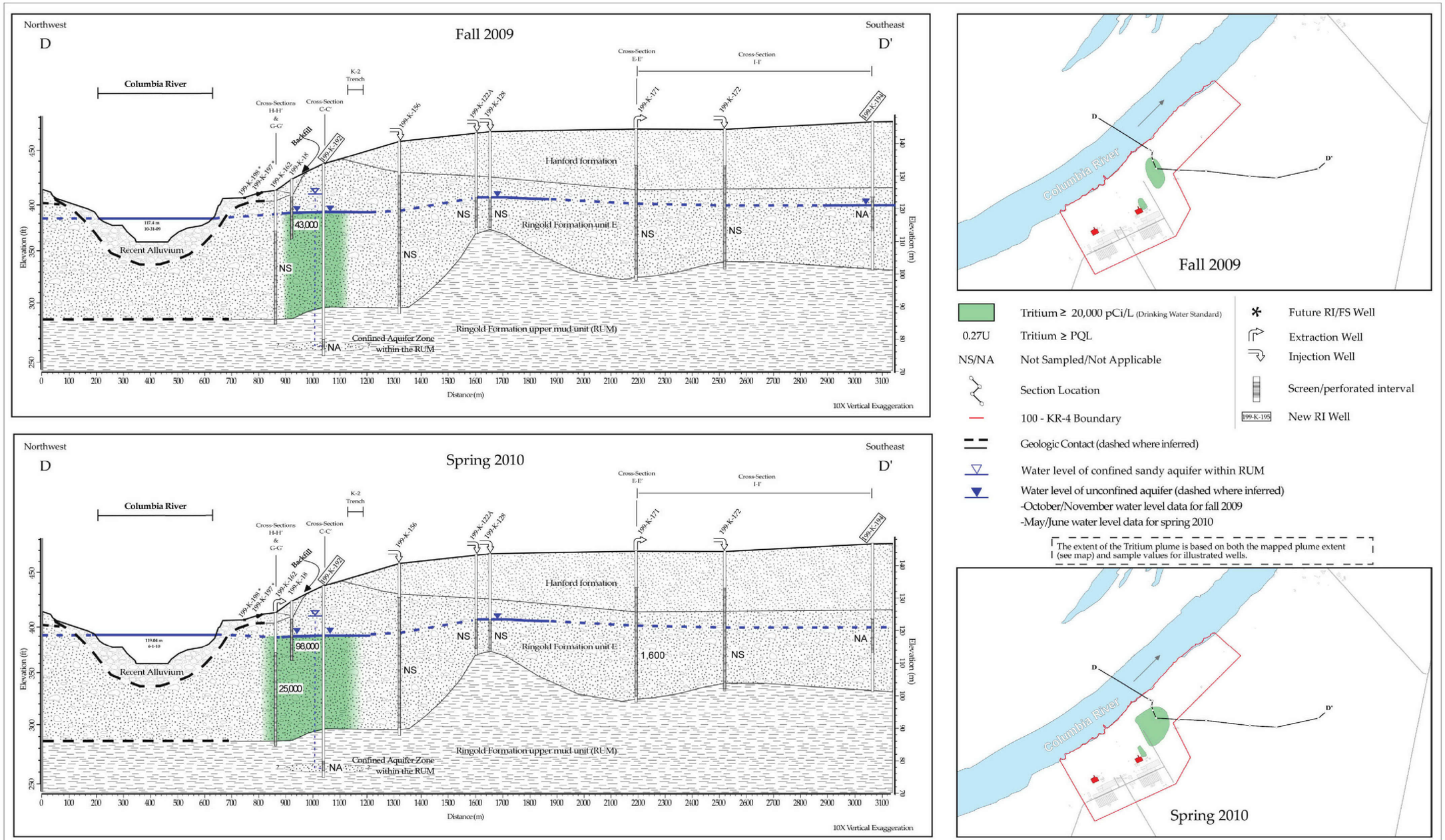
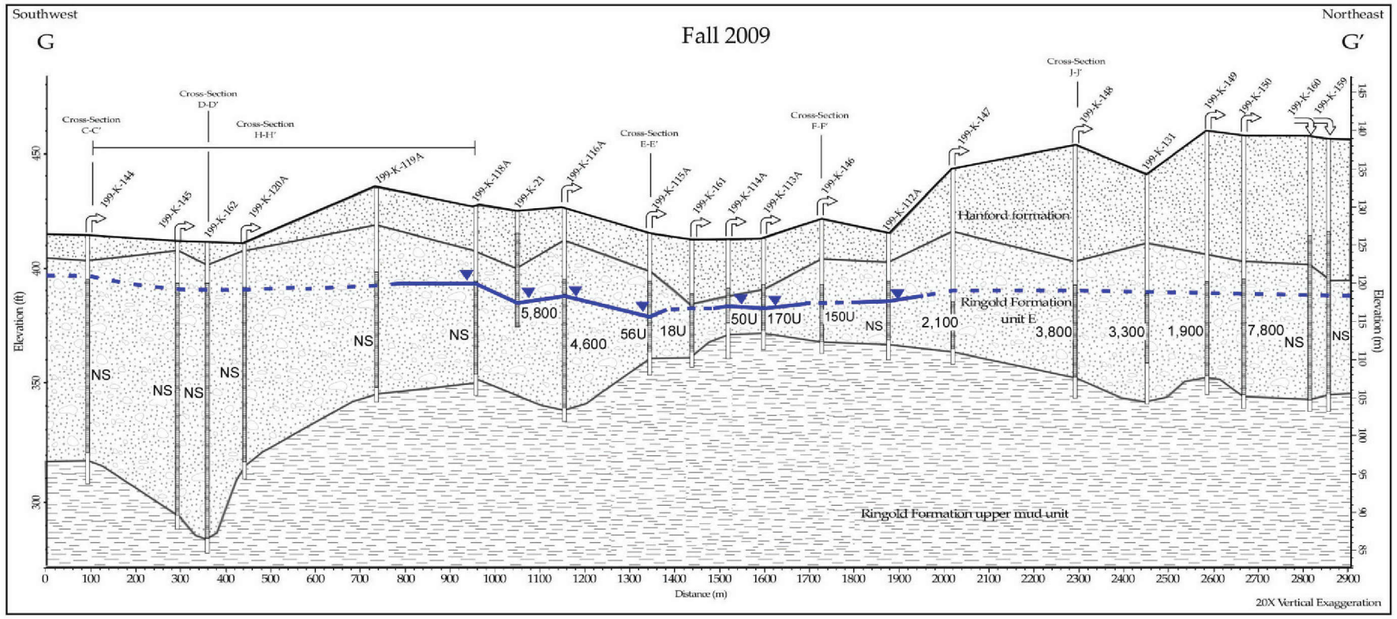
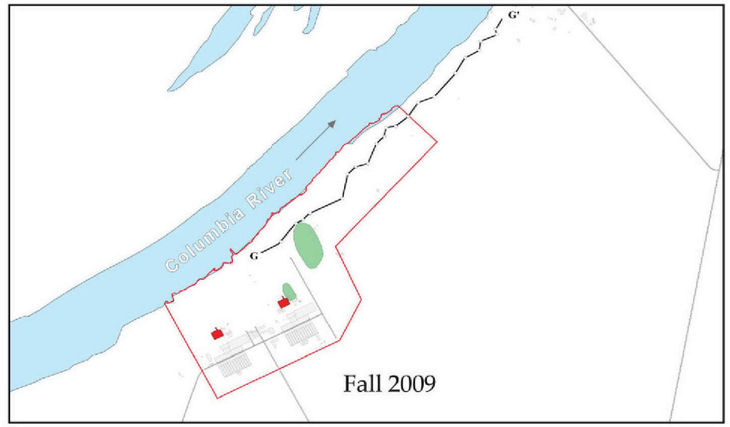


Figure 4-63. Tritium Activity Concentration on Cross Section D-D'





Tritium ≥ 20,000 pCi/L (Drinking Water Standard)

0.27U Tritium ≥ PQL

NS/NA Not Sampled/Not Applicable

Section Location

100 - KR-4 Boundary

Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010

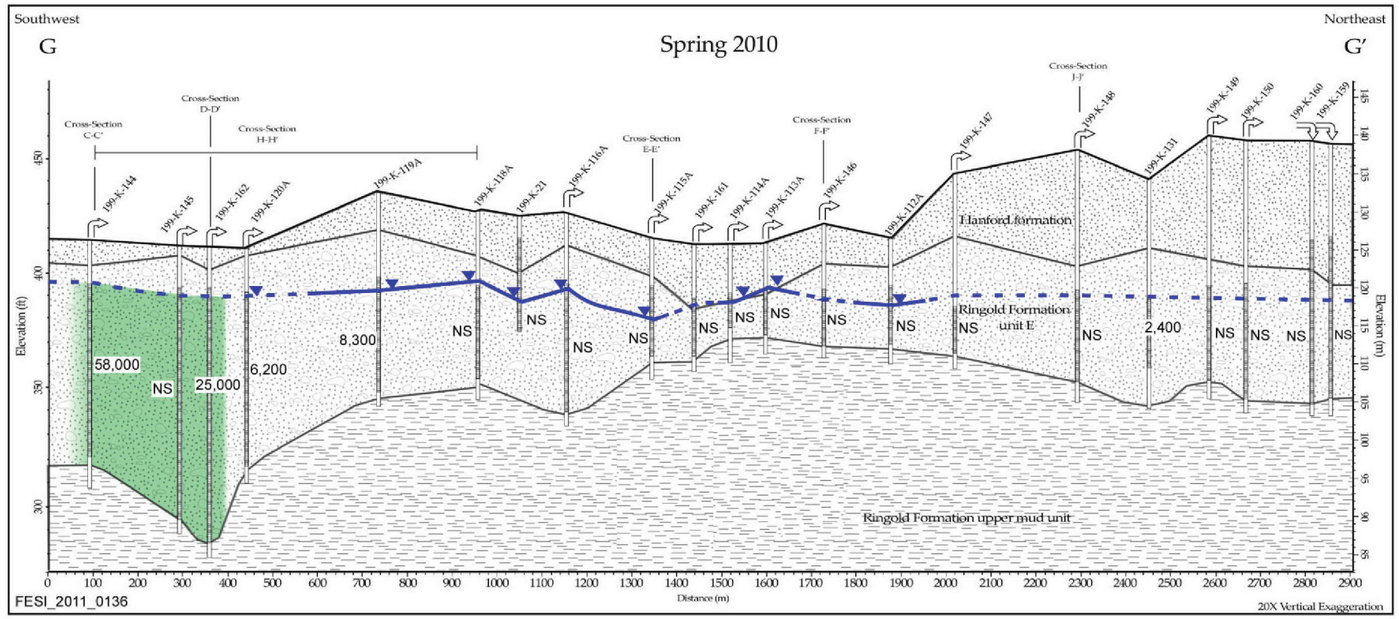
Future RI/FS Well

Extraction Well

Injection Well

Screen/perforated interval

The extent of the Tritium plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.



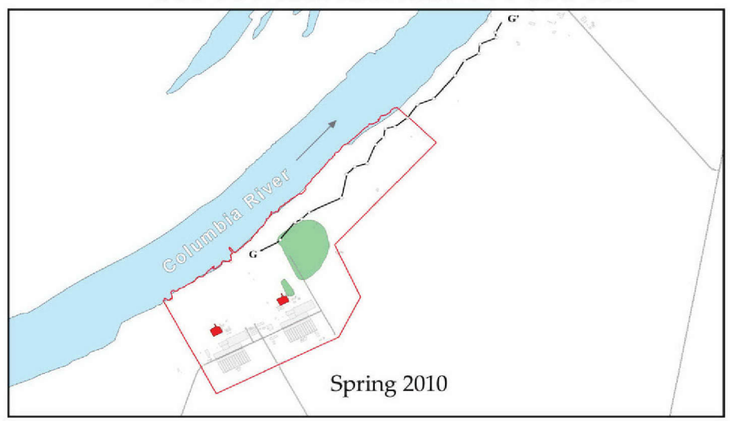


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Figure 4-64. Tritium Activity Concentration on Cross Section G-G'

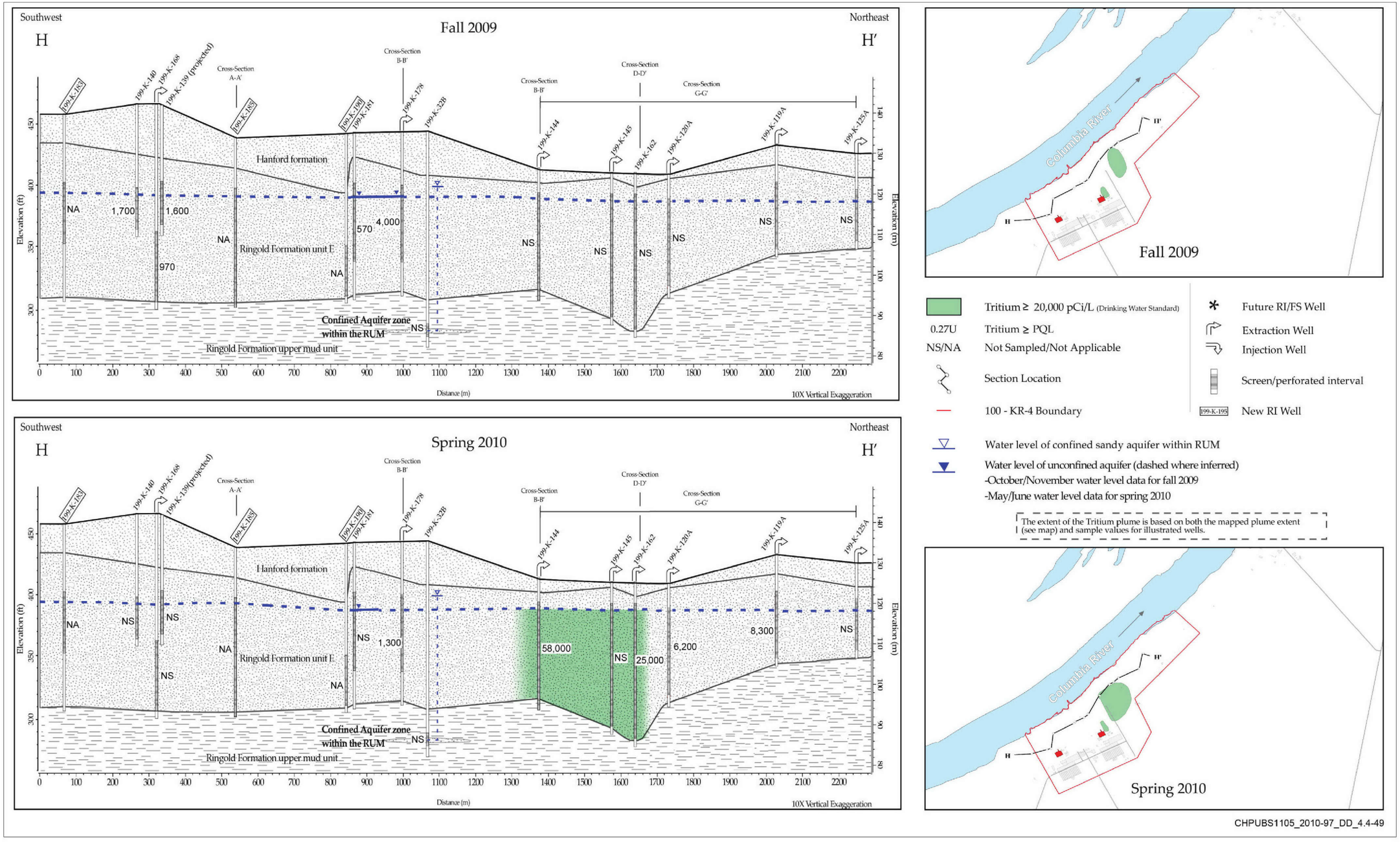

Figure 4-65. Tritium Activity Concentration on Cross Section H-H'

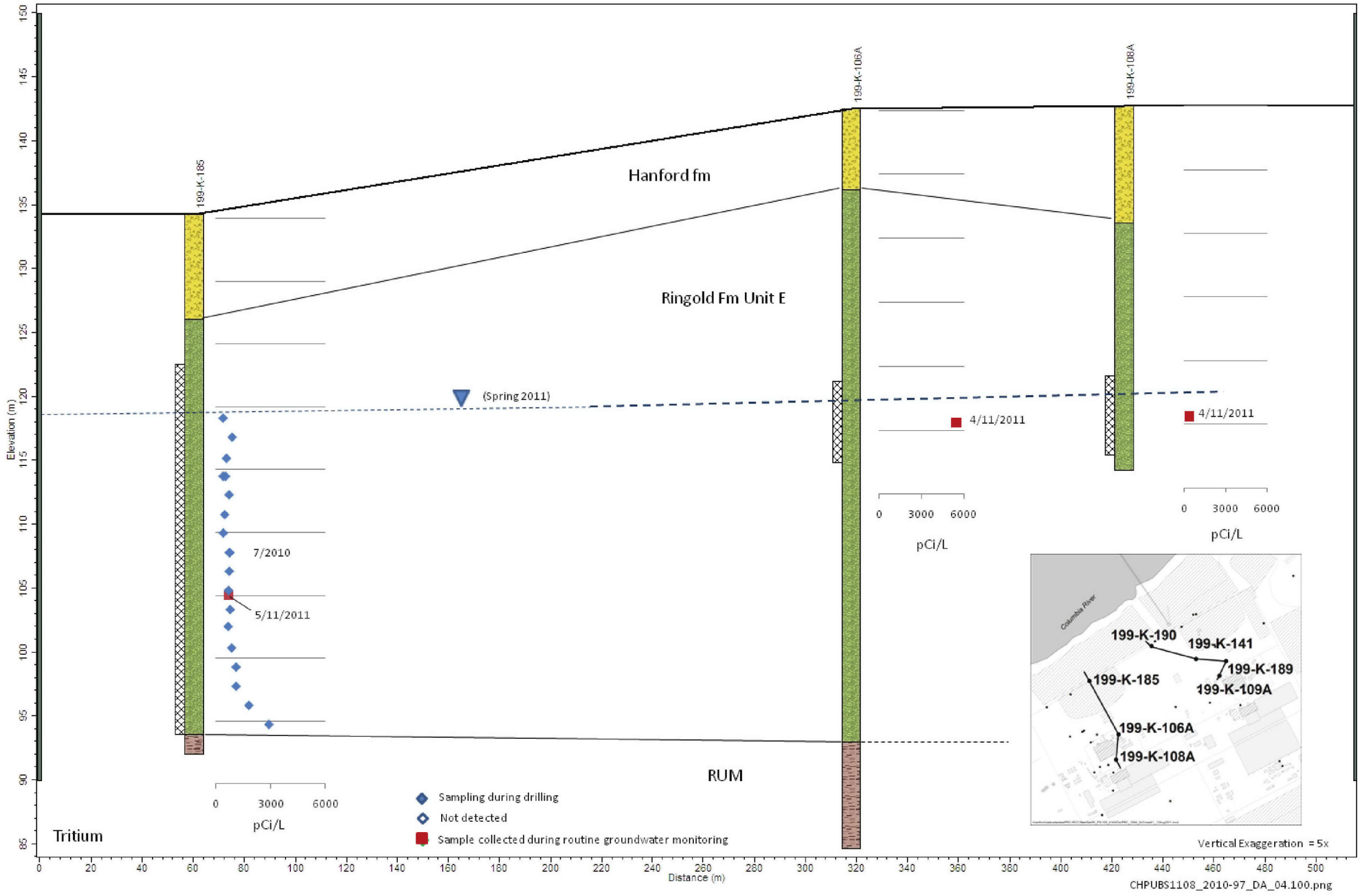

Figure 4-66. Vertical Distribution of Tritium

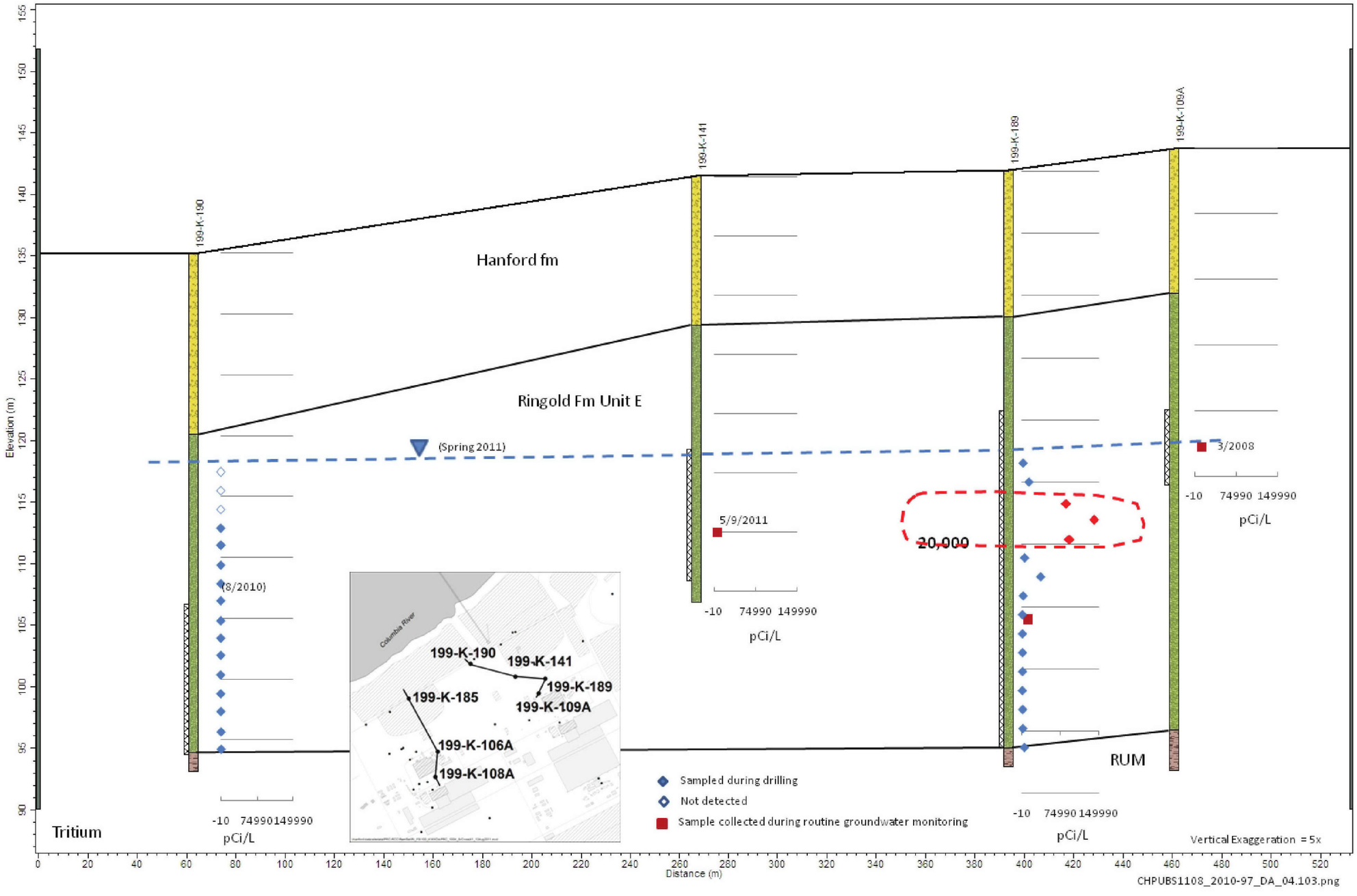

Figure 4-67. Vertical Distribution of Tritium

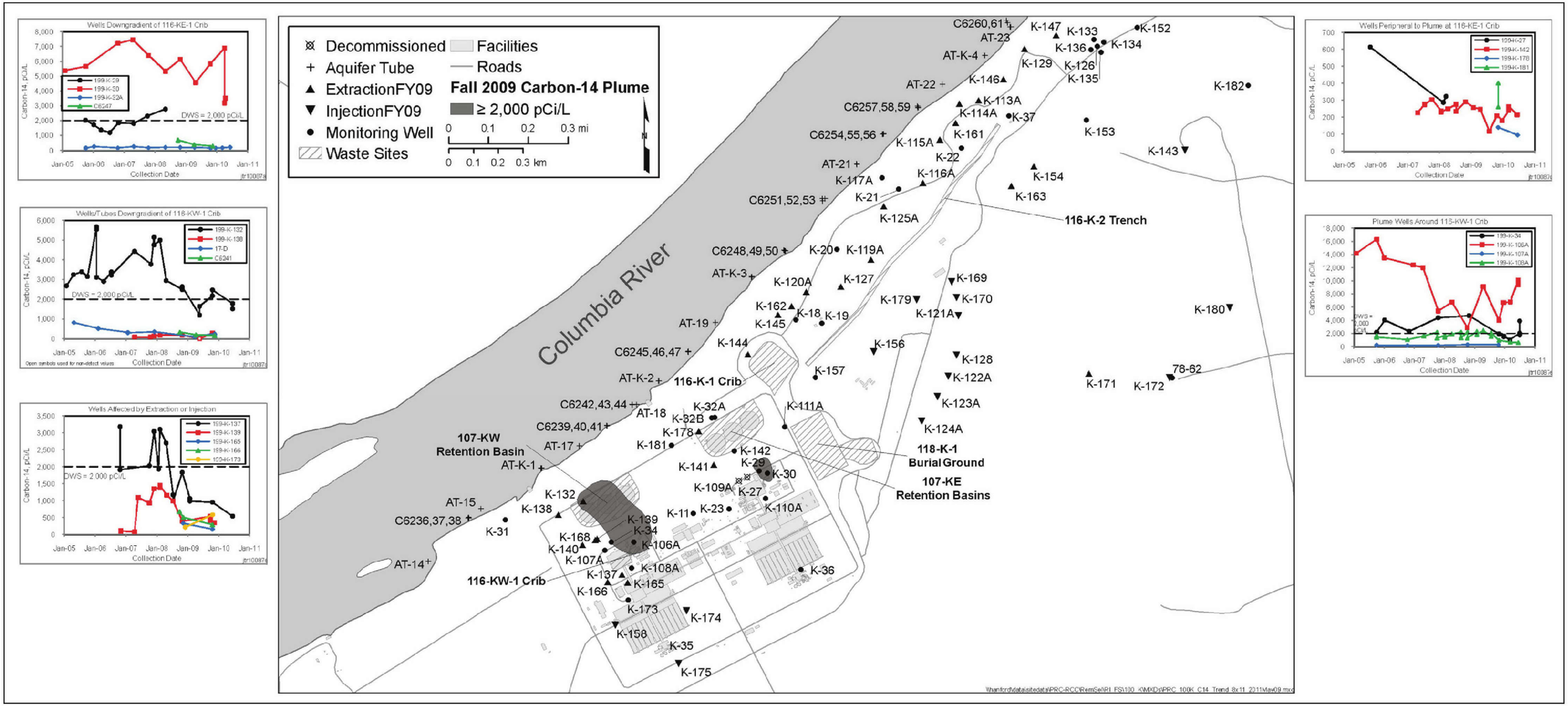

Figure 4-68. 100-K Area Carbon-14 Plume and Trend Plots

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The frequency of detection above the AL within the 100-K East plume is 13 percent with a median detection of 170 pCi/L and a maximum detected activity of 7,460 pCi/L. New RI Well 199-K-185 encountered carbon-14 at concentrations of 2,390 and 2,070 pCi/L at depths of 17.4 and 19.1 m (57 and 62.5 ft) bgs, within the top 4.6 m (15 ft) of the aquifer.

The highest activity occurs near the 105-KE Reactor building and downgradient of the 116-KE-1 Gas Condensate Crib. Activity of carbon-14 in K-West is significantly higher than 100-K East. The frequency of detection above the AL within the 100-K West plume is 33 percent with a median detection of 950 pCi/L and a maximum detected activity of 13,500 pCi/L. The highest activities occur downgradient of the 116-KW-1 Gas Condensate Crib.

Figure 4-68 shows carbon-14 activity and trend plots for 100-K. Carbon-14 activity in 100-K varies; but is generally decreasing in 100-K. Wells 199-K142 and 199-K-106A show increasing trends. In fall 2009, four wells (199-K-29, 199-K-30, 199-K-106A, and 199-K-132) exceeded the AL. The ability to monitor the carbon-14 plume downgradient of the 116-KE-1 Crib has been lost due to the decommissioning of 199-K-29 and 199-K-30 due to adjacent structure demolition.

Figure 4-69 shows bar charts for carbon-14 fall 2009 and spring 2010 activities for 100-K wells. There were no 100-K aquifer tubes were sampled for carbon-14 in spring 2010. Therefore, bar charts were not constructed for aquifer tubes. Sixteen groundwater wells were sampled for carbon-14 in fall 2009 and spring 2010. Activities greater than the 2,000 pCi/L AL were measured in three wells (19 percent) of both the fall 2009 and spring 2010 well samples. Carbon-14 activities were higher in fall 2009 than in spring 2010 in six (38 percent) of the wells.

The seasonal variation of 100-K carbon-14 plume extent is shown in plain view in Figure 4-70. Activity and sizes of the fall 2009 and spring 2010 carbon-14 plumes are very similar. Due to their inland locations, there does not appear to be any seasonal variations in concentrations.

No near-river plume carbon-14 activities exceeded the AL of 2,000 pCi/L in 100-K. None of the aquifer tubes located along the Columbia River shoreline downgradient of the 100-KE Reactor, 100-KW Reactor, or the 116-K-2 Trench areas detected carbon-14 above the AL. Activity of carbon-14 was either nondetected or below the AL in samples collected from the new RI aquifer tube cluster, which is consistent with adjacent aquifer tubes presented in Table 4-25.

During RI field activities, carbon-14 was detected above the action level (2,000 pCi/L) at Monitoring Well 199-K-185 as shown in Figure 4-71. Table 4-30 presents the maximum detected concentration of carbon-14 measured in groundwater samples collected from all RI borings and monitoring wells. In the remaining RI monitoring wells, carbon-14 was not detected above the detection limit or the AL. Routine sampling at the RI wells will be performed in April to May 2011.

Figures 4-72 through 4-74 show 100-K cross sections depicting C-14 contamination. Figure 4-75 is a cross section depicting the vertical extent of C-14. This section shows wells that are in the C-14 plume near the 100-KW Reactor (Figure 4-68).

Summary. Carbon-14 is found in both the 100-K East and 100-K West plumes, with the highest activity found in wells located near the former 116-KE-1 and 116-KW-1 Cribs (Figure 4-84). Carbon-14 activity in 100-K varies, but generally is decreasing. One RI monitoring well was installed within the historically downgradient portion of the carbon-14 plume near the KW Reactor. The well was screened within the unconfined aquifer. The maximum detected activity of carbon-14 measured in RI monitoring well was 2,390 pCi/Lin one interval within the shallow aquifer and is consistent with previous detections observed in the 100-K West plume. The lack of carbon-14 in samples collected in the lower RUM unit suggests that vertical migration into the confined aquifer is not occurring.

Sr-90. Sr-90 has been monitored extensively before and during the recent RI activities conducted in 2010 and 2011. Sr-90 is present in groundwater in 100-K in discrete areas located in all three plumes (100-K East, 100-K West, and 100-K North). The groundwater plumes are related to fuel rod failures both during 100-K Reactor operations and in the subsequent storage of N fuel rods in the KE and KW FSBs. The contaminated liquid was transported to the 116-K-2 Trench as well as the 116-KE-3 and 116-KW-2 Cribs and from leaks at the 105-KE FSB itself. Potential sources of Sr-90 plumes include discharges to the vadose zone within and near the 116-KE-3 and 116-KW-2 Cribs (Figure 4-4).

The total footprint of the Sr-90 plume areas exceeding the AL of 8 pCi/L is approximately 0.03 km^2 (0.01 mi^2). Figure 4-76 shows Sr-90 activity and trend plots for 100-K. Trend plots show Sr-90 activity is generally stable, but may be increasing at Well 199-K-141.

Concentrations in Wells 199-K-19, 199-K-20, 199-K-21, 199-K-22, 199-K-113A, 199-K-114A, and 199-K-115A, all downgradient of the 116-K-2 Trench, have exceeded the AL at some point between 2006 and 2010. Former Well 199-K-109A, located within the 100-K East plume area, downgradient of the 116-KE-3 Crib, has the historically high Sr-90 concentration of 1,610 pCi/L in 2007. Within the 100-K West area, Sr-90 concentrations at wells downgradient of the KW FSB and 116-KW-2 Crib are much lower—45 pCi/L at Well 199-K-34 and 14 pCi/L at Well 199-K-107A. Of the wells that exceed the AL, most show decreasing trends. Only Well 199-K-141 has increased to between 8.2 and 12 pCi/L in 2011.

Figure 4-77 shows bar charts for Sr-90 fall 2009 and spring 2010 concentrations for 100-K wells. No 100-K aquifer tubes were sampled for Sr-90 in spring 2010. Therefore, bar charts were not constructed for aquifer tubes. Six groundwater wells were sampled for Sr-90 in fall 2009 and spring 2010. Concentrations greater than the 8 pCi/L AL were measured in two wells (33 percent). Sr-90 concentrations were higher in fall 2009 than in spring 2010 in 5 (83 percent) of the wells.

The seasonal variation of 100-K Sr-90 plume extent is shown in plan view in Figure 4-78. The Sr-90 plumes downgradient to the north of the 116-K-2 Trench and closer to the river appear to vary seasonally, contracting in the fall and expanding in the spring, partially downgradient of the KW Reactor. This is consistent with the varying concentrations observed in 199-K-34 and 199-K-132. The plume downgradient of the 100-KW Reactor is too far inland to be affected by the changing river stage.

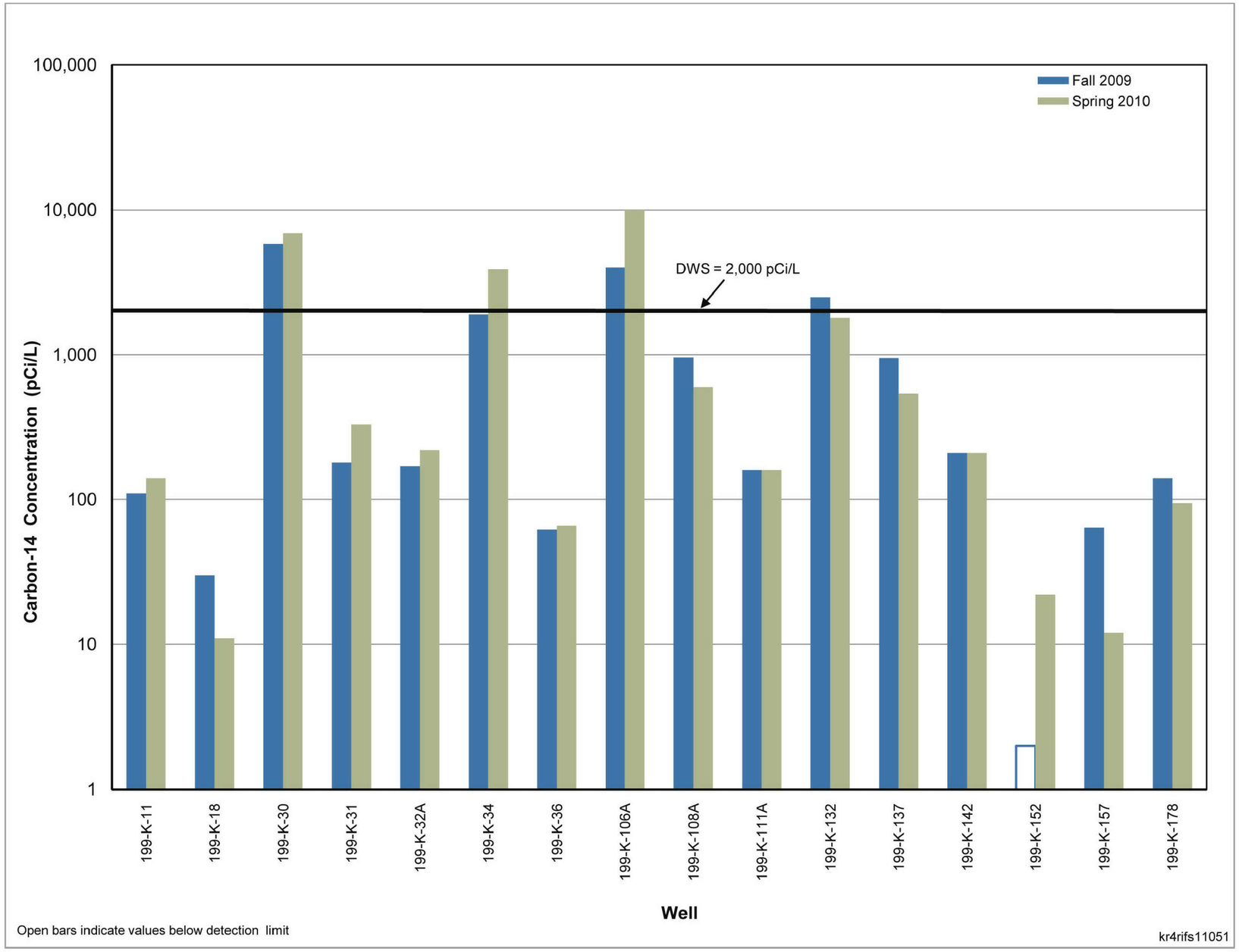


Figure 4-69. 100-K Area Bar Charts of Carbon-14 Activity in Wells, Fall 2009 and Spring 2010

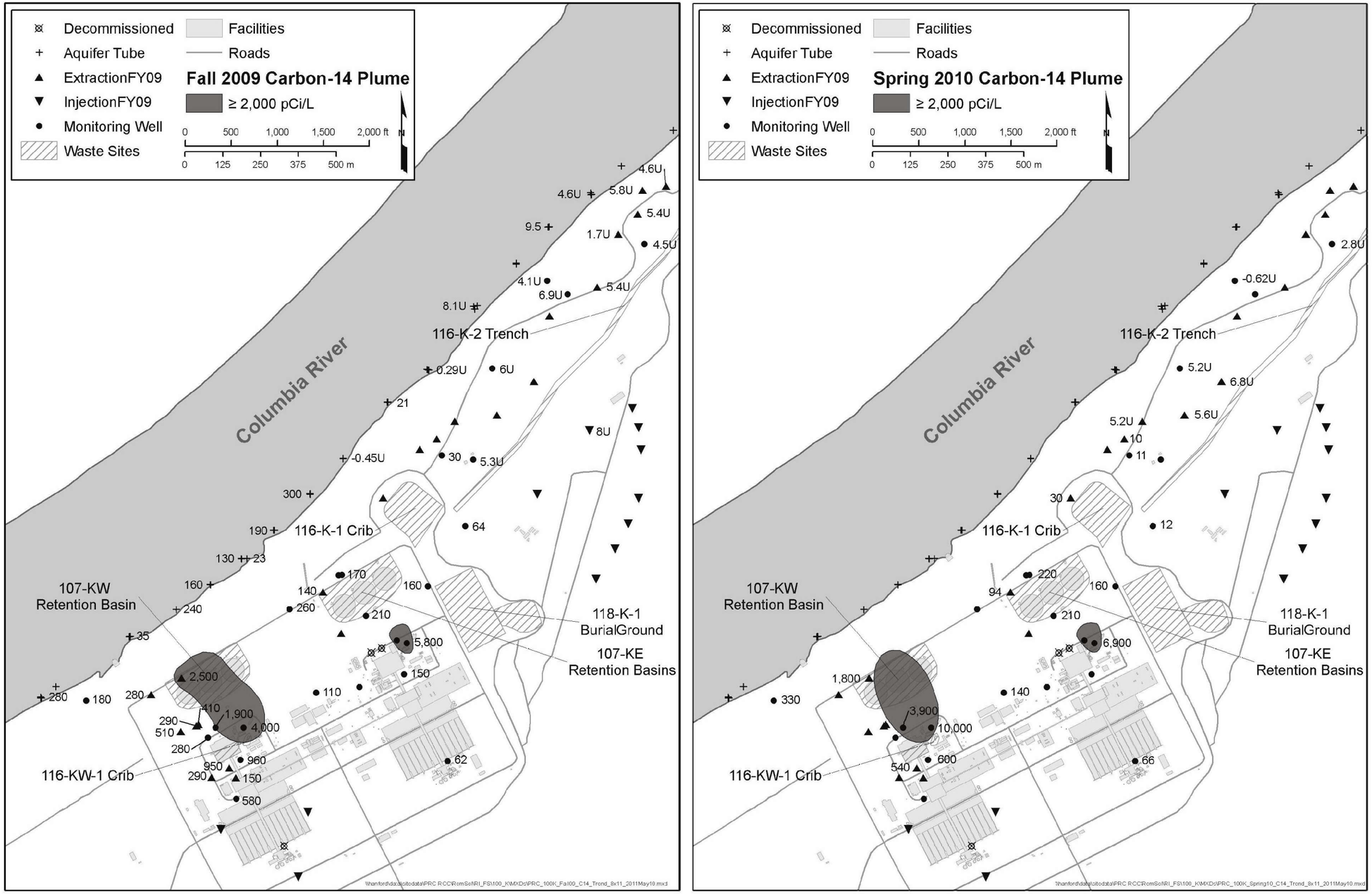


Figure 4-70. Fall 2009 and Spring 2010 Carbon-14 Plumes in 100-K

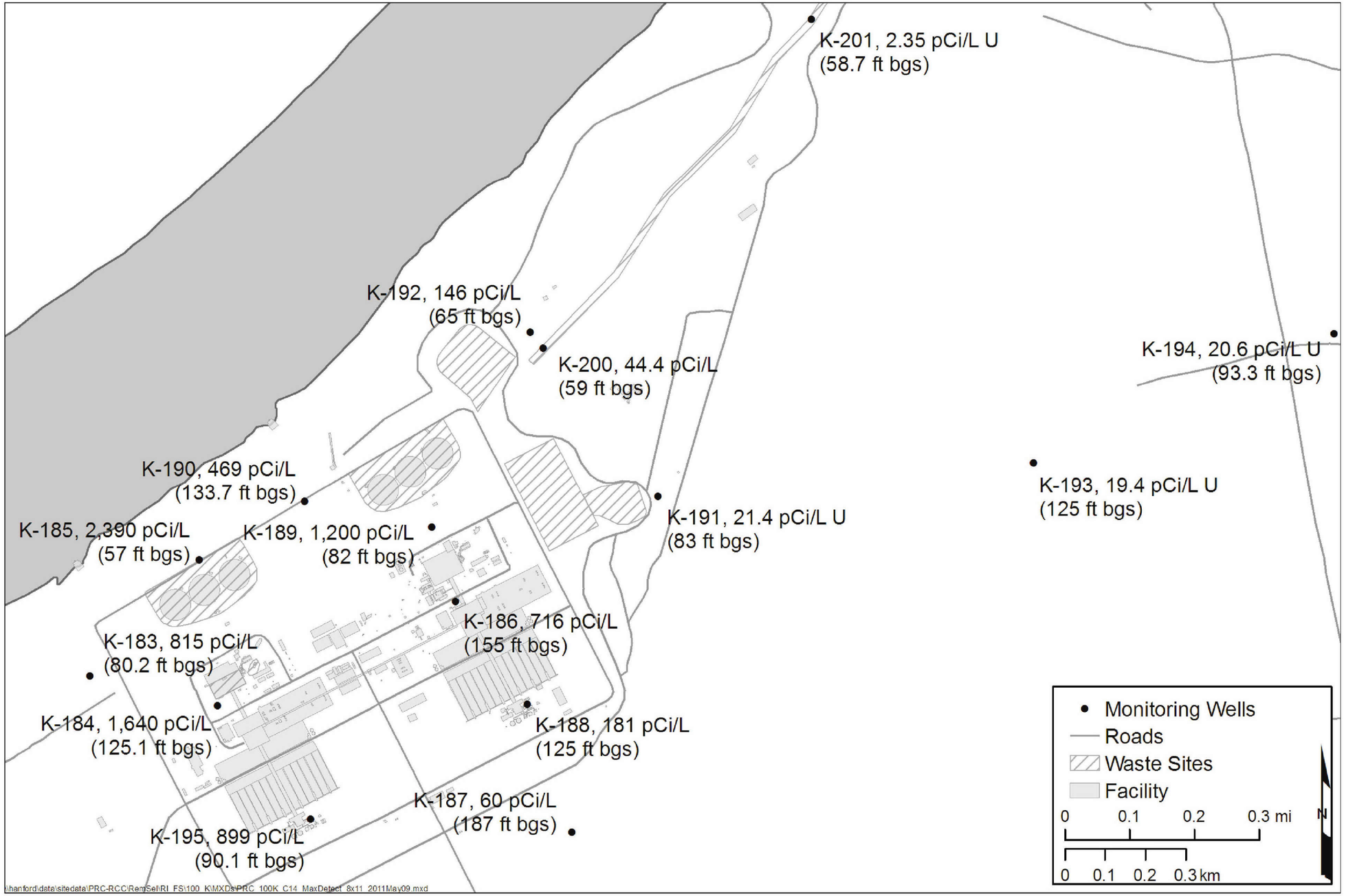


Figure 4-71. Maximum Activity of Carbon-14 from Discrete RI Well Samples

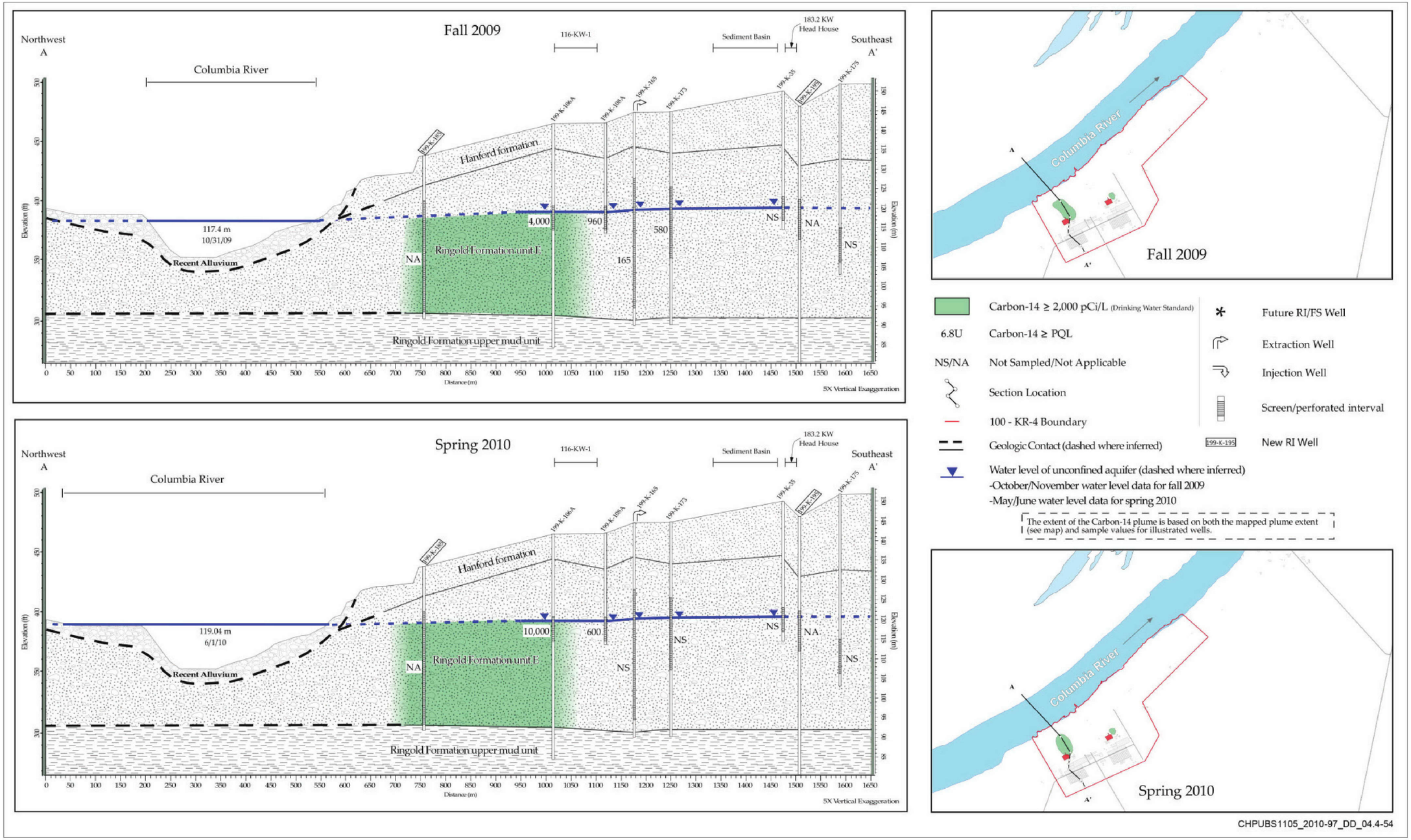
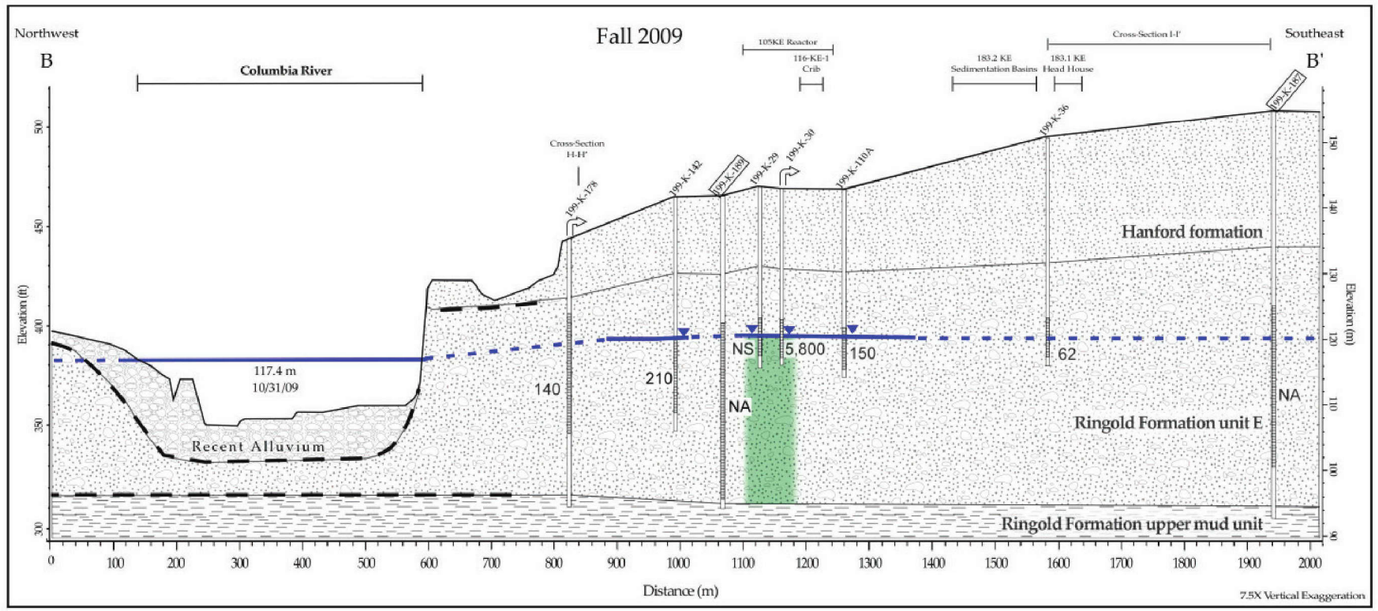
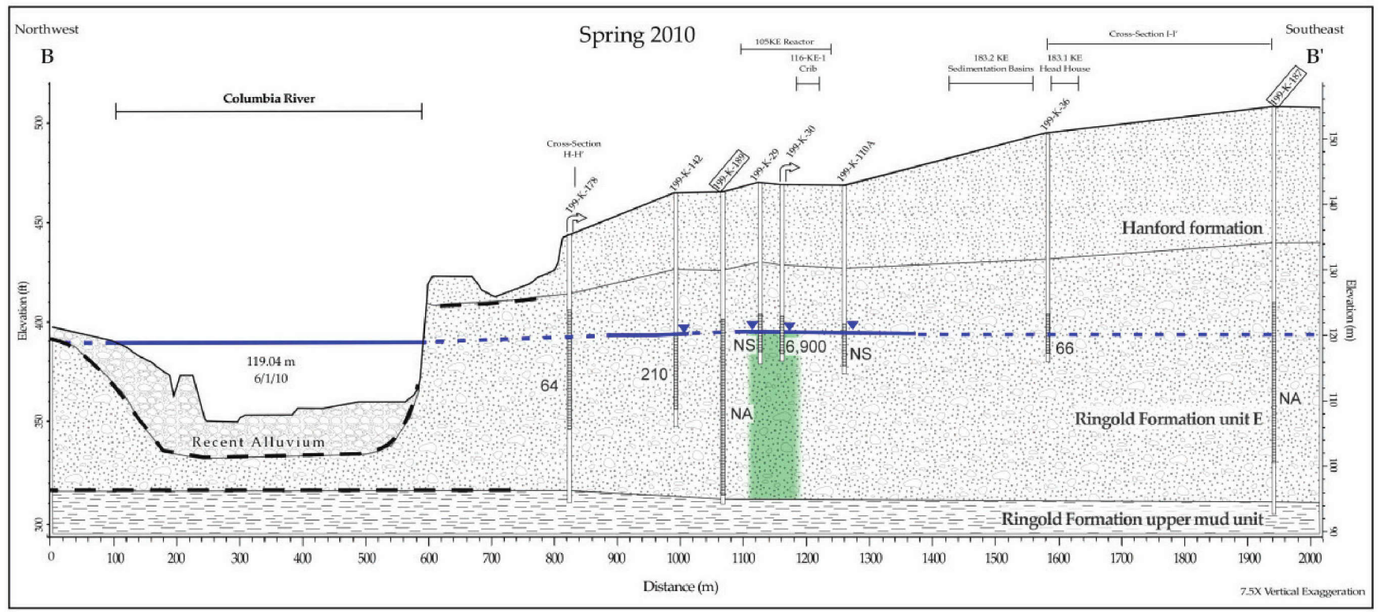
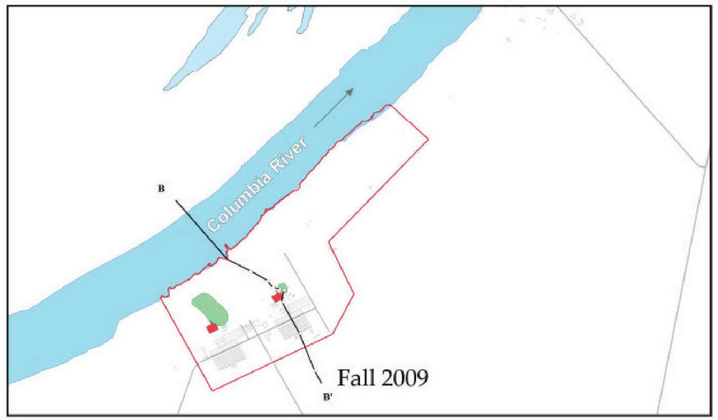


Figure 4-72. Carbon-14 Activity Concentration on Cross Section A-A'







Carbon-14 ≥ 2,000 pCi/L (Drinking Water Standard)

6.8U Carbon-14 ≥ PQL

NS/NA Not Sampled/Not Applicable

Section Location

100 - KR-4 Boundary

Geologic Contact (dashed where inferred)

Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010

The extent of the Carbon-14 plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.

* Future RI/FS Well

Extraction Well

Injection Well

Screen/perforated interval

199-K-195 New RI Well

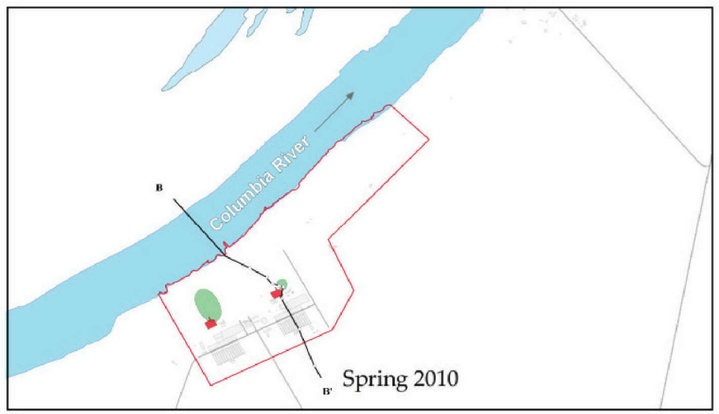


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Figure 4-73. Carbon-14 Activity Concentration on Cross Section B-B'

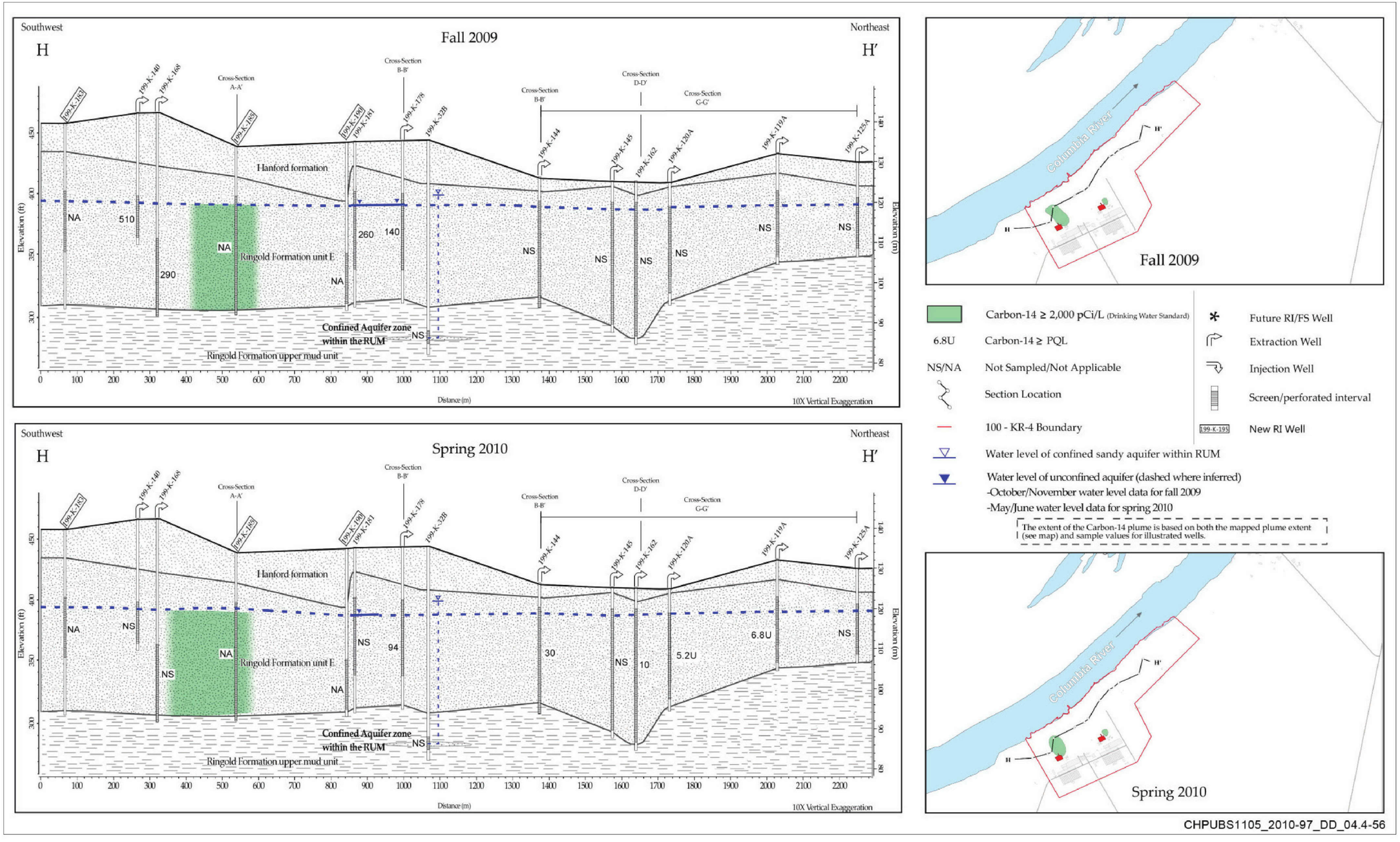


Figure 4-74. Carbon-14 Activity Concentration on Cross Section H-H'

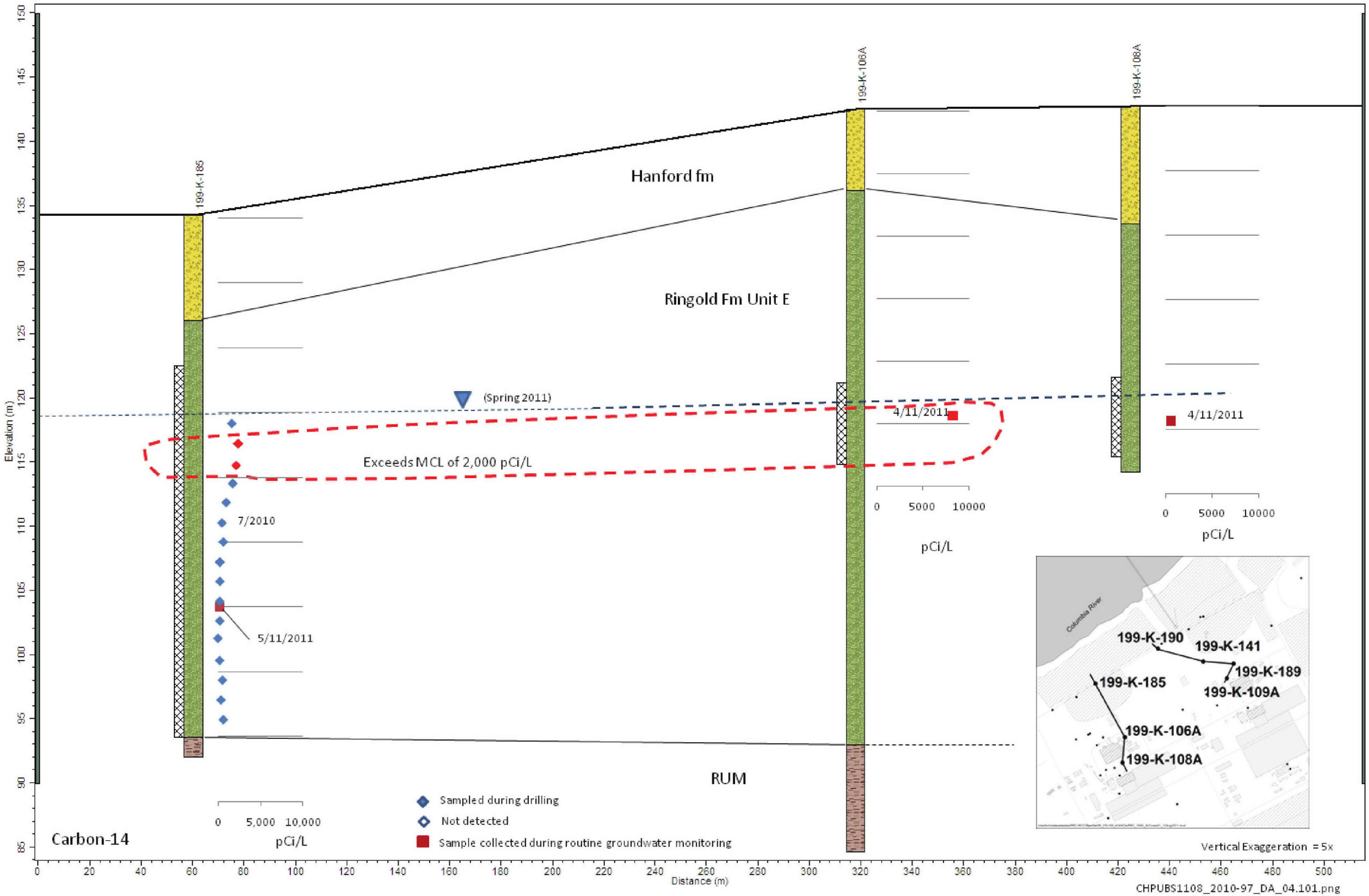


Figure 4-75. Vertical Distribution of Carbon-14

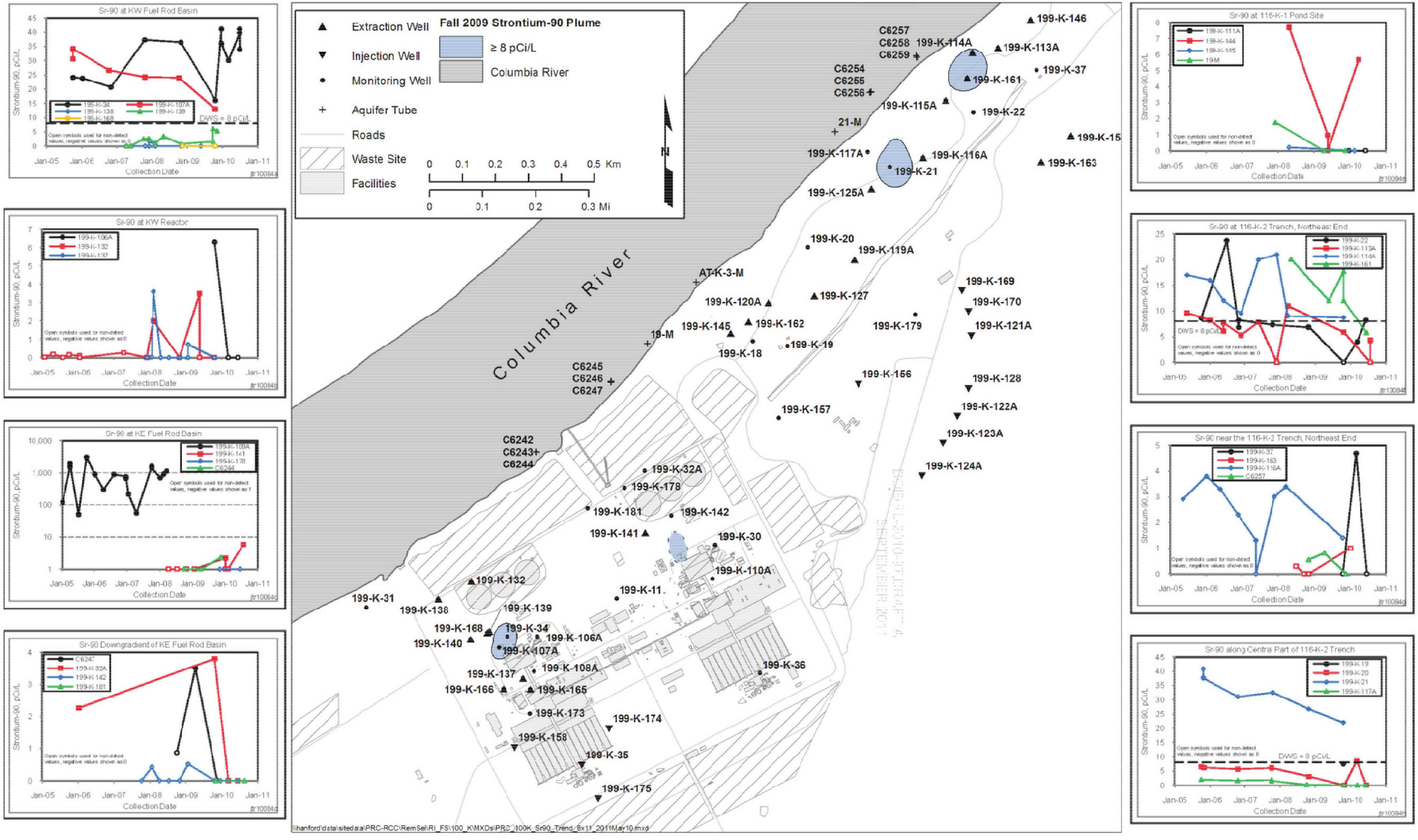


Figure 4-76. 100-K Area Sr-90 Plume and Trend Plots.

Table 4-30. Detected Activity of Carbon-14 above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	C-14 Grab Groundwater (pCi/L)
Constituent Action Level								**2,000**
199-K-185	C7685	2	7/6/2010	17.37	57.00	16.93 (53.26) to 40.70 (133.50)	B264P0	2,390
199-K-185	C7685	2	7/6/2010	19.05	62.50		B264P1	2,070

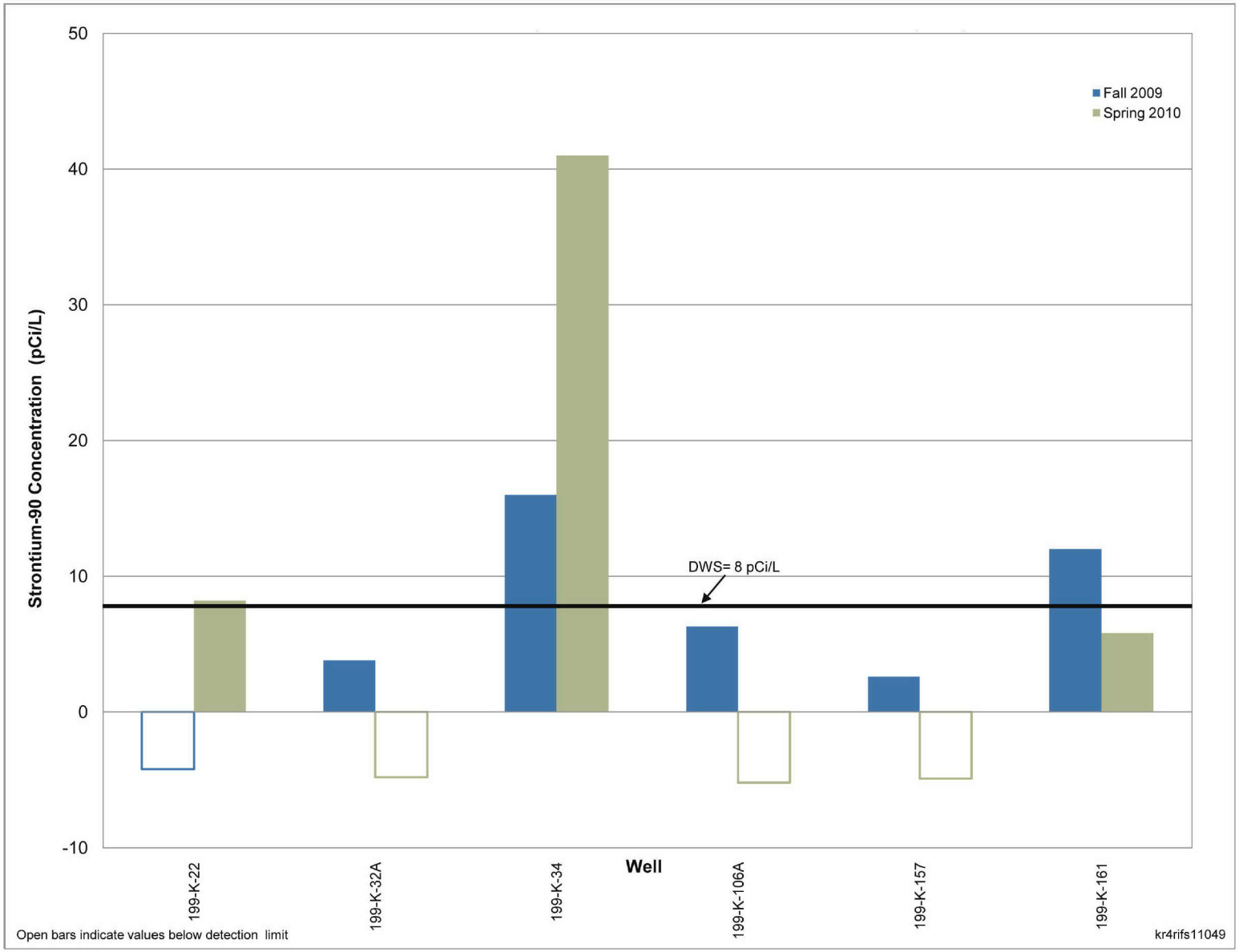


Figure 4-77. 100-K Area Bar Charts of Sr-90 Activity in Wells, Fall 2009 and Spring 2010

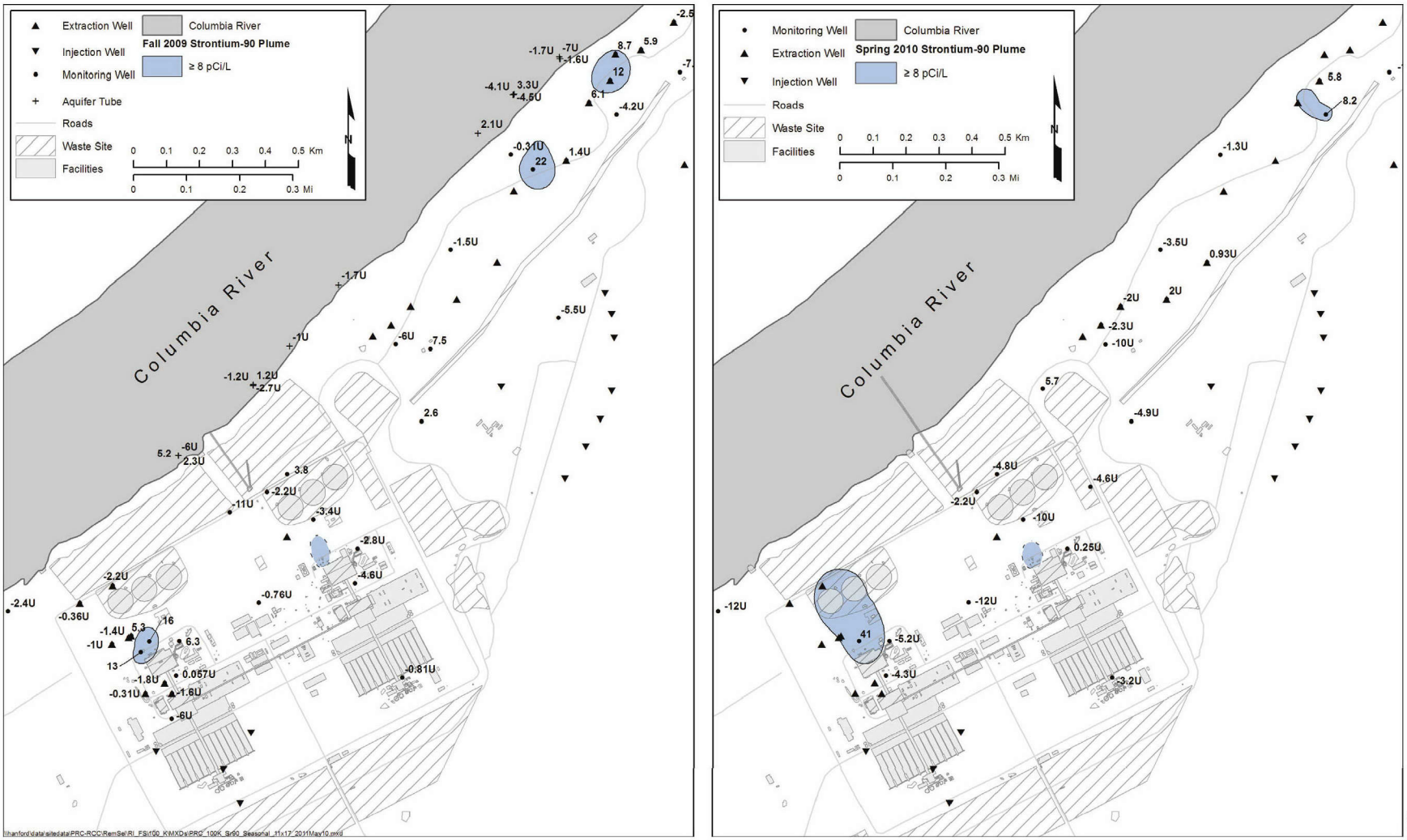


Figure 4-78. Fall 2009 and Spring 2010 Sr-90 Plumes in 100-K

Table 4-31. Detected Activity of Sr-90 above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Sr-90 Grab Groundwater (pCi/L)
Constituent Action Level								**8**
199-K-192	C7692	R2	8/31/2010	16.76	55		B277B3	19
199-K-200	C7831	116-K-2 West	8/26/2010	17.86	58.6	TBD to TBD	B26WY5	130
199-K-200	C7831	116-K-2 West	9/17/2010	17.98	59		B28375	160
199-K-200	C7831	116-K-2 West	1/31/2011	18.07	59.3		B2BHJ3	190

The concentrations of the 100-K North plume are lower in the spring and at concentrations only slightly above the AL. The second plume located downgradient of the 116-K-2 Trench (fall 2009) was not observed in spring 2010.

In the fall 2009 sampling round, the highest activity occurred downgradient of the 116-K-2 Trench at 199-K-21 (22 pCi/L). The plumes to the north and south each contained similar concentrations of 12 and 13 pCi/L, respectively. Based on the maximum activity levels observed in 199-K-192 (19 pCi/L) and 199-K-200 (160 pCi/L) at an approximate depth of 18 to 19 m (58 ft) bgs, a small plume of Sr-90 is evident near the southern end of the 116-K-2 Trench and north of the 116-K-1 Crib. The detections of Sr-90 above the AL at 199-K-192 and 199-K-200 occurred in mid-August and mid-September during the transitional river stage from higher to lower flow and higher to lower water levels, creating conditions for potentially more saturation and opportunity for contaminant contact. No detections above the AL were observed during the fall period, corresponding to the contracting plume conditions observed around 199-K-21, 199-K-161, and 199-K-107A during fall. The historical groundwater statistical results show similar activity levels in monitoring wells located within the 100-K North plume, indicating a maximum detected activity of 37 pCi/L with a 15 percent frequency of detections above the AL over a five-year period. The frequency of detection above the AL within the 100-K West plume is 14 percent with a median detection of 14.5 pCi/L and a maximum detected concentration of 41 pCi/L.

A historical residual plume near the KE Reactor is illustrated in Figure 4-79, based on 2008 data. This plume is located downgradient of the KE Reactor at Well 199-K-109A in 100-K East. The maximum historical activity level was 18,600 pCi/L in 1997 and ranged from 55 to 1,610 pCi/L between 2006 and 2008. The median detection of Sr-90 in the 100-K East area was below the Al at an activity of 5 pCi/L, with 6 percent of samples detected above the AL. Well 199-K-109A has been decommissioned and can no longer be sampled. However, the analytical results from 199-K-189, located cross-gradient from former Well 199-K-109A, show activity below the AL.

Figures 4-80 through 4-84 show 100-K cross sections depicting Sr-90 contamination. Figure 4-85 is a cross section showing the vertical extent of Sr-90. Wells 199-K-141 and 199-K-109A are not depicted in any of the plumes (Figure 4-78).

Summary. Sr-90 is present in groundwater in 100-K in discrete areas located in all three plumes. Trend plots show Sr-90 concentrations are generally stable to decreasing. The lack of Sr-90 activity in deeper grab groundwater samples collected at 199-K-192 suggests that no vertical dispersion is occurring between the unconfined aquifer and the RUM unit near the 116-K-1 Trench and southern portion of the 116-K-2 Trench.

Trichloroethene. TCE is a minor contaminant found at wells primarily in the 100-KW Reactor (100-K West plume) and to a small degree in the 100-K East area. In fall 2009 and spring 2010, most of the 1000-KW Reactor area wells, plus selected wells inside the 100-KE Reactor area and downgradient of the 116-K-2 Trench, were analyzed for TCE. TCE was not detected at wells near the 116-K-2 Trench. On average, wells associated with the 100-KE Reactor area had detections of TCE at concentrations below the AL of 0.49 µg/L. Thirteen wells detected concentrations greater than the AL in 2009 and seven wells exceeded the AL in 2010.

Figure 4-86 shows the TCE plume in fall 2009. The fall 2009 plume is near the 105-KW Reactor and 107-KW Retention Basin.

Figure 4-87 shows bar charts of TCE fall 2009 and spring 2010 concentrations for 100-K wells. No 100-K aquifer tubes were sampled for TCE in spring 2010. Therefore, bar charts were not constructed for aquifer tubes. Concentrations of TCE measured in water samples collected from the new RI aquifer tube

cluster were nondetect or below the AL (Table 4-25). The highest concentration of TCE was seen at 199-K-106A in spring 2010.

The seasonal variation of 100-K TCE plume extent is shown in plain view in Figure 4-88. There is a slight variation in plume sizes between fall 2009 and spring 2010, with the plume reaching the river interface during the fall and contracting in the spring. In general, the TCE concentrations in spring 2010 are similar (some slightly higher and some slightly lower) than the fall 2009. Taken together, it does not appear that TCE concentrations vary seasonally.

All 15 RI monitoring wells were sampled between May 2010, and March 2011 for the presence of TCE. TCE was detected above the AL (0.49 µg/L) at 199-K-183 through 199-K-188, 199-K-190, and 199-K-195 as shown in Figure 4-89. Table 4-32 presents the maximum detected concentration of TCE measured in groundwater samples collected from all RI borings and monitoring wells. TCE was not detected above the detection limit or the action level in the remaining RI monitoring wells.

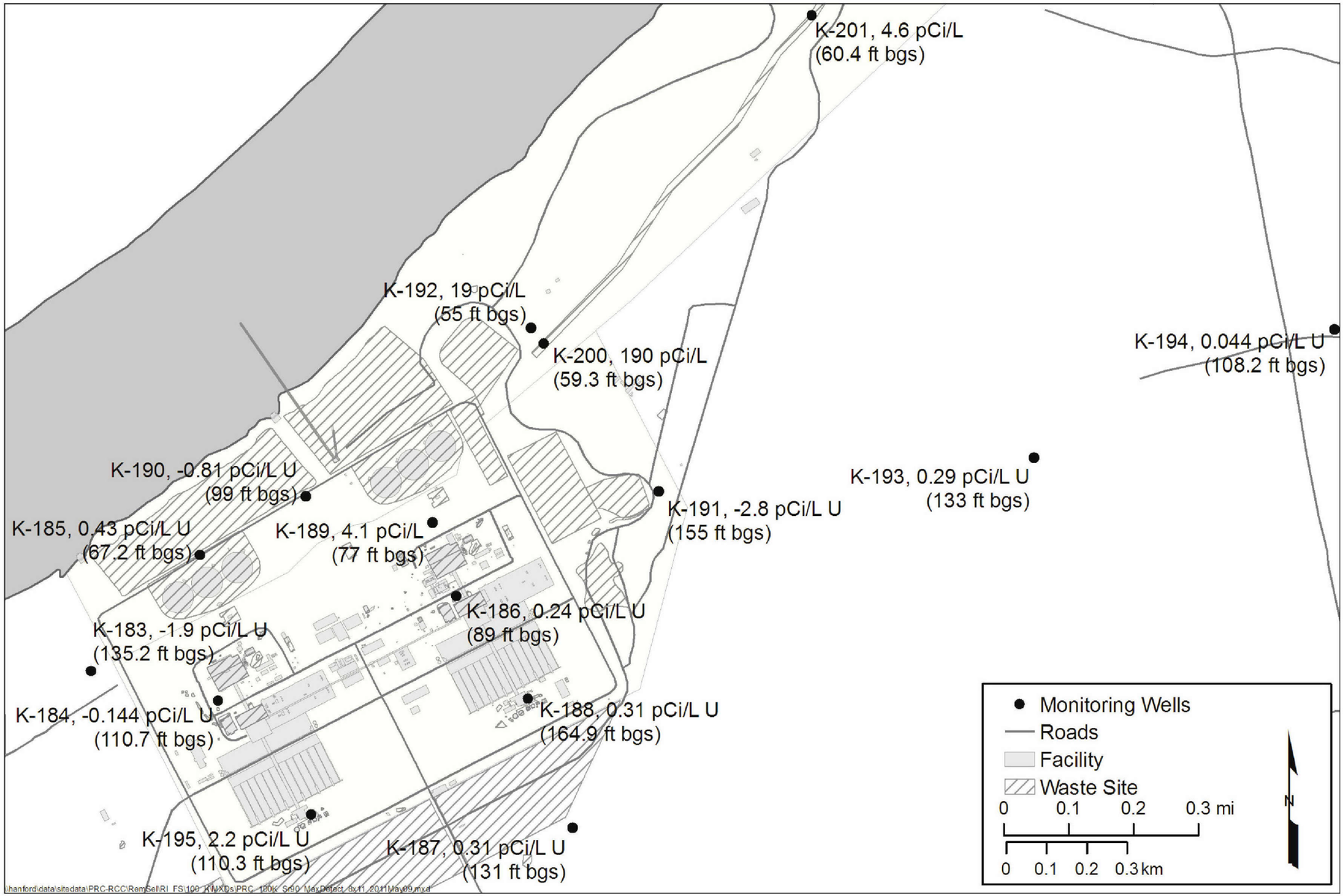


Figure 4-79. Maximum Activity of Sr-90 from Discrete RI Well Samples

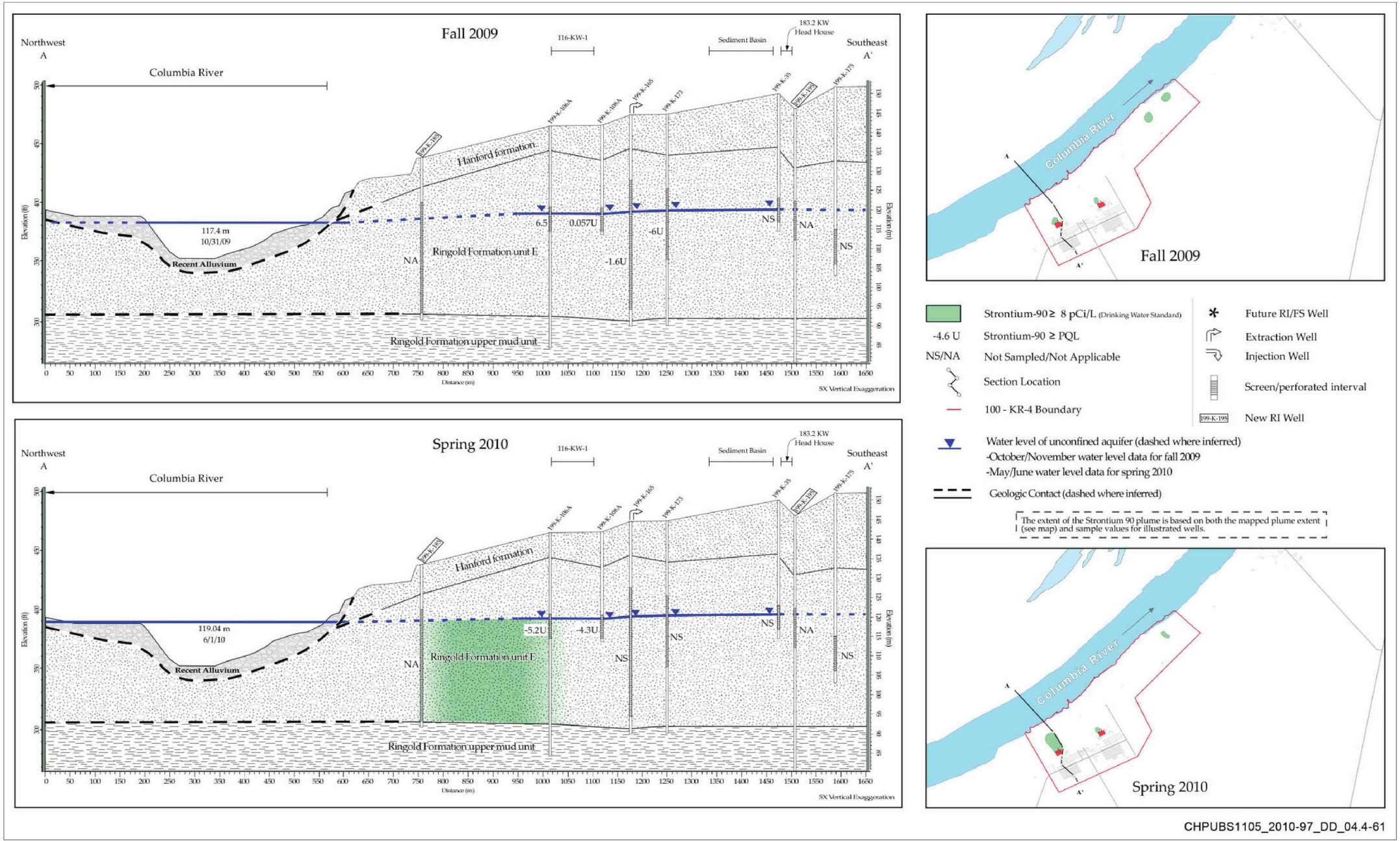


Figure 4-80. Stronium-90 Activity Concentration on Cross Section A-A'

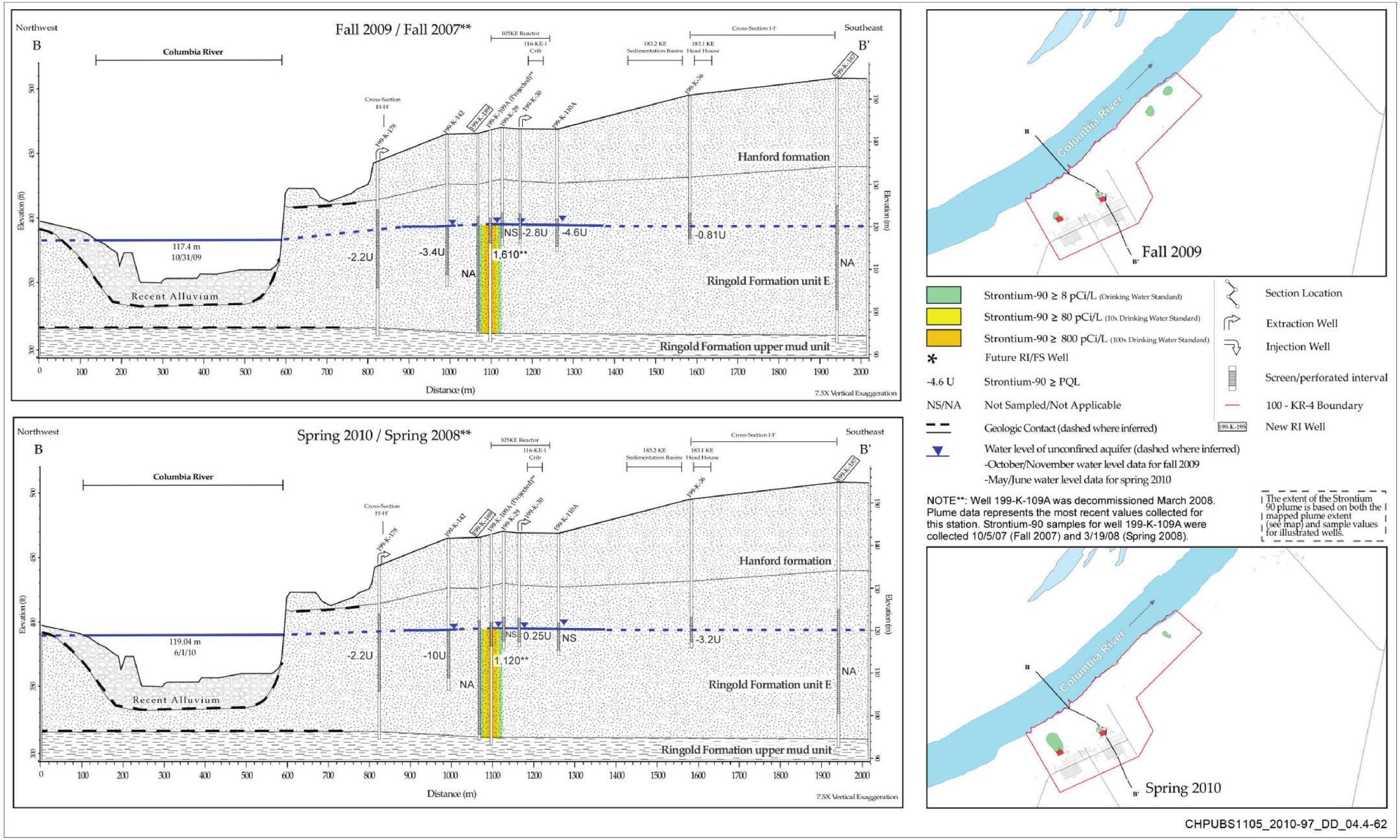


Figure 4-81. Sr-90 Activity Concentration on Cross Section B-B'

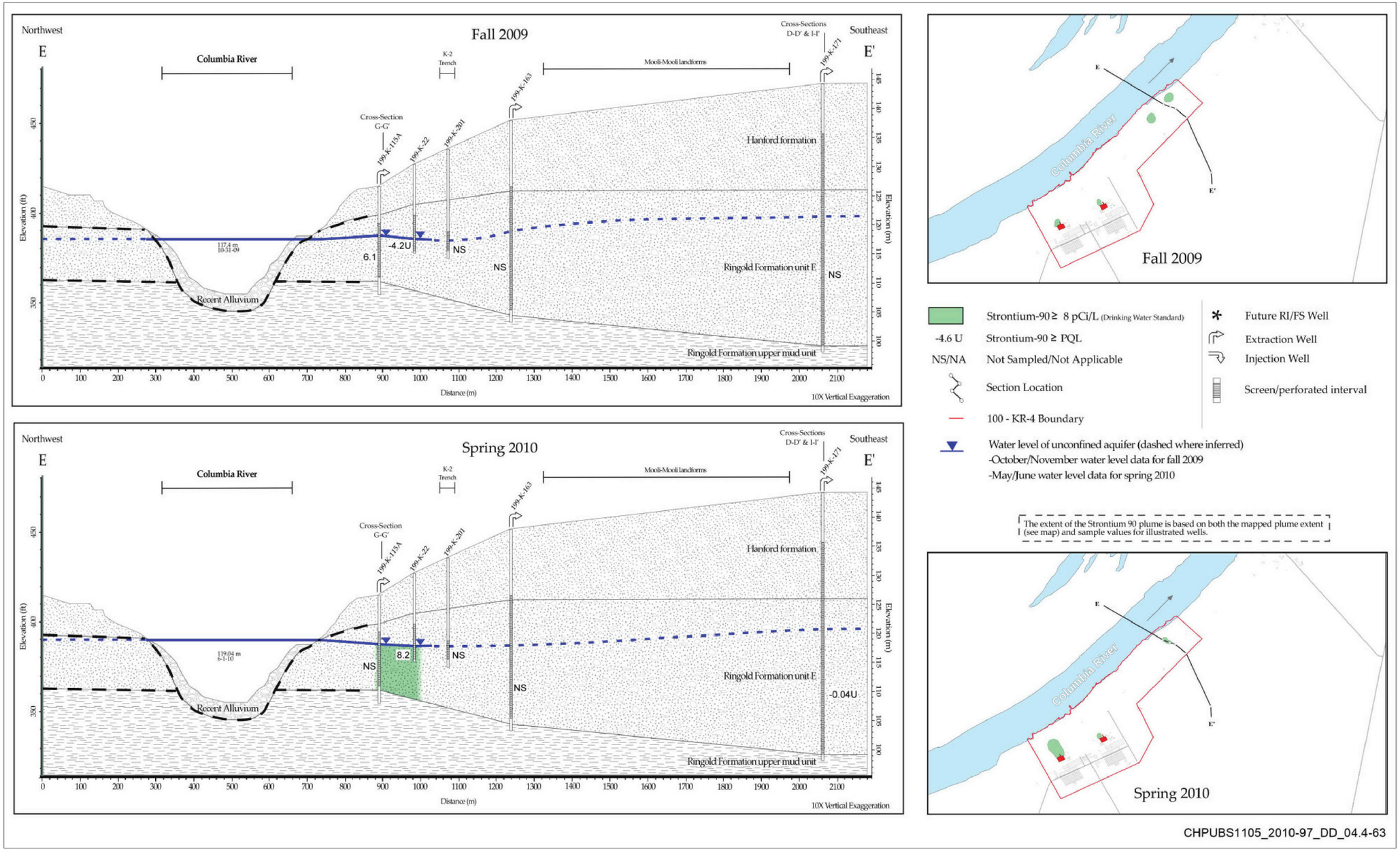
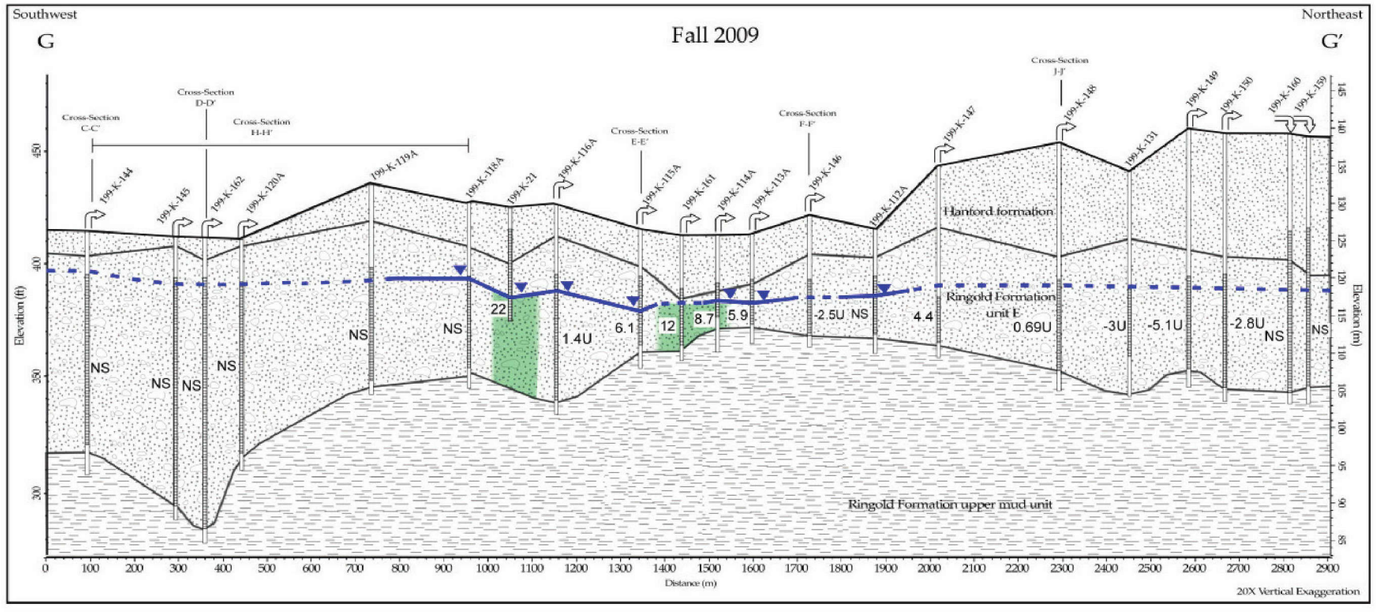
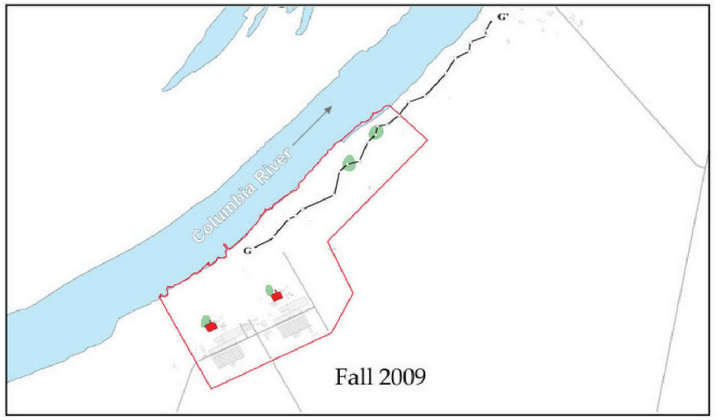


Figure 4-82. Sr-90 Activity Concentration on Cross Section E-E'

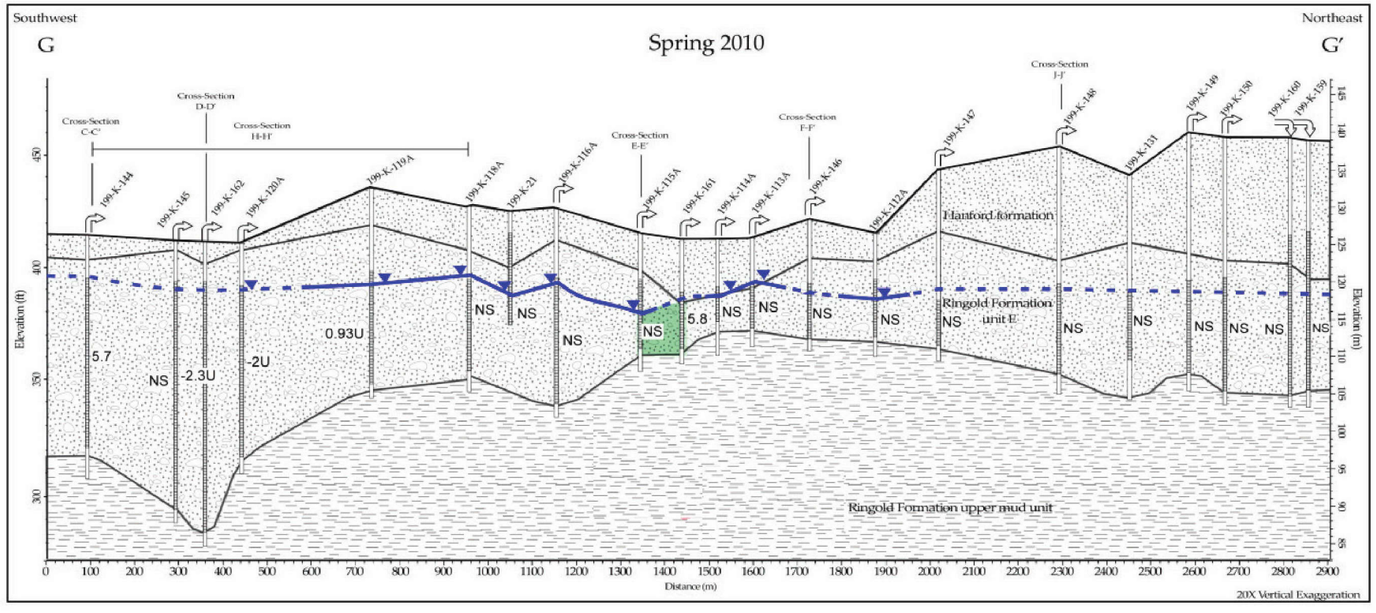




Strontium-90 ≥ 8 pCi/L (Drinking Water Standard)
-4.6 U Strontium-90 ≥ PQL
NS/NA Not Sampled/Not Applicable
Section Location
100 - KR-4 Boundary
Water level of unconfined aquifer (dashed where inferred)
-October/November water level data for fall 2009
-May/June water level data for spring 2010

* Future RI/FS Well
Extraction Well
Injection Well
Screen/perforated interval

The extent of the Strontium 90 plume is based on both the mapped plume extent (see map) and sample values for illustrated wells.



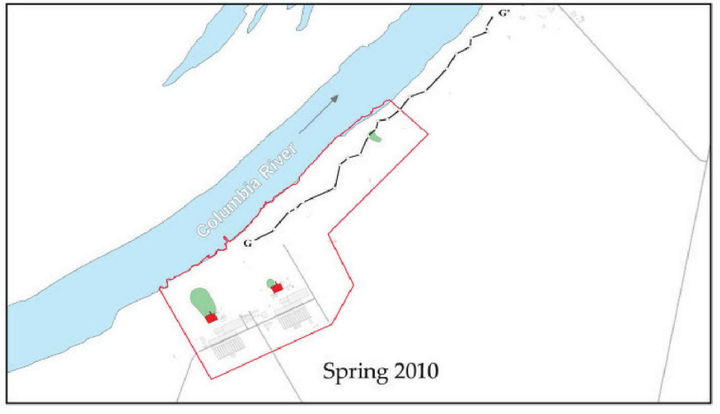


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Figure 4-83. Sr-90 Activity Concentration on Cross Section G-G'

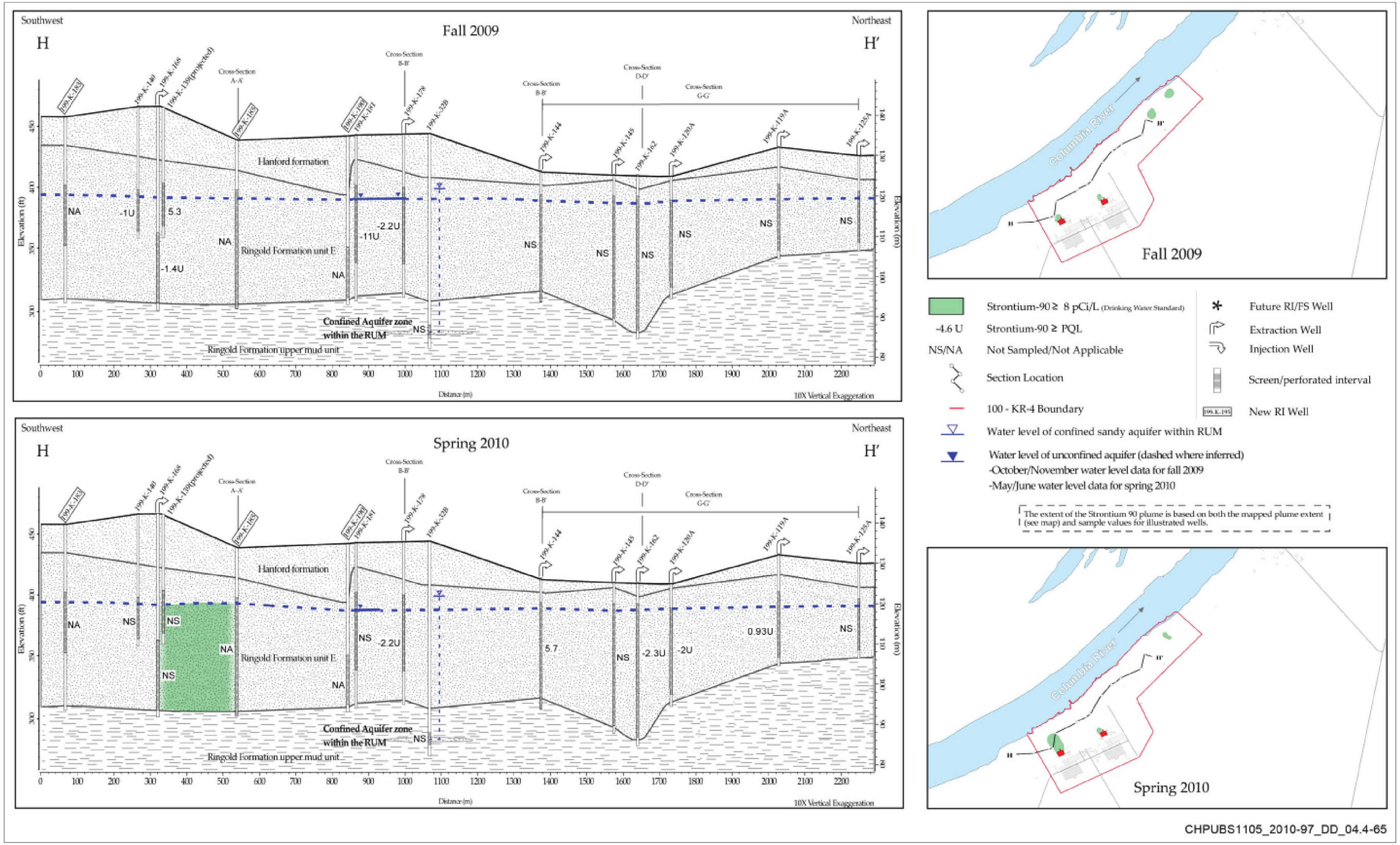

Figure 4-84. Sr-90 Activity Concentration on Cross Section H-H'

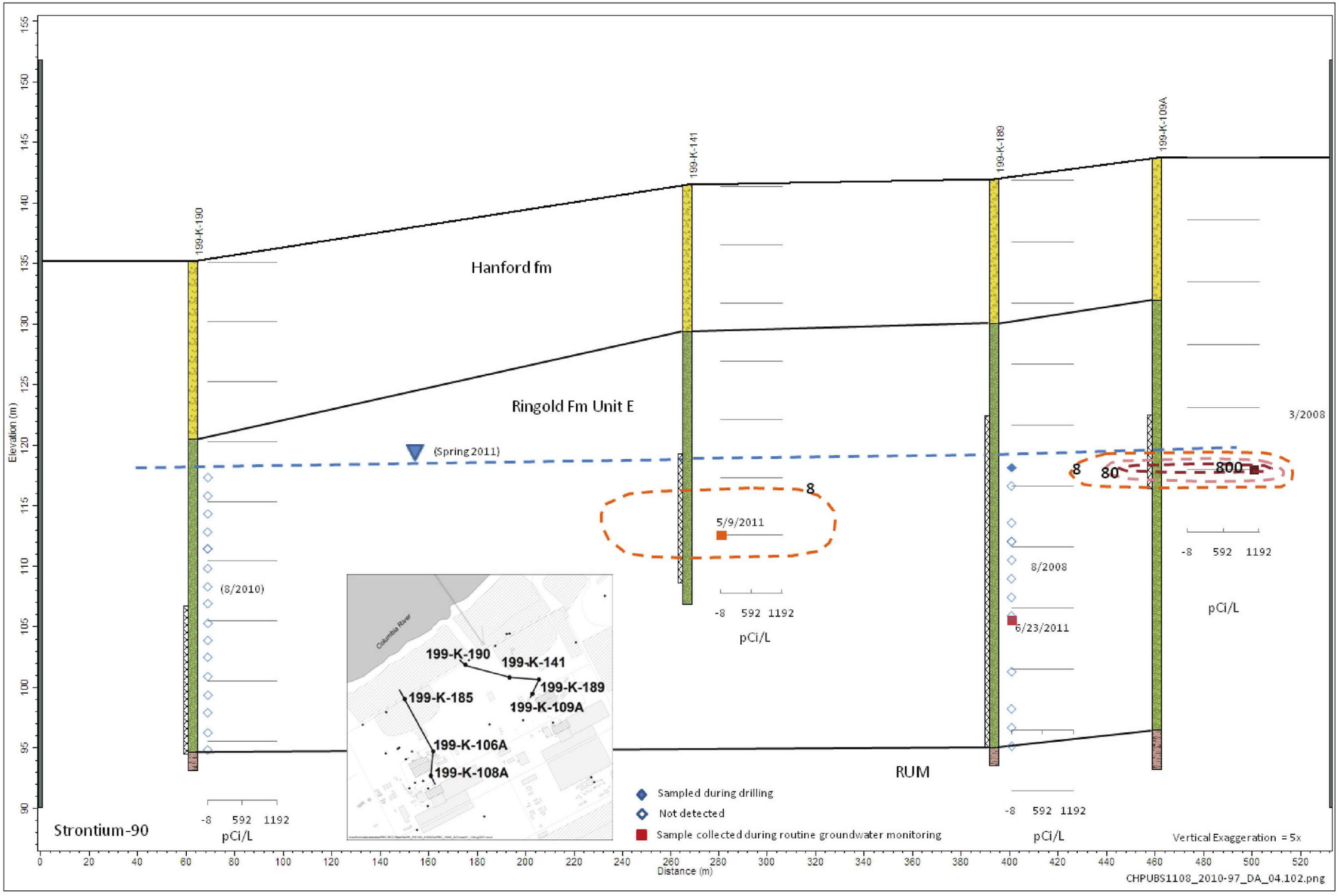

Figure 4-85. Vertical Distribution of Strontium-90

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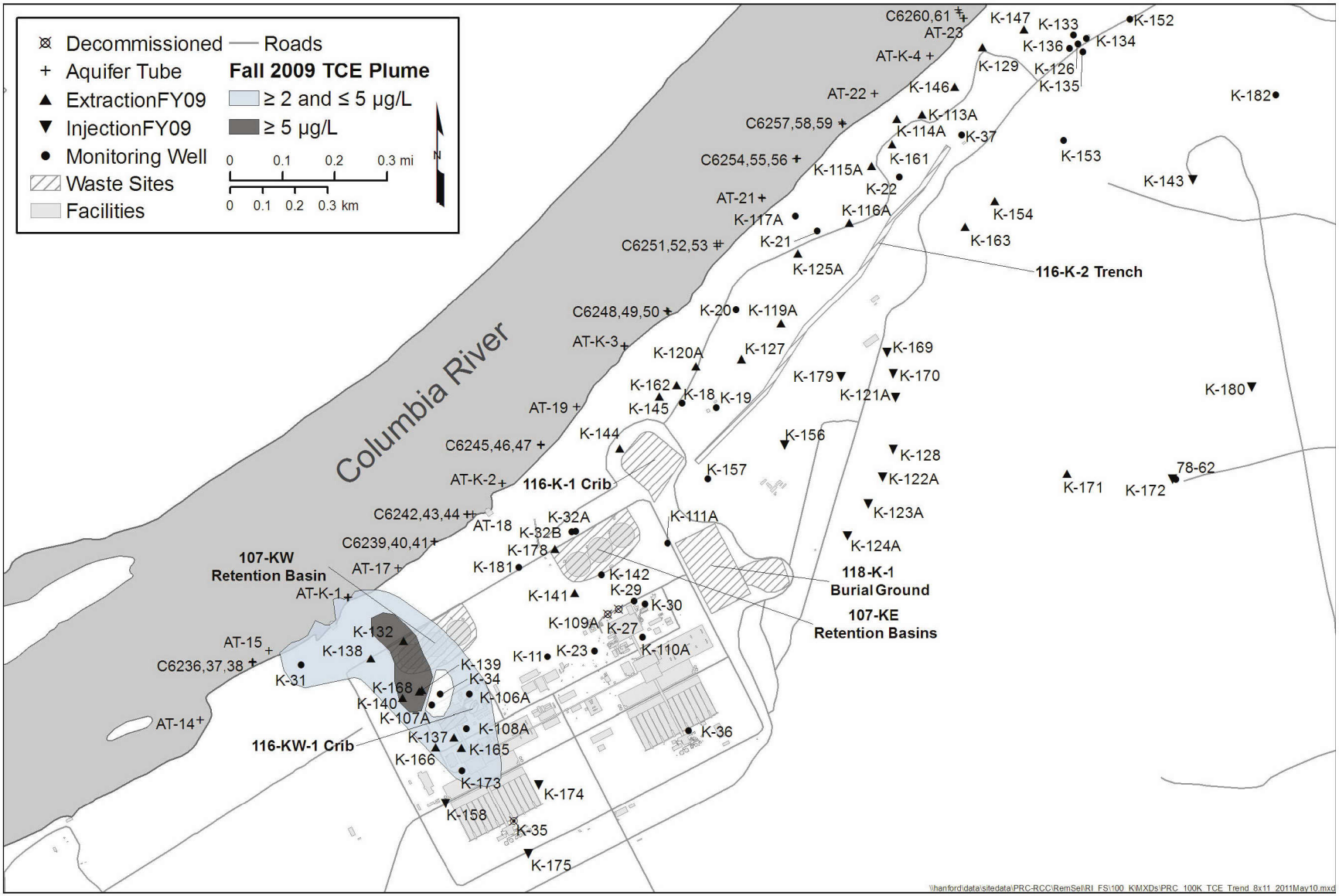


Figure 4-86. 100-K Area TCE Plume

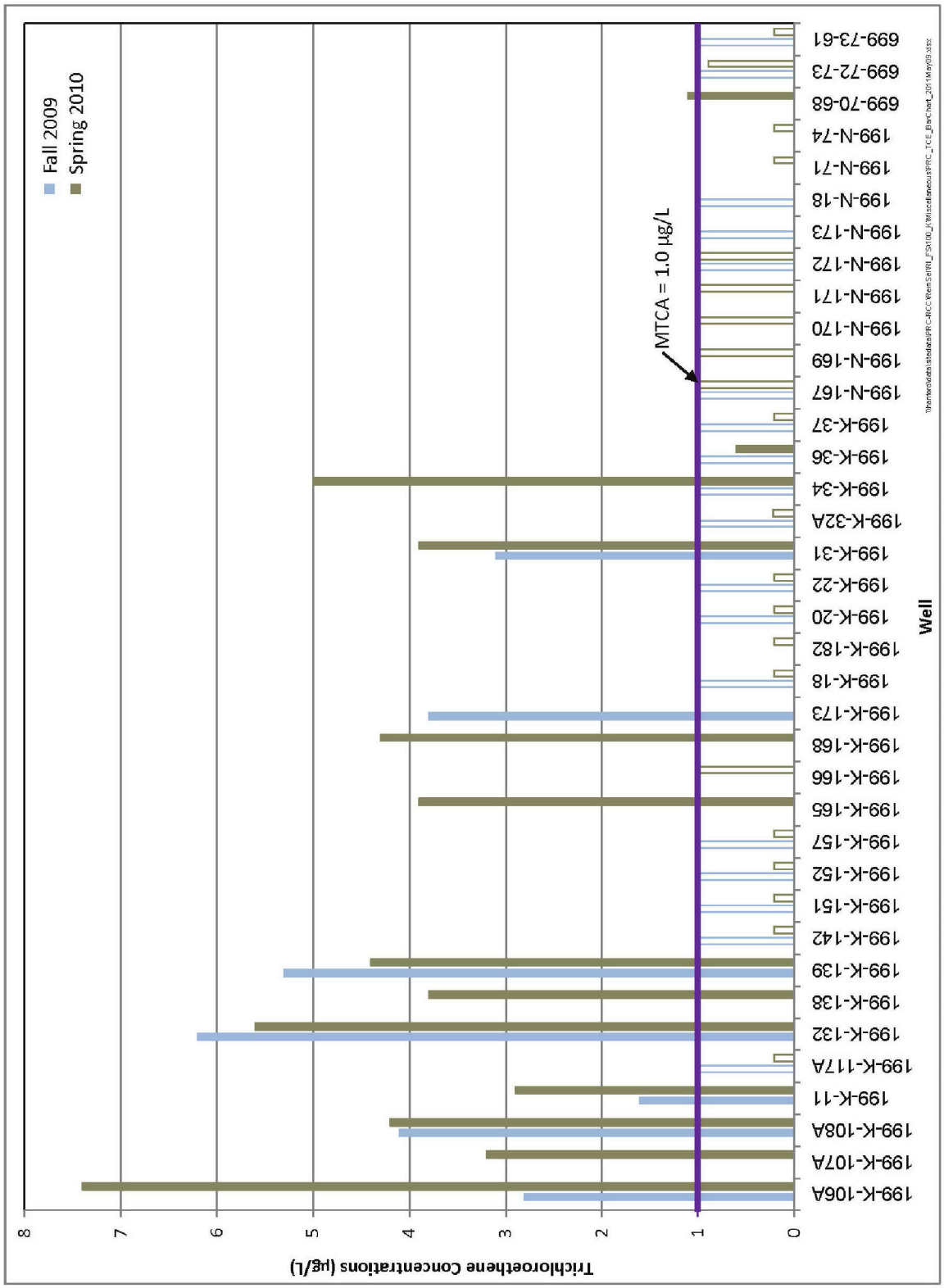


Figure 4-87. 100-K Area Bar Charts of TCE Concentrations in Wells, Fall 2009 and Spring 2010

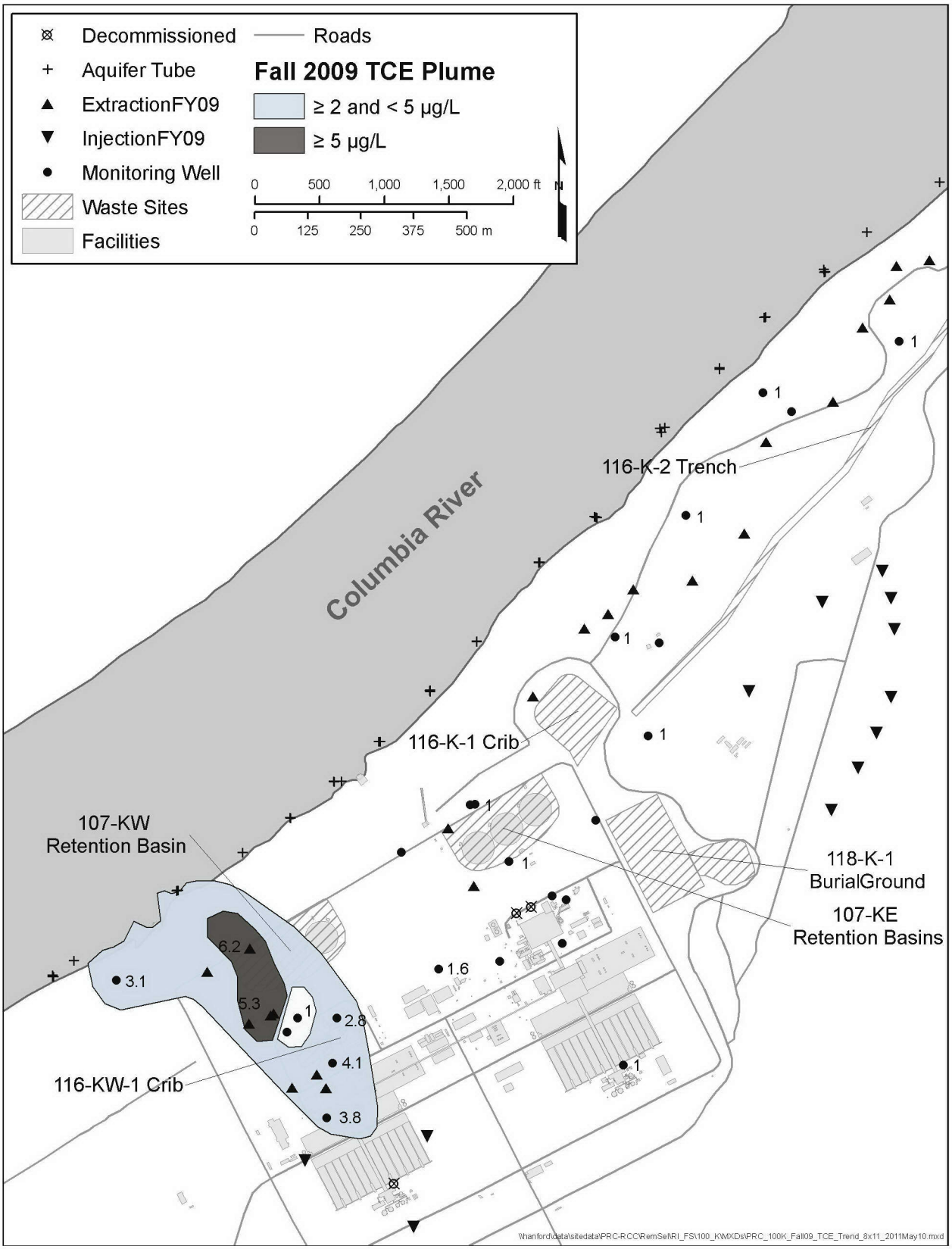


Figure 4-88. Fall 2009 and Spring 2010 TCE Plumes in 100-K

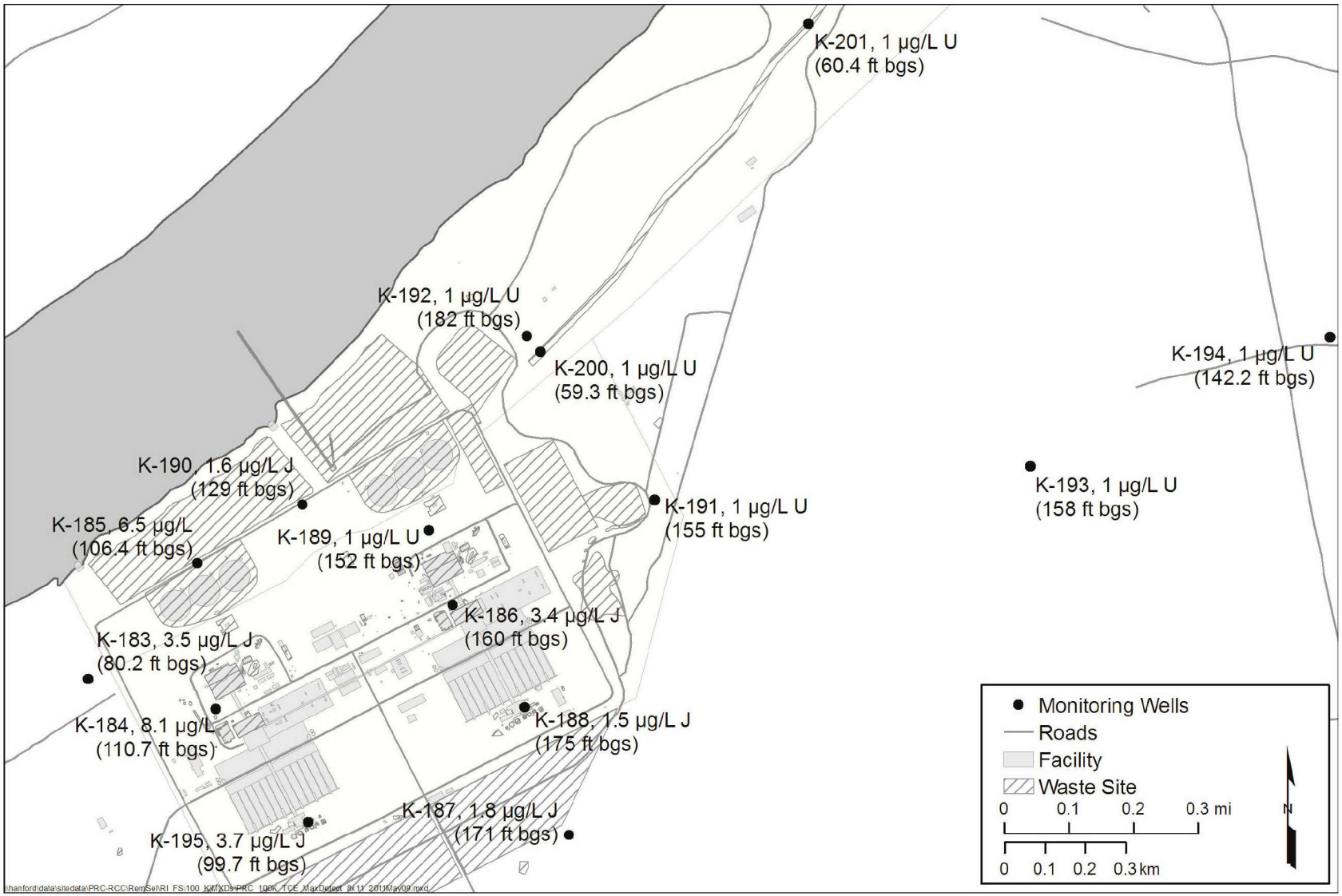


Figure 4-89. Maximum Concentrations of TCE from Discrete RI Well Samples

Table 4-32. Detected Concentration of Trichloroethene above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Trichloroethene Grab Groundwater (µg/L)
Constituent Action Level								**0.49**
199-K-183	C7683	1	5/21/10	24.4	80.2	21.74 [69.04] to 44.97 [147.50]	B25TN6	3.5
199-K-183	C7683	1	6/3/10	36.6	120		B25TP5	1.4
199-K-184	C7684	R1	1/15/10	44.2	145		B27LJ7	2.9
199-K-184	C7684	R1	12/29/10	26.4	86.7	24.7 [78.75] to 49.63 [162.80]	B27LH5	2.8
199-K-184	C7684	R1	12/30/10	27.4	90		B27LH6	2.8
199-K-184	C7684	R1	12/30/10	29.0	95		B27LH7	3.2
199-K-184	C7684	R1	1/4/11	32.1	105.2		B27LH9	3.7
199-K-184	C7684	R1	1/6/11	33.7	110.7		B27LJ0	3.3
199-K-184	C7684	R1	1/6/11	33.7	110.7		B27LK5	8.1
199-K-184	C7684	R1	1/7/11	35.2	115.5		B27LJ1	2.9
199-K-184	C7684	R1	1/10/11	36.4	119.4		B27LJ2	3.6
199-K-184	C7684	R1	1/13/11	39.4	129.4		B27LJ4	2.7
199-K-184	C7684	R1	1/14/11	41.1	135		B27LJ5	2.8
199-K-184	C7684	R1	1/15/11	42.7	140		B27LJ6	3.1
199-K-184	C7684	R1	1/15/11	42.7	140		B28374 (DUPLICATE)	3.1
199-K-184	C7684	R1	1/17/11	45.7	149.8		B27LJ8	2.5

Table 4-32. Detected Concentration of Trichloroethene above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Trichloroethene Grab Groundwater (µg/L)
199-K-184	C7684	R1	1/18/11	47.3	155.3		B27LJ9	3.2
199-K-184	C7684	R1	1/21/11	48.7	159.9	16.93 [53.26] to 40.70 [133.50]	B27LK0	3.4
199-K-185	C7685	2	7/6/10	19.1	62.5		B264P1	5.5
199-K-185	C7685	2	7/8/10	20.5	67.2		B264P2	5.5
199-K-185	C7685	2	7/8/10	20.5	67.2		B264P3 (DUPLICATE)	5.1
199-K-185	C7685	2	7/8/10	21.9	72		B264P4	2.4
199-K-185	C7685	2	7/9/10	23.5	77.2		B264P5	4
199-K-185	C7685	2	7/9/10	25.0	82		B264P6	3.5
199-K-185	C7685	2	7/12/10	26.5	87.1		B264P8	1.3
199-K-185	C7685	2	7/13/10	28.0	92		B264P9	3.2
199-K-185	C7685	2	7/13/10	29.6	97		B264R0	4.5
199-K-185	C7685	2	7/15/10	32.4	106.4		B264R2	6.5
199-K-185	C7685	2	7/16/10	34.1	112		B264R3	5.8
199-K-185	C7685	2	7/16/10	35.7	117		B264R4	4.9
199-K-185	C7685	2	7/19/10	38.7	127		B264R6	3.5
199-K-185	C7685	2	7/20/10	40.2	132		B264R7	4.8
199-K-186	C7686	9	2/14/11	46.3	151.8		B29LT4	1.5

Table 4-32. Detected Concentration of Trichloroethene above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Trichloroethene Grab Groundwater (µg/L)
199-K-186	C7686	9	2/16/11	48.8	160	TBD to 49.39 [162.00]	B29LV0	3.4
199-K-187	C7687	3	6/3/10	52.1	171	35.42 [113.90] to 60.21 [197.50]	B25V00	1.8
199-K-188	C7688	R3	1/20/11	45.7	150		B28FJ2	1
199-K-188	C7688	R3	1/26/11	50.7	166.2		B28FJ6	1
199-K-188	C7688	R3	1/27/11	53.3	175	30.79 [98.70] to 55.79 [183.00]	B28FJ7	1.5
199-K-190	C7690	4	8/10/10	31.6	103.7	17.89 [56.41] to 40.55 [133.00]	B26VF6	1.6
199-K-190	C7690	4	8/13/10	37.6	123.5		B26VH0	1.3
199-K-190	C7690	4	8/16/10	39.3	129		B26VH1	1.6
199-K-195	C7695	R4	11/17/10	30.4	99.7	26.61 [85.00] to 54.33 [178.20]	B27HJ6	3.7
199-K-195	C7695	R4	11/18/10	31.9	104.6		B27HJ7	3.1
199-K-195	C7695	R4	11/19/10	33.6	110.3		B27HJ8	1.6
199-K-195	C7695	R4	11/19/10	33.6	110.3		B27RD1 (DUPLICATE)	1.5
199-K-195	C7695	R4	11/23/10	35.0	114.9		B27HJ9	2.2
199-K-195	C7695	R4	11/29/10	36.4	119.5		B27HK0	1.9
199-K-195	C7695	R4	11/30/10	38.2	125.2		B27HK1	1.7

Table 4-32. Detected Concentration of Trichloroethene above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Trichloroethene Grab Groundwater (µg/L)
199-K-195	C7695	R4	12/2/10	41.1	134.8		B27HK3	1.8
199-K-195	C7695	R4	12/3/10	42.7	140		B27HK4	1.2
199-K-195	C7695	R4	12/8/10	45.7	150		B27HK6	1.3
199-K-195	C7695	R4	12/13/10	48.8	160		B27HK8	1.8
199-K-195	C7695	R4	12/14/10	50.3	165		B27HK9	2.2
199-K-195	C7695	R4	12/15/10	51.8	170		B27HL0	1.9
199-K-195	C7695	R4	12/15/10	53.6	175.8		B27HL1	2.4

TBD = to be determined

In 100-K West, the highest concentrations of TCE were 9.2 and 9.0 µg/L, reported at 199-K-132 in a May 2009 sample, but concentrations declined to 6.2 µg/L in October 2009. Wells on the west side of the Cr(VI) plume/pump-and-treat system reported the next highest concentrations of TCE (199-K-140 at 5.9 µg/L, and 199-K-138 at to 6.2 µg/L). Wells on the east side of the plume/pump-and-treat system reported lower concentrations ranging from 1.0 µg/L (nondetect at 199-K-34), 3.3 µg/L (estimated value at 199-K-106A), and 4.1 µg/L (estimated value at 199-K-108A). Upgradient Wells 199-K-173, 199-K-174, and 199-K-175 reported TCE concentrations of 3.8, 3.9, and 3.0 µg/L, respectively (estimated). This distribution suggests a plume source upgradient and, in part, west of the KW Reactor area. In the 100-K West plume, the maximum detected concentration measured in routine groundwater monitoring wells over a five-year period was 7.7 µg/L. The frequency of detection above the AL was 90 percent. In contrast to 100-K West, the maximum detected concentration measured in routine groundwater samples in 100-K East was 2.9 µg/L with a frequency of detections above the AL of 19 percent.

Detections above the AL are confined mainly to areas within and surrounding the 100-KW Reactor (Figure 4-89). The maximum detected concentration of TCE measured during RI activities occurred in 199-K-184 with a concentration of 8.1 µg/L at a depth of 33 m (110 ft) bgs. RI Monitoring Well 199-K-184 is located in the central axis of the TCE plume within the 100-K West area. The range of TCE detected above the AL in grab groundwater samples collected from RI wells located in the KW plume was 1.2 µg/L at 199-K-195 from a depth of 42 m (140 ft) bgs to 8.1 µg/L at 199-K-184.

The maximum detected concentrations measured in RI Wells 199-K-186, 199-K-187, 199-K-188, and 199-K190 ranged from 1.5 to 3.4 µg/L, and are consistent with historical concentrations observed in samples collected within and near the 1000-KE Reactor. TCE spills and leaks may have occurred near the 183.3 KE Head House, which would explain the presence of TCE in 199-K-188. The alignment of 199-K-190 in relation to 199-K-11 suggests horizontal migration of the plume toward the Columbia River in much the same fashion as groundwater containing Cr(VI) and other COPCs. The use or handling of TCE near both the 100-KW and 100-KE railroad-unloading sites adjacent the 183.3 Head Houses is supported by the presence of TCE at a concentration of 0.6 µg/L. This is further reinforced by the detection of TCE above the AL at 199-K-187 at a concentration of 1.8 µg/L.

Summary. TCE is present at wells primarily in the 100-KW Reactor (100-K West plume) and to a lesser degree in 100-K East. The maximum detected concentrations measured in RI wells are consistent with historical concentrations observed in samples collected within and near the 1000-KE and 100-KW Reactor areas. Because of the slightly elevated concentrations in the vicinity of the 100-KW Reactor area, TCE is a COPC for risk assessment analysis.

Total Chromium. Total chromium was identified as a COPC in the 100-K SAP (DOE/RL-2009-41) and during risk assessment activities for 100-K. Total chromium has been detected above the AL (65 µg/L) in all three plume areas (100-K East, 100-K West, and 100-K North). The highest frequency of detections above the AL (45 percent) in groundwater monitoring wells is found in 100-K West, with a maximum detection of 3,550 µg/L. In the 100-K East plume area, the extent and maximum concentration are less than half that observed in the 100-K West area. The maximum detected concentration in the 100-K East plume area is 427 µg/L with a frequency of detection above the AL of 15 percent. Total chromium concentrations measured in the new aquifer tube cluster were either nondetect or below the AL, which is consistent with concentrations observed in adjacent aquifer tubes to the north and south (Table 4-25).

Table 4-33 presents analytical results for total chromium measured in groundwater samples collected from all 15 RI monitoring wells. Total chromium was detected above the AL in monitoring wells 199-K-184, 199-K-195, and 199-K-201 (Figure 4-90).

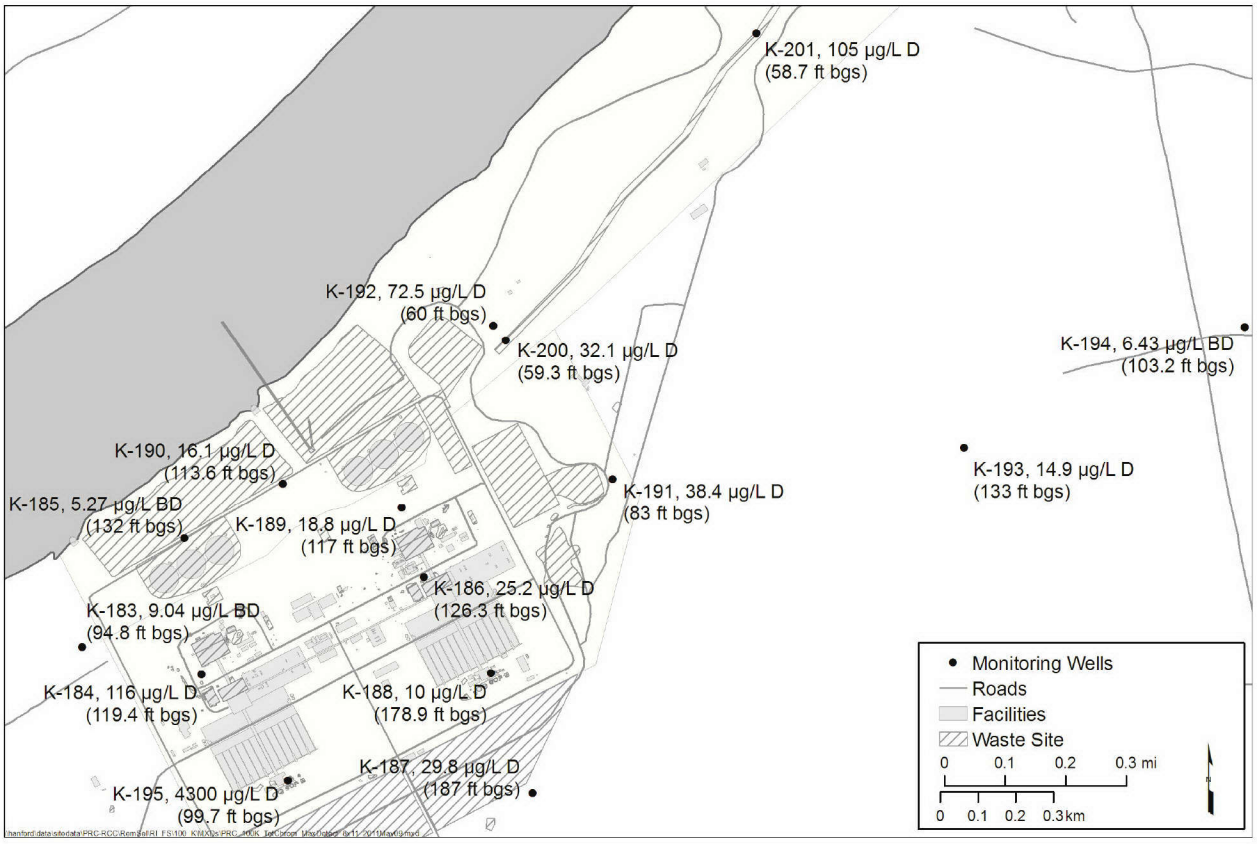


Figure 4-90. Maximum Concentrations of Total Chromium from Discrete RI Well Samples

The maximum detected concentration of total chromium measured in 199-K-195 was 4,300 µg/L at a depth of 30 m (99 ft) bgs. The concentration of total chromium detected in grab groundwater samples collected from 199-K-184 was 116 µg/L at a depth of 36 m (119 ft) bgs.

Total chromium was detected in grab groundwater samples collected from 199-K-201, located at the eastern end of the 116-K-2 Trench. The maximum detected concentration of total chromium in 199-K-201 was 105 µg/L. No other RI wells sampled in either the 100-K East or 100-K North plumes contained measurable concentrations of total chromium above the AL.

Coupled with historical groundwater monitoring results, the predominant plume of total chromium exists within the 100-K West area and immediately east of the 183-KW Settling Basin and head house area. The evidence of total chromium present in grab groundwater samples collected from the lower unconfined aquifer at Wells 199-K-184 and 199-K-195 suggests the possibility of vertical migration to the lower unconfined aquifer.

Table 4-33. Detected Concentration of Total Chromium above the AL in RI Groundwater Samples Collected from Borings and Monitoring Wells

Well ID	Borehole ID	SAP Location ID	Sample Date	Sample Depth (m bgs)	Sample Depth (ft bgs)	Depth below Top of Water Level (m [ft] bgs) to Aquifer Depth Thickness (m [ft])	Sample Tracking ID No.	Total Chromium Grab Groundwater (µg/L)
Constituent Action Levels								**74**
199-K-184	C7684	R1	1/10/2011	36.39	119.40		B27LJ2	116
199-K-195	C7695	R4	11/16/2010	28.99	95.1	26.61 [85.00] to 54.33 [178.20]	B27HJ5	325
199-K-195	C7695	R4	11/17/2010	30.39	99.7		B27HJ6	4300
199-K-195	C7695	R4	11/18/2010	31.88	104.6		B27HJ7	1780
199-K-195	C7695	R4	11/19/2010	33.62	110.3		B27HJ8 (DUPLICATE)	248
199-K-195	C7695	R4	11/19/2010	33.62	110.3		B27RD1	243
199-K-195	C7695	R4	11/23/2010	35.02	114.9		B27HJ9	488
199-K-195	C7695	R4	11/29/2010	36.42	119.5		B27HK0	192
199-K-195	C7695	R4	12/14/2010	50.29	165		B27HK9	701
199-K-201	C7832	116-K-2 East	1/31/2011	17.89	58.7	TBD to TBD	B2BHK1	105

TBD = to be determined

Chloroform. Chloroform is a minor contaminant found in wells in the 100-K North plume (199-K-151) and 100-K-East plume (199-K-18, 199-K-32A, and 199-K-190). Wells 199-K-18 and 199-K-32A are located downgradient of the 116-K-1 Trench and 107-KE Retention Basins, respectively. Chloroform has only been sampled and analyzed in these wells twice. The concentration has typically been 2.0 µg/L for each well.

Figures 4-91 and 4-92 show chloroform fall 2009 and spring 2010 concentrations for 100-K wells. No 100-K aquifer tubes were sampled for chloroform in spring 2010. Therefore, bar charts were not constructed for aquifer tubes. Chloroform concentrations measured in the new aquifer tube cluster were nondetect (Table 4-25).

Chloroform was not detected above the constituent action level (5.7 µg/L) in any of the RI monitoring wells. Well 199-K-190 was sampled and analyzed 16 times for chloroform. Chloroform has been detected twice (12 percent). The median and maximum concentration at this well location was 2.2 µg/L. Historical groundwater results show chloroform has not been detected above the AL in any other wells located in the 100-K West or 100-K East plume areas. The maximum detected concentration of chloroform within the 100-K North plume was 7.1 µg/L with a median detection of 0.77 µg/L, below the action level of 5.7 µg/L.

Technetium-99. Technetium-99 is tracked in the KW Reactor treatment system area because it occurs in wells but at activities far below the 900 pCi/L MCL. The highest concentration reported in CY 2009 was 56 pCi/L at 199-K-168. Other wells within the KW monitoring system have ranged from nondetect at 199-K-106A and 199-K-108A to 51 pCi/L at 199-K-173 and 47 pCi/L at 199-K-175. Well 199-K-157 near the west end of the 116-K-2 Trench also reported technetium-99 concentrations of 56 pCi/L, but this result is under review.

Technetium-99 was not detected in any of the groundwater samples collected from RI monitoring wells.

Total Petroleum Hydrocarbons. TPH analyses were performed on groundwater samples collected in October 2009, but none of the three TPH categories (diesel, gasoline, and kerosene) was detected at any of the wells upgradient or downgradient of the 166-KW fuel bunker.

TPH was not identified as a COPC in the 100-K Work Plan (DOE/RL-2008-46-ADD2) or 100-K SAP (DOE/RL-2009-41), but was sampled as part of RI activities between May 2010 and February 2011. TPH was not detected in groundwater samples collected in any of the RI borings or groundwater monitoring wells.

Other Constituents. The RI characterization of 100-K included an assessment of both major COPCs and minor constituents that were included in Table 2-10 of the 100-K SAP (DOE/RL-2009-41). The analytical results revealed the presence of five additional minor COPCs detected above the AL—antimony, lead, manganese, zinc, and nitrite. Typically, these compounds have not been identified in results from historical groundwater monitoring for 100-K. With the exception of nitrite, these constituents have not been associated with operational sources or waste site activities.

Antimony was detected above the AL of 5.6 µg/L at 199-K-183, 199-K-185, 199-K-186, 199-K-187, 199-K-189, 199-K-190, 199-K-191, 199-K-192, 199-K-193, 199-K-195, 199-K-200, and 199-K-201. The maximum detected concentration was 485 µg/L measured in 199-K-191. Detections of antimony above the AL are not isolated to a particular portion of 100-K and the magnitude of distribution is minimal. Lead was detected above the AL of 2.1 µg/L in 199-K-189, 199-K-190, 199-K-191, and 199-K-192. The maximum detected concentration was 5.2 µg/L at 199-K-191.

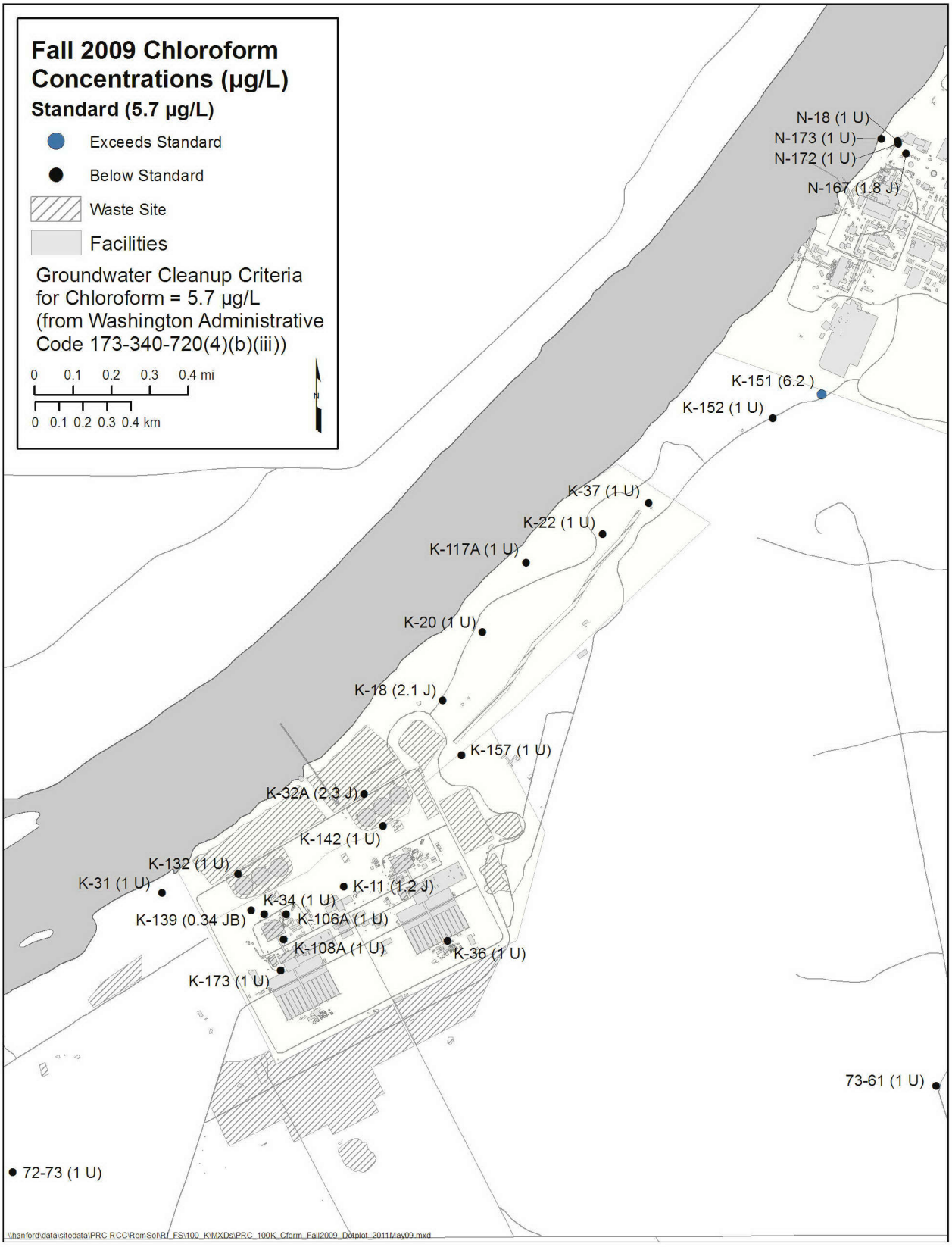


Figure 4-91. Chloroform Concentrations for Fall 2009

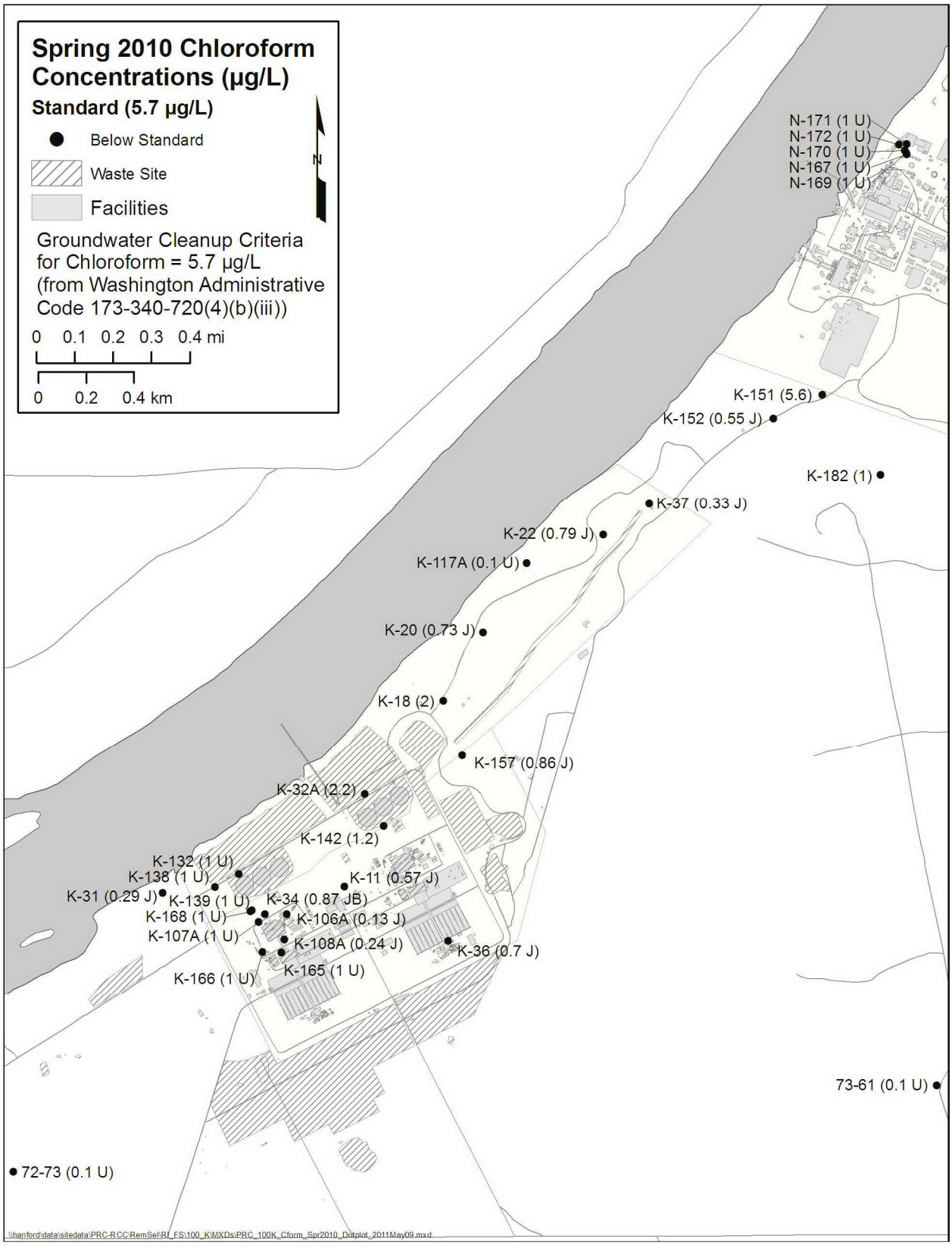


Figure 4-92. Chloroform Concentrations for Spring 2010

Manganese was detected in multiple RI wells above the AL of 50 µg/L, including 199-K-183 through 199-K-192, 199-K-194, 199-K-195, and 199-K-200. The maximum detected concentration of manganese was 665 µg/L in 199-K-183. Zinc was detected at 199-K-191 at a concentration of 201 µg/L, above the AL of 91 µg/L. The sources for manganese and zinc are not currently associated with a defined waste site, reactor process, operation, or chemical storage facility within 100-K.

Nitrite was detected above the AL of 1,000 µg/L in 199-K-191 at a maximum detected concentration of 1,710 µg/L. The presence of nitrite in groundwater samples collected from 199-K-191 may be attributed to the elevated concentrations of nitrate (76 mg/L) measured in 199-K-191. The waste materials deposited in the 126-K-1 Waste Site contained nitrate in concentrations high enough to increase the presence of denitrifying bacteria in the saturated zone. Through the process of denitrification, nitrate is reduced to nitrite, and this mechanism may be responsible for the elevated concentration of nitrite found in the groundwater immediately below the 126-K-1 Waste Site.

4.2.6.10 Key Conclusions of Nature and Extent and Extent of Groundwater

- The current state of Cr(VI) contamination in groundwater at 100-K consists of three plume areas. Tritium, nitrate, C-14, and Sr-90 plumes are also located in the groundwater over smaller areas.
- The 100-K West plume contains the highest frequency of detections above the groundwater AL in any of the three plume areas. High concentrations of Cr(VI) identified upgradient of the 100-KW Reactor suggest that the plume sources were past leaks or spills of concentrated sodium dichromate solution near the 183-KW Head House. The 100-K West plume footprint has been reduced by the pump-and-treat system.
- The original Cr(VI) plume associated with the 116-K-2 Trench was one large plume in the past; however, the row of current and former injection wells extending from K-124A to K-169 has separated it into two distinct plumes (100-K East and 100-K North). The split appears to have been helped by the presence of a higher hydraulic conductivity in sediments within the middle of the 116-K-2 Trench.
- The overall size of the two plume (100-K East and 100-K North) components appears to be decreasing with treatment.
- Nitrate concentrations in 100-K show stable to decreasing trends in both the 100-K West and the 100-K East plumes. Sources for these plumes appear to be related to the Gas Condensate Cribs. There is no evidence of nitrate migration between the unconfined aquifer and the water-bearing zone encountered in the RUM.
- Carbon-14 is found in both the 100-K East and 100-K West plumes, with the highest activity found in locations near the former 116-KE-1 and 116-KW-1 Cribs. Carbon-14 activity in 100-K varies, but generally is decreasing. The lack of carbon-14 in samples collected in the lower RUM unit suggests that vertical migration into the confined aquifer is not occurring.
- TCE is present at wells primarily in 100-KW Reactor (100-K West plume) and to a small degree in the 100-K East area. The maximum detected concentrations measured in RI wells are consistent with historical concentrations observed in samples collected within and near the 100-KE and 100-KW Reactor. The discovery of TCE in 199-K-190 and 199-K-195 suggests a wider area of concern for TCE contamination within both the unconfined aquifer and confined RUM unit.
- Sr-90 is present in groundwater in 100-K in discrete areas located in all three plumes. In general, trend plots show Sr-90 concentrations are generally stable to decreasing. The lack of Sr-90 activity in

deeper grab groundwater samples collected at 199-K-192 suggests that no vertical dispersion is occurring between the unconfined aquifer and the RUM unit near the 116-K-1 Trench and western portion of the 116-K-2 Trench.

4.3 Nature and Extent of Contamination in the Columbia River

Evaluation of contaminants in riparian and nearshore media is presented in Appendix L. This evaluation addressed, on a reactor area basis, the potential for Hanford Site contaminants in soil or groundwater to migrate to riparian or nearshore areas at concentrations that could be of concern to ecological receptors. This evaluation supplements the analysis of the River Corridor-wide ecological risks presented in the ecological risk assessment of the RCBRA (DOE/RL-2007-21). The RCBRA identified on a site-wide basis some contaminants of ecological concern in riparian and nearshore media (soil, sediment, and water) that could warrant further evaluation. Based on the results of the evaluation in Appendix L, with the exception of Cr(VI), detected concentrations of contaminants in riparian or nearshore media are not reliably detectable at levels of ecological concern, or are not associated with contamination in soil or groundwater resulting from Hanford Site operations. Therefore, for purposes of alternatives evaluation in the 100-K FS, Cr(VI) in groundwater should be considered the only contaminant of ecological concern, with regard to riparian or nearshore media.

4.3.1 Columbia River Surface Water and Sediment Investigation

In 2004, a process was established to compile, classify, and manage environmental data (e.g., surface water and sediment) associated with the Columbia River in the *Columbia River Component of the River Corridor Baseline Risk Assessment: Basis and Assumptions on Project Scope* (DOE/RL-2004-09). The Columbia River Component (CRC) database was created because of these efforts and was documented in the *Existing Source Information Summary Report Compilation/Evaluation Effort: December 2004 to September 2005: Columbia River Component of the River Corridor Baseline Risk Assessment* (WCH-64). The subsequent *Columbia River Component Data Evaluation Summary Report* (WCH-91) described the activities that were undertaken to evaluate the data collected in the compilation effort and to assist in defining the extent of Hanford Site related contamination. The compiled data were used to identify potential data gaps in the spatial, temporal, and chemical composition of the existing data set. The *Columbia River Component Data Gap Analysis* (WCH-201) presented the results of that analysis and formed by the foundation for the sampling plan documented in the Columbia River RI Work Plan (DOE/RL-2008-11).

During this time, sampling was already underway supporting the *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2004-37). Samples of surface water, groundwater, nearshore sediment, soils, and biota were being collected and analyzed to support the RCBRA. Evaluation of that data is presented in the RCBRA Report (DOE/RL-2007-21) and summarized in Appendix L.

Sampling to fulfill the needs defined in the Columbia River RI Work Plan (DOE/RL-2008-11) was initiated in October 2008 and was completed in June 2010. Media sampled included surface water, porewater, sediment (shoreline, shallow, cores), island soils, and six species of fish. The RI field activities associated with the collection of sediment, river water, and island soil in the Columbia River adjacent to and downstream of the Hanford Site and in nearby tributaries are documented in the *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, River Sediments, and Island Soils* (WCH-352). The *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, River Sediments, and Island Soils* (WCH-352) describes the sampling locations, identifies samples collected, and describes modifications and additions made to the

100-K SAP (DOE/RL-2009-41). Groundwater upwelling field activities and data collection are documented in the *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* (WCH-380).

Groundwater beneath the Hanford Site discharges to the Columbia River via seeps and upwelling to the riverbed. This flow path for groundwater provides a means for transporting Hanford Site associated contaminants that entered the groundwater from past waste disposal practices to the Columbia River. The nearshore groundwater conditions are directly affected by river stage. The greatest contaminant flux and highest concentrations at exposure locations are postulated to occur during periods of low river stage. During this period, the hydraulic gradient toward the river is greatest and mixing between river water and groundwater is minimal.

Sediment samples, were analyzed for a range of radiological and nonradiological analytes, including metals, pesticides, SVOCs, VOCs, PCBs and other chemicals. Sediment samples were obtained as close to the pore water sample locations as reasonably possible, with a preference given to locations with fine sediment deposits. Sample volume was limited in some locations due to the dominance of cobbles on the riverbed. In locations where sediment sample volume was limited, not all analyses could be performed at each location. Additional sediment, island soils, and surface water samples were collected in areas identified in the *Columbia River Component Data Gap Analysis* (WCH-201) and the Columbia River RI Work Plan (DOE/RL-2008-11).

Further discussion of the sediment, surface water, and pore water samples collected during the CRC RI is presented in the following sections.

4.3.2 Groundwater Upwelling Investigation at 100-K Area

Data were collected near 100-K to address the uncertainty related to the level of contamination entering the Columbia River via upwelling, including the contaminant transport mechanisms. Pore water, surface water, and sediment sampling in the Columbia River was conducted in 2009 and 2010, as outlined in the Columbia River RI Work Plan (DOE/RL-2008-11).

Measurement of specific conductance or conductivity in pore water can be used as an indicator of the presence of groundwater, since surface water conductivity in the Columbia River is typically lower (130 to 145 µS/cm) than groundwater (400 to 600 µS/cm). In a similar manner, pore water temperatures can be used as an indication of groundwater by comparing them to surface water temperatures. In this region of the Columbia River, surface water temperatures typically range from approximately 0.5°C (33°F) in the winter months to more than 27°C (80°F) during the late summer months, whereas groundwater typically stays between 7°C (45°F) and 15°C (60°F) (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* [WCH-380]).

The influence of contaminants on the water quality immediately above groundwater upwelling locations was determined by taking surface water column samples. River water was collected concurrently during pore water sample collection at approximately 0.3 m (12 in.) above the riverbed. At 100-K, surface water sample analysis at all sample locations included radiological and nonradiological analytes including metals, SVOCs, VOCs, PCBs, and other chemicals.

Phase IIa and Phase IIb Sampling. Pore water samples collected as part of the Phase IIa groundwater upwelling investigation portion of the work defined in the Columbia River RI Work Plan (DOE/RL-2008-11) helped to delineate areas of groundwater upwelling into the river bottom.

Measurements of conductivity and temperature in pore water were used to guide selection of stations for Phase IIb, which were sampled for indicator contaminants. Cr(VI) was the indicator contaminant at 100-K. Further discussion of this investigation is found in the *Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* (WCH-380). Additional discussion of the analytical results from these areas can be found in the Hanford Site Releases Data Summary (WCH-398).

Pore water conductivity levels measured near 100-K during Phase IIb were generally higher than the values measured at these sites during Phase IIa. Although some pore water conductivity variation was apparent throughout 100-K, the presence of groundwater was detected at all 32 pore water sample locations. Both intake structures (181-KE and 181-KW River Pump Stations) showed a consistent pattern of elevated conductivity as compared to other stations measured. In general, the pore water conductivity decreased as distance from the shoreline increased.

Of the 32 pore water samples analyzed for Cr(VI), 12 results were reported above the Practical Quantitation Level (PQL) of 3.7 µg/L near 100-K. Of the 12 sample results above the PQL, 9 were at or above the AWQS (10 µg/L; results ranged from 10 to 44 µg/L). Of those nine results, three were collected nearshore and six were collected in offshore locations. The highest Phase IIb Cr(VI) result (44 µg/L) was collected from a location that was the furthest offshore, at a depth of approximately 6.4 m (21 ft) below the low water mark.

Phase III Sampling. Phase III sample locations were selected as a subset of the previous sample locations for pore water, surface water (defined as water 0.3 m [1 ft] above the riverbed), and collocated sediment and analyzed for a broad range of analytes, as defined in the Columbia River RI Work Plan (DOE/RL-2008-11). Sediment samples were collected as close to the pore water sample location as reasonably possible, with a preference given to locations with sediment deposits. Additional discussion of these results and all other analyses performed can be found in the Hanford Site Releases Data Summary (WCH-398).

Six sample locations were selected for Phase III sampling near 100-K, of which five were found to contain sediment (sample location T100K1C lacked sediment at the time of sampling). Pore water and surface water samples were collected at all six locations. Pore water conductivity values ranged from 164 to 483 µS/cm while surface water conductivity measurements ranged from 140 to 158 µS/cm. Site J100K24 yielded the maximum 100-K pore water conductivity (483 µS/cm) during Phase III. This site was found to have 36 µg/L of Cr(VI) during Phase IIb with a pore water conductivity of 350 µS/cm.

Cr(VI), total uranium, and Sr-90 were not detected in surface water samples collected during Phase III. Cr(VI) concentrations in pore water samples ranged from 18 to 56 µg/L. At locations T100K3A and T100K24, the Cr(VI) concentrations were 56 and 55 µg/L, respectively, which represents an increase increase in concentration from Phase IIb sampling event. Cr(VI) concentrations during the Phase IIb sampling event were 17 and 36 µg/L, respectively. At the four other locations, the Cr(VI) concentrations during Phase III were less than Phase IIb. Tritium was also detected in pore water with concentrations ranging from 658 to 6,500 pCi/L with the maximum found at location T100K3A. Neither total uranium nor Sr-90 were detected in pore water in 100-K during the Phase III sampling event.

4.3.3 Additional RI Sampling in the Vicinity of the 100-K Area

In addition to the sampling performed during the groundwater upwelling investigation, samples of sediment, surface water, and island soil were obtained from select locations to develop a better

understanding of the nature and extent of potential contaminants released from the Hanford Site and to support subsequent human health and ecological risk assessments.

For 100-K, shallow sediment cores were collected near the 181-KE and 181-KW river pump stations, five sediment samples were collected from the shoreline across the river, and a surface water sample was collected immediately upstream and on the opposite side of the river from the 181-KW river pump station. The analytical results for these samples are presented in the Hanford Site Releases Data Summary (WCH-398). An evaluation of the human health and ecological risk represented by all the data collected as directed in the Columbia River RI Work Plan (DOE/RL-2008-11) is presented in the *Columbia River Component Risk Assessment* (DOE/RL-2010-117, hereafter referred to as the CRC). The evaluation presented in the CRC (DOE/RL-2010-117) addresses all the data collected throughout the Hanford Reach and downstream to McNary Dam.

4.3.4 Biota

This section summarizes ecological sampling or biological monitoring data that have been collected for 100-K. Biota data is useful to understand biological receptors, which are evaluated in Chapter 7.

Biota data from two main environmental sampling projects conducted at Hanford were reviewed and summarized for this section. The SESP is a multimedia environmental surveillance project conducted by PNNL. The primary goal of SESP is to measure concentrations of radionuclides and chemicals in environmental media to demonstrate compliance with applicable environmental quality standards and public exposure limits, and to assess environmental impacts. Project personnel annually collect samples of ambient air, surface water, agricultural products, fish, wildlife, and sediments. Soil and vegetation samples are collected about every five years. SESP analytical capabilities include the measurement of radionuclides at environmental concentrations. In selected media, SESP can also measure environmental concentrations of nonradiological constituents including metals, anions, VOCs, and total organic carbon (TOC). The SESP sampling design is described in DOE/RL-91-50, *Environmental Monitoring Plan United States Department of Energy Richland Operations Office.*

Fish tissue has been a part of monitoring at the Hanford Site for many years, resulting in a wide variety of species and fish tissue in the database of historical samples. Within the historical fish tissue data set, there is considerable inconsistency in species evaluated, tissue type (whole body, fillet, skin on, skin off, etc.), and analytes. Additionally, multiple collection and analysis approaches, as well as variability in species lifespans, are believed to have introduced significant variability in analytical results. The Columbia River RI fish sampling program was specifically created to support the HHRA within the CRC, and provided a consistent sampling and analysis approach among species, tissue types, and analytes. Therefore, fish tissue data from only 2009-2010 were used in the CRC. The 2009-2010 program focused on target fish species intended to be most representative of the exposure scenarios identified for the HHRA:

- Common carp (Cyprinus carpio)
- Mountain whitefish (*Prosopium williamsoni*)
- Walleye (Stizostedion vitreum)
- Smallmouth bass (Micropterus dolomieui)
- Bridgelip sucker (Catostomus columbianus)
- White sturgeon (Acipenser transmonatnus)

These six fish species are year-round resident fish that reflect a range of trophic levels and have a higher rate of harvest and consumption among the local population. As described in the RI Work Plan (DOE/RL-2008-11), salmon were not sampled as part of this study because they spend a majority of their life cycle in the ocean as opposed to the Hanford Site Study Area.

For all species except sturgeon, fish tissue samples were composite samples composed of tissue from approximately five fish. Generally, five samples of each fish species were collected from each area, and each sample included separate fillet, carcass (which included the head and skeleton of the fish), and combined liver and kidney tissue for analysis. For carp, sufficient tissue mass was available to obtain separate liver and kidney samples. Fillet samples for all of these species except sturgeon were prepared with the skin on, since skin for these types of fish is often left on during preparation and consumed. Sturgeon samples were not composited, and thus samples represent tissue from individual fish. Sturgeon fillet samples were collected with the skin off, and separate liver and kidney samples were prepared.

Biota data are also summarized from ecological samples collected to support the RCBRA ecological risk assessment. The primary goal of RCBRA is to evaluate current and potential future risks to the environment posed by releases of hazardous substances. RCBRA appraises relevant sources of contamination, exposure pathways, and contaminants for several environmental media and receptors including surface soil, vegetation, soil invertebrates, small mammals, and birds. RCBRA analytical capabilities include the measurement of radionuclides, metals, anions, SVOCs, herbicides, and pesticides at environmental concentrations as well as physical properties (pH, moisture, particle size) in selected media. The majority of the RCBRA environmental samples were collected in 2006 and 2007. The RCBRA sampling and analytical specifications are documented in DOE/RL-2005-42.

The location of SESP and RCBRA biota samples summarized are shown in Figure 4-93. The terrestrial plant and animal species collected and the tissues analyzed are as follows:

- Perennial vegetation: stems and leaves (combined)
  - Dominant shrub: current year's growth
  - Dominant grass: current year's growth
  - Balsamroot: leaves, roots
- Terrestrial invertebrate: whole body composites
- Mouse: whole body composites; kidney and liver (combined)
- Mule Deer: antler
- Bird: Western Kingbird organs, crop

Table 4-34 summarizes the plant tissue samples collected within the 100-K Area for the SESP and RCBRA projects. Samples collected for RCBRA were analyzed for radioactive and nonradioactive constituents. The samples collected for SESP were analyzed for radionuclides and total uranium only. The table also shows a summary of plant tissue samples collected from several reference areas (unimpacted areas) as a part of the RCBRA project. The reference samples were analyzed for the same suite of analytes as the RCBRA study site samples. The plant tissue sample results from the 100-K study sites are within the range of the results for the reference area samples.

Table 4-35 summarizes the invertebrate tissue samples collected within the 100-K Area for the RCBRA project. The samples were analyzed for metals and radionuclides only. Due to insufficient sample volumes, organic constituents were not analyzed. The table also shows a summary of invertebrate tissue samples collected from several reference areas (unimpacted areas) as a part of the RCBRA project. The reference samples were analyzed for the same suite of analytes as the RCBRA study site samples. For the

inorganic analytes, the invertebrate tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of aluminum, arsenic, total uranium, lead, nickel, silicon, and zinc, which show slightly higher concentrations. For the radionuclides, the invertebrate tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of technecium-99 and uranium-233/234, which show slightly higher concentrations.

Table 4-36 summarizes the mouse tissue samples collected within 100-K for the RCBRA project. The samples were analyzed for radioactive and nonradioactive constituents. The table also shows a summary of mouse tissue samples collected from several reference areas (unimpacted areas) as a part of the RCBRA project. The reference samples were analyzed for the same suite of analytes as the RCBRA study site samples. For the inorganic analytes, the mouse tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of boron, sodium, and tin, which show slightly higher concentrations. For the radionuclides, the invertebrate tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of potassium-40 and radium-228, which show slightly higher concentrations.

Table 4-37 summarizes two mule deer antler samples collected for SESP. The samples were analyzed for Sr-90 only. No anomalies were observed for Sr-90. There are no comparable reference samples for the mule deer antler samples.

Table 4-38 summarizes the western kingbird organ and crop tissue samples collected within 100-K for the RCBRA project. The samples were analyzed for metals and radionuclides only. Due to insufficient sample volumes, organic constituents were not analyzed. The table also shows a summary of bird tissue samples collected from several reference areas (unimpacted areas) as a part of the RCBRA project. The reference samples were analyzed for the same suite of analytes as the RCBRA study site samples. For the inorganic analytes, the bird tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of boron, phosphorus, and zinc, which show slightly higher concentrations. For the radionuclides, the invertebrate tissue sample results from the 100-K study sites are within the range of the results for the reference area samples with the exception of potassium-40, which shows slightly higher concentrations.

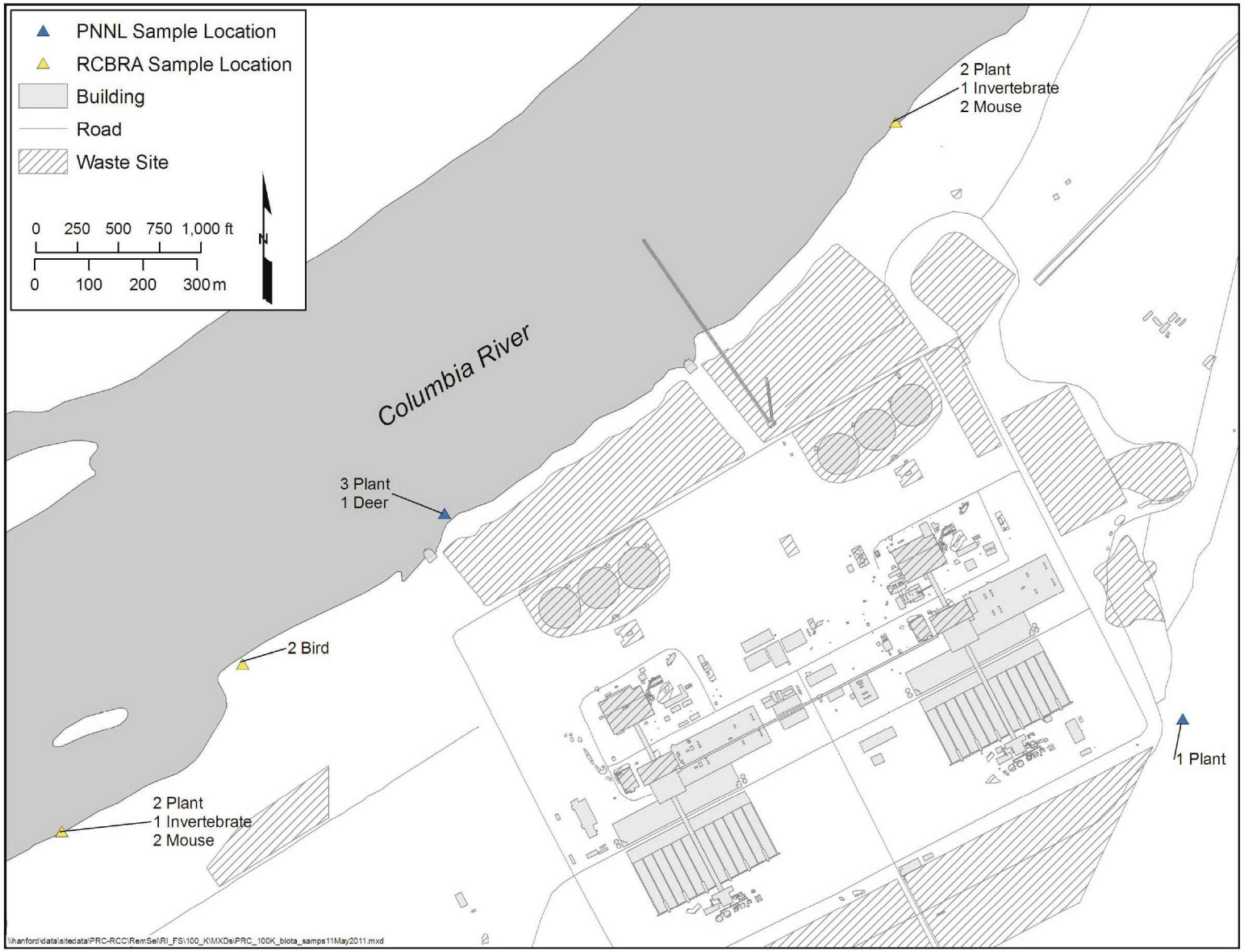


Figure 4-93. Terrestrial Upland Biota Sampling Locations in the 100-K Decision Area

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Inorganics (mg/kg)													
Aluminum	RCBRA	--	--	--	4	3.7	168	4	3.7	168	36	1.7	470
Antimony	RCBRA	3	0.21	0.43	1	0.29	0.29	4	0.21	0.43	36	0.3	2.7
Arsenic	RCBRA	4	0.39	0.6	--	--	--	4	0.39	0.6	36	0.39	3.7
Barium	RCBRA	--	--	--	4	3.5	7.3	4	3.5	7.3	36	1.3	38.5
Beryllium	RCBRA	3	0.01	0.02	1	0.02	0.02	4	0.01	0.02	36	0.01	0.12
Bismuth	RCBRA	4	0.38	0.5	--	--	--	4	0.38	0.5	36	0.31	3.1
Boron	RCBRA	--	--	--	4	0.49	5.9	4	0.49	5.9	36	0.36	52
Cadmium	RCBRA	4	0.05	0.07	--	--	--	4	0.05	0.07	36	0.03	0.43
Calcium	RCBRA	--	--	--	4	722	3220	4	722	3220	36	235	33200
Calculated total uranium	SESP	2	0.0014	0.0033	1	0.0029	0.0029	3	0.0014	0.0033	--	--	--
	RCBRA	4	0.000005	0.0125	--	--	--	4	0.000005	0.0125	36	-0.0190	0.155
Chromium	RCBRA	2	0.17	0.37	2	0.3	0.63	4	0.17	0.63	36	0.14	3.5
Cobalt	RCBRA	3	0.08	0.14	1	0.18	0.18	4	0.08	0.18	36	0.09	0.86
Copper	RCBRA	--	--	--	4	1.6	2.5	4	1.6	2.5	36	1.2	13.3
Iron	RCBRA	2	18.3	33.4	2	189	342	4	18.3	342	36	16.8	850
Lead	RCBRA	2	0.32	0.33	2	0.37	0.49	4	0.32	0.49	36	0.27	1.9
Lithium	RCBRA	2	0.03	0.06	2	0.1	0.21	4	0.03	0.21	36	0.03	0.96
Magnesium	RCBRA	--	--	--	4	386	793	4	386	793	36	164	4740
Manganese	RCBRA	--	--	--	4	3.8	17.5	4	3.8	17.5	36	2.3	87.5

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Mercury	RCBRA	4	0.01	0.02	--	--	--	4	0.01	0.02	36	0.01	0.08
Molybdenum	RCBRA	2	0.15	0.28	2	0.23	0.57	4	0.15	0.57	36	0.13	1.8
Nickel	RCBRA	--	--	--	4	0.26	1.9	4	0.26	1.9	36	0.18	2.3
Nitrogen in nitrite and nitrate	RCBRA	--	--	--	2	8.2	97.6	2	8.2	97.6	--	--	--
Phosphorus	RCBRA	--	--	--	4	334	1120	4	334	1120	36	335	3140
Potassium	RCBRA	--	--	--	4	3840	6490	4	3840	6490	36	3800	22300
Selenium	RCBRA	4	0.41	0.46	--	--	--	4	0.41	0.46	36	0.36	2.9
Silicon	RCBRA	--	--	--	4	63	277	4	63	277	36	47.3	726
Silver	RCBRA	4	0.07	0.09	--	--	--	4	0.07	0.09	36	0.07	1.1
Sodium	RCBRA	2	12	12.2	2	16.8	40.9	4	12	40.9	36	7.8	71.2
Strontium (elemental)	RCBRA	--	--	--	4	2.8	10.8	4	2.8	10.8	36	1.1	134
Thallium	RCBRA	4	0.68	0.79	--	--	--	4	0.68	0.79	36	0.54	4.3
Tin	RCBRA	4	1	2.5	--	--	--	4	1	2.5	36	1	6.6
Titanium	RCBRA	--	--	--	2	8.6	13.3	2	8.6	13.3	30	0.58	32.9
Uranium (inorganic)	RCBRA	4	0.85	1.4	--	--	--	4	0.85	1.4	36	0.82	5.4
Vanadium	RCBRA	2	0.08	0.08	2	0.28	0.55	4	0.08	0.55	36	0.08	1.7
Zinc	RCBRA	--	--	--	4	8.8	11.5	4	8.8	11.5	36	4.4	43.8
Zirconium	RCBRA	2	1	1	--	--	--	2	1	1	30	0.99	6.5
Organics (mg/kg)													
1,2,4-Trichlorobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
1,2-Dichlorobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
1,3-Dichlorobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
1,4-Dichlorobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2,4,5-Trichlorophenol	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
2,4,6-Trichlorophenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2,4-Dichlorophenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2,4-Dimethylphenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2,4-Dinitrophenol	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
2,4-Dinitrotoluene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2,6-Dinitrotoluene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2-Chloronaphthalene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2-Chlorophenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2-Methylnaphthalene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2-Methylphenol [cresol, o-]	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
2-Nitroaniline	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
2-Nitrophenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
3,3*-Dichlorobenzidine	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
3+4 Methylphenol [cresol, m+p]	RCBRA	3	8	16	1	0.43	0.43	4	0.43	16	35	3.4	52
3-Nitroaniline	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
4,6-Dinitro-2-methylphenol	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
4-Bromophenylphenyl ether	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
4-Chloro-3-methylphenol	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
4-Chloroaniline	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
4-Chlorophenylphenyl ether	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
4-Nitroaniline	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
4-Nitrophenol	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
Acenaphthene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Acenaphthylene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Aldrin	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Alpha-BHC	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
alpha-Chlordane	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Anthracene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Aroclor 1016	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1221	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1232	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1242	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1248	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1254	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Aroclor 1260	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.08	1.9
Benzo[a]anthracene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Benzo[a]pyrene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Benzo[b]fluoranthene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Benzo[ghi]perylene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Benzo[k]fluoranthene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
beta-1,2,3,4,5,6-Hexachloro-cyclohexane	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.01	0.24
Bis[2-chloro-1-methylethyl] ether	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Bis[2-Chloroethoxy]methane	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Bis[2-chloroethyl] ether	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Bis[2-ethylhexyl] phthalate	RCBRA	3	8	16	1	0.27	0.27	4	0.27	16	36	0.36	52
Butylbenzylphthalate	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Carbazole	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Chrysene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Delta-BHC	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.008	0.24
Dibenz[a,h]anthracene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Dibenzofuran	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Dichlorodiphenyldichloroethane	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.01	0.24
Dichlorodiphenyldichloroethylene	RCBRA	3	0.008	0.02	1	0.073	0.073	4	0.008	0.073	36	0.0061	0.34
Dichlorodiphenyltrichloroeth	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.0091	0.24

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
ane													
Dieldrin	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.012	0.24
Diethylphthalate	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Dimethyl phthalate	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Di-n-butylphthalate	RCBRA	4	2	16	--	--	--	4	2	16	36	0.33	52
Di-n-octylphthalate	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Endosulfan I	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.0042	0.24
Endosulfan II	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Endosulfan sulfate	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Endrin	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Endrin aldehyde	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Endrin ketone	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.013	0.24
Fluoranthene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Fluorene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Gamma-BHC (lindane)	RCBRA	3	0.008	0.02	1	0.013	0.013	4	0.008	0.02	36	0.0051	0.24
gamma-Chlordane	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.017	0.24
Heptachlor	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.0067	0.24
Heptachlor epoxide	RCBRA	3	0.008	0.02	1	0.0085	0.0085	4	0.008	0.02	36	0.0042	0.24
Hexachlorobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Hexachlorobutadiene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Hexachlorocyclopentadiene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Hexachloroethane	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Indeno[1,2,3-cd]pyrene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Isophorone	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Methoxychlor	RCBRA	4	0.008	0.02	--	--	--	4	0.008	0.02	36	0.0055	0.24
Naphthalene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Nitrobenzene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
N-Nitroso-di-n-dipropylamine	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
N-Nitrosodiphenylamine	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Pentachlorophenol	RCBRA	4	5	40	--	--	--	4	5	40	35	8.6	130
Phenanthrene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Phenol	RCBRA	4	2	16	--	--	--	4	2	16	35	0.65	52
Pyrene	RCBRA	4	2	16	--	--	--	4	2	16	35	3.4	52
Toxaphene	RCBRA	4	0.08	0.2	--	--	--	4	0.08	0.2	36	0.024	2.4
Radionuclides (pCi/g)													
Americium-241	RCBRA	4	0.081	0.75	--	--	--	4	0.081	0.75	36	0.02	1.6
Antimony-125	SESP	5	-0.0071	0.0020	--	--	--	5	-0.0071	0.0020	--	--	--
	RCBRA	4	0.19	0.32	--	--	--	4	0.19	0.32	36	0.046	0.5
Beryllium-7	SESP	--	--	--	5	0.254	1.1	5	0.254	1.1	--	--	--
	RCBRA	3	-0.3	1.7	1	3.11	3.11	4	-0.3	3.11	36	0	3.2
Carbon-14	RCBRA	4	-0.3	3.11	--	--	--	4	-0.3	3.11	2	0.167	2.67

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Cesium-134	SESP	5	-0.0111	0.0008	--	--	--	5	-0.0111	0.0008	--	--	--
	RCBRA	4	0.13	0.175	--	--	--	4	0.13	0.175	36	0.025	0.24
Cesium-137	SESP	5	0.0005	0.0136	--	--	--	5	0.0005	0.0136	--	--	--
	RCBRA	4	0.11	0.143	--	--	--	4	0.11	0.143	36	0.02	0.22
Cobalt-60	SESP	5	-0.0108	0.0046	--	--	--	5	-0.0108	0.0046	--	--	--
	RCBRA	4	0.11	0.151	--	--	--	4	0.11	0.151	36	0.019	0.22
Europium-152	SESP	1	0.0050	0.0050	--	--	--	1	0.0050	0.0050	--	--	--
	RCBRA	4	0.15	0.373	--	--	--	4	0.15	0.373	36	0.047	0.58
Europium-154	SESP	5	-0.0043	0.0451	--	--	--	5	-0.0043	0.0451	--	--	--
	RCBRA	4	0.36	0.463	--	--	--	4	0.36	0.463	36	0.063	0.69
Europium-155	SESP	5	-0.0070	0.015	--	--	--	5	-0.0070	0.015	--	--	--
	RCBRA	4	0.079	0.31	--	--	--	4	0.079	0.31	36	0.031	0.73
Plutonium-238	SESP	3	-0.000004	0.000007	--	--	--	3	-0.000004	0.000007	--	--	--
Plutonium-239/240	SESP	2	0.000013	0.000017	1	0.0002	0.0002	3	0.000013	0.0002	--	--	--
Potassium-40	SESP	--	--	--	5	2.42	12.9	5	2.42	12.9	--	--	--
	RCBRA	2	0	0.027	2	4.16	5.38	4	0	5.38	36	0	11
Radium-226	RCBRA	4	0.19	0.307	--	--	--	4	0.19	0.307	36	0.036	0.5
Radium-228	RCBRA	4	0.49	0.66	--	--	--	4	0.49	0.66	36	0.077	1

Table 4-34. Plant Tissue Samples from 100-K Area Compared to RCBRA Reference Sample Results

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Ruthenium-106	SESP	5	-0.0353	0.01774	--	--	--	5	-0.0353	0.0177	--	--	--
	RCBRA	4	0.87	1.33	--	--	--	4	0.87	1.33	36	0.18	2
Sr-90	SESP	3	0.0008	0.0015	2	0.0778	0.672	5	0.0008	0.6720	--	--	--
	RCBRA	4	-0.042	0.006	--	--	--	4	-0.042	0.006	36	-0.17	15.8
Technetium-99	RCBRA	2	0.108	0.182	--	--	--	2	0.108	0.182	--	--	--
Thorium-228	RCBRA	4	-0.059	0.054	--	--	--	4	-0.059	0.054	36	-0.146	0.17
Thorium-230	RCBRA	3	0.006	0.108	1	0.322	0.322	4	0.006	0.322	36	-0.162	0.469
Thorium-232	RCBRA	4	-0.029	0.006	--	--	--	4	-0.029	0.006	36	-0.04	0.096
Tritium	RCBRA	2	-2.17	-0.995	--	--	--	2	-2.17	-0.995	--	--	--
Uranium-233/234	SESP	2	-0.0004	0.0011	1	0.0025	0.0025	3	-0.0004	0.0025	--	--	--
	RCBRA	4	-0.017	0.03	--	--	--	4	-0.017	0.03	36	-0.01	0.083
Uranium-235	SESP	2	0.0001	0.0003	1	0.0012	0.0012	3	0.0001	0.0012	--	--	--
	RCBRA	4	0	0.027	--	--	--	4	0	0.027	36	-0.008	0.025
Uranium-238	SESP	2	0.0004	0.0009	1	0.0010	0.0010	3	0.0004	0.0010	--	--	--
	RCBRA	4	0	0	--	--	--	4	0	0	36	-0.007	0.052

-- = not applicable

SESP = Surface Environmental Surveillance Project (PNNL)

RCBRA = River Corridor Baseline Risk Assessment (DOE/RL-2007-21)

Table 4-35. Invertebrate Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Inorganics (mg/kg)													
Aluminum	RCBRA	--	--	--	2	12.5	54.2	2	12.5	54.2	18	11.6	49.7
Antimony	RCBRA	2	0.22	0.42	--	--	--	2	0.22	0.42	18	0.21	0.66
Arsenic	RCBRA	1	0.59	0.59	1	1.7	1.7	2	0.59	1.7	18	0.57	1.3
Barium	RCBRA	--	--	--	2	0.59	2.1	2	0.59	2.1	18	0.59	3
Beryllium	RCBRA	2	0.01	0.02	--	--	--	2	0.01	0.02	18	0.01	0.03
Bismuth	RCBRA	2	0.4	0.49	--	--	--	2	0.4	0.49	18	0.38	0.76
Boron	RCBRA	--	--	--	2	0.39	3.4	2	0.39	3.4	18	1.1	5.6
Cadmium	RCBRA	--	--	--	2	0.12	0.46	2	0.12	0.46	18	0.05	0.12
Calcium	RCBRA	--	--	--	2	211	641	2	211	641	18	222	714
Calculated total uranium	RCBRA	1	0.17	0.17	--	--	--	1	0.17	0.17	3	0.00000419	0.0863
Chromium	RCBRA	--	--	--	2	0.22	0.55	2	0.22	0.55	18	0.12	0.7
Cobalt	RCBRA	2	0.08	0.13	--	--	--	2	0.08	0.13	18	0.08	0.24
Copper	RCBRA	--	--	--	2	7.9	10.9	2	7.9	10.9	18	3.8	13.4
Iron	RCBRA	--	--	--	2	40.8	130	2	40.8	130	18	43.3	170
Lead	RCBRA	--	--	--	2	0.32	0.48	2	0.32	0.48	18	0.29	0.46
Lithium	RCBRA	1	0.1	0.1	1	0.06	0.06	2	0.06	0.1	18	0.03	0.17
Magnesium	RCBRA	--	--	--	2	244	588	2	244	588	18	352	1030
Manganese	RCBRA	--	--	--	2	6.8	8.4	2	6.8	8.4	18	3.7	8.4
Mercury	RCBRA	2	0.01	0.02	--	--	--	2	0.01	0.02	18	0.01	0.36

Table 4-35. Invertebrate Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Molybdenum	RCBRA	1	0.28	0.28	1	0.43	0.43	2	0.28	0.43	18	0.26	0.79
Nickel	RCBRA	1	0.23	0.23	1	0.44	0.44	2	0.23	0.44	18	0.22	0.37
Phosphorus	RCBRA	--	--	--	2	1740	2170	2	1740	2170	18	2010	2840
Potassium	RCBRA	--	--	--	2	2010	2590	2	2010	2590	18	2220	3060
Selenium	RCBRA	1	0.69	0.69	1	1	1	2	0.69	1	18	0.44	0.88
Silicon	RCBRA	--	--	--	2	18.5	108	2	18.5	108	18	27.2	84.3
Silver	RCBRA	2	0.07	0.09	--	--	--	2	0.07	0.09	18	0.07	0.12
Sodium	RCBRA	--	--	--	2	656	670	2	656	670	18	259	1040
Strontium (elemental)	RCBRA	--	--	--	1	5.7	5.7	1	5.7	5.7	13	1.1	6
Thallium	RCBRA	2	0.67	0.79	--	--	--	2	0.67	0.79	18	0.65	1
Tin	RCBRA	2	1	2.9	--	--	--	2	1	2.9	18	1	4
Titanium	RCBRA	--	--	--	1	1.1	1.1	1	1.1	1.1	5	1.3	1.9
Uranium (inorganic)	RCBRA	2	0.85	1.4	--	--	--	2	0.85	1.4	18	0.82	2.2
Vanadium	RCBRA	--	--	--	2	0.09	0.12	2	0.09	0.12	18	0.08	0.4
Zinc	RCBRA	--	--	--	2	43.1	60.2	2	43.1	60.2	18	27.4	49.9
Zirconium	RCBRA	1	1	1	--	--	--	1	1	1	12	0.99	1.6
Radionuclides (pCi/g)													
Sr-90	RCBRA	1	-0.011	-0.011	--	--	--	1	-0.011	-0.011	3	-0.076	0.067
Technetium-99	RCBRA	1	0.179	0.179	--	--	--	1	0.179	0.179	3	-0.04	0.069

Table 4-35. Invertebrate Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Thorium-228	RCBRA	1	-0.068	-0.068	--	--	--	1	-0.068	-0.068	3	0	0.344
Thorium-230	RCBRA	1	-0.034	-0.034	--	--	--	1	-0.034	-0.034	3	-0.04	-0.029
Thorium-232	RCBRA	1	-0.034	-0.034	--	--	--	1	-0.034	-0.034	3	0	0.065
Uranium-233/ 234	RCBRA	1	0.057	0.057	--	--	--	1	0.057	0.057	3	0	0
Uranium-235	RCBRA	1	0	0	--	--	--	1	0	0	3	0	0.029
Uranium-238	RCBRA	1	0.057	0.057	--	--	--	1	0.057	0.057	3	-0.076	0.067

-- = not applicable

RCBRA = River Corridor Baseline Risk Assessment (DOE/RL-2007-21)

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Inorganics (mg/kg)													
Aluminum	RCBRA	--	--	--	4	4.4	56.7	4	4.4	56.7	38	1.7	115
Antimony	RCBRA	4	0.22	0.43	--	--	--	4	0.22	0.43	38	0.21	0.43
Arsenic	RCBRA	2	0.59	0.6	2	0.42	0.57	4	0.42	0.6	38	0.39	0.76
Barium	RCBRA	--	--	--	4	0.11	2.8	4	0.11	2.8	38	0.04	6.6
Beryllium	RCBRA	3	0.01	0.02	1	0.01	0.01	4	0.01	0.02	38	0.01	0.02
Bismuth	RCBRA	4	0.39	0.5	--	--	--	4	0.39	0.5	38	0.38	0.5
Boron	RCBRA	3	0.23	0.35	1	2.2	2.2	4	0.23	2.2	38	0.22	0.9
Cadmium	RCBRA	2	0.05	0.07	2	0.1	0.28	4	0.05	0.28	38	0.05	0.44
Calcium	RCBRA	--	--	--	4	99.6	12700	4	99.6	12700	38	46.3	18400
Calculated total uranium	RCBRA	2	0.16	0.17	--	--	--	2	0.16	0.17	19	-0.0804	0.241
Chromium	RCBRA	--	--	--	4	0.17	0.68	4	0.17	0.68	38	0.12	0.91
Cobalt	RCBRA	4	0.08	0.14	--	--	--	4	0.08	0.14	38	0.08	0.14
Copper	RCBRA	--	--	--	4	3.7	7	4	3.7	7	38	2.5	11.3
Iron	RCBRA	--	--	--	4	97.2	148	4	97.2	148	38	82.4	233
Lead	RCBRA	2	0.3	0.32	2	0.35	0.49	4	0.3	0.49	38	0.29	1.2
Lithium	RCBRA	3	0.03	0.09	1	0.05	0.05	4	0.03	0.09	38	0.03	0.16
Magnesium	RCBRA	--	--	--	4	233	575	4	233	575	38	111	656
Manganese	RCBRA	--	--	--	4	2.7	4.9	4	2.7	4.9	38	1.8	7.4
Mercury	RCBRA	2	0.01	0.02	2	0.02	0.04	4	0.01	0.04	38	0.01	0.07

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Molybdenum	RCBRA	1	0.28	0.28	3	0.39	1.4	4	0.28	1.4	38	0.25	1.9
Nickel	RCBRA	2	0.23	0.26	2	0.35	1	4	0.23	1	38	0.22	2.9
Phosphorus	RCBRA	--	--	--	4	3060	8050	4	3060	8050	38	2,420	10,300
Potassium	RCBRA	--	--	--	4	2400	3100	4	2400	3100	38	1,980	3,200
Selenium	RCBRA	--	--	--	4	0.63	2.3	4	0.63	2.3	38	0.45	2.6
Silicon	RCBRA	--	--	--	4	4.6	67.6	4	4.6	67.6	38	2.6	91.7
Silver	RCBRA	4	0.07	0.09	--	--	--	4	0.07	0.09	38	0.06	0.15
Sodium	RCBRA	--	--	--	4	1130	1780	4	1130	1780	38	905	1,690
Strontium (elemental)	RCBRA	--	--	--	2	0.13	6.3	2	0.13	6.3	28	0.05	12.7
Thallium	RCBRA	4	0.68	0.78	--	--	--	4	0.68	0.78	38	0.65	0.79
Tin	RCBRA	2	1	3.4	2	1.3	2.4	4	1	3.4	38	0.99	2.8
Titanium	RCBRA	1	0.03	0.03	1	0.55	0.55	2	0.03	0.55	14	0.03	9.1
Uranium (inorganic)	RCBRA	3	0.85	1.4	1	1.4	1.4	4	0.85	1.4	38	0.81	1.5
Vanadium	RCBRA	3	0.08	0.09	1	0.11	0.11	4	0.08	0.11	38	0.08	0.4
Zinc	RCBRA	--	--	--	4	28.4	95.4	4	28.4	95.4	38	19.5	120
Zirconium	RCBRA	--	--	--	2	0.63	0.7	2	0.63	0.7	21	0.31	1.1
Organics (mg/kg)													
1,2,4-Trichlorobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
1,2-Dichlorobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
1,3-Dichlorobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
1,4-Dichlorobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2,4,5-Trichlorophenol	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
2,4,6-Trichlorophenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2,4-Dichlorophenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2,4-Dimethylphenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2,4-Dinitrophenol	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
2,4-Dinitrotoluene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2,6-Dinitrotoluene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2-Chloronaphthalene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2-Chlorophenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2-Methylnaphthalene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2-Methylphenol [cresol, o-]	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
2-Nitroaniline	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
2-Nitrophenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
3,3*-Dichlorobenzidine	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
3+4 Methylphenol [cresol, m+p]	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	0.18	4.5
3-Nitroaniline	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
4,6-Dinitro-2-methylphenol	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
4-Bromophenylphenyl ether	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
4-Chloro-3-methylphenol	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
4-Chloroaniline	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
4-Chlorophenylphenyl ether	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
4-Nitroaniline	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
4-Nitrophenol	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
Acenaphthene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Acenaphthylene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Aldrin	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.011	0.028
Alpha-BHC	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
alpha-Chlordane	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Anthracene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Aroclor 1016	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Aroclor 1221	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Aroclor 1232	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Aroclor 1242	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Aroclor 1248	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Aroclor 1254	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.079	0.8
Aroclor 1260	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.081	0.8
Benzo[a]anthracene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Benzo[a]pyrene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Benzo[b]fluoranthene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Benzo[ghi]perylene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	0.22	4.5
Benzo[k]fluoranthene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
beta-1,2,3,4,5,6-Hexachlorocyclohexane	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.064
Bis[2-chloro-1-methylethyl]ether	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Bis[2-Chloroethoxy]methane	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Bis[2-chloroethyl] ether	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Bis[2-ethylhexyl] phthalate	RCBRA	1	2	2	1	0.57	0.57	2	0.57	2	19	0.17	3.3
Butylbenzylphthalate	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Carbazole	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Chrysene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Delta-BHC	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.012	0.033
Dibenz[a,h]anthracene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Dibenzofuran	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Dichlorodiphenyldichloroethane	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Dichlorodiphenyldichloroethylene	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Dichlorodiphenyl-trichloroethane	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.01	0.02
Dieldrin	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Diethylphthalate	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Dimethyl phthalate	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Di-n-butylphthalate	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	0.16	4.5
Di-n-octylphthalate	RCBRA	1	3.9	3.9	1	0.36	0.36	2	0.36	3.9	19	0.42	4.3
Endosulfan I	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.012	0.02
Endosulfan II	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Endosulfan sulfate	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Endrin	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Endrin aldehyde	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Endrin ketone	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Fluoranthene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Fluorene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Gamma-BHC (lindane)	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.0073	0.02
gamma-Chlordane	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Heptachlor	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Heptachlor epoxide	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.02
Hexachlorobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Hexachlorobutadiene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Hexachlorocyclopentadiene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Hexachloroethane	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Indeno[1,2,3-cd]pyrene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Isophorone	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Methoxychlor	RCBRA	2	0.018	0.019	--	--	--	2	0.018	0.019	19	0.014	0.03
Naphthalene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Nitrobenzene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
N-Nitroso-di-n-dipropylamine	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
N-Nitrosodiphenylamine	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Pentachlorophenol	RCBRA	2	9.6	9.8	--	--	--	2	9.6	9.8	19	6.8	11
Phenanthrene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Phenol	RCBRA	1	3.9	3.9	1	0.26	0.26	2	0.26	3.9	19	0.16	4.5
Pyrene	RCBRA	2	3.8	3.9	--	--	--	2	3.8	3.9	19	2.7	4.5
Toxaphene	RCBRA	2	0.18	0.19	--	--	--	2	0.18	0.19	19	0.14	0.2
Radionuclides (pCi/g)													
Americium-241	RCBRA	2	0.179	0.21	--	--	--	2	0.179	0.21	19	0.041	2.2
Antimony-125	RCBRA	2	0.116	0.13	--	--	--	2	0.116	0.13	19	0.071	1.4
Beryllium-7	RCBRA	2	0	0.53	--	--	--	2	0	0.53	7	0.032	0.079
Carbon-14	RCBRA	1	-0.23	-0.23	--	--	--	1	-0.23	-0.23	19	0	8.1
Cesium-134	RCBRA	2	0.061	0.079	--	--	--	2	0.061	0.079	3	-1.92	-0.622
Cesium-137	RCBRA	2	0.056	0.064	--	--	--	2	0.056	0.064	19	0.034	0.69
Cobalt-60	RCBRA	2	0.048	0.075	--	--	--	2	0.048	0.075	19	0.031	0.65

Table 4-36. Small Mammal (Mouse) Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Europium-152	RCBRA	2	0.14	0.16	--	--	--	2	0.14	0.16	19	0.032	0.64
Europium-154	RCBRA	2	0.136	0.2	--	--	--	2	0.136	0.2	19	0.076	1.5
Europium-155	RCBRA	2	0.13	0.17	--	--	--	2	0.13	0.17	19	0.092	1.8
Potassium-40	RCBRA	2	0	2.2	--	--	--	2	0	2.2	19	0.073	1.4
Radium-226	RCBRA	2	0.112	0.14	--	--	--	2	0.112	0.14	11	-0.036	0.051
Radium-228	RCBRA	2	0.224	0.32	--	--	--	2	0.224	0.32	11	-0.032	0.043
Ruthenium-106	RCBRA	2	0.419	0.51	--	--	--	2	0.419	0.51	19	0	11
Sr-90	RCBRA	2	0.024	0.116	--	--	--	2	0.024	0.116	19	0.055	1.1
Technetium-99	RCBRA	1	0.155	0.155	--	--	--	1	0.155	0.155	19	0.13	2.7
Thorium-228	RCBRA	2	-0.07	0.021	--	--	--	2	-0.07	0.021	19	0.28	5.7
Thorium-230	RCBRA	1	0.175	0.175	1	0.362	0.362	2	0.175	0.362	19	-0.082	0.505
Thorium-232	RCBRA	2	0	0.007	--	--	--	2	0	0.007	19	-0.112	0.186
Uranium-233/234	RCBRA	2	0	0.028	--	--	--	2	0	0.028	19	0	0.064
Uranium-235	RCBRA	2	0	0	--	--	--	2	0	0	19	0	0.1
Uranium-238	RCBRA	2	0.053	0.056	--	--	--	2	0.053	0.056	19	-0.027	0.081

-- = not applicable

RCBRA = *River Corridor Baseline Risk Assessment* (DOE/RL-2007-21)

Table 4-37. Mule Deer Antler Samples from 100-K Area

Analyte	Data Source	Detect Samples			Total of All Samples		
		Number	Minimum	Maximum	Number	Minimum	Maximum
Radionuclides (pCi/g)							
Sr-90	SESP	2	0.151	0.932	2	0.151	0.932

SESP = Surface Environmental Surveillance Project (PNNL)

1

Table 4-38. Western Kingbird Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Inorganics (mg/kg)													
Aluminum	RCBRA	--	--	--	2	6.8	39.7	2	6.8	39.7	21	2.3	2,420
Antimony	RCBRA	1	0.21	0.21	1	0.26	0.26	2	0.21	0.26	21	0.2	1.3
Arsenic	RCBRA	2	0.4	0.41	--	--	--	2	0.4	0.41	21	0.38	1.8
Barium	RCBRA	--	--	--	2	0.57	7.5	2	0.57	7.5	21	0.2	36.1
Beryllium	RCBRA	1	0.01	0.01	1	0.01	0.01	2	0.01	0.01	21	0.009	0.08
Bismuth	RCBRA	2	0.39	0.4	--	--	--	2	0.39	0.4	21	0.37	1.5
Boron	RCBRA	1	0.35	0.35	1	5.9	5.9	2	0.35	5.9	21	0.23	2.6
Cadmium	RCBRA	2	0.05	0.05	--	--	--	2	0.05	0.05	21	0.05	0.42
Calcium	RCBRA	--	--	--	2	6,410	8,700	2	6,410	8,700	21	239	68,500
Calculated total uranium	RCBRA	1	-0.0057	-0.0057	--	--	--	1	-0.0057	-0.0057	11	-0.00185	0.134
Chromium	RCBRA	--	--	--	2	0.24	0.29	2	0.24	0.29	21	0.17	4.5

Table 4-38. Western Kingbird Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Cobalt	RCBRA	2	0.08	0.08	--	--	--	2	0.08	0.08	21	0.07	0.94
Copper	RCBRA	--	--	--	2	1.6	3.5	2	1.6	3.5	21	2	14.4
Iron	RCBRA	--	--	--	2	33.8	60.5	2	33.8	60.5	21	29.1	2,830
Lead	RCBRA	2	0.32	0.33	--	--	--	2	0.32	0.33	21	0.29	0.89
Lithium	RCBRA	--	--	--	2	0.03	0.18	2	0.03	0.18	21	0.01	1.4
Magnesium	RCBRA	--	--	--	2	352	706	2	352	706	21	153	1,820
Manganese	RCBRA	--	--	--	2	0.77	4.8	2	0.77	4.8	21	0.61	225
Mercury	RCBRA	1	0.03	0.03	1	0.02	0.02	2	0.02	0.03	21	0.01	0.04
Molybdenum	RCBRA	--	--	--	2	0.16	0.19	2	0.16	0.19	21	0.15	0.99
Nickel	RCBRA	1	0.26	0.26	1	0.55	0.55	2	0.26	0.55	21	0.23	1.7
Phosphorus	RCBRA	--	--	--	2	278	5,820	2	278	5,820	21	610	4,630
Potassium	RCBRA	--	--	--	2	2,150	2,480	2	2,150	2,480	21	1,090	3,260
Selenium	RCBRA	1	0.43	0.43	1	1.4	1.4	2	0.43	1.4	21	0.41	2.2
Silicon	RCBRA	--	--	--	2	9	131	2	9	131	21	2.5	866
Silver	RCBRA	2	0.09	0.09	--	--	--	2	0.09	0.09	21	0.07	0.2
Sodium	RCBRA	--	--	--	2	1,150	1,190	2	1,150	1,190	21	524	1,850
Strontium (elemental)	RCBRA	--	--	--	2	6.8	47.7	2	6.8	47.7	21	1.1	71.6
Thallium	RCBRA	2	0.78	0.8	--	--	--	2	0.78	0.8	21	0.66	2
Tin	RCBRA	--	--	--	2	0.98	2.6	2	0.98	2.6	21	0.93	6.2
Uranium (inorganic)	RCBRA	2	1.4	1.4	--	--	--	2	1.4	1.4	5	0.09	6.6

Table 4-38. Western Kingbird Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Vanadium	RCBRA	2	0.08	0.08	--	--	--	2	0.08	0.08	21	0.83	3.1
Zinc	RCBRA	--	--	--	2	20.2	32.1	2	20.2	32.1	21	0.07	4.8
Radionuclides (pCi/g)													
Americium-241	RCBRA	1	0.067	0.067	--	--	--	1	0.067	0.067	11	0.056	0.95
Antimony-125	RCBRA	1	0.151	0.151	--	--	--	1	0.151	0.151	11	0.153	0.95
Beryllium-7	RCBRA	1	0.009	0.009	--	--	--	1	0.009	0.009	3	0.11	0.4
Cesium-134	RCBRA	1	0.074	0.074	--	--	--	1	0.074	0.074	11	0	3.9
Cesium-137	RCBRA	1	0.065	0.065	--	--	--	1	0.065	0.065	11	0.079	0.68
Cobalt-60	RCBRA	1	0.076	0.076	--	--	--	1	0.076	0.076	11	0.065	0.57
Europium-152	RCBRA	1	0.164	0.164	--	--	--	1	0.164	0.164	11	0.064	0.7
Europium-154	RCBRA	1	0.19	0.19	--	--	--	1	0.19	0.19	11	0.151	0.96
Europium-155	RCBRA	1	0.106	0.106	--	--	--	1	0.106	0.106	11	0.2	1.9
Potassium-40	RCBRA	--	--	--	1	3.05	3.05	1	3.05	3.05	11	0.107	0.87
Radium-226	RCBRA	1	0.125	0.125	--	--	--	1	0.125	0.125	11	-0.004	21.4
Radium-228	RCBRA	1	0.269	0.269	--	--	--	1	0.269	0.269	11	0.124	2.02
Ruthenium-106	RCBRA	1	0.531	0.531	--	--	--	1	0.531	0.531	11	0.349	2.5
Sr-90	RCBRA	1	-0.008	-0.008	--	--	--	1	-0.008	-0.008	11	-0.067	0.376
Thorium-228	RCBRA	1	0.027	0.027	--	--	--	1	0.027	0.027	11	-0.058	0.066
Thorium-230	RCBRA	1	-0.134	-0.134	--	--	--	1	-0.134	-0.134	11	-0.189	0.301
Thorium-232	RCBRA	1	-0.027	-0.027	--	--	--	1	-0.027	-0.027	11	-0.034	0.047

Table 4-38. Western Kingbird Tissue Samples from 100-K Area

Analyte	Data Source	Nondetect Samples			Detect Samples			Total of All Samples			RCBRA Reference Sample Results		
		No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
Uranium-233/234	RCBRA	1	0	0	--	--	--	1	0	0	11	-0.02	0.062
Uranium-235	RCBRA	1	0.007	0.007	--	--	--	1	0.007	0.007	11	-0.004	0.034
Uranium-238	RCBRA	1	-0.003	-0.003	--	--	--	1	-0.003	-0.003	11	0	0.045

-- = not applicable

RCBRA = *River Corridor Baseline Risk Assessment* (DOE/RL-2007-21)

4.3.5 Air

As discussed in Section 2.1.6, near-facility air sampling monitors (NFM) measure the effectiveness of waste management, environmental remediation controls, and effluent treatment systems in reducing effluents and emissions. These air samplers also monitor diffuse source emissions. Air radioactivity was sampled by a network of continuously operating samplers at 11 locations in 100-K in 2008.

The Hanford Site Air Operating Permit (Federal Facility License FF-01) requires regulatory notification for composite (isotopic) air sample results that exceed 10 percent of EPA Table 2 (National Emission Standards for Hazardous Air Pollutants" [40 CFR 61], Appendix E, Table 2) values. During 2008, the following notifications were submitted to the Washington State Department of Health for the following 100-K East NFM sampling stations:

- N401, plutonium-239/240 and americium-241, second half of 2008
- N402, plutonium-239/240 and americium-241, second half of 2008
- N403, cesium-137, plutonium-239/240, and americium-241, second half of 2008
- N404, plutonium-239/240 and americium-241, second half of 2008

A radiological contamination event that occurred in July during D4 activities was the probable cause of these elevated results. Concentrations of Pu-239/240 and Am-241 at all four locations were greater than 10 percent of EPA's concentration values. The concentration of Cs-137 at one location was also greater than 10 percent of EPA's concentration value. A review of the biweekly air sample results during the period revealed several statistically elevated alpha and beta concentrations. For all of 100-K during 2008:

- U-234, U-238, and Am-241 were detected in about 95 percent of the samples
- Pu-239/240 was detected in about 63 percent of the samples
- Cs-137, U-235, Pu-238, and Pu-241 were detected in about 25 percent of the samples

Figures 4-94 to 4-96 are presented to put the 2008 elevated levels of Cs-137, Pu-239/240, and Am-241, in historical perspective regarding air-monitoring results for these radionuclides at 100-K. The dashed line represents the lower limit of detection for each analyte. These results do not indicate a significant impact based on air monitoring of the constituents.

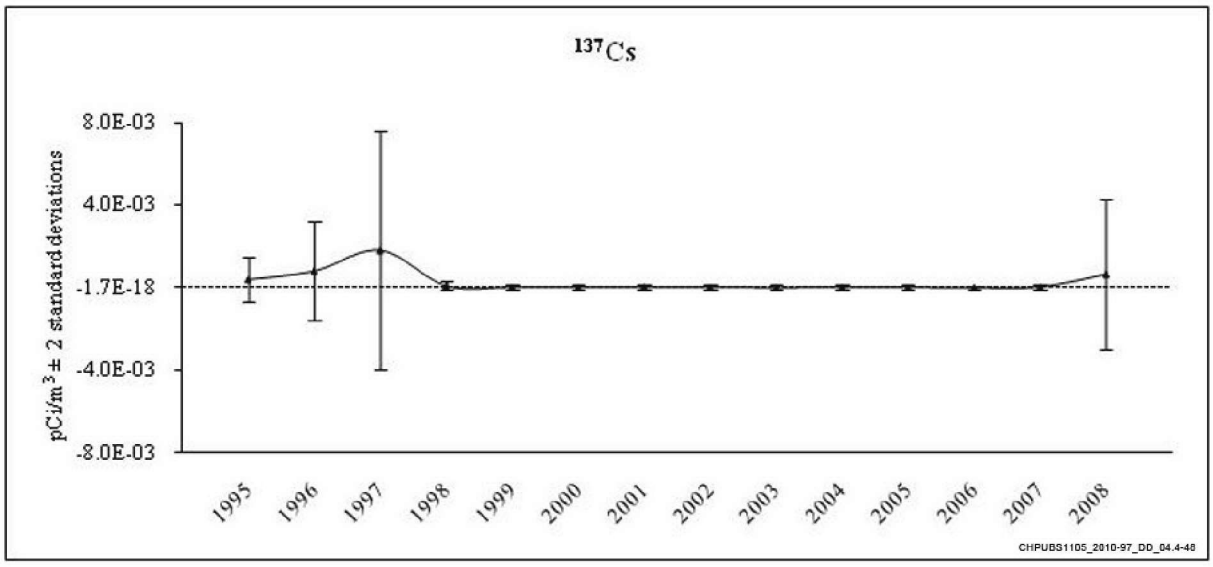


Figure 4-94. Air Monitoring Results for Cs-137 Radionuclides at 100-K in 2008

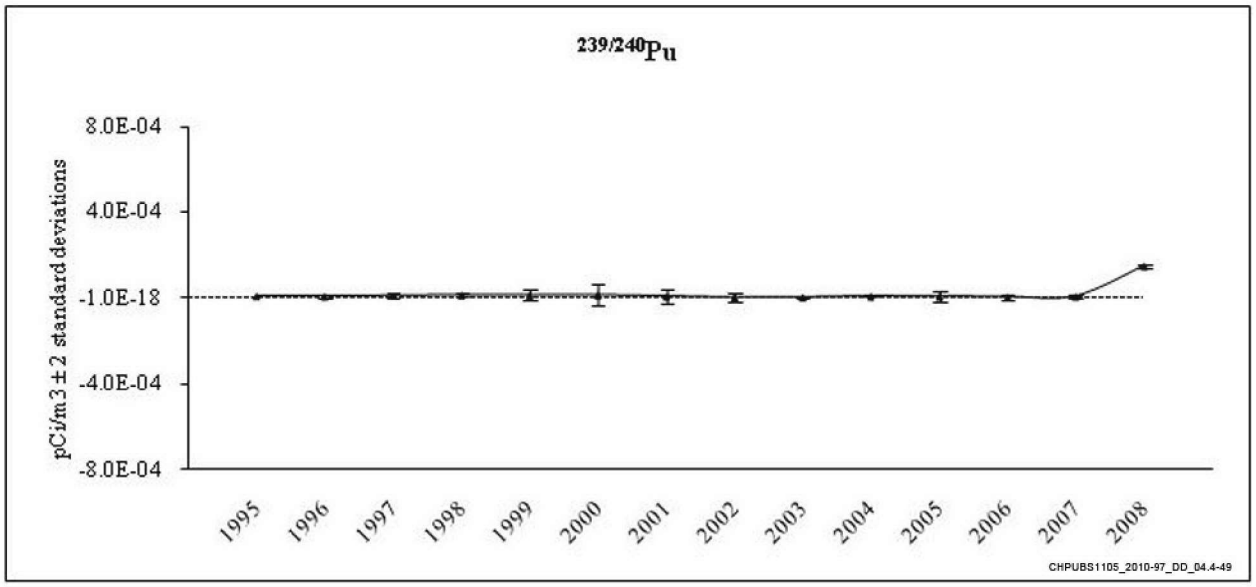


Figure 4-95. Air Monitoring Results for Pu-239/240 Radionuclides at 100-K in 2008

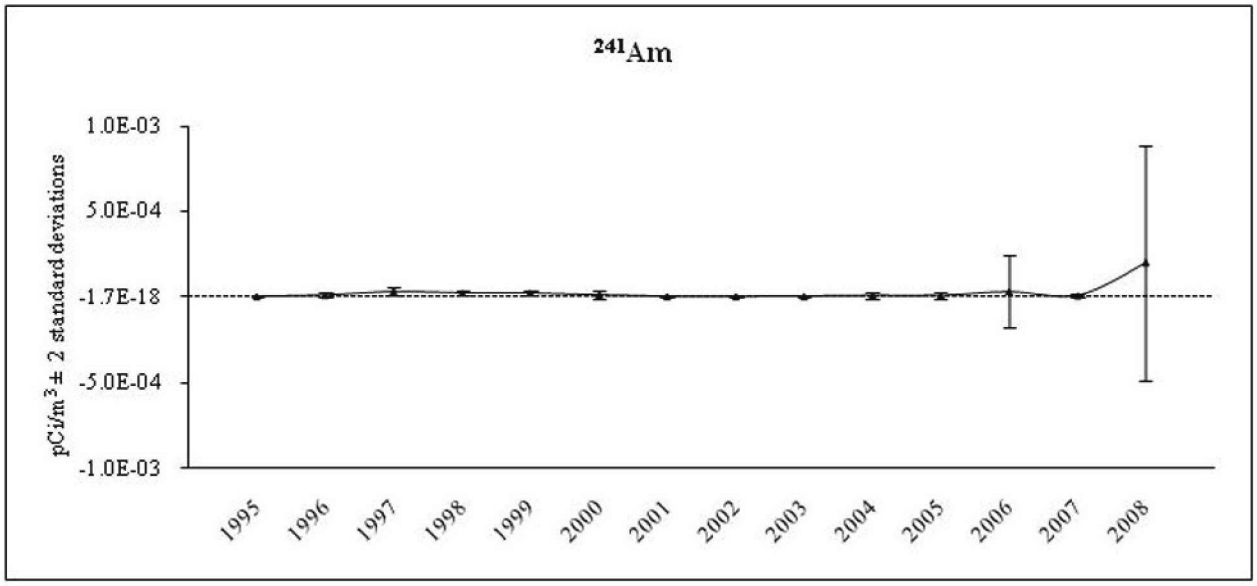


Figure 4-96. Air Monitoring Results for Am-241 Radionuclides at 100-K in 2008

4.3.6 Risk Conclusions for Columbia River Relative to 100-K

The CRC Volume 1 presented a final list of eight COPECs for ecological risk (nitrate, nitrite, TPH-diesel, TPH-motor oil, chromium, Cr(VI), lead, and selenium) and Volume 2 presented a table of COPCs for human health.

COPECs presented in Volume 1 of the CRC were further broken down by media and sub-area (100 Area, 300 Area, Lake Wallula). With respect to the 100-KR4 groundwater OU and the riparian soils of 100-K, the list of COPECs can be reduced to just chromium and Cr(VI) in sediment. Though the CRC only presents final conclusions by sub area, analysis of the results presented within the CRC reveal that the other 6 COPECs are not above medium-specific ecotoxicological thresholds within the abiotic media collected in the 100-K area. Total chromium sediment concentrations in the 100-K area are not above

ecotoxicological thresholds and there is no threshold for Cr(VI). Therefore, the only potential linkage from the 100-K area toward potential risks observed in the Columbia River is from elevated levels of Cr(VI) that exceed ambient water quality in groundwater and may contribute to observed detected concentrations in sediment.

The human health risk assessment presented in Volume 2 of the CRC evaluated four exposure scenarios (avid angler, casual user, the Native American [Yakima Nation], and hypothetical future user upland resident). Results indicated that ingestion of certain recreational finfish species may pose a health risk exceeding EPA and Ecology criteria. The risks estimated from abiotic media were significantly lower than those from fish and generally lower than EPA and Ecology risk management criteria. With the identified risk for the angler and Native American (Yakima Nation) scenarios being attributed to ingestion of mobile species (i.e., finfish), identifying a potential pathways and apportionment of risk specific to 100-K, or other specific areas is difficult. Further investigation is recommended into the reality of the risks identified based on detections of PCBs, pesticides, and mercury in fish tissues. However, none of these COPCs was identified as a COPC in groundwater in the 100-KR4 OU, as levels are below ambient water quality criteria (see Appendix L). Further, riparian soil concentrations were either not detected or were detected but below riparian soil background levels for all COPCs except Carbon-14. Carbon-14 was identified as a COPC in one of 6 fish species (Bridgelip sucker). The presence of Carbon-14 in one fish species suggests a potentially complete exposure pathway from the 100-K riparian soil because Carbon-14 was not detected in groundwater from the 100-KR4 groundwater.

4.4 Conceptual Site Model

The purpose of this CSM is to describe the features, events, and processes that resulted in the observed environmental contamination conditions at 100-K and affect the future migration of existing contamination in soil and groundwater at the site. The objectives of this conceptual site model description are to describe the following aspects of the site conditions:

- Identify the historical primary sources of contamination and delineate those contaminants and mechanisms originating on the front side of the reactor where preparatory activities were conducted for cooling water treatment versus the backside of the reactor where irradiated fuel slugs and used cooling water exited the reactor pile (Chapter 1).
- Describe the physical environment of the site, including natural and artificial features, soil, groundwater, and surface water features, climatic and biological features that affect the potential migration of contaminants and exposure to potential receptors (Chapter 2).
- Identify the historical primary sources, including the locations where releases occurred. This discussion includes description of transient conditions related to these releases (e.g., development of a groundwater recharge mound beneath the reactor cooling water discharge sites, Chapter 3).
- Identify the locations of contaminated environmental media relative to the processes on the front side and the backside of the reactor that may have contributed to expanded soil and groundwater contamination as secondary sources (Chapter 4).
- Describe the potential secondary release mechanisms of contaminants at these locations (Chapter 5).
- Describe the driving forces and transport mechanisms that may affect contaminants at 100-K (Chapter 5).
- Identify potential exposure points for site contaminants (discussed in Chapters 6 and 7).

The resulting CSM integrates all these elements to provide a basis for understanding contaminant fate and transport in the environment. This understanding is an important part of the RI/FS process and provides a technical basis for the description and understanding of site conditions, assessment of the actual and potential risks posed by site conditions, and evaluation of the need for remedial action(s).

The approach to presentation of the CSM in this section is to synthesize our knowledge of the site conditions and operating history to provide a description for understanding the interrelations of the various site elements. Chapters 1 through 4 describe the conceptualization and characterization process. These results are synthesized in the next chapter to describe the fate of contaminants in the system as they move through the vadose zone and aquifer to the river. Chapters 6 and 7 determine the risk posed by these contaminants from the distribution and amounts of contaminants present at potential exposure points. For those contaminants with an actionable risk, the CSM is used in Chapters 8 though 10 to identify appropriate remedial technologies and to evaluate remedial alternatives.

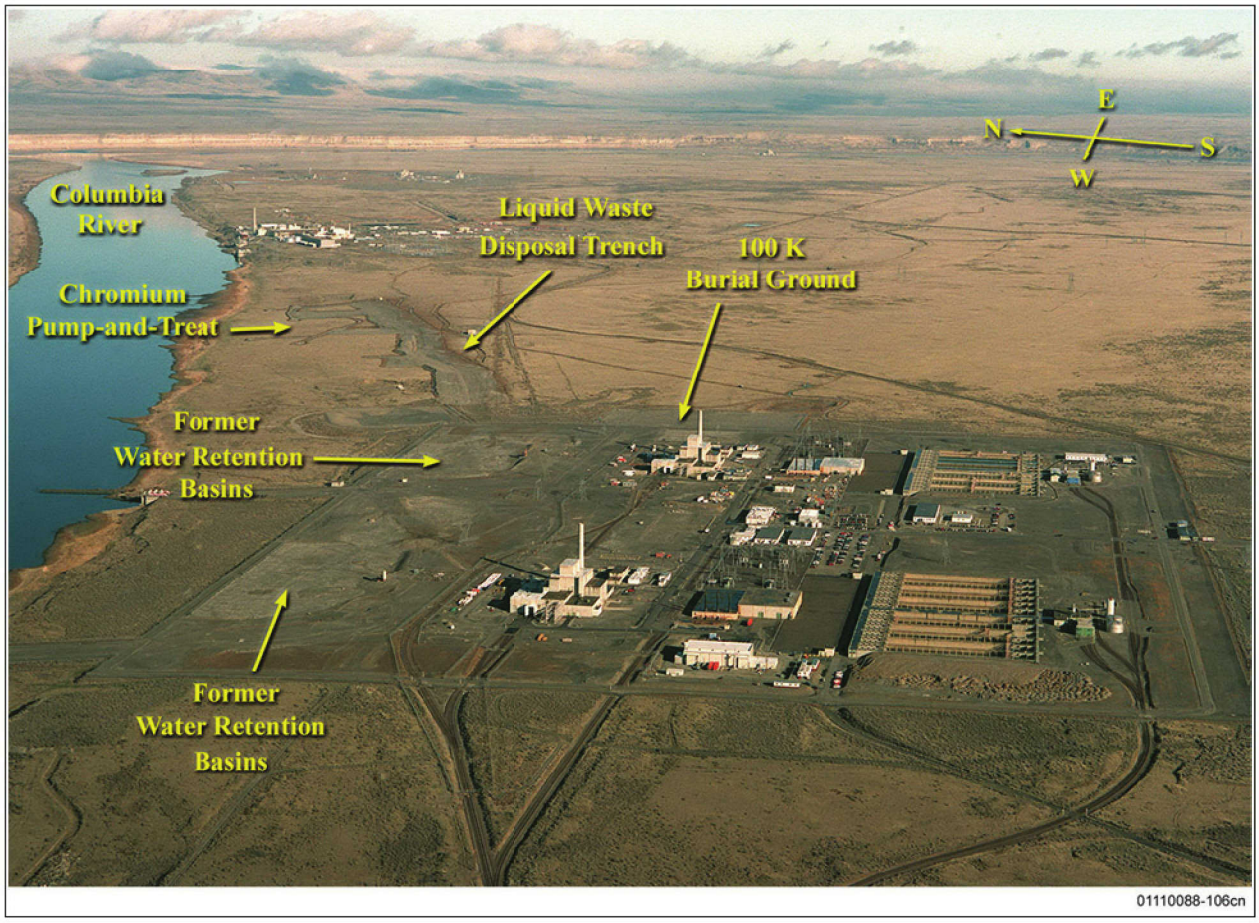
Cr(VI) is recognized as a primary COPC in groundwater at 100-K because of its mobility, widespread presence, and potential impact to human health and the environment. Other contaminants of interest include nitrate, arsenic, barium, total chromium, mercury, lead, C-14, Cs-137, Co-60, Eu-152, Ni-63, Pu-239, Pu-240, Sr-90 U-238, U-233, U-234, tritium, and other radionuclides. Soil contaminants are found over the thickness of the vadose zone, depending on the location of their initial release, the quantity of water or other liquid discharged with them, and their relative mobility in soil. Contaminants that migrated to groundwater have developed into identified groundwater plumes. Nitrate concentrations in 100-K show either stable or decreasing trends in both the 100-K North and 100-K East plumes. In contrast, the plume in 100-K West indicates detections nearly double the 100-K East plume. Tritium concentrations in the aquifer are generally declining, as are C-14, which is found in both the 100-K East and the 100-K West plumes. Most of the metallic contaminants (e.g., lead, arsenic, barium, mercury, Cs-137, and radioisotopes of cobalt, europium, nickel, plutonium, and uranium) are found near the points of historical release.

4.4.1 Physical Environment of 100-K

The physical environment of 100-K varies from industrial area near the reactors to the natural shrub-steppe ecosystem present outside the 100-K operational area. The natural features and the artificial infrastructure of the reactor areas are described in Chapters 1 and 2. The hydrologic cycle provides a sufficient annual water supply to support the shrub-steppe ecosystem at Hanford. The plants are adapted to use the available moisture by rooting deep to take advantage of moisture stored over the winter in the upper few meters of soil. Groundwater supplements the flow in the Columbia River and serves as a source of nutrients and constant temperature water where it upwells and discharges into the river. This serves as an important component of the habitat required by aquatic species in the river.

Construction activities in the reactor areas along the river resulted in removal of much of the vegetation and top soil. Much of the surface was maintained as bare gravel; weeds were strictly controlled. Almost immediately, the hydrologic cycle was impacted in the reactor areas. Without any native vegetation or top soil, significant portions of the rainwater and snowmelt water could infiltrate the soil unabated. Some water evaporated, but without any consumptive use by plants, water passing through the vadose zone to the groundwater increased.

Figure 4-97 is an aerial view clearly showing the major features of 100-K. The rail lines that bring in raw materials to the head end or front side of the reactor to the right and the rail lines leaving the reactors with the finished product to the left. The head houses are adjacent to the large storage basins where the cooling water was prepared. Water was then pumped downhill through the reactors and into the retention basins and K-2 Trench to the left.



Source: PNNL-14031, Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K.

Figure 4-97. Aerial Photograph of 100-K

The vadose zone in 100-K is dominated by the coarse textured sand and gravel of the Hanford formation. This geologic material provides significant physical and chemical interaction with the liquid wastes and the dissolved contaminants in those wastes. The moisture content varies between a few percent in the coarse-grained portion of the unit, up to 15 percent in the finer-grained portions of the unit. Recent research suggests that these reactions with iron may be catalyzed by bacteria. The depth to the water table is variable with surface elevation, but averages about 24 m (80 ft) below ground surface. The saturated zone is dominated by the Ringold unit E in 100-K and is composed of sands and gravels.

4.4.2 Primary Sources of Contamination and Primary Release Mechanisms

Historical releases of various liquid and solid wastes produced contamination of the vadose zone and underlying groundwater. Contaminated groundwater migrated downgradient toward the Columbia River and discharged into the river through surface springs and direct interaction of groundwater with surface water of the river in the hyporheic zone. Since reactor operations ceased in the early 1970s at 100-K, releases of primary contamination sources are no longer occurring and evaluation of soil data collected from previously remediated soil waste sites indicates that none of those sites presents a continuing secondary source of groundwater contamination.

The locations at which contaminants entered the ground and produced the waste sites that exist at 100-K are tied directly to the reactor operations. The expected contaminants at each waste site are directly

related to the subset of reactor operations that occurred in that location. The geography of these reactor operations was presented in Section 1.2.2. This CSM subdivides the reactor operation process into those operations that occurred before fuel slugs were irradiated and those that occurred afterwards. These processes are distinguished as either belonging to the front side of the reactor prior to irradiation or the back side of the reactor when the irradiated fuel exits the pile into the FSB and the hot cooling water is routed to the retention basins and K-2 Trench prior to return to the river. On the front side of the reactor, the concentrated water treatment chemicals are delivered to the site and mixed into the large volumes of water prior to their trip through the reactor at the 183-KE and 183-KW facilities. Spills of these concentrated chemicals at the head houses (chemical addition buildings) have resulted in one of the most significant environmental problems in relatively small areas on the ground with a large potential to impact groundwater.

On the backside of the reactor, extremely large volumes of cooling water with relatively low concentrations of nonradioactive chemicals such as Cr(VI) were routed into the 107-KE and 107-KW Retention Basins where the water was held for thermal cooling and decay of short-lived activation products prior to discharge to the Columbia River. Each of the 100-K Reactors had three retention basins, which were operated sequentially, with one basin filling, one cooling, and one draining at all times during reactor operation. In the event of a fuel element rupture during reactor operations, the contaminated cooling water stream was diverted to the 116-K-2 Trench where it infiltrated the soil. Cooling water contaminated by a fuel cladding failure contained the full spectrum of radioactive fission and activation products, as well as the uranium fuel. In addition, the water of the fuel storage basins became contaminated with fission products from irradiated fuel slugs with broken cladding released radioactive contaminants as soon as they dropped into the cooling water of the 100-KE and 100-KW fuel storage basins upon exiting the pile during de-fueling

4.4.2.1 Primary Sources

The identified sources of contamination at 100-K fall into two types, primary sources and secondary sources. Primary sources are the process chemicals, working solutions, and radioactive and nonradioactive wastes that were released into the environment during the period of operations at 100-K. Secondary sources consist of environmental media (e.g., soil, surface water, groundwater) that were impacted by the initial releases of primary sources and subsequently retain sufficient levels of mobile contamination that they can act as continuing sources of contamination entering adjacent soil, surface water, groundwater, or air. The release of primary sources of contamination at 100-K has ceased and future remedial actions will focus on control of contamination associated with secondary sources. The primary sources consisted of low volume highly concentrated water treatment chemicals, widely variable volumes of liquid effluent released from various points in the reactor process, and solid waste. The 100-K waste sites are grouped into waste source types according to the common characteristics of physical state of the waste, quantity, and duration of disposal, and type of facility that generated the waste. Appendix A provides maps showing the location of each waste site. The primary sources included both intentional and unplanned releases. Specific sources of contaminants include the following:

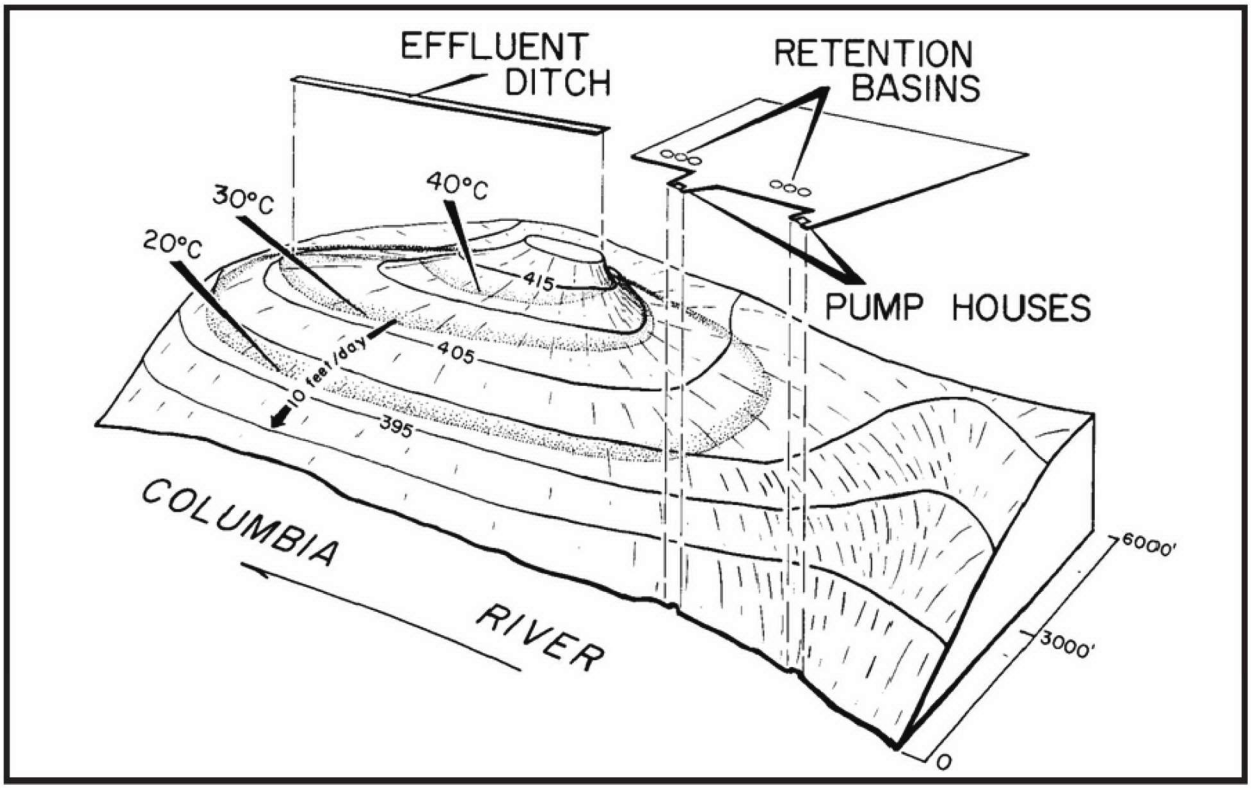
- Episodic disposal of solid waste materials, including construction materials and debris, repair and maintenance wastes, and radiologically-contaminated tools, materials, and reactor components placed in burial grounds. It should be noted that reactor operations at 100-KE and –KW, unlike the other single-pass reactors at Hanford, did not rely on coal-fired steam plants to provide steam for process and building head; instead, required steam at 100-K was provided by a fuel-oil fired steam package plant that also provided back-up electrical generation for reactor operations. As a result, fly ash and bottom ash were not generated at 100-K Area. Substantial amounts of radiologically-contaminated solid waste was buried at the 118-K-2 burial ground.

- Episodic planned disposal and unplanned releases of liquid waste materials, including radiologically-contaminated decontamination solutions associated with reactor repair and maintenance activities, off-spec or surplus water treatment chemicals, reactor cooling gas condensate, fuel storage basin leakage, and ion exchange regeneration solutions. This category of primary source material includes spills, leaks, and wash-down of high-concentration sodium dichromate dihydrate stock solution, which, at the 100-K Reactors, was metered directly into the reactor cooling water. The historical release of concentrated sodium dichromate dihydrate solution appears to account for persistent groundwater plumes near 100-KE and 100-KW Reactor water treatment facilities. Other concentrated chemical products used in the water treatment process include the following: raw bauxite ore, sulfuric acid, sodium hydroxide solution, granular sodium chloride, and alum solution (hydrous potassium-aluminum sulfate). Soil samples collected in the vicinity of the head houses indicate the presence of constituents of all of the concentrated water treatment chemicals over the full thickness of the vadose zone. This includes constituents such as mercury that was found to be a substantial impurity in sulfuric acid used at the head houses from 1968 to 1971 ("Removal of Sulfuric Acid Sludge from the 183 KW/KE Facilities" [Dorian, 1985]). This condition is best demonstrated by analysis of soil samples from Well 199-K-195, located near the former KW head house where elevated soil concentrations of numerous metals and anions are found over the vadose zone soil profile. Reactor cooling gas condensate releases at cribs adjacent to the reactors appear to account for persistent plumes of nitrate (from oxidation of ammonia accumulated in the gas condensate), tritium, and C-14 immediately downgradient of the reactors. Unplanned release of fuel oil and other POL products near the fuel oil storage tanks and boiler/generator facility likely accounts for the petroleum hydrocarbons and PAH compounds found in the vadose zone near those facilities. Historical releases of water from the reactor spent fuel storage basins is the likely source for Sr-90 observed in groundwater in the vicinity of the 100-K Reactor buildings. Other intentional releases of primary liquid contaminants include the FSB sub-drainage reverse wells 116-KW-2 and 116-KE-3. These reverse wells were configured to discharge accumulated drainage at a depth below the water surface in the shallow unconfined aquifer and also included a shallow leach-field structure below the ground surface in the vadose zone to provide back-up drainage. The waste stream was later rerouted to the process sewer. This waste stream contained mixed fission products, activation products and fuel residues resulting from fuel cladding failures.

- Nearly continuous planned disposal and unplanned releases of large volumes of reactor cooling water. Reactor cooling water was treated for corrosion control by adding sodium dichromate working solution to the water to achieve an operating sodium dichromate dihydrate concentration of 2,000 μg/L. The operating concentration of sodium dichromate dihydrate was reduced as experience indicated that lower concentrations produced acceptable corrosion control. Cooling water was also routinely contaminated with short-lived activation products and, following a reactor fuel failure event, with the entire suite of uranium and mixed fission and activation products present in the irradiated fuel. Releases of cooling water are responsible for most of the soil and groundwater contamination observed near the cooling water retention basins, the 116-K-1 Crib and 116-K-2 Trench. Releases of cooling water to the ground resulted in a widespread, persistent groundwater mound centered beneath the crib and head end of the trench. The chemical sewer drained nonradiologically-contaminated wastes from the vicinity of the water treatment plants at 100-K, as well as nonradiological liquid waste from the other 100-K facilities. This sewer drained into the cooling water discharge stream. Precipitated solids from the water treatment plant sedimentation basins were also discharged into the chemical sewer and flushed into the cooling water stream to facilitate their final discharge into the river.

4.4.2.2 Primary Liquid Source Release Mechanisms

The primary release mechanisms of liquid wastes at 100-K fall into two general categories—intentional or planned releases and unplanned releases. Planned releases fell into two broad groups—high-volume, low-concentration liquids (e.g., reactor cooling water) that were released directly to the Columbia River or directly to the vadose zone, and lower volume liquids with higher contaminant concentrations (e.g., contaminated reactor cooling water during upset conditions, reactor cooling gas condensate, captured fuel storage basin leakage) that were released directly to the land surface and allowed to infiltrate, or were discharged to engineered subsurface waste infiltration structures (e.g., cribs and covered trenches).The evaluation of risks posed by the identified primary sources to human health and the environment through direct exposure are discussed in Chapters 6 and 7, respectively. The most dramatic effects of planned liquid releases occurred at the 116-K-2 Trench, where continued releases of cooling water to the trench produced a groundwater mound in the underlying unconfined aquifer that extended to nearly the ground surface vertically and lateral for a distance of approximately 3 km to the south and 2 km to the west and east of the head end of the trench. This extensive groundwater mound consisted primarily of reactor cooling water, which is suspected to have displaced much of the water within the unconfined aquifer in that area. The cooling water contained about 2 mg/L of sodium dichromate dihydrate (about 0.7 mg/L Cr(VI)) and radioactive fission and activation products associated with normal reactor operations and fuel failure upsets. The cooling water also exhibited high temperature (i.e., about 95° C on exiting the reactors). A graphic representation of the groundwater mound at 100-K is shown in Figure 4-98. This figure was prepared in 1963 and was based on groundwater elevation and temperature measurements collected at 100-K during reactor operation.



Source: HW-77170, Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963.

Figure 4-98. Inferred Distribution of Cooling Water Mound beneath 116-K-1 Crib and 116-K-2 Trench, during Reactor Operations

Other planned releases at 100-K that appear to have made substantial impacts on vadose soil and groundwater include releases to the 116-KE-1 and 116-KW-1 Cribs that received reactor cooling gas condensate. This gas condensate contained carbon-14 (originally as CO_2), now converted into calcium carbonate within the vadose zone and aquifer matrix sediment and is mobile in the groundwater. Accumulation of ammonia in the cooling gas and subsequently dissolved in the cooling gas condensate discharged to the condensate cribs is the likely source of the nitrate plumes observed in groundwater in the vicinity of the 100-K Reactors. Ammonia is readily oxidixed to nitrate by common soil microorganisms. The 100-K Reactors were estimated to generate ammonia in the cooling gas stream at about one to four pounds of ammonia per day (*Ammonia Generation Rate in K Reactor Gas—Its Effect and Proposed Remedies* [DUN-2018]).

During 100-K Reactor operations, high volumes of process effluent, steam condensate, reactor cooling water, and fuel storage basin water were intentionally released to the land surface and surface water through ponds, outfalls to the Columbia River, and trenches via radioactive process sewers, pipelines, and control structures. Additionally, liquid wastes were intentionally released to the subsurface via cribs, trenches, French drains, and sewage disposal systems. Random spills of liquids potentially occurred during various material transfers, although the magnitude and location of these releases is unknown. Liquid wastes released from pipelines reach the vadose zone through leaks at joints or material failure between joints due to corrosion or other damage.

4.4.2.3 Low Concentration/High Volume Waste Sites

The low concentration/high volume waste sites primarily received cooling water during operations coming off the backside of the reactor. Chromium and Cr(VI) are key contaminants for this type of waste site (retention basins and selected trenches such as the K-2 Trench). Large volumes of water discharged to the K-2 Trench displaced groundwater over a large area. The flux of water to the trench saturated the soil column in the Hanford formation connecting with the main aquifer in the Ringold Formation unit E. Due to the limited depth of the high conductivity sediments combined with the magnitude of water discharged to the trench, the cooling water mounded to the surface, as evidenced in historical photos of the area showing a warm water spring adjacent to the K-2 Trench toward the river. At the same time, cooling water flowed inland at least 3 km, based on water level rise observed in nearby monitoring wells.

As these large fluxes of water with low-concentration of Cr(VI) passed through the saturated vadose zone and aquifer sediment, a small fraction would tend to reduce and become immobile. This process would be expected to continue over time continually adding a small fraction of the total flux, resulting in relatively large concentrations of trivalent chromium in sediments associated with these low concentrations, high volume sites.

After operations ceased, the groundwater mound near the trench collapsed as water drained down to the water table, leaving relatively normal groundwater levels formed by the newly emplaced cooling water. A remnant of cooling water also was present in the vadose zone in a volume roughly equal to the specific retention (porosity minus specific yield) or field capacity. This is approximately 2 to 5 percent of the total volume, depending on the sediment composition (sand versus silt versus gravel).

Key aspects of these waste sites and migration of associated contaminants include the following:

- Very large volumes of water containing relatively low concentrations of Cr(VI) and radionuclides were discharged at these sites.
- A small fraction of the daily Cr(VI) flux would be reduced as it passed through the sediment, dropping out of solution, and building up in the soil column and aquifer sediment.

- Effluent moved vertically through the vadose zone, and flowed laterally in the aquifer. These high volume discharges created a water table mound beneath the reactor area. Distribution of contaminants inland also occurred because of the mounding.

- Cooling water effluent retained in the vadose zone at concentrations less than or equal to the maximum of 700 µg/L of Cr(VI) would not produce soil with the significant concentrations required for removal under the Interim ROD. However, given the large fluxes of effluent over a long period, of time, there could be significant build-up of reduced trivalent chromium over time.

- Contaminants were transported into the vadose zone or unconfined aquifer according to their relative mobility. Highly mobile constituents, such as Cr(VI) and tritium, migrated with the water, while less mobile constituents such as strontium-90 migrated more slowly through the vadose zone.

- Cooling water ran to the K-2 Trench.

4.4.2.4 High Concentration/Low Volume Waste Sites

The high concentration/low volume waste sites were primarily liquid and solid waste disposal sites and surface spills. These waste sites are significant because high concentration Cr(VI) and nitrate plus Sr-90, tritium, and carbon-14 originate from these types of sources. These include leaks of concentrated chromium solutions and leaks from the FSBs. Key aspects of these sites and migration of contaminants associated with them include the following:

- High concentration sodium dichromate (70 percent solution) was received at the 100-K head house railcar-unloading site and French drain. Concentrated solution and rinse water was discharged into the French drain via connection hoses and other piping. Spills occurred within and around the facilities and migrated downward through the vadose zone to the aquifer. This is the most likely source for the present day high-concentration Cr(VI) plumes near the 100-KE and 100-KW Reactors as well as past high concentration groundwater near 100-KE that has already been partially remediated.

- Soil remediated for Cr(VI) appears to have been impacted by concentrated solutions near the head house and within areas near the distribution system.

- Some of these high concentration solutions may have been the result of cleaning operations at the head house that went into the 100-K process sewer, which discharged into the K-2 Trench as well. One likely scenario is that at the end of operations, concentrated solution would have been cleaned out via the process sewer, ending up in the K-2 Trench. Consequently, there could be multiple types and characters of discharges at the K-2 Trench.

- Precipitated sludge containing substantial mercury concentration accumulated in sulfuric acid storage tanks at the 100 Area cooling water head houses. This sludge as periodically flushed to French drains near the tanks.

- The overall volume of these leaks and spills was relatively small in comparison to reactor cooling water volumes. Natural precipitation, water use, and leakage contributed to migration through the vadose zone and into the aquifer.

- The 100-K carbon-14 groundwater plume likely originated as carbon dioxide condensate coming off the reactor piles that was sent to the 116-KE-1 and 116-KW-1 condensate cribs.

- The 100-K nitrate groundwater plumes are distributed at various locations within the operating area. The highest nitrate concentrations in groundwater are associated with the 116-KW-1 condensate crib. The likely source is oxidation of ammonia discharged in the condensate solution. Additional sources

of nitrate may include historic use of nitric acid-based solvents in the reactor buildings, including laboratory areas. Some additional contribution from septic sources is possible.

- Elevated sulfate in groundwater at 100-K likely originated from the use of sulfuric acid (e.g., for pH adjustment of cooling water, neutralization of waste caustic, and production of alum from bauxite) and the use of alum (hydrous potassium aluminum sulfate) for water treatment. This may include maintaining water quality in the FSBs.

- Zinc originating from the fuel slugs and cladding may have been introduced during leaks from the FSBs and is a component of the 100-K CSM. Zinc has a high K_d in alkaline environments such as those found at Hanford and exhibits generally low mobility. Zinc may also have been associated with sulfuric acid used in the water treatment system, some of which was reportedly obtained as reclaimed acid from offsite industrial uses.

- Groundwater data from the Cr(VI) plume near the K-2 Trench indicates that this plume is most likely a lingering expression of the chromium in the cooling water historically discharged to that area.

4.4.2.5 Primary Dry Waste Release Mechanisms

Contaminants associated with dry solid waste were released to the environment through intentional disposal at waste sites or through unplanned spills of particulate material. The contaminants may be transferred to the environment through leaching or dissolution. Insoluble dry contaminants such as friable asbestos or contaminated solid waste particulates may also become windborne, suspended in surface runoff, or transferred to the surface through physical contact with a contaminated surface.

4.4.3 Secondary Sources of Contamination and Release Mechanisms

The releases of primary contaminant source materials to the environment resulted in contaminated vadose zone material beneath facilities and waste sites. Some of this resulting contamination may be mobile and subject to leaching to groundwater, transport by surface run-on or runoff, or transport by wind as particulates or vapors. Secondary sources consist of environmental media (e.g., soil, surface water, groundwater) that were impacted by the initial releases of primary sources and subsequently retain sufficient levels of mobile contamination that they can act as continuing sources of contamination entering adjacent soil, surface water, groundwater, or air. If left unremediated, this contaminated material acts as a secondary source for the further spread of contaminants through the environment and potential exposure to human and ecological receptors.

The main secondary source of concern in 100-K is vadose zone soil contaminated with mobile Cr(VI) that may be present in unremediated waste sites and residues in the vadose zone soil, periodically rewetted zone, and the unconfined aquifer. The potential for Cr(VI) contained in the RUM formation has been considered as a possible secondary source; however, sampling conducted during the RI indicates that the RUM is not a likely secondary source at 100-K.The evaluation of risks posed by the identified secondary sources to human health and the environment through direct exposure are discussed in Chapters 6 and 7, respectively. The potential for secondary sources to provide a significant ongoing source of contamination to groundwater is evaluated through the comparison of contaminant EPCs in vadose zone material to the 100:0 irrigation scenario screening levels (Section 5.1) and base case scenario PRGs (Section 5.6) for groundwater and surface water protection. The persistence of Cr(VI) groundwater plumes within 100-K suggests the presence of secondary sources of groundwater contamination, particularly near the cooling water treatment head houses. Other locations where conditions suggest potential for continuing vadose contribution include the cooling gas condensate cribs (tritium, C-14, nitrate), and the FSBs (Sr-90). The persistent Cr(VI) plume beneath the 116-K-2 Trench appears to result from migration of residual

contamination within the aquifer associated with the previously-extensive contaminated groundwater mound at that site.

4.4.3.1 Secondary Sources

Based on the persistence of specific groundwater plumes in 100-K, the following general locations are potential historical secondary sources of groundwater contamination:

Chromium-contaminated vadose zone soil underlying the sodium dichromate dihydrate solution transfer facilities associated with the water treatment head houses at 100-KE and 100-KW. This area also appears to have contributed to other constituents present in soil and groundwater that are not identified as COPCs (e.g., sodium, aluminum, and sulfate).

Vadose zone soil underlying the 116-KW-1 and 116-KE-1 condensate cribs, contaminated with tritium, C-14, Sr-90, and nitrate.

Vadose zone soil underlying the FSBs and the basin leak disposal cribs/injection wells, contaminated with Cr(VI) and mixed fission products (e.g., Sr-90, tritium, Cs-137).

Vadose zone soil underlying the vicinity of the head end (west end) of the 116-K-2 Trench contaminated with nitrate, nitrite, tritium, and Cr(VI). Groundwater plume configurations in this vicinity suggest that vadose soil beneath the trench may not be the sole contributor to the observed plume(s). It is possible that contaminated soil beneath the 118-K-1 Burial Ground may have contributed to observed groundwater contamination.

Groundwater beneath the footprint of 116-K-2 Trench and the former extensive groundwater mound that is contaminated with elevated concentrations of Cr(VI) likely accounts for most, if not all, of the residual Cr(VI) plume in the vicinity of the trench.

Based on observations and measurements of site-related contaminants, contaminated groundwater beneath the 100-K Reactor areas may be a continuing source of contamination discharging to the river and to the riparian/river shore area during high river stage.

A unique type of secondary source is residual process chemicals that may be contained within pipelines or other storage and conveyance components and may be encountered during facility demolition. These materials may potentially be released to the surface or subsurface soil.

Some waste sites have already been remediated (e.g., 116-K-2 Trench) and are no longer considered to be contributing to groundwater contamination. Other sites may be remediated in the future and will not be considered as potential contributors to groundwater contamination following remediation.

4.4.3.2 Secondary Source Release Mechanisms

Contaminated material in the vadose zone or aquifer is considered a potential ongoing secondary source of some contaminants released to groundwater surface water, and to the riparian surface. Secondary sources remaining in pipelines and control structures in the form of pipe scaling, corrosion products, sludge, and sediment may be released through structural failure of the pipeline and exposed to net infiltration. The secondary release mechanisms for contaminants include the following:

- Volatilization of contaminants in/or near surface soil to the atmosphere or soil gas (applicable to VOCs and tritium)
- Resuspension of particulates in air (applicable to all contaminants) from contaminants at the soil surface

- Transport of contaminants from surface soil in surface water runoff, both as dissolved constituents and suspended particles (applicable to all contaminants)
- Desorption and/or dissolution from contaminated vadose zone soil and transport with infiltrating precipitation (applicable to soluble and mobile contaminants)
- Biotic uptake (applicable to soluble and mobile contaminants) and translocation in plants and animals
- Groundwater discharge to surface water and to the riparian ground surface when contaminated groundwater discharges in seeps and springs associated with seasonal high river stages (applicable to soluble contaminants contained in groundwater)
- Direct release of reactor-related chemicals that may be encountered during facility demolition

4.4.4 Driving Force

The driving forces of contamination are either artificial or natural. The artificial forces during operations were related to the reactor operations and waste disposal practices, including the large groundwater mound at the K-2 Trench. The practice of disposing high volumes of liquid waste-to-waste facilities created subsurface distribution of contamination over widespread areas. Maintaining safe work conditions during remediation by applying water to control dust is postulated to have been a transient driving force. However, the long-term driving force is the natural system, as described by the hydrologic cycle.

The hydrologic cycle plays an important role in the CSM. Most of the precipitation occurs during the fall and winter months when evaporation and plant use are the lowest. This water is stored in the upper few meters of the soil column. Plants use up this soil moisture during the dry summer months. A small fraction of water is able to percolate below the root zone where it will continue to drain essentially undisturbed vertically through the vadose zone to the water table with little lateral migration. The exception to this is for snowmelt when snow has drifted in selected areas. The uneven areal distribution results in zones of infiltration, which can result in lateral migration locally.

At 100-K, the groundwater currently flows toward the Columbia River. The transition area between the aquifer and the river is called the hyporheic zone. The Columbia River is free flowing through 100-K and river stage, which can vary as much as 3 m (10 ft), is controlled by the Priest Rapids Dam. When the river rises, it pushes into the riverbank, pushing back on the aquifer and causing the water table to rise in the nearby aquifer. When the river stage drops, groundwater in the aquifer flows again into the river. This results in a significant back and forth motion in the hyporheic zone such that an individual water molecule may see-saw a number of times before reaching the river.

In addition to discharge of groundwater to the river through the hyporheic zone, groundwater seasonally discharges in springs or seeps at elevations above the river stage. This occurs generally during the period following seasonal high river stage in the early summer. As the river stage recedes after the spring thaw, groundwater that has become elevated as it equilibrated with the high river stage may drain directly to the ground surface in the riparian zone, bringing with it dissolved or suspended contaminants that then may be deposited on the ground surface in the riparian zone, or may flow overland to the Columbia River.

4.4.5 Contaminant Migration

Contaminants migrate along flow paths. Understanding of the flow path is important because in the development of the remedies in Chapters 8 and 9, the goal of a remedy or combination of remedies is to break the flow path, and isolate or remove the contaminant from the flow path. The major components of the flow path are illustrated in Figure 4-91. The upland zone to the right of the figure is the location of the reactors and facilities and associated waste sites. Once contaminants entered the ground through leaks at

basins or pipes, planned released at cribs and trenches, and other unplanned releases, the contaminant fluids combine with the ambient water already in the vadose zone soil plus continuing additions from precipitation and begin to leach down toward the water table. Excavation of waste sites is intended to remove leachable material before it impacts the water. Excavation-based remediation also removes contaminants from the surface and near-surface soil, thus reducing, or eliminating, the potential for direct contact exposures, or migration of these near-surface contaminants in surface water run-on/runoff or as wind blown suspended particles. However, in some instances, the more mobile constituents, particularly Cr(VI), tritium, carbon-14, and nitrate, have already migrated deep into the vadose zone and/or into the underlying groundwater.

Contaminants in 100-K include highly mobile constituents that do not adsorb readily to the geologic materials in either the vadose zone or the aquifer. These contaminants include Cr(VI), nitrate, sulfate, and tritium. Other contaminants such as strontium-90 may have migrated to the deep vadose zone or to groundwater, but tend to adsorb readily to the geologic materials in the vadose zone and aquifer and do not move much further in the future under natural conditions. Trivalent chromium adsorbs and precipitates out of solution and becomes very immobile. The mobile contaminants migrate readily with water. Residual contaminants that remain in the vadose zone after the cessation of waste discharges can migrate downward by any of three mechanisms: they may continue to move by gravity drainage of residual wastewater within the vadose zone (there is no indication that this process is continuing at this time); they may be mobilized in the fraction of annual precipitation that actually percolates deep into the vadose zone to recharge into the aquifer; or they may be mobilized into groundwater from the vadose zone during seasonal increases in groundwater table elevation due to high river stages (Figure 4-99).

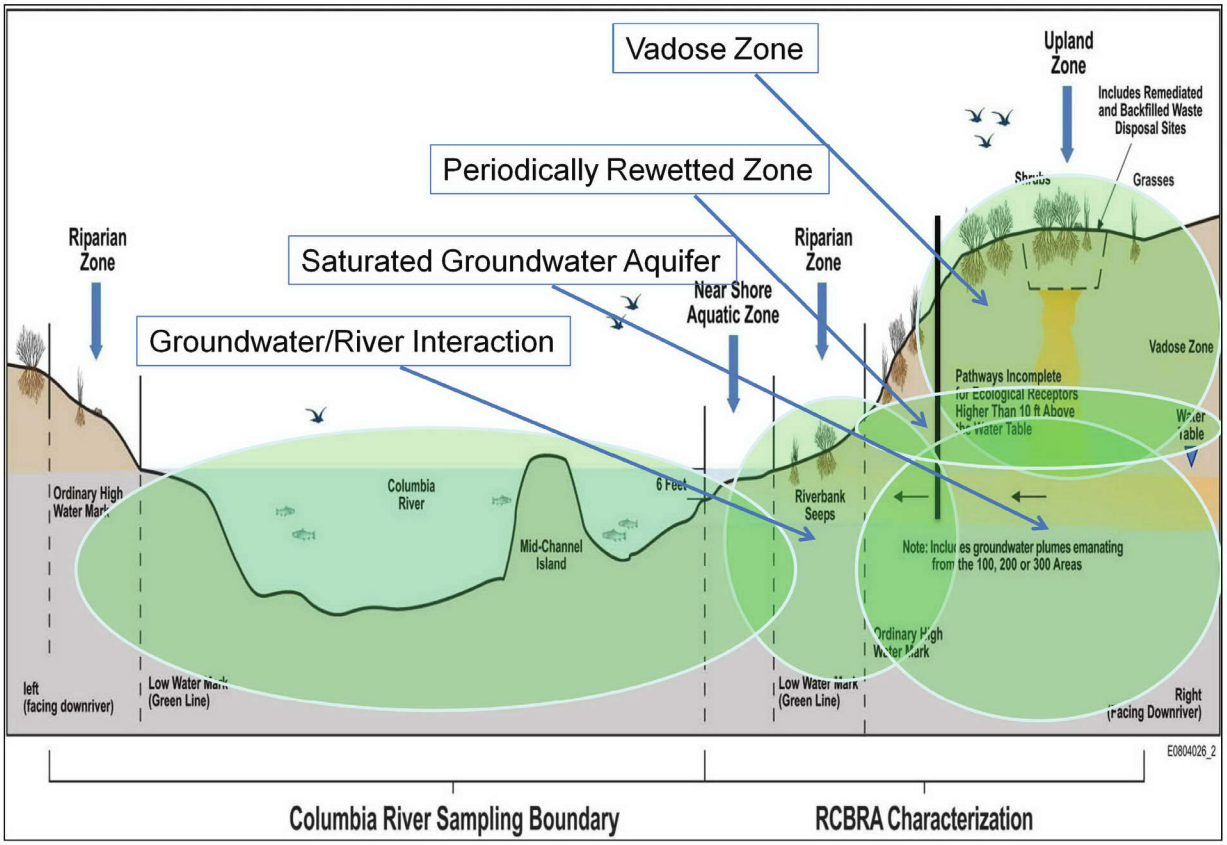


Figure 4-99. Schematic of Areas of Contaminant Interaction with Vadose Zone Soil, Groundwater, and Surface Water

The chemistry of sodium dichromate is important. While chromium is in the hexavalent state (with a plus 6 valence), the chemical form is typically either the dichromate anion ($Cr_2O_7^{2-}$) or chromate anion (CrO_4^{2-}). Most soil types, including Hanford soil, tend to be negatively charged as well, so there is no significant force of attraction between the chromium anions and the sediment, such that typically the adsorption is assumed to be very low for dichromate passing through the sediment. However, at locations where iron and bacteria are available to chemically and biologically react with the dichromate anion, reaction occurs and very immobile trivalent chromium forms can precipitate out of solution. Chapter 5 discusses in detail the fate and transport for contaminants in 100-K.

An important concept to understanding the CSM and the flow paths in 100-K is the difference between site conditions during operation of the reactors and the current site conditions, which have developed since reactor operations ended. The following text summarizes the effects of conditions during operations that contributed to the currently observed contamination conditions:

- During operations, reactor-cooling water was held up in retention basins before discharge directly to the Columbia River. This hold-up time allowed for decay of short-lived activation products and a slight reduction in temperature. Cooling water retention basins at the 100-KE and 100-KW Reactors were all constructed of steel plates. The basins, however, developed leaks, most likely due to temperature-related failure of joints and seams. In addition, the 100-K area retention basins were equipped with large-diameter valves used to divert the cooling water discharge from the river outfall to the 116-K-1 Crib and 116-K-2 Trench during off-normal conditions. These valves leaked so that a substantial fraction of the cooling water flow was discharged to the crib and trench on a fairly continuous basis. As a result, quantities of cooling water, still at elevated temperature and containing Cr(VI), were released to the vadose zone. This water reached the underlying groundwater and migrated to the Columbia River shoreline, where it entered the river through springs along the shore. Because the volume of water released to the vadose zone was sufficient to create groundwater mounds underlying the retention basins, contaminated water also flowed radially away from the retention basins in all directions.

- Contaminants were transported to various depths in the vadose zone or into the unconfined aquifer at some waste sites, according to their relative mobility and discharge volume. Highly mobile constituents, such as Cr(VI), migrated at essentially the same velocity as the water, while less mobile constituents, such as Sr-90, migrated more slowly.

- The water table beneath the K-2 Trench was elevated during operations such that the soil column was fully saturated immediately beneath the head end of the trench and cooling water appears to have displaced the native water in the aquifer approximately 3 km inland from the trench. Water likely perched atop the Hanford/Ringold contact, where the large volume of water, combined with the relatively low hydraulic conductivity of the Ringold Formation, would have resulted in lateral spreading of water along the contact. Transient increases in groundwater elevation that appear related to the discharge to the crib and trench are observed as far away as 3 km inland from the Columbia River, and possibly as far as the base of Gable Mountain to the south. The resulting groundwater mound created an increased hydraulic gradient as the water flowed out from the source area at the trench and, therefore, increased transport of contaminants toward the Columbia River as well as inland. The resulting groundwater mound created an increased hydraulic gradient as the water flowed out from the source area at the trench and, therefore, increased transport velocity of contaminants toward the Columbia River as well as inland. Groundwater flow velocity was measured at about 3 m/day (10 ft /day) between the 116-K-2 Trench and the Columbia River when the groundwater mound was at its highest.

- Cr(VI) and other highly mobile contaminants were transported in the saturated zone and discharged with groundwater to the Columbia River via direct discharge to the river within the hyporheic zone and via overland flow of water from multiple seeps along the riverbank.

Groundwater mounding beneath the cooling water discharge sites likely began shortly after the start of reactor operations. In addition, as a result of vegetation removal and surface disturbance at initial construction, an elevated amount of precipitation infiltrating through the vadose zone had continued in the post-operational period, driving contaminants downward and facilitating continued geochemical reactions. However, this increase did not match the net infiltration rates during the operational period. The post-operational conditions (the high volume liquid effluent releases ended when operations ceased in 1971) at a typical waste site exhibited the following characteristics:

- Secondary sources of contamination may remain in soil at waste sites due to sorption to vadose zone material or entrapment in small pores. The concentrations of residual contaminants at remediated sites were evaluated in their respective CVP reports and reported to be below the applicable cleanup criteria.

- If bare soil is replaced with some vegetated or artificial land cover, reductions in net infiltration and recharge will slow the migration of contaminants through the vadose zone to the aquifer.

- Grain size variations in the vadose zone stratigraphy can slow the rate of contaminant movement by changing the hydraulic and geochemical characteristics. The finer-grained intervals retain water better than the coarser-grained, gravel-dominated intervals under arid climate conditions and may retain some dissolved chromium. Furthermore, the larger pore spaces in the relatively thick gravel-dominated intervals serve as high resistance layers to the downward movement of water from the smaller pores of the finer-grained intervals. This condition is particularly evident at the contact between the coarse-textured Hanford and the finer-textured Ringold unit E that underlies it. The geometry of this contact at 100-K is discussed in Chapter 3.

- Chromium is present in vadose zone in several forms, and not all forms are mobile. Cr(VI) may sorb to mineral surfaces, precipitate in mineral phases with varying stability, and may be reduced to trivalent chromium and form low-mobility, pure trivalent chromium phases or ferric oxide/trivalent chromium solid solutions (*Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site: Part 2* [PNNL-17865]).

A portion of the vadose zone is periodically rewetted with seasonal and daily changes in the water level of the Columbia River. The RI/FS samples collected in this periodically rewetted zone did not indicate the presence of a secondary source significantly contributing to the persistence of Cr(VI) in the unconfined aquifer. Given the lower hydraulic conductivity and greater heterogeneity in the Ringold Formation, the nature and extent of contaminants may change across the boundary. This is discussed in detail in Chapter 3.

Groundwater flow and contaminant transport in the unconfined aquifer is also affected by Columbia River stage fluctuations. The increase in the surface water elevation in the spring pushes water inland and causes water table elevation increases throughout 100-K. Consequently, the hydraulic gradient is altered and less water flows into the river from the aquifer. During the low river stage in the fall, groundwater flow toward the river dominates. Depending on the location within 100-K, direction variability in flow occurs because of these competing influences.

The volume and location of groundwater discharges to the Columbia River were also affected by the proximity of the facilities to the river. These effects summarized as follows:

- Thermal seeps along the Columbia River were observed during reactor operations (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]). These seeps were associated with leaking retention basin tanks and liquid waste disposal. The thermal seeps are no longer present since water table elevations have diminished to pre-operational levels.

- Under current conditions, upwelling groundwater discharges were identified through surface water and pore water sampling that was conducted during the Columbia RI (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* [WCH-380]).

- Natural seeps observed along the shoreline in the riparian zone were associated with the early summer drop of the Columbia River water levels.

The largest discharges of Cr(VI) and other highly mobile contaminants to the Columbia River occurred during active reactor operations and then rapidly diminished when reactor operations at 100-K ceased. The configurations of the contaminant plumes were established during that time. Ongoing contaminant releases from secondary sources in the vadose zone to the unconfined aquifer are limited due to reduced net infiltration rates since operations ceased. The fate and transport of Cr(VI) and other contaminants in 100-K is complex and affected by many different factors, which will be discussed in Chapter 5.

4.4.5.1 Vadose Zone

With the cessation of operations, most discharges and releases ceased. Therefore, no new contamination was introduced into the ground. However, the contamination continued to migrate under the influence of the hydrologic cycle and continued to interact chemically with the sediment matrix. The following are key features of the fate and transport:

- Waste site characterization and remediation (RTD) was accelerated in 1996. Remediation generally included excavation to about 4.6 m (15 ft) bgs. Precipitation, dust suppression, and leakage from the FSBs became the driving forces for contaminant movement through the vadose zone. Net infiltration of 8 to 10 cm/yr (3 to 4 in/yr) likely continued at nonvegetated waste sites. Dust suppression water was used during demolition and remediation of waste sites. Once waste sites are revegetated, the plants consume the natural precipitation, limiting infiltration deep into the vadose zone. Revegetation of waste sites at 100-K is variable and is expected to accelerate after completion of remedial activities.

- Some of the contaminants may remain dissolved in the unsaturated volumetric water content at specific retention in the vadose zone material, but the mass in this phase is likely to be low (given the relative small volume of water) and slowly leachable because it is located in smaller pores.

- Known chemical reactions within the vadose zone can reduce Cr(VI) to its less toxic and less mobile trivalent state in conjunction with sorption and precipitation. Chromium reduction by ferrous iron and chemical precipitation with barium sulfate are two reactions that occur; iron constitutes approximately 5 percent of the composition of both the Ringold Formation unit E and the Hanford formation.

- Chemical analysis of the vadose zone material at RI wells indicates that much of the chromium in the vadose zone is in reduced form. This is consistent with known attenuation mechanisms for Cr(VI) described by *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water: Volume 2 – Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium* (EPA/600/R-07/140).

- Cr(VI) concentrations in borings and post remediation verification samples were less than expected. Based on the STOMP 1D modeling presented in Chapter 5, the remaining Cr(VI) in the vadose zone is expected to leach to groundwater at relatively low fluxes (mass per time). However, it is uncertain the extent to which this leaching can produce groundwater concentrations that will exceed standards. Because of this uncertainty, remedy selection will factor in sufficient robustness to account for larger than expected fluxes. The same conclusion is true for other contaminants that may be present at these sites.

- The great majority of Cr(VI) was discharged into the surrounding environment as a dissolved species in various liquids. The historical records information described in a previous section shows Cr(VI) was released into the environment primarily as a dissolved species in two types of solutions, the reactor coolant and the 70 percent stock solution used to make reactor coolant and reactor coolant itself. The differences in solution chemistry, associated production facilities, and discharge locations have had a substantial effect on current Cr(VI) distribution in the subsurface. In addition, other contaminants such as carbon-14 were produced in the reactors.

- With regard to ultimate Cr(VI) distribution in the environment, the significant solution properties are Cr(VI) concentration, pH, and specific density. The approximate Cr(VI) concentration was 466 g/L in the 70 percent by weight solution. This solution was acidic (pH about 1.5) and significantly more dense than water (specific gravity of 1.7 g/cm^3). Aquifer contamination from this stock solution occurred in two locations: storage tanks and piping near and under the 183 Complex at each reactor.

- As described in Chapter 2, the 70 percent solution was shipped by railcar to a 158,987 L (42,000 gal) storage tank next to the 183-KW and 183-KE facilities and then piped to mixing tanks containing treated Columbia River water. The total amount of 70 percent solution that passed through this system is not known but can be derived from the Cr(VI) content estimates in the reactor coolant. If the reactor coolant volumes and Cr(VI) content provided in Table 4-29 are assumed (6.3 million kg [13.9 million lbs]), a total 70 percent volume of about 13 million L (3.4 million gal) was stored and transferred from these two tanks. The delivery of the 70 percent solution into the storage tanks was not completely efficient, and yellowish-stained soil around the storage tank location indicates losses to the subsurface. In addition, some leakage in the transfer pipes or connection between the transfer pipes and the mixing tanks is plausible. The fraction of delivered 70 percent solution lost to the subsurface is not known. However, based on a comparison of groundwater contamination condition at 100-K versus 100-D, the fraction lost does not appear to be nearly as much as that lost at 100-D, even though more fluid was used at 100-K. The major difference appears to be the greater simplicity of the 100-K 70 percent solution feed system, which involved only the storage tanks and a short transfer line to mixing tanks.

- Following discharge of these Cr(VI)-rich dense fluids into the subsurface, vertical penetration occurred. The density of the fluid would have facilitated vertical migration into the subsurface with little lateral movement. However, very little information is available that describes the distribution of Cr(VI) initially from this fluid in the subsurface, and several factors suggest a broad range of possibilities. The vadose zone and the unconfined aquifer are each about 24 m (80 ft) thick beneath the storage tanks and transfer piping and composed primarily of the Ringold Formation unit E (Well 199-K-165 in Figure 3-11), which is partially cemented in places. This unit may have provided substantial resistance to vertical migration. Column studies conducted by PNNL show an initial large fraction of Cr(VI) leaching in the first pore volume followed by diminishing returns as the additional leachate contains increasingly smaller fractions tending asymptotically to zero. The opportunity for recharge would also have been limited because the 183-KW/KE basins provided partial shielding from precipitation and subsequent recharge. In addition, some sequestration by Cr(VI) reduction via

ferrous iron (*Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site* [PNNL-17674]) or physical entrapment in occasional silty lenses may have occurred in the vadose zone.

- The current RTD remediation strategy in the vadose zone appears to be protective once contaminated soils are removed from the affected waste sites. However, the potential remains for continuing sources in the vadose zone, which results in some uncertainty with respect to whether any source has been missed or will be missed in the future. The RI characterization data collected for this report suggests that there may be some remaining contamination in the periodically rewetted zone in the far end of the K-2 Trench. This source could bleed into the groundwater for a number of years and will be monitored in the groundwater. There does not appear to be such a significant source there that it will impact cleanup deadlines; however, there is uncertainty in how this residual contamination might behave at this site and potentially other sites. Therefore, reasonable monitoring will be conducted and mitigative actions taken as part of the CERCLA process, which provides for continued monitoring and contingencies as appropriate.

4.4.5.2 Periodically Rewetted Zone

The periodically rewetted zone is a thin zone located at the intersection of the lower vadose zone and the upper aquifer; it is the area between the high and low water table. Much of this zone is characterized as having coarse sediments; locations where the zone has finer sediments is important. The key concept with the periodically rewetted zone is to determine whether the zones can preferentially store and release contaminants. This would imply that contaminants would have a higher K_d under unsaturated conditions that would then be reduced as the material became saturated during water level rises, leading to a storage and release of contaminants. Characterization activities reveal selected waste sites where contamination in the periodically rewetted zone appears to be present. In addition, some locations (e.g., Well 199-K-35 near the 100-KW cooling water head house) have exhibited transient increases in Cr(VI) concentration following periods of increased groundwater elevation. At this well, Cr(VI) concentration increased from less than 200 µg/L to nearly 800 µg/L and then decreased again to about 200 µg/L following use of the well as a pump-and-treat injection point.

The key findings of the RI investigation are:

- There is evidence of buildup of Cr(VI) contamination in the periodically rewetted zone near the 100-K-2 Trench.
- Little evidence has been found of leachable Cr(VI) in this zone at other waste sites.
- A key source of uncertainty is the potential for local heterogeneities that might impact the flow regime. However, with likely vertical hydraulic conductivity in the Ringold unit E and the Hanford formation much greater than the likely annual vertical moisture flux of 8 to 10 cm/yr (3 to 4 in/yr), the known lithologies are unlikely to result in a vertical hydraulic conductivity that small.

4.4.5.3 Groundwater

Groundwater impacts at 100-K are limited to the shallow unconfined water table aquifer beneath the area. Samples collected from water-bearing units within the underlying RUM unit did not exhibit site-related contamination. In addition, the water-bearing units within the RUM appear to be confined, exhibiting peizometric head greater than that of the overlying unconfined aquifer. This indicates that in the vicinity of 100-K, the RUM provides effective isolation against downward vertical migration of groundwater contaminant below the shallow unconfined aquifer unit.

It appears that some fraction of the 70 percent solution has reached the unconfined aquifer because maximum Cr(VI) concentrations in a small number of wells exceed reactor coolant chromium concentrations (up to 700 µg/L). These wells (e.g., 199-K-137, 199-K-165, 199-K-195) have shown levels up to 3,000 µg/L, concentrations that could not be achieved if the Cr(VI) source were the reactor coolant only. These wells are also appropriately placed just downgradient of the piping that transferred the 70 percent solution to the mixing tanks in the 183-KW Complex. The newly generated depth-specific groundwater data from Well 199-K-165 suggest complete penetration of the 70 percent solution through the unconfined aquifer may not have occurred, given the relatively low groundwater concentration (286 µg/L) near the bottom of the aquifer.

Groundwater monitoring data indicate Cr(VI) from the 70 percent solution discharge has migrated in a narrow band toward the Columbia River along a northwest axis. This direction is consistent with the regional gradient and provides no indication of alteration to the natural gradient in the 105-KE and 105-KW Reactor areas caused by the historical 116-K-2 Trench groundwater mound or the more recent water injection mound about 1.6 km (1 mi) to the northeast. The plume appears to be migrating slowly, given its current limited extent and the small regional gradient that pushes it toward the Columbia River. Future migration is expected to be relatively slow as well, and currently operating extraction wells are both reducing and limiting the spread of high concentrations. Whether the trend will continue depends on the nature and extent of the remaining source term, which is highly uncertain.

Reactor coolant solutions, once passed through the 105-KW and 105-KE Reactors, were routed north to two sets of three retention basins and then piped either to the Columbia River through the 116-K-3 Outfall or to the 116-K-2 Trench. As discussed in Chapter 2, of the approximately 12 trillion L (3 trillion gal) of coolant that passed through the reactors, the greater fraction went through the outfall. The remainder, an estimated 100 million to 600 billion L (264 million to 158 billion gal) (about 2 percent to 5 percent of the total) containing about 100,000 to 200,000 kg (220,000 to 441,000 lbs) of Cr(VI), was piped into the 116-K-2 Trench. For the most part, the Cr(VI) discharged through the outfall entered the Columbia River, with the exception of leaks and spills near the shore.

The long-term releases of large volumes of reactor coolant into the 116-K-2 Trench caused the formation of a large groundwater mound (Figure 4-98) in the mid-to-late 1950s that grew until the late 1960s. The rapid formation of the groundwater mound shortly after discharges to the trench began indicates Cr(VI) migrated quickly through the vadose zone and likely penetrated much if not all of the unconfined aquifer. Relatively quick transport through the vadose zone was facilitated because the majority of the vadose zone beneath the 116-K-2 Trench comprises the more permeable Hanford formation (Figures 4-3 and 4-4). Given the radial migration of fluid along the trench axis, some portion of the source term, perhaps the majority, discharged into the Columbia River and is no longer present in the subsurface. Figure 4-98 also suggests the 116-K-2 Trench discharges overwhelmed reactor coolant releases from other locations such as beneath the retention basins.

The remainder of the source, probably thousands of kilograms of Cr(VI), was pushed inland by the growing groundwater mound. Figure 4-98 suggests the mound influence extended as much as 3 km (2 mi) inland and the highly soluble Cr(VI) would have been present throughout the impacted area at concentration levels less than 700 µg/L, the maximum concentration assumed in the early reactor coolant. At the outer edges of the groundwater mound, dispersion effects would have limited maximum Cr(VI) concentrations to smaller values (e.g., less than 100 µg/L). Mounding during operations from discharge to the 116-K-2 Trench is the most likely cause of the Cr(VI) detected in Well 699-78-62, located approximately 1,158 m (3,800 ft) inland from the trench. As the groundwater mound diminished, inland migration of the Cr(VI) also diminished, and by the mid-1970s, the regional gradient was essentially reestablished. At this point, Cr(VI) migration began to reverse and migrate slowly toward the Columbia River.

Extraction wells began removing contamination in 1997 at the north end of the 116-K-2 Trench. The wells were expanded in 2007 and 2008 to cover the remainder of the 100-KR-4 OU facilities to the southeast. In addition, a series of injection wells has been operational since 2007 at the southern end of the 116-K-2 Trench and upgradient of the 100-KW facilities to expedite Cr(VI) removal. Approximately 350 kg (772 lb) of Cr(VI) has been removed through 2007 (*Calendar Year 2007 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operation* [DOE/RL-2008-05]). These operations have decreased the areas of higher contamination (e.g., more than 100 µg/L). The remaining areas of higher contamination at the south and north end of the 116-K-2 Trench (around Wells 199-K-18 and 199-K-22, respectively) may be related to aquifer configuration. These areas are roughly coincident with the thicker aquifer zones created by depressions in the RUM Unit (shown in Figure 3-9). These zones may have acted as channels for preferential flow and provided greater storage of reactor coolant. The main group of injection wells has created a zone near the middle of the 116-K-2 Trench below concentrations of 20 µg/L.

The current configuration of the plume near the K-2 Trench appears to be impacted by injection wells upgradient of the trench that serve to divert and dilute groundwater in the center portion of the trench. The observed concentrations toward the end of the trench may just represent the old cooling water continuing to flow toward the river.

Groundwater flows at an average rate of 0.1 m/day to 0.3 m/day (0.33 ft/day to 0.98 ft/day), as estimated from hydraulic gradients and from migration rates of plumes (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]). The best supported estimate for the groundwater flow rate between the 105-KE Reactor and the river is 0.12 m/day (0.4 ft/day) (*Hanford Site Groundwater Monitoring for Fiscal Year 2001* [PNNL-13788]). Relatively faster flow is observed beneath the 105-KW Reactor than below the 105-KE Reactor (*Evaluation of Potential Sources for Tritium Detected in Groundwater at Well 199-K-111A, 100-K Area* [PNNL-14031]). These rates suggest that aquifer zones displaced by cooling water 3 km or more inland may take 30 or more years to drain to the river and reestablish the natural groundwater flow paths.

Primary features related to contaminant migration through the groundwater include the following:

- The unconfined aquifer beneath 100-K is found primarily within permeable/transmissive gravel and sand facies of the Ringold unit E.
- The groundwater gradient returned to a regional flow pattern toward the river within four years. Regional flow conditions and contaminant migration were relatively unaffected until the 100-K pump-and-treat systems came online in 1997.
- The sandy-clayey silts of the RUM underlie Ringold unit E in 100-K and form an aquitard, preventing further downward migration of groundwater and contaminants. The top of the RUM unit is an undulating surface. A depression coincides with the 100-K plume. These variations in the top of the RUM result in variable flow conditions in the aquifer.
- Cr(VI) plumes are located downgradient of the 105-KE and 105-KW Reactors as well as both upgradient and downgradient of the 116-K-2 Trench.
- Cr(VI) mass exists in finer-grained zones of the aquifer that have a lower hydraulic conductivity. Cr(VI) may migrate much more slowly in these zones, even under induced flow conditions of pump-and-treat.

- Stratification of Cr(VI) values is observed in some wells with others in proximity showing little or no stratification. This may be the result of different flow rates at different depths in the aquifer in some locations resulting in differential concentrations.

- The unconfined aquifer beneath 100-K discharges into the Columbia River in the sands, gravels, and cobbles lining the river channel.

- The current state of Cr(VI) contamination in groundwater at 100-K consists of three plume areas. The Cr(VI) plume overlaps the majority of the smaller plumes for other contaminants at 100-K, although it appears that the carbon-14 plume may be slightly offset from the 100-KE plume.

- Natural attenuation of Cr(VI) likely is the result of reduction with some adsorption and precipitation. Adsorption may facilitate the reduction process. Reductants associated with the aquifer matrix are most important; iron is an important component that is abundant within Hanford sediments.

- Much smaller plumes of tritium, carbon-14, nitrate, and Sr-90 are also present in 100-K.

- Pump and treat systems, using IX treatment, have been brought online since 1997 to contain and remediate Cr(VI) in 100-K. A major expansion at the KX pump-and-treat facility brought the total treatment capacity up to 1,100 gpm at 100-K. Pump-and-treat systems are designed to intercept Cr(VI) plumes as they migrate toward the Columbia River. Injection wells provide a driving force to move the plume toward the extraction wells and impose lateral containment to the plume as it moves downgradient.

- Flow paths in the groundwater/river zone of interaction vary with daily and seasonal fluctuations in river stage. River water infiltrates the banks during high river stages, moves inland, and then reverses flow as the river stage subsides and moves back through the hyporheic zone and discharges to the riverbed. Monitoring and modeling studies suggest that this back-and-forth motion of groundwater and river is cyclical in response to the diurnal river stage cycle, which typically includes two high stages and two low stages in response to power peaking demands. This motion occurs as laminar flow; consequently, the water is moving back and forth along streamlines within the greater potential field that defined groundwater discharge to the regional discharge point, the Columbia River. Review of modeling suggests that there is a significant back-and-forth motion in the groundwater such that an individual Cr(VI) atom experiences a significant lengthening of the flow path as it moves back and forth through the aquifer. It will experience numerous reversals in flow direction before it eventually reaches the water column in the river. This mechanism delays chromium from reaching the river and provides additional opportunities for chemical reduction of Cr(VI).

4.4.5.4 Hyporheic Zone

The hyporheic zone is the zone of interaction where groundwater transitions from the aquifer into the Columbia River. This area appears to be a very dynamic hydrologic and geochemical zone in the flow field. Water flows back and forth in this area as the water level rises and falls in the river pushing and pulling water into the bank.

It is important to understand the mechanics and chemistry of this flow in the hyporheic zone. Groundwater flow is laminar. The flow direction reverses according to river stage. In a groundwater aquifer, when flow reverses, flow should approximately follow the same streamline in the opposite direction with potentially a small component of deflection downstream. During this process, surface water infuses into the hyporheic zone and shoreline portion of the aquifer. River water refreshes some mineral surfaces and provides additional nourishment to bacteria in the form of organic carbon, phosphates, and other nutrients.

Once Cr(VI) enters the river or encounters a significant portion of river water in the hyporheic zone, it will be reduced relatively rapidly. The typical half-life of Cr(VI) in surface water is 1 to 7 days and should be mostly reduced to insoluble Cr(III) within 10 to 50 days.

There is relatively little evidence for wholesale mixing in the hyporheic zone. Under laminar flow with river stage changes, discharging groundwater will oscillate back and forth a number of times before it fully discharges into the surface water. During this process, there is significant likelihood for chemical reduction as the infusion of river water adds nutrients in the presence of bacteria and iron in the aquifer matrix. Consequently, there should be active reduction in the hyporheic zone, resulting in an attenuation factor between the nearest monitoring well in the aquifer and the river. This should result in a fairly small but constant rate of reduction. The rate is likely to be insignificant at high concentrations but as cleanup continues and concentrations are reduced, the rate likely will become significant, particularly as concentrations drop below the federal and state DWS.

A typical geochemical evolution along a flow line in the Horn area evidenced Cr(VI) dropping from 55 to 45 in wells to 12 in an aquifer tube. The associated specific conductance values were 420, 420, and 220 µS/cm. Consequently, natural attenuation from the nearshore aquifer through the hyporheic zone appears to be an important mechanism for chromium reduction before 100-K groundwater discharges into the river.

4.4.5.5 River/Riparian Zone

The riparian zone along the river is subject to periodic flooding and deposition of sediment and other detrital materials along with the flood water that contains contaminants from upstream. This includes both the immediately upstream portions of Hanford as well as the main upstream flow from Canada and northern and central Washington. Therefore, nonHanford contaminants may be introduced to the surface, vadose zone, and groundwater portion of the riparian zone through flooding. Most recently, significant riparian flooding was observed in 2011 due to the high runoff associated with the 2010-2011 snow pack.

Over the years of Hanford operations, direct discharges also have impacted the river. Data from the Columbia River RI suggest historical discharge from 100-K operations impacted the Columbia River. Large quantities of cooling water were discharged directly to the river via outfall pipes. Upstream data indicate that industrial and mining sources contributed contaminants to the Columbia River.

Upwelling studies showed several locations where measurable Cr(VI) was upwelling in the riverbed adjacent to the known groundwater plumes in 100-K. Evaluation of the flow regime on both sides of the river indicates that groundwater from 100-K does not upwell beyond the thalweg on the far side of the river. The upwelling studies (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling* [WCH-380]) indicate that during low flow stage in the river, water that is largely Hanford groundwater can upwell into the river. Given the large diurnal changes in river stage, this upwelling condition is likely to be ephemeral as groundwater flow reverses direction into and out of the river several times per day in response to operations upstream at Priest River Dam.

4.4.5.6 Pathways

A final aspect of the CSM is the different exposure pathways in which humans, animals, and plants potentially could be impacted by the presence of contaminants in the environment. The exposure pathways and risk assessments for humans are described in Chapter 6 and the exposure pathways and risk assessments for biota are described in Chapter 7. The exposure pathways for humans include various uses of the land and groundwater by Native Americans and by workers that might be employed at the National

Monument. Then the exposure pathways are described for the different ecological receptors in the river. The remedies are developed and applied in Chapters 8, 9, and 10; the remedies are chosen to break the exposure pathways, thereby providing effective mitigation from the potential risks that the contaminants pose. The general CSM elements that describe the full evolution of contaminants in the environment is described in Chapter 1 and is represented in the flow diagram in Figure 4-100.

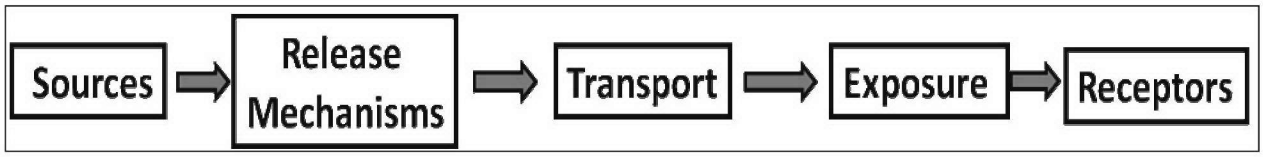


Figure 4-100. CSM Elements Describing the Movement of Contaminants in the Environment Summary

As presented in Chapters 1 and this chapter, contaminated wastes released from reactor support facilities, cooling water processing facilities, underground piping, liquid waste disposal sites, solid waste disposal sites, and surface spills were primary sources of contamination in 100-K during operations and secondary sources may have developed in vadose zone and aquifer materials. These concepts include the effects of high volume liquid waste disposal during operations on vadose zone moisture and the water table, the development of secondary sources of contamination in the vadose zone material, groundwater/surface water interactions, and the effect of Columbia River stage fluctuations on contaminant transport.

Chapter 1 has described the major waste sites at 100-K where contamination was observed and remediated to date under the interim remedies. In this chapter, specific characterization activities to address data gaps have been described. In addition, this chapter has described the locations in the aquifer with contaminant plumes, primarily Cr(VI), carbon-14, and nitrate associated with the 100-KE and 100-KW Reactors and the cooling water discharged to the K-2 Trench. The primary vadose zone hexavalent contamination is located near the head houses at the front side of the reactors. Sr-90 was remediated at the K-2 Trench under the interim action and is no longer a concern in that area. Ongoing remediation is occurring near the head houses under the interim action. Fifteen soil borings were advanced during the RI to investigate vadose zone materials. Samples were collected and analyzed per the 100-K Work Plan (DOE/RL-2008-46-ADD2) and 100-K SAP (DOE/RL-2009-41). Concentrations of target analyte list constituents were compared to background values to provide an indication of contamination.

Two borings were advanced at the 116-K-2 Trench to evaluate material remaining in the vadose zone beneath the depth of remediation. The samples from the boring advanced at the west end of the trench reported four metals and five radionuclides at concentrations greater than background. An additional three radionuclides were detected in one or more samples. Cr(VI) was not detected in the borehole samples, but was detected in soils remaining in the samples from the sidewalls and bottom of the trench during cleanup verification sampling. Samples from the boring at the east end of the trench reported five metals and five radionuclides at concentrations greater than background. Cr(VI) and three additional radionuclides were also detected in one or more samples. The maximum concentration reported for Cr(VI) was 0.72 mg/kg in the sample collected at a depth of 15.1 m (49.7 ft) bgs, which was 0.2 m (0.6 ft) above the top of the water table. Contaminant concentrations generally decreased with depth in the vadose zone beneath the 116-K-2 Trench, with only barium, chromium, copper, Cr(VI), nickel, Sr-90, and europium-152 detected or above background below 11 m (35 ft). Potential elevated Cr(VI) in the lower vadose periodically rewetted zone area suggests that some Cr(VI) could be a continuing source at this waste site. Therefore, the additional uncertainty of this finding will be factored into the potential treatment of this site.

Two soil borings were advanced to investigate waste sites 100-K-97 and 120-KE-6, and 11 soil borings were advanced at select locations not associated with individual waste sites to install groundwater

monitoring wells. Results from the boring advanced at 100-K-97 showed maximum contaminant concentrations in samples collected below 18 m (60 ft), while the samples from the boring at 120-KE-6 reported maximum contaminant concentrations from various depths.

Ten of the 11 borings for monitoring well installations reported up to 10 metals each at concentrations greater than background. One boring also reported VOCs and SVOCs and two additional metals above background. Chromium concentrations ranged from 2.56 to 211 mg/k, and Cr(VI) concentrations ranged from nondetect to 0.97 mg/kg. Both chromium and Cr(VI) concentrations generally decreased with depth.

Analytical data collected for waste site classification were evaluated to identify potential detected target analytes in shallow and deep vadose zone material for 14 previously remediated waste sites. Comparisons were conducted based on the depth of sampling and the sampling format. The significant waste sites were described in Table 4-23. In addition to the above mentioned waste sites, 100-K-55:1, 100-K-56:1, 116-K-1, 116-KE-1, and 116-KW-1 are all potential waste sites that suggest possible future risk based on the nature and extent described in this chapter. The potential COPCs in the vadose zone include cesium-137, cobalt-60, europium-152, europium-154, nickel-63, Sr-90, and mercury. The data sets are further evaluated for potential risk in Chapters 6 and 7.

Groundwater samples were collected and analyzed from 18 wells over three periods as a component of the RI/FS for spatial and temporal evaluation. The samples were collected and analyzed for COPCs following procedures in the 100-K Work Plan (DOE/RL-2008-46-ADD2) and 100-K SAP (DOE/RL-2009-41). Groundwater data for samples collected from 2006 to 2010 at 100-K as part of the annual groundwater monitoring program were also evaluated for contaminant identification and trends.

Groundwater plumes are discussed for three areas based on the highest observed Cr(VI) concentrations for fall 2009 and spring 2010 sampling. The depiction of these plumes integrates conservative assumptions on contaminant distribution, which results in overlap of two possibly distinct plumes observed at the 100-KE Reactor and west end of the 116-K-2 Trench. Cr(VI) is the most widely distributed contaminant at 100-K. Cr(VI) contaminant plumes are observed beneath the 100-KW, 100-KE Reactor area, and a split plume at the east end and west end of the 116-K-2 Trench. The plume at 116-K-2 has been split in the middle through ongoing groundwater pump-and-treat operations, with the west portion of the plume overlapping with the 100-K East plume. The east end of the 116-K-2 plume extends east to 100-N.

The KW Reactor area plume in groundwater showed a maximum concentration of Cr(VI) at 3,540 µg/L, and covered an estimated area of 0.10 km^2 (0.04mi^2) at a concentration of greater than or equal to 10 µg/L. The 100-KE Reactor Cr(VI) plume reported a maximum concentration of 421 µg/L, with an estimated areal extent of 0.35 km^2 (0.14 mi^2) exceeding or equaling a concentration of 10 µg/L. The estimated areal extent of the east end of the 116-K-2 Trench plume with a concentration above the 10 µg/L action level is 1.9 km^2 (0.74 mi^2), with a maximum reported concentration of 137 µg/L.

The other major constituents in groundwater are more localized than the Cr(VI) plume. Tritium is associated with the 100-KE plume and head end of 116-K-2. Carbon-14 is associated with both 100-KE and 100-KW plumes originating from the condensate cribs, although more extensive at 100-KW between 105-KW and the retention basins at 107-KW. Nitrate is primarily associated with the 100-KW plume and the head end area of 116-K-2. TCE is associated with 105-KW.

Evaluation of the spatial and temporal samples results is conducted in Chapter 6. Five groundwater COPCs were identified for 100-K based on this evaluation: Cr(VI), tritium, carbon-14, Sr-90, and nitrate. The COPCs other than Cr(VI) are distributed in localized plumes within the footprint of the Cr(VI) plumes and contained by the pump-and-treat groundwater extraction network for remediating Cr(VI).

The CSM describes the distribution of contaminants, their migration in the environment, and their impact to human health and the environment. The CSM presented builds on the information presented Chapters 1 through 4 and provides a framework for understanding the evolution of waste generation and migration to support the evaluation of long-term remedial alternatives. This chapter described the contaminants resulting from Hanford operations, how they have interacted, and where they are in the current setting. Contaminants can be harmful to human health and the environment if there is contact with sufficient concentrations, mass, and/or radioactive activity. This chapter also concludes with a summary of the CSM based on the information presented in Chapters 1 through this chapter that wraps up the site setting, site history, reactor operations, and resulting distribution of contaminants. Chapter 5 describes and predicts how quickly or slowly these contaminants will migrate through the setting (fate and transport). The potential to be harmful depends on specific human and environmental receptors as well as exposure times and patterns that might bring receptors and contaminants into contact. The ways that the contaminants could contact and impact human health and the environment are call pathways. Chapter 6 addresses the human health pathway. Scenarios of how humans might be exposed to contaminants in the setting with resultant health impacts are evaluated. Chapter 7 addresses the ecological receptor pathway. Scenarios of how plant, animal, bird, or invertebrate species might be exposed to contaminants in the setting and be impacted are evaluated.

5 Contaminant Fate and Transport

Chapter 5 presents an evaluation of the anticipated behavior of selected contaminants of concern in the vadose zone and groundwater at 100-K. An approach is presented for the assessment of anticipated future behavior of vadose zone contaminants that may function as secondary sources of contamination. The approach is intended to describe how these contaminants may be released into the environment to affect underlying groundwater. A simulation approach is also presented to describe the future behavior of contaminants already present in groundwater at 100-K. Factors affecting the fate and transport of contaminants, modeling methods and results, and uncertainties in the information and methods are discussed, as well as a summary of the chapter as a whole.

The purpose of the fate and transport information provided in this chapter is three-fold:

1. To describe the development of SSLs and PRGs for contaminated vadose zone soil in the 100 Area and to describe the application of the SSLs and PRGs to observed soil conditions to support assessment of potential threats to groundwater and surface water.

2. To use the SSLs and PRGs to evaluate whether contaminants present in the vadose zone at 15 previously remediated waste sites may act as a secondary source of groundwater contamination.

3. To describe the development and application of a computer simulation to evaluate predicted behavior of contaminants currently known to be present in groundwater beneath 100-K. A ROD for interim remedial action is in place that describes requirements for the initial remediation at waste sites at 100-K. As ongoing remediation activities are completed, the remaining contamination conditions at those sites will be evaluated by comparison to the SSLs and PRGs identified in this chapter.

Highlights

- The disposal of large volumes of liquid effluent to the vadose zone during reactor operations resulted in accelerated transport of contaminants to deeper portions of the vadose zone and unconfined aquifer groundwater in 100-K.
- Contaminant migration rates are currently much slower because liquid effluent discharges have stopped. No contaminants in the vadose zone at previously remediated waste sites were found to potentially cause continuing contributions to groundwater contamination. Some unremediated waste sites may continue to act as secondary sources contributing to existing groundwater plumes.
- Cr(VI) concentrations in soil do not exceed the groundwater and surface water PRG at any 100-K remediated waste site.
- Groundwater contaminant flow and transport modeling indicates that the groundwater pump-and-treat systems provide protection to the Columbia River along the shoreline in almost all areas.
- Mercury and arsenic soil concentrations at four previously-remediated waste sites near the cooling water head houses exceed PRG values. Uncertainties associated with these measurements, however, suggest the need for additional evaluation to support remedial action design.
- The Cr(VI) plume is captured by the existing extraction system except in small areas near the shoreline where recovery wells are absent or relatively sparsely placed. Cr(VI) concentrations and plume footprints in groundwater will decline over time.
- Tritium, Sr-90, and carbon-14 concentrations in 100-K groundwater above the MCLs are within the capture zone of the recovery wells. Concentrations and plume footprint areas in groundwater will decline over time, although the rate of decline is not uniform across the area.
- Nitrate at concentrations above the MCL in the area between the two reactors is not captured by the recovery wells and eventually discharges to the Columbia River. Concentrations will decline slowly over time.

Understanding contaminant fate and transport in the environment is an important part of the RI/FS process. Projections of future contaminant behavior and concentrations at points of exposure are needed to assess potential threats to human health and the environment (HHE). These simulations are especially important for sites where contaminants are long-lived or where groundwater contaminant plumes may migrate beyond the area covered by a monitoring well network. Contaminant fate and transport was simulated using a one-dimensional

computer model for the vadose zone and a three-dimensional computer model for groundwater contaminants.

This chapter describes key processes affecting the fate and transport of 100-K COPCs in environmental media, and the effect these processes have on the distribution of COPCs in the future. The information presented in this chapter was used to calculate SSLs and PRGs that are protective of groundwater and surface water under the modeling scenarios presented. Remediated waste site constituent concentrations are compared to the screening levels to identify waste sites requiring consideration in the FS for groundwater or surface water protection. The results from groundwater flow and transport models developed to simulate existing COPC fate and transport in groundwater for the 2012 through 2087 period are also presented.

5.1 Overview of the Fate and Transport Elements of the 100-K Conceptual Site Model

Contaminated wastes released from reactor support facilities, cooling water processing facilities, underground piping, liquid waste disposal sites, solid waste disposal sites, and surface spills were primary sources of contamination in 100-K during operations and secondary sources may have developed in vadose zone and aquifer materials. The potential for transport of contaminants within the vadose zone and the underlying shallow unconfined aquifer at 100-K is affected by the impact of historical high volume liquid waste disposal during operations on vadose zone moisture and the water table, the development of secondary sources of contamination in the vadose zone material, groundwater/surface water interactions, and the effect of Columbia River stage fluctuations on contaminant transport. The fate and transport of contaminants detected in the vadose zone and groundwater above applicable criteria will be discussed.

An element essential to understanding contaminant fate and transport in 100-K is the difference between site conditions during Hanford reactor operations at 100-K (1955 to 1971) and current site conditions, which have developed since reactor operations ended. The effects of conditions during operations are summarized as follows:

- During operations, large volumes of reactor cooling water containing water treatment chemicals (e.g., Cr(VI), sulfate, aluminum) and radionuclides (activation and fission products) were temporarily stored in retention basins prior to discharge to the Columbia River. The retention basins began leaking water to the 116-K-2 Trench, which was established to receive cooling water during fuel failure episodes, when the cooling water was contaminated with fuel and fission products (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]).

- The water table beneath 116-K-2 Trench was elevated during operations to as much as 10 m (33 ft) above pre-operations levels. The resulting groundwater mound created an increased hydraulic gradient as the water flowed out from the source area at the trench and, therefore, increased transport of contaminants toward the Columbia River as well as inland. The observed groundwater mound near 116-K-2 Trench was a result of the substantial cooling water discharge to the trench during reactor operations (e.g., 10,000 to 20,000 gal/min) and the local vadose/aquifer stratigraphy. The water discharged to the trench would have flowed downward through the near surface Hanford formation deposits until it encountered the contact with the underlying Ringold Formation, which exhibits a lower hydraulic conductivity than the Hanford formation. It then began to build vertically and spread laterally. The mound extended inland greater than 3 km (1.9 mi) from the Columbia River and greater than 2 km (1.2 mi) from the head of the trench in the upriver direction. The mound extended in the downriver direction to 100-N.

- Additional releases of contaminants occurred at other operating areas; burial grounds received wastes containing mobile contaminants that may have leached to groundwater. Reactor cooling gas condensate cribs received condensed gases containing carbon-14 and other nuclides. Cooling water treatment plants released concentrated sodium dichromate solutions at various times via planned and unplanned releases. Leakage from spent FSBs released radioactive and nonradioactive contaminants to the vadose zone where some migrated to underlying groundwater. Bulk petroleum storage tanks for 100-K steam boilers and backup generators may have leaked, releasing petroleum to the vadose zone.

- Contaminants were transported to various depths in the vadose zone or into the unconfined aquifer at some waste sites, according to their relative mobility and discharge volume. Highly mobile constituents such as Cr(VI), carbon-14, and tritium migrated at essentially the same velocity as the water, while less mobile constituents, such as Sr-90, migrated more slowly.

- Cr(VI), carbon-14, tritium, and other highly mobile contaminants were transported in the saturated zone and discharged with groundwater to the Columbia River. Groundwater discharges to the river occurred in the zone of interaction between groundwater and the river at the riverbank and through the unconsolidated sediments underlying the river. During historical periods of groundwater mounding beneath 100-K, groundwater also entered the river via overland flow from seeps as well as springs along the riverbank (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]).

The groundwater mound began developing shortly after discharge to the 116-K-2 Trench began and expanded until the late 1960s. The mounding of water beneath the 116-K-1 Crib and 116-K-2 Trench produced an increased groundwater gradient and resulting increase in groundwater flow velocity between the trench and the Columbia River. The groundwater velocity was measured at 3 m (10 ft) per day in 1962. The mound produced persistent thermal seeps and springs along the riverbank (Figure 5-1) during the operational period of the 100-K Reactors. After discharges to the trench ceased in 1971, the groundwater mound began to contract, and by approximately 1975, the groundwater mound had substantially dissipated and the groundwater flow regime had largely returned to its natural flow patterns near 100-K. In addition, as a result of vegetation removal and surface disturbance, the amount of natural precipitation infiltrating the ground increased.

The post-operational conditions at a typical waste site had the following characteristics:

- Most of the high volume liquid effluent releases ended when reactor operations ceased in 1971.

- Some uncertainty in definition of recent groundwater contaminant plume configuration may exist due to the effects of the following types of activities:

  - Operation of pump-and-treat systems with rotating injection well locations

  - Temporary inaccessibility of monitoring wells due to demolition activities

  - Transient effects of artificial recharge (e.g., use of dust-suppression water during demolition, accumulation of natural precipitation in open excavations

- The use of 100-K FSBs to support 100-N and PUREX operations from 1975 until 2007 resulted in additional long-lived fission product contamination of the soil and groundwater beneath the FSBs due to spent fuel contamination of the FSB water and leaks to the soil (Chapter 1).

Figure 5-1. Seeps and Thermal Springs at KE Retention Basins

- The 183-KE Water Treatment Plant and numerous associated facilities have continued to operate and discharge to the river until the present, maintaining water levels in the FSBs and providing project water needs during waste site remediation and facility D4 activities. The volume and disposition of chemicals used in the continued operation of the plant is expected to have been similar to previous operations, with the exception of the greatly reduced volume of treated water generated after termination of 100-K Reactor operations in 1971. Several campaigns of using the sedimentation basins for fish-rearing operations may have contributed to unquantified releases of water from the basins to the vadose zone. These water releases may have mobilized some contaminants within the vadose zone; however, the magnitude of this possible impact remains uncertain.

- Secondary sources of contamination may remain at both unremediated and remediated waste sites due to sorption of contaminants to vadose zone material. The concentrations of residual contaminants at remediated sites were evaluated in their respective CVP reports and reported to be below the applicable cleanup criteria. The waste site analyte exposure point concentrations (EPCs) are evaluated in this RI/FS as a result of changes in modeling methods and assumptions since the production of the CVP reports.

- If bare soil were replaced with some vegetated or artificial land cover (e.g., native vegetation), reductions in net infiltration and recharge would slow the migration of contaminants through the vadose zone to the aquifer.

- Variations in soil particle size distribution in the vadose zone can affect the rate of movement of water and associated contaminants. The finer-grained soil (e.g., silty or clayey soil) retains more water and exhibits lower hydraulic conductivity than the coarser-grained, gravel-dominated intervals under arid climate conditions. Areas of the vadose zone where fine-grained and coarse-grained strata contact each other along generally horizontal planes can cause interruptions in the vertical flow of soil water through the vadose zone. Soil water can be retained in either coarse soil overlying fine-textured soil or in fine-textured soil overlying coarse soil.

- Residual chromium is present in the vadose zone in several forms, and not all forms are mobile. Cr(VI) may sorb to mineral surfaces, precipitate in mineral phases with varying stability, and be reduced to trivalent chromium (Cr(III)) and form low-mobility, pure Cr(III) phases or ferric oxide/Cr(III) solid solutions (*Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site, Part 2* [PNNL-17865]). In localized areas (e.g., vadose soil beneath areas where concentrated sodium dichromate dihydrate solutions were released), chromium may still be found as soluble chromate or dichromate salts.

- A portion of the vadose zone is periodically rewetted with seasonal and daily changes in the water level of the Columbia River. Although the RI/FS samples collected in this periodically rewetted zone did not indicate the presence of a secondary source significantly contributing to the persistence of Cr(VI) in the unconfined aquifer, the potential for secondary sources within the vadose zone cannot be excluded.

- The concentrations of Cr(VI) in groundwater beneath 100-K are variably distributed vertically across the shallow unconfined aquifer. Graphical depiction of the Cr(VI) concentrations observed during drilling the RI wells is presented in Chapter 4 of this report. A conservative assumption is to describe the distribution as full thickness over the thickness of the shallow unconfined aquifer. The available measurements and observations are consistent with the assumption of full-thickness contamination. Groundwater flow and contaminant transport in the unconfined aquifer are also affected by Columbia River stage fluctuations. The increase in the river stage during the spring freshet pushes water inland and causes water table elevation increases throughout 100-K. Consequently, the hydraulic gradient is altered and less water flows into the river from the aquifer. During the low river stage in the fall, groundwater flow toward the river dominates. Depending on the location within 100-K, direction variability in flow occurs because of these competing influences.

The volume and location of groundwater discharges to the Columbia River were also affected by the proximity of the facilities to the river. These effects are summarized as follows:

- Thermal seeps along the Columbia River were observed during reactor operations (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]). These seeps were associated with leaking retention basin tanks and liquid waste disposal (Figure 5-1). The thermal seeps are no longer present since the discharge of hot water was discontinued with reactor operations and the water table elevations have diminished to pre-operational levels. Groundwater elevation currently exhibits natural seasonal variation with local transients related to operation of pump-and-treat systems. These historical seeps, along with overland flow, may have contributed to existing contamination within the riparian zone.

- Under current conditions, upwelling subaqueous groundwater discharges were identified through surface water and pore water sampling conducted during the Columbia River Component RI (*Field Summary Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford*

Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling [WCH-380]).

- Natural seeps are observed along the shoreline, in the riparian zone, associated with the early summer drop of the Columbia River water levels. These seasonal seeps continue to contribute migrating contamination to the riparian zone.

In summary, the largest discharges of Cr(VI) and other highly mobile contaminants to the Columbia River occurred during active reactor operations and then rapidly diminished when reactor operations at 100-K ceased. The configuration of the contaminant plumes was established during that time. Ongoing contaminant releases from secondary sources in the vadose zone to the unconfined aquifer are limited due to reduced net infiltration rates since operations ceased. The fate and transport of Cr(VI) and other contaminants in 100-K is complex and affected by many different factors that will be discussed in this chapter.

5.2 Contamination Sources

Historical releases of various liquid and solid wastes produced contamination of the vadose zone and underlying groundwater. Contaminated groundwater migrated downgradient toward the Columbia River and discharged into the river through surface springs and direct interaction of groundwater with surface water of the river in the hyporheic zone.

No releases of primary contamination sources are still occurring and evaluation of soil data collected from previously remediated soil waste sites indicates that none of those sites presents a continuing secondary source of groundwater contamination.

5.2.1 Primary Sources

The identified sources of contamination at 100-K fall into two types: primary sources and secondary sources. Primary sources are the process chemicals, working solutions, and radioactive and nonradioactive wastes that were released into the environment during the period of operations at 100-K. Secondary sources consist of environmental media (e.g., soil, surface water, and groundwater) that were impacted by the initial releases of primary sources and subsequently retain sufficient levels of mobile contamination that they can act as continuing sources of contamination entering adjacent soil, surface water, groundwater, or air. The release of primary sources of contamination at 100-K has ceased and future remedial actions will focus on control of contamination associated with secondary sources that may result in either direct contact exposure to identified receptors, or be released and transported to groundwater or surface water, where potential exposures may occur.

The primary sources consisted of low volume highly concentrated sodium dichromate, widely variable volumes of liquid effluent, and solid waste. In Chapter 4, the 100-K waste sites are grouped into waste source types according to the common characteristics of physical state of the waste, quantity, and duration of disposal, and type of facility that generated the waste. The primary sources included both intentional and unplanned releases. Specific sources of contaminants include the following:

- **Episodic disposal of solid waste materials, including construction materials and debris, repair and maintenance wastes, and radiologically contaminated tools, materials, and reactor components placed in burial grounds.** It should be noted that reactor operations at 100-KE and 100-KW, unlike the other single-pass reactors at Hanford, did not rely on coal-fired steam plants to provide steam for process and building head; instead, required steam at 100-K was provided by a fuel-oil fired steam package plant that also provided back-up electrical generation for reactor operations.

- **Episodic planned disposal and unplanned releases of liquid waste materials, including radiologically contaminated decontamination solutions associated with reactor repair and maintenance activities, off-spec or surplus water treatment chemicals, reactor cooling gas condensate, fuel storage basin leakage, and ion exchange regeneration solutions.** This category of primary source material includes spills, leaks, and washdown of high-concentration sodium dichromate dihydrate stock solution, and moderate-concentration sodium dichromate dihydrate working solution. The historical release of concentrated sodium dichromate dihydrate solution appears to account for persistent groundwater plumes near 100-KE and 100-KW Reactor water treatment facilities. Reactor cooling gas condensate releases at cribs adjacent to the reactors appear to account for persistent plumes of nitrate (from oxidation of ammonia accumulated in the gas condensate), tritium, and C-14 immediately downgradient of the reactors. Unplanned release of fuel oil and other petroleum, oil, or lubricant products near the fuel oil storage tanks and boiler/generator facility likely accounts for the petroleum hydrocarbons and PAH compounds found in the vadose zone near those facilities.

- **Nearly continuous planned disposal and unplanned releases of large volumes of reactor cooling water.** Reactor cooling water was treated for corrosion control by adding sodium dichromate working solution to the water to achieve an operating sodium dichromate dihydrate concentration of 2,000 µg/L. Cooling water was also routinely contaminated with short-lived activation products and, following a reactor fuel failure event, with the entire suite of uranium and mixed fission and activation products present in the irradiated fuel. Releases of cooling water are responsible for most of the soil and groundwater contamination observed near the cooling water retention basins, the 116-K-1 Crib, and the 116-K-2 Trench. Releases of cooling water to the ground resulted in a widespread, persistent groundwater mound centered beneath the crib and head end of the trench.

5.2.2 Secondary Sources

The releases of primary contaminant source materials to the environment resulted in contaminated vadose zone material beneath facilities and waste sites. Some of this resulting contamination may be mobile and subject to leaching to groundwater, transport by surface run-on or runoff, or transport by wind as particulates or vapors. If left unremediated, this contaminated material acts as a secondary source for the further spread of contaminants through the environment and potential exposure to human and ecological receptors. The main secondary source of concern in 100-K is vadose zone soil contaminated with Cr(VI) that may be present in unremediated waste sites and residues in the vadose zone soil, periodically rewetted zone, the unconfined aquifer, and possibly in low conductivity zones of the unconfined aquifer or within the RUM.

The evaluation of risks posed by the identified secondary sources to human health and the environment through direct exposure are discussed in Chapters 6 and 7, respectively. The potential for secondary sources to provide a significant ongoing source of contamination to groundwater is evaluated through the comparison of contaminant EPCs in vadose zone material to the soil screening levels (Section 5.1) and PRGs (Section 5.6) for groundwater and surface water protection. The persistence of Cr(VI) groundwater plumes within 100-K suggests the possible presence of secondary sources of groundwater contamination, particularly near the cooling water treatment head houses, the cooling gas condensate cribs, and the fuel storage basins. The persistent Cr(VI) plume associated with the 116-K-2 Trench appears to result from migration of residual contamination within the aquifer associated with the previously extensive contaminated groundwater mound at that site.

Based on the historical and current presence of specific groundwater plumes in 100-K, the following general locations are potential historical secondary sources of groundwater contamination:

- Chromium contaminated vadose zone soil underlying the sodium dichromate dihydrate solution transfer facilities associated with the water treatment head houses at 100-KE and 100-KW.
- Vadose zone soil underlying the 116-KE-1 and 116-KW-1 condensate cribs, contaminated with tritium, C-14, Sr-90, and nitrate.
- Vadose zone soil underlying the fuel storage basins and the basin leak disposal cribs/injection wells, contaminated with Cr(VI) and mixed fission products (e.g., Sr-90, tritium, Cs-137).
- Vadose zone soil underlying vicinity of the head end (west end) of the 116-K-2 Trench and contaminated with nitrate, nitrite, tritium, and Cr(VI).
- Groundwater beneath the footprint of the former groundwater mound associated with the 116-K-2 Trench contaminated with elevated concentrations of Cr(VI).

Some of these locations have already been remediated (e.g., vadose soil at 116-K-2 Trench) and are no longer considered to be contributing to groundwater contamination. Other locations may be remediated and will not be considered as potential contributors to groundwater contamination following remediation.

5.3 Release Mechanisms

Primary release mechanisms are the processes during operations that resulted in the initial distribution of contaminants to the environment. Secondary release mechanisms are the processes that result in the redistribution of secondary source contaminants to other environmental media.

5.3.1 Primary Liquid Waste Release Mechanisms

The primary release mechanisms of liquid wastes at 100-K fall into two general categories: intentional or planned releases and unplanned releases. Planned releases fall into two broad groups: high-volume, low-concentration liquids (e.g., reactor cooling water) that were released directly to the Columbia River, and lower volume liquids with higher contaminant concentrations (e.g., contaminated reactor cooling water during upset conditions, reactor cooling gas condensate, captured fuel storage basin leakage) that were released directly to the land surface and allowed to infiltrate, or were discharged to engineered subsurface waste infiltration structures (e.g., cribs and covered trenches). The most dramatic effects of planned liquid releases occurred at the 116-K-2 Trench, where continued releases of cooling water to the trench produced a groundwater mound in the underlying unconfined aquifer that extended to nearly the ground surface vertically and lateral for a distance of approximately 3 km to the south and 2 km to the west and east of the head end of the trench. This extensive groundwater mound consisted primarily of reactor cooling water, which is expected to have displaced much of the water within the unconfined aquifer in that area. The cooling water contained about 2 mg/L of sodium dichromate dihydrate (about 0.7 mg/L Cr(VI)) and radioactive fission and activation products associated with normal reactor operations and fuel failure upsets. Accumulated sludge from the cooling water treatment sedimentation basins was also released into the reactor cooling water stream.

Other planned releases at 100-K that appear to have made substantial impacts on vadose soil and groundwater include releases to the 116-KE-1 and 116-KW-1 Cribs that received reactor cooling gas condensate containing tritium, C-14, and ammonia.

Other intentional releases of primary liquid contaminants include the fuel basin sub-drainage reverse Wells 116-KW-2 and 116-KE-3.These reverse wells were configured to discharge accumulated drainage at a depth below the water table surface in the shallow unconfined aquifer. The FSB reverse wells were configured to include a shallow leach field structure below ground surface at each wellhead; the leach

field was intended to provide back-up drainage for this contaminated liquid stream. The drain system was later modified to allow diversion of the stream to the process sewer, when appropriate. In 1977, discharges to ground of this waste stream were stopped when the stream was diverted to a collection tank, or back into the basin(s). This waste stream contained mixed fission products, activation products, and fuel residues in the event that failed fuel contaminated the basins.

French drains were located at each cooling water head house and unquantified spills and leaks of concentrated water treatment chemicals are expected to have been historically washed to those dry wells during spill response and housekeeping activities. These discharges would have included concentrated sodium dichromate solution, sodium hydroxide solution, sulfuric acid solution, alum solution, and other materials handled in that area.

5.3.2 Primary Dry Waste Release Mechanisms

Contaminants associated with dry solid waste were released to the environment through intentional disposal at waste sites or through unplanned spills of particulate material. The contaminants may transfer to the environment through leaching or dissolution. Dry granular or crystalline chemical products or contaminated soil particulates may also become windborne, suspended in surface run-off, or transferred to the surface through physical contact with a contaminated surface. Intentional/planned releases of solid waste are expected to account for the large majority of historical dry waste releases to the environment.

5.3.3 Secondary Release Mechanisms

Contaminated material in the vadose zone or aquifer is considered an ongoing secondary source of some contaminants. Secondary sources remaining in pipelines and control structures in the form of pipe scaling, corrosion products, sludge, and sediment may be released through structural failure of the pipeline and exposure to net infiltration. The secondary release mechanisms for contaminants include the following:

- Volatilization to the atmosphere or soil gas (applicable to volatile organic contaminants and tritium)
- Resuspension of particulates in air (applicable to all contaminants located at the soil surface)
- Transport in surface water run-off, both as dissolved constituents and suspended particles (applicable to all contaminants)
- Dissolution, desorption, and transport with infiltrating precipitation (applicable to soluble contaminants)
- Biotic uptake (applicable to soluble contaminants)

5.4 Potential Routes of Migration

Contaminants released during 100-K Reactor operations or currently present as potential secondary sources have the ability to migrate through the air, vadose zone, groundwater, and surface water. Each of these migration routes is discussed in this subsection.

Air. Contaminants can potentially migrate to the air as vapors or solid particles. The meteorological conditions summarized here are presented in more detail in Chapter 3. In the 100 Area and along the Columbia River, local winds are strongly influenced by near-river topography and, at 100-K, the prevailing wind direction is from the west (NEPA Characterization Report [PNNL-6415]). During operations, contaminants may have been released with stack emissions. No specific stack release events are identified for 100-K Reactors and such events, if they occurred, would have been expected to be broadly distributed over the entire 100-K area. Under current conditions, strong winds can disperse contamination while waste

sites are exposed during excavation or demolition. A variety of methods is employed to minimize this hazard, including applying dust-suppression water and soluble adhesives to the surface as part of remedial activities. Air monitoring programs conducted during remediation activities are summarized in Chapter 4.

Vadose Zone. The stratigraphic units relevant to contaminant transport are the Hanford formation and Ringold Formation unit E (Figure 3-5). The characteristics for these three geologic units are detailed in Chapter 3 and summarized as follows:

- The Hanford formation consists of gravel with sandy interbeds. Cobble-size clasts are common and boulders may be present.
- Ringold unit E is made up of fluvial gravel with minor amounts of silt and sand. Ringold unit E gravels generally are consolidated and cementation may be locally well developed. The water table at 100-K is primarily located within Ringold unit E.

Transient saturated conditions were present during reactor operations in the material beneath high-volume liquid effluent waste sites (e.g., 116-K-1 Crib and 116-K-2 Trench). Pressure head and vertical saturated hydraulic conductivity would have been the dominant factors controlling the downward movement of water and contaminants during operational site conditions. The local saturation of the vadose zone due to creation of recharge mounds resulted in modification of local groundwater gradients, with water flowing radially away from the recharge mounds in all directions. Groundwater flow rates on the order of 3 m (10 ft) per day were observed in a 1962 evaluation of the groundwater mound beneath 116-K-2 Trench as shown in Figure 5-12 (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]). The vertical saturated hydraulic conductivity of the Hanford formation in 100-K vadose zone has a maximum measured value of 3.60E-02 and a minimum measured value of 3.40E-04 cm/sec (*STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* [ECF-HANFORD-11-0063], Appendix F). The measured vertical saturated hydraulic conductivity of the Ringold Formation in the 100-K vadose zone is 4.13E-04 cm/sec (*STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* [ECF-HANFORD-11-0063], Appendix F).

The matric potential of the vadose zone material controls the migration rate of contaminants, which is expected to be much slower in the future than during Hanford operations due to much lower recharge rates and moisture content. Gravel-dominated layers with low matric potential act as capillary impedance barriers to the downward movement of infiltrating water in the vadose zone because gravity is not sufficient to overcome the capillary forces that retain water in the finer-grained layers under the arid climate conditions at the Hanford Site. Under these conditions, movement of contaminant bearing fluids would require recharge rates above ambient post-operational levels.

Groundwater. Groundwater at 100-K is found primarily within the Ringold unit E and within water-bearing sand layers within the RUM. In some locations, the water table is encountered in the Hanford formation. The RUM unit, which is an aquitard, consists of silt and clay-rich overbank paleosol deposits, with infrequent layers of sand and gravel of varying thickness, some of which are water bearing. These water-bearing zones within the RUM exhibit varying piezometric head indicating that in some locations, they are locally confined or semiconfined. Historical water table mounding caused by discharge of reactor cooling water to the vadose zone resulted in groundwater movement through the Hanford formation over large areas. This condition allowed for contaminants associated with the cooling water to move largely unabated through the formation and spread to substantial distances from the point of release. This movement of contaminated (containing Cr(VI) and other contaminants) groundwater through the Hanford formation proceeded along the contact with the underlying Ringold Formation and produced

persistent hot water seeps near the river, as well as placement of contaminated groundwater as much as 3 km (1.9 mi) or more inland from the river.

The groundwater flow system beneath the Hanford Site remains a primary pathway for contaminants to migrate away from source areas and, for some contaminants, to discharge into the river. Characterization of hydrogeology at the 100 Area requires understanding of the properties and behavior of the vadose zone, groundwater, and surface water sources, interfaces, and interactions. Both natural and anthropogenic hydrologic processes have influenced groundwater flow patterns and contaminant distribution in the subsurface underlying 100-K. The effects of natural processes on contaminant migration are ongoing, while the effects of anthropogenic operations (e.g., the high-volume liquid discharges into the 116-K-2 Trench) have diminished over time with the cessation of reactor operations. However, some residual effects have not completely dissipated and other processes continue to influence contaminant migration, particularly ongoing pump-and-treat operations.

Generally, the groundwater flows southeast to northwest and perpendicular to the Columbia River. To the northeast, beyond the 116-K-2 Trench, flow transitions to a more northeasterly direction parallel to the Columbia River (100-K Work Plan [DOE/RL-2008-46-ADD2]). In addition, the groundwater flow is highly influenced by river stage. Groundwater flow toward the river dominates at low river stage and the surface water dominates the nearshore aquifer flow during periods of high river stage, as described in Chapter 3. River stage can also fluctuate several meters over short periods (i.e., hours to days) based on Columbia River dam operations (*Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action* [DOE/RL-96-84]). Changing river stage influences groundwater elevations several hundred meters inland from the river. The groundwater level response to changes in river stage is delayed and less pronounced than farther inland.

Surface Water. The Columbia River is the only surface water feature at 100-K, except for the overland flow of seep discharge water near 100-KE Sedimentation Basin, 100-KE and 100-KW clearwells up to 2011, and FSBs up to 2010. The routes of migration to the river include groundwater discharges upwelling to the riverbed, previous discharges to the river during operations, and overland flow of water discharged from seeps. Previous groundwater discharges to the Columbia River were observed as seeps on the riverbank that may have transported highly mobile contaminants (*Status of the Ground Water Beneath Hanford Reactor Areas April 1, 1962 through January, 1963* [HW-77170]). The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse population of plankton, benthic, and lotic invertebrates, fish, and other ecological communities.

Biotic Uptake. Plants may absorb contaminants through their roots. Wild game, such as deer and elk, may also uptake contaminants from surface deposits, which could accumulate in their tissues. This migration pathway is discussed further in Chapters 6 and 7. Impacts from biotic uptake of site contaminants is of particular concern in the riparian zone where contamination may be found at the ground surface, within plants growing in contaminated soil, and contaminated groundwater may discharge seasonally to the ground surface and flow overland to the river.

5.5 Contaminant Persistence

The persistence of various contaminants determines how long they are available to the environment and for transport to the different receptors. If a contaminant remains in the environment for a long time, and is highly mobile, it is more likely to be transported from the vadose zone to the groundwater, and eventually to the surface water. Persistence is defined by how long it takes a particular contaminant to be transformed into a less toxic or less available form, or how long it takes the contaminant to physically leave the affected area. Radionuclides undergo radioactive decay at varying rates specific to the

individual nuclides. Nonradioactive chemicals may also degrade, decay, or undergo chemical transformation that reduces the residual mass of the contaminant available for transport or direct exposure. The following paragraphs discuss the persistence of the selected COPCs.

Persistence of Chemical Constituents. The persistence and, alternatively, the decay of chemical constituents at 100-K is primarily driven by biological and geochemical reductive/oxidative processes, potential biological uptake, and physical processes (e.g., volatilization, water solubility). The chemical constituents identified for this assessment include metals (chromium, measured as Cr(VI), which is generally present as a dissolved oxyanion or as a metallic salt, and as total chromium, which includes Cr(VI) and chromium in other valence states); nonmetallic oxyanions (nitrate); and VOCs (trichloroethene in groundwater). These constituents are subject to a variety of transformational processes.

Cr(VI) is both relatively stable and persistent in the vadose and groundwater environment at 100-K. Chromium is typically present in the environment in one of two oxidation states (trivalent or hexavalent). Trivalent chromium is typically precipitated as a low-solubility hydroxide molecule, $Cr(OH)_3$, and, as such, is not mobile and exhibits low mammalian toxicity. Cr(VI), however, is acutely toxic and is typically present under ambient conditions at 100-K as a soluble oxyanion, $Cr_2O_7^{-2}$ or CrO_4^{-2}, depending primarily on pH (the dichromate oxyanion is dominant in acidic conditions, the chromate oxyanion is dominant in alkaline conditions). The ionic forms of Cr(VI) are relatively stable at the oxidation state typically found in soil and groundwater at 100-K and the constituent tends to remain mobile. The source of the Cr(VI) in the environment was the sodium dichromate dihydrate used for corrosion control in reactor cooling water. This compound is acidic in its concentrated form. However, the dichromate, or chromate, ion can react with other metals in the environment to form compounds of lesser solubility. These compounds can include potassium dichromate (which is about one tenth as soluble as sodium dichromate dihydrate) and lead chromate (which is essentially water insoluble). The Cr(VI) ions can also be subject to chemical reduction under moderately reducing conditions, or on reaction with reducing agents such as ferrous iron. Ferrous iron is very effective at reducing Cr(VI) to trivalent chromium, producing a very low solubility hydroxide molecule.

Trichloroethene is found at relatively low concentrations in groundwater underlying 100-K, and is expected to degrade very slowly, if at all, under the typical dissolved oxygen concentrations (i.e., moderately aerobic) in groundwater at 100-K, but can be reductively dechlorinated by facultative[1] and obligate[2] anaerobic microorganisms under anoxic conditions. Additionally, trichloroethene may volatilize from the land surface or surface water directly to the atmosphere. Trichloroethene dissolved in soil moisture or groundwater can partition to soil gas and then migrate to the atmosphere; however, gas exchange from the deep vadose (e.g., below a few meters bgs) or from groundwater accounts for only a tiny potential loss. Once in the atmosphere, this compound can be destroyed through photodegradation (sunlight). The potential for volatilization or biologically mediated degradation is dependent upon the specific physical and chemical characteristics of a constituent and the size and nature of the microbial populations. The chlorinated VOCs present at 100-K are expected to be persistent in soil and groundwater.

Persistence of Radiological Constituents. Radiological constituent persistence is primarily controlled by radioactive decay processes that can transform the parent isotope into another isotope of the same element or into another element. The daughter product of decay may be a radionuclide or a stable isotope. Radionuclides with relatively high mobility and longer half-lives ($T_{1/2}$) are of more environmental concern than radionuclides with lower mobility and shorter $T_{1/2}$. This is primarily due to the potential for constituents with higher mobility and longer half-lives to reach the saturated zone at higher activities and greater potential to migrate though

[1] In other words, can survive in both aerobic and anaerobic conditions.

[2] In other words, can survive only in anaerobic conditions.

groundwater. Chapter 6 identifies three radionuclides as groundwater COPCs (carbon-14, tritium, and Sr-90). The following text discusses the radionuclides, their half-lives, and daughter products (*Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* [PNNL-11800]):

- Carbon-14 is both an activation and fission product, although activation is the more important source, with a $T_{1/2}$ of 5,730 years, and the beta decay daughter product of carbon-14 is the stable nitrogen-14 isotope.
- Tritium is primarily an activation (10,000 times greater source than fission) product with a $T_{1/2}$ of 12.3 years. The beta decay daughter product of tritium is the stable helium-3 isotope.
- Sr-90 is a fission product with a $T_{1/2}$ of 28.8 years. The beta decay daughter product of Sr-90 is yttrium-90 ($T_{1/2}$ = 64.1 hours), which then beta decays to the stable zirconium-90 isotope.

The persistence in groundwater of these nuclides is also affected by their individual unique chemical and physical behaviors. Carbon-14 can commonly become combined with other elements and ions to form other carbon-containing compounds. The original form released to the reactory cooling gas condensate cribs at 100-K Reactors was most likely carbon-14 dioxide gas; it likely remains as carbon-14 carbonate or bicarbonate ions, or other carbon compounds. Tritium is found in the environment most commonly as tritiated water; tritium typically replaces one of the hydrogen ions in a water molecule. In the environment, tritium behaves as water (because it is most commonly a part of a water molecule). Sr-90 commonly remains as an exchangeable divalent cation in the environment. As such, it is not readily mobile and tends to be retained on soil particles near its point of release.

5.6 Contaminant Migration Assessment

Concepts affecting contaminant transport in the vadose zone are presented, followed by factors affecting contaminant transport in the saturated zone. Quantitative applications of these parameters and boundary conditions to develop analytical and numerical models of transport through the vadose and saturated zones are presented with the discussion of each factor affecting contaminant migration. The results of the application of these models to develop groundwater and surface water protection comparison criteria and predict future conditions are also presented.

Contaminants released from the 100-K sources were transported through the vadose zone and, in some cases, reached the water table. This discussion focuses on factors affecting contaminant transport through the unsaturated and saturated zones of the unconsolidated matrix above the basalt. The most significant factors affecting subsurface contaminant migration are the type of surface cover and its effects on net infiltration or recharge rates; the physical, chemical, and hydraulic characteristics of the matrix; and the physical and chemical properties of the contaminant (Section 5.6.1).

Once contaminants reached groundwater, mobile contaminants traveled with the groundwater in the direction of groundwater flow. Contaminated groundwater could migrate downgradient to discharge directly into the adjacent Columbia River, or may be seasonally discharged in springs or seeps to flow overland across the riparian zone to discharge into the river. Seasonal seep discharges may be an ongoing source of recontamination of the ground surface in the riparian zone.

The assessment of vadose zone contaminant migration is focused on evaluation of waste sites at which planned soil remediation is complete (i.e., the "previously remediated sites"). This provides a basis for confirming the completion of the soil remediation at these sites. The process described in this report was performed using cleanup verification package data from 15 previously remediated waste sites located in 100-K. The following are identified as previously remediated waste sites as discussed in this report:

- 100-K-29
- 100-K-30
- 100-K-31
- 100-K-32
- 100-K-33
- 100-K-55:1
- 100-K-56:1
- 100-K-78
- 116-K-1
- 116-K-2
- 116-KE-4
- 116-KE-5
- 116-KW-3
- 116-KW-4
- 128-K-1

The same process will be applied in the future to the remaining waste sites that will undergo soil remediation under the existing ROD for interim actions at 100-K.

5.6.1 Factors Affecting Contaminant Migration in the Vadose Zone

Contaminant migration from 100-K waste sites through the vadose zone to the underlying aquifer is controlled by the driving forces, interactions between water and sediments, and interactions between the contaminants and the sediments specific to the OUs. Driving forces include gravity; matric potential gradients; recharge, which is the result of competition between precipitation, evaporation, transpiration, infiltration, runoff, and run-on; and artificial discharges, such as those from septic tank leach fields, lagoons, pipe and tank leaks, and irrigation. The types, thicknesses, and properties of the sediments can all affect the rate and direction of solute and water movement to the aquifer. A contaminant's concentration in the groundwater and its concentration in the downgradient Columbia River, including the peak concentration, are dependent on the solute flux from the vadose zone; aquifer thickness, properties, and flux rates; travel distance; groundwater and river water mixing; and the location sampled. Each contaminant's decay rate and propensity to sorb to vadose zone or aquifer materials can also be important controlling factors on the peak concentration, from which the PRG or the screening level is calculated.

Surface Cover, Infiltration, and Recharge. The net infiltration into the vadose zone is driven by the competition between precipitation, potential evaporation, transpiration, runoff, and run-on. In an arid climate, downward fluxes resulting from this competition are episodic and usually infrequent. A number of studies have been carried out at the Hanford Site to ascertain representative long-term averages of the episodic fluxes (i.e., recharge rates), such as those compiled in the Vadose Zone Hydrogeology Package (PNNL-14702) for the 100 Area. The 100 Area specific recharge rates in the Vadose Zone Hydrogeology Package (PNNL-14702) varied with surface soil type and so provided an estimate of the range of possible recharge rates for various land uses. The four surface soil types were the Ephrata Sandy Loam, Ephrata Stony Loam, Burbank Loamy Sand, and Rupert Sand; however, recharge rates for the Ephrata Sandy Loam and the Ephrata Stony Loam were described as being identical (Vadose Zone Hydrogeology Package [PNNL-14702]); thus, the three different surface soil types were assumed to represent recharge rate variability for modeling purposes.

The long-term natural driving force for flow and transport through the vadose zone is the downward movement of water. This movement is expressed as follows (*Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates* [PNNL-17841]):

- Infiltration refers to water usually resulting from precipitation that enters the ground. Enhanced infiltration may result where surface depressions act as terminuses for overland flow
- Deep percolation or deep drainage refers to water that has percolated or drained below the zone of evaporation and the influence of plant roots
- Recharge is water that flows to the water table, and is the primary mechanism for transporting contaminants from the vadose zone to groundwater

Direct measurement of naturally occurring recharge resulting from surface infiltration at the Hanford Site is not practical. The measurement is made indirectly due to the thickness of the vadose zone and the time scale required for water to travel from the surface to the water table. In place of direct measurements of recharge at the water table, measurements and analyses of deep drainage in the unsaturated zone are used to approximate the recharge. The terms can be equated as long as the climate, land use, and land cover remain the same. Consequently, the terms 'deep percolation' or 'deep drainage' are often used synonymously with recharge.

There is ample evidence that revegetation of the disturbed land at the Hanford Site occurs both with and without human intervention. Data collected from the Prototype Hanford Barrier in 200 East Area indicate that the sagebrush community begins to reduce net infiltration very soon after planting. The species richness of the plant community on the Prototype Hanford Barrier dropped from 35 in 1997 to 12 in 2007. The dominance of *Artemisia tridentata* (sagebrush) on the surface may continue to reduce the species richness on the surface (Figure 5-2).

Grass cover has decreased from initial levels on the barrier surface, and continued decreasing from 2004 and 2007. Cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola kali*) are nearly nonexistent on the barrier surface. The western and northern side slopes of the barrier, which were not planted with sagebrush, show less plant cover but higher species diversity than the barrier surface. This may be due to the influence of windblown material and seeds from adjacent land, or the lack of shrubs competing for resources. Insects and small mammals infest the barrier surface, which indicates that the restored barrier surface is beginning to function like a recovering ecosystem.

Even if the ground surface remains disturbed, soil development processes will eventually reestablish and deepen the soil profile (*Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates* [PNNL-17841]). Those processes introduce windblown finer-grained materials and increase the organic matter content of the soil. The 200 East Area PUREX rail grade banks serve as indicators of unassisted, naturally occurring revegetation. The photograph in Figure 5-3 shows an artificial mound created in the 200 Area along the railroad tracks near PUREX. The age of the mound is less than 65 years, and there does not appear to have been an effort made or reason to reestablish vegetation, particularly a sagebrush community. Nevertheless, sagebrush plants are visible all over the mound.

The recharge rate affects the velocity of pore water through the vadose zone. The velocity of downward flow increases with increased recharge, after the field capacity is reached. The flow velocity in the vadose zone would be expected to have been greatest beneath the ponds, French drains, trenches, and cribs during the operational periods when percolation was at its greatest. A similar increase would have occurred in the vadose zone beneath unlined ditches. The velocity of downward movement would be expected to decrease after the waste disposal ceased as the subsurface water content profile began to equilibrate to new surface conditions. After the waste disposal operations ended, alterations to the surface cover (including excavation of contaminated soil, backfilling the excavation with clean fill, revegetation, and stabilization) began to alter the net infiltration rate into the vadose zone.

Source: Figures 4.1 and 4.2, from PNNL-17176, *200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Years 2005 Through 2007*.

Figure 5-2. Prototype Hanford Barrier Cover in 2007 Dominated by Sagebrush (*Artemisia tridentata*) with Cryptogamic Crust Covering Most of the Soil Surface, 13 Years after Plant Community Establishment

Figure 5-3. 200 East PUREX Rail Grade Banks Exhibiting Unassisted Revegetation by Sagebrush (*A. Tridentata*)

The recharge input values to the subsurface transport over multiple phases (STOMP) models for the screening levels (including deep percolation from irrigation) and the base case scenario PRGs (reflecting natural land cover conditions) were based on the vadose zone data package compiled in the Vadose Zone Hydrogeology Package (PNNL-14702). These data provided the basis for stipulating recharge rates in the two sequential models used to calculate screening levels and PRGs. The first simulation, called the pre-2010 model, was used to establish the initial matric potential distribution in the vadose zone for the post-2010 model, which simulated the migration of water and contaminants to the underlying aquifer. Summarized in the following paragraphs, the recharge rates are discussed in detail in *STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* (ECF-HANFORD-11-0063, Appendix F).

Three different time series of land use or land cover were evaluated in the post-2010 simulations. Maturation of shrub-steppe from bare soil to mixed grass and shrub cover to mature shrub-steppe cover was called the base case scenario. Irrigation following a period of bare soil cover was the irrigation scenario. Recharge rates for each scenario were determined using the rates for each of the three surface soil types. Rates were assumed to change over time in step function fashion for the two scenarios.

For the pre-2010 simulations, land use and recharge rates were assumed to change from shrub-steppe (pre-operations) to bare soil (operations). Recharge rates for each type of land cover for each soil type

were applied to the top boundary from the year 0 to 1944 for the pre-operations period and from 1944 to 2010 for the operations period (Table 5-1).

Three recharge periods were specified in the post-2010 simulations to represent changes in recharge rates. Bare soil was assumed the land cover above the waste site during the first recharge period, which spanned 2010 to 2015. For the base case scenario, the second recharge period of 30 years in duration represented grasses and shrubs covering bare soil, followed by establishment of a mature shrub-steppe for the remainder of the simulation period. Thus, recharge rates decreased with time.

Table 5-1. Recharge Rates for Pre-2010 Simulations

Soil Type	Recharge Rate for Different Period (mm/yr)	
	0 to 1944	1944 to 2010
Ephrata Sandy Loam and Stony Loam	1.5	17.0
Burbank Sandy Loam	3.0	52.0
Rupert Sand	4.0	44.0

Recharge rates for the irrigation scenario were estimated using the same approach employed to assess interim remediation at 100 Area waste sites (100 Area RDR/RAWP [DOE/RL-96-17]). These site assessments used RAGs calculated from RESRAD (RESidual RADiation) simulations that assumed total recharge was a combination of irrigation and nonirrigation (base case) recharge rates. As the base case rates used in the RESRAD simulations were different from those adopted from the Vadose Zone Hydrogeology Package (PNNL-14702), the RESRAD equation for total recharge was solved to determine the rate attributable to irrigation alone. Based on that approach, the calculated nonirrigation total recharge rate was 11.6 mm (0.5 in.)/yr and the recharge attributable to irrigation alone was 68.4 mm (2.7 in.)/yr. The irrigation rate was added to the base case recharge rates to determine a recharge rate for the irrigation scenario for each soil type. The resulting recharge rates for base case and irrigation scenarios for each soil type are shown in Table 5-2.

Table 5-2. Recharge Rates for Post-2010 Simulations

Soil Type	Recharge Scenario	Recharge Rate (mm/yr)		
		Period 1	Period 2	Period 3
Ephrata Sandy Loam and Stony Loam	Base case	17.0	3.0	1.5
	Irrigation	17.0	71.4	69.9
Burbank Sandy Loam	Base case	52.0	6.0	3.0
	Irrigation	52.0	74.4	71.4
Rupert Sand	Base case	44.0	8.0	4.0
	Irrigation	44.0	76.4	72.4

Stratigraphy. The characteristics of material in the vadose zone affecting contaminant mobility are the particle size, permeability, and organic content of the lithologies present beneath the waste site. The primary mechanism for transport in the vadose zone is the flow of infiltrating water in response to gravitational and capillary forces. The pore networks (represented by grain size distributions in each vertical lithologic sequence, the hydraulic and transport properties of each lithologic unit in the sequence,

and the thickness of each lithologic unit) affect water flow and contaminant transport through the vadose zone. The unsaturated hydraulic conductivity of each lithologic unit varies with moisture content and so is a function of matric potential. The effects of the different lithologic units and variations in their individual thicknesses in 100-K on screening level and PRG values were determined by running STOMP simulations for a number of stratigraphic columns that represented the range of variations in 100-K.

The Hanford formation, Ringold unit E, and the RUM were described in Section 5.4. Borehole data were used to identify representative stratigraphic columns for 100-K (Figure 5-4). Only two lithologic units are present in the 100-K vadose zone: the gravel-dominated Hanford formation and Ringold Formation unit E. Due to its coarse texture and higher hydraulic conductivity, the Hanford formation transmits water and dissolved or suspended contaminants more rapidly than the underlying Ringold Formation. The contact between the Hanford formation and the Ringold Formation forms a textural discontinuity that can result in temporary perching of soil water atop the interface. During historical high-volume water discharges, a substantial quantity of water, carrying dissolved Cr(VI) and other contaminants, was transmitted vertically and laterally through the Hanford formation to locations considerably distant from the points of release. This was particularly notable at the 116-K-2 Trench, where a substantial groundwater mound formed in the Hanford formation deposits beneath the trench and extended for thousands of meters inland both upstream and downstream. The variability in stratigraphy observed at 100-K was recognized during design of the vadose transport simulation model used to evaluate the potential for migration of contaminants from the vadose zone to groundwater. The representative stratigraphic columns shown in Figure 5-4 illustrate how the variability was integrated into the transport simulations.

Using the June 2008 water table elevations to represent the highest water table, a conservative (smaller) thickness of the vadose zone was computed for each well and borehole. The borehole data were also used to estimate the thickness of each lithologic unit within the vadose zone and within the aquifer. The boreholes were divided into groups based on the proportion of each lithologic unit and total vadose zone thickness. A representative stratigraphic column was selected for each borehole group, resulting in five stratigraphic columns for 100-K to be used in the STOMP simulations. Each column was assumed to also contain clean backfill to represent conditions following interim remediation. Backfill was assumed to replace the uppermost 4.5 m (15 ft) of each column. Additional details regarding the development of these stratigraphic columns are presented in *STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* (ECF-HANFORD-11-0063) (Appendix F).

Matric Potential. The matric potential is a measure of the attractive forces between water and porous or fractured materials that are important during variably saturated flow conditions (*Vadose Zone Processes* [Selker et al., 1999]). Moisture content and hydraulic conductivity are functions of matric potential. These functions are typically nonlinear and must be determined for each medium. The combination of matric potential gradients and gravity constitute the most important driving forces for vadose zone flow. The soil covers discussed in the preceding section will cause variations in the moisture and matric potential, in accordance with the net infiltration allowed by each cover.

Like pressure head, matric potential can be measured in the field and in the laboratory. In situ measurements of matric potential in the shallow Hanford vadose zone have been made using tensiometers and heat dissipation sensors in lysimeters, pits, and boreholes (*Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates* [PNNL-17841]; *Hydrologic Characterizations Using Vadose Zone Monitoring Tools: Status Report* [PNNL-14115]; ; and *Soil Water Balance and Recharge Monitoring at the Hanford Site – FY09 Status Report* [PNNL-18807]).

The nonlinear relationship between water content and matric potential, frequently called the moisture retention or characteristic curve, can usually be measured in the laboratory. The much greater nonlinearity

of the hydraulic conductivity and matric potential constitutive relation, termed the relative permeability, can typically be measured only over a small range of matric potential values. The remainder of the matric potential range must be inferred because the hydraulic conductivity can decrease several orders of magnitude for a much smaller decrease in matric potential.

The van Genuchten alpha and *n* parameters used in the STOMP 1D simulations were selected to represent materials from 100-K and help define the relationship between moisture content in variably saturated media, the matric potential, and relative permeability. The inputs used in the simulations are described in detail in *STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* [ECF-HANFORD-11-0063] (Appendix F).

Sorption. Mobility of constituents can be characterized using the soil/water K_d. This parameter is dependent upon the geochemical characteristics of the constituent, the properties of the transporting water, and the nature matrix. In general, organic constituents with lower molecular weights have lower K_ds than those with higher molecular weights and this is the case with the 100-K organic contaminants. Trichloroethylene is generally more mobile than other organic compounds (e.g., Aroclors and the PAHs). The K_ds of metallic radionuclides and nonradiological metals are primarily influenced by the sign and magnitude of charge of the dominant species in a given geochemical environment (i.e., positively charged ions tend to become attached to the negatively-charged soil particles, while negatively-charged ions tend to be repelled from soil particles and remain in solution.

Several metals of environmental concern exist in vadose zone material in more than one oxidation state: trivalent and pentavalent arsenic, trivalent and Cr(VI), and monovalent and divalent mercury. The oxidation state and mineral speciation of these metals determines their relative mobility. Cr(VI), originally released as high-solubility sodium dichromate dihydrate, is relatively mobile in solution, being only weakly sorbed. Cr(VI), however, for other mineral compounds and a fraction of soil residues, may be present in soil as relatively low-solubility mineral species such as potassium dichromate or lead chromate. Alternatively, trivalent chromium is relatively immobile, being generally present as relatively insoluble precipitates, such as chromic hydroxide, $Cr(OH)_3$ (*Behavior of Metals in Soils* [EPA/540/S-92/018]).

Arsenic, Cr(VI), carbon-14, and nitrate are assumed predominantly anionic species in the oxygen containing and near neutral pH pore water and groundwater observed in the subsurface at 100-K. Anionic species typically have relatively low K_d values and are considered to exhibit high to slight mobility in the 100-K subsurface environment. Cr(VI) may exist as the chromate ions $HCrO_4^-$ (predominant at pH <6.5), or CrO_4^{2-} (predominant at pH 6.5), and as the dichromate ion $Cr_2O_7^{2-}$ (predominant at concentrations >10 mM and at pH 2-6). In low ionic strength solutions, only the hexavalent chromate anion CrO_4^{2-} is found in oxidizing and near neutral pH conditions. Carbon-14 is assumed predominately present as the bicarbonate anion.

Tritium is often used as a tracer for water molecules in column breakthrough testing and is assumed to define the zero K_d condition. It is conceivable that tritium substituted for hydrogen in a water molecule or hydroxyl species can exchange with water molecules adsorbed to solids or with hydroxyl groups on the surfaces of solid hydrous oxides (*K_d Values for Agricultural and Surface Soils for Use in Hanford Site Farm, Residential, and River Shoreline Scenarios: Technical Report for Groundwater Protection Project—Characterization of Systems Task* [PNNL-16531]).

Sr-90, lead, and mercury are assumed to exist as cationic species in the 100-K subsurface environment. Cationic species, which have higher K_d values than the anions, are typically considered moderately mobile to essentially immobile. Cations are adsorbed by clay minerals, oxides, and organic matter. Adsorption is pH dependent, increasing with increasing pH. Sr-90, lead, and mercury may become immobilized by forming precipitates with phosphate, carbonate, and hydroxide (*Behavior of Metals in Soil* [EPA/540/S-92/018]).

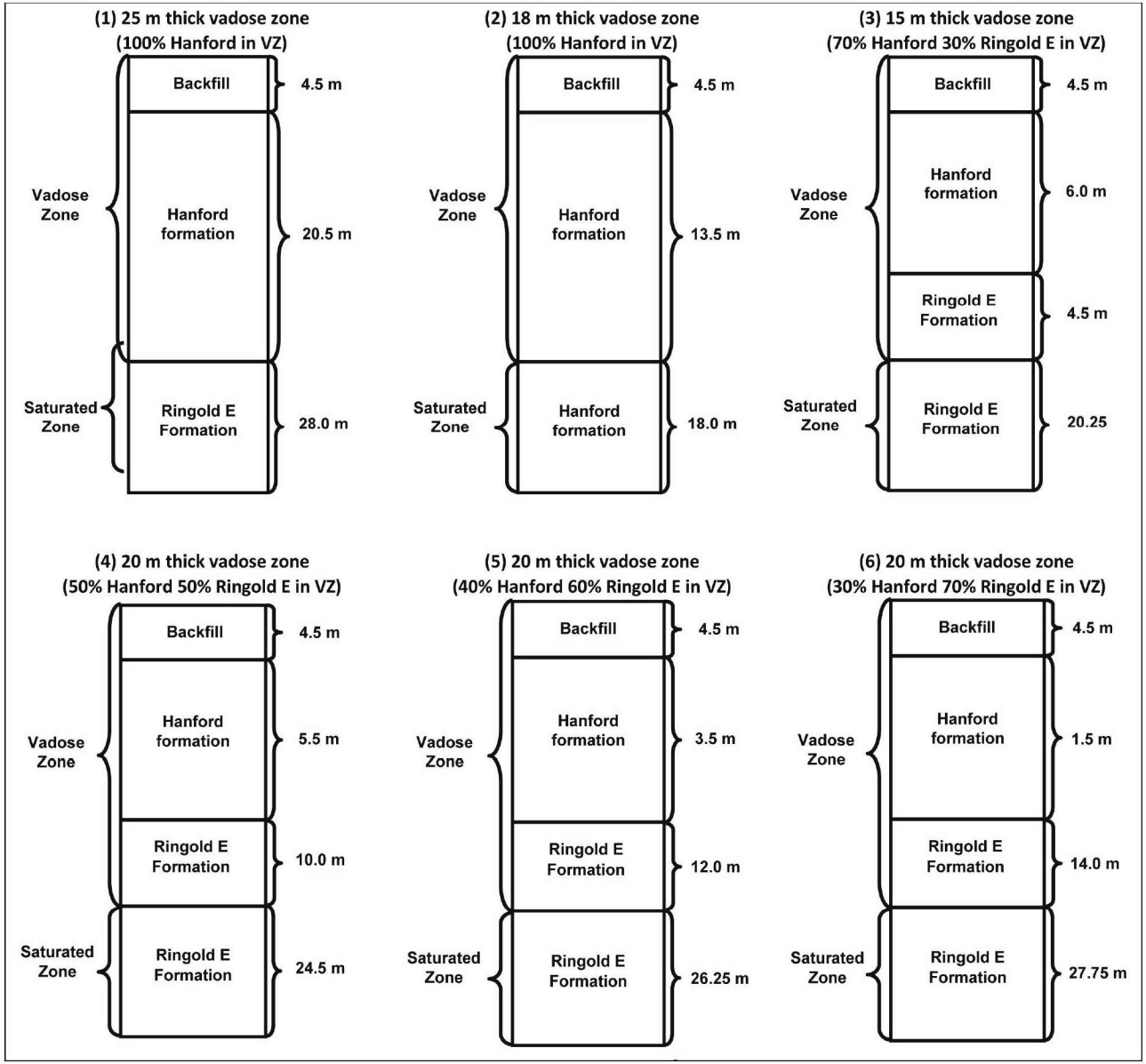


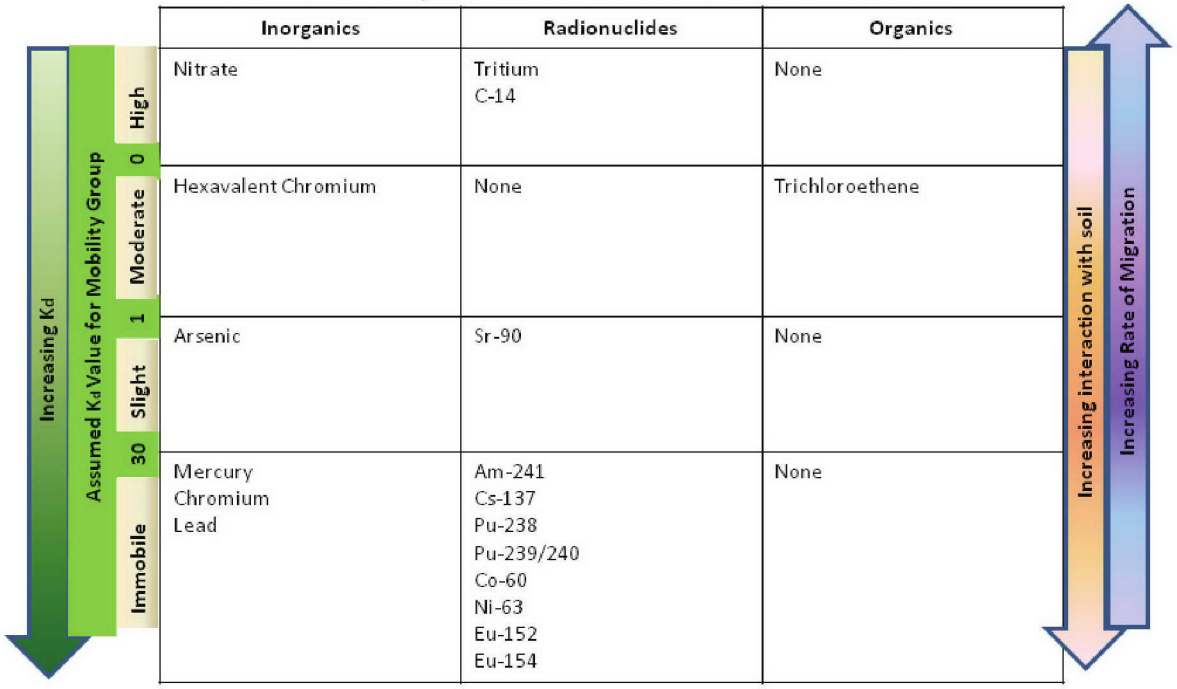
Figure 5-4. Representative Stratigraphic Columns for 100-K

Table 5-3 summarizes the mobility of these contaminants listed in Table 5-1. These contaminants are grouped by their relative mobility and the K_d values. The K_d values for the contaminants are provided in ECF-HANFORD-10-0442 (Appendix F). Analysis of batch leaching test results for soil samples collected from 100-K have led to derivation of a nonzero K_d for residual Cr(VI) as described in subsequent text.

Contaminants considered highly mobile move freely with the water in which they are dissolved, exhibiting no direct interaction with the vadose zone material or aquifer matrix that would remove contaminant mass from the groundwater as it moves through the aquifer. High mobility group contaminants are identified as those that exhibit a K_d of zero (no retardation).

Moderate mobility contaminants move readily with infiltrating water or groundwater but also exhibit a moderate degree of interaction with vadose zone or aquifer solids. Sorptive processes generally tend to slow the rate of migration of these contaminants. A reduction is observed in the concentration with depth in the vadose zone and in groundwater with downgradient migration through the aquifer system. The definition of moderately mobile is subjective; for purposes of this remedial investigation, moderate mobility contaminants are identified as those exhibiting K_d values greater than 0 but less than 1.

Table 5-3. Mobility of 100-K Contaminants of Potential Concern



Inorganics	Radionuclides	Organics
Nitrate	Tritium C-14	None
Hexavalent Chromium	None	Trichloroethene
Arsenic	Sr-90	None
Mercury Chromium Lead	Am-241 Cs-137 Pu-238 Pu-239/240 Co-60 Ni-63 Eu-152 Eu-154	None

Contaminants in the slight mobility group exhibit a high degree of interaction with vadose zone and aquifer solids and, as a result, migrate slowly through the vadose zone and aquifer. The concentration in the vadose zone decreases rapidly with increasing depth and their dissolved concentration in groundwater decreases dramatically with distance from a source or release point. The decrease in concentration is due to the relatively large fraction of the contaminant that interacts with vadose zone material and becomes sorbed to the vadose zone material and aquifer solids. The slight mobility group includes contaminants that exhibit K_d values greater than 1 but less than 30.

Contaminants considered essentially immobile sorb so strongly to vadose zone material that no migration is observed with infiltrating water under near neutral pH in the vadose zone. Liquid waste sources with highly acidic or basic pH values or those that contained complexing agents may have transported these

contaminants into the vadose zone at the time of disposal, but migration decreased as the liquid waste equilibrated with the vadose zone material. These constituents would not be expected to reach the unconfined aquifer except at waste sites with subsurface release mechanisms and a very thin vadose zone. Those that may have reached the unconfined aquifer would not be expected to migrate further through the aquifer. The essentially immobile contaminants are identified as those that exhibit K_d values greater than 30.

The K_d values used for the STOMP simulations were taken from ECF-HANFORD-10-0442. Simulations were run to produce peak groundwater concentrations for a subset of the entire range of K_ds required for all COPCs. Typically, the subset comprised 18 K_ds between 0 and 1 cm^3/g because these values almost always yielded peak groundwater concentrations within the 3,000-year simulation period for the range of vadose zone thicknesses and lithologies simulated. Peak concentrations were estimated for the remaining K_ds by scaling with retardation factor (*STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* [ECF-HANFORD-11-0063, Appendix F]).

Batch Leach Test. Batch leach tests were conducted on samples from six borings to establish K_d values to support modeling needs, as described in the 100-K SAP (*Sampling and Analysis Plan for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units Remedial Investigation/Feasibility Study* [DOE/RL-2009-40]). Contamination present in pore water within the bulk soil matrix was not analyzed or accounted for separately, as the associated contaminant mass is included within the bulk leachate concentrations. K_d calculations for each contaminant and each dilution ratio were performed using the analytical results from bulk soil analysis and leach testing of material collected from the same location.

Batch leach tests were performed on soil and aquifer sediment samples using a leach procedure based on *Standard Test Method for Shake Extraction of Solid Waste with Water* (ASTM D3987-06). The procedure was performed using a 2 mm sieve to include the entire sand fraction based on the USDA soil grain size classification scheme. Where insufficient sample mass with less than 2 mm particle diameter was available based on actual field conditions, a 3/8 in. mesh screen was used instead. Demineralized water, pH adjusted according to EPA's West Coast recommendation, was used as the leaching liquid. Selected soil samples were leached at soil to water weight ratios of 1 to 1, 1 to 2.5, and 1 to 5, with one test in each series duplicated. Soil/water mixtures were placed in clean, water-tight sample containers (extraction vessels) and rotated end over end through the vessel centerline at a rate of about 30 rotations per minute for 18 hours. Following 18 hours of mixing, the soil/water slurry was filtered using a 0.45 µm filter. The leachate was analyzed for pH and conductivity. The leachate, after the 18-hour extraction period, and untreated soil were analyzed for arsenic, barium, cadmium, total and Cr(VI), lead, selenium, and silver. Metals analysis for leachate and soil digests was performed using Method 6010, 6020, or 200.8 for ICP metals, as applicable (bulk soil was digested using Method 3050B or 3051 for metals and Method 3060A for Cr(VI) to prepare for analysis). Separate aliquots of material were used for bulk soil analysis and leaching.

The K_d is calculated as the ratio of the contaminant sorbed to material to the contaminant in solution by the following equation:

$$K_d = \frac{(C_S \times M_S) - (C_L \times V_L)}{M_S} \times \frac{1000}{C_L}$$

where:

K_d = soil-water distribution coefficient (mL/g)
C_S = contaminant concentration in bulk soil matrix prior to leaching (µg/g)
M_S = dry mass of soil used for leaching (g)
C_L = contaminant concentration in leachate (µg/L)

V_L = liquid volume used for leaching (L)

The borings, sample depth intervals, matrices, and K_d values are reported in Table 5-4. Values for selenium and silver are not shown in the table, as none of the soil samples had consistently detectable concentrations of these metals. The complete data sets for vadose zone samples are provided in Appendix D. In addition, analytical results for saturated zone material samples from borings C7684, C7688, and C7695 are reported under separate cover in *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234). Identification of the matrix for each sample interval is based upon the information presented in Table 2-7 (Well Summary Tables). In some cases, samples originally identified as vadose zone material were below the static water level provided in Table 2-7 and are now identified as saturated zone material in Table 5-4. Samples originally identified as collected from the saturated zone and reported in *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234) are listed in Table 5-5.

For each vadose zone soil sample, four replicate samples were analyzed for total soil metal concentrations. The average of the four measurements was used in the calculation of K_d. If one or more of the four replicates was found to be below reporting limit, the sample concentration was not considered reliable enough to report a K_d value. This was done because the reporting limit varied among replicates, with the reporting limit for one replicate often being several times that of another. This variation precluded the use of surrogate values such as half-reporting limits due to the significant uncertainty introduced by the variable reporting limits. In most cases, more than one or all four replicates were below reporting limit. For duplicate samples, the larger K_d of the two was reported in Table 5-4. In the common case where an average soil concentration was calculated but the leachate water concentration was below reporting limit, that reporting limit was used in the calculation of a minimum K_d value, and a greater than (>) sign was placed before the calculated K_d value in the table.

Batch Leach Testing Data Evaluation. The batch leach test results were further evaluated to provide a basis for estimating a K_d value to use in the vadose zone transport estimates used to prepare the soil screening levels and PRGs for Cr(VI). This data analysis includes evaluation of uncertainty and a focused statistical analysis to recommend an area wide conservative estimate for residual Cr(VI) K_d. The relative vertical distribution of soil batch leach results for chromium and Cr(VI) are presented in Figures 5-5 through 5-10.

In calculating K_d using the equation above, it was assumed that each soil sample was 100 grams, and the volumes of water used in the ratios were 100, 250, and 500 mL. Exact quantities of soil and water were not available from the laboratory, but the K_d value is not very sensitive to slight variances from these assumed values. Given these uncertainties, along with laboratory analytical uncertainty, the reported K_d values are considered accurate within approximately 30 percent.

In the case of the deeper samples from *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234), the K_d values are listed as reported in that document. The "ND" note for these samples indicates that the constituent was not detected in the soil sample, the water sample, or both.

Due to the nature of the procedure, these K_d values are to be viewed as *desorption* partition coefficients, as opposed to adsorption coefficients. It is common to observe differences in K_d between adsorption and desorption reactions, termed hysteresis ("Nonreversible Adsorption of Divalent Metal Ions (Mn^{II}, Co^{II}, Ni^{II}, Cu^{II}, and Pb^{II}) onto Goethite: Effects of Acidification, Fe^{II} Addition, and Picolinic Acid Addition" [Coughlin and Stone, 1995])), with the desorption K_d usually greater than the adsorption value.

Table 5-4. Calculated Soil-Water Partition Coefficients (K_d)

Sample Information				Arsenic K_d (L/kg)			Barium K_d (L/kg)			Cadmium K_d (L/kg)			Chromium K_d (L/kg)			Cr(VI) K_d (L/kg)			Lead K_d (L/kg)		
Boring	Matrix	Interval	Depth (ft bgs)	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5
C7684	H VZ	I-001	5–7.5	>16	>84	>81	3351	8377	7177	N/A	N/A	N/A	15060	14677	11817	N/A	N/A	N/A	>54	>275	827
		I-002	10.3–12.8	>12	>62	>59	826	4686	6024	N/A	N/A	N/A	>218	>1091	>1088	N/A	N/A	N/A	>22	>112	>109
		I-003	14.6–17.1	23	>55	>53	721	11191	11189	N/A	N/A	N/A	>195	>979	>977	N/A	N/A	N/A	>23	>115	>113
		I-004	19.8–20.3	>82	>410	>408	5794	21248	7495	>12	>63	>60	>1071	>5356	>5353	N/A	N/A	N/A	>108	>540	>538
		I-005	25.7–28.2	>23	>118	>115	6070	8767	13149	N/A	N/A	N/A	>766	>3831	>3828	N/A	N/A	N/A	>55	>277	>275
		I-006	30.1–32.6	>25	320	>124	10095	17666	23553	N/A	N/A	N/A	>378	>1893	>1891	N/A	N/A	N/A	>117	>586	>583
		I-007	35.4–37.9	>30	328	>149	15264	15263	25437	N/A	N/A	N/A	>475	>2380	>2377	N/A	N/A	N/A	>89	>449	>447
		I-008	40–42.5	>31	342	>156	8240	13183	21970	N/A	N/A	N/A	>799	>3998	>3995	N/A	N/A	N/A	>105	>530	>527
		I-009	44.5–47.0	>20	>101	>98	>2878	15344	6147	N/A	N/A	N/A	>772	>3864	>3862	N/A	N/A	N/A	>18	>93	>90
		I-010	49.9–52.4	>20	>102	>100	6140	13344	17837	N/A	N/A	N/A	>954	>4773	>4770	>28	>26	>24	>18	>94	>91
		I-013	64.5–67.0	>13	>69	>67	2172	12415	17380	N/A	N/A	N/A	2816	>5631	>5628	N/A	N/A	N/A	>20	>105	>102
		I-014	70.0–72.5	>9	>47	>44	>2419	20164	>12095	N/A	N/A	N/A	>1299	>6498	>6495	>16	>14	>12	>19	>96	>93
	H SZ	I-021	78.0–80.0	>9	>50	>47	>1920	>9603	>9600	N/A	N/A	N/A	>403	>2019	>2017	N/A	N/A	N/A	>17	>87	>84
		I-022	81.6–83.6	>8	>41	>38	5124	>10248	8537	N/A	N/A	N/A	>1797	>8989	>8987	N/A	N/A	N/A	>23	>119	>117
	RUM	I-042	163.0–165.5	515	541	1020	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1390
		I-044	186.9–189.4	503	573	846	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		I-045	213.6–216.1	288	323	446	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C7686	H VZ	I-001	5.0–6.0	>34	>32	>30	25974	>10388	>10385	>3	>2	>-1	511	875	>241	N/A	N/A	N/A	>164	>162	>160
		I-002	10.2–12.7	>44	>43	>40	26012	>10403	>10400	>5	>3	>1	>369	>368	>365	N/A	N/A	N/A	>191	>189	>187
		I-003	15.0–17.5	>42	>40	>38	>9584	>9583	>9580	>3	>2	>-1	2271	>452	>449	N/A	N/A	N/A	>168	>166	>164
		I-004	20.1–22.6	>43	111	105	8853	13279	>10620	>2	>1	>-2	>222	>221	>218	N/A	N/A	N/A	>104	>102	>100
		I-005	25.0–27.5	>17	>87	>85	>2338	19489	19487	>5	>30	>27	>582	>2913	>2910	N/A	N/A	N/A	>24	>121	>119
		I-006	29.6–32.1	>15	>78	>75	>2366	29585	19720	>5	>26	>24	>404	>2023	>2020	N/A	N/A	N/A	>23	>116	>114
		I-008	35.0–37.5	>20	>101	>99	>1961	>9808	>9805	>6	>30	>28	>298	>1493	>1490	N/A	N/A	N/A	>75	>378	>376
		I-010	40.4–42.9	>9	>47	>44	>2232	27910	27908	N/A	N/A	N/A	>410	>2052	>2049	N/A	N/A	N/A	>22	>111	>108
	Rg VZ	I-015	55.2–57.7	>27	>26	295	61099	30548	20362	N/A	N/A	N/A	>796	>795	>3980	N/A	N/A	N/A	>62	>60	>308
		I-016	60.3–62.8	>23	137	222	11982	35948	35945	N/A	N/A	N/A	>3899	>19498	>19495	N/A	N/A	N/A	>62	1054	>312

Table 5-4. Calculated Soil-Water Partition Coefficients (K_d)

Sample Information				Arsenic K_d (L/kg)			Barium K_d (L/kg)			Cadmium K_d (L/kg)			Chromium K_d (L/kg)			Cr(VI) K_d (L/kg)			Lead K_d (L/kg)		
Boring	Matrix	Interval	Depth (ft bgs)	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5
C7688	H VZ	I-001	5.0–6.3	>16	>85	>82	>3443	9564	9562	>27	>139	>136	310	582	370	12	32	8	>359	>1798	>1795
	H/Rg VZ	I-012	59.5–61.5	>15	>75	>73	>2282	14266	28533	N/A	N/A	N/A	>611	>3055	>3053	N/A	N/A	N/A	>22	>110	>108
	Rg VZ	I-014	62.9–64.2	>14	>73	>71	>2771	13858	17320	N/A	N/A	N/A	>892	>4464	>4462	N/A	N/A	N/A	>23	>116	>113
		I-016	64.9–66.7	>12	>61	>58	>2100	13129	17503	N/A	N/A	N/A	>661	>3305	>3303	N/A	N/A	N/A	>17	>86	>83
		I-018	70.0–72.5	>15	>80	>77	>2616	16354	21803	N/A	N/A	N/A	>7504	>37523	>37520	N/A	N/A	N/A	>20	>105	>102
		I-021	84.9–86.7	>10	>55	>52	>3067	12781	15335	N/A	N/A	N/A	>676	>3383	>3381	N/A	N/A	N/A	>18	>91	>89
		I-022	89.5–89.9	>7	>37	>35	1866	9331	9328	N/A	N/A	N/A	>2089	>10448	>10445	N/A	N/A	N/A	>14	>74	>71
		I-023	94.9–96.8	>9	>47	>45	>2471	8826	7720	N/A	N/A	N/A	>754	>3773	>3770	N/A	N/A	N/A	>20	>104	>102
	Rg SZ	I-024	99.0–101.5	>8	>44	>41	>1627	10173	13562	N/A	N/A	N/A	>1541	>7706	>7703	N/A	N/A	N/A	>20	>103	>101
		I-031	105.0–107.5	N/A	N/A	N/A	>1111	5558	9262	N/A	N/A	N/A	>726	>3631	>3628	N/A	N/A	N/A	>24	>120	>118
	Rg/ RUM	I-054	181.7–184.2	247	222	281	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	RUM	I-056	185.4–187.9	150	198	190	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		I-057	209.4–211.9	255	246	294	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		I-058	232.5–235.0	717	722	846	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C7695	H VZ	I-011	40.1–42.6	>24	>23	>20	5634	16886	22003	>4	>3	>0	>299	488	939	N/A	N/A	N/A	>133	>132	>129
		I-012	45.0–47.5	>20	>18	>16	3391	5457	1260	N/A	N/A	N/A	17	31	>205	N/A	N/A	N/A	>26	>25	>22
	H/Rg VZ	I-013	49.8–52.3	>31	>30	>27	9132	22569	18511	>2	>1	>-2	40	65	121	0.7	0.6	0.8	>69	>68	>65
	Rg VZ	I-014	55.0–57.5	>32	>31	>28	5026	15960	20103	>3	>1	>-1	14	27	52	-0.1	-0.7	-1.7	>66	>64	>62
		I-015	61.0–63.5	>31	>30	>27	8358	15953	17001	>3	>1	>-1	31	64	115	0.7	0.7	0.8	>94	>92	>90
		I-016	64.7–67.2	>34	>33	>30	8965	24957	22394	>3	>2	>-1	25	54	98	0.6	0.7	0.9	>61	>60	>57
		I-017	70.0–72.0	>29	>28	>25	8492	7660	9189	>4	>3	>0	1217	>602	2658	N/A	N/A	N/A	>74	>72	>70
		I-018	75.3–77.3	>25	>23	>21	10420	>14588	>14585	>4	>2	>0	>2055	>2054	>2051	N/A	N/A	N/A	>78	>76	>74
		I-019	80.2–82.7	>27	>25	>23	17789	52455	>24545	>8	>6	>4	>1771	>1770	>1767	N/A	N/A	N/A	>63	>62	>59
	Rg SZ	I-020	84.7–86.2	>17	>15	>13	19718	>7018	>7015	N/A	N/A	N/A	1967	>408	>406	N/A	N/A	N/A	>49	>48	>45
		I-026	89.8–92.0	>18	>16	>14	5858	8375	22367	N/A	N/A	N/A	>513	>512	>509	>54	>53	>50	>48	>46	>44
	Rg SZ/ RUM	I-048	178.0–181.1	99.3	129	171	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	RUM	I-049	180.0–182.5	86	108	150	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		I-050	203.0–205.0	180	195	229	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		I-051	228.0–230.5	1040	1250	1380	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 5-4. Calculated Soil-Water Partition Coefficients (K_d)

Sample Information				Arsenic K_d (L/kg)			Barium K_d (L/kg)			Cadmium K_d (L/kg)			Chromium K_d (L/kg)			Cr(VI) K_d (L/kg)			Lead K_d (L/kg)		
Boring	Matrix	Interval	Depth (ft bgs)	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5
C7831	H VZ	I-002	28.2–30.7	>37	>30	>27	1590	1015	1029	>23	>17	>15	>949	>789	2964	N/A	N/A	N/A	>63	>50	>48
		I-003	30.0–32.5	>29	>23	>20	510	341	274	>11	>7	>5	1454	802	722	N/A	N/A	N/A	>54	>44	>41
		I-004	33.0–35.5	>28	>22	>19	469	390	414	>6	>3	>1	3947	3115	3112	N/A	N/A	N/A	>53	>42	>40
		I-005	34.7–37.2	>22	>17	>14	145	63	621	>5	>3	>0	590	184	2732	N/A	N/A	N/A	158	66	>44
		I-006	37.2–39.7	>18	>21	>18	5769	8240	7208	N/A	N/A	N/A	>675	>809	>806	N/A	N/A	N/A	>37	>43	>41
		I-007	40.0–42.5	>27	>26	>23	5783	11565	16190	>4	>3	>0	2756	>770	>767	N/A	N/A	N/A	>54	>52	>50
		I-008	42.4–44.9	>22	>20	>18	7224	14448	14445	>4	>3	>0	>698	>697	>694	N/A	N/A	N/A	>60	>58	>56
	Rg VZ	I-009	45.0–47.5	>23	>22	>19	14768	59073	29533	>3	>1	>-1	>998	>997	>994	N/A	N/A	N/A	>65	>64	>61
		I-010	47.4–49.9	>23	>22	>19	246	197	289	N/A	N/A	N/A	1224	840	1220	N/A	N/A	N/A	>53	>51	>49
	Rg SZ	I-011	49.8–52.3	>15	>16	>14	4642	5414	4995	>3	>2	>-1	>592	>710	>707	N/A	N/A	N/A	>51	>60	>58
		I-012	53.7–56.2	>14	>15	>13	9474	9473	1969	N/A	N/A	N/A	>591	>708	>705	N/A	N/A	N/A	>47	>55	>53
		I-016	56.1–58.6	>17	>19	>16	4377	4376	11670	N/A	N/A	N/A	>632	>758	>755	N/A	N/A	N/A	>47	>56	>53
C7832	H VZ	AddOn 1	19.3–21.8	N/A	N/A	N/A	3673	3951	6840	N/A	N/A	N/A	14733	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		AddOn 2	21.0–23.5	N/A	N/A	N/A	2663	4660	7989	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		AddOn 3	23.2–25.7	>6	>11	>8	593	2876	2668	N/A	N/A	N/A	>256	>511	>508	N/A	N/A	N/A	>25	>49	>47
	H/Rg VZ	I-001	25.2–27.8	>26	>25	>22	1658	10120	10118	>55	>54	>51	>2627	>2626	>2623	N/A	N/A	N/A	>78	>76	>74
	Rg/VZ	I-003	30.4–32.9	>22	>20	>18	8228	17602	15372	>4	>2	>0	>830	2096	>826	N/A	N/A	N/A	140	>50	>47
		I-004	32.4–34.9	>25	>23	>21	6910	>13378	49186	>4	>2	>0	>1120	>1119	>1116	N/A	N/A	N/A	>51	>50	>47
		I-006	37.5–40.0	>17	>15	>13	20937	>13608	24562	>4	>2	>0	>730	>729	>726	N/A	N/A	N/A	>58	>56	>54
		I-007	39.7–42.2	>21	>19	>17	9276	10203	11334	>50	>48	>46	>1841	>1840	>1837	N/A	N/A	N/A	>77	>75	>73
		I-008	43.1–45.6	>23	>21	>19	6492	12983	7209	>8	>7	>4	>837	>836	>833	N/A	N/A	N/A	>60	>59	>56
		I-009	44.7–47.2	>20	>19	>16	2703	8135	6014	N/A	N/A	N/A	>616	>615	>612	N/A	N/A	N/A	>62	>61	>58
		I-010	47.2–49.7	>23	>22	>19	1890	2264	3247	N/A	N/A	N/A	>806	>805	>802	N/A	N/A	N/A	>56	>54	>52
	Rg VZ/ SZ	I-011	50.0–52.5	>16	>18	>16	5014	5276	7794	N/A	N/A	N/A	>486	>582	>579	N/A	N/A	N/A	>53	>62	>60
	Rg SZ	I-012	52.8–55.3	>13	>12	>12	5511	7598	9007	N/A	N/A	N/A	>544	>543	>649	N/A	N/A	N/A	>51	>50	>58
		I-021	55.2–57.7	>23	>21	>19	5768	7689	9884	>4	>3	>0	>755	>754	>751	N/A	N/A	N/A	>66	>64	>62

Table 5-4. Calculated Soil-Water Partition Coefficients (K_d)

Sample Information				Arsenic K_d (L/kg)			Barium K_d (L/kg)			Cadmium K_d (L/kg)			Chromium K_d (L/kg)			Cr(VI) K_d (L/kg)			Lead K_d (L/kg)		
Boring	Matrix	Interval	Depth (ft bgs)	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5	1:1	1:2.5	1:5

Notes: 1:1, 1:2.5, 1:5—ratios of soil mass (g) to leaching solution (mL).

H = Hanford formation material

Rg = Ringold Formation material

RUM = Ringold Formation upper mud unit material

VZ = Vadose Zone

SZ = Saturated Zone

N/A = At least one of the four replicate soil samples was below detection limit, so K_d was not calculated.

ND = Applies to *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234) samples only—indicates that concentration was below reporting limit for either soil, water, or both.

>-1 = K_d values with greater than (>) signs indicate that the constituent was below reporting limit in the leaching solution, and the minimum K_d was calculated using that reporting limit. Negative values indicate that the reporting limit was too high to calculate a minimum K_d above zero.

There does not appear to be a consistent relationship between the soil:water ratio and the calculated K_d. This is likely due to the inherent uncertainty in analytical methods. Trace metal analysis with ICP typically carries a ±20 percent uncertainty, and this can be magnified when total soil concentrations are calculated. If a total porosity of 35 percent is assumed, along with a soil particle density of 2.65 kg/L, a saturated soil will have a soil:water mass ratio of about 5:1, whereas in these batch leach tests, the ratios were 1:1, 1:2.5, and 1:5. The low ratios used in the batch tests are designed to estimate the maximum mass of metals that may be leached over multiple flushes of the vadose and saturated soil. Because the K_d values do not consistently decrease with decreasing soil:water ratios, the results suggest that the partition coefficients represent an approximate maximum leaching, or equilibrium, condition.

Among the consistently detected metals in vadose zone soil, barium was the only one that was detected in the majority of leaching solutions. The calculated K_d values ranged between 63 and about 61,000 L/kg, with the median value around 10,000 L/kg. Arsenic K_d ranged from 23 to 342 L/kg, with median value around 220 L/kg, although only nine samples could be quantified for K_d calculation. Cadmium was not detected in any of the leachate solutions, so no reliable partition coefficient could be calculated. The data suggest that K_d is greater than 140 L/kg, based on the largest value calculated using analytical reporting limits for the water analysis. Only five samples could be quantified for lead, and ranged from 66 to 1,054 L/kg. These data and the reporting limit calculations suggest a K_d in the hundreds of L/kg for lead.

Cr(VI) was only detected in a relatively few vadose soil samples, whereas total chromium was detected in nearly all samples. This indicates that the majority of chromium in the soil is in trivalent form. This form of chromium is known to be far less soluble and a much stronger adsorbing ion than Cr(VI).
The calculated K_ds for total chromium reflect the properties of Cr(III), with quantified values from 14 to 15,000 L/kg, and all data suggesting a K_d in the thousands. Only 45 of 210 samples could be quantified, due to the low solubility of Cr(III) in leach water. By contrast, only 15 samples could be quantified for Cr(VI), 12 of them from C7695, due to most soil samples being below detection limit.

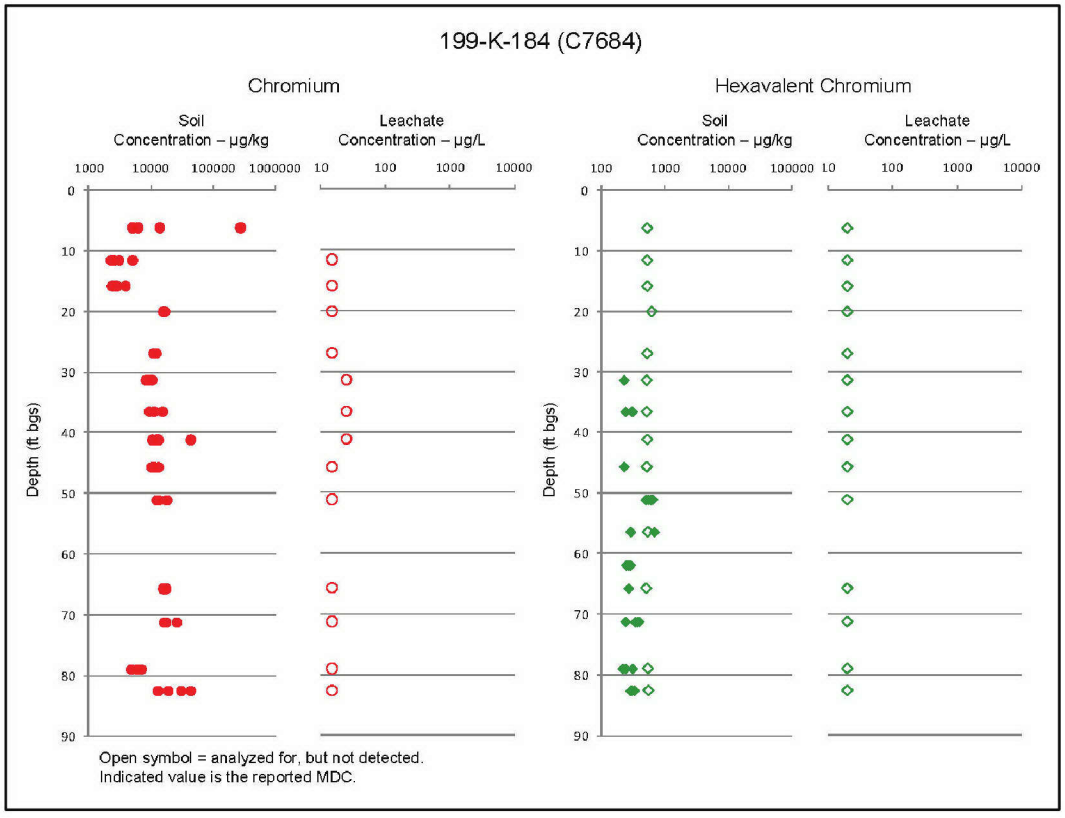
The calculated range in K_d for Cr(VI) was from below 0 (an artifact of analytical uncertainty) to 32 L/kg, with a median value of 0.7 L/kg. Because Cr(VI) is a weak adsorber and stays soluble in solution, the resulting low concentrations in soil make quantification of K_d highly uncertain, but the low measured values in these samples and in other literature sources suggest a K_d close to 0. It is important to note that the Cr(VI) sample extraction method used to prepare the solid soil samples for analysis for Cr(VI) is intended to extract low-water-solubility Cr(VI) compounds for measurement. Although mineralogical analysis to identify specific mineral species in the soil samples was not performed, some of these compounds (e.g., potassium dichromate, lead chromate) likely can be found in soil from 100-K as a result of simple ionic reactions between the sodium dichromate in reactor cooling water and other naturally occurring metal ions. The batch leach solution used in this test is intended to approximate acid precipitation and may not be as aggressive at dissolving low solubility Cr(VI) compounds.

For the deeper samples from the *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234), only arsenic produced quantifiable K_d values, which ranged from 86 to 1,380 L/kg, with a median value of 281 L/kg. Unlike the vadose zone soil, the arsenic deep samples had more consistently increasing K_d values with decreasing soil:water ratio. This suggests that a similar mass is being leached from the soil in each case, with a more dilute concentration in the leach water for lower soil:water ratios. Other than a single detection of lead in one of the deeper samples from C7684 (which is assumed to be the result of colloids passing through the filter), no other metals produced results that were quantified as K_d values in the *Report for Batch Leach Analyses on Sediments at 100-KR-4 Operable Unit, Boreholes C7684, C7688, and C7695* (PNNL-20234).

Table 5-5. Crosswalk Table for Saturated Zone Samples

Boring	HEIS #	Interval
C7684	B27LP4	I-042
	B27LP7	I-044
	B27LP8	I-045
C7688	B28FL5	I-054
	B28FL7	I-056
	B28FL8	I-057
	B28FL9	I-058
C7695	B27HR3	I-048
	B27HR5	I-049
	B27HR6	I-050
	B27HR7	I-051

1



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3 **Figure 5-5. Soil Batch Leach Vertical Profile Well 199-K-184**

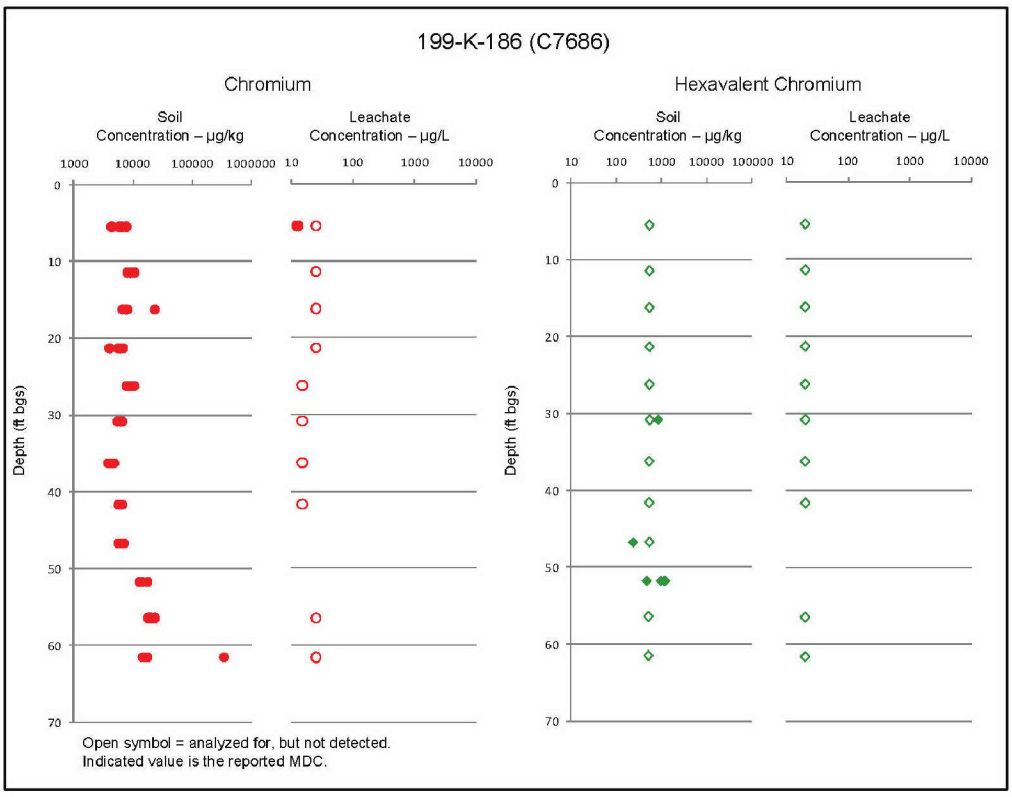

Figure 5-6. Soil Batch Leach Vertical Profile Well 199-K-186

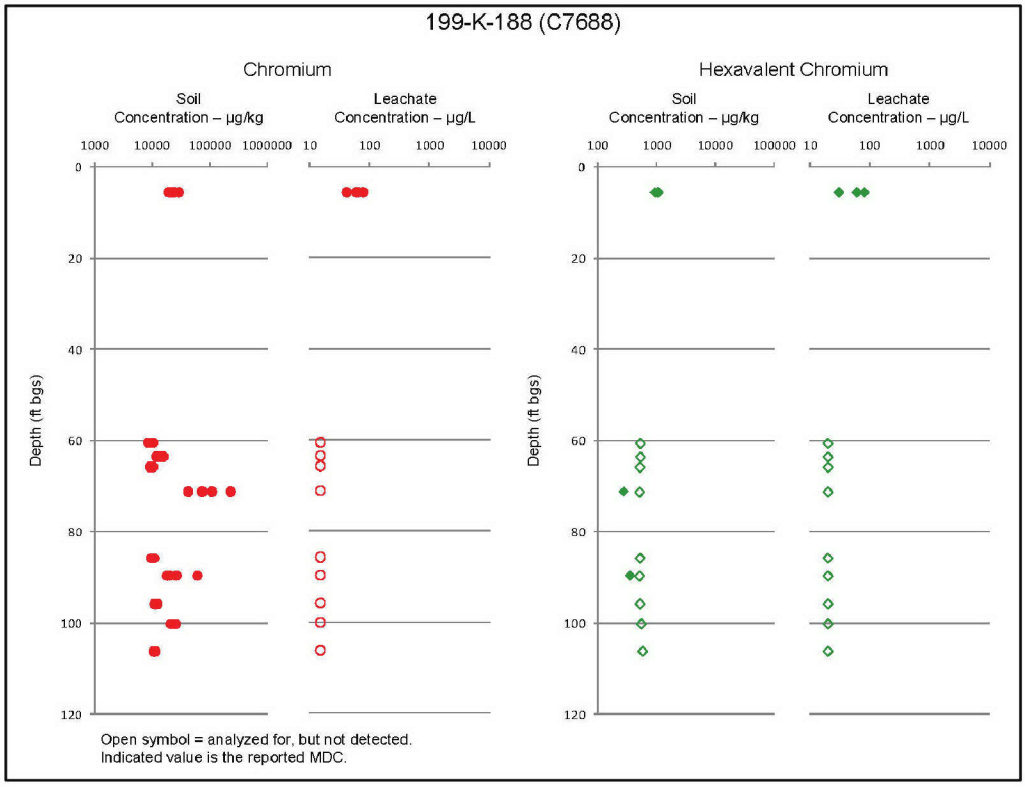

Figure 5-7. Soil Batch Leach Vertical Profile Well 199-K-188

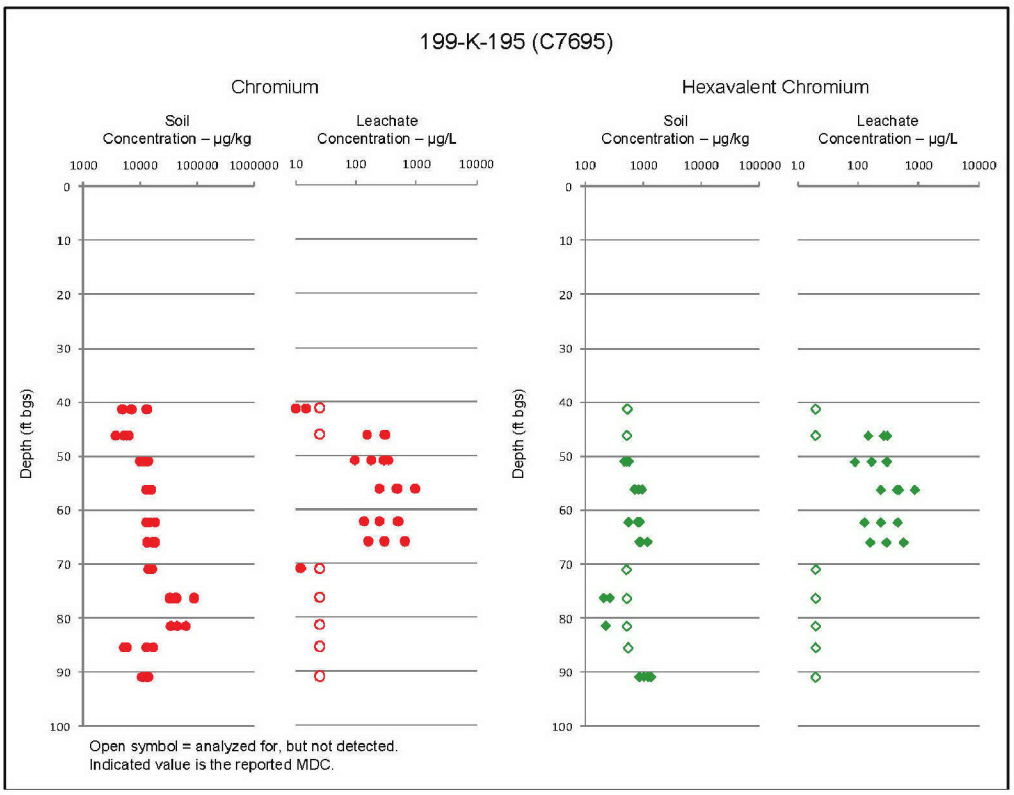

Figure 5-8. Soil Batch Leach Vertical Profile Well 199-K-195

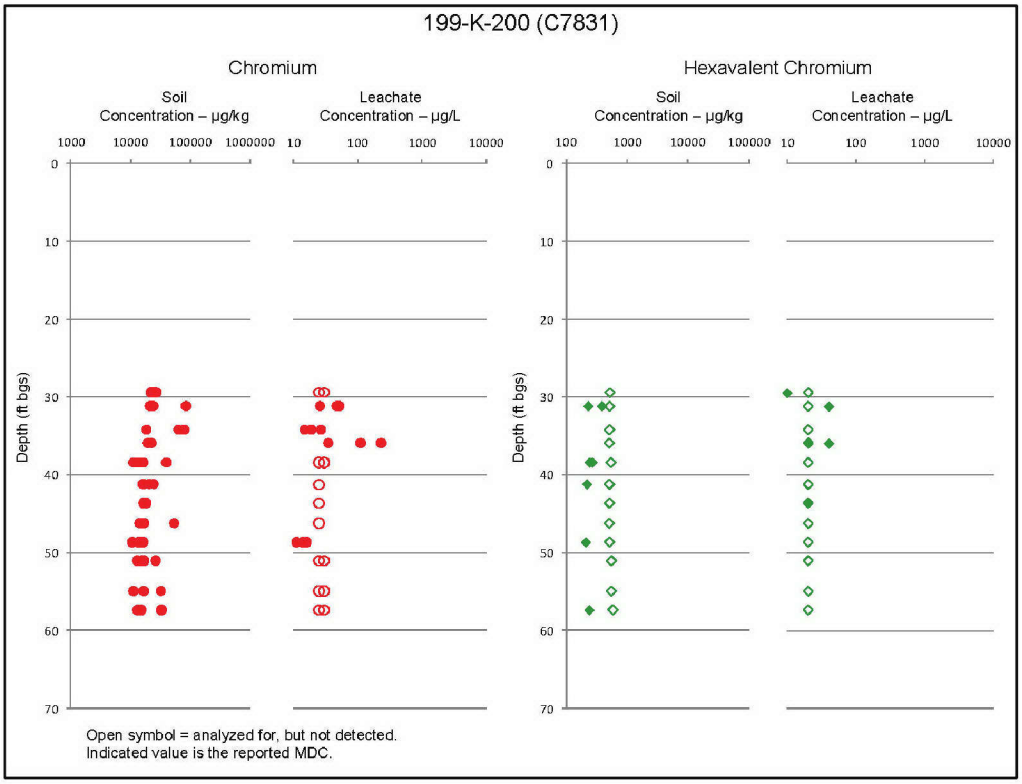

Figure 5-9. Soil Batch Leach Vertical Profile Well 199-K-200

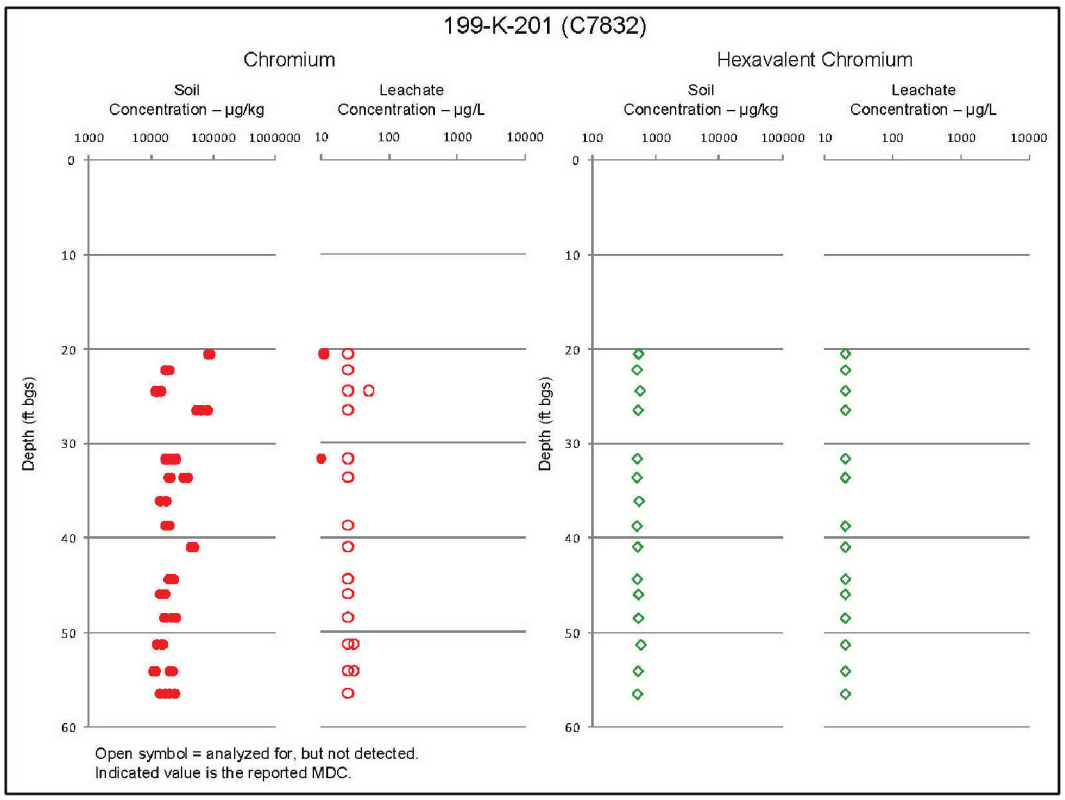

Figure 5-10. Soil Batch Leach Vertical Profile Well 199-K-201

Uncertainty in Batch Leach Testing Results. The results of batch leaching using the method specified in the SAP are subject to some degree of uncertainty due to the test method and the computational approach to calculating resulting K_d. Following are the primary contributors to uncertainty in the batch leach testing:

- The batch leaching procedure uses a slightly acidic leaching solution. This solution is intended to approximate acidic precipitation. This solution may not accurately represent soil water in the 100 Area of Hanford, where groundwater and soil water are typically alkaline buffered. The potential magnitude of any effect due to the use of two differing extractants to compare for K_d calculation has not been evaluated.

- Batch leaching techniques, in general, are subject to dilution effects. This is particularly evident when multiple soil water leach ratios are used. In samples that contain relatively low concentrations of constituents of interest, the leaching at multiple leach ratios may extract very similar masses in each extract. This can result in a lower measured constituent concentration in the extracts from progressively lower soil:water ratios (*Understanding Variation in Partition Coefficient, K_d, Values* [EPA 402-R-99-004A]). Using the extract concentrations to calculate a distribution coefficient can result in increasing calculated K_d values with decreasing soil:water ratios (i.e., the extracts from large relative water volumes will exhibit lower constituent concentration and correspondingly higher calculated K_d). The magnitude of this effect depends on the measured soil:water ratio used in the leach test relative to expected field conditions. For example, normalization of the 100-K batch leach results to a hypothetical saturated soil condition, and assuming the same mass would leach from the soil sample into the leachate solution, would produce batch leach dilution factors ranging from 5 (for the "1:1" leach ratio) to 25 (for the "1:5" leach ratio). Applying the dilution factors would reduce the calculated K_d value by the amount of the dilution factor. The K_d values used to derive the K_d for

Cr(VI) in this instance were normalized to the "1:1" leach ratio. This would indicate that the resultant K_d is subject to an estimated dilution ratio of about 5.

- Contaminant sorption and desorption, as quantified by K_d, are assumed to exhibit particular distributions; the simplest is a linear relationship between solid and solution-phase concentrations. The linearity of the K_ds calculated from the batch leach results cannot be readily evaluated without preparing distribution isotherms of solution and solid-phase concentrations. The linearity of the K_ds calculated for 100-K has not been examined and the potential effects of nonlinear relationships have not been quantified.

- The batch leach testing was performed on a selected size fraction of the soil samples collected. The bulk samples were sieved and the fraction exhibiting less than 2 mm particle diameter was used for the leach testing. For example, soil samples collected from Well 199-K-195 ranged from about 18 wt % to about 37 wt % passing the 2 mm sieve. This means that about 63 to 82 wt % of the soil samples tested exhibited particle sizes greater than 2 mm and were removed before testing. The magnitude of any effects from the testing of only a part of the entire soil body has not been evaluated; the one-dimensional transport model applied to 100-K assumes 100 percent distribution of the fine-textured material. This tends to overestimate the estimated contaminant inventory (a conservative estimation) while at the same time overestimating the overall formation retention capacity (a nonconservative estimation).

- In some instances, potable water was added to boreholes to aid drilling and/or retrieval of drill cuttings. An evaluation of drilling records and sample collection locations within the borehole(s) indicates that some soil samples may have exhibited increased soil moisture effects from addition of drilling water. The actual magnitude of potential effects on analytical laboratory results, including batch leach results, has not been quantified, but the samples that may be affected have been identified in Chapter 4.

Development of a K_d for Vadose Simulations from Batch Leach Testing Results. The results of the batch leach testing for Cr(VI) were further evaluated to identify a single derived K_d value to represent Cr(VI) behavior in the vadose zone model used the prepare soil screening concentrations and PRGs.

The results of leach tests described in Calculations 0100K-CA-V0081, 0100K-CA-V0081, 0100X-CA-V0058, 0100X-CA-V0059, and 0100X-CA-V0060 were analyzed to estimate a linear isotherm (K_d) value for residual Cr(VI) in the vadose zone. The assessment of K_d relies on collected field data and the corresponding laboratory analysis outlined in the 100-K SAP (DOE/RL-2009-41) to recommend a K_d value for use in the 100 Area. All methods used to calculate a value for K_d were outlined in the SAP for each respective OU along the River Corridor. The objective of this evaluation is to recommend a K_d for use in the River Corridor, including 100-K. Details of the analysis are described in Calculation Number ECF-HANFORD-11-0165, *Evaluation of Hexavalent Chromium Leach Test Data Conducted in Vadose Zone Sediment Samples from the 100-Area* (Appendix F).

The large number of K_d measurements and the lack of correlation of calculated K_d with possible explanatory parameters allow a conservative value to be used across the River Corridor for evaluation of future fate and transport of residual Cr(VI) after interim remedial actions have been implemented for source waste sites in the vadose zone. The evaluation of K_d for the soil samples indicates that more than 90 percent of the values are higher than 1.2 mL/g and more than 95 percent of the values are higher than 0.65 mL/g. If the K_d values are adjusted for the amount of water used during the tests (normalizing the values to the smallest soil:water extract ratio), the 90th percentile drops to about 0.8 mL/g. Based on the batch leach results for soil samples collected from the 100 Area, a K_d value of 0.8 mL/g is recommended as a conservative estimate for the lower limit on residual Cr(VI) K_d value for the River Corridor. This selected value is subject to the uncertainties identified previously.

5.6.1.1 Vadose Zone Modeling Methods and Results

The vadose zone fate and transport discussion in this section will focus on COPCs identified through the soil screening process illustrated in Figure 5-11. This process is intended to evaluate the potential for soil contaminants to migrate to underlying groundwater, and subsequently be discharged to surface water at concentrations that would pose a threat to human or ecological receptors.

The soil screening process for groundwater and surface water protection evaluation progresses through multiple steps and decision points. Most of the analytes of interest reached their peak concentration in groundwater within the 10,000-year simulation period, so no preliminary screening was required to eliminate late-arriving constituents. The estimated peak concentration arrival times for constituents detected at 100-K are shown in Table 5-6. The peak arrival time varies depending on the soil stratigraphy; the minimum and maximum times to concentration peak (based on the specified variability in site stratigraphy as illustrated in Figure 5-4) arrival are shown in the table.

The second step is to determine whether the modeled contaminant distribution of the remaining contaminants is sufficiently representative of the observed conditions. If not, then additional site-specific model simulations may be required. Subsequently, the derived representative exposure point concentrations for each waste site and soil group are compared to screening levels protective of groundwater and surface water to identify COPCs.

The fate and transport of these COPCs is discussed and the concentrations of the COPCs are then compared to preliminary remediation goals to identify waste sites that are carried forward into the FS.

5.6.1.2 Groundwater/Surface Water Protection Screening Level and Preliminary Remediation Goal Development

SSLs and PRGs are developed to provide an initial basis to identify waste site contaminants that may pose a threat for continuing contribution to groundwater and surface water contamination. The SSLs are based on a conservative simulation scenario that includes assumption of full-thickness vadose zone contamination and an infiltration/recharge condition based on irrigated agriculture. The comparison of site conditions to SSLs allows a conservative screening to identify those constituents that likely pose a continuing threat and those that do not.

PRGs represent the maximum concentration, whether mass or activity concentration in soil, of specific contaminants that can remain in the vadose zone without causing an exceedance of applicable standards. PRGs are defined for protection of groundwater and for protection of surface water by the choice of the applicable standard used in the calculation. The value of a PRG for a particular COPC depends on a small number of key factors. Waste site characteristics, specifically source contaminant distribution and distance to the water table, are key factors. Another key factor is land cover condition and the associated recharge rate. Interactions between vadose zone geology and water movement and between vadose zone geology and COPC chemistry are the two remaining key factors. For any particular COPC, the result is a set of PRG or screening level values from which selections are made that are appropriate to the waste site to be evaluated.

In the RI/FS process, waste sites are easily evaluated using PRGs. Known measured concentrations of COPCs are compared to the appropriate set of PRG values. If the concentration for one or more COPC exceeds either the groundwater-specific or surface water-specific PRG, then the site is carried into the FS, where the efficacy of treatment, waste removal, or institutional controls will be determined and evaluated using the CERCLA criteria.

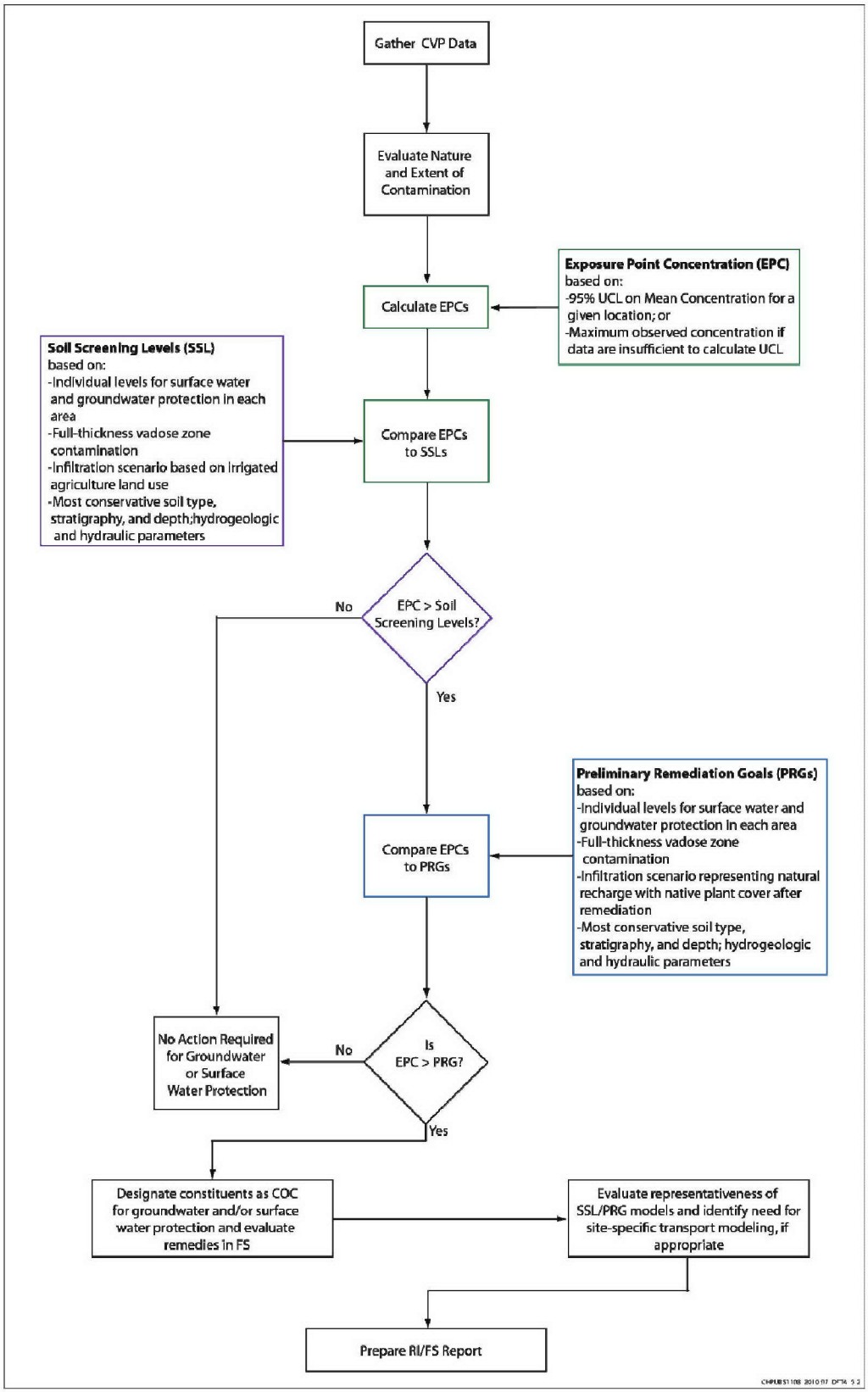

Figure 5-11. Waste Site Screening Process for Groundwater/Surface Water Protection at Sites with CVP Data

Table 5-6. 100-K Analyte-Specific Estimated Peak Groundwater Concentration Years

Analyte Name	Selected K_d (L/kg)	100:0 Irrigation Case Recharge Scenario	
		Min. Time to Peak (Years)	Max. Time to Peak (Years)
Ethylene glycol	0.0010	--	--
Cr(VI)	0.80	209	488
Uranium-233/234	2.0	--*	--*
Uranium-235	2.0	--*	--*
Uranium-238	2.0	--*	--*
Arsenic	3.0	740	1,754
Boron	3.0	740	1,754
Antimony	3.8	924	2,191
Selenium	5.0	1,223	2,904
Molybdenum	20	4,844	11,531
Copper	22	5,326	12,681
Barium	25	6,051	14,407
Iron	25	6,051	14,407
Total beta radiostrontium	25	--*	--*
Cadmium	30	7,258	17,283
Lead	30	7,258	17,283
Mercury	30	7,258	17,283
Nickel-63	30	--*	--*
Zinc	30	7,258	17,283
Cesium-137	50	--*	--*
Cobalt-60	50	--*	--*
Americium-241	200	--*	--*
Europium-152	200	--*	--*
Europium-154	200	--*	--*
Plutonium-238	200	--*	--*
Plutonium-239/240	200	--*	--*
Carbon-14	200	--*	--*

Table 5-6. 100-K Analyte-Specific Estimated Peak Groundwater Concentration Years

Analyte Name	Selected K_d (L/kg)	100:0 Irrigation Case Recharge Scenario	
		Min. Time to Peak (Years)	Max. Time to Peak (Years)
Fluoranthene	49	11,868	28,268
Cobalt	50	12,085	28,785
Manganese	50	12,085	28,785
Nickel	65	15,706	37,412
Pyrene	68	16,430	39,138
Aroclor 1254	76	18,265	43,509
Bis(2-ethylhexyl) phthalate	110	26,568	63,293
Chromium	200	48,293	115,056
Chrysene	200	48,293	115,056
Benzo(a)anthracene	360	86,914	207,078
Beryllium	790	190,709	454,386
Benzo(b)fluoranthene	803	193,847	461,863
Vanadium	1,000	241,399	575,165
Benzo(k)fluoranthene	1,230	296,917	707,446
Aluminum	1,500	362,090	862,733
Indeno(1,2,3-cd)pyrene	3,470	837,615	2.00E+06
Benzo(a)pyrene	5,500	1.33E+06	3.16E+06
Total petroleum hydrocarbons	--	--	--

Notes: Shaded values are those analytes with a peak greater than 10,000 years.

* Radionuclides are conservatively assumed to have a time to peak groundwater concentration of less than 10,000 years.

-- For analytes with no applicable STOMP 1D Soil Screening Level, a time to peak was not calculated.

PRGs were determined for each COPC by simulating peak groundwater concentrations for all representative stratigraphic columns and surface soil types, assuming a particular recharge scenario and contaminant source distribution, and then selecting the smallest PRG value calculated from the resulting peak concentrations. Screening levels, which identified analytes at each 100-K waste site that should be designated as COPCs, were determined in a similar manner to PRGs, but the most conservative source distribution and recharge scenarios were used in the SSL simulations. This section summarizes the modeling approach for calculation of SSL and PRG values that are protective of both surface water and groundwater, describes their application, and identifies the underlying assumptions, conservatism, and uncertainties in the calculations. Calculation of a PRG or SSL is straightforward:

- Simulate variably saturated transport of a unit concentration or activity of waste-derived COPCs from a specified interval in the vadose zone in which flow and solute transport are driven by a particular recharge scenario.
- Identify the peak groundwater concentration or activity that results.
- Divide the peak into the potential ARAR (Chapter 8) or risk-based value for groundwater or surface water and correct for units to give the groundwater-specific or surface water-specific PRG or screening level.
- Repeat the calculation for different COPC, contaminant mass distribution, net infiltration rate, vadose zone geology, or vadose zone thickness.

Calculation of PRG values for the 100-K source OU included the use of one-dimensional numerical fate and transport simulations for some COPCs and scaling computations for the remaining COPCs. The STOMP code was selected to perform the simulations on the basis of its ability to adequately simulate the vadose zone features, events, and processes relevant to calculating PRGs in the 100 Area and to satisfy the other code criteria and attributes identified in *Regulatory Criteria for the Selection of Vadose Zone Modeling in Support of the 200-UW-1 Operable Unit* (DOE/RL-2007-34), which describes the basis for using STOMP in this type of evaluation.

Many of the methodologies, model inputs, and assumptions for computing PRGs were developed to determine interim RAGs as part of the 100 Area RDR/RAWP (DOE/RL-96-17, Appendix B). Although the calculation methods are similar, the interim RAGs were calculated with the RESRAD model (100 Area RDR/RAWP [DOE/RL-96-17]), and the PRGs in this calculation were calculated with STOMP.

STOMP Flow and Transport Simulations. The numerical approach is described in detail in *STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* (ECF-HANFORD-11-0063, Appendix F), but a brief summary is presented here. One-dimensional numerical models were constructed to represent the key facets of the conceptual model and were solved using the STOMP code (*STOMP: Subsurface Transport Over Multiple Phases Version 2.0: Theory Guide* [PNNL-12030]). The STOMP-w mode was used to solve the Richards equation and the advection-dispersion equation that govern water flow and solute transport, respectively, under variably saturated conditions in porous media. The STOMP numerical simulations provided predictions of groundwater concentration and time to reach the peak for COPCs for recharge rates and sediment types, thicknesses, and properties appropriate to the 100-K OU. In keeping with time and resource constraints, simulation periods were limited to 10,000 years; thus, only a subset of the 100 Area COPCs that were likely to have peak groundwater concentrations occur within that period were simulated. Peak concentrations and times for other COPCs were estimated through scaling by retardation coefficient. Simulated peak groundwater concentrations were then used to compute PRGs and screening levels.

Conceptually, the model represents a column of sediments that comprise a vadose zone underlain by an aquifer. Recharge-driven flow moves downward through the vadose zone, where it encounters contamination that is eventually transported to an underlying aquifer, across which a pressure gradient drives horizontal flow. At the start of each post-2010 simulation, the vadose zone comprises a cover of clean fill with constant thickness as well as contaminated and uncontaminated sediments of varying thickness. The aquifer constitutes the base of the column with a minimum thickness of 5 m so that a 5 m long monitoring well screen could be simulated. Within the 100-K Source OU, the vadose zone is composed of either Hanford formation alone or a combination of Hanford and Ringold unit E, whereas the saturated zone can be only Hanford or only Ringold unit E. If present, the contact between the Ringold unit E and the RUM forms the bottom of the aquifer. The derived K_d for Cr(VI) of 0.8 ml/g was applied to Cr(VI) in all vadose zone strata in the model.

Based on observations of contaminant distribution made from analysis of soil samples from RI borings and wells, spatial distributions of contamination were identified for use in initial flow and transport simulations. Numerous contaminants were found to be distributed throughout the thickness of the vadose zone. As a result, a single source distribution, called the "100:0" source distribution, was assigned a uniform unit-source concentration of 1 mg/kg soil to the entire vadose zone thickness beneath 4.5 m of clean fill and was used to calculate soil screening level values. The 100:0 source distribution constituted a representative assumption for contaminant distribution in the vadose zone. Although the same contaminant distribution was applied to calculate both the SSLs and the PRGs, a different infiltration/recharge scenario was applied to each simulation. The SSL simulation uses a conservative recharge scenario based on an assumed irrigated agriculture land use. The PRG simulation, alternatively, uses a recharge scenario based on natural recharge, and assumes that a native plant population becomes reestablished at the surface.

Identification of Peak Groundwater Concentrations. Peak groundwater concentrations were calculated along a portion of the domain's downgradient boundary corresponding to the top 5 m of the aquifer. The average concentration for the topmost 5 m was assumed an estimate of the groundwater concentration that would be measured within a 6 m (20 ft) long monitoring well screen that straddled the water table. The concentration was conservatively estimated by calculating it at the aquifer edge beneath the downgradient edge of the waste site footprint and from which the peak contaminant concentration and breakthrough time were determined. For COPCs not simulated in STOMP, peak groundwater concentration and year of occurrence were calculated instead by scaling with the retardation factor. Depending on vadose zone thickness and hydraulic properties, the 10,000-year simulation time for the flow and transport simulations can suffice to identify peak groundwater concentrations for a limited number of COPCs. For the 100-K conditions, only COPCs with K_ds, the parameter governing linear sorption, that have values between 0 and 25 ml/g would typically yield a peak concentration within the simulation period. However, the K_ds of the COPCs in the 100 Area span such a large range that simulation periods of tens or hundreds of thousands of years would be necessary to predict the actual groundwater peaks. Such time-consuming simulations can be replaced with a straightforward scaling using the retardation factor (*STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* [ECF-HANFORD-11-0063, Appendix F]).

For radionuclides with radioactive decay and sufficiently large K_d values to preclude reaching a peak within the simulation period, the peak groundwater concentration and time of peak were estimated by assuming there is no radioactive decay, thereby yielding a conservative estimate of the peak concentration.

Comparison of Vadose Zone EPCs to SSLs. In order to be considered for comparison to the 100:0 irrigation scenario SSLs, analytes must be detected at least once at a site and may be excluded from further consideration under the following conditions:

- Essential nutrients (e.g., calcium, magnesium, potassium, and sodium) that are not excessively elevated above background or are not associated with the waste at a waste site
- Radionuclides that are associated with background conditions and not associated with waste site practices (e.g., potassium-40, radium-224, radium-226, radium-228, thorium-228, thorium-230, and thorium-232)
- Radionuclides with half-lives less than three years and that, upon decay, produce no significant daughter products
- The maximum concentration of an inorganic analyte is less than or equal to the 90th percentile value of the background concentrations

- Constituent is identified as requiring more than 10,000 years to migrate through the vadose zone and reach a peak concentration in groundwater (Table 5-6).

The EPCs of the remaining analytes for each waste site and soil group (e.g., overburden, shallow, shallow focused, and deep) as indicated in the CVP data for the previously remediated waste sites are calculated through the process presented in Chapter 6 and summarized here. The EPC of each waste site and soil group is the UCL-95 of the mean concentration or the maximum detected if too few detections were available to estimate a UCL-95 value. The waste site-specific EPC of each constituent is compared to vadose zone soil screening level calculated through the STOMP 100:0 irrigation scenario.
The comparison of constituent EPCs to the model-derived SSL concentrations is shown in Table 5-7.
The following are the waste sites and constituents with EPCs that exceed either the groundwater protection or surface water protection SSLs:

- Lead in shallow soil at Site 100-K-29
- Lead and mercury in shallow soil at Site 100-K-30
- Lead and mercury in shallow soil at Site 100-K-31
- Mercury in shallow soil at Site 100-K-32
- Arsenic, lead, and mercury in shallow soil at Site 100-K-33

The lead and arsenic concentrations observed at these locations are not dissimilar from the maximum concentrations observed in the background population, suggesting that these contaminants may actually represent background conditions. These conditions, however, do occur at locations within the general historical operating area of the water treatment head houses, where concentrated chemicals, including commercial grade sulfuric acid known to contain mercury, were used. Because of the uncertainty in the potential origin of the lead and arsenic, these constituents are carried forward for further analysis, including comparison to the PRGs.

Comparison of Vadose Zone EPCs to PRGs. If a waste site soil group COPC EPC exceeds the 100:0 irrigation scenario groundwater or surface water protection screening levels and requires less than 10,000 years to reach peak concentration, it is carried through to the second step for waste site assessment. The second step compares the EPCs of the COPCs that emerged from the 100:0 irrigation scenario screening to PRGs. As described previously, the modeled source distribution assumes a unit source distribution uniformly distributed across the entire vadose zone. This contaminant distribution model is shown to be conservative for most of the COPCs, which exhibit a more limited distribution focused within the upper portion of the vadose thickness, as shown in Chapter 4. The following are examples of this distribution:

- Boring C7832 (Figure 4-5) concentrations of cesium-137, cobalt-60, europium-152, europium-154, nickel-63, plutonium-239/240, and Sr-90 decrease orders of magnitude within a few feet below the bottom of the trench. Cadmium, total chromium, mercury, and zinc concentrations at several times the background value near the bottom of the 116-K-2 Trench drop to below background within less than 1.5 m (5 ft) below the trench.

- Boring C7831 (Figure 4-4) concentration trends versus depth at this boring are not as obvious because contaminant concentrations were much lower than those at C7832. However, the concentrations of nickel-63 decreased below the detection limit within approximately 3 m (10 ft) below the bottom of the trench and Sr-90 concentrations by more than half within 3 m (10 ft) of the trench bottom.

- Monitoring Well 199-K-41 (Figure 4-3) borehole samples show americium-241, carbon-14, cobalt-60, europium-152, europium-154, europium-155, plutonium-238, plutonium-239/240, Sr-90, and mercury concentrations 1.5 m (5 ft) above the bottom of the trench with concentration decreases of up to several orders of magnitude at the trench bottom. In addition, several contaminant concentrations are below the detection limit below that depth.

Residual distribution of Cr(VI), however, does not exhibit the limited distribution within any part of the vadose zone. Cr(VI) is found throughout the vadose zone thickness at locations where historical releases are expected to have resulted in full-thickness recharge by wastewater.

Recharge rates in 100-K, as well as in the rest of the 100 Area, are expected to decrease after demolition and remediation activities are complete and the native xerophyte plant cover becomes re-established. This is the basis for the natural recharge basis defined for the PRG simulations. The PRG values represent the maximum constituent mass or activity concentration in vadose zone soil that will not result in downgradient groundwater (Table 5-8) or surface water (Table 5-9) concentration exceeding the federal and state criteria listed in *STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K* (ECF-HANFORD-11-0063, Appendix F).

The EPCs for each constituent in previously-remediated waste sites and soil groups that exceed the SSLs are compared against the groundwater and surface water protection PRGs in Tables 5-8 and 5-9, respectively. The following are the waste sites and constituents with EPCs that exceed either the groundwater protection or surface water protection PRGs:

- Mercury in shallow soil at Site 100-K-30
- Mercury in shallow soil at Site 100-K-31
- Mercury in shallow soil at Site 100-K-32
- Arsenic and mercury in shallow soil at Site 100-K-33

Uncertainties that may affect the interpretation of the comparison of site-specific EPCs to the SSLs and PRGs are discussed in the Section 5.7.

5.6.1.3 COPCs Retained for Assessment in Feasibility Study

Contaminants were retained for further consideration as COPCs for groundwater and surface water protection if one of two conditions existed: the contaminant is already in groundwater and exhibits concentrations in excess of an action level, or the contaminant is present in soil at an EPC that exceeds the SSL concentration. In the assessment of soil analyses from the previously remediated waste sites, arsenic, lead, and mercury exceeded the SSLs for protection of either surface water, groundwater, or both. Subsequent comparison of those contaminant EPCs to the PRGs indicates that only arsenic and mercury in shallow soil at remediated waste sites near the cooling water head houses at 100-KE and 100-KW exceeded the PRGs.

Constituents that are immobile, as determined from their soil-water K_d, typically have a peak concentration occurring more than 10,000 years in the future, according to STOMP model simulations. These constituents were identified in Table 5-6 and were excluded from the comparison to SSLs for groundwater and surface water protection because no SSL values were developed for them.

Table 5-7. Comparison of EPCs from 100-K Source OUs Waste Site Decision Units to STOMP 1D Model Soil Screening Levels Protective of Groundwater and Protective of Surface Water (with Background Consideration) Highlighted Cells Indicate that EPC Exceeds the Indicated SSL

Waste Site/Decision Unit	Analyte Group	Analyte Name	CAS No.	Units	Exposure Point Concentration	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Groundwater Protection	Is EPC > Soil Screening Level Protective of Groundwater?	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Surface Water Protection	Is EPC > Soil Screening Level Protective of Surface Water?
100-K-29_Shallow_Focused	NonRad	Aroclor 1254	11097-69-1	mg/kg	0.01	--[a]	--	--[a]	--
100-K-29_Shallow_Focused	NonRad	Chromium	7440-47-3	mg/kg	24.7	--[a]	--	--[a]	--
100-K-29_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	3.2	16.8	No	3.5	No
100-K-29_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	63.2	182.1	No	25.6	Yes
100-K-29_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	0.05	24.3	No	0.15	No
100-K-30_Shallow_Focused	NonRad	Cadmium	7440-43-9	mg/kg	0.64	60.7	No	3.03	No
100-K-30_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.70	16.8	No	3.5	No
100-K-30_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	36.0	182.1	No	25.6	Yes
100-K-30_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	17.5	24.3	No	0.15	Yes
100-K-31_Shallow_Focused	NonRad	Barium	7440-39-3	mg/kg	169.0	2.02E+04	No	1.01E+04	No
100-K-31_Shallow_Focused	NonRad	Cadmium	7440-43-9	mg/kg	0.75	60.7	No	3.03	No
100-K-31_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	.02	16.8	No	3.5	No
100-K-31_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	43.4	182.1	No	25.6	Yes
100-K-31_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	5.2	24.3	No	0.15	Yes
100-K-32_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.23	16.8	No	3.49	No
100-K-32_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	2.4	24.28	No	0.15	Yes
100-K-33_Shallow_Focused	NonRad	Arsenic	7440-38-2	mg/kg	6.7	0.07	Yes	0.02	Yes
100-K-33_Shallow_Focused	NonRad	Cadmium	7440-43-9	mg/kg	1.0	60.69	No	3.04	No
100-K-33_Shallow_Focused	NonRad	Chromium	7440-47-3	mg/kg	22.9	--[a]	--	--[a]	--
100-K-33_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	1.4	16.80	No	3.49	No
100-K-33_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	27.8	182.07	No	25.58	Yes
100-K-33_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	6.8	24.28	No	0.15	Yes
100-K-55:1_Deep	Rad	Cobalt-60	10198-40-0	pCi/g	06.0E-04	177.69	No	17.69	No
100-K-55:1_Deep	Rad	Europium-152	14683-23-9	pCi/g	8.6E-04	16.15	No	16.15	No
100-K-55:1_Deep	Rad	Europium-154	15585-10-1	pCi/g	0.29	4,846	No	4,846	No

Table 5-7. Comparison of EPCs from 100-K Source OUs Waste Site Decision Units to STOMP 1D Model Soil Screening Levels Protective of Groundwater and Protective of Surface Water (with Background Consideration) Highlighted Cells Indicate that EPC Exceeds the Indicated SSL

Waste Site/Decision Unit	Analyte Group	Analyte Name	CAS No.	Units	Exposure Point Concentration	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Groundwater Protection	Is EPC > Soil Screening Level Protective of Groundwater?	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Surface Water Protection	Is EPC > Soil Screening Level Protective of Surface Water?
100-K-55:1_Overburden	Rad	Cobalt-60	10198-40-0	pCi/g	0.056	177,690	No	177,690	No
100-K-55:1_Overburden	Rad	Europium-152	14683-23-9	pCi/g	0.34	16,154	No	16,154	No
100-K-55:1_Overburden	Rad	Europium-154	15585-10-1	pCi/g	0.33	4,846	No	4,846	No
100-K-55:1_Shallow	Rad	Cobalt-60	10198-40-0	pCi/g	0.19	177,690	No	177,690	No
100-K-55:1_Shallow	Rad	Europium-152	14683-23-9	pCi/g	0.81	16,154	No	16,154	No
100-K-55:1_Shallow	Rad	Europium-154	15585-10-1	pCi/g	0.52	4,846	No	4,846	No
100-K-55:1_Shallow_Focused	Rad	Cobalt-60	10198-40-0	pCi/g	0.11	177,690	No	177,690	No
100-K-55:1_Shallow_Focused	Rad	Europium-152	14683-23-9	pCi/g	1.3	16,154	No	16,154	No
100-K-55:1_Shallow_Focused	Rad	Europium-154	15585-10-1	pCi/g	0.19	4,846	No	4,846	No
100-K-55:1_Shallow_Focused	Rad	Total beta radiostrontium	SR-RAD	pCi/g	0.37	672	No	672	No
100-K-56:1_Deep	Rad	Cesium-137	10045-97-3	pCi/g	21	59,822	No	59,822	No
100-K-56:1_Deep	Rad	Cobalt-60	10198-40-0	pCi/g	1.1	177,690	No	177,690	No
100-K-56:1_Deep	Rad	Europium-152	14683-23-9	pCi/g	22	16,154	No	16,154	No
100-K-56:1_Deep	Rad	Europium-154	15585-10-1	pCi/g	2.1	4,846	No	4,846	No
100-K-56:1_Shallow	Rad	Cesium-137	10045-97-3	pCi/g	1.3	59,822	No	59,822	No
100-K-56:1_Shallow	Rad	Cobalt-60	10198-40-0	pCi/g	0.32	177,690	No	177,690	No
100-K-56:1_Shallow	Rad	Europium-152	14683-23-9	pCi/g	1.9	16,154	No	16,154	No
100-K-56:1_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.94	16.8	No	3.49	No
100-K-56:1_Shallow_Focused	Rad	Cobalt-60	10198-40-0	pCi/g	0.15	177,690	No	177,690	No
100-K-56:1_Shallow_Focused	Rad	Europium-152	14683-23-9	pCi/g	3.1	16,154	No	16,154	No
100-K-56:1_Shallow_Focused	Rad	Europium-154	15585-10-1	pCi/g	0.33	4,846	No	4,846	No
100-K-56:1_Shallow_Focused	Rad	Total beta radiostrontium	SR-RAD	pCi/g	0.50	672	No	672	No
100-K-78_Shallow_Focused	NonRad	Antimony	7440-36-0	mg/kg	0.39	9.26	No	8.65	No
100-K-78_Shallow_Focused	NonRad	Chromium	7440-47-3	mg/kg	30.0	--[a]	--	--[a]	--
100-K-78_Shallow_Focused	Rad	Carbon-14	14762-75-5	pCi/g	1.7	43	No	43	No

Table 5-7. Comparison of EPCs from 100-K Source OUs Waste Site Decision Units to STOMP 1D Model Soil Screening Levels Protective of Groundwater and Protective of Surface Water (with Background Consideration) Highlighted Cells Indicate that EPC Exceeds the Indicated SSL

Waste Site/Decision Unit	Analyte Group	Analyte Name	CAS No.	Units	Exposure Point Concentration	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Groundwater Protection	Is EPC > Soil Screening Level Protective of Groundwater?	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Surface Water Protection	Is EPC > Soil Screening Level Protective of Surface Water?
100-K-78_Shallow_Focused	Rad	Cobalt-60	10198-40-0	pCi/g	0.073	177,690	No	177,690	No
100-K-78_Shallow_Focused	Rad	Europium-152	14683-23-9	pCi/g	0.27	16,154	No	16,154	No
100-K-78_Shallow_Focused	Rad	Nickel-63	13981-37-8	pCi/g	7.2	2,314	No	2,314	No
116-K-1_Deep	NonRad	Cr(VI)	18540-29-9	mg/kg	0.56	16.8	No	3.49	No
116-K-1_Deep	Rad	Cesium-137	10045-97-3	pCi/g	11	59,822	No	59,822	No
116-K-1_Deep	Rad	Cobalt-60	10198-40-0	pCi/g	3.3	177,690	No	177,690	No
116-K-1_Deep	Rad	Europium-152	14683-23-9	pCi/g	9.0	16,154	No	16,154	No
116-K-1_Deep	Rad	Europium-154	15585-10-1	pCi/g	2.5	4,846	No	4,846	No
116-K-1_Deep	Rad	Total beta radiostrontium	SR-RAD	pCi/g	8.6	672	No	672	No
116-K-1_Overburden	Rad	Europium-152	14683-23-9	pCi/g	0.26	16,154	No	16,154	No
116-K-1_Overburden	Rad	Total beta radiostrontium	SR-RAD	pCi/g	0.92	672	No	672	No
116-K-1_Shallow	NonRad	Cr(VI)	18540-29-9	mg/kg	0.26	16.8	No	3.49	No
116-K-1_Shallow	Rad	Cobalt-60	10198-40-0	pCi/g	0.038	177,690	No	177,690	No
116-K-1_Shallow	Rad	Europium-152	14683-23-9	pCi/g	0.22	16,154	No	16,154	No
116-K-1_Shallow	Rad	Total beta radiostrontium	SR-RAD	pCi/g	1.9	672	No	672	No
116-K-2_Deep	NonRad	Cr(VI)	18540-29-9	mg/kg	3.15	16.8	No	3.49	No
116-K-2_Deep	Rad	Americium-241	14596-10-2	pCi/g	3.2	1,212	No	1,212	No
116-K-2_Deep	Rad	Carbon-14	14762-75-5	pCi/g	3.6	43	No	43	No
116-K-2_Deep	Rad	Cesium-137	10045-97-3	pCi/g	119	59,822	No	59,822	No
116-K-2_Deep	Rad	Cobalt-60	10198-40-0	pCi/g	5.3	177,690	No	177,690	No
116-K-2_Deep	Rad	Europium-152	14683-23-9	pCi/g	103	16,154	No	16,154	No
116-K-2_Deep	Rad	Europium-154	15585-10-1	pCi/g	7.0	4,846	No	4,846	No
116-K-2_Deep	Rad	Nickel-63	13981-37-8	pCi/g	763	2,314	No	2,314	No
116-K-2_Deep	Rad	Plutonium-238	13981-16-3	pCi/g	0.53	1,212	No	1,212	No
116-K-2_Deep	Rad	Plutonium-239/240	PU-239/240	pCi/g	5.1	1,212	No	1,212	No

Table 5-7. Comparison of EPCs from 100-K Source OUs Waste Site Decision Units to STOMP 1D Model Soil Screening Levels Protective of Groundwater and Protective of Surface Water (with Background Consideration) Highlighted Cells Indicate that EPC Exceeds the Indicated SSL

Waste Site/Decision Unit	Analyte Group	Analyte Name	CAS No.	Units	Exposure Point Concentration	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Groundwater Protection	Is EPC > Soil Screening Level Protective of Groundwater?	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Surface Water Protection	Is EPC > Soil Screening Level Protective of Surface Water?
116-K-2_Deep	Rad	Total beta radiostrontium	SR-RAD	pCi/g	6.3	672	No	672	No
116-K-2_Overburden	NonRad	Cr(VI)	18540-29-9	mg/kg	0.30	16.8	No	3.49	No
116-K-2_Overburden	Rad	Europium-152	14683-23-9	pCi/g	0.21	16,154	No	16,154	No
116-K-2_Shallow	NonRad	Cr(VI)	18540-29-9	mg/kg	0.31	16.8	No	3.49	No
116-K-2_Shallow	Rad	Carbon-14	14762-75-5	pCi/g	3.0	43	No	43	No
116-K-2_Shallow	Rad	Europium-152	14683-23-9	pCi/g	0.59	16,154	No	16,154	No
116-K-2_Shallow	Rad	Europium-154	15585-10-1	pCi/g	0.30	4,846	No	4,846	No
116-K-2_Shallow	Rad	Nickel-63	13981-37-8	pCi/g	7.8	2,314	No	2,314	No
116-K-2_Shallow	Rad	Total beta radiostrontium	SR-RAD	pCi/g	0.26	672	No	672	No
116-KE-4_Shallow	NonRad	Cr(VI)	18540-29-9	mg/kg	0.58	16.8	No	3.49	No
116-KE-4_Shallow	Rad	Cobalt-60	10198-40-0	pCi/g	0.086	177,690	No	177,690	No
116-KE-4_Shallow	Rad	Europium-152	14683-23-9	pCi/g	0.70	16,154	No	16,154	No
116-KE-4_Shallow	Rad	Europium-154	15585-10-1	pCi/g	0.28	4,846	No	4,846	No
116-KE-4_Shallow	Rad	Nickel-63	13981-37-8	pCi/g	7.5	2,314	No	2,314	No
116-KE-4_Shallow	Rad	Total beta radiostrontium	SR-RAD	pCi/g	0.32	672	No	672	No
116-KE-5_Shallow_Focused	NonRad	Chromium	7440-47-3	mg/kg	30.0	--[a]	--	--[a]	--
116-KE-5_Shallow_Focused	NonRad	Ethylene glycol	107-21-1	mg/kg	0.06	--[b]	--	--[b]	--
116-KE-5_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.33	16.8	No	3.49	No
116-KE-5_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	11.3	182.07	No	25.58	No
116-KE-5_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	0.10	24.28	No	0.15	No
116-KW-3_Shallow	NonRad	Cr(VI)	18540-29-9	mg/kg	0.75	16.8	No	3.49	No
116-KW-3_Shallow	Rad	Americium-241	14596-10-2	pCi/g	0.53	1,212	No	1,212	No
116-KW-3_Shallow	Rad	Cobalt-60	10198-40-0	pCi/g	0.10	177,690	No	177,690	No
116-KW-3_Shallow	Rad	Europium-152	14683-23-9	pCi/g	1.5	16,154	No	16,154	No
116-KW-3_Shallow	Rad	Europium-154	15585-10-1	pCi/g	0.29	4,846	No	4,846	No

Table 5-7. Comparison of EPCs from 100-K Source OUs Waste Site Decision Units to STOMP 1D Model Soil Screening Levels Protective of Groundwater and Protective of Surface Water (with Background Consideration) Highlighted Cells Indicate that EPC Exceeds the Indicated SSL

Waste Site/Decision Unit	Analyte Group	Analyte Name	CAS No.	Units	Exposure Point Concentration	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Groundwater Protection	Is EPC > Soil Screening Level Protective of Groundwater?	STOMP 1D 100:0 Contaminant Source Model Soil Screening Level for Surface Water Protection	Is EPC > Soil Screening Level Protective of Surface Water?
116-KW-3_Shallow	Rad	Plutonium-239/240	PU-239/240	pCi/g	0.92	1,212	No	1,212	No
116-KW-4_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.24	16.8	No	3.49	No
128-K-1_Shallow_Focused	NonRad	Benzo(a)anthracene	56-55-3	mg/kg	0.10	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Benzo(a)pyrene	50-32-8	mg/kg	0.05	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Benzo(b)fluoranthene	205-99-2	mg/kg	0.08	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Benzo(k)fluoranthene	207-08-9	mg/kg	0.08	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Bis(2-ethylhexyl) phthalate	117-81-7	mg/kg	0.87	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Chrysene	218-01-9	mg/kg	0.15	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Fluoranthene	206-44-0	mg/kg	0.22	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Cr(VI)	18540-29-9	mg/kg	0.48	16.8	No	3.49	No
128-K-1_Shallow_Focused	NonRad	Indeno(1,2,3-cd)pyrene	193-39-5	mg/kg	0.03	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	10.80	182.07	No	25.58	No
128-K-1_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	0.03	24.28	No	0.15	No
128-K-1_Shallow_Focused	NonRad	Pyrene	129-00-0	mg/kg	0.15	--[a]	--	--[a]	--
128-K-1_Shallow_Focused	NonRad	Selenium	7782-49-2	mg/kg	0.80	102.25	No	10.22	No
128-K-1_Shallow_Focused	NonRad	Total petroleum hydrocarbons	TPH	mg/kg	14.4	--[b]	--	--[b]	--

a. For calculated soil activities or soil screening levels protective of groundwater, STOMP1D predicts these analytes will not reach peak groundwater concentration within 10,000 years assuming that 100% of the vadose zone is contaminated.

b. A soil screening level is not calculated because a groundwater cleanup level or MCL is not available for this analyte.

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Table 5-8. Comparison of EPCs for 100-K Source OU COPCs to STOMP 1D 100:0 Contaminant Source Model Preliminary Remediation Goals Protective of Groundwater for the Base Case Scenario

Waste Site/Decision Unit	Analyte Group	COPC	CAS No.	Units	Exposure Point Concentration	100:0 Source Base Case GWP Preliminary Remediation Goal	Is EPC > 100:0 Source Base Case GWP PRG?
100-K-33_Shallow_Focused	NonRad	Arsenic	7440-38-2	mg/kg	6.7	0.164	Yes

1

Table 5-9. Comparison of EPCs for 100-K Source OU COPCs to STOMP 1D 100:0 Contaminant Source Model Preliminary Remediation Goals Protective of Surface Water for the Base Case Scenario

Waste Site/Decision Unit	Analyte Group	COPC	CAS No.	Units	Exposure Point Concentration	100:0 Source Base Case SWP Preliminary Remediation Goal	Is EPC > 100:0 Source Base Case SWP PRG?
100-K-29_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	63.2	210.6	No
100-K-30_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	36.0	210.6	No
100-K-30_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	17.5	1.2	Yes
100-K-31_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	43.4	210.6	No
100-K-31_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	5.2	1.2	Yes
100-K-32_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	2.4	1.2	Yes
100-K-33_Shallow_Focused	NonRad	Arsenic	7440-38-2	mg/kg	6.7	0.051	Yes
100-K-33_Shallow_Focused	NonRad	Lead	7439-92-1	mg/kg	27.8	210.6	No
100-K-33_Shallow_Focused	NonRad	Mercury	7439-97-6	mg/kg	6.8	1.2	Yes

In addition to the soil constituents, the fate and transport of 100-KR-4 OU groundwater constituents with concentrations above federal MCLs, state MCLs, WAC 173-340-720 Cleanup Levels, and Aquatic Action Levels are evaluated in Sections 5.6.2 and 5.6.3. The groundwater contaminants of interest were identified in Chapter 4. The groundwater sample data set and the comparison process employed to identify these constituents are discussed in Chapter 6, with the resulting groundwater COPCs as follows:

- Inorganics: total chromium, Cr(VI), and nitrate
- Radionuclides: carbon-14, Sr-90, and tritium
- Organics: trichloroethene

The identified COPCs are summarized in Table 5-10.

Table 5-10. COPCs in 100-K Soil and Groundwater

COPC Category	COPC	Soil	Groundwater	Groundwater and/or Surface Water Protection
Organic Compounds	Trichloroethene		X	
Inorganics	Chromium (measured as total chromium)		X	
	Cr(VI)		X	
	Nitrate		X	
	Arsenic			X
	Mercury			X
Radionuclides	Tritium		X	
	Carbon-14	X	X	
	Sr-90	X	X	
	Americium-241	X		
	Cesium-137	X		
	Plutonium-238	X		
	Plutonium-239/240	X		
	Europium-152	X		
	Europium-154	X		
	Cobalt-60	X		
	Nickel-63	X		

5.6.2 Factors Affecting Contaminant Mobility in the Saturated Zone

Site-related contaminants at 100-K entered the groundwater system at various times and locations during the historical operations at the OU. Low-concentration Cr(VI), and periodically during upset conditions, low-concentration fission products entered the ground at locations of reactor cooling water discharge. These locations were primarily 116-K-1 Crib (for a limited period), followed by the 116-K-2 Trench. These discharges resulted in development of a large groundwater mound that extended for thousands of meters in all directions from the trench. The mound is hypothesized to have consisted primarily of discharged reactor cooling water that displaced the original groundwater. This mound would have exhibited a fairly uniform Cr(VI) content of about 700 ug/L, the concentration of that constituent in the working cooling water stream. This water stream likely also included various nonradiological contaminants associated with periodic discharges to the chemical sewer, which discharged into the cooling water stream and would have periodically entered the 116-K-2 Trench when cooling water was diverted to the trench. After cessation of cooling water discharges, the groundwater mound rapidly decayed to near-natural groundwater elevations; however, the body of contaminated water was still in place and is assumed to have moved slowly (at the more natural groundwater flow velocity of about 0.3 m/day [1 ft/day]) toward the Columbia River. Cr(VI) in the footprint of the former groundwater plume remains mobile and exhibits generally decreasing concentrations over most of that area.

Other historical releases to ground that apparently affected groundwater include spills and leaks of water treatment chemicals (including sodium dichromate dihydrate solution at high concentration, sodium hydroxide solution, sulfuric acid solution, sodium chloride solution, and alum solution [hydrated potassium aluminum sulfate]). These releases appear to have occurred over the operating period in the general vicinity of the water treatment head houses at both 100-K Reactors. French drains located near the bulk chemical storage areas likely received spills and leaks, and such releases are expected to have been periodically washed down the French drains with unspecified volumes of raw or potable water. It is expected that these releases reached groundwater over the operating period. Residual contamination in the vadose zone (particularly Cr(VI)) may potentially contribute to continuing groundwater contamination in these areas; however, the actual timing and concentration/mass of released contaminants is uncertain.

Historical releases of reactor cooling gas condensate to cribs located near each of the 100-K Reactors are the apparent source of carbon-14, nitrate, and some tritium in groundwater at 100-K. These cribs received modest, yet regular, discharges of aqueous condensate over the service life of the reactors. This condensate was known to contain substantial concentrations of carbon-14, generated as an activation product within the graphite carbon body of the reactor pile. The cooling gas condensate also contained substantial quantities of ammonia, which was generated at a rate of about one to four pounds of ammonia per day during reactor operation (*Ammonia Generation Rate in K Reactor Gas—Its Effect and Proposed Remedies* [DUN-2018]). Ammonia is readily oxidized by soil microorganisms to nitrate under moist aerobic conditions. Tritium is expected to have been present at variable concentrations in reactor cooling gas due to its presence as a fission product. As with the residual contamination associated with the release of water treatment chemicals at the head houses, residual contamination at the gas condensate cribs may potentially contribute to continuing groundwater contamination in these areas; however, the actual timing and concentration/mass of released contaminants are uncertain.

The transport velocity of contaminants in the saturated zone is dependent on the groundwater flow velocity and the specific retardation factor of each individual contaminant. The groundwater flow velocity increases with increasing hydraulic conductivity and hydraulic gradients, yet decreases with increasing porosity. The retardation factor of contaminants in a given geologic unit increases with increasing K_d. Each of these variables is dependent, in turn, upon other factors and will be discussed in some detail in this section.

Recharge. The recharge rate at 100-K has changed significantly from the period of reactor operations to current conditions. Large volumes of liquid wastes percolating through the vadose zone caused a mound in the water table in 100-K during operations. After the production ceased, the large volume effluent disposal ended and the hydraulic gradients began to return to natural conditions.

Discharged reactor effluent infiltrated to groundwater through the 116-K-2 Trench in 100-K. Reactor operations at 100-K ended in 1971. Hydrographs from wells near the 116-K-2 Trench indicate that significant groundwater mounding occurred between 1955 and 1970, and largely dissipated by approximately 1975 (Figure 5-13). A mapping analysis was undertaken to characterize the extent of mounding and to evaluate its effect on flow direction and potential contaminant migration pathways. Groundwater levels were measured on a reasonably regular basis in monitoring wells near the 116-K-2 Trench during and following the operation of the 100-K Reactors. Figure 5-12 clearly illustrates periods during which groundwater levels were elevated in response to effluent disposal in the trench.

To characterize the extent of mounding created by the infiltration at the 116-K-2 Trench, and to evaluate its effect on flow direction and potential contaminant migration pathways, an analysis was undertaken as part of this RI/FS to map the water levels measured during and following the infiltration, and to evaluate the resulting pattern of hydraulic gradients and resulting groundwater flow directions during each of these periods. To accomplish this, water elevations that were measured in monitoring wells were mapped using a water level mapping technique that incorporates mounding in response to injection of water (*Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance* [SGW-42305]). This technique combines universal kriging of the water levels with a linear trend and an additional term to account for aquifer response to infiltration at a line source of water.

Since the Columbia River influences groundwater elevations, an estimate of the river stage throughout the period of interest was required to construct the water level maps. Although water level data are available throughout the period of interest, only recent river stage data are available. To obtain estimated river stage elevations throughout the period of interest, an empirical function was developed for each river gauge location by developing a correlation between daily river gauge values for the period 2006 to 2009 and daily average dam discharge rates from the Columbia River gauge below Priest Rapids Dam for the same period. This empirical function was then used to calculate an approximate river stage at each river gauge for each event on which groundwater levels are available during the historical period of interest. Additionally, linear interpolation between these gauge level estimates provided a continuous estimate of the river stage along the shoreline for inclusion in the water level mapping.

Water level maps were prepared using the combined water level and river stage data. Two example water level maps are provided in Figure 5-13, illustrating approximate groundwater flow patterns during and at some time following the period of evident mounding. Maps reflecting conditions during operation of the 116-K-2 Trench (such as Figure 5-13, inset 1) indicate that the infiltration of effluent water provided a mechanism to transport contaminants at relatively low concentrations inland of the 116-K-2 Trench and toward the 100-N Reactor area. Water level maps prepared using data obtained some time after the cessation of the infiltration (such as Figure 5-13, inset 2) suggest that under current conditions, migration would be primarily toward the Columbia River.

The magnitude and extent of the estimated groundwater mound illustrated in this simulation is consistent with the description of the mound made in the early 1960s during an examination of groundwater conditions under the Hanford reactor areas (HW-17770).

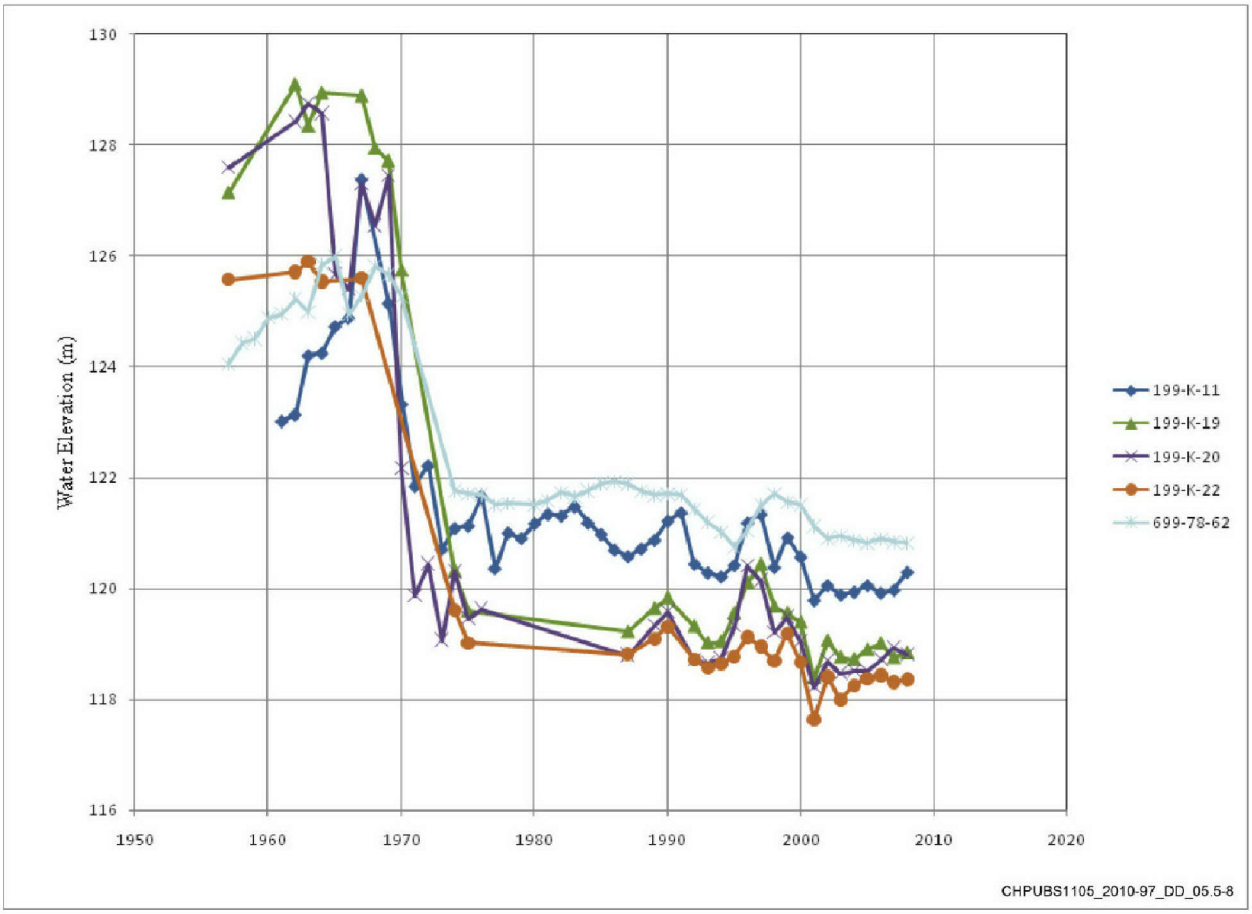

Figure 5-12. Water Level Hydrographs at Selected Wells near the 116-K-2 Trench since 1957

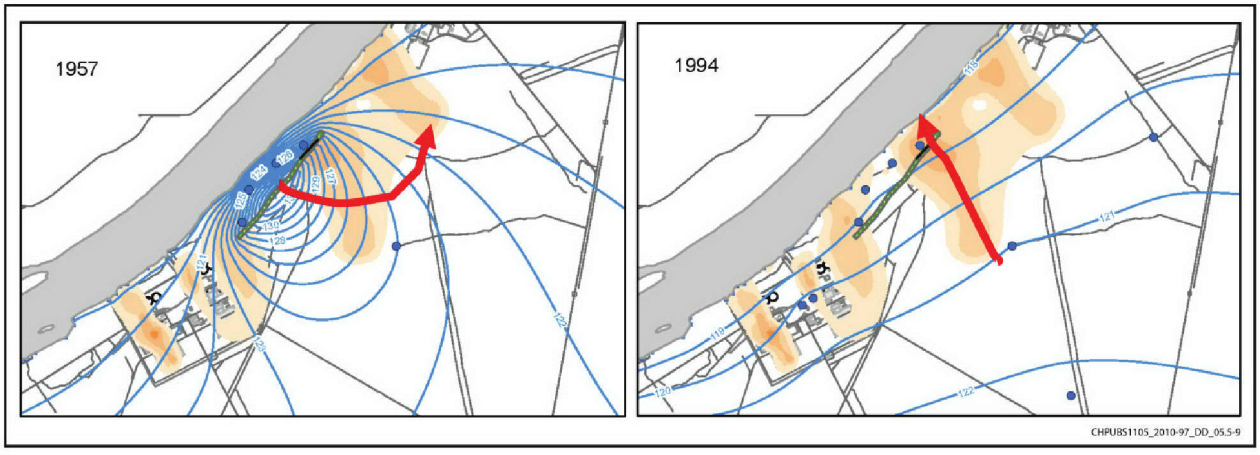

Figure 5-13. Water Level Distributions and Potential Plume Migration Pathways due to the 116-K-2 Trench Mounding

Sorption. The primary groundwater COPCs identified in Chapter 4 and discussed in detail in the annual groundwater reports for 100-K are total chromium, Cr(VI), nitrate, carbon-14, Sr-90, tritium, and trichloroethene.

Cr(VI), tritium, carbon-14, and nitrate are highly mobile (Table 5-3) and migrate at the same velocity as groundwater under ambient geochemical conditions. Sr-90 in 100-K groundwater is a divalent cation and is considered slightly mobile in near neutral or slightly basic groundwater. TCE is a moderately mobile chlorinated solvent. Cr(VI) is assumed to exhibit a K_d of zero in the groundwater transport simulations.

Groundwater Extraction and Reinjection Systems. The 100-K pump-and-treat systems are described in detail in Chapter 1. The 100-KR-4 pump-and-treat system began operating in 1997, the 100-KW system was added in 2007, and the 100-KX system began operating in 2009 to expand the area of influence around the 116-K-2 Trench and triple the capacity of the treatment system. The systems are operated to prevent Cr(VI) from reaching the Columbia River at concentrations greater than the 10 µg/L aquatic water quality criterion, and to prevent contaminant migration toward 100-N (*Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2* [DOE/RL-2010-11]).

The capture efficiency of these systems was evaluated using a numerical groundwater flow model. The modeling approach and the results of the evaluation are presented later in this report.

Columbia River Stage Variations. As discussed in Chapter 1, the nearby Columbia River is a discharge boundary for the aquifer system, and the aquifer is in direct communication with the river along the shoreline of 100-K. Changing river stage influences groundwater elevations several hundred meters inland from the river. Consequently, during high river stages, the inland flow direction in areas near the river and the reduced hydraulic gradients in more inland areas reduce the annual net groundwater flow velocity toward the Columbia River and the migration rate of contaminants dissolved in the groundwater.

5.6.3 Saturated Zone Modeling Methods and Results

A groundwater flow and contaminant transport model has been developed and calibrated for remedy design evaluation purposes in the 100 Area. The model development and calibration is comprehensively documented in *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* (SGW-46279). The groundwater flow model is constructed using the U.S. Geological Survey (USGS) modular groundwater flow model MODFLOW ("A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model" [McDonald and Harbaugh, 1988]). Particle tracking was performed using the USGS program MODPATH (*User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model* [Pollock, 1994]). MT3DMS (1998 to present) was used to simulate the contaminant plume migration (*MT3DMS: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide* [Zheng and Wang, 1999]).

A summary description of the model development and deployment is presented below and additional details are presented in Appendix F.

Model Structure. The groundwater flow model grid encompasses all 100 Area OUs. The model finite difference grid is constructed so the northwest and northeast boundaries of the flow model parallel and abut the Columbia River. The model extends southward, toward Gable Butte and Gable Mountain. The grid spacing is relatively coarse (about 100 m) throughout much of the domain, but it is refined (15 m) in the area of each 100 Area OU to support remedy evaluations.

Groundwater flow is simulated as three-dimensional using four layers to represent the Hanford formation (always present in Layer 1) and the Ringold Formation unit E (typically represented by Layers 2 through 4, except where absent east of 100-D). Throughout much of the western half of the modeled area (including 100-K and 100-D), the water table lies within the Ringold unit E sands, whereas toward the

east and north of the modeled area (including 100-H and 100-F), the water table lies within the Hanford formation sands and gravels. Near 100-BC, the water table fluctuates between the two formations.

The base of the model is assumed the top of the RUM where present and the top of the basalt where the RUM is absent, which typically occurs in the southern portions of the model approaching Gable Butte. The geologic characterization compiled as part of the Model Data Package (100-KR-4 RPO Mod Data Package [SGW-41213]) depicts the lateral transition from the Ringold unit E in the west and south of the model domain, to the Hanford formation sands and gravels in the east and north of the model domain, between 100-D and 100-H.

The establishment of the initial plume condition for the simulation was intended to describe an approximation of the current contaminant distribution and applied a conservative approach. The model domain for the saturated formation is subdivided into three layers of equal thickness between the water table and underlying RUM at any particular location in the domain. Contaminant measurements at individual monitoring wells were distributed uniformly across the three vertical layers at measurement locations. Subsequent transport simulations allow for movement of contaminants between the layers in the saturated zone. The model domain of the saturated zone is subject to uncertainty in contaminant distribution due to variability in actual well construction and screen placement. The placement of contaminants across the full thickness of the aquifer in the initial condition, along with selection of maximum observed concentrations at each well location over the selected baseline period, is expected to be conservative in light of vertical profile measurements that indicate actual substantial variation in vertical contaminant distribution.

The principal aquifer property specified in the flow model is the spatially varying hydraulic conductivity of the saturated aquifer materials. The hydraulic conductivity distribution in the model was developed based on the information included in the Model Data Package and a pilot-point approach implemented in the model calibration process. Estimates of hydraulic conductivity compiled as part of the Model Data Package were tabulated and assigned to their corresponding aquifer unit. The mean values for the aquifer hydraulic conductivity that resulted from the model calibration process are 6 m/day for Ringold unit E in the 100-K region of the aquifer and 63 m/day for the Hanford formation.

Areal recharge from precipitation was specified based on information included in the Groundwater Data Package for Hanford Assessments (*Groundwater Data Package for Hanford Assessments* [PNNL-14753]). An electronic version of the recharge package developed in this report was obtained, and the data were spatially distributed to the model grid cells and were subsequently adjusted during model calibration. Based on the results of the model calibration, the recharge value was set equal to 12 mm/yr throughout much of the model domain. Local recharge conditions (e.g., surface reservoirs) were assigned recharge rates based on reported values (*In Situ Redox Manipulation (ISRM) Annual Report Fiscal Year 2007* [DOE/RL-2008-10]). The calibrated typical recharge value of 12 mm/yr is lower than those used in the STOMP modeling for PRG calculation at 100-K. Groundwater flow is modeled for a much larger area and the surface cover over much of that area is undisturbed native vegetation. This contrasts with the 100-K specific and intentionally conservative bare soil net infiltration rates during 2010 and 2015 used for PRG development.

Effective porosity and specific yield values for the entire aquifer were identified from published sources and revised during the model calibration and are equal to 18 and 10 percent, respectively. Both values are within the range of values documented in previous investigations for Hanford (*Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report* [PNNL-10886]). Riverbed conductance values were also determined during calibration, separately for the stretches of the Columbia River within each area, to reflect the variability in geologic conditions in each area.

The groundwater flow model was calibrated to data included in the Model Data Packages for each OU, through a combined manual and automated process. The model calibration was facilitated by the use of the PEST parameter estimation software program (*User's Manual for PEST Version 11* [Doherty, 2007]) and post processing programs that calculate water-level responses to stresses. The model was calibrated to data from January 2006 to December 2010. Calibration focused on the transient response of water levels to changing stresses and how they compare to values measured at wells at each OU. In addition, maps of water level contours calculated by the model were compared to contours included in published reports to ensure that the simulated hydraulic gradient magnitude and direction agree with prior independent interpretations.

Further details about all parameter values used in the model are included in the comprehensive modeling report (*Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* [SGW-46279]).

Contaminant Transport Processes. The migration of Cr(VI) in response to current and projected extraction and injection well operations in 100-KR-4 was simulated to support remedy design evaluation; total chromium is anticipated to follow similar patterns. In addition to modeling of Cr(VI), transport simulations were performed for tritium, Sr-90, nitrate, and carbon-14 to evaluate corresponding migration patterns as a result of the current and projected extraction and injection well operations.

Transport simulations were based on the following:

- Transient flow fields calculated by the groundwater flow model
- An initial distribution for the Cr(VI) in groundwater
- A dual-domain formulation representing plume migration in a dual-porosity continuum with mass transfer between the mobile and immobile domains

Recent studies by PNNL (such as *Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site* [PNNL-17674]) suggest that Cr(VI) within vadose zone of the 100 Area exhibits migration characteristics that may be more complex than can be represented using simple advection. According to these tests, although the majority of the mass is highly mobile and migrates by advection, Cr(VI) mass can be held in heterogeneous parts of the aquifer of low hydraulic conductivity. This immobile Cr(VI) constitutes a longer-term continuing source of chromium to the mobile domain facilitated by mass transfer between the domains. Based on these observations, the migration of Cr(VI) can be described by a dual-domain (or dual-porosity) approach that divides the aquifer into two domains: the mobile and immobile. Advective transport occurs predominantly in the mobile domain while mass transfer occurs by diffusion between the mobile and immobile domain.

MT3DMS supports the use of a dual-domain formulation to simulate the transport of a contaminant in groundwater. To do so, the following parameters must be defined for the dual domain formulation: the fraction of mobile and immobile domains; the mass transfer coefficient between the mobile and immobile domains; and K_d describing sorption within the mobile and immobile domains. For the 100 Area transport model, it was assumed that sorption occurs only within the immobile domain so the K_d in the mobile domain is zero. The parameter values for the dual-domain formulation for transport simulation are listed in Appendix F. Further details on the development of the dual-domain parameters can be found in the comprehensive modeling report (*Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* [SGW-46279]).

Radioactive decay was considered for tritium ($T_{1/2}$ = 12.3 years), Sr-90 ($T_{1/2}$ = 28.8 years), and carbon-14 ($T_{1/2}$ = 5,730 years).

Contaminant Initial Conditions. Initial conditions for the Cr(VI) in groundwater within the 100-KR-4 OU were obtained using maximum sampled Cr(VI) concentrations at each monitoring location during the period 2009 to 2010. The selection of the maximum observed concentrations provides a more comprehensive and conservative view of the groundwater contamination conditions, particularly in situations where contaminant concentrations exhibit substantial temporal transients, as observed at 100-K. The result is an initial plume condition distribution that extends over a slightly larger contiguous area and indicates slightly higher concentrations than the plumes presented in Chapter 4, which are based on plotting of annual average concentrations from selected wells. In addition, the purpose of the plume depictions in Chapter 4 is to provide an overview of areas of the aquifer that exceed specific criteria (e.g., the MCL), whereas the plume depiction in Figure 5-14 is intended to be the starting point for the contaminant transport simulations. Calculation of the initial distribution was performed using Quantile Kriging, a robust interpolation method ("Spatial Interpolation Methods for Nonstationary Plume Data" [Reed et al., 2004]) and was based on a stepwise procedure that includes adjustments to the interpolated distribution to reflect institutional knowledge of the historical plume migration and the local conditions affecting the actual Cr(VI) distribution in the aquifer. The initial Cr(VI) distribution in 100-KR-4 is shown in Figure 5-14.

The same procedure was followed for the development of initial conditions for the other COCs. Figures 5-15 to 5-18 show the resulting distributions for tritium, Sr-90, nitrate, and carbon-14, respectively.

Model Deployment. The groundwater flow and transport model was used to simulate flow conditions and Cr(VI) plume migration patterns, assuming continued operation of the interim pump-and-treat system in the 100-KR-4 OU, which includes the KW, KR, and KX treatment plants and the associated extraction and injection wells. Appendix F includes a list of all pump-and-treat wells with their corresponding pumping rates.

Predictive simulations were based on transient-state (i.e., time-varying) conditions in the aquifer that reflect water-level changes due to river-stage variation. The modeling period corresponds to a 77-year period (CY 2011 to CY 2087) corresponding to the period 2011 to 2012 and a 75-year simulation period thereafter with constant rates for all pump-and-treat wells, representing December 2012 operations. For the period 2011 to 2037, the modeling period consists of a series of 12 monthly stress periods that are repeated in the same sequence. The stress periods correspond to monthly average river stages, each representing the average river stage for the particular calendar month over the period 2006 to 2010 (excluding 2007 values, when the river stage variation pattern was inconsistent to the other years). It is assumed that these conditions are representative of the typical conditions in the field and that future conditions will not vary significantly from these conditions. After 2037, a single stress period is used, with the river stage elevation remaining constant, reflecting annual average conditions corresponding to 2006 to 2010 average elevations for the month of January. This approach allows for generation of a substantial body of simulation information to evaluate the apparent effects of seasonal river stage transients on transport, but also provides for efficient long-term transport estimate and plume behavior calculations.

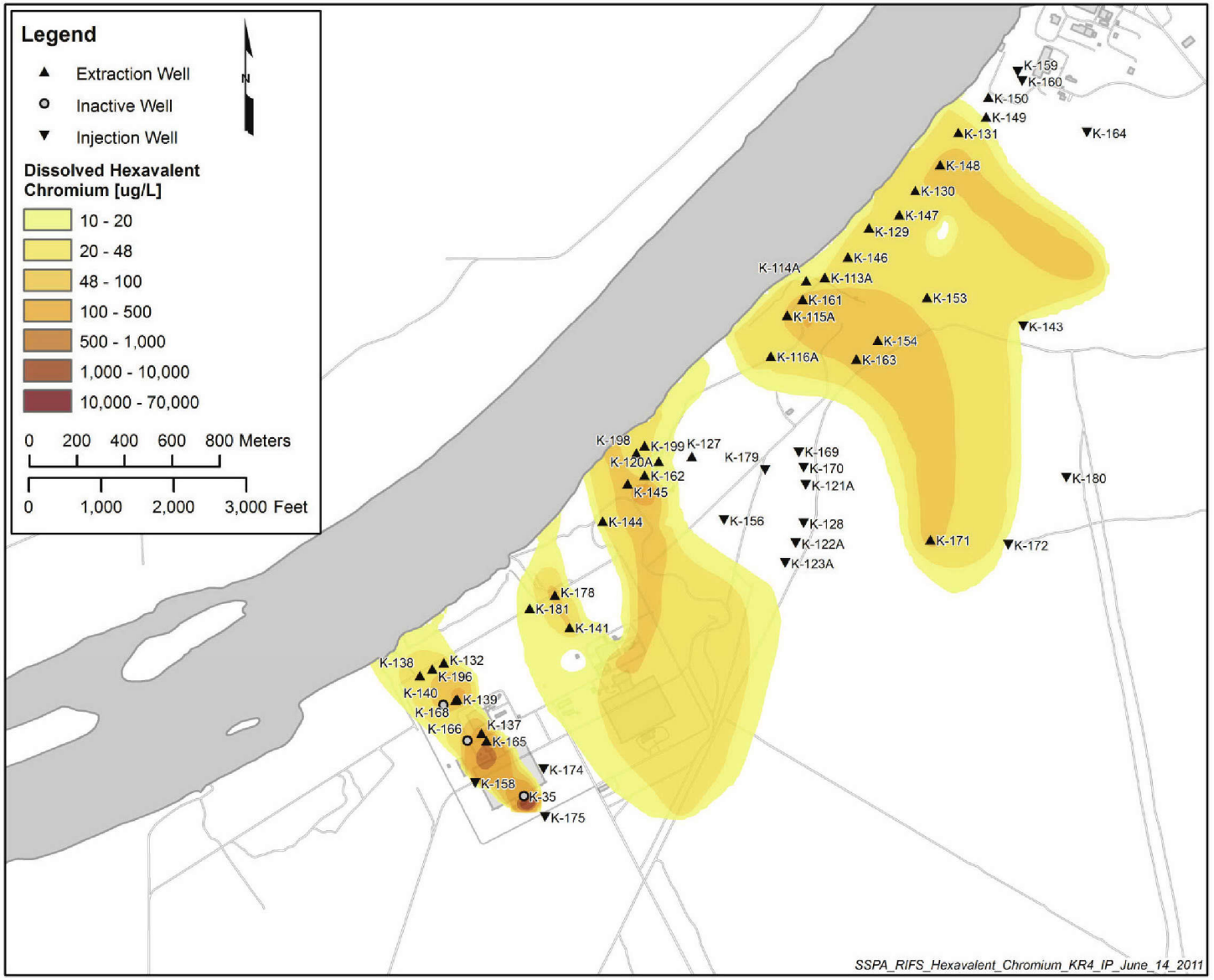

Figure 5-14. Well Configuration and Approximate Extent of Dissolved Cr(VI) in 100-KR-4

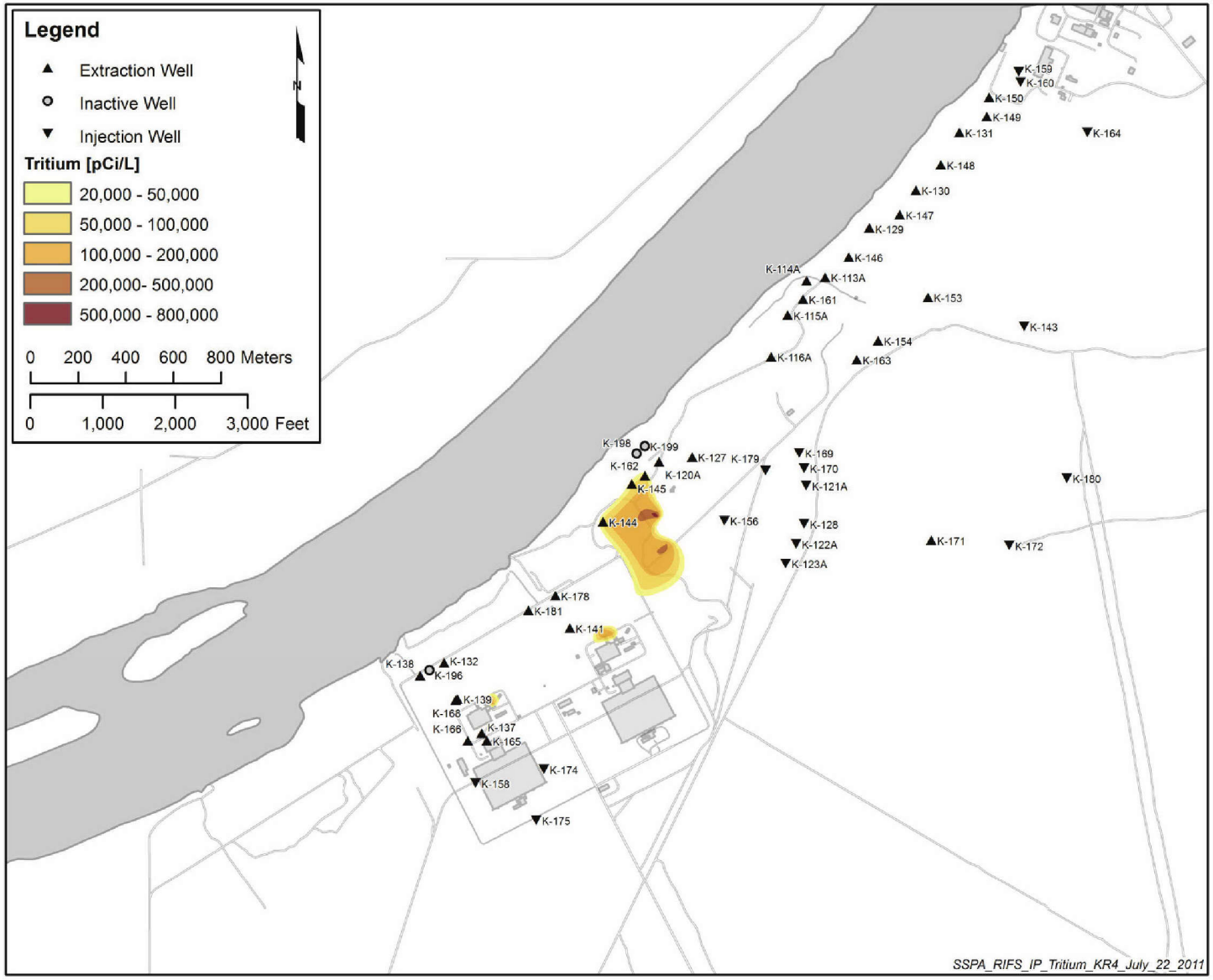

Figure 5-15. Well Configuration and Approximate Extent of Tritium in 100-KR-4

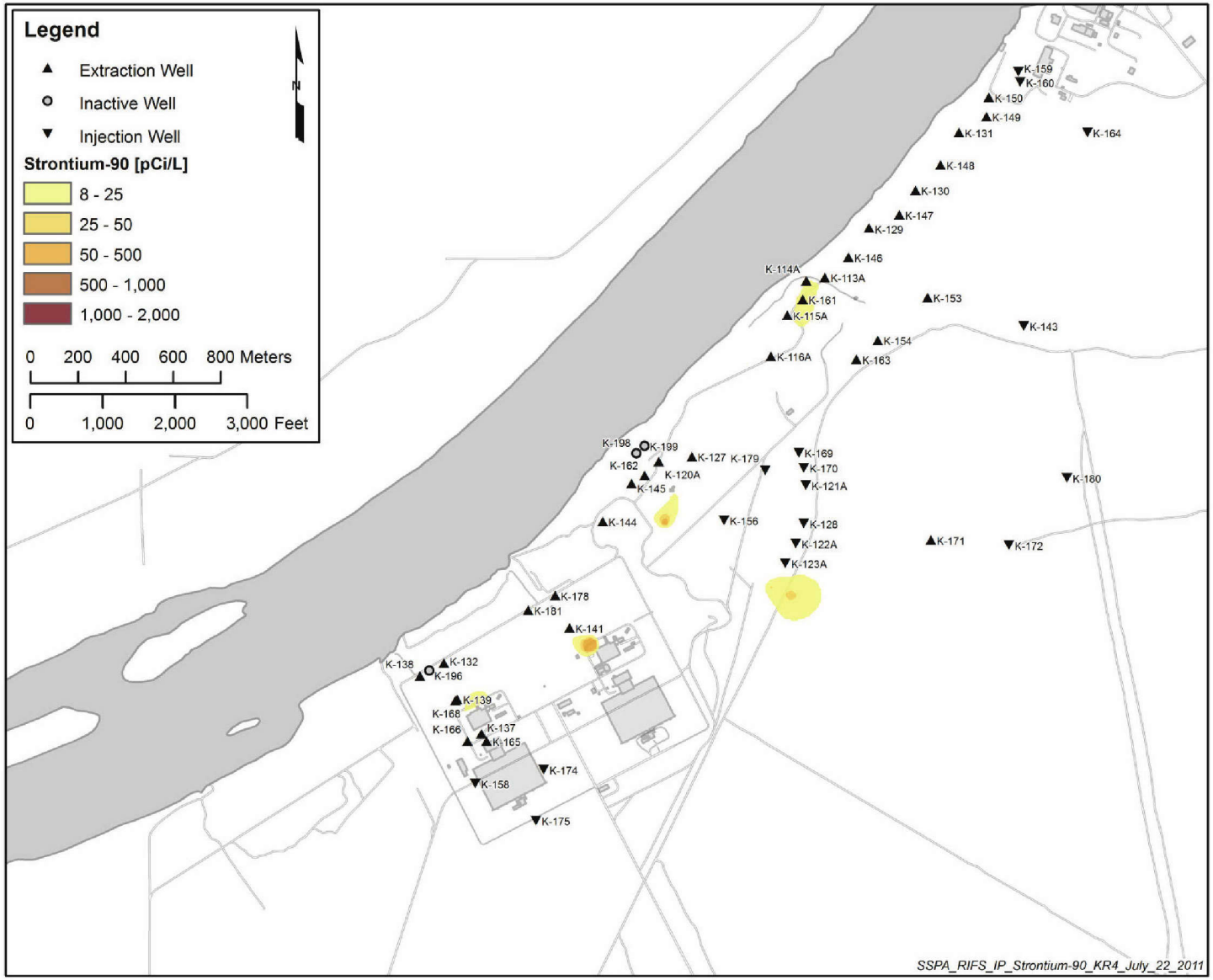

Figure 5-16. Well Configuration and Approximate Extent of Sr-90 in 100-KR-4

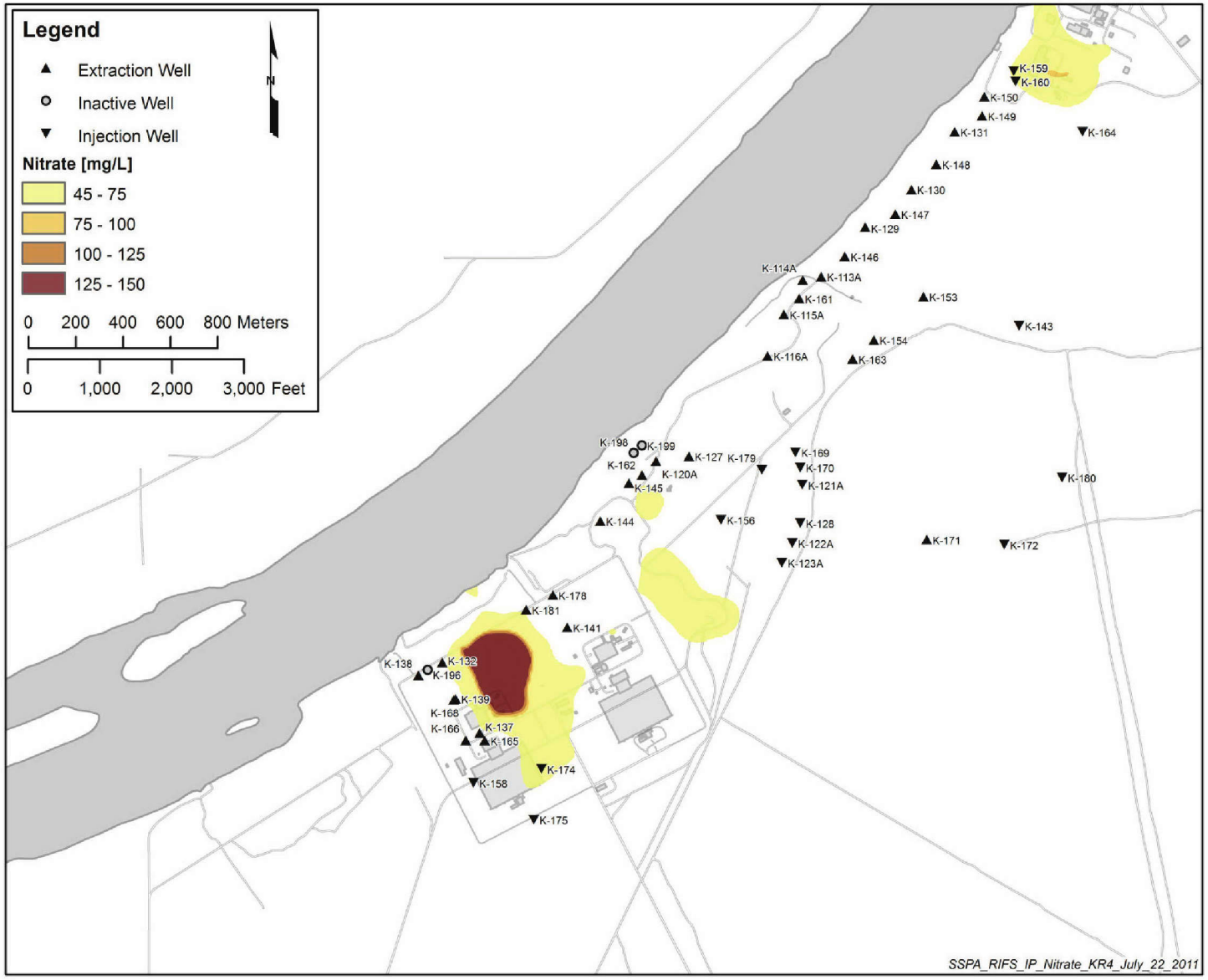

Figure 5-17. Well Configuration and Approximate Extent of Nitrate in 100-KR-4

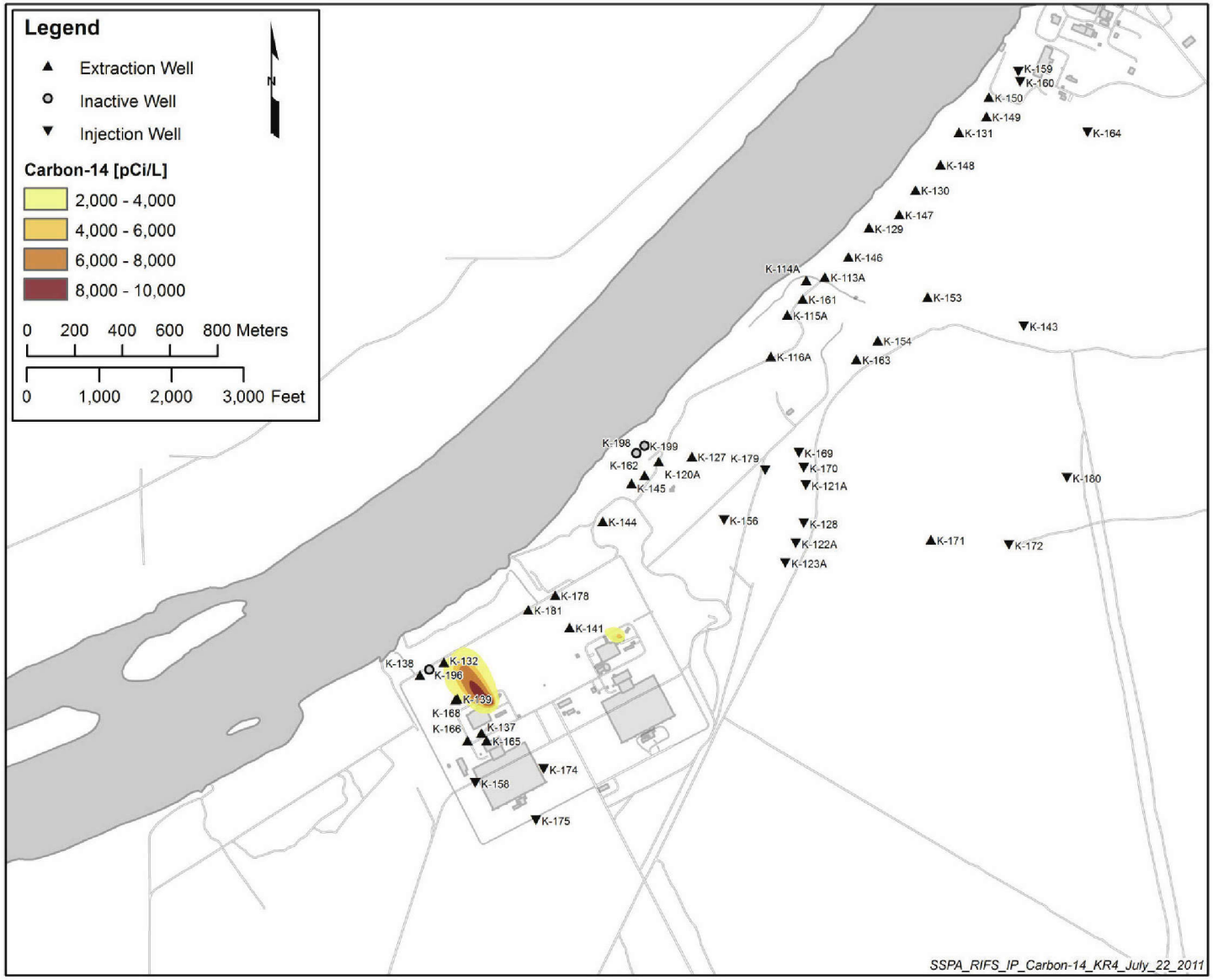

Figure 5-18. Well Configuration and Approximate Extent of Carbon-14 in 100-KR-4

Modeling results will support system performance evaluation considering attainment of river protection and aquifer cleanup goals. For this purpose, an estimate of hydraulic containment in 2012 and plume depictions in 2012, 2015, 2020, 2037, and 2087 are developed and discussed in the following text.

Hydraulic Containment in 2012. A systematic approach was developed and applied to estimated hydraulic containment in 2012 based on groundwater modeling. Although a single depiction of capture can be calculated using particle tracking when a model simulates quasi steady-state conditions, an estimate of the approximate extent of hydraulic capture was calculated with the transient model using an approach similar to that described in "The Capture Efficiency Map: The Capture Zone Under Time-Varying Flow" (Festger and Walter, 2002), and "Sources of Water to Wells for Transient Cyclic Systems" (Reilly and Pollock, 1996), focusing on the evaluation of the temporal variation in capture due to changing flow patterns and hydraulic gradients:

- Releasing particles near the end of each of the 12 monthly stress periods and simulating their migration using a very low effective porosity, ensuring that particle travel times are essentially instantaneous
- Recording the instantaneous fate of each particle during each stress period
- Calculating a capture zone for each stress period based on the "snapshot" of aquifer conditions at the time of the particle release, in this case, producing 12 instantaneous snapshots of the extent of capture
- Constructing a capture efficiency map by counting the number of times a particle originating from a location was captured by a well, and dividing this count by the total number of releases (i.e., 12)

Figure 5-19 shows the capture efficiency map developed for 100-KR-4 in 2012. The calculated capture efficiency suggests there are areas where the capture is satisfactory and areas where the capture is unsatisfactory. Areas of satisfactory capture encompass almost the entire Cr(VI) plume footprint providing protection to the river along the shoreline, particularly close to the pump-and-treat wells. Areas where capture is unsatisfactory include only parts of the plume footprint near the shoreline, where pump-and-treat wells are absent or relatively sparsely placed.

The continued operation of the current pump-and-treat system, as well as selected optimization schemes for extraction and injection well placement and operation, are discussed further in the feasibility study presented in Chapters 8 and 9 of this report.

Contaminant Plume Migration. To present a simulated baseline of groundwater contaminant migration at 100-K OU, the results of simulations described as Alternative 1 for groundwater action are shown in the following figures. Alternative 1 does not include continued active pump-and-treat groundwater remediation in future years. Figures 5-20 to 5-23 show the simulated dissolved Cr(VI) plume distribution in December 2012, and 2020, 2037, and 2087, respectively, based on the current well configuration and treatment system. Figures 5-24 to 5-27 show the simulated plume distributions for tritium in December 2012, 2015, 2020, and 2037, respectively. Figures 5-28 to 5-32 show the simulated plume distributions for Sr-90 in December 2012, 2015, 2020, 2037, and 2087, respectively. Figures 5-33 to 5-37 show the simulated plume distributions for nitrate in December 2012, 2015, 2020, 2037, and 2087, respectively. Figures 5-38 to 5-40 show the simulated plume distributions for carbon-14 in December 2012, 2015, and 2020, respectively.

Plume migration patterns, as estimated by the model, indicate migration of exsiting groundwater plumes toward the river. The predicted concentrations of the contaminants decrease according to their natural decay rate (e.g., for radionuclides), or due to dispersion as they move through the aquifer. Those contaminants with low attenuation (i.e., low K_d) move more rapidly toward the river than those with higher attenuation (i.e., higher K_d).

Figure 5-19. Approximate Extent of Capture throughout the 100-KR-4 Area for January to December 2012

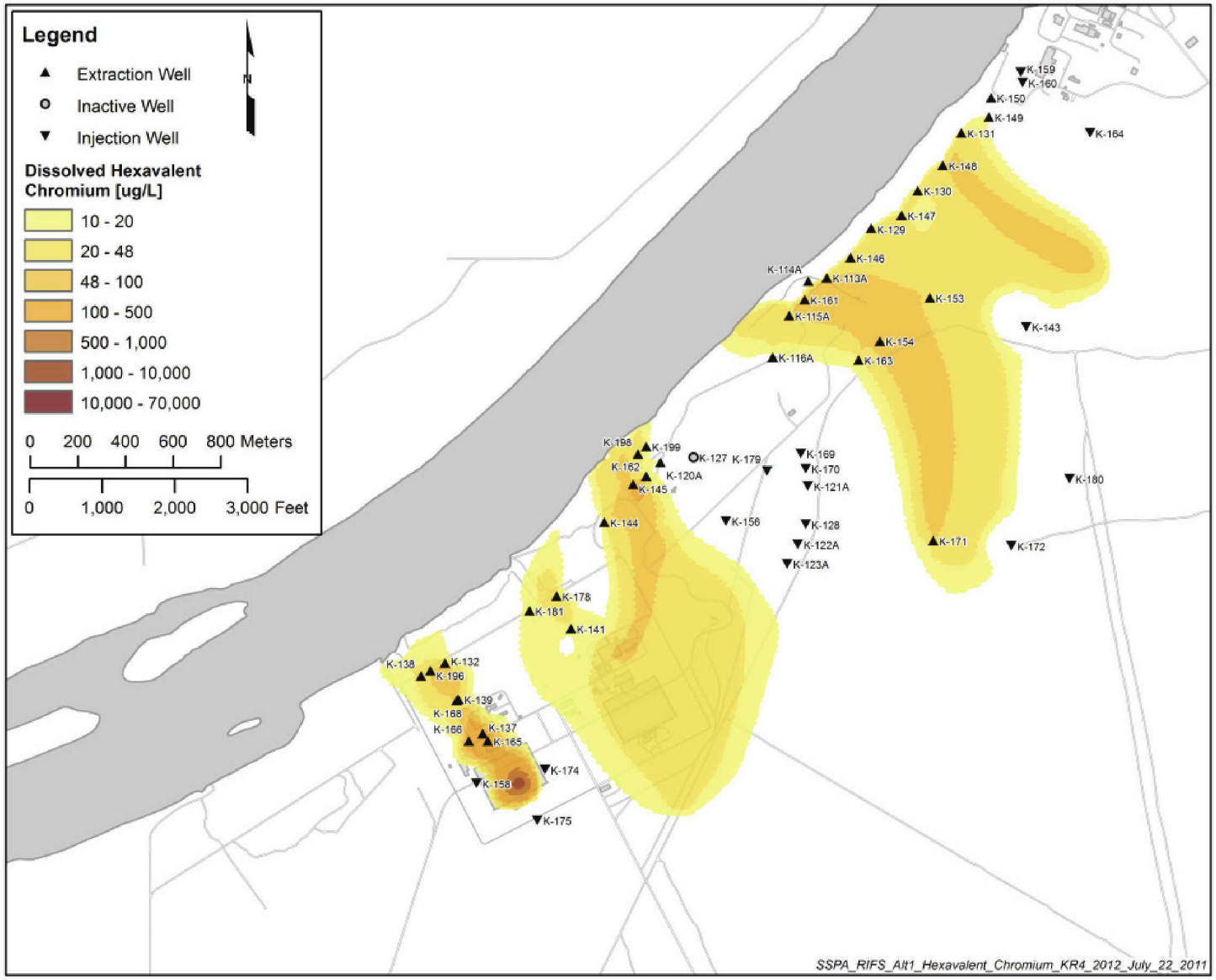

Figure 5-20. Model Simulated Dissolved Cr(VI) Distribution in December 2012

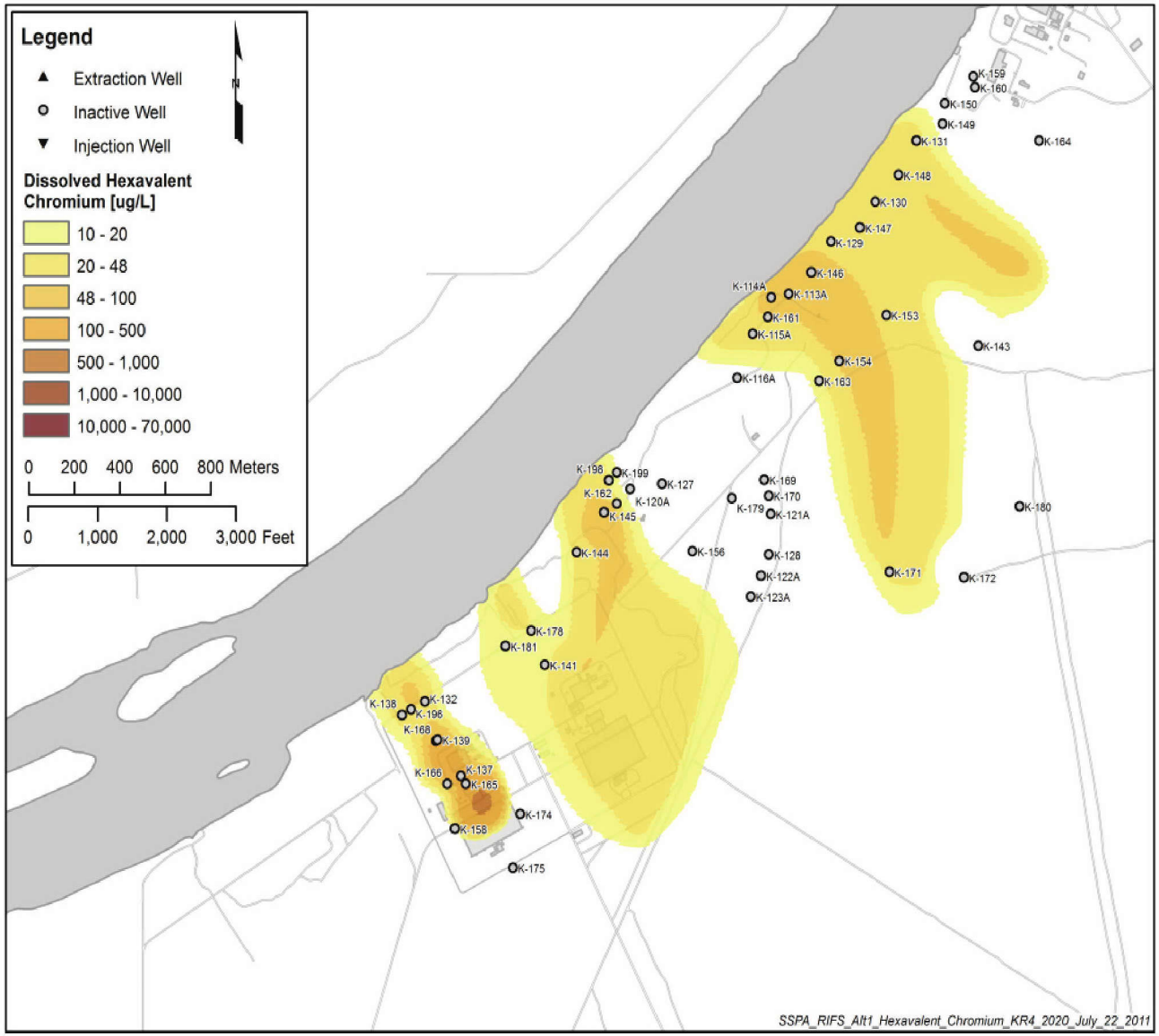

Figure 5-21. Model Simulated Dissolved Cr(VI) Distribution in December 2020

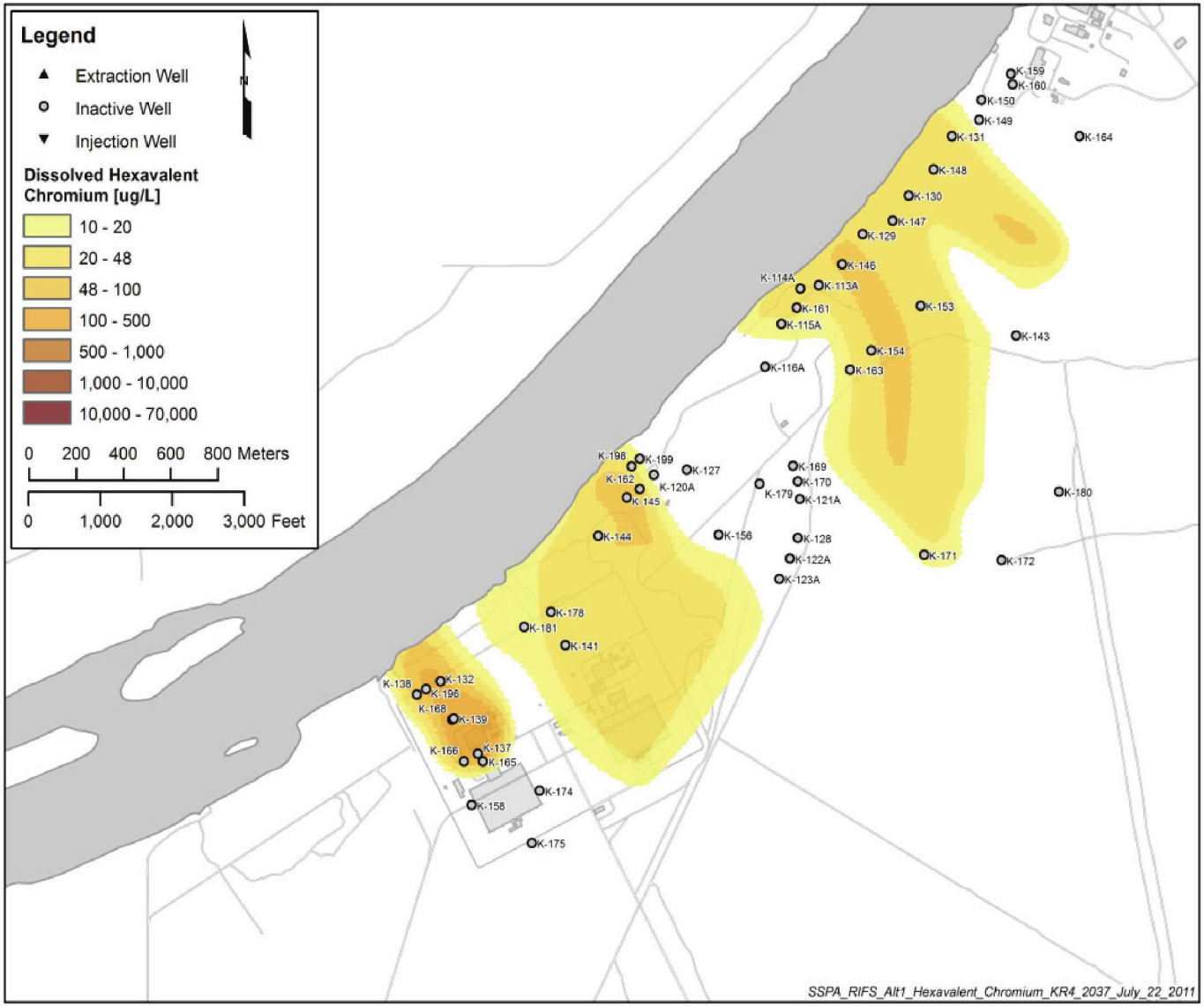

Figure 5-22. Model Simulated Dissolved Cr(VI) Distribution in December 2037

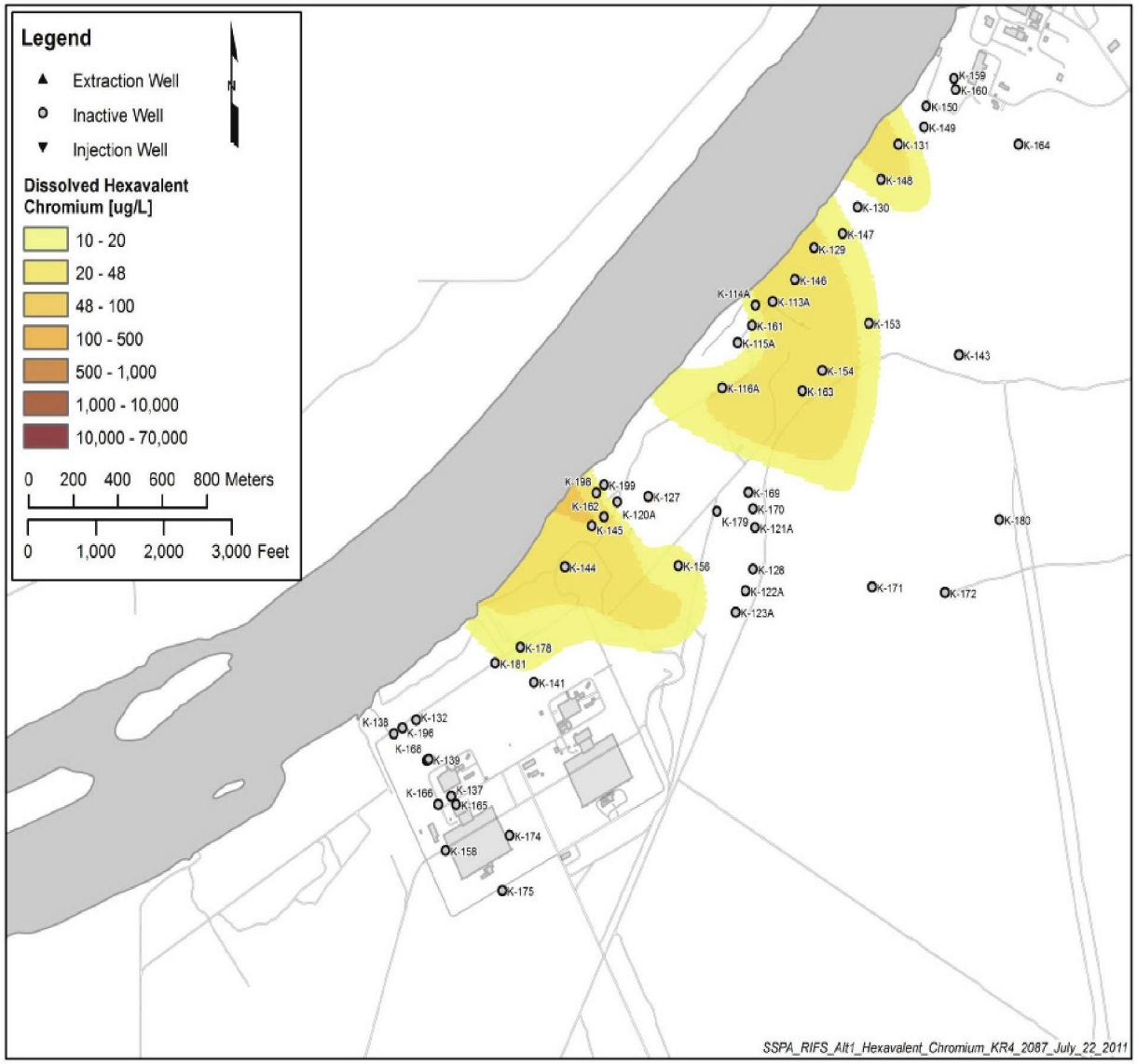

Figure 5-23. Model Simulated Dissolved Cr(VI) Distribution in December 2087

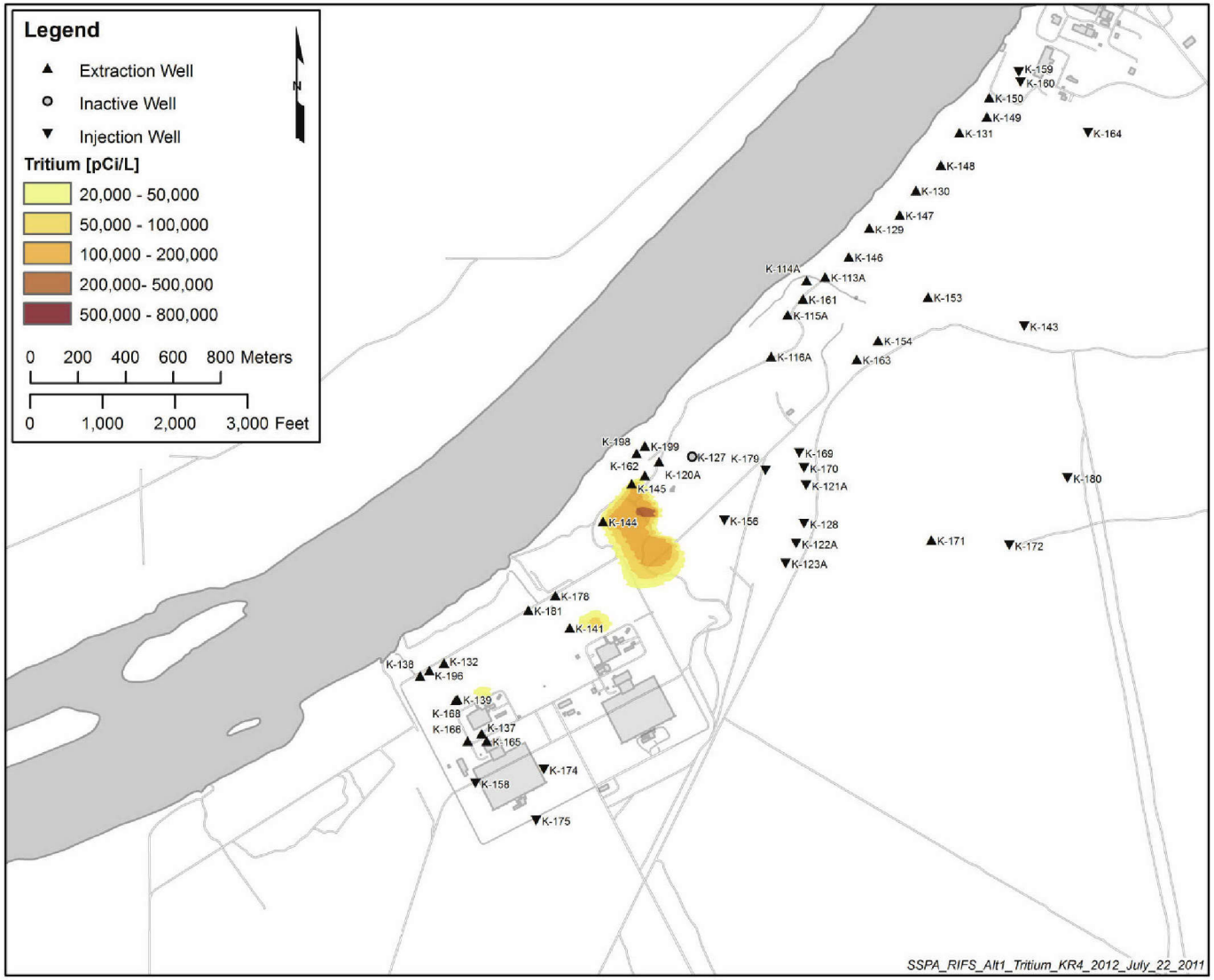

Figure 5-24. Model Simulated Tritium Distribution in December 2012

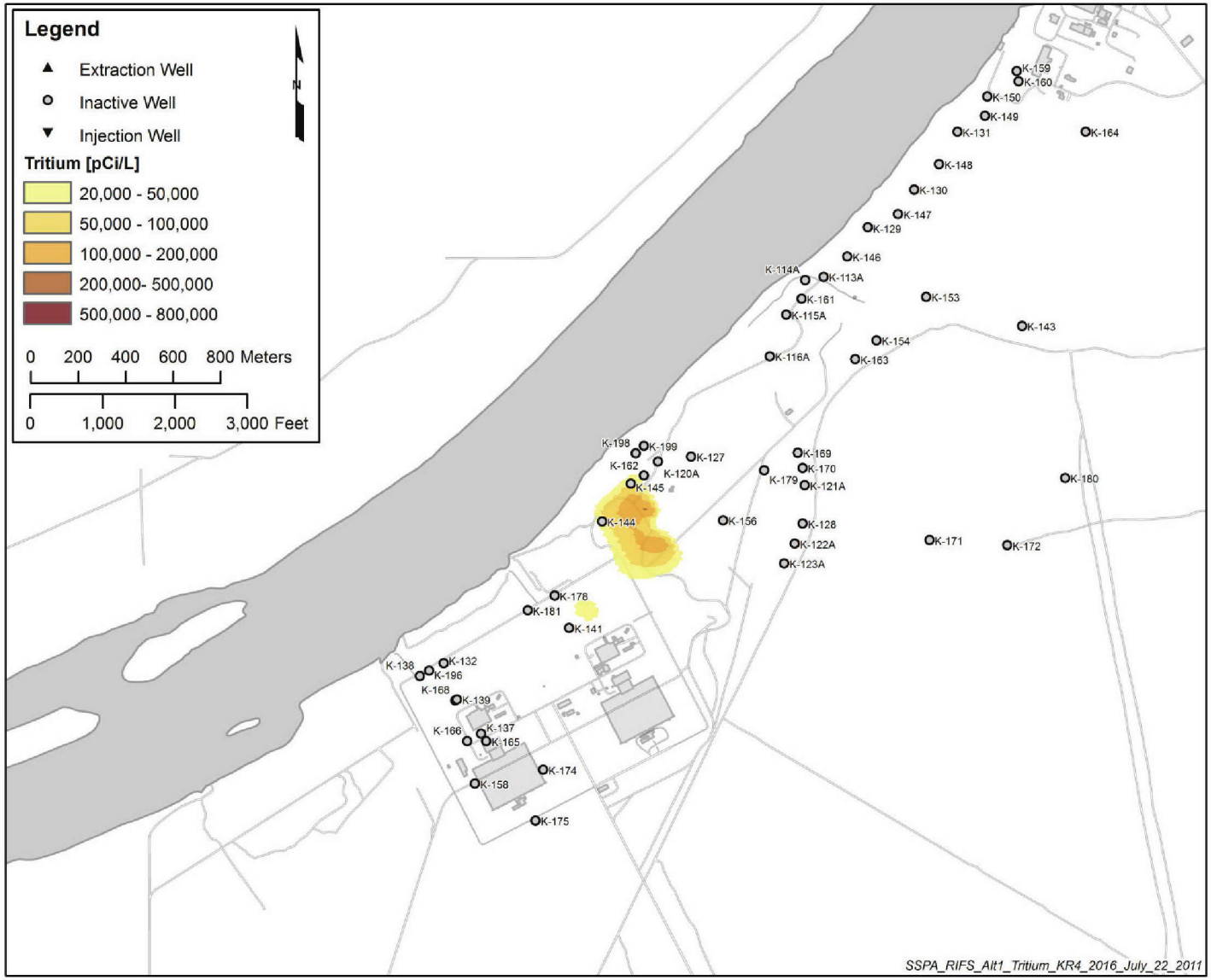

Figure 5-25. Model Simulated Tritium Distribution in December 2016

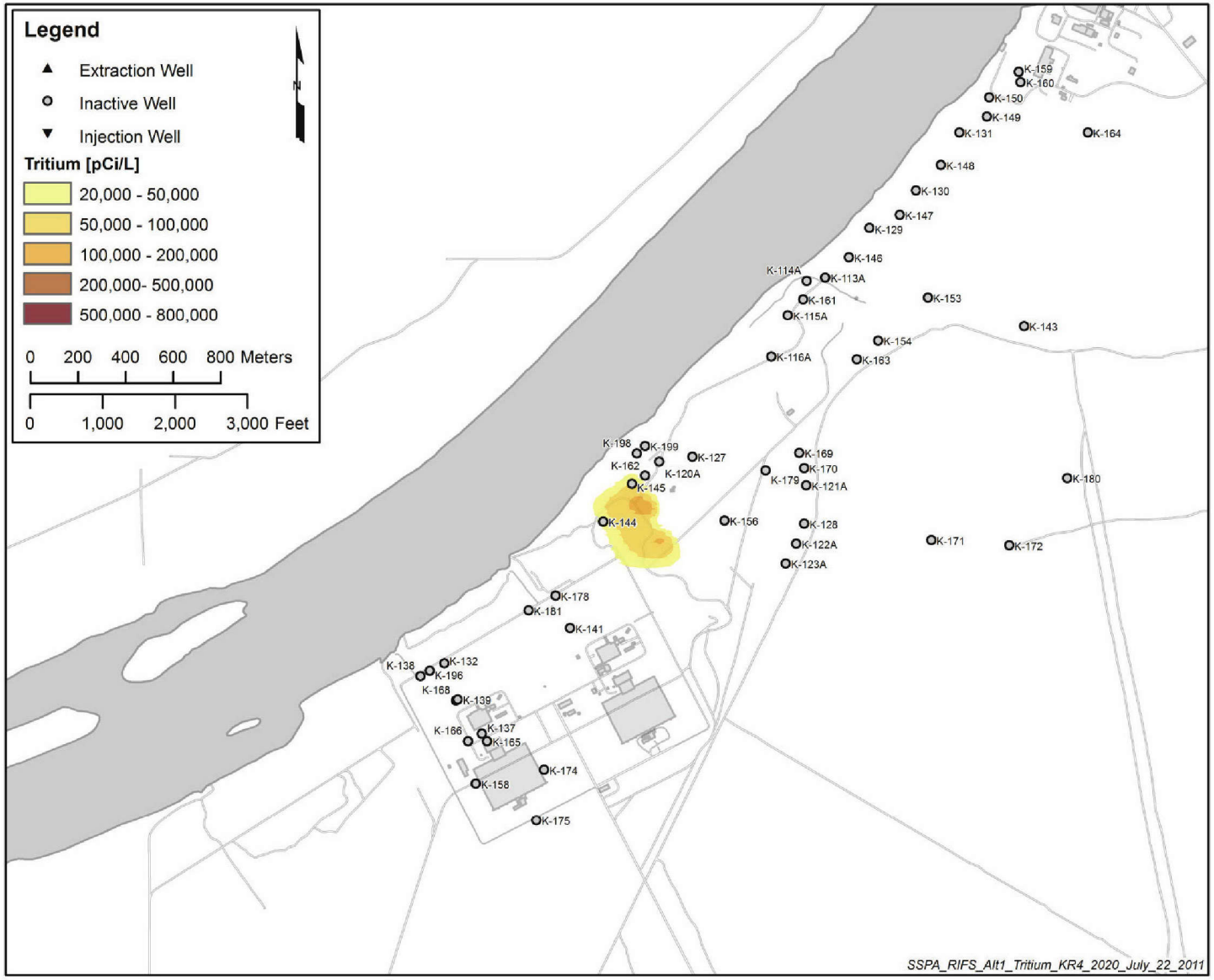

Figure 5-26. Model Simulated Tritium Distribution in December 2020

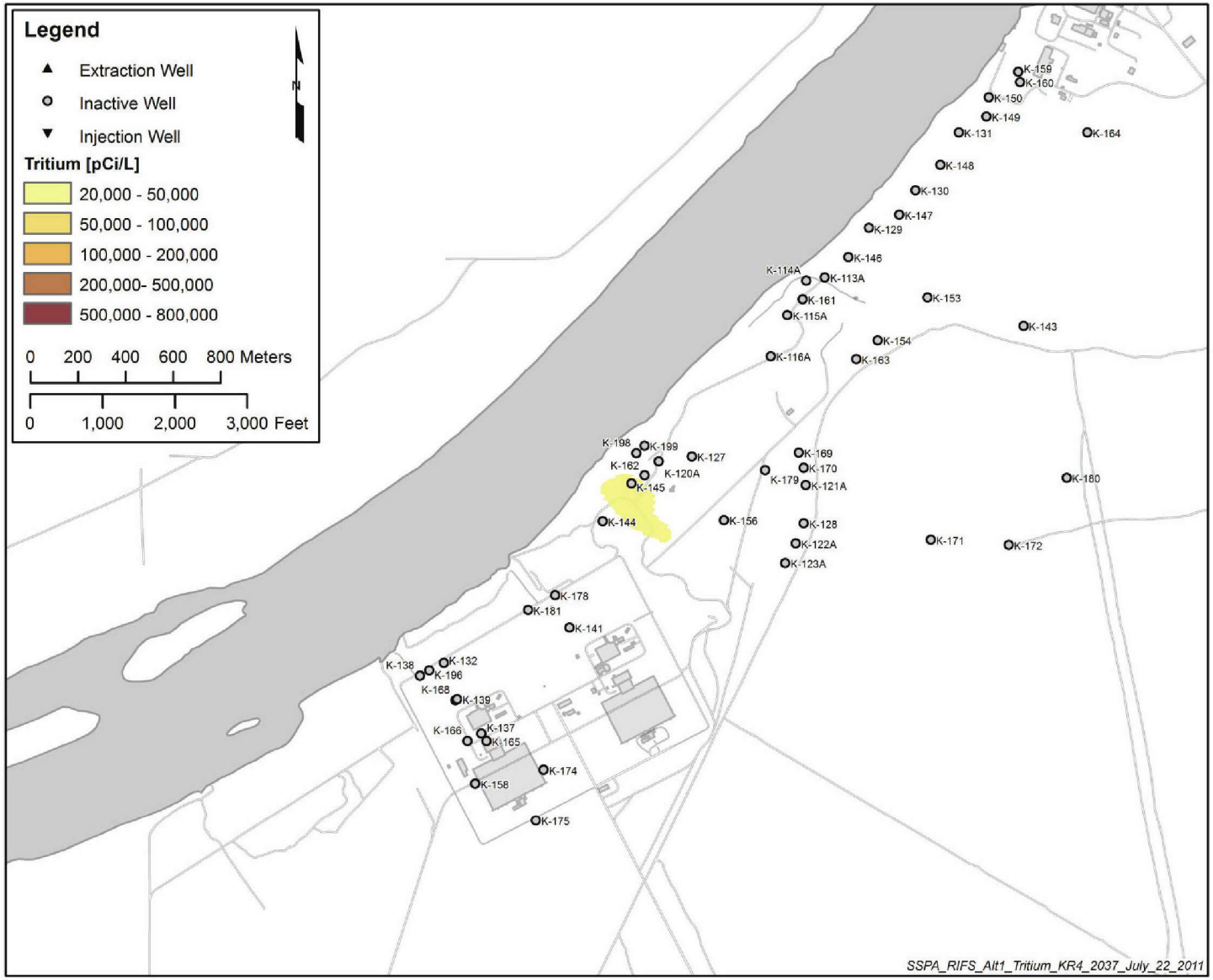

Figure 5-27. Model Simulated Tritium Distribution in December 2037

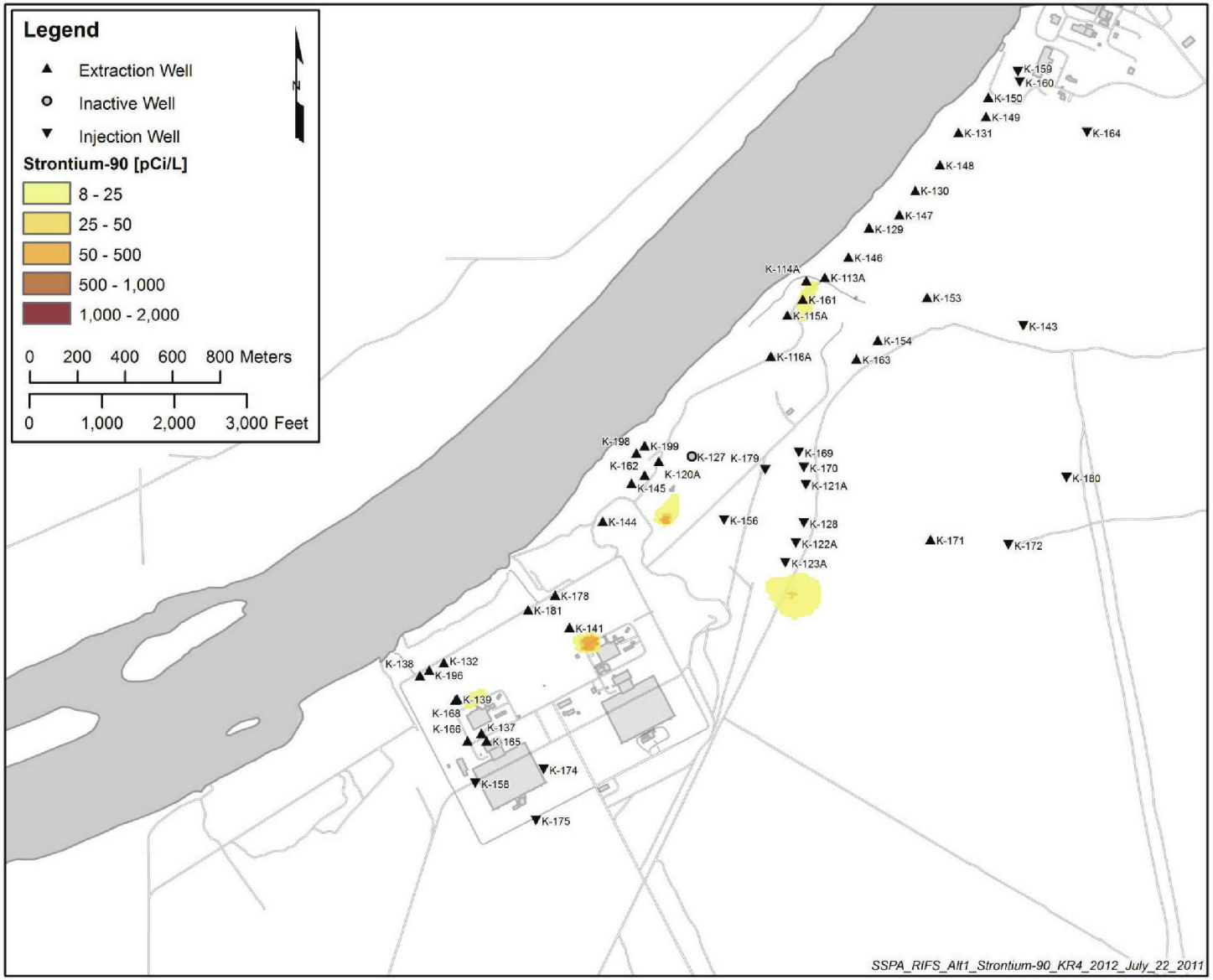

Figure 5-28. Model Simulated Sr-90 Distribution in December 2012

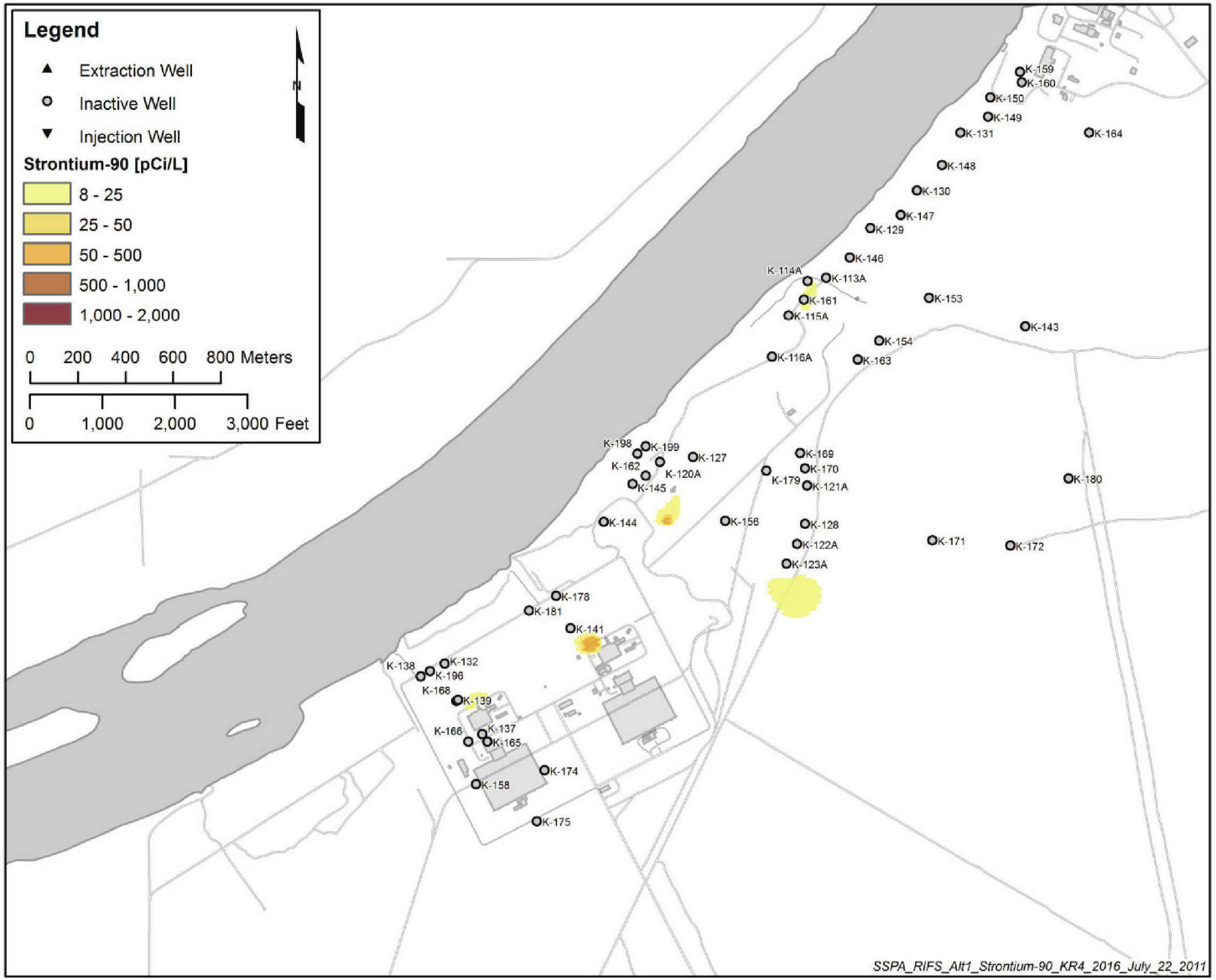

Figure 5-29. Model Simulated Sr-90 Distribution in December 2016

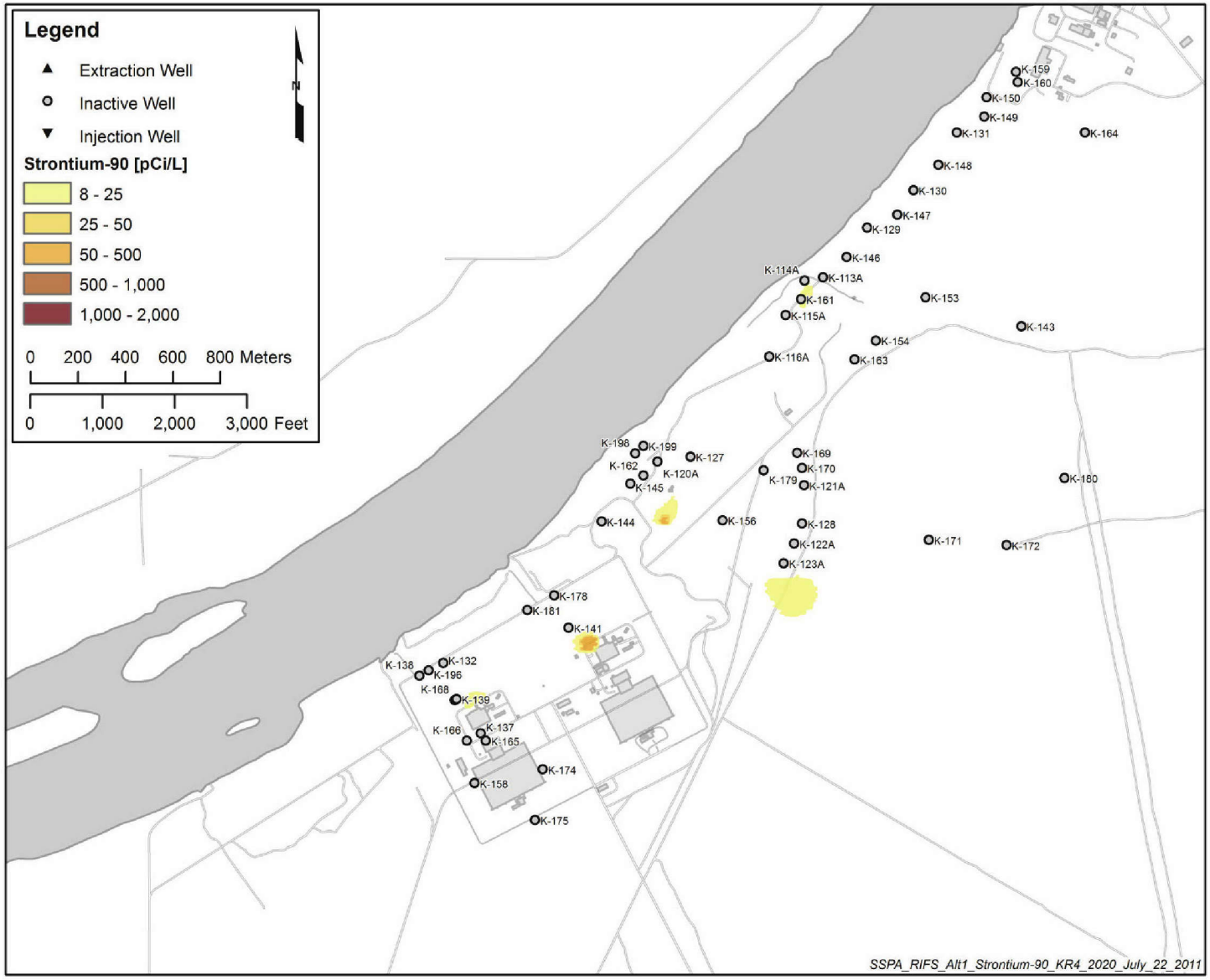

Figure 5-30. Model Simulated Sr-90 Distribution in December 2020

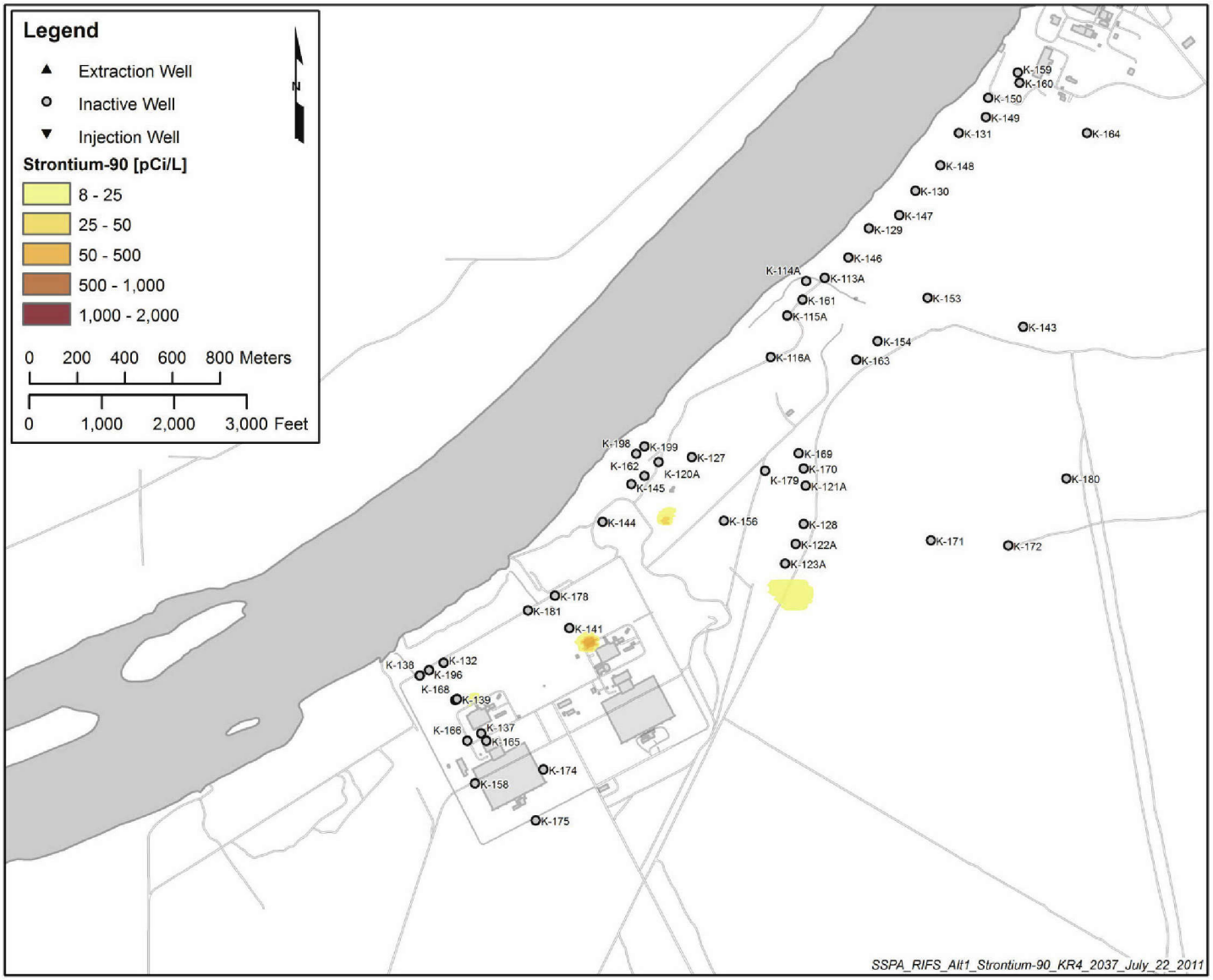

Figure 5-31. Model Simulated Sr-90 Distribution in December 2037

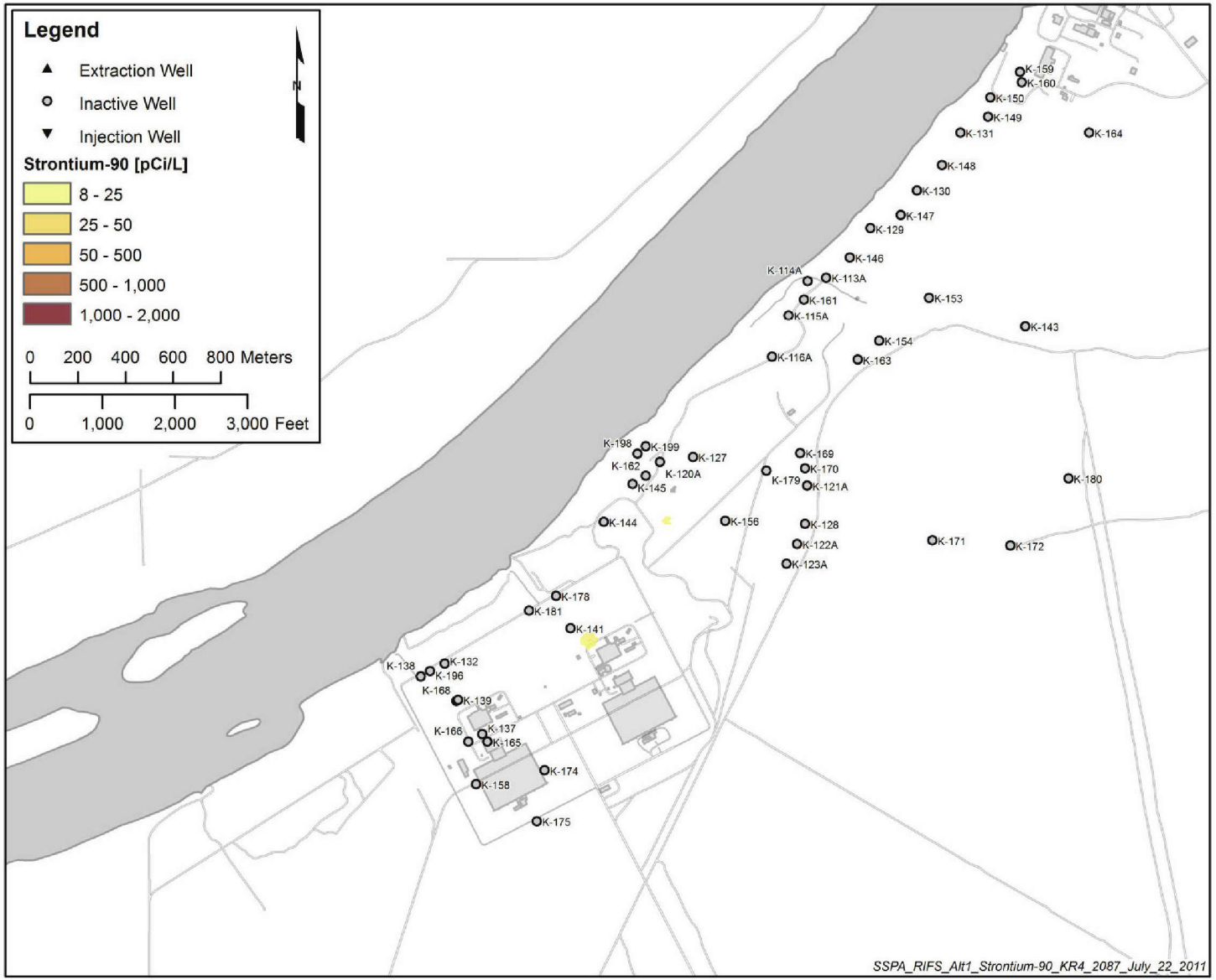

Figure 5-32. Model Simulated Sr-90 Distribution in December 2087

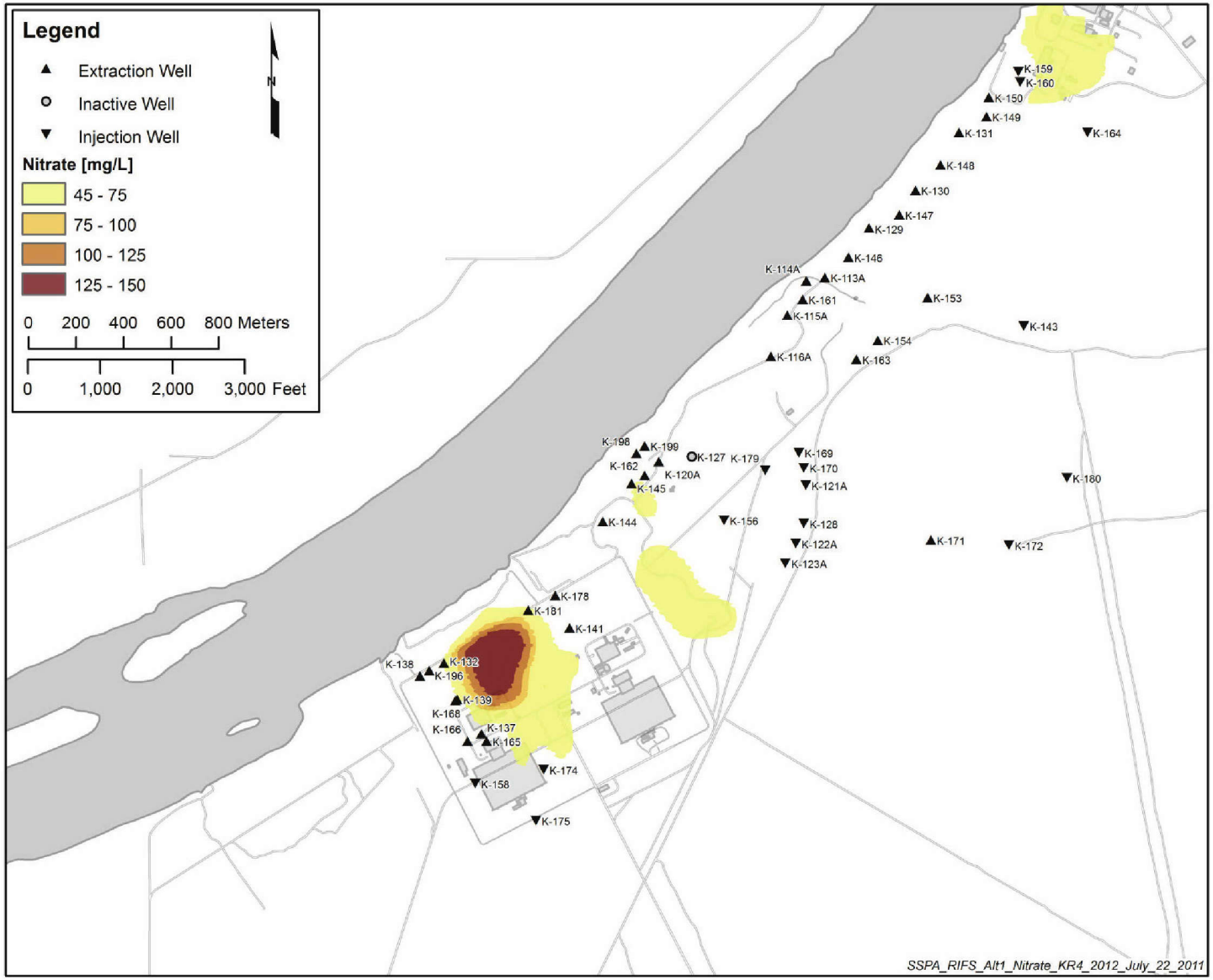

Figure 5-33. Model Simulated Nitrate Distribution in December 2012

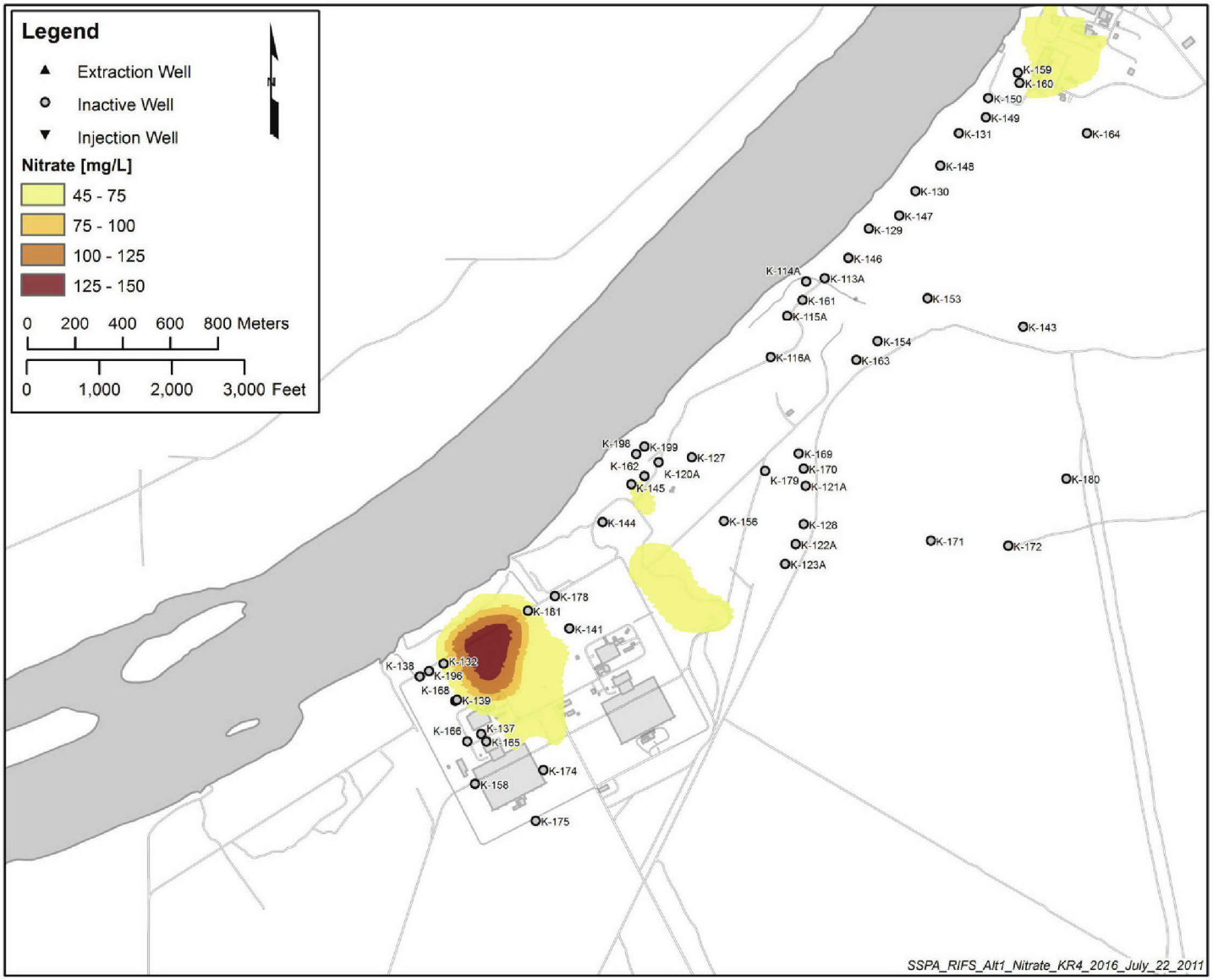

Figure 5-34. Model Simulated Nitrate Distribution in December 2016

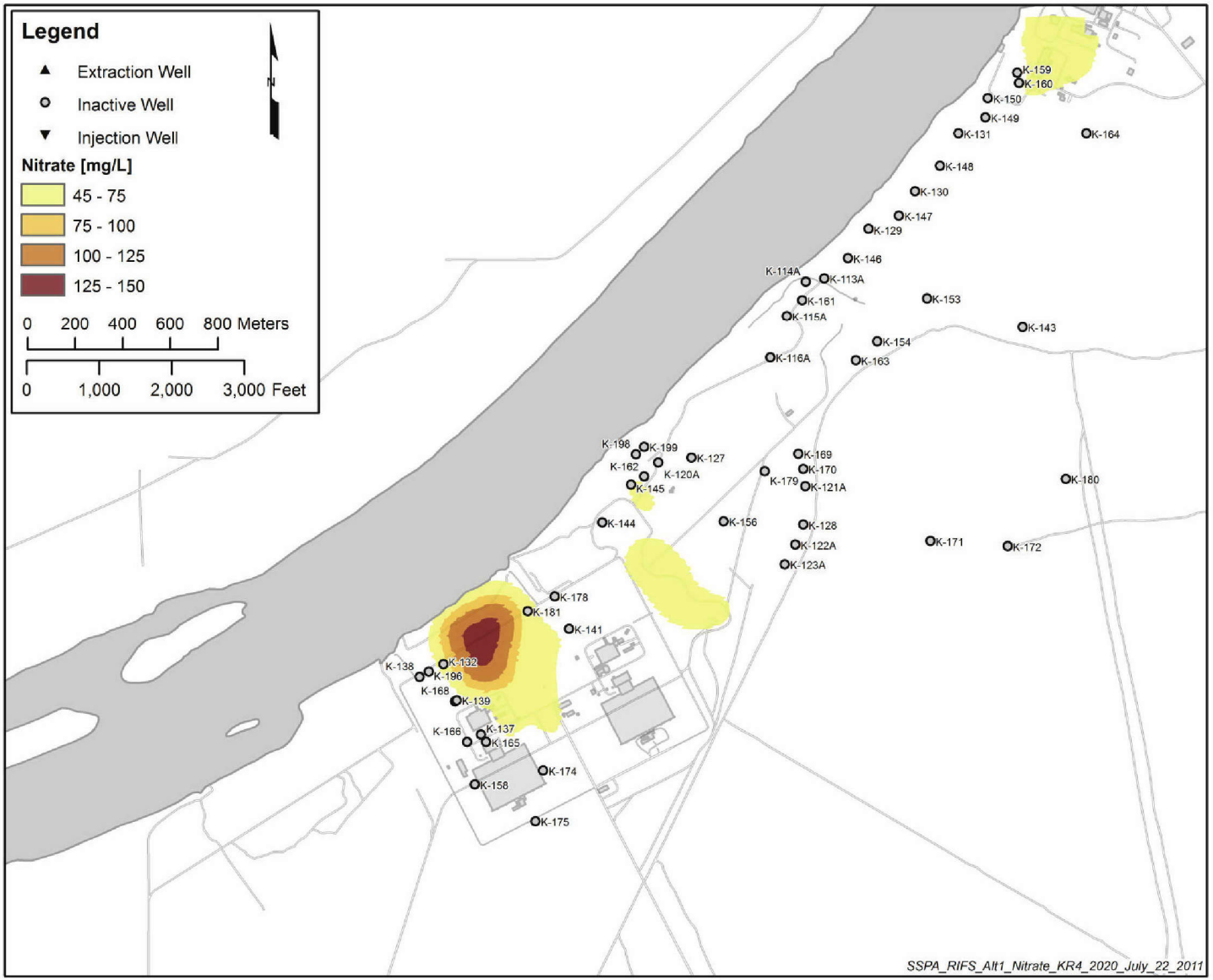

Figure 5-35. Model Simulated Nitrate Distribution in December 2020

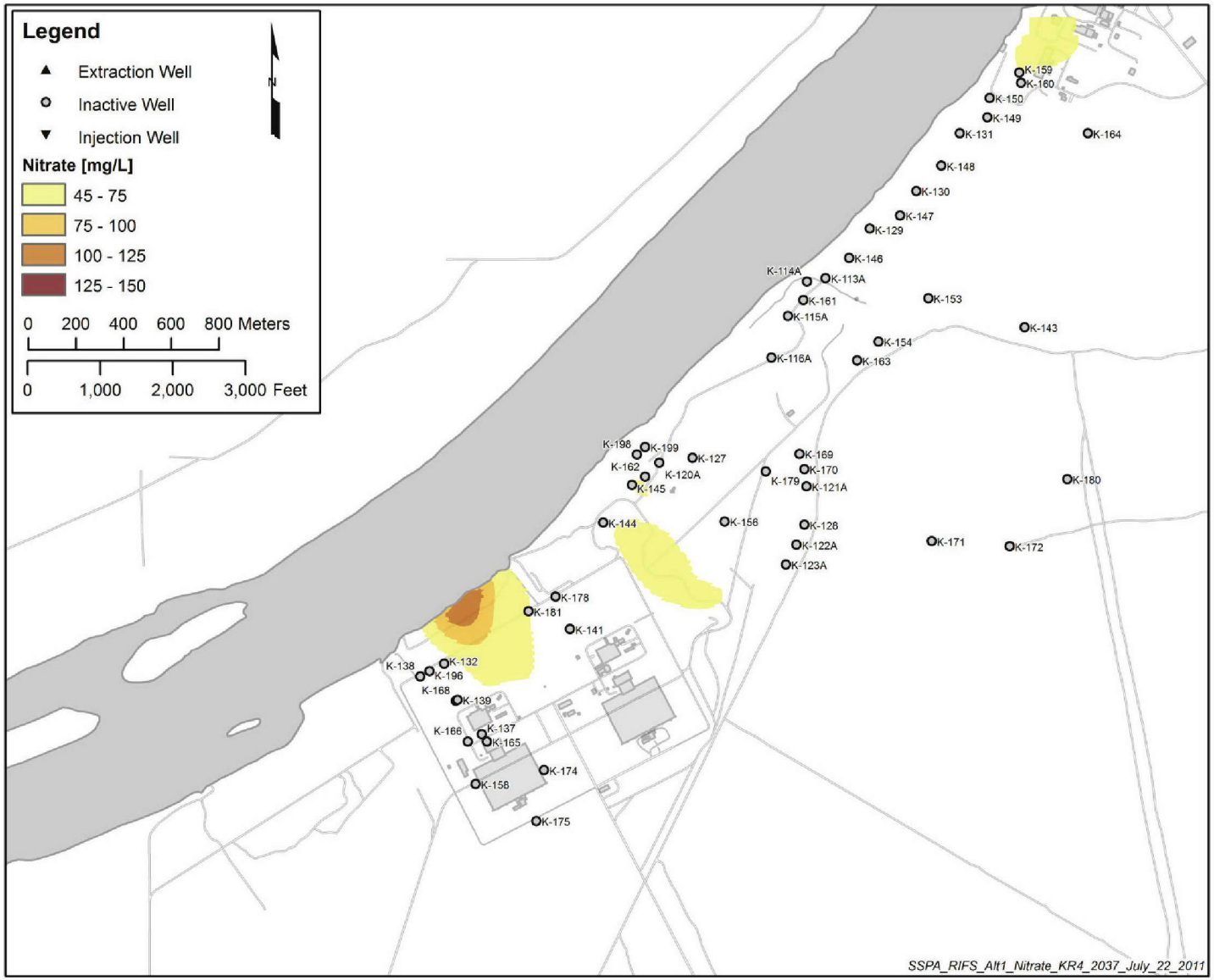

Figure 5-36. Model Simulated Nitrate Distribution in December 2037

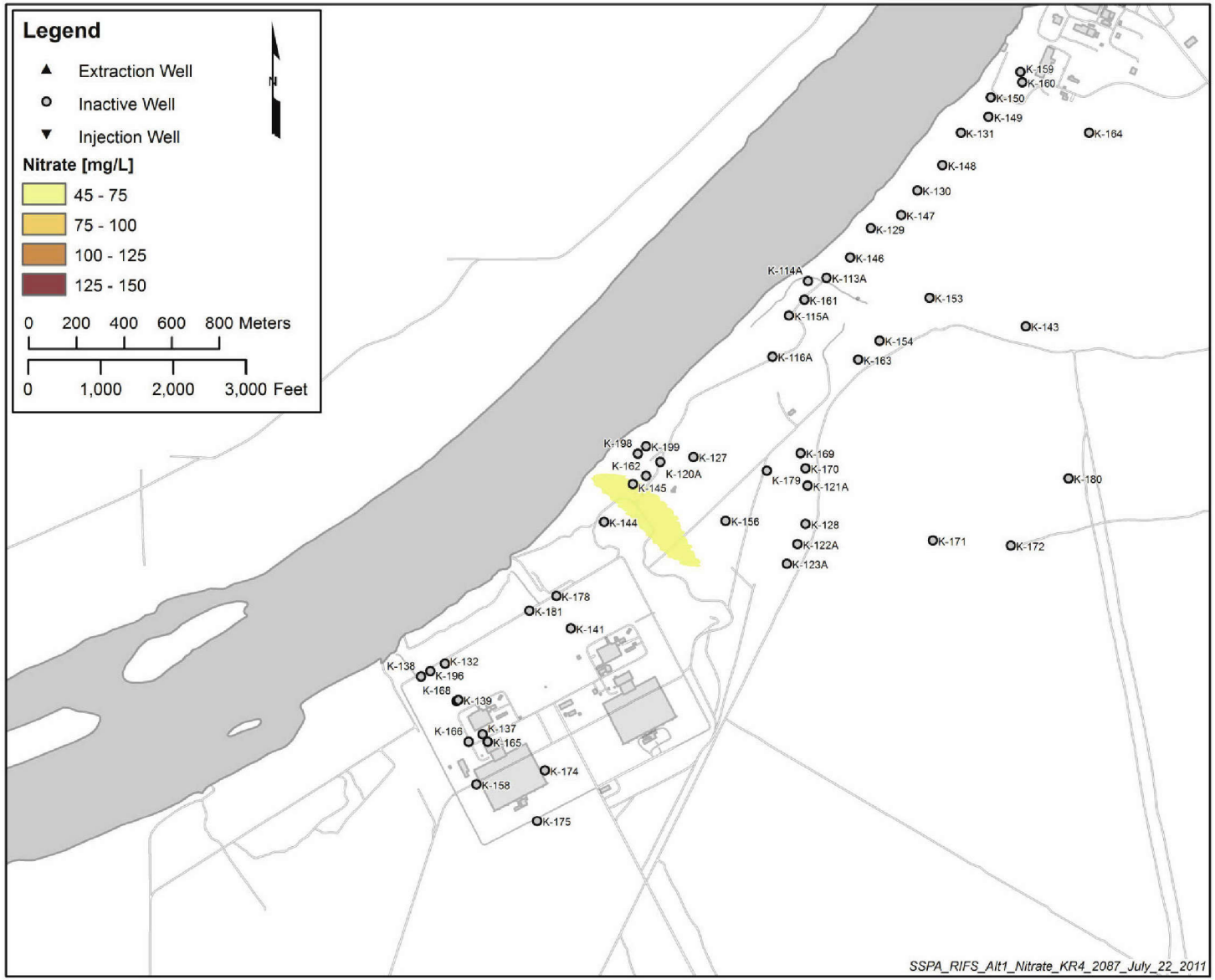

Figure 5-37. Model Simulated Nitrate Distribution in December 2087

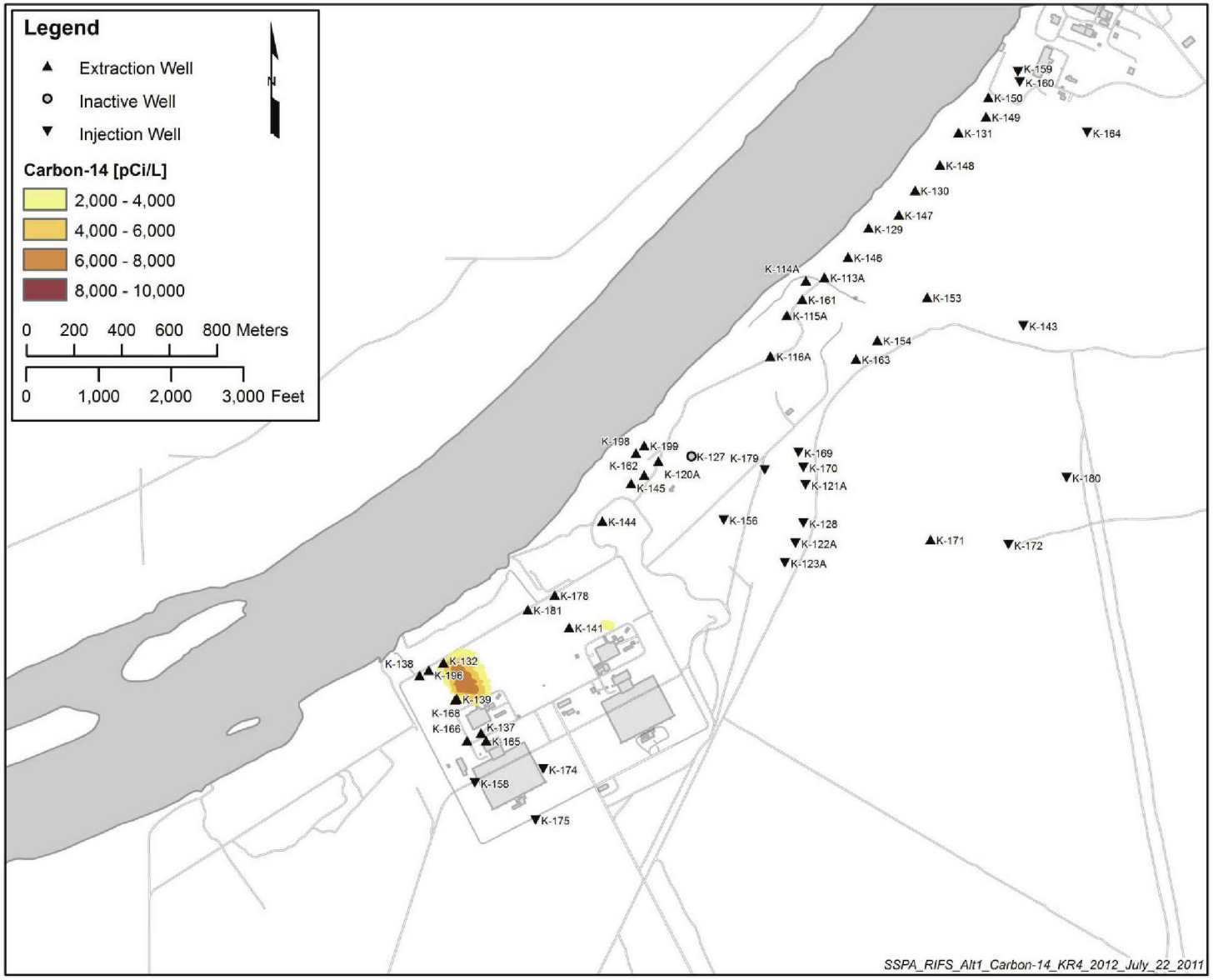

Figure 5-38. Model Simulated Carbon-14 Distribution in December 2012

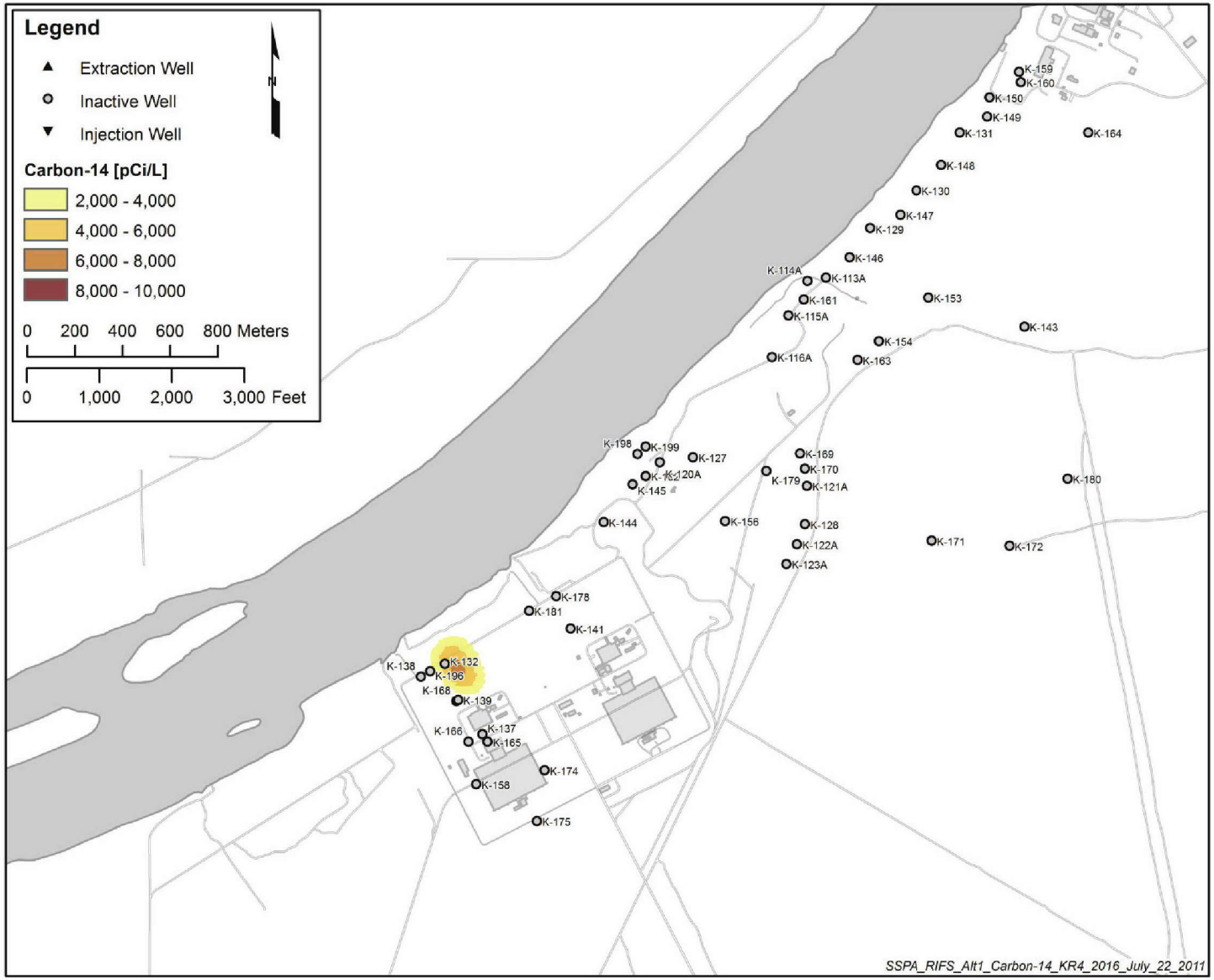

Figure 5-39. Model Simulated Carbon-14 Distribution in December 2016

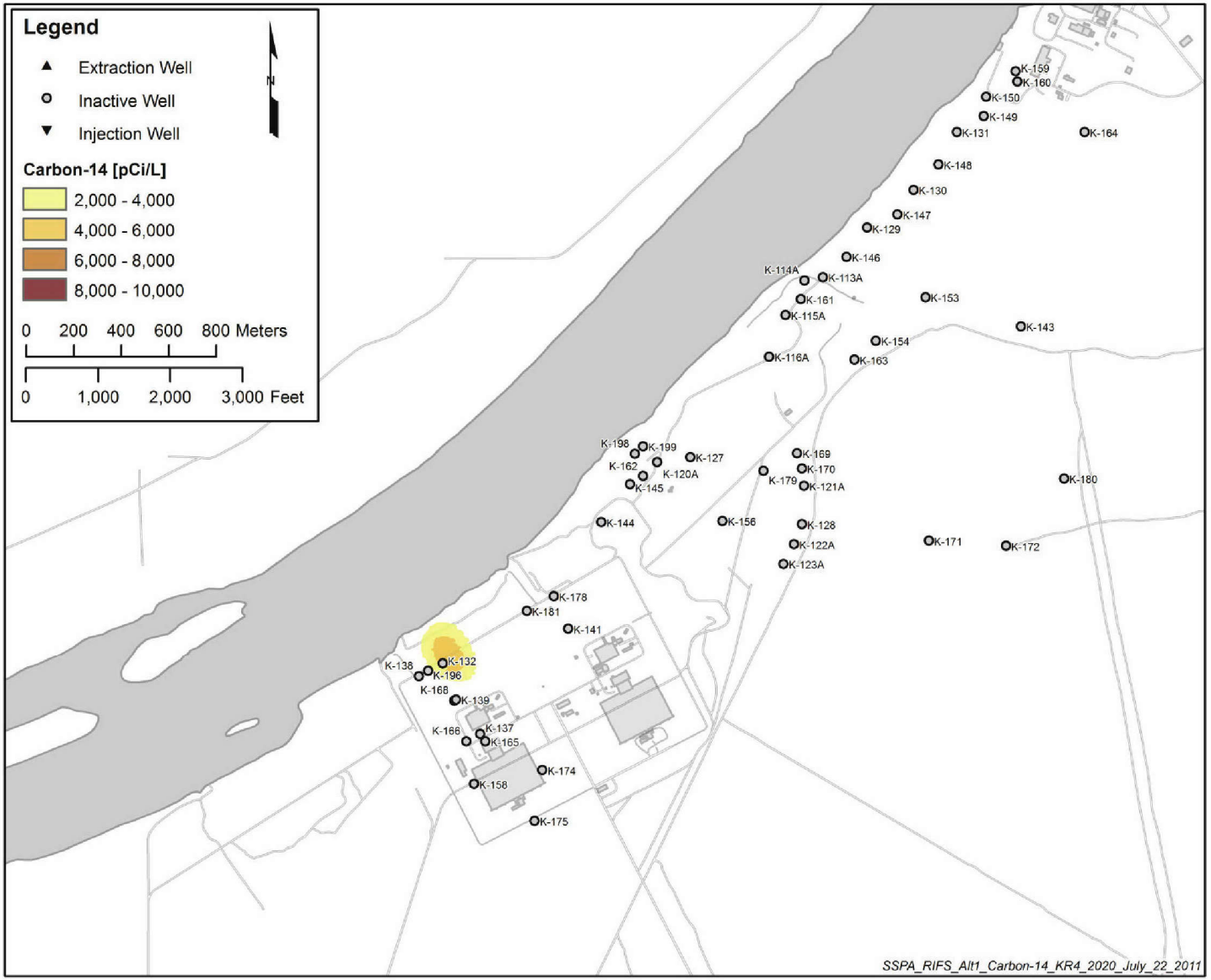

Figure 5-40. Model Simulated Carbon-14 Distribution in December 2020

The groundwater transport model is used to present the predicted efficacy of alternative pump-and-treat strategies in the FS.

5.7 Uncertainties that Apply to Groundwater and Vadose Zone Modeling

This uncertainty discussion is based primarily on the current vadose zone and groundwater modeling objectives, and the use of these models to evaluate future conditions under no action and active remediation scenarios. Although these uncertainties exist and must be considered in decision making, conservative assumptions incorporated into the vadose zone and groundwater transport simulations can reduce the effects of uncertainty on successfully remediating 100-K waste sites.

5.7.1 Uncertainty in the Conceptual Site Model

Conceptual model uncertainty is often the main uncertainty when using models to predict future contaminant fate and transport. Assumed values for vadose zone and aquifer physical properties, together with assumed values for contaminant transport properties, contribute to overall predictive uncertainty. Assumptions of spatially invariant material properties are often necessary to develop initial flow and transport model perform and and to obtain acceptable calibration, despite the recognition that the processes that deposited the soil materials produce stratified and heterogeneous sequences. Local variation in vadose and/or aquifer material properties can result in contaminants transport variations. For example, the assumption of constant effective porosity and saturated hydraulic conductivity values for a given stratigraphic unit is made in calculating screening levels and PRGs protective of groundwater and surface, as well as in converting the Darcy flux (as calculated by MODFLOW) to average linear groundwater velocity (as used in MODPATH and MT3DMS) for fate and transport calculations. In addition, the heterogeneity in the form of discontinuous structures (lenses), bar structures, and overbank deposits that is common at a scale below the grid size of the 100-K groundwater models is not accounted for in the Tier 1 screening level calculations or the Tier 2 STOMP 1D PRG model calculations. Some of these features can lead to locally faster contaminant movement than predicted by models that assume spatially invariant properties, although over broad areas, the average values for predictions will be similar whether small-scale heterogeneity is—or is not—represented. The effects of these local scale uncertainties upon predictions of groundwater and surface water protection metrics are minimized to the practical extent possible by building in conservatism using the lowest screening level and calculated PRG resulting from the STOMP simulations.

Perhaps one of the largest uncertainties in the CSM for groundwater simulations at 100-K is the uncertainty related to the potential for continued contribution of contaminants to groundwater from residual vadose zone sources. The groundwater contamination transport simulations discussed previously do not include the effects of any continuing releases to groundwater (i.e., they assess the behavior of existing groundwater contaminant plumes only). The potential for continued release of contaminants from contaminated vadose zone soil remains uncertain. Since cessation of reactor operations and cooling water treatment and disposal activities at 100-K, the driving force of artificial water discharge to the soil for downward movement of mobile contaminant has been largely eliminated. For example, groundwater Cr(VI) plumes near the 100-K head houses have exhibited persistent elevated concentrations in localized areas (e.g., near the 100-KE and KW cooling water head houses). This may be the result of some degree of continuing contribution from the vadose zone. The nature of this potential contribution is also uncertain. There are localized regions within the vadose zone that contain measureable quantities of mobile contaminants. Potentially, contributions may occur from natural or artificial (e.g., dust control water used during demolition) recharge water moving downward through the vadose zone and carrying mobile contaminants to groundwater. Historical groundwater monitoring data indicate that in some locations (e.g., near the K reactor cooling water head houses) groundwater Cr(VI) concentrations exhibit increasing concentration transient trends apparently associated with periods of anthropogenic increases in groundwater elevation.

This suggests the possibility that groundwater entering portions of the deep vadose zone at those locations at elevations above the normal natural seasonal fluctuation range may mobilize residual soil contaminants. Similar uncertainty may also exist at the reactor condensate cribs and the FSB French drains.

5.7.2 Uncertainty in the Initial Contaminant Distribution

Uncertainties with estimating contaminant distribution are primarily associated with the interpolation of individual sample contaminant concentration and the representativeness of individual samples with respect to the region surrounding the sample. The sample contaminant concentration is a minor contributor to overall uncertainty due to stringent quality controls applied by analytical laboratories. However, the representativeness in time and space of samples, together with the uncertainty associated with the interpolation of those point sample values to make a continuous distribution, are likely the greatest contributors to overall uncertainty in the initial contaminant distribution for both vadose zone and groundwater simulations.

The distribution of groundwater contaminants across the entire thickness of the saturated model domain for groundwater simulations and across the full thickness of the vadose for the SSL and PRG simulations is believed to be conservative based on observations of actual contaminant distribution made during the RI. This conservatism may actually be incorrect and contribute to uncertainty and inaccuracy in simulations if actual field conditions are substantially different from the simulated conditions. An example of such potential uncertainty includes the assessment of metals in soil at the cooling water head house waste sites, which indicated that arsenic and mercury exceed PRG concentrations. The data from the affected waste sites were collected from shallow, near-surface, depths (e.g., about 1 m [3 ft] bgs). The SSL and PRG simulation calculations assume that the contaminants are distributed uniformly over the vadose zone thickness beneath the remediated waste site. If contaminants are actually limited to the near-surface portion of the vadose zone, then the SSL and PRG simulations will be inaccurate and may lead to an overly conservative assessment of the potential threat to groundwater or surface water. Additional site-specific vadose zone characterization and site-specific transport simulations would contribute to reducing this uncertainty.

The majority of the residual contamination is expected to occur in the fine-grained (<2 mm size) portion of the sediments in the vadose zone. However, considerable uncertainty exists in the spatial variation in fraction of fine grained material within the vadose zone. For the purpose of modeling, the residual contaminant concentration determined in the laboratory on the fine-grained sediments is applied to the bulk volume, thereby increasing the initial mass estimate.

Additional uncertainty with respect to initial contaminant concentrations is introduced by measurement of contaminants at concentrations that exceed the 90th percentile background concentration, but are less than the maximum of the background concentration range. This condition has been observed in the concentrations of arsenic and lead in soil measured at waste sites 100-K-29, 100-K-30, 100-K-31, 100-K-32, and 100-K-33. These metals may actually fall within the observed range of background conditions as described in Appendix G of this report.

5.7.3 Uncertainty in Contaminant Transport Parameters

Parameters that affect contaminant transport include the K_d value of the contaminant and soil porosity. Soil porosity is variable throughout the soil column based on compaction and soil type heterogeneity. As soil porosity increases, so does the contaminant mass flux to the water table; accordingly, the uncertainty in actual formation porosity will be reflected in uncertainty in the contaminant mass flux. A best estimate of the porosity is used in constructing the model.

The K_d value of a contaminant for a soil type represents the degree of partitioning of the contaminant to the surface of the soil particles compared to the dissolved concentration. A high K_d value is typically found in contaminants such as aroclors (PCBs), which are generally considered hydrophobic. The lower the K_d, the more likely it is that the contaminant will move with water through the vadose zone. A K_d value can vary based on the water quality and chemistry (such as pH), the concentration of the contaminant, the type of sorbent, and the availability of sorption sites within the soil matrix. The K_d values used in evaluating the transport were primarily based on the assumption of dilute concentrations of contaminants in moisture within the vadose zone, and tend to represent the more mobile K_d conditions for a particular contaminant.

5.7.4 Uncertainties, Assumptions, and Limitations Specific to Vadose Modeling

Uncertainties based on the numerical equations used in modeling are expected to be small. *Regulatory Criteria for the Selection of Vadose Zone Modeling in Support of the 200-UW-1 Operable Unit* (DOE/RL-2007-34) provides a summary evaluation of the comparisons of field data and results to the model simulations of similar conditions using STOMP. The evaluations indicate that the STOMP code adequately simulates the natural processes.

The representativeness of soil samples collected during drilling and the resultant chemical analyses of those samples are subject to some degree of uncertainty. A limited number of soil samples in some boreholes may have been affected by water added during drilling in the vadose zone. The most likely effect of this condition, if it can be confirmed to have occurred, is that the added water may have wetted the underlying soil above its natural condition, and if wetting was sufficiently great, some movement of mobile contaminants may have occurred in soil immediately beneath the drill string at the point of water addition. The magnitude of the effect of this condition is difficult to quantify; however, it is believed that in most instances of water intrusion into the formation, the volume of water was modest and should not have caused dramatic removal of mobile contaminants. Additional uncertainties related to specific measurements (e.g., batch leaching tests) were discussed earlier in this chapter.

Assumptions within the model input parameters have an effect on the simulation outcomes. The key assumptions used for 100-K are as follow, with other assumptions presented in Appendix F:

- The recharge rates used for Rupert sand were all significantly larger than the rates used for the other soil types present at 100-K, and the Rupert sand results produced the minimum PRG or screening level values for most of the 3,000-year simulations. The smallest base case recharge rates are larger than the minimum of the range of rates determined for the Hanford shrub-steppe.

- The vadose zone is also considered homogeneous in nature, within the stratigraphic cross sections developed for the simulations, without consideration to the presence of thin finer-grained material, which can retard the downward migration of contaminants.

- Based on current revegetation activities, revegetation of a waste site after remediation is typically occurring within one to two growing seasons. In the modeling, revegetation of the area is assumed to start after five years, with bare soil present for the first five years. This assumption results in more water infiltrating to the vadose zone than may actually occur.

- Groundwater is assumed to have negligible mixing with the Columbia River. In calculating the values for surface water protection, the point of compliance is assumed at the groundwater below the waste site. No attenuation or decay of contaminants is assumed between the source area and the groundwater or the river. This contributes to a conservative PRG estimate because most waste sites are located some distance from the river and some mixing occurs where groundwater discharges into the river.

- The 100:0 Contaminant Source Model for SSL uses an irrigation recharge scenario and assumes the entire vadose zone is contaminated below clean fill. The PRG development used the same distribution, but a recharge scenario based on re-establishment of natural infiltration. Both the SSL and PRG simulations applied a derived K_d for Cr(VI) of 0.8 ml/g based on the results of the batch leach testing at the 100 Area.

- The initial conditions for matric potential at the start of the flow and transport simulations represent a wetter vadose zone than is expected for such gravel-dominated sediments in an arid climate, thus allowing significantly higher water and solute flux values. This is conservative in that it results in more rapid movement of water through the vadose zone.

- The median hydraulic gradient value for each source area may be too large by several fold for waste sites near the Columbia River and may be several times too large for waste sites that are far inland from the river.

- The assumption of a 5 m thick aquifer may or may not be conservative for those locations with aquifer thicknesses less than 5 m.

5.7.5 Uncertainties, Assumptions, and Limitations Specific to Groundwater Modeling

Uncertainties based on the numerical equations used in modeling are expected to be small. A groundwater flow and contaminant transport model has been developed and calibrated for remedy design evaluation purposes in the 100 Area. The model development and calibration is documented in a comprehensive modeling report (*Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* [SGW-46279]).

The groundwater flow model grid encompasses all 100 Area OUs. The model finite-difference grid is constructed so that the north and northeast boundaries of the flow model parallel and abut the Columbia River. The model extends southward, toward Gable Butte and Gable Mountain. The grid spacing is relatively coarse (about 100 m) throughout much of the domain, but it is refined (15 m) in the area of each 100 Area OU to support remedy evaluations.

Assumptions within the model input parameters have an effect on the simulation outcomes. The key assumptions used for 100-K are as follows, with other assumptions and the specific input parameters presented in Appendix F:

- Predictive simulations were based on transient-state (i.e., time-varying) conditions in the aquifer that reflect water-level changes due to river-stage variation. The modeling period corresponds to a 77-year period (CY 2011 to 2087). For the period 2011 to 2037, the modeling period consists of a series of 12 monthly stress periods that are repeated in the same sequence. The stress periods correspond to monthly average river stages, each representing the average river stage for the particular calendar month over the period 2006 to 2010 (excluding 2007 values, when the river stage variation pattern was inconsistent with the other years). It is assumed that these conditions are representative of the typical conditions in the field and that future conditions will not vary significantly from these conditions.

- Groundwater flow is simulated as three-dimensional using four layers to represent the Hanford formation (always present in Layer 1) and the Ringold Formation unit E (typically represented by Layers 2 through 4). The base of the model is assumed to be the top of the RUM where present and the top of the basalt where the RUM is absent. At 100-K, the water table is assumed to be present within the Ringold unit E.

- The principal aquifer property specified in the flow model is the spatially varying hydraulic conductivity of the saturated aquifer materials. Estimates of hydraulic conductivity compiled as part of the Model Data Package were tabulated and assigned to their corresponding aquifer unit. Following are the mean values for the aquifer hydraulic conductivity that resulted from the model calibration process:
  - 6 m/day (19 ft/day) for Ringold unit E in the 100-K region of the aquifer
  - 63 m/day(206 ft/day) for the Hanford formation
- Areal recharge from precipitation was specified based on information included in the *Groundwater Data Package for Hanford Assessments* (PNNL-14753). An electronic version of the recharge package developed in this report was obtained, and the data were spatially distributed to the model grid cells and were subsequently adjusted during model calibration. Based on the results of the model calibration, the recharge value was set equal to 12 mm/yr throughout much of the model domain.
- Effective porosity and specific yield values for the entire aquifer were identified from published sources and revised during the model calibration and are equal to 18 and 10 percent, respectively. Both values are within the range of values documented in previous investigations for Hanford (*Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report* [PNNL-10886]).
- The initial distribution of each COC in groundwater within the 100-KR-4 OU was obtained using maximum sampled COC concentrations at each monitoring location during the period 2009 to 2010. It is assumed that no continuous source is present in the aquifer or vadose zone that would affect the contaminant distribution.

5.8 Summary of Contaminant Fate and Transport

Intentional and unintentional releases of primary waste source materials occurred during nuclear material production at Hanford. The exposure point concentrations of each remediated waste site, soil group, and COPC were compared to the 100:0 base case scenario PRGs. After excluding COPCs with peak concentration times greater than 10,000 years, most remediated 100-K waste sites meet the criteria for groundwater and surface water protection. The following previously-remediated waste sites exhibit soil contamination in the near-surface vadose zone that exceeded calculated PRGs:

- Mercury in shallow soil at Site 100-K-30
- Mercury in shallow soil at Site 100-K-31
- Mercury in shallow soil at Site 100-K-32
- Arsenic and mercury in shallow soil at Site 100-K-33

These contaminants are subject to additional uncertainties that suggest the derived PRGs may be overly conservative at these waste sites. Arsenic concentrations (and lead, which was eliminated at the SSL screen) observed at these sites fall within the maximum observed background concentration range. Naturally occurring constituents should not be subject to remedial action. Mercury observed at these sites likely results from artificial sources; however, the actual distribution of mercury through the vadose zone is not defined for these waste sites. If mercury contamination is actually limited to the upper portion of the vadose zone, then the predicted magnitude of future groundwater/surface water impacts would be substantially less than the PRG prediction. Additional focused subsurface characterization for residual metals, followed by site-specific fate and transport modeling should be incorporated into remedial design activities.

Groundwater contaminant flow, transport modeling over an extended future period and historical monitoring indicate that the groundwater pump-and-treat systems provide protection to the river along the shoreline in almost all areas. The Cr(VI) plume is captured except in areas near the shoreline where pump-and-treat wells are absent or relatively sparsely placed.

Plume migration patterns indicate a diminishing footprint of the Cr(VI) plume as a result of the pump-and-treat operations. Concentrations above 20 μg/L appear sufficiently controlled by the combined extraction/injection activity across the area of interest. Concentrations between 10 and 20 μg/L are contained, except in areas downgradient of the 100-KE Reactor.

Tritium and Sr-90 concentrations above the DWS are within the capture zone of the recovery wells. Nitrate present in the area between the two reactors is not completely captured by the recovery wells. The nitrate plume east of the 100-KE Reactor is captured by the pump-and-treat wells. The carbon-14 plume is within the capture zone of the recovery wells and plume migration is sufficiently controlled.

Uncertainties remain regarding the potential for continued contribution of residual vadose zone contaminants to underlying groundwater. Development of simulated PRG values indicated that remediated waste sites should not contribute to continuing groundwater contamination. Remedial alternatives evaluated in the FS portion of this report should consider monitoring requirements that will verify the assumptions for vadose zone contaminant behavior. Existing groundwater plumes of Cr(VI), carbon-14, Sr-90, and nitrate near the reactor condensate cribs, the FSBs, and the cooling water head houses should be considered for specific monitoring of potential future vadose zone contributions.

Chapter 5 described and predicts how quickly or slowly contaminants migrate and their potential to enter the Columbia River. The potential to be harmful depends on specific human and environmental receptors as well as exposure times and patterns that might bring receptors and contaminates into contact. The ways that the contaminants could come into contact with and impact human health and the environment are called pathways. Chapter 6 addresses the human health pathway. Scenarios of how humans might come into contact with contaminants in the setting with resultant health impacts are evaluated. Chapter 7 addresses the biological receptor pathway. Scenarios of how plant, animal, bird, or invertebrate species might come into contact with contaminates in the setting and be impacted are evaluated.

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6 Supplemental Soil and Groundwater Risk Evaluation

Highlights

- Principal soil contaminants identified at one or more waste sites through the risk assessment included radionuclides, metals, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons.
- The principal contaminants in groundwater are Cr(VI), carbon-14, Sr-90, tritium, nitrate, chloroform, and trichloroethene.
- The baseline risk assessment identified Cr(VI), carbon-14, Sr-90, tritium, chromium, and nitrate as final COPCs for evaluation of potential remedial technologies in the FS.

The integration of past and ongoing human health risk assessments supports the development of remedial alternatives for waste sites and contaminated groundwater in the 100-K decision area. These risk assessments have been integrated with the cleanups performed under the interim action RODs to identify the need for further remedial action and, if needed, to develop PRGs.

As described in the previous sections, the remedial actions completed to date in the River Corridor were implemented primarily under interim action RODs. There is a requirement under CERCLA to perform a baseline risk assessment (BRA) to characterize current and potential threats to human health and the environment before RODs for final remedies can be issued. The RCBRA was prepared to address the regulatory requirement that a BRA be performed. The RCBRA Report (DOE/RL-2007-21) is a comprehensive human health risk assessment for the River Corridor considering relevant sources of contamination, exposure pathways, and contaminants to evaluate current and potential future risks posed by hazardous substance releases. The following is the purpose of the RCBRA, as described in Section 1.1:

> *The purpose of the RCBRA is to characterize current and potential future risks to human health and the environment that may be posed by releases of hazardous substances in the River Corridor of the Hanford Site. DOE is required to assess human and ecological risk under CERCLA, Resource Conservation and Recovery Act of 1976 (RCRA), National Environmental Policy Act of 1969, and DOE orders. The "National Oil and Hazardous Substances Contingency Plan" (40 Code of Federal Regulations [CFR] 300), which implements CERCLA, specifically requires a site-specific baseline risk assessment to determine the need for action at sites, determine levels of contaminants that can remain onsite and still be protective, and provide a basis for comparing health impacts of various cleanup alternatives (40 CFR 300.430[d][4]).*

Per the risk assessment guide (EPA/540/1-89/002), a BRA is an "analysis of the potential adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action)."

The BRA is part of the CERCLA RI/FS process. The RI/FS is the methodology that the CERCLA program has established for characterizing the nature and extent of contamination associated with releases of hazardous substances to the environment, for assessing the potential risks posed by the environmental contamination to human and ecological receptors, and for developing and evaluating remedial options. Because the RI/FS is a process designed to support risk management decision making for CERCLA sites, the assessment of human health and environmental risk serves an essential role in the RI/FS process. The BRA provides information to assist in the development, evaluation, and selection of appropriate response alternatives. The results of the BRA are used to determine whether additional response action is necessary at the site, modify PRGs, support selection of the "no action" remedial alternative where it is appropriate, and document the magnitude of risk and primary contributors (e.g., chemicals and exposure pathways) to risk at a site.

Interim action RODs were written for River Corridor sites to allow cleanup activities to move forward more rapidly. However, final remedy selection (development of final RODs) must be completed in order for the NPL CERCLA sites in the River Corridor to reach final closeout. One of the key evaluations needed to establish final remedy RODs for sites in the River Corridor was a BRA (*Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* [DOE/RL-2004-37]). The RCBRA human health risk assessment and the companion ecological risk assessment provided an evaluation of ecological and human health risk from residual contamination at waste sites remediated under the interim action RODs and from potentially affected environmental media under various exposure scenarios. The site-specific risk information provided by the RCBRA would be used to support final RODs for the River Corridor.

6.1 Role of the RCBRA and the RI/FS Risk Evaluation

The RCBRA provided the following range of analyses:

- An assessment of residual risks for remediated waste sites using the exposure scenarios that were the basis for the RAGs for the interim action ROD cleanups
- An assessment of residual risks for remediated waste sites and broad areas using a broad range of exposure scenarios

Portions of these analyses were considered in the human health risk assessment approach used to develop soil PRGs that are presented in the RCBRA. The following issues are addressed in this chapter as part of the integration of RCBRA and the RI/FS, which will support the development of final RODs for the 100-Area decision areas:

- Incoporation of PRG values from the RCBRA for radioisotopes and chemicals based on updated regulatory guidance
- Inclusion of all decision units associated with a remediated waste site
- Inclusion of analytical data from focused sampling designs
- Analysis time frame (i.e., waste sites cleaned up after the analysis conducted in the RCBRA)
- Use of exposure point concentrations consistent with the waste site decision units (e.g. shallow zone, deep zone) and based on current EPA guidance

The following sections discuss the integration of the RCBRA and the RI/FS risk evaluation:

- Section 6.1.1 summarizes the evaluation of residual risks performed in the RCBRA for waste sites cleaned up under the interim action ROD. The results from this evaluation have been compared with the PRGs developed for the RI/FS.
- Section 6.1.2 describes how scenarios reflecting reasonably anticipated future land uses, presented in the RCBRA, have been incorporated into the RI/FS.
- Section 6.1.3 describes other scenarios that reflect unrestricted uses in the River Corridor and their associated uncertainties.

The human health risk evaluation supporting the RI/FS is presented in two sections. Section 6.2 presents the methods and the results for the supplemental soil risk analysis and Section 6.3 presents the methods and results for the supplement analysis of groundwater risks.

The supplemental soil risk analysis (Section 6.2) provides the data analysis (Section 6.2.1), estimated exposure point concentrations (EPCs) (Section 6.2.2), exposure assessment (Section 6.2.3), toxicity assessment (Section 6.2.4), risk characterization (Section 6.2.5), and the uncertainties assessment (Section 6.2.6).

The supplemental analysis of groundwater risks (Section 6.3) discusses findings and uncertainties of the RCBRA (Section 6.3.1), as the Integrated Work Plan (DOE/RL-2008-46) added activities that would help reduce uncertainties, verifies conclusions, and ensures that no contaminants were inadvertently overlooked based on the use of the existing data set. The supplemental analysis itself involves the following steps: identification of COPCs (Section 6.3.2), exposure assessment (Section 6.3.3), toxicity assessment, (Section 6.3.4), risk characterization (Section 6.3.5), and the uncertainties assessment (Section 6.3.6). The results of Section 6.3 will be used to identify COPCs, which represent contaminants that will be evaluated in the FS to define the COCs and guide the selection of remedial alternatives.

6.1.1 Evaluation of Residual Risks for Interim Action ROD Cleanups from the RCBRA

Chapter 2 of the RCBRA presents a screening-level assessment of residual cancer risks and noncancer hazards for the remediated wastes sites using the exposure scenarios that were the basis of the residential RAGs for the interim action ROD cleanups. This assessment was done to provide information about the residual risks and noncancer hazards associated with post-interim action conditions at the remediated waste sites and help assess whether residual conditions are protective of human health.

Waste sites evaluated in the River Corridor were Interim Closed using RAGs related to soil exposure by human receptors and protection of groundwater [and surface water] from contaminants leaching from soil. Remedial action goals in the 100 Area of the River Corridor [for direct contact] were based on a residential exposure scenario. The interim action ROD residential scenario for radionuclides is a Rural Residential scenario that, in addition to direct contact, includes food chain exposure pathways (e.g., ingestion of homegrown produce, beef, and milk). The interim action ROD residential scenario for chemicals is based on the MTCA Method B Soil Cleanup Levels for Unrestricted Land Use ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740]). The MTCA Method B levels are based solely on incidental soil ingestion and do not address the food exposure pathways that were included for the radionuclide Rural Residential scenario.[1]

CVPs or RSVPs were prepared to document completion of interim action ROD cleanup actions in accordance with the applicable decision document and support waste site reclassification. The screening-level calculations presented in Chapter 2 of the RCBRA use the interim action ROD risk assessment models, but differ from the calculations used in the CVPs and RSVPs to document the interim action ROD cleanups in four ways.

- The analytes included in the evaluation for individual waste sites are those COPCs identified for each ROD area using the methodology in the RCBRA.
- Residual soil concentrations are calculated using cleanup verification sample data and the RCBRA protocols for calculating representative concentrations. The RCBRA protocols differ from those used in the interim action ROD cleanups.[2] For chemicals, guidance on calculating the 95 percent UCL under MTCA was followed in the interim action ROD cleanups. However, if 50 percent or more of a data set was nondetect, then the maximum chemical analytical results were used in lieu of a

[1] Note that for beryllium, cadmium, and Cr(VI), the RAG for direct contact is based on the inhalation pathway.

[2] The methodology used to calculate representative concentrations is described in Section 3.4 and provided in electronic format in Appendix C, Section C-3 of the RCBRA Report (DOE/RL-2007-21).

95 percent UCL for a chemical. For radionuclides, a 95 percent UCL was always calculated for the interim action ROD cleanups using a nonparametric method based on the "z" statistic.

- Current chemical toxicity criteria are used in the RCBRA. Toxicity criteria from EPA and other federal or state sources (as cited in "Regional Screening Levels for Chemical Contaminants at Superfund Sites" [EPA, 2009b]) were used to calculate current MTCA B values. Chemical toxicity criteria that were current as of the 2007 revision of MTCA were used for the interim action ROD cleanups.

- Radionuclide cancer risk is evaluated relative to a cancer risk range of 1×10^{-6} to 1×10^{-4} in the RCBRA, and a threshold of 1×10^{-4} was used to calculate radionuclide risk based screening levels in this section.[3] Radionuclide RAGs were calculated based on a radiation dose threshold of 15 mrem/yr for the interim action ROD cleanups.

Thirteen waste sites from the 100-K Source OU were evaluated in the RCBRA. Three additional waste sites have been remediated at the 100-K Source OU since 2005, and are not addressed in the RCBRA. Residual cumulative cancer risks from chemicals evaluated in the RCBRA are less than 1×10^{-5} using the interim action ROD residential scenario (i.e., MTCA Method B Unrestricted Use scenario). Residual cumulative cancer risks from radionuclides for all remediated waste sites are less than 1×10^{-4} based on the interim action ROD Rural Residential scenario. The noncancer HIs for chemicals do not exceed a threshold of 1.0 at the 13 remediated waste sites. A summary of the risk assessment results for a residential scenario using approaches from both RCBRA and the RI/FS is provided in Tables 6-1 through 6-3.

Table 6-1. Summary of Risk Assessment Results for Chemical Carcinogens

Waste Site Name	RI/FS Decision Unit	Chemical Carcinogens and Cancer Risk Drivers			
		RCBRA Chemical Risk	RCBRA Chemical Risk Driver	RI/FS Chemical Risk	RI/FS Chemical Risk Driver
100-K-29	Shallow Focused	Not Reported	Not Reported	3.7×10^{-6}	Arsenic (3.5×10^{-6})
100-K-30	Shallow Focused	4.0×10^{-6}	Arsenic (4.0×10^{-6})	3.9×10^{-6}	Arsenic (3.9×10^{-6})
100-K-31	Shallow Focused	4.0×10^{-6}	Arsenic (4.0×10^{-6})	4.2×10^{-6}	Arsenic (4.2×10^{-6})
100-K-32	Shallow Focused	4.0×10^{-6}	Arsenic (4.0×10^{-6})	4.5×10^{-6}	Arsenic (4.5×10^{-6})
100-K-33	Shallow Focused	4.0×10^{-6}	Arsenic (4.0×10^{-6})	1.0×10^{-5}	Arsenic (1.0×10^{-5})
100-K-55:1	Shallow	--	--	Not Analyzed	
	Shallow Focused	--	--	--	--

[3] The calculation of the risk-based concentrations used in the risk assessment is explained in detail in Section 7.5 of the RCBRA Report (DOE/RL-2007-21).

Table 6-1. Summary of Risk Assessment Results for Chemical Carcinogens

Waste Site Name	RI/FS Decision Unit	Chemical Carcinogens and Cancer Risk Drivers			
		RCBRA Chemical Risk	RCBRA Chemical Risk Driver	RI/FS Chemical Risk	RI/FS Chemical Risk Driver
100-K-56:1	Shallow	--	--	Not Analyzed	
	Shallow Focused	--	--	--	--
116-K-1	Shallow	--	--	--	--
116-K-2	Shallow	--	--	--	--
116-KE-4	Shallow	--	--	--	--
116-KE-5	Shallow Focused	6.0×10^{-6}	Arsenic (6.0×10^{-6})	5.6×10^{-6}	Arsenic (5.6×10^{-6})
116-KW-3	Shallow	--	--	--	--
116-KW-4	Shallow Focused	4.0×10^{-6}	Arsenic (4.0×10^{-6})	3.9×10^{-6}	Arsenic (3.9×10^{-6})

Source:
RCBRA data: DOE/RL-2007-21, Volume II, Part 2, Draft C, Table 2-10
RI/FS data: DOE/RL-2010-97, Draft A, Appendix G, Table G-19.
Notes: Chemical drivers shown have an associated risk greater than 1×10^{-6}.
The risk value for the individual drivers is shown in parentheses after the name of the risk driver chemical.
Risks are based on reasonable maximum exposure point concentrations.
— = Carcinogenic COPCs were not identified

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Table 6-2. Summary of Risk Assessment Results for Noncarcinogens

Waste Site Name	RI/FS Decision Unit	Noncancer Hazard Index and Noncancer Hazard Drivers			
		RCBRA Hazard Index	RCBRA Chemical Hazard Driver	RI/FS Hazard Index	RI/FS Chemical Hazard Driver
100-K-29	Shallow Focused	--	--	0.18	None
100-K-30	Shallow Focused	0.86	None	0.86	None
100-K-31	Shallow Focused	0.34	None	0.37	None
100-K-32	Shallow Focused	0.21	None	0.24	None
100-K-33	Shallow	0.23	None	0.60	None

Table 6-2. Summary of Risk Assessment Results for Noncarcinogens

Waste Site Name	RI/FS Decision Unit	Noncancer Hazard Index and Noncancer Hazard Drivers			
		RCBRA Hazard Index	RCBRA Chemical Hazard Driver	RI/FS Hazard Index	RI/FS Chemical Hazard Driver
	Focused				
100-K-55:1	Shallow	0.01	None	Not Analyzed	
	Shallow Focused	--	--	Not Analyzed	
100-K-56:1	Shallow	0.01	None	Not Analyzed	
	Shallow Focused	--	--	<0.01	None
116-K-1	Shallow	<0.01	None	<0.01	None
116-K-2	Shallow	0.01	None	<0.01	None
116-KE-4	Shallow	0.01	None	<0.01	None
116-KE-5	Shallow Focused	0.17	None	0.17	None
116-KW-3	Shallow	0.01	None	<0.01	None
116-KW-4	Shallow Focused	0.11	None	0.11	None

Source:
RCBRA data: DOE/RL-2007-21, Volume II, Part 2, Draft C, Table 2-10
RI/FS data: DOE/RL-2010-97, Draft A, Appendix G, Table G-19
Notes: Chemical drivers shown have an associated HQ greater than 1.
The HQ value for the individual drivers is shown in parentheses after the name of the risk driver chemical.
Hazard indices are based on reasonable maximum exposure point concentrations.
— = Noncarcinogenic COPCs were not identified

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Table 6-3. Summary of Risk Assessment Results for Radionuclides

Waste Site Name	RI/FS Decision Unit	Radionuclides and Radiological Risk Drivers			
		RCBRA Radiological Risk	RCBRA Radiological Risk Driver	RI/FS Radiological Risk	RI/FS Radiological Risk Driver
100-K-29	Shallow Focused	--	--	Not Analyzed	
100-K-30	Shallow Focused	--	--	Not Analyzed	
100-K-31	Shallow Focused	--	--	Not Analyzed	

Table 6-3. Summary of Risk Assessment Results for Radionuclides

Waste Site Name	RI/FS Decision Unit	Radionuclides and Radiological Risk Drivers			
		RCBRA Radiological Risk	RCBRA Radiological Risk Driver	RI/FS Radiological Risk	RI/FS Radiological Risk Driver
100-K-32	Shallow Focused	--	--	Not Analyzed	
100-K-33	Shallow Focused	--	--	Not Analyzed	
100-K-55:1	Shallow	1×10^{-4}	None	4.7×10^{-5}	None
	Shallow Focused	--	--	7.5×10^{-5}	None
100-K-56:1	Shallow	2.0×10^{-4}	Europium-152 (1.0×10^{-4})	9.2×10^{-5}	None
	Shallow Focused	--	--	1.3×10^{-4}	None
116-K-1	Shallow	2.0×10^{-4}	None	1.1×10^{-4}	None
116-K-2	Shallow	1.0×10^{-4}	None	6.1×10^{-5}	None
116-KE-4	Shallow	8.0×10^{-5}	None	5.2×10^{-5}	None
116-KE-5	Shallow Focused	--	--	Not Analyzed	
116-KW-3	Shallow	1.0×10^{-4}	None	5.8×10^{-5}	None
116-KW-4	Shallow Focused	--	--	Not Analyzed	

Source:
RCBRA data: DOE/RL-2007-21, Volume II, Part 2, Draft C, Table 2-10
RI/FS data: DOE/RL-2010-97, Draft A, Appendix G, Table G-19
Notes: Radionuclide drivers shown have an associated risk greater than 1×10^{-4}.
The risk value for the individual drivers is shown in parentheses after the name of the risk driver chemical.
Risks are based on reasonable maximum exposure point concentrations.
— = Radionuclide COPCs were not identified

6.1.2 RI/FS Risk Evaluation

As shown in Tables 6-1 through 6-3, the risk assessment results are similar between the RCBRA and the RI/FS. Differences in results are generally attributed to the COPC identification process, the method used to calculate EPCs, and the PRG value used for comparison. The risk evaluation provided in this chapter supplements the RCBRA because there are several key differences between the scope and purpose of the RCBRA and the scope and purpose of the RI/FS. The following summarizes the key differences and Table 6-4 provides additional detail about these differences:

Table 6-4. Comparison of Methods and Assumptions Used for the Residential Scenario

Parameter	Method used in RCBRA	Method Used in RI/FS	Overall Effect on RI/FS
Basis of PRG Values for Radioisotopes and Chemicals			
Residential PRG value for radioisotopes	Radionuclide cancer risk is evaluated using the interim action ROD rural residential exposure scenario reported in DOE/RL-96-17. Radionuclide RAGs were calculated based on a dose threshold of 15 mrem/yr. In the RCBRA, these RAGs were converted to risk-based screening levels based on a risk threshold of 1×10^{-4}. (pg 2-41 of the RCBRA). The interim action ROD rural residential exposure scenario is considered a local area exposure scenario (located on a waste site).	Radionuclide cancer risk is evaluated using the residential exposure scenario. This exposure scenario is similar to the interim action ROD rural residential scenario but incorporates updates to reflect recent EPA guidance.	The residential scenario used in the RI/FS reflects updates in methodology (risk-based versus dose-based threshold) and recent recommendations in exposure assumptions. RBSL/PRG values differ slightly between the RCBRA and the RI/FS for key COPCs (gamma emitters and Sr-90).
Updates to EPA guidance for residential PRG.	External gamma shielding factor is 0.7. Outdoor time fraction is 0. 2 (5 hours per day over 350 days per year) Target cancer risk value is 1×10^{-4}.	External gamma shielding factor is 0.4. Outdoor time fraction is 0. 12 (3 hours per day over 350 days per year) Target cancer risk value is 1×10^{-4}.	The gamma-shielding factor was revised from 0.7 to 0.4. The current assumption accounts for a 60 percent reduction in external exposure due to shielding from structures rather than a 30 percent reduction. The use of the updated assumption would result in slightly less exposure and a less conservative PRG value. The outdoor time fraction was revised from 0.2 to 0.12. The current assumption assumes the resident spends 3 hours per day outside rather than 5 hours per day. Use of the updated assumption would result in a less exposure and a less conservative PRG value (higher).

Table 6-4. Comparison of Methods and Assumptions Used for the Residential Scenario

Parameter	Method used in RCBRA	Method Used in RI/FS	Overall Effect on RI/FS
			The protective threshold value was updated from a dose-based value to a risk-based value. The overall outcome is that updated PRGs values used in the RI/FS are slightly lower for beta- and gamma-emitting radioisotopes and higher for alpha-emitting radioisotopes.
MTCA Method B soil cleanup levels for unrestricted land use.	MTCA Method B levels are based solely on incidental soil ingestion.	Separate MTCA Method B levels were calculated for incidental soil ingestion and inhalation.	Chemicals that only report toxicity values for the inhalation exposure route are not included in the RCBRA evaluation (beryllium, cadmium, cobalt, Cr(VI), and nickel). The RI/FS separately reports cancer risks and noncancer hazard indices for both incidental soil ingestion and inhalation exposure routes.
MTCA Method B inhalation cleanup levels for unrestricted land use.	MTCA Method B inhalation cleanup levels were not evaluated in the RCBRA. DOE/RL-96-17 reports RAGs for beryllium, cadmium, Cr(VI) based on the inhalation exposure pathway, WAC 173-340-750 (3), 1996. A PEF value of 1.0×10^7 m^3/kg was used to convert air concentrations to soil concentrations. The PEF value of 1.0×10^7 m^3/kg is based on the default mass loading factor in RESRAD. This is roughly two orders of magnitude greater than EPA's default PEF of 1.4×10^9 m^3/kg.	MTCA Method B inhalation cleanup levels were calculated for the inhalation exposure route. A PEF value of 7.3×10^{10} m^3/kg is used to convert air concentrations to soil concentrations. This PEF uses meteorological data from Boise, Idaho, and Hanford site-specific annual wind speed. The PEF of 7.3×10^{10} m^3/kg is within a factor of two of EPAs default PEF of 1.4×10^9 m^3/kg.	Inhalation pathway cleanup levels that use a PEF value based on the default mass loading factor in RESRAD are lower values (more conservative) that those cleanup levels that are based on EPA Methodology.

Table 6-4. Comparison of Methods and Assumptions Used for the Residential Scenario

Parameter	Method used in RCBRA	Method Used in RI/FS	Overall Effect on RI/FS
Data Analysis			
Waste site decision units and analysis time frame	For local area exposure scenarios (including the interim action ROD rural residential scenario), the RCBRA used only the CVP/RSVP data sets from shallow zone decision units. These data sets are from waste sites that were excavated /remediated through calendar year 2005. The shallow zone decision unit is typically represented by soils from the excavation floor if at or above 4.6 m (15 ft) and any sidewalls from grade level (0 m [0 ft]) to a depth of 4.6 m (15 ft).	The RI/FS used CVP/RSVP data sets from all decision units associated with an excavated/remediated waste site through May 2011. In addition to the shallow zone decision unit, the RI/FS evaluates the risk contribution from soils associated with the overburden, staging pile footprint area, and the deep zone decision units.	The RI/FS risk evaluation is intended to supplement the analysis in Chapter 2 of the RCBRA. The RI/FS risk evaluation results can be used to disposition the closeout document for each remediated waste site from an interim status to final closure status.
Statistical and focused sample designs	When both focused and statistical samples exist for an analyte at a waste site, only the statistical samples were used to calculate the representative concentrations. An uncertainty analysis was performed to evaluate the selection of focused and/or statistical samples has on the risk assessment results, representative concentrations for these waste sites are also calculated using the combined focused and statistical samples. The statistical representative concentrations were compared to the combined focused and statistical samples and shown in Table C3-11in Appendix C, Section C-3, "Representative Concentrations."	The approach used to evaluate the data set for each sample design is similar to that used for the closeout documentation. The layout and orientation of sampling designs are based on the size, shape, and depth of the site. The data sets from the sample design are used to confirm attainment of remedial action objectives.	Evaluation of only the data from statistical sample designs when focused sample data are also collected has the potential to understate risk. Frequently focused sample results are collected in areas with the highest potential for contamination to be present. The RI/FS risk evaluation results can be used to disposition the closeout document for each remediated waste site from an interim status to final closure status.

Table 6-4. Comparison of Methods and Assumptions Used for the Residential Scenario

Parameter	Method used in RCBRA	Method Used in RI/FS	Overall Effect on RI/FS
COPC Identification	COPC refinement process includes a number of complementary steps and criteria, including a pre-selected list of contaminants that were excluded and a list that were included, as determined and agreed upon among the Tri-Parties. Additional selection steps include evaluation of all data according to detection status, statistical comparisons of Hanford Site data to background and reference site data, and an analyte-specific evaluation. Each ROD area has a separate list of COPCs.	COPC identification uses the exclusion criteria defined in Section 3.2.2.1 of the RCBRA. The inclusion list and other refinement steps used in the RCBRA were not incorporated into the RI/FS. When a COPC was detected at least once in a waste site decision unit (and it did not meet the exclusion criteria) it was carried into all risk calculations.	COPC refinement in RCBRA often included analytes that were not detected at the waste site. The inclusion of analytes that were not detected at a waste site decision unit results in an overstatement of risk. The method used to identify COPCs in the RI/FS is similar to the method used in the closeout documentation. Although two different COPC identification processes were used, similar risk drivers were identified in the risk characterization step of the analysis.
Exposure point concentrations	Representative concentrations pertain to sampled medium, whereas EPCs also include modeled concentrations in other exposure media. In general, the process used in the RCBRA follows EPA guidance as provided in the *ProUCL Version 4.0 User Guide* (EPA/600/R-07/038). The ProUCL software was not used to calculate representative concentrations.	*Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) is the EPA guidance for UCL calculation and ProUCL 4.00.05 serves as the companion software package for this guidance. ProUCL 4.00.05 contains rigorous parametric and nonparametric (including bootstrap methods) statistical methods that can be used on full data sets without nondetects and on data sets with below detection or nondetect observations. Both ProUCL and *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*	*ProUCL Version 4.0 User Guide* (EPA/600/R-07/038) draws from guidance documented in *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10). Methodologies for calculating 95UCLs are similar between the RCBRA and the RI/FS.

Table 6-4. Comparison of Methods and Assumptions Used for the Residential Scenario

Parameter	Method used in RCBRA	Method Used in RI/FS	Overall Effect on RI/FS
		(OSWER 9285.6-10) were used to recalculate the UCLs for the 100-K Source OU.	
Waste Site-Specific Information			
Exclusion of focused sample design data from waste sites 100-K-55:1 and 100-K-56:1	Focused sample design data sets were not evaluated. Only statistical sample design data sets were evaluated.	Both focused and statistical sample design data sets were evaluated in the RI/FS.	Exclusion of some data sets has the potential to understate risks.
Waste site 100-K-29	Arsenic and Cr(VI) were not included in the risk evaluation for this waste site.	Arsenic and Cr(VI) were included in the risk evaluation for this waste site.	Exclusion of some analytes has the potential to understate risks.
Waste site 116-KE-5	Ethylene glycol reported with an EPC of 59,000 µg/kg. This value is incorrect and should be reported with an EPC of 59 µg/kg.	Ethylene glycol was reported with an EPC of 59 µg/kg.	Risks associated with ethylene glycol in the RCBRA are overstated.

Sources: DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*.

EPA/600/R-07/038, *ProUCL Version 4.00.05 User Guide (Draft)*.

OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*.

WAC 173-340-750, "Model Toxics Control Act—Cleanup," "Cleanup Standards to Protect Air Quality."

- Basis of PRG values for radioisotopes and chemicals
- Inclusion of all decision units associated with a waste site
- Inclusion of analytical data from focused sampling designs
- Analysis time frame
- Calculation of exposure point concentrations

Preliminary remediation goals (also used as risk-based screening levels) are developed in RCBRA and presented in this chapter and are the numeric values that represent the remedial action objectives (RAOs) presented in Chapter 8. Conversely, RAOs are narrative statements that define the extent to which waste sites require cleanup to protect human health and the environment. The RAO statement for protection of human health through the direct contact exposure pathway is provided in Section 8.1.4.

For the 100-K Source OU, the results of the supplemental soil risk evaluation presented in this chapter will be used to determine whether additional remedial action is necessary for waste sites where remediation has been completed, and whether the goals and objectives of the interim action RODs have been met, as demonstrated by verification sampling and analysis. The risk-based screening evaluation for the residential scenario in this chapter provides information necessary to resolve the following questions and provides information needed to support final remedial decisions that will ensure protection of human health and the environment:

- Are residual conditions for cleanup actions completed under the interim action RODs protective of human health and the environment based on comparison to risk-based screening levels (RBSLs) calculated in accordance with current EPA guidance?
- Are there waste sites with a no action or interim closed reclassification status that should be carried into the F/S?
- What uncertainties are associated with the risk results that require a risk management decision?

As discussed previously, waste sites evaluated in the River Corridor were Interim Closed using RAGs related to direct contact soil exposure by human receptors. These RAGs are reported in the 100 Area RDR/RAWP (DOE/RL-96-17). The RAGs for radionuclides have not been revised since originally published in 1996. Remedial action goals in the 100 Area of the River Corridor [for direct contact] were based on a rural residential exposure scenario. The interim action ROD residential scenario for radionuclides is a Rural Residential scenario that, in addition to direct contact, includes food chain exposure pathways (e.g., ingestion of homegrown produce, beef, and milk). Since the 100 Area RDR/RAWP (DOE/RL-96-17) was originally published, EPA has published a change in policy associated with health protectiveness thresholds as well as updates in guidance associated with several exposure assumptions. PRGs presented in this chapter incorporate exposure assumptions that were updated to reflect current EPA guidance. These assumptions include a decrease in the external gamma-shielding factor (decreased shielding) and a decrease in the outdoor time fraction. Health protective levels were also updated from a target annual dose rate of 15 mrem/yr to a target risk of 1×10^{-4} to be consistent with guidance recommended in *Radiation Risk Assessment at CERCLA Sites: Q & A* (EPA/540/R/99/006).

The interim action ROD residential scenario for chemicals is based on the *MTCA Method B Soil Cleanup Levels for Unrestricted Land Use* ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740]). The MTCA Method B levels are based solely on incidental soil ingestion and do not address the food exposure pathways that were included for the radionuclide Rural Residential scenario. The MTCA Method B cleanup levels developed in this chapter are similar to those published in the most recent version of the 100 Area RDR/RAWP (DOE/RL-96-17) with the exception of those chemicals whose RAG is based on the inhalation exposure route. RAGs reported in the 100 Area

RDR/RAWP (DOE/RL-96-17) incorporate the use of a particulate emission factor that is based on the mass loading rate reported in the RESRAD code. The PEF used to calculate the inhalation RAG is roughly two orders of magnitude greater than the site-specific PEF developed with EPA guidance for the Hanford Site and used in this chapter.

In addition to performing the risk-based screening evaluation, another purpose for updating the PRGs is to determine if the RAGs developed and reported in the 100 Area RDR/RAWP (DOE/RL-96-17) are protective when compared to current guidance. Chapter 8 will provide a summary of the RAGs reported in the 100 Area RDR/RAWP (DOE/RL-96-17) in addition to the PRGs presented in this chapter. To satisfy RAOs for protection of human health, the RAGs reported in the 100 Area RDR/RAWP (DOE/RL-96-17) will be compared to the PRGs presented in this chapter for the residential scenario. The lower of the two values will be selected to satisfy RAO 4 and RAO 5. This approach is used in Chapter 8 to ensure that PRGs for protection of human health from direct contact with soil achieve comparable or greater levels of protectiveness as was achieved by the RAGs presented in the interim action RODs.

Differences between the RCBRA and the RI/FS in the methodologies used for assessing residual risks are described in Table 6-4; these include methods for COPC identification, selection of exposure factors used for the RAGs and PRGs, inclusion of all decision units associated with a waste site, and inclusion of analytical data from focused sampling designs. As a result of these differences, the evaluation provided in the RI/FS more directly supports the evaluation of remedial alternatives in the FS.

6.1.2.1 Reasonably Anticipated Future Land Use Scenarios

The RCBRA evaluated risks for a range of exposure scenarios that represent a range of upper bound and reasonably anticipated receptors and activities. When soil cleanup goals were initially established for the River Corridor, the TPA signatories agreed that it was appropriate to protect for a range of potential exposures in the future so that cleanup actions did not limit future use of the site. For the purposes of the RI/FS, the resident Monument worker and the casual user scenario represent reasonably anticipated future land use. The casual user scenario was also evaluated in the RCBRA as a recreational scenario and applied on a broad area scale.

PRGs are also presented in this chapter for both scenarios for use in the risk-based screening evaluation. CVP and RSVP data are compared to these numeric values to confirm that cleanup actions are protective of the reasonably foreseeable land uses that DOE and USFWS anticipate for the river corridor.

The resident National Monument worker scenario was evaluated in the RCBRA as an occupational scenario and was applied on a local and broad area scale. In the RCBRA, the resident monument worker spent a fraction of the day on the waste site as his residence (local area) and spent a fraction of the same day in a region as large as an individual ROD decision area and potentially as large as the entire River Corridor conducting work activities (broad area). This exposure scenario was used to calculate forward risk estimates and was not developed for calculating a PRG. To incorporate the use of this exposure scenario in the RI/FS process, the scenario was modified to assume that the broad area concentration was equal to the RME broad area upland surface soil concentration reported in RCBRA. The PRG value represents the concentration of soil the resident monument worker is exposed to on the waste site (local area).

With the exception of the soil ingestion rate and exposure time, the exposure assumptions used to calculate the resident monument worker local area PRGs are the same as those that would be used to provide a Reasonable Maximum Exposure (RME) for the residential exposure scenario. With the exception of the soil ingestion rate, the exposure assumptions used to calculate the resident monument worker broad area risks are the same as those that would be used to provide an RME for the industrial worker exposure scenario defined in *Risk Assessment Guidance for Superfund Volume I: Human Health*

Evaluation Manual Supplemental Guidance "Standard Default Exposure Factors" Interim Final (OSWER Directive 9285.6-03). Some exposure assumptions were updated based on recent EPA guidance or modified to conform to recommended EPA methodology for calculation of PRGs. Exposure assumptions that were updated based on recent guidance include inhalation rates, PEFs, and the external gamma shielding factor. The exposure assumptions that were modified to lend themselves to standard PRGs equations include soil ingestion rates, indoor time fraction, onsite exposure time, and use of decay factors. These updates and modifications allow a numeric value to be developed to confirm that cleanup actions at the waste site are protective of reasonably foreseeable land uses. Table 6-5 summarizes the modifications made to the resident Monument worker exposure scenario for use as a PRG.

Table 6-5. Summary of Differences in Exposure Assumptions for the Resident Monument Worker between the RCBRA and RI/FS Risk

Parameter	RCBRA Resident Monument Worker	RI/FS Resident Monument Worker
Soil ingestion rate	A soil ingestion rate of 100 mg/day is assumed for this receptor. The soil ingestion rate is apportioned to the local area and the broad area based on the amount of time he spends at each area. The RCBRA allocated 52.2 mg/day to the residential portion (local area) of this scenario and 25 mg/day to the occupational portion (broad area) of this scenario.	A soil ingestion rate of 100 mg/day is assumed for this receptor. The RI/FS allocated 76.2 mg/day to residential portion (local area) of this scenario and 23.8 mg/day to the occupational portion (broad area) of this scenario for a total of 100 mg/day.
Inhalation rate	The RCBRA assumed an inhalation rate of 0.63 m^3/hour based on an inhalation rate of 15 m^3/day.	The RI/FS assumed an inhalation rate of 0.83 m^3/hour based on an inhalation rate of 20 m^3/day.
Particulate Emission Factor	The RCBRA used a PEF of 1.08×10^8 m^3/kg for the local area and a PEF of 4.3×10^8 m^3/kg for the broad area.	The RI/FS used the EPA default PEF of 7.3×10^{10} m^3/kg for the local area and a PEF of 2.6×10^{10} m^3/kg for the broad area.
Time spent on the local area and broad area scale	The RCBRA assumed an exposure time of 13 hours/day spent at the residence (local area), 8 hours spent at onsite at work (broad area), and 3 hours offsite (neither local nor broad area) for a total of 24 hours/day.	The RI/FS assumed that an exposure time of 16 hours/day was spent at the residence (local area) and 8 hours/day onsite at work (broad area) for a total of 24 hours per day.
Indoor and outdoor exposure time	The RCBRA assumed that the resident spent 13 hours/day indoors, 8 hours/day outdoors, and 3 hours per day offsite.	The RI/FS assumed that the resident spent 13 hours/day indoors and 3 hours/day outdoors (local area) and the worker spent 8 hours/day outdoors (broad area).
Gamma shielding factor	The RCBRA used an external gamma shielding factor is 0.7.	The RI/FS used an external gamma shielding factor is 0.4 based on current guidance.
Radiological decay factors	Decay of radioisotopes over the exposure duration was not accounted for.	Decay of radioisotopes over the exposure duration was incorporated.

The casual user scenario was evaluated in the RCBRA as a recreational scenario and was applied on a broad area scale. In the RCBRA, the casual user only spent time in a region as large as an individual ROD OU and potentially as large as the entire River Corridor conducting work activities (broad area). Similar to the resident monument worker, this exposure scenario was used to calculate forward risk estimates but was not developed for calculating a PRG. To incorporate the use of this exposure scenario in the RI/FS process, the scenario was modified to assume that all of the casual user time was spent on the waste site (local area). This assumption is the only modification made to this exposure scenario, no changes were made to the exposure assumptions used to calculate PRG values. This modification allows a conservative numeric value to be developed to confirm that cleanup actions at the waste site are protective of reasonably foreseeable land uses.

6.1.3 Other Land Use Scenarios in RCBRA

The RCBRA also evaluated three residential scenarios that describe exposures related to a rural land-use pattern that involves home-produced foods. The Subsistence Farmer scenario envisions a substantial quantity of home-produced foods, but not a diet composed solely of such foods. The two Native American Resident scenarios, however, envision a complete subsistence lifestyle where all foods are grown at the home or (in the case of fish) caught in the Columbia River. Residential receptors are assumed to spend effectively all of their time in the area around a residence located on a remediated waste site in order to protectively assign all soil-related exposures to that site.

DOE, through discussions with the Tribes (Brockman, 2007), has agreed to include quantitative analysis of Native American scenarios in risk assessments supporting RI/FS documents. The two scenarios considered are provided by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and the Yakama Nation. These tribal scenarios have been evaluated and presented in Hanford Site risk assessments to assist interested parties in providing input on remedial alternatives (*Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit* [DOE/RL-2007-28]), and have not been used for development of PRGs as part of alternatives analyses in FS (EPA, 2008).

The results of the local area risk assessment for the Residential scenarios indicate that present-day RME cancer risk is frequently greater than 1×10^{-4} and that RME chemical HI frequently exceeds the threshold of 1.0. Present-day RME cancer risks greater than 1×10^{-4} for the Subsistence Farmer exposure scenario are almost entirely related to one of three factors:

- External irradiation from short-lived radionuclides including europium-152, cesium-137, and cobalt-60
- Exposure to arsenic from ingestion of garden produce
- Exposure to the short-lived radionuclide strontium-90 from ingestion of produce and livestock products

By the year 2075, Subsistence Farmer RME cancer risks above 1×10^{-4} are related overwhelmingly to arsenic exposure from produce ingestion. Because the CTUIR Resident and Yakama Resident scenarios use very high (subsistence level) site-raised food ingestion rates, strontium-90 still plays a significant role in food-related exposures at year 2075 for these scenarios. By year 2150, however, CTUIR Resident and Yakama Resident cancer risks above 1×10^{-4} are dominated by arsenic exposure from ingestion of garden produce.

The RCBRA Subsistence Farmer cancer risk and chemical HI results were frequently above threshold criteria. There are two major differences between the risk assessment methods used in the RCBRA and the basis of the interim action ROD residential cleanup levels. These differences largely explain why

some waste sites remediated to meet the interim action ROD residential cleanup levels still appear to present high levels of residual risk under the Subsistence Farmer scenario:

Residential interim action ROD cleanup levels for chemicals are the MTCA Method B Soil Cleanup Levels for Unrestricted Land Use ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740]), which is a reasonable maximum exposure scenario based on incidental soil ingestion and does not address the food exposure pathways historically evaluated for radionuclides.

The interim action ROD cleanup level for arsenic is 20 mg/kg, which is an "adjusted" value established by the State of Washington to address a range of natural background levels ("Tables" [WAC 173-340-900]).

One of the primary uncertainties for site-specific results relates to modeled exposure concentrations in foods, particularly garden produce. Further discussion of the potential biases in modeled food chain exposures is provided in the RCBRA. As discussed in Section 5.9.4.2 of the RCBRA, in the case of the noncancer hazard index (HI) results for produce ingestion of mercury, uranium, and copper, a large conservative bias is anticipated because a linear plant uptake model was applied to soil concentrations that are far above naturally occurring levels. In the case of arsenic, produce ingestion provides the largest contribution to total cancer risk, even though the range of site soil concentrations is relatively small. Uncertainty in produce concentrations is attributable to intrinsic variability related to soil conditions, plant species and tissue type, harvest time, and other variables. A review of recommended plant-soil ratios from a number of sources, described in Section 5.9.2.4 of the RCBRA, shows that the range of soil to plant transfer ratios for arsenic (from 0.006 to 1.125) is approximately a factor of 200. The value of 0.53 used in the HHRA, from the RESidual RADioactivity (RESRAD) computer code that has been used to perform dose assessment at the Hanford Site and other DOE facilities, is near the upper end of this range. The high-end values for plant-soil concentrations, many of which were used in the RCBRA to assess exposure through food pathways, may result in a scenario that provides exposures to nonradionuclide contaminants higher than an RME. Therefore, these food chain pathways have not been incorporated into the development of PRGs for nonradiological constituents.

6.2 Supplemental Soil Risk Evaluation

The 100-K Source OU supplemental risk evaluation followed the approach described below:

- Identify all waste sites with a "no action" or "interim closed" reclassification status.
- Obtain verification sampling and analysis data for all "no action" and "interim closed" waste sites that have been remediated through May 2011.[4]
- Compute EPCs for each detected analyte measured at a waste site using the EPA's ProUCL version 4.00.05 software.
- Compare EPCs to direct contact RBSLs selected to represent baseline conditions and reasonably anticipated future site use.
- Calculate cancer risk and noncancer hazards for each detected analyte.
- Compare cancer risks and noncancer hazards to acceptable state and federal target risk and noncancer thresholds.

[4] Waste sites for which interim action cleanups had been completed under interim action RODS and for which the CVPs were completed through May 2011.

- Determine if the "no action" or "interim closed" waste site should be carried forward into the FS to select remedial alternatives.

This supplemental soil risk evaluation follows the guidance in risk assessment guide (EPA/540/1-89/002). The following subsections describe the four-step process. Because this supplemental soil risk evaluation is intended to complement the analysis performed in the RCBRA, where applicable, a brief description is provided to describe the similarities in approach.

6.2.1 Data Analysis

This section describes the sources of data used in the risk assessment (Section 6.2.1.1), describes the data quality assessment and data validation process (Section 6.2.1.2), and identifies contaminants of potential concern in vadose zone material that are accessible for human exposures (Section 6.2.1.3). During the course of this risk assessment, analytes were evaluated to identify COPCs and prioritize those estimated to pose an unacceptable risk and warrant evaluation in the feasibility study.

6.2.1.1 Sources of Analytical Data Used in Risk Assessment

This supplemental soil risk evaluation includes the evaluation of vadose zone material samples for remediated waste sites with a "no action" or "interim closed" reclassification status collected within the100-KR-1 and 100-KR-2 Source OUs. Waste sites where remediation and verification sampling and analysis were assessed by the end of May 2011 are included in the supplemental soil risk evaluation.

All samples were collected in accordance with the requirements stated in *100 Area Remedial Action Sampling and Analysis Plan* (DOE/RL-96-22). Data collected under *100 Area Remedial Action Sampling and Analysis Plan* (DOE/RL-96-22) are used to meet the purpose and objectives of the 100 Area RDR/RAWP (DOE/RL-96-17), which describes the design and the implementation of the remedial action processes required by the following:

- EPA/ROD/R10-99/039, *Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units, Hanford Site, Benton County, Washington (100 Area Remaining Sites)*

- EPA/AMD/R10-97/044, *Amendment to the Interim Remedial Action Record of Decision for the 100-BC-1, 100-DR-1, and 100-HR-1 Operable Units, Hanford Site, Benton County, Washington*

- EPA/541/R-00/121, *Declaration of the Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-2, 100-HR-2, and 100-KR-2 Operable Units, Hanford Site (100 Area Burial Grounds), Benton County, Washington*

Remediation of waste sites in the 100-K Source OU began in 2002. Analytical results for each waste site are included in the associated closeout documentation, which are listed in Appendix C, Table C-1, of the 100-K Work Plan (DOE/RL-2008-46-ADD2). The 100-K Work Plan (DOE/RL-2008-46-ADD2) and the 100 Area RDR/RAWP (DOE/RL-96-17) were both reviewed and approved by the Tri-Parties.

Sixteen waste sites in the 100-K Source OU have verification sampling and analysis data and are included in this risk evaluation. Thirteen of the 16 waste sites from the 100-K Source OU were evaluated in the RCBRA Report (DOE/RL-2007-21). A summary of the waste sites, associated decision unit(s), and reclassification status for 100-K Source OU is provided in Table G-1. Waste site decision units are defined in in Section 6.2.2.2. The waste sites listed in Table G-1 are a subset of the waste sites that were listed in Appendix C, Table C-1, of the 100-K Work Plan (DOE/RL-2008-46-ADD2). The following sources of analytical data were used in the soil risk assessment:

- All verification sampling and analysis soil data reside in the Environmental Remediation database (ENRE).
- All verification sampling and analysis data also reside in the HEIS database.
- All the closeout verification data used in this risk evaluation are included in Appendix D of this report.

6.2.1.2 Data Quality Evaluation and Data Validation

A data quality assessment (DQA) is performed and reported in each closeout documentation report. The DQA compares the verification sampling approach and resulting analytical data with the sampling and data quality requirements specified by the project objectives and performance specifications. The DQA determines if the data are of the right type, quality, and quantity to support site cleanup verification decisions within specified error tolerances. The DQA also determines if the analytical data are found acceptable for decision-making purposes and if the sample design was sufficient for the purpose of cleanup site verification. The cleanup verification sample analytical data and detailed DQA are summarized in the appendices associated with the cleanup verification packages. The results of each DQA are incorporated by reference and no further DQA was performed as part of this risk assessment.

All the analytical data are evaluated and a portion validated for compliance with QA project plan requirements as documented in the 100 Area RDR/RAWP (DOE/RL-96-17). Data evaluation is performed to determine if the laboratory carried out all steps required by the SAP and the laboratory contract governing the conduct of analysis and reporting of the data. This evaluation also examines the available laboratory data to determine if an analyte is present or absent in a sample and the degree of overall uncertainty associated with that determination. Data validation was done in accordance with validation procedures as part of data evaluation.

6.2.1.3 Identification of COPCs

For the purposes of this evaluation, a "COPC" is defined as an analyte suspected of being associated with site-related activities, that represent a potential threat to HHE, and whose data are of sufficient quality for use in a quantitative baseline risk assessment.

All analytes detected at least once in a waste site decision unit for the 16 waste sites included in the risk evaluation are identified as COPCs. As described in Section 6.2.2.2, the floor and sidewalls of an excavated waste site are divided into one or more decision units (e.g., shallow zone, deep zone, overburden). Verification sampling and analysis data are collected according to sample design requirements for the type of decision unit. For the purpose of this supplemental soil risk evaluation, an "exposure area" and a "decision unit" are operationally defined as being the same. Verification sampling and analysis data are subsequently grouped to calculate exposure point concentrations

The contribution from naturally occurring metals and anthropogenic radioisotopes are discussed in the risk characterization section in accordance with *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003). The risk characterization will discuss elevated background concentrations and their contribution to site risks as well as naturally occurring elements that are not CERCLA hazardous substances, pollutants, and contaminants but exceed the risk-based screening levels (i.e., RBSLs).

The RCBRA identifies a subset of analytes that are excluded from consideration as COPCs by agreement among the Tri-Parties based on relevant Hanford Site data. The following exclusion lists employed in the RCBRA Report (DOE/RL-2007-21) were also applied to the waste site verification data during the data reduction steps described in Section 6.2.2.2:

- **Radionuclides with a half-life of less than three years:** Radionuclides with half-lives less than 3 years would not be present as a result of historical Hanford Site operations due to radioactive decay that would have occurred since operations ceased.

- **Essential nutrients:** Essential nutrients that are present at relatively low concentrations and are toxic only at high concentrations need not be considered in a quantitative risk assessment.

- **Water quality or soil physical property measurements:** These analytes were measured to obtain information on water quality or soil properties to understand potential confounding factors for bioassays conducted for soil, sediment, or water or to interpret their influence on the toxicity of COPCs (e.g., grain size for soils, water hardness for metal effects).

- **Background radionuclides (potassium-40, radium-226, radium-228, thorium-228, thorium-230, and thorium-232):** These background radionuclides were identified by consensus of Tri-Party managers as not directly related to Hanford operations or processes.

The RCBRA includes two additional steps to identify COPCs that the supplemental soil risk evaluation did not apply:

- Analytes that are commonly reported in waste site cleanup verification reports based on frequency of detection. Inclusion list analytes was not consistently reported in the CVP and RSVP data; therefore, this step was not implemented.

- Evaluate remaining analytes as candidate COPCs, based on comparisons to Hanford Site background, reference areas, and an "analyte-specific" evaluation.

As a result of not applying the last two steps used in the RCBRA to identify COPCs, more analytes are identified as COPCs in this supplemental risk evaluation than were identified in the RCBRA. Identifying all detected analytes (except those on the exclusion list) as COPCs is a more streamlined approach that is consistent with *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003).

6.2.2 Exposure Point Concentrations

Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10) states that, "an exposure point concentration (EPC) is a conservative estimate of the average chemical concentration in an exposure medium." *Supplemental Guidance to RAGS: Calculating the Concentration Term* (OSWER Publication 9285.7-081) states that, "because of the uncertainty associated with estimating the true average concentration at a site, the 95 percent UCL of the arithmetic mean should be used for this variable." Use of the 95 percent UCL of the arithmetic mean yields risk estimates that correspond to a reasonable maximum exposure. Instances where a value different from a UCL is used as the EPC are clearly stated in this risk assessment. Reasons and/or justifications are also provided.

Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10) further states that, "The EPC is determined for each individual exposure unit within a site. An exposure unit is the area throughout which a receptor moves and encounters an environmental medium for the duration of the exposure. Unless there is site-specific evidence to the contrary, an individual receptor is assumed to be equally exposed to media within all portions of the exposure unit over the time frame of the risk assessment." For this supplemental soil risk evaluation, the "exposure unit" and the "decision unit" are operationally defined as being the same. As previously described, one or

more decision units are included within a waste site including shallow vadose zone material (0 to 4.6 m [0 to 15 ft] bgs), deep vadose zone material (greater than 4.6 m [15 ft] bgs), and overburden material.

Statistical Guidance for Ecology Site Managers (Ecology Publication 92-54) has been used to calculate EPCs for all closeout documentation to date. *Statistical Guidance for Ecology Site Managers* (Ecology Publication 92-54) was published in 1992 and this guidance has been superseded by *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10), which was published in 2002. For this supplemental soil risk evaluation, UCLs were recalculated for all waste sites and decision units to incorporate the updated guidance in *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10). UCLs that incorporate updated guidance use more rigorous statistical methods to estimate exposure concentrations and eliminate the use of the simple substitution method for nondetects where a proxy value of one-half the detection limit is assigned to all nondetected results. *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) notes that because of the complicated formulas used to compute UCLs, there is no general rule about which substitution rule will yield an appropriate UCL. The uncertainty associated with the substitution method increases and its appropriateness decreases as the detection limit becomes larger and as the number of nondetects in the data set increases.

The following describes the statistical methodology used for closeout documentation (Section 6.2.2.1) and the statistical methodology used for this supplemental soil risk evaluation (Section 6.2.2.2). While both evaluations used the same dataset, the differences in statistical methodologies may result in differences in the EPC values between the closeout documentation and this risk assessment for the same COPCs in a waste site decision unit. The following provides a basis for these potential differences.

6.2.2.1 Statistical Evaluation Methodology Used for Closeout Documentation

For waste sites closed using a statistical/random sampling design, the primary statistical calculation to support cleanup verification was the 95 percent UCL on the arithmetic mean of the data. Statistical calculations were performed in compliance with *Statistical Guidance for Ecology Site Manager*(Ecology Publication 92-54). This guidance addresses two kinds of data distributions: normal and lognormal. For normal data, the guidance recommends a UCL on the mean based on the Student's t-statistic. For lognormal data, the guidance recommends the Land method using the H-statistic. This guidance also implements the substitution method where a proxy value of one-half the detection limit is assigned to nondetected results.

Small data sets ($n<10$) were evaluated in accordance with Section 5.2.1.4 of *Statistical Guidance for Ecology Site Manager* (Ecology Publication 92-54) and a nonparametric distribution was assumed. When a nonradionuclide was detected in fewer than 50 percent of the samples collected and for focused sampling designs, the maximum detected value was used for comparison purposes.

6.2.2.2 Statistical Evaluation Methodology Used for the Supplemental Soil Risk Evaluation

Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10) is the EPA guidance for UCL calculation and ProUCL 4.00.05 serves as the companion software package for this guidance. ProUCL 4.00.05 contains rigorous parametric and nonparametric (including bootstrap methods) statistical methods that can be used on full data sets without nondetects and on data sets with nondetect observations. Both ProUCL and *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) were used to recalculate the UCLs for the 100-K Source OU.

To ensure that waste sites and decision units are grouped correctly and UCLs are accurately recalculated, all waste sites, decision unit groupings, and sample numbers were individually verified against the original closeout documentation. *Waste Site Evaluation Process for the 100-KR-1 and 100-KR-2 Source Operable Units* (ECF-100KR4-11-0007), which is provided in Appendix G, documents the process used to confirm a complete list of waste sites with a reclassification status of "interim closed" or "no action" through May 2011. Verification of sample numbers associated with each waste site was confirmed along with the decision unit grouping with which the sample is associated. This list of samples is used to verify the sampling results are complete. The analytical data that have undergone this review process become the final data set used to calculate the UCLs and associated summary statistics used in this supplemental soil risk evaluation. A list of the sample numbers associated with each waste site decision unit is provided in Table G-2. Table G-2 also lists the date the sample was collected, the type of sample design used, and the Washington state plane coordinates of the sample location.

Waste Site Decision Units. Verification sampling and analysis data that are associated with the samples listed in Table G-2 are from several different decision units within a waste site, including shallow vadose zone material, deep vadose zone material, and overburden material. The following describes the basis of each decision unit and briefly describes the sample designs used.

The floor and sidewalls of an excavated waste site are divided into one or more decision units (as defined in Section 6.2.2) and a sample design is developed for the decision unit. Sample design requirements for each decision unit are described in the *100 Area Remedial Action Sampling and Analysis Plan* (DOE/RL-96-22). In practice, the shallow zone decision unit is typically represented by material from the excavation floor if at or above 4.6 m (15 ft) and any sidewalls from grade level (0 m to a depth of 4.6 m (0 to 15 ft). The deep zone decision unit is represented by material from the excavation floor (if below 4.6 m [15 ft]) and by any sidewall materials below 4.6 m (15 ft). As needed, decision subunits and an associated sampling design are also established for suspect clean overburden stockpiles (i.e., to verify suitability for backfill material) and the footprint of the staging pile area. The layout and orientation of the sampling designs are based on the size, shape, and depth of the site. Sampling of a waste site decision unit to confirm attainment of remedial action objectives was performed according to one of three types of sampling designs: focused sampling design, random or statistical sampling, or a combination of both.

The decision unit naming convention is summarized in Table 6-6.

Table 6-6. Summary and Definition of Decision Unit Types

Decision Unit Name	Depth	Sampling Design Description
Shallow	0 to 4.6 m (15 ft) bgs	Samples collected using a statistical sampling design
Deep	Greater than 4.6 m (15 ft) bgs	
Overburden	Not applicable	
Shallow_Focused	0 to 4.6 m (15 ft) bgs	Samples collected using a focused sampling design
Deep_Focused	Greater than 4.6 m (15 ft) bgs	
Overburden_Focused	Not applicable	

The process used to calculate EPCs for each waste site and decision unit is documented in *Computation of Exposure Point Concentrations for the 100-KR-1 and 100-KR-2 Source Operable Units*

(ECF-100KR4-11-0008), which is provided in Appendix G. The purpose of *Computation of Exposure Point Concentrations for the 100-KR-1 and 100-KR-2 Source Operable Units* (ECF-100KR1-11-0008) is to document the data processing and reduction steps, methodology, decision logic, assumptions, input files, and output files used to determine the EPCs.

Data Processing and Reduction. This section describes the data processing and reduction steps that are taken prior to the calculation of UCLs. Figure 6-1 shows each of the data processing and data reduction steps and the number of records associated with each step for the 100-K Source OU.

Data Set Consistency with HEIS. The original source of the analytical data set resides in the ENRE database system. As such, database structure and naming conventions are not generally consistent with the structure and naming conventions in the HEIS database. In order to upload the sample data to the HEIS database, the data set required modification of certain fields and naming conventions so it would be compatible with HEIS fields and nomenclature. The following general steps were taken:

- Database fields were mapped to HEIS compatible fields
- Analyte names were mapped to HEIS compatible analyte names
- Analytical method names were mapped to HEIS compatible analytical method names
- All results were converted to units of µg/kg and pCi/g

Laboratory and Data Validation Flags. Analytical data are received from the laboratory with data qualification flags; validation qualifiers are assigned during the data validation process. The following rules are applied to determine how the sample results can be used for calculating UCLs.

- All sample results flagged with a "U" qualifier or combination of qualifiers that include a "U," such as a "UJ," are considered nondetected concentrations.
- All sample results without a "U" qualifier are considered detected concentrations, including results without a qualifier or with an "E" or a "J" qualifier.
- Sample results that are rejected and flagged with an "R" qualifier are not used for calculating UCLs.

Analytes Reported by Multiple Analytical Methods. Often, a sample is analyzed for an analyte using more than one analytical method, resulting in multiple results for the analyte from the same location and sample date. Because multiple sets of analytical results cannot be used to quantify risk (i.e., this would result in multiple counting of a chemical), the set of data that best represents the actual concentrations is retained. When analytes are reported by more than one analytical method for a sample, the results are processed to select the method that provides the most reliable results. Considerations for determining data to be retained include method-associated sample size, detection frequency, and detection limits. The most conservative (i.e., health protective) use of these types of data is the goal. Larger sample size, higher detection frequencies, and lower detection limits are given higher priority for method selection.

For example, lead may be analyzed using EPA Method 200.8 with an EQL of 500 µg/kg or EPA Method 6010 with an EQL of 5,000 µg/kg. For a sample with lead concentrations reported by both methods, the results reported by EPA Method 200.8 are chosen over EPA Method 6010 because of the more sensitive detection limit.

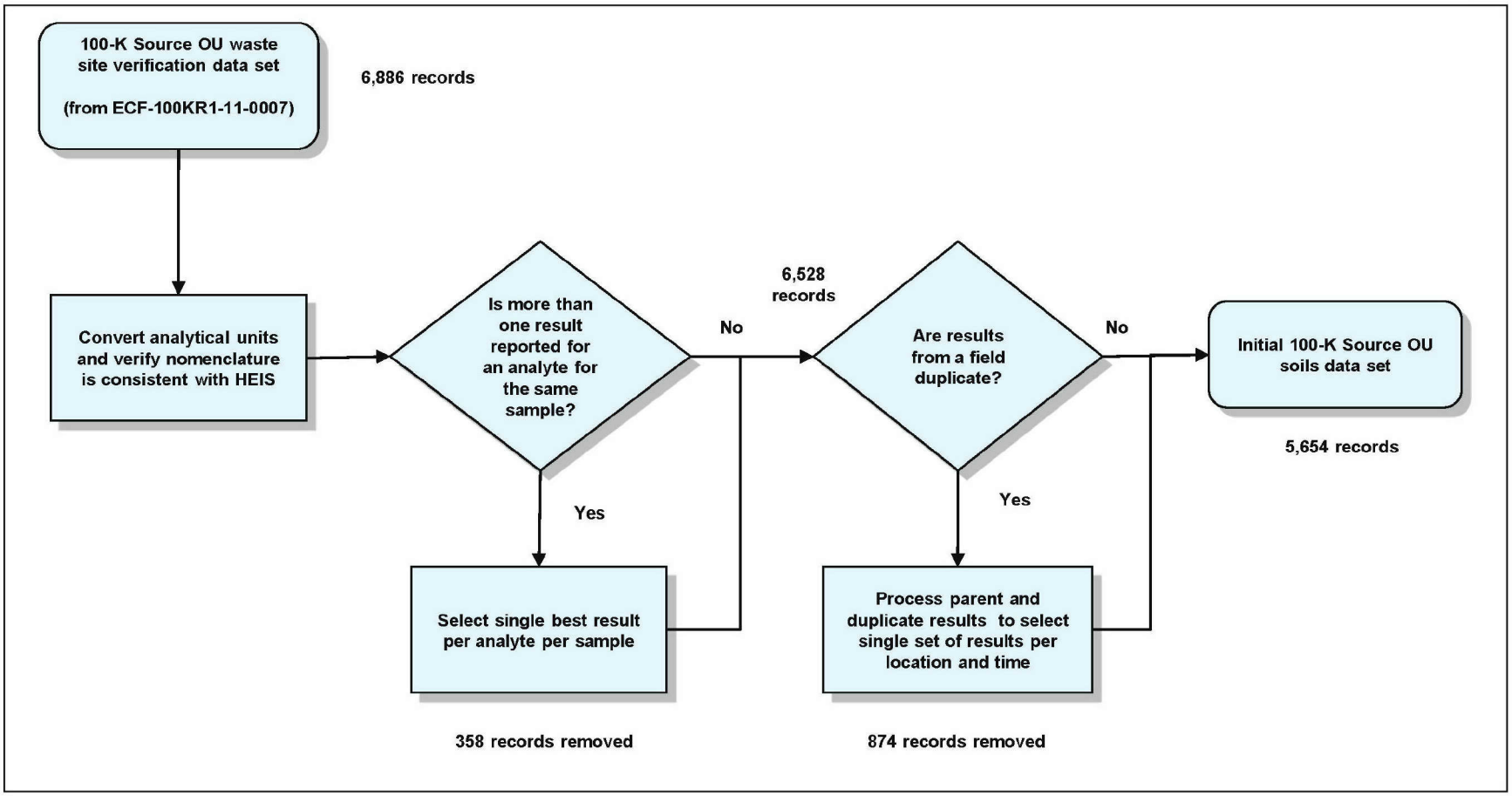

Figure 6-1. Data Processing and Reduction Steps for the 100-K Source OU

Field Duplicate Results. Field quality control samples (field duplicates) are collected in the field and analyzed by the laboratory as unique samples. The parent sample and field quality control samples are collected from the same location (i.e., sample node) and same date, resulting in more than one sample per location and date. Because multiple sets of analytical results cannot be used to quantify risk (i.e., this would result in multiple counting of a chemical), the results for the same location and date are reduced to a single result for each reported analyte. The following criteria are used to reduce multiple sample results for one location and date to a single result. The most conservative (i.e., health protective) result is the goal.

- If two or more detections are reported, the maximum concentration is used.
- If one detection and one or more nondetections are reported, the detected concentration is used.
- If two or more nondetections are reported, the lowest detection limit is used.

Identify Analytes for 95 percent UCL Calculation. After extracting and processing the data set, it is further reduced to identify a subset of analytes that require computation of a UCL. Analytes that meet any of the exclusion criteria or were not detected in any of the samples analyzed with the 100-K Source OU are not carried forward into the statistical calculations and EPC selection. The analyte identification steps and the number of records associated with each of the steps are presented in Figure 6-2 for the 100-K Source OU.

Apply Exclusion Criteria. The first step used to identify analytes that require a 95 percent UCL calculation is to apply exclusion criteria. Analytes that do not meet the exclusion criteria are carried forward into the next step of the process. Analytes that meet exclusion criteria are eliminated from further consideration. The following were excluded:

- Radionuclides that have half-lives of less than 3 years and that are not significant daughter products
- Background radionuclides that are not directly related to Hanford Site operations or processes
- Essential nutrients (minerals)
- Analytes without known toxicity information

Thirty-one analytes for the 100-K Source OU meet the exclusion criteria and are listed in Table G-3. Sampling dates, minimum and maximum detected concentrations, minimum and maximum method detection limits, and the basis for their exclusion are provided in this table.

Identify Nondetected Analytes. The next step used to identify analytes that require a 95 percent UCL calculation is to identify nondetected analytes. Analytes that are measured at appropriate sampling locations have adequate detection limits, and that have not been detected in any of the samples are eliminated from further consideration. Any analyte that is detected at least once in the 100-K Source OU is carried forward to the next step of the process.

A total of 83 analytes were not detected in the 100-K Source OU samples and are listed in Table G-4. The table also provides sampling dates, total number of samples, and minimum and maximum MDLs.

95 Percent UCL Calculation Methodology. A discussion of waste site decision units was provided earlier in this section. It should be noted that calculated UCLs and EPCs selected for shallow zone and deep zone decision units represent verification data collected from the floor and the sidewall of the excavated waste site. As a result, risks are likely overstated because the UCL and the EPC do not take credit for the existing clean backfill that covers the remediated waste site.

Analytical data for all analytes that have been detected at least once in each waste site decision unit are extracted from the data set and subsequently formatted so they can be directly imported into ProUCL where 95 percent UCL calculations and summary statistics are performed. The following information is obtained from the UCL calculations and summary statistics generated for each waste site decision unit.

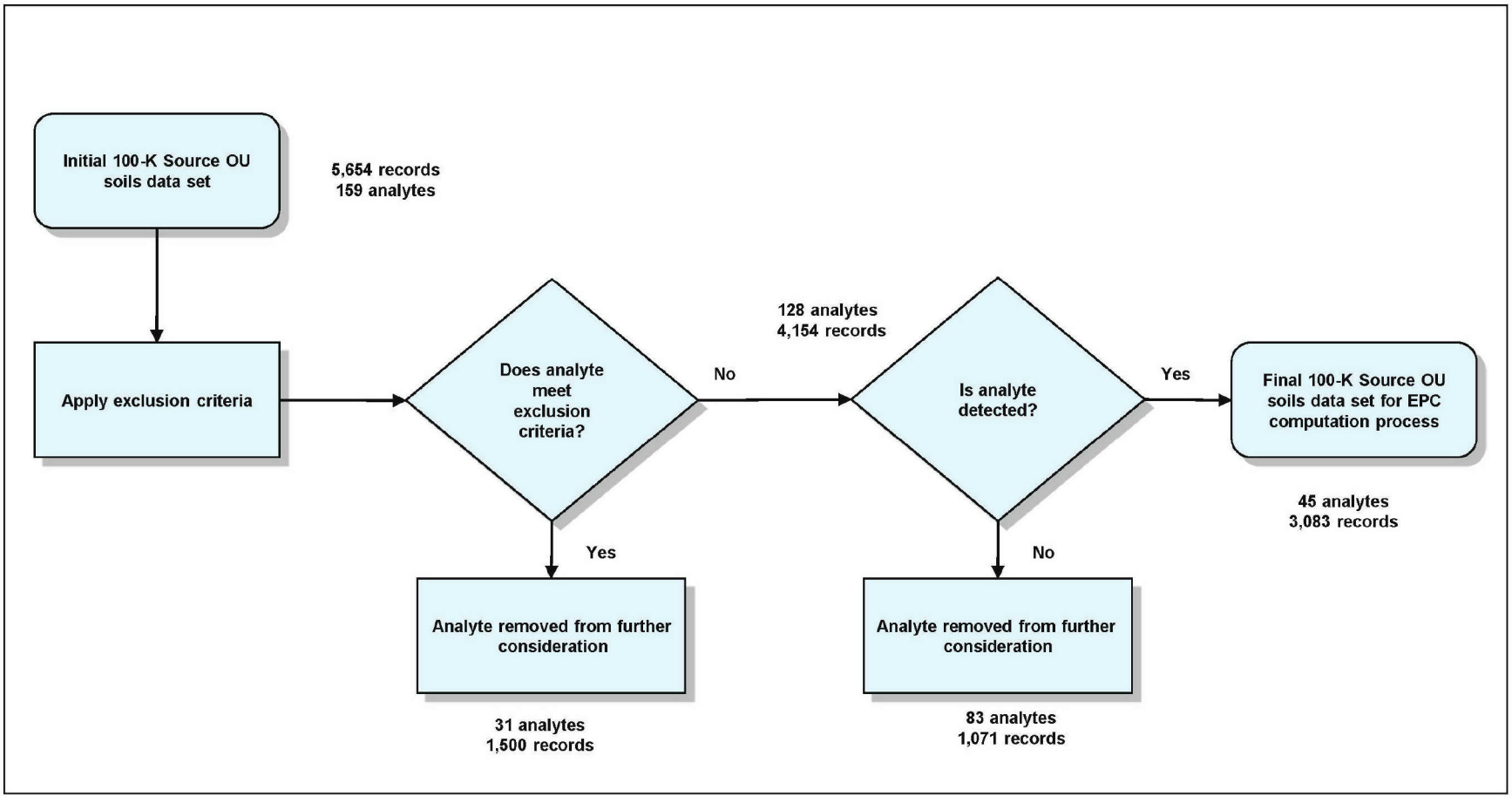

Figure 6-2. Analyte Identification Steps for the 100-K Source OU Data Set

- Waste site decision unit name
- Analyte name and Chemical Abstract Service (CAS) Registry number
- Total number of sample results, total number of detects, and total number of nondetects
- Minimum and maximum detection limits for each detected analyte (when available)[5]
- Minimum and maximum detected concentrations for each analyte
- Coefficient of variation for each analyte
- The UCL value, the UCL basis, and comments and/or warning statements for each analyte

For most data sets, ProUCL recommends a single UCL as the decision statistic. When a single decision statistic is recommended, this UCL is selected. However, ProUCL will recommend more than one decision statistic for some data sets. The most conservative (i.e., health protective) result is the goal when selecting the UCL to represent the EPC. When more than one decision statistic is given, the following logic is used to select the UCL:

- If more than one UCL is recommended as a decision statistic and the UCLs are less than or equal to the maximum observed concentration, then the highest recommended UCL is selected as the decision statistic.
- If more than one UCL is recommended as a decision statistic and the UCLs are greater than the maximum observed concentration, then the maximum observed concentration is selected as the decision statistic.
- If more than one UCL is recommended as a decision statistic, at least one is less than the maximum observed concentration, and at least one is greater than the maximum observed concentration, then the maximum observed concentration is selected as the decision statistic. There were only five analytes where more than one UCL was recommended and at least one of the UCLs was greater than the maximum observed concentration.

Selection of EPCs. The following logic was used to select the EPC for each detected analyte in a waste site decision unit:

- For samples collected in accordance with a focused sampling design, the maximum detected concentration is selected as the EPC for every detected analyte.
- For samples collected in accordance with a statistical sampling design, the following logic is applied.
  - If a valid 95 percent UCL can be calculated, then the highest potential 95 percent UCL value (if more than one potential UCL value is recommended) is selected.
  - If the recommended 95 percent UCL is greater than the maximum detected concentration, then the maximum detected concentration is selected.
  - If a valid 95 percent UCL cannot be calculated, then the maximum detected concentration is selected.

Selection of the EPC value using the above decision logic presented in Figure 6-3. A summary of the exposure point concentrations for each detected analyte in a given waste site decision unit is provided in Table G-5 for the 100-K Source OU.

[5] Minimum and maximum detection limits are summarized in the ProUCL output only when a valid UCL can be calculated.

Use of Maximum Detected Concentrations to Estimate the EPC. The EPC defaults to the maximum detected concentration when the following conditions are met:

- When samples are collected using a focused sampling design
- When a valid 95 percent UCL cannot be calculated due to small sample size
- When a valid 95 percent UCL is greater than the maximum detected concentration

The sampling plan for a focused decision unit was designed to sample the areas of suspected contamination. The results from this type of sampling design can introduce bias into statistical analyses to estimate means, such as calculations of UCLs. Guidance provided by *Supplemental Guidance to RAGS: Calculating the Concentration Term* (OSWER Publication 9285.7-081) states "a value other than the 95 percent UCL can be used, provided the risk assessor can document that high coverage of the true population mean occurs (i.e., the value equals or exceeds the true population mean with high probability)." Because the sampling design for these decision units focused on areas of suspected contamination, the conclusion that maximum detected concentration exceeds the true population mean in a focused decision unit can be made with certainty. Additionally, the closeout documentation for the focused decision units used the maximum detected concentration to determine if the remedial action goal has been attained (Section 3.6.3 of the 100 RDR/RAWP [DOE/RL-96-17]). Because of the potential for statistical bias and to maintain consistency with the 100 Area RDR/RAWP (DOE/RL-96-17), the maximum detected concentration is selected as a conservative estimate of the EPC for the focused decision units.

ProUCL has minimum size requirements to compute UCLs. For data sets of at least five results, a UCL is not calculated when there is only one detected result in the data set. ProUCL notes that in cases where the number of available detected samples is small (<5), the estimation of the EPC term is decided upon on a site-specific basis. ProUCL generates warning messages regarding the potential deficiencies associated with a small data set. For small data sets with very few detected values (<5), where a valid UCL cannot be calculated, the EPC defaults to the maximum (single) concentration for the 100-K Source OU.

Some of the distributional methods employed by ProUCL can produce very high estimates of the UCL (particularly the Land method). *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) acknowledges that the Land method can produce extremely high values for the UCL when data exhibit high variance and the sample size is small. *Supplemental Guidance to RAGS: Calculating the Concentration Term* (OSWER Publication 9285.7-081) recognizes the problem of extremely high UCLs, and recommends the maximum detected concentration become the default when the calculated UCL exceeds this value. When the recommended UCL exceeds the maximum detected concentration, ProUCL, however, advises that an alternative UCL (i.e., Chebyshev inequality) be selected instead of the maximum detected concentration for an EPC. When the recommended UCL is greater than the maximum detected result, the maximum detected value is selected as the EPC for the 100-K Source OU. ProUCL displays a warning message when the recommended 95 percent UCL of the mean exceeds the observed maximum concentration.

6.2.3 Exposure Assessment

This section defines the exposure scenarios used for various land use and receptor activities, describes the potential exposure pathways resulting from site contaminants, and provides the methodology for calculating the RBSLs for direct contact, based on currently available site information. The conceptual exposure model is formulated according to EPA guidance, taking into consideration information on contaminant sources, release mechanisms, routes of migration, potential exposure points, potential routes of exposure, and potential receptor groups associated with the 100-K Source OU. This results in a set of exposure pathways that reflect a reasonable maximum exposure.

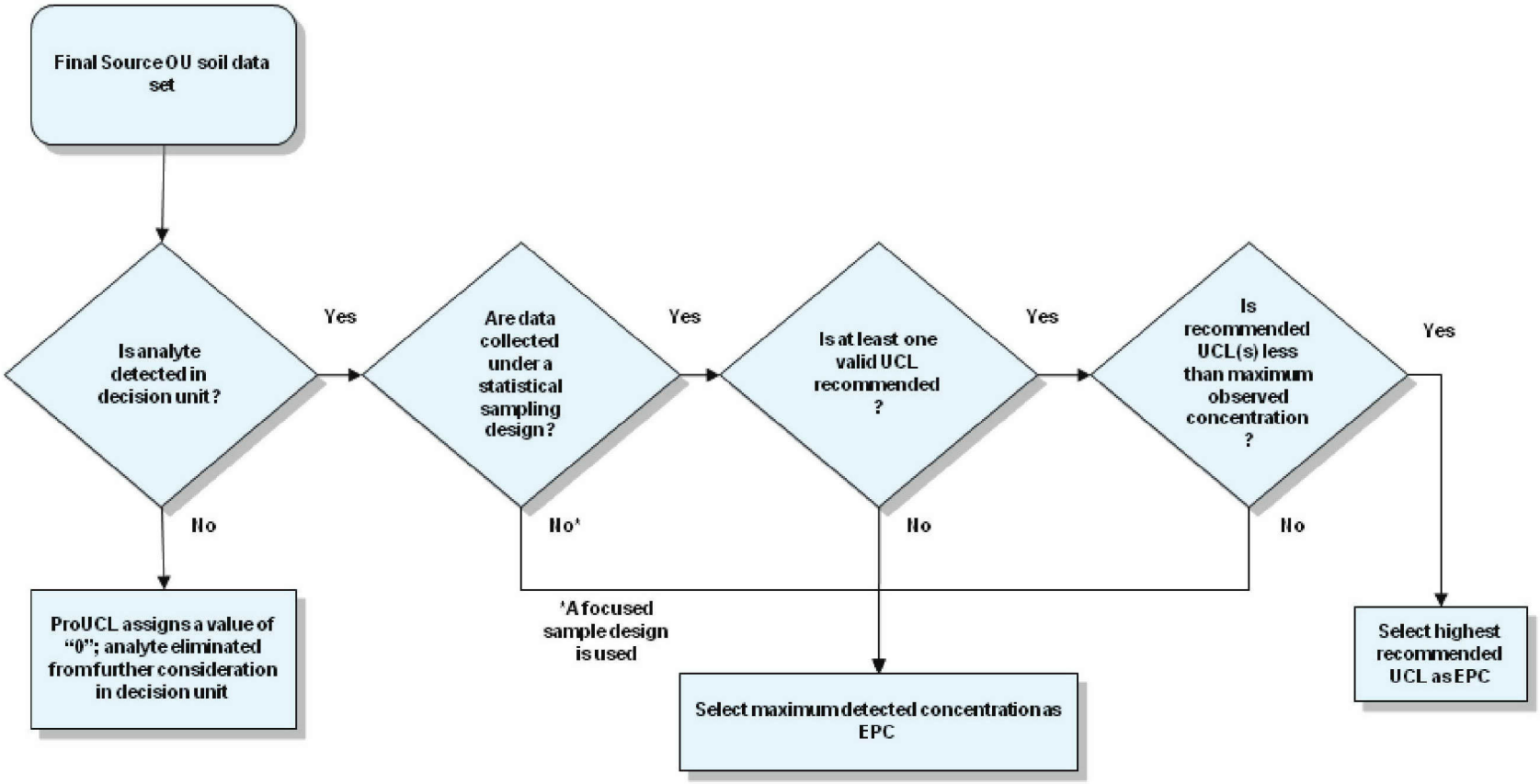

Figure 6-3. Decisions Logic for Computing 100-K Source OU Exposure Point Concentrations

An exposure pathway can be described as the physical course that a COPC takes from the point of release to a receptor. The route of exposure is the means by which a COPC enters a receptor. For an exposure pathway to be complete, all of the following components must be present:

- A source
- A mechanism of chemical release and transport
- An environmental transport medium
- An exposure point
- An exposure route
- A receptor or exposed population

In the absence of any one of these components, an exposure pathway is considered incomplete and, therefore, creates no risk or hazard. Contaminant Sources

6.2.3.1 Contaminant Sources

The primary sources of contamination in the 100-K Source OU are two water-cooled nuclear reactors (105-KE and 105-KW) and the structures (e.g., fuel storage basins) and processes (e.g., sodium dichromate process) associated with reactor operations. The reactors were built to irradiate uranium-enriched fuel rods from which plutonium and other special nuclear materials could be extracted. Effluent generated during operations consisted primarily of contaminated reactor cooling water, fuel storage basin water, and decontamination solutions.

Liquid and solid wastes from reactor operations and associated facilities were released to the vadose zone column and the Columbia River. Wastes released to the environment created secondary sources of contamination such as surface impoundments, cribs, ditches, burial grounds, and unplanned release sites. Contaminant sources (i.e., facilities and waste sites) are listed in Section 4.2.1 and Section 5.2 of this report.

6.2.3.2 Release Mechanisms and Environmental Transport Media

The primary COPC release mechanisms and transport pathways at 100-K are discussed in Sections 5.3 and 5.4, and include the following:

- Migration of contaminated liquids through the vadose zone column through infiltration, percolation, or leaching
- Direct contact and external radiation from vadose zone material containing COPCs (receptor contact with shallow vadose zone material replaces release and transport)
- Emission of dusts and vapors during former plant operations
- Generation of dust emanating from shallow vadose zone material to ambient air from wind, or during maintenance or excavation activities occurring at the 100-K Source OU
- Volatilization of COPCs emanating from shallow vadose zone material to ambient air at the 100-K Source OU

6.2.3.3 Potentially Complete Human Exposure Pathways and Receptors

Based on the current understanding of land use conditions near the 100-K Source OU, the most plausible exposure pathways for calculating PRGs and characterizing the human health risks have been identified (represented in Figures 6-4 and 6-5). The groundwater supplemental risk evaluation is provided in Section 6.3.

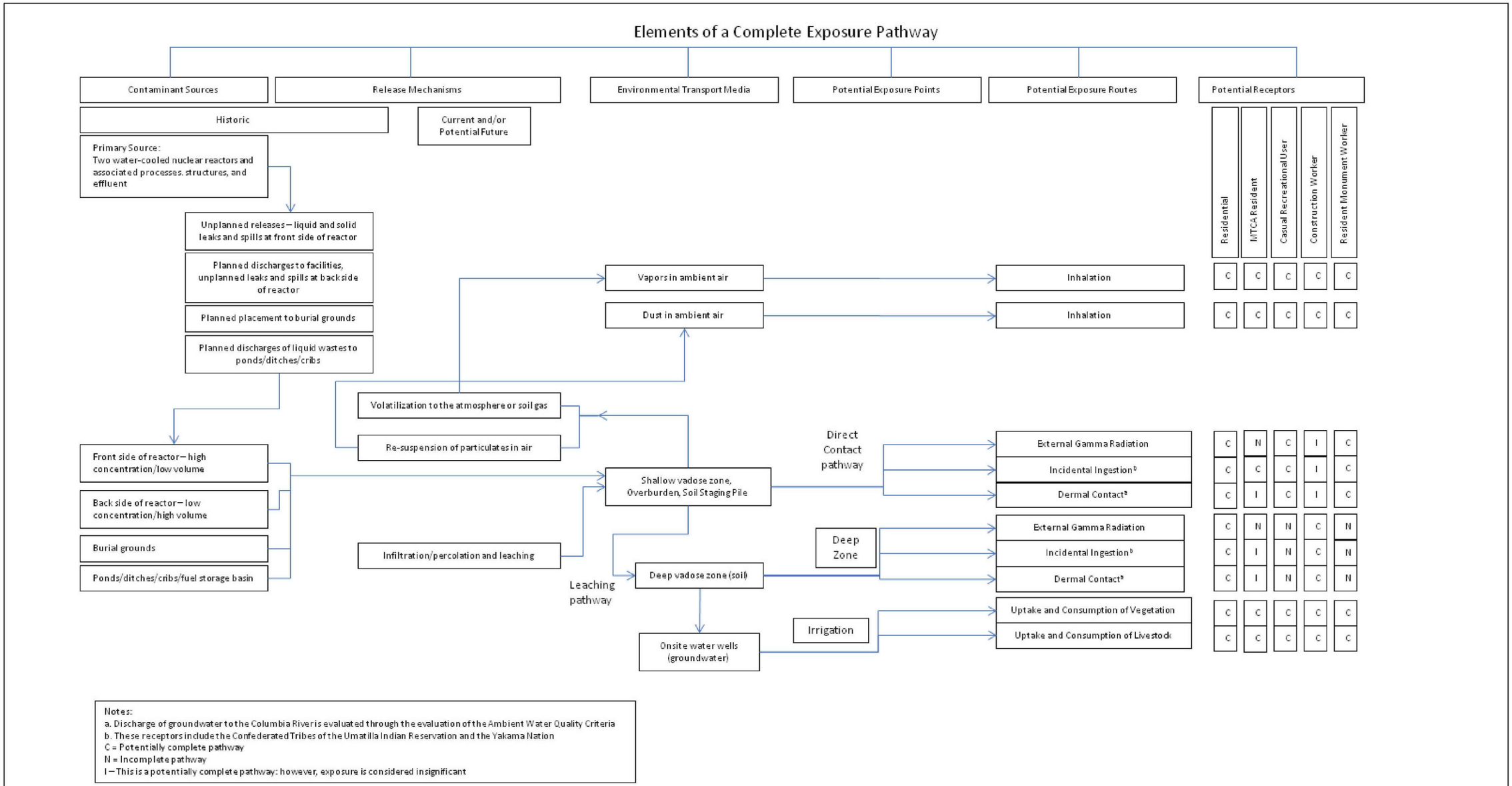

Figure 6-4. Conceptual Exposure Model 100-K Source OU

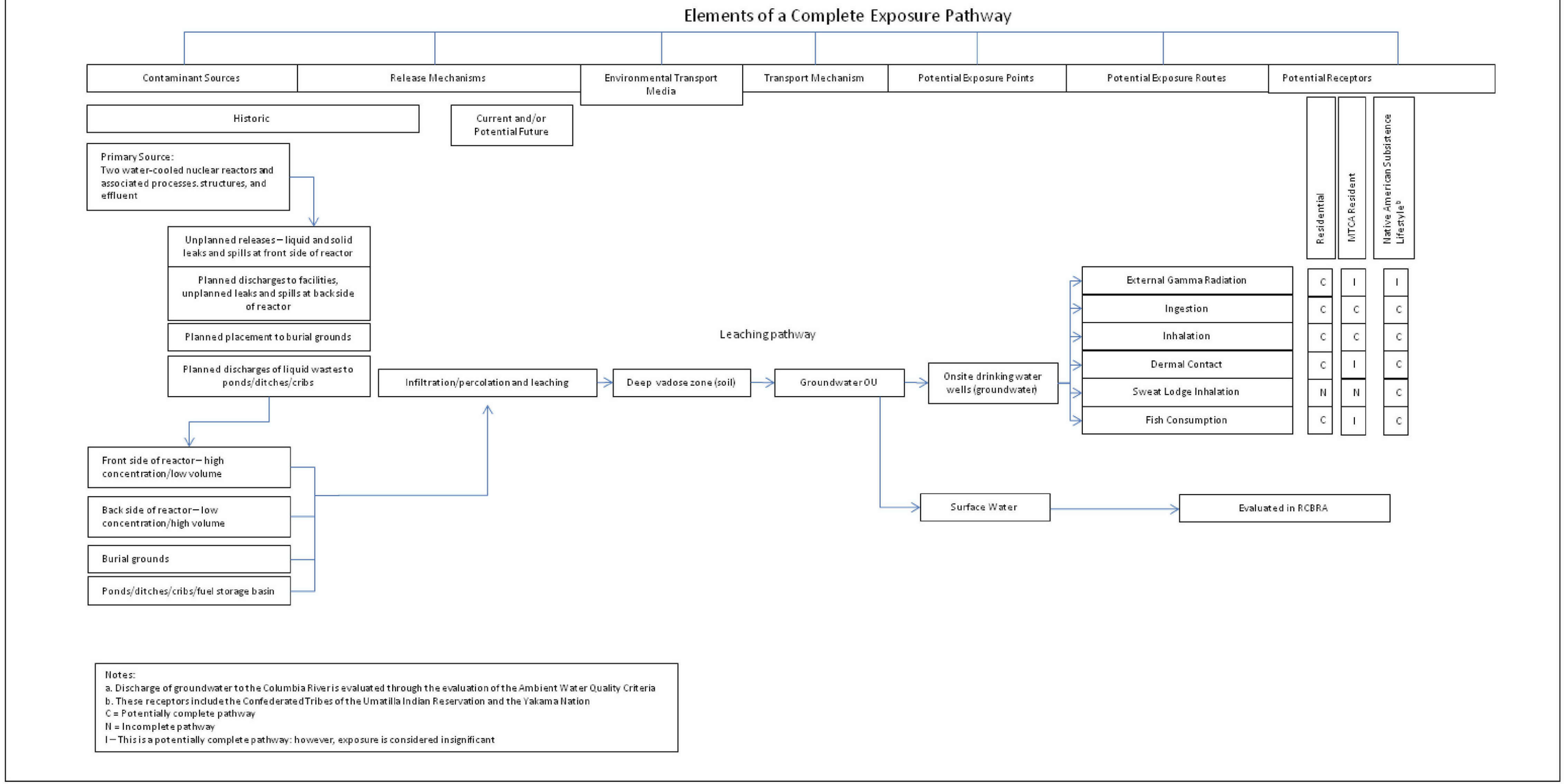

Figure 6-5. Conceptual Exposure Model for the 100-KR-4 Groundwater OU

For the purpose of this supplemental soil risk evaluation, shallow vadose zone material is represented by samples collected from 0 to 4.6 m (0 to 15 ft) bgs and deep vadose zone material is represented by samples collected from depths greater than 4.6 m (15 ft) bgs (Section 6.2.1.2, Table 6-6). Groundwater is represented by samples collected from the unconfined aquifer and discussed in Section 6.3.

Residential Scenario. PRGs (also used as risk-based screening levels) developed for the residential scenario are the numeric values that represent the remedial action objectives (RAOs) presented in Chapter 8. The results of comparing EPCs to the RBSLs in this supplemental risk evaluation will be used to help determine whether additional remedial action is necessary for waste sites where remediation has been completed, and whether the goals and objectives of the interim action RODs have been met, as demonstrated by verification sampling and analysis.

The residential scenario for radiological and nonradiological analytes is based on two different conceptual exposure models. The exposure pathways for radionuclides include direct contact in addition to dust inhalation, consumption of homegrown foodstuffs (e.g., produce, beef, and milk), and the leaching pathway (includes drinking water ingestion and fish ingestion). The exposure pathways for nonradiological analytes vadose zone material include direct contact from incidental ingestion and inhalation of vapors and dust in ambient air.

The residential scenarios described below are consistent with the exposure scenario and ARARs used to develop the interim action ROD RAGs for soil presented in the 100 Area RDR/RAWP (DOE/RL-96-17). This exposure scenario is also evaluated in the RCBRA to determine if cleanup actions completed under the interim action RODs are protective of human health and the environment relative to the range of exposure scenarios evaluated in this risk assessment.

Radiological. Consistent with the 100 Area RDR/RAWP (DOE/RL-96-17), the RESRAD code is used to evaluate exposure to radiological contaminants in vadose zone material. Revisions to this exposure scenario reflect updates in guidance since the 100 Area RDR/RAWP (DOE/RL-96-17) was originally published in 1996. With the exception of changes resulting from updates in guidance, the residential scenario is the same as that published in the 100 Area RDR/RAWP (DOE/RL-96-17). Exposure assumptions that were updated to reflect current EPA guidance include a decrease in the external gamma-shielding factor (increased shielding) and a decrease in the outdoor time fraction. Health protective levels were also updated from a target annual dose rate of 15 mrem/yr to a target risk of 1×10^{-4} to be consistent with guidance recommended in *Radiation Risk Assessment At CERCLA Sites: Q & A* (EPA/540/R/99/006). A detailed description of this exposure scenario is provided in *Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides Using the interim action ROD Exposure Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports* (ECF-HANFORD-10-0429).

Unrestricted future use conditions are represented by a resident in a subsistence farming setting. This assumes that each interim remediated waste site decision unit has the potential to be developed into a residence with a basement, vegetable and fruit crops are grown in a backyard garden, and a pasture is used to raise livestock sufficient for meat and milk production. A downgradient well is installed where exposure could potentially occur from contaminants leaching from the vadose zone material to groundwater beneath the residence (i.e., the leaching pathway). The resident could potentially come into direct contact with soil from the remediated waste site and potentially inhale dust in ambient air. The resident could potentially consume crops raised in a backyard garden and consume meat (beef, poultry, and fish) and milk raised on the pasture. Based upon the land uses identified in "Amended Record of Decision for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement" (73 FR 55824) and the

proclamation of "Establishment of the Hanford Reach National Monument" (65 FR 37253), it is unlikely that land within the l00-K OU will be used for residential purposes.

This scenario evaluates residential pathways that include exposure to shallow vadose zone material from residential yards or groundwater from domestic wells. Potential routes of exposure to shallow vadose zone material evaluated in the RESRAD code include direct external exposure, incidental material ingestion, and inhalation of dust generated from wind or from yard maintenance activities. This scenario also evaluates residential exposure to radiological contaminants through food chain pathways (uptake of contamination from vadose zone material to plants and animals). Food chain pathways include the consumption of fruits and vegetables grown in a backyard garden and consumption of meat and milk from livestock raised on the pasture. From the leaching pathway, this scenario evaluates residential consumption of drinking water from a downgradient well, use the well for irrigation of crops and watering livestock, and consume fish raised in a pond supplemented with water from the downgradient well.

Nonradiological. The residential scenario for nonradiological analytes measured in soil is also consistent with the exposure scenario used as interim action ROD RAGs for soil presented in the 100 Area RDR/RAWP (DOE/RL-96-17). The exposure scenario for protection of human health is based on the *Model Toxics Control Act* (MTCA), Standard Method B, "Soil Cleanup Levels for Unrestricted Land Use" ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740(3)]) and Standard Method B "Air Cleanup Levels" ("Cleanup Standards to Protect Air Quality" [WAC 173-340-750(3)]). The MTCA Standard Method B soil cleanup levels are based on exposure to a child receptor that includes incidental ingestion, and use residential exposure frequency and duration assumptions. The MTCA Standard Method B air cleanup levels are based on exposure to a child and adult receptor, includes inhalation of vapors and dust in ambient air, and assumes residential exposure frequency and duration assumptions.

Groundwater. Groundwater within the 100-KR-4 OU is currently contaminated, and withdrawal is prohibited as a result of ICs placed on it by DOE. Under current site use conditions, no complete human exposure pathways to groundwater are assumed to exist. In addition, groundwater currently discharges to the Columbia River through upwelling and seeps. Regardless of land use designations, groundwater within this OU is not anticipated to become a future source of drinking water until cleanup criteria are met and groundwater is restored to its highest beneficial use. However, groundwater in this risk analysis is evaluated for drinking water use and undiluted groundwater concentrations are compared to DWSs and aquatic criteria to support the determination of the basis for action and to support the development of PRGs for evaluating remedial alternatives in the FS.

The residential scenario for radiological and nonradiological analytes measured in groundwater is also consistent with the RAGs documented in the interim action RODs and in the 100 Area RDR/RAWP (DOE/RL-96-17). Groundwater concentrations are compared to current MCLs for radionuclides, which are set at 4 mrem/yr for the sum of the doses from beta particle and photon emitters, 15 pCi/L for gross alpha emitter activity (including radium-226, but excluding uranium and radon), and 5 pCi/L combined for radium-226 and radium-228. A mass based concentration MCL has been established for uranium as 30 µg/L. The exposure scenario for protection of human health is based on the MTCA Standard Method B, "Standard Method B Potable Groundwater Cleanup Levels" ("Groundwater Cleanup Standards" [WAC 173-340-720 (4)(b)]). The MTCA Standard Method B groundwater cleanup levels are based on exposure to child and adult receptors, includes drinking water ingestion and inhalation of vapors, and assumes residential exposure frequency and duration assumptions.

Residential Monument Worker Scenario. Land use within the River Corridor's 100 and 600 Areas is predominantly conservation/preservation. Reasonably anticipated future land use in 100-K is discussed in Section 3.8. In 2000, Presidential Proclamation 7319 was signed, creating the Hanford Reach National

Monument to be managed by USFWS and DOE ("Establishment of the Hanford Reach National Monument" [65 FR 37253]). The Monument was established for protecting the biological, historic, and scientific objects contained within. To support continued protection of natural and cultural resources, the proclamation stated that the Monument would not be developed for residential or commercial use in the future ("Establishment of the Hanford Reach National Monument" [65 FR 37253]).

For the purposes of the RI/FS, the resident Monument worker represents reasonably anticipated future land use. PRGs are developed for this scenario for use in the risk-based screening evaluation. CVP and RSVP data are compared to these numeric values to confirm that cleanup actions are protective of the reasonably foreseeable land uses that DOE and USFWS anticipate for the River Corridor. The resident Monument worker is selected as the receptor to represent potential exposures from occupational use along the River Corridor. This exposure scenario was included in the subset of occupational scenarios presented in the RCBRA. The resident Monument worker scenario is a site-specific scenario that envisions a resident employee of the Hanford Reach National Monument. These receptors are assumed to be exposed primarily in an outdoor environment as they lead tours, conduct ecological education, or perform similar activities. When not working, these receptors are envisioned to live in an onsite residence associated with the Monument. By use of a domestic well at their residence, these receptors may also be exposed to groundwater contaminants through domestic water use. Exposure to groundwater as a domestic source of water by the resident Monument worker is not included in the soil PRG value that is calculated for this exposure scenario. The risks from exposure to 100-KR-4 groundwater from use as a domestic source of water can be separately added to provide a total risk from exposure to soil and groundwater.

The residential Monument worker scenario for radiological and nonradiological analytes in vadose zone material is based on the same conceptual exposure model. The exposure pathways include direct contact and inhalation of vapors and dust in ambient air. Adults could potentially be exposed to site contaminants in shallow vadose zone material at their residence through direct external exposure, incidental ingestion, dermal absorption, and inhalation. During working activities, these adults may also be potentially exposed to contaminants in shallow vadose zone material by direct external exposure, incidental soil ingestion, dermal absorption, and inhalation. No food chain pathways are included in this exposure scenario.

Casual Recreational User Scenario. As discussed previously, reasonably anticipated future land use within the River Corridor's 100 and 600 Areas is predominantly conservation/preservation. The casual recreational user scenario is also used in the evaluation of balancing criteria in the FS. The casual recreational user is selected as the receptor to represent potential exposures from recreational use along the River Corridor. This exposure scenario was included in the subset of recreational use scenarios presented in the RCBRA. The casual recreational user scenario is a site-specific scenario representing occasional recreational use that focuses on activities such as walking and picnicking in areas along the Columbia River where paths and benches are likely to exist. These receptors are assumed to be exposed entirely in an outdoor environment. This scenario also assumes that drinking water is obtained from an offsite source.

For the purposes of the RI/FS, the casual user represents reasonably anticipated future land use. PRGs are developed for this scenario for use in the risk-based screening evaluation. CVP and RSVP data are compared to these numeric values to confirm that cleanup actions are protective of the reasonably foreseeable land uses that DOE and USFWS anticipate for the River Corridor. The casual recreational user scenario for radiological and nonradiological analytes in vadose zone material is based on the same conceptual exposure model. The exposure pathways include direct contact and inhalation of vapors and dust in ambient air. Adults and children could potentially be exposed to site contaminants in shallow vadose zone material along the river through direct external exposure, incidental ingestion, dermal absorption, and inhalation of vapors and dust in ambient air.

6.2.3.4 Quantification of Potential Exposures

Quantification of potential exposures in this risk assessment is evaluated through the comparison of exposure point concentrations to PRGs (which are also used as risk-based screening levels). *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim* (EPA/540/R-92/003) provides guidance on using EPA toxicity values and exposure information to calculate PRGs. It is recommended that PRGs should not be used as cleanup levels for a CERCLA site until the remedy selection identified in the relevant portion of the NCP (40 CFR 300) has been evaluated and considered. Once the baseline risk assessment has been performed, PRGs can be derived using site-specific risks; PRGs developed in the FS will usually be based on site-specific risks and ARARs and not on screening levels. PRGs are obtained from two general sources: concentrations based on ARARs (for example MTCA) and concentrations based on risk assessment. It should be recognized that the PRGs that are ARAR-based are also considered risk-based. Exposure assumptions published by the state and EPA and toxicity values published by EPA are used to derive risk-based PRGs.

PRGs based on risk assessment include the resident Monument worker and the casual user scenarios. PRGs for these scenarios are calculated using methodologies published in *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim* (EPA/540/R-92/003) and EPA's Superfund Radionuclide PRG download and calculation Web site (EPA, 2010). Toxicity values and exposure values published by EPA are used to derive risk-based PRGs.

PRGs for soil ingestion are calculated using the equations provided in "Unrestricted Land Use Soil Cleanup Standards" WAC 173-340-740(3). PRGs for the inhalation pathway are calculated using the equations provided in "Cleanup Standards to Protect Air Quality" (WAC 173-340-750(3)), "Method B Air Cleanup Levels." Air cleanup levels are converted to soil concentrations using EPA published volatilization factors for analytes that meet the operational definition of a volatile and a particulate emission factor for analytes that are not volatile. MTCA Method A soil cleanup levels for unrestricted land use, obtained from "Tables" (WAC 173-340-900), Table 740-1 are used as PRGs for arsenic and lead.

In addition to the guidance listed previously, radionuclide PRGs for the resident are calculated using the RESRAD code. The RESRAD code was used to calculate PRGs for the residential scenario because of unique exposure pathways. The RESRAD code was used for the residential scenario because this scenario includes the food chain pathway and the leaching to groundwater pathway. According to *User's Manual for RESRAD Version 6* (ANL/EAD-4), the RESRAD model and computer code were developed as a multifunctional tool to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material.

Table 6-7 summarizes the PRG values for each exposure scenario.

Calculation of Residential PRGs using RESRAD. The radionuclide PRGs for the residential scenario are calculated using the RESRAD (Version 6.5) model and code according to the guidance specified in *User's Manual for RESRAD Version 6* (ANL/EAD 4). The RESRAD model was used to calculate single radionuclide concentrations that correspond to a target cancer risk level of 1×10^{-4} for the residential scenario. For the purpose of this risk evaluation, the single radionuclide concentrations described in this section are used as PRGs for the residential scenario.

Table 6-7. Summary of Risk Based Screening Levels for the 100-K Source OU

Analyte	90th Percentile Background	Method A Soil Cleanup Level	Residential RBSL	Method B Direct Contact Soil Cleanup Level (carcinogen)	Method B Direct Contact Soil Cleanup Level (noncarcinogen)	Method B Inhalation Soil Cleanup Level (carcinogen)	Method B Inhalation Soil Cleanup Level (noncarcinogen)	Casual User RBSL (carcinogen)	Casual User RBSL (noncarcinogen)	Resident Monument Worker RBSL (carcinogen)
Radionuclides (pCi/g)										
Americium-241	--	--	155	--	--	--	--	2,570	--	275
Carbon-14	--	--	81	--	--	--	--	327,610	--	52,046
Cesium-137	1.1	--	4.4	--	--	--	--	27,833	--	6.2
Cobalt-60	0.0084	--	3.1	--	--	--	--	63	--	3.3
Europium-152	--	--	3.7	--	--	--	--	66	--	3.8
Europium-154	0.033	--	4.4	--	--	--	--	78	--	4.8
Nickel-63	--	--	608	--	--	--	--	575,308	--	91,576
Plutonium-238	0.0038	--	236	--	--	--	--	3,818	--	605
Plutonium-239/240	0.025	--	203	--	--	--	--	3,342	--	539
Total beta radiostrontium	0.18	--	2.3	--	--	--	--	13,733	--	518
Uranium-233/234	1.1	--	133	--	--	--	--	5,808	--	931
Uranium-235	0.11	--	16	--	--	--	--	309	--	22
Uranium-238	1.1	--	54	--	--	--	--	6,462	--	93
Nonradionuclides (mg/kg)										
Metals										
Aluminum	11,800	--	--	--	80,000	--	>1,000,000	--	912,453	--
Antimony	0.13	--	--	--	32	--	--	--	365	--
Arsenic	6.5	20	--	0.67	24	42,414	500,240	4.5	253	--
Barium	132	--	--	--	16,000	--	>1,000,000	--	182,481	--
Beryllium	1.5	--	--	--	160	75,991	666,986	>1,000,000	1,825	--
Boron	3.9	--	--	--	16,000	--	>1,000,000	--	182,500	--
Cadmium	0.56	--	--	--	40	101,322	333,493	>1,000,000	821	--
Chromium	19	--	--	--	120,000	--	--	--	>1,000,000	--
Cobalt	16	--	--	--	24	20,264	200,096	920,451	274	--
Copper	22	--	--	--	3,200	--	--	--	36,500	--

Table 6-7. Summary of Risk Based Screening Levels for the 100-K Source OU

Analyte	90th Percentile Background	Method A Soil Cleanup Level	Residential RBSL	Method B Direct Contact Soil Cleanup Level (carcinogen)	Method B Direct Contact Soil Cleanup Level (noncarcinogen)	Method B Inhalation Soil Cleanup Level (carcinogen)	Method B Inhalation Soil Cleanup Level (noncarcinogen)	Casual User RBSL (carcinogen)	Casual User RBSL (noncarcinogen)	Resident Monument Worker RBSL (carcinogen)
Hexavalent Chromium	--	--	--	--	240	2,171	>1,000,000	98,620	2,737	--
Iron	32,600	--	--	--	56,000	--	--	--	638,750	--
Lead	10	250	--	--	--	--	--	--	--	--
Manganese	512	--	--	--	11,200	--	>1,000,000	--	127,658	--
Mercury	0.01	--	--	--	24	--	>1,000,000	--	274	--
Molybdenum	0.47	--	--	--	400	--	--	--	4,563	--
Nickel	19	--	--	--	1,600	701,458	>1,000,000	>1,000,000	18,249	--
Selenium	0.78	--	--	--	400	--	>1,000,000	--	4,562	--
Vanadium	85	--	--	--	400	--	--	--	4,563	--
Zinc	68	--	--	--	24,000	--	--	--	273,750	--
Polycyclic Aromatic Hydrocarbons										
Benzo(a)anthracene	--	--	--	1.4	--	>1,000,000	--	1.7	--	--
Benzo(a)pyrene	--	--	--	0.14	--	165,799	--	0.17	--	--
Benzo(b)fluoranthene	--	--	--	1.4	--	>1,000,000	--	1.7	--	--
Benzo(k)fluoranthene	--	--	--	1.4	--	>1,000,000	--	1.7	--	--
Chrysene	--	--	--	14	--	>1,000,000	--	17	--	--
Fluoranthene	--	--	--	--	3,200	--	--	--	26,760	--
Indeno(1,2,3-cd)pyrene	--	--	--	1.4	--	>1,000,000	--	1.7	--	--
Pyrene	--	--	--	--	2,400	--	--	--	20,070	--
Other Organics										
Aroclor 1254	--	--	--	0.50	1.6	319,963	--	2.6	13	--
Bis(2-ethylhexyl) phthalate	--	--	--	71	1,600	>1,000,000	--	405	14,258	--
Ethylene glycol	--	--	--	--	160,000	--	>1,000,000	--	>1,000,000	--
Total petroleum hydrocarbons	--	2,000	--	--	--	--	--	--	--	--

-- = not applicable

The RESRAD model allows for the use of site-specific chemical and physical parameters to estimate single radionuclide concentrations. The potentially complete exposure pathways considered are direct contact, inhalation pathway, the food chain pathway, and leaching of contaminants in the vadose zone through the vadose zone column to the groundwater table. Exposure routes associated with the direct contact and inhalation pathways include external gamma exposure, incidental ingestion, and inhalation of dust. Exposure routes associated with the food chain exposure pathway include consumption of homegrown produce, meat, and milk. Exposure routes associated with the leaching pathway include crop irrigation, aquatic food consumption, and drinking water ingestion. A list of the site-specific RESRAD input parameters is provided in Table G-6. A detailed description of methodology, inputs, assumptions, and results of the calculations is presented in *Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides Using the interim action ROD Exposure Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports* (ECF-HANFORD-10-0429) (Appendix G).

Calculation of Unrestricted Land Use Cleanup Levels using MTCA Equations. The direct contact nonradiological cleanup levels (CULs) for unrestricted land use (i.e., the resident) are calculated using equations and input parameters described in "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(3)). The Standard Method B soil cleanup levels for unrestricted land use are based on ingestion and were calculated for noncarcinogens and carcinogens using equation 740-1 and equation 740-2, respectively. Default exposure parameters for calculating the CULs are defined in Table G-7. Standard Method B soil cleanup levels for unrestricted land use are based on an acceptable cancer risk level of 1×10^{-6} for carcinogens or a hazard quotient (HQ) of 1 for noncarcinogens. Reference dose and carcinogenic potency factors are determined using the recommended reference hierarchy as described in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). A detailed description of methodology, inputs, assumptions, and the results of the calculations are presented in *Calculation of Standard Method B Direct Contact Soil Cleanup Levels for Unrestricted Land Use* (ECF-HANFORD-10-0044) (Appendix G).

The inhalation nonradiological CULs for unrestricted land use (i.e., the resident) are calculated using equations and input parameters described in "Cleanup Standards to Protect Air Quality" (WAC 173-340-750(3)), "Method B Air Cleanup Levels." The Method B air cleanup levels are were calculated for noncarcinogens and carcinogens using equation 750-1 and equation 750-2, respectively. Air cleanup levels are converted to soil concentrations using EPA published volatilization factors for analytes that meet the operational definition of a volatile and a particulate emission factor for analytes that are not volatile. Default exposure parameters for calculating the inhalation PRGs are defined in Table G-8. Method B soil cleanup levels for the inhalation pathway are based on an acceptable cancer risk level of 1×10^{-6} for carcinogens or an HQ of 1 for noncarcinogens. Inhalation reference dose and inhalation carcinogenic potency factors are determined using the recommended reference hierarchy, as described in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). A detailed description of methodology, inputs and assumptions, and the results of the calculations are presented in *Calculation of Inhalation Pathway Preliminary Remediation Goals Using Standard Method B Air Cleanup Levels for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports* (ECF-HANFORD-11-0033) (Appendix G).

Direct Contact. The following represents the Standard Method B direct contact soil cleanup level equations for noncarcinogens and carcinogens. The parameters used for calculating the soil cleanup levels are defined in Table G-7.

Noncarcinogens. The equation below is obtained from "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(3)(b)(iii)(B)(I)) Equation 740-1.

$$Soil\ Cleanup Level\left(\frac{mg}{kg}\right)=\frac{RfD\times ABW\times UCF\times HQ\times AT_{nc}}{SIR\times AB1\times EF\times ED}$$

Carcinogens. The equation below is obtained from "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(3)(b)(iii)(B)(II)) Equation 740-2.

$$Soil Cleanup Level\left(\frac{mg}{kg}\right)=\frac{RISK\times ABW\times AT_c\times UCF}{CPF\times SIR\times AB1\times ED\times EF}$$

Inhalation. The following represents the Standard Method B inhalation soil cleanup level equations for noncarcinogens and carcinogens. The parameters used for calculating the soil cleanup levels are defined in Table G-8.

Noncarcinogens. The equation below is obtained from "Cleanup Standards to Protect Air Quality" (WAC 173-340-750(3)(b)(ii)(A)) Equation 750-1.

$$Air\ Cleanup\ Level\left(\frac{\mu g}{m^3}\right)=\frac{RfD\times ABW\times UCF\times HQ\times AT}{BR\times ABS\times ED\times EF}$$

Carcinogens. The equation below is obtained from "Cleanup Standards to Protect Air Quality" (WAC 173-340-750(3)(b)(ii)(B)) Equation 750-2.

$$Air\ Cleanup Level\left(\frac{\mu g}{m^3}\right)=\frac{RISK\times ABW\times AT\times UCF}{CPF\times BR\times ABS\times ED\times EF}$$

The air cleanup levels calculated using the above equations are intended to protect air quality. However, concentrations of contaminants in air were not directly measured; therefore, emission and dispersion modeling are used to estimate a soil cleanup level protective of residential use. Conversion of air concentrations to soil cleanup levels is consistent with the methodology presented in *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (OSWER 9355.4-24). The air cleanup levels calculated using the above equation are converted to a soil cleanup level using the equation shown below.

$$Soil\ Cleanup\ Level\ (mg/kg)=\frac{Air\ Cleanup\ Level\times CF}{\left(\left(\frac{1}{PEF}\right)+\left(\frac{1}{VF}\right)\right)}$$

Calculation of Resident Monument Worker PRGs for Radiological Analytes using EPA Equations. The radiological PRGs for the resident Monument worker are calculated using equations consistent with those published on the EPA Preliminary Remediation Goals for Radionuclides. As described in Section 6.2.3.3, the resident Monument worker is a site-specific exposure scenario; site-specific exposure parameters for calculating the PRGs are defined in Table G-9. Resident Monument worker PRGs are based on an acceptable cancer risk level of 1×10^{-4} for carcinogens. A detailed description of methodology, inputs, and assumptions and the results of the calculations are presented in *Documentation of Radiological Preliminary Remediation Goals in Soil for a Resident Monument Worker Exposure Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports* (ECF-HANFORD-11-0142).

6.2.3.5 PRG Equations for Incidental Soil Ingestion

The exposure assumptions used to calculate PRGs for the incidental soil ingestion route are presented and defined in Table G-9. The following equations were used to calculate the risks from incidental ingestion of broad area soils for the occupational portion of the resident Monument worker exposure scenario:

$$CDI_{rmw_rad_ing_occ} = \frac{\left(1 - e^{(-\lambda \times t_{rmw})}\right) \times C_s \times IRS_{rmw_occ_adj} \times EF_{rmw_occ} \times ED_{rmw} \times UCF1}{t_{rmw} \times \lambda}$$

where:

$$IRS_{rmw_occ_adj} = IRS_{rmw} \times \frac{EF_{rmw_occ}}{EF_{rmw_res}} \times \frac{ET_{rmw_occ}}{24hr/day}$$

Radiological cancer risk is calculated using the following equation:

$$RISK_{rmw_rad_ing_occ} = CDI_{rmw_rad_ing_occ} \times SF_s$$

The following equations were used to calculate PRGs from incidental ingestion of local area soils for the residential portion of the resident Monument worker exposure scenario:

$$RBSL_{rmw_rad_ing_res} = \frac{\left(TR_{_RAD} - RISK_{rmw_rad_ing_occ}\right) \times t_{rmw} \times \lambda}{\left(1 - e^{(-\lambda \times t_{rmw})}\right) \times SF_s \times IRS_{rmw_res_adj} \times EF_{rmw_res} \times ED_{rmw} \times UCF1}$$

where:

$$IRS_{rmw_res_adj} = IRS_{rmw} \times \left[\left(\frac{EF_{rmw_occ}}{EF_{rmw_res}} \times \frac{ET_{rmw_res}}{24hrs/day} \right) + \left(\frac{EF_{rmw_res} - EF_{rmw_occ}}{EF_{rmw_res}} \right) \right]$$

6.2.3.6 PRG Equations for External Exposure to Ionizing Radiation

The exposure assumptions used to calculate PRGs for the external exposure to ionizing radiation route are presented and defined in Table G-9. The following equations were used to calculate risks from external exposure to ionizing radiation from broad area soils for the occupational portion of the resident Monument worker exposure scenario:

$$CDI_{rmw_rad_ext_occ} = \frac{\left(1 - e^{(-\lambda \times t_{rmw})}\right) \times C_s \times \left[\left(ET_{rmw_occ_out} \times GSF_{out}\right) + \left(ET_{rmw_occ_in} \times GSF_{in}\right)\right] \times EF_{rmw_occ} \times ED_{rmw} \times UCF3}{t_{rmw} \times \lambda}$$

Radiological cancer risk is calculated using the following equation:

$$RISK_{rmw_rad_ext_occ} = CDI_{rmw_rad_ext_occ} \times SF_x$$

The following equations were used to calculate PRGs for the external exposure to ionizing radiation from local area soils for the residential portion of the resident Monument worker exposure scenario:

$$RBSL_{rmw_rad_ext_res} = \frac{\left(TR_{_RAD} - RISK_{rmw_rad_ext_occ}\right) \times t_{rmw} \times \lambda}{\left(1 - e^{(-\lambda \times t_{rmw})}\right) \times SF_s \times \left[\left(ET_{rmw_res_out} \times GSF_{out}\right) + \left(ET_{rmw_res_in} \times GSF_{in}\right)\right] \times EF_{rmw_res} \times ED_{rmw} \times UCF3}$$

6.2.3.7 PRG Equations for the Inhalation of Dust in Soil

The exposure assumptions used to calculate PRGs for the inhalation of vapors and dust route are presented and defined in Table G-9. The following equations were used to calculate risks from inhalation of dust from broad area soils for the occupational portion of the resident Monument worker exposure scenario:

$$CDI_{rmw_rad_inh_occ} = \frac{\left(1-e^{(-\lambda \times t_{rmw})}\right) \times C_s \times UCF2 \times \frac{1}{PEF_B} \times IRA_{rmw} \times ET_{rmw_occ} \times EF_{rmw_occ} \times ED_{rmw}}{t_{rmw} \times \lambda}$$

Radiological cancer risk is calculated using the following equation:

$$RISK_{rmw_rad_inh_occ} = CDI_{rmw_rad_inh_occ} \times SF_i$$

The following equations were used to calculate PRGs from inhalation of dust from local area soils for the residential portion of the resident Monument worker exposure scenario:

$$RBSL_{rmw_rad_inh_res} = \frac{\left(TR_{_RAD} - RISK_{rmw_rad_inh_occ}\right) \times t_{rmw} \times \lambda}{\left(1-e^{(-\lambda \times t_{rmw})}\right) \times SF_i \times UCF2 \times \frac{1}{PEF_L} \times IRA_{rmw} \times ET_{rmw_res} \times EF_{rmw_res} \times ED_{rmw}}$$

6.2.3.8 Total PRG Equations

The following presents the equations used to calculate the total PRGs for all exposure routes combined. The basis for the equation is provided in *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim* (EPA/540/R-92/003).

$$RBSL_{rmw_rad_total_res} = \frac{1}{\left(\left(\frac{1}{RBSL_{rmw_rad_ing_res}}\right) + \left(\frac{1}{RBSL_{rmw_rad_ext_res}}\right) + \left(\frac{1}{RBSL_{rmw_rad_inh_res}}\right)\right)}$$

Calculation of Casual Recreational User PRGs for Radiological Analytes using EPA Equations. The radiological PRGs for the casual recreational user are calculated using equations consistent with those published on the EPA Preliminary Remediation Goals for Radionuclides Web site. As described in Section 6.2.3.3, the casual recreational user is a site-specific exposure scenario. Site-specific exposure parameters for calculating the PRGs are defined in Table G-10. Casual recreational user radiological PRGs are based on an acceptable cancer risk level of 1×10^{-4} for carcinogens. A detailed description of methodology, inputs, assumptions, and the results of the calculations are presented in *Calculation of Radiological Preliminary Remediation Goals in Soil for a Casual Recreational User Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Reports* (ECF-HANFORD-10-0446).

PRG Equations for Incidental Soil Ingestion. The exposure assumptions used to calculate PRGs for the incidental soil ingestion route are presented and defined in Table G-10. The following equations were used to calculate the PRG for the incidental soil ingestion route:

$$PRG_{cu_rad_ing} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1-e^{(-\lambda t_{cu})}\right) \times SF_s \times IRS_{adj_cu_rad} \times EF_{cu} \times ED_{a+ccu} \times UCF3}$$

where:

$$IRS_{adj_cu_rad} = \frac{(ED_{ccu} \times IRS_{ccu}) + ((ED_{a+ccu} - ED_{ccu}) \times IRS_a)}{ED_{a+ccu}}$$

PRG Equations for External Exposure to Ionizing Radiation. The exposure assumptions used to calculate PRGs for the external exposure to ionizing radiation route are presented and defined in Table G-10. The following equation was used to calculate the PRG for the external exposure to ionizing radiation route:

$$PRG_{cu_rad_ext} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1 - e^{(-\lambda t_{cu})}\right) \times SF_x \times ACF \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \frac{1\,day}{24\,hours} \times UCF\,5}$$

PRG Equations for the Inhalation of Vapors and Dust. The exposure assumptions used to calculate PRGs for the inhalation of vapors and dust route are presented and defined in Table G-10. The following equations were used to calculate the PRG for the inhalation of vapors and dust route:

$$PRG_{cu_rad_inh} = \frac{TR_{_RAD} \times t_{cu} \times \lambda}{\left(1 - e^{(-\lambda t_{cu})}\right) \times SF_i \times IRA_{adj_cu} \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \left(\frac{1}{PEF} or \frac{1}{VF}\right) \times UCF\,4}$$

where:

$$IRA_{adj_cu} = \frac{(ED_{ccu} \times IRA_{ccu}) + ((ED_{a+ccu} - ED_{ccu}) \times IRA_a)}{ED_{a+ccu}}$$

Total PRG Equations. The following presents the equations used to calculate the total PRGs for all exposure routes combined. The basis for the equation is provided in *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim* (EPA/540/R-92/003).

$$PRG_{cu_rad_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_rad_ing}}\right) + \left(\frac{1}{PRG_{cu_rad_ext}}\right) + \left(\frac{1}{PRG_{cu_rad_inh}}\right)\right)}$$

Calculation of Casual Recreational User PRGs for Nonradiological Analytes using EPA Equations. The nonradiological PRGs for the casual recreational user are calculated using equations consistent with those published on the EPA Regional Screening Values Web site. As described in Section 6.2.3.3, the casual recreational user is a site-specific exposure scenario. Exposure parameters for calculating the PRGs are defined in Table G-10. Casual recreational user nonradiological PRGs are based on an acceptable cancer risk level of 1×10^{-6} for carcinogens or an HQ of 1 for noncarcinogens. Reference dose and carcinogenic potency factors are determined using the recommended reference hierarchy as described in "Human Health Toxicity Values in Superfund Risk Assessments." A detailed description of methodology, inputs and assumptions, and the results of the calculations are presented in *Calculation of Nonradiological Preliminary Remediation Goals in Soil for a Casual Recreational User Scenario for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports* (ECF-HANFORD-10-0445).

PRG Equations for Incidental Soil Ingestion. The exposure assumptions used to calculate PRGs for the incidental soil ingestion route are presented and defined in Table G-10.

Incidental Soil Ingestion—Carcinogenic and Noncarcinogenic Effects. The following equations are used to calculate the carcinogenic PRG for incidental soil ingestion:

$$PRG_{cu_ca_ing} = \frac{TR \times AT_{ca}}{CSF_o \times IRS_{adj_cu} \times EF_{cu} \times UCF1}$$

where:

$$IRS_{adj_cu} = \left(\frac{ED_{ccu} \times IRS_{ccu}}{BW_{ccu}}\right) + \left(\frac{(ED_{a+ccu} - ED_{ccu}) \times IRS_a}{BW_a}\right)$$

The following equation is used to calculate the noncarcinogenic PRG for incidental soil ingestion:

$$PRG_{cu_nc_ing} = \frac{THQ \times AT_{nc_ccu} \times BW_{ccu}}{\frac{1}{RfD_o} \times IRS_{ccu} \times EF_{cu} \times ED_{ccu} \times UCF1}$$

Incidental Soil Ingestion—Mutagenic Effects. The following equations are used to calculate the mutagenic mode of action PRG for incidental soil ingestion:

$$PRG_{cu_mu_ing} = \frac{TR \times AT_{ca}}{CSF_o \times IRSM_{adj_cu} \times EF_{cu} \times UCF1}$$

where:

$$IRSM_{adj_cu} = \frac{ED_{0-2} \times IRS_{ccu} \times 10}{BW_{ccu}} + \frac{ED_{2-6} \times IRS_{ccu} \times 3}{BW_{ccu}} + \frac{ED_{6-16} \times IRS_a \times 3}{BW_a} + \frac{ED_{16-30} \times IRS_a \times 1}{BW_a}$$

Incidental Soil Ingestion—Vinyl Chloride. The following equations are used to calculate the vinyl chloride PRG for incidental soil ingestion:

$$PRG_{cu_vc_ing} = \frac{TR}{\left(\frac{CSF_o \times IRS_{adj_cu} \times EF_{cu} \times UCF1}{AT_{ca}} + \frac{CSF_o \times IRS_{ccu} \times UCF1}{BW_{ccu}}\right)}$$

where:

$$IRS_{adj_cu} = \left(\frac{ED_{ccu} \times IRS_{ccu}}{BW_{ccu}}\right) + \left(\frac{(ED_{a+ccu} - ED_{ccu}) \times IRS_a}{BW_a}\right)$$

PRG Equations for Dermal Contact with Soil. The exposure assumptions used to calculate PRGs for the dermal contact with soil route are presented and defined in Table G-10. The following equations were used to calculate the PRG for the dermal contact with soil route:

Dermal Contact with Soil—Carcinogenic and Noncarcinogenic Effects. The following equations are used to calculate the carcinogenic PRG for the dermal contact route:

$$PRG_{cu_ca_dc} = \frac{TR \times AT_{ca}}{\left(\frac{CSF_o}{GIABS}\right) \times EF_{cu} \times DFS_{adj_cu} \times ABS_d \times UCF1}$$

where:

$$DFS_{adj_cu} = \left(\frac{ED_{ccu} \times SA_{ccu} \times AF_{ccu}}{BW_{ccu}} \right) + \left(\frac{(ED_{a+ccu} - ED_{ccu}) \times SA_a \times AF_a}{BW_a} \right)$$

The following equation is used to calculate the noncarcinogenic PRG for the dermal contact route:

$$PRG_{cu_nc_dc} = \frac{THQ \times AT_{nc_cu} \times BW_{ccu}}{\left(\frac{1}{RfD_o} \times GIABS \right) \times SA_{ccu} \times AF_{ccu} \times EF_{cu} \times ED_{ccu} \times ABS_d \times UCF1}$$

Dermal Contact with Soil—Mutagenic Effects. The following equations are used to calculate the mutagenic mode of action PRG for the dermal contact route:

$$PRG_{cu_mu_dc} = \frac{TR \times AT_{ca}}{\frac{CSF_o}{GIABS} \times DFSM_{adj_cu} \times EF_{cu} \times ABS_d \times UCF1}$$

where:

$$DFSM_{adj_cu} = \frac{ED_{0-2} \times SA_{ccu} \times AF_{ccu} \times 10}{BW_{ccu}} + \frac{ED_{2-6} \times SA_{ccu} \times AF_{ccu} \times 3}{BW_{ccu}} + \frac{ED_{6-16} \times SA_a \times AF_a \times 3}{BW_a} + \frac{ED_{16-30} \times SA_a \times AF_a \times 1}{BW_a}$$

Dermal Contact with Soil—Vinyl Chloride. The following equations are used to calculate the vinyl chloride PRG for the dermal contact route:

$$PRG_{cu_vc_dc} = \frac{TR}{\left(\frac{\frac{CSF_o}{GIABS} \times DSF_{adj_cu} \times EF_{cu} \times ABS_d \times UCF1}{AT_{ca}} + \frac{\frac{CSF_o}{GIABS} \times SA_{ccu} \times AF_{ccu} \times ABS_d \times UCF1}{BW_{ccu}} \right)}$$

where:

$$DFS_{adj_cu} = \left(\frac{ED_{ccu} \times SA_{ccu} \times AF_{ccu}}{BW_{ccu}} \right) + \left(\frac{(ED_{a+ccu} - ED_{ccu}) \times SA_a \times AF_a}{BW_a} \right)$$

PRG Equations for the Inhalation of Vapors and Dust in Soil. The exposure assumptions used to calculate PRGs for the inhalation of vapors and dust route are presented and defined in Table G-10. The following equations were used to calculate the PRG for the inhalation route:

Inhalation of Vapors and Dust in Soil—Carcinogenic and Noncarcinogenic Effects. The following equation is used to calculate the carcinogenic PRG for the inhalation route:

$$PRG_{cu_ca_inh} = \frac{TR \times AT_{ca} \times 24 \frac{hours}{day}}{IUR \times UCF2 \times EF_{cu} \times ED_{a+ccu} \times ET_{cu} \times \left(\frac{1}{VF} + \frac{1}{PEF} \right)}$$

The following equation is used to calculate the noncarcinogenic PRG for the inhalation route:

$$PRG_{cu_nc_inh} = \frac{THQ \times AT_{nc_cu} \times 24\frac{hours}{day}}{EF_{cu} \times ED_{ccu} \times ET_{cu} \times \frac{1}{RfC} \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Inhalation of Vapors and Dust in Soil—Mutagenic Effects. The following equation is used to calculate the mutagenic mode of action PRG for the inhalation route:

$$PRG_{cu_mu_inh} = \frac{TR \times AT_{ca} \times 24\frac{hours}{day}}{UCF2 \times ET_{cu} \times EF_{cu} \times \left[\left(ED_{0-2} \times IUR \times 10\right) + \left(ED_{2-6} \times IUR \times 3\right) + \left(ED_{6-16} \times IUR \times 3\right) + \left(ED_{16-30} \times IUR \times 1\right)\right] \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Inhalation of Vapors and Dust in Soil—Vinyl Chloride. The following equation is used to calculate the vinyl chloride PRG for the inhalation route:

$$PRG_{cu_vc_inh} = \frac{TR}{\left(\frac{IUR \times ED_{a+ccu} \times EF_{cu} \times ET_{cu} \times UCF2}{AT_{ca} \times 24\frac{hours}{day} \times VF}\right) + \left(\frac{IUR}{VF} \times UCF2\right)}$$

Calculation of Particulate Emission Factor and Volatilization Factors. The default input parameters used to calculate the particulate emission factor for the resident Monument worker are presented and defined in Table G-11. The default input parameters used to calculate the particulate emission factor and volatilization factors for the casual recreational user are presented and defined in Table G-12. The input parameters used to calculate chemical-specific volatilization factors are listed in Table G-13. Volatilization factors are only calculated for volatile organic compounds (VOCs). A VOC is defined by *Soil Screening Guidance: Users Guide* (EPA/540/R-96/018) as a chemical with a Henry's Law constant of 1×10^{-5} or greater and with a molecular weight of less than 200 g/mole.

The volatilization factor for tritium is not a calculated value, but is a default value published in Superfund Radionuclide Preliminary Remediation Goal (PRG) download and calculation website (EPA, 2010). The following presents the equations used to calculate the chemical-specific volatilization factors.

$$VF = \frac{\frac{Q}{C} \times \left(3.14 \times D_A \times T\right)^{\frac{1}{2}} \times 10^{-4}\left(\frac{m^2}{cm^2}\right)}{2 \times \rho_b \times D_A}$$

where:

$$\frac{Q}{C} = A \times \exp\left[\frac{\left(\ln\left[A_S\right] - B\right)^2}{C}\right]$$

and:

$$D_A = \left[\frac{\left(\theta_a^{\frac{10}{3}} \times D_i \times H' + \theta_w^{\frac{10}{3}} \times D_w \right)}{n^2} \right] \Bigg/ \left[\rho_b \times k_{oc} \times f_{oc} + \theta_w + \theta_a \times H' \right]$$

Particulate Emission Factor. The particulate emission factor is calculated using the following equations:

$$PEF = \frac{Q}{C} \times \frac{3{,}600}{0.036 \times (1 - V) \times \left(\frac{u_m}{u_t} \right)^3 \times F(x)}$$

where:

$$\frac{Q}{C} = A \times \exp\left[\frac{(\ln(A_s) - B)^2}{C} \right]$$

and:

$$F(x) = 0.18(8x^3 + 12x)\exp(-x^2)$$

and:

$$x = 0.886\left(\frac{u_t}{u_m} \right)$$

Total PRG Equations. The following presents the equations used to calculate the total PRGs for all exposure routes combined. The basis for the equation is provided in *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Interim* (EPA/540/R-92/003).

Carcinogenic Effects.

$$PRG_{cu_ca_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_ca_ing}} \right) + \left(\frac{1}{PRG_{cu_ca_dc}} \right) + \left(\frac{1}{PRG_{cu_ca_inh}} \right) \right)}$$

Noncarcinogenic Effects.

$$PRG_{cu_nc_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_nc_ing}}\right)+\left(\frac{1}{PRG_{cu_nc_dc}}\right)+\left(\frac{1}{PRG_{cu_nc_inh}}\right)\right)}$$

Mutagenic Effects.

$$PRG_{cu_mu_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_mu_ing}}\right)+\left(\frac{1}{PRG_{cu_mu_dc}}\right)+\left(\frac{1}{PRG_{cu_mu_inh}}\right)\right)}$$

Vinyl Chloride.

$$PRG_{cu_vc_total} = \frac{1}{\left(\left(\frac{1}{PRG_{cu_vc_ing}}\right)+\left(\frac{1}{PRG_{cu_vc_dc}}\right)+\left(\frac{1}{PRG_{cu_vc_inh}}\right)\right)}$$

6.2.4 Toxicity Assessment

This toxicity assessment evaluates the relationship between the magnitude of exposure to a contaminant at the 100-K Source OU and the likelihood of adverse health effects to potentially exposed populations. This assessment provides, where possible, a numerical estimate of the increased likelihood of adverse effects associated with contaminant exposure. The toxicity assessment contains two steps—hazard characterization and dose-response evaluation—as discussed in the following subsections.

6.2.4.1 Hazard Characterization

Hazard characterization identifies the types of toxic effects that a chemical can exert. For the toxicity assessment, chemicals can be divided into two broad groups—noncarcinogens and carcinogens—based on their effects on human health.

Carcinogens are those contaminants that are known or suspected causes of cancer following exposure; noncarcinogenic compounds are associated with a wide variety of systemic effects, such as liver toxicity or developmental effects. Some contaminants (e.g., arsenic) are capable of eliciting both carcinogenic and noncarcinogenic responses; therefore, these contaminants are evaluated for both effects.

For cancer effects, EPA has developed a carcinogen classification system (*Risk Assessment for Carcinogens* [EPA, 1986b]) that uses a weight of evidence (WOE) approach for classifying the likelihood that a chemical is a human carcinogen. Information considered in developing the classification includes human studies of the association between cancer incidence and exposure, as well as long-term animal studies under controlled laboratory conditions. Other supporting evidence considered includes short-term tests for genotoxicity, metabolic and pharmacokinetic properties, toxicological effects other than cancer, structure-activity relationships, and physical and chemical properties of the chemical.

For noncancer effects, toxicity values are derived based on the critical toxic endpoint (i.e., the most sensitive adverse effect following exposure). Table G-14 lists the COPCs detected at the 100-K Source OU area that have been identified as having documented systemic effects.

Dose Response Evaluation. The magnitude of toxicity of a contaminant depends on the dose to a receptor. Dose refers to exposure to a contaminant concentration over a specified period of time. Human exposures are generally classified as acute (typically less than 2 weeks), subchronic (about 2 weeks to 7 years), or chronic (7 years to a lifetime). This HHRA specifically addresses chronic exposure. Acute exposures and risks are evaluated only when chronic exposure estimates pose a high risk. A dose-response curve describes the relationship between the degree of exposure (i.e., dose) and the incidence of the adverse effects (i.e., response) in the exposed population. EPA uses this dose-response information to establish toxicity values for particular chemicals, as described in the following sections.

Reference Doses for Noncancer Effects. The toxicity value describing the dose-response relationship for noncancer effects is the reference dose (RfD) value. For noncarcinogenic effects, the body's protective mechanisms must be overcome before an adverse effect is manifested. If exposure is high enough and these protective mechanisms (or thresholds) are exceeded, adverse health effects can occur. EPA attempts to identify the upper bound of this tolerance range in the development of noncancer toxicity values. EPA uses the apparent toxic threshold value, in conjunction with uncertainty factors based on the strength of the toxicological evidence, to derive an RfD value. EPA defines an RfD value as follows:

> *In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfD is generally expressed in units of mg/kg-day.*

Available chronic RfD values for the oral and inhalation exposure routes are used to calculate PRGs. Because EPA has not derived toxicity values specific to skin contact, dermal slope factors and RfD values were derived from oral toxicity factors in accordance with EPA guidance. The RfD values for the contaminants evaluated in the 100-K Source OU are summarized in Table G-14.

Slope Factors for Cancer Effects. The dose-response relationship for cancer effects is expressed as a cancer slope factor that converts estimated intake directly to excess lifetime cancer risk (ELCR). Slope factors are expressed in units of risk per level of exposure (or intake). The data used for estimating the dose-response relationship are taken from lifetime animal studies or human occupational or epidemiological studies where excess cancer risk has been associated with exposure to the chemical. However, because risk at low intake levels cannot be directly measured in animal or human epidemiological studies, a number of mathematical models and procedures have been developed to extrapolate from the high doses used in the studies to the low doses typically associated with environmental exposures. The model choice leads to uncertainty associated with the carcinogenic response at very low levels of exposure. EPA assumes linearity at low doses when uncertainty exists about the mechanism of action of a carcinogen and when information suggesting nonlinearity is absent.

It is assumed, therefore, that if a cancer response occurs at the dose levels used in the study, then there is some probability that a response will occur at all lower exposure levels (i.e., a dose-response relationship with no threshold is assumed). Moreover, the dose-response slope chosen is usually the 95 percent UCL on the mean on the actual dose-response curve observed in the laboratory studies. As a result, uncertainty and conservatism are built into the EPA risk extrapolation approach. EPA has stated that cancer risks estimated by this method produce estimates that "provide a rough but plausible upper limit of risk." The cancer slope factors used in this assessment are summarized in Table G-14.

6.2.4.2 Toxicity Values

The analyte-specific toxicity values presented Table G-14 are determined using the recommended reference hierarchy as described in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). The hierarchy is summarized below.

- Tier 1—The EPA Integrated Risk Information System (IRIS)
- Tier 2—The EPA Provisional Peer Reviewed Toxicity Values (PPRTVs)
- Tier 3—Other Toxicity Values

Tier 1—IRIS. The preferred source of toxicity data is EPA's IRIS database. Expert toxicologists at EPA have derived the values in this database and the values have undergone a thorough review and validation both within and outside EPA. If a toxicity value is available in IRIS, that value is used in preference to any other value.

Tier 2—PPRTVs. If a toxicity value is not available in IRIS, the next source is EPA's PPRTVs. This source includes toxicity values that have been developed by the Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC). This database is not available to the public, but is accessible to EPA risk assessors via EPA's intranet. These values are also published at "Regional Screening Levels for Chemical Contaminants at Superfund Sites" (EPA, 2009b).

Tier 3—Other Toxicity Values. Tier 3 includes additional EPA and nonEPA sources of toxicity information, including the following:

- The California EPA (CalEPA) Toxicity Criteria Database contains toxicity values that are peer reviewed and address both cancer and noncancer effects.
- The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) for Hazardous Substances are peer-reviewed estimates of the daily human exposure to hazardous substances that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.
- Toxicity values in *Health Effects Assessment Summary Tables: FY 1997 Update* (EPA 540-R-97-036).

When Tier 1, Tier 2, or Tier 3 toxicity values are not available for a COPC, the toxicity values from the National Center for Environmental Assessment (NCEA) are used. NCEA values can be found in the Risk Assessment Information System (RAIS) (ORNL, 2010).

A derived RfD for nitrate was calculated from the RfD reported in IRIS (1.6 mg/kg-day) for nitrate as nitrogen (NO_3--N) using the mass fraction of nitrogen in nitrate. The mass fraction of nitrogen in nitrate = mol wt N/mol wt NO_3- = (14 g/mol)/(62 g/mol) = 0.226. The derived RfD for nitrate = (1.6 mg NO_3-N/kg-day) × (1 mg NO_3-/0.226 mg NO_3--N) = 7.1 mg NO_3-/kg-day.

A derived RfD for nitrite was calculated from the RfD reported in IRIS (0.1 mg/kg-day) for nitrite as nitrogen (NO_2--N) using the mass fraction of nitrogen in nitrite. The mass fraction of nitrogen in nitrite = mol wt N/mol wt NO_2- = (14 g/mol)/(46 g/mol) = 0.304. The derived RfD for nitrite = (0.1 mg NO_2-N/kg-day) × (1 mg NO_2-/0.304 mg NO_2--N) = 0.3 mg NO_2-/kg-day.

Toxic equivalence factors (TEFs) were used to calculate toxicity values for dioxins, furans, and carcinogenic PAHs as described in "Human Health Risk Assessment Procedures" (WAC 173-340-708(8)(D)(iii)(A)).

For several nonradionuclide analytes, the toxicity value used was obtained from a different source than recommended by the EPA Superfund hierarchy ("Human Health Toxicity Values in Superfund Risk Assessments" [Cook, 2003]). The differences in toxicity values are summarized below.

- For consistency with previous Hanford analyses of trichloroethene, the oral cancer slope factor of 0.089 $(mg/kg\text{-}day)^{-1}$ and inhalation unit risk of 2.5E-05 $(\mu g/m^3)^{-1}$ published in Health Effects Assessment Summary Table (HEAST) are used for this assessment. HEAST has not been updated since 1997 and does not reflect the most current source of information. The oral cancer slope factor and inhalation unit risk currently implemented by EPA in the "Regional Screening Levels for Chemical Contaminants at Superfund Sites" (EPA, 2009b) are established by the CalEPA Office of Health Hazard Assessment (OEHHA). The oral slope factor of 0.0059 $(mg/kg\text{-}day)^{-1}$ and the Inhalation Unit Risk of 2.0E-06 $(\mu g/m^3)^{-1}$ derived by OEHHA are presented in *Public Health Goal for Chemicals In Drinking Water, Trichloroethylene* (OEHHA, 2009). Use of the HEAST values in this assessment has the potential to over-estimate cancer risk.

- For fluoride, the oral reference dose of 0.06 mg/kg-day published on IRIS is used for this assessment. The value reported on IRIS has not been updated since 1989 and does not reflect the most current source of information. The oral reference dose currently implemented by EPA in the "Regional Screening Levels for Chemical Contaminants at Superfund Sites" (EPA, 2009b) is established by the CalEPA OEHHA. The oral reference dose derived by OEHHA is 0.04 mg/kg-day as documented in *Chronic Toxicity Summary: Fluorides including Hydrogen Fluoride* (OEHHA, 2003). Use of the IRIS value in this assessment has the potential to under-estimate noncancer hazards.

- For Cr(VI), the current assessment considers cancer effects only for inhalation exposures. An oral cancer slope factor has recently been published by the New Jersey Department of Environmental Protection (NJDEP). The oral cancer slope factor derived by NJDEP is 0.5 $(mg/kg\text{-}day)^{-1}$, as presented in *Derivation of an Ingestion-Based Soil Remediation Criterion for Cr+6 Based on the NTP Chronic Bioassay Data for Sodium Dichromate Dihydrate* (NJDEP, 2009). Assessing only inhalation cancer effects from Cr(VI) has the potential to under-estimate cancer risk.

- When evaluating toxicity, 1,1-dichloroethane is not considered a carcinogen by the Washington State Department of Ecology. Therefore, the oral slope factor of 5.7E-03 $(mg/kg\text{-}day)^{-1}$ and inhalation unit risk of 1.5E-06 $(\mu g/m^3)^{-1}$ presented in the"Regional Screening Levels for Chemical Contaminants at Superfund Sites" (EPA, 2009b) are not used to evaluate toxicity. This is consistent with the Washington State Department of Ecology's "Cleanup Levels and Risk Calculations" (CLARC) database (Ecology, 2009). In addition, the reference concentration of 0.7 (mg/m^3) published by HEAST is used to evaluate noncarcinogenic inhalation risk. This is also consistent with the CLARC database (Ecology, 2009).

- For consistency with previous Hanford analyses of carbon tetrachloride, the toxicity assessment uses an oral cancer slope factor of 0.13 $(mg/kg\text{-}day)^{-1}$, an oral reference dose of 0.0007 (mg/kg-day), and an inhalation unit risk factor of 1.5E-05 $(\mu g/m^3)^{-1}$ previously published in IRIS, as well as the inhalation reference concentration of 0.19 (mg/m^3) published by ATSDR. These values do not reflect the most current toxicity values published for carbon tetrachloride. The oral cancer slope factor of 0.07 $(mg/kg\text{-}day)^{-1}$, oral reference dose of 0.004 (mg/kg-day), inhalation unit risk of 6E-06 $(\mu g/m^3)^{-1}$, and inhalation reference concentration of 0.1 (mg/m^3) for carbon tetrachloride is currently implemented by the "Regional Screening Levels for Chemical Contaminants at Superfund Sites" (EPA, 2009b) and established by IRIS. Use of the current IRIS values in this assessment has the potential to over-estimate both cancer risks and noncancer hazards.

The analyte-specific toxicity values, decay constants, and half-life presented Table 6-15 are determined using the recommended values from HEAST Radionuclides Table.

6.2.5 Risk Characterization

The risk characterization step is completed through the comparison of the EPC to the preliminary remediation goal. This comparison step is used to determine whether the post-remediation soil concentrations are protective of human health. It is also used to determine if current material concentrations have the potential to exceed an HI greater than 1 or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use.

Although this risk evaluation produces numerical estimates of risk, it should be recognized that these numbers might not predict actual health outcomes because they are based largely on hypothetical assumptions. Their purpose is to provide a frame of reference for risk management decision making. Interpretation of the risk estimates provided should consider the nature and WOE supporting these estimates, as well as the magnitude of uncertainty surrounding them.

For the purpose of this risk characterization step, the potential for unacceptable human health risk is identified using the following risk thresholds:

- ELCR values are compared to the "target range" of 10^{-6} to 10^{-4} that is generally used by regulatory agencies. "Model Toxics Control Act—Cleanup" (WAC 173-340) states that cancer risks resulting from multiple hazardous substances should not exceed 1×10^{-5} for unrestricted land use. ELCR values within or exceeding this target range require a risk management decision that includes evaluating site-specific characteristics and exposure scenario factors to assess whether remedial action is warranted.

- An HI (the sum of the ratios of the chemical intake to the RfDs for all COPCs) greater than 1 indicates that some potential exists for adverse noncancer health effects associated with exposure to the COPCs.

Cancer Risk Estimation Method. To estimate the cancer risks from exposure to an individual nonradiological carcinogen from all exposure routes considered, the following equation is used:

$$Risk_I = \frac{EPC_{soil}}{PRG_{carcinogen}} \times TR$$

where:

$Risk_I$ = ELCR for individual chemical or radioisotope (unitless)

EPC_{soil} = Exposure point concentration in soil (µg/kg or pCi/g)

$PRG_{carcinogen}$ = Soil PRG based on 10^{-6} carcinogenic effect for chemical (µg/kg) or 10^{-4} carcinogenic effect for radioisotope (pCi/g)

TR = Target ELCR of 10^{-6} for individual hazardous substance or 10^{-4} for individual radioisotope for unrestricted land use

To estimate the cancer risks from exposure to multiple carcinogens from all exposure routes considered, the following equation is used. The equation presented below is consistent with that published on the EPA Regional Screening Values Web site.

$$Risk_T = \sum_i \frac{EPC_{soil}}{PRG_{carcinogen}} \times TR$$

where:

$Risk_T$ = Total ELCR for all chemicals and radioisotopes

EPC_{soil} = Exposure point concentration in soil (µg/kg or pCi/g)

$PRG_{carcinogen}$ = Soil PRG based on 10^{-6} carcinogenic effect for chemical (µg/kg) or 10^{-4} carcinogenic effect for radioisotope (pCi/g)

TR = Target ELCR of 10^{-6} for individual hazardous substance or 10^{-4} for individual radioisotope for unrestricted land use

i = The sum of the ratios for the ith chemical

Noncancer Risk Estimation Method. For noncancer effects, the likelihood that a receptor will develop an adverse effect is estimated by comparing the predicted level of exposure for a particular chemical with the highest level of exposure that is considered protective (i.e., its RfD). The ratio of the chronic daily intake divided by RfD is termed the HQ.

To estimate the HQ from all exposure routes considered for an individual hazardous substance, the following equation is used:

$$HQ = \frac{EPC_{soil}}{PRG_{noncarcinogen}}$$

where:

HQ = HQ for individual chemical

EPC_{soil} = Exposure point concentration in soil (µg/kg)

$PRG_{noncarcinogen}$ = Preliminary remediation goal based on HQ=1 noncarcinogenic effects (µg/kg)

To estimate the HI from all exposure routes considered for multiple hazardous substances, the following equation is used. The equation presented below is consistent with that published on the EPA's Regional Screening Values Web site.

$$HI_T = \sum_i \frac{EPC_{soil}}{PRG_{noncarcinogen}}$$

where:

HI_T = Total HI for all chemicals

EPC_{soil} = Exposure point concentration in soil (µg/kg)

$PRG_{noncarcinogen}$ = Preliminary remediation goal based on HQ=1 noncarcinogenic effects (µg/kg)

i = The sum of the ratios for the ith chemical

Comparisons of Lead and Arsenic to MTCA A Soil Cleanup Levels. Potential risks from lead concentrations were evaluated using a different method than what is conventionally used for other carcinogens and noncarcinogens. For direct contact pathways, the EPCs for lead were compared to the "Tables" (WAC 173-340-900), Table 740-1 Method A, soil cleanup level for Unrestricted Land Use of 250 mg/kg.

The Method A cleanup level is based on the EPA's Integrated Exposure Uptake Biokinetic (IEUBK) model, which is available on the EPA Web site. The IEUBK model is designed to predict probable blood-lead concentrations for children between 6 months and 84 months (i.e., up to 7 years) of age who have been exposed to lead through various sources (e.g., air, water, soil, dust, and in utero contributions from the mother).

Additionally, arsenic EPCs were compared to the "Tables" (WAC 173-340-900), Table 740-1, Method A soil cleanup level for Unrestricted Land Use of 20 mg/kg. The concentration of 20 mg/kg is based on the 90th percentile background value for Washington State documented in *Natural Background Soil Metals Concentrations in Washington State* (Ecology Publication 94-115).

Consideration of Background in Risk Assessment. *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003) provides national policy considerations for application of background data in risk assessment and remedy selection. This policy recommends an approach that addresses site-specific background issues in the risk characterization. *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003) indicates the following:

> *COPCs that have both release-related and background-related sources should be included in the risk assessment. When concentrations of naturally occurring elements at a site exceed risk-based screening levels, that information should be discussed qualitatively in the risk characterization.*

Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites (EPA 540-R-01-003) defines background constituents as the following: anthropogenic—natural and artificial substances present in the environment as a result of human activities (not specifically related to the CERCLA release in question), and naturally occurring—substances present in the environment in forms that have not been influenced by human activity.

Sources of Background Concentrations. The 90th percentile and maximum background concentrations for the Hanford Site have been developed for both inorganic chemicals and radionuclides and are considered representative of both naturally occurring and anthropogenic substances. The maximum inorganic background concentrations used in this evaluation are identified as the "overall maximum concentrations" in the Non-Rad Soil Background document (DOE/RL-92-24), Summary Table 1, and the 90th percentile inorganic background concentrations are identified as the "lognormal distribution 90th percentiles" in the Non-Rad Soil Background document (DOE/RL-92-24), Summary Table 2. The exceptions to this are described in the following paragraph. Two types of sampling were conducted to determine the inorganic background values: systematic random sampling and judgment sampling. The overall maximum concentrations were determined by considering the analytical results from both systematic random samples and judgmental samples. The 90th percentile values were calculated using the analytical results from the systematic random samples only.

The Hanford Site background values for antimony, boron, cadmium, lithium, mercury, molybdenum, selenium, silver, and thallium, are documented in ECF-HANFORD-11-0038 (Appendix G). Boron was not analyzed for in the Non-Rad Soil Background document (DOE/RL-92-24) and the analytical data associated with the remaining analytes in the Non-Rad Soil Background document (DOE/RL-92-24) are

considered unusable for statistical analyses because of elevated method detection limits. The background concentration values documented in ECF-HANFORD-11-0038 (Appendix G) reference *A Review of Metal Concentrations Measured in Surface Soil Samples Collected On and Around the Hanford Site* hereafter referred to as Review of Metal Concentrations (PNNL-18577). The ECF documents a review of the data sets from the the Non-Rad Soil Background document (DOE/RL-92-24) and Review of Metal Concentrations (PNNL-18577) that indicates the data are comparable and issues associated with elevated detection limits were eliminated as a result of improvements in analytical methods used for Review of Metal Concentrations (PNNL-18577). It is noted that ECF-HANFORD-11-0038 (Appendix G) recalculates the percentile values based using a nonparametric (Kaplan-Meier) method, consistent with the methodology used in the the Non-Rad Soil Background document (DOE/RL-92-24). Review of Metal Concentrations (PNNL-18577) calculated the 90th percentile values based on an assumption of normally-distributed data.

The background concentration values documented in ECF-HANFORD-11-0038 (Appendix G) for selenium reference *Natural Background Soil Metals Concentrations in Washington State* (Publication 94-115) because neither the Non-Rad Soil Background document (DOE/RL-92-24) nor Review of Metal Concentrations (PNNL-18577) had adequate analytical results.

Radionuclide background values (lognormal 90th percentile and maximum) are identified in the Rad Soil Background document (DOE/RL-96-12), Table 5-1. The background values for naturally occurring radionuclides were determined primarily by analyzing a subset of the inorganic systematic random samples from the vadose zone (upper 30 cm of the soil column). The background values for the anthropogenic radionuclides were determined from analytical results from surface sampling (upper 2.5 cm of the soil column).

The composition of background samples described in the Non-Rad Soil Background document (DOE/RL-92-24), Rad Soil Background document (DOE/RL-96-12), and Review of Metal Concentrations (PNNL-18577) is representative of the sedimentary facies in the vadose zone at the 100-K Source OU. These background data are recommended for use in environmental-restoration activities on the Hanford Site to maintain consistency between projects, and they have been peer reviewed for technical credibility. Table G-15 lists the maximum and 90th percentile background concentration values for inorganic chemicals and radionuclides.

Comparison of Site and Background Risk Contributions. Understanding the contribution to risk from naturally occurring elements is important because cleanup levels are not set at concentrations below natural background levels under CERCLA. Similarly, "Overview of Cleanup Standards" (WAC 173-340-700(6)(d)), "Requirements for Setting Cleanup Levels, Natural Background and Analytical Considerations," states that:

> *In some cases, cleanup levels calculated using the methods specified in this chapter are less than natural background levels or levels that can be reliably measured. In those situations, the cleanup level shall be established at a concentration equal to the practical quantitation limit or natural background concentration, whichever is higher.*

Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Site (EPA 540-R-01-003) states, "When background concentrations are high relative to the concentrations of released hazardous substances, pollutants, and contaminants, a comparison of site and background concentrations may help risk managers make decisions concerning appropriate remedial actions. The contribution of background concentrations to risks associated with CERCLA releases may be important for refining specific cleanup levels for contaminants of concern that warrant remedial action."

The 90th percentile value is used as a fixed benchmark concentration for the purpose of determining which contaminants should be evaluated for purposes of background risk. To assist risk managers make decisions concerning appropriate remedial actions, a comparison of background risks to risks from CERCLA releases is provided using the approach described in the following text.

- EPCs from each decision unit are compared to the background value for metals and radionuclides listed in Table G-15. A comparison of EPCs to the lognormal 90th percentile value for each decision unit is provided in Table G-16 for the 100-K Source OU.
- If the EPC is less than or equal to the background value, then a risk estimate or an HQ is not calculated.
- If the EPC is greater than the background value, then a risk estimate or an HQ is calculated.
- If a background value is not available for an analyte, then a risk estimate or an HQ is calculated.
- The total ELCR is summed for all analytes with EPCs greater than their background value.
- The HI is summed for all analytes with EPCs greater than their respective background value.

6.2.5.1 Summary of Risk Estimates by Exposure Scenario

This section summarizes the risk estimates for each of the exposure scenarios considered for the 100-K Source OU. For completeness in analysis, risk estimates for each waste site decision unit are provided in Appendix G, which includes all COPCs regardless of their EPCs relative to the background value (Tables G-17 through G-23).

Appendix G also includes risk estimates for each waste site decision unit, which includes only those COPCs with EPCs greater than background values or that do not have a background value (Tables G-24 through G-31). Only these results are discussed in the risk characterization because it is this information that is used for decisions concerning appropriate remedial actions.

Residential Scenario. PRGs developed for the residential scenario are the numeric values that represent the RAOs presented in Chapter 8. The results of comparing EPCs to the RBSLs in this supplemental risk evaluation will be used to help determine whether additional remedial action is necessary for waste sites where remediation has been completed, and whether the goals and objectives of the interim action RODs have been met, as demonstrated by verification sampling and analysis. A complete description of the residential exposure scenario is provided in Section 6.2.3.3.

Risk estimates were calculated for each decision unit within a waste site including shallow vadose zone material, deep vadose zone material, and overburden material. The results for the residential scenario are summarized in Tables G-24 through G-26.

Shallow Zone. A total of 18 shallow zone decision units (from 16 waste sites) are included in the 100-K Source OU. Of the 16 waste sites, 10 were sampled using a focused sampling design, 4 were sampled using a statistical sampling design, and 2 were sampled using both a statistical and a focused sampling design; resulting in 18 decision units. The residential scenario results for shallow vadose zone materials are summarized in Tables G-27 through G-28.

As presented in Table G-27, the potential cumulative ELCR from all radiological COPCs without background contribution ranges from 1.3×10^{-5} to 1.2×10^{-4} for nine of the 18 decision units. The potential cumulative ELCR is greater than the upper range of the regulatory target risk threshold value of 10^{-4} for one

decision unit. Radiological COPCs were not reported at nine decision units. No individual radiological COPCs were reported with a risk greater than 1×10^{-4}.

As presented in Table G-27, the potential cumulative ELCR from direct contact for all nonradiological carcinogenic COPCs without background contribution ranges from 2.0×10^{-7} to 1.0×10^{-5} for three of the 18 decision units. The potential cumulative ELCR is less than or equal to the WAC 173-340-708(5) cumulative risk threshold of 1×10^{-5} for the three decision units. Carcinogenic analytes were not reported at 15 decision units.

As presented in Table G-27, the potential HI from direct contact for noncancer effects for all decision units is less than 1, which is less than the EPA target HI of 1 and the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740) target HI of 1.

As presented in Table G-28, the potential cumulative ELCR for the inhalation pathway from all nonradiological carcinogenic COPCs ranges from 1.1×10^{-10} to 1.5×10^{-9} for 13 of the 18 decision units. The potential cumulative ELCR is less than the lower risk threshold of 1×10^{-6} for all decision units. Carcinogenic analytes were not reported at five decision units

A presented in Table G-28, the potential HI from the inhalation pathway for noncancer effects is less than 1 for all decision units. The potential HI is less than the EPA target HI of 1 and the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740) target HI of 1.

As shown in Table G-26, all lead and arsenic EPCs are less than their respective Method A soil cleanup level of 250 mg/kg and 20 mg/kg, respectively.

Overburden. There are three overburden decision units (from three waste sites) in the 100-K Source OU. Of the three decision units, all samples were collected using a statistical sampling design. The residential scenario results for overburden materials are summarized in Tables G-29 and G-30.

As presented in Table G-29, the potential cumulative ELCR from all radiological COPCs without background contribution ranges from 5.8×10^{-6} to 4.8×10^{-5} for the decision units. The potential cumulative ELCR is less than the upper target risk value of 10^{-4} for all the decision units.

As presented in Table G-29, no risk estimates were calculated for direct contact because nonradiological carcinogenic analytes were not reported in the three decision units.

As presented in Table G-29, the potential HI from direct contact for noncancer effects is less than 1 for all decision units. The potential HI is less than the EPA target HI of 1 and the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740) target HI of 1.

As presented in Table G-30, the potential cumulative ELCR for the inhalation pathway from all nonradiological carcinogenic COPCs is 1.4×10^{-10} for one decision unit. The potential cumulative ELCR is less than the lower risk threshold of 1×10^{-6} for this decision unit. Carcinogenic analytes were not reported at two decision units.

As presented in Table G-30, the potential HI from the inhalation pathway for noncancer effects is less than 1 for one decision unit. The potential HI is less than the EPA target HI of 1 and the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740) target HI of 1. Noncarcinogenic analytes were not reported at two decision units.

Arsenic and lead were not analyzed in the overburden decision units.

Deep Zone. Deep zone soil samples are compared to RBSLs developed for the residential exposure scenario, although residents are unlikely to be exposed to contaminants in deep zone soil. Deep zone soil

samples are collected from depths greater than 4.6 m (15 ft) bgs; as a result, direct contact within the point of compliance is incomplete. Additionally, the residential exposure scenario does not reflect reasonably anticipated future land use in the River Corridor. This comparison is included because it is the most conservative land use basis for the evaluation of waste sites and presentation of these results is only included to provide additional information for risk management decisions. There are four deep zone decision units (four waste sites) in the 100-K Source OU. All were sampled using a statistical sampling design. Tables G-31 summarizes the residential scenario results for deep vadose zone materials.

As presented in Table G-31, the potential cumulative ELCR from all radiological COPCs without background contribution ranges from 4.9×10^{-5} to 6.3×10^{-3} for the four decision units. The potential cumulative ELCR is greater than the upper range of the regulatory target risk threshold of 10^{-4} for three decision units. Three waste sites report concentrations of site-related COPCs that exceed the upper range of the regulatory target risk threshold. The cancer risk levels are as follows:

- 100-K-56:1 (cesium-137—4.7×10^{-4} and europium-152—6.1×10^{-4})
- 116-K-1 (cesium-137—2.5×10^{-4}, cobalt-60—1.1×10^{-4}; europium-152—2.5×10^{-4}, and Sr-90—3.8×10^{-4})
- 116-K-2 (cesium-137—2.7×10^{-3}, cobalt-60—1.7×10^{-4}; europium-152—2.8×10^{-3}, europium-154—1.6×10^{-4}, nickel-63—1.3×10^{-4}, and Sr-90—2.8×10^{-4})

Resident Monument Worker Scenario. The resident Monument worker represents reasonably anticipated future land use. The results of this comparison are used to confirm that cleanup actions are protective of the reasonably foreseeable land uses that DOE and the USFWS anticipate for the river corridor. The resident Monument worker scenario is described in Section 6.2.3.3.

For completeness in analysis, risk estimates for each waste site decision unit are provided in Appendix G, which includes all radiological COPCs regardless of their EPCs relative to the background value (Tables G-32 through G-34).

Appendix G also includes risk estimates for each waste site decision unit, which includes only those radiological COPCs with EPCs greater than background values or that do not have a background value (Tables G-35 through G-37). Only these results are discussed in the risk characterization because it is this information that is used for decisions concerning appropriate remedial actions.

Risk estimates were calculated for the shallow and overburden decision units within a waste site. Risk estimates were not calculated for the deep zone decision units because the direct contact exposure pathway is incomplete (i.e. samples are collected from depths greater than 4.6 m [15 ft] bgs). The results for the resident Monument worker scenario are summarized in Table G-35.

Shallow Zone. A total of 18 shallow zone decision units (from 16 waste sites) are included in the 100-K Source OU. Of the 16 waste sites, ten waste sites were sampled using a focused sampling design, four waste sites were sampled using a statistical sampling design, and two waste sites were sampled using both a statistical and a focused sampling design; resulting in 18 decision units. The resident monument worker scenario results for shallow vadose zone materials are summarized in Table G-36.

As presented in Table G-36, the potential cumulative ELCR from all radiological COPCs without background contribution ranges from 7.4×10^{-6} to 9.3×10^{-5} for nine of the 18 decision units. The potential cumulative ELCR is less than the upper range of the regulatory target risk threshold value of 10^{-4} for all decision units. Radiological COPCs were not reported at nine decision units. No individual radiological COPCs were reported with a risk greater than 1×10^{-4}.

Overburden. There are three overburden decision units (from three waste sites) in the 100-K Source OU. Of the three decision units, all samples were collected using a statistical sampling design. The resident monument worker scenario results for overburden materials are summarized in Table G-37.

As presented in Table G-37, the potential cumulative ELCR from all radiological COPCs without background contribution ranges from 7.1×10^{-6} to 1.7×10^{-5} for the decision units. The potential cumulative ELCR is less than the upper range of the regulatory target risk threshold value of 10^{-4} for all decision units.

Casual Recreational User Scenario. The casual user represents reasonably anticipated future land use. The results of this comparison are used to confirm that cleanup actions are protective of the reasonably foreseeable land uses that DOE and USFWS anticipate for the River Corridor. The casual recreational user scenario is described in Section 6.2.3.3.

For completeness in analysis, risk estimates for each waste site decision unit are provided in Appendix G, which includes all COPCs regardless of their EPCs relative to the background value (Tables G-38 through G-40).

Appendix G also includes risk estimates for each waste site decision unit, which includes only those COPCs with EPCs greater than background values or that do not have a background value (Tables G-41 through G-43). Only these results are discussed in the risk characterization because it is this information that is used for decisions concerning appropriate remedial actions.

Risk estimates were calculated for the shallow and overburden decision units within a waste site. Risk estimates were not calculated for the deep zone decision unit because the direct contact exposure pathway is incomplete (i.e., samples are collected from depths greater than 4.6 m [15 ft] bgs). The results for the casual recreation user scenario are summarized in Tables G-41.

Shallow Zone. A total of 18 shallow zone decision units (from 16 waste sites) are included in the 100-K Source OU. Of the 16 waste sites, ten waste sites were sampled using a focused sampling design, four waste sites were sampled using a statistical sampling design, and two waste sites were sampled using both a statistical and a focused sampling design; resulting in 18 decision units. The casual recreational user scenario results for shallow zone materials are summarized in Tables G-42.

As presented in Table G-42, the potential cumulative ELCR from all radiological COPCs ranges from 4.4×10^{-7} to 5.4×10^{-6} for nine of the 18 decision units. The potential cumulative ELCR is within the regulatory target risk range of 10^{-6} to 10^{-4} for seven of the decision units and less than the lower EPA target risk threshold of 1×10^{-6} for two decision units. No individual radiological COPCs were reported with an ELCR of greater than 1×10^{-4}. Radiological COPCs were not analyzed at nine decision units.

As presented in Table G-42, the potential cumulative ELCR from direct contact for all nonradiological carcinogenic COPCs without background contribution ranges from 2.3×10^{-12} to 1.5×10^{-6} for 13 of the 18 decision units. The potential cumulative ELCR is within the EPA target risk range of 1×10^{-6} to 1×10^{-4} for one decision unit and less than the lower EPA risk threshold of 1×10^{-6} for 12 decision units. Carcinogenic analytes were not detected in five decision units.

As presented in Table G-42, the potential HI from noncancer effects from direct contact for all noncarcinogenic COPCs without background contribution is less than 1 for all decision units. The HI is less than the EPA target HI of 1.

Overburden. There are three overburden decision units (from three waste sites) in the 100-K Source OU. Of the three decision units, all samples were collected using a statistical sampling design. The residential scenario results for shallow vadose zone materials are summarized in Table G-43.

As presented in Table G-43, the potential cumulative ELCR from direct contact for all radiological COPCs without background contribution ranges from 5.3×10^{-7} to 1.0×10^{-6} for all decision units. The potential cumulative ELCR is within the EPA target risk range of 10^{-6} to 10^{-4} for one decision unit and less than the lower EPA target risk threshold of 1×10^{-6} for two decision units. No radiological COPCs were reported with an individual ELCR greater than 1×10^{-4}.

As presented in Table G-43, the potential cumulative ELCR from direct contact for all nonradiological COPCs without background contribution is 3.0×10^{-12} for one decision unit. No carcinogenic analytes were detected in two decision units.

As presented in Table G-43, the potential HI from noncancer effects from direct contact for all noncarcinogenic COPCs without background contribution is less than 1 for all decision units. The HI is less than the EPA target HI of 1.

6.2.6 Uncertainties in the Supplemental Soil Risk Evaluation

The purpose of this risk assessment is to determine whether a further remedial action is warranted under CERCLA. Waste sites included in this supplemental soil risk evaluation represent current site conditions following remedial actions documented in the 100 Area RDR/RAWP (DOE/RL-96-17). Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks.

In this assessment, uncertainties are associated with sampling and analysis data, sampling design, the exposure point concentrations, radiological decay, exposure, toxicity assumptions, and risk characterization.

6.2.6.1 Uncertainties Associated with Sampling and Analysis Data

Sampling and analysis data used in this supplemental soil risk evaluation represent post-remediation conditions of waste sites with a "no action" or an "interim closed" remediation status. All soil samples were collected in accordance with the requirements stated in the *100 Area Remedial Action Sampling and Analysis Plan* (DOE/RL-96-22). These data were collected specifically to determine if the remedial action processes implemented under the work plan met the remedial action objectives and remedial action goals stated in the records of decisions listed in Section 6.2.1.1.

Some uncertainties may be associated with the changing requirements associated with the analysis of COCs identified in each record of decision. When remediation initially began in 1996 in the 100 Area, only those analytes identified as COCs were analyzed and reported by the laboratory. However, as remediation continued, analytical methods improved, guidance was superseded, and reporting requirements changed. Currently, analytes identified as COCs are analyzed using a methods based approach, which requires each laboratory to report the concentration of the COC and all associated target analytes included in the analytical method.

Waste sites associated with the earliest RODs are generally the radioactive high volume liquid effluent sites. In general, verification samples collected to determine if remedial action objectives had been met report fewer analytes than those that have been remediated more recently. Waste sites that are associated with the remaining sites ROD tend to have verification samples analyzed using a methods-based approach. These generally include burial grounds and waste sites identified during discovery process. Risks may be understated for waste sites that did implement a method-based approach for sampling because fewer analytes are reported.

6.2.6.2 Uncertainties Associated with Sampling Design and Exposure Point Concentrations

Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (OSWER 9285.6-10) recommends using a 95 percent UCL on the mean for estimating EPCs. Section 6.2.2.2 describes the methodology for calculating the EPCs for detected analytes.

When the following conditions were met, the maximum concentration rather than the 95 percent UCL was selected as the EPC:

- When samples are collected using a focused sampling design
- When a valid 95 percent UCL cannot be calculated due to small sample size
- When a valid 95 percent UCL is greater than the maximum detected concentration

When these conditions are met, statistical bias is introduced, resulting in the potential to overstate risk.

In addition, EPCs selected for shallow zone and deep zone decision units represent verification data collected from the floor and the sidewall of the excavated waste site. As a result, risks are likely overstated because the EPC does not take credit for the existing clean backfill that covers the remediated waste site.

6.2.6.3 Uncertainties Associated with Decay of Radioisotopes

Section 6.2.5.2 provides a summary of the risk estimates by exposure scenario evaluated. The results of the supplemental risk evaluation for the residential scenario identified 100-K-56:1, 116-K-1, and 116-K-2 with concentrations of site-related COPCs that result in individual risks greater than the upper range of the regulatory target threshold of 1×10^{-4}. Table G-44 lists the three waste sites, the radioisotopes reported with concentrations greater than their respective residential RBSL for each waste site, the year the samples were collected, the EPCs, the half-life for each radioisotope, and the year that each radioisotope decays to an activity level less than the residential RBSL. Deep zone soil samples are collected from depths greater than 4.6 m (15 ft) bgs; as a result, contact within the point of compliance is incomplete. Additionally, the residential exposure scenario does not reflect reasonably anticipated future land use in the River Corridor. This comparison is included because it is the most conservative land use basis for the evaluation of waste sites and presentation of these results is only included to provide additional information for risk management decisions.

To determine the elapsed time at which the activity level would decay below the residential RBSL was based on the radioactive decay law using the following equation:

$$\tau = \frac{\log \frac{A_E}{A_O}}{\log 0.5} \times \tau \frac{1}{2}$$

where:

A_E = The remaining amount of substance (the PRG) (pCi/g)

A_O = The original amount of substance (the EPC) (pCi/g)

$\tau_{1/2}$ = The half-life of the substance (years)

τ = The elapsed amount of time (years)

The following lists the year that concentrations of radioisotopes currently measured in deep decision units decay to activity levels less than residential RBSLs:

- 100-K-56:1 deep decision unit—decay to levels less than residential RBSLs in year 2072
- 116-K-1 deep decision unit—decay to levels less than residential RBSLs in year 2059
- 116-K-2 deep decision unit—decay to levels less than residential RBSLs in year 2148

6.2.6.4 Uncertainties Associated with Exposure Assumptions

The exposure assumptions used to develop the RBSLs for each exposure scenario represent an RME. For estimating the RME, 95 percentile values (or upper-bound estimates of national averages) are generally used for exposure assumptions, and exposed populations and exposure scenarios are also selected to represent upper-bound exposures. The intent of the RME, as discussed by the EPA Deputy Administrator and the Risk Assessment Council "Guidance on Risk Characterization for Risk Managers and Risk Assessors" (Habicht, 1992) is to present risks as a range from central tendency to high-end risk (above the 90th percentile of the population distribution). This descriptor is intended to estimate the risks that are expected to occur in small but definable "high-end" segments of the subject population ("Guidance on Risk Characterization for Risk Managers and Risk Assessors" [Habicht, 1992]). EPA distinguishes between those scenarios that are possible but highly improbable and those that are conservative but more likely to occur within a population, with the latter being favored in risk assessment. In general, these assumptions are intended to be conservative and yield an upper bound of the true risk or hazard.

6.2.6.5 Uncertainties Associated with Toxicity Assessment

The toxicological database was also a source of uncertainty. EPA has outlined some of the sources of uncertainty as defined in the risk assessment guide (EPA/540/1-89/002) and in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). These sources may include or result from the extrapolation from high to low doses and from animals to humans. This is contingent on the species, gender, age, and strain differences in the uptake, metabolism, organ distribution, and target site susceptibility of a toxin. The human population's variability with respect to diet, environment, activity patterns, and cultural factors are also sources of uncertainty.

Traditionally, EPA has developed toxicity criteria for carcinogens by assuming that all carcinogens are nonthreshold contaminants. However, EPA has recently published revised cancer guidelines (*Guidelines for Carcinogen Risk AssessmentI* [EPA/630/P-03/001F]) where they have modified their former position of assuming nonthreshold action for all carcinogens. This new guidance emphasizes establishing the specific toxicokinetic mode of action that leads to development of cancer. In the future, toxicity criteria for carcinogens in the United States will be developed assuming no threshold for contaminants that exhibit genotoxic modes of action, or where the mode of action is not known. However, currently available EPA toxicity criteria for carcinogens were all derived assuming a nonthreshold model.

In most of the world, nonthreshold toxicity criteria are developed only for those carcinogens that appear to cause cancer through a genotoxic mechanism (Health Canada, Netherlands). Specifically, for genotoxic contaminants, the cancer dose-response model is based on high-dose to low-dose extrapolation and assumes there is no lower threshold for the initiation of toxic effects. Cancer effects observed at high doses are found in laboratory animals or are extrapolated from occupational or epidemiological studies. Cancer effects observed at low doses are commonly found in environmental exposures. These models are essentially linear at low doses, so no dose is without some risk of cancer.

Slope Factors for Cr(VI). The oral reference dose of 0.003 mg/kg-day published by IRIS is used to develop the "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740) direct contact soil cleanup level for Cr(VI). NJDEP has recently published an oral carcinogenic potency factor of 0.5 $(mg/kg\text{-}day)^{-1}$ (NJDEP, 2009). If the NJDEP value were used to calculate the "Unrestricted Land Use Soil Cleanup Standards"

(WAC 173-340-740) direct contact soil cleanup level, the concentration would decrease from 240 mg/kg to 2.0 mg/kg. The use of the oral reference dose published by IRIS may result in underestimating risk.

6.2.6.6 Uncertainties Associated with Risk Characterization

In the risk characterization, the assumption was made that the total risk of developing cancer from exposure to site contaminants is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of noncancer adverse effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach, in accordance with EPA guidance, did not account for the possibility that constituents act synergistically or antagonistically, resulting in an overestimation or underestimation of risk.

6.3 Supplemental Groundwater Risk Evaluation

EPA guidance provided in "Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration" (Woolford and Reeder, 2009) clarifies EPA's policies for determining whether a groundwater remedial action is warranted under CERCLA. In discussing the role of the BRA, the EPA memorandum ("Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration" [Woolford and Reeder, 2009]) quotes the preamble to the NCP (40 CFR 300):

> *The results of the baseline risk assessment are used to determine whether remediation is necessary, to help provide justification for performing remedial action, and to assist in determining what exposure pathways need to be remediated.*

The memorandum then continues to clarify when a CERCLA remedial action is appropriate (page 5):

> *A CERCLA remedial action generally is appropriate*[6] *in various circumstances, including a regulatory standard that helps define protectiveness (e.g., a federal or state MCL or nonzero MCLG for current or potential drinking water aquifers) is exceeded; when the estimated risk calculated in a risk assessment exceeds a noncarcinogenic level for an adverse health effect or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use;*[7] *the noncarcinogenic hazard index is greater than one (using reasonable maximum exposure assumptions for either the current or reasonably anticipated future land use); or the site contaminants cause adverse environmental impacts.*[8] *It is important to note that all conditions do not need to be present for action and the conditions may be independent of each other.*

EPA guidance provided in "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions" (Clay, 1991) describes how to use the BRA to make risk management decisions such as determining whether remedial action under CERCLA Section 104 or Section 106 is necessary. "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions" (Clay, 1991) describes the following conditions when a CERCLA action is generally warranted:

- The BRA indicates that a cumulative site risk to an individual using RME assumptions for either current or future land use exceeds the 10^{-4} ELCR end of the risk range.

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[6] See EPA 540-R-97-013, *Rules of Thumb for Superfund Remedy Selection.*

[7] See Clay, 1991, "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions."

[8] See EPA 540-R-97-013, *Rules of Thumb for Superfund Remedy Selection.*

- For groundwater actions, MCLs and nonzero MCLGs will generally be used to gauge whether remedial action is warranted.

- Chemical-specific standards that define acceptable risk levels also may be used to determine whether an exposure is associated with an unacceptable risk to HHE and whether remedial action is warranted.

Protectiveness of human health is evaluated by comparing groundwater concentrations to existing federal or state MCLs or nonzero MCLGs. Similarly, protectiveness of aquatic receptors is determined by the comparison of groundwater concentrations to water quality criteria established under Section 304 or Section 303 of the *Clean Water Act of 1977* as well as Washington State water quality standards. Groundwater concentrations are compared to "Groundwater Cleanup Standards" (WAC 173-340-720) and "Surface Water Cleanup Standards (WAC 173-340-730) to determine whether EPCs result in an HI greater than one. The EPCs also are used to calculate ELCRs that are compared to the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use.

EPA guidance provided in "Clarification of the Role of Applicable, or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA" (Fields, 1997) clarifies the relationship between two statutory mandates of CERCLA: protect HHE and attain or waive, if justified, based on site-specific circumstances, ARARs. It remains EPA's policy that ARARs will generally be considered protective, absent multiple contaminants or pathways of exposure. However, the guidance clarifies that, in rare situations, even absent multiple pathways or contaminants, PRGs should be set at levels more protective than required by a given ARAR, where application of the ARAR would not be protective of HHE.

A supplemental groundwater risk evaluation was performed for the 100-KR-4 Groundwater OU. The 100-KR-4 Groundwater OU supplemental risk evaluation followed the strategy outlined as follows:

- Evaluate current groundwater data to identify contaminants present in groundwater in the OU. Analytical measurement data collected to resolve spatial, chemical, and temporal uncertainties described in DOE/RL-2008-46 were used.

- Identify action levels for detected contaminants, using ARARs to establish a basis for screening COPCs.

- Compare the detected contaminant concentrations to ARARs in order to identify COPCs within the entire 100-KR-4 Groundwater OU.

- Further evaluate the COPCs to identify and refine a set of COPCs within the entire OU.

- Conduct the risk characterization step on the set of COPCs, including a determination that ARARs have been exceeded.

Results of this supplemental groundwater risk evaluation indicate that concentrations of contaminants in the 100-KR-4 Groundwater OU exceed action levels and warrant investigation in an FS to address groundwater contamination within the OU. The COPCs represent contaminants that will be evaluated in the FS to define the COCs and select remedial alternatives. The CEM shows that exposure to groundwater contaminants is through direct contact and fish consumption, while other exposure pathways are considered incomplete or insignificant. The supplemental groundwater risk evaluation identifies multiple contaminants within the 100-KR-4 Groundwater OU that exceed chemical-specific ARARs. "Human Health Risk Assessment Procedures" (WAC 173-340-708(5)(a) and WAC 173-340-708(6)(b)) require that cleanup levels be adjusted downward to take into account exposure to multiple hazardous substances or multiple pathways of exposure. This adjustment needs to be made only if, without this adjustment, the

HI would exceed 1, or the total ELCR would exceed 1 in 100,000 (1×10^{-5}). As a result, the supplemental groundwater risk evaluation does not identify the need to develop cleanup levels that are more protective than ARARs.

Additionally, several local and regional Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, the CTUIR (*Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper, 2004]) and the Yakama Nation (*Yakama Nation Exposure Scenario for Hanford Site Risk Assessment* [Ridolfi, Inc., 2007]) have provided scenarios. A quantitative risk evaluation is included for both Tribal use scenarios to evaluate each of the potentially complete groundwater exposure pathways. The results for the Native American Risk Assessment are provided in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100-KR4-10-0475) (Appendix G). Section 6.3.5.6 provides a summary of this evaluation. A quantitative evaluation of human health risk to a resident from exposure to tap water is included for comparison to the Native American Risk Assessment. The results of the Tap Water Risk Assessment are provided in *Tap Water Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0476) (Appendix G).

6.3.1 Findings of the River Corridor Baseline Risk Assessment

The RCBRA Report (DOE/RL-2007-21) provides a screening level groundwater risk assessment for the 100-KR-4 Groundwater OU to evaluate potential risks associated with groundwater exposure. The results of the groundwater screening-level risk assessment indicate potential risk above EPA thresholds within the 100-KR-4 Groundwater OU. Noncancer chemical hazard results were also above the EPA's threshold value of 1.

Uncertainties associated with the groundwater data set were identified in the RCBRA Report (DOE/RL-2007-21). These uncertainties relate to the ability of the groundwater data set collected from 1998 to 2008 to represent current baseline conditions and potential exposure within each groundwater OU. Analytical data used for the screening level assessment were collected to fulfill a variety of state and federal regulations, including RCRA, CERCLA, the *Atomic Energy Act of 1954*, and Section 173 of the *Washington Administrative Code*. While the monitoring data can be used for risk assessment purposes, there are uncertainties associated with its use. Specifically, target analytes, sampling frequencies, and method detection limits (or reporting limits) are different between programs because the information is used to meet different requirements.

As a result of the uncertainties identified in the RCBRA Report (DOE/RL-2007-21), the Integrated Work Plan (DOE/RL-2008-46) added activities that would help reduce uncertainties, verify conclusions of the HHRA presented in the RCBRA Report (DOE/RL-2007-21), and ensure that no contaminants were inadvertently overlooked based on the use of the existing data set. Section 3.6.5.1 of the Integrated Work Plan (DOE/RL-2008-46) identifies the following activities to reduce uncertainties:

- Identify existing and/or install new monitoring wells that are spatially representative of the groundwater. This set of wells will represent locations where a receptor potentially could contact groundwater.
- Conduct multiple rounds of sampling to obtain temporal representation of the unconfined aquifer from influence of river stage. Additional rounds of sampling at spatially representative monitoring wells will represent current groundwater conditions and capture the influence of river fluctuations on COPC concentrations.
- Analyze all spatially representative monitoring wells for a focused list of groundwater COPCs identified for each round of sampling. Analyzing each of the monitoring wells for COPCs will provide a data set that is representative of potential releases to the groundwater.

- Evaluate sample results from characterization activities to support final remedial action decisions for groundwater.

The RCBRA (DOE/RL-2007-21) evaluated exposure to groundwater for three residential scenarios (Subsistence Farmer, CTUIR Resident, and Yakama Resident scenarios) and the residential component of the Resident National Monument/Refuge Exposure scenario. Direct exposure to contaminants in groundwater was evaluated for household uses of groundwater in each of these scenarios, such as drinking and cooking (ingestion) and bathing (dermal absorption). If VOCs were measured in groundwater, indirect exposure by inhalation of VOCs in air may occur while bathing or when using groundwater in the home for other purposes. The inhalation pathway for VOCs associated with household use of groundwater is evaluated for VOCs that are identified as COPCs in groundwater. Additionally, ingestion, inhalation, and dermal exposures to COPCs in groundwater used in a sweat lodge were evaluated in the CTUIR Resident and Yakama Resident scenarios.

The results of the screening level groundwater risk assessment identified carbon-14, Sr-90, tritium, Cr(VI), nitrate, and uranium as the primary contributor to risk through ingestion and dermal contact with groundwater.

6.3.2 Identification of Contaminants of Potential Concern

The first step of this supplemental groundwater risk evaluation is data evaluation to select the COPCs for protection of HHE. A preliminary COPC evaluation was conducted in 2008 to support the 100-K Work Plan (DOE/RL-2008-46-ADD2) and the 100-K SAP (DOE/RL-2009-41). The work plan effort evaluated groundwater analytical data collected over a 16-year period (1992 to 2008) and resulted in the identification of 31 COPCs, which are listed in Table 6-8.

Table 6-8. List of Contaminants of Potential Concern in the 100-KR-4 OU

Metals			
Antimony	Arsenic	Barium	Beryllium
Cadmium	Chromium	Cobalt	Copper
Cr(VI)	Lead	Manganese	Mercury
Nickel	Selenium	Thallium	Uranium
Vanadium	Zinc		
Volatile Organic Compounds			
1,1-Dichloroethene	1,1,2-Tichloroethane	Benzene	Carbon tetrachloride
Chloroform	Tetrachloroethene	Trichloroethene	Vinyl chloride
Radiological			
Carbon-14	Tritium	Sr-90	
Anions			
Chloride	Fluoride	Nitrate (as N)	Nitrite (as N)
Sulfate			

Source: DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*, Table 1-3.

The COPCs identified during the work plan phase were validated by using groundwater samples analyzed using the analytical methods documented in the 100-K SAP (DOE/RL-2009-41), Table 2-4. The groundwater data set used for COPC identification consists of sampling and analysis data collected from 18 monitoring wells within the 100-KR-4 OU. The monitoring well network represents locations where human or ecological receptors could potentially encounter groundwater within the OU. The primary exposure pathway for humans is through groundwater obtained from a residential or community water well, assuming development of the land for future human habitation.

Identification of groundwater COPCs for the 100-KR-4 Groundwater OU is a two-step process. The first step of the process identifies an set of COPCs that will be carried forward to identify a set of COPCs for the entire Groundwater OU. The set of COPCs is evaluated in the risk characterization step of the supplemental groundwater risk evaluation where COPCs are identified. The process used to identify data for COPC selection and the selection of action levels for this supplemental groundwater risk evaluation is described in Section 6.3.2.1. The second step of the process identifies the COPCs for the OU and is described in Section 6.3.2.2. The process used to identify the COPCs and the methodology used to calculate exposure point concentrations is described in Section 6.3.2.3.The exposure assessment and toxicity assessment are presented in Sections 6.3.3 and 6.3.4, respectively. Finally, the risk characterization step is described in Section 6.3.5. The primary objective of this evaluation is to provide information necessary to identify what remedial actions will be necessary in the remedy selected for the 100-KR-4 Groundwater OU.

6.3.2.1 Data Used to Identify Contaminants of Potential Concern

The sampling and analysis data were collected over an 8-month period between October 22, 2009 and June 30, 2010. Three sampling events were used to capture the effects that temporal fluctuations of river stage have on groundwater conditions. Samples collected from May to mid-June 2010 represent the aquifer when the river stage is at its highest elevation. Samples collected from mid-September to mid-October 2009 represent the aquifer when the river is at its lowest elevation. Samples collected from March to April and July to August 2010 represent the aquifer when the river is transitioning from high to low river stage.

All monitoring wells used in this monitoring network were screened in the unconfined aquifer. All the wells in the network were existing monitoring or compliance wells. Table 6-9 lists each well in the 100-KR-4 Groundwater OU and Figure 6-6 shows their locations.

The analytical data set for the 100-KR-4 Groundwater OU evaluation is extracted from the HEIS database. After extraction, the analytical data are processed to obtain a single set of results per sampling location and time of collection. A total of 10,080 records were obtained from HEIS, and 101 analytes were included in the data set prior to analytical data processing. After analytical data processing (as described in the next section), the final data set used for the COPC identification process contained a total of 4,953 records, with 101 analytes included in the data set.

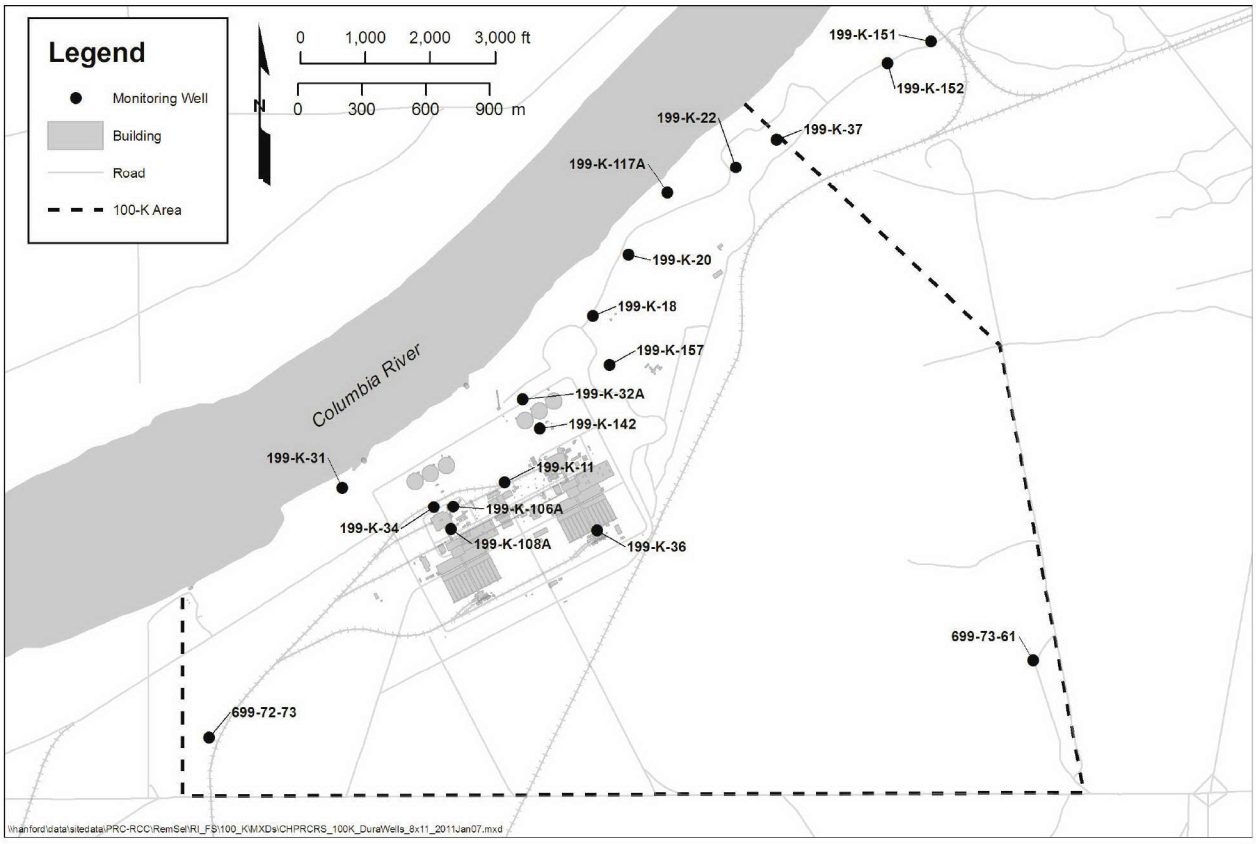

Figure 6-6. Monitoring Well Locations within the 100-KR-4 Groundwater OU

Table 6-9. Monitoring Wells Used in the Supplemental Groundwater Risk Evaluation from the 100-KR-4 Groundwater OU

Well Name		
199-K-106A	199-K-108A	199-K-11
199-K-117A	199-K-142	199-K-151
199-K-152	199-K-157	199-K-18
199-K-20	199-K-22	199-K-31
199-K-32A	199-K-34	199-K-36
199-K-37	699-72-73	699-73-61

Analytical Data Processing. The data set obtained from HEIS included the following types of information:

- Analytical results from both unfiltered and filtered samples
- Data qualification and data validation flags, including rejected results
- Results for a given analyte reported by more than one analytical method
- Parent, field duplicate, and field split sample results

The analytical data were processed to eliminate unusable results and thus identify one set of results per sampling location and date of sample collection. The data processing steps and the numbers of records associated with each step are presented in Figure 6-7. Descriptions of the data processing steps follow.

Unfiltered Sample Results. Only analytical results from unfiltered samples are used in identifying COPCs; results from filtered samples are excluded. Unfiltered sample results represent total concentrations of the analytes, while filtered sample results represent only dissolved concentrations. Use of filtered sampling results might lead to underestimation of chemical and radiological concentrations (e.g., in water from an unfiltered tap).

The risk assessment guide (EPA/540/1-89/002) addresses this issue in providing guidance on estimating exposure concentrations in groundwater:

> *While filtration of ground-water samples provides useful information for understanding chemical transport within an aquifer, the use of filtered samples for estimating exposure is very controversial, because these data may underestimate chemical concentrations in water from an unfiltered tap. Therefore, data from unfiltered samples should be used to estimate exposure concentrations.*

Laboratory and Data Validation Flags. Analytical data are received from the laboratory with data qualification flags. Validation qualifiers are assigned during the data validation process. The following rules determine how flagged and/or qualified sample results are used in identifying COPCs.

- Sample results flagged with a "U" qualifier or combinations of qualifiers that include a "U," such as a "UJ," are considered nondetected results.
- Sample results without a "U" qualifier are considered detected concentrations, including results with no qualifier or with a "J" qualifier.
- Sample results that are rejected and flagged with an "R" qualifier are not used in identifying COPCs.

Analytes Reported by Numerous Analytical Methods. Often analytes are reported by more than one analytical method. This results in multiple results for an analyte at the same location and sample date. Because multiple sets of analytical results cannot be used to quantify risk (i.e., this would result in multiple counting of a chemical), the set of data that best represents the actual concentration will be retained. The results are processed to select the method that provides the most reliable results. Considerations for determining data to be retained include method-associated sample size, detection frequency, and detection limits. The most conservative (i.e., health protective) use of these types of data will be the goal. Larger sample size, higher detection frequencies, and lower detection limits are given higher priority for method selection.

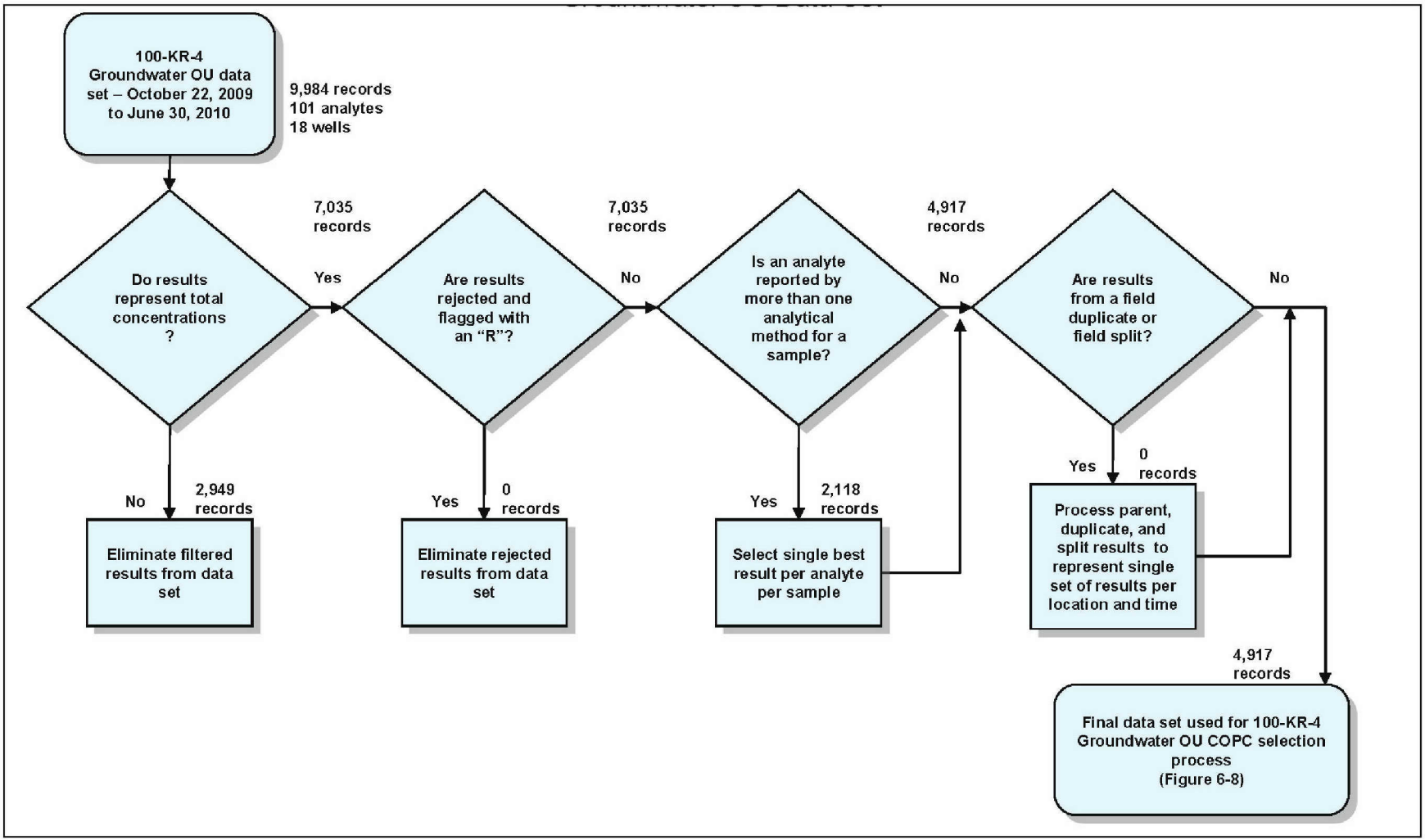

Figure 6-7. Data Processing and Reduction Steps for the 100-KR-4 Groundwater OU Data Set

For example, lead may be analyzed using EPA Method 200.8 (*Methods for the Determination of Metals in Environmental Samples, Supplement I* [EPA-600/R-94/111]), with an EQL of 2 µg/L, or EPA Method 6010 (*Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update IV-B* [SW-846]), with an EQL of 50 µg/L. For a sample with lead concentrations reported using both methods, the results reported by EPA Method 200.8 is selected over EPA Method 6010 because of the more sensitive detection limit.

Field Duplicate and Field Split Results. Field quality control samples (field duplicates and field splits) are collected in the field and analyzed by the laboratory as unique samples. The parent sample and quality control samples are collected from the same location (i.e., monitoring well) on the same date, resulting in more than one sample per location/date. The following criteria are used to reduce multiple sample results for an individual location/date to a single result:

- If two or more detections exist, the maximum concentration is used.
- If at least one detection and one or more nondetected results exist, the detected concentration is used.
- If only (two or more) nondetected results exist, the lowest detection limit is used.

Identify Action Levels. Action levels are derived from available sources of chemical-specific ARARs and default exposure assumptions. All sources of chemical-specific ARARs for each of the 101 analytes reported in the HEIS database for the 100-KR-4 OU are identified in Table 6-10.

For the COPC identification process and the COPC identification process, the action level is the lowest of the available chemical-specific ARARs for protection of human health and aquatic receptors.

ARAR Based Remediation Goals. The sources of the chemical-specific ARARs from federal regulations are:

- "National Primary Drinking Water Regulations" (40 CFR 141), MCLs, secondary MCLs, and nonzero MCLGs established under the *Safe Drinking Water Act of 1974* (SDWA)
- National Recommended Water Quality Criteria, AWQC established under Section 304 of the *Clean Water Act of 1977*
- "Water Quality Standards" (40 CFR 131) for states not complying with Section 303 of the *Clean Water Act of 1977*

The sources of the chemical-specific ARARs from Washington State regulations are:

- WAC 173-201A, "Water Quality Standards for Surface Waters of the State of Washington"
- WAC 173-340-720, "Groundwater Cleanup Standards"
- WAC 173-340-730, "Surface Water Cleanup Standards"
- WAC 246-290-310 , "Group A Public Water Supplies" "Maximum Contaminant Levels (MCLs) and Maximum Residual Disinfectant Levels (MRDLs)"

Derivation of State of Washington groundwater cleanup levels is provided in a separate calculation brief (*Environmental Calculation of WAC 173-340-720 Method B Groundwater Cleanup Levels for Potable Groundwater in the 100 Areas and 300 Areal* [ECF-100NPL-10-0462]). Derivation of State of Washington surface water cleanup levels is provided in a separate calculation brief (*Environmental Calculation of WAC 173-340-730 Method B Surface Water Cleanup Levels for the 100 Area and 300 Area* [ECF-100NPL-10-0463]).

6.3.2.2 COPC Identification Process

The COPC identification process is used to identify those analytes to be carried forward to categorize a set of COPCs for the entire Groundwater OU. This step of the process uses sampling and analysis data collected from the 100-KR-4 Groundwater OU network of 18 monitoring wells. The purpose of grouping all sampling and analysis data together is to identify those analytes with detected concentrations above the lowest available action level before an EPC is calculated. A detailed description of the screening process is provided in *Identification of Contaminants of Potential Concern for Groundwater Risk Assessment at the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0470) (Appendix G). The COPC identification steps, number of records, and number of analytes associated with each step are depicted in Figure 6-8 and listed as follows:

- Apply exclusion criteria
- Identify nondetected analytes
- Identify analytes with maximum detected concentrations less than action levels

The results of the COPC selection process identified 16 analytes to be carried into the COPC process.

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
630-20-6	1,1,1,2-Tetrachloroethane	--	µg/L	--	--	--	--	1.7	--	--	--	--	--	--	--	6.2	1.7	WAC 173-340-720(4)(b)(iii)(A) and (B)
71-55-6	1,1,1-Trichloroethane	--	µg/L	200	200	--	--	16,000	--	--	--	--	--	--	--	925,926	200	40 CFR 141—Federal MCL
79-34-5	1,1,2,2-Tetrachloroethane	--	µg/L	--	--	--	--	0.22	--	--	0.17	--	--	--	0.17	6.5	0.17	Clean Water Act--Human Health Water + Organism
79-00-5	1,1,2-Trichloroethane	--	µg/L	5.0	3.0	--	--	0.77	--	--	0.59	--	--	--	0.60	25	0.59	Clean Water Act—Human Health Water + Organism
75-34-3	1,1-Dichloroethane	--	µg/L	--	--	--	--	1,600	--	--	--	--	--	--	--	73,549	1,600	WAC 173-340-720(4)(b)(iii)(A) and (B)
75-35-4	1,1-Dichloroethene	1,1-Dichloroethylene	µg/L	7.0	7.0	--	--	400	--	--	330	--	--	--	0.057	23,148	0.057	40 CFR 131—Human Health Water + Organism
96-18-4	1,2,3-Trichloropropane	--	µg/L	--	--	--	--	0.0015	--	--	--	--	--	--	--	0.017	0.0015	WAC 173-340-720(4)(b)(iii)(A) and (B)
96-12-8	1,2-Dibromo-3-chloropropane	--	µg/L	0.20	--	--	--	0.055	--	--	--	--	--	--	--	0.70	0.055	WAC 173-340-720(4)(b)(iii)(A) and (B)
106-93-4	1,2-Dibromoethane	--	µg/L	0.050	--	--	--	0.022	--	--	--	--	--	--	--	0.22	0.022	WAC 173-340-720(4)(b)(iii)(A) and (B)
107-06-2	1,2-Dichloroethane	--	µg/L	5.0	--	--	--	0.48	--	--	0.38	--	--	--	0.38	59	0.38	Clean Water Act—Human Health Water + Organism
540-59-0	1,2-Dichloroethene (Total)	1,2-Dichloroethylene Mixed Isomers	µg/L	--	--	--	--	72	--	--	--	--	--	--	--	2,102	72	WAC 173-340-720(4)(b)(iii)(A) and (B)
78-87-5	1,2-Dichloropropane	--	µg/L	5.0	--	--	--	1.2	--	--	0.50	--	--	--	--	44	0.50	Clean Water Act—Human Health Water + Organism
106-46-7	1,4-Dichlorobenzene	--	µg/L	75	75	--	--	8.1	--	--	63	--	--	--	400	22	8.1	WAC 173-340-720(4)(b)(iii)(A) and (B)

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
123-91-1	1,4-Dioxane	--	µg/L	--	--	--	--	4.0	--	--	--	--	--	--	--	--	4.0	WAC 173-340-720(4)(b)(iii)(A)(B)
71-36-3	1-Butanol	N-Butanol	µg/L	--	--	--	--	800	--	--	--	--	--	--	--	82,044	800	WAC 173-340-720(4)(b)(iii)(A)(B)
78-93-3	2-Butanone	Methyl Ethyl Ketone	µg/L	--	--	--	--	4,800	--	--	--	--	--	--	--	492,264	4,800	WAC 173-340-720(4)(b)(iii)(A)(B)
591-78-6	2-Hexanone	--	µg/L	--	--	--	--	80	--	--	--	--	--	--	--	3,429	80	WAC 173-340-720(4)(b)(iii)(A)(B)
108-10-1	4-Methyl-2-pentanone	4-Methyl-2-Penatone	µg/L	--	--	--	--	640	--	--	--	--	--	--	--	61,002	640	WAC 173-340-720(4)(b)(iii)(A)(B)
67-64-1	Acetone	--	µg/L	--	--	--	--	7,200	--	--	--	--	--	--	--	738,397	7,200	WAC 173-340-720(4)(b)(iii)(A)(B)
75-05-8	Acetonitrile	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
107-02-8	Acrolein	--	µg/L	--	--	--	--	4.0	--	3.0	6.0	--	--	--	320	--	3.0	Clean Water Act—Freshwater CCC
107-05-1	Allyl chloride	--	µg/L	--	--	--	--	2.1	--	--	--	--	--	--	--	62	2.1	WAC 173-340-720(4)(b)(iii)(A)(B)
7429-90-5	Aluminum	--	µg/L	50	--	--	--	16,000	750	87	--	--	--	--	--	5,185	50	40 CFR 141—Federal MCL
7440-36-0	Antimony	Antimony (metallic)	µg/L	6.0	6.0	6.0	--	6.4	--	--	5.6	--	--	--	14	1,037	5.6	Clean Water Act—Human Health Water + Organism
7440-38-2	Arsenic	Arsenic, Inorganic	µg/L	10	--	10	--	0.058	340	150	0.018	190	360	190	0.018	0.098	0.018	Clean Water Act—Human Health Water + Organism
7440-39-3	Barium	--	µg/L	2,000	2,000	2,000	--	3,200	--	--	1,000	--	--	--	--	129,630	1,000	Clean Water Act—Human Health Water + Organism
71-43-2	Benzene	--	µg/L	5.0	--	--	--	0.80	--	--	2.2	--	--	--	1.2	23	0.80	WAC 173-340-720(4)(b)(iii)(A(B)

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
7440-41-7	Beryllium	Beryllium and Compounds	µg/L	4.0	4.0	4.0	--	32	--	--	--	--	--	--	--	273	4.0	40 CFR 141—Federal MCL
7440-69-9	Bismuth	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7440-42-8	Boron	Boron And Borates Only	µg/L	--	--	--	--	3,200	--	--	--	--	--	--	--	--	3,200	WAC 173-340-720(4)(b)(iii)(A)(B)
24959-67-9	Bromide	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
75-27-4	Bromodichloromethane	--	µg/L	--	--	--	--	0.71	--	--	0.55	--	--	--	0.27	28	0.27	40 CFR 131—Human Health Water + Organism
75-25-2	Bromoform	--	µg/L	--	80	--	--	5.5	--	--	4.3	--	--	--	4.3	219	4.3	Clean Water Act—Human Health Water + Organism
74-83-9	Bromomethane	--	µg/L	--	--	--	--	11	--	--	47	--	--	--	48	968	11	WAC 173-340-720(4)(b)(iii)(A)(B)
7440-43-9	Cadmium	Cadmium (Water)	µg/L	5.0	5.0	5.0	--	8.0	2.0	0.25	--	0.91	3.9	1.0	--	20	0.25	Clean Water Act—Freshwater CCC
7440-70-2	Calcium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
75-15-0	Carbon disulfide	--	µg/L	--	--	--	--	800	--	--	--	--	--	--	--	13,295	800	WAC 173-340-720(4)(b)(iii)(A)(B)
56-23-5	Carbon tetrachloride	--	µg/L	5.0	--	--	--	0.34	--	--	0.23	--	--	--	0.25	2.7	0.23	Clean Water Act—Human Health Water + Organism
14762-75-5	Carbon-14	--	pCi/L	2,000	--	--	--	--	--	--	--	--	--	--	--	--	2,000	40 CFR 141 - Federal MCL
16887-00-6	Chloride	--	µg/L	250,000	--	250,000	--	--	860,000	230,000	--	230,000	--	--	--	--	230,000	Clean Water Act—Freshwater CCC
108-90-7	Chlorobenzene	--	µg/L	100	100	--	--	160	--	--	130	--	--	--	680	5,034	100	40 CFR 141—Federal MCL
75-00-3	Chloroethane	Ethylchloride	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
67-66-3	Chloroform	--	µg/L	80	--	80	--	1.4	--	--	5.7	--	--	--	5.7	56	1.4	WAC 173-340-720(4)(b)(iii)(A)(B)
74-87-3	Chloromethane	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
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CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
126-99-8	Chloroprene	2-Chloro-1,3-butadiene	µg/L	--	--	--	--	160	--	--	--	--	--	--	--	2,412	160	WAC 173-340-720(4)(b)(iii)(A)(B)
7440-47-3	Chromium	--	µg/L	100	100	100	--	24,000	570	65	--	156	550	180	--	19,444	65	Clean Water Act—Freshwater CCC
156-59-2	cis-1,2-Dichloroethylene	--	µg/L	70	70	--	--	80	--	--	--	--	--	--	--	2,336	70	40 CFR 141—Federal MCL
10061-01-5	cis-1,3-Dichloropropene	--	µg/L	--	--	--	--	0.44	--	--	0.34	--	--	--	--	34	0.34	Clean Water Act—Human Health Water + Organism
7440-48-4	Cobalt	--	µg/L	--	--	--	--	4.8	--	--	--	--	--	--	--	2.6	2.6	WAC 173-340-720(4)(b)(iii)(A)(B)
7440-50-8	Copper	--	µg/L	1,300	1,300	--	--	640	13	9.0	1,300	--	17	11	--	2,881	9.0	Clean Water Act—Freshwater CCC
124-48-1	Dibromochloromethane	--	µg/L	60	60	--	--	0.52	--	--	0.40	--	--	--	0.41	21	0.40	Clean Water Act—Human Health Water + Organism
74-95-3	Dibromomethane	Methylene Bromide	µg/L	--	--	--	--	80	--	--	--	--	--	--	--	4,216	80	WAC 173-340-720(4)(b)(iii)(A)(B)
75-71-8	Dichlorodifluoromethane	--	µg/L	--	--	--	--	1,600	--	--	--	--	--	--	--	84,312	1,600	WAC 173-340-720(4)(b)(iii)(A)(B)
107-12-0	Ethyl cyanide	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
97-63-2	Ethyl methacrylate	--	µg/L	--	--	--	--	720	--	--	--	--	--	--	--	26,365	720	WAC 173-340-720(4)(b)(iii)(A)(B)
100-41-4	Ethylbenzene	--	µg/L	700	700	--	--	4.0	--	--	530	--	--	--	3,100	16	4.0	WAC 173-340-720(4)(b)(iii)(A)(B)
16984-48-8	Fluoride	--	µg/L	4,000	4,000	4,000	--	480	--	--	--	--	--	--	--	--	480	WAC 173-340-720(4)(b)(iii)(A)(B)
18540-29-9	Cr(VI)	Chromium (VI)	µg/L	--	--	--	--	48	16	11	--	10	15	10	--	486	10	40 CFR 131—Freshwater CCC
74-88-4	Iodomethane	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
7439-89-6	Iron	--	µg/L	300	--	300	--	11,200	--	1,000	300	--	--	--	--	9,074	300	40 CFR 141—Federal MCL
78-83-1	Isobutyl alcohol	--	µg/L	--	--	--	--	2,400	--	--	--	--	--	--	--	246,132	2,400	WAC 173-340-720(4)(b)(iii)(A) and (B)
7439-92-1	Lead	Lead and Compounds	µg/L	15	--	--	15	--	65	2.5	--	2.1	65	2.5	--	--	2.1	WAC 173-201A
7439-93-2	Lithium	--	µg/L	--	--	--	--	32	--	--	--	--	--	--	--	--	32	WAC 173-340-720(4)(b)(iii)(A)(B)
7439-95-4	Magnesium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7439-96-5	Manganese	Manganese (Water)	µg/L	50	--	50	--	2,240	--	--	50	--	--	--	--	907	50	40 CFR 141—Federal MCL
7439-97-6	Mercury	Mercury (elemental)	µg/L	2.0	2.0	2.0	--	2.6	1.4	0.77	--	0.012	2.1	0.012	0.14	131	0.012	40 CFR 131—Freshwater CCC
126-98-7	Methacrylonitrile	--	µg/L	--	--	--	--	0.80	--	--	--	--	--	--	--	82	0.80	WAC 173-340-720(4)(b)(iii)(A)(B)
80-62-6	Methyl methacrylate	--	µg/L	--	--	--	--	11,200	--	--	--	--	--	--	--	960,219	11,200	WAC 173-340-720(4)(b)(iii)(A)(B)
75-09-2	Methylene chloride	--	µg/L	5.0	--	--	--	5.8	--	--	4.6	--	--	--	4.7	960	4.6	Clean Water Act—Human Health Water + Organism
7439-98-7	Molybdenum	--	µg/L	--	--	--	--	80	--	--	--	--	--	--	--	1,296	80	WAC 173-340-720(4)(b)(iii)(A)(B)
7440-02-0	Nickel	Nickel Soluble Salts	µg/L	--	100	100	--	320	470	52	610	137	1,400	160	610	1,103	52	Clean Water Act—Freshwater CCC
14797-55-8	Nitrate	--	µg/L	45,000	45,000	45,000	--	113,600	--	--	45,000	--	--	--	--	--	45,000	40 CFR 141—Federal MCL
14797-65-0	Nitrite	--	µg/L	3,300	3,300	3,300	--	5,280	--	--	--	--	--	--	--	--	3,300	40 CFR 141—Federal MCL
14265-44-2	Phosphate	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7440-09-7	Potassium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7782-49-2	Selenium	--	µg/L	50	50	50	--	80	--	5.0	170	5.0	20	5.0	--	2,701	5.0	Clean Water Act—Freshwater CCC

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
7440-21-3	Silicon	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7440-22-4	Silver	--	µg/L	100	--	100	--	80	3.2	--	--	2.6	3.4	--	--	25,926	2.6	WAC 173-201A
7440-23-5	Sodium	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7440-24-6	Strontium	Strontium, Stable	µg/L	--	--	--	--	9,600	--	--	--	--	--	--	--	25,926	9,600	WAC 173-340-720(4)(b)(iii)(A)(B)
10098-97-2	Sr-90	--	pCi/L	8.0	--	--	--	--	--	--	--	--	--	--	--	--	8.0	40 CFR 141—Federal MCL
100-42-5	Styrene	--	µg/L	100	100	--	--	1,600	--	--	--	--	--	--	--	38,409	100	40 CFR 141—Federal MCL
14808-79-8	Sulfate	--	µg/L	250,000	--	250,000	--	--	--	--	--	--	--	--	--	--	250,000	40 CFR 141—Federal MCL
127-18-4	Tetrachloroethene	Perchloroethylene (PCE)	µg/L	5.0	--	--	--	0.081	--	--	0.69	--	--	--	0.80	0.39	0.081	WAC 173-340-720(4)(b)(iii)(A)(B)
109-99-9	Tetrahydrofuran	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7440-28-0	Thallium	Thallium (Soluble Salts)	µg/L	2.0	0.50	2.0	--	--	--	--	0.24	--	--	--	1.7	--	0.24	Clean Water Act—Human Health Water + Organism
7440-31-5	Tin	--	µg/L	--	--	--	--	9,600	--	--	--	--	--	--	--	519	519	WAC 173-340-720(4)(b)(iii)(A)(B)
7440-32-6	Titanium	--	µg/L	--	--	--	--	64,000	--	--	--	--	--	--	--	--	64,000	WAC 173-340-720(4)(b)(iii)(A)(B)
108-88-3	Toluene	--	µg/L	1,000	1,000	--	--	640	--	--	1,300	--	--	--	6,800	19,384	640	WAC 173-340-720(4)(b)(iii)(A)(B)
156-60-5	trans-1,2-Dichloroethylene	--	µg/L	100	100	--	--	160	--	--	140	--	--	--	--	32,818	100	40 CFR 141—Federal MCL
10061-02-6	trans-1,3-Dichloropropene	--	µg/L	--	--	--	--	0.44	--	--	0.34	--	--	--	--	34	0.34	Clean Water Act—Human Health Water + Organism
110-57-6	trans-1,4-Dichloro-2-butene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 6-10. Summary of Federal and State Water Quality Criteria and Action Levels for the 100-KR-4 Groundwater Operable Unit

				Groundwater					Surface Water								Action Level Value	
				40 CFR 141[a]		WAC 246-290-310[b]	WAC 173-340-720[c]		Clean Water Act National Recommended Water Quality Criteria[d]			WAC 173-201A[e]	40 CFR 131[f]			WAC 173-340-730[g]		
CAS#	Analyte Name	Alternate Analyte Name	Units	Federal MCL	Federal MCLG	State MCL	Groundwater Method A Cleanup Levels	Groundwater Method B Unrestricted Land Use	Acute Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Freshwater CCC	Freshwater CMC	Freshwater CCC	Human Health Water + Organism	Surface Water Method B Unrestricted Land Use	Action Level	Action Level Basis
79-01-6	Trichloroethene	Trichloroethylene (TCE)	µg/L	5.0	--	--	--	0.49	--	--	2.5	--	--	--	2.7	6.6	0.49	WAC 173-340-720(4) (b)(iii)(A)(B)
75-69-4	Trichloromono-fluoromethane	Trichlorofluoromethane	µg/L	--	--	--	--	2,400	--	--	--	--	--	--	--	--	2,400	WAC 173-340-720(4) (b)(iii)(A)(B)
10028-17-8	Tritium	--	pCi/L	20,000	--	--	--	--	--	--	--	--	--	--	--	--	20,000	40 CFR 141—Federal MCL
7440-61-1	Uranium	Uranium (Soluble Salts)	µg/L	30	--	--	--	48	--	--	--	--	--	--	--	778	30	40 CFR 141—Federal MCL
7440-62-2	Vanadium	Vanadium and Compounds	µg/L	--	--	--	--	80	--	--	--	--	--	--	--	--	80	WAC 173-340-720(4) (b)(iii)(A)(B)
108-05-4	Vinyl acetate	--	µg/L	--	--	--	--	8,000	--	--	--	--	--	--	--	820,441	8,000	WAC 173-340-720(4) (b)(iii)(A)(B)
75-01-4	Vinyl chloride	--	µg/L	2.0	--	--	--	0.061	--	--	0.025	--	--	--	2.0	7.7	0.025	Clean Water Act—Human Health Water + Organism
1330-20-7	Xylenes (total)	Xylenes (mixture)	µg/L	10,000	10,000	--	--	1,600	--	--	--	--	--	--	--	--	1,600	WAC 173-340-720(4) (b)(iii)(A)(B)
7440-66-6	Zinc	Zinc (Metallic)	µg/L	5,000	--	5,000	--	4,800	120	120	7,400	91	110	100	--	16,548	91	WAC 173-201A

Sources:

40 CFR 131, "Water Quality Standards."

40 CFR 141, "National Primary Drinking Water Regulations."

EPA, 2009a, *National Recommended Water Quality Criteria*.

WAC 173-201A, "Water Quality Standards for Surface Waters of the State of Washington."

WAC 173-340-720(4), "Groundwater Cleanup Standards," "Noncarcinogens and Carcinogens."

WAC 173-340-730(3), Surface Water Cleanup Standards," "Noncarcinogens and Carcinogens."

WAC 246-290-310, "Group A Public Water Supplies," "Maximum Contaminant Levels (MCLs) and Maximum Residual Disinfectant Levels (MRDLs)."

MCL = Maximum Contaminant Limit

MCLG = Maximum Contaminant Limit Goal

CCC = Criteria Continuous Concentration

CMC = Criteria Maximum Concentration

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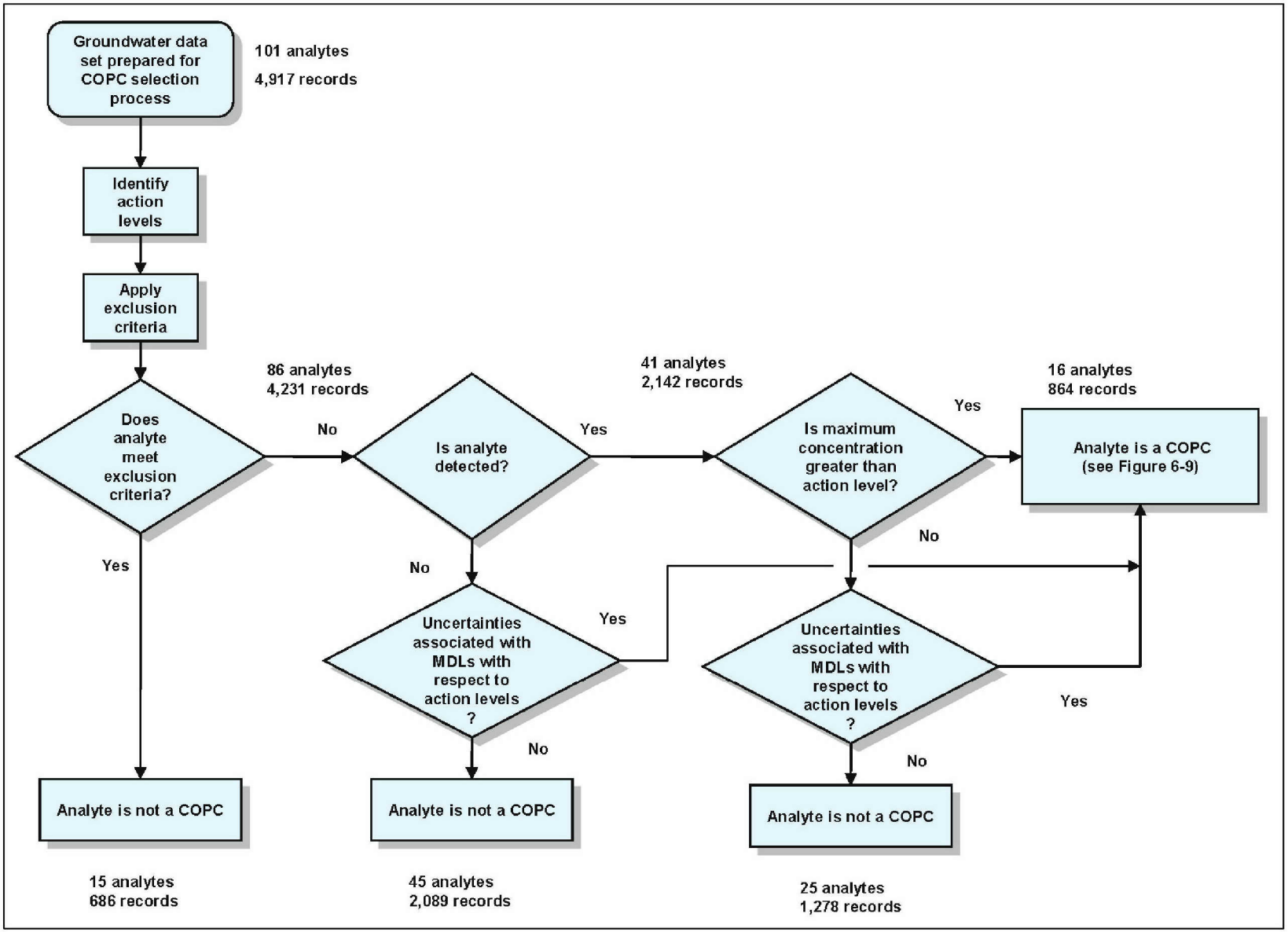

Figure 6-8. COPC Identification Process for the 100-KR-4 Groundwater OU

Apply Exclusion Criteria. The first step in the groundwater COPC identification process is to apply certain exclusion criteria. Analytes that met one or more of the exclusion criteria were eliminated as COPCs. The eliminated analytes are listed in Table 6-11. Analytes that did not meet any of the exclusion criteria were carried forward into the next step. The exclusion criteria are:

- Naturally occurring radionuclides associated with background radiation
- Radionuclides that have half-lives of less than three years and are not significant daughter products
- Essential nutrients (minerals)
- Analytes without known toxicity information
- Groundwater samples were not analyzed for natural background radioisotopes; therefore, none were excluded.
- Groundwater samples were not analyzed for radioisotopes with short half-lives, therefore, none were excluded.

Essential nutrients are those analytes considered essential for human nutrition. The essential nutrients calcium, magnesium, potassium, and sodium were detected in the groundwater in the 100-KR-4 OU, but are excluded from further consideration as COPCs.

Some analytes do not have an action level, because a promulgated chemical-specific ARAR is not available in any of the sources listed in Table 6-10. For some analytes without an action level, there is also no available toxicological information that could be considered in assessing any risks they may present. Eleven analytes were eliminated from further consideration as COPCs because they do not have an action level and they do not have available toxicological information.

Identify Nondetected Analytes. The next step in the groundwater COPC identification process was to identify nondetected analytes. Chemicals and radionuclides that have been analyzed for, but not detected in any sample (collected from appropriate locations with adequate detection limits), were eliminated as COPCs. All analytes detected at least once were carried forward to the next step.

A total of 45 analytes were not detected in the 100-KR-4 OU groundwater samples. They are listed in Table 6-12, each with sampling dates, minimum and maximum MDLs, the action level, the basis of the action level, and the level of exceedance.

Section 4.2.3.3 presents the nature and extent of contamination in groundwater based on the last five years of data that were considered to be representative of current groundwater conditions (i.e., samples collected between January 1, 2006 and December 31, 2010). The nature and extent evaluation uses a subset of data from the work plan for wells screened in the unconfined aquifer and includes all the groundwater data used in this supplemental groundwater risk evaluation. The conclusions of the nature and extent evaluation support the findings of this risk evaluation for benzene, 1,1-dichloroethene, 1,1,2-trichloroethane, tetrachloroethene, and vinyl chloride. These five analytes were not detected in samples collected specifically for the RI nor were they detected in any groundwater sample collected over the past five years. All MDLs associated with these analytes were less than the action level and the EQL listed in the 100-K SAP (DOE/RL-2009-41). Therefore, these five analytes are not COPCs and will not be carried forward into the risk characterization section or into the FS.

Antimonyand carbon tetrachloride were not detected in any of the groundwater samples collected for the RI and used in this supplemental groundwater risk evaluation. The nature and extent evaluation indicates that antimony and carbon tetrachloride have historically been detected in groundwater at a low frequency (less than 2 percent). These historic detections of antimony and carbon tetrachloride were above the

action level, however their presence was not associated with a specific location or with a trend. The results of this evaluation indicate that although antimony and carbon tetrachloride were not detected in samples collected specifically for the RI, their historic presence at low frequencies at concentrations above the action level result in an uncertaintain status. Therefore, antimony and carbon tetrachloride are considered COPCs that warrant further evaluation in the FS where they should be monitored and remedial actions implemented for COPCs with a certain status will address their uncertainties.

Mercury was not detected in any of the groundwater samples collected for the RI and used in this supplemental groundwater risk evaluation. The nature and extent evaluation indicates that mercury has been present in groundwater but at concentrations less than the action level. The results of this evaluation indicate that mercury was not detected in samples collected specifically for the RI and mercury concentrations over the past five years are less than the action level, therefore mercury is not a COPC and will not be carried forward into the risk characterization section or into the FS.

Identify Analytes with Maximum Detected Concentrations Less than Action Levels. This step identifies analytes with maximum concentrations less than action levels. In this screening, the maximum concentration of each analyte detected in groundwater was compared to its action level, to identify analytes not likely to contribute significantly to overall risk. If the maximum detected concentration of an analyte was less than its action level, the analyte was eliminated as an COPC, unless the uncertainty analysis indicated otherwise.

Twenty-five analytes were detected at least once and had maximum detected concentrations less than their respective action levels. A list of these analytes is presented in Table 6-13, each with sampling dates, minimum and maximum MDLs, minimum and maximum detected concentrations, the action levels, and the basis for each action level.

Uncertainty Analysis. An additional evaluation was performed on those analytes that were detected at concentrations that were near but did not exceed their respective action level (i.e., the maximum detected concentration was at least greater than one-tenth the action level, or one order of magnitude). The purpose of this evaluation is to determine if there is a potential for underestimating cumulative effects when the concentrations of analytes are only slightly less than their action levels. Additionally, MDLs associated with these analytes were evaluated to determine if the limits are adequate for confirming presence or absence of the analytes near their respective action levels.

The analytes detected at concentrations that are near but do not exceed their respective action levels (i.e., with maximum detected concentrations greater than one-tenth of their respective action level, or one order of magnitude) are aluminum, bromodichloromethane, bromomethane, chloride, cobalt, copper, fluoride, lithium, molybdenum, silver, sulfate, uranium, and vanadium.

The results of the uncertainty analysis indicate that concentrations of these analytes are consistently below the action level and that elimination of these analytes would not likely lead to underestimation of cumulative health effects.

Barium, beryllium, chloride, cobalt, copper, fluoride, nitrite, sulfate, selenium, uranium, and vanadium were identified as COPCs in the work plan. Section 4.2.3.3 presents the nature and extent of contamination in groundwater based on the last five years of data for these analytes.

Barium, chloride, fluoride, selenium, uranium, and vanadium were detected in groundwater samples collected for the RI at concentrations below their respective action level. The results of the nature and extent evaluation are similar, these six analytes have historically been detected in groundwater at concentrations below their action level. Based on these similarities, barium, chloride, fluoride, selenium, uranium, and vanadium are not COPCs and will not be carried forward into the risk characterization

section or into the FS. It should also be noted that concentrations of fluoride and selenium in filtered groundwater samples are less than their 90th percentile Hanford Site background value.

Beryllium, cobalt, copper, and nitrite were detected in groundwater samples collected for the RI at concentrations below their respective action level. The nature and extent evaluation indicates that beryllium has historically been detected in groundwater at a low frequency (less than 2 percent). The historic detections of beryllium were above the action level; however, its presence was not associated with a specific location or with a trend. Similarly, the nature and extent evaluation indicates that cobalt, copper, and nitrite have historically been detected in groundwater (less than 20 percent). These historic detections of beryllium, cobalt, copper, and nitrite were above the action level; however, their presence was not associated with a specific location or with a trend. The results of this evaluation indicate that although beryllium, cobalt, copper, and nitrite were detected at concentrations less than the action level in samples collected for the RI, their historic presence with infrequent detections above the action level result in an uncertaintain status. Therefore, beryllium, cobalt, copper, and nitrite are not considered COPCs, however they warrant further evaluation in the FS where they should be monitored.

Sulfate were detected in groundwater samples collected for the RI at concentrations below the action level. The nature and extent evaluation indicates that sulfate is historically detected in groundwater. Sulfate concentrations are associated with a trend at wells 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136 where concentrations are above the action level. However, the presence of sulfate in these wells is associated with the calcium polysulfide treatment test conducted at the OU and is not the result of a site-release. Therefore, sulfate is not considered a COPC and will not be carried forward into the risk characterization section or into the FS.

Table 6-11. Summary of Groundwater Analytes that Meet Exclusion Criteria in the 100-KR-4 Groundwater OU

Analyte Name	Analyte Class	Begin Sample Date	End Sample Date	Total Samples	Total Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Minimum Detected Result	Maximum Detected Result	Basis for Exclusion
Bromide	ANION	10/22/2009	6/30/2010	37	19	51.35%	µg/L	24	90	70	430	No Action Level/No Toxicity Values
Phosphate	ANION	10/22/2009	6/30/2010	37	2	5.41%	µg/L	166	429	205	797	No Action Level/No Toxicity Values
Bismuth	METAL	3/5/2010	6/30/2010	36	0	0.00%	µg/L	23	23	--	--	No Action Level/No Toxicity Values
Calcium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	25,700	83,000	Essential Nutrient
Magnesium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	5,390	19,100	Essential Nutrient
Potassium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	1,800	8,690	Essential Nutrient
Silicon	METAL	3/5/2010	6/30/2010	36	36	100.00%	µg/L	--	--	7,620	20,100	No Action Level/No Toxicity Values
Sodium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	2,670	27,600	Essential Nutrient
Acetonitrile	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	2.0	2.0	--	--	No Action Level/No Toxicity Values
Chloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.085	1.0	--	--	No Action Level/No Toxicity Values
Chloromethane	VOC	10/22/2009	6/30/2010	54	7	12.96%	µg/L	0.077	1.0	0.10	0.19	No Action Level/No Toxicity Values
Ethyl cyanide	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	1.2	2.0	--	--	No Action Level/No Toxicity Values
Iodomethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.092	0.092	--	--	No Action Level/No Toxicity Values
Tetrahydrofuran	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	1.1	2.0	--	--	No Action Level/No Toxicity Values
trans-1,4-Dichloro-2-butene	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.29	0.29	--	--	No Action Level/No Toxicity Values

Table 6-12. Summary of Analytes that Were Not Detected in the 100-KR-4 Groundwater OU

Analyte Name	Analyte Class	Begin Sample Date	End Sample Date	Total Samples	Total Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Action Level	Action Level Basis	Level of Exceedance
Antimony	METAL	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.60	1.1	5.6	Clean Water Act—Human Health Water + Organism	1.07E-01
Mercury	METAL	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.10	0.10	0.012	40 CFR 131—Freshwater CCC	8.33E+00
Titanium	METAL	6/16/2010	6/16/2010	1	0	0.00%	µg/L	4.0	4.0	64,000	WAC 173-340-720(4)(b)(iii)(A) and (B)	6.25E-05
1,4-Dichlorobenzene	SVOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.12	1.0	8.1	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.48E-02
1,1,1,2-Tetrachloroethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.090	0.090	1.7	WAC 173-340-720(4)(b)(iii)(A) and (B)	5.36E-02
1,1,1-Trichloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.067	1.0	200	40 CFR 141—Federal MCL	3.35E-04
1,1,2,2-Tetrachloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.098	1.0	0.17	Clean Water Act—Human Health Water + Organism	5.76E-01
1,1,2-Trichloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.063	1.0	0.59	Clean Water Act—Human Health Water + Organism	1.07E-01
1,1-Dichloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.068	1.0	1,600	WAC 173-340-720(4)(b)(iii)(A) and (B)	4.25E-05
1,1-Dichloroethene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.051	1.0	0.057	40 CFR 131—Human Health Water + Organism	8.95E-01
1,2,3-Trichloropropane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.15	0.15	0.0015	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.03E+02
1,2-Dibromo-3-chloropropane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.41	0.41	0.055	WAC 173-340-720(4)(b)(iii)(A) and (B)	7.50E+00
1,2-Dibromoethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.13	0.13	0.022	WAC 173-340-720(4)(b)(iii)(A) and (B)	5.94E+00
1,2-Dichloroethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.10	1.0	0.38	Clean Water Act—Human Health Water + Organism	2.63E-01
1,2-Dichloroethene (Total)	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.13	1.0	72	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.81E-03
1,2-Dichloropropane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.097	1.0	0.50	Clean Water Act—Human Health Water + Organism	1.94E-01
1,4-Dioxane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	7.6	7.6	4.0	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.91E+00
1-Butanol	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	12	100	800	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.50E-02
2-Butanone	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.52	1.0	4,800	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.08E-04
2-Hexanone	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.22	1.0	80	WAC 173-340-720(4)(b)(iii)(A) and (B)	2.75E-03
4-Methyl-2-pentanone	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.12	1.0	640	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.88E-04
Acrolein	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	2.8	2.8	3.0	Clean Water Act—Freshwater CCC	9.33E-01
Allyl chloride	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.091	0.11	2.1	WAC 173-340-720(4)(b)(iii)(A) and (B)	4.38E-02
Benzene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.045	1.0	0.80	WAC 173-340-720(4)(b)(iii)(A) and (B)	5.65E-02
Bromoform	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.094	1.0	4.3	Clean Water Act—Human Health Water + Organism	2.19E-02
Carbon disulfide	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.050	1.0	800	WAC 173-340-720(4)(b)(iii)(A) and (B)	6.25E-05
Carbon tetrachloride	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.063	1.0	0.23	Clean Water Act—Human Health Water + Organism	2.74E-01

Table 6-12. Summary of Analytes that Were Not Detected in the 100-KR-4 Groundwater OU

Analyte Name	Analyte Class	Begin Sample Date	End Sample Date	Total Samples	Total Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Action Level	Action Level Basis	Level of Exceedance
Chloroprene	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.086	0.097	160	WAC 173-340-720(4)(b)(iii)(A) and (B)	5.38E-04
cis-1,2-Dichloroethylene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.083	1.0	70	40 CFR 141—Federal MCL	1.19E-03
cis-1,3-Dichloropropene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.073	1.0	0.34	Clean Water Act—Human Health Water + Organism	2.15E-01
Dibromochloromethane	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.057	1.0	0.40	Clean Water Act—Human Health Water + Organism	1.43E-01
Dibromomethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.21	0.21	80	WAC 173-340-720(4)(b)(iii)(A) and (B)	2.63E-03
Dichlorodifluoromethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.070	0.084	1,600	WAC 173-340-720(4)(b)(iii)(A) and (B)	4.38E-05
Ethyl methacrylate	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.11	0.11	720	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.53E-04
Ethylbenzene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.086	1.0	4.0	WAC 173-340-720(4)(b)(iii)(A) and (B)	2.16E-02
Isobutyl alcohol	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	8.7	8.7	2,400	WAC 173-340-720(4)(b)(iii)(A) and (B)	3.63E-03
Methacrylonitrile	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.050	0.50	0.80	WAC 173-340-720(4)(b)(iii)(A) and (B)	6.25E-02
Methyl methacrylate	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.26	0.26	11,200	WAC 173-340-720(4)(b)(iii)(A) and (B)	2.32E-05
Methylene chloride	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.11	1.0	4.6	Clean Water Act—Human Health Water + Organism	2.39E-02
Tetrachloroethene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.088	1.0	0.081	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.09E+00
trans-1,2-Dichloroethylene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.083	1.0	100	40 CFR 141—Federal MCL	8.30E-04
trans-1,3-Dichloropropene	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.083	1.0	0.34	Clean Water Act—Human Health Water + Organism	2.44E-01
Trichloromonofluoromethane	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.041	0.11	2,400	WAC 173-340-720(4)(b)(iii)(A) and (B)	1.71E-05
Vinyl acetate	VOC	3/5/2010	6/30/2010	36	0	0.00%	µg/L	0.17	0.18	8,000	WAC 173-340-720(4)(b)(iii)(A) and (B)	2.13E-05
Vinyl chloride	VOC	10/22/2009	6/30/2010	54	0	0.00%	µg/L	0.032	1.0	0.025	Clean Water Act—Human Health Water + Organism	1.28E+00

Sources:

40 CFR 131, “Water Quality Standards.”

40 CFR 141, “National Primary Drinking Water Regulations.”

WAC 173-340-720(4), “Groundwater Cleanup Standards,” “Noncarcinogens and Carcinogens.”

Note: Shading indicates that a constituent is identified in the list of contaminants of potential concern in DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*.

Table 6-13. Summary of Groundwater Analytes that Do Not Exceed an Action Level in the 100-KR-4 Groundwater OU

Analyte Name	Analyte Class	Begin Sample Date	End Sample Date	Total Samples	Total Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Minimum Detected Result	Maximum Detected Result	Action Level	Action Level Basis
Chloride	ANION	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	1,090	36,000	230,000	Clean Water Act—Freshwater CCC
Fluoride	ANION	10/22/2009	6/30/2010	54	41	75.93%	µg/L	30	68	45	380	480	WAC 173-340-720(4)(b)(iii)(A) and (B)
Nitrite	ANION	10/22/2009	6/30/2010	54	1	1.85%	µg/L	9.9	118	147	147	3,300	40 CFR 141—Federal MCL
Sulfate	ANION	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	9,020	100,000	250,000	40 CFR 141—Federal MCL
Aluminum	METAL	10/22/2009	6/30/2010	54	22	40.74%	µg/L	10	10	7.5	49	5.00E+01	40 CFR 141—Federal MCL
Barium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	19	54	1,000	Clean Water Act—Human Health Water + Organism
Beryllium	METAL	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.10	0.11	0.23	0.23	4.0	40 CFR 141—Federal MCL
Boron	METAL	3/5/2010	6/30/2010	36	16	44.44%	µg/L	19	19	13	155	3.20E+03	WAC 173-340-720(4)(b)(iii)(A) and (B)
Cobalt	METAL	10/22/2009	6/30/2010	54	20	37.04%	µg/L	0.10	0.22	0.10	1.4	2.6	WAC 173-340-730(3)(b)(iii)(A) and (B)
Copper	METAL	10/22/2009	6/30/2010	54	25	46.30%	µg/L	0.20	0.20	0.22	3.9	9.0	Clean Water Act—Freshwater CCC
Lithium	METAL	3/5/2010	6/30/2010	36	33	91.67%	µg/L	4.0	4.0	4.1	29	3.20E+01	WAC 173-340-720(4)(b)(iii)(A) and (B)
Molybdenum	METAL	3/5/2010	6/30/2010	36	36	100.00%	µg/L	--	--	0.17	8.8	8.00E+01	WAC 173-340-720(4)(b)(iii)(A) and (B)
Selenium	METAL	10/22/2009	6/30/2010	54	42	77.78%	µg/L	0.60	0.60	0.72	4.0	5.0	Clean Water Act—Freshwater CCC
Silver	METAL	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.040	0.20	0.48	0.48	2.61E+00	WAC 173-201A
Strontium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	131	449	9.60E+03	WAC 173-340-720(4)(b)(iii)(A) and (B)
Tin	METAL	3/5/2010	6/30/2010	36	3	8.33%	µg/L	0.10	0.10	0.11	1.5	5.19E+02	WAC 173-340-730(3)(b)(iii)(A) and (B)
Uranium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	0.38	11	30	40 CFR 141—Federal MCL
Vanadium	METAL	10/22/2009	6/30/2010	54	23	42.59%	µg/L	4.1	12	10	26	80	WAC 173-340-720(4)(b)(iii)(A) and (B)
Acetone	VOC	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.34	1.0	5.1	5.1	7.20E+03	WAC 173-340-720(4)(b)(iii)(A) and (B)
Bromodichloromethane	VOC	10/22/2009	6/30/2010	54	5	9.26%	µg/L	0.082	1.0	0.10	0.16	2.70E-01	40 CFR 131—Human Health Water + Organism
Bromomethane	VOC	10/22/2009	6/30/2010	54	21	38.89%	µg/L	0.084	1.0	0.11	1.6	1.12E+01	WAC 173-340-720(4)(b)(iii)(A) and (B)
Chlorobenzene	VOC	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.15	1.0	0.17	0.17	1.00E+02	40 CFR 141—Federal MCL
Styrene	VOC	10/22/2009	6/30/2010	54	2	3.70%	µg/L	0.036	1.0	0.12	0.21	1.00E+02	40 CFR 141—Federal MCL
Toluene	VOC	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.062	1.0	0.12	0.12	6.40E+02	WAC 173-340-720(4)(b)(iii)(A) and (B)
Xylenes (total)	VOC	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.11	1.0	0.24	0.24	1.60E+03	WAC 173-340-720(4)(b)(iii)(A) and (B)

Sources:
40 CFR 131, "Water Quality Standards."
40 CFR 141, "National Primary Drinking Water Regulations."
WAC 173-340-720(4), "Groundwater Cleanup Standards," "Noncarcinogens and Carcinogens."
WAC 173-340-730(3), Surface Water Cleanup Standards," "Noncarcinogens and Carcinogens."
Note: Shading indicates that a constituent is identified in the list of contaminants of potential concern in DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*.

Identify Analytes with Maximum Detected Concentrations Greater than Action Levels. This step identifies analytes with maximum concentrations greater than their respective action levels. Such analytes have the potential to contribute to overall risk. If the maximum detected concentration of an analyte is greater than its action level, the analyte is identified as an COPC, unless the uncertainty analysis indicates otherwise.

Sixteen analytes were detected at least once, with maximum detected concentrations greater than their respective action levels. A list of these analytes is presented in Table 6-14, each with sampling dates, minimum and maximum MDLs, minimum and maximum detected concentrations, the action level, and the basis of the action level.

6.3.2.3 COPC Identification Process

Analytes with maximum detected concentrations greater than the action level are carried forward to the COPC identification process. The COPC identification process identifies those analytes for evaluation in the risk characterization section. COPCs are identified by comparing EPCs to their respective action levels, which is different from the process used to identify COPCs. COPCs with a 90th percentile value greater than the action level are generally distributed throughout the entire OU. A COPC can also be defined as a contaminant hot spot that has localized observation and measurements above the action level. Additional detail is provided in this section for those COPCs identified based on localized observation and measurements.

As discussed in Section 6.3.2.1, the action level represents the lowest of the available chemical-specific ARARs appropriate for the exposure area. Groundwater in the 100-KR-4 OU area has potential as a future drinking water source and is discharged to the Columbia River (through known seeps or through direct discharge); therefore, chemical-specific ARARs consider the protection of human health and aquatic receptors.

A flow-chart depicting the COPC identification process and the number of analytes associated with each process step is provided in Figure 6-9.

Calculate EPCs for Each COPC. COPCs are identified by comparing statistical EPC estimates to action levels for each detected COPC and exposure area. EPCs are calculated as the 90th percentile value for each COPC from the groundwater data set collected specifically for the RI. The MDL is used as the concentration for nondetect results in the percentile calculations. The 90th percentile exposure is identified in EPA risk assessment guidance for describing and characterizing health risks and producing risk estimates corresponding to an RME. A description of the methodology used to calculate the 90th percentile values is provided in *Calculation of Exposure Point Concentrations for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0472) (Appendix G).

In general, EPA Superfund guidance (*Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* [OSWER 9285.6-10]) recommends using a 95 percent UCL on the average for estimating EPCs. However, experience at the Hanford Site indicates that averages and UCLs cannot be reliably calculated for groundwater data sets. The 100-KR-4 Groundwater OU exhibits an aquifer setting where multiple groundwater contaminants are present in overlapping plumes, and the highest concentrations of the various COPCs have different locations within the plumes.

Use of the 90th percentile value from a distribution of groundwater concentration data as an estimate of the EPC is a different approach for estimating EPCs than that provided in some Superfund guidance (*Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* [OSWER 9285.6-10]). However, as described in the following text, the 90th percentile exposure concentration is identified in other EPA risk assessment guidance as appropriate for describing and characterizing health risks; its use yields risk estimates that correspond to an RME.

According to *An Examination of EPA Risk Assessment Principles and Practices* (EPA/100/B-04/001), the RME is an appropriate exposure scenario for risk calculations, within the realistic range of exposure, since the goal of the Superfund program is to protect against high-end, not average, exposures. The "high end" is defined as that part of the exposure distribution that is above the 90th percentile, but below the 99.9th percentile. The approach is consistent with the peer-reviewed *Guidelines for Exposure Assessment* (EPA/600/Z-92/001). Groundwater concentrations directly reflect potential exposures and risks; so, a 90th percentile concentration reflects an RME scenario.

Groundwater data sets at the Hanford Site are highly skewed, with a large proportion of below detection limit (BDL) values. *Data Quality Assessment: Statistical Methods for Practitioners* (EPA/240/B-06/003), provides guidance for estimating statistical parameters (whether means or upper percentiles) depending on the variability in the data set. The variability of the data set is assessed in terms of the coefficient of variation (CV) and the proportion of observations that are BDL. For data sets with CVs greater than 0.5 and 50 percent or more observations that are BDL, EPA recommends using upper percentiles as opposed to means to develop summary statistics.

Therefore, the rationale for using a 90th percentile value as an estimate of the EPC is consistent with the definition of an RME scenario, and is an appropriate statistic for groundwater data sets at the Hanford Site. Additional statistical evaluation of the 100-KR-4 Groundwater OU data sets that support the selection of the 90th percentile value as the EPC is provided in *Calculation of Exposure Point Concentrations for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0472) (Appendix G). This evaluation includes an estimation of the 95 percent UCL value for each detected analyte, along with the analysis of variability, to assess the reliability of the 95 percent UCL estimates. Results of the evaluation indicate that, for the majority of COPCs, a reliable and meaningful 95 percent UCL estimate cannot be calculated because of an insufficient number of samples, an insufficient number of detections, or a high variance of the data. Therefore, the 90th percentile is adopted as the estimated EPC for all COPCs. A comparison of the 90th percentile and 95 percent UCL values is provided in Table 6-15. Section 6.3.8.2 discusses the uncertainties associated with the use of the 90th percentile groundwater concentration as an estimate of the EPC and provides an uncertainty analysis.

Identify COPCs with 90th Percentile Values Less than Action Levels. The 90th percentile values are compared to the lowest available chemical-specific ARARs for protection of human health and aquatic receptors (i.e., action levels). A comparison of EPCs to action levels for the 100-KR-4 Groundwater OU is provided in Table 6-16.

Analyte Specific Evaluation. An analyte-specific evaluation step is conducted when the 90th percentile for an COPC is less than its action level, but one or more individual sample results are greater than the action level. A flow-chart depicting this analyte-specific evaluation is provided in Figure 6-10. This step is performed to confirm that the COPC has not been inappropriately eliminated as a COPC, and takes into consideration specific attributes of the groundwater contamination plume.

- Is the COPC collocated with one or more refined COPCs, with some sample concentrations above its action level?
- Is the COPC associated with a significant local trend?
- Is the COPC associated with a discrete local exposure point, with some concentrations above its action level?

Seven of the 16 COPCs have been detected at least once in groundwater and have 90th percentile values less than their respective action levels (Table 6-16). Of these seven COPCs, carbon-14 and Sr-90 are retained as COPCs.

Table 6-14. Summary of Analytes that Exceed an Action Level in the 100-KR-4 Groundwater OU

Analyte Name	Analyte Class	Begin Sample Date	End Sample Date	Total Samples	Total Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Minimum Detected Result	Maximum Detected Result	Action Level	Action Level Basis
Arsenic	METAL	10/22/2009	6/30/2010	54	47	87.04%	µg/L	0.80	0.80	0.86	7.3	0.018	Clean Water Act—Human Health Water + Organism
Cadmium	METAL	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.055	0.20	0.31	0.31	0.25	Clean Water Act—Freshwater CCC
Chromium	METAL	10/22/2009	6/30/2010	54	54	100.00%	µg/L	--	--	1.2	203	65	Clean Water Act—Freshwater CCC
Cr(VI)	METAL	10/22/2009	6/30/2010	54	38	70.37%	µg/L	2.0	9.7	2.1	201	10	40 CFR 131—Freshwater CCC
Iron	METAL	10/22/2009	6/30/2010	54	42	77.78%	µg/L	18	18	20	1,280	300	40 CFR 141—Federal MCL
Lead	METAL	10/22/2009	6/30/2010	54	3	5.56%	µg/L	0.17	0.20	0.36	16	2.1	WAC 173-201A
Manganese	METAL	10/22/2009	6/30/2010	54	11	20.37%	µg/L	3.3	4.0	4.3	70	50	40 CFR 141—Federal MCL
Nickel	METAL	10/22/2009	6/30/2010	54	4	7.41%	µg/L	4.0	4.0	4.6	109	52	Clean Water Act—Freshwater CCC
Nitrate	METAL	10/22/2009	6/30/2010	54	51	94.44%	µg/L	178	178	726	96,062	45,000	40 CFR 141—Federal MCL
Thallium	METAL	10/22/2009	6/30/2010	54	1	1.85%	µg/L	0.10	0.10	1.5	1.5	0.24	Clean Water Act—Human Health Water + Organism
Zinc	METAL	10/22/2009	6/30/2010	54	18	33.33%	µg/L	5.2	6.0	6.0	1,270	91	WAC 173-201A
Carbon-14	RAD	10/22/2009	6/30/2010	54	31	57.41%	pCi/L	-3.72E+00	22	11	10,100	2,000	40 CFR 141.66
Sr-90	RAD	10/22/2009	6/30/2010	54	10	18.52%	pCi/L	-1.20E+01	1.2	2.6	40	8.0	40 CFR 141—Federal MCL
Tritium	RAD	10/22/2009	6/30/2010	54	40	74.07%	pCi/L	-5.30E+01	170	160	290,000	20,000	40 CFR 141—Federal MCL
Chloroform	VOC	10/22/2009	6/30/2010	54	35	64.81%	µg/L	0.10	1.0	0.11	6.3	1.4	WAC 173-340-720(4)(b)(iii)(A) and (B)
Trichloroethene	VOC	10/22/2009	6/30/2010	54	20	37.04%	µg/L	0.21	1.0	0.22	7.4	0.49	WAC 173-340-720(4)(b)(iii)(A) and (B)

Sources:

40 CFR 131, “Water Quality Standards.”

40 CFR 141, “National Primary Drinking Water Regulations.”

40 CFR 141.66, “National Primary Drinking Water Regulations,” “Maximum Contaminant Levels for Radionuclides.”

WAC 173-201A, “Water Quality Standards for Surface Waters of the State of Washington.”

WAC 173-340-720(4), “Groundwater Cleanup Standards,” “Noncarcinogens and Carcinogens.”

Note: Shading indicates that a constituent is identified in the list of contaminants of potential concern in DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*.

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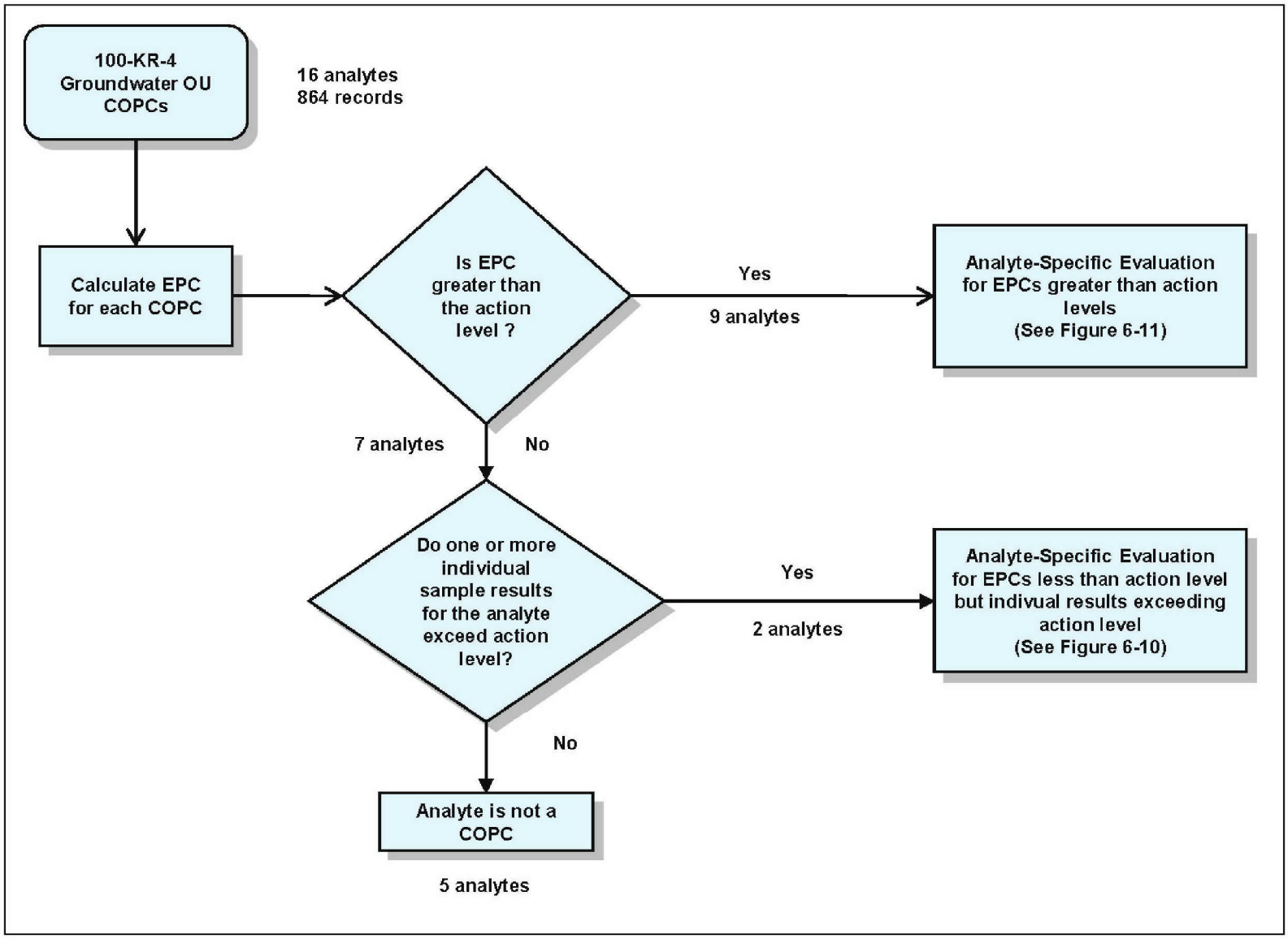

Figure 6-9. COPC Identification Process for the 100-KR-4 Groundwater OU

Table 6-15. Percentile Concentrations and Summary Statistics for the 100-KR-4 Operable Unit Data Set

COPC	Units	Number of Measurements	Number of Detections	90th Percentile	Maximum	Mean	95% UCL	Is 90th Percentile >95% UCL
Arsenic	µg/L	54	47	5.3	7.3	3.1	3.2	Yes
Cadmium	µg/L	54	1	0.2	0.31	0.31	Not Calculated[a]	--
Carbon-14	pCi/L	54	31	1,465	10,100	1,060	3,022	No
Chloroform	µg/L	54	35	2.2	6.3	1.3	1.8	Yes
Chromium	µg/L	54	54	121	203	40	71	Yes
Cr(VI)	µg/L	54	38	117	201	46	62	Yes
Iron	µg/L	54	42	360	1,280	150	245	Yes
Lead	µg/L	54	3	0.2	16	5.9	Not Calculated[a]	--
Manganese	µg/L	54	11	11	70	22	13	No
Nickel	µg/L	54	4	4	109	72	--	--
Nitrate	µg/L	54	51	71,700	96,062	28,476	41,713	Yes
Sr-90	pCi/L	54	10	7.3	40	12	6	Yes
Thallium	µg/L	54	1	0.1	1.5	1.5	Not Calculated[a]	
Trichloroethene	µg/L	54	20	3.8	7.4	2.5	1.5	Yes
Tritium	pCi/L	54	40	34,500	290,000	17,560	71,868	No
Zinc	µg/L	54	18	303	1,270	182	183	Yes

-- = the number of detected results is insufficient for ProUCL to calculate meaningful and reliable results
COPC = contaminant of potential concern
UCL = upper confidence limit

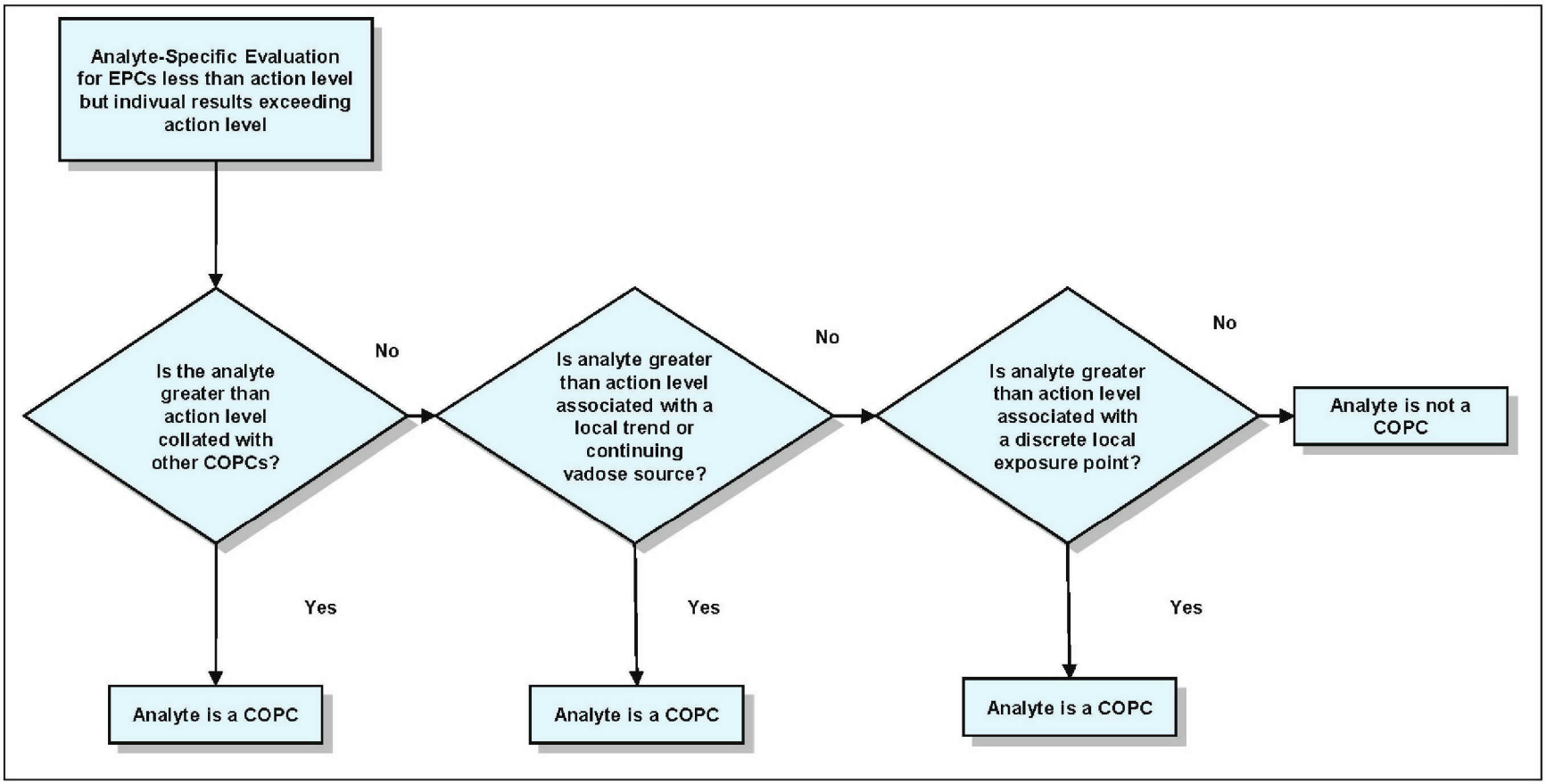

Figure 6-10. Analyte-Specific Evaluation of COPCs with EPCs Less than Action Levels

Carbon-14 was detected at concentrations above the action level (2,000 pCi/L) during all three sampling events at Well 199-K-106A (3,970 pCi/L; 6,770 pCi/L; and 10,100 pCi/L). In addition, during the high river stage sampling event, carbon-14 was detected at Well 199-K-34 at a concentration (3,880 pCi/L) greater than the action level. The presence of carbon-14 at 199-K-106A and 199-K-34 is associated with a long-term trend and with a local source: the 116-KW-1 Condensate Crib. Carbon-14 is identified as a COPC because it is associated with a long-term trend.

Sr-90 was detected at concentrations above the action level of 8 pCi/L during all three sampling events at Well 199-K-34 (16 pCi/L, 30 pCi/L, and 41 pCi/L). Sr-90 concentrations were also above the action level of 8 pCi/L during a single sampling event at Monitoring Wells 199-K-20 (8.5 pCi/L) and 199-K-22 (8.2 pCi/L). The presence of Sr-90 at Wells 199-K-34, 199-K-22, and 199-K-20 likely originated from the 116-K-2 Trench. Sr-90 is identified as a COPC because it is associated with a long-term trend.

Cadmium, lead, manganese, nickel, thallium, C-14, and Sr-90 were identified as COPCs in the work plan and are also listed on Table 6-16 because EPCs are less than their respective action levels. Section 4.2.3.3 presents the nature and extent of contamination in groundwater based on the last five years of data for these analytes.

Carbon-14 and Sr-90 were detected in groundwater samples collected for the RI and their EPCs are less than the action level. The findings of the nature and extent evaluation conclude that there are localized areas of contamination where concentrations of C-14 and Sr-90 are above the DWS. The distribution of these COPCs within the groundwater OU are discussed in detail in Section 4.2.3.3. Based on the results of the nature and extent evaluation and the supplemental risk evaluation, C-14 and Sr-90 are COPCs and are carried forward into the risk characterization section.

Thallium was detected in one groundwater sample collected for the RI at a concentration above the action level but below the EQL identified in the 100-K SAP (DOE/RL-2009-41). In addition, the EPC is less than the action level. The results of the nature and extent evaluation for thallium indicate that thallium was present in groundwater but at concentrations less than the EQL. Based on these similarities, thallium is not a COPC and will not be carried forward into the risk characterization section or into the FS. It should also be noted that concentrations of thallium in filtered groundwater samples are less than the 90th percentile Hanford Site background value.

Cadmium and lead were detected in at least one groundwater sample collected for the RI and EPCs are less than their respective action level. The nature and extent evaluation indicates that cadmium has historically been detected in groundwater at a low frequency (less than 2 percent). The historic detections of cadmium were above the action level, however its presence was not associated with a specific location or with a trend. Similarly, the nature and extent evaluation indicates that lead has historically been detected in groundwater (less than 20 percent). These historic detections of lead were above the action level, however their presence was not associated with a specific location or with a trend. The results of this evaluation indicate that although the EPCs for cadmium and lead are less than the action level in samples collected for the RI, their historic presence with infrequent detections above the action level result in an uncertaintain status. Therefore, cadmium and lead are not considered COPCs, however they warrant further evaluation in the FS where they should be monitored.

Manganese was detected in groundwater samples collected for the RI and the EPC is less than the action level. The nature and extent evaluation indicates that manganese is historically detected in groundwater. Manganese concentrations are associated with a trend at wells 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136 where concentrations are above the action level. However, the presence of manganese in these wells is associated with the calcium polysulfide treatment test conducted at the OU

and is not the result of a site-release. Therefore, manganese is not considered a COPC and will not be carried forward into the risk characterization section or into the FS.

Nickel was detected in groundwater samples collected for the RI and the EPC is less than the action level. The nature and extent evaluation indicates that nickel has historically been detected in groundwater (less than 20 percent). Nickel concentrations are associated with a trend at wells 199-K-36 and 199-K-110A where concentrations have ranged between 1.2 and 1.9 times greater than the action level. However, the presence of nickel in these wells is likely associated with corrosion of the well casing, as these wells were installed in 1992 and 1994, respectively. Therefore, nickel is not considered a COPC and will not be carried forward into the risk characterization section or into the FS.

Identify COPCs with 90th Percentile Values Greater than Action Levels in Each Exposure Area. The 90th percentile values are compared to the lowest available chemical-specific ARARs for protection of human health and aquatic receptors (i.e., action levels). A comparison of EPCs to action levels for the 100-KR-4 Groundwater OU is provided in Table 6-16.

Analyte-Specific Evaluation. An analyte-specific evaluation is performed on COPCs with 90th percentile values greater than their respective action levels. A flowchart depicting this analyte-specific evaluation is provided in Figure 6-11. This step is performed to confirm that the 90th percentile value has not inappropriately identified an COPC as a COPC, and takes into consideration the effects that data quality, naturally occurring levels of metals, and action level selection have on COPC identification.

- Is the COPC at or below background levels and thus a naturally occurring substance?
- Is the ARAR-based action level (Table 6-10) only a secondary MCL that is not enforceable?

Nine of the 16 COPCs have been detected at least once in groundwater and have 90th percentile values greater than their respective action levels (Table 6-16). Of these nine COPCs, chromium, Cr(VI), chloroform, nitrate, trichloroethene, and tritium are identified as COPCs that are carried forward into the risk characterization section. Arsenic and lead are not identified as COPCs.

Arsenic, chloroform, chromium, Cr(VI), nitrate, trichloroethene, tritium, and zinc were identified as COPCs in the work plan and are also listed on Table 6-16 because EPCs are greater than their respective action levels. Section 4.2.3.3 presents the nature and extent of contamination in groundwater based on the last five years of data for these analytes.

Chromium, Cr(VI), nitrate, trichloroethene, and tritium were detected in groundwater samples collected for the RI and their EPCs are greater than the action level. The findings of the nature and extent evaluation conclude that concentrations of Cr(VI), nitrate, and tritium are widely distributed and are consistently present at concentrations above the DWS (nitrate and tritium) or the ambient water quality criteria (Cr(VI)). The findings of the nature and extent evaluation conclude that there are localized areas of contamination where concentrations of trichloroethene are above the DWS. The distribution of these COPCs within the groundwater OU are discussed in detail in Section 4.2.3.2. Total chromium concentrations in groundwater are greater than the AWQC. It is assumed that dissolved concentrations of total chromium are present in the form of Cr(VI) and total chromium is not presented separately from Cr(VI) in the nature and extent evaluation. Based on the results of the nature and extent evaluation and the supplemental risk evaluation, chromium, Cr(VI), nitrate, trichloroethene, and tritium are COPCs and are carried forward into the risk characterization section.

Chloroform was detected in groundwater samples collected for the RI and the EPC is greater than the action level. Chloroform has historically been detected in groundwater samples (57 percent). Chloroform concentrations above the action level are associated with a trend at 199-K-18, 199-K-32A, 199-K-151,

and 199-N-72 where concentrations have ranged been 1.1 to 5.1 times greater than the action level. Based on the results of the nature and extent evaluation and the supplemental risk evaluation, chloroform is a COPC and is carried forward into the risk characterization section.

Arsenic is detected in groundwater samples collected for the RI and the EPC is above the action level but is less than the 90th percentile Hanford Site background value. The nature and extent evaluation indicates that arsenic has historically been detected in groundwater. Arsenic concentrations in filtered samples are within the range of background concentrations except for 2 of 71 sample results, these historic detections were not associated with a specific location or with a trend. In addition, the EPC for arsenic is less than the 90th percentile Hanford Site background value. The results of this evaluation indicate that the EPC for arsenicis less than the background value in samples collected for the RI, however the historic presence of arsenic with infrequent detections above the background value result in an uncertaintain status. Therefore, arsenic is not considered a COPC but it warrants further evaluation in the FS where it should be monitored.

Iron was detected in groundwater samples collected for the RI and the EPC is greater than the action level. The nature and extent evaluation indicates that iron was historically detected in groundwater. Iron concentrations are associated with a trend at wells 199-K-126, 199-K-133, 199-K134, 199-K-135, and 199-K-136 where concentrations are above the action level. However, the presence of iron in these wells is associated with the calcium polysulfide treatment test conducted at the OU and is not the result of a site-release. Therefore, iron is not considered a COPC and will not be carried forward into the risk characterization section or into the FS.

Zinc was detected in groundwater samples collected for the RI and the EPC is greater than the action level. The nature and extent evaluation indicates that zinc has historically been detected in groundwater. Zinc concentrations are associated with a trend at wells 199-K-19, 199-K-22, 199-K-108A, and 699-73-61 where concentrations have ranged between 1.1 and 3.7 times greater than the action level. However, the presence of zinc in these wells is likely associated with corrosion of the well casing, as these wells were installed between 1955 and 1994. Therefore, zinc is not considered a COPC and will not be carried forward into the risk characterization section or into the FS.

Table 6-16. Exposure Point Concentration Summary for the 100-KR-4 OU

Analyte Name	Analyte Class	Total Number of Samples	Number of Detects	Frequency of Detection	Units	Minimum Detection Limit	Maximum Detection Limit	Minimum Detected Result	Maximum Detected Result	90th Percentile	Action Level	Action Level Basis	90th Percentile > Action Level?	Level of Exceedance
Arsenic	METAL	54	47	87.04%	µg/L	0.80	0.80	0.86	7.3	5.3	0.018	Clean Water Act -- Human Health Water + Organism	Yes	2.95E+02
Cadmium	METAL	54	1	1.85%	µg/L	0.055	0.20	0.31	0.31	0.20	0.25	Clean Water Act -- Freshwater CCC	No	8.00E-01
Chromium	METAL	54	54	100.00%	µg/L	--	--	1.2	203	121	65	Clean Water Act -- Freshwater CCC	Yes	1.86E+00
Hexavalent Chromium	METAL	54	38	70.37%	µg/L	2.0	9.7	2.1	201	117	10	40 CFR 131 -- Freshwater CCC	Yes	1.17E+01
Iron	METAL	54	42	77.78%	µg/L	18	18	20	1,280	360	300	40 CFR 141 - Federal MCL	Yes	1.20E+00
Lead	METAL	54	3	5.56%	µg/L	0.17	0.20	0.36	16	0.20	2.1	WAC 173-201A	No	9.48E-02
Manganese	METAL	54	11	20.37%	µg/L	3.3	4.0	4.3	70	11	50	40 CFR 141 - Federal MCL	No	2.27E-01
Nickel	METAL	54	4	7.41%	µg/L	4.0	4.0	4.6	109	4.0	52	Clean Water Act -- Freshwater CCC	No	7.69E-02
Nitrate	METAL	54	51	94.44%	µg/L	178	178	726	96,062	71,700	45,000	40 CFR 141 - Federal MCL	Yes	1.59E+00
Thallium	METAL	54	1	1.85%	µg/L	0.10	0.10	1.5	1.5	0.10	0.24	Clean Water Act -- Human Health Water + Organism	No	4.17E-01
Zinc	METAL	54	18	33.33%	µg/L	5.2	6.0	6.0	1,270	303	91	WAC 173-201A	Yes	3.32E+00
Carbon-14	RAD	54	31	57.41%	pCi/L	-3.72E+00	22	11	10,100	1,465	2,000	40 CFR 141.66	No	7.33E-01
Sr-90	RAD	54	10	18.52%	pCi/L	-1.20E+01	1.2	2.6	40	7.3	8.0	40 CFR 141 - Federal MCL	No	9.06E-01
Tritium	RAD	54	40	74.07%	pCi/L	-5.30E+01	170	160	290,000	34,500	20,000	40 CFR 141 - Federal MCL	Yes	1.73E+00
Chloroform	VOC	54	35	64.81%	µg/L	0.10	1.0	0.11	6.3	2.2	1.4	WAC 173-340-720(4)(b)(iii)(A) and (B)	Yes	1.52E+00
Trichloroethene	VOC	54	20	37.04%	µg/L	0.21	1.0	0.22	7.4	3.8	0.49	WAC 173-340-720(4)(b)(iii)(A) and (B)	Yes	7.72E+00

Sources:
40 CFR 131, “Water Quality Standards.”
40 CFR 141, “National Primary Drinking Water Regulations.”
40 CFR 141.66, “National Primary Drinking Water Regulations,” “Maximum Contaminant Levels for Radionuclides.”
WAC 173-201A, “Water Quality Standards for Surface Waters of the State of Washington.”
WAC 173-340-720(4), “Groundwater Cleanup Standards,” “Noncarcinogens and Carcinogens.”

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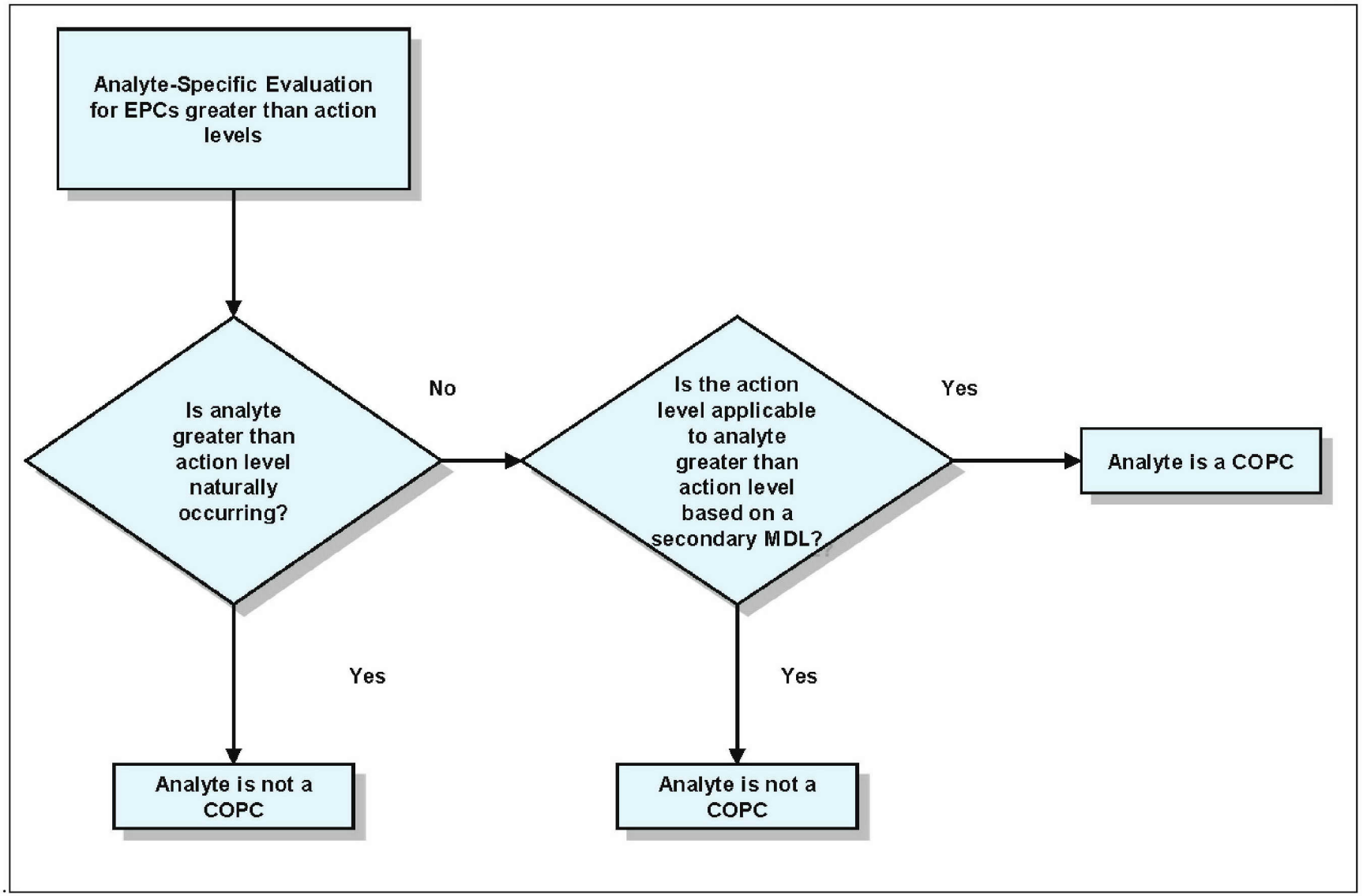

Figure 6-11. Analyte-Specific Evaluation of COPCs with EPCs Greater than Action Levels

6.3.2.4 Summary of COPCs

Table 6-17 presents a summary of the COPCs identified through the for the 100-KR-4 Groundwater OU. This list of COPCs represents the analytes most likely to contribute to overall risk within each 100-KR-4 Groundwater OU exposure area and are evaluated in the risk characterization section.

Table 6-17. Summary of Groundwater COPCs Identified for the 100-KR-4 Groundwater OU

Metals	VOCs	Radionuclides
Chromium	Chloroform	Carbon-14*
Cr(VI)	Trichloroethene*	Sr-90*
		Tritium
Nonradioactive Anions		
Nitrate		

* EPC did not exceed action level, but was retained as a COPC due to localized contamination.

With the exception of carbon-14 and Sr-90, all COPCs were identified because the 90th percentile concentration exceeded the action level. As described in Section 6.3.2.3, carbon-14 and Sr-90 are identified as COPCs because they are associated with a long-term trend and with a continuing local source.

6.3.3 Exposure Assessment

The exposure assessment component of the risk assessment typically identifies the populations that may be exposed, the routes by which these receptors may become exposed, and the magnitude, frequency, and duration of potential exposures.

6.3.3.1 Contaminant Sources

The primary sources of contamination in the 100-K Source OU are two water-cooled nuclear reactors (105-KE and 105-KW) and the structures (e.g., fuel storage basins) and processes (e.g., sodium dichromate process) associated with reactor operations. The reactors were built to irradiate uranium-enriched fuel rods from which plutonium and other special nuclear materials could be extracted. Effluent generated during operations consisted primarily of contaminated reactor cooling water, fuel storage basin water, and decontamination solutions.

Liquid and solid wastes from reactor operations and associated facilities were released to the vadose zone column and the Columbia River. Wastes released to the environment created secondary sources of contamination such as surface impoundments, cribs, ditches, burial grounds, and unplanned release sites. Contaminant sources (i.e., facilities and waste sites) are listed in Section 4.2.1 and Section 5.2.

6.3.3.2 Release Mechanisms and Environmental Transport Media

The primary COPC release mechanisms and transport pathways at 100-K are discussed in Sections 5.3 and 5.4, and include the following:

- Direct contact with groundwater containing COPCs
- Volatilization of COPCs in groundwater from showering or household activities
- Discharge of groundwater to the Columbia River through upwelling and seeps

6.3.3.3 100-KR-4 Groundwater OU Exposure area

The 100-KR-4 Groundwater OU is generally distinguished by the presence of Cr(VI) plumes found near the 105-KE and 105-KW Reactor buildings and the 116-K-2 Trench. The 100-KR-4 Groundwater OU represents all the plume sources in 100-K.

The 100-KR-4 Groundwater OU is evaluated as a single exposure area. The primary objective for evaluating the 100-KR-4 Groundwater OU as a single exposure area is to provide information necessary to determine the need for remedial action and to use the information to select the best remedy. Evaluating the 100-KR-4 Groundwater OU as a single exposure area captures the highest contaminant concentrations from the primary sources of contamination. The single exposure area is representative of how groundwater contaminants are geographically distributed across the OU.

6.3.3.4 Potentially Complete Human Exposure Pathways and Receptors

This section describes the potentially complete exposure pathways and receptors that specifically addressed in the federal and state chemical-specific ARARs evaluated in this supplemental groundwater risk evaluation.

Chemical-Specific ARARs for Protection of Human Health. All the chemical-specific ARARs for use as a drinking water source consider ingestion as a complete and significant pathway for exposure. Washington State regulations assume that inhalation of vapors for VOCs is also a complete and significant exposure pathway. Washington State regulations do not include the dermal contact exposure route in the equations for calculation of potable groundwater cleanup levels, whereas federal regulations consider dermal contact exposure a complete but insignificant groundwater contaminant exposure pathway. Elimination of the dermal contact exposure route from chemical-specific ARARs may result in an underestimation of the cleanup level; uncertainties associated with exclusion of this exposure route are addressed in Section 6.3.6.4.

For groundwater with the potential to impact surface water, federal water quality standards assume that exposure to humans occurs through ingestion of water and consumption of fish tissue. These federal standards are developed for protection of human health where groundwater discharges to surface water that is used as a drinking water source and used for fishing. Washington State regulations as defined in "Surface Water Cleanup Standards" (WAC 173-340-730(3)(b)) developed surface water standards that assume that exposure occurs through consumption of fish tissue.

Chemical-Specific ARARs for Protection of Aquatic Receptors. The objectives and methodology for deriving the numerical AWQC are described in *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (PB85-227049). The AWQC are intended to provide a reasonable level of protection of all except a small fraction (0.05) of the taxa, unless a commercially or recreationally important species is very sensitive. Protection of the following aquatic organisms and their uses are defined in *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (PB85-227049) as prevention of unacceptable long-term and short-term effects:

- Commercially, recreationally, and other important species
- Fish and benthic invertebrate assemblages in rivers and streams
- Fish, benthic invertebrate, and zooplankton assemblages in lakes, reservoirs, estuaries, and oceans

Numeric values are expressed as two numbers, the criteria maximum concentration (CMC) and criteria continuous concentration (CCC), which provide an appropriate degree of protection of aquatic organisms and their uses from acute and chronic toxicity to animals, toxicity to plants, and bioaccumulation by

aquatic organisms. The CMC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. EPA derives acute criteria from 48- to 96-hour tests of lethality or immobilization. The CCC is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. EPA derives chronic criteria from longer-term (often greater than 28 days) tests that measure survival, growth, reproduction or, in some cases, bioconcentration. The CMC and the CCC are two of the six parts of the aquatic life criterion. The other four parts are the acute averaging period, chronic averaging period, acute frequency of allowed exceedance, and chronic frequency of allowed exceedance. The lower of the CMC or the CCC is the numeric water quality criteria used as the chemical-specific ARAR for protection of freshwater species.

6.3.4 Toxicity Assessment

The toxicity assessment component evaluates the relationship between the magnitude of exposure to an analyte and the likelihood of adverse health effects to potentially exposed populations. Similar to the exposure assessment, the comparison to chemical-specific ARARs takes into consideration the likelihood of an adverse health effect to occur to the potentially exposed population. The risk-based concentrations, such as the "Groundwater Cleanup Standards" (WAC 173-340-720), are developed using toxicological information published at EPA's IRIS database and EPA's hierarchy of toxicity values described in Section 6.2.2.2. The assignment of chemical-specific ARARs to COPCs is described in Section 6.2.2.2.

6.3.4.1 State and Federal Maximum Contaminant Levels for Nonradionuclides

The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse health effects occur, allowing for an adequate margin of safety. MCLGs are nonenforceable health goals. EPA establishes the MCL, an enforceable standard, based on the MCLG. The MCL is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. Prior to the 1996 SDWA Amendments, the MCL was set as close to the MCLG as was feasible.
The 1996 Amendments to the SDWA permit consideration of costs and benefits in establishing an MCL.

Six-Year Review Chemical Contaminants Health Effects Technical Support Document (EPA 822-R-03-008), describes how MCLGs are derived. MCLGs are developed using an oral RfD for contaminants that exhibit a threshold toxic effect. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious noncancer effects during a lifetime. EPA generally assumes that the relative source contribution from drinking water is 20 percent of the RfD, unless other exposure data for the chemical are available. This allows 80 percent of the total exposure to come from sources other than drinking water, such as exposure from food, inhalation, or dermal contact.

6.3.4.2 Maximum Contaminant Levels for Radionuclides in Drinking Water

Current MCLs for radionuclides are set at 4 mrem/yr for the sum of the doses from beta particle and photon emitters, 15 pCi/L for gross alpha emitter activity (including radium-226, but excluding uranium and radon), and 5 pCi/L combined for radium-226 and radium-228. A mass-based concentration MCL of 30 μg/L has been established for uranium . The current regulations for beta emitters specify that MCLs are to be calculated based upon an annual dose equivalent of 4 mrem to the total body or any internal organ. It is further specified that the calculation be performed based on a 2 liter per day drinking water intake using the 168-hour data listed in *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure* (NBS Handbook 69).

6.3.4.3 Washington State Regulations

Toxicological parameter values are obtained from the CLARC Web-based compendium of technical information related to the calculation of cleanup levels under the "Model Toxics Control Act—Cleanup" regulation (WAC 173-340). The sources for the oral cancer potency values and RfDs are provided in the CLARC database. The sources for identifying reference doses and carcinogenic potency factors are defined in the "Human Health Risk Assessment Procedures" WAC 173-340-708(7) and WAC 173-340-708(8), respectively.

6.3.4.4 Toxicity Values

The sources of toxicity values for human health are the same as those described in Section 6.2.4.2 of this report.

As discussed in Section 6.3.2.2, the lower of the CMC or the CCC is the numeric water quality criteria used as the chemical-specific ARAR for protection of freshwater species. *Technical Support Document for Water Quality-Based Toxics Control* (EPA/505/2-90-00) explains that development of national numerical water quality criteria for the protection of aquatic organisms is a complex process that uses information from many areas of aquatic toxicology After a decision is made that a national criterion is needed for a particular material, all available information concerning toxicity to and bioaccumulation by aquatic organisms is collected and reviewed for acceptability. If enough acceptable data for 48- to 96-hour toxicity tests on aquatic animals are available, they are used to derive the acute criterion. If sufficient data on the ratio of acute to chronic toxicity concentrations are available, they are used to derive the chronic or long-term exposure criteria. If justified, one or both of the criteria may be related to another water quality characteristic (e.g., pH, temperature, or hardness). Separate criteria are developed for fresh water and salt water.

6.3.5 Risk Characterization

Risk characterization is the final step of the HHRA process. In this step, the toxicity values are combined with the estimated chemical intakes for the receptor populations in order to quantitatively estimate both carcinogenic risks and risks from noncarcinogens. The risk characterization step is completed through the comparison of the EPC to the chemical-specific ARAR using the equations presented in Section 6.3.5.1. As described earlier in this section, the comparison to chemical-specific ARARs determines whether existing groundwater concentrations are protective of HHE. It is also used to determine if current groundwater concentrations have the potential to exceed an HI greater than 1 or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use.

6.3.5.1 Protectiveness Evaluation

Protectiveness of human health is determined by the comparison of 90th percentile groundwater concentrations to existing federal or state MCLs. Similarly, protectiveness of human and aquatic receptors is determined by the comparison of 90th percentile groundwater concentrations to water quality criteria established under Section 304 or 303 of the *Clean Water Act of 1977* and Washington State water quality standards.

This risk characterization step is included to address the presence of multiple exposure pathways or the potential for exposure to multiple contaminants. The presence of either one of these conditions may render ARARs to be not adequately protective. This step is also included to address the requirements of the "Human Health Risk Assessment Procedures" (WAC 173-340-708(5)(a) and WAC 173-340-708(6)(b)). These regulations require that cleanup levels be adjusted downward to take into account exposure to multiple hazardous substances or multiple pathways of exposure. This adjustment needs to be made only if without this adjustment, the HI would exceed 1 or the total ELCR would exceed 1 in 100,000 (1×10^{-5}).

To determine the potential to exceed an HI greater than 1 or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use, the following standards are used:

- WAC 173-340-720, "Groundwater Cleanup Standards"
- WAC 173-340-730, Surface Water Cleanup Standards"
- *National Recommended Water Quality Criteria* (EPA, 2009a)

For the purposes of this evaluation, the potential for unacceptable human health risk is identified using the following risk thresholds:

- ELCR values are compared to the "target range" of 10^{-6} to 10^{-4} that is generally used by EPA. "Model Toxics Control Act—Cleanup" (WAC 173-340) states that cancer risks resulting from multiple hazardous substances should not exceed 1×10^{-5} for unrestricted land use. ELCR values within or exceeding the target range require a risk management decision that includes evaluating site-specific characteristics and exposure scenario factors to assess whether remedial action is warranted.
- An HI (the sum of the ratios of the chemical intake to the RfDs for all COPCs) greater than 1 indicates that some potential exists for adverse noncancer health effects associated with exposure to the COPCs.

Although this supplemental groundwater risk evaluation produces numerical estimates of risk, it should be recognized that these numbers might not predict actual health outcomes because they are based largely on hypothetical assumptions. Their purpose is to provide a frame of reference for risk management decision making. Interpretation of the risk estimates provided should consider the nature and weight of evidence supporting these estimates, as well as the magnitude of uncertainty surrounding them.

Protectiveness of humans from exposure to beta/photon emitters is determined by an annual dose equivalent to the body or any internal organ and determined by comparison to activity concentrations in drinking water for alpha emitters; therefore, a risk evaluation is not conducted for refined COPCs that are radionuclides.

Cancer Risk Estimation Method. The potential for cancer effects is evaluated by estimating the ELCRs. This risk is the incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer (that is, if no exposure to site chemicals occurs). To estimate the cancer risks from exposure to an individual carcinogen from all exposure routes considered, the following equation is used:

$$Risk_I = \frac{EPC_{water}}{CUL_{carcinogen}} \times TR$$

where:

$Risk_I$ = ELCR for individual chemical

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{carcinogen}$ = Groundwater cleanup level based on 10^{-6} carcinogenic effect (µg/L)

TR = Target ELCR for individual hazardous substance for unrestricted land use (10^{-6})

To estimate the cancer risks from exposure to multiple carcinogens from all exposure routes considered, the following equation is used:

$$Risk_T = \sum_i \frac{EPC_{water}}{CUL_{carcinogen}} \times TR$$

where:

$Risk_T$ = Total ELCR for all chemicals

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{carcinogen}$ = Groundwater cleanup level based on 10^{-6} carcinogenic effect (µg/L)

TR = Target ELCR for individual hazardous substance for unrestricted land use (10^{-6})

i = The sum of the ratios for the ith chemical

Noncancer Risk Estimation Method. For noncancer effects, the likelihood that a receptor will develop an adverse effect is estimated by comparing the predicted level of exposure for a particular chemical with the highest level of exposure that is considered protective (i.e., its RfD). The ratio of the chronic daily intake divided by RfD is termed the HQ.

When the HQ for a chemical exceeds 1 (i.e., exposure exceeds RfD), a concern exists for potential noncancer health effects. To estimate the HQ from all exposure routes considered for an individual hazardous substance, the following equation is used:

$$HQ = \frac{EPC_{water}}{CUL_{noncarcinogen}}$$

where:

HQ = HQ for individual chemical

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{noncarcinogen}$ = Groundwater cleanup level based on HQ = 1 noncarcinogenic effects (µg/L)

To estimate the HI from all exposure routes considered for multiple hazardous substances, the following equation is used:

$$HI_T = \sum_i \frac{EPC_{water}}{CUL_{noncarcinogen}}$$

where:

HI_T = Total HI for all chemicals

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{noncarcinogen}$ = Groundwater cleanup level based on HQ=1 noncarcinogenic effects (µg/L)

i = The sum of the ratios for the ith chemical

Estimating the Sum of Fractions and 4 mrem/yr Dose Equivalent. An annual cumulative dose equivalent of 4 mrem to the total body or any internal organ from beta and photon emitters is considered protective of human health. The sum of fractions is used to determine whether the contribution of each radioisotope is

greater than the cumulative annual dose equivalent of 4 mrem. The following equation is used to determine if the 4 mrem standard is exceeded when a mixture of radioisotopes is present:

$$Sum\ of\ Fractions = \left(\frac{A\left(\frac{pCi}{L}\right)}{MCL_A\left(\frac{pCi}{L}\right)} + \frac{B\left(\frac{pCi}{L}\right)}{MCL_B\left(\frac{pCi}{L}\right)} + \bullet\bullet\bullet \right)$$

where:

A = The EPC activity concentration of specific beta/photon emitting nuclide A

B = The EPC activity concentration of specific beta/photon emitting nuclide B

MCL_A = The derived single-nuclide beta/photon emitting MCL-equivalent activity concentration for nuclide A

MCL_B = The derived single-nuclide beta/photon emitting MCL-equivalent activity concentration for nuclide B

The 4 mrem standard is not exceeded if the sum of fractions is less than 1. Each fraction is converted to a dose equivalent of 4 mrem/yr by multiplying the fraction by 4.

6.3.5.2 Results of the Chemical-Specific Applicable or Relevant and Appropriate Requirements Analysis

A comprehensive set of chemical-specific ARARs that are considered protective of HHE were used to identify COPCs. The lowest of the available chemical-specific ARARs was selected for comparison if more than one chemical-specific ARAR exists for a certain analyte. The analytes listed in Table 6-18 are considered COPCs because the 90th percentile groundwater concentration is greater than the lowest available chemical-specific ARAR or the analyte is measured at concentrations above the lowest chemical-specific ARAR in a localized area.

Groundwater in the 100-KR-4 Groundwater OU is evaluated as a potential drinking water source and has the potential to discharge to the Columbia River. Table 6-18 provides a summary of the COPCs, the 90th percentile groundwater concentration, federal and state MCLs, and the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup standards for carcinogenic and noncarcinogenic effects. Table 6-19 provides a summary of the COPCs, the 90th percentile groundwater concentration, and federal and state surface water quality standards. These standards (listed in Tables 6-18 and 6-19) represent the chemical-specific ARARs that were exceeded by at least one COPC.

Table 6-18. Summary of Current Conditions 90th Percentile Groundwater Concentrations, Federal and State MCLs, and WAC 173-340-720 Groundwater Cleanup Levels (Human Health Action Levels)

COPCs	Units	90th Percentile Value	Federal MCL	State MCL	WAC 173-340-720 Cleanup Levels		
					Noncarcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Carbon-14	pCi/L	1,470	2,000	--	--	--	--
Sr-90	pCi/L	7.3	8	--	--	--	--

Table 6-18. Summary of Current Conditions 90th Percentile Groundwater Concentrations, Federal and State MCLs, and WAC 173-340-720 Groundwater Cleanup Levels (Human Health Action Levels)

COPCs	Units	90th Percentile Value	Federal MCL	State MCL	WAC 173-340-720 Cleanup Levels		
					Noncarcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Tritium	pCi/L	34,500	20,000	--	--	--	--
Chloroform	µg/L	2.2	80	80	80	1.4	14
Trichloroethene	µg/L	3.8	5	5	--	0.49	4.9
Chromium	µg/L	121	100	100	24,000	--	--
Cr(VI)	µg/L	117	--	--	48	--	--
Nitrate	µg/L	71,700	45,000	45,000	113,600	--	--

COPC = contaminant of potential concern
MCL = maximum contaminant level

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Table 6-19. Summary of Current Conditions 90th Percentile Groundwater Concentrations, and Federal and State Water Quality Standards (Aquatic Action Levels)

COPCs	Units	90th Percentile Value	AWQC		WAC 173-201A	CFR 131 Water Quality Standards	
			Freshwater CMC (acute)	Freshwater CCC (chronic)	Freshwater CCC (chronic)	Freshwater CMC (acute)	Freshwater CCC (chronic)
Carbon-14	pCi/L	1,470	--	--	--	--	--
Sr-90	pCi/L	7.3	--	--	--	--	--
Tritium	pCi/L	34,000	--	--	--	--	--
Chloroform	µg/L	2.2	--	--	--	--	--
Trichloroethene	µg/L	3.8	--	--	--	--	--
Chromium	µg/L	121	570	65	156	550	180
Cr(VI)	µg/L	117	16	11	10	15	10
Nitrate	µg/L	71,700	--	--	--	--	--

CCC = criterion continuous concentration
CMC = criteria maximum concentration
COPC = contaminant of potential concern

6.3.5.3 Protectiveness Evaluation for Human Health

The protectiveness evaluation for human health is performed to help determine if a CERCLA remedial action is appropriate. *Rules of Thumb for Superfund Remedy Selection* (EPA 540-R-97-013) states that a remedial action is generally appropriate when a regulatory standard that helps define protectiveness (a federal or state MCL or nonzero MCLG for current or potential drinking water aquifers) is exceeded.

The 90th percentile groundwater concentration for tritium is greater than the federal MCL developed for the protection of human health. Tritium is identified as a COPC indicating the need to evaluate potential remedial technologies for tritium in the FS. As Table 6-20 shows, potential exposure to groundwater as a drinking water source would result in a dose greater than 4 mrem yr from tritium. Of the 18 wells, two monitoring wells (199-K-157 and 199-K-18) were reported with tritium concentrations greater than the MCL of 20,000 pCi/L. Section 4.2.3.2 provides a detailed discussion of the distribution of tritium in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.3.

The 90th percentile groundwater concentration of C-14 is less than the federal MCL and is a minimal contribution to overall dose. C-14 has been detected in Wells 199-K-106A and 199-K-34 at concentrations above the MCL, indicating its presence is localized downgradient of the 116-KW-1 Condensate Crib. The 90th percentile concentration does not exceed the federal MCLs developed for the protection of human health. However, C-14 is identified as a COPC and its presence warrants design considerations for any engineered controls or remedial actions performed in this OU. Section 4.2.3.2 provides a detailed discussion of the distribution of C-14 in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.3.

The 90th percentile groundwater concentration of Sr-90 is less than the federal MCL developed for the protection of human health and is a minimal contribution to overall dose. Sr-90 has only been detected in Wells 199-K-20, 199-K-22, and 199-K-34 at concentrations above the MCL, indicating its presence is localized downgradient of the 116-K-2 Trench. Although the 90th percentile groundwater concentration is less than the federal MCL, Sr-90 is identified as a COPC and its presence warrants design considerations for any engineered controls or remedial actions performed in this OU. Section 4.2.3.2 provides a detailed discussion of the distribution of Sr-90 in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.2.

Table 6-20. Summary of 90th Percentile Current Groundwater Concentrations and Associated Sum of Fractions

COPC	Units	90th Percentile Value	Federal MCL	Individual Fraction
Carbon-14	pCi/L	1,470	2,000	0.74
Sr-90	pCi/L	7.3	8	0.91
Tritium	pCi/L	34,500	20,000	1.7
Sum of Fractions				**3.4**
Cumulative Annual Dose (mrem)				**13**

Notes: MCL; derived single-nuclide MCL-equivalent activity concentration.

COPC = contaminant of potential concern

MCL = maximum contaminant level

The 90th percentile groundwater concentration for chromium is greater than the federal and state MCL of 100 µg/L developed for the protection of human health. Chromium is identified as a COPC indicating the need to evaluate potential remedial technologies for chromium in the FS. Of the 18 monitoring wells, four monitoring wells were reported with concentrations of chromium above 100 µg/L. Section 4.2.3.2 provides a detailed discussion of the distribution of chromium in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.3.

A federal MCL is not available for Cr(VI); therefore, the protectiveness evaluation was not performed. Cr(VI) is discussed in the protectiveness evaluation for aquatic organisms and the risk evaluation.

The 90th percentile groundwater concentration for nitrate is greater than the federal and state MCL of 45,000 µg/L developed for the protection of human health. Nitrate is identified as a COPC indicating the need to evaluate potential remedial technologies for nitrate in the FS. Of the 18 monitoring wells, five were reported with concentrations of nitrate above the federal MCL of 45,000 µg/L. Section 4.2.3.2 provides a detailed discussion of the distribution of nitrate in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.3.

The 90th percentile groundwater concentration for chloroform is less than its federal and state MCL of 80 µg/L. Chloroform is not identified as a COPC and a need for further review in the FS is not established based on the results of this evaluation. Section 4.2.3.2 provides a detailed discussion of the distribution of chloroform in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level, and trends is provided in Section 4.2.3.3.

The 90th percentile groundwater concentration of trichloroethene is less than the federal and state MCL of 5 µg/L. However, trichloroethene was detected during two sampling rounds in Well 199-K-106A at concentrations above the MCL. In addition to 199-K-106A, trichloroethene has been detected in wells 199-K-107A, 199-K-165, 199-K-166, 199-K-168, 199-K-173, and 699-70-68 at concentrations at or near the MCL. Trichlorethene is identified as a COPC indicating the need to evaluate potential remedial technologies in the FS. Section 4.2.3.2 provides a detailed discussion of the distribution of trichloroethene in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the MCL, and trends is provided in Section 4.2.3.3.

6.3.5.4 Protectiveness Evaluation for Aquatic Receptors

The protectiveness evaluation for aquatic receptors is performed to help determine if a CERCLA remedial action is appropriate. *Rules of Thumb for Superfund Remedy Selection* (EPA 540-R-97-013) states that a remedial action is generally appropriate when a regulatory standard that helps define protectiveness (National Recommended Water Quality Criteria) is exceeded. As described in the exposure assessment, groundwater discharges to the Columbia River through upwelling and seeps. The point of compliance for surface water cleanup levels is defined in "Surface Water Cleanup Standards" (WAC 173-340-730(7)(a)) as the point or points at which hazardous substances are released to surface waters of the state. "Surface Water Cleanup Standards" (WAC 173-340-730(7)(b)) indicate that no mixing zone shall be allowed to demonstrate compliance with surface water cleanup levels. Groundwater EPCs from the entire 100-KR-4 Groundwater OU are compared to the ambient water quality standards to determine if groundwater concentrations discharging to the Columbia River are in compliance with federal and state standards.

Chemical-specific ARARs for tritium, carbon-14, and Sr-90 are not included because the federal MCL for protection of human health is considered protective of aquatic organisms. A need to evaluate potential

remedial technologies for tritium, carbon-14, and Sr-90 in the FS was established based on the results of the protectiveness evaluation for human health.

Federal and state water quality standards for the protection of freshwater organisms are not published for chloroform, trichloroethene, or nitrate; therefore, a protectiveness evaluation is not included. Chloroform, nitrate, and trichloroethene are evaluated in the protectiveness evaluation for human health in Section 6.3.5.3 and the risk evaluation is presented in Section 6.3.5.5.

The 90th percentile groundwater concentration for chromium is greater than the federal freshwater CCC value of 65 µg/L. The 90th percentile groundwater concentration is not considered protective of aquatic organisms and chromium is identified as a COPC. The results of this evaluation indicate the need to evaluate potential remedial technologies for chromium in the FS. Of the 18 monitoring wells, four were reported with concentrations of chromium above the freshwater CCC value of 65 µg/L. It is assumed that a portion of the dissolved concentrations of total chromium are present in the form of Cr(VI) and total chromium is not presented separately from Cr(VI) in the nature and extent evaluation and the FS.

The 90th percentile groundwater concentration for Cr(VI) is greater than the "Water Quality Standards for Surface Waters of the State of Washington" (WAC 173-201A) freshwater CCC value of 10 µg/L. The 90th percentile groundwater concentration is not considered protective of aquatic organisms and Cr(VI) is identified as a COPC. The results of this evaluation indicate the need to evaluate potential remedial technologies for Cr(VI) in the FS. Of the 18 monitoring wells, 10 were reported with concentrations of chromium above the "Water Quality Standards for Surface Waters of the State of Washington" (WAC 173-201A) freshwater CCC value of 10 µg/L. Section 4.2.3.3 provides a detailed discussion of the distribution of Cr(VI) in the 100-KR-4 Groundwater OU. A discussion of the footprint of the plume, wells with concentrations above the AWQC, and trends is presented in Section 4.2.3.3.

6.3.5.5 Risk Evaluation

The risk evaluation is also performed to help determine whether a CERCLA remedial action is appropriate. *Rules of Thumb for Superfund Remedy Selection* (EPA 540-R-97-013) states that a remedial action is generally appropriate when the estimated risk calculated in a risk assessment exceeds a noncarcinogenic level for an adverse health effect or the upper end of the NCP risk range for "cumulative carcinogenic site risk" to an individual based on RME for both current and future land use.

The potential cumulative ELCR from all nonradiological carcinogenic COPCs is 9.4×10^{-6}, which is less than the "Human Health Risk Assessment Procedures" (WAC 173-340-708) risk threshold of 1×10^{-5} for multiple hazardous substances and less than the upper NCP threshold of 1×10^{-4}. Table 6-21 shows the contributors to risk include chloroform (1.6×10^{-6}, 17 percent contribution) and trichloroethene (7.8×10^{-6}, 83 percent contribution).

Chloroform is not identified as a COPC, based on the results of this evaluation. As discussed previously, the nature and extent evaluation of groundwater presented in Section 4.2.3.3 also supports the conclusion of this analysis. Over the past five years, chloroform has been associated with a trend at 199-K-18, 199-K-32A, 199-K-151, and 199-N-72 where concentrations have ranged been 1.1 to 5.1 times greater than the action level of 1.4 µg/L. However, there have been no measured concentrations above the 10^{-5} level of 14 µg/L.

Trichloroethene is identified as COPC based on further analysis of the nature and extent evaluation presented in Section 4.2.3.2.Trichloroethene has been detected in 10 wells over the past five years with concentrations above the 10^{-6} risk cleanup level of 0.49 µg/L (action level is 1µg/L based on EQL in the 100-K SAP [DOE/RL-2009-41]) and two detections were above the 10^{-5} level of 4.9 µg/L or the DWS of 5 µg/L.

Table 6-21. Summary of 90th Percentile Current Groundwater Concentrations and Associated Cancer Risk and Noncancer Hazard Index

COPC	Units	90th Percentile Value	WAC 173-340-720 Cleanup Levels			
			Noncarcinogens	HQ	Carcinogens at 10^{-6} Risk Level	ELCR
Chloroform	µg/L	2.2	80	0.03	1.4	1.6×10^{-6}
Trichloroethene	µg/L	3.8	--	--	0.49	7.8×10^{-6}
Total ELCR					**--**	**9.4×10^{-6}**
Chromium	µg/L	121	24,000	<0.01	--	--
Cr(VI)	µg/L	117	48	2.4	--	--
Nitrate	µg/L	71,700	113,600	0.63	--	--
Hazard Index				**3.1**		

COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index
HQ = hazard quotient

The HI for the 100-KR-4 Groundwater OU is 3.1, which is greater than the EPA and MTCA (WAC 173-340) target HI of 1. The primary contributor to the noncancer HI is Cr(VI) (HQ = 2.4, 79 percent contribution). The individual HQs for chromium and nitrate are each less than 1. The primary noncancer health effects associated with exposure to Cr(VI) is nasal septum atrophy. Cr(VI) is identified as a COPC based on the results of this evaluation, while chromium and nitrate are not.

6.3.5.6 Risk Characterization Results of the Supplemental Native American Risk Evaluations

Several local and regional Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* (Harris and Harper, 2004) and *Application of the CTUIR Traditional Lifeways Exposure Scenario in Hanford Risk Assessments* (Harris, 2008) have been provided by the CTUIR; *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment* (Ridolfi, Inc., 2007) has been provided by the Yakama Nation.

The CTUIR and Yakama Nation scenarios reflect exposure conditions that assume groundwater from the 100-KR-4 Groundwater OU is restored to its highest beneficial use and is used as a drinking water source and to generate steam in a sweat lodge. Use of groundwater to irrigate crops and water livestock is not evaluated in this risk evaluation because those exposure pathways, although potentially complete, are considered insignificant and secondary to the drinking water and sweat lodge exposure pathways. Food chain pathways are generally evaluated quantitatively in the source area OUs because the RESRAD model (RESRAD, Version 6.5 [ANL, 2009]) estimates exposure from these pathways.

Potentially complete exposure routes for adult and child Tribal members associated with use of groundwater as a drinking water source are as follows:

- Ingestion of drinking water
- Inhalation of volatiles when showering and other domestic purposes
- Dermal contact with skin while showering and using groundwater for other domestic purposes (such as washing dishes)

Potentially complete exposure routes for adult Tribal members associated with the use of groundwater to generate steam in a sweat lodge are as follows:

- Inhalation of tritium, volatiles, and semivolatiles as vapors
- Inhalation of aerosolized nonvolatiles
- Dermal contact with vapors from volatile and semivolatile compounds
- Dermal contact with vapor and aqueous condensate

A complete description of each of the Tribal use exposure scenarios is provided in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0475) (Appendix G). This calculation describes the methodology, assumptions, and inputs, and the calculation of risks and hazards, and discusses the results of the supplemental risk evaluation for each of the Native American scenarios.

6.3.5.7 Summary of the CTUIR Supplemental Risk Evaluation

This section summarizes the results for each of the exposure pathways associated with use of groundwater as a drinking water source and use of groundwater to generate steam in a sweat lodge.

Use of Groundwater as a Potential Drinking Water Source. Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact,[9] and inhalation of volatiles during household activities. Table 6-22 provides a summary of the risk estimates by exposure route for the 100-KR-4 Groundwater OU. Additional detail including COPC-specific risk contributions is provided in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0475) (Appendix G).

Table 6-22. Confederated Tribes of the Umatilla Indian Reservation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	4.9×10^{-4}	5.6
Dermal	3.5×10^{-6}	0.48
Inhalation	2.2×10^{-6}	<0.01
Total	**5.0×10^{-4}**	**6.1**

[9] The dermal contact exposure route is only evaluated for nonradionuclide COPCs.

Table 6-22. Confederated Tribes of the Umatilla Indian Reservation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

	Radionuclide COPCs	
Ingestion	4.2×10^{-4}	--
Inhalation	1.5×10^{-5}	--
Total	**4.4×10^{-4}**	**--**
Total ELCR*	**9.3×10^{-4}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.

-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 5.0×10^{-4} for nonradiological COPCs and 4.4×10^{-4} for radiological COPCs, which is greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon-14 and tritium are greater than the EPA regulatory target risk threshold of 1×10^{-4}. Individual ELCR values associated with chloroform, trichloroethene, and Sr-90 are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 6.1, which is greater than the EPA target HI of 1.0. The primary contributor to the noncancer HI is Cr(VI) with an HQ of 2.7.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of $1 \times 10^{-4}$and the HQ is greater than 1.0, the 90th percentile value of 5.3 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

The individual ELCR associated with bromodichloromethane is within the EPA range of 1×10^{-4} to 1×10^{-6}. However, bromodichloromethane is not considered a contributor to the ELCR because it was detected in only 5 of 54 water samples, all of which were flagged with a "J" indicating the results are estimated values.

Use of Groundwater to Generate Steam for Sweat Lodge Use. Potential exposure to groundwater as steam in a sweat lodge is evaluated under this scenario. Potential routes of exposure to steam generated from groundwater include inhalation of vaporized volatiles and semivolatiles and aerosolized nonvolatiles and dermal contact with vaporized volatiles, semivolatiles, and nonvolatiles and condensed liquid while spending time in a sweat lodge. Table 6-23 provides a summary of the risk estimates by exposure route. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0475) (Appendix G).

Table 6-23. CTUIR Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	8.8×10^{-6}	0.02
Nonvolatile (aerosol)	7.9×10^{-2}	17
Total	**7.9×10^{-2}**	**17**
Dermal Exposure in Sweat Lodge		
Volatile and Semivolatile (vapor only)	1.1×10^{-9}	<0.01
Nonvolatile (vapor and aqueous condensate)	2.0×10^{-6}	0.83
Total	**2.0×10^{-6}**	**0.83**
Total Nonradionuclide COPCs	**7.9×10^{-2}**	**17.8**
Radionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	4.8×10^{-5}	--
Nonvolatile (aerosol)	4.7×10^{-5}	--
Total Radionuclide COPCs	**9.5×10^{-5}**	--
Total ELCR*	**7.9×10^{-2}**	--

* Sum of total ELCR values for nonradionuclide and radionuclide COPCs.

-- = not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 7.9×10^{-2} for nonradiological COPCs and 9.5×10^{-5} for radiological COPCs, which is greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR value for Cr(VI) is greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values associated with chloroform, cobalt, trichloroethene, carbon-14, tritium, and Sr-90 are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 17.8, which is greater than the EPA target HI of 1.0. The primary contributor to the noncancer HI is Cr(VI) with an HQ of 10.8.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 1×10^{-4} and the HQ is greater than 1.0, the 90th percentile value of 5.3 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

The individual ELCR associated with bromodichloromethane is within the EPA range of 1×10^{-4} to 1×10^{-6}. However, bromodichloromethane is not considered a contributor to the ELCR because it was detected in only 5 of 54 water samples, all of which were flagged with a "J" indicating the results are estimated values.

Although the individual ELCR values associated with beryllium, cadmium, and nickel are within the EPA range of 1×10^{-4} to 1×10^{-6}, they are not considered contributors to the ELCR. Beryllium was detected in 1 of 54 water samples at Well 199-K-18 and is not considered associated with a trend or local exposure point. Cadmium was detected once at Well 699-73-61 and the result was flagged with a "B," indicating an estimated concentration. Cadmium does not appear to be associated with a trend or local exposure point. Nickel was detected in 4 of 54 water samples at Well 199-K-36 and its presence is suspected to be associated with corrosion of the well casing. This is supported by the presence of elevated iron concentration at this well.

Although the individual HQ associated with manganese is greater than 1.0, manganese is not considered a contributor to the HI because the 90th percentile value of 11 µg/L is below the secondary MCL of 50 µg/L and the secondary MCL is based on aesthetic qualities and is not federally enforceable.

Summary of the Yakama Nation Supplemental Risk Evaluation. This section summarizes the results for each of the exposure pathways associated with use of groundwater as a drinking water source and use of groundwater to generate steam in a sweat lodge.

Use of Groundwater as a Potential Drinking Water Source. Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact,[10] and inhalation of volatiles during household activities. Table 6-24 provides a summary of the risk estimates by exposure route for the 100-KR-4 Groundwater OU. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0475) (Appendix G).

Table 6-24. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	5.3×10^{-4}	5.6
Dermal	3.5×10^{-6}	0.48
Inhalation	2.2×10^{-6}	<0.01
Total	**5.4×10^{-4}**	**6.1**
Radionuclide COPCs		
Ingestion	4.3×10^{-4}	--
Inhalation	1.6×10^{-5}	--
Total	**4.5×10^{-4}**	**--**

[10] The dermal contact exposure route is only evaluated for nonradionuclide COPCs.

Table 6-24. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

Exposure Route	ELCR	HI
Total ELCR*	**9.8×10^{-4}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.

-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 5.4×10^{-4} for nonradiological COPCs and 4.5×10^{-4} for radiological COPCs, which is greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon-14 and tritium are greater than the EPA regulatory target risk threshold of 1×10^{-4}. The individual ELCR values associated with chloroform, trichloroethene, and Sr-90 are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 6.1, which is greater than the EPA target HI of 1.0. The primary contributor to the noncancer HI is Cr(VI) with an HQ of 2.7.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 1×10^{-4} and the HQ is greater than 1.0, the 90th percentile value of 5.3 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

The individual ELCR associated with bromodichloromethane is within the EPA range of 1×10^{-4} to 1×10^{-6}. However, bromodichloromethane is not considered a contributor to the ELCR because it was detected in only 5 of 54 water samples, all of which were flagged with a "J," indicating the results are estimated values.

Use of Groundwater to Generate Steam for Sweat Lodge Use. Potential exposure to groundwater as steam in a sweat lodge is evaluated under this scenario. Potential routes of exposure to steam generated from groundwater include inhalation of vaporized volatiles and semivolatiles and aerosolized nonvolatiles and dermal contact with vaporized volatiles, semivolatiles, and nonvolatiles and condensed liquid while spending time in a sweat lodge. Table 6-25 provides a summary of the risk estimates by exposure route. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in *Native American Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0475) (Appendix G).

Table 6-25. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Inhalation in Sweat Lodge		
• Volatile and Semivolatile (vapor)	1.8×10^{-5}	0.037
• Nonvolatile (aerosol)	1.6×10^{-1}	35.3
Total	**1.6×10^{-1}**	**35.3**

Table 6-25. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Dermal Exposure in Sweat Lodge		
• Volatile and Semivolatile (vapor only)	2.3×10^{-9}	<0.01
• Nonvolatile (vapor and aqueous condensate)	4.0×10^{-6}	1.7
Total	**4.0×10^{-6}**	**1.7**
Total Nonradionuclide COPCs	**1.6×10^{-1}**	**37**
Radionuclide COPCs		
Inhalation in Sweat Lodge		
• Volatile and Semivolatile (vapor)	1.0×10^{-4}	--
• Nonvolatile (aerosol)	9.8×10^{-5}	--
Total Radionuclide COPCs	**2.0×10^{-4}**	**--**
Total ELCR*	**1.6×10^{-1}**	**--**

* Sum of total ELCR values for nonradionuclide and radionuclide COPCs.

-- = HI is not applicable

COPC = contaminant of potential concern

ELCR = excess lifetime cancer risk

HI = hazard index

The cumulative ELCR is 1.6×10^{-1} for nonradiological COPCs and 2.0×10^{-4} for radiological COPCs, which is greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR value for Cr(VI) is greater than the EPA regulatory target risk threshold of 1×10^{-4}. The individual ELCR values associated with chloroform, cobalt, trichloroethene, carbon-14, tritium, and Sr-90 are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 37.0, which is greater than the EPA target HI of 1.0. The primary contributors to the noncancer HI are Cr(VI) with an HQ of 22.4, and barium with an HQ of 1.6.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 1×10^{-4} and the HQ is greater than 1.0, the 90th percentile value of 5.3 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

The individual ELCR associated with bromodichloromethane is within the EPA range of 1×10^{-4} to 1×10^{-6}. However, bromodichloromethane is not considered a contributor to the ELCR because it was detected in only 5 of 54 water samples, all of which were flagged with a "J," indicating the results are estimated values.

Although the individual ELCR values associated with beryllium, cadmium, and nickel are within the EPA range of 1×10^{-4} to 1×10^{-6}, they are not considered contributors to the ELCR. Beryllium was detected in 1 of 54 water samples at Well 199-K-18 and is not considered associated with a trend or local exposure point. Cadmium was detected once at Well 699-73-61 and the result was flagged with a "B," indicating an estimated concentration. Cadmium does not appear to be associated with a trend or local exposure point. Nickel was detected in 4 of 54 water samples at Well 199-K-36 and its presence is suspected to be

associated with corrosion of the well casing. This is supported by the presence of elevated iron concentration at this well.

Although the individual HQ associated with manganese is greater than 1.0, manganese is not considered a contributor to the HI because the 90th percentile value of 11 µg/L is below the secondary MCL of 50 µg/L and the secondary MCL is based on aesthetic qualities and is not federally enforceable.

Risk Characterization Results of the EPA Tap Water Scenario. This section summarizes the results for each of the exposure pathways associated with use of groundwater as a drinking water source. The EPA tap water scenario is included in this section to provide a similar scenario using exposure assumptions that represent reasonable maximum exposure. The EPA tap water scenario is consistent with a residential exposure scenario as it incorporates default residential exposure assumptions. The results of the Tap Water Risk Evaluation are provided in *Tap Water Risk Assessment for the 100-KR-4 Groundwater Operable Unit* (ECF-100KR4-10-0476) (Appendix G). Potentially complete exposure routes for EPA tap water scenario include exposure of adult and children residents to groundwater used as a drinking water source and include the following:

- Ingestion of drinking water
- Inhalation of volatiles when showering and other domestic purposes
- Dermal contact with skin while showering and using groundwater for other domestic purposes (such as washing dishes)

Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact, and inhalation of volatiles during household activities. Table 6-26 provides a summary of the risk estimates by exposure route for the 100-KR-4 Groundwater OU.

Table 6-26. Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source Using EPA Tap Water Equations

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	1.3×10^{-4}	2.7
Dermal	1.6×10^{-6}	0.46
Inhalation	9.0×10^{-7}	<0.01
Total	**1.3×10^{-4}**	**3.1**
Radionuclide COPCs		
Ingestion	8.4×10^{-5}	--
Inhalation	5.1×10^{-6}	--
Total	**8.9×10^{-5}**	**--**
Total ELCR*	**2.2×10^{-4}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.

-- = HI is not applicable

Table 6-26. Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source Using EPA Tap Water Equations

Exposure Route	ELCR	HI

COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCRs are 1.3×10^{-4} for nonradiological COPCs and 8.9×10^{-5} for radiological COPCs. The nonradiological ELCR is greater than the EPA upper target risk threshold of 1×10^{-4} and the radiological ELCR is within the EPA range of 1×10^{-4} to 1×10^{-6} The individual ELCRs associated with carbon-14, chloroform, Sr-90, trichloroethene, and tritium are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 3.1, which is greater than the EPA target HI of 1.0. The primary contributor to the noncancer HI is Cr(VI) with an HQ of 1.5.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 1×10^{-4} and the HQ is greater than 1.0, the 90th percentile value of 5.3 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

The individual ELCR associated with bromodichloromethane is within the EPA range of 1×10^{-4} to 1×10^{-6}. However, bromodichloromethane is not considered a contributor to the ELCR because it was detected in only 5 of 54 water samples, all of were flagged with a "J," indicating the results are estimated values.

Comparison of Native American and EPA Tap Water Risk Characterization Results. Table 6-27 provides a summary of the risk estimates and hazard indices for each of the Native American Scenarios and the EPA tap water scenario. Results are provided for ingestion, dermal contact, and inhalation of volatiles during household activities.

Exposure parameters for the Native American exposure scenarios and the EPA tap water scenario differ in exposure frequency (Native American 365 day/yr; EPA tap water 350 day/yr); exposure duration (Native American 70 years; EPA tap water 30 years); drinking water ingestion rate (Native American 4 L/day [1 gal/day]; EPA tap water 2 L/day [0.5 gal/day]); and inhalation rate (CTUIR 25 m^3/day [883 ft^3/day], Yakama Nation 26 m^3/day [918 ft^3/day]; EPA tap water 20 m^3/day [706 ft^3/day]). As a result, the EPA tap water scenario has a lower total ELCR and HI than the Native American exposure scenarios.

The total cumulative ELCRs for the CTUIR and Yakama Nation exposure scenarios are 9.3×10^{-4} and 9.8×10^{-4}, respectively. The primary contributors to risk for the Native American exposure scenarios are carbon-14, chloroform, tritium, Sr-90, and trichloroethene. The total ELCR for the EPA tap water scenario is 2.2×10^{-4}. These primary contributors to risk are the same as those that contribute to the Native American scenarios. The total HI is 6.1 for both the CTUIR and Yakama Nation exposure scenarios. The HI for the EPA tap water equations is 3.1. Cr(VI) is the primary contributors to the noncancer HI for the Native American scenario and the EPA tap water exposure scenario.

Table 6-27. Comparison of Risk Estimates and Hazard Indices for the CTUIR, Yakama Nation, and EPA Tap Water Equations

Exposure Scenario	COPC Type	Drinking Water Ingestion		Inhalation of Volatiles		Dermal Contact with Water		Total			
		ELCR	Hazard Index	ELCR	Hazard Index	ELCR	Hazard Index	ELCR	Primary Contributors to Risk	Hazard Index	Primary Contributors to Hazard Index
CTUIR	Nonradiological	4.9×10^{-4}	5.6	2.2×10^{-6}	<0.01	3.5×10^{-6}	0.48	5.0×10^{-4}	**C-14 (2.2E-04), H3 (1.8E-04)**, Sr-90 (3.9E-05), TCE (2.3E-05), chloroform (4.7E-06)	6.1	**Cr(VI) (HQ = 2.7)**
	Radiological	4.2×10^{-4}	--	1.5×10^{-5}	--	--	--	4.4×10^{-4}		--	
	Total	9.1×10^{-4}	5.6	1.7×10^{-5}	<0.01	3.5×10^{-6}	0.48	9.3×10^{-4}		6.1	
Yakama Nation	Nonradiological	5.3×10^{-4}	5.6	2.2×10^{-6}	<0.01	3.5×10^{-6}	0.48	5.4×10^{-4}	**C-14 (2.2E-04), H3 (1.9E-04)**,Sr-90 (4.0E-04), TCE (2.4E-05), chloroform (5.0E-06)	6.1	**Cr(VI) (HQ = 2.7)**
	Radiological	4.3×10^{-4}	--	1.6×10^{-5}	--	--	--	4.5×10^{-4}		--	
	Total	9.6×10^{-4}	5.6	1.8×10^{-5}	<0.01	3.5×10^{-6}	0.48	9.8×10^{-4}		6.1	
EPA Tap Water	Nonradiological	1.3×10^{-4}	2.7	9.0×10^{-7}	<0.01	1.6×10^{-6}	0.46	1.3×10^{-4}	C-14 (4.3E-05),H3 3.8E-05),Sr-90 (7.7E-06), TCE 6.3E-06), chloroform (1.3E-06)	3.1	**Cr(VI) (HQ= 1.5)**
	Radiological	8.4×10^{-5}	--	5.1×10^{-6}	--	--	--	8.9×10^{-5}		--	
	Total	2.1×10^{-4}	2.7	6.0×10^{-6}	0.46	1.6×10^{-6}	<0.01	2.2×10^{-4}		3.1	

Notes: Bolded COPCs indicate that the individual ELCR is greater than 1×10^{-4} or has an HQ greater than 1.

COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
ELCR = excess lifetime cancer risk
EPA = U.S. Environmental Protection Agency
TCE = trichloroethene

6.3.6 Uncertainties in Supplemental Groundwater Risk Evaluation

The purpose of this supplemental groundwater risk evaluation is to determine whether a groundwater remedial action is warranted under CERCLA. Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks.

In this assessment, uncertainties relate to the selection of COPCs and the development of media concentrations to which receptors may be exposed, the assumptions about exposure and toxicity, and the characterization of health risks. Uncertainties exist regarding the quantification of health risks in terms of several assumptions about exposure and toxicity, including site-specific and general uncertainties. Based on the anticipation of uncertainty when quantifying exposure and toxicity, the health risks and hazards presented in this risk evaluation are more likely to provide an upper bound on risk.

6.3.6.1 Uncertainties Associated with Sampling and Analysis Data

Sampling and analysis data used in this supplemental groundwater risk evaluation were collected specifically to address the uncertainties identified in the RCBRA Report (DOE/RL-2007-21) and the 100-K Work Plan (DOE/RL-2008-46-ADD2). These uncertainties were generally associated with the chemical, spatial, and temporal representativeness of the data set used to evaluate current baseline conditions in the RCBRA Report (DOE/RL-2007-21). Uncertainties with chemical representativeness were related to the analysis of varying analytical methods between monitoring wells within the OU. Uncertainties with spatial and temporal representativeness were associated with varying sampling frequencies between monitoring wells due to differing monitoring programs.

Current baseline conditions are presented by groundwater data collected over an 8-month period between October 22, 2009 and June 30, 2010. Three sampling events were used to capture the effects that temporal fluctuations of river stage have on groundwater conditions. The COPCs identified during the work plan phase were validated by using groundwater samples analyzed for the analytical methods documented in the 100-K SAP (DOE/RL-2009-41). The groundwater data set used for COPC identification consists of sampling and analysis data collected from 18 monitoring wells within the 100-KR-4 OU. The monitoring well network represents locations where human or ecological receptors could potentially encounter groundwater within the OU. The primary exposure pathway for humans is through groundwater obtained from a residential or community water well, assuming development of the land for future human habitation.

All samples were analyzed using methods that could accurately measure analytes to concentrations equal or less than the lowest chemical-specific ARAR. When analytical methods could not achieve the lowest chemical-specific ARAR, the action level defaulted to the method detection limit that could reasonably be achieved. These detection limits are documented in Table 2-4 of the 100-K SAP (DOE/RL-2009-41).

6.3.6.2 Uncertainties Associated with Exposure Point Concentrations

The EPCs for groundwater are calculated as the 90th percentile concentration. The protectiveness and risk evaluation methodology uses an RME concentration for each COPC for the entire OU rather than performing the evaluation on a specific well or location. In general, EPA Superfund guidance recommends using a 95 percent UCL on the arithmetic mean for estimating EPCs. However, experience at the site indicates that averages and UCLs cannot be reliably calculated for groundwater data sets using this approach.

Groundwater data sets at the Hanford Site are highly skewed, with a large proportion of BDL values. Guidance from *Data Quality Assessment: Statistical Methods for Practitioners* (EPA/240/B-06/003) is for estimating statistical parameters (whether means or upper percentiles) depending on the variability in the data set. The variability of the data set is assessed in terms of the CV and the proportion of observations

that are BDL. For data sets with CVs greater than 0.5 and 50 percent or more observations that are BDL, EPA recommends using upper percentiles as opposed to means to develop summary statistics.

Use of the 90th percentile value from a distribution of groundwater concentration data as an estimate of the EPC is a different approach for estimating EPCs than that provided in some Superfund guidance (*Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* [OSWER 9285.6-10]). However, as described below, the 90th percentile exposure concentration is identified in other EPA risk assessment guidance as appropriate for describing and characterizing health risks; its use yields risk estimates that correspond to an RME.

Table 6-28 provides the percentile concentrations used for the protectiveness and risk evaluations, as well as the number of measurements, number of detections, maximum, average, 95 percent UCL concentrations, and action levels using all of the data within the OU. For the COPCs, the 90th percentile concentrations are greater than the 95 percent UCL values for all COPCs except for carbon-14 and tritium.

Table 6-28. Percentile Concentrations and Summary Statistics

COPC	Units	Number of Measurements	Number of Detections	90th Percentile	Average	95% UCL	Action Level
Carbon-14	pCi/L	54	31	1,470	1,060	3,020	2,000
Chloroform	µg/L	54	35	2.2	1.3	1.8	1.4
Chromium	µg/L	54	54	121	40	71	65
Cr(VI)	µg/L	54	38	117	46	63	10
Nitrate	µg/L	54	51	71,700	28,500	41,700	45,000
Sr-90	pCi/L	54	10	7.3	12	6.0	8
Trichloroethene	µg/L	54	20	3.8	2.5	1.5	0.49
Tritium	pCi/L	54	40	34,500	17,600	71,900	20,000

COPC = contaminant of potential concern
UCL = upper confidence limit

The groundwater data set is considered robust when the 90th percentile value is greater than the 95 percent UCL value. For the COPCs, the 90th percentile concentrations are greater than the 95 percent UCL values for all COPCs except carbon-14 and tritium.

For carbon-14, the 95 percent UCL value of 3,020 µg/L is greater than the 90th percentile value of 1,470 µg/L. This data set is considered skewed, as the maximum concentration is 10,100 pCi/L with five results greater than the 90th percentile and four results greater than the 95 percent UCL. Although the 95 percent UCL is greater than action level of 2,000 pCi/L and the 90th percentile value is not, carbon-14 was identified as a COPC because of contamination localized in two monitoring wells. Selection of the 90th percentile concentrations may have the potential to underestimate exposure from ingestion of carbon-14.

For manganese, the 95 percent UCL value of 13 µg/L is greater than the 90th percentile value of 11 µg/L. Both the 95 percent UCL and the 90th percentile concentration are less than the action level for manganese. In both cases, manganese would not be identified as a COPC.

For tritium, the 95 percent UCL value of 71,900 µg/L is greater than the 90th percentile value of 34,500 µg/L. This data set is considered skewed, as the maximum concentration is 290,000 pCi/L with five results greater than the 90th percentile and three results greater than the 95 percent UCL. Although the 95 percent UCL is greater than the 90th percentile value, both concentrations are greater than the federal MCL of 20,000 pCi/L. Selection of the 90th percentile concentrations may have the potential to underestimate exposure from ingestion of tritium.

The 95 percent UCL is less than the 90th percentile concentration for the remaining six COPCs. Both the 95 percent UCL and the 90th percentile concentration are greater than the action level for chloroform, chromium, Cr(VI), Sr-90, and trichloroethene. Only the 90th percentile concentration is greater than the action level for nitrate. Selection of the 90th percentile value for these COPCs is considered conservative and provides an upper bound on exposure from ingestion when compared to the 95 percent UCL.

6.3.6.3 Uncertainties Associated with Exposure Assumptions

The exposure assumptions used to develop the chemical-specific ARARs represent an RME. For estimating the RME, 95 percent UCL values (or upper-bound estimates of national averages) are generally used for exposure assumptions, and exposed populations and exposure scenarios are selected to represent upper-bound exposures. The intent of the RME, as discussed by the EPA Deputy Administrator and the Risk Assessment Council "Guidance on Risk Characterization for Risk Managers and Risk Assessors" (Habicht, 1992), is to present risks as a range from central tendency to high-end risk (above the 90th percentile of the population distribution). This descriptor is intended to estimate the risks that are expected to occur in small but definable "high-end" segments of the subject population (Habicht, 1992). EPA distinguishes between those scenarios that are possible but highly improbable and those that are conservative but more likely to occur within a population, with the latter being favored in risk assessment. In general, these assumptions are intended to be conservative and yield an upper bound of the true risk or hazard.

6.3.6.4 Uncertainties Associated with Dermal Contact Exposure

The chemical-specific ARARs for use as a drinking water source consider ingestion and inhalation of vapors as complete and significant pathways for exposure. For the chemical-specific ARARs, the dermal contact pathway is considered a complete but insignificant pathway of exposure for the contaminants detected in groundwater. The exclusion of the dermal contact exposure route from the chemical-specific ARARs may have the potential to underestimate the actual cleanup level.

EPA considers the dermal contact route to be significant if it contributes at least 10 percent of the exposure derived from the oral pathway. These results are based on comparing two main household daily uses of water: as a source for drinking and for showering or bathing (*Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final* [EPA/540/R/99/005]). Exhibit B-3 and Exhibit B-4 of *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment): Final* (EPA/540/R/99/005) provide a screening tool to focus the dermal risk assessment on those chemicals that are more likely to contribute to the overall risk. Exhibit B-3 indicates that dermal exposure exceeds 10 percent of drinking water for chromium, Cr(VI), and TCE. The ratio of the dermal absorbed dose (DAD) from dermal to oral is 40 percent for chromium, 42 percent for Cr(VI), and 17 percent for TCE. Based on this comparison, the chemical-specific ARARs concentrations may have the potential to underestimate exposure to these COPCs.

6.3.6.5 Uncertainties Associated with Toxicity Assessment

The toxicological database was also a source of uncertainty. EPA has outlined some of the sources of uncertainty as defined in the risk assessment guide (EPA/540/1-89/002) and in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). These sources may include or result from the extrapolation from high to low doses and from animals to humans. This is contingent on the species, gender, age, and strain differences in the uptake, metabolism, organ distribution, and target site susceptibility of a toxin. The human population's variability with respect to diet, environment, activity patterns, and cultural factors are also sources of uncertainty.

Traditionally, EPA has developed toxicity criteria for carcinogens by assuming that all carcinogens are nonthreshold contaminants. However, EPA has recently published revised cancer guidelines (*Guidelines for Carcinogen Risk Assessment* [EPA/630/P-03/001F]) modifying its former position of assuming nonthreshold action for all carcinogens. This new guidance emphasizes establishing the specific toxicokinetic mode of action that leads to development of cancer. In the future, toxicity criteria for carcinogens in the United States will be developed assuming no threshold for contaminants that exhibit genotoxic modes of action, or where the mode of action is not known. However, currently available EPA toxicity criteria for carcinogens were all derived assuming a nonthreshold model.

In most of the world, nonthreshold toxicity criteria are developed only for those carcinogens that appear to cause cancer through a genotoxic mechanism (Health Canada, Netherlands). Specifically, for genotoxic contaminants, the cancer dose-response model is based on high-dose to low-dose extrapolation and assumes there is no lower threshold for the initiation of toxic effects. Cancer effects observed at high doses are found in laboratory animals or are extrapolated from occupational or epidemiological studies. Cancer effects observed at low doses are commonly found in environmental exposures. These models are essentially linear at low doses, so no dose is without some risk of cancer.

Slope Factors for Trichloroethene. The oral cancer potency factor of 0.089 $(mg/kg\text{-}day)^{-1}$ is used to develop the "Groundwater Cleanup Standards"" (WAC 173-340-720) groundwater cleanup level and is obtained from HEAST (January 1, 1991). HEAST has not been updated since 1997 and, in this case, the oral cancer potency factor does not reflect the most current source of information.

The oral slope factor currently recommended by EPA for TCE is established by the CalEPA Office of Environmental OEHHA. The source of this toxicity value is consistent with the hierarchy of toxicity values recommended in "Human Health Toxicity Values in Superfund Risk Assessments" (Cook, 2003). The oral slope factor is 0.013 $(mg/kg\text{-}day)^{-1}$ (*Public Health Goal for Trichloroethylene in Drinking Water* [OEHHA,1999]).

The OEHHA value is lower than the value of 0.089 $(mg/kg\text{-}day)^{-1}$ for oral exposures published in the 1991 HEAST.

If the CalEPA value were used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would increase from 0.49 to 3.4 µg/L. The groundwater risks at the 90th percentile would decrease from 6.7×10^{-6} to 9.7×10^{-7} in groundwater. However, the cumulative risk would remain above 1×10^{-5}. Use of the oral cancer potency factor from HEAST results in an overestimation of risks when compared to the oral slope factor established by CalEPA.

Slope Factors for Cr(VI). The oral reference dose of 0.003 mg/kg-day published by IRIS is used to develop the WAC 173-340-720 groundwater cleanup level for Cr(VI). An oral carcinogenic potency factor has recently been published by NJDEP (2009, *Derivation of an Ingestion-Based Soil Remediation Criterion for Cr+6 Based on the NTP Chronic Bioassay Data for Sodium Dichromate Dihydrate*). The oral carcinogenic potency factor derived by NJDEP is 0.5 $(mg/kg\text{-}day)^{-1}$ (*Derivation of an Ingestion-Based*

Soil Remediation Criterion for Cr+6 Based on the NTP Chronic Bioassay Data for Sodium Dichromate Dihydrate [NJDEP, 2009]). If the NJDEP value were used to calculate the "Groundwater Cleanup Standards" (WAC 173-340-720) groundwater cleanup level, the groundwater concentration would decrease from 48 to 0.18 µg/L.

6.3.6.6 Uncertainties Associated with Risk Characterization

In the risk characterization, the assumption was made that the total risk of developing cancer from exposure to site contaminants is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of noncancer adverse effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach, in accordance with EPA guidance, did not account for the possibility that constituents act synergistically or antagonistically.

As discussed in Section 6.3.4.2, MCLs for radionuclides are set at 4 mrem/yr for the sum of the doses from beta particle and photon emitters, 15 pCi/L for gross alpha emitter activity (including Ra-226, but excluding uranium and radon), and 5 pCi/L combined for Ra-226 and Ra-228. A mass concentration MCL has been established for uranium as 30 µg/L. At this time, no additional federal or state standards are associated with evaluating the effects of exposure to radionuclides. Risks were estimated for radioisotopes identified as COPCs using inputs and equation 720-2 from WAC 173-340-720(4)(iii) (B) and radionuclide slope factors from HEAST. The MCL concentrations reported for each of the radionuclide COPCs do not individually exceed the 10^{-4} ELCR end of the NCP risk range (Table 6-29).

Table 6-29. Summary of 90th Percentile Current Groundwater Concentrations, Associated Cancer Risk and Associated Sum of Fractions for Radioactive COPCs

COPC	90th Percentile Value (pCi/L)	Federal or State MCL (pCi/L)	ELCR at Federal MCL	Individual Fraction	Individual ELCR
Carbon-14	1,470	2,000	5.9×10^{-5}	0.74	4.3×10^{-5}
Sr-90	7.3	8	8.5×10^{-6}	0.91	7.7×10^{-6}
Tritium	34,500	20,000	1.9×10^{-5}*	1.7	3.3×10^{-5}
Sum of Fractions				**3.4**	**-**
Cumulative Annual Dose (mrem)				**13**	**-**
Cumulative ELCR for Radioactive COPCs				**-**	**8.4×10^{-5}**

* An excess lifetime cancer risk for tritium, which includes the ingestion and inhalation exposure routes, would be 1.3×10^{-4}. The ELCR for tritium would be 1.9×10^{-5} for the ingestion exposure route only.

MCL = derived single-nuclide MCL-equivalent activity concentration

COPC = contaminant of potential concern

MCL = maximum contaminant level

6.4 Risk Assessment Conclusions of the Riparian and Nearshore Environment from RCBRA

The assessment of human health risks was based on "broad-area" environmental data that characterized concentrations of COPCs in upland and riparian surface soils, river water and sediment, and fish tissue.

The exposure scenarios considered for riparian and near-shore areas were an Avid Angler, Casual User and Tribal scenarios, including Nonresident Tribal scenario, and ingestion of fish in the CTUIR and Yakama residential scenarios. The Casual User scenario addresses occasional recreational use and is focused on activities such as walking and picnicking in riparian areas near the river. The Avid Angler is focused on individuals who are not engaged in a subsistence lifestyle. The Avid Angler application is associated with exposure in the near-shore region of the River Corridor, and takes into consideration potential exposures to sediments and fish. The Nonresident Tribal scenario is focused on individuals engaged in a subsistence lifestyle who reside offsite but use the River Corridor for various activities such as hunting, gathering plants, and fishing.

EPCs in soil in the riparian environment were calculated using MULTI-INCREMENT® sampling from riparian locations in the 100-K OU (*100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan* [DOE/RL-2005-42]). Discrete sediment samples used to calculate EPCs were obtained from sites in the River Corridor selected from locations of known groundwater plumes, areas of groundwater discharge to the river, results of past biota sampling locations, or areas of fine-grained sediment deposits. Data from sculpin, clams, and benthic macroinvertebrates (primarily crayfish) were used to estimate fish ingestion risks to Avid Angler and Nonresident Tribal Receptors.

The results of the broad area risk assessment in the 100-K OU area for the Casual User and Avid Angler scenarios showed that lifetime cancer risks generally were near or below 1×10^{-6} and were below a noncancer HI of one for direct exposures to soil, sediment, and surface water.

Risks for riparian soils were higher than 1×10^{-4} cancer risk and above a noncancer HI of one for the Nonresident Tribal scenario. Modeled concentrations of arsenic and carbon-14 from riparian soil into native vegetation provided the largest contribution to cancer risks and noncancer hazard indices. However, as discussed in the RCBRA, uncertainties in the food chain modeling methods considerably overstate risks from plant ingestion exposure pathways, particularly for arsenic. Cancer risks from fish ingestion, based on data in sculpin and clams, were higher than 1×10^{-4} for the Tribal scenarios.

Carbon-14 was detected in riparian soil sample "RCBRA 2CRIP" at a concentration of 12 pCi/g, which is less than the residential RBSL of 81 pCi/g. Carbon-14 was also detected in riparian soil sample "RCBRA RIP5" at concentrations of 22 pCi/g and 112 pCi/g, one detection is above the residential RBSL of 81 pCi/g. The carbon-14 detection is from an MIS collected from a location near the 116-K-2 Trench waste site.

Carbon-14 was the risk driver for fish ingestion. While carbon-14 was also detected in some sediment samples near the 100-K OU area, the RCBRA concluded that carbon-14 related to the 100 K OU area plume would not be expected to impact food fish with large home ranges. Cancer risk estimates based on the combination of localized concentrations in sculpin with subsistence ingestion rates are probably overstated. Fish tissue was collected as part of the Colunbia River RI fish sampling program specifically to support the human health risk assessment of the CRC. Carbon-14 was identified as a COPC in one of six fish tissue samples collected from a Bridgelip sucker.

Based on the results from this analysis, carbon-14 is a COPC in riparian soils that warrants further evaluation in the FS. Carbon-14 is also identified as a COPC in fish tissue, which will warrant further evaluation the the Columbia River RI. There are no COPCs in the near-shore sediments and surface water that warrant further evaluation in the FS. Uncertainties in the estimation of human health risks, as described in the RCBRA, suggest that these risks have been considerably overstated.

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6.5 Summary and Conclusions

The supplemental soil and groundwater risk evaluation for the 100-K source and groundwater OU accomplishes the following objectives:

- Proposes direct contact PRGs in soil for use in the FS from values presented in the RCBRA.
- Evaluates the effectiveness of source interim actions for the 100-K Source OU.
- Evaluates that wastes sites are remediated to the remedial action objectives and remedial action goals published in the 100 Area RDR/RAWP (DOE/RL-96-17) and also achieve the direct contact PRGs proposed for the FS (in other words, sites cleaned up under interim action do not need to be revisited in the FS to demonstrate protection of human health).
- Identifies the waste sites and contaminants of concern in the vadose zone that require further evaluation in the FS.
- Waste sites that have not been remediated are carried forward into FS.
- Identifies the contaminants of concern in groundwater that require further evaluation in the FS.

The methodology used to assess risks for the RI/FS uses PRGs developed in the RCBRA, and incorporates the most current agency guidance. COPCs in the vadose zone and groundwater were identified in a conservative manner, using exclusions identified in the RCBRA to identify COPCs. The methods for developing EPCs are based on EPA's ProUCL guidance manual. The residential scenario used to develop PRGs and characterize risks to human health from contaminants in the vadose zone is drawn from the scenario that was used to develop cleanup levels for the 100 Area RDR/RAWP (DOE/RL-96-17), and was brought up to date to be consistent with most recent regulatory guidance. PRGs for the vadose zone were developed to reflect a range of exposure scenarios include those that represent the remedial action objectives (residential scenario) and reasonably anticipate future land use (resident-Monument worker and casual-recreational user).

Contaminant concentrations in groundwater were compared with a range of groundwater and surface water standard for protection of human health and aquatic organisms. In addition, risks from contaminants in groundwater were assessed using Tribal scenarios based on assumptions provided by the CTUIR and Yakama Nation. The EPA tap water scenario is also evaluated to provide a similar scenario using exposure assumptions that represent reasonable maximum exposure.

Cumulative risks were calculated for multiple contaminants and multiple exposure pathways by exposure media (i.e., soil or groundwater). Cumulative risks summed across soil and groundwater were not calculated for the residential scenario because the RME for this scenario does not include combined exposures to both media; therefore, they are presented separately.

The protection of groundwater and surface water from contaminants currently in the vadose zone was discussed in Chapter 5. The ecological risk assessment that evaluates the protection of terrestrial receptors is discussed in Chapter 7.

6.5.1 Conclusions for the Supplemental Soil Risk Evaluation

The principal contaminants in the vadose zone are radionuclides and metals. The radionuclides can be categorized as being related to waste disposal, including cesium-137, cobalt-60, europium-152, europium-154, and Sr-90. Cancer risks associated with the resident-Monument worker scenario are similar to the residential scenario. Cancer risks for a casual-recreational user scenario are approximately two orders

of magnitude lower than the residential scenarios. The risks from those radionuclides in the top 4.6 m (15 ft) of the vadose zone that are related to waste disposal are no greater than 2×10^{-4}, under the residential, resident monument worker, and casual recreational user scenarios. This slight exceedance of target risk thresholds is a result of health protective levels being updated from a target annual dose rate of 15 mrem/yr to a target risk of 1×10^{-4} to be consistent with *Radiation Risk Assessment At CERCLA Sites: Q & A* (EPA/540/R/99/006).

Deep zone soil samples are compared to RBSLs developed for the residential exposure scenario, although residents are unlikely to be exposed to contaminants in deep zone soil. Deep zone soil samples are collected from depths greater than 4.6 m (15 ft) bgs, as a result, direct contact within the point of compliance is incomplete. Additionally, the residential exposure scenario does not reflect reasonably anticipated future land use in the River Corridor. This comparison is included because it is the most conservative land use basis for the evaluation of waste sites and presentation of these results is only included to provide additional information for risk management decisions. The following summarizes the waste sites that warrant further evaluation in the FS.

Waste site 100-K-56:1, 116-K-1, and 116-K-2 are reported with concentrations of one or more radioisotopes (Cs-137, Co-60, Eu-152, Eu-154, or Ni-63) in the deep zone. These waste sites will decay to residential RBSLs within 10 and 140 years.

The principal nonradioactive COPCs are metals, PCBs, and PAHs. For all exposure scenarios, the cancer risks and noncancer hazard indices for nonradioactive contaminants fell within EPA's target risk ranges. In one decision unit, risks from PAHs in vadose zone material were higher than the state of Washington's target risk of 10^{-6} for individual carcinogens and 10^{-5} for cumulative risk from multiple carcinogens. Concentrations of arsenic in vadose zone material are associated with cancer risks higher than 10^{-6} under unrestricted (residential) exposure assumptions. The concentrations of arsenic in vadose zone material posing risks greater than 10^{-6} are consistent with site-wide naturally occurring background in vadose zone material.

The results from several of the waste sites are based on small data sets, which create uncertainties in obtaining reliable exposure point concentrations in vadose zone material. The uncertainties relating to small data sets could result in risks either being over- or understated. EPCs selected for shallow zone and deep zone decision units represent verification data collected from the floor and the sidewall of the excavated waste site. EPCs developed from the floor and sidewall of the excavated waste site overstates risk because the contaminant is assumed to be uniformly distributed across the entire decision unit and exposure is assumed to occur at the surface. However, these sample locations are actually at depth and take no credit for the existing clean backfill that covers the remediated waste site. Should the contaminants be disturbed in the future, their distribution within decision unit would be blended with the clean backfill resulting in an overall reduction of the exposure point concentration for the decision unit. The approach for identifying COPCs is conservative because it excludes few contaminants and, therefore, probably overstates risks. The exposure factors and toxicity values used to develop the PRGs generally are conservative and tend to provide upper bound estimates of risks in vadose zone material.

Based on the results of the supplemental soil risk evaluation for the 100-K Source OU, cleanups in vadose zone material conducted as part of the interim actions appear to have been effective in reducing human health risks to within EPA's target risk range. In some cases, residual risks are higher than the State of Washington's cancer risk threshold; however, in all cases, the contaminant exceeding the State of Washington's cancer risk threshold is arsenic and is present at concentrations consistent with naturally occurring background. Cleanup of shallow vadose zone material (4.6 m [15 ft]) to achieve residential or unrestricted uses is also protective of a range of exposure scenarios, including a casual recreational user and a resident-Monument worker. While concentrations of radionuclides in deep soil (deeper than 4.6 m

[15 ft]) are associated with risks to residents that are higher than EPA's risk reduction ranges, these concentrations do not pose significant risks, and would decay to levels protective of future residents within 50 to 60 years.

6.5.2 Conclusions for the Supplemental Groundwater Risk Evaluation

The principal contaminants in groundwater are metals and a few radionuclides (carbon-14, Sr-90, and tritium), nitrate, and two VOCs (chloroform and trichloroethene). The EPCs in groundwater were compared with federal and state surface water standards for protection of human health and aquatic organisms, primary and secondary MCLs, and state groundwater cleanup levels.

The EPC for tritium in groundwater is greater than the federal MCL developed for the protection of human health. Tritium is identified as a COPC, indicating the need to evaluate potential remedial technologies for tritium in the FS. Although the EPCs for carbon-14, Sr-90, and trichloroethene are less than their respective MCLs, they are present at concentrations above the MCL in localized areas. Although the EPCs for carbon-14, Sr-90, and trichloroethene are less than the federal MCL developed for protection of human health, their presence warrants design considerations for any engineered controls or remedial actions performed in this OU.

Metals concentrations in groundwater higher than ambient water quality standards and state groundwater cleanup levels are chromium and Cr(VI). Tthe EPCs for chromium and Cr(VI) in groundwater both are higher than the ambient water quality criteria for protection of aquatic receptors. In addition, the EPC for chromium is greater than the federal MCL. Therefore, the EPCs for both chromium species are greater than the MCL or AWQC developed for the protection of human health or aquatic organisms, indicating the need to evaluate potential remedial technologies for chromium and Cr(VI) in the FS.

The EPC for nitrate was greater than the federal MCL and is not considered protective of human health, indicating the need to evaluate potential remedial technologies for nitrate in the FS.

The EPC for chloroform was greater than the MTCA Method B groundwater cleanup level, which is based on a 1×10^{-6} target cancer risk level. However, the cumulative risk for chloroform is less than the "Human Health Risk Assessment Procedures" (WAC 173-340-708) cumulative risk level of 1×10^{-5} for multiple contaminants. The EPC for chloroform is also less than the federal MCL. The results of the evaluation for chloroform does not indicate the need to evaluate potential remedial technologies in the FS.

Based on the results of the supplemental groundwater risk evaluation, the following analytes are identified as COPCs and indicate the need evaluate potential remedial technologies in the FS: carbon-14, Sr-90, tritium, trichloroethene, chromium, Cr(VI), and nitrate.

A number of metals, nitrite, and carbon tetrachloride have been historically present in groundwater. These analytes have been detected at concentrations above their action level on an infrequent basis, and their presence cannot be associated with a specific location nor are they associated with a trend. As a result, these analytes are considered uncertainties and warrant further evaluation in the FSand monitored with an appropriate trace analytical method. The following analytes are identified with an uncertain status and require monitoring:

- Arsenic, beryllium, cadmium, cobalt, copper, lead, nitrite, and carbon tetrachloride

In addition to the chemical-specific ARARs analysis, risks were evaluated using the Native American scenarios and the EPA tap water scenario. The total cumulative ELCRs for the CTUIR and Yakama Nation exposure scenarios are 9.3×10^{-4} and 9.8×10^{-4}, respectively, when groundwater used as a drinking water source. The primary contributors to risk for the Native American exposure scenarios are

carbon-14, chloroform, tritium, Sr-90, and trichloroethene. The total ELCR for the EPA tap water scenario is 2.2×10^{-4}. The primary contributors to risk are the same for the EPA tap water scenario and the Native American scenarios. The total HI is 6.1 for both the CTUIR and Yakama Nation exposure scenarios. The HI for the EPA tap water equations is 3.1. Cr(VI) is the primary contributors to the noncancer HI for the Native American scenario and the EPA tap water exposure scenario.

The cumulative ELCR is 7.9×10^{-2} for nonradiological COPCs and 9.5×10^{-5} for radiological COPCs, when groundwater is used as a source of steam for a sweat lodge for the CTUIR exposure scenario. The cumulative ELCR for the CTUIR scenario is greater than the EPA upper target risk threshold of 1×10^{-4}. For the Yakima Nation exposure scenario, the cumulative ELCR is 1.6×10^{-1} for nonradiological COPCs and 2.0×10^{-4} for radiological COPCs, both of which are greater than the EPA upper target threshold of 1×10^{-4}. For both scenarios, the individual ELCR value for Cr(VI) is greater than the EPA upper target risk threshold of $1 \times 10^{-4}$and the individual ELCR values associated with chloroform, cobalt, trichloroethene, carbon-14, tritium, and Sr-90 are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI is 18 for the CTUIR scenario and is 37 for the Yakima Nation exposure excenario,, both of which is greater than the EPA target HI of 1.0. The primary contributor to the noncancer HI is Cr(VI) with an HQ of 11 for the CTUIR exposure scenario and the primary contributors for the Yakima Nation exposure scenario are Cr(VI) with an HQ of 22, and barium with an HQ of 1.6.

The key uncertainties in the assessment of groundwater risks are with the assessment of dermal contact exposure pathways, selection of the toxicity value for trichloroethene, and recent developments with the toxicity value for Cr(VI). The evaluation of potential risks from VOCs is based on ingestion and inhalation exposure pathways and does not consider exposure through dermal contact with water. Not including the dermal contact, exposure pathway potentially results in risks from these contaminants being understated. The cancer slope factor used by the State of Washington to develop the Method B groundwater cleanup level for trichloroethene has not yet been updated to reflect current agency guidelines. Use of this toxicity value overstates risks from trichloroethene by approximately a factor of 7-fold. Use of a current cancer slope factor would decrease the groundwater risk from trichloroethene to less than 1×10^{-6}. Ingestion exposure to Cr(VI) currently is assessed as a noncarcinogen for purposes of developing groundwater cleanup levels for protection of human health and Cr(VI) currently does not have a federal MCL. However, some state agencies, particularly the New Jersey Department of Environmental Protection, have developed a cancer slope factor for Cr(VI). Assessing ingestion of Cr(VI) in groundwater as a carcinogen is not yet incorporated into regulatory requirements or guidance at this time; however, groundwater standards for protection of human health for Cr(VI) would be considerably lower if these were based on carcinogenic effects.

The results from the assessment of groundwater risks were based on three additional rounds of groundwater sampling across the 100-KR-4 Groundwater OU, which were intended to provide a more definitive identification of contaminants of potential concern. The results of this supplemental groundwater risk evaluation did not identify any COPCs in addition to those identified in the work plan. The results of the supplemental groundwater risk evaluation identified tritium, carbon-14, Sr-90, chromium (including Cr(VI)), and nitrate as contaminants warranting further evaluation in the feasibility study.

7 Ecological Risk Assessment

Highlights

- The ecological risk assessment evaluated soil contaminant concentrations at interim closed and no action waste sites.
- The screening levels for radionuclides were not exceeded.
- The baseline risk assessment and ecological risk assessment indicate that interim remedial actions that have been completed at 100-K under interim action ROD remedial action goals are protective of human health and the environment.

The integration of past and ongoing ecological risk assessments supports the development of remedial alternatives for waste sites and contaminated groundwater in the 100-K OUs. These risk assessments have been integrated with the cleanups performed under the interim action RODs to identify the need for further remedial action and development of ecological PRGs.

As described in the previous chapters, the remedial actions completed to date in the River Corridor were implemented under interim action RODs. The RAOs in the 100 Area interim action RODs were developed to achieve protection of human health from direct contact with vadose zone material or to protect groundwater and surface water from contaminants leaching from vadose zone material. Protection of ecological receptors from direct contact with contaminated vadose zone material was not addressed directly in the Interim action RODs, but indirectly with the assumptions that attainment of standards for protection of human health or that reduced contaminant leaching would also be protective of ecological receptors.

CERCLA requires a baseline risk assessment to characterize current and potential threats to human health and the environment prior to issuance of the ROD. The source and groundwater component of the RCBRA was prepared to address the regulatory requirement to perform a baseline risk assessment. The RCBRA was a comprehensive examination of current and potential risks in areas potentially affected by Hanford Site processes within the 100 and 300 Area OUs. One of the objectives of the RCBRA was to determine if the interim actions were protective of ecological receptors (*Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* [DOE/RL 2004-37]). The scope of the RCBRA addressed the following portions of the River Corridor:

- Upland areas, including remediated CERCLA waste sites within 100-BC, 100-D, 100-F, 100-H, 100-K, and 100-N; the White Bluffs and Hanford townsites; and the 300 Area
- Riparian and nearshore aquatic zones on the south and west shoreline of the Columbia River on the Hanford Site
- Groundwater and areas of groundwater emergence on the south and west shoreline of the Columbia River on the Hanford Site.

The RCBRA used multiple measures of exposure, ecological effect, and ecosystem/receptor characteristics to evaluate risks at 20 study sites across the River Corridor associated with remediated waste sites (10 excavated/backfilled sites and 10 surface removal/native soil sites) and 10 reference areas, as described in the RCBRA SAP (DOE/RL-2005-42). The sites studied were selected from high priority waste sites that had been remediated at the time the study was developed and represent the types of waste sites and remedial actions addressed by the interim action RODs. Based on this set of study sites, the results from the RCBRA identified some contaminants in soil as contaminants of ecological concern. Contaminants of ecological concern principally were metals and pesticides.

The study design of the ecological risk assessment in the RCBRA provided risk conclusions that applied across the entire 100 Area. The study design, coupled with results that identified contaminants of ecological concern across the River Corridor, required development of a supplemental ecological risk

evaluation approach for the RI/FS that allowed evaluation of risks on a site-by-site basis as well as supported development of PRGs. That approach incorporates the use of ecological soil screening levels (SSLs) and ecological preliminary remediation goals (PRGs), which have been developed using the tiered process as outlined in the report *Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-00784) and *Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-01311), respectively. This tiered process allows the incorporation of more sophisticated ecological risk assessment methods and increasing levels of ecological site-specific information, to provide SSLs and PRGs that are more representative of Hanford Site conditions. Development of the risk-based concentration values (SSLs) and PRGs incorporates the problem formulation, the conceptual ecological exposure models, and selected bioaccumulation data sets developed in the RCBRA. These values were used to screen the 16 waste sites in the 100-K OUs with verification sampling and analytical information, to provide site-specific ecological risk information for each site.

The following approach has been used for addressing ecological risks potentially associated with waste sites in the 100-K OUs:

- **Updating the identification of COPCs (Section 7.1).** The RCBRA went through a process to identify COPCs for ecological receptors, based on a site-wide review of River Corridor data. This identification process has been updated to account for verification sampling data specifically in individual 100-K waste sites. Sixteen waste sites from the 100-K Source OUs were evaluated in the RCBRA. Three additional waste sites have been remediated at the 100-K Source OUs since 2005, and are not addressed in the RCBRA.

- **Presenting the problem formulation (Section 7.2).** This section summarizes the problem formulation used in developing the risk-based concentration values used in this evaluation as ecological SSLs. This problem formulation reflects conditions in upland environments across the Hanford Site, and incorporates information developed from the RCBRA.

- **Presenting effects and exposure assessments (Section 7.3).** This section summarizes the quantitative assessments used in developing the Tier 1 and Tier 2 risk-based concentration values, including the wildlife exposure factors, biotransfer factors, and wildlife toxicity reference values. The data and methods used to develop risk-based concentrations protective of plants and soil invertebrates are discussed in this section. More detailed descriptions of the data and methods used to calculate all of the ecological risk-based concentrations in soil are presented in *Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-00784) and *Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-01311). In addition, these values are also incorporated into the ecological risk assessment volume (Volume 1) of the RCBRA.

- **Updating the ecological risk characterization for 100-K waste sites (Section 7.4).** Verification sampling and analysis data for the 16 100-K waste sites were used to calculate EPCs, which were then compared with the ecological SSLs, and as appropriate, the PRGs. The results from these comparisons were used to identify receptors of interest and contaminants of ecological concern, for purposes of identifying the need for further action at 100-K sites. In addition, the results of this risk characterization were used to determine which of the risk-based concentration values should be recommended for use as PRGs.

Section 6.3 evaluates the protection of aquatic receptors from groundwater that has the potential to discharge to the Columbia River because the approach used to identify COPCs that warrant further evaluation in the FS is based on comparison of groundwater concentrations to the lowest available

chemical-specific ARARs published for the protection of human health and aquatic receptors. Combining the evaluation of human health provides a streamlined approach that addresses the restoration of groundwater to highest beneficial use and the protection of aquatic receptors.

In addition to the analysis of waste sites, Chapter 7 summarizes an evaluation of ecological risks in riparian and nearshore areas based on the analysis developed in the RCBRA and risk in the Columbia River developed for the CRC. Chapter 4 evaluates ecological risks identified within the Columbia River and the relationship between potential sources to the Columbia River in the 100-K OU, transport pathways, and ecological receptors. The RCBRA evaluated risks to an array of assessment endpoints using multiple measures of exposure, effect, and ecosystem/receptor characteristics at representative nearshore study sites. The study sites were selected to represent locations that may be adjacent to or directly affected by known contaminated media (groundwater seeps and springs, soil, sediment). The assessment conducted in the RCBRA has been supplemented through the development of a conceptual model depicting the relationships between sources in the 100-K OU and riparian and nearshore media (soil, sediment, pore water and surface water). This conceptual model is presented as Appendix L.

7.1 Identification of Contaminants of Potential Concern

This section describes the sources of data used in the supplemental ecological risk evaluation, the data quality assessment and data validation process, and the process for identifying COPCs in soil. Three different data sets were evaluated for this supplemental ecological risk evaluation: CVP data collected within 16 waste sites in the 100-K Source OU, riparian and nearshore data collected for the RCBRA, and the data collected for the CRC. Only the CVP data are discussed at length in Chapter 7, with the RCBRA data discussion in Appendix L, and the CRC data discussion in Chapter 4. During the course of this risk evaluation, COPCs were examined to identify COPECs estimated to pose a site-related ecological risk to receptor populations and to provide input to required risk management decisions. The COPECs will be carried into the risk management decisions at the end of this supplemental ecological risk evaluation, which will identify the chemicals of ecological concern (COECs) to be carried into the FS.

7.1.1 Data Summary

Remediation of waste sites in the 100-K Source OUs began in 2003. The RCBRA included evaluation of 20 waste sites and CVP data from 16 waste sites. Of the 20 waste sites directly evaluated, only 2 were from within the 100-K OUs. However, the 20 evaluated in the RCBRA represent the range of residual conditions at the surface. This supplemental risk evaluation included CVP verification sampling and analysis data for 16 waste sites in the 100-K Source OUs. Thirteen of the 16 waste sites from the 100-K Source OUs were evaluated in the RCBRA Report (DOE/RL-2007-21). Table 6-1 summarizes the waste sites, associated decision unit(s), and reclassification status for the 100-K Source OUs. The waste sites listed in Table 6-1 are a subset of the waste sites that were listed in Appendix C, Table C-1, of the 100-K Work Plan (DOE/RL-2008-46-ADD2). The following sources of analytical data were used in the soil risk assessment:

- All verification sampling and analysis soil data reside in the ENRE.
- All verification sampling and analysis soil data also reside in the HEIS database.

All the closeout verification data used in this risk evaluation are included in Appendix D of this report.

7.1.2 Data Quality Evaluation

A data quality assessment (DQA) is performed and reported in each closeout documentation report. The DQA compares the verification sampling approach and resulting analytical data with the sampling and data quality requirements specified by the project objectives and performance specifications. The DQA determines if the data are of the right type, quality, and quantity to support site cleanup verification

decisions within specified error tolerances. The DQA also determines if the analytical data are found acceptable for decision making purposes and if the sample design was sufficient for the purpose of clean site verification. The cleanup verification sample analytical data and detailed DQA are summarized in the appendices associated with the cleanup verification packages. The results of each DQA are incorporated by reference and no further DQA was performed as part of this risk assessment.

All of the analytical data are then evaluated and a portion is validated for compliance with QA project plan requirements as documented in the 100 Area RDR/RAWP (DOE/RL-96-17). Data evaluation is performed to determine if the laboratory carried out all steps required by the SAP and the laboratory contract governing the conduct of analysis and reporting of the data. This evaluation also examines the available laboratory data to determine if an analyte is present or absent in a sample and the degree of overall uncertainty associated with that determination.

7.1.3 Identification of COPCs

All analytes detected at least once in a waste site decision unit for the 16 waste sites included in the risk evaluation are identified as COPCs. As described in Section 6.2.2.2, the floor and sidewalls of an excavated waste site are divided into one or more decision units (e.g., shallow zone and overburden). Verification sampling and analysis data are collected according to sample design requirements for the type of decision unit. For the purpose of this supplemental ecological risk evaluation, an "exposure area" and a "decision unit" are operationally defined as being the same. Verification sampling and analysis data are subsequently grouped to calculate exposure point concentrations

The contribution from naturally occurring metals and anthropogenic radioisotopes is discussed in the risk characterization section in accordance with *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003). The risk characterization will discuss elevated background concentrations and their contribution to site risks as well as naturally occurring elements that are not CERCLA hazardous substances, pollutants, and contaminants but exceed the risk-based screening levels (i.e., RBSLs).

The RCBRA identifies a subset of analytes that are excluded from consideration as COPCs by agreement among the Tri-Parties based on relevant Hanford Site data. The following exclusion lists employed in the RCBRA Report (DOE/RL-2007-21) were also applied to the waste site verification data during the data reduction steps described in Section 6.2.2.2:

- **Radionuclides with a half-life of less than three years:** Radionuclides with half-lives less than 3 years would not be present as a result of historical Hanford Site operations due to radioactive decay that would have occurred since operations ceased.

- **Essential nutrients:** Essential nutrients that are present at relatively low concentrations and are toxic only at high concentrations need not be considered in a quantitative risk assessment.

- **Water quality or soil physical property measurements:** These analytes were measured to obtain information on water quality or soil properties to understand potential confounding factors for bioassays conducted for soil, sediment, or water or to interpret their influence on the toxicity of COPCs (e.g., grain size for soils, water hardness for metal effects).

- **Background radionuclides (potassium-40, radium-226, radium-228, thorium-228, thorium-230, and thorium-232):** As identified and implemented in the RCBRA, these background radionuclides were identified by consensus of Tri-Party managers as not directly related to Hanford operations or processes.

The RCBRA includes two additional steps to identify COPCs that the supplemental soil risk evaluation did not apply:

- Analytes that are commonly reported in waste site cleanup verification reports based on frequency of detection. Inclusion list analytes were not consistently reported in the CVP and RSVP data; therefore, this step was not implemented.

- Evaluate remaining analytes as candidate COPCs, based on comparisons to Hanford Site background, reference areas, and an "analyte-specific" evaluation.

As a result of not applying the last two steps used in the RCBRA to identify COPCs, more analytes are identified as COPCs in the ERA than were identified in the RCBRA. Identifying all detected analytes (except those on the exclusion list) as COPCs is a more streamlined approach that is consistent with *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (EPA 540-R-01-003).

In addition to the steps described above, aluminum and iron were excluded as COPCs for all decision units within the 100-K Source OUs. The Eco-SSLs for aluminum and iron are based on soil pH (*Ecological Soil Screening Level for Aluminum: Interim Final* [OSWER Directive 9285.7-60]), and the potential for toxicity is identified in soils when the pH is 5.5 or less. While some concentrations of aluminum may have exceeded this risk-based value, all measurements of soil pH in the River Corridor are greater than the 5.5 threshold. Data collected during the RCBRA (RCBRA Report [DOE/RL-2007-21]) indicated that pH in soils range between 7 and 9. Thus, aluminum and iron concentrations are not bioavailable and do not pose a risk to ecological receptors.

The COPC list will be evaluated to develop a COPEC list in this risk assessment. A COPEC is defined as a COPC with concentrations exceeding both the background concentration and ecological screening level. The process to identify COPECs is discussed in Section 7.4.

7.2 Problem Formulation

The problem formulation includes the physical layout of the site, its history and ecology, and the development of a CSM that evaluates potential exposure pathways and identifies the representative species that were used to assess ecological risk to those and other similar species. The problem formulation includes identification of the important aspects of the 100-K Source OUs waste site areas to be protected (referred to as "assessment endpoints"), and the means by which the assessment endpoints are evaluated (measures of exposure and effects).

7.2.1 Site Setting

The 100-K Source OUs are situated between 100-BC and 100-N (Figure 1-1), and collectively cover an area of approximately 22 km^2 (8.49 mi^2). The Columbia River section along the 100-K Source OUs defines a portion of the Hanford Reach, an important ecological, cultural, historical, and recreational feature. This upland environment is described here while the riparian and nearshore habitats are described in the conceptual model presented in Appendix L.

The predominant plant community in the 100 Area is sagebrush/Sandberg's bluegrass/cheatgrass. No plant species on the Hanford Site are currently listed as threatened or endangered under the *Endangered Species Act of 1973*. Plant species listed as threatened or endangered by Washington State include the awned halfchaff sedge (*Lipocarpha aristulata*), grand redstem (*Ammannia robusta*), lowland toothcup (*Rotala ramosior*), and persistentsepal yellowcress (*Rorippa columbiae*). All of these plant species are restricted to wetlands in the riparian zone of the Columbia River (*Hanford Site National Environmental*

Policy Act (NEPA) Characterization [PNNL-6415, Rev. 13]). Table 3-18 presents the complete list of state-listed flora.

While shrub and grassland habitats supporting a variety of wildlife species dominate the Hanford Site, the 100 Area is predominantly developed and use of this area by wildlife is expected to be minimal. Common species include large animals like Rocky Mountain elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*); predators such as coyote (*Canis latrans*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*); and herbivores including deer mice (*Peromyscus maniculatus*), harvest mice (*Riethrodontonomys megalotis*), ground squirrels (*Spermophilus* spp.), voles (*Lemmiscus curtatus, Microtus* spp.), and black-tailed jackrabbits (*Lepus californicus*). The most abundant mammal on the Hanford Site is the Great Basin pocket mouse (*Perognathus parvus*). Other nonburrowing animals including cottontails (*Sylvilagus nutalli*), jackrabbits, snakes, and burrowing owls (*Athene cunicularia*) may use abandoned burrows of other animals.

Peregrine falcons are rare visitors to the Hanford Site and are currently listed as threatened or endangered under the *Endangered Species Act of 1973*. These species, which generally use the same areas as the bald eagles (river shores), are addressed under *Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington Hanford Site, South-Central Washington* (DOE/RL-94-150). Species listed as threatened or endangered by Washington State include such species as the burrowing owl (*Athene cunicularia*), Merriam's shrew (*Sorex merriami*), and Washington ground squirrel (*Urocitellus washingtoni*). However, no species are known to be located onsite or expected to occur onsite due to the highly developed nature of this area. Appendix H presents the complete list of state listed fauna.

Although the bald eagle has been removed from the list of federally endangered species, it is still protected under the *Bald and Golden Eagle Protection Act of 1940*. In addition, DOE has decided to continue to protect nest and roost sites on the Hanford Site under *Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington Hanford Site, South-Central Washington* (DOE/RL-94-150). This plan is currently under revision to account for the de-listing of the bald eagle. Changes have been made to reduce the buffer zones surrounding winter night roosts and nest sites from 800 to 400 m.

Bald eagles have generally been observed at the Hanford Site from November to March (Fitzner and Hanson, 1979). During daylight hours, bald eagles perch along the Hanford Reach of the Columbia River and a few kilometers inland (*Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington Hanford Site, South-Central Washington* [DOE/RL-94-150]). The primary perching areas occur in trees from the Hanford town site to the Vernita Bridge. Bald eagles predominantly forage on the banks of the river and the island where waterfowl roost and salmon carcasses can be found. Two roosting sites are located in this same area (*Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington Hanford Site, South-Central Washington* [DOE/RL-94-150]). These areas along the Columbia River are primarily located between 100-D and 100-H, not near 100-K. The 100-K Sources OUs are outside of the nesting buffer zones and important foraging areas. Additional consideration of these species is not required for this risk assessment. Additional site setting discussion is located in Section 3.9 and site history is described in Section 1.2.

7.2.2 Simplified Ecological Exposure Model

Development of the ecological exposure model involves characterizing the exposure pathways and ecological receptors that might be associated with the habitat types in the upland environment of the waste sites within the 100-K Source OUs. Appropriate exposure pathways and representative endpoint species for the upland environment of the 100-K Source OUs were developed based on information from earlier ERAs, primarily the RCBRA.

With consideration of the ecological setting, land use, and COPC release mechanisms and transport pathways known at the 100-K Source OUs upland environments, the ecological exposure pathways considered most plausible are graphically displayed in Figure 7-1 and include the following:

- Direct contact of vegetation with analytes in surface soil (less than 4.6 m [15 ft]) bgs) as defined by the Standard Point of Compliance in the MTCA (WAC 173-340).
- Direct contact with, or ingestion of, surface soil by terrestrial invertebrates (e.g., beetles and ants).
- Direct contact with, or ingestion of, surface soil by terrestrial avian and mammalian wildlife.
- Dietary exposure of terrestrial and mammalian wildlife to COPCs bioaccumulated in food items (e.g., plants or prey).
- Dietary exposure to emissions from radionuclides bioaccumulated and retained within the tissues of plants, terrestrial invertebrates, and terrestrial wildlife.
- External exposure of plants, terrestrial invertebrates, and terrestrial wildlife to emissions from radionuclides in soil.
- Ecological receptors are not likely to have complete exposure pathways to soils below 4.6 m (15 ft) bgs (*Model Toxics Control Act Cleanup Regulation Chapter 173-340 WAC* [Ecology Publication 94-06]). Therefore, deep soil was not evaluated in this supplemental ecological risk evaluation.

A food web model for the upland environment of the Hanford Site (Figure 7-2) has been developed based upon an understanding of the ecology of the area and documented in the previous ERAs. Entities (represented by trophic guilds), and their associated organizational level that have been identified for evaluation, are as follows:

- Terrestrial plants—community level
- Terrestrial invertebrates—community level
- Soil microorganisms and microbial processes—community level
- Herbivorous birds—population level
- Herbivorous mammals—population level
- Insectivorous birds—population level
- Insectivorous mammals—population level
- Omnivorous birds—population level
- Omnivorous mammals—population level
- Carnivorous birds—population level
- Carnivorous mammals—population level
- Reptiles and amphibians[1]

To calculate ecological SSLs, representative endpoint species of functional groups that could use the site were identified. For example, a red-tailed hawk may be considered representative of raptors visiting the site. Consistent with *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments, Interim Final* ([ERAGS], EPA 540-R-97-006), *Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), and "Site-Specific Terrestrial Ecological Evaluation

[1] Although part of the food web for the upland environment, effects data for reptiles and amphibians are limited. Therefore, SSLs were not developed for this trophic guild.

Procedures" (WAC 173-340-7493), endpoint species should preferably be ones that have ecological relevance, are of societal value, are susceptible to chemical stressors at the site, and allow risk managers to meet policy goals. These factors were used to select representative receptor species common to the Hanford Site upland environment that are within the trophic guilds identified above. Selected receptors are conservative indicators of the potential for risk to the trophic guilds identified for evaluation. The representative receptor species selected for each of the trophic guilds are as follows:

- Herbivorous birds—California quail (*Callipepla californica*)
- Herbivorous mammals—Great Basin pocket mouse (*Perognathus parvus*)
- Insectivorous birds—killdeer (*Charadrius vociferus*)
- Insectivorous mammals—northern grasshopper mouse (*Onychomys leucogaster*)
- Omnivorous birds—western meadowlark (*Sturnella neglecta*)
- Omnivorous mammals—deer mouse (*Peromyscus maniculatus*)
- Carnivorous birds (raptors)—red-tailed hawk (*Buteo jamaicensis*)
- Carnivorous mammals—badger (*Taxidea taxus*)

Unlike birds and mammals, methods to differentiate exposure and/or effects among different plant species or among different invertebrate species are unavailable. Therefore, individual species for terrestrial vegetation and invertebrates were not selected to represent the plant or invertebrate populations/ communities for evaluation.

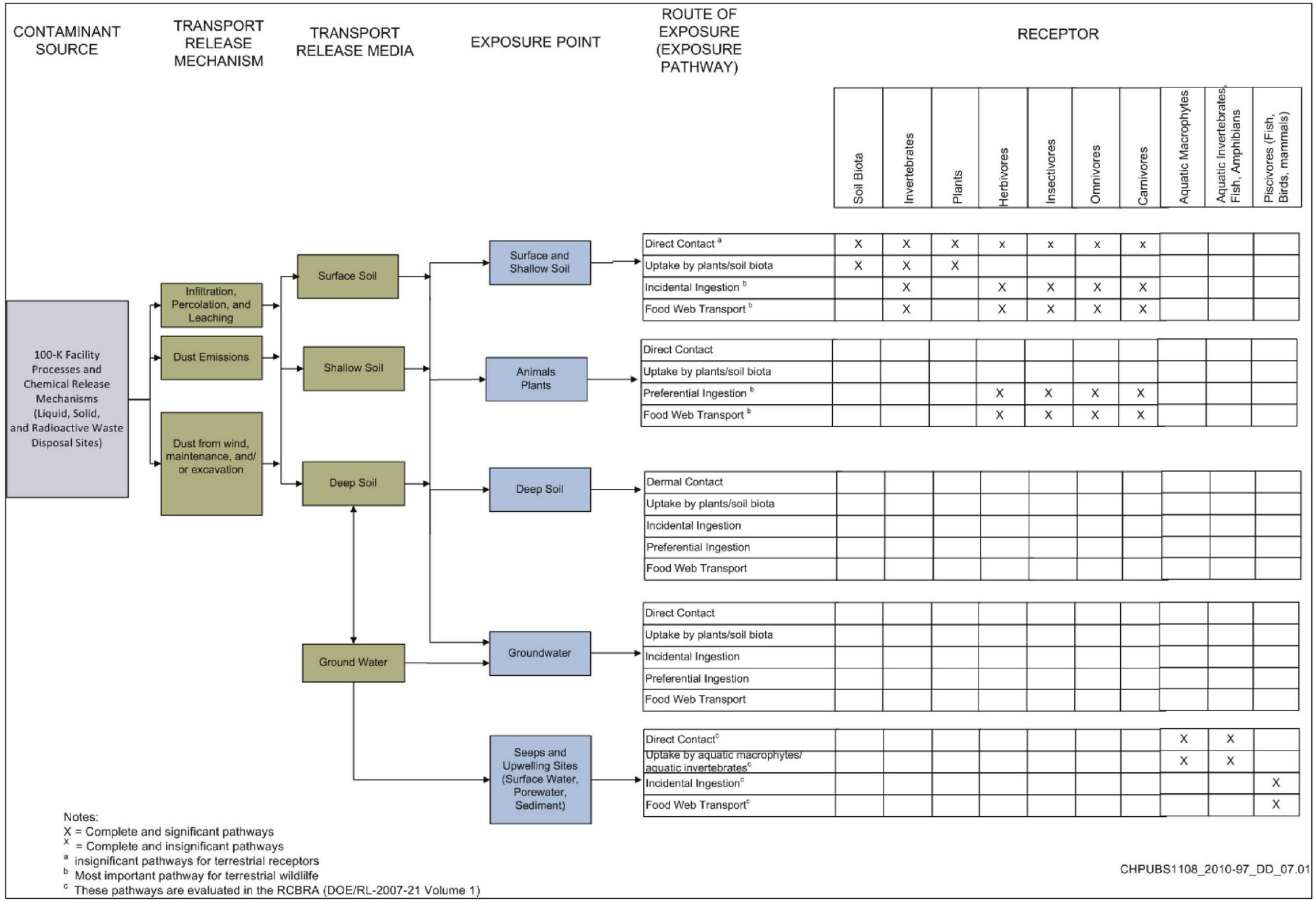

Figure 7-1. Ecological Conceptual Site Model for Terrestrial Habitats in Hanford Site Upland Environment

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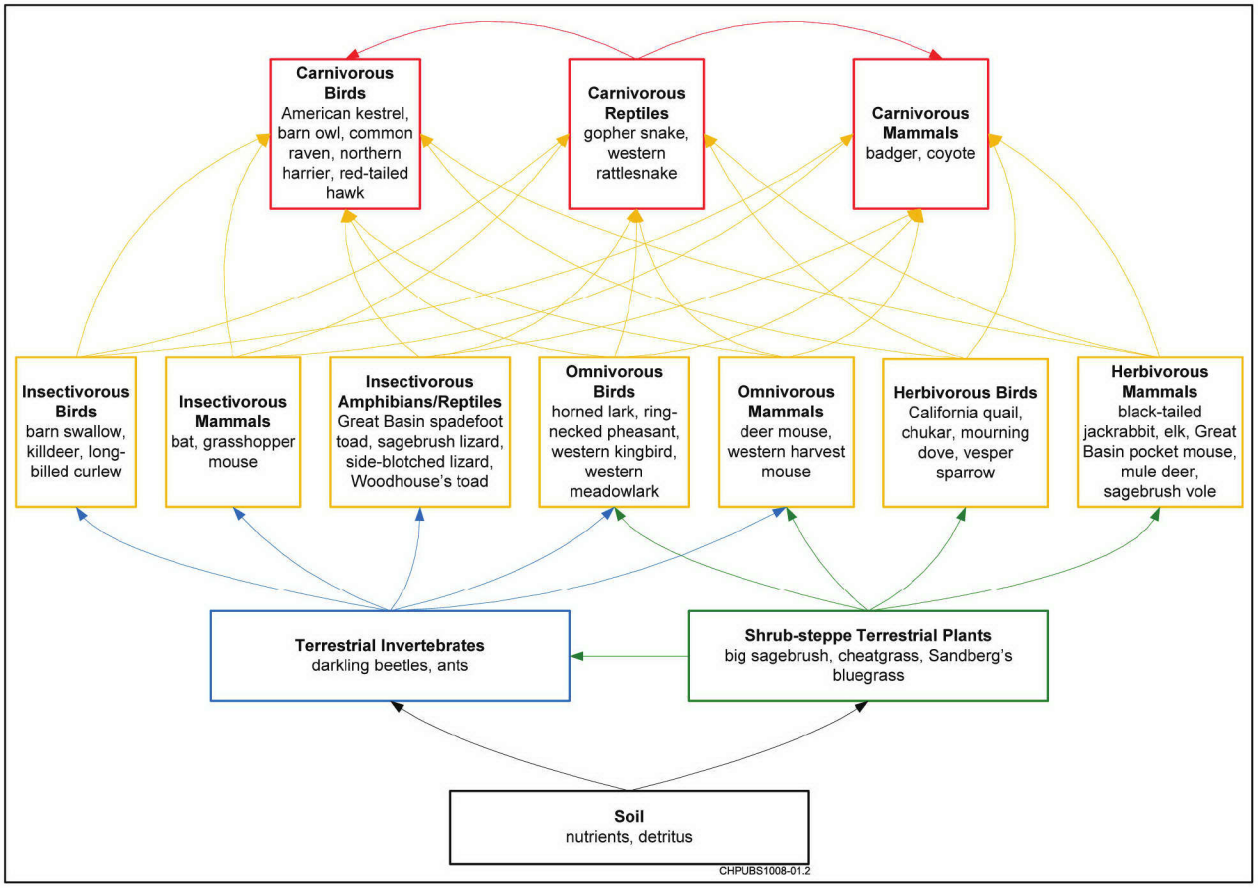

Figure 7-2. Hanford Site Upland Environment Terrestrial Food Web

7.2.3 Assessment Endpoints

Assessment endpoints are an expression of the important ecological values that are to be protected at a site (*Ecological Risk Assessment* [Suter, 1993]; *Guidelines for Ecological Risk Assessment* [EPA/630/R-95/002F]; *Ecological Risk Assessment for Contaminated Sites* [Suter et al., 2000]). Assessment endpoints are based on known information concerning the analytes present, the study area, the ecological CSM, and risk hypotheses. There are three components to each assessment endpoint: an *entity* (e.g., migratory birds), an *attribute* of that entity (e.g., individual survival), and a *measure* (e.g., a measurable value, such as an effect level). Measures are described following the general description of assessment endpoints (*Guidelines for Ecological Risk Assessment* [EPA/630/R-95/002F]; *Ecological Risk Assessment for Contaminated Sites* [Suter et al., 2000]).

The assessment endpoint entities for the 100-K Source OUs waste sites were selected based on the following principal criteria:

- Ecological relevance
- Societal relevance
- Susceptibility (or high exposure) to known or potential stressors at the Hanford Site

The attribute selected for each entity was based on the organizational level of the entity and the primary criteria that were used to select it. Entities and attributes were selected for community and population levels of assessment.

7.2.4 Measures of Exposure and Effects

Measures (formerly referred to as measurement endpoints) are measurable attributes used to evaluate the risk hypotheses and are predictive of effects on the assessment endpoints (*Guidelines for Ecological Risk Assessment* [EPA/630/R-95/002F]). The three categories of measures include the following:

- Measures of exposure are used to evaluate intake of a contaminant from contact with environmental media (e.g., soil). Measures of exposure can be an EPC of a COPC in an environmental medium or food item. A measure of exposure also can be a dose occurring through ingestion, inhalation, or dermal contact with a contaminant in an environmental medium. SSLs were estimated by back-calculating from a target dose associated with the selected assessment endpoint to a corresponding concentration in soil (Section 7.3.1 provides further discussion).

- Measures of effect are used to evaluate the response of an organism that is exposed to a stressor. Measures of effects used in this evaluation include toxicity reference values (TRV) for wildlife and lowest observed effect concentrations (LOECs) in soil for plants and soil invertebrates (Section 7.3.1). The maximum acceptable adverse effect levels generally selected for population- and community-level assessment endpoints are LOECs or lowest observed adverse effects levels (LOAELs), when available.

- Measures of ecosystem and receptor characteristics are used to evaluate the ecosystem characteristics that influence the assessment endpoints, the distribution of stressors, and the characteristics of the assessment endpoints that may affect exposure or response to the stressor. Measures of ecosystem and receptor characteristics are used to characterize ecological risks as part of a baseline ERA. These kinds of ecological information were not used directly in calculating SSLs. However, measures of ecosystem and receptor characteristics may represent additional lines of evidence that can be used along with SSLs in evaluating remedial alternatives in the RI/FS.

7.3 Effects and Exposure Assessment

The effects and exposure assessments were conducted and then integrated to develop two levels of thresholds for evaluating the 100-K data. This follows the tiered-process referred to earlier and as described in ERAGS. The initial evaluation versus conservative thresholds (SSLs) helps to focus the evaluation down to those COPEC-receptor-waste sites combinations that might require further evaluation. The additional evaluation completed with a comparison to PRGs helps identify which COPEC-receptor-waste sites combinations should be brought forward to the scientific management decision point (SMDP) at the end of Chapter 7.

The effects assessment presents TRVs that have been derived from available literature-based toxicity information on COPCs and that can be used in determining the potential for adverse effects to ecological receptors. Two types of effects based values are presented in this supplemental ecological risk evaluation; initial conservative values from the published literature (e.g., Ecology, EPA, and DOE guidance or compendiums) and the more Hanford Site-specific values (values established using data collected at the Hanford Site).

The exposure assessment identifies exposure pathways associated with the representative receptor species listed in Section 7.2.2. As with the effects values, the exposure assessment employs two types of exposure evaluations: the avian and mammalian SSLs and the more site-specific avian and mammalian PRGs. It also describes the models used to calculate SSLs and PRGs.

The TRVs were combined with the exposure information to calculate SSLs and PRGs. This section presents the salient features of the effects and exposure assessments as they were used to calculate the

SSLs and PRGs. An overview of the development of the nonradionuclide and radionuclide SSLs and PRGs is described in the exposure assessment for each receptor group (i.e., plants, soil invertebrates, and wildlife). The methodology used to develop the SSLs is detailed in *Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-00784). The methodology used to develop the PRGs for wildlife is detailed in *Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-01311). The methodology used to develop the Hanford Site-specific risk thresholds and to select PRGs for plants and invertebrates is detailed in *Tier 2 Terrestrial Plant and Invertebrate Preliminary Remediation Goals (PRGs) for Nonradionuclides for Use at the Hanford Site* (ECF-HANFORD-11-0158).

7.3.1 Effects Assessment

The ecological effects assessment consists of an evaluation of available toxicity or other effects information that can be used to interpret the significance of the exposures to COPCs relative to potential adverse effects to ecological receptors. Data that can be used include literature-derived or site-specific single-chemical toxicity data, site-specific ambient-media toxicity tests, and site-specific field surveys (*Ecological Risk Assessment for Contaminated Sites* [Suter et al., 2000]). The effects data used in this supplemental ecological risk evaluation are represented by single-chemical toxicity data from literature sources and are summarized below for nonradionuclides and radionuclides.

7.3.1.1 Radionuclides

Radionuclide toxicity data for plants and wildlife are represented by DOE's Biota Concentration Guides (BCGs) for radionuclides presented in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002). Two radionuclide effect thresholds, as determined by consensus of international radiation regulatory agencies, form the basis for effect thresholds used to develop screening levels of radionuclides in soil for protection of plants and animals. General guidance from the International Council for Radiological Protection (ICRP) *1990 Recommendations of the International Commission on Radiological Protection* (ICRP Publication 60), the International Atomic Energy Agency (IAEA) *Proliferation Resistance Fundamentals for Future Nuclear Energy Systems* (STR-332), and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) *Sources and Effects of Ionizing Radiation Report to the General Assembly,* with scientific annexes (Sales No. E.00.IX.4), concluded that radiological doses to terrestrial plants and terrestrial vertebrates should not exceed 1.0 and 0.1 rad/day, respectively. If radiation exposure does not exceed these biota dose levels, the consensus opinion of the international radiological organizations is that ecological populations will be protected. DOE has adopted these effect thresholds and integrated them into *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002).

A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota (DOE-STD-1153-2002) includes a screening method and three more detailed levels of analysis for demonstrating compliance with applicable dose limits for protection of biota:

- A general screening that involves comparing maximum radionuclide concentrations in environmental media (i.e., soil) with a set of BCGs to evaluate compliance with the biota dose limits.
- Site-specific screening using more realistic site representative lumped parameters (e.g., bioaccumulation factors) in place of conservative default parameters, using mean radionuclide concentrations in place of maximum values, and taking into account time dependence and spatial extent of contamination.
- Site-specific analysis employing a kinetic-allometric modeling methodology. Multiple parameters, which represent contribution to an organism's internal dose, can be modified to represent site- and

organism-specific characteristics. These parameters include body mass, consumption rates of food or soil, inhalation rate, lifespan, and biological elimination rates. Development of the organism-specific characteristics involves using allometric equations that relate these parameters to body mass.

- Site-specific biota dose assessment involving the collection and analysis of biota samples.

BCGs can be calculated using dose models, equations, and default parameters that are presented in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002). The values in soil, calculated using these default methods, are found in Table 6.4 in DOE-STD-1153-2002. These dose models, equations, and default parameters are also incorporated into the RESRAD-BIOTA Version 1.5 model (*RESRAD-BIOTA: A Tool for Implementing a Graded Approach to Biota Dose Evaluation, User's Guide, Version 1* [DOE/EH-0676]). RESRAD-BIOTA presents three levels of analysis, which correspond to the following levels in the graded approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota:

- Level 1—general screening approach
- Level 2—site-specific screening with representative parameters
- Level 3—site-specific analysis using the kinetic/allometric modeling methodology

The BCGs for this supplemental ecological risk evaluation were calculated using the Level 1 analysis in RESRAD-BIOTA, as shown in Table 7-1 for plants and terrestrial wildlife.

Because the dose from radionuclides is additive (*Principles and Issues in Radiological Ecological Risk Assessment* [Jones et al., 2003]), the total contribution of radionuclides known to be associated with Hanford Site processes was also calculated. A total radionuclide exposure estimate was calculated using the sum-of-fractions (SOF) method. With the SOF method, the contributions of various radionuclides were reviewed to determine their contribution to dose. Contributions were considered significant if the radionuclide EPC was greater than the SSL and detected frequently.

Wildlife PRGs were not developed for radionuclide COPCs due to limitations present in the RESRAD-BIOTA program. The most current and realistically modeled concentrations are the same values modeled for the SSLs, presented in Table 7-1.

7.3.1.2 Nonradionuclides

Effects data for the nonradionuclide COPCs are presented below for plants and invertebrates and for wildlife.

Plants and Invertebrates. Single-chemical screening-level toxicity values for terrestrial plants and soil invertebrates were available from the following sources:

- EPA's Ecological Soil Screening Levels (http://www.epa.gov/ecotox/ecossl/).
- Screening benchmark concentrations in soil developed by the Oak Ridge National Laboratory (ORNL); many of the Ecological Indicator Soil Concentrations published by Ecology (see below) were drawn from ORNL screening benchmark concentrations.
- Washington Department of Ecology's Ecological Indicator Soil Concentrations, found in "Site-Specific Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7493(2)(a)(i)), Table 749-3.

The lowest available plant or invertebrate value from these sources was selected as the SSL for each analyte. These SSLs are presented in Table 7-1. A brief discussion of each source is provided below.

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Inverte-brate	Reference	Plants	Inverte-brate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Bench-mark-
Radionuclides	Americium-241	pCi/g	---	---	---	---	---	21500	3890	---	---	21500	---	21500
	Antimony-125	pCi/g	---	---	---	---	---	---	---	---	---	---	---	---
	Carbon-14	pCi/g	---	---	---	---	---	60700	4760	---	---	60700	---	60700
	Cesium-134	pCi/g	---	---	---	---	---	1090	11.3	---	---	1090	---	1090
	Cesium 137	pCi/g	---	---	---	---	---	2210	20.8	---	---	2210	---	2210
	Cobalt-60	pCi/g	---	---	---	---	---	6130	692	---	---	6130	---	6130
	Curium-244	pCi/g	---	---	---	---	---	153000	4060	---	---	153000	---	153000
	Europium-152	pCi/g	---	---	---	---	---	14700	1520	---	---	14700	---	14700
	Europium-154	pCi/g	---	---	---	---	---	12500	1290	---	---	12500	---	12500
	Europium-155	pCi/g	---	---	---	---	---	153000	15800	---	---	153000	---	153000
	Hydrogen-3 (tritium)	pCi/g	---	---	---	---	---	1680000	174000	---	---	1680000	---	1680000
	Neptunium-237	pCi/g	---	---	---	---	---	8150	3860	---	---	8150	---	8150
	Nickel-63	pCi/g	---	---	---	---	---	---	---	---	---	---	---	---
	Plutonium-238	pCi/g	---	---	---	---	---	17500	5270	---	---	17500	---	17500
	Plutonium-239/240	pCi/g	---	---	---	---	---	12700	6110	---	---	12700	---	12700
	Radium-226	pCi/g	---	---	---	---	---	288	50.6	---	---	288	---	288
	Radium-228	pCi/g	---	---	---	---	---	245	43.9	---	---	245	---	245
	Strontium 90	pCi/g	---	---	---	---	---	3580	22.5	---	---	3580	---	3580
	Technetium-99	pCi/g	---	---	---	---	---	21900	4490	---	---	21900	---	21900
	Thorium-232	pCi/g	---	---	---	---	---	23500	1510	---	---	23500	---	23500
	Uranium-234	pCi/g	---	---	---	---	---	51600	5130	---	---	51600	---	51600
	Uranium-235	pCi/g	---	---	---	---	---	27400	2770	---	---	27400	---	27400
	Uranium-238	pCi/g	---	---	---	---	---	15700	1580	---	---	15700	---	15700
Metals	Aluminum	mg/kg	Narrative Statement		OSWER Dir. 9285.7-60	50	---	---	---	50	---	50	---	50
	Antimony	mg/kg	---	78	OSWER Dir. 9285.7-61	5	---	---	---	5	---	5	78	5
	Arsenic, Total all valence states	mg/kg	18	---	OSWER Dir. 9285.7-62	10	60	---	---	---	---	10	60	10
	Arsenic (III)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Arsenic (V)	mg/kg	---	---	---	---	---	---	---	10	60	10	60	10

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Invertebrate	Reference	Plants	Invertebrate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Benchmark
Metals (cont.)	Barium	mg/kg	---	330	OSWER Dir. 9285.7- 63	500	---	---	---	500	---	500	330	330
	Beryllium	mg/kg	---	40	OSWER Dir. 9285.7- 64	10	---	---	---	10	---	10	40	10
	Bismuth	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Boron	mg/kg	---	---	---	0.5	---	---	---	0.5	---	0.5	---	0.5
	Cadmium	mg/kg	32	140	OSWER Dir. 9285.7-65	4	20	---	---	4	20	4	20	4
	Chromium (total) [c,d]	mg/kg	---	---	OSWER Dir. 9285.7- 66	1	0.4	---	---	42	42	1	0.4	0.4
	Chromium (+3)	mg/kg	---	---	OSWER Dir. 9285.7- 66	1	0.4	---	---	42	42	1	0.4	0.4
	Chromium (+6)	mg/kg	---	---	OSWER Dir. 9285.7- 66	---	---	---	---	---	---	---	---	---
	Cobalt	mg/kg	13	---	OSWER Dir. 9285.7-67	20	---	---	---	20	---	13	---	13
	Copper	mg/kg	70	80	OSWER Dir. 9285.7-68	100	50	---	---	100	50	70	50	50
	Lead	mg/kg	120	1700	OSWER Dir. 9285.7-70	50	500	---	---	50	500	50	500	50
	Lithium [d]	mg/kg	---	---	---	2	---	---	---	35	---	2	---	2
	Manganese [d]	mg/kg	220	450	OSWER Dir. 9285.7-71	500	---	---	---	1100	---	220	450	220
	Mercury	mg/kg	---	---	---	0.3	0.1	---	---	0.3	0.1	0.3	0.1	0.1
	Molybdenum	mg/kg	---	---	---	2	---	---	---	2	---	2	---	2
	Nickel	mg/kg	38	280	OSWER Dir. 9285.7-76	30	200	---	---	30	200	30	200	30
	Selenium	mg/kg	0.52	4.1	OSWER Dir. 9285.7-72	1	70	---	---	1	70	0.52	4.1	0.52
	Silver	mg/kg	560	---	OSWER Dir. 9285.7-77	2	---	---	---	2	---	2	---	2
	Strontium	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Thallium	mg/kg	---	---	---	1	---	---	---	1	---	1	---	1
	Tin	mg/kg	---	---	---	50	---	---	---	50	---	50	---	50
	Uranium	mg/kg	---	---	---	5	---	---	---	5	---	5	---	5

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Invertebrate	Reference	Plants	Invertebrate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Benchmark-
Metals (cont.)	Vanadium	mg/kg	---	---	OSWER Dir. 9285.7-75	2	---	---	---	2	---	2	---	2
	Zinc [d]	mg/kg	160	120	OSWER Dir. 9285.7-73	50	200	---	---	86	200	50	120	50
General Inorganics	Ammonia/Ammonium	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Chloride	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Cyanide	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Fluoride	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Iodine	mg/kg	---	---	---	4	---	---	---	4	---	4	---	4
	Nitrate/Nitrite	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Phosphate	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Sulfate/Sulfite	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Total Organic Carbon	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
Volatile Organics	1,1-dichloroethane	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,1-dichloroethene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,1,1-trichloroethane	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,1,2-trichloroethane	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,1,2,2-tetrachloroethane	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,2-dichlorobenzene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,2-dichloroethane (DCA)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	1,3-dichlorobenzene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	2-butanone (Methyl Ethyl Ketone/MEK)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	2-hexanone	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Benzene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Butanol	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Carbon Tetrachloride	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Chlorobenzene	mg/kg	---	---	---	---	40	---	---	---	40	---	40	40
	Chloroform	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Invertebrate	Reference	Plants	Invertebrate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Benchmark
Volatile Organics (cont.)	Cis-1,2-dichloroethylene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Dichloromethane (Methylene Chloride)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Ethyl Benzene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Methyl Isobutyl Ketone	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	n-butyl Benzene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Tetrachloroethylene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Toluene	mg/kg	---	---	---	200	---	---	---	200	---	200	---	200
	Trans-1,2-dichloroethylene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Trichloroethylene (TCE)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Xylene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	---	29	OSWER Dir. 9285.7-75	20	---	---	---	20	---	20	29	20
	Acenaphthylene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	Anthracene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	Benzo(a)pyrene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Benzo(a)anthracene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Benzo(b)fluoranthene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Benzo(ghi)perylene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
Polycyclic Aromatic Hydrocarbons (cont.)	Benzo[k]fluoranthene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Chrysene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Dibenz(ah)anthracene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Fluoranthene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Inverte-brate	Reference	Plants	Inverte-brate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Bench-mark-
Polycyclic Aromatic Hydrocarbons (cont.)	Fluorene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	30	---	---	---	30	---	29	29
	Indeno[1,2,3-cd]pyrene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	2-Methylnaphthalene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	Naphthalene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	Phenanthrene	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	Pyrene	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
	Total PAHs	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Low MW PAHs [e]	mg/kg	---	29	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	29	29
	High MW PAHs [f]	mg/kg	---	18	OSWER Dir. 9285.7-75	---	---	---	---	---	---	---	18	18
Petroleum	Gasoline Range Organics	mg/kg	---	---	---	---	---	---	---	---	100	---	100	100
	TPH - diesel	mg/kg	---	---	---	---	---	---	---	---	200	---	200	200
	TPH - kerosene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
Semivolatile Organics	Normal paraffin hydrocarbons	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Phenol	mg/kg	---	---	---	70	30	---	---	70	30	70	30	30
	2-methylphenol (ocresol)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	4-methylphenol (pcresol)	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	2,4-dinitrotoluene	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Bis[2-ethylhexyl] phthalate [g]	mg/kg	---	---	---	100	---	---	---	100	---	100	---	100
	Polychlorinated Biphenyls (PCB) [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1016 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1221 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1232 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1242 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1248 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40

Table 7-1. SSL in Upland Soil for Plants and Soil Invertebrates

Group	Soil Constituent	Units	EPA Eco-SSLs			ORNL ES/ER/TM-85/R3, ES/ER/TM-126/R2		DOE BCGs		Ecology MTCA (WAC 173-340, Table 749-3)		Lowest Screening Benchmark by Receptor Type		
			Plants	Invertebrate	Reference	Plants	Invertebrate	Terrestrial Plant	Terrestrial Animal	Plant	Soil Biota	Plant	Inverts	Overall Lowest Screening Benchmark
Semivolatile Organics (cont.)	Aroclor 1254 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1260 [h,i]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
	Aroclor 1262 [h,i,j]	mg/kg	---	---	---	40	---	---	---	40	---	40	---	40
Herbicide	Dichloroprop	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
Pesticide	Aldrin	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	beta-1,2,3,4,5,6-Hexachlorocyclohexane [k,l]	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	alpha-Chlordane [m]	mg/kg	---	---	---	---	---	---	---	---	1	---	1	1
	gamma-Chlordane [m]	mg/kg	---	---	---	---	---	---	---	---	1	---	1	1
	Dichlorodiphenyldichloroethylene [n, o]	mg/kg	---	---	OSWER Dir. 9285.7-57	---	---	---	---	---	---	---	---	---
	Dichlorodiphenyltrichloroethane [o]	mg/kg	---	---	OSWER Dir. 9285.7-57	---	---	---	---	---	---	---	---	---
	Dieldrin	mg/kg	---	---	OSWER Dir. 9285.7-56	---	---	---	---	---	---	---	---	---
	Endosulfan I	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Endosulfan II	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Endosulfan sulfate	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Endrin aldehyde [p]	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---
	Methoxychlor	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---

EPA's EcoSSLs for plants and soil invertebrates were derived using data from tests performed with soil conditions favoring relatively high bioavailability for upland soils. The soil chemistry conditions of relatively high bioavailability were defined by low soil pH and organic matter content. From the studies reviewed, the measure of toxic effects to either plants or soil invertebrates were grouped into one of four ecologically relevant endpoints (EREs): reproduction, population characteristics, growth, or physiological changes. Toxicity parameters used in deriving the Eco-SSLs were the EC20 (effective concentration affecting 20 percent of a test population), the maximum acceptable toxicant concentration (MATC), and the EC10 (effect concentration affecting 10 percent of a test population). The MATC was calculated by EPA from studies that reported a no-observed-adverse-effects concentration (NOAEC) and a LOAEC. The MATC was calculated as the geometric mean of the LOAEC and NOAEC. Studies that reported only a LOAEC or only a NOAEC were not considered to provide a reliable assessment of the dose response, and were not used for EcoSSL development. The EcoSSL for plants and soil invertebrates was calculated as the geometric mean of all the toxicity parameters from studies conducted under conditions of high bioavailability. Note that use of the EC20, MATC, and EC10 as toxicity parameters means that EcoSSLs for plants and soil invertebrates are not based on NOAECs.

The ORNL benchmarks for the toxicity to plants from chemical analytes in soil were based on thresholds for effects on growth and reproduction derived from published toxicity studies conducted in soil or solution. The benchmarks are concentrations of chemicals that correspond to the LOEC for the 10th percentile of plant species tested. The ORNL benchmarks for toxicity to soil invertebrates and heterotrophic processes from analytes in soil represent thresholds (LOECs) for statistically significant effects on growth, reproduction, or activity. The toxicity benchmarks were derived by rank ordering the LOEC values and then selecting a value that approximated the 10th percentile.

If 10 or fewer values were available for a chemical, the lowest LOEC was used. If the 10th percentile fell between LOEC values, a value was chosen by interpolation. If a chemical concentration in soil represented a 50 percent or higher reduction in survivorship of plants, the concentration was divided by 5 to approximate the more sensitive endpoints of growth or production. Plant toxicity benchmarks for metals are usually lower than those for soil invertebrates or microbial processes, and they are lower than most preliminary remediation goals calculated for wildlife.

The Ecology's Ecological Indicator Soil Concentrations presented in Table 749-3 represent soil concentrations that are expected to be protective at any MTCA site and are provided for use in eliminating hazardous substances from further consideration under "Site-Specific Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7493(2)(a)(i)). The Ecological Indicator Soil Concentrations for plants are based on benchmarks published in ORNL's *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Terrestrial Plants: 1997 Revision* (ES/ER/TM-85/R3). The Ecological Indicator Soil Concentrations for soil biota are based on benchmarks published in ORNL's *Toxicological Benchmarks for Potential Contaminants of Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process* (ES/ER/TM-126/R2).

For plants and soil invertebrates, PRGs were selected from among the following sources: Hanford Site-specific values from bioassays conducted in 2011 (ECF HANFORD-11-0158 [Appendix H]); published values from Ecology and the EPA; Hanford Site-specific values previously established for the RCBRA (DOE/RL-2007-21); values recently published by Ecology for the based on Hanford Site-specific bioassays (*Ecological Soil Screening Levels for Arsenic and Lead in the Tacoma Smelter Plume Footprint and Hanford Site Old Orchards Ecology*, Publication 11-03-006); values published by ORNL (ES/ER/TM-85/R3 and ES/ER/TM-126/R2); and Hanford Site-specific background. The final recommended PRG represented the most appropriate value, that of the highest confidence or the lower of two values with equally high confidence.

Wildlife (Birds and Mammals). Bird and mammal TRVs for both the NOAELs and LOAELs, used in the SSL and PRG evaluations, were obtained from various sources and focus was given to the most recent sources and those derived or endorsed by EPA and Ecology (as evidenced by their use in either EcoSSLs or in the MTCA [WAC 173-340]). The primary literature source used was EcoSSLs. The toxicity studies used were initially selected from the following sources, which have been listed in order of preference:

- OSWER Directives
  - 9285.7-56, *Ecological Soil Screening Levels for Dieldrin: Interim Final*
  - 9285.7-57, *Ecological Soil Screening Levels for DDT and Metabolites: Interim Final*
  - 9285.7-60, *Ecological Soil Screening Level for Aluminum: Interim Final*
  - 9285.7-61, *Ecological Soil Screening Levels for Antimony: Interim Final*
  - 9285.7-62, *Ecological Soil Screening Levels for Arsenic: Interim Final*
  - 9285.7-63, *Ecological Soil Screening Levels for Barium: Interim Final*
  - 9285.7-64, *Ecological Soil Screening Levels for Beryllium: Interim Final*
  - 9285.7-65, *Ecological Soil Screening Levels for Cadmium: Interim Final*
  - 9285.7-66, *Ecological Soil Screening Levels for Chromium: Interim Final*
  - 9285.7-67, *Ecological Soil Screening Levels for Cobalt: Interim Final*
  - 9285.7-68, *Ecological Soil Screening Levels for Copper: Interim Final*
  - 9285.7-69, *Ecological Soil Screening Level for Iron: Interim Final*
  - 9285.7-70, *Ecological Soil Screening Levels for Lead: Interim Final*
  - 9285.7-71, *Ecological Soil Screening Levels for Manganese: Interim Final*
  - 9285.7-72, *Ecological Soil Screening Levels for Selenium: Interim Final*
  - 9285.7-73, *Ecological Soil Screening Levels for Zinc: Interim Final*
  - 9285.7-75, *Ecological Soil Screening Levels for Vanadium: Interim Final*
  - 9285.7-76, *Ecological Soil Screening Levels for Nickel: Interim Final*
  - 9285.7-77, *Ecological Soil Screening Levels for Silver: Interim Final*
  - 9285.7-78, *Ecological Soil Screening Levels for Polycyclic Aromatic Hydrocarbons (PAHs): Interim Final*
- MTCA (WAC 173-340), Table 749-5.
- Other available literature—primarily *Toxicological Benchmarks for Wildlife: 1996 Revision* (ES/ER/TM-86/R3).
- NOAEL and LOAEL values selected for chemicals and reported in Integrated Risk Information System (IRIS).

- NOAEL and LOAEL values presented in Wildlife Toxicity Assessments developed by United States Army Center for Health Promotion and Preventive Medicine (USACHPPM).

For analytes with EcoSSLs for birds and mammals, the NOAEL used to derive the final Eco-SSL was selected as the NOAEL for SSL development. In some cases, this value was the highest NOAEL below the lowest LOAEL for studies evaluating growth and reproduction endpoints. In these cases, the paired LOAEL from the study was selected as the LOAEL for this risk evaluation. In other cases, the geometric mean of the NOAELs for growth and reproduction endpoints was selected to derive the Eco-SSL. A LOAEL in these cases was selected as the lowest LOAEL above the geometric mean NOAEL. In rare cases (e.g., arsenic TRVs for birds), a study not cited in the available EcoSSLs was selected because the study was of higher quality and had more ecologically relevant endpoints than those used to develop the Eco-SSL values.

For analytes lacking Eco-SSLs, other primary and secondary sources of studies were used. Whenever possible, the primary literature sources were obtained and evaluated. Appropriate toxicity studies were selected from these sources based on several criteria:

- Studies were of chronic exposures or exposures during a critical stage of life (e.g., reproduction).
- Exposure was oral through food ingestion to ensure data were representative of oral exposures expected for wildlife in the field.
- Emphasis was placed on studies of reproductive impacts to ensure relevancy to population level effects.
- Studies presented adequate information to evaluate and determine the magnitude of exposure and effects (or no effects concentrations).

Specifically, toxicity studies were selected to serve as the TRV if exposure was chronic or during reproduction (a critical life stage), the dosing regime was sufficient to identify both a NOAEL and a LOAEL, and the study considered ecologically relevant effects (e.g., growth, reproduction, or survival). If multiple studies for a given COPC meet these criteria, the study generating the lowest reliable toxicity value was selected to be the TRV.

The selected bird and mammal TRVs and study descriptions are presented in Tables 7-2 and 7-3, respectively.

7.3.2 Exposure Assessment

A summary of the exposure assessment for plants and invertebrates, wildlife, and radionuclide exposures is provided below. Additionally, a brief description of SSL development is provided.

7.3.2.1 Terrestrial Plants and Soil Invertebrates

Terrestrial plants and soil invertebrates experience exposure primarily through the soil in which they live. This exposure occurs as a consequence of living in a contaminated medium (i.e., receptors are directly exposed to COPCs). Although other exposure pathways (e.g., dietary exposure for invertebrates or foliar uptake) may contribute to total exposure for these receptors, exposure through the soil predominates. Consequently, estimates of exposure for terrestrial plants and soil invertebrates are represented directly by the concentration of COPCs in the soil (mg/kg).

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Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Metals	Aluminum	aluminum sulfate	Carriere et al., 1986	ringed dove	0.155	4 month	oral in diet	reproduction				109.7	---	ES/ER/TM-86/R3		109.7	---
	Antimony															---	---
	Arsenic	arsenic oxide	Holcman and Stibilj, 1997*	chicken	1.6	19 days during reproduction	oral in diet	reproduction	progeny count			2.24	---	OSWER Directive 9285.7-62		---	---
	Arsenic	sodium arsenate	Stanley et al., 1994	mallard	1	>10 weeks	oral in diet	reproduction				9.3	40.3			9.3	40.3
	Barium	barium hydroxide	Johnson et al., 1960	1-day old chicks	0.121	4 weeks	oral in diet	mortality		0.1	subchronic-chronic	20.8	41.7	ES/ER/TM-86/R3		20.8	41.7
	Beryllium															---	---
	Bismuth															---	---
	Boron	boric acid	Smith and Anders 1989	mallard	1	3 weeks pre-, during, and 3 weeks post-reproduction	oral in diet	reproduction	egg fertility, duckling growth, embryo and duckling mortality			28.8	100	ES/ER/TM-86/R3		28.8	100
	Cadmium	multiple forms	multiple studies*	multiple species								1.47	---	OSWER Directive 9285.7-65	Geometric mean of NOAELs for reproduction and growth	1.47	---
	Cadmium	cadmium sulfate	Leach et al., 1979*	chicken	1.6	12 weeks during egg laying	oral in diet	reproduction	egg production, progeny count			0.593	2.37	OSWER Directive 9285.7-65	lowest bounded reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	2.37
	Chromium (3+)	multiple forms	multiple studies*	chicken				reproduction and growth				2.66	---	OSWER Directive 9285.7-66	Geometric mean of NOAELs for reproduction and growth	2.66	---
	Chromium (3+)	chrome alum dodecahydrate	Haseltine et al., unpublished*	black duck	1.17	180-190 days	oral in diet	reproduction	reproductive success			0.569	2.78	OSWER Directive 9285.7-66	lowest bounded reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	2.78
	Cobalt	multiple forms	multiple studies*	multiple species				growth	body weight			7.61		OSWER Directive 9285.7-67	Geometric mean of NOAELs for reproduction and growth	7.61	
	Cobalt	cobalt chloride	Hill, 1979*	chicken	0.328	5 weeks	oral in diet	growth	body weight			3.89	7.8	OSWER Directive 9285.7-67	lowest bounded reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	7.8
	Copper	copper	al Ankari et al., 1998*	chicken	1.5161	84 days during egg laying	oral in diet	reproduction	eggs per nest			4.05	12.1	OSWER Directive 9285.7-68	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	4.05	12.1

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Metals (cont.)	Lead	lead acetate	Edens and Garlich, 1983*	chicken	1.81	4 weeks during egg laying	oral in diet	reproduction	progeny count			1.63	3.26	OSWER Directive 9285.7-70	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	1.63	3.26
	Lithium															---	---
	Manganese	multiple forms	multiple studies*	multiple species				reproduction and growth				179	---	OSWER Directive 9285.7-71	Geometric mean of NOAELs for reproduction and growth	179	---
	Manganese	manganese chloride tetrahydrate	Southern and Baker, 1983*	chicken	0.316	14 days	oral in diet	growth	body weight			261	348	OSWER Directive 9285.7-71	lowest bounded growth or reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	348
	Mercury	methyl mercury	Heinz and Hoffman, 1998; Heinz, 1979	mallard	1	2.5 months to two generations	oral in diet	reproduction				0.068	0.37			0.068	0.37
	Molybdenum	Sodium molybdate	Lepore and Miller, 1965	chicken	1.5	21 days through reproduction	oral in diet	reproduction	embryonic viability	0.1	LOAEL-NOAEL	3.53	35.3	ES/ER/TM-86/R3		3.53	35.3
	Nickel	multiple forms	multiple studies*	multiple species				reproduction and growth				6.71	---	OSWER Directive 9285.7-76	Geometric mean of reproduction and growth studies	6.71	---
	Nickel	nickel chloride hexahydrate	Martinez and Diaz, 1996*	chicken	1.8901	42 days	oral in diet	growth	body weight			5.76	11.5	OSWER Directive 9285.7-76	lowest bounded growth or reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	11.5
	Selenium	sodium selenite	El-Begearmi and Combs, 1982*	chicken	0.328	2 weeks	oral in diet	survival	mortality			0.29	0.579	OSWER Directive 9285.7-72	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.29	0.579
	Silver	silver acetate	Jensen et al., 1974*	turkey	0.662	5 weeks	oral in diet		growth	0.1	LOAEL-NOAEL	2.02	20.2	OSWER Directive 9285.7-77	lowest growth, reproduction, or survival LOAEL, with NOAEL estimated by application of UF	2.02	20.2
	Strontium															---	---
	Thallium											---	---			---	---
	Tin	bis(Tributyltin) oxide (TBTO)	Schlatterer et al., 1993	Japanese quail	0.15	6 weeks during reproduction	oral in diet	reproduction	egg weight and hatchability			6.8	16.9	ES/ER/TM 86/R3		6.8	16.9

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Metals (cont.)	Uranium	depleted metallic	Haseltine and Sileo, 1983	black duck	1.25	6 weeks	oral in diet	growth, mortality, organ pathology	mortality, body weight, blood chemistry, liver or kidney effects	0.1	subchronic-chronic	16	---	ES/ER/TM-86/R3		16	---
	Vanadium	sodium metavanadate	Hill, 1979*	chicken	1.042	5 weeks	oral in diet	growth	body weight			0.344	0.688	OSWER Directive 9285.7-75	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.344	0.688
	Zinc	multiple forms	multiple studies*	multiple species				reproduction and growth				66.1	---	OSWER Directive 9285.7-73	Geometric mean of reproduction and growth studies	66.1	---
	Zinc	zinc acetate	Gibson et al., 1986*	chicken	2	10 weeks	oral in diet	reproduction	progeny count			57.3	66.5	OSWER Directive 9285.7-73	lowest bounded growth or reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	66.5
General Inorganics	Ammonia/Ammonium															---	---
	Chloride															---	---
	Cyanide															---	---
	Fluoride		Pattee et al., 1988	screech owl	0.18	1 mo	oral in diet	reproduction	hatching success			7.8	32	ES/ER/TM-86/R3		7.8	32
	Iodine															---	---
	Nitrate/Nitrite															---	---
	Phosphate															---	---
	Sulfate/Sulfite															---	---
	Total Organic Carbon															---	---
Volatile Organics	1,1-dichloroethane	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,1-dichloroethene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,1,1-trichloroethane	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,1,2-trichloroethane	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,1,2,2-tetrachloroethane	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Volatile Organics (cont.)	1,2-dichlorobenzene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,2-dichloroethane (DCA)	NA	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	1,3-dichlorobenzene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	2-butanone (Methyl Ethyl Ketone/MEK)	2-hexanone	Abou-Donia et al., 1982	chicken	1.7	90 days	oral gavage	survival, pathology, neurotoxicity	weight loss and ataxia	0.1	LOAEL-NOAEL	10	100			10	100
	2-hexanone	NA	Abou-Donia et al. 1982	chicken	1.7	90 days	oral gavage	survival, pathology, neurotoxicity	weight loss and ataxia	0.1	LOAEL-NOAEL	10	100			10	100
	Benzene	xylene	Hill and Camardese, 1986	Japanese quail		5 days	oral in diet	growth and mortality		0.01	subacute-chronic	40.7	---		5 day dietary exposure to 4066 mg/kg/d had no effect	40.7	---
	Butanol															---	---
	Carbon Tetrachloride	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Chlorobenzene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Chloroform	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Cis-1,2-dichloroethylene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Dichloromethane (Methylene Chloride)	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Ethyl Benzene	xylene	Hill and Camardese, 1986	Japanese quail		5 days	oral in diet	growth and mortality		0.01	subacute-chronic	40.7	---		5 day dietary exposure to 4066 mg/kg/d had no effect	40.7	---
	Methyl Isobutyl Ketone	2-hexanone	Abou-Donia et al., 1982	chicken	1.7	90 days	oral gavage	survival, pathology, neurotoxicity	weight loss and ataxia	0.1	LOAEL-NOAEL	10	100			10	100
	n-butyl Benzene	xylene	Hill and Camardese, 1986	Japanese quail		5 days	oral in diet	growth and mortality		0.01	subacute-chronic	40.7	---		5 day dietary exposure to 4066 mg/kg/d had no effect	40.7	---
	Tetrachloroethylene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Toluene	xylene	Hill and Camardese, 1986	Japanese quail		5 days	oral in diet	growth and mortality		0.01	subacute-chronic	33.3	---		5 day dietary exposure to 4066 mg/kg/d had no effect	40.7	---

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Volatile Organics (cont.)	Trans-1,2-dichloroethylene	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Trichloroethylene (TCE)	1,2-dichloroethane (DCA)	Alumot et al., 1976b	chicken	1.6	2 yr	oral in diet	reproduction	reduced egg production			17.2	34.4	ES/ER/TM-86/R3		17.2	34.4
	Xylene	NA	Hill and Camardese, 1986	Japanese quail		5 days	oral in diet	growth and mortality		0.01	subacute-chronic	40.7	---		5 day dietary exposure to 4066 mg/kg/d had no effect	40.7	---
Polycyclic Aromatic Hydrocarbons	Acenaphthene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		*Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Acenaphthylene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Anthracene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Benzo(a)pyrene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Benzo(a)anthracene	NA	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Benzo(b)fluoranthene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Polycyclic Aromatic Hydrocarbons (cont.)	Benzo(ghi)perylene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Benzo(k)fluoranthene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Chrysene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Dibenz(ah)anthracene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Fluoranthene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Fluorene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Indeno[1,2,3-cd]pyrene	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	2-Methylnaphthalene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Polycyclic Aromatic Hydrocarbons (cont.)	Naphthalene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Phenanthrene	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	Pyrene	Benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
	Low MW PAHs	aromatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth	liver weight			32.5	325		* Mixture of ethylbenzene, 1,2,3,4-tetrahydronaphthalene, dimethylnaphthalene, 2,3,3-trimethylindolenine, acenaphthene, acenaphthylene, phenanthrene, 2-methylbenzothiazole, dibenzothiophene, and 2,6-dimethylquinoline	32.5	325
	High MW PAHs	benzo(a)anthracene	Beall, 2007	bobwhite quail		60 d	oral in diet	growth				0.65	---		NOAEL based on mean exposure over 60-day duration of the study.	0.65	---
Petroleum	Gasoline Range Organics	No. 2 Fuel	Szaro et al., 1981	mallard	1	18 weeks	oral in diet	mortality and growth	reduced growth			500	5000			500	5000
	TPH - Diesel	No. 2 Fuel	Szaro et al., 1981	mallard	1	18 weeks	oral in diet	mortality and growth	reduced growth			500	5000			500	5000
	TPH - Kerosene	No. 2 Fuel	Szaro et al., 1981	mallard	1	18 weeks	oral in diet	mortality and growth	reduced growth			500	5000			500	5000

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Semivolatile Organics	Normal paraffin hydrocarbons	aliphatic hydrocarbon mixture	Patton and Dieter, 1980	mallard	1.23	7 mo	oral in diet	growth				813	---		* Mixture of n-paraffins (tridecane, pentadecane, hexadecane, heptadecane, octadecane, and nonadecane), iso-paraffins (2,2,4,6,6-pentamethylheptane, 2,2,4,4,6,8,8-heptamethylnonane, and 2,6,10,14-tetramethylpentadecane), and 2-ring cyclo-paraffins (decahydronaphthalene)	813	---
	Phenol															---	---
	2-methylphenol (ocresol)															---	---
	4-methylphenol (pcresol)															---	---
	2,4-dinitrotoluene	NA	Johnson et al., 2005	bobwhite quail		60 d	oral gavage	hematoxicity and mortality	hematoxicity and mortality	0.01(for NOAEL) 0.25 (for LOAEL)	subchronic-chronic, inter-species differences	0.01	1.3	39-EJ-1138-01D	study and value selected based on an extensive review of available literature - documented in USACHPPM	0.01	1.3
	Bis[2-ethylhexyl] phthalate	NA	Peakall, 1974	ringed dove	0.155	4 wk (during reproduction)	oral in diet	reproduction		NA		1.1		ES/ER/TM-86/R3		1.1	---
	Total PCBs	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1016	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1221	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1232	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1242	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1248	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1254	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Semivolatile Organics (cont.)	Aroclor 1260	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
	Aroclor 1262	Aroclor 1254	Dahlgren et al., 1972	ring-necked pheasant	1	17 weeks during egg laying	oral via gelatin capsule	reproduction	reduced egg hatchability	0.1	LOAEL-NOAEL	0.18	1.8	ES/ER/TM-86/R3		0.18	1.8
Herbicide	Dichloroprop															---	---
Pesticide	Aldrin	NA	Hall et al., 1971	ring-necked pheasant		6 weeks	oral via gelatin capsule	growth		0.1(for NOAEL) 0.25 (for LOAEL)	subchronic-chronic	0.007	0.035	39-EJ-1138-01J	study and value selected based on an extensive review of available literature - documented in USACHPPM	0.007	0.035
	beta-1,2,3,4,5,6-Hexachlorocyclohexane	gamma hexachlorobenzene (lindane)	Chakravarty and Lahiri, 1986; Chakravarty et al., 1986	mallard	1	8 wks	oral intubation	reproduction	eggshell thickness, egg number, etc.	0.1	for interspecies uncertainty	0.571	0.857	87-MA02T6-05C	study and value selected based on an extensive review of available literature - documented in USACHPPM	0.571	0.857
	alpha-Chlordane	chlordane	Stickel et al., 1983	red-winged blackbird	0.064	84 d	oral in diet	mortality				2.14	10.7	ES/ER/TM-86/R3		2.14	10.7
	gamma-Chlordane	chlordane	Stickel et al., 1983	red-winged blackbird	0.064	84 d	oral in diet	mortality				2.14	10.7	ES/ER/TM-86/R3		2.14	10.7
	Dichlorodiphenyldichloroethylene	DDT	Cecil et al., 1978	chicken		30 d	oral in diet	growth	body weight			0.227	2.27	OSWER Directive 9285.7-57	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.227	---
	Dichlorodiphenyldichloroethylene	DDT	Heath et al., 1969	mallard		1 yr	oral in diet	reproduction	reproductive success			0.563	1.892	OSWER Directive 9285.7-57	value is lowest reproductive LOAEL above the NOAEL used for the EcoSSL; NOAEL is from same study	---	1.892
	Dichlorodiphenyltrichloroethane	NA	Cecil et al., 1978	chicken		30 d	oral in diet	growth	body weight			0.227	2.27	OSWER Directive 9285.7-57	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.227	---
	Dichlorodiphenyltrichloroethane	NA	Heath et al., 1969	mallard		1 yr	oral in diet	reproduction	reproductive success			0.563	1.892	OSWER Directive 9285.7-57	value is lowest reproductive LOAEL above the NOAEL used for the EcoSSL; NOAEL is from same study	---	1.892

Table 7-2. Avian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor Type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Avian NOAEL TRV (mg/kg/d)	Selected Avian LOAEL TRV (mg/kg/d)
Pesticide (cont.)	Dieldrin	NA	Nebeker et al., 1992	mallard		24 d	oral in diet	growth	body weight			0.0709	3.78	OSWER Directive 9285.7-56	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.0709	---
	Dieldrin	NA	Wiese et al., 1968	crowned guinea fowl		21 month	oral in diet	reproduction	number of progeny			0.0671	0.223	OSWER Directive 9285.7-56	value is lowest reproductive LOAEL above the NOAEL used for the EcoSSL; NOAEL is from same study	---	0.223
	Endosulfan I	endosulfan	Abiola, 1992	gray partridge	0.4	4 wk (during reproduction)	oral in diet	reproduction				10	---	ES/ER/TM-86/R3		10	---
	Endosulfan II	endosulfan	Abiola, 1992	gray partridge	0.4	4 wk (during reproduction)	oral in diet	reproduction				10	---	ES/ER/TM-86/R3		10	---
	Endosulfan sulfate	endosulfan	Abiola, 1992	gray partridge	0.4	4 wk (during reproduction)	oral in diet	reproduction				10	---	ES/ER/TM-86/R3		10	---
	Endrin aldehyde	endrin	Spann et al., 1986	mallard	1.15	>200 d	oral in diet	reproduction				0.3	---	ES/ER/TM-86/R3		0.3	---
	Methoxychlor															---	---

Sources are provided in Chapter 11, References.

Notes: Uncertainty factors were used to adjust all measured effect concentrations to chronic NOAELS and chronic LOAELs as follows:

LOAEL to NOAEL = 0.1

Subchronic to chronic = 0.1

where:

chronic = >12 weeks or during critical life stage

subchronic = 4 to 12 weeks

These uncertainty factors are consistent with methods used in development of the Eco-SSLs (EPA, 2007a) and are more conservative than uncertainty factors recommended in EPA 540-R-97-006.

*Study information and calculated NOAELs and LOAELs for these sources were taken directly from the cited Eco-SSL report developed by the EPA. All other primary sources were obtained, reviewed, and TRVs were extracted or developed from the study.

EcoSSL = Ecological Soil Screening Level

EPA = United States Environmental Protection Agency

LOAEL = lowest observable adverse effect level

NOAEL = no observable adverse effect level

mg/kg/d = milligram per kilogram per day

TRV = toxicity reference value

USACHPPM = United States Army Center for Health Promotion and Preventive Medicine

Bold = values selected as the avian TRVs

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Metals	Aluminum	aluminum chloride	Ondreicka et al., 1966	mouse	0.03	3 generations	oral in water	reproduction	offspring growth	0.1	LOAEL-NOAEL	1.93	19.3	ES/ER/TM-86/R3	Note that soil pH must be <5.5 (EPA, 2003) for Al to be bioavailable.	1.93	19.3
	Antimony	antimony trichloride	*Rossi et al., 1987	rat	0.33	31 days	oral in water	reproduction	progeny body weight			0.059	0.59	OSWER Directive 9285.7-61	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.059	0.59
	Arsenic	sodium arsenite	*Neiger and Osweiler, 1989	dog	10.1	8 weeks	oral in diet	growth	reduced body weight			1.04	1.66	OSWER Directive 9285.7-62	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	1.04	1.66
	Barium	multiple forms	*multiple studies	multiple species								51.8		OSWER Directive 9285.7-63	geometric mean of NOAELs for reproduction and growth	---	---
	Barium	barium chloride	NTP, 1994	rat	0.35	105 weeks	oral in water	Nephro-toxicity	increased kidney weight			45	75		study selected because NOAEL is similar to EcoSSL, study is of long duration, and a LOAEL was identified.	45	75
	Beryllium	beryllium sulfate	*Schroeder and Mitchener, 1975	rat	0.486	lifetime	oral in water	longevity				0.532		OSWER Directive 9285.7-64	Same study as ES/E/TM-86/R3, but used different body weight in calculation of NOAEL	0.532	---
	Bismuth															---	---
	Boron	boric acid or Borax	Weir and Fisher, 1972	rat	0.35	three generations	oral in diet	reproduction	sterility			28	93.6	ES/ER/TM-86/R3		28	93.6
	Cadmium	cadmium acetate	*Yuhas et al., 1979	rat	0.43	2 weeks	oral in water	growth	body weight			0.77	7.7	OSWER Directive 9285.7-65	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	---	---
	Cadmium	cadmium chloride	Sutou et al., 1980a and 1980b	rat	0.303	6 weeks during reproduction	oral gavage	reproduction	reduced fetal survival			1	10	ES/ER/TM-86/R3	The ORNL TRV for cadmium was selected as it represents reproductive effects, is a longer study, and is comparable to the TRV used for EcoSSLs	1	10
	Chromium (6+)	multiple forms	*multiple studies	multiple species				reproduction and growth				9.24		OSWER Directive 9285.7-66	geometric mean of NOAELs for reproduction and growth	9.24	---
	Chromium (6+)	sodium dichromate	Chowdhury and Mitra, 1995	rat	0.3084	90 days	oral gavage	reproduction	testes weight			20	40	OSWER Directive 9285.7-66	lowest bounded reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	40
	Chromium (3+)	multiple forms	*multiple studies	multiple species				reproduction and growth				2.4		OSWER Directive 9285.7-66	geometric mean of NOAELs for reproduction and growth	2.4	---

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Metals (cont.)	Chromium (3+)	chromium sulfate	*Zahid et al., 1990	mouse	0.0249	35 days	oral in diet	reproduction	sperm cell counts	0.1	LOAEL-NOAEL	0.962	9.62	OSWER Directive 9285.7-66	lowest reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	9.62
	Cobalt	multiple forms	*multiple studies	multiple species				reproduction and growth				7.33		OSWER Directive 9285.7-67	geometric mean of NOAELs for reproduction and growth	7.33	---
	Cobalt	cobalt chloride	*Domingo et al., 1985	rat	0.3	28 days	gavage	reproduction	progeny body weight			5.45	10.9	OSWER Directive 9285.7-67	lowest bounded reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	10.9
	Copper	copper sulfate pentahydrate	*Allcroft et al., 1961	pig	100	4 weeks	oral in diet	growth	body weight			5.6	9.34	OSWER Directive 9285.7-68	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	5.6	9.34
	Lead	lead acetate	*Kimmel et al., 1980	rat	0.3	7 weeks during gestation	oral in water	growth	body weight			4.7	8.9	OSWER Directive 9285.7-68	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	4.7	8.9
	Lithium	lithium carbonate	Marathe and Thomas, 1986	rat	0.35	days 6-15 of gestation	oral in diet	reproduction	reduced number of offspring			9.4	18.8	ES/ER/TM-86/R3		9.4	18.8
	Manganese	multiple forms	*multiple studies	multiple species				reproduction and growth				51.5		OSWER Directive 9285.7-71	geometric mean of NOAELs for reproduction and growth	51.5	---
	Manganese	manganese oxide	*Rehnberg et al., 1980	rat	0.0566	20 days	gavage	reproduction, growth	reproductive organ histology, body weight			21	71	OSWER Directive 9285.7-71	lowest bounded growth or reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	71
	Mercury	methylmercury chloride	Verschuuren et al., 1976a	rat	0.35	three generations	oral in diet	reproduction	pup viability			0.032	0.16	ES/ER/TM-86/R3		0.032	0.16
	Molybdenum	molybdate (MoO4)	Schroeder and Mitchener, 1971	mouse	0.03	three generations	oral in water	reproduction	reproductive success, number of runts	0.1	LOAEL-NOAEL	0.26	2.6	ES/ER/TM-86/R3		0.26	2.6
	Nickel	nickelous chloride	*Pandey and Srivastava, 2000	mouse	0.025	35 days	oral (other)	reproduction	sperm cell counts			1.7	3.4	OSWER Directive 9285.7-76	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	1.7	3.4
	Selenium	sodium selenite	*Mahan and Moxon, 1984	pig	17.8	37 days	oral in diet	growth	body weight			0.143	0.215	OSWER Directive 9285.7-72	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.143	0.215

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Metals (cont.)	Silver	silver acetate	*Van Vleet, 1976	pig	8.86	40 days	oral in diet	growth	body weight	0.1	LOAEL-NOAEL	6.02	60.2	OSWER Directive 9285.7-77	lowest growth, reproduction, or survival LOAEL, with NOAEL estimated by application of UF	6.02	60.2
	Strontium	strontium chloride	Skoryna, 1981	rat	0.35	3 yrs	oral in water	growth	body weight			263		ES/ER/TM-86/R3		263	---
	Thallium	thallium sulfate	Formigli et al., 1986	rat	0.365	60 days	drinking water	reproduction	sperm motility	0.05 and 0.25	subchronic LOAEL-chronic NOAEL; subchronic LOAEL-chronic LOAEL	0.015	0.075	ES/ER/TM-86/R3; 37-EJ1138-01O	study and value selected based on an extensive review of available literature - documented in USACHPPM	0.015	0.075
	Tin	bis(tributyltin) oxide (TBTO)	Davis et al., 1987	mouse	0.03	days 6-15 of gestation	oral intubation	reproduction	reduced fetal weight and fetal survival			23.4	35	ES/ER/TM-86/R3		23.4	35
	Uranium	uranyl acetate	Paternain et al., 1989	mouse	0.028	60 d prior to gestation, gestation, delivery, lactation	oral intubation	reproduction	pup survival and body weight			3.07	6.13	ES/ER/TM-86/R3	Note that the study selected by ES/ER/TM-86/R3, is one of the studies reviewed by Sheppard et al., 2005. The selected LOAEL approximates the mean of developmental values referenced in Sheppard et al., 2005	3.07	6.13
	Vanadium	sodium orthovanadate	*Sanchez et al., 1991	mouse	0.047	12 days during gestation	gavage	reproduction	ODVP			4.16	8.31	OSWER Directive 9285.7-75	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	4.16	8.31
	Zinc	various forms	*multiple studies	multiple species				reproduction and growth				75.4		OSWER Directive 9285.7-73	geometric mean of NOAELs for reproduction and growth	75.4	---
	Zinc	zinc sulfate	*Miller et al., 1989	cattle	580	14 weeks	oral in diet	reproduction	progeny body weight			37.9	75.9	OSWER Directive 9285.7-73	lowest bounded growth or reproductive LOAEL above the geometric mean NOAEL from EcoSSL	---	75.9
General Inorganics	Ammonia/Ammonium															---	---
	Chloride															---	---
	Cyanide	potassium cyanide	Tewe and Maner, 1981	rat	0.273	gestation and lactation	oral in diet	reproduction	juvenile growth			68.7	---	ES/ER/TM-86/R3		68.7	---
	Fluoride	sodium fluoride	Aulerich et al., 1987	mink	1	382 days	oral in diet	reproduction	kit survival			31.37	52.75	ES/ER/TM-86/R3		31.37	52.75
	Iodine	potassium iodide	Aulerich et al., 1978	mink	1	breeding through lactation	oral in diet	reproduction	kit survival			1.37	13.7			1.37	13.7

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
General Inorganics (cont.)	Nitrate/Nitrite	potassium nitrate	Sleight and Atallah, 1968	guinea pig	0.86	143-204 days	oral in water	reproduction	number of live births			507	1130	ES/ER/TM-86/R3		507	1130
	Phosphate															---	---
	Sulfate/Sulfite															---	---
	Total Organic Carbon															---	---
Volatile Organics	1,1-dichloroethane	1,2-dichloroethane (DCA)	Lane et al., 1982	mouse	0.035	2 generations	oral in water	reproduction				50	---	ES/ER/TM-86/R3		50	---
	1,1-dichloroethene	NA	Quast et al., 1983	rat	0.35	2 years	oral in water	mortality, body weight				30	---	ES/ER/TM-86/R3		30	---
	1,1,1-trichloroethane	NA	Lane et al., 1982	mouse	0.035	2 generations	oral in water	reproduction				1000	---	ES/ER/TM-86/R3		1000	---
	1,1,2-trichloroethane	1,1,1-trichloroethane	Lane et al., 1982	mouse	0.035	2 generations	oral in water	reproduction				1000	---	ES/ER/TM-86/R3		1000	---
	1,1,2,2-tetrachloroethane	1,1,1,2-tetrachloroethane	NTP, 1983	rat		103 wks	oral gavage	nephrotoxicity		0.1	LOAEL-NOAEL	8.93	89.3	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0265.htm) Dec 11, 2009	8.93	89.3
	1,2-dichlorobenzene	NA	NTP, 1985	rat		2 yrs	oral gavage	survival and pathology				85.7	---	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0408.htm) Dec 11, 2009	85.7	---
	1,2-dichloroethane (DCA)	NA	Lane et al., 1982	mouse	0.035	2 generations	oral in water	reproduction				50	---	ES/ER/TM-86/R3		50	---
	1,3-dichlorobenzene	1,2-dichlorobenzene	NTP, 1985	rat		2 yrs	oral gavage	survival and pathology				85.7	---	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0408.htm) Dec 11, 2009	85.7	---
	2-butanone (Methyl Ethyl Ketone/MEK)	NA	Cox et al., 1975	rat	0.35	2 generations	oral in water	reproduction	reduced litter size and pup survival			1771	4571	ES/ER/TM-86/R3		1771	4571
	2-hexanone	NA	O'Donoghue et al., 1978	rat		13 month	oral in water	neurotoxicity				5	36.1	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/1019.htm) Dec 11, 2009; NOAEL is BMDL10 value; LOAEL is BMD10 value	5	36.1
	Benzene	NA	Wolf et al., 1956	rat	0.175-0.250	187 days	oral gavage	survival and pathology	Hemo-toxicity			0.7	7			0.7	7
	Butanol	NA	EPA, 1986a	rat		13 weeks	oral gavage	hypoactivity/ataxia				125	500	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0140.htm) Dec 11, 2009	125	500
	Carbon Tetrachloride	NA	Alumot et al., 1976a	rat	0.35	2 yrs	oral in diet	reproduction				16	---	ES/ER/TM-86/R3		16	---

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Volatile Organics (cont.)	Chlorobenzene	NA	Monsanto Co., 1967	dog		13 weeks	oral in capsules	liver pathology				19.5	38.7	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0399.htm) Dec 11, 2009	19.5	38.7
	Chloroform	NA	Palmer et al., 1979	rat	0.35	13 wk	oral intubation	liver, kidney, gonad condition	Gonadal -atrophy	0.1	subchronic-chronic	15	41	ES/ER/TM-86/R3		15	41
	Cis-1,2-dichloroethylene	1,2-dichloroethylene	Palmer et al., 1979	mouse	0.03	90 days	oral in water	body and organ weights				45.2	---	ES/ER/TM-86/R3		45.2	---
	Dichloromethane (Methylene Chloride)	NA	NCA, 1982	rat	0.35	2 yrs	oral in water	liver histology				5.85	50	ES/ER/TM-86/R3		5.85	50
	Ethyl Benzene	NA	Wolf et al., 1956	rat	0.175-0.250	182 days	oral gavage	survival and pathology	liver and kidney histopathology			136	408			97.1	291
	Methyl Isobutyl Ketone	2-butanone (Methyl Ethyl Ketone/MEK)	Cox et al., 1975	rat	0.35	2 generations	oral in water	reproduction	reduced litter size and pup survival			1771	4571	ES/ER/TM-86/R3		1771	4571
	n-butyl Benzene	isopropyl benzene	Wolf et al., 1956	rat	0.175-0.250	194 days	oral gavage	survival and pathology	increased kidney weight			110	330			110	330
	Tetrachloroethylene	1,1,2,2-tetrachloroethylene	Buben and O'Flaherty, 1985	mouse	0.03	6 weeks	oral gavage	hepatotoxicity		0.1	LOAEL-NOAEL	1.4	7	ES/ER/TM-86/R3		1.4	7
	Toluene	NA	Gospe et al., 1994	rat	0.2	gestation days 6-19	oral gavage	reproduction	maternal weight loss			52	520			52	520
	Trans-1,2-dichloroethylene	1,2-dichloroethylene	Palmer et al., 1979	mouse	0.03	90 days	oral in water	body and organ weights				45.2	---	ES/ER/TM-86/R3		45.2	---
	Trichloroethylene (TCE)	NA	Buben and O'Flaherty, 1985	mouse	0.03	6 weeks	oral gavage	hepatotoxicity		0.01	LOAEL-NOAEL subchronic-chronic	0.7	7	ES/ER/TM-86/R3		0.7	7
	Xylene	xylene mixture	NTP, 1986	rat		103 wks	oral gavage	behavior growth mortality				179	350			179	350
Polycyclic Aromatic Hydrocarbons	Acenaphthene	NA	EPA, 1989a	mouse	0.03	90 days	oral gavage	Hepato-toxicity	liver weight changes and cellular hypertrophy			175	350	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0442.htm) Dec 9, 2009	175	350
	Acenaphthylene	acenaphthene	EPA, 1989a	mouse	0.03	90 days	oral gavage	Hepato-toxicity	liver weight changes and cellular hypertrophy			175	350	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0442.htm) Dec 9, 2009	175	350
	Anthracene	NA	EPA, 1989b	mouse	0.03	90 days	oral gavage	survival and pathology	reduced body weight			1000	---	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0434.htm) Dec 9, 2009	1000	---

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Polycyclic Aromatic Hydrocarbon (cont.)	Benzo(a)pyrene	NA	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Benzo(a)anthracene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Benzo(b)fluoranthene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Benzo(ghi)perylene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Benzo(k)fluoranthene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Chrysene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Dibenz(ah)anthracene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	Fluoranthene	NA	EPA, 1988b	mouse	0.03	13 weeks	oral gavage	nephropathy	increased liver wt and pathology			125	250	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0444.htm) Dec 9, 2009	125	250
	Fluorene	NA	EPA, 1989c	mouse	0.03	13 weeks	oral gavage	hemotoxicity				125	250	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0435.htm) Dec 9, 2009	125	250
	Indeno[1,2,3-cd]pyrene	benzo(a)pyrene	Mackenzie and Angevine, 1981	mouse	0.03	gestation days 7-16	oral intubation	reproduction	reduced pregnancy rate and fertility	0.1	LOAEL-NOAEL	1	10	ES/ER/TM-86/R3; 39-EJ-1138-01P	study and value selected based on an extensive review of available literature - documented in USACHPPM	1	10
	2-Methylnaphthalene	NA	Murata et al., 1997	mouse	0.0425	81 wks	oral in diet	survival and pathology	pulmonary pathology			50.3	113.8			50.3	113.8
	Naphthalene	NA	NTP, 1991	rat	0.24	days 6-15 of gestation	oral gavage	reproduction	maternal weight loss			50	150			50	150
	Phenanthrene	anthracene	EPA, 1989b	rat	0.03	90 days	oral gavage	survival and pathology	reduced body weight			1000	---	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0434.htm) Dec 9, 2009	1000	---

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Polycyclic Aromatic Hydrocarbon (cont.)	Pyrene	NA	EPA, 1989d	mouse	0.03	13 weeks	oral gavage	nephropathy				75	125	IRIS	Verified on IRIS (http://www.epa.gov/ncea/iris/subst/0445.htm) Dec 9, 2009	75	125
	Low MW PAHs	1-naphthaleneacetic acid	*Verschuuren et al., 1976b	rat	0.247	6 weeks	oral in diet	growth	reduced body weight			65.6	328	OSWER Directive 9285.7-78	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	65.6	328
	High MW PAHs	benzo(a)pyrene	*Culp et al., 1998	mouse	0.038	55 weeks	oral in diet	survival	reduced survival			0.615	3.07	OSWER Directive 9285.7-78	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.615	3.07
Petroleum	Gasoline Range Organics	JP-8 jet fuel	Cooper and Mattie, 1996	rat	0.35	gestation days 6-15	oral gavage	reproduction	adult and fetal weight; fetal mortality			1000	1500			1000	1500
	TPH - Diesel	JP-8 jet fuel	Cooper and Mattie, 1996	rat	0.35	gestation days 6-15	oral gavage	reproduction	adult and fetal weight; fetal mortality			1000	1500			1000	1500
	TPH - Kerosene	JP-8 jet fuel	Cooper and Mattie, 1996	rat	0.35	gestation days 6-15	oral gavage	reproduction	adult and fetal weight; fetal mortality			1000	1500			1000	1500
Semivolatile Organics	Normal paraffin hydrocarbons	JP-8 jet fuel	Cooper and Mattie, 1996	rat	0.35	gestation days 6-15	oral gavage	reproduction	adult and fetal weight; fetal mortality			1000	1500			1000	1500
	Phenol	NA	EPAOTS0573686	rat		gestation days 6-15	oral gavage	reproduction	reduced fetal weight	0.1	for interspecies uncertainty	12	36	87-MA02T6-05E	study and value selected based on an extensive review of available literature - documented in USACHPPM	12	36
	2-methylphenol (ocresol)	NA	Hornshaw et al., 1986	mink	0.958	6 month	oral in diet	reproduction				313	---	ES/ER/TM-86/R3	calculations have been updated to use body weight and ingestion data from primary source	313	---
	4-methylphenol (pcresol)	2-methylphenol (ocresol)	Hornshaw et al., 1986	mink	0.958	6 month	oral in diet	reproduction				313	---	ES/ER/TM-86/R3	calculations have been updated to use body weight and ingestion data from primary source	313	---
	2,4-dinitrotoluene	NA	Ellis et al., 1979	dog		24 months	oral in capsules	hemotoxicity and mortality	hemotoxicity and mortality			0.67	1.4	39-EJ-1138-01D	NOAEL and LOAEL are LED10 and ED10 values, respectively calculated using EPA benchmark dose software. Study for benchmark calculation selected based on an extensive review of available literature - documented in USACHPPM	0.67	1.4
	Bis[2-ethylhexyl] phthalate	NA	Lamb et al., 1987	mouse	0.03	105 days (during reproduction)	oral in diet	reproduction				18.3	183	ES/ER/TM-86/R3		18.3	183

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Semivolatile Organics (cont.)	Total PCBs	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68
	Aroclor 1016	Aroclor 1016	EPA/600/3-80-033	mink	1	18 months	oral in diet	reproduction	reduced kit growth			1.37	3.43	ES/ER/TM-86/R3		1.37	3.43
	Aroclor 1221	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68
	Aroclor 1232	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68
	Aroclor 1242	Aroclor 1242	Bleavins et al., 1980	mink	1	7 months	oral in diet	reproduction	total reproductive failure	0.1	LOAEL-NOAEL	0.069	0.69	ES/ER/TM-86/R3		0.069	0.69
	Aroclor 1248	Aroclor 1248	Barsotti et al., 1976	Rhesus monkey	5	14 months	oral in diet	reproduction	reduced pregnancy and live birth rates	0.1	LOAEL-NOAEL	0.0087	0.087	ES/ER/TM-86/R3	recalculated: study reports PCB consumption of 0.43 mg PCB/day	0.0087	0.087
	Aroclor 1254	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68
	Aroclor 1260	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Semivolatile Organics (cont.)	Aroclor 1262	Aroclor 1254	McCoy et al., 1995	Oldfield mouse	0.014	12 months	oral in diet	reproduction	reduced number of litters, pup body weight, and pup survival	0.1	LOAEL-NOAEL	0.068	0.68	ES/ER/TM-86/R3		0.068	0.68
Herbicide	Dichloroprop															---	---
Pesticide	Aldrin	NA	Treon and Cleveland, 1955	rat	0.35	3 generations	oral in diet	reproduction	number of litters and offspring mortality		---	0.2	1	ES/ER/TM-86/R3		0.2	1
	beta-1,2,3,4,5,6-Hexachlorocyclohexane	NA	Van Velsen et al., 1986	rat	0.35	13 weeks	oral in diet	growth, blood chemistry, organ histology	gonadal atrophy in male and female rats	0.1	chronic-subchronic	0.4	2	ES/ER/TM-86/R3		0.4	2
	alpha-Chlordane	chlordane	Narotsky and Kavlock, 1995	rat		GD-6-19	oral gavage	reproduction	post natal pup viability	0.1	LOAEL-NOAEL	2.1	21	87-MA02T6-05A	study and value selected based on an extensive review of available literature - documented in USACHPPM	2.1	21
	gamma-Chlordane	chlordane	Narotsky and Kavlock, 1995	rat		GD-6-19	oral gavage	reproduction	post natal pup viability	0.1	LOAEL-NOAEL	2.1	21	87-MA02T6-05A	study and value selected based on an extensive review of available literature - documented in USACHPPM	2.1	21
	Dichlorodiphenyldichloroethylene (DDE)	DDT	Wrenn et al., 1970	rat		15 days (during gestation)	oral gavage	reproduction				0.147	0.735	EPA, 2007a	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.147	0.735
	Dichlorodiphenyltrichloroethane (DDT)	NA	Wrenn et al., 1970	rat		15 days (during gestation)	oral gavage	reproduction				0.147	0.735	EPA, 2007a	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.147	0.735
	Dieldrin	NA	Harr et al., 1970	rat		750 days	oral in diet	reproduction			---	0.015	0.03	EPA, 2007b	value is highest bounded NOAEL lower than the lowest bounded LOAEL value for reproduction, growth or survival; LOAEL is from same study	0.015	0.03
	Endosulfan I	endosulfan	Dikshith et al., 1984	rat	0.35	30 days (not during reproduction)	oral intubation	reproduction and blood chemistry		0.1	chronic-subchronic	0.15	---	ES/ER/TM-86/R3	no effects observed at highest dose	0.15	---
	Endosulfan II	endosulfan	Dikshith et al., 1984	rat	0.35	30 days (not during reproduction)	oral intubation	reproduction and blood chemistry		0.1	chronic-subchronic	0.15	---	ES/ER/TM-86/R3	no effects observed at highest dose	0.15	---
	Endosulfan sulfate	endosulfan	Dikshith et al., 1984	rat	0.35	30 days (not during reproduction)	oral intubation	reproduction and blood chemistry		0.1	chronic-subchronic	0.15	---	ES/ER/TM-86/R3	no effects observed at highest dose	0.15	---

Table 7-3. Mammalian Toxicity Reference Values for SSL and PRG Calculation

Group	Soil Constituent	Form/ Surrogate Analyte	Primary Study	Test Species	Test Species Body Weight (kg)	Duration	Exposure Route	General Effect Endpoint	Specific Effect Endpoint	Uncertainty Factors Applied	Uncertainty Factor type	NOAEL (mg/kg/d)	LOAEL (mg/kg/d)	Secondary Source	Notes	Selected Mammalian NOAEL TRV (mg/kg/d)	Selected Mammalian LOAEL TRV (mg/kg/d)
Pesticide (cont.)	Endrin aldehyde	endrin	Good and Ware, 1969	mouse	0.03	120 d (during reproduction)	oral in diet	reproduction	reduced parental survival, litter size, and no. yng/d	0.1	LOAEL-NOAEL	0.092	0.92	ES/ER/TM-86/R3		0.092	0.92
	Methoxychlor	NA	Gray et al., 1988	rat	0.35	11 month (during reproduction)	oral in diet	reproduction	fertility and litter size reduced		---	4	8	ES/ER/TM-86/R3		4	8

Sources are provided in Chapter 11, References.

Notes: Uncertainty factors were used to adjust all measured effect concentrations to chronic NOAELS and chronic LOAELs as follows:

LOAEL to NOAEL = 0.1

Subchronic to chronic = 0.1

where:

chronic = >12 weeks or during critical lifestage

subchronic = 4 to 12 weeks

These uncertainty factors are consistent with methods used in development of the EcoSSLs (EPA, 2007a) and are more conservative than uncertainty factors recommended in EPA 540-R-97-006.

*Study information and calculated NOAELs and LOAELs for these sources were taken directly from the cited EcoSSL report developed by the EPA. All other primary sources were obtained, reviewed, and TRVs were extracted or developed from the study.

Bold = values selected as the mammalian TRVs

7.3.2.2 Wildlife (Birds and Mammals)

In contrast to plants and soil invertebrates, birds and mammals experience chemical exposure through multiple pathways, including ingestion of surface water and sediment/soil and biotic media (food), in addition to inhalation and dermal contact. To assess this multiple pathway exposure, modeling can be/or is often employed. The end product, or exposure estimate, for birds and mammals is a dosage (amount of chemical in milligrams per kilogram receptor body weight per day [mg/kg/day]). Following is the general form of the model used to estimate exposure of birds and mammals to chemicals in environmental media (Suter et al., 2000):

$$E_t = E_o + E_d + E_i$$

where:

E_t = total chemical exposure experienced by wildlife

E_o = oral exposure

E_d = dermal exposure

E_i = inhalation exposure

As described in *Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-00784) and *Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* (CHPRC-01311), both dermal and inhalation exposure were assumed negligible. Additionally, exposure pathways associated with water were not addressed because drinking water sources for wildlife are not available at the 100-K Source OUs waste sites. Therefore, only oral exposures via ingestion of soil and food were included in the development of risk-based concentrations for birds and mammals.

By replacing E_o with a generalized exposure model modified from *Ecological Risk Assessment for Contaminated Sites* (Suter et al., 2000) to only include soil and food ingestion, the previous equation was rewritten as follows:

$$E_t = \left[\left[\sum_{i=1}^{n} B_{ij} \times P_i \times FIR\right] + \left[Soil_j \times P_s \times FIR\right]\right] x\, AUF$$

where:

E_t = total exposure (mg/kg/day)

$Soil_j$ = chemical concentration in soil (mg/kg dry weight)

P_s = soil ingestion rate as proportion of diet (unitless)

FIR = food intake rate (kg food/kg body weight/day, dry weight)

B_{ij} = chemical concentration in biota type (i) (mg/kg, dry weight)

P_i = proportion of biota type (i) in diet (unitless)

AUF = area use factor (area of site/home range of receptor) (unitless)

The bird and mammal effects data (Section 7.3.1.1) were combined with the wildlife exposure model to calculate avian/mammal SSLs and PRGs for nonradionuclides. These SSLs and PRGs consist of soil concentrations that are associated with estimated dietary exposures equivalent to a selected effect level, and were calculated using the following basic equation:

$$1 = \frac{TRV}{\sum (SSLorPRG \times DFI) \times [(Frac_v \times C_v) + (Frac_i \times C_i) + (Frac_m \times C_m) + (Frac_s)]}$$

where:

TRV = Toxicity reference value (mg/kg body weight/day)

SSL = soil screening level (mg/kg)

PRG = preliminary remediation goal (mg/kg)

$Frac_v$ = fraction of diet represented by vegetation (unitless)

DFI = daily ingestion rate of all food items (kg/kg body weight/day dry wt.)

C_v = concentration in vegetation tissue (mg/kg dry wt.)

$Frac_i$ = fraction of diet represented by terrestrial invertebrates (unitless)

C_i = concentration in soil invertebrate tissue (mg/kg dry wt.)

$Frac_m$ = fraction of diet represented by small mammals/birds (unitless)

C_m = concentration in small mammal tissue (mg/kg dry wt.)

$Frac_s$ = fraction of diet represented by incidentally ingested soil (unitless)

The TRV denotes the level of toxicity of the chemical, as reported from literature sources. The wildlife SSLs and PRGs use the LOAELs, which is consistent with protecting ecological receptors at the population and community level. The daily ingestion rate and dietary fractions are specific to bird and mammal receptors identified for the upland environment of the Hanford Site. The chemical concentration in the food item (vegetation, soil invertebrate, and small mammal) is estimated by using bioaccumulation factors (BAFs) or bioaccumulation regression models to extrapolate to the food source. This equation is solved for wildlife SSLs or PRGs using the Microsoft Office Excel® goal seek tool, such that exposure (the denominator) equals the TRV (the numerator).

For the purposes of this risk assessment, the LOAEL-based wildlife SSLs and PRGs were used to evaluate residual risks at the 100-K Source OUs remediated waste sites. The SSLs and PRGs were compared to EPCs developed for the 100-K Source OUs as described in Section 7.4.1.

Wildlife Exposure Factors. Species-specific exposure parameters are required to estimate exposure. These include body weight, food ingestion rate, diet composition represented by dietary fractions, and percent or fraction of diet as incidental soil ingestion. The following assumptions were part of the calculation of wildlife exposures used to develop the wildlife SSLs and PRGs:

- For the purposes of this supplemental ecological risk evaluation, 100 percent site use was conservatively assumed, resulting in an AUF of 1.
- Incidental soil ingestion was not included as part of the total dietary composition, but instead was added to the total; for calculation purposes, it was treated as a percentage of total dietary intake.
- All animals were assumed year-round residents, and migration away from areas contaminated with COPCs was not assumed to occur.

® Microsoft Office Excel is a registered trademark of Microsoft Corporation.

- Bioavailability of analytes was assumed equivalent to the chemical form used for developing TRVs in the toxicity studies.

- 100 percent of the estimated soil concentrations (the EPCs) were assumed to be bioavailable for uptake into tissues within the exposure models.

The exposure parameters and source references used for each representative receptor species are summarized in Table 7-4. All weight-based exposure parameters are listed on a dry-weight basis. Species-specific biological information was unavailable for some parameters. When this occurred, allometric equations that express general biological relationships for broader classes of animals were used to estimate the exposure parameters ("Food Requirements of Wild Animals: Predictive Equations for Free-living Mammals, Reptiles, and Birds" [Nagy, 2001]). These allometric conversions are detailed in the Environmental Calculation document (Appendix G).

Estimation of Bioaccumulation into Food Items. The bioaccumulation models and assumptions for calculation of wildlife SSLs and PRGs are as follows:

- **SSL**—The concentrations of COPCs in each food item were estimated rather than measured. For the purposes of exposure estimation, partitioning of analytes from environmental media to prey was estimated from literature values and models. The models presented in the EPA EcoSSLs methodology (*Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55]) were used preferentially for estimation of bioaccumulation into biota from soil. Consistent with the approach employed for the EcoSSLs, regression-based models (if available) and median BAFs from the source selected by EPA were used. In the absence of applicable bioaccumulation models, a default value of 1 was assumed. In all cases, it was assumed that tissue uptake occurs under steady-state conditions. Bioaccumulation models used to derive wildlife SSLs are presented in Table 7-5.

- **PRG**—Development of the PRGs for birds and mammals focused on the integration of available site-specific bioaccumulation data for plants, terrestrial arthropods, and small mammals with data from existing bioaccumulation models (i.e., those from *Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55] used to develop the Eco-SSLs) to develop a set of partially-site-specific bioaccumulation models[2]. The following Hanford Site-specific and literature-based data sets were used to develop the partially site-specific bioaccumulation models:

  - Hanford Site-specific bioaccumulation data have been collected in support of the RCBRA and other projects at the site. Data representing tissue from terrestrial plants (foliage, shoots, and other aboveground parts of grasses, shrubs, and trees), small mammals (whole single mice or composites of multiple whole mice), and terrestrial arthropods (whole single or composites of multiple whole invertebrates), and collocated soil data were extracted from HEIS. Only paired samples in which the target analytes were detected in both tissue and in soil were retained for the bioaccumulation database. Observations in which either soil or tissue concentrations were below detection limits were excluded from consideration.

  - Data from previously developed and published bioaccumulation models for plants and small mammals were used to augment the Hanford Site-specific data. Specifically, the plant bioaccumulation database from *Empirical Models for the Uptake of Inorganic Chemicals from*

[2] These bioaccumulation models are defined as partially site-specific because they are based on both site-specific data and data from published literature sources. This combining of Hanford-specific and literature data was performed to maximize utility of the Hanford-specific data collected over comparatively narrow concentration ranges by expanding the data set to include literature data collected across a wider concentration range.

Soil by Plants (BJC/OR-133) and "Ecotoxicity Test Data for Total Petroleum Hydrocarbons in Soil: Plants and Soil Dwelling Invertebrates" (Efroymson et al., 2004), and the small mammal bioaccumulation database from *Development and Validation of Bioaccumulation Models for Earthworms* (ES/ER/TM-220) were used. Electronic copies of the original databases were obtained from the authors to facilitate integration with Hanford Site-specific data.

- Estimating exposures to insectivorous or omnivorous wildlife involved estimating bioaccumulation into soil invertebrates. Soil invertebrate bioaccumulation models used for SSLs consisted of the earthworm models from Sample et al. (*Development and Validation of Bioaccumulation Models for Earthworms* [ES/ER/TM-220] and "Literature-Derived Bioaccumulation Models for Earthworms: Development and Validation" [Sample et al., 1999]). Hanford Site-specific observations (as detailed in the RCBRA Report [DOE/RL-2007-21] and *Central Plateau Terrestrial Ecological Risk Assessment Data Package Report* [DOE/RL-2007-50]) indicate that earthworms are nonexistent in upland soils, and have little or no contribution to the invertebrate portion of bird and mammal diets at the Hanford Site. Rather, insects and other arthropods (e.g., beetles, ants, spiders) are the primary prey of invertebrate-feeding birds and mammals at the site. Consequently, the data collected to address site-specific bioaccumulation into invertebrate prey of birds and mammals focused on arthropods (RCBRA Report [DOE/RL-2007-21]). Additional bioaccumulation data for terrestrial arthropods were identified and extracted from published literature to supplement the Hanford Site-specific data.

- A literature search was performed for studies that reported chemical concentrations in collocated biota and media samples. Literature databases searched included those hosted by EPA (ECOTOX Database Systems), and the National Library of Medicine (TOXLINE: Toxicology Literature Online).

- The Hanford Site-specific plant, soil invertebrate, and small mammal data were integrated with the literature-derived bioaccumulation data. Bioaccumulation analyses were performed once biota data were converted to standard units (mg/kg-dry weight). Analyses were restricted to observations where the chemical of interest was detected in both soil and the matched tissue sample; all observations in which either soil or tissue concentrations were nondetects were excluded from the analyses. Analyses consisted of development of BAFs and nonlinear regression analyses. BAFs are simply the ratio between concentrations measured in tissue and that in soil. BAFs for all paired soil tissue observations and summary statistics (arithmetic mean, standard deviation, minimum, maximum, median, and 90th percentile) were calculated.

- To evaluate if a log-linear relationship between the chemical concentration in soil and that in terrestrial biota existed, simple log-linear regressions were performed using SAS PROC REG (*SAS/STAT User's Guide* [SAS Institute, 1999]). Chemical concentrations in both soil and biota tissues were transformed to natural-log (ln) prior to regression analyses. Regression analyses were considered significant and suitable for estimation purposes if all three of the following criteria were met: $p>0.05$, $r2>0.1$, and a positive slope. If regression analyses did not meet any one of these criteria, the median BAFs were used to estimate tissue concentrations in exposure models.

The wildlife SSLs are presented in Table 7-6 while the wildlife PRGs (metals only) are first presented in Table H-5. For the purposes of this risk evaluation, the LOAEL-based SSLs were used to evaluate residual risks at the 100-K remediated waste sites. To focus the evaluation down to those COPEC-receptor-waste sites combinations that might require further evaluation, the SSLs were compared to EPCs developed for 100-K as described in Section 7.4.1. To then identify which COPEC-receptor-waste sites combinations

should be brought forward to the scientific management decision point SMDP, PRGs were compared to EPCs for COPCs that exceeded SSLs and background, as described in Section 7.4.3.

7.3.2.3 Radionuclide Exposures

Exposure to radionuclides differs from chemical exposure. Terrestrial biota receive exposure to radionuclides through a combination of both internal and external pathways. Internal exposure is a function of radiation emitted from radionuclides that are retained in tissues. At a terrestrial site such as the 100-K Source OUs, external exposure is due to radiation from radionuclides in soil with which biota come into contact (or come near). For the purposes of developing SSLs, radionuclide exposure was estimated based on the internal and external radiation exposure models used to develop BCGs as described in the *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002).

The BCGs for terrestrial plants and animals represent SSLs for radionuclides in soil for assessing ecological risks at the 100-K Source OUs waste sites (Table 7-1). The BCGs for radionuclides use conservative assumptions for internal and external exposure. While existing effects data support the application of these dose limits to representative individuals within populations of plants and animals, the assumptions and parameters applied in the derivation of the BCGs are based on a maximally exposed individual, representing a conservative approach for screening purposes. The following assumptions are used for estimating doses from external exposure for purposes of developing BCGs:

- The source medium is infinite in extent and contains uniform concentrations of radionuclides (i.e., there are no "hot spots").
- The exposed organism is very small; consequently, 100 percent of the radionuclide energies are absorbed.
- Organisms exposed to soil are uniformly surrounded by the source medium.

The following assumptions are used in estimating doses from internal exposure for purposes of developing BCGs:

- All radionuclide decay energies are retained in tissue (100 percent of energies absorbed).
- Exposure for a given radionuclide includes all decay chain progeny.
- All radionuclides are uniformly distributed such that all target tissues may be affected.

7.3.3 Estimation of Exposure Point Concentrations in Waste Sites

A total of 16 interim remediated waste sites at the 100-K Source OUs were verification sampled and data were included in this supplemental ecological risk evaluation.

Section 6.1.2 details the computation of the EPCs for the waste sites at the 100-K Source OUs. Briefly, the 95 percent UCL of the arithmetic mean was calculated as the EPC for each decision unit (shallow, staging pile area, and overburden) within each waste site. Two separate statistical evaluations were performed, one used for the closeout documentation and one used for human health and ecological risk evaluations, as follows:

- **Statistical Evaluation Used for Closeout Documentation:** For the closeout documentation, the primary statistical calculation to support cleanup verification was the 95 percent UCL on the arithmetic mean of the data. As in Ecology Publication 92-54, a 95 percent UCL on the mean based on the Student's t-test statistic was used for normally distributed data, and the Land method (WSDOE, 1992) using the H-statistic was used for lognormal data. This guidance also employs the use of a proxy value of one-half the detection limit for nondetect values. For small data sets ($n<10$),

the calculations were performed assuming a nonparametric distribution, so no test for distribution was performed (i.e., the maximum detected concentration was used as the EPC).

- **Statistical Evaluation Used for Soil Risk Evaluation:** Both *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) (the most recent EPA guidance for UCL calculation) and ProUCL 4.00.05 were used to recalculate EPCs for the human health and ecological risk evaluations of the 100-K Source OUs. Although *Statistical Guidance for Ecology Site Managers* (Ecology Publication 92-54) has been used to calculate EPCs for all closeout documentation to date, EPCs were recalculated according to *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (OSWER 9285.6-10) to allow for the use of more rigorous statistical methods to estimate exposure concentration and to eliminate the use of the one-half the detection limit used in *Statistical Guidance for Ecology Site Managers* (Ecology Publication 92-54), which has the potential to underestimate exposure concentrations.

The process used to calculate EPCs for each waste site and decision unit is documented in *Computation of Exposure Point Concentrations for the 100-KR-1 and 100-KR-2 Source Operable Units* (ECF-100KR1-11-0008, Appendix G) to document the data processing and reduction steps, methodology, decision logic, assumptions, input files, and output files used to determine the EPCs. A summary of the EPCs generated for use in this evaluation for each waste site, decision unit, and detected analyte at the 100-K Source OUs is provided in Section 7.4.1, Table 7-7.

7.4 Risk Characterization

The outcome of this step is a list of COPECs for each medium-pathway-receptor combination evaluated. Risks at the 100-K Source OUs waste sites were estimated using the hazard quotient (HQ) method as follows:

$$HQ = EPC/SSL \text{ or } PRG$$

where:

HQ = Ecological hazard quotient (unitless)

EPC = Soil concentration (µg/kg for nonradionuclides and pCi/g for radionuclides)

SSL = plant/invertebrate or wildlife soil screening level (µg/kg for nonradionuclides and pCi/g for radionuclides)

PRG = plant/invertebrate or wildlife preliminary remediation goal (µg/kg for nonradionuclides)

Table 7-4. Exposure Factors for Bird and Mammal Endpoint Species

Assessment Endpoint Functional Group	Endpoint Species	Body Weight (kg)	Notes	Source	Food Intake (kg/kg-bw/d, dw)	Notes	Source	Diet Composition						Soil Ingestion Site (kg/kg-(bw/d)[b]	Notes	Source
								% of Diet as Mammals/ Birds	% Diet as Invertebrates	% of Diet as Plants	Major Food Items	Source	% of Diet as Soil			
Granivorous bird	California Quail	**0.18**	Median from multiple studies	Robel, 1969 Roseberry and Klimstra, 1971 Guthery et al., 1988	**0.078**	Average of food ingestion rates over 4 seasons from exposure factors handbook for bobwhite (EPA, 1993). Rate based on diet of commercial game food with only 5 to 10 percent water content; therefore, assumed dry weight.	Koerth and Guthery, 1990		0	**100**	Primarily a granivore, but also ingests some animal matter (primarily snails) and green forage. It is assumed this species ingests 100 percent plants (seeds) for screening-level dose calculation purpose.		**6.1**	**0.00476**	Value for mourning dove assumed representative of California Quail. Median soil ingestion rate estimated for mourning dove in Table 3 of the EcoSSL guidance. The median was selected as the best measure of central tendency that is unbiased by outliners.	OSWER Directive 9285.7-55
Omnivorous bird	Meadowlark	**0.0995**	Median from multiple studies	Wiens and Rotenberry, 1980 Maher, 1979	**0.12**	Allometric estimation for 'omnivorous birds' normalized to kg/kg-bw/d using median body weights from multiple studies	Nagy, 2001[a]	0	**63**	**37**	Ground forager that consumes both plant material (primarily seeds) and invertebrates (primarily arthropods). Percentages represent averages for >1900 meadowlarks studied across North America.	Lanyon, 2008	**2.08**	**0.0025**	Data regarding soil ingestion of western meadowlarks are unavailable. For the purposes of this supplemental ecological risk evaluation, it was assumed that soil ingestion for meadowlarks is similar to that derived for the American robin.	ES/ER/TM-125
Insectivorous bird	Killdeer	**0.0756**	Median from multiple studies	Purdue and Haines, 1977 Stegeman, 1955 Jackson and Jackson, 2000 Dunning, 1993	**0.192**	Allometric estimation for 'Charadriiformes' normalized to kg/kg-bw/d using median body weights from multiple studies	Nagy, 2001[a]	0	**100**	0	Primarily consume terrestrial invertebrates, especially earthworms, grasshoppers, beetles, and snails. Forages in terrestrial and aquatic habitats.	Jackson and Jackson, 2000	**7.3**	**0.0140**	Data regarding soil ingestion of killdeer are unavailable. For the purposes of this supplemental ecological risk evaluation, it was assumed that soil ingestion for killdeer is similar to that of the least sandpiper. However, it should be noted that this value is likely somewhat higher than the actual soil ingestion for killdeer because killdeer do not probe in the soil/sediment. Jackson and Jackson (2000) reported grit to be 4.5% by volume of the esophageal contents in 15 killdeer, which suggests that a value of 7.3% may be a conservative estimate.	Beyer et al., 1994
Carnivorous bird	Red-tailed Hawk	**1.179**	Median from multiple studies	Craighead and Craighead,1956 Steenhof,1983 Springer and Osborne,1983	**0.035**	High end estimate (estimate* 1.25) presented in Table 1 of the EcoSSL guidance (OSWER Directive 9285.7-55). Based on empirical ingestion data from Craighead and Craighead (1956)	OSWER Directive 9285.7-55	**100**	0	0	Primarily eat small mammals such as mice, shrews, voles, rabbits, and squirrels, but also eat birds, lizards, snakes, and large insects, depending on availability. Assumed 100 percent small mammal diet for screening-level dose calculation purposes.	EPA,1993	**2.4**	**0.00085**	Median soil ingestion rate estimated for red-tailed hawk in Table 3 of the EcoSSL guidance. The median was selected as the best measure of central tendency that is unbiased by outliners.	OSWER Directive 9285.7-55

Table 7-4. Exposure Factors for Bird and Mammal Endpoint Species

Assessment Endpoint Functional Group	Endpoint Species	Body Weight (kg)	Notes	Source	Food Intake (kg/kg-bw/d, dw)	Notes	Source	Diet Composition						Soil Ingestion Site (kg/kg-(bw/d)[b]	Notes	Source
								% of Diet as Mammals/ Birds	% Diet as Invertebrates	% of Diet as Plants	Major Food Items	Source	% of Diet as Soil			
Granivorous mammal	Great Basin pocket mouse	**0.0175**	Median from multiple studies	Scheffer,1938 O'Farrell et al.,1975 Schreiber,1978	**0.123**	Allometric estimation for 'granivorous mammals' normalized to kg/kg-bw/d using mean weight as reported by Scheffer, 1938, O'Farrell et al., 1975, and Schreiber, 1978	Nagy, 2001[a]	0	0	**100**	Diet consists primarily of seeds; however, insects (e.g., insect larvae reported in pocket mice from eastern Washington; Kritzman, 1974) may be consumed in the spring before seeds become available. Diet assumed to be 100 percent plants (seeds) for screening-level dose calculation purpose.	Kritzman,1974	**2**	**0.00246**	Data regarding soil ingestion of granivorous mammals are unavailable. For the purposes of this supplemental ecological risk evaluation, it was assumed that soil ingestion for pocket mice is similar to that of the white-footed mouse.	Beyer et al., 1994
Omnivorous mammal	Deer Mouse	**0.0194**	Median from multiple studies	O'Farrell, et al., 1975 Silva and Downing, 1995	**0.166**	Allometric estimation for 'omnivorous mammals' normalized to kg/kg-bw/d using median body weights from multiple studies	Nagy, 2001[a]	0	**50**	**50**	Diet consists of plant material (primarily seeds) and terrestrial invertebrates (mainly insects). Approximation for diet of deer mice in Colorado over all seasons was 50 percent plants and 50 percent invertebrates.	EPA, 1993	**2**	**0.0033**	Assumed to be similar to the white-footed mouse because of similar dietary and foraging habits.	Beyer et al., 1994
Insectivorous mammal	Grasshopper mouse	**0.0346**	Median from multiple studies	Wied, Maximilian, Prinz zu., 1839 McKinney and Pasley, 1974 BHI-01757	**0.098**	Allometric estimation for 'insectivorous mammals' normalized to kg/kg-bw/d using median body weights from multiple studies	Nagy, 2001[a]	0	**100**	0	Animal material contributed 89 percent of the total food consumed and cultivated grains represented less than 5 percent of the total in the stomach contents of field-trapped grasshopper mice from 90 locations across 13 states. Diet assumed to be 100 percent invertebrates for screening-level dose calculation purposes.	Bailey and Sperry, 1929	**0.9**	**0.00088**	Assumed to be similar to the short-tailed shrew because of similar dietary and foraging habits. Median soil ingestion rate estimated for short-tailed shrew in Table 3 of the EcoSSL guidance. The median was selected as the best measure of central tendency that is unbiased by outliners.	OSWER Directive 9285.7-55

Table 7-4. Exposure Factors for Bird and Mammal Endpoint Species

Assessment Endpoint Functional Group	Endpoint Species	Body Weight (kg)	Notes	Source	Food Intake (kg/kg-bw/d, dw)	Notes	Source	Diet Composition						Soil Ingestion Site (kg/kg-(bw/d)[b]	Notes	Source
								% of Diet as Mammals/ Birds	% Diet as Invertebrates	% of Diet as Plants	Major Food Items	Source	% of Diet as Soil			
Carnivorous mammal	Badger	**7.6**	Median from multiple studies	Messick and Hornocker, 1981 Silva and Downing, 1995	**0.0347**	Allometric estimation for 'carnivorous mammals' normalized to kg/kg-bw/d using median body weights from multiple studies	Nagy, 2001[a]	**100**	0	0	Carnivores that primarily eat small rodents (rats, mice, ground squirrels, pocket gophers), thought some reptiles, insects, birds, and carrion are consumed. Assumed 100 percent small mammal diet for screening-level dose calculation purposes.	Long, 1973	**5.2**	**0.00181**	Data regarding soil ingestion of badgers are unavailable. Because the badger is a burrowing mammal, soil ingestion may be similar to that of the prairie dog. It was assumed that the median soil ingestion of the two prairie dog species with available data (2.7 and 7.7 percent) would be representative of the badger.	Beyer et al., 1994

Sources are provided in Chapter 11, References.

Notes: Bold and underlined text indicates life-history parameters that were used in the initial screening exposure calculations.

a. Nagy (2001) regression equation format --> dry matter g/day/g body weight = a(grams body weight)^b/g body weight

b. Soil ingestion is equal to the percent soil in diet multiplied by the food ingestion rate as follows: soil ingestion = (percent soil/100* food ingestion rate)

BW = body weight

DW = dry weight

EPA = United States Environmental Protection Agency

Group	*a*	*b*
Birds		
omnivorous birds	0.670	0.627
Galliformes	0.088	0.891
Charadriiformes	0.522	0.769
Mammals		
carnivorous mammals	0.153	0.834
granivorous mammals	0.659	0.413
insectivorous mammals	0.373	0.622

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Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Soil to Plants								
Radionuclides	Americium-241					0.00496	Beresford et al., 2008	CR review
	Antimony-125					0.025	Beresford et al., 2008	From Coughtrey et al. (1983) suggested value for natural vegetation (A.A. Balkema Vol. 3); Note one CR review value of CR=41
	Carbon-14					890	Beresford et al., 2008	Specific activity model; FASSET
	Cesium-134					0.693425575	Beresford et al., 2008	CR review
	Cesium 137					0.693425575	Beresford et al., 2008	CR review
	Cobalt-60					0.0135	Beresford et al., 2008	IAEA TRS364 value for grass
	Curium-244					0.000275	Beresford et al., 2008	IAEA TRS364 value for grass
	Europium-152					0.00519802	Beresford et al., 2008	Estimated from stable concs. in soils & angiosperms values presented Coughtrey and Thorne (1983; A.A. Balkema Vol. 1)
	Europium-154					0.00519802	Beresford et al., 2008	Estimated from stable concs. in soils & angiosperms values presented Coughtrey and Thorne (1983; A.A. Balkema Vol. 1)
	Europium-155					0.00519802	Beresford et al., 2008	Estimated from stable concs. in soils & angiosperms values presented Coughtrey and Thorne (1983; A.A. Balkema Vol. 1)
	Hydrogen-3 (tritium)					150	Beresford et al., 2008	Specific activity model; FASSET
	Neptunium-237					0.01725	Beresford et al., 2008	IAEA TRS363 value for grass
	Nickel-63					0.1875	Beresford et al., 2008	CR review
	Plutonium-238					0.014425378	Beresford et al., 2008	CR review; note some reviews report values in range 10-2 - 10-8 but present data in manner that cannot be used. Primary source here is Sheppard review of IUR data
	Plutonium-239/240					0.014425378	Beresford et al., 2008	CR review; note some reviews report values in range 10-2 - 10-8 but present data in manner that cannot be used. Primary source here is Sheppard review of IUR data
	Radium-226					0.039440524	Beresford et al., 2008	CR review
	Radium-228					0.039440524	Beresford et al., 2008	CR review
	Strontium 90					0.206811821	Beresford et al., 2008	CR review
	Technetium-99					20.00829611	Beresford et al., 2008	CR review
	Thorium-232					0.043740981	Beresford et al., 2008	CR review
	Uranium-234					0.0145507	Beresford et al., 2008	CR review
	Uranium-235					0.0145507	Beresford et al., 2008	CR review
	Uranium-238					0.0145507	Beresford et al., 2008	CR review
Metals	Aluminum					0.00287	BJC/OR-133	Median - Table D-1 validation data
	Antimony	-3.233	0.938	OSWER Directive 9285.7-55	Derived from measured data in Appendix A	0.0102	BJC/OR-133	Median - Table D-1 validation data
	Arsenic, Total all valence states	-1.992	0.564	BJC/OR-133	Single variable regression; EcoSSLs used BAF	0.0375	BJC/OR-133	Median - Table 6; cited in OSWER Directive 9285.7-55

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Metals (cont.)	Arsenic (III)	-1.992	0.564	BJC/OR-133	Single variable regression; EcoSSLs used BAF	0.0375	BJC/OR-133	Median - Table 6; cited in OSWER Directive 9285.7-55
	Arsenic (V)	-1.992	0.564	BJC/OR-133	Single variable regression; EcoSSLs used BAF	0.0375	BJC/OR-133	Median - Table 6; cited in OSWER Directive 9285.7-55
	Barium					0.156	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Beryllium	-0.5361	0.7345	OSWER Directive 9285.7-55	Derived from measured data in Appendix A			
	Bismuth					0.005	ORNL-5786	Figure 2.2
	Boron					5.714	USACHPPM, 2004	Median - Table 4-6 leaf tissue
	Cadmium	-0.476	0.546	BJC/OR-133	Cited in OSWER Directive 9285.7-55 (Table 4a)	0.586	BJC/OR-133	Median - Table 6
	Chromium (total)					0.041	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Chromium (+3)					0.041	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Chromium (+6)					0.041	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Cobalt					0.00745	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Copper	0.669	0.394	BJC/OR-133	Cited in OSWER Directive 9285.7-55 (Table 4a)	0.124	BJC/OR-133	Median - Table 6
	Lead	-1.328	0.561		Cited in OSWER Directive 9285.7-55 (Table 4a)	0.0389	BJC/OR-133	Median - Table 6
	Lithium					0.004	ORNL-5786	Figure 2.2
	Manganese					0.0792	BJC/OR-133	Median - Table D-1 validation data; cited in OSWER Directive 9285.7-55
	Mercury	-0.996	0.544	BJC/OR-133	Single variable regression	0.0652	BJC/OR-133	Median - Table 6
	Molybdenum					1.2504	USACHPPM, 2004	Median - Table 4-6 leaf tissue
	Nickel	-2.224	0.748	BJC/OR-133	Cited in OSWER Directive 9285.7-55 (Table 4a)	0.018	USACHPPM, 2004	Median - Table 6
	Selenium	-0.678	1.104	BJC/OR-133	Cited in OSWER Directive 9285.7-55 (Table 4a)	0.672	USACHPPM, 2004	Median - Table 6
	Silver					0.014	BJC/OR-133	Median - Table D-1 validation data
	Strontium					0.207	Beresford et al., 2008	CR review
	Thallium					0.004	ORNL-5786	Figure 2.2
	Tin					1	Default	
	Uranium					0.021	USACHPPM, 2004	Median - Table 4-6 leaf tissue
	Vanadium					0.00485	BJC/OR-133	Median - Table D-1 validation data
	Zinc	1.575	0.555	BJC/OR-133	Cited in OSWER Directive 9285.7-55 (Table 4a)	0.366	BJC/OR-133	Median - Table 6
General Inorganics	Ammonia/Ammonium							
	Chloride							
	Cyanide							
	Fluoride					0.006	ORNL-5786	Figure 2.2

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
General Inorganics (cont.)	Iodine					0.05	ORNL-5786	Figure 2.2
	Nitrate/Nitrite							
	Phosphate							
	Sulfate/Sulfite							
	Total Organic Carbon							
Volatile Organics	1,1-dichloroethane						OSWER Directive 9285.7-55	Kow (1.79) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,1-dichloroethene						OSWER Directive 9285.7-55	Kow (2.13) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,1,1-trichloroethane						OSWER Directive 9285.7-55	Kow (2.48) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,1,2-trichloroethane						OSWER Directive 9285.7-55	Kow (2.05) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,1,2,2-tetrachloroethane						OSWER Directive 9285.7-55	Kow (2.39) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,2-dichlorobenzene					2.45	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.43 (EPA, 1995)
	1,2-dichloroethane (DCA)						OSWER Directive 9285.7-55	Kow (1.47) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	1,3-dichlorobenzene					2.23	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.53 (EPA, 2010)[c]
	2-butanone (Methyl Ethyl Ketone/MEK)						OSWER Directive 9285.7-55	Kow (0.29) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	2-hexanone						OSWER Directive 9285.7-55	Kow (1.38) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Benzene						OSWER Directive 9285.7-55	Kow (2.13) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Butanol						OSWER Directive 9285.7-55	Kow (0.8) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Carbon Tetrachloride						OSWER Directive 9285.7-55	Kow (2.73) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Chlorobenzene						OSWER Directive 9285.7-55	Kow (2.86) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Chloroform						OSWER Directive 9285.7-55	Kow (1.92) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Cis-1,2-dichloroethylene						OSWER Directive 9285.7-55	Kow (1.86) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Dichloromethane (Methylene Chloride)						OSWER Directive 9285.7-55	Kow (1.25) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Volatile Organics (cont.)	Ethyl Benzene					3.21	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.14 (EPA, 1995)
	Methyl Isobutyl Ketone						OSWER Directive 9285.7-55	Kow (1.19) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	n-butyl Benzene					1.67	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.84 (EPA, 2010)[c]
	Tetrachloroethylene						OSWER Directive 9285.7-55	Kow (2.67) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Toluene						OSWER Directive 9285.7-55	Kow (2.75) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Trans-1,2-dichloroethylene						OSWER Directive 9285.7-55	Kow (2.07) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Trichloroethylene (TCE)						OSWER Directive 9285.7-55	Kow (2.71) outside of range of Kow-based models for plants (OSWER Directive 9285.7-55); BAF is undefined.
	Xylene					3.43	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.07 (EPA, 1995)
Polycyclic Aromatic Hydrocarbons	Acenaphthene	-5.562	-0.8556	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Acenaphthylene	-1.144	0.791	OSWER Directive 9285.7-55	Modeled using the rinsed PAH-specific equation			
	Anthracene	-0.9887	0.7784	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Benzo(a)pyrene	-2.0615	0.975	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Benzo(a)anthracene	-2.7078	0.5944	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Benzo(b)fluoranthene					0.31	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C
	Benzo(ghi)perylene	-0.9313	1.1829	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Benzo[k]fluoranthene	-4.6482	0.1668	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Chrysene	-2.7078	0.5944	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Dibenz(ah)anthracene					0.13	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C
	Fluoranthene					0.5	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C
	Fluorene	-5.562	-0.8556	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Indeno[1,2,3-cd]pyrene					0.11	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Polycyclic Aromatic Hydrocarbons (cont.)	2-Methylnaphthalene	-1.3205	4.544	OSWER Directive 9285.7-55	Based on LMW PAH rinsed model in Figure 4			
	Naphthalene					12.2	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C
	Phenanthrene	-0.1665	0.6203	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Pyrene					0.72	OSWER Directive 9285.7-55	Median BAF calculated from measured data in Appendix C
	Total PAHs	0.083	0.3015	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	Low MW PAHs	-1.3205	0.4544	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	High MW PAHs	-1.7026	0.9469	OSWER Directive 9285.7-55	Derived from measured data in Appendix C or Figure 4			
	TPH - Diesel							
	TPH - Kerosene							
	Normal paraffin hydrocarbons							
	Phenol						OSWER Directive 9285.7-55	Kow (1.48) outside of range of Kow-based models for plants (OSWER Directive 9285.7 55); BAF is undefined.
Semivolatile Organics	2-methylphenol (ocresol)						OSWER Directive 9285.7-55	Kow (1.99) outside of range of Kow-based models for plants (OSWER Directive 9285.7 55); BAF is undefined.
	4-methylphenol (pcresol)						OSWER Directive 9285.7-55	Kow (1.95) outside of range of Kow-based models for plants (OSWER Directive 9285.7 55); BAF is undefined.
	2,4-dinitrotoluene	1.873	-0.3768	Tsao and Sample, 2005		0.376	Tsao and Sample, 2005	Median BAF for foliage, all plants, from Table 3.3-1
	Bis[2-ethylhexyl] phthalate					0.07	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 7.30 (EPA, 1995)[c]
	Total PCBs					0.17	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.29 (EPA, 2010)[c]
	Aroclor 1016					0.30	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 5.69 (ChemIDPlus Lite)[c]
	Aroclor 1221					0.78	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4.65 (ChemIDPlus Lite)[c]
	Aroclor 1232					0.99	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4.4 (ChemIDPlus Lite)[c]
	Aroclor 1242					0.16	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.34 (ChemIDPlus Lite)[c]
	Aroclor 1248					0.18	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.2 (ChemIDPlus Lite)[c]
	Aroclor 1254					0.14	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.5 (ChemIDPlus Lite)[c]

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Semivolatile Organics (cont.)	Aroclor 1260					0.05	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 7.55 (ChemIDPlus Lite)[c]
	Aroclor 1262							
Pesticides	Dichloroprop							
	Aldrin					0.14	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.50 (EPA, 1995)[c]
	beta-1,2,3,4,5,6-Hexachlorocyclohexane					1.72	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 3.81 (EPA, 1995)[c]
	alpha-Chlordane					0.16	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.32 (EPA, 1995)[c]
	gamma-Chlordane					0.16	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 6.32 (EPA, 1995)[c]
	Dichlorodiphenyldichloroethylene	-2.5119	0.7524	OSWER Directive 9285.7-55	Regression model for total DDTs from Table 4b			
	Dichlorodiphenyltrichloroethane	-2.5119	0.7524	OSWER Directive 9285.7-55	Regression model for total DDTs from Table 4b			
	Dieldrin					0.41	OSWER Directive 9285.7-55	Empirical BAF from Table 4b
	Endosulfan I					1.31	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4.10 (EPA, 1995)[c]
	Endosulfan II					1.31	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4.10 (EPA, 1995)[c]
	Endosulfan sulfate					1.98	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4.10 (EPA, 2010)c
	Endrin aldehyde					1.44	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 4 (EPA, 1995)[c]
	Methoxychlor					0.52	OSWER Directive 9285.7-55	Log Kow model for nonionic organics (rinsed plants); log Kow = 5.08 (EPA, 1995)[c]
Soil to Terrestrial Invertebrates								
Radionuclides	Americium-241					0.1006	Beresford et al., 2008	CR review
	Antimony-125					0.2525	Beresford et al., 2008[b]	Same as gastropod (most conservative invertebrate CR)
	Carbon-14					430	Beresford et al., 2008	Assume same as worm
	Cesium-134					0.1341	Beresford et al., 2008	CR review
	Cesium 137					0.1341	Beresford et al., 2008	CR review
	Cobalt-60					0.0035	Beresford et al., 2008	CR review
	Curium-244					0.1374	Beresford et al., 2008	CR review

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Radionuclides (cont.)	Europium-152					0.0008	Beresford et al., 2008	Same as soil invertebrate
	Europium-154					0.0008	Beresford et al., 2008	Same as soil invertebrate
	Europium-155					0.0008	Beresford et al., 2008	Same as soil invertebrate
	Hydrogen-3 (tritium)					150	Beresford et al., 2008	Assume same as worm
	Neptunium-237					0.1006	Beresford et al., 2008	Same as Am gastropod
	Nickel-63					0.0086	Beresford et al., 2008	CR review
	Plutonium-238					0.0388	Beresford et al., 2008	CR review
	Plutonium-239/240					0.0388	Beresford et al., 2008	CR review
	Radium-226					0.0900	Beresford et al., 2008	CR review
	Radium-228					0.0900	Beresford et al., 2008	CR review
	Strontium 90					0.4066	Beresford et al., 2008	CR review
	Technetium-99					0.3700	Beresford et al., 2008	Assume maximum available value in lack of data
	Thorium-232					0.0088	Beresford et al., 2008	Assume U Soil invertebrate
	Uranium-234					0.0088	Beresford et al., 2008	Same as soil invertebrate
	Uranium-235					0.0088	Beresford et al., 2008	Same as soil invertebrate
	Uranium-238					0.0088	Beresford et al., 2008	Same as soil invertebrate
Metals	Aluminum					0.043	ES/ER/TM-220	Median - Table C.1
	Antimony					1	ORNL-5786 cited in EPA 2007i	Assumed earthworm conc = soil conc according to (Table 4a)
	Arsenic	-1.421	0.706	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7-55 (Table 4a)	0.224	ES/ER/TM-220	Median - Table 11
	Arsenic (III)	-1.421	0.706	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7-55 (Table 4a)	0.224	ES/ER/TM-220	Median - Table 11
	Arsenic (V)	-1.421	0.706	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7-55 (Table 4a)	0.224	ES/ER/TM-220	Median - Table 11
	Barium					0.091	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55
	Beryllium					0.045	ES/ER/TM-220	Median - Table C.1; cited in OSWER Directive 9285.7 55
	Bismuth					1	Default	
	Boron					1	Default	
	Cadmium	2.114	0.795	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7-55 (Table 4a)	7.708	ES/ER/TM-220	Median - Table 11
	Chromium					0.306	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55
	Chromium (+3)					0.306	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55
	Chromium (+6)					0.306	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Metals (cont.)	Cobalt					0.291	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55
	Copper	1.675	0.264	ES/ER/TM-220	General regression - low r^2	0.515	ES/ER/TM-220	Median - Table 11; cited in OSWER Directive 9285.7 55
	Lead	-0.218	0.807	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7 55 (Table 4a)	0.266	ES/ER/TM-220	Median - Table 11
	Lithium					0.046	ES/ER/TM-220	Median - Table C.1
	Manganese	-0.809	0.682	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7 55 (Table 4a)	0.054	ES/ER/TM-220	Median - Table 11
	Mercury	0.0781	0.3369	ES/ER/TM-220	General regression, not including validation data	1.693	ES/ER/TM-220	Median - Table 11
	Molybdenum					0.953	ES/ER/TM-220	Median - Table C.1
	Nickel	3.677	-0.26	ES/ER/TM-220	regression not significant	1.059	ES/ER/TM-220	Median - Table 11
	Selenium	-0.075	0.733	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7 55 (Table 4a)	0.985	ES/ER/TM-220	Median - Table 11
	Silver					2.045	ES/ER/TM-220	Median - Table C.1; cited in OSWER Directive 9285.7 55
	Strontium					0.4066	Beresford et al., 2008	CR review
	Thallium					0.0541	USACHPPM, 2004	Median - Table 4-5 (Insecta)
	Tin					0.08	ORNL-5786	No data available for invertebrates; assumed to be similar to uptake to small mammals (from Figure 2.25)
	Uranium					0.033	ES/ER/TM-220	Median - Table C.1
	Vanadium					0.042	ES/ER/TM-220	Median - Table C.1; cited in OSWER Directive 9285.7 55
	Zinc	4.449	0.328	ES/ER/TM-220	Sample et al., 1999 cited in OSWER Directive 9285.7 55 (Table 4a)			
General Inorganics	Ammonia/Ammonium							
	Chloride							
	Cyanide							
	Fluoride							
	Iodine							
	Nitrate/Nitrite							
	Phosphate							
	Sulfate/Sulfite							
	Total Organic Carbon							
Volatile Organics	1,1-dichloroethane					1.010	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,1-dichloroethene					1.011	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Volatile Organics (cont.)	1,1,1-trichloroethane					1.013	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,1,2-trichloroethane					1.010	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,1,2,2-tetrachloroethane					1.013	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,2-dichlorobenzene					1.018	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,2-dichloroethane (DCA)					0.988	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	1,3-dichlorobenzene					1.018	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	2-butanone (Methyl Ethyl Ketone/MEK)					0.094	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	2-hexanone					0.207	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Benzene					1.011	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Butanol					0.478	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Carbon Tetrachloride					1.015	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Chlorobenzene					1.015	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Chloroform					1.011	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Cis-1,2-dichloroethylene					1.011	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Dichloromethane (Methylene Chloride)					1.007	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Ethyl Benzene					1.016	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Methyl Isobutyl Ketone					0.197	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	n-butyl Benzene					1.022	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Tetrachloroethylene					1.018	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Toluene					1.014	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Volatile Organics (cont.)	Trans-1,2-dichloroethylene					1.011	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Trichloroethylene (TCE)					1.012	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Xylene					1.016	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
Polycyclic Aromatic Hydrocarbons	Acenaphthene					1.470	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Acenaphthylene					22.9	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Anthracene					2.42	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Benzo(a)pyrene					1.33	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Benzo(a)anthracene					1.59	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Benzo(b)fluoranthene					2.6	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Benzo(ghi)perylene					2.94	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Benzo[k]fluoranthene					2.6	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Chrysene					2.29	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Dibenz(ah)anthracene					2.31	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Fluoranthene					3.04	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Fluorene					9.57	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Indeno[1,2,3-cd]pyrene					2.86	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	2-Methylnaphthalene					1.020	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Naphthalene					4.4	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Phenanthrene					1.72	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Pyrene					1.75	OSWER Directive 9285.7-55	Modeled from Kow based on Jager (1998) [Table 5]
	Total PAHs							
	Low MW PAHs							
	High MW PAHs							
	TPH - Diesel							
	TPH - Kerosene							
	Normal paraffin hydrocarbons							
	Phenol					0.235	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Semivolatile Organics	2-methylphenol (ocresol)					0.336	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	4-methylphenol (pcresol)					0.333	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	2,4-dinitrotoluene					0.184	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Bis[2-ethylhexyl] phthalate					41.144	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7-55 and log Koc and Kow from EPA, 2010e
	Total PCBs	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1016	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1221	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1232	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1242	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1248	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1254	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1260	1.41	1.36	Sample et al., 1999	Combined model and validation data sets, Table 3	6.67	Sample et al., 1999	Median, combined model and validation datasets, Table 2
	Aroclor 1262							
Pesticides	Dichloroprop							
	Aldrin					1.033	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	beta-1,2,3,4,5,6-Hexachlorocyclohexane					1.021	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	alpha-Chlordane					1.031	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	gamma-Chlordane					1.036	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	Dichlorodiphenyldichloroethylene	2.4771	0.8804	OSWER Directive 9285.7-55	Regression derived from measured data			
	Dichlorodiphenyltrichloroethane	2.1247	0.8689	OSWER Directive 9285.7-55	Regression derived from measured data			
	Dieldrin					14.70	OSWER Directive 9285.7-55	Median BAF
	Endosulfan I					1.184	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	Endosulfan II					1.184	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	Endosulfan sulfate					1.184	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Pesticides (cont.)	Endrin aldehyde					6.686	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
	Methoxychlor					3.739	OSWER Directive 9285.7-55	Calculated using model from OSWER Directive 9285.7 55 and log Koc and Kow from EPA, 2010e
Soil to Small Mammal								
Radionuclides	Americium-241					0.041	Beresford et al., 2008	CR review
	Antimony-125					2.1465E-06	Beresford et al., 2008	Constant dietary CR [assume shrub diet] Beresford et al., 2004
	Carbon-14					1340	Beresford et al., 2008	Specific activity model; FASSET
	Cesium-134					2.87	Beresford et al., 2008	CR review - reindeer data not included
	Cesium 137					2.87	Beresford et al., 2008	CR review - reindeer data not included
	Cobalt-60					0.30	Beresford et al., 2008	CR review
	Curium-244					0.041	Beresford et al., 2008	Assume Am mammal
	Europium-152					0.002	Beresford et al., 2008	Allometric prediction using USDOE (EPIC vole parameters, grass CR of 1E-2)
	Europium-154					0.002	Beresford et al., 2008	Allometric prediction using USDOE (EPIC vole parameters, grass CR of 1E-2)
	Europium-155					0.002	Beresford et al., 2008	Allometric prediction using USDOE (EPIC vole parameters, grass CR of 1E-2)
	Hydrogen-3 (tritium)					150	Beresford et al., 2008	Specific activity model; FASSET
	Neptunium-237					0.041	Beresford et al., 2008	Same as Am mammal
	Nickel-63					0.072	Beresford et al., 2008	CR review but based on stable Ni concentrations in mammalian tissues and 'general' soil concentrations FWCR = 3.87e-3 (in: Coughtrey and Thorne, 1983, A.A. Balkema, Vol. 2). Note 1 study gives high conc. in bone which may increase CR circa 10x)
	Plutonium-238					0.023	Beresford et al., 2008	CR review
	Plutonium-239/240					0.023	Beresford et al., 2008	CR review
	Radium-226					0.027	Beresford et al., 2008	CR review - reindeer data not included
	Radium-228					0.027	Beresford et al., 2008	CR review - reindeer data not included
	Strontium 90					1.74	Beresford et al., 2008	CR review - reindeer data not included
	Technetium-99					0.37	Beresford et al., 2008	FASTer prediction
	Thorium-232					0.00012	Beresford et al., 2008	CR review
	Uranium-234					0.00011	Beresford et al., 2008	CR review
	Uranium-235					0.00011	Beresford et al., 2008	CR review
	Uranium-238					0.00011	Beresford et al., 2008	CR review
Metals	Aluminum					0.0263	ES/ER/TM-219	Median - Table C.1 (general)
	Antimony						ORNL-5786 cited in OSWER Directive 9285.7-55	0.001* 50 * Cdiet (from Table 4a)

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Metals (cont.)	Arsenic	-4.8471	0.8188	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0038	ES/ER/TM-219	Median - Table 2 (general)
	Arsenic (III)	-4.8471	0.8188	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0038	ES/ER/TM-219	Median - Table 2 (general)
	Arsenic (V)	-4.8471	0.8188	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0038	ES/ER/TM-219	Median - Table 2 (general)
	Barium					0.0168	ES/ER/TM-219	Median - Table 2 (general); cited in OSWER Directive 9285.7 55
	Beryllium						ORNL-5786 cited in OSWER Directive 9285.7-55 (table 4a)	0.001 * 50 * Cdiet (from Table 4a)
	Bismuth					1	Default value	Default Value
	Boron					1	Default value	Default Value
	Cadmium	-1.2571	0.4723	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - herbivore	0.7568		
	Chromium	-1.4599	0.7338	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0605	ES/ER/TM-219	Median - Table 2 (general)
	Chromium (+3)	-1.4599	0.7338	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0605	ES/ER/TM-219	Median - Table 2 (general)
	Chromium (+6)	-1.4599	0.7338	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.0605	ES/ER/TM-219	Median - Table 2 (general)
	Cobalt	-4.4669	1.307	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.1000	ES/ER/TM-219	Median - Table 2 (general)
	Copper	2.042	0.1444	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.5999	ES/ER/TM-219	Median - Table 2 (general)
	Lead	0.0761	0.4422	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.1233	ES/ER/TM-219	Median - Table 2 (general)
	Lithium					1	Default value	Default Value
	Manganese					0.0205	ES/ER/TM-219	Median - Table C.1 (general)
	Mercury					0.054	ES/ER/TM-219	Median - Table 2 (general)
	Molybdenum					1	Default value	
	Nickel	-0.2462	0.4658	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.3524	ES/ER/TM-219	Median - Table 2 (general)
	Selenium	-0.4158	0.3764	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - general	0.2107	ES/ER/TM-219	Median - Table 2 (general)
	Silver					0.0040	ES/ER/TM-219	Median - Table C.1 (general)
	Strontium					1.74	Beresford et al., 2008	CR review - reindeer data not included
	Thallium					0.1124	ES/ER/TM-219	Median - Table 2 (general)
	Tin					0.08	ORNL-5786	Figure 2.25
	Uranium					0.0002	ORNL-5786	Figure 2.25
	Vanadium					0.0123	ES/ER/TM-219	Median - Table C.1 (general)
	Zinc	4.3632	0.0706	ES/ER/TM-219	cited in OSWER Directive 9285.7-55 (Table 4a) - herbivore	0.8984	ES/ER/TM-219	Median - Table 2 (general)

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
General Inorganics	Ammonia/Ammonium							
	Chloride							
	Cyanide							
	Fluoride							
	Iodine							
	Nitrate/Nitrite							
	Phosphate							
	Sulfate/Sulfite							
	Total Organic Carbon							
Volatile Organics	1,1-dichloroethane					0.0109	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
	1,1-dichloroethene					0.0186	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.13 (EPA, 1995)[d]
	1,1,1-trichloroethane					0.0305	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.48 (EPA, 1995)[d]
	1,1,2-trichloroethane					0.0165	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.05 (EPA, 1995)[d]
	1,1,2,2-tetrachloroethane					0.0270	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.39 (EPA, 1995)[d]
	1,2-dichlorobenzene					0.0882	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.43 (EPA, 1995)[d]
	1,2-dichloroethane (DCA)					0.0063	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.47 (EPA, 1995)[d]
	1,3-dichlorobenzene					0.0963	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.53 (EPA, 2010)[d]
	2-butanone (Methyl Ethyl Ketone/MEK)					0.0006	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 0.29 (EPA, 2010)[d]
	2-hexanone					0.0053	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.38 (EPA, 2010)[d]
	Benzene					0.0186	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.13 (EPA, 1995)[d]
	Butanol					0.0017	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 0.8 (EPA, 1995)[d]
	Carbon Tetrachloride					0.0420	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.73 (EPA, 1995)[d]
	Chlorobenzene					0.0490	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.86 (EPA, 1995)[d]

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Volatile Organics (cont.)	Chloroform					0.0135	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.92 (EPA, 1995)[d]
	Cis-1,2-dichloroethylene					0.0122	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.86 (EPA, 1995)[d]
	Dichloromethane (Methylene Chloride)					0.0042	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.25 (EPA, 1995)[d]
	Ethyl Benzene					0.0666	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.14 (EPA, 1995)[d]
	Methyl Isobutyl Ketone					0.0037	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.19 (EPA, 1995)[d]
	n-butyl Benzene					0.1227	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.84 (EPA, 2010)d
	Tetrachloroethylene					0.0390	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
	Toluene					0.0430	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
	Trans-1,2-dichloroethylene					0.0170	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
	Trichloroethylene (TCE)					0.0410	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
	Xylene					0.0619	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.79 (EPA, 1995)[d]
Polycyclic Aromatic Hydrocarbons	Acenaphthene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Acenaphthylene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Anthracene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Benzo(a)pyrene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Benzo(a)anthracene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Benzo(b)fluoranthene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Benzo(ghi)perylene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Benzo[k]fluoranthene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Chrysene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Dibenz(ah)anthracene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Fluoranthene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Fluorene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Indeno[1,2,3-cd]pyrene					0	OSWER Directive 9285.7-55	Assumed to be negligible

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Polycyclic Aromatic Hydrocarbons (cont.)	2-Methylnaphthalene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Naphthalene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Phenanthrene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Pyrene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Total PAHs					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Low MW PAHs					0	OSWER Directive 9285.7-55	Assumed to be negligible
	High MW PAHs					0	OSWER Directive 9285.7-55	Assumed to be negligible
	TPH - Diesel					0	OSWER Directive 9285.7-55	Assumed to be negligible
	TPH - Kerosene					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Normal paraffin hydrocarbons					0	OSWER Directive 9285.7-55	Assumed to be negligible
	Phenol					0.0064	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.48 (EPA, 1995)[d]
Semivolatile Organics	2-methylphenol (ocresol)					0.0150	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.99 (EPA, 1995)[d]
	4-methylphenol (pcresol)					0.0141	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 1.95 (EPA, 1995)[d]
	2,4-dinitrotoluene					0.0155	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 2.01 (EPA, 1995)[d]
	Bis[2-ethylhexyl] phthalate					0.0945	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 7.3 (EPA, 1995)[d]
	Total PCBs					0.1792	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.29 (EPA, 2010)[d]
	Aroclor 1016					0.2104	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 5.69 (ChemIDPlus Lite)[d]
	Aroclor 1221					0.1883	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 4.65 (ChemIDPlus Lite)[d]
	Aroclor 1232					0.1704	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 4.4 (ChemIDPlus Lite)[d]
	Aroclor 1242					0.1756	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.34 (ChemIDPlus Lite)[d]
	Aroclor 1248					0.1855	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.2 (ChemIDPlus Lite)[d]
	Aroclor 1254					0.1630	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.5 (ChemIDPlus Lite)[d]
	Aroclor 1260					0.0750	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 7.55 (ChemIDPlus Lite)[d]

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]
Semivolatile Organics (cont.)	Aroclor 1262							
Pesticides	Dichloroprop							
	Aldrin					0.1630	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.5 (EPA, 1995)[d]
	beta-1,2,3,4,5,6-Hexachlorocyclohexane					0.1201	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.81 (EPA, 1995)[d]
	alpha-Chlordane					0.1771	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.32 (EPA, 1995)[d]
	gamma-Chlordane					0.1771	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.32 (EPA, 1995)[d]
	Dichlorodiphenyldichloroethylene	3.6401	0.641	OSWER Directive 9285.7-55	Regression derived from measured data [Appendix D]	0.1410	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.76 (EPA, 1995)[d]
	Dichlorodiphenyltrichloroethane	1.1788	0.7254	OSWER Directive 9285.7-55	Regression derived from measured data [Appendix D]	0.1606	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 6.53 (EPA, 1995)[d]
	Dieldrin					1.20	OSWER Directive 9285.7-55	Median BAF
	Endosulfan I					0.1455	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 4.1 (EPA, 1995)[d]
	Endosulfan II					0.1455	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 4.1 (EPA, 1995)[d]
	Endosulfan sulfate					0.1072	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 3.66 (EPA, 2010)d
	Endrin aldehyde					0.1368	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 4 (EPA, 1995)[d]
	Methoxychlor					0.2093	RTI, 2005	logKow model for organics with logKow between -0.67 and 8.2; log Kow = 5.08 (EPA, 1995)[d]

Table 7-5. Biotransfer Factors and Regression Models Used for SSL Calculations

Group	Analyte	Regression Models[a]				Bioaccumulation Factors		
		B0	B1	Source	Notes[b]	BAF	Source	Notes[b]

Sources are provided in Chapter 11, References..

a. Regression models are in the form of LN (plant, invertebrate, or small mammal concentration) = B0 + B1(LN (soil concentration).

b. Notes refer to tables and appendices in the cited references, not tables or appendices of this report.

c. BAFs for uptake of organics with log Kows between 3 and 8 to plants were derived using log BAF = -0.4057*(logKow)+1.781 (rinsed plants, *Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55]).

d. BAFs for uptake of organics to small mammals were derived using log BAF = $-0.099(\log Kow)^2 + 1.07(\log Kow) - 3.56$; this regression is for uptake to fat and represents the lipid concentration rather than whole body.

e. BAFs for uptake of organics to invertebrates were derived using BAF = (0.87*(logKow)/(Koc*foc) (*Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55]), where foc = 0.01.

BAF = Bioaccumulation Factor
Cdiet = concentration in small mammal diet (assumed to be 50 percent plants and 50 percent invertebrates)
EPA = United States Environmental Protection Agency
IAEA = International Atomic Energy Association
PCBs = polychlorinated biphenyls
TPH = total petroleum hydrocarbons
USACHPPM = United States Army Center for Health Promotion and Preventive Medicine

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest
Radionuclides	Americium-241	pCi/g	---	---	---	---	---	---	---	---	---	28900	25000	11900	17800	72100	48700	41400	4840	4840
	Carbon-14	pCi/g	---	---	---	---	---	---	---	---	---	54	60	56	50	61	60	135	32	32
	Curium-244	pCi/g	---	---	---	---	---	---	---	---	---	389000	252000	105000	207000	2300000	722000	499000	50800	50800
	Cobalt-60	pCi/g	---	---	---	---	---	---	---	---	---	805	805	805	863	805	805	806	1000	805
	Cesium-134	pCi/g	---	---	---	---	---	---	---	---	---	1140	1190	1200	854	1160	1180	1270	562	562
	Cesium 137	pCi/g	---	---	---	---	---	---	---	---	---	2390	2700	2800	1430	2510	2630	3280	924	924
	Europium-152	pCi/g	---	---	---	---	---	---	---	---	---	1740	1740	1740	1880	1740	1740	1740	2220	1740
	Europium-154	pCi/g	---	---	---	---	---	---	---	---	---	1610	1610	1610	1740	1610	1610	1610	2060	1610
	Europium-155	pCi/g	---	---	---	---	---	---	---	---	---	33400	33400	33400	37300	33400	33400	33400	48600	33400
	Hydrogen-3 (tritium)	pCi/g	---	---	---	---	---	---	---	---	---	1430	1280	936	1130	3270	2290	2830	420	420
	Neptunium-237	pCi/g	---	---	---	---	---	---	---	---	---	8190	8140	7880	9150	8250	8170	8180	11200	7880
	Nickel-63	pCi/g	---	---	---	---	---	---	---	---	---									
	Plutonium-238	pCi/g	---	---	---	---	---	---	---	---	---	36300	56200	20900	26800	291000	161000	161000	5980	5980
	Plutonium-239/240	pCi/g	---	---	---	---	---	---	---	---	---	38800	60300	22300	28400	324000	175000	176000	6270	6270
	Radium-226	pCi/g	---	---	---	---	---	---	---	---	---	168	142	58	377	285	165	199	193	58
	Radium-228	pCi/g	---	---	---	---	---	---	---	---	---	169	140	55	418	306	165	203	193	55
	Antimony-125	pCi/g	---	---	---	---	---	---	---	---	---	4580	4580	4580	5040	4580	4580	4580	6130	4580
	Strontium 90	pCi/g	---	---	---	---	---	---	---	---	---	521	302	151	112	706	519	413	91	91
	Technetium-99	pCi/g	---	---	---	---	---	---	---	---	---	5360	11500	137000	280000	8670	12100	412000	128000	5360
	Thorium-232	pCi/g	---	---	---	---	---	---	---	---	---	5070	12900	5340	12400	34400	32500	86200	4560	4560
	Uranium-234	pCi/g	---	---	---	---	---	---	---	---	---	12700	21800	6370	40900	30300	24800	51600	14200	6370
	Uranium-235	pCi/g	---	---	---	---	---	---	---	---	---	6340	7810	4360	10200	8600	8130	9630	8060	4360
	Uranium-238	pCi/g	---	---	---	---	---	---	---	---	---	8020	10400	5150	22100	11900	11000	13900	13400	5150
Metals	Aluminum	mg/kg	22020	18602	4921	61782	687	271	380	710	271	---	---	---	---	6872	2708	3799	7101	2708
	Antimony	mg/kg	---	---	---	---	8.82	0.66	0.60	16.66	0.60	---	---	---	---	97	7	6	167	6
	Arsenic, Total all valence states	mg/kg	1800	1981	425	10344	265	105	171	549	105	8104	10559	2132	45439	459	190	318	881	190
	Arsenic (III)	mg/kg	1800	1981	425	10344	265	105	171	549	105	8104	10559	2132	45439	459	190	318	881	190
	Arsenic (V)	mg/kg	1800	1981	425	10344	265	105	171	549	105	8104	10559	2132	45439	459	190	318	881	190
	Barium	mg/kg	1229	1271	660	14442	2082	1889	4605	18843	660	2464	2548	1323	28954	3470	3148	7676	31405	1323
	Beryllium	mg/kg	---	---	---	---	14	18	101	283	14	---	---	---	---	---	---	---	---	---

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest
Metals (cont.)	Bismuth	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Boron	mg/kg	64	86	140	797	40	50	284	767	40	222	300	485	2766	133	167	949	2563	133
	Cadmium	mg/kg	151	2.8	0.9	1375	76	1.5	1.3	455	0.9	278	5	2	2335	2065	28	24	5228	2
	Chromium (total)	mg/kg	334	97	37	1286	320	75	78	752	37	349	101	38	1355	1284	299	313	3536	38
	Chromium (+3)	mg/kg	334	97	37	1286	320	75	78	752	37	349	101	38	1355	1284	299	313	3536	38
	Chromium (+6)	mg/kg	---	---	---	---	1233	288	300	3380	288	---	---	---	---	5340	1245	1300	16583	1245
	Cobalt	mg/kg	1425	305	109	1601	2174	261	250	1346	109	1461	313	111	1633	3233	388	372	1869	111
	Copper	mg/kg	485	85	36	3728	873	100	109	2640	36	1914	272	107	13021	1894	176	182	4672	107
	Lead	mg/kg	247	49	16	979	1204	151	153	2005	16	537	115	36	2433	2544	332	336	4108	36
	Lithium	mg/kg	---	---	---	---	3189	1258	1749	257	257	---	---	---	---	6379	2517	3498	515	515
	Manganese	mg/kg	16369	24184	9588	113951	4227	4115	18430	20464	4115	31823	48820	19636	221536	5828	5798	27720	28213	5798
	Mercury	mg/kg	3.1	0.4	0.04	25	0.5	0.03	0.03	8.7	0.03	36	21	4	134	8	2	3	43	2
	Molybdenum	mg/kg	35	27	18	98	1.7	1.4	2.8	7.1	1.4	345	270	179	977	17	14	28	71	14
	Nickel	mg/kg	1081	79	31	6037	303	18	16	637	16	1912	136	53	11078	676	36	33	1438	33
	Selenium	mg/kg	5.6	3.7	1.7	158	2.1	1.2	1.8	32	1.2	10	8	4	417	3	2	3	60	2
	Silver	mg/kg	345	13	5.0	2044	1442	35	30	3097	5.0	3453	128	50	20437	14418	346	300	30969	50
	Strontium	mg/kg	---	---	---	---	9442	4849	6476	4228	4228	---	---	---	---	---	---	---	---	---
	Thallium	mg/kg	---	---	---	---	5.1	1.8	2.4	2.6	1.8	---	---	---	---	25	9	12	13	9
	Tin	mg/kg	82	128	231	1852	187	252	2691	5107	82	204	318	575	4603	279	377	4025	7639	204
	Uranium	mg/kg	2502	2691	785	18730	610	393	748	1694	393	---	---	---	---	1217	786	1494	3383	786
	Vanadium	mg/kg	67	58	16	268	1363	577	835	1864	16	134	116	31	537	2723	1153	1668	3723	31
	Zinc	mg/kg	4973	714	67	70825	4612	633	794	38590	67	5015	726	68	71294	4661	644	810	38866	68
General Inorganics	Ammonia/Ammonium	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Chloride	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Cyanide	mg/kg	---	---	---	---	27971	20693	78123	38061	20693	---	---	---	---	---	---	---	---	---
	Fluoride (fluorine)	mg/kg	1492	2812	556	9206	9825	8216	35673	17379	556	6123	11539	2281	37771	16521	13816	59985	29224	2281
	Iodine	mg/kg	---	---	---	---	159	183	1558	759	159	---	---	---	---	1594	1834	15579	7590	1594
	Nitrate/Nitrite	mg/kg	---	---	---	---	206422	152711	576537	280885	152711	---	---	---	---	460073	340361	1284984	626035	340361
	Phosphate	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest
General Inorganics (cont.)	Sulfate/Sulfite	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Total Organic Carbon	%	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Volatile Organics	1,1-dichloroethane	mg/kg	3615	217	83	13955	20357	574	502	22894	83	7230	435	165	27909	---	---	---	---	165
	1,1-dichloroethene	mg/kg	3615	217	83	11433	12214	344	301	12238	83	7230	434	165	22866	---	---	---	---	165
	1,1,1-trichloroethane	mg/kg	3615	217	82	8936	407144	11444	10016	349074	82	7230	433	165	17871	---	---	---	---	165
	1,1,2-trichloroethane	mg/kg	3615	217	83	12031	407144	11472	10041	420572	83	7230	434	165	24063	---	---	---	---	165
	1,1,2,2-tetrachloroethane	mg/kg	3615	217	82	9549	3636	102	89	3255	82	7230	433	165	19098	36358	1022	894	32554	165
	1,2-dichlorobenzene	mg/kg	88	91	82	4343	282	294	854	17612	82	176	182	164	8687	---	---	---	---	164
	1,2-dichloroethane (DCA)	mg/kg	3615	222	84	16084	20357	586	513	24710	84	7230	444	169	32168	---	---	---	---	169
	1,3-dichlorobenzene	mg/kg	96	96	82	4051	310	314	854	16652	82	192	192	164	8103	---	---	---	---	164
	2-butanone (Methyl Ethyl Ketone/MEK)	mg/kg	2102	1041	312	11538	721052	159713	176661	970851	312	21017	10406	3123	115382	1861055	412224	455968	2505793	3123
	2-hexanone	mg/kg	2102	548	186	9653	2036	244	237	2512	186	21017	5483	1856	96532	14698	1759	1708	18135	1708
	Benzene	mg/kg	8554	513	195	27053	285	8	7	286	7	---	---	---	---	2850	80	70	2856	70
	Butanol	mg/kg	---	---	---	---	50893	2906	2626	67049	2626	---	---	---	---	203572	11625	10503	268194	10503
	Carbon Tetrachloride	mg/kg	3615	216	82	7382	6514	183	160	4904	82	7230	433	165	14765	---	---	---	---	165
	Chlorobenzene	mg/kg	3615	216	82	6672	7939	223	195	5561	82	7230	433	165	13345	15756	442	387	11036	165
	Chloroform	mg/kg	3615	217	83	13003	6107	172	151	6600	83	7230	434	165	26006	16693	470	412	18041	165
	Cis-1,2-dichloroethylene	mg/kg	3615	217	83	13446	18403	518	453	20271	83	7230	434	165	26892	---	---	---	---	165
	Dichloromethane (Methylene Chloride)	mg/kg	3615	218	83	17281	2382	67	59	2999	59	7230	436	166	34562	20357	576	504	25632	166
	Ethyl Benzene	mg/kg	159	183	194	12721	342	384	1357	33025	159	---	---	---	---	1027	1151	4075	99076	1027
	Methyl Isobutyl Ketone	mg/kg	2102	573	193	10211	721052	90040	87996	915292	193	21017	5729	1927	102114	1861055	232395	227119	2362393	1927
	n-butyl Benzene	mg/kg	301	263	193	7857	530	485	1092	18135	193	---	---	---	---	1589	1454	3275	54406	1454
	Tetrachloroethylene	mg/kg	3615	216	82	7733	570	16	14	443	14	7230	431	164	15467	2850	80	70	2216	70
	Toluene	mg/kg	8554	512	195	17200	21171	594	520	15763	195	---	---	---	---	211715	5944	5202	157633	5202
	Trans-1,2-dichloroethylene	mg/kg	3615	217	83	11881	18403	518	453	18869	83	7230	434	165	23763	---	---	---	---	165
	Trichloroethylene (TCE)	mg/kg	3615	217	82	7498	285	8	7	217	7	7230	434	165	14996	2850	80	70	2169	70
	Xylene	mg/kg	149	175	194	13419	422	481	1787	45266	149	---	---	---	---	826	940	3494	88509	826

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	6831	285	110	38362	71250	1396	1211	96952	110	68306	2849	1096	383617	142500	2793	2422	193905	1096
	Acenaphthylene	mg/kg	3506	19	7	38362	24321	91	78	96952	7	43766	186	74	383617	54132	183	156	193905	74
	Anthracene	mg/kg	3405	170	68	38362	178811	4784	4213	554013	68	43405	1716	678	383617	---	---	---	---	678
	Benzo(a)pyrene	mg/kg	47	6.0	2.4	767	60	8.1	7.6	554	2.4	---	---	---	---	635	81	76	5540	76
	Benzo(a)anthracene	mg/kg	118	5.2	2.0	767	307	7.3	6.4	554	2.0	---	---	---	---	3636	73	64	5540	64
	Benzo(b)fluoranthene	mg/kg	22	3.0	1.3	767	25	4.1	3.9	554	1.3	---	---	---	---	247	41	39	5540	39
	Benzo(ghi)perylene	mg/kg	12	2.6	1.1	767	13	3.5	3.5	554	1.1	---	---	---	---	89	32	35	5540	32
	Benzo[k]fluoranthene	mg/kg	136	3.2	1.3	767	406	4.6	3.9	554	1.3	---	---	---	---	4069	46	39	5540	39
	Chrysene	mg/kg	118	3.6	1.4	767	307	5.1	4.5	554	1.4	---	---	---	---	3636	51	45	5540	45
	Dibenz(ah)anthracene	mg/kg	44	3.5	1.4	767	54	4.9	4.4	554	1.4	---	---	---	---	543	49	44	5540	44
	Fluoranthene	mg/kg	15	2.5	1.1	767	1957	421	420	69252	1.1	---	---	---	---	3915	841	839	138503	839
	Fluorene	mg/kg	6831	45	18	38362	50893	157	134	69252	17.5	68306	446	175	383617	101786	313	267	138503	175
	Indeno[1,2,3-cd]pyrene	mg/kg	49	2.9	1.2	767	63	4.0	3.6	554	1.2	---	---	---	---	626	40	36	5540	36
	2-Methylnaphthalene	mg/kg	5	5.7	155	38362	5.0	5.5	500	27867	5.0	8	9	1547	383617	6	7	1132	63047	6
	Naphthalene	mg/kg	34	37	416	38362	33	36.2	116	27701	33.3	340	369	378	383617	100	109	348	83102	100
	Phenanthrene	mg/kg	4329	236	94	38362	301134	6731	5919	554013	94.3	56061	2406	943	383617	---	---	---	---	943
	Pyrene	mg/kg	11	3.9	1.9	767	825	360	436	41551	1.9	---	---	---	---	1375	600	727	69252	600
	Total PAHs	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Low MW PAHs	mg/kg	6592	12623	2316	38362	25369	19170	74597	36343	2316	67600	128679	23165	383617	130652	97560	372987	181716	23165
	High MW PAHs	mg/kg	40	72	46	767	29	39	699	341	29					157	209	3491	1701	157
Petroleum	Gasoline Range Organics	mg/kg																		
	TPH - diesel	mg/kg	105086	199535	35638	590179	407144	301205	1137154	554013	35638	1050862	1995354	356382	5901794	610716	451807	1705732	831020	356382
	TPH - kerosene	mg/kg	105086	199535	35638	590179	407144	301205	1137154	554013	35638	1050862	1995354	356382	5901794	610716	451807	1705732	831020	356382
Semivolatile Organics	Normal paraffin hydrocarbons	mg/kg	170870	324445	57948	959632	407144	301205	1137154	554013	57948	---	---	---	---	610716	451807	1705732	831020	451807
	Phenol	mg/kg	---	---	---	---	4886	526	504	5919	504	---	---	---	---	14657	1578	1511	17756	1511
	2-methylphenol (ocresol)	mg/kg	---	---	---	---	127436	10038	9293	134503	9293	---	---	---	---	---	---	---	---	---
	4-methylphenol (pcresol)	mg/kg	---	---	---	---	127436	10102	9358	136361	9358	---	---	---	---	---	---	---	---	---
	2,4-dinitrotoluene	mg/kg	0.29	0.30	0.20	7.17	13.78	13.46	35.58	285.89	0.20	38	39	26	932	29	28	74	597	26

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest
Semivolatile Organics (cont.)	Bis[2-ethylhexyl] phthalate	mg/kg	111.06	0.35	0.14	263.03	1733.20	5.35	4.55	3599.39	0.14	---	---	---	---	17332	54	45	35994	45
	Polychlorinated Biphenyls (PCB) [b]	mg/kg	10.01	0.65	0.33	25.09	2.92	0.30	0.27	8.47	0.27	100	3.6	1.8	251	29	1.6	1.5	85	1.5
	Aroclor 1016[b]	mg/kg	6.45	0.64	0.33	21.75	35.21	2.75	2.47	150.41	0.33	64	3.6	1.8	218	88	5.3	4.8	377	1.8
	Aroclor 1221[b]	mg/kg	2.73	0.61	0.33	24.02	0.69	0.25	0.27	8.15	0.25	27	3.4	1.8	240	7	1.5	1.5	82	1.5
	Aroclor 1232[b]	mg/kg	2.19	0.59	0.33	26.24	0.55	0.24	0.27	8.81	0.24	22	3.4	1.8	262	5	1.4	1.5	88	1.4
	Aroclor 1242[b]	mg/kg	10.36	0.65	0.33	25.55	3.09	0.30	0.27	8.74	0.27	104	3.6	1.8	256	31	1.6	1.5	87	1.5
	Aroclor 1248[b]	mg/kg	9.41	0.65	0.33	24.33	0.35	0.06	0.06	1.06	0.06	94	3.6	1.8	243	3	0.3	0.3	11	0.3
	Aroclor 1254	mg/kg	11.52	0.65	0.33	27.26	3.48	0.30	0.27	9.11	0.27	115	3.6	1.8	273	35	1.6	1.5	91	1.5
	Aroclor 1260[b]	mg/kg	20.38	0.66	0.33	51.49	7.67	0.30	0.27	15.42	0.27	204	3.6	1.8	515	77	1.6	1.5	154	1.5
	Aroclor 1262[b]	mg/kg	37.83	71.83	12.83	212.46	27.69	20.48	77.33	37.67	12.83	378	718	128	2125	277	205	773	377	128
Herbicide	Dichloroprop	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pesticide	Aldrin	mg/kg	0.45	0.08	0.03	1.1	10.2	2.0	2.0	27	0.03	2.2	0.4	0.2	5.3	51	9.9	9.8	134	0.2
	beta-1,2,3,4,5,6-Hexachlorocyclohexane	mg/kg	4.1	3.6	2.7	112.2	1.9	1.7	4.0	67	1.7	6.2	5.5	4.1	168	9.4	8.7	20	335	4.1
	alpha-Chlordane	mg/kg	122	24	10	302	93	21	21	264	10	608	121	50	1508	925	205	207	2641	50
	gamma-Chlordane	mg/kg	122	24	10	302	93	20	21	264	10	608	121	50	1508	925	204	206	2641	50
	Dichlorodiphenyldichloroethane (DDD)[c]	mg/kg	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Dichlorodiphenyldichloroethylene (DDE)[c]	mg/kg	30.4	0.21	0.07	0.06	20.48	0.11	0.09	0.03	0.03	300	2.3	0.8	1.7	136	0.7	0.6	0.4	0.4
	Dichlorodiphenyltrichloroethane	mg/kg	30.4	0.30	0.10	2.53	20.48	0.16	0.14	1.41	0.10	300	3.5	1.2	46.3	136	1.0	0.9	12.7	0.9
	Dieldrin	mg/kg	1.9	0.06	0.02	1.64	0.28	0.01	0.01	0.35	0.01	6.1	0.20	0.08	5.2	0.57	0.02	0.02	0.69	0.02
	Endosulfan I	mg/kg	93.4	66.32	41.40	1671.48	0.92	0.71	1.29	21.88	0.71	---	---	---	---	---	---	---	---	---
	Endosulfan II	mg/kg	93.4	66.32	41.40	1671.48	0.92	0.71	1.29	21.88	0.71	---	---	---	---	---	---	---	---	---
	Endosulfan sulfate	mg/kg	62.9	55.40	41.40	2159.84	0.61	0.56	1.29	27.15	0.56	---	---	---	---	---	---	---	---	---
	Endrin aldehyde	mg/kg	2.6	0.52	0.23	52.86	0.51	0.14	0.14	14.04	0.14	---	---	---	---	5.1	1.4	1.4	140.4	1.4
	Methoxychlor	mg/kg	---	---	---	---	59.78	11.20	10.92	441.01	10.92	---	---	---	---	120	22	22	882	22

Table 7-6. SSLs for Wildlife (Birds and Mammals)

Group	Soil Constituent	Units	NOAEL-based site-specific SSLs									LOAEL-based site-specific SSLs								
			California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	NOAEL Lowest	California Quail	Meadow-lark	Killdeer	Red-tailed Hawk	Great Basin Pocket Mouse	Deer Mouse	Grass-hopper Mouse	Badger	LOAEL Lowest

a. Values for diethyl phthalate and di-n-butyl phthalate were used as a surrogate for bis(2)ethylhexyl phthalate.

b. Aroclor 1254 value was used as surrogate.

c. DDT values used as a surrogate for DDE and DDD.

High MW PAHs = High molecular weight polycyclic aromatic hydrocarbons

Low MW PAHs = Low molecular weight polycyclic aromatic hydrocarbons

mg/kg = Milligram per kilogram

pCi/g = Pico Curie per gram

SSL = Soil screening level

TPH = Total petroleum hydrocarbons

--- = Value not available

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HQ values less than 1.0 indicate that adverse effects associated with exposure to a given analyte are unlikely (*Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments: Interim Final* [EPA 540/R-97/006]). These analytes were not considered to present a significant risk and were excluded from further evaluation. An HQ greater than or equal to 1.0 indicates data are insufficient to exclude the potential for risk, but does not indicate that risks are actually present; therefore, these COPCs were carried forward for further evaluation.

In the screening evaluation, the soil EPC for each waste site and decision unit (as applicable) was compared to the plant/invertebrate SSL and the wildlife SSL for all COPCs. The HQs for these comparisons are provided in Appendix H, Table H-1. COPCs with HQs equal to or greater than 1.0 were carried forward for further evaluation. COPCs for which appropriate toxicity data were unavailable were not further evaluated, but were retained as uncertainties.

Because the dose from radionuclides are additive, the total contributions of radionuclides were also calculated using SOF. With the SOF method, contributions were considered significant if the EPC was greater than the SSL. The SOF method equation is as follows:

$$SOF = \sum_{j=1}^{n} Exposurej / SSLj$$

where:

SOF = sum of fractions

Exposurej = exposure concentration for radionuclides

SSLj = soil screening level for radionuclidej

For the purposes of this evaluation, the HQs for each radionuclide and each aroclor was summed within each decisional unit to equal an SOF. If the SOF was greater than 1, then individual radionuclide isotope COPCs were carried forward to the background evaluation.

For those COPCs that exceeded one or more SSLs, the EPC was then compared to the background value and summarized in subsequent tables (Table H-2) in Section 7.4.2. Background concentrations for inorganic analytes in soil at the Hanford Site are described in the Non-Rad Soil Background document (DOE/RL-92-24). That document provides the 90th percentile and maximum background concentrations for several inorganic analytes. For selected inorganic analytes not included in the Non-Rad Soil Background document (DOE/RL-92-24), the 90th percentile statewide concentration has been obtained from Ecology (*Natural Background Soil Metals Concentrations in Washington State* [Ecology Publication 94-115]) or from PNNL (*A Review of Metal Concentrations Measured in Surface Soil Samples Collected on and Around the Hanford Site* [PNNL-18577]), and in the 100 Area RDR/RAWP (DOE/RL-96-17) for uranium. Background concentrations for radiological analytes in soil at the Hanford Site are described in Rad Soil Background document (DOE/RL-96-12), which provides the 90th percentile concentration of background concentrations for several radiological analytes. Background concentrations were not identified for organics; therefore, those with HQs greater than or equal to 1.0 were carried forward. In addition, COPCs with concentrations not within the range of site background were carried forward for comparison to the PRGs.

In the PRG evaluation, the soil EPC for each waste site and decision unit (as applicable) was compared to the plant/invertebrate PRG and the wildlife PRG for all remaining COPCs. COPCs with HQs equal to or greater than 1.0 were retained as COPECs. COPECs were then given further consideration under the

SMDP. The methodology used in this step of the risk characterization is provided in Appendix H, *Ecological Risk Evaluation for the 100-K Source OU* (ECF-100-KR1-11-0010).

7.4.1 Screening Evaluation Results

The comparisons to plant/invertebrate and wildlife SSLs are provided in Table H-1 for the 100-K Source OUs. A detailed description of the results of the screening evaluation (i.e., comparison of EPCs with SSLs) in soil is provided below.

The 100-K Source OUs have 16 waste sites with 14 waste sites reclassified as "interim closed" and two waste sites reclassified as "no action." The plant/invertebrate and wildlife SSL HQs for all 16 waste sites are provided in Table H-1. Radionuclide SOFs and individual radionuclide isotope SSL based HQs were less than 1 for all waste sites; therefore, radionuclide isotopes were eliminated from further evaluation. The SSL-based HQs were less than 1.0 for all COPCs in all of the decision units evaluated at 5 of the 16 waste sites. These waste sites did not require further evaluation of ecological risk:

- 100-K Sites: 100-K-55:1, 100-K-56:1
- 116-K Sites: 116-K-2, 116-KE-4, 116-KW-3

SSLs, background, and PRGs were not available for nickel-63, ethylene glycol, and total petroleum hydrocarbons. These COPCs were retained as an uncertainty and are further discussed in Section 7.4.4. The EPCs for the inorganic analytes boron, chromium, lead, manganese, mercury, selenium, and vanadium exceeded one or both of the SSLs in 12 waste site decision units, as presented in Table H-1. Within the remaining 11 waste sites, EPCs of analytes exceeded the plant/ invertebrate SSLs at each waste site, while fewer analytes exceeded the wildlife SSLs at fewer waste sites. These waste site decision units were carried forward into the background evaluation.

7.4.2 Background Evaluation

Although in exceedance of a SSL, EPCs for many of these COPCs within the 11 remaining waste sites were below the 90th percentile background concentrations, so were eliminated from further evaluation. The comparisons of COPC EPCs to the 90th percentile background for the remaining 11 waste sites are provided in Table H-2.

Within the remaining 11 waste sites, 8 decision units had COPC EPCs in exceedance of both an SSL and background. COPC EPCs detected in exceedance of background were carried forward to the PRG evaluation. The inorganic analytes chromium, lead, mercury, and selenium were detected outside the range of background. A summary of the SSLs and background evaluations in soil for the 8 waste sites is provided in Table H-3.

7.4.3 PRG Evaluation Results

Further evaluation was conducted on the 8 waste sites that were not eliminated in the screening and background evaluations. Risks were evaluated based on the resulting HQs and are provided in Table H-4 and summarized in Table H-5. The following 4 waste sites did not exceed the plant/invertebrate or the wildlife PRGs (HQs were less than 1) and were eliminated from further evaluation:

- 100-K-29
- 100-K-78
- 116-KE-5
- 128-K-1

The EPCs for mercury exceeded both groups of PRGs (plants/invertebrates, wildlife). This COPC was retained as the COPEC in the remaining 4 waste site in the shallow-focused decision units:

- 100-K-30
- 100-K-31
- 100-K-32
- 100-K-33

7.4.4 Uncertainties Assessment

Uncertainties are present in all risk assessments because of the limitations of the available data and the need to make certain assumptions and extrapolations based on incomplete information. In addition, the use of various models (e.g., uptake and food web exposures) carries with it some associated uncertainty as to how well the model reflects actual conditions. Since conservative assumptions were generally used in the exposure and effects assessments, these uncertainties are more likely to result in an overestimation rather than an underestimation of the likelihood and magnitude of risks to ecological receptor. The following uncertainties and limitations associated with the proposed methodology and available data for the ERA are discussed:

- **Data Use**—The quantitative evaluation of chemical concentrations in soils included surface soils from the 0 to 4 m (0 to 15 ft) depth range. Ecology uses a standard point of compliance in soil of 4.6 m (15 ft) for demonstrating protection of ecological receptors ("Terrestrial Ecological Evaluation Procedures" [WAC 173-340-7490(4)(b)]).This depth range may over estimate the depth to which many terrestrial receptors would be exposed. MTCA identifies the biologically active zone in 0 to 1.8 m (0 to 6 ft) (MTCA [WAC 173-340]). Evaluation of data that extends beyond the biologically active zone could either over or under estimate risk.

  No toxicological data were available for some COPCs (nickel-63, ethylene glycol, and total petroleum hydrocarbons) or were limited for some COPC/receptor combinations. Therefore, SSLs could not be calculated for all receptors or COPCs. Exclusion of COPCs from SSL development may not adequately address aggregate risk at a site, though it should be noted that remedial alternatives that are protective of receptors with SSLs may also be protective of receptors lacking sufficient toxicity data. In addition, the absence of SSLs for plants and soil invertebrates can be addressed through performing site-specific bioassays, which are a component of Tier 2 and Tier 3 SSL development. As stated previously, Tier 3 SSL development is not discussed in this report as it is not warranted.

  Bioavailability and toxicity of metals are functions of many factors including soil pH, with metals generally being more bioavailable and toxic at low pHs (*Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55]). The pH range for soil used to develop plant toxicity values range from 3 to 8. (mean=6.3) (*Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* [CHPRC-00784]). The pH range for soil used to develop invertebrate toxicity values range from 3.8 to 8.1 (mean=5.6) (*Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* [CHPRC-00784]). The minimum soil pH reported in the RCBRA Report (DOE/RL-2007-21) in riparian and upland soil was 6.6. Because the range of pH values in soils associated with plant and soil invertebrate toxicity values include values that are substantially lower than those present throughout most of the Hanford Site, it is likely that the resulting SSLs for plants and soil invertebrates do not accurately represent toxicity. Since metals are more bioavailable at lower pH, the SSLs may overestimate concentrations in Hanford Site soils that would be toxic to plants and soil invertebrates; thus, risk estimates may be overly conservative.

- **Wildlife Toxicity Reference Values (TRVs)**—Data on the toxicity of many chemicals to the receptor species were sparse or lacking, requiring the extrapolation of data from other wildlife species or from laboratory studies with nonwildlife species. This is a typical limitation and extrapolation for ERAs because so few wildlife species have been tested directly for most chemicals. The uncertainties associated with toxicity extrapolation were minimized through the selection of the most appropriate test species for which suitable toxicity data were available. The factors considered in selecting a test species to represent a receptor species included taxonomic relatedness, trophic level, foraging method, and similarity of diet.

  A second uncertainty related to the derivation of TRVs applies to metals. Most of the toxicological studies on which the TRVs for metals were based used forms of the metal (such as salts) that have high water solubility and high bioavailability to receptors. Since the analytical samples on which site-specific exposure estimates were based measured total metal, regardless of form, and these highly bioavailable forms are expected to compose only a fraction of the total metal concentration, this is likely to result in an overestimation of potential risks for these chemicals.

- **Chemical Mixtures**—The SSLs employed in this assessment are based on exposure to individual analytes. Information on the ecotoxicological effects of chemical interactions is generally lacking, which required (as is standard for ERAs) that the chemicals be evaluated on a compound-by-compound basis during the comparison to SSLs. This could result in an underestimation of risk (if there are additive or synergistic effects among chemicals) or an overestimation of risks (if there are antagonistic effects among chemicals). Assessment of data in this report resulted in a description of potential exposure risks due to metals, which are typically known to be additive. In this case, effects may be underestimated.

- **Receptor Species Selection**—Reptiles were identified as being part of the food web present at Hanford, but were not evaluated quantitatively even when exposure pathways were complete. A qualitative assessment of potential risk to these taxa can be made by using the results of quantitative evaluation for other fauna with similar diets and assumed similarity in metabolizing COPECs to make inferences. Considering the results of quantitative evaluation of avian receptors can provide some idea as to the potential for risks to these taxa.

  The uncertainty associated with the lack of toxicological data for reptiles and inferring risk from other fauna either could over or underestimate risks.

  It was also assumed that reptiles were neither exposed to significantly higher concentrations of chemicals or were more sensitive to chemicals than the other receptor species evaluated in the foodweb model. This assumption was a source of uncertainty in the ERA. In addition, there is some uncertainty associated with the use of specific receptor species to represent larger groups of organisms (e.g., guilds).

- **Food Web Exposure Modeling**—No life history data specific to the Hanford Site were available; therefore, exposure parameters were either modeled based on allometric relationships (e.g., FIRs) or based on data from the same species in other portions of its range. Because diet composition as well as food and soil ingestion rates can differ among individuals and locations, published parameter values may not accurately reflect individuals present at the Hanford Site. Consequently, SSLs may be either overconservative or underconservative. For example, diets used to establish SSLs under MTCA (e.g., Ecological Indicator Soil Concentrations in MTCA [WAC 173-340], Table 749-3) focus on selected food items, but do not provide 100 percent of the receptor's diet. The wildlife SSLs were derived with a model that incorporates prey tissue items that comprise 100 percent of the receptor's diet. Therefore, the assumed contributions of ingestion of analytes of prey tissues for the wildlife

SSLs are greater than those used to develop the MTCA values and would be expected to overestimate risk. (Note: wildlife SSLs for wildlife are usually higher than MTCA values through the use of more realistic BAFs.)

No site-specific data on COPC concentrations in terrestrial plants, soil invertebrates, and small mammals or birds were used for wildlife exposure estimate calculations. Therefore, concentrations in these food items were estimated from literature-reported bioaccumulation models (BAFs or regressions). The suitability of these bioaccumulation models to conditions at the Hanford Site is unknown. Consequently, modeled concentrations of COPCs in food items of wildlife may be either greater or lesser than concentrations under actual conditions and, consequently, SSLs may be either overconservative or underconservative. For example, models used to develop the generic wildlife SSLs based on MTCA wildlife values (MTCA [WAC 173-340], Table 749-3) rely upon BAFs to estimate the concentration of analytes in invertebrate and plant tissues that are assumed to be linear and constant across all soil concentrations and do not account for other environmental factors. While uptake factors for plants may be appropriate for small ranges of concentrations of some COPCs within nontoxic ranges ("Effect of Different Forms and Sources of Arsenic on Crop Yield and Arsenic Concentration" [Jiang and Singh, 1994]; "Growth Reduction in American Sycamore (*Plantanus occidentalis* L.) Caused by Pb-Cd Interaction" [Carlson and Bazzaz, 1977], as cited in *Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants* [BJR/OR-133]), there is evidence to suggest that accumulation decreases with increasing soil concentration. Earthworm studies have shown this to be true (*Development and Validation of Bioaccumulation Models for Earthworms* [ES/ER/TM-220] and "Bioconcentration and Biokinetics of Heavy Metals in the Earthworm" [Neuhauser et al., 1995]). A number of empirically derived regression models have been developed describing the relationship of concentrations in biotic media to concentrations in their surrounding abiotic environmental media, which were incorporated into the methodology for establishing EPA's EcoSSLs for wildlife (*Guidance for Developing Ecological Soil Screening Levels* [OSWER Directive 9285.7-55]). Hence, these models were employed in the development of the refined wildlife SSLs as available. For certain inorganics such as uranium, the default BAFs prescribed by MTCA that can be used to develop generic SSLs for wildlife when an Ecological Indicator Soil Concentration is not available are considerably greater than literature-based contaminant-specific values for BAFs.

The exposure depth evaluated for ecological receptors was 0 to 4.6 m (0 to 15 ft) bgs. There is evidence to suggest that the biologically active zone for most sites is 0 to 1.8 m (0 to 6 ft) bgs. At the Hanford Site, some exposure may occur at depths up to 2.4 to 3 m (8 to 10 ft) bgs (*Evaluation of Biointrusion at the Hanford Site for Protection of Ecological Receptors*, CHPRC-00651). For this ecological evaluation, the depth from 1.8 to 4.6 m (6 to 15 ft) is also included because human activities could bring materials from that depth to the surface, creating a complete exposure pathway.

- **Central Tendency Versus Maximum Exposure Concentration Estimates**—As is typical in an ERA, a finite number of samples of environmental media are used to develop the exposure estimates. The maximum measured concentration provides a conservative estimate for immobile biota or those with a limited home range. The most realistic exposure estimates for mobile species with relatively large home ranges and for species populations (even those that are immobile or have limited home ranges) are those based upon an estimate of central tendency of chemical concentrations in each medium to which these receptors are exposed. This is reflected in the wildlife dietary exposure models contained in Wildlife Exposure Factors Handbook, Volume I and II (EPA/600/R-93/187a). It is possible, however, that receptors could spend additional time foraging at a nearby waste site and be exposed to analytes from more than one site. Thus, exposure point concentration estimates of

contaminants in individual waste site media and food sources may not accurately represent contaminant exposure to a receptor ranging into other sites. It is likely, however, that assuming an Area Use Factor of 1 will result in a conservative estimate of exposure because it is likely that offsite foraging would be conducted in uncontaminated areas than at other waste sites. Given the mobility of the upper trophic level receptor species used in the ERA, the use of maximum chemical concentrations as EPCs when UCLs were not calculated by ProUCL to estimate the exposure via food webs is very conservative. This conservatism was reduced to levels that are more realistic when the number of samples collected in a site was adequate in sample size to develop a UCL on the mean.

- **Comparisons to Background Concentrations**—Background concentrations were used to judge whether measured concentrations within waste sites are reflective of site-related activities, background, or a combination thereof. If site chemical concentrations were consistent with these background levels, it was assumed that the concentrations were not site related. There exists the possibility that concentrations below background were indeed site related, rendering the assumption false. However, the impact of this possibility is minimal since metals and radioisotopes at concentrations consistent with background conditions should exhibit no different ecological effects than commonly occurring in areas not affected by releases, regardless of their source.

7.5 SMDP Considerations

Within the process for conducting ERAs at CERCLA sites, there are several decision points at which risk managers, risk assessors, and other stakeholders agree on a path forward with respect to ecological risk associated with a site. Typical variations include the following risk assessment outcomes:

- There are no unacceptable potential risks to ecological receptors, e.g., risks are sufficiently low and below risk-based thresholds such as SSLs or PRGs.
- There is the potential for risks to ecological receptors but the risks do not warrant the evaluation of remedial alternatives in the FS due to a number of considerations[3].
- There is the potential for risks to ecological receptors but there is uncertainty in one or more components of the ecological risk assessment that warrants the evaluation of remedial alternatives in the FS.
- There is the need to evaluate remedial alternatives in the FS based on the protection of another receptor or exposure pathway (e.g., human health) that would address any potential ecological risks.
- There is the potential for risk to ecological receptors warranting evaluation of remedial alternatives in the FS.

With the various risk assessment outcomes listed above, agreement is needed on the following elements to assist in the evaluation of remedial alternatives in the FS: the COCs, the assessment endpoints, the exposure pathways, and the risk questions. To confidently achieve one of the risk assessment outcomes, a number of factors and supporting information are considered in the conclusion of the risk assessment to assist risk management decisions. Often, these outcomes are considered within the context of other exposure pathways and receptors evaluated at the same site. Some of the factors that are considered to interpret the results of the risk characterization and determine if the site requires evaluation of remedial alternatives in the FS include the following:

[3] For example, a wildlife risk for a specific contaminant was driven by an estimated exposure to a badger but the size of the site is 20 m^2, representing a minimal portion of the total required foraging area for a badger and the site does not represent a preferential feeding area.

- The spatial characteristics of the remediated waste site (area and excavation depth of the remediated waste site)
- The proximity and size of nearby unremediated waste sites and unimpacted habitat
- The number and location of samples collected at the site
- The data quality (presence of qualifiers, adequacy of detection limits)
- The frequency that risk-based thresholds are exceeded and the location(s) of those exceedances
- The chemical-specific properties of each COC (e.g., does it have the potential to biomagnify in the food web or is it persistent in the environment?)
- The identification of specific receptors that have the potential for adverse health effects (feeding guild [plants or omnivorous wildlife], proportion of receptors affected, likelihood of population or community level effects, home range of the receptors at risk relative to the area exceeding risk-based thresholds)
- Recalculation of the EPC based on the home range of the receptor or to estimate the residual risk after the removal action has been implemented
- Evaluation of PRG (i.e., level of confidence, basis, relation to other PRGs such as those for human health or groundwater protection)

Four waste sites within the 100-K OU were reported with concentrations of COPECs greater than their respective PRGs. Figures showing the location and concentration of COPECs reported with an HQ greater than 1 are provided in Appendix H. Risk managers and risk assessors agreed in a final recommendation that all four of the waste sites be carried forward into the FS for evaluation of remedial alternatives. The decisions for 100-K OUs were based on a subset of the factors described above, including the following:

- The depth of samples exceeding thresholds relative to the 4.6 m (15 ft) bgs standard point of compliance for ecological receptors defined by MTCA
- The number and frequency of exceedances of the risk thresholds (PRGs)
- The magnitude of exceedance relative to the risk thresholds (the HQ)
- The confidence in the ecological risk thresholds defining the exceedances
- The quality of the sample data defining the exceedances
- The location of the samples exceeding thresholds, sample frequency, and proximity of other exceedances
- The area of exceedance relative to home range of receptor exceeding and relative to area of unimpacted nearby habitat

7.6 Assessment of Risks in Riparian, Nearshore Media, and Columbia River

RCBRA evaluated soil, sediment, and water located in riparian and nearshore areas. The RAGs used in the interim actions addressed risks to human health from direct contact with soil and threats to groundwater and surface water from leaching from soil, but did not directly address risks to ecological receptors. The ecological risk assessment conducted as part of the RCBRA addresses residual

contaminant concentrations at remediated waste sites in the upland zones and the transport of contaminants from waste sites to the Columbia River riparian and nearshore zones (Integrated Work Plan [DOE/RL-2008-46]). CRC evaluated island soil, sediment, water, and fish tissue located in the Columbia River beyond the nearshore environment.

Table 7-7 presents the 12 COECs identified by RCBRA and CRC and the one COEC identified in this report in the riparian and nearshore media. Except for Cr(VI) in groundwater and carbon-14 in soil, there are potential sources for the COECs that are unrelated to the Hanford Site. These sources are summarized in the RCBRA (DOE/RL-2007-21) and the *Columbia River Component Risk Assessment* (Draft DOE/RL-2010-117). Taking into consideration what is understood to be principal threat constituents in soil and groundwater at the 100-K, compared with the contaminants identified by RCBRA as posing ecological risks in riparian and nearshore media, additional work was warranted to better understand the conceptual site model in the riparian and nearshore environment. The interrelationships between sources, transport mechanisms, exposure pathways, and receptors have been examined in more detailed and the results of this evaluation are presented in Appendix L.

Table 7-7. COECS from the RCBRA for 100-K and CRC for 100 Area

COEC	Receptors	Media	Elevated in 100-K Sites?
Arsenic	Terrestrial Plants	Riparian Soil	No
Cadmium	Aquatic Plants and Invertebrates	Sediment	No
Carbon 14	Terrestrial Wildlife	Riparian Soil	Yes, Rip 5
Chromium	Bufflehead	Sediment	No
	Aquatic Plants	Pore Water	No
	And Invertebrates		
	Terrestrial Plants and Invertebrates	Riparian Soil	No
Hexavalent Chromium	Fish	Pore water	Yes, Cr-1
	Amphibians		
	Aquatic Invertebrates		
	Aquatic Plants		
Lead	Terrestrial Plants	Riparian Soil	No
Manganese	Aquatic Plants	Sediment	No
	Aquatic Invertebrates		
Mercury	Terrestrial Invertebrates	Riparian Soil	No
TPH Diesel and TPH Motor Oil	Terrestrial Invertebrates	Riparian Soil	No

Table 7-7. COECS from the RCBRA for 100-K and CRC for 100 Area

COEC	Receptors	Media	Elevated in 100-K Sites?
Uranium	Aquatic Plants and Invertebrates	Pore Water	No
Zinc	Terrestrial Plants	Riparian Soil	No
	Terrestrial Invertebrates		
	Kingbird		

7.6.1.1 Riparian Soils

The RCBRA evaluated ecological risks at representative riparian study sites located adjacent to, or where they may be directly affected by, known contaminated media (groundwater seeps, soil, or sediment). The RCBRA concluded that six COPECs identified for the riparian environment (arsenic, chromium, lead, mercury, zinc, and TPH-diesel) may present an unacceptable level of risk to one or more of the assessment endpoint entities, based on soil bioassays, comparison of COPEC concentrations to plant or terrestrial invertebrate toxicity benchmarks, or the results of wildlife exposure analyses.

Most concentrations detected in riparian soils within the 100-K OU fell below ecological screening levels (ESLs, in this case specifically the SSLs described previously, but also appropriate levels for sediment and water) and all but one were below PRGs, and do not warrant further evaluation in the FS. Carbon-14 was not identified as a COPC in the RCBRA, based on comparison with the BCG. However, development of the SSL concentrations for wildlife for radionuclides relied on more current bioaccumulation data, which resulted in lower concentrations compared with BCGs (*Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* [CHPRC-00784]). The carbon-14 concentration, analyzed using MULTI INCREMENT® sampling results, reflects an average concentration of 112 pCi/g collected throughout a one hectare plot. This concentration is above the site-specific thresholds developed for Hanford for seven of eight wildlife species. The one hectare plot is a small area compared with the home range of these wildlife receptors. However, the exposure concentration represents an average of nearly one hundred samples, indicating that a potential source may exist in the area. Therefore, carbon-14 is a COEC for the riparian soils in the100-K OU and should be addressed further in the FS.

7.6.1.2 Nearshore and Columbia River

The RCBRA evaluated ecological risks at nearshore study sites potentially affected by contamination from Hanford Site sources in comparison to reference sites. Study sites were selected in areas where known contaminated groundwater plumes enter the Columbia River and in areas between the plumes. The RCBRA concluded that five (cadmium, chromium, Cr(VI), manganese, and uranium) COPECs identified for the nearshore environment may present an unacceptable level of risk for one or more of the assessment endpoint entities. These results are primarily based upon the comparisons of COPEC concentrations to toxicity benchmarks, measures of exposure and effects in biota, or the results of wildlife exposure analyses (RCBRA Report [DOE/RL-2007-21], Volume 1).

The results from the evaluation in Appendix L showed that a range of inorganic and radiological contaminants was detected in near-river groundwater samples collected from the 100-KR-4 OU. In some cases, these contaminants also could be detected in aquifer tube, pore water, spring/seep, and surface water samples. In most cases, the analytical results that were most relevant to assessing aquatic water

quality (i.e., from filtered analyses) were at concentrations below levels protective of aquatic life (e.g., National Ambient Water Quality Criteria). In other cases, where concentrations higher than aquatic criteria were observed, these results were associated with analytical data quality issues such as presence of contamination in blank samples, or elevated detection limits relative to the criteria. Though the biological measures collected do not represent all seasonal conditions and river stage fluctuations, the results of pore water bioassays on aquatic invertebrates and amphibians also suggest little or no correlation between COPEC concentrations and observed responses in the bioassays and the responses were not different from those of upstream references. Benthic invertebrate community structure data also suggest no differences between reference sites and locations adjacent to the Hanford Site. The results from this analysis confirm the results from the evaluation presented in Section 4.2.3, that with the exception of Cr(VI) in groundwater, there are no COECs affecting aquatic life exposed to pore water or surface water.

The results from the evaluation in Appendix L showed there were concentrations of endosulfan I and inorganics detected at a concentration higher than ESLs. Likewise, the Columbia River Component Screening Level Environmental Risk Assessment indentified chromium, Cr(VI), and TPH in sediment as COECs. As outlined in Table 7-7, concentrations of some of these COECs in sediments in the 100-K nearshore environment either are below ESLs (chromium, manganese, and selenium) and/or below reference (endosulfan I, manganese, and TPH-diesel), suggesting that sediments upstream of the Hanford Site potentially contribute to concentrations observed in the 100-K nearshore area. Further, riparian soils for all but three COECs are lower than upstream sediment and Hanford reference soil concentrations, suggesting that the riparian soils in the 100-K area are not a source of the observed sediment concentrations for the COECs identified. Biological measures such as amphipod bioassays, clam tubes, and community surveys from rock baskets show no clear indication of toxicity or correlation of response with COEC concentrations. Though they do represent only a snapshot in time and do not represent all seasonal conditions and river stage fluctuations, they do support the analysis that Hanford operations at 100-K are not adversely affecting aquatic receptors exposed to sediment in the 100-K nearshore area. Based on these findings as summarized here and presented in detail in Appendix L, carbon-14 in soil and Cr(VI) in groundwater warrant further evaluation in the FS.

7.7 Risk Conclusions and SMDP

COPCs were identified in 16 100-K Source OUs waste sites, which had been reclassified as "interim closed" or "no action" through the TPA process. COPC EPCs for each decision unit (shallow, shallow-focused, and overburden) at each waste site were compared to the plant/invertebrate SSL, the wildlife SSL, background, the plants/invertebrates PRG, and wildlife PRG values.

Analytes that exceeded an SSL, background, and a PRG were considered COPECs. A total of four waste sites were retained for additional consideration based on EPC exceedances of one COPEC (mercury).

At the SMDP, the results of the ERA were considered in the context of other factors (spatial coverage, data, chemical specifics, receptors at risk, confidence in PRGs) to reach a final decision on the COECs to be brought forward to the FS and agreement on the assessment endpoints, representative receptors, and complete exposure pathways that correspond to those COECs. The SMDP concluded there are unacceptable risks to ecological receptors within four waste sites of the100-K Source OU (100-K-30, 100-K-31, 100-K-32, and 100-K-33). Risks at these waste sites are considered unacceptable because detected concentrations of mercury at all four waste sites are greater than risk-based thresholds for wildlife.

8 Identification and Screening of Technologies

The CSM is a representation of site conditions and what is known or suspected about the contaminant sources, release mechanisms, and transport. The exposure pathways, potential receptors, and risk to the receptors are the conceptual exposure model. This information is presented in Chapters 4 through 7. Technologies are evaluated in this chapter to determine their effectiveness to remove the contaminants or interrupt the exposure pathway.

This chapter begins the feasibility study of the RI/FS. The FS consists of three phases: screening of remedial technologies, development of remedial alternatives, and detailed analysis of selected alternatives. Remedial technologies are assembled into alternatives that address contamination on a media or source specific basis.

Chapter 8 presents the development of ARARs, PRGs, RAOs, and GRAs, and identifies and screens remedial technologies and associated process options to clean up the contamination. Chapter 9 assembles the alternatives and Chapter 10 provides a detailed analysis of the alternatives to address contaminated media at 100-K.

Highlights

- Waste sites that have undergone interim remedial action do not remain a significant ongoing source of contaminants to groundwater.
- RAOs were developed for groundwater, surface water, soil, land use, and resources.
- PRGs are based on the reasonably anticipated future land use.
- The data from waste sites that have been remediated through interim actions were evaluated for risks to human health, ecological receptors, groundwater protection, and surface water protection in preceding chapters. Of those sites, three waste sites exceeded the Tier 2 criteria for ecological receptors and are considered in the FS for further remediation.
- Waste sites that have not yet been remediated, which are the majority of sites at 100-K, are evaluated in the FS for remediation based on several factors, including process knowledge.
- A range of general response actions to meet RAOs was evaluated for waste sites and contaminated groundwater at 100-K, and includes no action, monitoring, institutional controls, removal, treatment, and containment. Process options and technologies under these response actions were evaluated for relative effectiveness, implementability, and cost.
- Response actions retained for waste sites include no action, RTD, biological treatment, soil flushing, surface barriers, and supplemental institutional controls.
- Response actions retained for groundwater include no action, MNA, pump-and-treat, biological treatment, flushing, and supplemental institutional control.

8.1 Remedial Action Objectives

RAOs are general descriptions of what the remedial action is expected to accomplish (that is, medium-specific or site-specific goals for protecting HHE). They are defined as specifically as possible to address the following concerns:

- Media of interest (soil or groundwater)
- Types of contaminants (radionuclides and chemical constituents)
- Potential receptors (human and ecological)
- Exposure pathways (external radiation, dermal contact, ingestion, or inhalation)

The RAOs provide a basis for evaluating the capability of a specific remedial alternative to achieve compliance with potential ARARs and/or an intended level of risk protection for HHE in accordance with "Remedial Investigation/Feasibility Study and Selection of Remedy" (NCP [40 CFR 300], Section 430(e)(2)(i)) and CERCLA RI/FS Guidance (EPA/540/G-89/004). RAOs for the 100-K Source and Groundwater OU are presented in Section 8.1.4. Background information used in developing the RAOs is presented in Sections 8.1.1 through 8.1.3.

8.1.1 Contaminants of Concern

In the RI/FS process, contaminants are referred to as COPCs until ecological and health risk evaluation is complete. The contaminants that exceed target ecologic and health goals at the end of the risk evaluation process are referred to as COCs.

8.1.1.1 Waste Site Soil

As evaluated in Chapters 5, 6, and 7, and further described in Section 8.3.1, 16 waste sites at 100-K had closeout verification data and could be quantitatively evaluated. Based on the evaluations provided in Chapters 5, 6, and 7, the following analytes were identified as COCs in soil: cesium-137, cobalt-60, europium-152, europium-154, nickel-63, Sr-90, and mercury.

Additionally, remedial actions will not be started on 66 waste sites at 100-K until after the ROD is signed. Many of these sites have limited or no data available; therefore, these yet-to-be remediated waste sites could not be evaluated in Chapters 5, 6, or 7. For yet-to-be remediated waste sites, additional COCs are identified based on LFI data and process knowledge and are listed in Table 8-1. Additional information on waste sites with limited data is presented in Section 8.3.1.

Table 8-1. Summary of Soil COCs Based on Process Knowledge

Radionuclides	Metals	Inorganic Anions and Total Petroleum Hydrocarbons
Americium-241	Antimony	Nitrate (as Nitrogen)
Carbon-14	Arsenic	Nitrite (as Nitrogen)
Cesium-137	Barium	Sulfate
Cobalt-60	Boron	TPH (diesel range, motor oil)
Europium-152	Cadmium	**Semivolatiles**
Europium-154	Chromium, total	Ethylene Glycol
Europium-155	Chromium, hexavalent	**Polychlorinated Biphenyls**
Plutonium-238	Copper	Aroclor 1016
Plutonium-239/240	Lead	Aroclor 1221
Sr-90	Manganese	Aroclor 1232
Tritium (H-3)	Mercury	Aroclor 1242
Uranium-233/234	Nickel	Aroclor 1248
Uranium-235	Selenium	Aroclor 1254
	Vanadium	Aroclor 1260
	Zinc	

8.1.1.2 Groundwater

The following contaminants were identified as COCs for the 100-KR-4 OU groundwater: carbon-14, chromium, Cr(VI), nitrate, Sr-90, tritium, and trichloroethylene.

8.1.2 Applicable or Relevant and Appropriate Requirements

Substantive standards of promulgated regulations pertaining to CERCLA response actions are identified through the ARAR identification process, which is based on CERCLA Section 121(d) and EPA guidance (CERCLA RI/FS Guidance [EPA/540/G-89/004]; *CERCLA Compliance with Other Laws Manual: Interim Final* [EPA/540/G-89/006]; and *CERCLA Compliance with Other Laws Manual: Interim Final* [EPA/540/G-89/006] and *CERCLA Compliance with Other Laws Manual: Part II* [EPA/540/G-89/009]). Section 121(d) requires, with exceptions, that any promulgated substantive ARAR standard, requirement, criterion, or limitation under any federal environmental law, or any more stringent state requirement pursuant to a state environmental statute, or facility siting laws be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain onsite after completion of remedial action. Additionally, "Remedial Design/Remedial Action, Operation and Maintenance" (40 CFR 300.435(b)(2)) requires that ARARs be attained (unless waived) during the remedial action. Identifying ARARs is part of the 100-K FS process.

Waste sites and groundwater in 100-K will be remediated under a CERCLA decision document. Any remedial action(s) implemented will be required to meet ARARs. In many cases, the ARARs form the basis for the PRGs to which contaminants must be remediated to protect HHE. ARARs also define or restrict how specific requirements of a remedial alternative can be implemented based on the nature of the activity or the location of the site.

8.1.2.1 The ARARs Evaluation Process

The ARARs evaluation prepared for this RI/FS was conducted in accordance with the NCP as described in "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430(f)(1)(ii)(B)(2)).

A distinction and clarification related to ARARs involves onsite and offsite actions. Onsite actions are defined to be "the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action" (NCP [400 CFR 300]). Onsite actions must comply with ARARs, but need only comply with the substantive parts of those requirements. Offsite actions must comply with both the substantive and administrative requirements. For onsite activities, a requirement under federal and state environmental laws may be either applicable or relevant and appropriate, but not both.

The identification of ARARs is a two-step process. First, it must be determined if the law or regulation is applicable. If not applicable, it must be determined if the law or regulation is both relevant and appropriate. The terms "applicable" and "relevant and appropriate" are defined in "Definitions" (40 CFR 300.5) as follows.

"Applicable requirements" are those substantive standards that specifically address the situation at a CERCLA site and would legally apply to remedial actions in the absence of CERCLA authority. All jurisdictional prerequisites of the requirement must be met in order for the requirement to be applicable, including specific application to federal agencies (e.g., through a waiver of federal sovereign immunity).

"Relevant and appropriate" requirements mean those environmental requirements such as cleanup standards that address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site ("General" [40 CFR 300.400(g)(2)]). A requirement that is relevant and appropriate may not meet one or more jurisdictional prerequisites for applicability but still make sense at the site, given the circumstances of the site and the release.

In evaluating the relevance and appropriateness of a requirement, the eight comparison factors in "General" (40 CFR 300.400(g)(2)) are considered:

1. The purpose of the requirement and the purpose of the CERCLA action
2. The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site
3. The substances regulated by the requirement and the substances found at the CERCLA site
4. The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site
5. Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site
6. The type of place regulated and the type of place affected by the release or CERCLA action
7. The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action
8. Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site

To be considered (TBC) information represents another category of nonpromulgated advisories or guidance issued by federal or state governments that are not legally binding and do not have the status of ARARs. In some circumstances, TBC information will be evaluated, along with ARARs, in determining the remedial action necessary to protect HHE. TBC information complements ARARs in determining protectiveness at a CERCLA site or in assessing implementation of certain actions. For example, because cleanup standards do not exist for all contaminants, health advisories, which would be TBC information, may be helpful in defining cleanup levels.

Section 161 of the *Atomic Energy Act of 1954* (AEA), as amended, provides DOE the authority to establish DOE Orders containing instructions and operational requirements considered important to protect HHE from nuclear material, source material, and byproduct materials. While the requirements of DOE Orders must be met, they are not ARARs and are independent of the TBC and ARARs identification process at the Hanford Site.

Potential ARARs for 100-K are examined to determine if they fall into one of three categories: chemical-specific, location-specific, or action-specific requirements. These categories are defined as follows:

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of public and worker safety levels and site cleanup levels.
- Location-specific requirements are restrictions placed on the concentration of dangerous substances or the conduct of activities solely because they occur in special geographic areas.
- Action-specific requirements are usually technology- or activity-based requirements or limitations triggered by remedial actions performed at the site.

8.1.2.2 Waivers from ARARs

The CERCLA lead agency delegated authority under Section 121 may waive ARARs, with EPA's concurrence, and select a remedial action that does not attain the same level of cleanup as that identified by the ARARs. In Executive Order 12580, the President delegated Section 121 authority to DOE for

cleanup of DOE facilities. Section 121 of the *Superfund Amendments and Reauthorization Act* identifies the following six circumstances in which DOE may waive ARARs for onsite remedial actions:

- The remedial action selected is only a part of a total remedial action (such as an interim action), and the final remedy will attain the ARAR upon its completion.
- Compliance with the ARAR will result in a greater risk to HHE than alternative options.
- Compliance with the ARAR is technically impracticable from an engineering perspective.
- An alternative remedial action will attain an equivalent standard of performance using another method or approach.
- The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
- In the case of Section 104 (Superfund financed remedial actions), compliance with the ARAR will not provide a balance between protecting HHE and the availability of Superfund money for response at other facilities.

After remedy implementation (post-ROD), if performance-monitoring data indicate that attainment of ARARs is technically impracticable from an engineering perspective, then an evaluation may be conducted to assess whether a technical impracticability (TI) waiver from one or more chemical-specific ARARs is warranted. TI waivers only apply to that portion of the groundwater contaminant plume for which restoration to ARARs is determined to be technically impracticable. ARAR waivers can be in the ROD or if post-ROD information shows an ARAR cannot be met because it is technically impracticable from an engineering perspective, but remedy will still be protective, an ARAR waiver can be granted through a ROD amendment, after a proposed plan and public comment period.

8.1.2.3 Potential ARARs Identified

Table 8-2 presents potential Federal and Washington State ARARs. When the final remedy selection is documented in the ROD, all federal and state ARARs, with which the final remedy must comply, are also finalized. Key potential ARARs are identified in following text.

Potential Chemical-Specific ARARs. The chemical-specific ARARs that may affect remediation of 100-K OU are the elements of the *Washington Administrative Code* regulations that implement the "Model Toxics Control Act—Cleanup" (WAC 173-340). Within this branch of the *Washington Administrative Code*, there are detailed regulations with developing standards for remedial actions involving soil cleanup ("Unrestricted land use soil cleanup standards" [WAC 173-340-740]) and groundwater cleanup standards ("Groundwater cleanup standards" [WAC 173-340-720]). These standards are in the form of risk-based concentrations that help establish soil and groundwater cleanup standards for nonradioactive contaminants. Following is a list of additional Washington State and Federal regulations:

- MTCA (WAC 173-340) ("Selection of Cleanup Actions" [WAC 173-340-360] and "Overview of Cleanup Standards" [WAC 173-340-700] through "Site-Specific Terrestrial Ecological Evaluation Procedures" [WAC 173-340-7493]) (2007)
- Nonzero MCL goals and MCLs promulgated under the *Safe Drinking Water Act of 1974* (SDWA) ("National Primary Drinking Water Regulations" [40 CFR 141]) and/or by the State of Washington ("Group A Public Water Supplies" [WAC 246-290])

- The AWQC developed under the *Clean Water Act* (Section 304) and/or promulgated by the State of Washington ("Water Quality Standards for Ground Waters of the State of Washington" [WAC 173-200] and "Water Quality Standards for Surface Waters of the State of Washington" [WAC 173-201A])
- The *Toxic Substances Control Act* (TSCA) (implemented via "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions" [40 CFR 761])
- "National Primary and Secondary Ambient Air Quality Standards" (40 CFR 50)
- "National Emissions Standards for Hazardous Air Pollutants" (40 CFR 61)

Potential Location-Specific ARARs. Potential location-specific ARARs that have been identified for the 100-K OU include those that protect cultural, historic, and Native American sites and artifacts under the *Native American Graves Protection and Repatriation Act of 1990*, *Archeological and Historic Preservation Act of 1974, National Historic Preservation Act of 1966* (NHPA), and those that protect listed endangered and threatened species or their critical habitat under the *Endangered Species Act of 1973*. The *Migratory Bird Treaty Act of 1918* has been identified as substantive standards for DOE compliance in executive orders and a Memorandum of Understanding between DOE and USFWS, and are pertinent for CERCLA response actions when there is a potential to adversely affect protected bird species.

Potential Action-Specific ARARs. Action-specific ARARs that could be pertinent to possible remediation activities at 100-K relate to waste management activities, solid and dangerous waste regulations (for management of characterization and remediation wastes and performance standards for waste left in place), and radioactive waste management under AEA regulations. The other major category of action-specific ARARs concern standards for controlling emissions to the environment. When a CERCLA remedial action involves the construction or modification of drinking water systems, the SDWA is an ARAR, while such onsite work is exempt from SDWA permit requirements.

8.1.2.4 Waste Management Standards

Remedial action alternatives proposed in Chapter 9 of this FS have the potential to generate a variety of waste streams that contain both radioactive and chemical constituents. It is anticipated that most of the waste will be designated as low-level. However, quantities of dangerous or mixed waste, PCB-contaminated waste, and asbestos and asbestos containing material could be generated. In the event that waste is managed as either SNF or as transuranic, the appropriate management procedures as outlined in DOE Orders will be followed. The great majority of the waste will be in a solid form.

The identification, storage, treatment, and disposal of hazardous waste and the hazardous component of mixed waste generated during the remedial action would be subject to the substantive provisions of RCRA. In the State of Washington, RCRA is implemented through"Dangerous Waste Regulations" (WAC 173-303), which is an EPA-authorized state RCRA program. The substantive portions of the dangerous waste standards for generation and storage would apply to the management of any dangerous or mixed waste generated during this remedial action. Treatment standards for dangerous or mixed waste that is subject to RCRA land disposal restrictions are specified in"Land Disposal Restrictions" (WAC 173-303-140), which incorporates "Land Disposal Restrictions" (40 CFR 268) by reference. Radioactive waste is managed by DOE under the authority of the AEA.

The TSCA and regulations at"Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions" (40 CFR 761) generally govern the management and disposal of PCB wastes. The TSCA regulations contain specific provisions for PCB waste, including PCB waste that contains a radioactive component. The PCBs also are considered underlying hazardous constituents under

RCRA and thus could be subject to "Dangerous Waste Regulations" (WAC 173-303) and "Land Disposal Restrictions" (40 CFR 268) requirements.

Removal and disposal of asbestos and asbestos-containing material are regulated under the *Clean Air Act of 1990* and "National Emission Standards for Hazardous Air Pollutants," Subpart M, "National Emission Standards for Asbestos" (40 CFR 61). These regulations provide for special precautions to prevent environmental releases or exposure to personnel of airborne emissions of asbestos fibers during remedial actions.

Waste generated through the CERCLA remedial actions and designated as low-level radioactive waste that meets ERDF acceptance criteria (*Environmental Restoration Disposal Facility Waste Acceptance Criteria* [WCH-191]) will presumably be disposed at ERDF, which is engineered to meet appropriate performance standards for mixed radioactive and hazardous waste. ERDF is considered onsite with Hanford remedial actions for the purpose of management and/or disposal of waste.[1] There is no requirement to obtain a permit to manage or dispose of CERCLA waste at ERDF.

Waste designated as dangerous or mixed waste would be treated as appropriate to meet land disposal restrictions and ERDF acceptance criteria and disposed at ERDF. ERDF is an engineered facility that provides a high degree of protection to HHE and meets RCRA minimum technical requirements for landfills, including standards for a double liner, a leachate collection system, leak detection, monitoring, and final cover. Construction and operation of ERDF was authorized using a separate CERCLA ROD (*Declaration of the Interim Record of Decision for the Environmental Restoration Disposal Facility* [EPA/ROD/R10-95/100]; *Record of Decision Amendment for the Environmental Restoration Disposal Facility* [EPA/AMD/R10-02/030]). ERDF ESD (EPA/ESD/R10-96/145) modified the ERDF ROD to clarify the eligibility of waste generated during cleanup of the Hanford Site. Per ERDF ESD, ERDF is eligible for disposal of any low-level waste, mixed waste, and hazardous/dangerous waste generated as a result of cleanup actions (e.g., remedial/removal action waste and investigation derived waste), provided the waste meets ERDF *Washington Administrative Code* and appropriate CERCLA decision documents are in place.

Some of the aqueous waste designated as low-level waste, dangerous, or mixed waste would be transported to the Effluent Treatment Facility for treatment and disposal. The Effluent Treatment Facility is a RCRA-permitted facility authorized to treat aqueous waste streams generated on the Hanford Site and dispose of these streams at a designated state-approved land disposal facility in accordance with applicable requirements.

Waste designated as PCB remediation waste likely would be disposed at ERDF, depending on whether it meets the waste acceptance criteria. The PCB waste that does not meet ERDF waste acceptance criteria would be retained at a PCB storage area that meets the requirements for the TSCA storage and would be transported for future disposal at an appropriate disposal facility. Asbestos and asbestos containing material would be removed, packaged as appropriate, and disposed in ERDF.

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[1] CERCLA Section 104(d)(4), "where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the threat or potential threat to the public health or welfare or the environment, the President may, at his discretion, treat these facilities as one." The preamble to the NCP (40 CFR 300) clarifies the stated EPA interpretation that when noncontiguous facilities are reasonably close to one another, and wastes at these sites are compatible for a selected treatment or disposal approach, CERCLA Section 104(d)(4) allows the lead agency to treat these related facilities as one for response purposes. This allows the lead agency to manage waste transferred between such noncontiguous facilities without having to obtain a permit. The ERDF is considered to be onsite for response purposes under this remedial/removal/removal action. It should be noted that the scope of work covered in this remedial/removal/removal action is for a facility and waste contaminated with hazardous substances. Materials encountered during implementation of the selected remedial/removal/removal action that are not contaminated with hazardous substances will be dispositioned by DOE.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Groundwater					
Safe Drinking Water Act of 1974 **(Public Law 93-523, as amended; 42 U.S.C. 300f, et seq.); "National Primary Drinking Water Regulations" (40 CFR 141)**					
"Maximum Contaminant Levels for Organic Contaminants" (40 CFR 141.61) "Maximum Contaminant Level Goals for Organic Contaminants" (40 CFR 141.50)	Chemical	Establishes MCLs and non-zero MCLGs as criteria for groundwater and surface water that are or may be used for drinking water. The standards/ goals are designed to protect human health from adverse effects of organic contaminants in the drinking water.	Groundwater in 100-K contains contaminants that may require remediation. Although groundwater is not currently used for drinking water, it is a potential drinking water source and discharges into the Columbia River (which is used for drinking water).	ARAR	Groundwater remediation and management activities (e.g., groundwater treatment, discharge of treated groundwater, in situ remediation of groundwater, MNA).
"Maximum Contaminant Levels for Inorganic Contaminants" (40 CFR 141.62) "Maximum Contaminant Level Goals for Inorganic Contaminants" (40 CFR 141.51)	Chemical	Establishes MCLs and nonzero MCLGs as criteria for groundwater and surface water that are or may be used for drinking water. The standards/goals are designed to protect human health from adverse effects of inorganic contaminants in the drinking water.	Groundwater in 100-K contains contaminants that may require remediation. It is not currently used for drinking water but is a potential drinking water source (it discharges into the Columbia River, which is used for drinking water).	ARAR	Groundwater remediation and management (e.g., discharge of treated groundwater, in situ remediation of groundwater, MNA).
"Maximum Contaminant Levels for Radionuclides" (40 CFR 141.66)	Chemical	Establishes MCLs as criteria for groundwater and surface water that are or may be used for drinking water. The standards are designed to protect human health from adverse effects radionuclides in the drinking water.	Groundwater in 100-K contains contaminants that may require remediation. It is not currently used for drinking water but is a potential drinking water source (it discharges into the Columbia River, which is used for drinking water).	ARAR	Groundwater remediation and management (e.g., discharge of treated groundwater, in situ remediation of groundwater, MNA).

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Water Pollution Control" (Chapter 90.48 RCW, as amended); "Underground Injection Control Program" (Chapter 173-218 WAC)					
"UIC Well Classification Including Allowed and Prohibited Wells" (WAC 173-218-040)	Action	Establishes criteria and standards for an underground injection control program.	Groundwater in 100-K contains contaminants that may require remediation; treated groundwater may be discharged through underground injection wells.	ARAR	Groundwater remedial activities may involve underground injection.
"Model Toxics Control Act Statute and Regulation" (Chapter 70.105D RCW, as amended); "MTCA Cleanup Regulation" (Chapter 173-340 WAC)					
"Ground Water Cleanup Standards" (WAC 173-340-720) Method B Cleanup Levels for Potable Ground Water" (WAC 73-340-720(4)(b)(i-iii) (A)&(B)) Adjustments to Cleanup Levels" (WAC 173-340-720(7))	Chemical	Groundwater cleanup levels are based on estimates of the highest beneficial use and the reasonable maximum exposure expected to occur under both current and potential future site use conditions. Method B equations (720-1 and 720-2) to calculate groundwater cleanup levels for noncarcinogens and carcinogens, respectively, only if "sufficiently protective, health-based criteria or standards have not been established under applicable state and federal laws. Groundwater cleanup levels are established at concentrations that do not directly or indirectly cause violations of surface water, sediments, soil, or air cleanup standards.	Groundwater in 100-K contains contaminants that may require remediation. It is not currently used for drinking water but is a potential drinking water source (it discharges into the Columbia River, which is used for drinking water).	ARAR	Groundwater remediation and management (e.g., discharge of treated groundwater, in situ remediation of groundwater, MNA).
"Hazardous Waste Management Act of 1976" (Chapter 70.105 RCW, as amended); "Dangerous Waste Regulations" (Chapter 173-303 WAC)					
"Requirements" (WAC 173-303-64620(4))	Chemical	Provides standards for groundwater protection including background, MCLs, and ACLs. The MCLs are established at the same levels as SDWA MCLs; where SDWA MCLs do not exist, health based ACLs may be established that are protective of	Some portions of 100-K are regulated under corrective action of the state's dangerous waste regulations and may require groundwater remediation.	ARAR	Groundwater remediation and management (e.g., discharge of treated groundwater, in situ remediation of groundwater, MNA).

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
		human health and environment.			
"Water Well Construction Act of 1971" (Chapter 18.104 RCW, as amended); "Minimum Standards for Construction and Maintenance of Wells" (Chapter 173-160 WAC)					
"How Shall Each Water Well Be Planned and Constructed?" (WAC 173-160-161)	Action	Identifies well planning and construction requirements.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Requirements for the Location of the Well Site and Access to the Well?" (WAC 173-160-171)	Action	Identifies the requirements for locating a well.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Requirements for Preserving the Natural Barriers to Ground Water Movement Between Aquifers?" (WAC 173-160-181)	Action	Identifies the requirements for preserving natural barriers to groundwater movement between aquifers.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Minimum Standards for Resource Protection Wells and Geotechnical Soil Borings?" (WAC 173-160-400)	Action	Identifies the minimum standards for resource protection wells and geotechnical soil borings.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the General Construction Requirements for Resource Protection Wells?" (WAC 173-160-420)	Action	Identifies the general construction requirements for resource protection wells.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"What Are the Minimum Casing Standards?" (WAC 173-160-430)	Action	Identifies the minimum casing standards.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Equipment Cleaning Standards?" (WAC 173-160-440)	Action	Identifies the equipment cleaning standards.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Are the Well Sealing Requirements?" (WAC 173-160-450)	Action	Identifies the well sealing requirements.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.
"What Is the Decommissioning Process for Resource Protection Wells?" (WAC 173-160-460)	Action	Identifies the decommissioning process for resource protection wells.	Groundwater monitoring and treatment wells and borings occur in 100-K.	ARAR	Investigative and remediation activities that require siting, installation, construction, operation, maintenance, and decommissioning of wells and borings.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Radionuclide ARAR Dose Compliance Concentrations for Superfund Sites					
"Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination" (Luftig and Weinstock, 1997 [OSWER Directive 9200.4-18]) "Distribution of OSWER Radiation Risk Assessment Q & A's Final Guidance" (Luftig and Page, 1999 [distributing OSWER Directive 9200.4-31P])	Chemical	This memorandum presents clarification for establishing protective cleanup levels in media for radioactive contamination at CERCLA sites. EPA has determined that the dose limits established by the NRC in 62 FR 39058, "Radiological Criteria for License Termination" (25 mrem/yr, which is equivalent to 5×10^{-4} increase lifetime risk), will not provide a protective basis for establishing PRGs under CERCLA. A dose of 15 mrem/yr effective dose (approximately equivalent to 3×10^{-4} increase in lifetime risk) is preferred as the maximum dose limit for humans. In the final guidance, EPA further clarifies that 15 mrem/yr is not a presumptive cleanup level under CERCLA. Rather, site decision makers should continue to use the CERCLA risk range when ARARs are not used to set cleanup levels. This is for several reasons, as using dose based guidance would result in unnecessary inconsistency regarding how radiological and nonradiological (chemical) contaminants are addressed at CERCLA sites.	Groundwater in 100-K contains radioactive contaminants that, if not remediated, could pose unacceptable risk to human health.	TBC	Development of groundwater cleanup levels.
Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (OSWER Directive 9200.4-17P)	Action	Provides the framework and appropriateness for using the MNA as a remedy component for organic and inorganic contaminants.	Groundwater in 100-K contains contaminants that may require remediation. The use of MNA as a remedy may be appropriate.	TBC	Groundwater remediation activities including MNA.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Surface Water					
***Clean Water Act of 1972* (Public Law 107-303, as amended; 33 U.S.C. Section 1251, et seq.), Section 303c; "Water Quality Standards" (40 CFR 131)**					
"Toxics Criteria for Those States Not Complying with Clean Water Act Section 303(c)(2)(B)" (40 CFR 131.36(b)(1))	Chemical	Establishes numeric water quality criteria for the protection of human health and aquatic organisms. Toxic criteria for the protection of aquatic life is provided in the water quality criteria regulations 40 CFR 131.36(b)(1), "EPA's Section 304(a), Criteria for Priority Toxic Pollutants," supersede criteria adopted by the state, except where the state criteria are more stringent than the federal criteria.	Groundwater in 100-K contains contaminants that may require remediation and discharges into the Columbia River.	ARAR	Groundwater remediation activities that impact surface water (e.g., discharge of treated groundwater, in situ remediation of groundwater, and MNA).
"Model Toxics Control Act Statute and Regulation" (Chapter 70.105D RCW, as amended); "MTCA Cleanup Regulation" (Chapter 173-340 WAC)					
"Surface Water Cleanup Standards" (WAC 173-340-730)	Chemical	Surface water cleanup levels are based on estimates of the highest beneficial use and the reasonable maximum exposure expected to occur under both current and potential future site use conditions.	Groundwater in 100-K contains contaminants that may require remediation and discharges into the Columbia River. The Columbia River is a current and future source of drinking water.	ARAR	Groundwater, remediation activities that impact surface water (e.g., discharge of treated groundwater, in situ remediation of groundwater, and MNA).
"Water Pollution Control" (Chapter 90.48 RCW, as amended); "Water Quality Standards for Surface Waters of the State of Washington" (Chapter 173-201A WAC)					
"Toxic Substances" (WAC 173-201A-240(3))	Chemical	Establishes water quality standards for surface waters of the State of Washington consistent with public health and public enjoyment of the waters and the propagation and protection of fish, shellfish, and wildlife.	Groundwater in 100-K contains contaminants that may require remediation and discharges into the Columbia River. The Columbia River is a current and future source of drinking water. The use designations for the Columbia River include aquatic life use (spawning and rearing), primary contact recreation, water supply (drinking, irrigation, and	ARAR	Groundwater, remediation activities that impact surface water (e.g., discharge of treated groundwater, in situ remediation of groundwater, and MNA).

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
			agriculture), and miscellaneous uses (wildlife habitat, harvesting, commerce, boating, and aesthetics).		
Soil and Vadose Zone					
"Model Toxics Control Act Statute and Regulation" (Chapter 70.105D RCW, as amended); "MTCA Cleanup Regulation" (Chapter 173-340 WAC)					
"Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(3))	Chemical	Establishes soil cleanup levels where residential land use represents the reasonable maximum exposure under both current and future site use conditions. Cleanup standards require specification of the following: • Hazardous substance concentrations that protect HHE (cleanup levels) • Location of the site where cleanup levels must be attained ("points of compliance") • Other regulatory requirements that apply to the cleanup action because of the type of action or location of the site	Soil in 100-K contains contaminants that may require remediation. The requirements corresponding to Method B soil cleanup levels may be used to calculate cleanup levels based on an unrestricted land use, which is more conservative than the conservation/mining land use assigned to this area.	ARAR	Soil cleanup actions where concentration of hazardous substances in the soil exceeds Method B cleanup levels using WAC 173-340-740(3)(b) and (c).

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Deriving Soil Concentrations for Ground Water Protection" (WAC 173-340-747(3) through (8))	Chemical	Establishes soil concentrations that will not cause contamination of groundwater at levels that exceed the groundwater cleanup levels established under WAC 173-340-720. Provides an overview of the methods for deriving these soil concentrations to meet relevant criteria. Certain methods are tailored for particular types of hazardous substances or sites and certain methods are more complex than others and/or require the use of site-specific data.	Soil in 100-K contains contaminants that may require remediation. The requirements corresponding to soil cleanup levels may be used to calculate cleanup levels to ensure protection of groundwater. Although groundwater is not currently used for drinking water, it is a potential drinking water source and discharges into the Columbia River (which is used for drinking water).	ARAR	Soil cleanup actions where concentration of hazardous substances in the soil exceeds soil concentration for protection of groundwater. As allowed, WAC 173-340-747(8), Alternative fate and transport models, one of the seven allowable methods under WAC 173-340-747, will be used to determine appropriate cleanup levels.
Guidance for Developing Ecological Soil Screening Levels (OSWER Directive 9285.7-55)	Chemical	Provides a set of risk-based soil screening levels (Eco-SSLs) for several soil contaminants that are of ecological concern for terrestrial plants and animals at hazardous waste sites. Also describes the process used to derive these levels and provides guidance for their use.	Soil in 100-K contains contaminants that may require remediation. Comparison to SSLs may be appropriate for defining potential COPCs or to default to an Eco-SSL for COPCs that lacks corresponding published state cleanup criteria.	TBC	Soil cleanup actions to protect Ecological Receptors.
"Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7490) "Site-Specific Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7493) "Priority Contaminants of Ecological Concern" (WAC 173-340-7494)	Chemical	Defines goals and procedures for determining whether a release of hazardous substances to soil may pose a threat to the terrestrial environment. Characterizes existing or potential threats to terrestrial plants or animals exposed to hazardous substances in soil; establishes site-specific cleanup standards for the protection of terrestrial plants and animals. Section 173-340-7494 provides for numeric concentrations of hazardous substances determined to persist, bioaccumulate, or be highly toxic to	Soil in 100-K contains contaminants that may require evaluation to determine if ecological exposures have the potential to cause significant adverse effects.	ARAR	Soil remediation activities including containment, RTD, and MNA. After using the generic screening levels available in Table 749-3, site-specific terrestrial ecological cleanup levels have been developed using WAC 173-340-7493.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
		terrestrial ecological receptors.			
Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (OSWER Directive 9200.4-17P)	Action	Provides the framework and appropriateness for using MNA as a remedy component for organic and inorganic contaminants.	Soil in 100-K contains contaminants that may require remediation. The use of MNA as a remedy may be appropriate.	TBC	Soil remediation activities including MNA.
Air					
"Washington Clean Air Act" (Chapter 70.94 RCW, as amended); "General Regulations for Air Pollution Sources" (Chapter 173-400 WAC)					
"General Regulations for Air Pollution Sources" (WAC 173-400)	Action	Defines methods of control to be employed to minimize the release of air contaminants associated with fugitive emissions resulting from materials handling, construction, demolition, or other operations. Emissions are to be minimized through application of best available control technology.	Soil and/or groundwater remedial actions implemented in 100-K have the potential to emit emissions subject to these standards because soil and groundwater hazardous contaminants detected in 100-K include covered hazardous air pollutants.	ARAR	Actions performed at 100-K that could result in the emission of hazardous air pollutants, including decontamination, demolition, and excavation activities implemented during a remedial action that have the potential to emit visible, particulate, fugitive, and hazardous air emissions and odors.
"General Standards for Maximum Emissions" (WAC 173-400-040)	Action	All sources and emission units are required to meet the general emission standards unless a specific source standard is available. General standards apply to visible emissions, particulate fallout, fugitive emissions, odors, emissions detrimental to health and property, sulfur dioxide, and fugitive dust.	Soil and/or groundwater remedial actions implemented in 100-K have the potential to emit emissions subject to these standards because hazardous contaminants detected in 100-K include covered regulated hazardous air pollutants.	ARAR	Remedial actions that have the potential to release hazardous air emissions.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Emission Standards for Sources Emitting Hazardous Air Pollutants" (WAC 173-400-075)	Action	Establishes national emission standards for hazardous air pollutants. Adopts, by reference, 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," and appendices.	Soil and/or groundwater hazardous contaminants detected in 100-K include covered regulated hazardous air pollutants.	ARAR	Actions performed at 100-K that could result in the emission of hazardous air pollutants, including decontamination, demolition, and excavation activities implemented during the remedial action that have the potential to emit visible, particulate, fugitive, and hazardous air emissions and odors.
"Washington Clean Air Act" (Chapter 70.94 RCW, as amended); "Controls for New Sources of Toxic Air Pollutants" (Chapter 173-460 WAC)					
"Purpose" (WAC 173-460-010) "Applicability" (WAC 173-460-030) "Control Technology Requirements" (WAC 173-460-060) "Ambient Impact Requirement" (WAC 173-460-070) "First Tier Review" (WAC 173-460-080) "Table of ASIL, SQER and de Minimis Emission Values" (WAC 173-460-150)	Action	Establishes control of new sources emitting toxic air pollutants to prevent air pollution, reduce emissions to the extent reasonably possible, and maintain such levels of air quality as will protect human health and safety. Toxic air pollutants include carcinogens and noncarcinogens listed in WAC 173-460-150. Three major requirements of this regulation are implementation of best available control technology for toxics, quantification of toxic air pollutant emissions, and demonstration of health and safety protection.	Hazardous contaminants detected in soil and/or groundwater in 100-K include constituents that would constitute toxic air pollutants if released to the air.	ARAR	Groundwater and soil remediation activities, such as 100-K treatment systems with the potential to emit hazardous air emissions and that would be considered a new source.
"Washington Clean Air Act" (Chapter 70.94 RCW, as amended); "Ambient Air Quality Standards and Emission Limits for Radionuclides" (Chapter 173-480 WAC)					
"Ambient Standard" (WAC 173-480-040)	Action	Defines the maximum allowable level for radionuclides in the ambient air, which shall not cause a maximum accumulated dose equivalent of 25 mrem/yr to the whole body or	Hazardous contaminants detected in soil and groundwater in 100-K include radionuclides that could be emitted to ambient	ARAR	Investigative and remediation activities (e.g., excavation, RTD, demolition, ventilation, vacuuming/exhaust) that have the potential to emit

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
		75 mrem/yr to any critical organ. However, ambient air standard under 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities," and Subpart I, "National Emission Standards for Radionuclide Emissions from Federal Facilities Other Than Nuclear Regulatory Commission Licensees and Not Covered by Subpart H," are not to exceed amounts that result in an effective dose equivalent of 10 mrem/yr to any member of the public.	air during remedial actions.		radionuclides above maximum acceptable levels.
"General Standards for Maximum Permissible Emissions" (WAC 173-480-050)	Action	At a minimum, all emission units shall make every reasonable effort to maintain radioactive materials in effluents to unrestricted areas; control equipment of sites operating under ALARA shall be defined as reasonably available control technology and as low as reasonably achievable control technology.	The potential for fugitive and diffuse emissions due to demolition and excavation and related activities will require efforts to minimize those emissions.	ARAR	Investigative and remediation activities (e.g., excavation, RTD, demolition, ventilation, vacuuming/exhaust) that have the potential to emit radionuclides above maximum acceptable levels.
"Emission Monitoring and Compliance Procedures" (WAC 173-480-070)	Action	Requires that radionuclide emissions shall be determined by calculating the dose to members of the public using Department of Health approved sampling procedures at the point of maximum annual air concentration in an unrestricted area where any member of the public may be.	Hazardous contaminants detected in soil and groundwater in 100-K includes radionuclides that could be emitted to unrestricted areas during remedial actions.	ARAR	Investigative and remediation activities (e.g., excavation, RTD, demolition, ventilation, and vacuuming/exhaust) that have the potential to emit radionuclides to unrestricted areas above maximum acceptable levels.
"Emission Standards for New and Modified Emission Units" (WAC 173-480-060)	Action	Requires that construction, installation, or establishment of new air emission control units use best available	Hazardous contaminants detected in soil and groundwater in 100-K includes radionuclides that could be emitted from air	ARAR	Investigative and remediation activities (e.g., excavation, RTD, demolition, ventilation, and vacuuming/exhaust) that

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
		radionuclide control technology.	emission control units during remedial actions.		require air pollution control equipment and have the potential to emit radionuclides.
"Nuclear Energy and Radiation" (Chapter 70.98 RCW, as amended); "Radiation Protection—Air Emissions" (Chapter 246-247 WAC)					
"National Standards Adopted by Reference for Sources of Radionuclide Emissions" (WAC 246-247-035 (1)(a)(i) [adopts by reference 40 CFR 61.05, "Prohibited Activities"])	Action	Identifies prohibition of any owner or operator of any stationary source subject to a national emission standard for hazardous air pollutants from constructing or operating the new or existing source in violation of any such standard.	Substantive requirements of this standard are applicable because the remedial actions in 100-K may be subject to NESHAP's Air Pollutant Standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial action.	ARAR	Investigative and remedial activities.
(WAC 246-247-035 (1)(a)(i) [adopts by reference 40 CFR 61.12, "Compliance with Standards and Maintenance Requirements"])	Action	Requires the owner or operator of each stationary source of hazardous air pollutants subject to a national emission standard for a hazardous air pollutant to determine compliance with numerical emission limits in accordance with emission tests established in "Emission Tests and Waiver of Emission Tests" (40 CFR 61.13) or as otherwise specified in an individual subpart. Compliance with design, equipment, work practice, or operational standards shall be determined as specified in the individual subpart. Also, maintain and operate the source, including associated equipment for air pollution control, in a manner consistent with good air pollution control practice for minimizing emissions.	Hazardous contaminants that would be subject to NESHAP's Air Pollutant Standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial actions in 100-K. Associated design, equipment, work practice, or equipment for air pollution control may also be maintained and operated.	ARAR	Investigative and remedial actions involve stationary sources that provide a potential to emit regulated hazardous air pollutants (e.g., vapor extraction systems, decontamination stations, deactivation, demolition, or waste removal or storage activities). Associated design, equipment, work practice, or air emissions controls may be maintained and operated.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
(WAC 246-247-035 (1)(a) (i) [adopts by reference 40 CFR 61.14, "Monitoring Requirements"])	Action	Requires the owner or operator to maintain and operate each monitoring system as specified in the applicable subpart, and in a manner consistent with good air pollution control practice for minimizing emissions. Approvals of alternatives to any monitoring requirements or procedures are obtained from the regulatory agency.	Hazardous contaminants that would be subject to NESHAP's Air Pollutant Standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial actions in 100-K. The hazardous contaminants will be monitored as identified under each applicable NESHAP subpart.	ARAR	Investigative and remedial soil, air, and groundwater monitoring systems, and decontamination and stabilization of contaminated structures, treatment of sludge, and operation of exhausters and vacuums, that may produce airborne emissions of hazardous pollutants to unrestricted areas.
(WAC 246-247-035 (1)(a)(ii) [adopts by reference 40 CFR 61.92, "Standard"])	Chemical	Establishes emission standards for radionuclides equivalent to 40 CFR 61, Subpart H, by reference. U.S. DOE Hanford Site radionuclide airborne emissions shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent.	Hazardous radionuclide contaminants that would be subject to NESHAP; Radionuclide Air Pollutant Standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil or groundwater involved in the remedial actions in 100-K.	ARAR	Investigative and remedial soil, air, groundwater monitoring systems and decontamination and stabilization of contaminated structures, treatment of sludge, and operation of exhausters and vacuums, that may produce airborne emissions of hazardous radionuclide pollutants to unrestricted areas.
(WAC 246-247-035 (1)(a)(ii) [adopts by reference 40 CFR 61.93, "Emission Monitoring and Test Procedures"])	Action	Specifies that radionuclide emissions shall be determined and effective dose equivalent values to members of the public calculated to determine compliance with the 10 mrem/yr effective dose equivalent standard. Radionuclide emissions shall be collected and measured using approved methods. A quality assurance program shall be conducted that meets the performance requirements described in	Hazardous radionuclide contaminants that would be subject to NESHAP; Radionuclide Air Pollutant Standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial actions in 100-K. The hazardous contaminants will	ARAR	Investigative and remedial soil, air, and groundwater monitoring systems, and decontamination and stabilization of contaminated structures, treatment of sludge, and operation of exhausters and vacuums, that may produce airborne emissions of hazardous radionuclide pollutants to unrestricted areas.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
		Appendix B, Method 114. Measurement by methods specified in the paragraph (b) shall be made at all release points that have the potential to discharge radionuclides to the air in quantities that cause an effective dose equivalent in excess of 1 percent of the 10 mrem/yr standard. For other release points that have a potential to release radionuclides into the air, periodic confirmatory measurements shall be made to verify the low emissions.	be monitored as identified under each applicable NESHAP subpart.		
"General Standards" (WAC 246-247-040(3)) "General Standards" (WAC 246-247-040(4))	Action	Requires that emissions be controlled to ensure ALARA-based and Best Available Controls standards are not exceeded.	Hazardous contaminants that would be subject to radionuclide air emission standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial actions in 100-K.	ARAR	Investigative and remedial soil, air, and groundwater monitoring systems, and decontamination and stabilization of contaminated structures, treatment of sludge, and operation of exhausters and vacuums, that may produce airborne emissions of hazardous radionuclide pollutants to unrestricted areas.
"Monitoring, Testing and Quality Assurance" (WAC 246-247-075)	Action	Establishes the monitoring, testing, and quality assurance requirements for radioactive air emissions. Emissions from nonpoint and fugitive sources of airborne radioactive material will be measured. Measurement techniques may include but are not limited to sampling, calculation, smears, or other reasonable method for identifying emissions as determined by the lead agency.	Hazardous contaminants in 100-K waste sites that would be subject to radionuclide air emission standards and resultant requirements may be detected in, and potentially emitted from, structures, components, debris, soil, or groundwater involved in the remedial actions.	ARAR	Investigative and remedial soil, air, and groundwater monitoring systems, and decontamination and stabilization of contaminated structures, treatment of sludge, and operation of exhausters and vacuums, that may produce airborne emissions of hazardous radionuclide pollutants to unrestricted areas.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
***Clean Air Act of 1990* and amendments; 40 CFR 61, Subpart M, "National Emission Standard for Asbestos"**					
40 CFR 61.140, "Applicability" 40 CFR 61.145, "Standard for Demolition and Renovation"	Action	Defines regulated ACM and regulated removal and handling requirements. Specifies sampling, inspection, handling, and disposal requirements for regulated sources having the potential to emit asbestos. Specifically, no visible emissions are allowed during handling, packaging, and transport of ACM.	Encountering ACM on pipelines or buried asbestos within the 100-K area is possible during the during remediation activities.	ARAR	Site investigation and remediation activities that include demolition and/or renovation and associated handling, packaging, and transportation of ACM, including IDW management and disposal.
40 CFR 61.150, "Standard for Waste Disposal for Manufacturing, Fabricating, Demolition, Renovation, and Spraying Operations"	Action	Identifies requirements for the removal and disposal of asbestos from demolition and renovation activities.	Encountering ACM on pipelines or buried asbestos within the 100-K area is possible during the during remediation activities.	ARAR	Site investigation and remediation activities that include demolition and/or renovation and associated handling, packaging, and transportation of ACM including IDW management and disposal.
Solid Wastes					
***Toxic Substances Control Act of 1976* (Public Law 107-377, as amended; 15 USC Section 2605, et seq.); "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions" (40 CFR 761)**					
"Applicability," "PCB Waste" (40 CFR 761.50(b)1, 2, 3, 4 and 7) "Applicability," "Storage for Disposal" (40 CFR 761.50(c))	Action	Establishes general PCB disposal requirements for the storage and disposal of PCB wastes including liquid PCB wastes, PCB items, PCB remediation waste, PCB bulk product wastes, and PCB/radioactive wastes at concentrations greater than 50 ppm.	PCB wastes may be encountered and or generated during the remediation of 100-K.	ARAR	Soil excavation and remediation, equipment and debris handling and disposal, and IDW management and disposal.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Disposal Requirements," "PCB Liquids" (40 CFR 761.60(a)) "Disposal Requirements," "PCB Articles" (40 CFR 761.60(b)) "Disposal Requirements," "PCB Containers" (40 CFR 761.60(c))	Action	Establishes requirements applicable to the handling and disposal of PCB liquids, PCB articles, and PCB containers.	PCB liquids, articles, and/or containers may be encountered and/or generated during the remedial actions for 100-K.	ARAR	Equipment and debris handling, storage, and disposal; IDW management and disposal.
"PCB Remediation Waste" (40 CFR 761.61)	Action	Provides cleanup and disposal options for PCB remediation waste based on the concentration at which the PCBs are found.	PCB remediation wastes may be encountered and/or generated during the remedial actions for 100-K.	ARAR	Soil remediation, RTD, and IDW management and disposal.
"Hazardous Waste Management" (Chapter 70.105 RCW, as amended); "Dangerous Waste Regulations" (Chapter 173-303 WAC)					
"Identifying Solid Waste" (WAC 173-303-016) "Recycling Processes Involving Solid Waste" (WAC 173-303-017)	Action	Establishes criteria for solid and recycled solid wastes.	Solid wastes and/or recycled solid wastes may be generated during 100-K remedial actions.	ARAR	Investigative and remediation activities.
"Designation of Dangerous Waste" (WAC 173-303-070)	Action	Establishes the method for determining if a solid waste is a dangerous waste (or an extremely hazardous waste).	Dangerous/hazardous waste may be generated during 100-K remedial actions.	ARAR	Investigative and remediation (including waste treatment) activities that generate wastes (e.g., drums, barrels, tanks, containers, bulk wastes, debris, and contaminated soil).

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Conditional Exclusion of Special Wastes" (WAC 173-303-073)	Action	Establishes the conditional exclusion and the management requirements of special wastes, as defined in WAC 173-303-040, "Definitions."	Special wastes may be generated during 100-K remedial actions.	ARAR	FS remediation activities (disposal, storage, recycling, and onsite treatment) that manage special wastes consistent with the requirements of the *Washington Administrative Code.*
"Requirements for Universal Waste" (WAC 173-303-077)	Action	Identifies those wastes exempted from regulation under WAC 173-303-140, "Land Disposal Restrictions," and WAC 173-303-170 through 173-303-9907 (excluding WAC 173-303-960, "Special Powers and Authorities of the Department"). These wastes are subject to regulation under WAC 173-303-573, "Standards for Universal Waste Management."	Universal wastes may be generated during the 100-K remedial actions.	ARAR	FS remediation activities (disposal, storage, recycling, and onsite treatment) that manage universal wastes consistent with the requirements of the *Washington Administrative Code.*
"Recycled, Reclaimed, and Recovered Wastes" (WAC 173-303-120) "Recycled, Reclaimed, and Recovered Wastes" (WAC 173-303-120(3)) "Recycled, Reclaimed, and Recovered Wastes" (WAC 173-303-120(5))	Action	Defines the requirements for the recycling of materials that are solid and dangerous waste. Specifically, WAC 173-303-120(3) provides for the management of certain recyclable materials, including spent refrigerants, antifreeze, and lead acid batteries. WAC 173-303-120(5) provides for the recycling of used oil.	Recycled, reclaimed, and recovered wastes may be generated during 100-K remedial actions.	ARAR	FS remediation recycling activities consistent with the requirements of the *Washington Administrative Code* and not otherwise subject to CERCLA as hazardous substances.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Land Disposal Restrictions" (WAC 173-303-140)	Action	Establishes treatment requirements and disposal prohibitions for land disposal of dangerous waste and incorporates by reference (WAC 173-303-140(2)(a)) the federal land disposal restrictions of 40 CFR 268, "Land Disposal Restrictions," that are applicable to solid waste that is designated as dangerous or mixed waste in accordance with WAC 173-303-070(3), "Designation of Dangerous Waste."	Onsite land disposal may be a selected remedy for 100-K dangerous waste and debris.	ARAR	Investigative and remediation wastes destined for onsite land disposal.
"Requirements for Generators of Dangerous Waste" (WAC 173-303-170)	Action	Establishes the requirements for dangerous waste generators. WAC 173-303-170(3) includes the substantive provisions of WAC 173-303-200, "Accumulating Dangerous Waste On-Site," by reference. WAC 173-303-200 further includes certain substantive standards from WAC 173-303-630, "Use and Management of Containers," and WAC 173-303-640, "Tank Systems," by reference. Specifically, the substantive standards for management of dangerous/ mixed waste are applicable to the management of dangerous waste that will be generated during the remedial action.	Dangerous wastes may be generated from the remedial actions in 100-K.	ARAR	IDW and remediation wastes (contaminated soil and groundwater, personnel protective gear, treatment chemicals).
"Accumulating Dangerous Waste On-Site" (WAC 173-303-200)	Action	Establishes the requirements for accumulating wastes onsite. WAC 173-303-200 further includes certain substantive standards from "Use and Management of Containers, WAC 173-303-630 and -640 by reference.	Dangerous waste may be generated from the remedial actions in 100-K.	ARAR	Management of dangerous waste during remedial and investigative actions.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
"Solid Waste Management—Reduction and Recycling" (Chapter 70.95 RCW, as amended); "Solid Waste Handling Standards" (Chapter 173-350 WAC)					
"Owner Responsibilities for Solid Waste (WAC 173-350-025) "Performance Standards" (WAC 173-350-040) "On Site Storage, Collection and Transportation Standards" (WAC 173-350-300) "Remedial Action" (WAC 173-350-900)	Action	Establishes minimum functional performance standards for the proper handling and disposal of solid waste. Requirements for the proper handling of solid waste materials originating from residences, commercial, agricultural and industrial operations, and other sources and identifies those functions necessary to ensure effective solid waste handling programs at both the state and local level.	Solid, nondangerous waste will be generated during implementation of 100-K remedial actions.	ARAR	Investigative and remedial actions that generate solid, nondangerous waste.
Historical and Archeological Resources					
***National Historic Preservation Act of 1966* (Public Law 89-665, as amended, 16 USC 470, et seq.)**					
"Protection of Historic Properties" (36 CFR 800)	Location	Legislation intended to preserve historical and archaeological sites in the United States of America. Requires federal agencies to consider the impacts of their undertaking on cultural properties through identification, evaluation, mitigation processes, and consultation with interested parties.	Cultural and historic sites have been identified within 100-K.	ARAR	Investigation and remediation activities that occur in areas near cultural or historic sites.
***Protection and Enhancement of the Cultural Environment* (Executive Order 11593)**					
"National Historic Landmarks Program" (36 CFR 65) "National Register of Historic Places" (36 CFR 60)	Location	Requires federal agencies to consider the impacts of their undertaking on cultural properties through identification, evaluation, mitigation processes, and consultation with interested parties.	Cultural and historic sites have been identified within 100-K.	ARAR	Investigation and remediation activities that occur in areas near cultural or historic sites.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Native American Graves Protection and Repatriation Act of 1990 **(Public Law 101-601, as amended, 25 U.S.C. 3001, et seq.); "Native American Graves Protection and Repatriation Regulations" (43 CFR 10)**					
"Native American Graves Protection and Repatriation Regulations" (43 CFR 10)	Location	Establishes federal agency responsibility for discovery of human remains, associated and unassociated funerary objects, sacred objects, and items of cultural patrimony. Requires Native American Tribal consultation in the event of discovery.	Native American archaeological, cultural and historic sites have been identified within 100-K; Native American remains and associated objects may be present.	ARAR	Investigations and remedial activities that affect Native American archaeological, cultural areas and historic sites that contain associated remains and objects.
Archeological and Historic Preservation Act of 1974 **(Public Law 93-291, as amended; 16 USC 469a-1 through 469a-2(d))**					
"Applicant Requirements" 16 USC 469a-1 through 469a-2(d)	Location	Requires that remedial actions do not cause the loss of any archaeological or historic data. This act mandates preservation of the data; it does not require protection of the actual waste site or facility.	Archaeological and historic sites have been identified within 100-K.	ARAR	Investigation and remediation activities that occur in areas near archeological or historic sites.
Natural and Ecological Resources					
Floodplain Management **(Executive Order 11988)**					
"Compliance with Floodplain and Wetland Environmental Review Requirements" (10 CFR 1022)	Location	Take action to avoid adverse effects, minimize potential harm, and restore and preserve natural and beneficial values of the floodplain.	Some of the waste sites within 100-K subject to remediation are located within the Columbia River floodplain.	ARAR	Remedial actions will occur in the floodplain.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Endangered Species Act of 1973 **(Public Law 93-205, as amended; 7 U.S.C. Section 136; 16 U.S.C. Ch. 1531, et seq.)**					
"Interagency Cooperation—Endangered Species Act of 1973, as Amended" (50 CFR 402)	Location	Prohibits actions by federal agencies that are likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of habitat critical to them. Mitigation measures must be applied to actions that occur within critical habitats or surrounding buffer zones of listed species, in order to protect the resource.	Federal endangered and/or threatened species including fish, plants, and animals are found within 100-K.	ARAR	Remediation actions and investigation activities that occur within critical habitats or designated buffer zones of federal listed species.
Migratory Bird Treaty Act of 1918 **(16 U.S.C. 703-712; Ch. 128; July 13, 1918; 40 Stat. 755), as amended**					
Migratory Bird Treaty Act of 1918 (16 U.S.C. 703-712)	Location	Protects all migratory bird species and prevents "take" of protected migratory birds, their young, or their eggs."	Migratory birds occur in 100-K.	ARAR	Remedial actions that require mitigation measures to deter nesting by migratory birds on, around, or within remedial action site and methods to identify and protect occupied bird nests.
"Habitat Buffer Zone for Bald Eagles—Rules" (Chapter 77.12.655 RCW), "Habitat Buffer Zone for Bald Eagles—Rules"; "Bald Eagle Protection Rules" (Chapter232-12-292 WAC)					
"Permanent Regulations," "Bald Eagle Protection Rules" (WAC 232-12-292)	Location	Protects eagle habitat to maintain eagle populations so the species is not classified as threatened, endangered, or sensitive in Washington State.	Bald eagles nest, feed, and overwinter along the shores of the Columbia River in 100-K.	ARAR	Investigative and remediation activities that impact bald eagle habitat.

Table 8-2. Potential Federal and Washington State ARARs and TBCs for 100-K

Regulatory Citation	ARAR Category	Description of Regulatory Requirement	Rationale for Including	Potential Relevancy	Possible Application
Fish and Wildlife Conservation Act of 1980, "Nongame Act" (Public Law 96-366, as Amended; 16 U.S.C. 2901-2911)					
"Rules Implementing the Fish and Wildlife Conservation Act of 1980" (50 CFR 83)	Location	Preserve and promote conservation of non-game fish and wildlife and their habitats.	Non-wildlife and their habitats may occur in 100-K.	ARAR	Remedial action that impact non-game fish, and wildlife and/or their habitats.
Land Use and Exposure Scenarios					
Final Hanford Comprehensive Land Use Plan Environmental Impact Statement (DOE/EIS-0222-F)	Location	Establishes the future land use projections for the Central Plateau.	Land use, as stated in the Hanford Comprehensive Land Use Plan, is conservation/mining for land outside either (1) the Hanford Reach National Monument, or (2) the River Corridor, which includes 100-K.	TBC	

Sources: Chapter 11, References, provides complete source information.

8.1.2.5 Standards Controlling Emissions to the Environment

Remedial action alternatives proposed in Chapter 9 of this FS have the potential to generate airborne emissions of both radioactive and toxic/criteria airborne emissions. Implementation of these activities and associated air monitoring will be discussed in the RD/RAWP for 100-K.

8.1.2.6 Radiological Air Emissions

The federal *Clean Air Act Amendments of 1990* (and the *Washington Clean Air Act* each require regulation of radioactive air emissions. The state implementing regulation"Ambient Air Quality Standards and Emission Limits for Radionuclides" (WAC 173-480) sets standards that are as stringent or more than the standards under the federal *Clean Air Act Amendments of 1990*, including the federal implementing regulation, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (40 CFR 61, Subpart H). The EPA's partial delegation of the Subparts A and H authority to the State of Washington includes all substantive emissions monitoring, abatement, and reporting aspects of the federal regulation. These state standards protect the public by conservatively establishing exposure standards applicable to the maximally exposed public individual. Members of the public can travel on the Columbia River through the Hanford Reach, but they cannot "abide or reside" there.

"Ambient Air Quality Standards and Emission Limits for Radionuclides" (WAC 173-480) limits emissions of radionuclides to the ambient air by requirement that emissions of radionuclides in the air shall not cause a maximum effective dose equivalent of more than 10 mrem/yr to the whole body to any member of the public. Under the state implementing regulations, "Radiation Protection—Air Emissions" (WAC 246-247) in "Radiation Protection—Air Emissions" (WAC 246-247-030(15)), defines the member of the public (real or hypothetical) who abides or resides in an unrestricted area, and may receive the highest total effective dose equivalent from the emission unit(s) under consideration, taking into account all exposure pathways affected by the radioactive air emissions. In addition, by its adoption of the federal standard at "Standard" (40 CFR 61.92), the state limits radionuclide airborne emissions from the DOE Hanford Site (i.e., facility) to not exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent. The state implementing regulation"Radiation Protection—Air Emissions" (WAC 246-247), which adopts the "Ambient Air Quality Standards and Emission Limits for Radionuclides" (WAC 173-480) standards, and the "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities"(40 CFR 61, Subpart H) standard, requires verification of compliance with the 10 mrem/yr standard, and would be applicable to the remedial action.

"Radiation Protection—Air Emissions" (WAC 246-247) further addresses sources emitting radioactive airborne emissions by requiring monitoring of such sources (emission units). Such monitoring may involve various methods depending upon the configuration of the source. Most stacks or vents are monitored by extracting a sample of the effluent stream from the stack or vent, with subsequent analysis of the sample. Emissions that do not pass through a stack, vent, or other orifice are termed diffuse emissions, and these are normally monitored by extraction of a sample of the ambient air, with subsequent laboratory analysis. The substantive provisions of "Radiation Protection—Air Emissions" (WAC 246-247) that require monitoring of radioactive airborne emissions potentially would be applicable to remedial action would generally be an "applicable" ARAR.

The above state implementing regulations further require control of radioactive airborne emissions to the extent economically and technologically feasible ("General Standards" and associated definitions [WAC 246-247-040(3) and -040(4)]). To address the substantive aspect of these requirements, best or reasonably achieved control technology could be addressed by ensuring that applicable emission control technologies (those successfully operated in similar applications) would be used when economically and

technologically feasible (i.e., based on cost/benefit). Controls will be administered as appropriate using the best methods from among those that are reasonable and effective.

8.1.2.7 Criteria/Toxic Air Emissions

Under"General Regulations for Air Pollution Sources" (WAC 173-400) and "Controls for New Sources of Toxic Air Pollutants" (WAC 173-460), requirements are established for the regulation of emissions of criteria/toxic air pollutants. The primary nonradioactive emissions resulting from remedial actions will be fugitive particulate matter. In accordance with "General Standards for Maximum Emissions" (WAC 173-400-040), reasonable precautions must be taken to (1) prevent the release of air contaminants associated with fugitive emissions resulting from excavation, materials handling, or other operations; and (2) prevent fugitive dust from becoming airborne from fugitive sources of emissions. The use of treatment technologies that would result in emissions of toxic air pollutants that would be subject to the substantive applicable requirements of "Controls for New Sources of Toxic Air Pollutants" (WAC 173-460) are not anticipated to be a part of remedial actions selected for 100-K.

If treatment of some waste encountered during the remedial action is required to meet ERDF waste acceptance criteria, the type of treatment anticipated would consist of solidification/stabilization techniques such as microencapsulation or grouting, and "Controls for New Sources of Toxic Air Pollutants" (WAC 173-460) would not be considered an ARAR. If treatment that is more aggressive is required, that would result in the emission of regulated air pollutants, the substantive requirements of "Requirements for New Sources in Attainment or Unclassifiable Areas" (WAC 173-400-113(2)) and"Control Technology Requirements" (WAC 173-460-060) would be evaluated to determine potential applicability.

Emissions to the air will be minimized during implementation of remedial actions through use of standard industry practices such as the application of water sprays and fixatives. These techniques are considered reasonable precautions to control fugitive emissions as required by the regulatory standards.

8.1.2.8 Groundwater Beneficial Use

CERCLA and NCP establish separate requirements for a groundwater remedy: to be protective of HHE, and to meet ARARs. This is a concept of central importance to the development of the groundwater remedy for the 100-KR-4 OU. These separate requirements are further clarified in a memorandum ("Clarification of the Role of Applicable, or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA" [Fields, 1997]).

The requirement to achieve threshold protectiveness and ARAR-based requirements is established by the NCP. NCP also establishes the requirement to return useable groundwater to beneficial use within a reasonable time frame. EPA generally defers to state agency definitions of useable groundwater provided under the various comprehensive state groundwater protection programs, administered by the states across the United States and a state's determination of groundwater usability at CERCLA sites (*Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites* [EPA/540/G-88/003]). The State of Washington defines groundwater as potable in "Ground Water Cleanup Standards" (WAC 173-340-720(2)), unless the exclusion criteria in "Ground Water Cleanup Standards" (WAC 173-340-720(2)(a) through (c)) can be demonstrated (insufficient yield, natural constituents that make it unsuitable as a drinking water source). The groundwater within the100-KR-4 OU does not meet the exclusion criteria; therefore, it is classified as potable and must be restored to beneficial use wherever practicable, and within a time frame that is reasonably consistent with NCP requirements. The State of Washington has further determined that the highest beneficial use for potable groundwater at most of the cleanup sites within the state, including the site, is as a potential source of domestic drinking water ("Ground Water Cleanup Standards" [WAC 173-340-720(1)(a)]).

Groundwater within the 100-KR-4 OU is currently contaminated, and withdrawal is prohibited as a result of ICs placed on it by DOE. Under current site use conditions, no complete exposure pathways to the general public from groundwater are assumed to exist. Further, regardless of land use designations for soils, groundwater within this OU is not anticipated to become a future source of drinking water until cleanup criteria are met and groundwater is restored to its highest beneficial use. However, groundwater in this risk analysis is evaluated for drinking water use to support the determination of the basis for action and to support the development of PRGs for evaluating remedial alternatives in the FS.

8.1.2.9 Surface Water Beneficial Use

Surface water beneficial use is considered because groundwater within the 100-KR-4 OU currently discharges to the Columbia River through upwelling and seeps."Use Designations—Fresh Waters" (WAC 173-201A-600) and "Table 602—Use Designations for Fresh Waters by Water Resource Inventory Area" (WAC 173-201A-602) identify the beneficial use (or designated uses) for rivers and streams of Washington State. Designated uses for waters of Washington State can include public water supply; protection for fish, shellfish, and wildlife; and recreational, agricultural, industrial, navigational, and aesthetic purposes. Water quality criteria are designed to protect the designated uses and are used to assess the general health of Washington surface waters and set permit limits.

Designated uses of the Columbia River, identified in "Table 602—Use Designations for Fresh Waters by Water Resource Inventory Area" (WAC 173-201A-602), include the following:

- Aquatic life uses—spawning and rearing
- Recreational uses—primary contact
- Water supply uses—drinking water, industrial water, agricultural water, and stock water
- Miscellaneous uses—wildlife habitat, harvesting, commercial/navigation, boating, and aesthetics

The groundwater risk assessment presented in Section 6.2 of this report evaluates potential exposure of aquatic organisms to contaminants in the 100-KR-4 OU. This assessment uses the most stringent federal and state water quality criteria to support the basis for action and to support PRG development.

8.1.3 Preliminary Remediation Goals

To meet the RAOs, PRGs are established. These goals generally are quantitative cleanup levels that would meet ARARs and risk-based levels and would be protective of HHE. The preliminary remediation goals will be used to assess the effectiveness of the selected remedial alternatives in meeting the RAOs. A summary of the 100-K Human Health, Groundwater Protection, Surface-Water Protection, and Ecological Soil PRGs are listed in Table 8-3. The interim action ROD RAGs identified in the interim action RDR/RAWP (DOE/RL-96-17) are listed in Table 8-3 for a direct comparison to the PRGs from this RI/FS.

PRGs represent a core component of the overall technology screening and remedial alternative development process in the FS. PRGs are numerical values expressed as concentrations for a chemical or radionuclide in an environmental media. A remedial action achievement of PRGs results in residual contamination that is protective of HHE ("Remedial Investigation/Feasibility Study and Selection of Remedy" [40 CFR 300.430(e)(2)(i)]). PRGs are also used to identify the area and volume of environmental media that must be addressed; therefore, PRGs are determined prior to the development of the remedial alternatives.

Meeting PRGs and the potential ARARs and, by extension, achieving RAOs, can be accomplished by reducing concentrations (or activities) of contaminants to PRG levels or by eliminating potential exposure pathways/routes. Contaminant-specific and numeric soil PRGs for direct exposure, protection of groundwater, and protection of surface water typically are presented as concentrations, which for nonradionuclides are in mg/kg for soil and for radionuclides are in pCi/g. Contaminant-specific and

numerical cleanup levels for groundwater typically are exposure in µg/L for nonradiological COCs and pCi/L for radiological COCs.

Residual risks following completion of remediation of the waste sites must meet the 10^{-4} to 10^{-6} ELCR for radiological and carcinogenic COCs and must be less than or equal to an HI value of 1.0 for hazardous substances.

8.1.3.1 Development Approach

PRGs are presented for each environmental media of interest (soil and groundwater), each type of contaminant (hazardous substances and radionuclides), human and ecological receptors, and each potentially complete exposure pathway. The following sections describe the approach that was taken to develop PRGs for each media, receptor, and exposure pathway.

8.1.3.2 Direct Contact Exposure PRGs for Nonradiological Contaminants

Development of the PRGs for direct contact exposure to nonradiological contamination for both human and ecological receptors is described in the following subsections.

Human Exposure. For human receptors, soil PRGs developed for direct contact and inhalation exposure pathways are risk-based standards for hazardous substances. Risk-based standards for individual hazardous substances are established using applicable federal and state laws and risk equations. Risk-based standards for individual carcinogens in an unrestricted exposure scenario are based on an ELCR of 1×10^{-6} and an HQ of 1.0 for individual noncarcinogenic substances as described in "Unrestricted Land Use Soil Cleanup Standards" (WAC 173-340-740(3)(b)(iii)(B)).

Consistent with this approach, the methodology described for unrestricted land use under "Method B Soil Cleanup Levels for Unrestricted Land Use" (WAC 173-340-740(3)) is used to calculate the risk-based standards for soil ingestion. Risk-based standards for inhalation pathway use equations and input parameters described in "Method B Air Cleanup Levels" (WAC 173-750(3)) and EPA published volatilization factors and particulate emission factors.

For arsenic and lead, Table 740-1 in the Method A "Soil Cleanup Levels for Unrestricted Land Use" (WAC 173-340-900) are used as the PRG for direct contact exposure.

Soil PRG values are also developed for the direct contact and inhalation pathways combined using the casual user exposure scenario. The casual user scenario is used to represent reasonably anticipated future land use. The casual recreational user scenario is a site-specific scenario representing occasional recreational use that focuses on activities such as walking and picnicking in areas along the Columbia River where paths and benches are likely to exist. Adults and children could potentially be exposed to site contaminants in shallow vadose zone material along the river through incidental soil ingestion, dermal absorption, and inhalation of vapors and dust in ambient air.PRG values for individual carcinogens are based on an ELCR of 1×10^{-6} and an HQ of 1.0 for individual noncarcinogenic substances.

Risk-based standards for some contaminants are calculated to be less than area background values or practical quantitation limits. Where risk-based standards are less than area background concentrations, PRGs may be set at concentrations that are equal to the agreed upon site or area background concentrations. Area background values for selected nonradioactive contaminants in soil have been characterized for the Hanford Site (*Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes* [DOE/RL-92-24]). Similarly, where risk-based standards are less than practical quantitation limits, PRGs will default to the practical quantitation limits. Therefore, the PRGs for individual nonradioactive contaminants in solid waste and particulate reflect the value that is greatest among risk-based standards, area background values, or practical quantitation limits.

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Table 8-3. Summary of 100-K Operable Unit Human Health, Groundwater Protection, Surface Water Protection, and Ecological Soil PRGs

				Human Health PRGs						PRGs Protective of Groundwater and Surface Water						Ecological PRGs			
Analyte Name	CAS No.	Units	Hanford Site Background Concentration[a]	RI/FS Soil MTCA B—Direct Contact PRG[b]	RI/FS Residential PRG[c]	RI/FS Soil Method B Inhalation PRG[d]	RI/FS Casual Recreational User—Direct Contact PRG[e,f]	RI/FS Resident Monument Worker—Direct Contact PRG[g]	DOE/RL 96-17 Residential RAG[h]	100:0 Contaminant Source Model GWP SSL[i]	100:0 Contaminant Source Model GWP PRG[i]	DOE/RL 96-17 GWP RAG[h]	100:0 Contaminant Source Model SWP SSL[i]	100:0 Contaminant Source Model SWP PRG[i]	DOE/RL 96-17 SWP RAG[h]	Plant PRG[j]	Invertebrate PRG[j]	Avian PRG[j]	Mammal PRG[j]
Radionuclides																			
Americium-241	14596-10-2	pCi/g	--	--	155	--	2,570	275	32	1,212	9,990	--	1,212	9,990	--	21,500	--	11,900	4,840
Carbon-14	14762-75-5	pCi/g	--	--	81	--	327,610	52,046	8.7	43	80	--	43	80	--	60,700	--	50	32
Cesium-137	10045-97-3	pCi/g	1.1	--	4.4	--	100	6.2	6.2	59,822	143,128	1,465	59,822	143,128	2,930	2,210	--	1,430	924
Cobalt-60	10198-40-0	pCi/g	0.0084	--	3.1	--	63	3.3	1.4	177,686	198,457	13,900	177,686	198,457	27,800	6,130	--	805	805
Europium-152	14683-23-9	pCi/g	--	--	3.7	--	66	3.8	3.3	16,154	133,202	--	16,154	133,202	--	14,700	--	1,740	1,740
Europium-154	15585-10-1	pCi/g	0.033	--	4.4	--	78	4.8	3.0	4,846	39,961	--	4,846	39,961	--	12,500	--	1,610	1,610
Europium-155	14391-16-3	pCi/g	0.054	--	327	--	5,869	354	125	48,462	399,606	--	48,462	399,606	--	153,000	--	33,400	33,400
Nickel-63	13981-37-8	pCi/g	--	--	608	--	575,308	91,576	4,013	2,314	9,438	83	2,314	9,438	166	--	--	--	--
Plutonium-238	13981-16-3	pCi/g	0.0038	--	236	--	3,818	605	39	1,212	9,990	--	1,212	9,990	--	17,500	--	20,900	5,980
Plutonium-239/240	PU-239/240	pCi/g	0.025	--	203	--	3,342	539	35	1,212	9,990	--	1,212	9,990	--	12,700	--	22,300	6,270
Total beta radiostrontium (Sr-90)	SR-RAD	pCi/g	0.18	--	2.3	--	5,064	518	4.5	672	1,518	28	672	1,518	55	3,580	--	112	91
Tritium	10028-17-8	pCi/g	--	--	623	--	15,376	1,265,436	459	1,038	1,127	13	1,038	1,127	25	1,680,000	--	936	420
Uranium-233/234	U-233/234	pCi/g	1.1	--	133	--	5,808	931	1.1	17	38	1.1	17	38	1.1	51,600	--	6,370	14,200
Uranium-235	15117-96-1	pCi/g	0.11	--	16	--	295	22	0.61	17	38	0.50	17	38	0.50	27,400	--	4,360	8,060
Metals																			
Antimony	7440-36-0	mg/kg	0.13	32	--	--	365	--	32	9.3	24	5.0	8.6	22	5.0	842	842	--	146
Arsenic	7440-38-2	mg/kg	6.5	0.67	--	42,414	4.5	--	20	0.072	0.16	20	0.022	0.051	20	128	128	2,284	127
Barium	7440-39-3	mg/kg	132	16,000	--	>1,000,000	182,481	--	5,600	20,238	166,573	200	10,119	83,286	400	500	358	1,687	2,265
Boron	7440-42-8	mg/kg	3.9	16,000	--	>1,000,000	182,500	--	7,200	3,960	8,999	320	--[k]	--[k]	--	30	58	91	91
Cadmium	7440-43-9	mg/kg	0.56	40	--	101,322	821	--	14	61	500	0.81	3.0	25	0.81	9.8	20	29	624
Chromium	7440-47-3	mg/kg	18.5	120,000	--	--	>1,000,000	--	80,000	--[l]	--[l]	19	--[l]	--[l]	19	259	149	109	517
Copper	7440-50-8	mg/kg	22	3,200	--	--	36,500	--	2,960	5,701	46,910	59	80	660	22	70	58	213	579
Cr(VI)	18540-29-9	mg/kg	--	240	--	2,171	2,737	--	2.1	17	28	4.8	3.5	5.9	2.0	--	--	--	--
Lead	7439-92-1	mg/kg	10.2	250	--	--	--	--	353	182	1,499	10	26	211	10	9,090	1,700	156	1,578
Manganese	7439-96-5	mg/kg	512	11,200	--	>1,000,000	127,658	--	3,760	--[l]	--[l]	512	--[l]	--[l]	512	1,260	1,260	14,407	3,322
Mercury	7439-97-6	mg/kg	0.013	24	--	>1,000,000	274	--	24	24	200	0.33	0.15	1.2	0.33	0.3	12.5	2.0	1.6

Table 8-3. Summary of 100-K Operable Unit Human Health, Groundwater Protection, Surface Water Protection, and Ecological Soil PRGs

				Human Health PRGs						PRGs Protective of Groundwater and Surface Water						Ecological PRGs			
Analyte Name	CAS No.	Units	Hanford Site Background Concentration[a]	RI/FS Soil MTCA B—Direct Contact PRG[b]	RI/FS Residential PRG[c]	RI/FS Soil Method B Inhalation PRG[d]	RI/FS Casual Recreational User—Direct Contact PRG[e,f]	RI/FS Resident Monument Worker—Direct Contact PRG[g]	DOE/RL 96-17 Residential RAG[h]	100:0 Contaminant Source Model GWP SSL[i]	100:0 Contaminant Source Model GWP PRG[i]	DOE/RL 96-17 GWP RAG[h]	100:0 Contaminant Source Model SWP SSL[i]	100:0 Contaminant Source Model SWP PRG[i]	DOE/RL 96-17 SWP RAG[h]	Plant PRG[j]	Invertebrate PRG[j]	Avian PRG[j]	Mammal PRG[j]
Nickel	7440-02-0	mg/kg	19	1,600	--	701,458	18,249	--	1,600	--[l]	--[l]	19	--[l]	--[l]	27	38	280	361	247
Selenium	7782-49-2	mg/kg	0.78	400	--	>1,000,000	4,562	--	400	102	335	5.0	10	34	1.0	2.0	4.1	2.4	1.4
Vanadium	7440-62-2	mg/kg	85	400	--	--	4,563	--	560	--[l]	--[l]	85	--[l]	--[l]	--	89	127	43	260
Zinc	7440-66-6	mg/kg	68	24,000	--	--	273,750	--	24,000	58,262	384,000	480	1,105	9,101	68	621	8,980	856	1,037
Other Inorganics																			
Nitrate	14797-55-8	mg/kg	52	568,000	--	--	>1,000,000	--	128,000	968	1,808	1,000	968	1,808	2,000	--	--	--	340,361
Nitrite	14797-65-0	mg/kg	--	24,000	--	--	273,750	--	8,000	71	133	100	--[k]	--[k]	200	--	--	--	340,361
Sulfate	14808-79-8	mg/kg	237	--	--	--	--	--	--	5,375	10,045	25,000	--[k]	--[k]	--	--	--	--	--
Polychlorinated Biphenyls (PCBs)																			
Aroclor 1016	12674-11-2	mg/kg	--	5.6	--	>1,000,000	46	--	0.50	--[l]	--[l]	0.017	--[l]	--[l]	0.017	40	--	1.82	4.85
Aroclor 1221	11104-28-2	mg/kg	--	0.50	--	319,963	2.0	--	0.50	0.18	0.94	0.017	0.00027	0.0014	0.017	40	--	1.82	1.47
Aroclor 1232	11141-16-5	mg/kg	--	0.50	--	319,963	2.0	--	0.50	0.18	0.94	0.017	0.00027	0.0014	0.017	40	--	1.82	1.44
Aroclor 1242	53469-21-9	mg/kg	--	0.50	--	319,963	2.6	--	0.50	--[l]	--[l]	0.017	--[l]	--[l]	0.017	40	--	1.82	1.49
Aroclor 1248	12672-29-6	mg/kg	--	0.50	--	319,963	2.6	--	0.50	--[l]	--[l]	0.017	--[l]	--[l]	0.017	40	--	1.82	0.32
Aroclor 1254	11097-69-1	mg/kg	--	0.50	--	319,963	2.6	--	0.50	--[l]	--[l]	0.017	--[l]	--[l]	0.017	40	--	1.82	1.47
Aroclor 1260	11096-82-5	mg/kg	--	0.50	--	319,963	2.6	--	0.50	--[l]	--[l]	0.017	--[l]	--[l]	0.017	40	--	1.82	1.47
Other Organics																			
Ethylene glycol	107-21-1	mg/kg	--	160,000	--	>1,000,000	>1,000,000	--	160,000	--[k]	--[k]	320	--[k]	--[k]	--	--	--	--	--
Total Petroleum Hydrocarbons–Diesel Range	TPHDIESEL	mg/kg	--	2,000	--	--	--	--	200	--[k]	--[k]	200	--[k]	--[k]	200	--	200	356,382	451,807
Total petroleum hydrocarbons–motor oil (high boiling)	TPH/OILH	mg/kg	--	2,000	--	--	--	--	200	--[k]	--[k]	200	--[k]	--[k]	200	--	--	--	--

Table 8-3. Summary of 100-K Operable Unit Human Health, Groundwater Protection, Surface Water Protection, and Ecological Soil PRGs

				Human Health PRGs						PRGs Protective of Groundwater and Surface Water						Ecological PRGs			
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Note: Yellow highlighted values are the most conservative PRGs listed above the background value for each analyte, except for Arsenic, which is compared to the WAC 173-340-900, Table 740-1, Method A soil cleanup level for unrestricted Land Use, and Cr(VI) which is compared to the interim action RAG of 2.0 mg/kg.

a. Hanford Site background values for nonradionuclides: DOE/RL-92-24, Vol. 1, Rev. 4, Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes, ECF-Hanford-11-0038, Soil Background Data for Interim Use at the Hanford Site; Hanford Site background values for radionuclides: DOE/RL-96-12, Rev. 0, Hanford Site Background: Part 2, Soil Background for Radionuclides.

b. ECF-HANFORD-10-0444, Documentation of Standard Method B Contact Cleanup Levels for Unrestricted Land Use; WAC 173-340-740 (3) Method B Soil Cleanup Levels for Unrestricted Land Use; PRGs for Total Petroleum Hydrocarbons and Lead are based on MTCA Method A values.

c. ECF-HANFORD-10-0429, Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides Using the IAROD Exposure Scenario for the 100 and 300 Area Remedial Investigation/Feasibility Study (RI/FS) Report.

d. ECF-HANFORD-11-0033, Calculation of Inhalation Pathway Preliminary Remediation Goals Using Standard Method B Air Cleanup Levels for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports; WAC 173-340-750, "Cleanup Standards to Protect Air Quality."

e. ECF-HANFORD-10-0445, Documentation of Preliminary Remediation Goals (PRGs) for Nonradionuclides for the Casual Recreational User Exposure Scenario.

f. ECF-HANFORD-10-0446, Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides for the Casual Recreational User Exposure Scenario.

g. ECF-HANFORD-11-0142, Documentation of Preliminary Remediation Goals (PRGs) for Radionuclides for the Resident Monument Worker Exposure Scenario.

h. DOE/RL 96-17, Remedial Design Report/Remedial Action Work Plan for the 100 Area, Rev. 6.

i. ECF-HANFORD-11-0063, STOMP 1-D Modeling for Determination of Preliminary Remediation Goals for 100 Area Source Operable Units D, H, and K.

j. ECF-HANFORD-11-0060, Preliminary Remediation Goals (SSLs in Upland Soil for Terrestrial Ecological Receptors for 100 Area RI/FSs).

k. A GWP or SWP PRG is not calculated because a groundwater cleanup level or MCL is not available for this analyte.

l. For calculated soil activities or PRGs protective of groundwater STOMP 1-D predicts these analytes will not reach peak groundwater concentration within 10,000 years assuming that 100% of the vadose zone is contaminated.

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The following subsections describe how ecological PRGs are developed for the 100-K OU. Ecological COPECs are identified using a tiered screening process for wildlife (birds and mammals), plants, and soil invertebrates. Ecological PRGs are developed using a tiered approach, the appropriate tier is identified through answering key questions.

Ecological Exposure. Ecological PRGs for the protection of plants, soil invertebrates, and wildlife (birds and mammals) are developed using a tiered approach (*Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site* [CHPRC-00784]). The objective of a tiered approach is to refine available generic screening levels (EcoSSLs in MTCA [WAC 173-340], Table 749-3, or BCGs) as needed with additional literature-derived or site-specific information to more realistically represent Hanford Site-specific ecological risks. These tiers as applied to the development of PRGs in the 100-K RI/FS are as follows:

- Generic Screening Levels: these represent conservative literature-based screening values that are not specific to the Hanford Site-specific.
- Tier 1 PRGs: these are calculated for wildlife species found at the Hanford Site, and are intended to reflect Hanford-specific conditions using information obtained from the literature.
- Tier 2 PRGs: these are calculated for wildlife species, plants, and soil invertebrates, and better reflect Hanford-specific conditions through the use of additional Hanford site-specific information.

Selection of the appropriate tier for developing a PRG for a particular COPEC involves answering two questions:

- Whether or not the value at the lower tier is sufficient for use as a PRG.
- Whether or not progression to a higher tier would reduce uncertainties and/or increase confidence in the values used for cleanup decision.

For each COC, distinct PRGs are proposed for plants, soil invertebrates, birds, and mammals. The highest tier value available for each COPEC is proposed for use as an ecological PRG for protection of plants, soil invertebrates, and wildlife.

For plants and soil invertebrates, PRGs were selected from the following sources:

- Hanford Site-specific values from bioassays conducted in 2011 (*Tier 2 Terrestrial Plant and Invertebrate Preliminary Remediation Goals (PRGs) for Nonradionuclides for Use at the Hanford Site* [ECF-HANFORD-11-0158]),
- Published values from Ecology and the EPA,
- Hanford Site-specific values previously established for the RCBRA (DOE/RL-2007-21),
- Values recently published by Ecology for the based on Hanford-Site-specific bioassays (*Ecological Soil Screening Levels for Arsenic and Lead in the Tacoma Smelter Plume Footprint and Hanford Site Old Orchards Ecology* [Ecology Publication 11-03-006]),
- Values published by ORNL (*Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision* [ES/ER/TM-85/R3] and *Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision* [ES/ER/TM-126/R2]), and
- Site-specific background.

The final recommended PRG represented the most appropriate value, that of the highest confidence, or the lower of two values with equally high confidence.

PRGs for wildlife incorporate bioaccumulation data, both from literature sources and Hanford Site-specific studies, for the food chain present at the Hanford Site. For COPECs with insufficient Hanford-specific bioaccumulation data available (i.e., no matched soil and tissue residue data), PRGs rely exclusively on literature data. PRGs have been developed for a range of bird and wildlife feeding guilds found at the Hanford Site. For each COPEC, the lowest value among the avian feeding guilds has been proposed as the ecological PRG for birds and similarly, the lowest value form mammalian feeding guilds has been proposed for mammals.

8.1.3.3 Direct Contact Exposure PRGs for Radiological Contaminants

The PRGs for direct contact exposure to radioactive contamination for both human and ecological receptors are described in the following subsections.

Human Exposure. PRGs for radioactive wastes and radioactively contaminated soils for human receptor direct contact exposures are based on EPA radionuclide soil cleanup guidance. As established by the NCP (40 CFR 300), CERCLA cleanup actions generally should achieve a level of risk within the 10^{-4} to 10^{-6} ELCR based on the RME for an individual. Furthermore, EPA policy has noted that the upper boundary of the risk range is not a discrete line at 10^{-4} and that a specific risk estimate around 10^{-4} may be considered acceptable, if justified based on site-specific conditions (*Radiation Risk Assessment At CERCLA Sites: Q&A* [EPA 540/R/99/006, OSWER Directive 9200.4-31P]). Demonstration that the 10^{-4} to 10^{-6} residual risk-range goal has been achieved will be accomplished through final verification sampling during closeout of individual sites.

PRGs for radiological contaminants are developed using a residential exposure scenario. Residents could potentially be exposed to shallow zone soil from residential yards or groundwater from domestic wells. Residents could potentially be exposed to soil from direct external exposure, incidental soil ingestion, or inhalation of dust generated from wind or from yard maintenance activities. Residents could also be potentially exposed to radiological contaminants through food chain pathways (uptake of contamination from soil to plants and animals). From the leaching pathway, residents could potentially consume drinking water from a downgradient well, use the well for irrigation of crops and watering livestock, and consume fish raised in a pond filled with water from the downgradient well. The PRGs are calculated using a target cancer risk level of 1×10^{-4}, which is comparable with the cleanup achieved through the interim actions as established by the interim RODs. An annual dose rate of 15 mrem/yr was used in the interim action RODs as an RAO for protection of human health, which is approximately equivalent to an increased lifetime cancer risk of 3×10^{-4} for the residential exposure scenario.

Soil PRG values are developed for the direct contact and inhalation pathways combined using the resident-monument worker exposure scenario. The resident-monument worker scenario is used to represent reasonably anticipated future land use. This scenario assumes that the resident monument worker spends a fraction of the day on the waste site as his residence and spends the remaining fraction of the same day in a region as large as an individual ROD decision area and potentially as large as the entire River Corridor conducting worker activities. The PRG value represents the concentration of soil the resident monument worker is exposed to on the waste site. An adults could potentially be exposed to site contaminants in shallow vadose zone material from the waste site through direct external exposure, incidental soil ingestion, and inhalation of dust in ambient air. PRG values for individual radioisotopes are based on an ELCR of 1×10^{-4}.

Soil PRG values are also developed for the direct contact and inhalation pathways combined using the casual user exposure scenario. The casual user scenario is used to represent reasonably anticipated future land use. The casual recreational user scenario is a site-specific scenario representing occasional recreational use that focuses on activities such as walking and picnicking in areas along the Columbia River where paths and benches are likely to exist. Adults and children could potentially be exposed to site contaminants in shallow vadose zone material along the river through direct external exposure, incidental ingestion, and inhalation of dust in ambient air. PRG values for individual radioisotopes are based on an ELCR of 1×10^{-4}.

Ecological Exposure. BCGs are proposed for use as ecological PRGs for radionuclides for terrestrial plants and animals (including soil invertebrates). While these are generic screening levels, they are higher than PRGs for protection of human health. Therefore, BCGs are sufficient for use as a PRG, and refinement to higher tier values is not warranted.

8.1.3.4 Soil Concentrations Protective of Groundwater and Surface Water PRGs

Modeling was conducted to assess the fate and transport of contaminants in the vadose zone and their potential impacts on groundwater or surface water. One-dimensional numerical simulations were constructed to represent the key factors of the conceptual model for 100-K using the STOMP, Subsurface Transport Over Multiple Phases, code (PNNL-12030). Modeling with STOMP was performed with different waste distributions, recharge scenarios, and stratigraphic columns that represented the range of conditions expected within 100-K. Constituents that were persistent (i.e., do not degrade or decay in a reasonable time frame) and that had a peak concentration in groundwater occurring within 10,000 years in the future were evaluated.

PRGs were calculated for COCs, assuming that the contaminant source was uniformly distributed through the entire vadose zone thickness beneath the backfill and assuming recharge rates that represented the re-establishment of the native xerophytic plant communities on the land surface (Table 8-3). This set of assumptions is referred to as the 100:0 base case scenario, as described in Section 5.6.

8.1.3.5 Groundwater and Surface Water Cleanup Levels

A groundwater risk assessment was presented in Section 6.2 of this report. The list of COCs presented in Table 8-4 was determined in Section 6.2 by comparing the 90th percentile groundwater concentration to the DWS, federal and state water quality standards, or the "Ground Water Cleanup Standards" (WAC 173-340-720) groundwater cleanup levels corresponding to a 1×10^{-5} acceptable target risk level for carcinogens or an HQ of 1.0 for noncarcinogens. Contaminants with 90th percentile concentrations greater than or equal to the DWS, federal or state water quality standard, or "Ground Water Cleanup Standards" (WAC 173-340-720) groundwater cleanup level were retained as COCs. Those with 90th percentile concentrations less than the DWS, federal or state water quality standard, or federal MCL, federal or state water quality standard, or "Ground Water Cleanup Standards" (WAC 173-340-720) groundwater cleanup levels were not carried forward as COCs. Carbon-14, Sr-90, and trichloroethene have 90th percentile concentrations less than the DWS but have areas of localized contamination above the DWS. Based on the results of this evaluation, the list of COCs includes carbon-14, Sr-90, tritium, chromium (total), hexavalent chromium, nitrate, and trichloroethene.

Arsenic, beryllium, cadmium, cobalt, copper, lead, nitrite, and carbon tetrachloride are not identified specifically as COCs but have been detected at concentrations above an AWQS or groundwater cleanup level on an infrequent basis, and their presence cannot be associated with a specific location nor are they associated with a trend. As a result, these analytes will be analyzed using the appropriate trace method as part of the groundwater performance monitoring program.

8.1.4 Remedial Action Objectives

Under CERCLA and NCP (40 CFR 300), a soil and groundwater remedies must be protective of HHE, and meet ARARs (or satisfy criteria for an ARAR to be waived). RAOs must be developed to address COPCs, media of concern, potential receptors, and exposure pathways. RAOs are general descriptions of what a cleanup under CERCLA is expected to accomplish. They are narrative statements that define the extent to which waste sites require cleanup to protect HHE.

The RAOs were based on existing River Corridor regulatory documents (e.g., interim action RODs) and were expanded to cover gaps when integrating all media and resources for an area. Media-specific RAOs were developed for groundwater (RAO 1), surface water (RAO 2), and soil (RAOs 3 through 5). The combined RAO list is as follows:

RAO 1. Prevent unacceptable risk to human health from ingestion of and incidental exposure to groundwater containing contaminant concentrations above federal and state standards and risk-based thresholds.

RAO 2. Prevent unacceptable risk to human health and ecological exposure to surface water containing contaminant concentrations above federal and state standards and risk-based thresholds.

RAO 3. Prevent unacceptable risk from contaminants migrating and/or leaching through soil that will result in groundwater concentrations that exceed standards and risk based thresholds for protection of surface water and groundwater.

RAO 4. Prevent unacceptable risk to human health and ecological receptors from exposure to the upper 4.6 m (15 ft) of soil contaminated with nonradiological constituents at concentrations above the unrestricted land use criteria for human health (provided in MTCA B) or soil contaminant levels for ecological receptors.

RAO 5. Prevent unacceptable risk to human health and ecological receptors from exposure to upper 4.6 m (15 ft) of soils and to structures and debris contaminated with radiological constituents.

- Prevent exposure to radiological constituents at concentrations at or above a dose rate limit that causes an excess cancer lifetime risk threshold of 10^{-6} to 10^{-4} above background for the rural residential exposure scenario.
- Protect ecological receptors based on a dose rate limit of 0.1 rad/day for terrestrial wildlife populations, which is a TBC criterion.

For the purpose of this FS, RAO 1 is satisfied when the following objectives are met:

- Groundwater concentrations for nonradiological COCs are reduced to levels that would not exceed federal drinking water MCLs and concentrations are reduced to levels that would not exceed the "Human Health Risk Assessment Procedures" (WAC 173-340-708).
- Groundwater concentrations for radiological COCs are reduced to levels that would not exceed federal drinking water MCLs.

For the purpose of this FS, RAO 2 is satisfied when the following objectives are met:

- Groundwater concentrations for nonradiological COCs are reduced to levels that would not exceed state and federal water quality standards at the point of compliance where hazardous substances are released to the Columbia River.

Table 8-4. 100-KR-4 Groundwater OU Cleanup Levels

Contaminant	Units	90th Percentile Concentration	Dose Based on 90th Percentile Concentration (mrem/yr)	ELCR Based on 90th Percentile Concentration	HI Based on 90th Percentile Concentration	DWS	WAC 173-340-720 Cleanup Levels		AWQC		WAC 173-201A	40 CFR 131 Water Quality Standard		100-KR-4 Groundwater OU Cleanup Level[a]
							Noncarcinogens at HQ = 1	Carcinogens at 1 × 10-5 Risk Level	Freshwater CMC (acute)	Freshwater CCC (chronic)	Freshwater CCC (chronic)	Freshwater CMC (acute)	Freshwater CCC (chronic)	
COCs—for Remedial Technology Screening and Alternative Development														
Carbon-14	pCi/L	1,470	3.0	5.9×10^{-5}	--	2,000	--	--	--	--	--	--	--	2,000
Sr-90	pCi/L	7.3	3.6	8.5×10^{-6}	--	8	--	--	--	--	--	--	--	8
Tritium	pCi/L	34,500	6.8	1.9×10^{-5}	--	20,000	--	--	--	--	--	--	--	20,000
Chromium	µg/L	121	--		<0.01	100	24,000	--	570	65	156	550	180	65
Cr(VI)[b]	µg/L	117	--		2.4	--	48	--	16	11	10	15	10	10
Nitrate[c]	µg/L	71,700	--		0.63	45,000	113,600	--	--	--	--	--	--	45,000
Trichloroethene	µg/L	3.8	--	7.8×10^{-6}	--	5	--	4.9	--	--	--	--	--	4.9

Notes: DWSs from 40 CFR 141, "National Primary Drinking Water Regulations."

a. The final cleanup levels achieved at the conclusion of the RA will correspond to an ELCR less than 1×10^{-6} and HI of less than 1.

b. There is no DWS specific to Cr(VI).

c. Nitrate may be expressed as nitrate (NO_3) or as nitrate-nitrogen (NO_3-N). The DWS for NO_3-N is 10,000 µg/L and 45,000 µg/L for NO_3^-.

COC = contaminant of concern
COPC = contaminant of potential concern
DWS = drinking water standard
ELCR = excess lifetime cancer risk
EPA = U.S. Environmental Protection Agency
HI = hazard index
N/A = not applicable
OU = operable unit
RA = remedial action

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- Groundwater concentrations for radiological COCs are reduced to levels that would not exceed federal drinking water MCLs at the point of compliance where hazardous substances are released to the Columbia River.

For the purpose of this FS, RAO 3 is satisfied when the following objectives are met:

- Fate and transport modeling demonstrates that nonradiological and radiological contaminant concentrations within the soil column would not impact groundwater above drinking water MCLs.
- Fate and transport modeling demonstrates that nonradiological and radiological contaminant concentrations within the soil column would not impact surface water above state and federal water quality standards and TBC criteria for aquatic organisms from radionuclides.

For the purpose of this FS, RAO 4 is satisfied when the following objectives are met:

- Prevent or mitigate direct contact exposure by human receptors in the top 4.6 m (15 ft) of soil from multiple nonradiological COCs that would exceed an HI of 1 or the total excess cancer risk would not exceed one hundred thousand (1×10^{-5}) based on "Use of Method B" (WAC 173-340-705 (5)).
- Prevent or mitigate direct contact exposure by ecological receptors in the top 4.6 m (15 ft) of soil from individual nonradiological COCs that would exceed a noncancer HQ of 1 or a total HI of 1.

For the purpose of this FS, RAO 5 is satisfied when the following objectives are met:

- Prevent or mitigate direct contact exposure by human receptors in the top 4.6 m (15 ft) of soil from individual radiological COCs that would not exceed an individual or cumulative ELCR of 1×10^{-4}.
- Prevent or mitigate direct contact exposure to radiological COCs by terrestrial receptors (wildlife, plants, and biota) in the top 4.6 m (15 ft) of soil that would exceed a dose rate of 0.1 rad/day for animals and 1 rad/day for plants.

8.2 General Response Actions

GRAs consistent with RAOs were identified for 100-K. GRAs are basic actions that might be undertaken to remediate a site, and are assembled based on nature and extent of contamination, as presented in the RI. For each GRA, several possible remedial technologies may exist, which can be further divided into a number of process options. This section discusses the remedial technology selection process.

Remedial technologies are selected for evaluation based on their potential ability to mitigate the identified risks or achieve compliance with ARARs for the remedial action. Technologies and process options selected for evaluation are assessed with respect to their implementability, effectiveness, and relative cost in accordance with CERCLA RI/FS Guidance (EPA/540/G-89/004) and "Remedial Investigation/ Feasibility Study and Selection of Remedy" (40 CFR 300.430(e)). The selected final remedy must comply with ARARs and protect HHE.

CERCLA RI/FS Guidance (EPA/540/G-89/004) suggests development and evaluation of a range of responses, including a no action alternative, to ensure identification and selection of an appropriate remedy. The technology screening process consists of the following steps:

- Identify GRAs that may meet RAOs, either individually or in combination with other GRAs
- Identify, screen, and evaluate remedial technology types for each GRA
- Select representative process option(s)

Following the technology screening, representative process options are assembled into remedial alternatives (presented in Chapter 9) that are evaluated further in the detailed and comparative analyses of alternatives (presented in Chapter 10).

GRAs identified for waste sites in 100-K include the following:

- No action
- Institutional controls
- Removal, ex situ treatment, and disposal
- In situ treatment
- Containment

GRAs identified for contaminated groundwater in 100-K include the following:

- No action
- Institutional controls
- Pump-and-treat (collection, ex situ treatment, and discharge)
- In situ treatment
- Containment

8.2.1 Target Remediation Areas

In accordance with CERCLA RI/FS Guidance (EPA/540/G-89/004), the FS is required to determine the areas or volumes of media to which GRAs might be applied. This section summarizes the waste sites and groundwater areas that will be evaluated in the FS, based on the PRGs and findings of the HHRA, ERA, and RI presented in the preceding chapters.

8.2.1.1 Waste Sites

As discussed in Chapter 1, the determination of which areas of 100-K are waste sites has been performed following specific procedures defined in the Tri-Party Agreement documents (Ecology et al., 1989a; and *Hanford Federal Facility Agreement and Consent Order Action Plan*, Ecology et al., 1989b). The areas that have been suspected waste sites are summarized and tracked in the WIDS database. As information is learned about the sites, or as they are remediated and confirmation data collected, they are classified or reclassified, depending on their status. As discussed in more detail in Chapter 1, of the 165 sites (including subsites) in 100-K, 29 were classified or reclassified as "Rejected," "Not Accepted," or "Closed Out." These sites were not considered further in this RI/FS. Six additional waste sites without verification data were not considered further in this RI/FS because they were tanks that have been removed. In addition, the 105-KW and 105-KE Reactors at 100-K (Waste Sites 118-KE-1 and 118-KW-1) are not discussed in the FS. In September 1993, DOE issued a NEPA ROD (58 FR 48509) that established a path forward for the Hanford reactors. An "Amended Record of Decision for the Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, WA" (75 FR 43158) was issued in July 2010. Additional information developed through the risk assessments in Chapters 5, 6 and 7 do not change the above determinations. Figure 8-1 presents the location of the waste sites that are not evaluated in the FS. Chapter 1 presents additional information on these waste sites not carried forward.

The remaining 128 waste sites evaluated in the RI process are discussed in Chapters 4 through 7. Sixteen waste sites have undergone interim action, have verification data, and could be quantitatively evaluated against the PRGs, as discussed in Chapters 5, 6, and 7. Those sites with data that indicate no unacceptable risk to human health or the environment will not be discussed further in this RI/FS. Of the 16 evaluated

sites, 9 sites (128-K-1, 100-K-29, 100-K-78, 100-K-85, 116-KE-4, 116-KE-5, 116-KW-3, 116-KW-4, and 100-K-55:1) indicated no risk exceedances, with the analysis presented in Chapters 5, 6, and 7.

Of the 16 sites evaluated, 3 sites (116-K-1, 116-K-2, and 100-K-56:1) were shown to have concentrations of COPCs above the upper range of the regulatory risk target threshold of 1×10^{-4}. Contamination was detected in deep zone soil samples collected from depths greater than 4.6 m (15 ft) bgs and, as a result, there is no direct exposure pathway for reasonably anticipated future land use. Rough order magnitude cost for excavating and removing the contaminants is $500 million. However, the contaminants at these sites will decay within 10 to 140 years and, during this time, DOE or the federal government will maintain controls on the land to prevent exposure to these materials. For this reason, these sites are not carried forward into the FS.

The remaining 116 waste sites are carried into the FS and are evaluated further in Chapter 9 for remedial alternatives. The 116 waste sites include 4 waste sites completed under interim actions that had exceedances to the ecological risk PRG for mercury; 46 waste sites that are currently or anticipated to be remediated under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039), or are anticipated to be by the time the final ROD is signed (these are termed "Pre-ROD To-Go Sites"); and 66 waste sites for which remedial actions will not be started until after the final ROD is signed (these are termed "Post-ROD To-Go Sites"). Table 8-5 summarizes the 165 waste sites evaluated through the RI/FS and which sites are, and are not, carried forward into the FS as discussed previously.

Four of the 16 waste sites that have undergone interim action and with verification data did not achieve the ecological risk PRG for mercury in shallow samples. The four waste sites are 100-K-30, 100-K-31, 100-K-32, and 100-K-33. Figure 8-2 presents location of the waste sites carried forward due to exceedances of ecological risk criteria. Additional information on these exceedances is presented in Chapter 7.

Following completion of the interim actions of the 46 Pre-ROD To-Go sites, the verification data for these sites will be evaluated against final RAGs. The FS treats these sites as no further action because interim action RAGs are as protective of HHE as the PRGs proposed in this RI/FS, except for cesium-137 and strontium-90 for radionuclides; arsenic and boron for metals; sulfate for inorganics; and Aroclor 1221 and Aroclor 1232 for PCBs. Sites that do not meet the PRGs will be evaluated depending on the risk drivers that remain and a remedy will be selected from the final ROD. Based on LFI data and process knowledge, seven of the 46 Pre-ROD To-Go sites (100-K-18, 100-K-34, 100-K-42, 100-K-63, 120-KW-1, 120-KW-2, and 120-KW-5) are identified to have one or more of the constituents where the interim action RAG exceeds the proposed PRGs. The selected remedial actions will be considered minor modifications to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL fact sheet, with public notification. These waste sites will be added to the appropriate RD/RAWP for implementation of the remedial action.

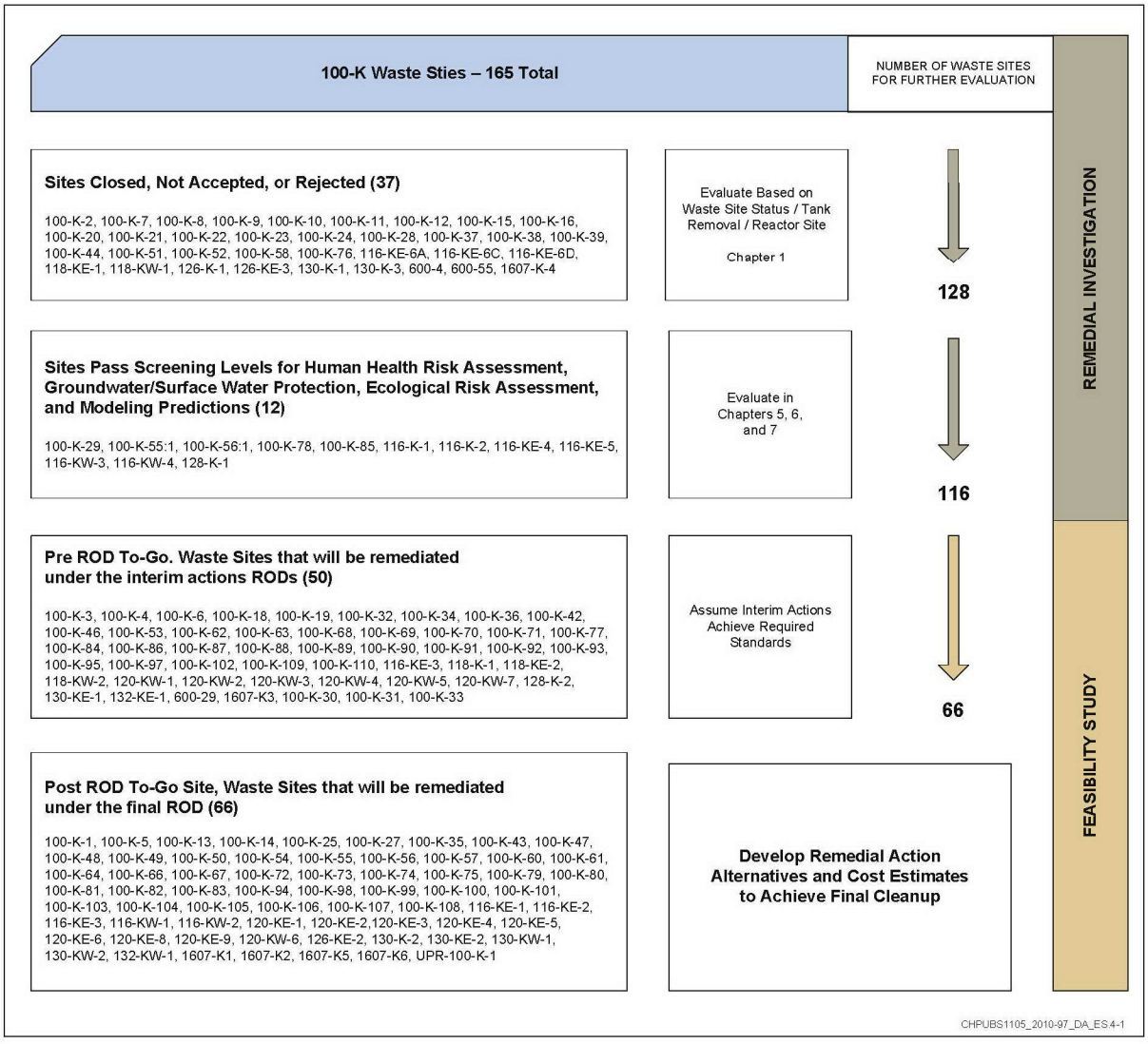
The 66 Post-ROD To-Go Sites will be managed using a decision logic approach, as discussed further in Section 9.1.1. Risk drivers have not been quantitatively determined for these sites through a risk assessment evaluation. For the purpose of alternatives evaluation for this FS, a preliminary evaluation of the risk drivers has been made based on knowledge of the process that was performed at the sites and remediation results at similar sites in the River Corridor. The remedial approaches for the major risk drivers are developed for each alternative and presented in Chapter 9. The specific remedial approach will be determined during the remedial design process following the final ROD. The remedial approach will be based on the risk drivers that are estimated either through a detailed evaluation of the process history or from design sampling.

The location of Pre- and Post-ROD To-Go waste sites at 100-K is depicted in Figures 8-3 and 8-4. Figure 8-3 illustrates the location of Pre-ROD To-Go sites, and Figure 8-4, the location of Post-ROD To-Go sites.

8.2.1.2 Groundwater

Areas exceeding groundwater PRGs are illustrated for Cr(VI) in Figures 4-26, 4-27, and 4-28. Total chromium follows the same pattern as Cr(VI). Nitrate, tritium, carbon-14, and Sr-90 are shown in Figures 4-45, 4-54, 4-63, and 4-70, respectively.

Table 8-5. Waste Site Evaluation for 100-K RI/FS



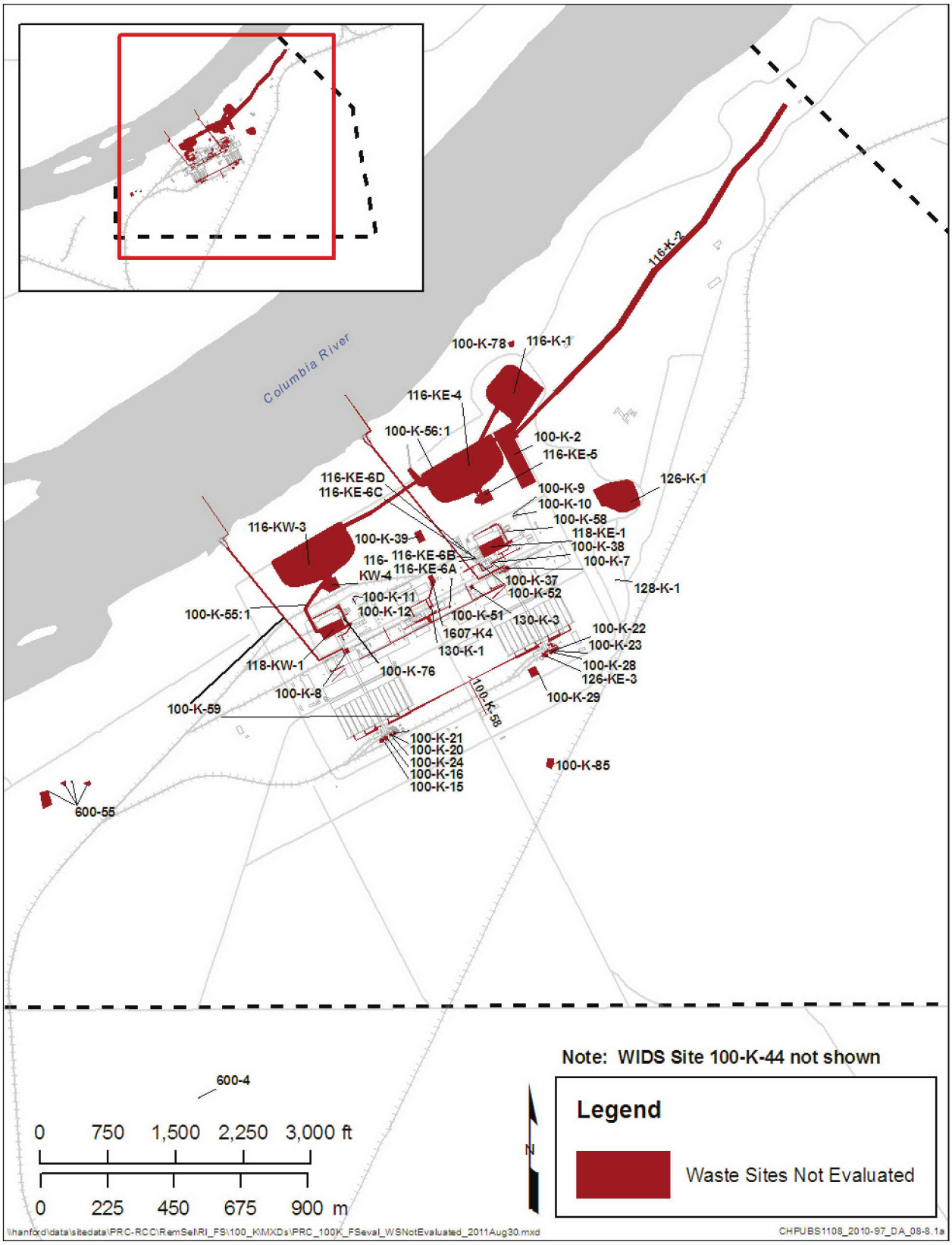


Figure 8-1. Waste Sites Not Evaluated in the FS

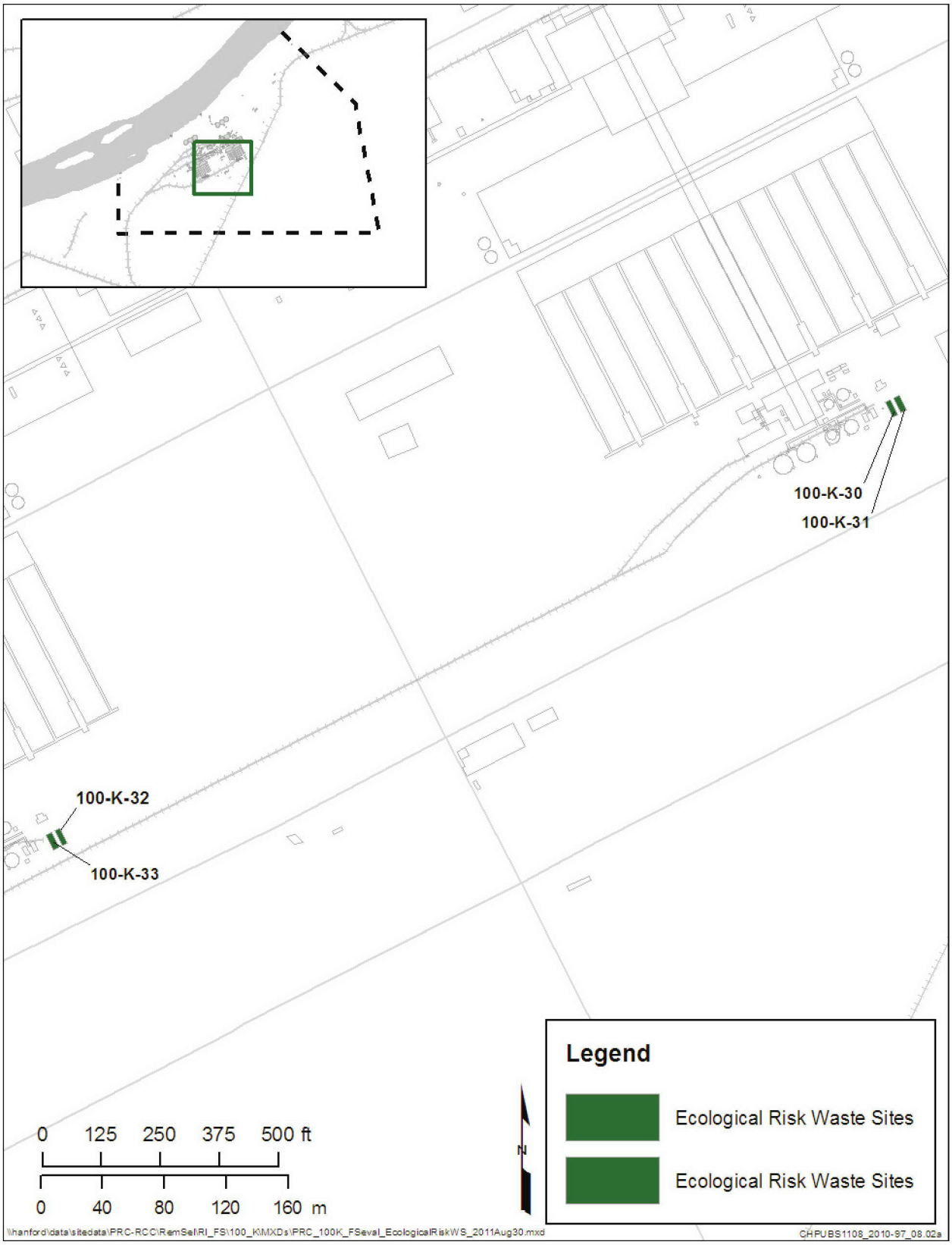


Figure 8-2. Interim Closed Waste Sites with Ecological Risk

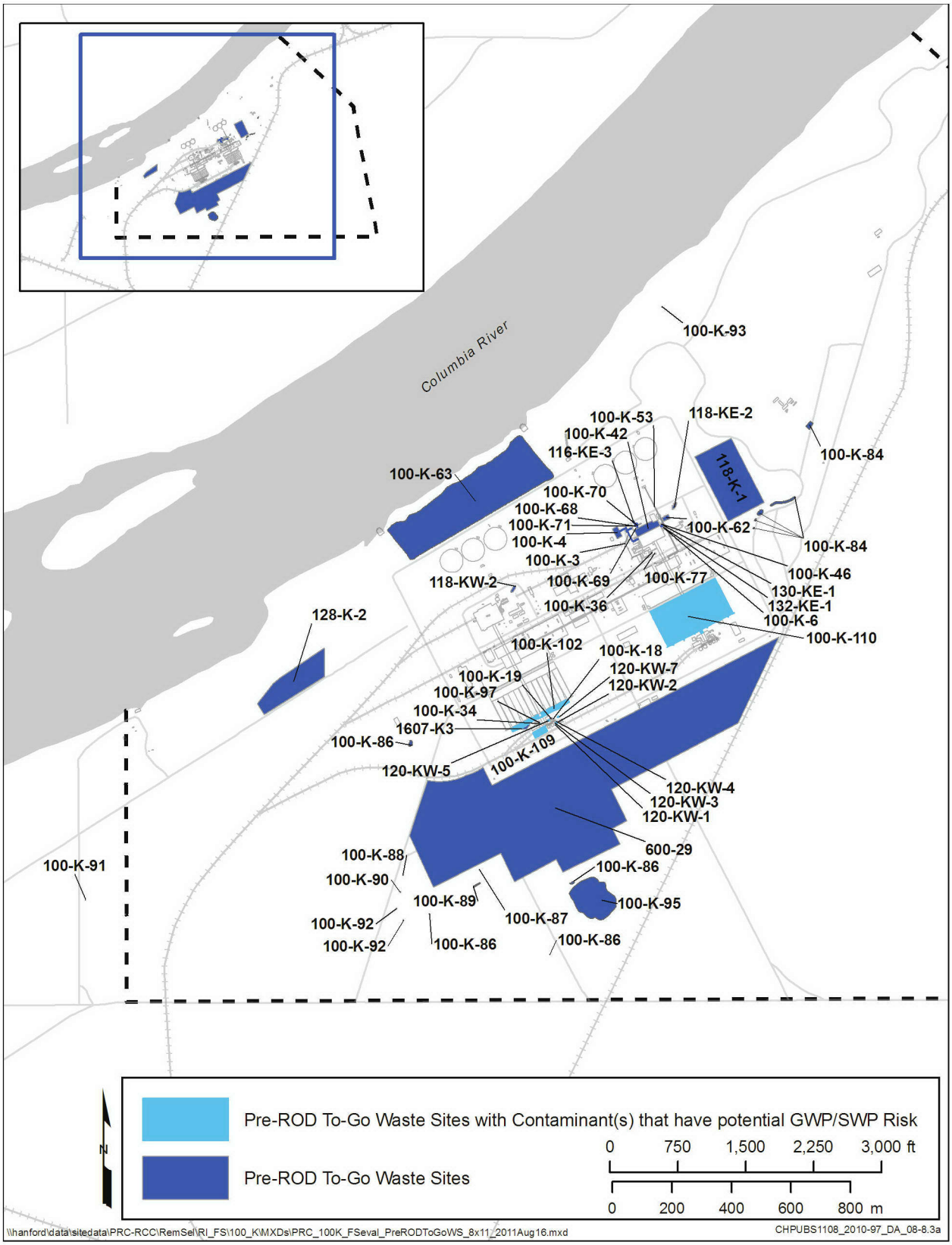


Figure 8-3. Pre-ROD To-Go Waste Sites

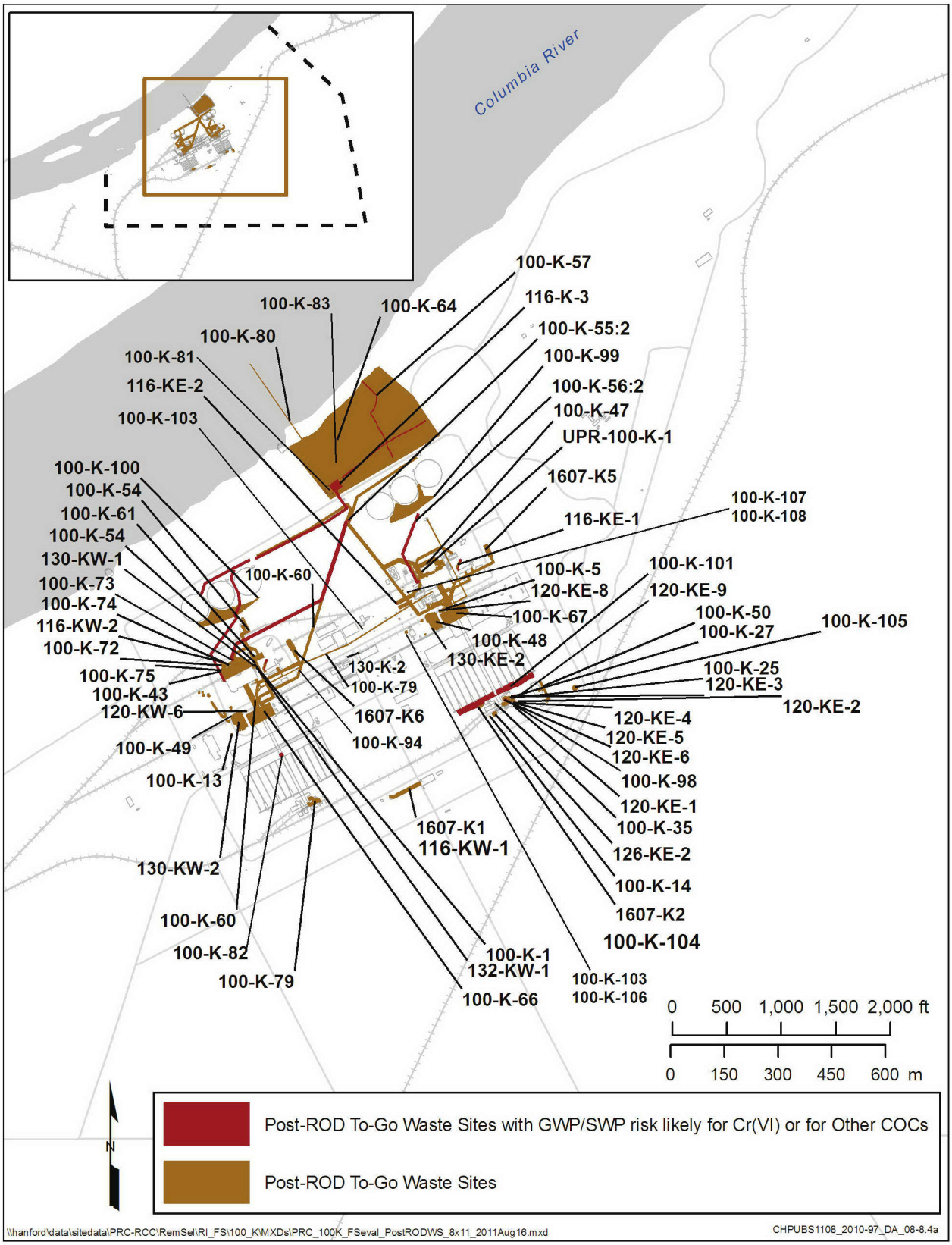


Figure 8-4. Post-ROD To-Go Waste Sites

8.2.1.3 Riparian Soils

Carbon-14 was detected in a riparian soil sample at a concentration greater than both human health and ecological PRGs. Carbon-14 was detected at sampling location "RCBRA 2CRIP," from the RCBRA, located near the 116-K-2 trench. In addition, Carbon-14 was detected in one fish species (Bridgelip Sucker) and identified as a COPC in the CRC. Based on current information, response actions taken for soil and groundwater at 100-K will address COPCs identified in the Columbia River.

8.3 Identification and Screening of Technology Types and Process Options

This section presents remedial technologies and process options that are subsets of the selected GRAs, and that may potentially meet RAOs for contaminated waste sites and groundwater at 100-K. The potential remedial technologies are evaluated or screened for implementability; effectiveness in eliminating, reducing, or controlling risks to HHE; and relative cost. The identified technologies are then combined into a range of remedial alternatives in Chapter 9.

8.3.1 Identification and Screening of Technologies

The following text summarizes the technologies and process options considered as part of this evaluation. Although no action and ICs are not considered remedial technologies, they are important response actions to be considered as part of the remediation approach and are discussed herein.

Tables 8-6 and 8-7 present the identification and screening of technologies and remedial process options for 100-K in tabular form. Table 8-6 presents technologies for waste site treatment for radionuclides, Cr(VI) and other metals, and organic compounds. Table 8-7 presents GRAs and process options for groundwater impacted with Cr(VI) and other COPCs.

8.3.1.1 Identification and Screening of Technologies for Waste Site Contamination

No Action. The no action response entails any further action to remove, remediate, monitor, or restrict access to contaminated sites. Source areas and residual soil contaminants in the waste sites would be left untreated and current monitoring activities would cease. The CERCLA RI/FS Guidance (EPA/540/G-89/004) and the NCP (40 CFR 300) require this response to remain in the FS process, where it serves as a baseline against which to compare all other alternatives. Although generally considered unacceptable as a remedial alternative, no action may be an appropriate alternative component where interim actions have been completed as dictated by the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) (as presented in Table 1-2) and verification sampling data suggest the waste site does not present risks to HHE.

Institutional Controls. ICs are nonengineered instruments, such as administrative and/or legal controls, that help to minimize the potential for human exposure to contamination and/or protect the integrity of a remedy. ICs work by limiting land or resource use and/or by providing information that helps modify or guide human behavior at the site. The requirements for ICs are evaluated in the FS and recorded in CERCLA decision documents. The decision document is part of the Administrative Record for the selection of remedial actions.

As they are identified, DOE will apply and implement ICs in an integrated manner such that mechanisms in place will ensure controls are effective, implemented as planned, properly maintained, inventoried, periodically re-evaluated, and modified as necessary to reflect changes in conditions, needs, or technological advancements. DOE will maintain the ICs as long as necessary to perform their intended protective purposes and seek sufficient funds ("Use of Institutional Controls" [DOE P 454.1]).

The sitewide IC Plan (DOE/RL-2001-41) developed by DOE-RL describes how DOE-RL will implement and maintain OU-specific ICs specified in CERCLA decision documents. The sitewide IC Plan is updated based on final CERCLA decision documents within 180 days after issuance of the final decision document. The

sitewide IC Plan addresses the elements of *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (EPA 540-F-00-005). In addition, ICs are reviewed during the CERCLA five-year review process.

Table 8-8 identifies DOE categories of ICs and the examples of ICs currently in use at Hanford, including whether the IC will be retained for further evaluation in the FS.

In September 1993, DOE issued a NEPA ROD (58 FR 48509) that established a path forward for the Hanford reactors. An "Amended Record of Decision for the Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, WA" (75 FR 43158) was issued in July 2010. The NEPA ROD provided options for immediate dismantlement for reactor decommissioning, and one-piece disposal of the reactor cores after an ISS period of approximately 75 years, which allowed for decay of the radionuclide that presented the major risk for site workers. As detailed in the June 2010 *Cleanup Completion Framework* (DOE/RL-2009-10), the NEPA ROD (58 FR 48509) indicated DOE's intent to complete these decommissioning actions consistent with the proposed cleanup schedule for remedial actions, which includes the KW and KE Reactors at 100-K. Until reactor removal is complete, DOE will continue to conduct routine maintenance, surveillance, and radiological monitoring activities to ensure continued protection of HHE during the ISS period. Waste sites that cannot be remediated because of their location near reactors will be capped and/or safely contained until they can be accessed after the reactors have been dispositioned. Following reactor removal, remediation of any remaining waste sites will occur.

Removal. Removal technologies include excavation of contaminated materials. Excavation of sites with contaminated soil follows the observational approach, allowing waste characterization and treatment to occur as excavation proceeds. Excavation must be coupled with analytical assessment, dust control, efficient transportation, treatment as required, and disposal. Excavated soil is segregated (either by an automated or laboratory based approach) to determine disposal or treatment requirements.

Excavation can use conventional equipment and methods, including excavators, bulldozers, and wheeled loaders. Earthmoving equipment removes clean overburden, which can be staged for later use in backfilling, and contaminated media to stage for appropriate waste management activities. Contaminated media typically are removed in lifts (layers of uniform thickness) to allow screening for contamination. Field screening supports waste designation and helps determine achievement of remedial goals.

Process options under the removal GRA include standard (shallow) and deep excavation (greater than 6 m [20 ft] depths). At excavations exceeding 6 m (20 ft) bgs, implementation requires technologies that are more complex, such as large layback for open pit type excavation or use of shoring. Given the increased complexity, deep excavations have an increased cost compared to shallow.

None of the contamination in 100-K is expected to be in high enough concentrations that the excavation efforts are considered nuclear activities. Consequently, standard excavation and personal protection practices are acceptable.

Ex Situ Treatment. Following excavation, soil can be treated with ex situ methods to reduce contaminant concentrations or toxicity, remove contaminants (transfer to different media), or reduce volume, and allow for less costly disposal. Treatment can be achieved by applying physical, chemical, biological, or thermal techniques.

For this effort, ex situ treatment does not include treatment performed for ultimate disposal, such as at ERDF. Treatment performed as required to meet disposal restrictions is included in the disposal process option, and assumed part of the "disposal to onsite/offsite landfill" process options. This ex situ treatment process option only covers technologies that could be used to treat the soil so part or all of the soil volume could be backfilled at the location from which it was removed.

Ex situ treatment process options include the following:

- Ex situ solidification/stabilization
- Soil washing
- Ex situ vitrification
- Ex situ thermal desorption

Disposal. Following excavation, contaminated soil needs to be properly disposed, either at the onsite or offsite landfill, or by backfilling treated soil. Prior to implementation of a disposal option, waste acceptance criteria must be evaluated. Treatment required to meet ERDF waste acceptance criteria is evaluated under the disposal GRA under the onsite landfill disposal process option.

Backfilling treated soil involves excavation and ex situ treatment, followed by onsite disposal. Prior to implementation of this disposal option, treated soil will need to be compared to PRG criteria to verify backfilling is appropriate.

Disposal at the onsite landfill includes transport of excavated soil to EDRF. The waste acceptance criteria for ERDF are based on regulatory requirements (e.g., RCRA LDRs) and risk-based considerations for long-term protection of HHE. If waste cannot be accepted at ERDF, a suitable offsite disposal facility will be used. Part of this process option is treatment required to meet ERDF waste acceptance criteria. Therefore, an ex situ treatment process option does not need to be evaluated if excavation and disposal at ERDF are selected as remedial options.

In Situ Treatment. In situ treatment consists of actions that treat contamination in place using physical, chemical, or biological treatment techniques. Advantages of in situ treatment include significantly reduced exposure to site workers relative to removal of contaminated media for disposal or ex situ treatment. For this evaluation, in situ process options were subdivided by technologies that require delivery of a reagent to the subsurface for treatment, and those that implement another technique. Within actions requiring delivery of a reagent, technologies can be further subdivided by the reagent approach (physical, chemical, or biological), and the method for delivering the reagent to the subsurface. For treatment of contaminated soil in 100-K, the following in situ remedial technologies and process options were evaluated:

- Reagent Approach:
  - In situ solidification
  - In situ stabilization/sequestration
  - Chemical reduction
  - In situ chemical oxidation (ISCO)
  - Surface bioremediation (land farming)
  - Biological reduction
  - Combined chemical/biological reduction
  - Gaseous ammonia injection
  - Bioventing
  - Reductive dechlorination using zero-valent metals or bioremediation of PCBs

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Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
No Action	No Action	No Action	All	Shallow/ Deep	No further actions to address contamination. Source areas and residual contaminants in vadose zone are left untreated.	Low/High No remedial actions are taken, but effectiveness could be high if risk is previously mitigated.	High No administrative or technical implementability challenges are associated with implementation of this option, since no actions are required.	Low No associated cost.	Low No associated cost.	Little impacts.	Retained	Retained per the NCP (40 CFR 300).
Removal	Excavation	Standard Excavation	All	Shallow	Shallow soil is removed using conventional construction equipment. Excavation limited to approximately 6 m [20 ft] bgs. Excavated soil is segregated (automated or laboratory based) to determine disposal or treatment requirements.	High Shallow contaminated soil removed.	High Shallow excavation is typically straightforward. A permit is required for excavation in the 100, 200, and 300 Areas and the Hanford Reach National Monument.	Moderate/High	Low No associated cost.	Waste generation if excavated soil is disposed of, GHG and energy for excavation equipment.	Retained	
		Deep Excavation	All	Shallow/ Deep	Soil is removed to deeper depths. Deep excavation would require implementation of more complex technologies, for example, large layback for open pit type excavation or, alternatively, use of shoring. Excavated soil is segregated (automated or laboratory based) to determine disposal or treatment requirements.	High Locations of the deep contaminated soil will be difficult to identify, meaning large areas would have to be excavated to depth to ensure that the deep sources were removed.	Moderate Has been performed at Hanford using laybacks. Shoring may be difficult with cobbles and boulders. Increased safety challenges with very deep excavations. A permit is required for excavation in the 100, 200, and 300 Areas and the Hanford Reach National Monument.	High	Low No associated cost.	Waste generation if excavated soil is disposed of, GHG and energy for excavation equipment.	Retained	
Ex Situ Treatment and Processing[e]	Ex Situ Treatment and Processing[e]	Ex Situ Solidification/ Stabilization	Mobile to semimobile contaminants (Cr(VI), Sr-90, uranium)	Depends on excavation method	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization). Agents include soluble phosphates, pozzolan/Portland cement, and polyethylene extrusion. The stabilized mass is returned to its original location and capped to shed water and prevent weathering. The location is engineered to withstand seismic activity.	Low/Moderate Effective at immobilizing contaminants in excavated material. However, the stabilized mass must be protected from weathering and seismic activity for long-term durability.	Moderate Well-established technology. Site-specific studies need to be completed to evaluate equipment required and appropriate solidification/ stabilization agents. Mechanically intense process; additional handling of the excavated soil could increase the potential for contaminant exposure, which could pose risk to workers.	High	Low	GHG and energy for production and delivery of reagent used, and for transport and mixing.	Not Retained	Screened out in favor of the safer alternative of disposal in ERDF, a centralized facility engineered to protect against weathering and seismic activity.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
Ex Situ Treatment and Processing[e] (cont.)	Ex Situ Treatment and Processing[d] (cont.)	Soil Washing	Cr(VI), nitrate, possibly uranium	Depends on excavation method	Consists of size separation of highly contaminated soil fractions (fines) from minimally contaminated soil fractions (coarse), followed by mechanical abrasion or washing to remove surface contamination. Final contaminated fraction is typically treated by technologies such as solidification/stabilization prior to onsite or offsite disposal.	Low/Moderate Effectiveness is driven by the binding processes that exist between the contaminants and the soil particles (adsorbed or precipitated). Pilot testing at Hanford suggests a number of contaminants strongly sorb to all sizes of soil. Pilot test is necessary for Cr(VI).	Low/Moderate Mechanically intense. Conventional aggregate washing and screening technology is used to separate soil particles by size fraction. Contaminated soils and water are disposed of, or further treated. Soils that meet cleanup criteria (remediated coarse soil) can be returned to the site. Rinseate will require treatment prior to disposal.	Moderate/High	Low No associated cost.	Additional resource impact (water used in process), GHG, and energy for process and additional treatment of contaminated fines and water.	Not Retained	Mechanically intense. Not proven for conditions similar to the Hanford Site.
		Ex Situ Vitrification	All	Depends on excavation method	Thermal treatment process that converts excavated soil and other materials into stable crystalline substances. The thermal treatment process is typically performed inside a chamber using plasma torches or electric arc furnaces to melt the soil. Organic contaminants are typically destroyed during the process by pyrolysis, while metals and radionuclides are retained in the molten soil.	High Heavy metals and radionuclides are incorporated into the glass structure, which is generally resistant to leaching.	Low High complexity of equipment required. Ex situ joule heating vitrification uses furnaces that have evolved from the glass industry. Implementability is higher than for in situ application, given use of proven technology (furnaces).	High	Low No associated cost.	GHG and energy for heat generation. High energy requirements to sustain required heat.	Not Retained	Complex technology, safety concerns with implementation.
		Ex Situ Thermal Desorption	Organics	Depends on excavation method	Direct application of heat to soil piles to increase the temperature of soil and destroy or volatilize organic compounds. A vapor cover and vacuum system are needed to transport volatilized water and organics to the gas treatment system. Also completed using mechanical systems (e.g., rotary drum).	High Technology can achieve rapid removal/destruction of a mix of volatile and semivolatile organics at low residual levels.	Low Equipment readily available and commonly used, but can be mechanically complex.	High	Low No associated cost.	GHG and energy for production of heat vapor treatment.	Not Retained	Complex and challenging to implement.
Disposal	Disposal	Backfill Treated Soil	All	Shallow/ Deep	Excavation and ex situ treatment followed by onsite disposal (backfill).	High Contaminated material has been treated by ex situ technologies.	High Excavated and treated soil will need to be compared to cleanup criteria to verify backfill is appropriate.	Low/Moderate	Low No associated cost.	GHG and energy for backfill.	Not Retained	No ex situ treatment technologies are retained.
		Disposal to ERDF	All	Shallow/ Deep	Disposal of excavated soil at onsite landfill (ERDF). Treatment performed at the facility as required to meet land disposal restrictions.	High	High Implementability limited by COPC concentrations and onsite landfill requirements.	Low/Moderate	Low No associated cost.	GHG and energy for transport.	Retained	
		Offsite Landfill	All	All	Disposal of excavated soil at offsite landfill.	High Contaminated material has been treated by ex situ technologies.	High Implementability limited by COPC concentrations and offsite landfill requirements.	Moderate	Low No associated cost.	GHG and energy for transport.	Not Retained	Assuming disposal of ERDF is adequate and reliable for impacted media at 100-K.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology		Process Option		COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
In Situ Treatment	In Situ Treatment via Reagent	Reagent Approach	Physical/ Chemical/ Biological	In Situ Solidification	Mobile COCs to semimobile Radionuclides, Other Metals, and Organics	Shallow	Contaminants are physically bound or enclosed within a stabilized mass. Agents include pozzolan/Portland cement and polyethylene extrusion. With organics, typically only used for free phase to reduce mobility.	Low/Moderate There is debate about the long-term durability of the monolith and whether it is, in fact, permanent. Potential for exposure still exists if waste is shallow.	Moderate Depends on delivery method.	High	Low Assuming monolith is permanent.	GHG and energy for production and delivery of substrate/reagent.	Not Retained	Potential for incomplete contact of grout in the targeted treatment zone, and uncertainty regarding the durability of shallow soil encapsulation.
				In Situ Stabilization/ Sequestration	Radionuclides and Metals	Shallow/ Deep	Chemical reactions are induced between the stabilizing agent and contaminant to reduce mobility. Agents include soluble phosphates and polyphosphates.	Low Potential for direct exposure still exists if waste is shallow.	Low/Moderate Depends on delivery method.	Moderate	Low Assuming stabilized mass is permanent.	GHG and energy for production and delivery of substrate/reagent.	Not Retained	Uncertainty with uniform phosphate delivery and adequacy in removing risk associated with Sr-90. Not retained in favor of excavation.
In Situ Treatment (cont.)	In Situ Treatment via Reagent (cont.)	Reagent Approach (cont.)	Physical/ Chemical/ Biological (cont.)	Chemical Reduction	Cr(VI) uranium	Shallow/ Deep	Chemical reductant (e.g., calcium polysulfide, dithionite, hydrogen sulfide gas, ferrous sulfate, zero-valent iron) is applied to the subsurface to treat contaminants within vadose zone. Chemical can be combined with solidification/ stabilization or other treatment mechanisms.	Low/Moderate Chemical reductants are instantly reactive, which requires overloading to maintain reactive strength at depth. Reduction of uranium is potentially reversible.	Moderate Depends on delivery method. Localized temporary generation of secondary byproducts may occur. May temporarily mobilize COPCs toward groundwater. Handling chemical reductants is an H&S concern.	Moderate	Moderate/High	GHG and energy for production and delivery of chemical agent.	Not Retained	More challenging to implement and costly as compared to biological reduction.
				ISCO	Organics	Shallow/ Deep	Subsurface delivery of chemical oxidant (e.g., hydrogen peroxide, ozone, permanganate, persulfate, percarbonate) to degrade organic COPCs. Oxidants cause chemical destruction of toxic organic chemicals. Petroleum hydrocarbons and PAHs can be treated with a variety of oxidants (including peroxide, percarbonate, persulfate, and ozone); however, there are limited case studies demonstrating the successful treatment of PCBs with ISCO. Ozone is the most likely oxidant.	Low/Moderate Effectiveness is a function of oxidant distribution and contact. Injection of ozone a possible alternative, but more complex than bioventing alone. Multiple applications may be required to achieve complete treatment.	Low/Moderate Chemical oxidants can be delivered using soil mixing, horizontal injections wells, or vertical injection wells.	Moderate	Low/High O&M costs would be low, assuming complete treatment can be achieved with a single application, or high if multiple applications are required to achieve treatment.	GHG and energy for production and delivery of substrate/reagent.	Not Retained	More challenging to implement as compared to bioventing.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology		Process Option		COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
In Situ Treatment (cont.)	In Situ Treatment via Reagent (cont.)	Reagent Approach (cont.)	Physical/ Chemical/ Biological (cont.)	Surface Bioremediation (Land Farming)	Organics	Shallow	Surface bioremediation involves tilling the soil and adding moisture and an amendment to stimulate natural degradation at shallow depths 0 to 1.2 m (0 to 4 ft) bgs. Organic compounds are degraded by indigenous or inoculated microorganisms.	Moderate/High Surface bioremediation is effective for remediating low level residual petroleum hydrocarbons in conjunction with source removal. PAHs and PCBs are more difficult to degrade. Effectiveness can be hindered by nonuniform amendment distribution, lack of appropriate microorganisms, or nonoptimal moisture and temperature.	Moderate Tilling equipment limits achievable treatment depth. Implementation is challenging in gravelly/ cobbly lithologies. Maintaining appropriate temperature and moisture conditions is more challenging for surface treatment.	Low	Low	GHG and energy for production and delivery of substrate/reagent.	Retained	
				Biological Reduction	Cr(VI), uranium, nitrate	Shallow/ Deep	Biological carbon source (e.g., molasses, sodium lactate, emulsified oil, butane) is applied to the subsurface to treat contaminants within vadose zone.	Moderate/High Carbon source follows source release pathways. Biological reductants are activated by microbial activity, so reactive strength is maintained over relatively longer distances. Reduction of uranium is potentially reversible.	Moderate Depends on delivery method. Localized temporary generation of secondary byproducts may occur. May temporarily mobilize COPCs (in first pore volume) toward groundwater.	Low/Moderate	Moderate	GHG and energy for production and delivery of substrate. Depends on which substrate is used.	Retained	
				Combined Chemical/ Biological Reduction	Cr(VI), Uranium, Nitrate	Shallow/ Deep	Chemical reductant (e.g., calcium polysulfide, hydrogen sulfide gas, ferrous sulfate, zero-valent iron) and biological carbon source (e.g., molasses, sodium lactate, and emulsified oil) are applied in combination to the subsurface to treat contaminants within vadose zone.	Moderate Amendments follow source release pathways. Combined chemical and biological might improve performance. Reduction of uranium is potentially reversible.	Moderate Depends on delivery method. Localized temporary generation of secondary byproducts may occur. May temporarily mobilize COPCs (in first pore volume) toward groundwater. Handling chemical reductants is an H&S concern.	Low/Moderate	Moderate	GHG and energy for production and delivery of substrate/reagent. Depends on which substrate is used.	Not Retained	More challenging to implement and costly as compared to biological reduction.
				Gaseous Ammonia Injection	Mobile COPCs	Shallow/ Deep	One of a number of possible gaseous reagents that are being investigated (along with ISGR, below). It involves the injection of ammonia gas to increase pH to dissolve silica. The pH naturally decreases to ambient conditions over time and aluminosilicate minerals precipitate and possibly coat and immobilize various contaminants.	Unknown Effectiveness is being studied as part of a laboratory-scale investigation.	Unknown Implementation is unknown at a full-scale level. Containment of injected gases in the shallow vadose zone may be an issue.	Unknown Technology evaluation has been limited to laboratory tests.	Unknown Technology evaluation has been limited to laboratory tests.	GHG emissions from injection activities.	Not Retained	Evaluation of results from the ongoing treatability study is needed prior to making a decision regarding its full-scale use at the Hanford Site. This technology could be evaluated as a remedial alternative later.
				Bioventing	Organics	Shallow/ Deep	Process that stimulates the natural biodegradation of aerobically degradable compounds in soil by providing oxygen to existing soil microorganisms. Bioventing uses low air flow rates to provide only enough oxygen to sustain microbial activity.	Moderate/High Technology is proven for remediating soils contaminated by petroleum hydrocarbons, but is less effective for PAHs, and not effective for PCBs. Effectiveness can be limited by extremely low soil moisture content, which would limit biodegradation.	Moderate/High Applied using horizontal or vertical wells. Implementability depends on depth of application,	Moderate	Low	GHG and energy for installation of delivery mechanism and delivery of air; waste generation from soil cuttings.	Retained	

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GRAs	Remedial Technology		Process Option		COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
In Situ Treatment (cont.)	In Situ Treatment via Reagent (cont.)	Reagent Approach (cont.)	Physical/ Chemical/ Biological (cont.)	Reductive Dechlorination Using Zero-Valent metals and bioremediation	PCBs	Shallow/ Deep	Zero-valent metals have the potential to reductively dechlorinate PCBs. Metals include iron, palladium, and other combinations. The contaminated soil and the metals are mixed in some fashion to allow the reactions to occur. Bioremediation, via the addition of an organic substrate, is a very similar process and can be combined with zero valent metal addition.	Unknown Very little published testing results are available.	Moderate Could be implemented by soil mixing with conventional excavation equipment if the contamination is shallow.	High	Low No associated cost.		Not Retained	Reductive dechlorination using zero valent metals and bioremediation are not proven technologies and were not retained for further consideration. More field studies must be conducted to test methods of bioaugmentation and biostimulation for PCB-dechlorinators.
				In Situ Gaseous Reduction with Chemical Reductant or Biological Substrate	Cr(VI), Uranium, Nitrate	Shallow/ Deep	A gaseous mixture of chemical reductants (e.g., hydrogen sulfide) or biological substrate (e.g., butane) is injected into and drawn through the vadose zone to reduce Cr(VI), and uranium. Research is underway to evaluate other reagents to immobilize contaminants.	Unknown Soil heterogeneity will result in preferential flow and limit treatment effectiveness of lower permeability soil. Reduction of uranium is potentially reversible.	Unknown Vapor extraction wells are installed around injection well at a radial spacing of approximately 4.6 m (15 ft). Large numbers of wells are required. Due to H&S risks, monitoring and emergency response plan are required for transporting, storing, and handling.	Unknown	Unknown	GHG emissions from injection activities.	Not Retained	Evaluation of results from the ongoing treatability study is needed prior to making a decision regarding its full-scale use at the Hanford Site. This technology could be evaluated as a remedial alternative later.
		Delivery Method	Mixing with Conventional Excavation Equipment		Depends on type of reagent used	Shallow	Use of conventional excavation equipment (backhoes, excavators, front-end loaders) to mix amendments into the soil.	High Agents are uniformly mixed with soil column, providing good contact and reaction between COPC and chemical.	Moderate Simple technology. Dust mitigation techniques will need to be implemented to control/prevent mechanical dispersion of contaminants.	Low/Moderate	Low No associated cost.	GHG emissions from machinery.	Not Retained	Not retained in favor of surface infiltration. Could be retained if shallow mobile contaminants are identified in the future.
			Deep Soil Mixing (Vertical/ Horizontal)		Depends on type of reagent used	Shallow/ Deep	Large mixing augers (1.5 to 3 m [5 to 10 ft] in diameter) or horizontally rotating heads are used to blend and homogenize reactants with soil. The reactants may be chemical reductants, biological substrate, or solidification/stabilization agents.	High Chemical agents are uniformly mixed with soil column, providing good contact and reaction between COPC and chemical. Cement or clay can also be mixed with the chemical slurry to reduce the hydraulic conductivity and leachability of the soil.	Low/Moderate Implementation will be more challenging in gravelly/cobbly lithologies. Although deep soil mixing has been performed to depths of 30 m (100 ft) bgs, most field applications have been limited to approximately 15 m (50 ft) bgs.	High	Low No associated cost.	GHG emissions from machinery	Not Retained	Deep soil mixing implementability will be limited by site conditions and required depth of treatment.
			Foam Delivery of Reagents		Depends on type of reagent used	Shallow/ Deep	Injection of a foam into vadose zone. The foam is a mixture of a surfactant solution to create the foam, and a reagent, such as phosphate to calcium polysulfide. The foam increases the horizontal migration of the reagent away from the injection well.	Unknown Technology evaluation has been limited to laboratory-scale tests. The stability of the foam, which will dictate the well spacing, is unknown, as is the ability of the foam to sweep a large volume of the vadose zone.	Unknown Technology evaluation has been limited to laboratory-scale tests.	Unknown Technology evaluation has been limited to laboratory-scale tests.	Unknown Technology evaluation has been limited to laboratory-scale tests.	Waste generation from soil cuttings for well installation.	Not Retained	Evaluation of results from the ongoing treatability study is needed prior to making a decision regarding its full-scale use at the Hanford Site. This technology could be evaluated as a remedial alternative later.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

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In Situ Treatment (cont.)	In Situ Treatment via Reagent (cont.)	Delivery Method (cont.)	Gas Delivery of Reagents	Dependent on type of reagent used	Shallow/ Deep	A gaseous mixture of chemical reagent is injected into and drawn through the vadose zone to reduce mobile COPCs.	Unknown Soil heterogeneity will result in preferential flow and limit treatment effectiveness of lower permeability soil.	Unknown Vapor extraction wells are installed around injection well at a radial spacing of approximately 4.6 m (15 ft). Large numbers of wells are required. Due to H&S risks, monitoring and emergency response plan are required for transporting, storing, and handling.	Unknown	Unknown	GHG emissions from injection activities. Waste generation from soil cuttings for well installation.	Not Retained	Evaluation of results from the ongoing treatability study is needed prior to making a decision regarding its full-scale use at the Hanford Site. This technology could be evaluated as a remedial alternative later.
			Injection Wells (Horizontal)	Dependent on type of reagent used	Shallow/ Deep	Delivery of amendments using horizontal wells. Wells are installed using horizontal drilling techniques.	Moderate Effectiveness can be hindered by nonuniform amendment distribution. Soil heterogeneity will result in preferential flow and limit treatment effectiveness of lower permeability soil. Multiple injections could be required.	Low Implementation is challenging in gravelly/cobbly lithologies. Lithology would also pose challenges with maintaining target depth and alignment with horizontal drilling. A pilot test of this technology encountered signification implementation challenges.	Moderate/High	Low	GHG emissions from well installation, development, and injection activities; waste generation from soil cuttings.	Not Retained	Testing at the Hanford Site has not been successful.
			Injection Wells (Vertical)	Dependent on type of reagent used	Shallow/ Deep	Delivery of amendments using conventional vertical wells.	Low/Moderate Effectiveness can be hindered by nonuniform amendment distribution. Distribution of liquid amendments is highly ineffective because of gravelly/ cobbly lithology. Distribution in lower permeability soil can be enhanced with the use of shear thinning fluids.	Moderate Radius of influence likely to be low, requiring large number of injection wells.	Moderate/High	Low	GHG emissions from well installation, development, and injection activities; waste generation from soil cuttings.	Retained	Retained for bioventing.
			Jet Grouting	Dependent on type of reagent used	Shallow/ Deep	High pressure injection of reactive slurry into soil to hydraulically mix the soil with the slurry. Fluidization of the soil is preferred.	Low/Moderate While jet grouting is capable of reaching the required treatment depth, jet grouting is not likely to achieve uniform distribution or a radius of influence greater than an order of 1.5 m (5 ft). Jet grouting of apatite and phosphate was pilot tested at 100-N for shallower and more limited application. Altered/decreased permeability of soil resulted from amendment precipitation and/or liquefaction of fine grained sediment fractures.	Low/Moderate Implementation will be more challenging in gravelly/cobbly lithologies. Jet grouting has been performed to depths of up to 91 m (300 ft). Many closely spaced injection points (approximately 1.5 m [5 ft] spacing) will be required.	High Limited radius of influence would make jet grouting cost prohibitive over a large area.	Low	GHG emissions from injection activities.	Not Retained	Not retained. Could be considered in the future if technology develops. Currently, jet grouting has potentially limited effectiveness.

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In Situ Treatment (cont.)	In Situ Treatment via Reagent (cont.)	Delivery Method (cont.)	Surface Infiltration		Dependent on type of reagent used	Shallow/ Deep	Reagent is applied to ground surface to treat contaminants within vadose zone. Surface infiltration can be done through drip irrigation and shallow basin systems. Systems are generally designed to be 30.5 cm (12 in.) below the surface and covered to be protected.	Moderate/High Amendments follow source release pathways. Distribution not likely to be uniform.	High Surface infiltration systems are simple to install and accessible for O&M.	Low	Low	Limited infrastructure. GHG emissions from production and delivery of substrate.	Retained	Retained for liquid substrates.
			Void Filling/Grouting		Dependent on type of reagent used	NA (Pipelines)	Grouting for solidification of buried wastes. Void grouting is considered for filling large voids, specifically pipelines.	High Established and commonly used technology for removing voids in pipelines.	Moderate/High Established and commonly used technology for removing voids in pipelines. Pipe branch lines/breaks need to be identified. Implementability can be more challenging and costly with long or large diameter pipelines.	Low	Low No associated cost.	GHG and energy for production and delivery of grout used.	Not Retained	Pipelines of a smaller adequate for void fill grouting are not encountered as waste sites at 100-K.
	In Situ Treatment Other		Physical/ Chemical/ Biological	Soil Blending	All except mobile COPCs	Depends on excavation method.	Contaminated soils are mechanically blended with clean soil or fill to reduce effective contaminant concentrations.	High	High Conventional equipment can be used.	Moderate/	Low No associated cost.	GHG and energy for tilling equipment.	Not Retained	Not effective since it relies on contaminant dilution.
				Desiccation	Mobile COPCs	Deep	Remediation by injecting hot dry air and withdrawing moist air from soil, immobilizing contaminants by preventing their aqueous phase transport.	Unknown A treatability test for this technology will be conducted for waste sites in the Central Plateau contaminated with Technetium-99. Theoretically, desiccation would reduce moisture content in the vadose zone. Reduction of COPC migration would be effective until the soil is re-wetted. The technology is not effective in the long term without concurrent infiltration control.	Unknown Implementation requires installation of injection and extraction wells, which are proven technology. However, there is uncertainty related to the number of wells, well spacing, and well configuration details required for optimal field/full-scale implementation. Would also require implementation of infiltration control.	Unknown	Unknown	GHG and energy for air injection. Waste generation from soil cuttings for well installation.	Not Retained	Evaluation of results from the ongoing treatability study is needed prior to making a decision regarding its full-scale use at the Hanford Site. This technology could be evaluated as a remedial alternative later.
				In Situ Thermal Desorption	Organics	Shallow/ Deep	Direct application of heat (e.g., using electrical heating elements, electrical resistive heating, injection of hot air, steam or hot water, radio frequency) to increase the temperature of soil and destroy or volatilize organic compounds.VOC capture required.	High Technology can achieve rapid removal/destruction of a mix of volatile and semivolatile organics, and achieve low residual concentrations.	Low Technology is applied using vertical drilling methods, and requires a spacing of 1.5 to 3 m (5 to 10 ft). Recovery of COPC vapors will require soil vapor extraction network and vapor barrier over entire treatment area.	High	Low No associated cost.	GHG and energy for production of heat and vapor recovery; waste generation from soil cuttings.	Not Retained	Mechanically complex challenging to implement.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology	Process Option		COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
In Situ Treatment (cont.)	In Situ Treatment Other (cont.)	Physical/ Chemical/ Biological (cont.)	In Situ Vitrification	All	Shallow/ Deep	Thermal treatment process that converts soil and other materials into stable crystalline substances. Contaminants are incorporated into the glass structure, which is generally strong, durable, and resistant to leaching.	High Heavy metals and radionuclides are retained within the treated soil, which is generally resistant to leaching.	Low High complexity of equipment required. Process uses an electric current to melt soil or other earthen materials at extremely high temperatures (1,600 to 2,000 °C or 2,900 to 3,650 °F). It is important to also account for safety considerations from exposure to high heat.	High	Low No associated cost.	GHG and energy for heat generation. High energy requirements to sustain required heat.	Not Retained	Complex and challenging to implement.
			Soil Flushing—Vadose Zone, Water	Contaminants with high to moderate solubility (e.g., Cr(VI) uranium, nitrate)	Shallow/ Deep	Clean or treated water is applied to the ground surface or in infiltration trenches to flush contaminants out of the vadose zone to the water table, where it would be captured/treated.	Moderate Water follows source release pathways, but contaminants that remain in adsorbed phase will not be treated. May create a larger groundwater problem if the groundwater capture is not effective.	High Drip irrigation system or trenches are simple to install and accessible for O&M.	Low/Moderate	Low	GHG and energy for installation.	Retained	
			Phytoremediation	Bio-available Metals and Organics	Shallow	Phytoremediation uses plants and their associated rhizospheric microorganisms to remove, degrade, or contain contaminants.	Low Phytoremediation is only effective when plants are active, thus the technology is not effective during the winter. Phytoremediation only treats soils to the approximate depth of the plant roots, and is only appropriate for low concentrations of contaminants. It is a slow process that is applied over long periods of years or decades. Many metals and radionuclides are only taken up by the plants and not transformed to innocuous forms.	Moderate Involves large land requirements, and considerable work would be required to make a plot of land at Hanford suitable for plant growth. If used to treat contaminants that are merely taken up and not transformed to innocuous forms, plants would need to be disposed elsewhere to avoid ultimately returning the contaminants to the soils they came from. Concerns about contaminants in the plants entering the food chain may need to be addressed.	Low	Low	GHG and energy for installation, and potential disposal of harvested plants containing metals. Implementation of phytoremediation could lead to a GHG reduction credit.	Not Retained	Phytoremediation would only be effective for low concentrations of contaminants in shallow soils over long periods, and many metals and radionuclides would accumulate in the plants and would not actually be treated, posing risks to ecological receptors.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment
Containment	Surface Barrier	Surface Barriers (e.g. Modified RCRA Subtitle C and/or D Barrier, Asphalt/Concrete barrier, Vegetative barrier [Evapotranspiration barrier], Hanford Barrier)	All	Shallow/ Deep	Surface barriers are generally designed to be impermeable to prevent surface water infiltration through the vadose zone and limit contaminant leaching to groundwater. Surface barriers may also prevent direct contact to contaminants. Modified RCRA Subtitle C Barriers are designed for hazardous waste, category 3 and category 1 (mixed) low-level waste. Modified RCRA Subtitle D Barriers are designed for non-radiological and non-hazardous solid waste, or category 1 low level waste where hazardous constituents are not present. Evapotranspiration barriers consist of a fine-grained soil layer overlying a relatively coarse-grained soil layer designed to functionally increase the water-holding capacity. Asphalt/concrete barriers can be placed around structures to remain in place (e.g., reactors) in the short term (75-years) to promote drainage, prevent infiltration into possible sources below the reactors, and prevent exposure to contaminated soil. The Hanford Barrier design was developed for sites containing low-level waste greater than Class C, and/or significant inventories of transuranic constituents.	Moderate/High Leaching of near-surface source COPCs will be controlled, but residual COPCs in capillary fringe and deeper vadose zone pore water will continue to impact groundwater due to water table fluctuation. Prevention of direct contact will depend on specific design. Effectiveness for asphalt caps is high in the short term; for increased effectiveness, barrier needs to be properly sealed, given that asphalt and concrete are permeable.	Low/High Implementability of the Hanford Barrier is low; installation of large number of layers makes this technology more difficult to implement. No technical or administrative challenges are associated with implementing asphalt/concrete caps (high implementability). Modified RCRA Subtitle C and/or D Barrier and Evapotranspiration barriers are simple to install. Biointrusion may need to be considered as part of the barrier/cap design.	Low/High Hanford Barrier (High); Modified RCRA Subtitle C and/or D Barrier (Moderate); Asphalt/Concrete Cap and Evapotranspiration Barrier (Low)	Low/High Dependent on type of barrier and depth of contamination.	GHG and energy for installation. Continued impact to soil resources.	Retained	
	Subsurface Barriers	Jet grouting, soil freezing, or wire saw barriers	All	Shallow/ Deep	Barriers placed beneath the contaminated zone to limit further migration. Jet grouting is as discussed above at one specific depth. Soil freezing involves placement of cooling media distribution systems into the subsurface to freeze a soil layer below the contamination. Wire saw barrier involves cutting a thin horizontal trench that is filled with grout using a diamond wire saw. The saw is placed in an excavation around the soil mass to be contained.	Low Significant uncertainty on the completeness of the barrier with all methods.	Low Would be difficult or impossible to implement at Hanford due to presence of gravels and cobbles, and/or the depth of application.	High	Low	Large amount of wastes would be generated during installation and GHG and energy for installation.	Not Retained	Difficult to implement.
	Compaction	Dynamic compaction	All	Shallow/ Deep	Dynamic compaction is used for consolidation of soils and buried wastes, and can be used to minimize the potential subsidence for a subsequent barrier. The process involves dropping a weight from a predetermined height onto the area to be compacted.	Moderate/High Effective at removing void spaces and compacting surface soil, where voids exist around buried waste. Not effective for native soils. Not effective for treatment of hazardous wastes.	Moderate Simple and widely used technology.	Low	Low No associated cost.	GHG and energy for installation.	Not Retained	No waste sites including solid and buried wastes are present at the site.

Table 8-6. Screening Table—Technologies for Radionuclides, Cr(VI), Other Metals, and Organic Compounds in Waste Sites—100-K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Depth Range[b]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[c]	Retained/ Not Retained[d]	Screening Comment

a. Indicates the contaminants that can be addressed by a technology based on geochemical properties. A COPC Applicability of "All" indicates implementation of a technology is not dependent on the nature of a chemical.

b. Depth range is based on practical limitations of implementing the given technology.

c. Sustainability includes potential impacts to the environment that could arise from implementing this technology (e.g., GHG emissions, waste generation, water use and resource impacts, energy use).

d. Additional details on technologies not retained are provided in Appendix I.

e. Ex situ treatment does not include treatment done for ultimate disposal at ERDF. Treatment performed at ERDF or the site as required to meet disposal restrictions is assumed to be part of the "disposal to onsite landfill" process option.

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs		Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
No Action		No Action	No Action	All	No remedial actions taken.	Low/High No remedial actions are taken, but effectiveness could be high if risk is previously mitigated.	High	Low	Low	Little impacts	Retained	Retained per the NCP (40 CFR 300).
Pump-and-Treat	Collection	Extraction	Groundwater Extraction System	All dissolved	Operation of existing and/or new groundwater extraction wells.	Moderate/High Pump-and-treat is a proven treatment technology for Cr(VI) in groundwater, although there is some uncertainty as to its ability to achieve standards everywhere, and for other COPCs, such as C-14.	High System already in place, but existing wellfield may not be appropriate to capture all of the COPCs.	Low System exists	Moderate/ High	Energy consumption and GHG emissions from pumping systems.	Retained	
	Ex Situ Treatment	Chemical	Ion Exchange	Cr(VI), Nitrate	Ions from the aqueous phase are removed by exchange with innocuous ions on the exchange medium.	Moderate/High Effective for Cr(VI) treatment. Variable, depending on COPC.	High Vendors and equipment readily available. Currently used at the site.	Low/Moderate System exists, but may need to be expanded or upgraded for other COPCs	Moderate/ High	Waste generation from IX regeneration disposal or regeneration. Energy consumption from process equipment.	Retained	
			Chemical Reduction/ Softening and Precipitation	Cr(VI), C-14	Dissolved COPCs are transformed into an insoluble solid, which is removal by flocculation, sedimentation, and filtration. COPCs are removed with the sludge.	Low/Moderate Effective for Cr(VI) treatment. For C-14, additional evaluation and site specific testing will be required to verify that this technology will work.	Moderate/High Vendors and equipment readily available, but no experience with the technology at Hanford. Large volume of sludge would be produced.	Moderate/ High	Moderate	Waste generation from chemical precipitation. Energy consumption from process equipment.	Not Retained	For C-14, not retained in favor of air stripping due to large volume of sludge generated. For Cr(VI), implementability challenges given large sludge volume and the fact that the IX treatment plants are in place.
			Electrocoagulation	Cr(VI)	Relies on electrochemical generation of ferrous iron. The ferrous iron reduces metals that are susceptible to reduction and converts them to insoluble solids, which are removal by sedimentation and filtration.	Low/Moderate Not widely used for Cr(VI) removal. Pilot testing at the site had challenges.	Low/Moderate Additional development and testing would be required. Potential negative impacts on re-injection of water.	Moderate/ High	Moderate	Waste generation from chemical precipitation. Energy consumption from process equipment.	Not Retained	Implementability challenges since the IX treatment plants are in place.
Pump-and-Treat (cont.)	Ex Situ Treatment (cont.)	Biological	Wetlands	Cr(VI), Nitrate	Extracted groundwater is pumped to a constructed wetland where contaminants are biologically reduced, or taken up by plants and algae. Petroleum aerobically degraded. TCE may volatilize.	Moderate Effective for nitrate, but additional research/pilot testing is required to verify effectiveness for other COPCs.	Low/Moderate May require large surface area for extended period.	Moderate Depends on land requirements	Low	Little impacts, except for land required	Not Retained	Performance uncertainty. Implementability challenges given large area required and since IX treatment system is already in place.
			Subgrade Bioreactors	Cr(VI), Nitrate	Extracted groundwater is pumped into a lined excavated area that has been backfilled with organic media (e.g., wood mulch with zero-valent iron). Cr(VI) and nitrate are biologically reduced as it passes	Moderate/High Effective for nitrate, but treatability testing is required to verify	Moderate/High Excavation and backfilling is easy to implement. Piping can be incorporated into the	Low/Moderate Depends on land	Low	Impacts include spent media disposal land required	Not Retained	Has not been demonstrated on a full scale for Cr(VI) or nitrate remediation.

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs		Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
					through the media. A second stage aeration/filtration stage could be provided to remove any biological byproducts (e.g., iron), petroleum, and solids prior to infiltrating or injecting back to groundwater.	effectiveness for other COPCs.	design to facilitate future delivery of liquid carbon sources (e.g., vegetable oil). Treatability testing required to verify implementability.	requirements				
			Bioreactors	Cr(VI), Nitrate	Groundwater is amended with electron donor (carbon source) and passes through a matrix (fixed bed, fluidized bed, or membranes) with microbial films, where contaminants are biologically reduced. Effluent is oxygenated, filtered, and amended prior to recharge into the ground.	Low/Moderate Bioreactors commonly used for nitrate removal, but less commonly for Cr(VI) reduction. Little experience with other COPCs.	Moderate/High Vendors and equipment readily available, but no current experience with the technology at Hanford.	High	Moderate	Waste generation from biological sludge. Energy consumption from process equipment.	Not Retained	Performance uncertainty for Cr(VI). Considering large and complex system requirements for nitrate removal, and since in situ bioremediation or subgrade bioreactors could be used, ex situ bioreactors have not been retained.
			Phytoremediation	Cr(VI), Nitrate	Use of plants and their associated rhizospheric microorganisms to remove, reduce/degrade, or contain chemical contaminants in soil or groundwater. Contaminants in groundwater can also be removed by applying it as irrigating water for plants.	Low/Moderate Low/Moderate for Cr(VI). Additional research/pilot testing is required to verify effectiveness for site conditions. Could be used as a barrier approach, but there would be challenges with the depth to the water table even close to the river. Commonly used for nitrate removal. Plants used for remediating radionuclides would require harvesting.	Low/Moderate Requires large surface area for plants. Potential cultural challenges with implementation near river.	Low	Low	Impacts include land required and potential disposal of harvested plants containing radionuclides.	Not Retained	Would only be effective for low concentrations of contaminants where groundwater is shallow over long periods, or when applied as irrigation water. Many metals and radionuclides would accumulate in the plants and not actually be treated, posing risks to ecological receptors.
Pump-and-Treat (cont.)	Ex Situ Treatment (cont.)	Physical	Air Stripping	Carbon-14	Water is passed through an air stripper where air is injected and strips out volatile compounds or carbon dioxide from the water phase. The stripper maybe a packed tower, tray stripper, or similar device. The off-gas is collected and treated in activated carbon or similar process. Off-gas treatment would only be required if emissions exceed limits.	High With appropriate design and operation, can achieve discharged standards.	High Currently used at the site for VOCs. Testing required for C-14.	Moderate Air strippers are relatively inexpensive	Low/Moderate	GAC would be the only waste, some energy for the blower. Energy consumption from process equipment.	Retained	
			Membrane Separation (e.g., Reverse Osmosis)	All Except Tritium	Water pressure is used to force water molecules through a very fine membrane, leaving the contaminants behind. Purified water is collected from the "clean" or "permeate" side of the membrane, and water containing the concentrated contaminants is disposed.	High With the appropriate design, RO can be effective for almost any compound.	Low/Moderate Vendors and equipment readily available, although additional site specific testing would be required. Pretreatment likely necessary, and a large volume of brine would be produced that would need to be treated and handled.	High	High	Waste generation inform of brine and high energy use. Energy consumption from process equipment.	Not Retained	Implementability challenges from large volumes of brine produced would require further reduction and then disposal.
	Discharge	Onsite Discharge	Groundwater Injection Wells	All	Treated groundwater is injected into onsite wells.	High Will enhance contaminant flushing, hydraulic control, and capture of plume.	High Readily implementable at the site; currently used in existing pump-and-treat system. The wells may be subject to clogging due to the buildup of chemical precipitates or	Low	Low/Moderate	Waste generation from soil cuttings for well installation.	Retained	

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs		Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
							microbial biofouling.					
			Surface Infiltration	All	Treated groundwater is infiltrated into onsite trenches, located outside of zones of known waste sites.	High Effective means of disposal and may enhance contaminant flushing, hydraulic control, and capture of plume if they can be located appropriately.	Moderate/High Infiltration would be easy to engineer and implement.	Low Trenches are lower cost than wells	Low/Moderate	Little impacts	Retained	
			Beneficial Reuse of Treated Water	All	Use of treated water for a beneficial use such as irrigation, cooling water, or dust control.	High Effective means of treated water disposal, although it may impact the in situ removal mechanisms.	Moderate No nearby facility that could use large quantities of water. May be simple to implement for dust control for nearby earthwork.	High	Low	Water needs to be transported for reuse.	Retained	May be useful if water can be used for dust control and similar uses.
		Offsite Discharge	Surface Water Discharge (NPDES)	All	Discharge of treated groundwater directly to the river at a permitted outfall.	High Effective means of treated water disposal	Low Although surface water discharge is commonly practiced for treated wastewater, no new NPDES outfalls are allowed on the Hanford Reach National Monument. The use of existing N Springs NPDES outfall is not feasible.	Low	Low Little or no maintenance required	Little impacts	Not Retained	Not allowed.
In Situ Treatment	Reagent Approach	Chemical	In Situ Chemical Reduction	Cr(VI)	Subsurface delivery of chemical reductants (such as calcium polysulfide) within plume to stimulate reduction of contaminant.	Moderate Chemical reductants instantly reactive; thus, strongest reduction achieved near injection well, requiring tighter spacing of injection wells. Recirculation approach may increases size of reducing zone, and allows broader well spacing. Iron and sulfate reduction increases reductive capacity of subsurface, which makes the formation less sensitive to rebound.	Moderate May require large number of wells.	Moderate/ High Dependant on number and type of wells. Likely higher capital cost compared to in situ biological	Moderate	Waste generation from soil cuttings for well installation. GHG and energy for production and delivery of chemicals	Not Retained	More challenging to implement and costly as compared to biological reduction.
		Biological	In Situ Biological Treatment (Anaerobic)	Cr(VI), Nitrate	Subsurface delivery and recirculation of various organic substrates in a regular pattern of wells in the aquifer to stimulate anaerobic bioreduction of Cr(VI) and reduction of nitrate. Cr(VI) and nitrate on groundwater that is reinjected would be reduced in situ.	High Reactive life of biological electron donors is longer than chemical reductants so that reactive strength is maintained over relatively longer distances compared to in situ chemical treatment. Iron and sulfate reduction increases reductive capacity of subsurface, which makes the formation less sensitive to rebound.	Moderate/High Requires large number of wells to cover a large area.	Moderate/ High Dependant on number and type of wells	Moderate	Waste generation from soil cuttings for well installation. GHG and energy for production and delivery of substrate. Depends on which substrate is used.	Retained	

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs		Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
			Hydrogen or other Organic Gas Sparging	Cr(VI)	Injection of biodegradable organic gasses (e.g., propone or butane) or hydrogen into sparge wells that are screened below the water table.	Moderate Distribution of gasses likely to be poor in the coarse formation. Has not been demonstrated for Cr(VI).	Low The radius of influence around each sparge well is likely to be low, so a large number of wells would be required. Safety challenges exist because of residual explosive gasses that may accumulate.	High Large number of wells would be required	Moderate	Waste generation from soil cuttings for well installation. GHG and energy for production and delivery of chemicals	Not Retained	Challenge in the distribution of the gases and safety risk associated with using explosive gases.
		Chemical/ Biological	In Situ Treatment using Combination of Biological & Chemical Substrates	Cr(VI), Nitrate	Subsurface delivery and recirculation of both chemical reductants and electron donors within plume to stimulate chemical and anaerobic biological reduction of Cr(VI).	High Chemical reductants could be used to treat smaller hot spot areas, while biological reductants could be used to sustain treatment over larger dilute plume areas. Recirculation approach increases the size of reducing zone, and allows broader well spacing. Iron and sulfate reduction increases reductive capacity of subsurface. Less sensitive to rebound from residual sources because of residual reactive phase.	Moderate Recirculation will likely be limited by extraction rate; addition of fresh water can be used to enhance coverage around injection wells. The formation of secondary byproducts may impact restoration to beneficial use.	Moderate/ High Dependant on number and type of wells	Moderate	Waste generation from soil cuttings for well installation. GHG and energy for production and delivery of chemicals	Not Retained	More challenging to implement and costly as compared to biological reduction.
In Situ Treatment (cont.)	Reagent Approach (cont.)	Physical	Flushing—Saturated Zone, Water	Cr(VI), Nitrate, and possibly Carbon-14	Clean/treated water is injected to flush out contaminated groundwater to expedite remediation of plumes. Would be component of a pump-and-treat system.	Moderate/High The extraction wells system should be able to capture any contaminants mobilized. However, performance will depend on residual contamination in lower permeability layers. There is performance uncertainty with C-14.	High Standard wells or infiltration trenches used for injection.	Moderate Costs for wells and piping	Low	GHG and energy for installation. Waste generation from soil cuttings for well installation.	Retained	
	Delivery Method	Surface Infiltration	Surface Infiltration	NA	Trenches, French drains, or drip irrigations systems are used to inject water or reagents.	High With appropriate design, installation, and maintenance, they can be effective.	Moderate Would be more acceptable to stakeholders if known vadose zone impacts are close or in contact with the water table.	Low	Moderate	Less GHG and energy for installation	Retained	
		Groundwater circulation wells (GCWs)	Groundwater circulation wells (GCWs)	NA	Installation of wells with two screened zones. Groundwater is typically pumped out of the formation from lower screen zone, and injected back into the formation in the upper zone. A circulation pattern is created in the formation. The groundwater can be stripped inside the well to remove VOCs, or the wells can be used to deliver reagents.	Low/Moderate The establishment of a reasonable circulation pattern depends on the formation characteristics. The low permeability lenses present in some locations may be problematic. Very high permeability may result in a small radius of influence so more wells will be required.	Low/Moderate A large number of wells may be required.	Moderate Depends on the number of wells required	Moderate	Waste generation from soil cuttings for well installation.GHG and energy for operation.	Not Retained	Asymmetrical groundwater flow and groundwater flow short circuiting, may limit the effectiveness of GCWs.
		Vertical Wells	Vertical Wells	NA	Standard vertical wells are used to inject water or reagents.	High With appropriate design, installation, and maintenance, they can be effective.	High Use extensively at Hanford.	Moderate/ High Wells at Hanford are generally	Moderate	Waste generation from soil cuttings, GHG and energy for installation	Retained	

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
							expensive				
	Horizontal Wells	Horizontal Wells	NA	Horizontally drilled wells are used to inject water or reagents.	Moderate/High Uncertain performance.	Low Pilot test was not successful.	Moderate/ High Costs are high but fewer wells are required	Moderate	Waste generation from soil cuttings, GHG and energy for installation	Not Retained	Pilot test was not successful.
Containment	Physical	Containment Wall (e.g. slurry wall or grout wall)	All	Slurry or grout wall barriers consist of a vertical barrier perpendicular to the groundwater flow direction, partially filled with bentonite slurry, grout, or other low permeability material. The barrier is typically keyed into a lower permeability zone. The slurry/grout could be jet injected, mixed with the soils using large augers, or excavated.	Moderate Effectiveness is dependent on the continuity of the wall and the ability to key into the RUM, which will be difficult to achieve because of depth. Does not reduce toxicity or volume of contaminants by itself. This technology requires groundwater extraction to control groundwater pressures from building up behind the barrier and potentially damaging the barrier or causing groundwater to flow under, over, or around the barrier.	Low Installation of wall through cobbles and boulders to key into the RUM is very difficult and cost prohibitive. Driven sheet piles near the river have been attempted but failed because of the presence of cobbles.	High	Low/Moderate	GHG and energy for installation, waste from trench spoils.	Not Retained	Not required since there is an existing hydraulic containment system and not likely to be implementable.
Containment (cont.)	Chemical/ Biological (cont.)	Reactive Chemical Barrier (ISRM)	Cr(VI)	Subsurface delivery and/or recirculation of chemical reductants along cross-gradient rows transecting plume. Residual reducing chemicals are retained in the aquifer matrix so Cr(VI) is passively removed as groundwater moves through the treatment zone barriers. Sodium dithionite or zero-valent iron maybe used as reductants. ISRM is authorized under the interim ROD at 100-D (*Interim Remedial Action Record of Decision Amendment: 100-HR-3 Operable Unit* [EPA/541/R-00/122])	Moderate/High Effective if barrier treatment zone conditions are maintained. High flows of highly toxic groundwater, and changing water levels are likely to reduce effectiveness and require more frequent amendments. The current ISRM has experienced some breakthrough. Not effective in treating the bulk of the plume.	Moderate/High Can be implemented with injection wells or recirculation dipole wells. Broad zones of secondary byproduct generation within treatment area may occur.	Moderate/ High Dependant on number and type of wells	Moderate	ISRM already exists, limited GHG and energy to augment	Retained	Existing ISRM will be allowed to function as it is, but it will not be amended since a barrier approach will not support the cleanup of the plume.
		Reactive Biological Barrier	Cr(VI), Nitrate	Subsurface delivery and recirculation of electron donors along cross-gradient rows transecting plume. Residual reducing byproducts and biomass are retained in the aquifer matrix so that contaminants are passively removed as groundwater moves through the treatment zone barriers.	Low/Moderate Effective if barrier treatment zone conditions are maintained. Given the highly aerobic groundwater, re-amendment of the barrier would need to be frequent. Not effective in treating the bulk of the plume.	Moderate/High Can be implemented with injection wells or recirculation dipole wells—latter option reduces number of wells required and is more cost effective. Broad zones of secondary byproduct generation within treatment area may occur—requires re-oxygenation of groundwater prior to discharge to the river.	Moderate/ High Dependant on number and type of wells	Moderate	GHG and energy for installation	Not Retained	Not retained in favor of existing hydraulic containment system
	Hydraulic Control	Hydraulic Containment via Extraction	All	Install extraction wells along downgradient edge of plumes to control migration of COPCs to the river.	Moderate Extraction should control plume migration to the river, but upgradient plumes and hot spots are left untreated.	High Compatible with existing infrastructure, and can be designed to work with other remedial technologies.	Low Facilities in place	Moderate	GHG and energy for operations	Retained.	

Table 8-7. Screening Table—Technologies for Cr(VI) and Other COPCs in Groundwater—Hanford River Corridor 100 K

GRAs	Remedial Technology	Process Option	COPC Applicability[a]	Description	Relative Effectiveness	Relative Implementability	Relative Capital Cost	Relative O&M Cost	Sustainability[b]	Retained/Not Retained[c]	Screening Comment
		Hydraulic Containment via Injection	All	Injection of river water or groundwater parallel to the river. Manages hydraulic gradients to create conditions (e.g., an inward gradient) throughout the year that mimic natural conditions of low plume discharge encountered during periods of high river stage. Barrier comprising closely spaced injection wells, infiltration trenches, and/or horizontal wells. Source of water from existing permitted Columbia River supply and/or groundwater.	LowModerate Should rapidly control plume migration to the river. However, some flushing and dilution of the contamination already close to the river may occur and may not be viewed favorably.	Moderate Can be accomplished using practically achievable injection rates. Injection only required 2-3 seasons (6-9 months). Infiltration trenches will be more cost effective than injection/horizontal wells but could cause seepage faces to develop along river cliff faces.	Moderate	Moderate	GHG and energy for operations	Not Retained	Not retained in favor of existing hydraulic containment system

Notes: Other COPCs include carbon-14, chromium, Cr(VI), nitrate, and tritium.

a. Indicates the contaminants that can be addressed by a technology based on geochemical properties. A COPC Applicability of "All" indicates implementation of a technology is not dependent on the nature of a chemical.

b. Sustainability includes potential impacts to the environment that could arise from implementing this technology (e.g., GHG emissions, waste generation, water use and resource impacts, energy use). Alternative design will dictate sustainability of an approach.

c. Additional details on technologies not retained are provided in Appendix I.

Table 8-8. Categories and Types of Current Hanford ICs

DOE Categories of ICs[a]	DOE Categorical Description	Types of Current Hanford ICs	Examples of ICs
Active/Passive Controls	These controls have long been understood to apply to the long-term management of radioactive waste. Active controls require clear institutional and human responsibilities and the active performance of responsibilities such as controlling access to a disposal site by means such as guards, performing maintenance operations or remedial actions at a site, controlling or cleaning up releases from a site, or monitoring parameters related to disposal system performance. Passive controls are defined by their dependence on the design of controls and structures such as permanent markers placed at a disposal site; public records and archives; government ownership and regulations regarding land or resource use; and other methods of preserving knowledge about the location design and contents of a disposal system.	**Warning Notices:** Provide visual identification and warning of hazardous or sensitive areas. A mechanism of warning notices includes signs that provide visual identification and warning of hazardous or sensitive areas.	**Warning Notices** – Requirement for placement of permanent signs and/or markers at specific areas of the site. – Applies to all COPCs. – *Effectiveness*: Good. Reduces or eliminates the potential for direct contact with radiological contamination for the duration of elevated risk period, and for preserving knowledge about a specific area or design. – *Implementability:* Very Good. Readily implemented, requires periodic surveillance and maintenance. – *Cost:* Low. *Retained*
Proprietary/Government Controls	This type of control is based on the legal authority of landowners to control the use of their land. Proprietary controls, such as easements, are based on the rights associated with ownership of an interest in land. Government controls rely on the powers of governments to protect the public health and safety through zoning, legislation, land ownership, or permit programs.	**Land Use Management:** Ensures that use of the land is compatible with any hazards that exist. As presented in *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41), "DOE will restrict the use of land on waste sites and prohibit activities that would interfere with the remedial activity in accordance with the ICs requirements of the CERCLA decision documents and as described in applicable work plans." Implementation of land use management controls can ensure that any changes in use of the land are assessed before being allowed, and that ICs are maintained beyond change of ownership, as appropriate. Mechanisms include land use and real property controls (e.g., proprietary controls including easements and covenants) and excavation permits. Land use and real property controls ensure that the use of land is in accordance with Hanford Site plans and CERCLA decision documents. Site evaluations are required prior to any land disturbance activity, and excavation permits are required for excavations on the Hanford Site to prevent unplanned disturbance or infiltration as prohibited by CERCLA decision documents. **Groundwater Use Management:** Ensures proper use of groundwater through groundwater controls. As described in *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41), groundwater use on the Hanford Site is generally restricted, except for limited research purposes and for monitoring and treatment, as approved by EPA or Ecology, or as authorized in EPA- or Ecology approved documents. Excavation permits and the land use process also control groundwater use. Section 8.3.1.2 provides additional groundwater use management discussion.	**Land Use Management** – Land use and real property controls (e.g., proprietary controls including easements and covenants). – Applies to all COPCs. – *Effectiveness:* Good. Reduces or eliminates the potential for direct contact with contaminated groundwater when well-implemented and maintained for the duration of elevated risk period. Ensures compatible land use. – *Implementability:* Very Good. Readily implemented, must identify and comply with all necessary legal requirements. – *Cost:* Low. *Retained* **Groundwater Use Management** – Groundwater controls. – Applies to all COPCs. – *Effectiveness:* Good. Ensures no improper use of groundwater. – *Implementability:* Very Good. Readily implemented, but will likely require ongoing oversight and coordination with state water resource managers. – *Cost:* Low. *Retained*

Table 8-8. Categories and Types of Current Hanford ICs

DOE Categories of ICs[a]	DOE Categorical Description	Types of Current Hanford ICs	Examples of ICs
Structural/Nonstructural Controls	Structural controls include physical barriers (e.g., gates, fences, and natural barriers) to keep trespassers away from a site, signs to warn people of dangers, and engineered barriers (e.g., tanks) restricting or containing actual or potential contaminant migration. Nonstructural controls are all other limitations on the use of land that do not require physical means of exposure prevention.	**Entry Restrictions:** Prevent or limit the access of humans to particular hazardous or sensitive areas. They can also be used to avoid disturbance and exposure to remedies such as excavation areas, engineered barriers, or an effective vegetative soil layer, and serve to ensure adequate training for those who enter these areas. Procedural requirements for access, warning signs, and fencing can be implemented to provide entry restrictions.	**Entry Restrictions** – Procedural requirements for access Excavation/Drilling permits. – Applies to all COPCs. – *Effectiveness*: Good. Reduces or eliminates the potential for direct contact with contaminated groundwater when well-implemented and maintained for the duration of elevated risk period. Protects integrity of active remedies. – *Implementability:* Very Good. Readily implemented, requires periodic surveillance and maintenance. – *Cost:* Low. *Retained*
Informational Tools[b]	Provide information or notification about whether a remedy is operating as designed and/or that residual or contained contamination may remain onsite. Information devices include state registries, deed notices, and advisories.	**Waste Site Information Management:** This is an administrative mechanism implemented to maintain and provide access to information on the location and nature of contamination. The WIDS database identifies waste management units on the Hanford Site, their location, waste type, and status. Other descriptive information contained in WIDS includes size, extent, and appearance; testing or sampling efforts; regulatory information; bibliographic references; images; change history; and data validation. RL maintains the system in accordance with the WIDS change control system, which documents and traces additions, deletions, and/or other changes dealing with the status of waste management units.	**Waste Site Information Management** – Administrative – Applies to all COPCs. – *Effectiveness:* Good. Ensures access to information on the location and nature of contamination. – *Implementability:* Very Good. Readily implemented, but requires maintenance of the information management system. – *Cost:* Low. *Retained*

a. *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41, Rev. 4, August 2009). Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0095932.

b. An "Informational Tool" is an EPA category of an IC that is used at the Hanford Site as discussed in *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41, Rev. 4).

1

In situ gaseous reduction (ISGR) with chemical reductant or biological substrate

- Delivery Method:
  - Mixing with conventional excavation equipment
  - Deep soil mixing (vertical/horizontal)
  - Foam delivery of reagents
  - Gas delivery of reagents
  - Horizontal injection wells
  - Vertical injection wells
  - Jet grouting
  - Surface infiltration
  - Void fill grouting
- In Situ Treatment—Other:
  - Soil blending
  - Desiccation
  - In situ thermal desorption
  - In situ vitrification
  - Soil flushing—vadose zone, water
  - Phytoremediation

Containment. Containment actions consist of physical measures to restrict contaminant migration to groundwater. Containment remedial technologies include surface barriers, horizontal subsurface barriers, and compaction. Containment options were evaluated for waste sites impacted by mobile contaminants that have the potential to impact groundwater.

Surface barrier technologies are constructed over contaminated waste sites to control the vertical entry of water into contaminated media, which, in turn, reduces leaching of contamination to groundwater. In addition to their hydrological performance, barriers can function as physical obstructions to prevent intrusion by human and ecological receptors, limit wind and water erosion, and attenuate radioactivity. Surface barriers include Hanford Barrier, modified RCRA Subtitle C or Subtitle D barrier, asphalt/concrete cap, and vegetative cap (evapotranspiration cap). The Hanford Barrier design was developed specifically for use at Hanford for sites containing low-level waste greater than Class C, and/or significant inventories of transuranic (TRU) constituents.

Emplaced horizontal subsurface barriers are placed beneath existing in situ contaminants. These bottom barriers have features similar to those of vertical barriers in that they minimize movement of contaminants, restrict infiltration of groundwater, and consist of similar materials with comparable technologies. Horizontal barrier technologies can include jet grouting, soil freezing, and wire saw barriers.

Dynamic compaction can consolidate soil and buried wastes, and minimize the potential subsidence for a subsequent barrier. The process involves dropping a weight from a predetermined height onto the area to be compacted.

8.3.1.2 Identification and Screening of Technologies for Groundwater

No Action. The no action response entails any further action to remove, remediate, monitor, or restrict access to contaminated groundwater. The CERCLA RI/FS guidance (EPA/540/G-89/004) and NCP (40 CFR 300) guidance require this response to remain in the FS process for comparative purposes, where it is used as a baseline against which all other alternatives will be compared.

Institutional Controls. ICs are administrative controls and legal restrictions imposed on land use to prevent or reduce exposure to hazardous wastes or hazardous constituents and/or to protect the integrity of a remedy. Section 8.3.1.1 and Table 8-8 describe ICs for the Hanford Site.

For soils, ICs will be used to prevent human or ecological exposure to contaminants. These ICs will remain in place until the waste site is remediated. For groundwater, ICs include administrative controls, access, and drilling restrictions until achievement of RAOs. Groundwater use management controls are in place to ensure proper use of groundwater. Groundwater use on the Hanford Site is generally restricted, except for limited research purposes and for monitoring and treatment, as approved by EPA or Ecology, or as authorized in EPA- or Ecology-approved documents. Table 8-8 presents an evaluation of groundwater use management restrictions.

Pump-and-Treat. The pump-and-treat GRAs identify collection, ex situ treatment, and discharge as remedial technologies. The following text details these remedial technologies and applicable process options.

- **Collection.** Three pump-and-treat systems (KR-4, KX, and KW) currently operate within 100-K. This process option involves extraction of contaminated groundwater through continued operation of existing groundwater extraction wells. Chapter 1 presents information regarding the history and operation of these systems.

- **Ex Situ Treatment.** Aboveground treatment may involve physical, biological, or chemical processes. Ex situ treatment process options include the following:

  - Ion exchange
  - Chemical reduction and precipitation
  - Electrocoagulation
  - Wetlands
  - Subgrade bioreactors
  - Bioreactors
  - Phytoremediation
  - Air stripping
  - Membrane separation (reverse osmosis)

- **Discharge**

  - Onsite discharge includes groundwater injection wells, surface infiltration, and beneficial reuse of treated water.

  - Offsite discharge includes surface water discharge (NPDES).

In Situ Treatment. In situ treatment consists of actions that treat contamination in place. In situ treatment of contaminated groundwater generally includes methods to degrade contaminants, such as adding agents to groundwater (via injection wells or permeable barriers) that facilitate chemical or biological destruction or immobilization. For this evaluation, technologies are subdivided by the reagent approach (physical, chemical, or biological), and the method for delivering the reagent to the subsurface. For treatment of contaminated groundwater in 100-K, the following in situ remedial technologies and process options were evaluated:

- Reagent Approach:
  - In situ chemical treatment/reduction
  - In situ biological treatment (anaerobic)
  - Hydrogen or other organic gas sparging

  - In situ treatment using combination of biological and chemical substrates
  - Flushing—saturated zone, water
- Delivery Method:
  - Surface infiltration
  - Groundwater circulation wells (GCWs)
  - Vertical wells
  - Horizontal wells

Containment. Containment technologies assist in preventing or significantly reducing the migration of contaminants in groundwater through physical barriers or treatment barriers. For treatment of contaminated groundwater in 100-K, the following containment process options were evaluated:

- Containment wall (e.g., slurry wall or grout wall)
- ISRM
- Reactive biological barrier
- Hydraulic containment via extraction
- Hydraulic containment via injection

8.3.2 Evaluation of Technologies and Selection of Representative Technologies

Tables 8-7 and 8-8 present the identification and screening of technologies and remedial process options for 100-K. Table 8-7 presents GRAs and process options for waste sites impacted with radionuclides, Cr(VI) and other metals, and organic compounds. Table 8-8 presents GRAs and process options for groundwater impacted with Cr(VI) and other COPCs.

The various technologies screened in the tables include demonstrated and proven processes, innovative technologies, and potential processes that have undergone laboratory trials or bench scale testing. Factors considered in this evaluation include the state of technology development, site conditions, waste characteristics, nature and extent of contamination, and presence of constituents that could limit the effectiveness of the technology. A qualitative comparison of implementability, effectiveness, and cost provided additional evaluation of technologies. The screening tables also present information pertaining to the sustainability of a process option. It is important to note, however, that sustainability was not considered as a criterion for the screening of process options.

Implementability refers to the relative degree of difficulty anticipated in implementing a particular process option under regulatory, technical, and schedule constraints posed by the site. As suggested by CERCLA RI/FS Guidance (EPA/540/G-89/004), process options and entire technology types can be eliminated from further consideration if a technology or process option cannot be effectively implemented at the site. As discussed in Section 4.2.5 of the CERCLA RI/FS Guidance, "technical implementability is used as an initial screen of technology types and process options to eliminate those that are clearly ineffective or unworkable at a site." Institutional or administrative implementability, which includes "the ability to obtain necessary permits for offsite actions, the availability of treatment, storage, and disposal services (including capacity), and the availability of necessary equipment and skilled workers to implement the technology," is also considered in the initial screening.

Effectiveness refers to the ability of the process option to perform as part of a comprehensive remediation plan to meet RAOs under the conditions and limitations present at site. Additionally, the NCP (40 CFR 300) defines effectiveness as the "degree to which an alternative reduces toxicity, mobility, or volume through treatment; minimizes residual risk; affords long-term protection; complies with ARARs; minimizes short-term impacts; and how quickly it achieves protection." This is a relative measure for comparison of

process options that perform the same or similar functions. Section 4.2.5 of the CERCLA RI/FS Guidance (EPA/540/G-89/004) states that the evaluation of process options with respect to effectiveness should focus on: "(1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the remedial action objectives; (2) the potential impacts to HHE during the construction and implementation phase; and (3) how proven and reliable the process is with respect to the contaminants and conditions at the site."

For the initial screening of technology types and process options, the cost criterion is relative. It compares processes and technologies that perform similar functions and have similar effectiveness. Section 4.2.5 of the CERCLA RI/FS Guidance (EPA/540/G-89/004) states that "cost plays a limited role in the screening of process options. Relative capital and O&M costs are used rather than detailed estimates. At this stage in the process, the cost analysis is made on the basis of engineering judgment, and each process is evaluated as to whether costs are high, low, or medium relative to other process options in the same technology type." For this evaluation, cost is used to screen out process options that have a high relative cost if there are other choices that perform similar functions with similar effectiveness. The cost criterion includes a cursory consideration of the rough order of magnitude costs of construction and any long-term costs to operate and maintain the technologies.

Technologies that are not technically feasible based on implementability, effectiveness, and cost were screened out. Technical implementability is the first screening criteria evaluated as part of this process, per EPA guidance. However, for technologies with significant technical implementability challenges, an evaluation of effectiveness and cost was still completed to allow for a more complete evaluation. Technologies that were considered technically impracticable based on unsuccessful case studies at the site, challenges associated with existing site conditions (lithology), a potential increased risk to worker safety, or increased complexity as compared to other technologies of comparable effectiveness were screened out. Technologies were also removed from further consideration if they were considered to have limited treatment effectiveness for the specified COPC or performance uncertainties. Appendix I provides a thorough discussion of the technologies not retained, including a detailed screening rationale. Remedial technology types and process options considered viable for remediating contaminated soil at 100-K are carried forward into the development (Chapter 9) and detailed analysis of alternatives (Chapter 10). The list of retained options should be considered dynamic, flexible, and subject to revision based on subsequent design investigation findings, results of treatability studies, or technological developments. An evaluation of the state and potential full-scale application of innovative technologies that were not retained may also be considered during the five-year review process once additional information on these technologies becomes available.

8.3.2.1 Evaluation of Technologies and Selection of Representative Technologies for Waste Site Contamination

For remediation of waste sites (Table 8-6) at 100-K, the following response actions were retained to remove contaminants or interrupt the exposure pathway to receptors:

- Institutional controls—provides controls during remediation to interrupt the exposure pathway
- Standard excavation—provides for removal of contaminants
- Deep excavation—provides for removal of contaminants
- Onsite landfill (ERDF) disposal—provides for removal of contaminants
- In situ surface bioremediation (land farming)—provides for treatment of contaminants

- In situ biological reduction—provides for treatment of contaminants
- In situ bioventing—provides for treatment of contaminants
- Delivery of liquid amendments through surface infiltration (biological reduction) and vertical wells (bioventing)—provides for removal of contaminants from the vadose zone and treatment through groundwater pump-and-treat
- Soil flushing (vadose zone, water)—provides controls during remediation to interrupt the exposure pathway
- Surface barrier—provides engineered structure to interrupt the exposure pathway

The "No Action" GRA does not provide capability to remove contaminants or interrupt the exposure pathway to receptors but is also retained per the NCP (40 CFR 300).

8.3.2.2 Evaluation of Technologies and Selection of Representative Technologies for Groundwater Contamination

For treatment of contaminated groundwater (Table 8-7) at 100-K, the following response actions and were retained to remove contaminants or interrupt the exposure pathway to receptors:

- Institutional controls—provides controls during remediation to interrupt the exposure pathway
- Pump-and-treat—provides for treatment of contaminants
  - Collection through groundwater extraction system
  - Ex situ ion exchange
  - Air stripping (for carbon-14)
  - Groundwater injection wells discharge
  - Discharge through surface infiltration
  - Discharge through beneficial reuse of treated water
- In situ biological treatment (anaerobic) through liquid substrate—provides for treatment of contaminants
- Flushing—saturated zone, water—provides for treatment of contaminants as a component of pump-and-treat
- Delivery of amendments through surface infiltration—provides for treatment of contaminants
- Vertical wells—provides for treatment of contaminants as a component of pump-and-treat
- Reactive chemical barrier (existing ISRM)—provides for treatment of contaminants
- Hydraulic containment via extraction—provides engineered system to interrupt the exposure pathway

The "No Action" GRA does not provide capability to remove contaminants or interrupt the exposure pathway to receptors but is also retained per the NCP (40 CFR 300).

Figures 8-5 through 8-22 present specific information on technologies that have been retained. For 100-K, Chapter 9 presents technologies that are applicable for each waste site type group, which will be developed into alternatives. Appendix I provides a thorough discussion of the technologies not retained. This appendix describes each technology, followed by relevant case studies and the screening rationale.

Standard Excavation

Key Components

- Completed using standard earthmoving equipment.
- Conventional open-pit (standard) excavation limited to approximately 20 feet below ground surface; standard excavation typically done to 15 feet at Hanford.
- Extent of excavation required can be determined using an observational approach.
- Clean overburden soil is removed and stockpiled.
- Contaminated soil is removed and segregated to determine disposal or treatment requirement, or direct-loaded into containers for disposal.
- Confirmation sampling can be performed to verify cleanup to RAOs.
- Excavations are backfilled and compacted using clean overburden and borrow soil.

Shallow excavation at 100-B-19.

Examples of Relevant Experience

- Removal, treatment, and disposal (RTD) has been selected as a remedial alternative in previous 100 Area decision documents. Full-scale remediation in the 100 Areas using RTD began in July 1996. Over one million tons of contaminated soil and debris have been disposed of. *(EPA/ROD/R10-99/039)*
- Excavations completed at Trenches 216-B-26 and 216-B-53A and at 216-B-14 Crib for Sr-90 and Cs-137 bearing soils. *(HNF-36881)*
- Uranium-contaminated sediments at Process Trench 316-5 were also excavated. *(WHC-SA-2062-FP)*

Risk Reduction Mechanism

- Contaminated materials removed, eliminating source of exposure.
- Mitigates further migration of contaminants to groundwater.

Screening Criteria *(dashed line indicates range)*

	Low	Moderate	High
Relative Effectiveness			
Relative Implementability			
Relative Capital Cost			
Relative O&M Cost	*No associated costs.*		

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Figure 8-5. Standard Excavation

Deep Excavation

Key Components

- Excavation using standard equipment, requiring implementation of complex mechanisms such as shoring or lay backs to provide stability.
- Excavation complexity increases with greater depth.
- Requires careful evaluation of the side walls and anchoring systems selected to support the excavation, including stability calculations.
- Clean overburden soil is removed and stockpiled.
- Excavated soil is segregated to determine disposal or treatment requirements.
- Confirmation sampling can be performed to verify cleanup to RAOs and extent of excavation required.
- Excavations are backfilled and compacted using clean overburden and borrow soil.

Deep excavation at 100-B-27.

Examples of Relevant Experience

- Removal, treatment, and disposal (RTD) has been selected as a remedial alternative in previous 100 Area decision documents. Full-scale remediation in the 100 Areas using RTD began in July 1996. Over one million tons of contaminated soil and debris have been disposed of. *(EPA/ROD/R10-99/039)*

Risk Reduction Mechanism

- Contaminant sources in deep vadose zone soils are physically removed.
- Mitigates further migration of contaminants to groundwater.

Screening Criteria *(dashed line indicates range)*

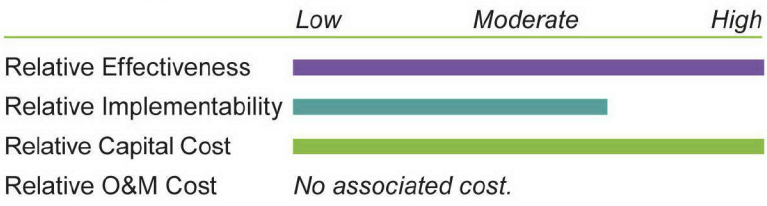

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Figure 8-6. Deep Excavation

On-Site Disposal: Environmental Restoration Disposal Facility (ERDF)

Key Components

- Contaminated soil and waste material transported from waste site to on-site disposal facility at Hanford—Environmental Restoration Disposal Facility (ERDF).
- Treatment (*e.g.,* macro-encapsulation) performed at the facility as required to meet land disposal restrictions (LDR).
- Engineered to meet appropriate performance standards under 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," and meet minimum technical requirements for landfills under WAC 173-303-665, "Landfills."
- Facility can accept the majority of remediation waste streams. Liquid wastes that cannot be solidified and certain LDR wastes that cannot be accepted would need to be sent off-site for disposal.
- ERDF consists of a series of disposal areas (cells). Each pair of cells is 70 feet deep, 500 feet by 1,000 feet at the base, and over 1,400 feet wide at the top.
- Cell pairs have a disposal capacity of 3 million tons. As of June 2010, over 11 million tons of contaminated material have been deposited into ERDF. *(www.handford.gov/page.cfm/ERDF)*

Hanford's Environmental Restoration Disposal Facility

Examples of Relevant Experience

- Hanford's ERDF, in the 200 West Area, is a landfill regulated by USEPA and capable of receiving about 16,000,000 tons of waste.
- Accepts low-level radioactive, hazardous, and mixed wastes that are generated during the cleanup activities at the Hanford Site.
- First started operations in 1996. Over 11,000,000 tons of contaminated soil and debris have been disposed at the facility. *(RLI-D02-14)*

Risk Reduction Mechanism

- Waste material is placed in an engineered landfill with physical and regulatory controls to greatly restrict or eliminate environmental mobility.
- Waste material is consolidated at a single location. Risk reduction primarily achieved through excavation.

Screening Criteria *(dashed line indicates range)*

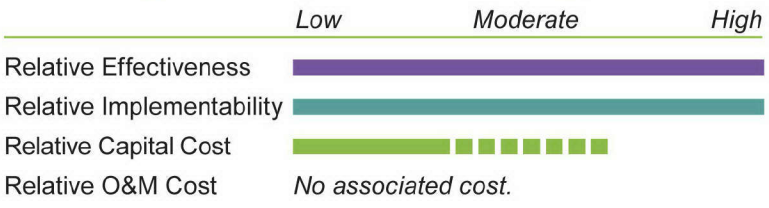

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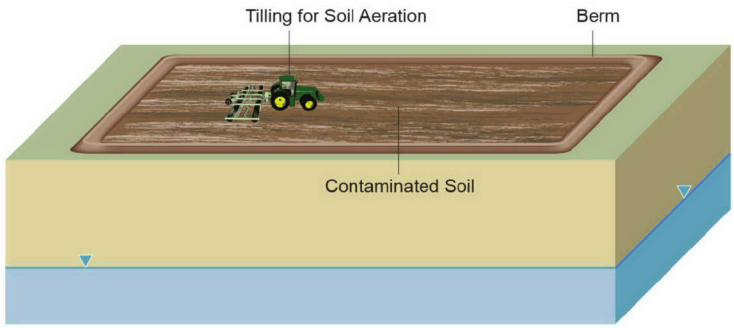
Figure 8-7. Onsite Disposal: The Environmental Restoration Disposal Facility

Surface Bioremediation-Landfarming (Vadose Zone)

Key Components

- Involves periodic tilling of soil to achieve aeration, adding moisture, and if necessary, nutrients to stimulate natural degradation at shallow depths.
- Organic compounds are degraded by indigenous or amended microorganisms.
- Extremely low soil moisture content and/or low temperatures may limit biodegradation rates.

Conceptual Schematic



Examples of Relevant Experience

- Surface soil bioremediation is performed at the Libby Superfund Site in Libby, MT. Soil contaminated with pentachlorophenol (PCP) and creosote (PAHs) is applied to cells in 9-inch lifts and treated until target contaminant levels are achieved within each lift. *(EPA/540/F-95/506A)*
- Soil bioremediation has been proven successful in treating petroleum hydrocarbons and other less volatile, biodegradable contaminants.

Risk Reduction Mechanism

- Biological treatment can degrade organic compounds to the less or non- toxic products.
- Can reduce volume by removing contaminants as they are completely degraded.
- Land treatment is a medium- long-term technology.

Screening Criteria *(dashed line indicates range)*

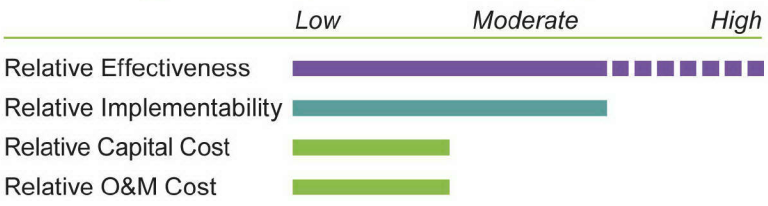


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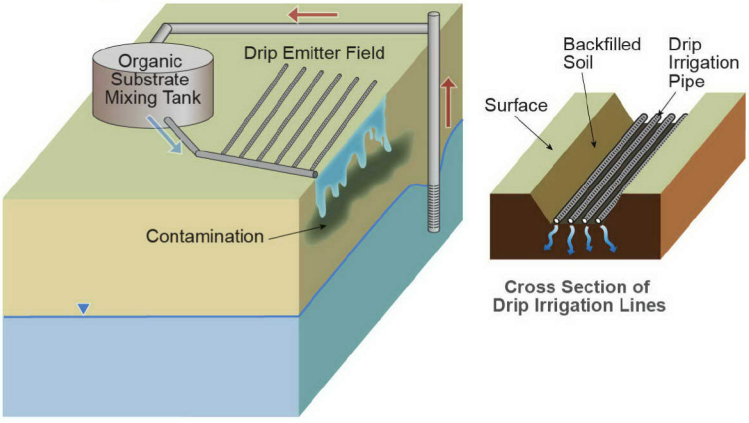
Figure 8-8. In Situ Surface Bioremediation (Land Farming)

In-Situ Biological Treatment (Vadose Zone)

Key Components

- Uses native microorganisms to reduce contaminants to less- or non-toxic compounds, either directly by the microbes through dissimilatory or enzymatic reduction, or indirectly by a reduced electron acceptor (*e.g.,* ferrous iron or sulfide).
- Natural process are enhanced by adding organic substrates (a carbon source) to stimulate microorganisms in the subsurface and change the geochemistry to anaerobic conditions.
- Localized temporary generation of secondary byproducts (reduced manganese, iron, and arsenic) should be expected.
- Organic substrate application methods include surface infiltration (shown in conceptual schematic), aqueous injection using wells, gas injection using wells, and soil mixing using solid reagents.
- Components for surface infiltration include:
  - Reagent tank
  - Subsurface drip irrigation system
  - Infiltration basin

Conceptual Schematic



Examples of Relevant Experience

- Treatability test is planned for evaluating the practicality of in situ bioremediation in the vadose zone at the 100 K West (100 KW) Area of the Hanford Site. Specifically, the test is designed to determine if chemically reducing conditions suitable for remediating hexavalent chromium contamination can be established by stimulating anaerobic microbes via infiltration of an organic nutrient solution from the ground surface. (report pending)

Risk Reduction Mechanism

- Biological treatment can reduce Cr(VI) to the less-toxic and less mobile Cr(III), and nitrate to nitrogen gas.
- Volume of Cr(III) will not change, but toxicity will be reduced.
- Can reduce contaminant volume by removing contaminants as they are completely degraded, and/or mobility and toxicity reduced by transforming contaminants to less-toxic and/or less soluble forms.

Screening Criteria *(dashed line indicates range)*

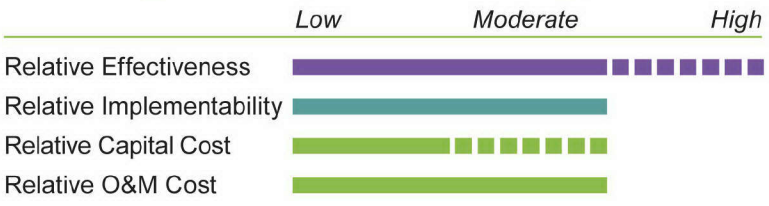


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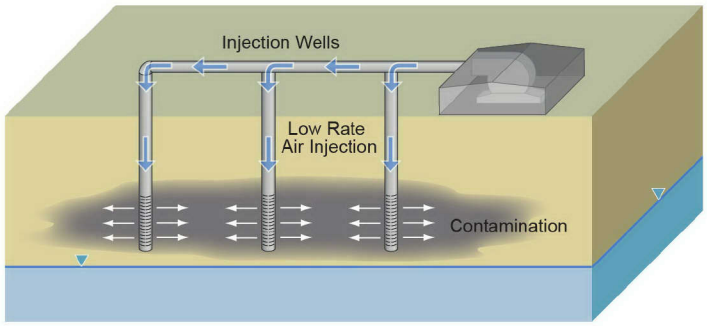
Figure 8-9. In Situ Biological Treatment (Vadose Zone)

Bioventing (Vadose Zone)

Key Components

- Involves the injection of oxygen (in air) through vertical wells at low flow rates to stimulate natural aerobic biodegradation of organic compounds in soil. Aerobically degradable compounds include petroleum hydrocarbons, non-chlorinated solvents, some pesticides, wood preservatives, etc.
- In addition to adsorbed organics, volatile compounds are biodegraded as vapors move through biologically active soil.
- Monitoring of off-gases may be required. Buildup of vapors may need to be extracted using a soil vapor extraction system.
- Extremely low soil moisture content and/or low temperatures may limit biodegradation rates.

Conceptual Schematic



Example of Relevant Experience

- A bioventing pilot study is being conducted at the 100-N Area (waste site UPR-100-N-17) to treat petroleum hydrocarbons in the shallow and deep vadose zone. Results of the study are pending.

Risk Reduction Mechanism

- Biological treatment can degrade organic compounds to the less- or non- toxic products.
- Can reduce volume by removing contaminants as they are completely degraded.

Screening Criteria *(dashed line indicates range)*

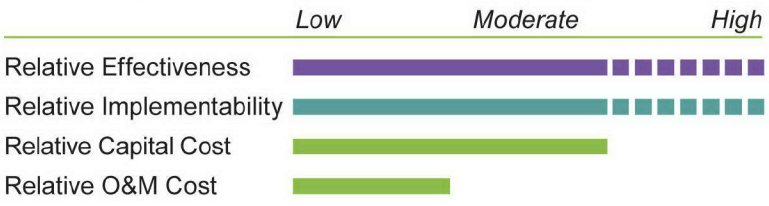


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Figure 8-10. In Situ Bioventing

Vertical Wells

Key Components

- Vertical wells can be used to inject reagents into groundwater, to treat contaminant plumes, extract groundwater, and monitor groundwater.
- Three methods typically used for drilling injection wells are rotosonic, air rotary-casing hammer, and hollow-stem auger.
- Soil profiling during drilling of vertical wells may serve to characterize lithology and contaminant distribution within the aquifer.
- For injection applications, injection reagents must be compatible with the mechanical components of the injection well system and natural formation of the aquifer.
- Site assessment and aquifer characterization may be required to determine suitability of vertical injection.

In this photo, workers prepare to begin drilling operations for wells at the 100-NR-2 operable unit. www.hanford.gov

Examples of Relevant Experience

Summary of Groundwater Pump-and-Treat Systems Operating at Hanford (2008-2009)

Pump and Treat System	Number of Extraction/ Injection Wells
100-DR-5[a]	4 Extraction / 1 Injection
100-HR-3[a]	10 Extraction / 4 Injection
100-KR-4[a]	10 Extraction / 5 Injection
100-KW[a]	7 Extraction / 3 Injection
100-KX[a]	14 Extraction / 9 Injection
200-ZP-1[b]	14 Extraction / 5 Injection
200-UP-1[b]	2 Extraction / 5 Injection

a) DOE/RL 2009 15. *Calendar Year 2008 Annual Summary Report for the 100 HR 3, 100 KR 4, and 100 NR 2 Pump and Treat Operations.*
b) DOE/RL-2010-11 Revision 1. *Hanford Site Groundwater Monitoring and Performance Report for 2009.*

Risk Reduction Mechanism

- Does not reduce risk as a stand-alone technology. Reduction in toxicity, mobility, and volume of contaminants is achieved through the injection of reagents that treat groundwater contaminants.

Screening Criteria *(dashed line indicates range)*

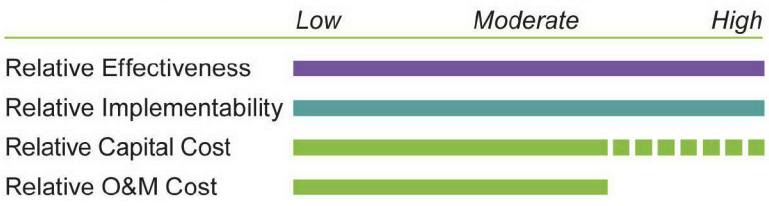

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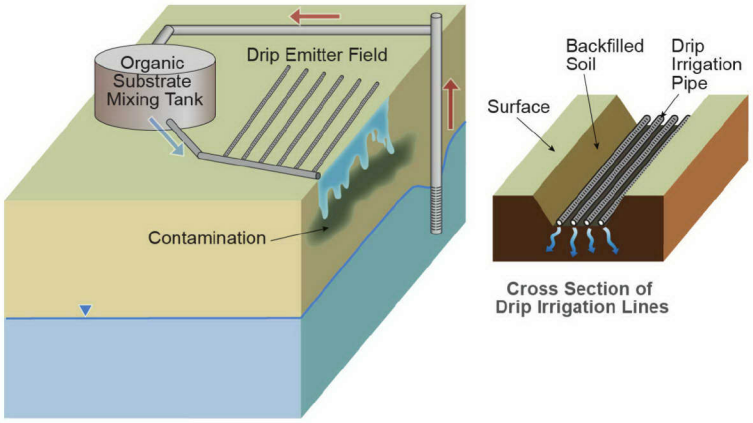
Figure 8-11. Vertical Wells

Surface Infiltration (Groundwater and Vadose Zone)

Key Components

- A delivery method that applies reagents (biological and chemical) to the ground surface to target remediation, primarily on the vadose zone.
- Surface infiltration can be done through drip irrigation (shown at right) and shallow-basin systems.
- Systems are generally designed to be 12 inches below the surface and covered for protection.

Conceptual Schematic



Examples of Relevant Experience

- An ongoing study in the 100-N area sequesters strontium-90 subsurface contamination using surface infiltration of an apatite solution. *(PNNL-18303)*
- PNNL conducted a surface infiltration application of phosphate at the 300 area for uranium. Results of the study are pending. *(PNNL Report Pending)*

Risk Reduction Mechanism

- Does not reduce risk as a stand-alone technology. Risk reduction is primarily achieved by reagent approach (chemical, biological, or physical reactions based on amendment delivered).

Screening Criteria Applies to Both Media

(dashed line indicates range)

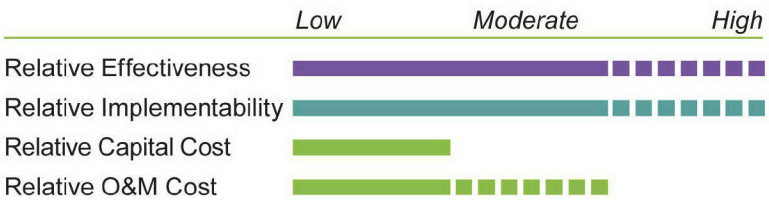


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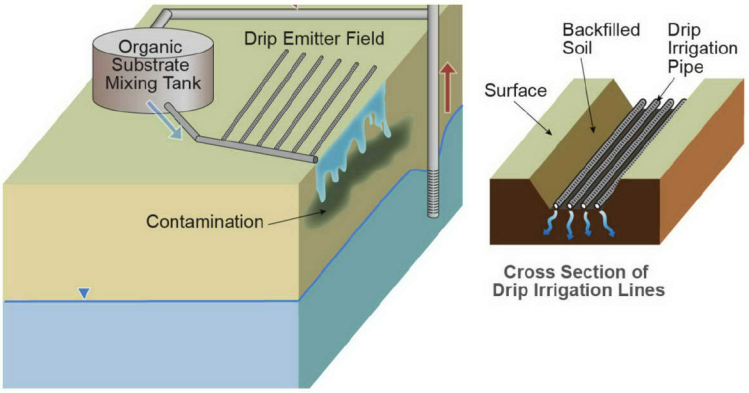
Figure 8-12. Surface Infiltration (Groundwater and Vadose Zone)

Soil Flushing – Vadose Zone, Water

Key Components

- Involves the infiltration of clean or treated water into a zone of contaminated soil to flush contaminants out of the vadose zone to the water table.
- Applicable for media impacted with contaminants with high to moderate solubility (*e.g.,* Cr(VI), Tc-99, uranium, nitrate, and possible C-14).
- Solubility-enhancing solutions may be added to enhance mobility.
- Infiltrating water with desorbed contaminants need to be captured and treated to meet discharge standards.
- Enhancement of conventional pump and treat with in-situ flushing of source area may speed site remediation and closure; however ineffective groundwater capture may create a larger groundwater plume.

Conceptual Schematic



Examples of Relevant Experience

- Soil flushing was used to treat soil and groundwater contaminated with Cr(VI) by United Chrome Products, Corvallis, OR. Delivery of solution was completed through two infiltration basins and one infiltration trench to flush Cr(VI) from the vadose zone to the water table. Extraction wells were used to recover the solution and extract groundwater. A 1998 report indicates 9.7 million gallons of impacted groundwater containing 26,732 pounds of Cr(VI) were removed in a 3-year period. *(TS-98-01)*

Risk Reduction Mechanism

- Toxicity and/or volume of source area in the vadose zone is reduced by mass transfer to groundwater.
- Reduction in toxicity, mobility, and volume of contaminants is achieved through a groundwater capture and treatment system.
- Treatment of impacted media in shallow soil may reduce direct contact risk and exposure to ecological receptors.

Screening Criteria *(dashed line indicates range)*

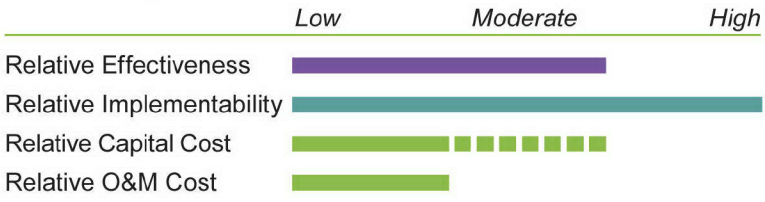


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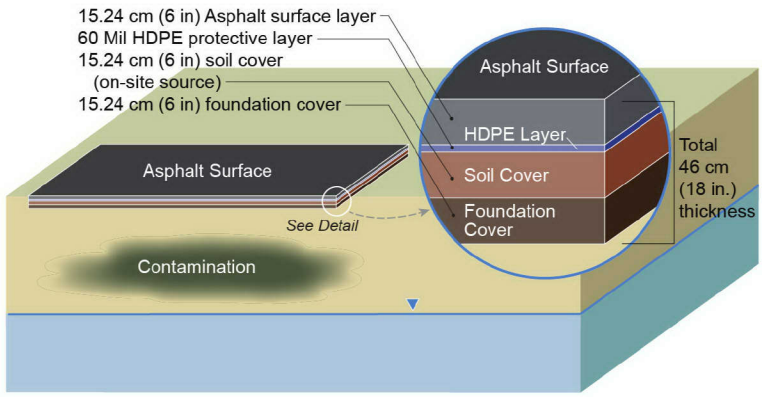
Figure 8-13. Soil Flushing—Vadose Zone, Water

Surface Barriers

Key Components

- Surface barriers are earthen and/or manufactured covers placed on the ground surface above contaminated media.
- Designed to be impermeable, to prevent surface water infiltration through the vadose zone, and to limit contaminant leaching to groundwater. May also prevent direct contact to contaminants.
- Types of surface barriers include: Modified RCRA Subtitle C and/or D, Asphalt/Concrete, Vegetative and the Hanford Barrier.
- Asphalt/Concrete caps (shown in conceptual schematic) can be placed around structures to remain in place (e.g., reactors) in the short term to promote drainage, prevent infiltration into possible sources below the reactors, and prevent exposure to contaminated soil.
- Excavation, handling, and transport of contaminated soil are reduced.
- Can also be implemented at the bottom of an excavation to limit infiltration through contaminated soil left in place. Implementation may require soil characterization and soil compaction tests.
- Periodic inspection and repair required.

Conceptual Schematic



Examples of Relevant Experience

- In 2010, approximately 1.8 acres of modified asphalt was placed over the TY Tank Farm with approximately 5 USTs suspected of leaking radioactive and hazardous chemical waste. The asphalt barrier was installed to prevent rain water and snow melt from infiltrating into the ground surface. *(www.hanfordnews.com/2010/08/13/15712/asphalt-being-laid-over-underground.html)*

Risk Reduction Mechanism

- Prevents surface water infiltration and reduces contaminant migration through vadose zone, limiting potential leaching to groundwater.
- When coupled with Institutional Controls, may reduce direct contact and exposure to ecological receptors.
- Toxicity of contaminants is not reduced.

Screening Criteria *(dashed line indicates range)*

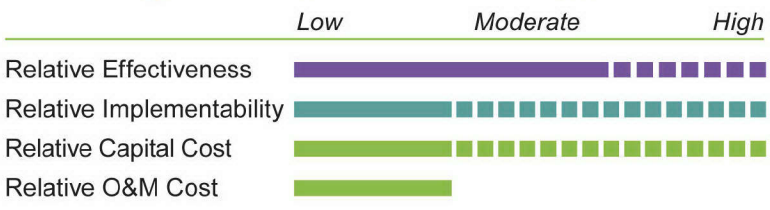


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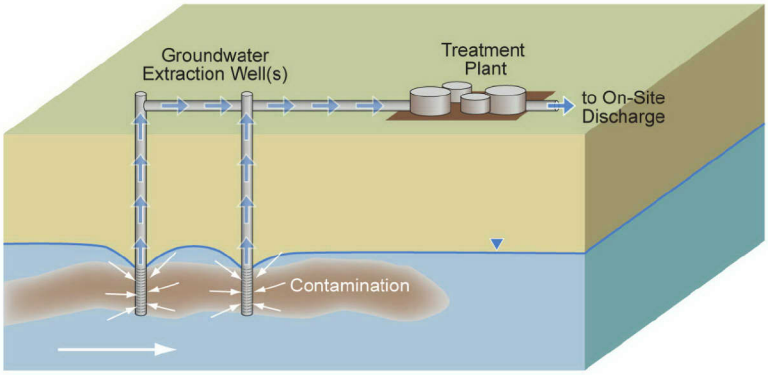
Figure 8-14. Surface Barrier

Groundwater Extraction System and On-Site Discharge

Key Components

- Involves continued operation of existing groundwater extraction systems with the potential to expand the system configuration based on remediation goals.
- Treated water is discharged on site.
- Groundwater extraction and on-site discharge are components of a pump-and-treat system, where ex-situ treatment of extracted groundwater can include bioreactors, ion exchange, air stripping, etc.
- Incorporates long-term groundwater monitoring to evaluate system performance, effectiveness, and compliance with remedial action objectives.

Conceptual Schematic



Examples of Relevant Experience

Summary of Groundwater Pump-and-Treat Systems Operating at Hanford (2008-2009)

Pump and Treat System	Startup Date	Contaminant	Number of Extraction/ Injection Wells
100-DR-5[a]	2004	Cr(VI)	4 Extraction / 1 Injection
100-HR-3[a]	1997	Cr(VI)	10 Extraction / 4 Injection
100-KR-4[a]	1997	Cr(VI)	10 Extraction / 5 Injection
100-KW[a]	2007	Cr(VI)	7 Extraction / 3 Injection
100-KX[a]	2008	Cr(VI)	14 Extraction / 9 Injection
200-ZP-1[b]	1994	PCE	14 Extraction / 5 Injection
200-UP-1[b]	1994	Carbon Tetrachloride, Nitrate, Tc-99, and U	2 Extraction / 5 Injection

a) DOE/RL 2009 15. *Calendar Year 2008 Annual Summary Report for the 100 HR 3, 100 KR 4, and 100 NR 2 Pump and Treat Operations.*
b) DOE/RL-2010-11 Revision 1. *Hanford Site Groundwater Monitoring and Performance Report for 2009.*

Risk Reduction Mechanism

- Extraction of groundwater removes contaminants from the subsurface and contains plume to prevent further migration.
- Contaminant volume, toxicity, and mobility are reduced through pump-and-treat process.

Screening Criteria *(dashed line indicates range)*

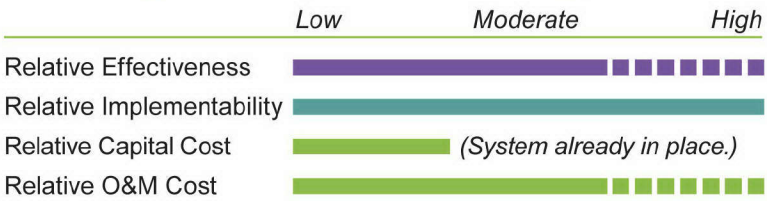


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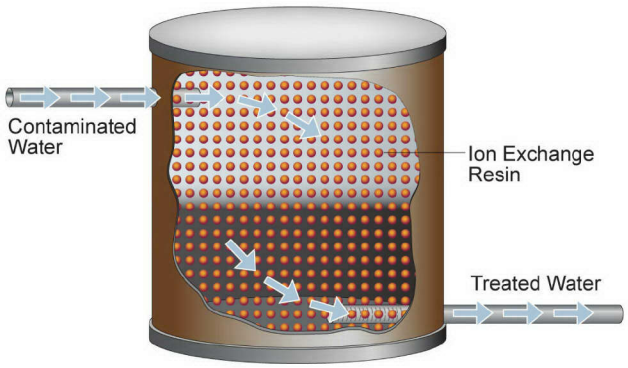
Figure 8-15. Groundwater Extraction System and Onsite Discharge

Ion Exchange

Key Components

- Ions are removed from an aqueous solution and replaced with innocuous ions from the exchange medium.
- Can remove dissolved metals and radionuclides from water.
- Exchange medium can be synthetic resins and inorganic or natural polymeric materials.
- Resins can be regenerated for reuse or disposed of.
- Ion exchange is a non-destructive technology (removal is achieved through mass transfer).

Conceptual Schematic



Examples of Relevant Experience

- Ion exchange (IX) is the current Hanford groundwater treatment for many pump-and-treat systems: *(DOE/RL-2010-11)*
  - 100-D/H Areas, including the new DR-5 system: Removed ~613 kg Cr(VI) through Calendar Year 2009 (CY09)
  - KW system: Removed ~80 kg Cr(VI) through CY09
  - 100-KR-4 system: Removed ~338 kg Cr(VI) through CY09
  - KX system: Removed ~44 kg Cr(VI) through CY09
  - 200-UP-1, 200-ZP-1, and 241-T systems

Risk Reduction Mechanism

- Contaminant is transferred to the ion exchange resin which ultimately requires disposal.
- Contaminant volume, toxicity, and migration are reduced through pump-and-treat process.

Screening Criteria *(dashed line indicates range)*

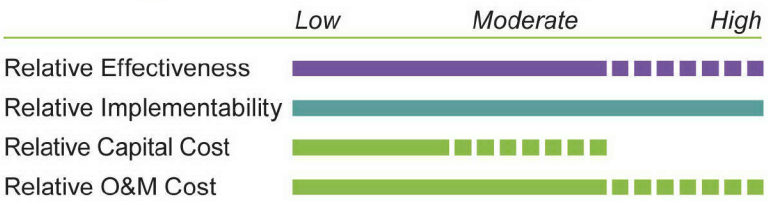


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Figure 8-16. Ion Exchange

Air Stripping

Key Components

- An ex-situ treatment technology for extracted groundwater.
- Air is passed through the contaminated water and volatile contaminants are stripped (volatilized) and transferred into the air stream.
- Stripper configurations include tray-strippers (shown at right) and packed-towers.
- Removal of C-14 may require pH adjustment.
- May required additives to prevent scaling or biological fouling.
- Off-gas treatment (*e.g.*, activated carbon, oxidizer, C-14 sorbtion, etc.) may be necessary to meet air emission standards.

Conceptual Schematic

Examples of Relevant Experience

- The Hanford 200-ZP-1 air stripper is successfully removing carbon tetrachloride (544 kg removed in CY2009)) *(DOE/RL-2010-11)*

Risk Reduction Mechanism

- Contaminant volume, toxicity, and mobility are reduced through pump-and-treat process.
- Air stripping is a mass-transfer technology and therefore does not reduce risk as a stand-alone technology.
- Contaminant is transferred from extracted groundwater into air, where further treatment may be required to meet emissions standards, possibly requiring media diposal (*e.g.,* activated carbon).

Screening Criteria *(dashed line indicates range)*

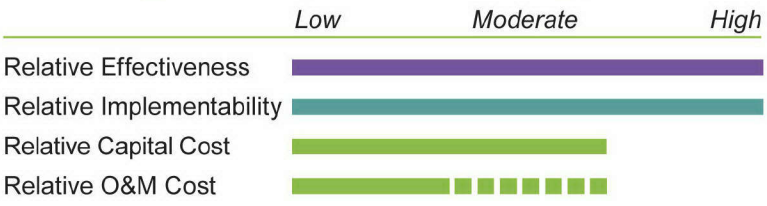

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Figure 8-17. Air Stripping

Beneficial Reuse of Treated Water

Key Components

- Discharge component of a groundwater extraction-and-treatment system.
- Treated water is discharged through an on-site beneficial use, such as dust control, etc.
- Return of treated groundwater to the subsurface may help to conserve groundwater as a resource or can be used to augment hydraulic containment or flush a contaminant source.

Dust suppression being used at a demolition site in the Hanford 200 North Area. www.hanford.gov

Examples of Relevant Experience

- In the 300 Area, water supply well (399-4-12) supplies water for the research aquariums in the 331 Building. The well has been in operation since approximately 1982. *(DOE/RL-2008-36)*

Risk Reduction Mechanism

- Does not reduce risk as a standalone technology.
- Contaminant volume and toxicity is reduced through pump-and-treatment process.

Screening Criteria *(dashed line indicates range)*

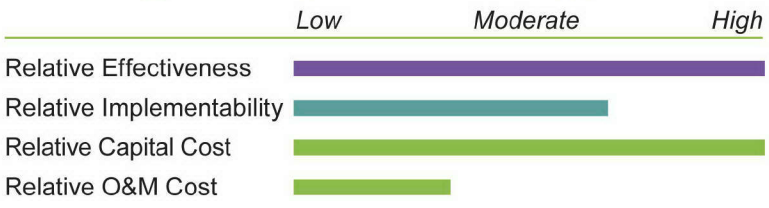

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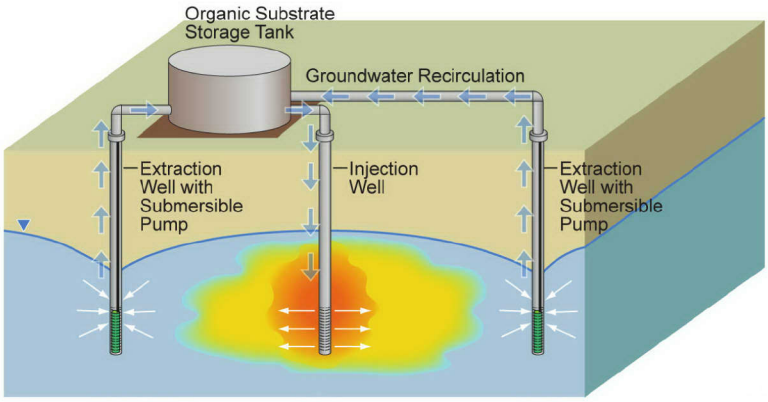
Figure 8-18. Beneficial Reuse of Treated Water

In-Situ Biological Treatment – Anaerobic (Groundwater)

Key Components

- Uses native microorganisms to reduce or break down the contaminants into less- or non-toxic substances.
- Natural process enhanced by adding organic substrates to stimulate anaerobic microorganisms in the subsurface.
- The addition of a recirculation system (extract and reinject groundwater) can enhance the subsurface delivery and increase the zone of influence.
- In-situ reduction of contaminants that are contained in the recycled groundwater reduces the need for more costly ex-situ treatment.
- Localized temporary generation of secondary byproducts (reduced manganese, iron, and arsenic) could be expected.

Conceptual Schematic



Examples of Relevant Experience

- A review of demonstration projects for in situ biological treatment of hexavalent chromium in groundwater is presented in the technology overview appendix (Appendix I).

Risk Reduction Mechanism

- Biological treatment can reduce Cr(VI) to the less-toxic and less-mobile Cr(III), and nitrate to nitrogen gas.
- Reduction of Tc-99 and uranium are potentially reversible.

Screening Criteria *(dashed line indicates range)*

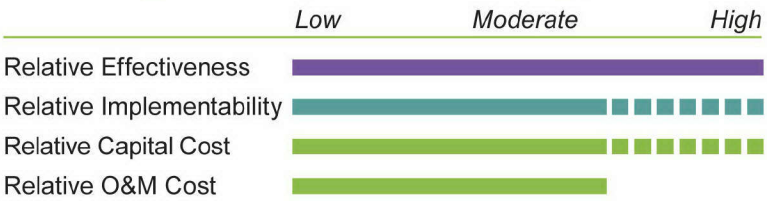


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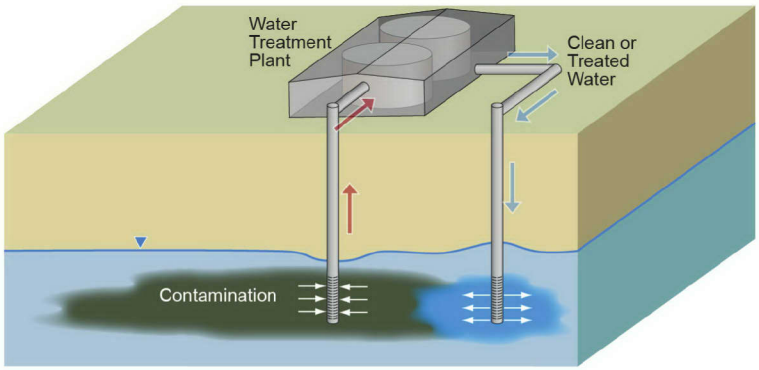
Figure 8-19. In Situ Biological Treatment—Anaerobic (Groundwater)

Flushing – Saturated Zone, Water

Key Components

- Involves the injection of clean or treated water into a zone of contaminated groundwater to expedite remediation of plume.
- Groundwater is captured and treated to meet discharge standards.
- Applicable for media impacted with contaminants with high to moderate solubility (*e.g.,* Cr(VI), Tc-99, uranium, nitrate, and possibly carbon-14).
- Effective groundwater capture is required to contain the plume.
- Groundwater flushing performance depends on residual contamination in lower-permeability layers, lenses, or sorbed to soil.

Conceptual Schematic



Examples of Relevant Experience

- At Topock Compressor Station, Needles, California, the U.S. Department of the Interior proposed water flushing as a preferred alternative for remediation of Cr(VI) in groundwater. This alternative involves injection of fresh and carbon-amended water to flush Cr(VI) and push the plume through in-situ biological treatment barriers located downgradient of the water injection wells. *(DOI060410A)*

Risk Reduction Mechanism

- Extraction of groundwater removes contaminants from the subsurface and contains plume to prevent further migration.
- Reduction in toxicity, mobility, and volume of contaminants is achieved through a groundwater capture and treatment system.

Screening Criteria *(dashed line indicates range)*

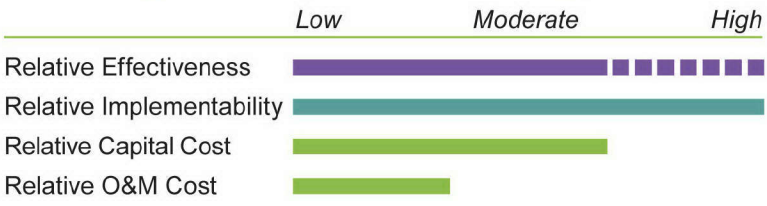


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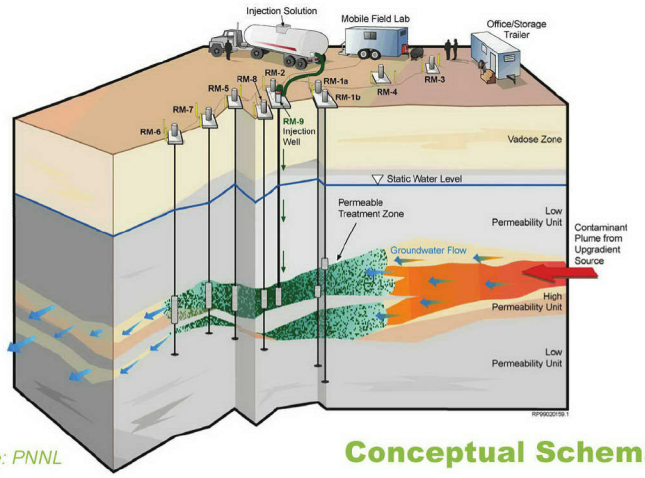
Figure 8-20. Flushing—Saturated Zone, Water

Reactive Chemical Barrier (In-Situ Redox Manipulation) (Groundwater)

Key Components

- Zone of chemically reactive material that transforms (reduces) contaminants in groundwater as it flows through.
- Reactive zone can be generated by a series of injection/recirculation wells or a trench that transects the groundwater flow pathway.
- Reactive material is a reducing chemical (*e.g.,* sodium dithionite or zero valent iron).
- Generation of secondary byproducts and/or break-through may occur.
- Occasional amendments/ applications may be necessary.
- Used to control migration; not effective in treating the bulk of the plume.
- Dispersing reactive material into the aquifer can make implementation complex. Varying hydraulic gradients, and varying water levels can reduce the effectiveness.



Source: PNNL

Conceptual Schematic

Examples of Relevant Experience

- Currently in use in Hanford 100 D; geochemical parameters indicate success in producing the desired Cr-reducing conditions; concentration reductions have been noted, but concentrations in downgradient wells have been variable (*i.e.,* some breakthrough has occurred). *(DOE/RL-2010-11)*

Risk Reduction Mechanism

- Risk reduction achieved through treatment. Risk reduction limited to zone of active treatment and further migration. Does not adequately reduce risk throughout the bulk of the plume.
- Chemical reagents transform (reduce) contaminant to non-or less-toxic compound [*e.g.,* Cr(VI) to Cr(III)]; generation of secondary byproducts may occur .
- ISRM acts as a barrier; when effective, reduces contaminant plume migration/mobility.

Screening Criteria *(dashed line indicates range)*

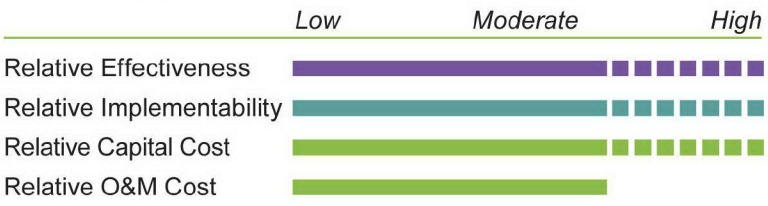


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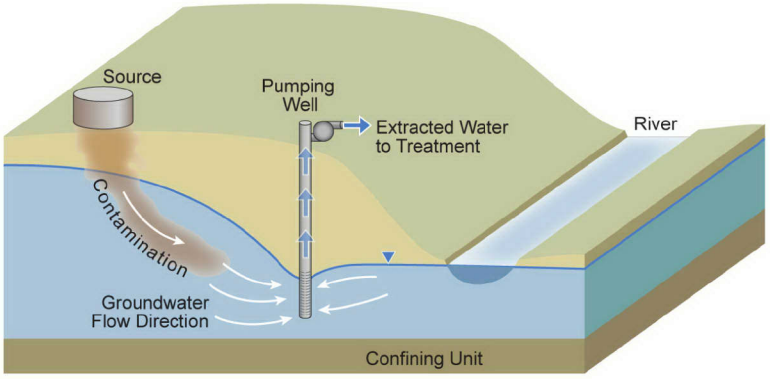
Figure 8-21. Reactive Chemical Barrier (In Situ Redox Manipulation) (Groundwater)

Hydraulic Containment via Extraction (Groundwater)

Key Components

- Extraction wells are used to pump groundwater from the plume edge to control contaminant migration.
- Changes groundwater flow characteristics and pulls contaminated groundwater towards the extraction wells.
- Removed groundwater will require treatment or proper disposal.

Conceptual Schematic



Examples of Relevant Experience

- At least eight pump-and-treat systems are successfully operating at Hanford to provide hydraulic containment in addition to removing contamination. Information regarding capture zone efficiency for each system can be found in *Hanford Site Groundwater Monitoring and Performance Report for 2009.* *(DOE/RL-2010-11)*

Risk Reduction Mechanism

- Reduces mobility by providing a barrier between the contaminated groundwater and the Columbia River.
- Reduces volume by removing dissolved phase contaminant mass; toxicity reduced by subsequent treatment at a temporary or permanent facility.

Screening Criteria *(dashed line indicates range)*

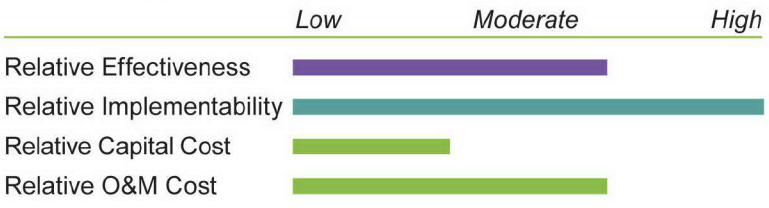


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Figure 8-22. Hydraulic Containment via Extraction (Groundwater)

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9 Development and Screening of Alternatives

This chapter discusses the development of remedial action alternatives for 100-K. Primary inputs for this process were the physical characteristics of the site (Chapter 3); waste site characterization information, contaminant transport mechanisms, and CSM (Chapters 4 and 5); the identified risks (Chapters 6 and 7); and the RAOs, target remediation areas, and the remedial technology screening results (Chapter 8).

In this chapter, the remedial technologies retained from the screening described in Section 8.3 are combined into remedial alternatives for 100-K that provide a range of technology groupings for combined waste site and groundwater remediation. With the exception of the No Action Alternative, the remedial alternatives were developed to target achievement of the RAOs by considering the CERCLA program goals and expectations identified in the NCP (40 CFR 300). The remedial alternatives presented in this chapter are carried forward for detailed and comparative evaluation in Chapter 10.

Highlights

- Remedial action alternatives were developed for 100-K that provide a range of technology groupings for combined waste site and groundwater remediation, in accordance with "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430) and CERCLA RI/FS Guidance (EPA/540/G-89/004).
- The Post-ROD To-Go sites require special consideration related to the development of alternatives. For development of alternatives and cost estimates for the FS, a preliminary evaluation of the risk drivers has been made. To deal with this uncertainty, a Decisional Logic Flow diagram will be followed based on available data and process knowledge. The final actions may change based on the decision logic and the actual risk drivers found.
- Treatment of Cr(VI) and carbon-14 is included in groundwater remediation.
- The remaining groundwater COCs lie largely within the extent of the hexavalent chromium plumes.
- Following are the resulting alternatives:
  - Alternative 1: No Action
  - Alternative 2: RTD and Groundwater Pump-and-Treat Optimized with Other Technologies
  - Alternative 3: RTD and Expanded Groundwater Treatment

9.1 Development of Remedial Alternatives

EPA considers the following expectations in developing appropriate remedial alternatives:

- To use treatment to address the principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- To use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable.
- To use a combination of methods, as appropriate, to achieve protection of HHE. In appropriate site situations, treatment of the principal threats posed by a site, with priority placed on treating waste that is liquid, highly toxic, or highly mobile, will be combined with engineering controls (such as containment) and ICs, as appropriate, for treatment residuals and untreated waste.
- To use ICs such as water use and deed restrictions, to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. ICs may be used during the conduct of the RI/FS and implementation of the remedial action and, where necessary, as a component of the completed remedy. The use of ICs shall not substitute for active response measures (e.g., treatment and/or containment of source material, restoration of groundwaters to their beneficial uses) as the sole remedy unless such active measures are determined not to be practicable, based on the balancing of trade-offs among alternatives that is conducted during the selection of remedy.

- To consider using innovative technology when such technology offers the potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs for similar levels of performance than demonstrated technologies.

- To return usable groundwaters to their beneficial uses wherever practicable, within a time frame that is reasonable, given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction.

- For groundwater response actions, a limited number of remedial alternatives should be developed to achieve site-specific remediation levels within different restoration periods using one or more technologies. Where the contaminated groundwater is not currently used, or an alternate water source is readily available, and there is no near-term future need for the resource, it will likely be appropriate to consider a longer time frame for achieving restoration cleanup levels (*Rules of Thumb for Superfund Remedy Selection* [EPA 540-R-97-013]).

- The No Action Alternative (no further action if some removal or remedial action has already occurred at a site) shall also be developed.

The purpose of the remedy selection process is to implement remedies that eliminate, reduce, or control risks to human health and the environment.

The remedial alternatives for 100-K have been developed to encompass all waste sites carried forward and groundwater plumes within 100-K. This section briefly summarizes the target remediation areas so the alternative development can focus on the specific areas and COCs at 100-K and integrate the remedial alternatives for waste sites and groundwater.

9.1.1 Waste Sites

As presented in Table 8-5, 116 waste sites have been included for evaluation in the FS. Development of the alternative components for the particular waste sites was based on their type of risk exceedances.

As discussed in Chapter 7, four waste sites that have undergone interim actions did not achieve the ecological-risk PRG for mercury in shallow samples (100-K-30, 100-K-31, 100-K-32, and 100-K-33). Waste sites 100-K-30 and 100-K-31 are within the remediation footprint of Post-ROD To-Go site 120-KE-1. Waste sites 100-K-32 and 100-K-33 are within the remediation footprint of Pre-ROD To-Go site 120-KW-1. Individual alternatives for 100-K-30, 10-K-31, 100-K-32, and 100-K-33 were not developed.

As identified in Section 8.2.1.1, the 46 Pre-ROD To-Go waste sites that do not meet the final PRGs after completion of remediation under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039), will be evaluated for further remedial actions following the Post-ROD To-Go decision logic approach identified as follows. The selected remedial actions will be considered minor modifications to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL fact sheet, with public notification. These waste sites will be added to the appropriate remedial design/remedial action work plan (RD/RAWP) for implementation of the remedial action.

The 66 Post-ROD To-Go waste sites require special consideration related to the development of alternatives. These sites have limited site-specific data so the primary risk drivers have not been quantitatively determined through a risk assessment evaluation. Consequently, it is not possible to definitively determine the remedial components for all the alternatives. To deal with this uncertainty, a decision logic approach has been developed. The heart of this approach will be the application of a

decision process that will be documented in flow diagrams contained in the final ROD and followed during implementation. The decisions will be based on what is known about the site, and the results of design and verification sampling. The final actions taken will depend on the risk drivers that are present. The selected remedial actions will be considered minor modifications to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL fact sheet, with public notification. Section 9.2 discusses the alternative-specific logic flow diagrams for each alternative.

To allow the development of the remedial alternatives and conceptual designs adequate for cost estimating for the 66 Post-ROD To-Go sites, a preliminary evaluation of the risk drivers has been made based on knowledge of the process that was performed at the sites and remediation results at similar sites in the River Corridor. It is important to note that the term COC is used, given that the actions proposed in this section would be taken after the ROD is signed. One or more of the following risk drivers were assumed for each site:

- Human health direct contact risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
- Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
- Groundwater/surface water protection risk for Cr(VI)
- Groundwater/surface water protection risk for other COCs

Additional waste site groups considered in the alternative analysis include the following:

- **Pre-ROD To-Go Sites:** waste sites currently being remediated under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) or are anticipated to be by the time the final ROD is signed. These waste sites are denoted as "Pre-ROD To-Go Sites" in Table 8-5. For this analysis, it has been assumed that the interim actions will achieve the required standards, so no additional actions will be required. If analysis of verification data suggests that these waste sites have exceedances for any of the risk drivers, they will be dealt with after the ROD is finalized as a Post-ROD To-Go site as described in Section 8.2.1.1.

- **Sites near Reactors:** waste sites where remedial actions are currently limited due to proximity of the site to the reactor. After the reactors are removed, these sites will be dealt with as the Post-ROD To-Go sites.

9.1.2 Groundwater

Section 8.2.1.2 presented the COCs for groundwater at 100-K. Figures 4-26, 4-27, and 4-28 illustrate areas exceeding groundwater PRGs for Cr(VI). Total chromium follows the same pattern as Cr(VI). Nitrate, tritium, carbon-14, and Sr-90 distribution are illustrated in Figures 4-45, 4-54, 4-63, and 4-70, respectively.

The groundwater COCs lie largely within the extent of the hexavalent chromium plumes. The extraction well network installed for the pump-and-treat systems for remediating the hexavalent chromium plumes will capture these contaminants. Alternatives development include the following approaches:

- Carbon-14 will be treated where it is extracted from groundwater extraction wells at concentrations greater than the DWS. Appendix F presents groundwater modeling runs that were performed with this approach to evaluate the fate of carbon-14. Carbon-14 is found mainly in K-West and at low concentrations in a small area in K-East. In both areas, the plume is within the capture zone of the recovery wells and plume migration is sufficiently controlled. Modeling results suggest that carbon-14 concentrations will decline over time and recovery of the plume is expected.

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- Tritium, Nitrate, Strontium-90, and TCE are being co-extracted from groundwater, along with the chromium and carbon-14 plumes, and will achieve DWS upon injection.

- Total chromium is a COC (Section 8.2.1.2). However, since the vast majority of total chromium in groundwater at the geochemical conditions at the site is likely Cr(VI), it will not be specifically addressed in the alternatives. Cr(III), the only other form of chromium that is likely to be present, has a very low solubility, and is not likely to exist in the groundwater. Achieving the Cr(VI) standards will also result in the total chromium standard being achieved, since they are lower than the total chromium.

- Remedy performance monitoring is conducted to evaluate effectiveness of the alternative to attain the cleanup levels as described in section 9.2.3.5.

As part of the development and evaluation of the groundwater alternatives, a groundwater model has been used as an evaluation and conceptual design tool. Groundwater flow and transport simulations and particle tracking analyses were performed for each conceptual design to determine the feasibility of each design. The model was also used to perform a limited amount of optimization of well locations and pumping schemes, including pumping schemes to achieve groundwater remediation within the period to meet TPA target milestones for remediation for groundwater. However, the conceptual designs developed for this FS are not final. They will be updated with additional modeling during the final design phase after the final ROD is prepared.

The groundwater flow model is constructed using the USGS modular groundwater flow model MODFLOW. Particle tracking was performed using the USGS program MODPATH. To simulate the contaminant plume migrations, the model MT3DMS was used. Model development and calibration is documented in a comprehensive modeling report (*Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* [SGW-46279]). The results of the groundwater alternative modeling are included in Appendix F. These supplemental documents also discuss the uncertainty with the model results due to variability in subsurface conditions and other factors.

9.1.3 Orchard Lands

The River Corridor includes approximately 3,359 ha (8,300 ac) of historical (pre-Hanford) farmsteads of which approximately 2,023 ha (5,000 ac) were cultivated as orchards. A 90-acre orchard existed within the boundaries of 100-K. Lead arsenate was commonly applied as a pesticide within orchards. This type of application has been demonstrated to often result in low-to-moderate concentration, shallow-soil contamination that is dispersed over large areas (area-wide contamination). Hanford operations resulted in some waste sites being located within, or intersecting, orchard land boundaries.

Ecology generally views arsenic concentrations of up to 100 ppm and lead concentrations of up to 500 to 700 ppm as “low-to-moderate” levels of contamination in soils at schools, childcare centers, and residences. For properties where exposure of children is less likely or less frequent, such as commercial properties, parks, and camps, arsenic concentrations of up to 200 ppm and lead concentrations of up to 700 to 1,000 ppm are within the low-to-moderate range (e.g., Background Information on Area-Wide Soil Contamination” in Ecology’s Area-Wide Soil Contamination Toolbox [Ecology, 2006]). For comparison, unrestricted site use cleanup levels for arsenic and lead under MTCA are 20 and 250 ppm, respectively. Ecology has already approved a number of cleanup actions at sites where children had the potential to be exposed to area-wide contamination (e.g., schools, residences, childcares, parks) that use the 20 mg/kg Method A value as a trigger for cleanup. Additional information is available from Department of Ecology State of Washington web site: http://www.ecy.wa.gov/programs/tcp/area_wide/area_wide_hp.html.

In 2001/2002, Ecology collected surface soil from six orchard areas in the River Corridor and reported concentrations for arsenic up to 270 ppm and lead up to1900 ppm. A strong correlation was identified between lead and arsenic results. Additional subsurface sampling (up to approximately 0.5 m (1.5 ft) bgs) was performed at the locations of the highest concentrations. Results for the subsurface samples generally declined with depth, though significantly more so for lead than arsenic. Arsenic concentrations at the maximum sample depths were above 20 ppm while lead concentrations were slightly above background. The study also noted that the measured lead and arsenic concentrations were generally similar to other former orchard areas within Washington and elsewhere in the United States. More recent characterization activities have reported arsenic concentrations up to 311 ppm and lead concentrations up to 804 ppm.

Historical orchard lands within the River Corridor that have not been impacted by waste disposal activities or releases related to Hanford Site operations are not identified as waste sites and remedial alternatives are not evaluated in feasibility studies. These lands will be managed and addressed consistent with area wide soil contamination practices in other parts of Washington State (e.g., *Area-Wide Task Force Report* [Ecology, 2003]) taking into consideration land use. Management of these lands includes the use of institutional controls to reduce potential for exposure. A rough order-of-magnitude cost to excavate and dispose of contaminated soil within 100-K orchard lands is $55 million with ecological disturbance of 90 ac of land along the river. If applied across the River Corridor, the cost might exceed $3 billion and disturb many thousands of acres.

Where Hanford operations have resulted in waste sites that are collocated with former orchard areas, the waste sites are addressed in the feasibility studies. Investigation and/or remediation of each waste site extends only to the waste site boundary and not into surrounding or underlying soil contamination resulting from former orchard use.

9.2 Description of Remedial Alternatives

As suggested by CERCLA RI/FS Guidance (EPA/540/G-89/004), alternatives were developed incorporating process options and technologies retained in Chapter 8 and include an appropriate range of waste management options to ensure the protection of HHE. In addition, per EPA guidance, the alternatives were assembled to address contamination for impacted media at the entire 100-K area (e.g., waste sites and groundwater combined in each alternative).

As discussed in Section 5.6.3, active groundwater remediation using the current pump-and-treat systems would have to be carried out through 2087, with operating costs of over $400 million in discounted dollars, to achieve groundwater RAOs. DOE does not consider active groundwater remediation through 2087 to be consistent with program commitments and alternatives are developed to complete groundwater remediation by 2037.

Each alternative was developed based on the strategy presented in the following subsections. Table 9-1 summarizes the components that are included in each alternative, and Appendix J summarizes the remedial components of the alternatives for each waste site.

The text presented in this section provides a general description of the components of each alternative. The conceptual designs of the components are present in tabular form, and a pictorial summary of each alternative is provided.

The conceptual designs presented here were developed to the level required to prepare a cost estimate that will allow comparison of the alternatives. The cost estimate accuracy recommended in CERCLA RI/FS Guidance [EPA/540/G-89/004]) is a range of -30 to +50 percent. Significantly, more detail on the selected remedy for

100-K will be developed during the design phase, after the ROD is finalized. An RD/RAWP will be developed to discuss in detail the design of the specific components for each waste site and groundwater plume.

The Post-ROD To-Go sites require special consideration related to the development of alternatives. These sites have limited site-specific data, so the primary risk drivers have not been quantitatively determined through a risk assessment evaluation. Decision logic flowcharts have been developed for Alternatives 2 and 3 to guide the selection of a remedial action that is appropriate for the waste site. This process includes formulating a decision based on what is known, and the results of design and verification sampling as the action proceeds. The actions taken will depend on the risk drivers that are found. This decision process will be documented in the ROD.

The decision process that will be implemented for the groundwater remedies to deal with the uncertainty in groundwater conditions is continuous RPO. Adjustments to remedial actions, among the actions identified in the ROD, will occur based on continuous review of the performance of selected remedies. Changes to selected remedial actions are considered minor modifications to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL fact sheet, with public notification. The affected groundwater areas will be identified in the appropriate RD/RAWP for implementation of the remedial action.

Additionally, the waste site and groundwater remedial action will be evaluated as part of the five-year review process. The five-year review will assess the remedy effectiveness and determine if additional or altered actions are necessary.

9.2.1 Alternative 1—No Action Alternative

The NCP (Remedial Investigation/Feasibility Study and Selection of Remedy" [40 CFR 300.430(e)(6)]) requires consideration of a No Action Alternative. The No Action Alternative, which serves as a baseline for evaluating other remediation action alternatives, is retained throughout the FS process. No action means that no remediation would be implemented to alter the existing conditions. For this alternative, it has been assumed that all site remedial activities and interim actions (with the possible exception of backfilling any open excavations that are not safe) will be discontinued in December 2012. This includes ceasing operation of the existing KR-4, KW, and KX pump-and-treat systems and any additional monitoring. No conceptual designs or cost estimates are prepared for Alternative 1 because no actions are proposed.

Figures 9-1 and 9-2 present the groundwater model prediction of Cr(VI) and nitrate for this alternative at years 2012, 2020, 2037, and 2087. Groundwater model predictions to 2087 have been developed to illustrate the groundwater plume behavior at 75 years. The modeled fate of the other contaminants of interest is presented in Appendix F. Since the pump-and-treat systems are shut down after 2012, the containment of the plume along the river that is obvious at 2012 is lost, as can be seen in the 2020 model prediction. Some mass removal is predicted to occur via natural flushing, as can be seen in the changes in concentrations out to 2087. However, relatively large areas with greater than 10 μg/L Cr(VI) are predicted to remain at 2087. For nitrate (Figure 9-2), the K-West plume migrates toward the river in 2037 and has mostly dissipated by 2087.

Table 9-1. Summary of Waste Site and Groundwater Alternative Components

Type of Exceedance (Post-ROD To-Go Sites)	Waste Site Vadose Zone Alternative Components								Groundwater Alternative Components					
	No Action/No Further Action	Institutional Controls[b]	RTD[c]	Bioinfiltration[e]	Soil Flushing—Vadose Zone, Water[f]	Temporary Surface Barrier[g]	Land Farming[h]	Bioventing[h]	No Action	Institutional Controls[b]	P&T[i]	Ex Situ Ion Exchange	Bioinjection[j]	Air Stripping for Carbon-14
Alternative 1														
Human health direct contact risk in shallow soil	X													
Ecological risk in shallow soil	X													
GWP/SWP risk likely for Cr(VI)	X													
GWP/SWP risk likely for Other COCs	X													
Pre-ROD To-Go sites	X													
Sites near reactors[a]	X													
Groundwater—Cr(VI) and carbon-14									x					
Alternative 2														
Human health direct contact risk in shallow soil			X[d]				X	X						
Ecological risk likely in shallow soil			X[d]											
GWP/SWP risk likely for Cr(VI)		X	X	X	X									
GWP/SWP risk likely for Other COCs		X	X		X									
Pre-ROD To-Go sites	X													
Sites near reactors[a]						X								
Groundwater—Cr(VI), carbon-14, and tritium										X	X	X	X	X
Alternative 3														
Human health direct contact risk in shallow soil			X[d]											
Ecological risk in shallow soil			X[d]											
GWP/SWP risk likely for Cr(VI)		X	X											
GWP/SWP risk likely for Other COCs		X	X											
Pre-ROD To-Go sites	X													
Sites near reactors[a]						X								
Groundwater—Cr(VI), carbon-14, and tritium										X	X	X		X

Table 9-1. Summary of Waste Site and Groundwater Alternative Components

Type of Exceedance (Post-ROD To-Go Sites)	Waste Site Vadose Zone Alternative Components								Groundwater Alternative Components					
	No Action/No Further Action	Institutional Controls[b]	RTD[c]	Bioinfiltration[e]	Soil Flushing—Vadose Zone, Water[f]	Temporary Surface Barrier[g]	Land Farming[h]	Bioventing[h]	No Action	Institutional Controls[b]	P&T[i]	Ex Situ Ion Exchange	Bioinjection[j]	Air Stripping for Carbon-14

a. Temporary surface barriers will be in place up to 75 years. Additional actions will be taken after the reactors are removed. The actions will be based on the risk drivers that exist, using the same process as other Post-ROD To-Go sites.

b. Additional information on institutional controls is presented in section 8.3.1.

c. Process options of RTD include removal through standard or deep excavation and disposal to ERDF. Also includes demolition of structures when required.

d. Excavation limited to 4.6 m (15 ft)

e. Process options of biological infiltration (bioinfiltration) include in situ biological reduction and delivery of liquid amendments through surface infiltration.

f. Soil flushing with water is applied to waste sites close to the Columbia River, to prevent byproducts of biological reduction (e.g., iron, arsenic, manganese and, potentially, residual organics) from entering the river.

g. Temporary surface barriers may also be applied at waste sites where cultural resources preclude active remediation of the site.

h. Land farming and bioventing are retained for sites with TPHs as a COC. Land farming is identified for sites with an impacted depth of 0.3 m (1 ft) bgs. Bioventing is identified for sites with impacted soil at a depth greater than 0.3 m (1 ft).

i. Process options of pump-and-treat include hydraulic containment via extraction, collection through groundwater extraction system, groundwater vertical injection wells discharge and/or discharge, through beneficial reuse of treated water. Flushing the saturated zone with water is also a component of pump-and-treat.

j. Process options of biological injection (bioinjection) include in situ biological treatment (anaerobic) through liquid substrate and delivery of amendments through surface infiltration.

GWP/SWP = Groundwater Protection/Surface Water Protection

9.2.2 Alternative 2—RTD and Groundwater P&T Optimized with Other Technologies

Alternative 2 uses a strategy of optimizing the risk reduction as well as the cost by using a mixture of RTD with other technologies. The actions will vary, depending on the nature and extent of contamination at the waste site, as will be determined following the Decision Logic flowchart (Figure 9-7). The actions could include one or more of the following:

- RTD of shallow vadose zone areas. RTD would also include demolition of structures (e.g., buildings) when necessary.
- Soil flushing with treatment of groundwater.
- Biological infiltration.
- Bioventing or land farming for sites with TPH as a COC.
- Temporary surface barriers.
- For groundwater, optimization of the pump-and-treat system with biological infiltration and biological injection.
- Supplemental ICs to mitigate exposure, where potentially required.

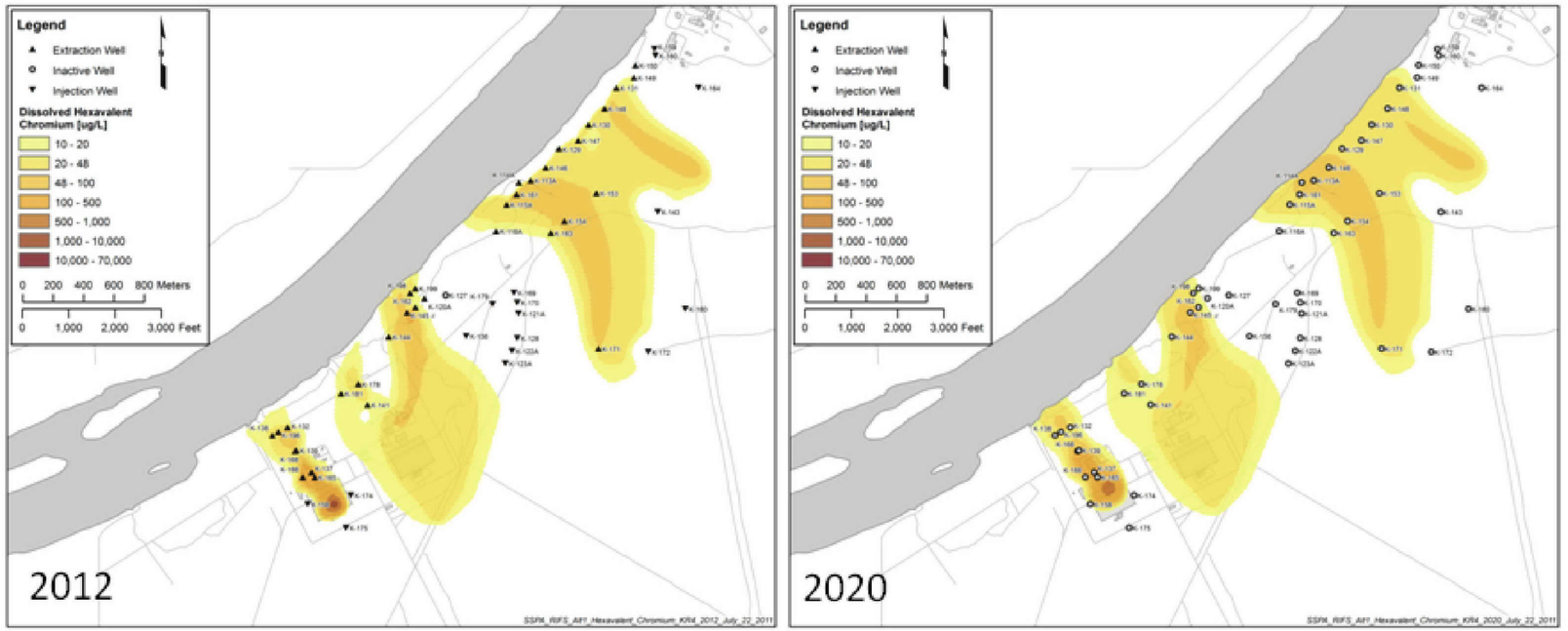
Table 9-2 presents the waste site and groundwater components of this alternative and Figure 9-3 presents a pictorial summary of alternative. It should be noted that not every component in Table 9-2 would be applied at every waste site. Conceptual exposure models for waste sites and groundwater are presented in Chapters 6 and 7 for human health and ecological receptors, respectively. Figures 9-4 and 9-5 reflect how this alternative will remove, treat, and/or interrupt the human health exposure pathway of contamination to the receptor for soil and groundwater, respectively. Figure 9-6 shows how this alternative will remove, treat, and/or interrupt the pathway to ecological receptors.

Appendix J presents a summary of the remedial components for each waste site selected based on assumed risk and contaminants in the waste sites and assumed depth of contamination. Cost estimates to remedy each waste site are also presented in Appendix J. Remedial actions for Post-ROD To-Go sites and groundwater remediation will follow the process defined in the Decision Logic flowchart (Figure 9-7).

Waste Sites: The following are the key steps in the waste sites remedial action decision process.

1. **Install a surface barrier at sites near the reactors:** If the sites are near the reactors, a temporary surface barrier will be applied to the site to limit infiltration into the subsurface. The surface barrier will be maintained for approximately 75 years, or until the reactors are removed. At that time, the remedial approach will be determined for the waste site using the approach described below. Temporary surface barriers are being used when other remedial actions, such as RTD, could structurally compromise the reactors if implementation requires excavation close to the structure's foundation.
2. **Collect design samples:** Design samples for the site will be collected to design the remedy. The design sampling approach will depend on the expected and actual risk drivers (media and contaminants of concern). Existing information including process knowledge similar sites at Hanford or data from previous work at the site is used in developing the sampling design approach. The sampling design will also be developed to address uncertainty with waste sites identified to have contaminants which have a risk to groundwater and/or surface water as this risk contributes to additional uncertainty with the extent of contamination due to potential for lateral migration to have occurred at the Handford-Ringold contact as discussed in the CSM in chapter 4. EPCs will be calculated from the design sample data to design the remedy. .

3. **Compare EPCs from shallow (less than 4.6 m [15 ft] bgs) samples to Human Health Direct Contact RAGs and ecological risk-based RAGs:** RTD will be the remedial action if a shallow EPC exceeds either one of these criteria. The excavation will continue laterally and vertically up to 4.6 m (15 ft) bgs, collecting verification samples along the way, until the new shallow EPC data is less than the RAGs. Land farming or bioventing will be the remedial action for the sites with TPH as the only COC exceeding RAGs.



1
2 **Figure 9-1. Alternative 1—Modeled Cr(VI) Plumes (2012 to 2087)**

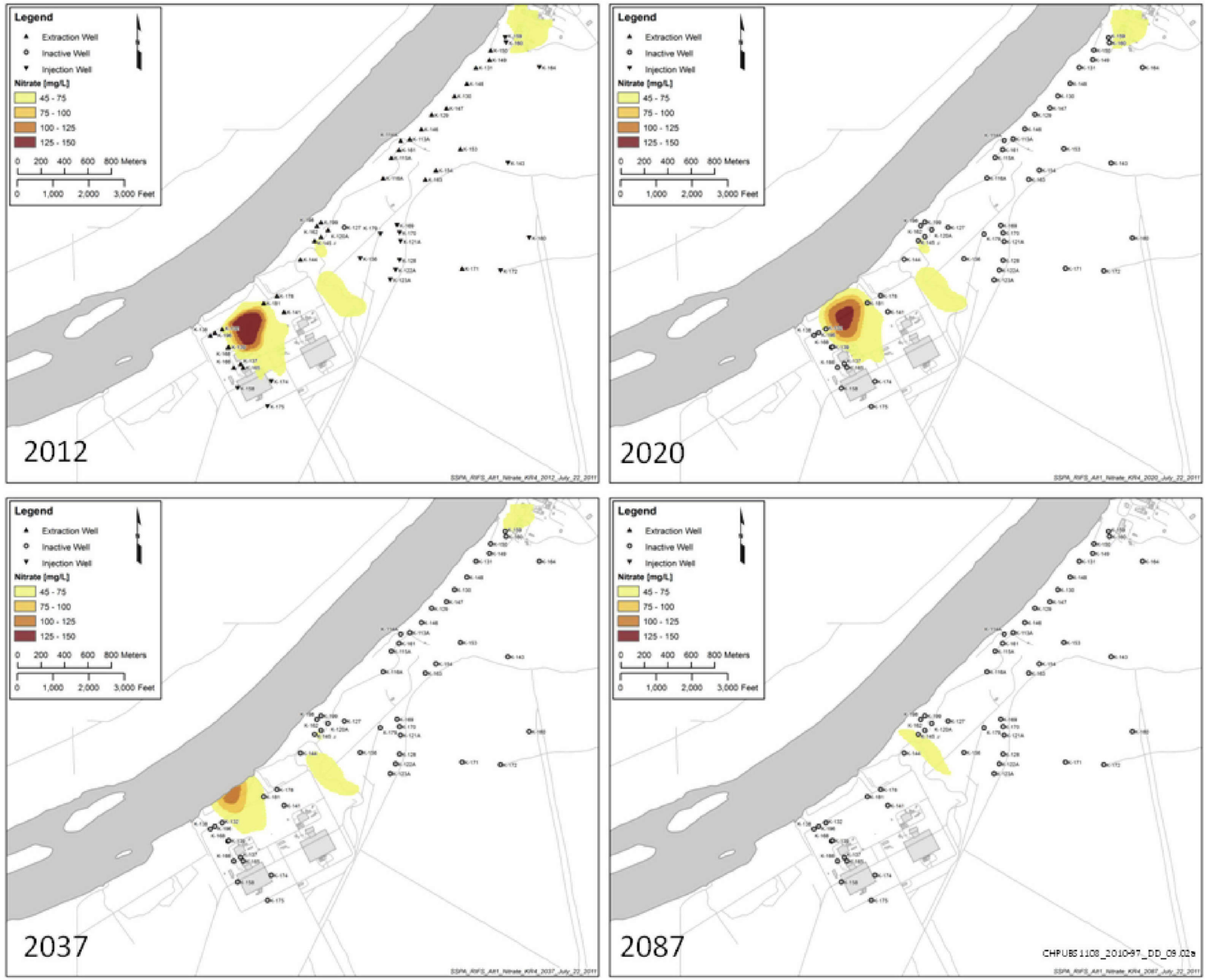


Figure 9-2. Alternative 1—Modeled Nitrate Plumes (2012 to 2087)

Table 9-2. Description of Alternative Components for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Waste Site Components[a,b]		
	General Components	
	No Action	No additional remedial actions are taken at Pre-ROD To-Go sites where results are expected to confirm the interim actions completed under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) meet PRGs.
	Institutional Controls	Institutional controls to be implemented over all OUs within this geographic area include land-use management (permits for land disturbance and irrigation restrictions) and waste site information management. Additional institutional controls implemented at specific waste sites include land-use management (permits for land disturbance including excavation restrictions on depth), warning notices, and entry restrictions. Additional information on institutional controls is presented in section 8.3.1.
	Temporary Surface Barrier (e.g., Asphalt Cap)	Surface barrier, such as an asphalt cap for sites located in proximity to a reactor, until the reactors are removed. After this time, these sites will be managed as Post-ROD To-Go sites (Figure 9-3).
	For Waste Sites that Exceed Human Health or Ecological PRGs	
	RTD	RTD up to 4.6 m (15 ft). Sampling to clarify extent of remediation. Treatment at ERDF as required. Disposal at ERDF or other approved disposal facility. Includes demolition of structures (e.g., buildings) where required.
	For Waste Sites that Exceed Surface/Groundwater Protection PRGs	
	Perform Cost/Benefit Evaluation	Determine which technology, or combination of technologies, best addresses risk reduction. Technologies to be evaluated are RTD, biological infiltration, and soil flushing.
	RTD	RTD to depth of contamination for constituents that cannot be remediated by other retained technology methods. Where waste site is a structure, RTD will be used to remove the structure. Deep excavation methods will likely be required for these sites. Treatment at ERDF as required. Disposal at ERDF or other approved disposal facility.

Table 9-2. Description of Alternative Components for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Waste Site Components (cont)[a,b]	Soil Flushing—Vadose Zone, Water	Soil flushing using clean or treated water through surface infiltration at sites exceeding surface/groundwater protection criteria for mobile compounds that can be remediated through the groundwater pump-and-treat systems. Soil flushing may be supplemented with biological infiltration for further treatment of reducible compounds (Cr(VI)) , except at locations in close to the Columbia River (e.g., within 100 to 300 m [328 to 984 ft])were byproducts of biological reduction (e.g., iron, arsenic, manganese and, potentially, residual organics) may enter the river. Soil flushing will also be used for sites that exceed surface/groundwater protection for carbon-14 (specifically sites 116-KE-1 and 116-KW-1). Components include: • Collection and analysis of samples to clarify extent of remediation required. • Drip irrigation system with instrumentation and controls. • Installation of extraction wells at waste sites that are not collocated with existing groundwater extraction wells. • Continued monitoring of groundwater beneath the waste sites with COCs exceeding surface/groundwater protection criteria. • Air stripping to treat carbon-14 (when applicable) that is flushed from the vadose zone to the groundwater during the operation of the soil flushing system. Air stripping includes offgas treatment through granular activated carbon (GAC).
	Biological Infiltration	Biological treatment supplements soil flushing through surface infiltration at sites exceeding surface/groundwater protection criteria for mobile and reducible compounds (Cr(VI)). Components include: • Collection and analysis of samples to clarify extent of remediation required. • Substrate (e.g., lactate) drip irrigation system with instrumentation and controls. • Biosubstrate mixing plants with instrumentation and controls. • Installation of extraction wells at waste sites that are not collocated with existing groundwater extraction wells. • Installation of monitoring wells directly downgradient of bioinfiltration system. Continued monitoring of groundwater beneath the waste sites with COCs exceeding surface/groundwater protection criteria.
	For Waste Sites Impacted with TPH	
	Perform Cost/Benefit Evaluation	Determine which technology, or combination of technologies, best addresses risk reduction. Technologies to be evaluated are RTD, bioventing, and land farming.
	RTD	RTD up to 4.6 m (15 ft). Sampling to clarify extent of remediation required. Treatment at ERDF as required. Disposal at ERDF or other approved disposal facility. Includes demolition of structures (e.g., buildings) where required.

Table 9-2. Description of Alternative Components for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Waste Site Components (cont)[a,b]	Bioventing	Bioventing for contaminated soil located in the unsaturated zone. For sites with TPH as a COC with an impacted depth greater than 0.30 m [1 ft] bgs. System components include: • Installation of bioventing wells and manifold connecting blower to wells. • Injection blower system. • Installation of soil gas monitoring points. • Instrumentation and controls.
	Land Farming	Land farming for sites with TPH as a COC with an impacted depth of (or less than) 0.30 m (1 ft) bgs. Contaminated soil is mixed with soil amendments and then both are tilled into the earth.
Groundwater Components[a]	Pump-and-Treat System	Operation of pump-and-treat system optimized with bioinjection and bioinfiltration (described previously). Includes installation of about 35 additional injection/extraction wells. Designed with active remediation out to Cr(VI) 10 µg/L contour. Treatment of extracted water through ion exchange. Operation of pump-and-treat system and biological injection components to meet AWQS.
	Biological Injection	System optimized with biological injection. Components of biological injection include: • Injection biological substrate (e.g., cheese whey) into biological injection wells with closed loop recirculation from downgradient wells. • Bionode mixing facilities. • Biosubstrate mixing plants.
	Air Stripping	• For the treatment of carbon-14 from Extraction Well 199-K-132 or other wells with carbon-14 greater than DWS. • Surface barriers installed over carbon-14 source will limit infiltration recharge to groundwater that could impact migration of carbon-14 in groundwater. • Does not incorporate additional extraction wells to capture carbon-14. • Offgas treatment using GAC. Preliminary risk modeling suggests carbon-14 may be lower than risk-based standards. Detailed calculations would be performed in the final design.
	ICs	• Manage the plumes until concentrations are below the action levels in the fringes of the plume as well as after the pump-and-treat system is shut off. • ICs including groundwater use restrictions (Table 8-8).
	Monitoring Requirements	• Remedy performance monitoring will be defined as part of the remedial design. • Conducted to evaluate the effectiveness of the selected alternative to attain the cleanup levels. • The existing monitoring program will expand by adding a number of specific monitoring wells. For cost estimating purposes, it has been assumed that six new monitoring wells will be installed. Groundwater performance monitoring is presented section 9.2.4.7 and identifies constituents included in the monitoring program.

Notes: Additional information on Alternative 2 is presented in Figure 9-2.

a. Additional information on the conceptual design details for identified components for Alternative 2 is presented in Sections 9.2.4 and 9.2.5. Table 9-5 presents the specific alternative components for each evaluated waste site. Tables 9-7 and 9-8 show the numerical components (e.g., number of sites evaluated, volume of material treated) for waste sites and groundwater, respectively.

b. Shallow soil is defined as less than 4.6 m (15 ft) bgs.

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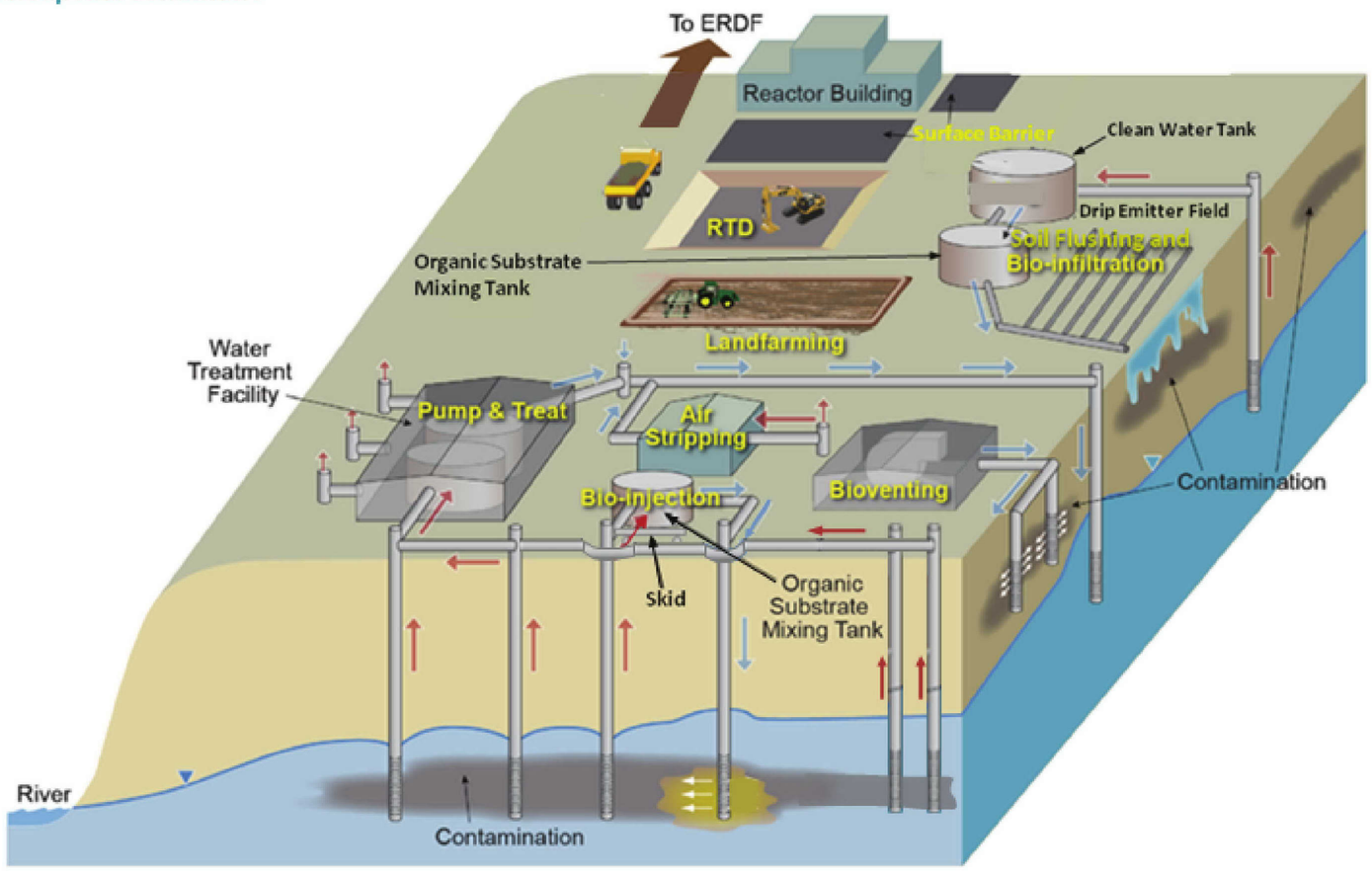
Alternative 2: RTD and Groundwater Pump-and-Treat, Optimized With Other Technologies

Conceptual Schematic



Cost	Waste Site Treatment	Groundwater Treatment	Total
Total Present Value of Alternative (Discounted)	$422,494,000	$194,314,000	$616,808,000
Total Non-Discounted Cost	$764,611,000	$265,540,000	$1,030,151,000

Note: Waste site treatment costs include the cost for institutional controls.

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Figure 9-3. Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

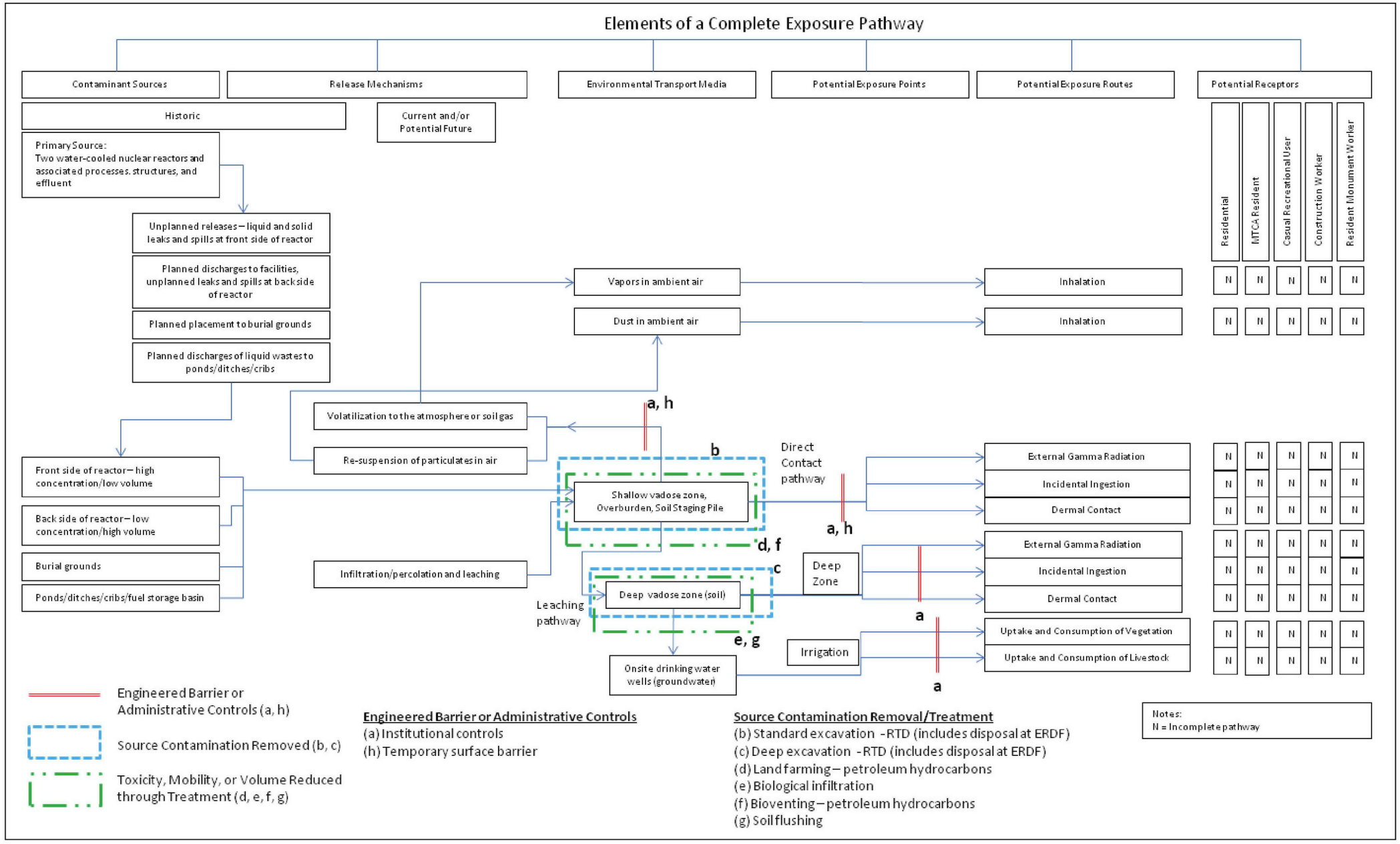

Figure 9-4. Applying Alternative 2 to the Source Exposure Pathway

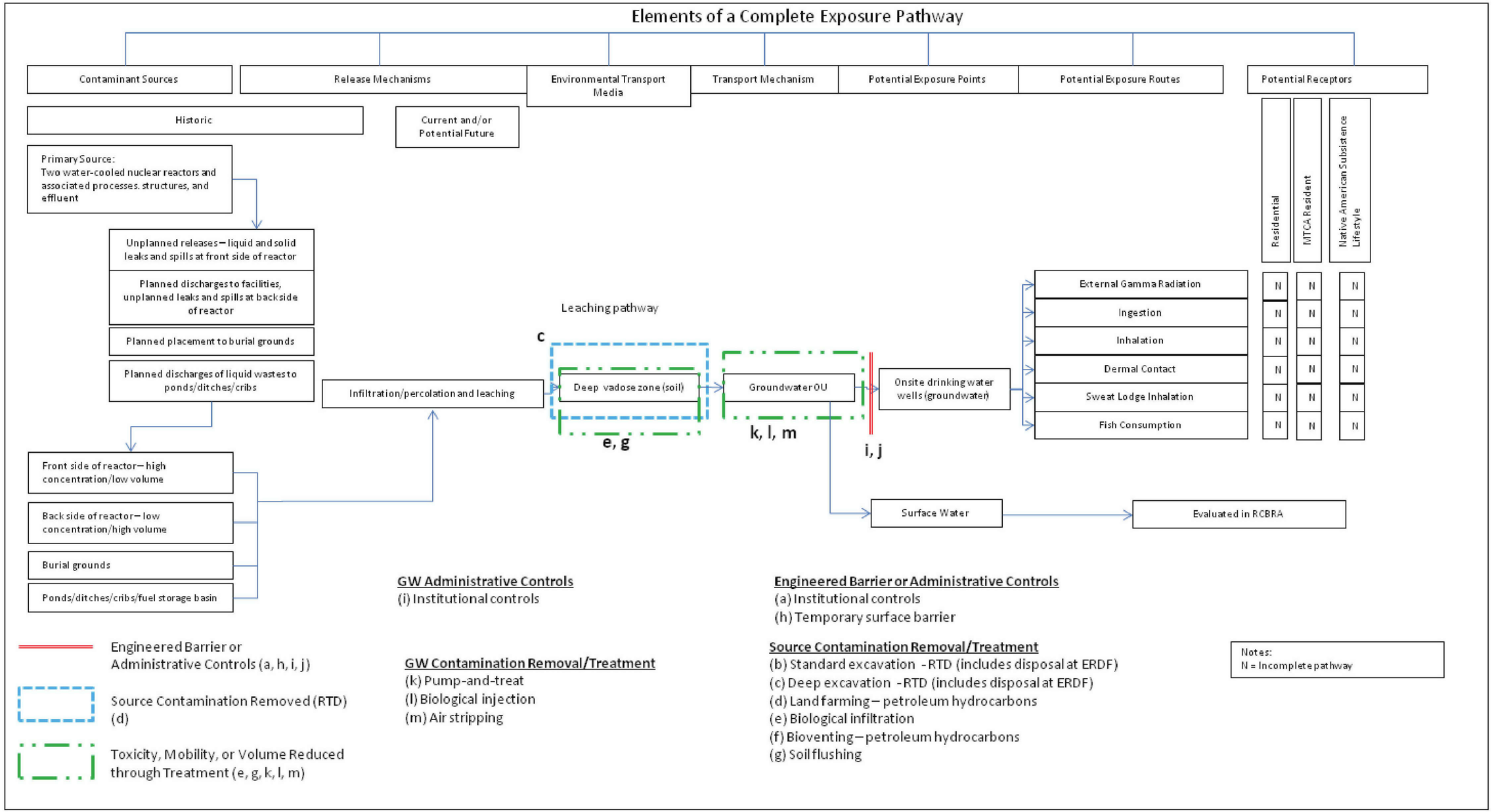

Figure 9-5. Applying Alternative 2 to the Groundwater Exposure Pathway

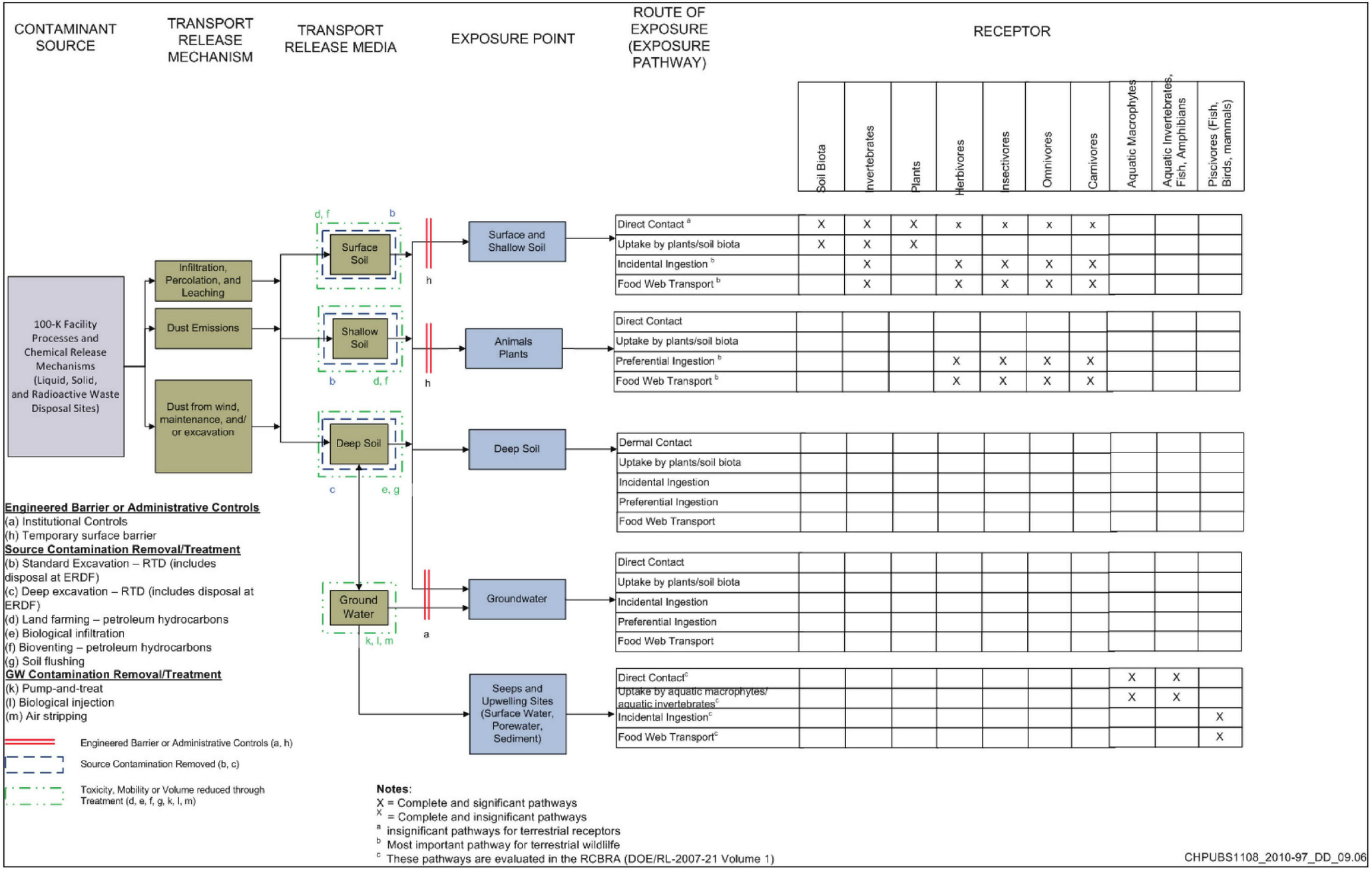

Figure 9-6. Applying Alternative 2 to the Ecological Exposure Pathway

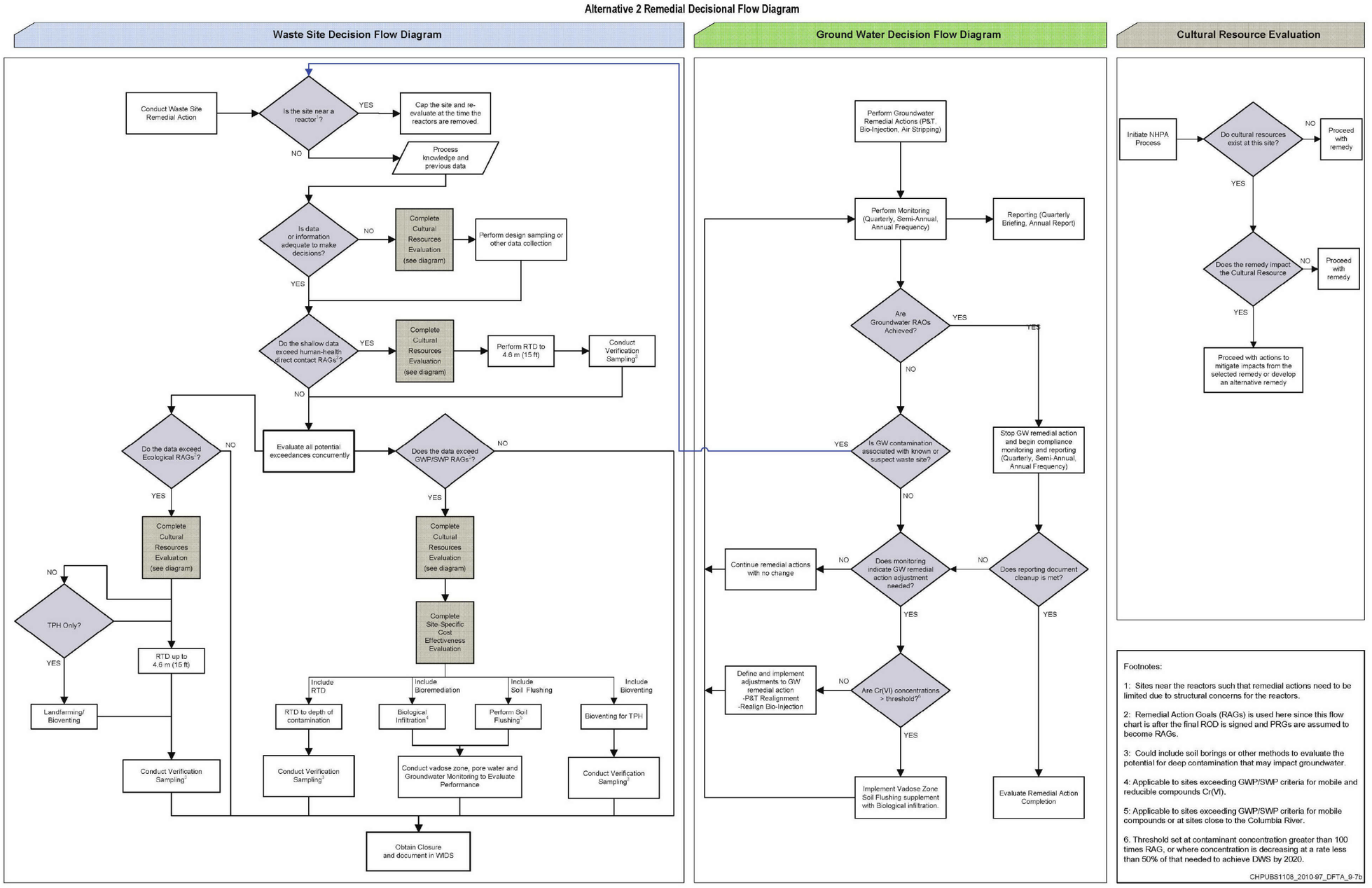

Figure 9-7. Alterative 2—Remedial Decision Flow Diagram

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4. **Compare the EPCs for Cr(VI) and other COCs from deep samples to groundwater and surface water protection RAGs:** If the EPCs exceed these RAGs, technologies for remediation will be implemented based on contaminants contributing to the groundwater/surface water protection risk:

   a. Land farming or bioventing will be implemented for TPH-only contaminated sites. Land farming is applicable for the sites with an impacted depth of less than 0.30 m (1 ft) bgs. Bioventing is applicable for sites with an impacted depth greater than 0.30 m (1 ft) bgs.

   b. RTD will be implemented to remediate nonreducible constituents (such as mercury) that cannot be remediated by one of the other technologies identified below. Where waste site is a structure, RTD will be used to remove the structure.

   c. Soil flushing is applicable to sites with mobile compounds or is applied to waste sites close to the Columbia River (e.g., within 100 to 300 m [328 to 984 ft]), to prevent byproducts of biological reduction (e.g., iron, arsenic, manganese, and, potentially, residual organics) from entering the river. Soil flushing will be implemented at sites where mobile contaminants flushed to groundwater can be remediated through the groundwater pump-and-treat systems. Soil flushing will also be used for sites that exceed surface/groundwater protection for carbon-14, which will be treated by air stripping of extracted groundwater flushed through the site.

   d. Biological infiltration will be implemented to supplement soil flushing to treat mobile and reducible compounds, such as hexavalent chromium. At waste sites where these are the only COCs, biological infiltration will be implemented. Otherwise, RTD will be implemented to remove other COCs to depth where only reducible contaminants remain for biological infiltration. In these cases, a cost/benefit evaluation will be performed to determine best implementation of the technologies to remediate the waste site.

   e. Soil flushing supplemented with bioinfiltration will be used at specific waste sites, and as a contingency for all sites if needed to achieve cleanup levels.

   f. A cost/benefit evaluation will be completed to determine the approach that most cost effectively addresses risk reduction. If the evaluation selects a different approach than identified in Appendix J, this change will be considered a minor modification to the ROD. These minor modifications to the ROD will be made through an administrative process, such as an NPL fact sheet, with public notification, and the appropriate RD/RAWP updated for implementation of the remedial action.

5. **Obtain closure:** Once the above steps are performed and verification sampling demonstrates acceptable levels of the COCs, closure will be obtained, following the procedures as contained in the ROD and RD/RAWP.

Groundwater: For groundwater, this alternative optimizes the operation of the interim action pump and treat by including biological injection (bioinjection) for treatment of contaminated groundwater. Biological injection will be used for specific well pairs or clusters in a closed loop fashion separate from the IX treatment plants. This reduces the likelihood of biodegradation byproducts reaching the IX treatment systems.

Pump-and-treat is efficient for treating highly contaminated groundwater. However, the efficiency of the pump and treat begins to diminish as the concentrations decrease and the plume is cleaned up. Pump-and-treat is also not as effective in low permeability aquifer areas as limited pumping rates can be sustained. In these instances, biological treatment is implemented to augment the remediation. Biological treatment will also be used to reduce the amount of groundwater that must be sent to the IX plants, thereby increasing the total capacity of the system and reducing the O&M cost. Biological treatment could also be used in possible saturated zone hot spots to provide longer-term reducing conditions, which may provide longer-term

treatment of the chromium that may be present in lower permeability layers or in deeper layers of the aquifer.

In addition to biological injection, soil flushing and biological infiltration technologies are also implemented to address uncertainties identified in the CSM with unidentied continuing source(s) to groundwater contamination. The following are the key steps for groundwater remedial action and determination of when soil flushing supplemented with biological infiltration will be implemented in the decision process.

1. **Evaluate if groundwater contamination is beneath a waste site source:** If groundwater concentrations exceed RAGs and waste site source has not been remediated, continue groundwater remediation activities and complete waste site remedation as identified in the waste site decision process.

2. **Evaluate groundwater remedation performance to determine if system adjustments are necessary:** System performance monitoring will be conducted throughout this remedial action. Performance monitoring data will be evaluated to compare actual groundwater cleanup progress with predicted cleanup through modeling to determine if adjustments to the remediation system is needed. Adjustments to the remediation system would include well field realignments to extract from areas with higher concentrations and/or inject at locations to manipulate plume and push contaminated groundwater towards extraction wells. Adjustments to the biological injection approach would include optimization of injection locations and/or frequency and duration of biological substrate injection.

3. **Compare COC concentrations to threshold criteria for implementing soil flushing and biological infiltration:** Threshold criteria are established to evaluate conditions where a continuing source may be present and contributing to the groundwater plume. The threshold criteria include conditions where contaminant concentrations in groundwater exceed 100 times the RAG, or concentration is decreasing at a rate less than 50% needed to achieve DWS by 2020 as calculated through groundwater model simulations. Another criteria for determining presence of continuing source to groundwater contamination is if rebound of contamination is observed through performance/compliance monitoring after RAGs have been achieved.

4. **Perform soil flushing supplemented with biological infiltration:** For groundwater contamination locations where the threshold criteria are exceeded, soil flushing supplemented with biological infiltration technologies will be implemented. Biological infiltration is preceded with soil flushing using clean water, or treated effluent from the pump-and-treat systems. This flush will support determining if mobile contamination is present above the unconfined aquifer in the vadose zone. Mobilized contamination will be observed in groundwater monitoring wells with soil flushing, whereas biosubstrate in the bioinfiltration media may reduce Cr(VI) contamination and mask contamination that may be flushing into the groundwater. If presence of mobile contamination is not observed by soil flushing, then bioinfiltration can target remediation of groundwater rather than the vadose zone. Initially, this focuses on the K-East and K-West head house areas as well as the former area of the 116-K-2 trench.

    a. Soil flushing supplemented with biological infiltration at the K-East and the K-West head house areas is being implemented to address Cr(VI) contamination observed in the groundwater from unplanned release of high concentration sodium dichromate solutions at these areas. Biological infiltration may be used near these head houses to reduce any Cr(VI) that might remain in the vadose zone that is not associated with a waste site, and to enhance the flushing in the groundwater plume. Bioinfiltration provides for larger area reducing conditions for reduction of Cr(VI) to Cr(III) to address uncertainties associated with potential source of Cr(VI) contamination in the vadose or periodically rewetted zone.

b. Pump-and-treat will aggressively target areas of persistent hexavalent chromium contamination such as the lateral ends of the K-2 Trench. Groundwater underneath suspected source contamination waste sites will be monitored for rebound or extended contamination persistence to determine if implementation of vadose zone technologies (such as biological infiltration or soil flushing) would support accelerated groundwater cleanup durations.

c. In all groundwater locations, if rebound occurs following remediation to the DWS, additional remedial technologies within the actions selected in the ROD will be evaluated and implemented following the decision logic process steps identified for this alternative.

5. **Evaluate for Remedial Action Completion:** Once the above steps are performed and ongoing compliance monitoring demonstrates the cleanup requirements have been achieved, completion will be obtained, following the procedure contained in the ROD and RD/RA Work Plan.

To define if the monitoring data collected during the compliance monitoring phase of the project meets the cleanup requirements, three years of quarterly groundwater monitoring data will be evaluated. The data will be expressed and reported as both individual measurements (maximum, minimum and mean) and as an exposure point concentration (EPC) using 4 defined plume exposure areas. These areas will include the K-West plume area, K-East plume area, K-North plume area and River proximity area. EPCs values will be calculated as either a 90th percentile value per COC or a 95 upper confidence limit (UCL) per COC using the groundwater compliance monitoring dataset.

In general, EPA Superfund guidance (OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*) recommends using an average 95 percent upper confidence limit for estimating EPCs. However, experience at the Hanford Site indicates that averages and UCLs at times in certain operable units cannot be reliably calculated for groundwater data sets. The problem lies in operable units with multiple groundwater contaminants present with overlapping plumes, and the highest concentrations having different locations within those plumes. The 100 Area operable units do not exhibit this condition in most locations, but that will have to be determined based on the compliance dataset.

The 90th percentile EPC is identified by EPA as appropriate for describing and characterizing health risks/exposures as its use yields risk estimates that correspond to a reasonable maximum exposure (RME) value. The RME is an appropriate exposure scenario for risk calculations and risk comparison within the realistic range of exposure since the goal of the Superfund program is to protect against high-end, not average exposures. The "high-end" is defined as that part of the exposure distribution that is above the 90th percentile but below the 99.9^{th} percentile. The 90th percentile value is based on ranking the analytical results from lowest to highest and selecting the position that corresponds to the 90th percentile.

The 100-K dataset will be reduced, managed and reported using both mathematical methods mentioned above and the most appropriate method selected to express the EPC values for the 4 various exposure areas. Individual measurements will be used to defined areas within the plume exposure areas that may indicate persistant waste site area groundwater contributing. From this information, and in consultation with the lead regulatory agency, the project will define if the final cleanup levels have been met.

If additional remediation is needed due to rebound of certain COCs in specific areas of the plume (hot spot locations) to achieve the EPC target completion cleanup level, the system will be optimized to focus on that /those specific areas. System operation and monitoring will be halted within exposure areas where the target EPC values per COC have been demonstrated to meet the cleanup levels.

Implementation of waste site and groundwater remediation are integrated in this alternative to provide for containment of contaminants that may reach groundwater during waste site remediation activities. Figure 9-8 shows the groundwater extraction well network for this alternative relative to the waste sites that are identified to have potential groundwater and/or surface water risk. Capture efficiency of the well field is provided in the model simulations for this alternative in Appendix F. Waste sites remediated with bioinfiltration or soil flushing will require containment by downgradient extraction wells to keep contaminants flushed into the unconfined aquifer from reaching the river. Where groundwater containment is not adequately provided, additional extraction/monitoring wells will be added as needed as part of the waste site remedy.

National Historic Preservation Act of 1966 is an ARAR for remedial actions where cultural resources are present. Remediation may have the potential to impact cultural resources. An additional step that will be taken prior to any remedial action is an analysis of cultural resource impacts (as shown in the flow diagram). Such an analysis is required by the ARARs discussed in Chapter 8. This will include an assessment of the cultural resources present at a site in accordance with the *Hanford Cultural Resources Management Plan* (DOE/RL-98-10). The guidelines and strategies have been developed based on Hanford's unique history and cultural resources, and through recurring discussions with the State Historic Preservation Office (SHPO) and the Native American Tribes and Nations regarding the nature and extent of protective and mitigative measures that are needed. Should the selected remedy impact cultural resources, actions will be taken to mitigate impacts or develop an alternative remedy.

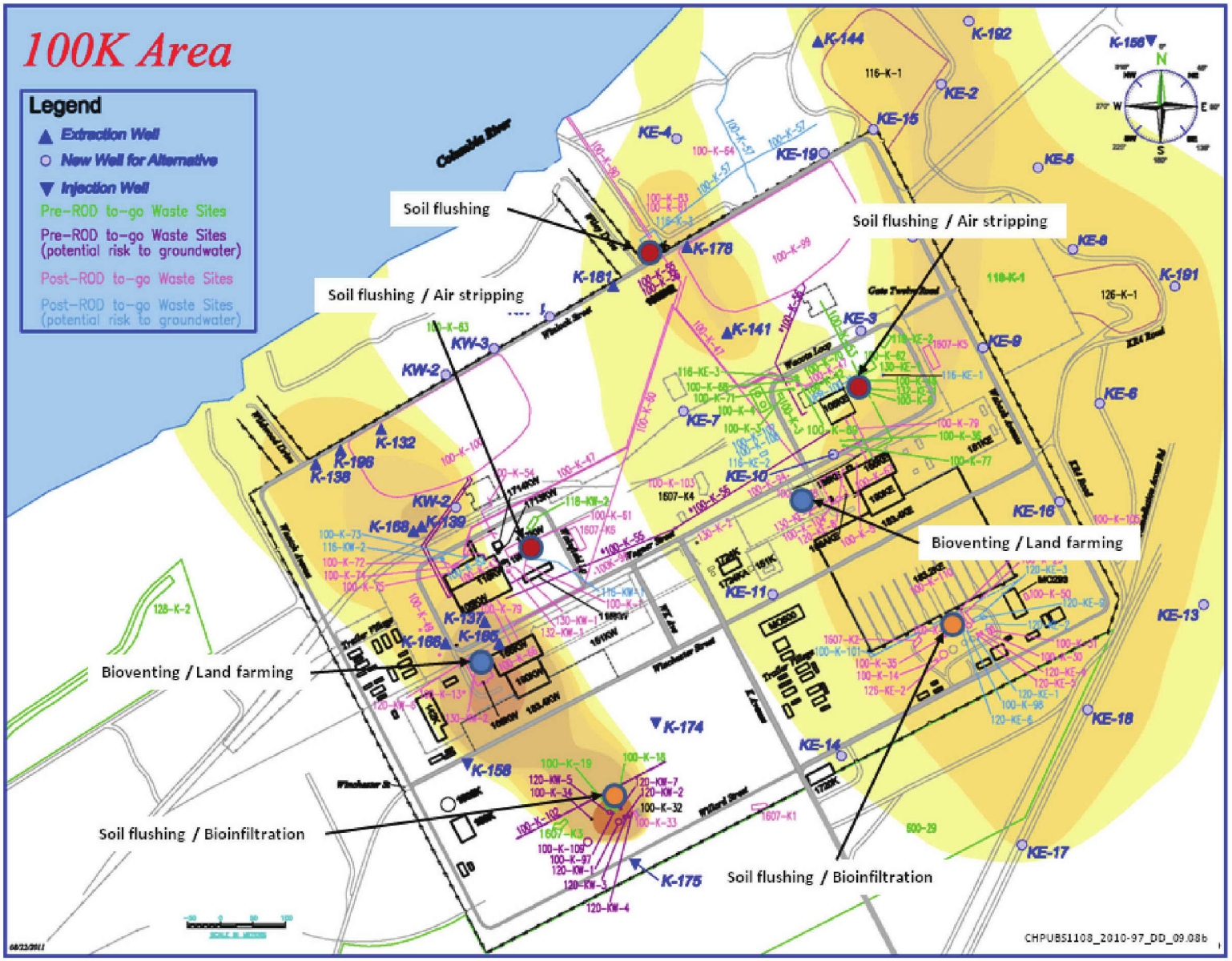


Figure 9-8. Alternative 2—Extraction Well Network around Waste Sites with Risk to GWP/SWP

This alternative is designed to operate until the groundwater plume is substantially reduced to less than the DWS. Wells along the river will be used to contain the plume above 10 µg/L, thereby reducing migration to the river so the AWQS can be maintained.

The groundwater extracted from within the carbon-14 plume (i.e., Wells 199-K-132, 199-KW-1, and 199-KW-2) are likely to have carbon-14 greater than the DWS. Water from the wells will be treated in an air stripper to reduce the carbon-14 to below the DWS prior to re-injection.

Figures 9-9 and 9-10 show the layout of the alternative, with the modeled hexavalent chromium and nitrate groundwater plumes in December 2012, 2016, 2020, and 2037, respectively. Based on the modeling results, by 2020, hexavalent chromium plumes will have been remediated to meet DWS, with a few pockets above the 10 µg/L aquatic standard. Wells downgradient of areas above 10 µg/L will continue remediation of the plume and maintain containment while the rest of the inland systems are shut down. The pump-and-treat systems will continue operating through 2037 to remediate the Cr(VI) plume below 10 µg/L. Three new extraction wells are included in this alternative to capture the nitrate plume between K-West and K-East. As shown in Figure 9-9, the nitrate plume is nearly completely below 45 mg/L in the K-West area by 2020 and is reduced to below 45 mg/L by 2037. To deal with the uncertainty in groundwater modeling simulations, RPO activities will be conducted throughout the life of the project.

9.2.3 Alternative 3—RTD and Expanded Groundwater Treatment

Alternative 3 uses a strategy of RTD almost exclusively for waste site contamination to rapidly achieve the RAOs, with the greatest degree of certainty, as well as aggressive pump-and-treat for groundwater. The remedial action will include the following activities:

- RTD for waste sites, with excavation until standards are achieved. RTD would also include demolition of structures (e.g., buildings) when necessary.
- Temporary surface barriers.
- For Cr(VI) in groundwater, aggressive pump-and-treat.
- Supplemental ICs to mitigate exposure, where potentially required.

Table 9-3 presents the waste site and groundwater components of this alternative and Figure 9-11 provides a pictorial summary of the alternative. It should be noted that not every component in Table 9-3 would be applied at every waste site. Conceptual exposure models for waste sites and groundwater are presented in Chapters 6 and 7 for human health and ecological receptors, respectively. Figures 9-12 and 9-13 reflect how this alternative will remove, treat, and/or interrupt the human health exposure pathway of contamination to the receptor for soil and groundwater, respectively. Figure 9-14 shows how this alternative will remove, treat, and/or interrupt the pathway to ecological receptors.

Appendix J presents a summary of the remedial components for each waste site that were assumed for the development of cost estimates. For Post-ROD To-Go sites, the actual approach will be determined following the Decision Logic process.

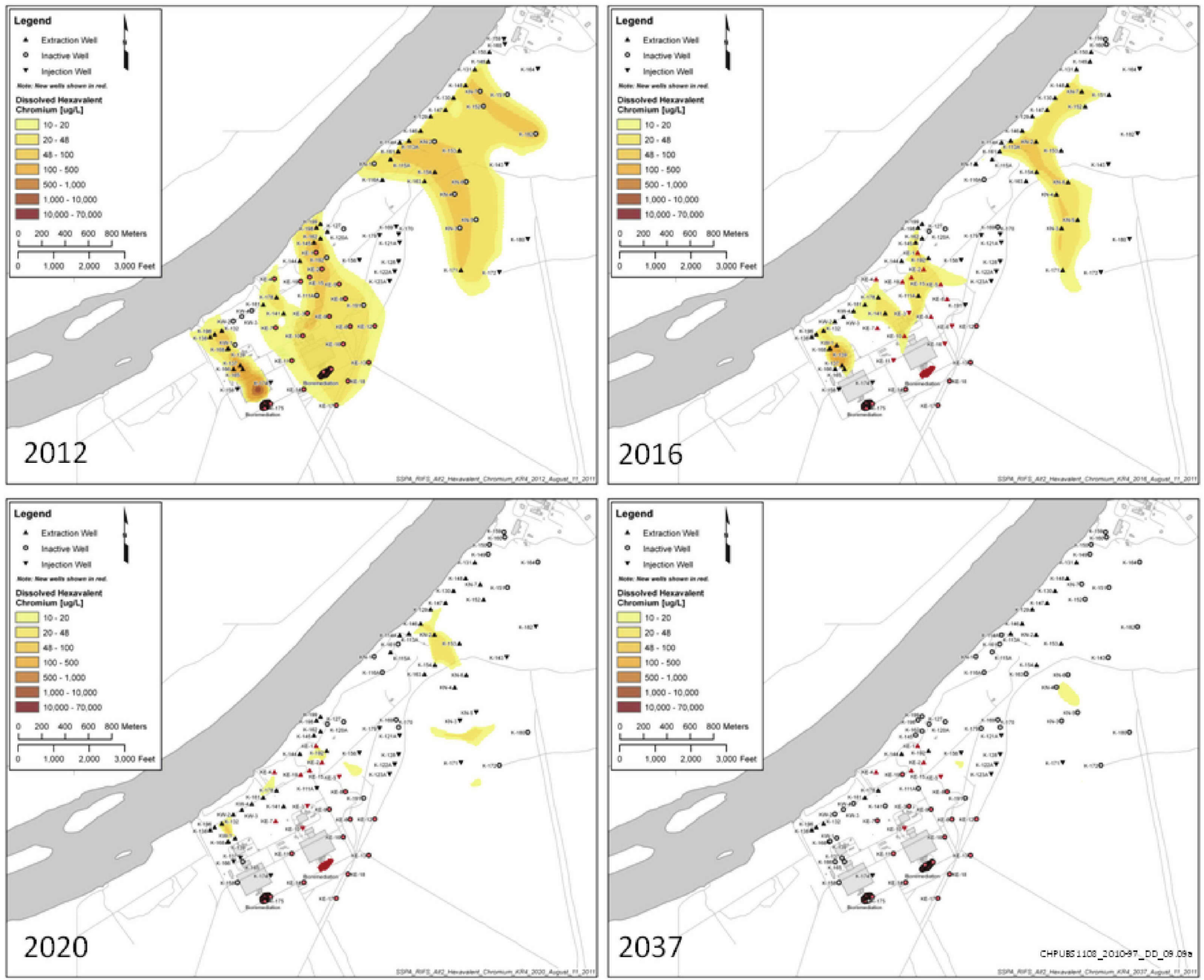


Figure 9-9. Alternative 2—Modeled Cr(VI) Plumes (2012 to 2037)

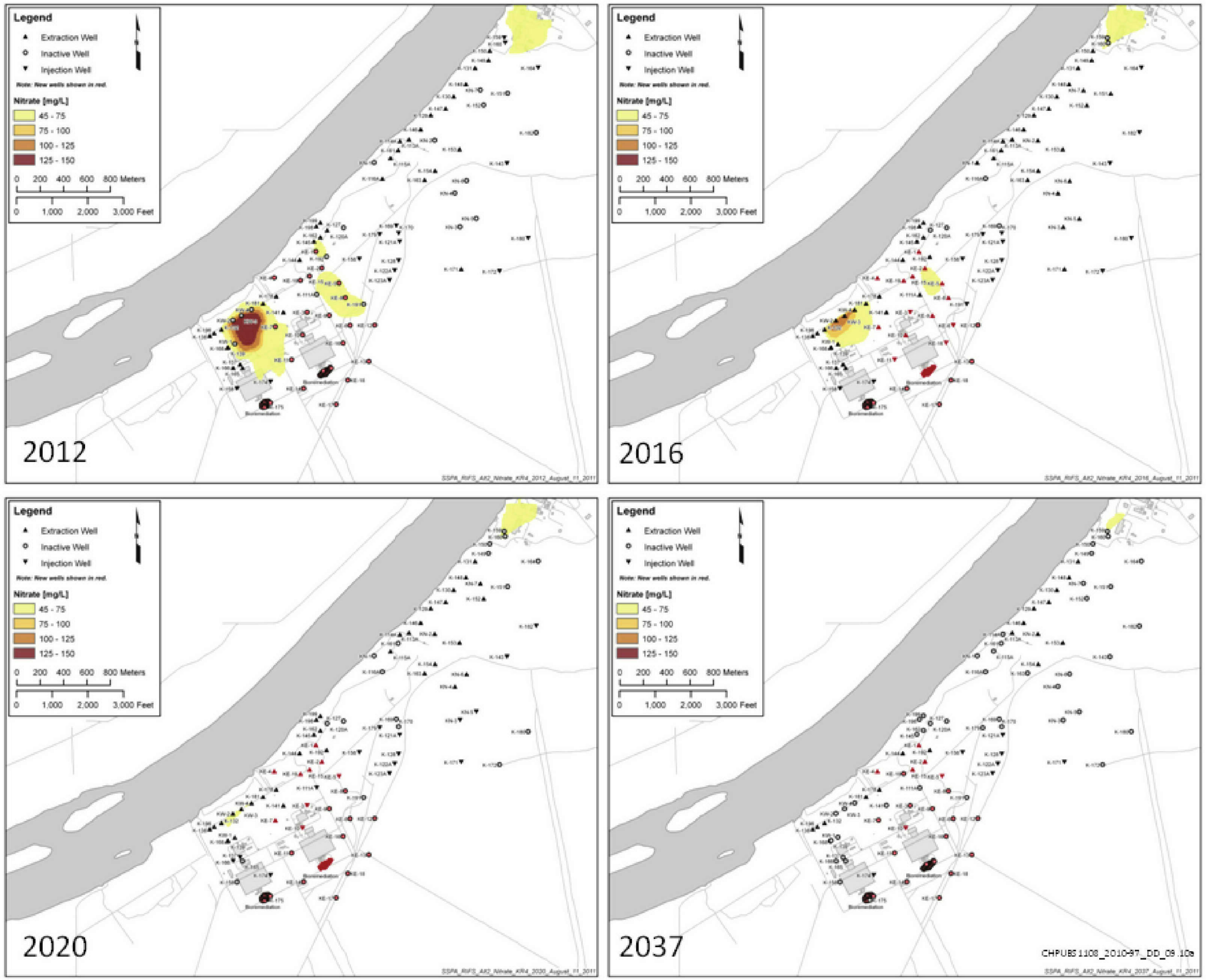


Figure 9-10. Alternative 2—Modeled Nitrate Plumes (2012 to 2037)

Table 9-3. Description of Alternative Components Alternative 3—RTD and Expanded Groundwater Treatment

Waste Site Components[a,b]	No Action	No additional remedial actions are taken at Pre-ROD To-Go sites where results are expected to confirm the interim actions completed under the100 Area Remaining Sites ROD (EPA/ROD/R10-99/039) meet PRGs.
	Institutional Controls	Institutional controls to be implemented over all OUs within this geographic area include land-use management (permits for land disturbance and irrigation restrictions) and waste site information management. Additional institutional controls implemented at specific waste sites include land-use management (permits for land disturbance including excavation restrictions on depth), warning notices, and entry restrictions. Additional information on institutional controls is presented in section 8.3.1.
	Temporary Surface Barrier (e.g., Asphalt Cap)	Surface barrier, such as an asphalt cap for sites located in proximity to a reactor, until the reactors are removed. After this time, these sites will be managed as Post ROD To-Go sites (Figure 9-15).
	RTD	For sites exceeding human health, ecological risk (shallow), and/or surface/groundwater protection criteria. Components of RTD include: • Sampling to clarify extent of remediation required. • RTD to 4.6 m (15 ft) for sites exceeding shallow human health or ecological risk criteria. • RTD to depth of contamination for sites exceeding surface/groundwater protection criteria. Deep excavation methods will likely be required for these sites. • Treatment at ERDF as required. • Disposal at ERDF or other approved disposal facility. • Includes demolition of structures (e.g., buildings) where required.
Groundwater Components[a]	Pump-and-Treat	Operation of existing pump-and-treat system. • Includes installation of 65 additional injection/extraction wells. • Designed with active remediation out to Cr(VI) 10 µg/L contour. • Treatment of extracted water through ion exchange. • Includes installation of one new 4,920 lpm (1,300 gpm) pump-and-treat facility. • Operation of pump-and-treat system until 2020.
	Air Stripping	For the treatment of carbon-14 from Extraction Well 199-K-132 or other wells with carbon-14 greater than the DWS. Does not incorporate additional extraction wells to capture carbon-14. Off-gas treatment using GAC. Preliminary risk modeling suggests carbon-14 will be lower than risk-based standards. Detailed calculations would be performed in the final design. Surface barriers installed over carbon-14 source will limit infiltration recharge to groundwater that could impact migration of carbon-14 groundwater.

Table 9-3. Description of Alternative Components Alternative 3—RTD and Expanded Groundwater Treatment

Groundwater Components[a] (cont.)	ICs	ICs including groundwater use restrictions until the plumes are completely remediated (Table 8-8).
	Monitoring Requirements	Remedy performance monitoring will be defined in the SAP developed as part of the remedial design. Conducted to evaluate the effectiveness of the selected alternative to attain the cleanup levels. The existing monitoring program will expand by adding a number of specific monitoring wells. For cost estimating purposes, it has been assumed that six new monitoring wells will be installed. Groundwater performance monitoring is presented in section 9.2.4.7 and identifies constituents included in the monitoring program.

Notes: Additional information on Alternative 3 is presented in Figure 9-15.

a. Additional information on the conceptual design details for components identified for Alternative 3 is presented in Section 9.2.4. Table 9-5 presents the specific alternative components for each evaluated waste site. Tables 9-7 and 9-8 show the numerical components (e.g., number of sites evaluated, volume of material treated) for waste sites and groundwater, respectively.

b. Shallow soil is defined as less than 4.6 m (15 ft) bgs.

Waste Sites: Figure 9-15 presents the Decision Logic flow diagram for Post-ROD To-Go sites for Alternative 3. The following are the key steps in the decisional process.

1. **Install a surface barrier at sites near the reactors:** If the sites are near the reactors, a temporary surface barrier will be applied to the site to limit infiltration into the subsurface. The surface barrier will be maintain for approximately 75 years, or until the reactors are removed. At that time, the remedial approach will be determined for the waste site using the approach described below. Temporary surface barriers are being used when other remedial actions, such as RTD, could structurally compromise the reactors if implementation requires excavation close to the structure's foundation.

2. **Collect design samples:** Design samples for the site will be collected to design the remedy. The design sampling approach will depend on the expected and actual risk drivers (media and contaminants of concern). Existing information including process knowledge similar sites at Hanford or data from previous work at the site is used in developing the sampling design approach. The sampling design will also be developed to address uncertainty with waste sites identified to have contaminants which have a risk to groundwater and/or surface water as this risk contributes to additional uncertainty with the extent of contamination due to potential for lateral migration to have occurred at the Handford-Ringold contact as discussed in the CSM in chapter 4. EPCs will be calculated from the design sample data to design the remedy.

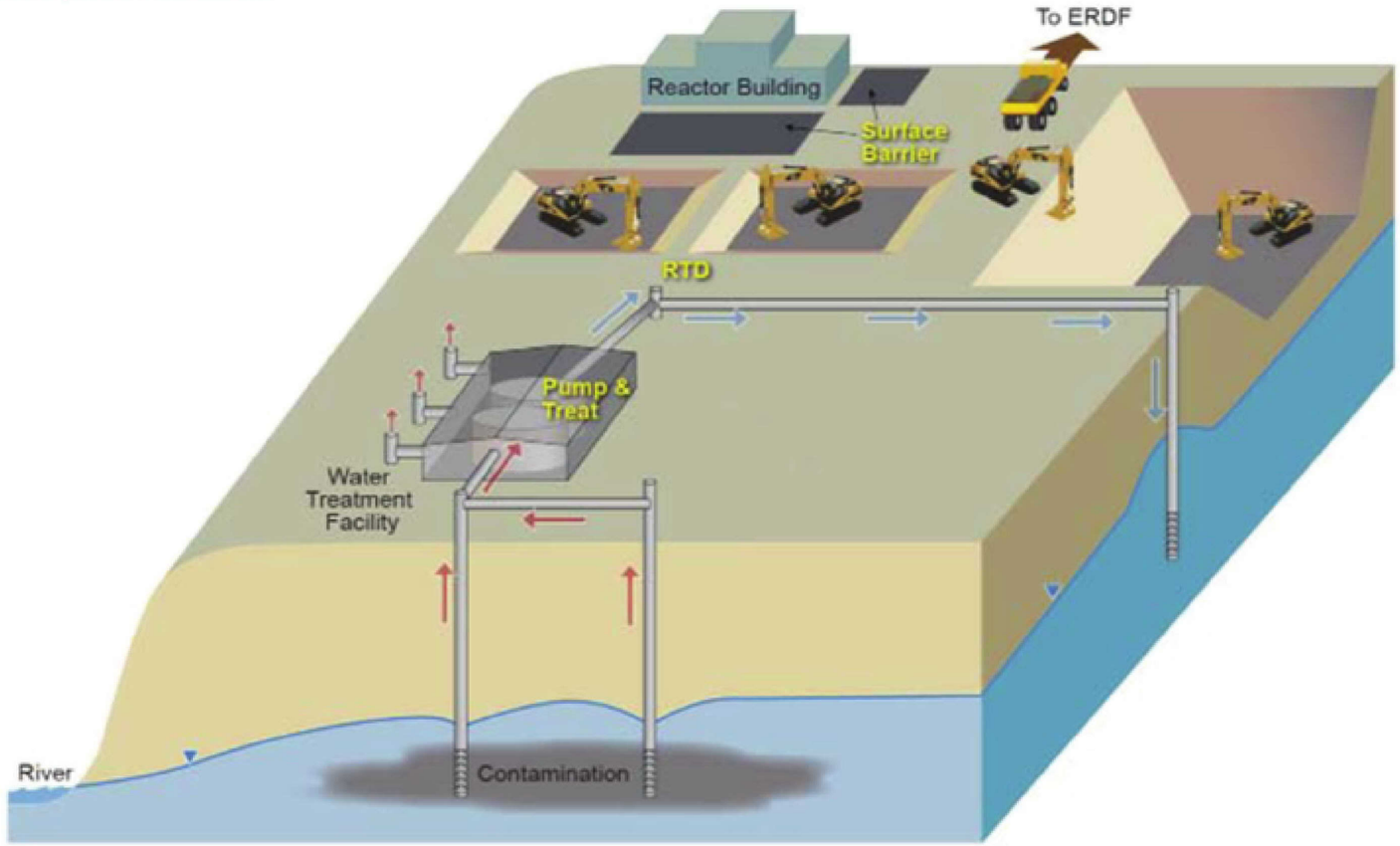
3. **Compare EPCs from shallow (less than 4.6 m [15 ft] bgs) samples to Human Health Direct Contact RAGs and ecological risk-based RAGs:** RTD will be the first step in the remedial action if a shallow EPC exceeds either one of these criteria. The excavation will continue laterally and vertically up to 4.6 m (15 ft), collecting verification samples along the way, until the new shallow EPC data are less than the RAGs.

4. **Compare the EPCs for Cr(VI) and other COCs from deep samples to groundwater and surface water protection RAGs:** If the EPCs exceed these RAGs, RTD will be continued until the EPCs no longer exceed the specific RAGs.

5. **Obtain closure:** Once the above steps are performed and verification sampling demonstrates acceptable levels of the COCs, closure will be obtained, following the procedures contained in the ROD and the RD/RAWP.

Alternative 3: RTD and Expanded Groundwater Treatment

Conceptual Schematic



Cost	Waste Site Treatment	Groundwater Treatment	Total
Total Present Value of Alternative (Discounted)	$467,525,000	$247,129,000	$714,654,000
Total Non-Discounted Cost	$812,687,000	$275,810,000	$1,088,497,000

Note: Waste site treatment costs include the cost for institutional controls.

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Figure 9-11. Alternative 3—RTD and Expanded Groundwater Treatment

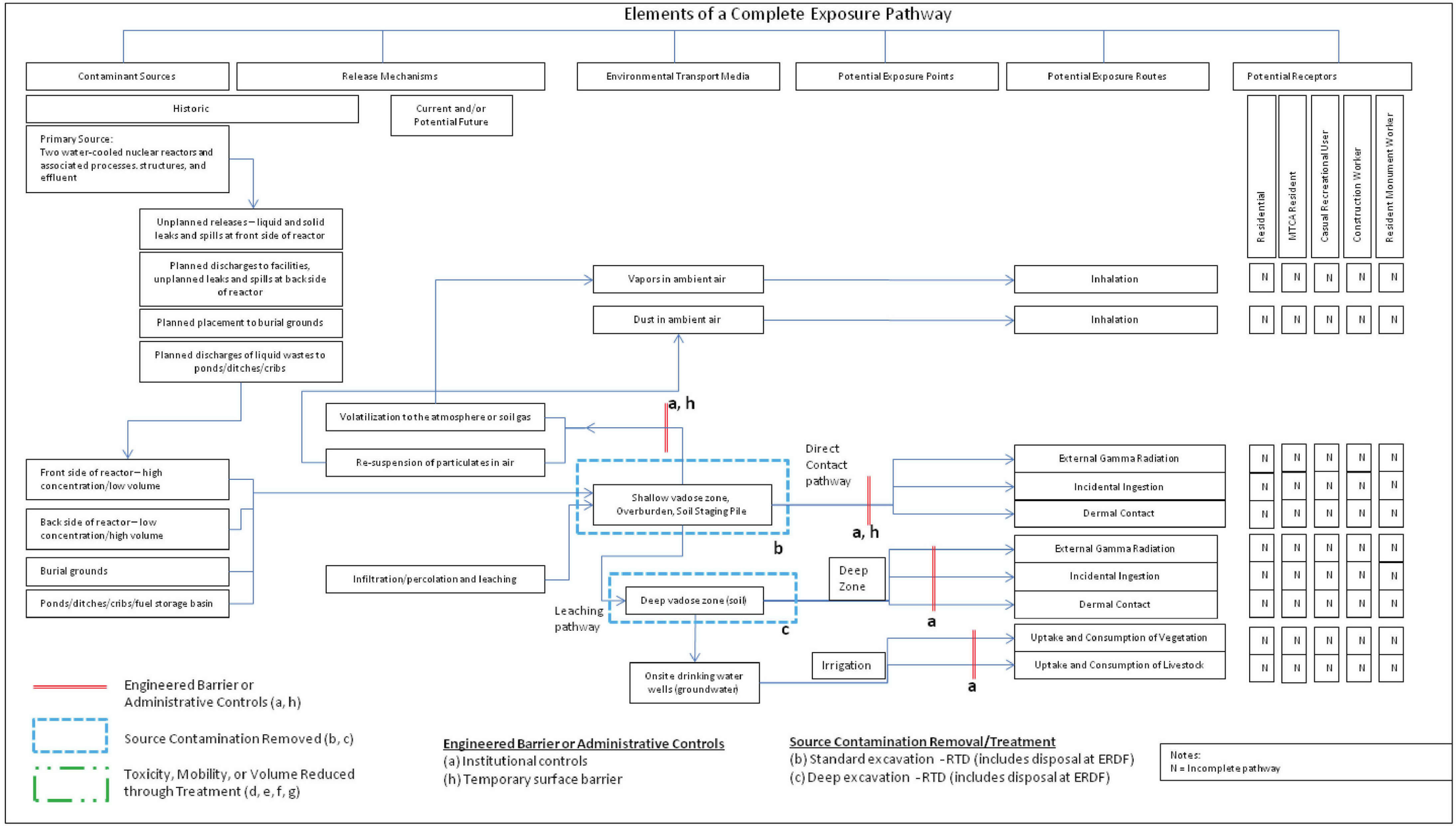

Figure 9-12. Applying Alternative 3 to the Source Exposure Pathway

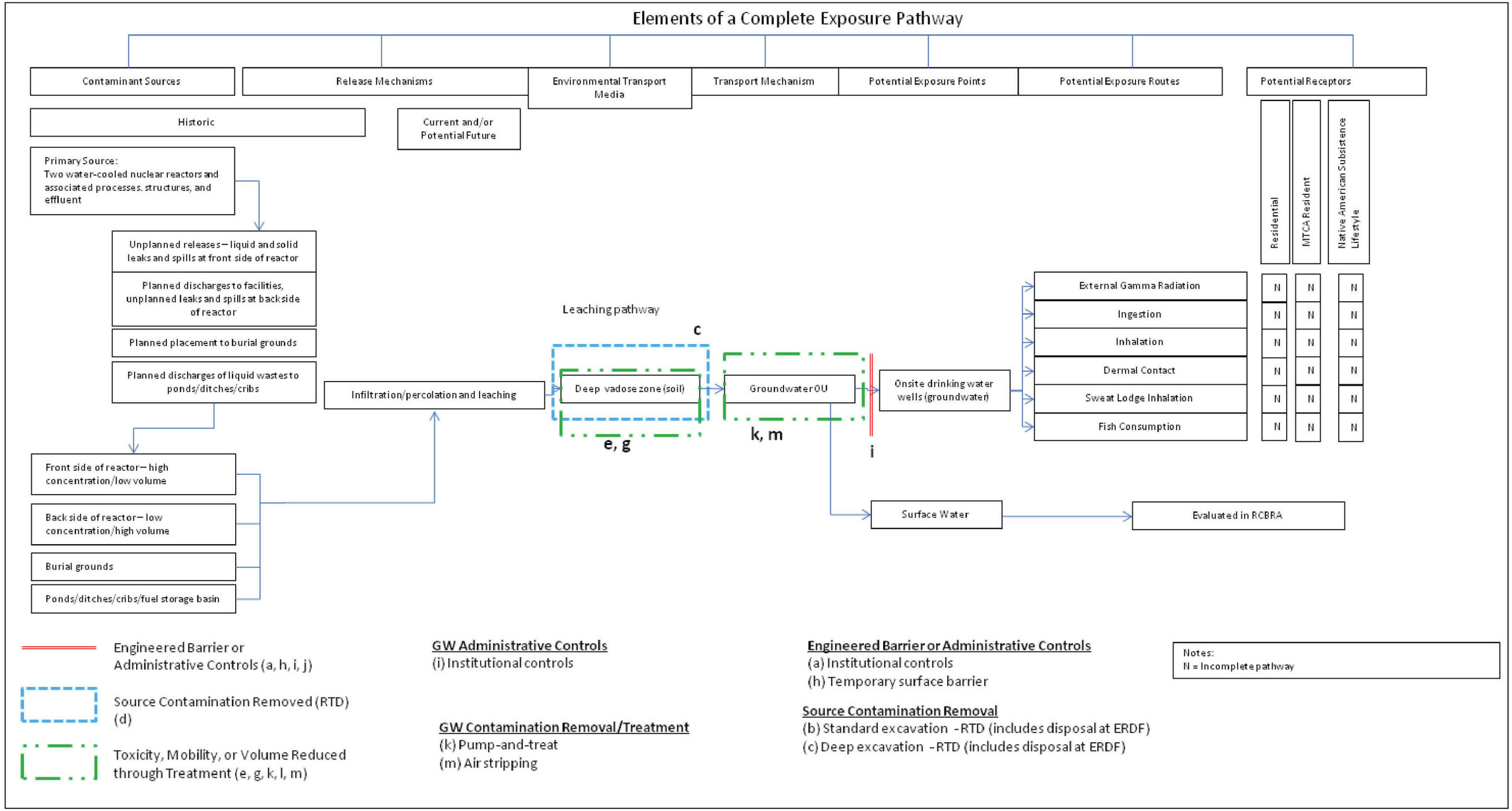

Figure 9-13. Applying Alternative 3 to the Groundwater Exposure Pathway

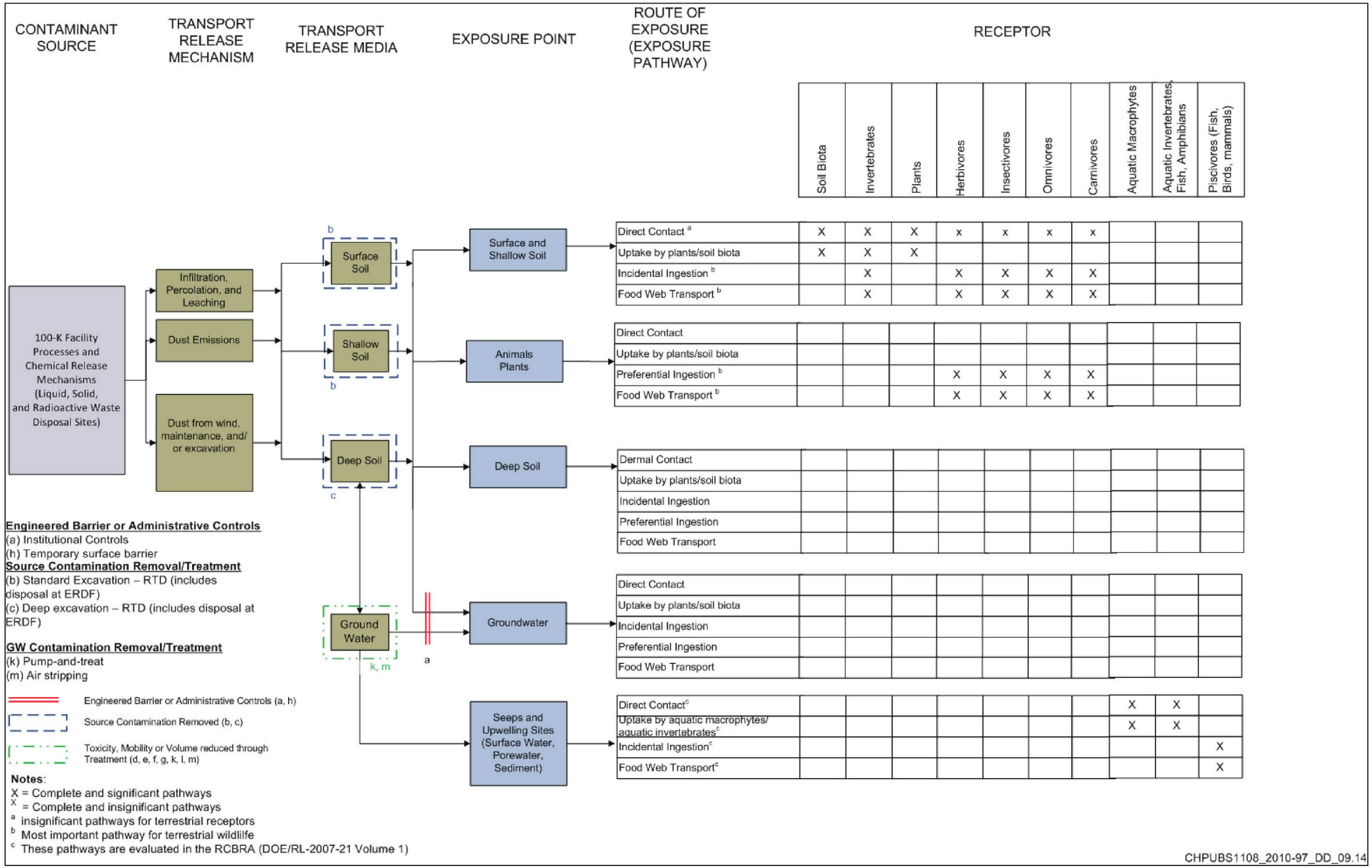

Figure 9-14. Applying Alternative 3 to the Ecological Exposure Pathway

Alternative 3 Remedial Decisional Flow Diagram

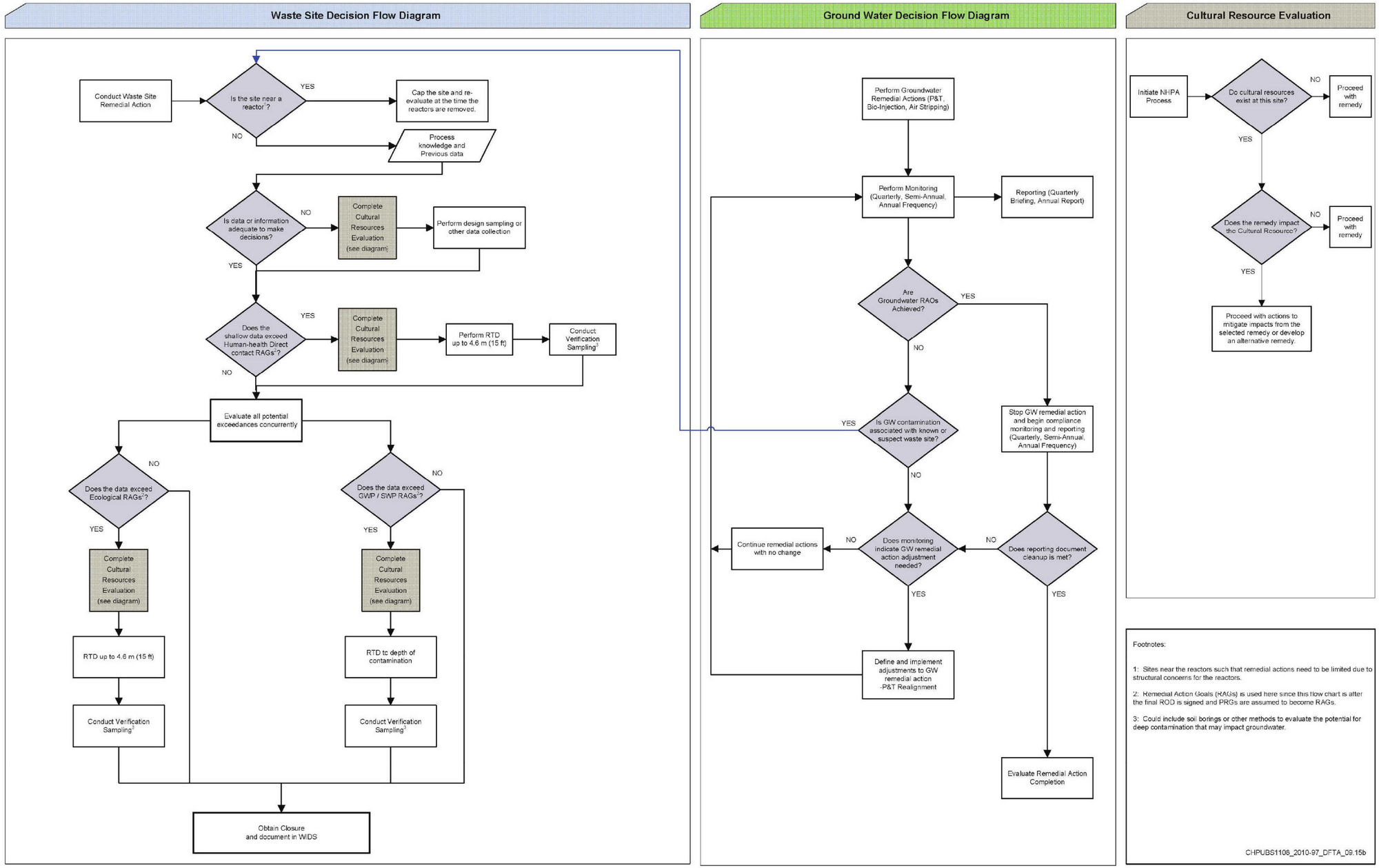

Figure 9-15. Alterative 3—Remedial Decision Flow Diagram

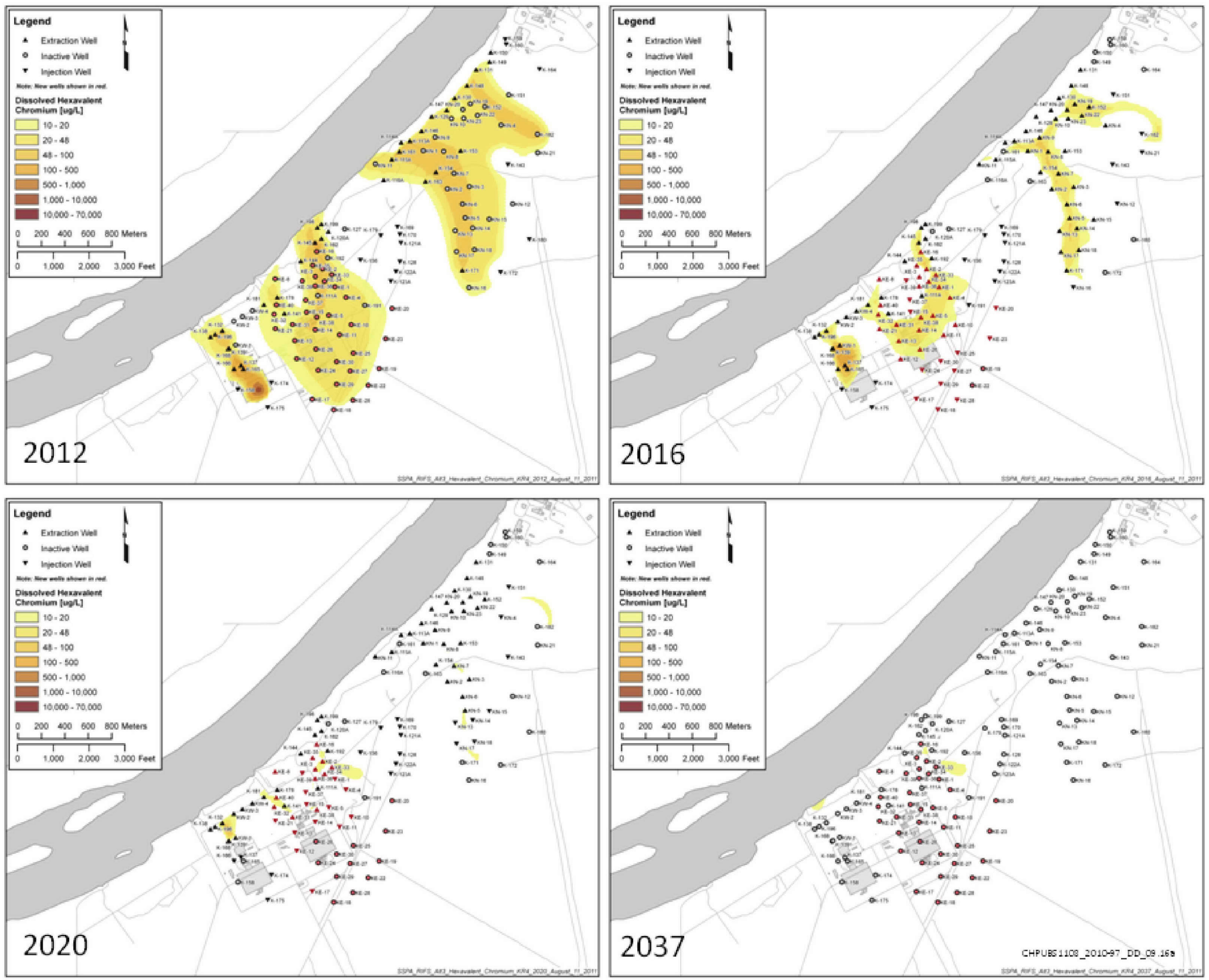

Figure 9-16. Alternative 3—Modeled Cr(VI) Plumes (2012 to 2037)

Figure 9-17. Alternative 3—Modeled Nitrate Plumes (2012 to 2037)

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As described in Alternative 2 and similar to Alternative 3, an analysis of cultural resource impacts would also be conducted.

Groundwater: For groundwater, this alternative expands the operation of the interim action pump-and-treat systems. The expansions are designed to achieve complete cleanup of the plume to 10 µg/L by 2020. New extraction and injection wells will be installed, along with new treatment plants to handle the additional flow. This alternative also treats the carbon-14 in a manner similar to Alternative 2.

The groundwater extracted from within the carbon-14 plume (i.e., Wells 199-K-132, 199-KW-1, and 199-KW-2) are likely to have carbon-14 greater than the DWS. Water from this well will be treated in an air stripper to reduce the carbon-14 to below the DWS prior to re-injection.

Figure 9-16 shows the layout of the expanded system, with the modeled Cr(VI) groundwater plume in December 2012, 2016, 2020, and 2037. The modeling predicts that by 2020, the majority of plumes are gone with only very small pockets of chromium remaining at low concentrations. Similar to Alternative 3, three new extraction wells are included to capture the nitrate plume between K-West and K-East. Figure 9-17 shows the modeled nitrate plumes in December 2012, 2016, 2020, and 2037. The modeling predicts that by 2020, only low concentrations of nitrate remain in the K-West plume in a small, localized area. When evaluating these groundwater modeling results, the uncertainty in the model needs to be appreciated. To deal with the uncertainty, RPO activities will be conducted throughout the life of the project.

The following are the key steps for groundwater remedial action implemented in the decision process.

1. **Evaluate if groundwater contamination is beneath a waste site source:** If groundwater concentrations exceed RAGs and waste site source has not been remediated, continue groundwater remediation activities and complete waste site remedation as identified in the waste site decision process.

2. **Evaluate groundwater remedation performance to determine if system adjustments are necessary:** System performance monitoring will be conducted throughout this remedial action. Performance monitoring data will be evaluated to compare actual groundwater cleanup progress with predicted cleanup through modeling to determine if adjustments to the remediation system is needed. Adjustments to the remediation system would include well field realignments to extract from areas with higher concentrations and/or inject at locations to manipulate plume and push contaminated groundwater towards extraction wells.

3. **Evaluate for Remedial Action Completion:** Once the above steps are performed and ongoing compliance monitoring demonstrates the cleanup requirements have been achieved, completion will be obtained, following the procedure contained in the ROD and RD/RA Work Plan.

   To define if the monitoring data collected during the compliance monitoring phase of the project meets the cleanup requirements, three years of quarterly groundwater monitoring data will be evaluated. The data will be expressed and reported as both individual measurements (maximum, minimum and mean) and as an exposure point concentration (EPC) using 4 defined plume exposure areas. These areas will include the K-West plume area, K-East plume area, K-North plume area and River proximity area. EPCs values will be calculated as either a 90th percentile value per COC or a 95 upper confidence limit (UCL) per COC using the groundwater compliance monitoring dataset.

   In general, EPA Superfund guidance (OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*) recommends using an average 95 percent upper confidence limit for estimating EPCs. However, experience at the Hanford Site indicates that averages and UCLs at times in certain operable units cannot be reliably calculated for groundwater data sets. The problem lies in operable units with multiple groundwater contaminants present with

overlapping plumes, and the highest concentrations having different locations within those plumes. The 100 Area operable units do not exhibit this condition in most locations, but that will have to be determined based on the compliance dataset.

The 90th percentile EPC is identified by EPA as appropriate for describing and characterizing health risks/exposures as its use yields risk estimates that correspond to a reasonable maximum exposure (RME) value. The RME is an appropriate exposure scenario for risk calculations and risk comparison within the realistic range of exposure since the goal of the Superfund program is to protect against high-end, not average exposures. The "high-end" is defined as that part of the exposure distribution that is above the 90th percentile but below the 99.9th percentile. The 90th percentile value is based on ranking the analytical results from lowest to highest and selecting the position that corresponds to the 90th percentile.

The 100-K dataset will be reduced, managed and reported using both mathematical methods mentioned above and the most appropriate method selected to express the EPC values for the 4 various exposure areas. Individual measurements will be used to defined areas within the plume exposure areas that may indicate persistant waste site area groundwater contributing. From this information, and in consultation with the lead regulatory agency, the project will define if the final cleanup levels have been met.

If additional remediation is needed due to rebound of certain COCs in specific areas of the plume (hot spot locations) to achieve the EPC target completion cleanup level, the system will be optimized to focus on that /those specific areas. System operation and monitoring will be halted within exposure areas where the target EPC values per COC have been demonstrated to meet the cleanup levels.

9.2.4 Common Elements for Alternatives 2 and 3

Elements that are common to the remedial action developed for 100-K for Alternatives 2 and 3 are discussed in this section.

9.2.4.1 Institutional Controls

ICs are defined and discussed in more detail in Section 8.3.1 and Table 8-8. ICs are designed to achieve the substantive restrictions needed during the period of remedial actions to achieve cleanup objectives. Instiutional controls that are in place to prevent exposure to contamination will remain in place until all waste sites are remediated. It should be noted that ICs would be implemented on a River Corridor-wide basis, and not independently, for each waste site or groundwater plume (as assumed for the development of cost estimates). The ICs are addressed in the detailed discussion of the alternatives presented previously.

9.2.4.2 Removal, Treatment, and Disposal

RTD, which can be used to manage contamination in soil, consists of the following actions:

- Collecting design samples based on the expected and actual risk drivers (media and contaminants of concern).
- Demolition of any surface structures, as required.
- Excavation and demolition of the waste site subgrade structures.
- Excavation of the waste site structures and vadose zone where contaminant concentrations are above RAGs.

- Excavation using best practices, which includes appropriately sloped sidewalls based on the type of the material being removed, benching, shoring, and proper placement of the stockpiled material per Occupational Safety and Health Administration (OSHA) standards. Sidewall protection is incorporated for any excavation greater than 1.5 m (5 ft) deep. This includes appropriate sidewall laybacks and ramps for equipment.

- Sampling and field screening during excavation to ensure that remediation is adequate to meet the RAGs. If contamination above the RAGs is encountered beyond the planned limits of excavation, the extent of removal could be increased.

- Dust suppression during excavation to ensure that contaminants are not spread due to wind during removal activities.

- Excavated material (low-level waste) is disposed to ERDF as long as it meets disposal criteria. Hazardous or mixed waste is treated to meet land disposal restrictions prior to disposal at ERDF. Offsite disposal would be considered if required and cost effective.

- Backfilling the excavation to the original ground surface and restoring/revegetating the site. Sources for backfill material include local borrow pits and the excavated material that is determined to be clean (verified as clean by meeting RAGs). Sites are revegetated after backfilling.

- Verification sampling is performed to demonstrate that contamination removal has been effective and the soil remaining in the excavated area does not exceed RAGs.

Figures 8-5, 8-6, and 8-7 illustrate the components of RTD, which has been the basic part of the interim actions performed for the waste sites at Hanford. Chapter 1 provides additional information on the interim actions that have been or will be completed at 100-K by December 2012. Where RTD is called for in the particular alternative in this FS, it will be performed following the same approach as it has been for the interim actions.

9.2.4.3 Temporary Surface Barriers

Temporary surface barrier technologies are applicable for groundwater, human health, and ecological protection (*Central Plateau Vadose Zone Remediation Technology Screening Evaluation* [RPP-ENV-34028]). Surface barriers are constructed over contaminated waste sites to control the vertical entry of water into contaminated media, which in turn, reduces leaching of contamination to groundwater. In addition to their hydrological performance, barriers also can function as physical impediments to prevent intrusion by human and ecological receptors, limit wind and water erosion, and attenuate radioactivity.

Implementation of temporary surface barriers is proposed for waste sites where active remedial alternatives such as RTD may require to be delayed due to the proximity of the waste site to a reactor or possible significant cultural issues. For cost estimating purposes, surface asphalt barriers have been evaluated in this study; however, the application of other barriers (e.g., RCRA modified D, vegetative cap, evapotranspiration) are considered effective and implementable at the site. Given ISS for the reactors at 100-K, the surface barriers are intended to remain functional for a 75-year period. Additional information on surface barriers is presented in Figure 8-14.

The conceptual design for a surface barrier includes the following:

- 15.24 cm (6 in.) asphalt surface layer
- 60 mi high-density polyethylene (HDPE) layer
- 15.24 cm (6 in.) soil cover (onsite source)

- 15.24 cm (6 in.) foundation cover
- Total 46 cm (18 in.) thickness
- Surface asphalt barriers remain functional until the reactor is removed (75 years)
- O&M includes inspection of the surface barrier and patching, as needed

Evaluation of remaining contamination that will be under the surface barrier area may lead to a less robust barrier put in place as the surface barrier is only intended to be in place for up to 75 years.

9.2.4.4 Groundwater Pump-and-Treat

Groundwater pump-and-treat systems can be used to contain groundwater plumes through hydraulic containment systems or to remediate the entire groundwater plume through extraction of the mass. A pump-and-treat system consists of an extraction well network, a treatment system, and an injection well network. Figures 8-16 and 8-17 illustrate some of the components of a pump-and-treat system.

Three pump-and-treat systems (KR-4, KX, and KW) currently operate within 100-K as part of the interim action. The objectives of the existing systems are to provide hydraulic containment of the Cr(VI) such that no additional chromium reaches the river, and to begin remediation of the entire plume. Figure 8-23 illustrates the concept of hydraulic containment through groundwater extraction. Flushing the saturated zone using treated water (Figure 8-21) is another component of pump-and-treat and can be achieved through re-injection of treated groundwater to the 100-K aquifer.

All the groundwater alternative components presented here, with the exception of the No Action Alternative, build upon these existing systems. The alternative-specific enhancements of the system are described under each alternative in Sections 9.2.2 and 9.2.3. Table 9-4 summarizes the existing pump-and-treat systems at 100-K.

Table 9-4. Summary of the Existing Groundwater Pump-and-Treat Components

Groundwater Pump-and-Treat Systems	General	• Components of system well network: – Extraction wells o 25 cm (10 in.) diameter wells o 70% fully penetrating, 30% partially penetrating the aquifer o 6 m (20 ft) to 36 m (120 ft) screen lengths – Injection wells o 25 cm (10 in.) diameter wells o 70% fully penetrating, 30% partially penetrating screens into the aquifer – Wellhead infrastructure o Adjustable Frequency Drive (AFD) driven pumps o Piping/supports o Access roads to the wells o Electrical and control utilities o Piping, cabling, and electrical components

Table 9-4. Summary of the Existing Groundwater Pump-and-Treat Components

Groundwater Pump-and-Treat Systems (cont.)	KR4 P&T System (installed in 1997)	• System installed to treat the Cr(VI) plume associated with the 116-K-2 Trench. • Pump-and-treat is being carried out under the 100-HR-3 and 100-KR-4 OU ROD (EPA/ROD/R10-96/134). • System components currently consist of: – 10 extraction wells – 5 injection wells – Treatment using IX resin – Treatment capacity of 1,136 L/min (300 gpm) – Extracted groundwater transferred to treatment building in 100-K though aboveground pipeline – Treated water injected through wells into 100-K aquifer
	KW P&T System (installed in 2007)	• System installed to treat the groundwater in the KW Reactor area. • System components currently consist of: – 7 extraction wells – 3 injection wells – Treatment using IX resins – Treatment capacity of 757 L/min (200 gpm) – Extracted groundwater transferred to treatment building in 100-K though aboveground pipeline – Treated water injected through wells into 100-K aquifer
	KX P&T System (installed in 2009)	• System designed to treat the Cr(VI) plume located between the 116-K-2 Trench and fence line at the N Reactor. The extraction well system was realigned to treat contaminated groundwater associated with the KE Reactor plume at Wells 199-K-141 and 199-K-178. • System components currently consist of: – 14 extraction wells – 9 injection wells – Treatment using IX resins – Treatment capacity of 2,271 L/min (600 gpm) – Extracted groundwater transferred to treatment building in 100-K though aboveground pipeline – Treated water injected through wells into 100-K aquifer

Table 9-4. Summary of the Existing Groundwater Pump-and-Treat Components

Groundwater Pump-and-Treat Systems (cont.)	100-K IX Treatment Facilities	• Three separate facilities house all process treatment equipment and control systems for the pump-and-treat systems. • The IX treatment systems consist of several parallel trains with four IX vessels (lead, lag1, lag2, and polish) per train. • The KW pump-and-treat facility includes the following subsystems as described in the Functional Design Criteria for the KW Pump-and-Treat (WMP-29491): – Influent groundwater and effluent storage tanks (11,356 L [3,000 gal]) – Sulfuric acid pH adjustment to reduce the groundwater pH to nominally 7.0 to prevent precipitation of calcium carbonate on the piping and IX columns – Two AFD-controlled process pumps to transfer water through the IX columns at a maximum throughput capacity of 757 L/min (200 gpm) – Two skid-mounted IX treatment trains with four columns per train; the flow through each train is 379 L/min (100 gpm) – Backwash and resin sluicing system, with DOWEX™ 21K resin load-in/load-out area to remove resins for regeneration – Compressed air system for operational use throughout the process building – pH monitoring of the influent and effluent – Totes (1.1 m^3 [40 ft^3] each) for resin storage and shipment
		• The KX pump-and-treat facility includes the following subsystems, as described in *Design Criteria for the 100-K Expansion Pump and Treat* (WMP-30899) – Influent and effluent groundwater storage tanks (19,300 L [5,100 gal]) – Sulfuric acid pH adjustment to reduce the groundwater pH to nominally 7.0 to prevent precipitation of calcium carbonate on the piping and IX columns – Five AFD-controlled process pumps to transfer water through the IX columns at a maximum throughput capacity of 2,271 L/min (600 gpm) – Six skid-mounted IX treatment trains with four columns per train; the flow through each train is 379 L/min (100 gpm). – Backwash and resin sluicing system, with DOWEX 21K resin load-in/load-out area to remove resins for regeneration – Compressed air system for operational use throughout the process building – pH monitoring of the effluent – Totes (1.1 m^3 [40 ft^3] each) for resin storage and shipment – Transfer building(s) to house the 11,356 L (3,000 gal) transfer tank, AFD transfer pumps, filters, piping manifold, and associated controls

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Table 9-4. Summary of the Existing Groundwater Pump-and-Treat Components

Groundwater Pump-and-Treat Systems (cont.)		• The KR4 pump-and-treat facility include the following subsystems, as described in *Functional Design Criteria for the 100-KR-4 Pump-and-Treat System* (SGW-45611): – Influent and effluent groundwater storage tank (11,356 L [3,000 gal]) to receive groundwater from wells or transfer stations – Sulfuric acid pH adjustment to reduce the groundwater pH to nominally 7.0 to prevent precipitation of calcium carbonate on the piping and IX columns – Three AFD-controlled process pumps to transfer water to the IX column trains at a maximum throughput capacity of 1,136 L/min (300 gpm) – Three skid-mounted IX treatment trains with four columns per train; the flow through each train is 379 L/min (100 gpm) – Backwash and resin sluicing system, with DOWEX 21K resin load-in/load-out area to remove resins for regeneration – Compressed air system for operational use throughout the process building – pH monitoring of the influent and effluent – Totes (1.1 m^3 [40 ft^3] each) for resin storage and shipment – Transfer building(s) to house the 7,570 L (2,000 gal) transfer tank, AFD transfer pumps, filters, piping manifold, and associated controls

9.2.4.5 Air Stripping

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. Air stripping using a packed tower design is a common approach for removing dissolved carbon dioxide in distillation, desalination, and reverse osmosis processes (a process known as decarbonation). The same air stripping process can be used to remove dissolved phase carbon-14 that is in the form of mixed carbonate, bicarbonate, and carbon dioxide. Figure 8-18 illustrates the process of air stripping. The pH of the water affects equilibrium between bicarbonate ions and carbon dioxide. Prior to running water down the air stripper tower, hydrochloric acid would be added in-line to bring the pH down to approximately 5.5 to 6. A polyphosphate-type anti-scalent would also be dosed in-line prior to the air stripper to minimize scale formation on the air stripper packing media. After the carbon dioxide is stripped from the groundwater, the pH will increase (approximately to 7.8 to 8.2). A second amendment of hydrochloric acid would be added to bring the pH back down to about 7.0 to 7.5 to minimize scale forming potential when the groundwater is re-injected. The conceptual design for air stripping incorporates GAC for offgas treatment; however, preliminary risk modeling suggests carbon-14 will be lower than risk-based standards. Calculations that are more detailed will be performed in the final design.

For 100-K, implementation of air stripping is limited to the proposed treatment of carbon-14 in an isolated area. System components of air stripping include the following:

- 7.62 cm (3 in.) HDPE pipeline.
- One 37 m^2 (400 ft^2) facility building.
- Equalization tank where water from the extraction wells is collected, offgassing of carbon dioxide from groundwater is allowed, and from which an inlet to the transfer pump exits.

- Transfer pump to supply the necessary dynamic head from the equalization tank to the air stripper sprayers.
- Two hydrochloric acid storage tanks (UL listed, double containment) capable of safely storing acid. Includes inlet to tank for acid filling, outlet to peristaltic feed pump, and level gauges.
- Anti-scalent storage tank including inlet to tank for chemical filling, outlet to peristaltic feed pump, and level gauges.
- Low profile tray tower air stripper (0.6 to 1 m [2 to 3 ft] diameter, 3 m [10 ft] high)
- Blower (air-to-water ratio: 300 to 1).
- Flow meters (turbine) and totalizers for the groundwater inlet.
- Positive displacement/peristaltic pumps for two acid tanks and anti-scalent tank. The inlets to the main water line from the feed tanks will have a check valve to prevent backflow.
- Valves (such as globe or butterfly valves) to control flow to injection wells (individually) and infiltration treatment zones (individually).
- A centrifugal booster pump.
- GAC vessel for offgas treatment.

9.2.4.6 Operations and Maintenance

O&M of each remedial alternative is required to ensure that the remedy is operated and maintained in a manner that ensures long-term effectiveness and permanence. O&M requirements of the selected remedy will be described in an O&M plan, which details performance monitoring needs, post-closure monitoring requirements, monitoring methods, analytes and intervals, maintenance activities and frequencies, and associated procedures.

The nature and scope of O&M activities vary by alternative component. For example, O&M activities primarily include inspection, maintenance, and periodic replacement of monitoring wells, whereas groundwater pump-and-treat components include routine and preventive maintenance programs as well as replacement of pump-and-treat system components at the end of their design life (typically 25 years). Alternatives with longer durations include multiple replacements of system components on a 25-year frequency.

The scope and cost of O&M activities are included in each of the remedy components.

9.2.4.7 Remedy Performance Monitoring

Remedy performance monitoring will be conducted to evaluate the effectiveness of the selected alternative, to attain the cleanup levels that will be identified in the 100-K decision document. The nature and scope of the performance monitoring program will vary by alternative component, and will be developed during the remedial design process and included in a performance monitoring plan.

The largest component of remedy performance monitoring is expected to be associated with the groundwater remedial components. Performance monitoring of the pump-and-treat system would be designed to evaluate contaminant mass removal from 100-K groundwater. The design would include both hydraulic and chemical monitoring of the extraction wells. Hydraulic monitoring would consist of measuring flow rates and total flow, as well as a distribution of water levels within and adjacent to the affected area. The injection well network would also be monitored for hydraulic performance. Water level

measurements would be used to evaluate whether extraction and injection wells are operating within their design criteria to contain and capture the plume. Results of the evaluation would be used to optimize the remedy by changing the extraction and injection pattern or adding wells locally, if necessary. Chemical monitoring would consist of sampling monitoring wells for COCs, potential degradation byproducts, and geochemical parameters to support the evaluation of biological infiltration and injection. The geochemical groundwater parameters used in the natural attenuation evaluation of Cr(VI) is anticipated to be the COCs, dissolved oxygen, iron (II), sulfate, and methane (*Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* [EPA/600/R-98/128]). In addition to these parameters, site-specific parameters may be identified to better understand the ability of natural attenuation processes, given the aquifer conditions at 100-K..

A series of groundwater monitoring plans has been developed under the interim actions via the 100 Area RDR/RAWP (DOE/RL-96-17), *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90), and *Sampling and Analysis Plan for Soil and Groundwater at the In Situ Bioremediation Design Test Wells at the Hanford 100-D Area* (DOE/RL-2010-56), as described in the *Central Plateau Industrial Building D4 Project Waste DQO and Sampling and Analysis Plan* (DOE/RL-2010-57). The number of wells monitored and the frequency of remedy performance monitoring is anticipated to vary, depending on the phase of remediation. A geostatistical analysis will be conducted to determine the optimum spatial distribution for the performance monitoring network. The frequency of monitoring is assumed to be quarterly, semiannually, or annually.

For the development of conceptual design cost estimates, the following was assumed:

- Remedy performance monitoring will be defined in the SAP developed as part of the remedial design. For this FS, the following was assumed:
  - Conducted to evaluate the effectiveness of the selected alternative to attain the cleanup levels.
  - Nature and scope are specific to alternative components, and would be developed during remedial design process.
  - Monitoring components include hydraulic and chemical monitoring of the extraction wells designed to evaluate contaminant mass removal.
  - Frequency: semiannual to annual for remediation alternatives.

9.2.5 Remedial Components Specific to Alternative 2

Elements that are specific to the remedial action developed for Alternative 2 are discussed in this section.

9.2.5.1 Biological Infiltration

Biological infiltration systems can be used to treat shallow and deep Cr(VI) (or other biologically reducible contaminants [e.g., nitrate]) in waste site soil. The infiltration of organic substrate amended water from the ground surface will stimulate microbial growth in the vadose zone, depleting the available oxygen, and facilitating the development of Cr(VI) reducing conditions in the treated section of the vadose zone. Some leaching of the Cr(VI) is likely to occur during the initial applications, and groundwater extraction wells must be used to capture this Cr(VI). The extracted water will be recycled to the biological infiltration system. Figure 8-9 illustrates biological treatment and Figure 8-12 illustrates delivery of liquid substrates through surface infiltration.

Conceptual design components for biological infiltration included in this FS are as follows:

- The system includes the following components:

  - Surface infiltration of organic substrate-amended water (e.g., with lactate).
  - Source water is treated groundwater supplemented with untreated water amended with substrate.
  - Construction of bioreagent mixing facilities at infiltration areas, and potential implementation of standalone smaller bionodes if required due to distance limitations.
  - Reagent delivery using drip emitter lines buried approximately 30.5 cm (12 in.) bgs (or placed at the bottom of an excavation, if the area is previously excavated).
- Monitoring and verification sampling (lysimeters and soil borings). Includes installation of monitoring wells to monitor potential impacts to groundwater. Initially designed for one-half to one acre in size, and will include the following components:
  - Main inlet water line running through its center of the drip system
  - From this main water line, drip emitter lines branched off at approximately 30.5 cm (12 in.) spacing
  - Drip emitters that dispense water based on their flow ratings and pressure in the line
- Estimated system flow rate ranges from 50 to 300 gpm.
- Pulsed operations will likely be used.

The size of the system will vary, depending on the size of the impacted area at a particular site. However, a standard design that can be scaled to the requirements of each site has been developed. Waste sites that overlap or are near other sites could use one larger system, or they could share common facilities. Appendix I provides additional information on bioremediation as a potential remedial action for Cr(VI) in the groundwater and vadose zone of the 100 Area.

9.2.5.2 Soil Flushing

Soil flushing will enhance the migration of mobile contaminants from the vadose zone to groundwater, where they can be captured by groundwater extraction wells. It can be used for any mobile contaminant and is proposed for Cr(VI) sites, instead of biological infiltration, at waste sites that are located in proximity to the Columbia River to prevent the potential byproducts of biological reduction (e.g., iron, arsenic, manganese and, potentially, residual organics) from migrating to the Columbia River. Soil flushing can also be used to remove carbon-14 and other soluble contaminants from vadose zone soil.

The proposed conceptual design for soil flushing mirrors biological infiltration, where treated or fresh water is infiltrated to the vadose zone, instead of a biological substrate. Figure 8-13 illustrates soil flushing in the vadose zone using water and Figure 8-12 illustrates delivery of liquid substrates through surface infiltration. Conceptual design components for soil flushing included in this FS are as follows:

- The system infrastructure is similar to bioinfiltration. System components include the following:
  - Surface infiltration of clean or treated water (no amendment applied)
  - Source water is groundwater from extraction wells treated through the ion exchange systems supplemented with clean water as necessary
  - Water delivery using drip emitter lines buried approximately 15.2 cm (6 in.) bgs (or placed at the bottom of an excavation, if the area is previously excavated)
- Monitoring and verification sampling (lysimeters and soil borings). Includes installation of monitoring wells to monitor potential impacts to groundwater.

- Initially designed for one-half to one acre in size, and will include the following components:
  - Main inlet water line running through the center of the drip system
  - From this main water line, drip emitter lines branched off at approximately 30.5 cm (12 in.) spacing
  - Drip emitters that dispense water based on their flow ratings and pressure in the line
- Estimated system flow rate ranges from 100 to 300 gpm.
- Pulsed operations will likely be used.
- Soil flushing also includes air stripping to treat carbon-14 (when applicable) that is flushed from the vadose zone to the groundwater during the operation of the soil flushing system. The following paragraphs provide additional information on air stripping.

9.2.5.3 Bioventing

Implementation of bioventing is proposed at waste sites at 100-K where TPH has been identified as a COC at depths exceeding 0.3 m (1 ft) bgs. This process involves providing oxygen using low air flow rates to sustain microbial activity, thereby stimulating the natural biodegradation of aerobically degradable compounds in soil.

The conceptual design for a bioventing at 100-K includes the following:

- System components include:
  - One 18.6 m^2 (200 ft^2) facility building
  - Blower used to inject ambient air into contaminated soil
  - Vent wells; the number is based on size of contamination and radius of influence of the injected ambient air
  - Manifold piping connecting blower to vent wells
  - Soil gas monitoring points installed in the contaminated soil zones to monitor the changes in pressure and soil gas
  - Instrumentation and controls
- Flow meters at well heads, manifold, and blower discharge
- Vacuum/pressure gauges at wells heads, manifold, and before blower
- Flow control valves at well heads and manifold
- Sampling ports at well heads, manifold, and after blower
- Temperature sensors at manifold to blower and blower discharge
- Optional equipment could include nutrient delivery systems, or vapor treatment systems

Additional information on bioventing is presented in Figure 8-10.

9.2.5.4 Land Farming

Implementation of land farming is proposed at waste sites in 100-K where TPH has been identified as a COC at shallow depths (impacted media at 0.3 m [1 ft] bgs). The execution of land farming involves mixing contaminated soil with an amendment using a common tracker with ripper teeth or a disc to

encourage degradation of TPH. The conceptual design for a landfarming at 100-K includes the following components:

- Depth of tilling ranges from 0.3 to 0.5 m (12 to 18 in.).
- Frequency for tilling should occur twice per month with two passes (different directions) per day.
- To maintain proper moisture content, a watering frequency occurs four times per month. Monitoring moisture content of the land farm soil should occur to ensure optimum moisture content is maintained.
- After the soils have been remediated, the soil will be leveled and revegetated.

Additional information on land farming is presented in Figure 8-8.

9.2.5.5 Biological Injection

In situ groundwater bioremediation, hereafter called biological injection (bioinjection), can be used to provide in situ biological reduction of Cr(VI). Bioinjection is proposed for Alternative 2 to enhance the pump-and-treat systems for Cr(VI) remediation. Bioinjection is the process of adding an organic substrate to water injected into the saturated zone to induce growth or activity of indigenous bacteria for reducing chromate. The injected water will be groundwater extracted from a downgradient well to create a closed loop injection-extraction system. This will be done in part to avoid any groundwater impacted with the organic substrate from reaching an IX treatment plant. Additionally, this approach will biologically reduce any Cr(VI) in the extracted groundwater, which will reduce the flow rate to the IX treatment plants, thereby reducing the O&M costs. Figure 8-20 illustrates bioinjection.

The conceptual design for a single bioinjection, extraction-injection well pair for the proposed alternatives is as follows:

- Organic substrates can include :
  - Soluble (miscible) substrates (e.g., lactate and cheese whey)
  - Immiscible substrates (e.g., emulsified vegetable oil)
- Injection of organic substrate performed at upgradient wells in pulsed operation to reduce well fouling.
  - Groundwater from extraction wells will be used as the source water for the bioinjection and piped directly to the reagent mixing facility.
  - After the source groundwater is mixed with a carbon source at the reagent mixing facility, a pipeline would carry fluid from the reagent mixing facility to the injection wells or injection trench.
- System components:
  - Reagent mixing facility, pipelines, injection wells, pumps, valves
  - Stand-alone injection wells
  - Injection well components to allow the well to operate efficiently without aeration of the injection water:
    - A packer located 3 m (10 ft) from the top of casing to prevent injection well overtopping

    - A pressure transducer to measure pressure on the packer
    - A drop pipe and a foot valve at the bottom of the drop pipe to maintain a standing column of water in the drop pipe
    - A water level indicator/transducer to monitor water levels in the injection wells
    - A cleanout for the pipeline from the mainline to the injection well (a tee in the line where cleaning tools can be inserted)
    - A sampling port that would allow sampling of the injection water
  - A pipeline to each injection well, installed on the ground surface
  - Proposed injection rates range from 15 to 43 gpm for each well
- A preventive well-cleaning program to mitigate well fouling includes the following activities:
  - Flushing the wells with clean water on a regular basis
  - Physically cleaning the wells with appropriate cleaning solutions (e.g., acidic acid or bleach)

Section 9.2.2 presents the specific extraction-injection well layouts for the alternative. It is likely that a pulsed/intermittent operation will be used to optimize the performance of the bioinjection system. Appendix I provides additional information on bioremediation as a potential remedial action for Cr(VI) in the groundwater and vadose zone of the Hanford 100 Area.

9.2.6 Summary of Alternatives

Remedies implemented for Post-ROD To-Go waste sites in Alternatives 2 and 3 are based on types of contaminants, risk for exceedance of human health direct contact or ecological RAGs, and proximity to reactor facilities as summarized below:

- Waste sites near a reactor facility that cannot be remediated until after removal of reactor facility will have temporary surface barriers placed over the waste sites for up to 75 years of reactor ISS for both Alternatives 2 and 3.
- Cultural resources evaluation will be conducted in both Alternatives 2 and 3 to evaluate impacts from remedial activities to cultural resources that exist at the remediation site. Should the remedy impact cultural resources, actions will be taken to mitigate or develop an alternative remedy.
- Waste sites with Cr(VI) contamination resulting in a risk to groundwater/surface water protection:
  - Alternative 2 implements RTD of soil with contamination other than Cr(VI) exceeding human health direct contact, ecological, and/or groundwater/surface water RAGs followed by soil flushing and/or bioinfiltration for the remaining vadose zone depth
  - Alternative 3 implements RTD to depth of contamination, which may be to groundwater
- Waste sites with mobile carbon-14 contamination resulting in a risk to groundwater/surface water protection:
  - Alternative 2 implements RTD of soil with COPCs other than carbon-14 exceeding human health direct contact, ecological, and/or groundwater/surface water RAGs followed by soil flushing, groundwater extraction, and air stripping of extracted groundwater to remove carbon-14 that gets flushed to the groundwater

  - Alternative 3 implements RTD to depth of contamination, which may be to groundwater, groundwater extraction, and air stripping of extracted groundwater to remove carbon-14 that migrates to groundwater as a result of RTD

- Waste sites with other COPCs (e.g., lead, mercury) resulting in a risk to groundwater/surface water protection:
  - Alternatives 2 and 3 implement RTD to depth of contamination, which may be to groundwater
- Waste sites with only TPH contamination:
  - Alternative 2 implements land farming for contamination less than 0.30 m [1 ft] bgs, or bioventing into the vadose zone for contamination greater than 0.30 m [1 ft] bgs
  - Alternative 3 implements RTD to depth of contamination
- Alternatives 2 and 3 both implement RTD for waste sites with contamination exceeding human health direct contact and/or ecological RAGs in shallow soil (less than 4.6 m [15 ft] bgs).

Table 9-5 presents the individual alternative components for each Post-ROD To-Go waste sites evaluated at 100-K grouped by the types of contaminants, types of exceedances, and proximity to reactor facilities as described above. Table 9-5 also indicates where cultural resource review applies to waste sites located in a culturally sensitive area.

Table 9-6 presents the Pre-ROD To-Go waste sites at 100-K evaluated for types of contaminants and types of exceedances that required remediation via the interim action. Pre-ROD To-Go waste that do not meet the final PRGs after completion of remediation under the 100 Area Remaining Sites ROD (EPA/ROD/R10-99/039), will be evaluated for further remedial actions following the Post-ROD To-Go decision logic approach.

Appendix J provides additional information for each waste site evaluated in the development of alternatives. Details regarding the development of cost estimates are presented in Appendix J.

Groundwater remediation is accomplished in Alternative 2 through a combination of pump-and-treat, biological treatment through bioinfiltration and bioinjection. Alternative 3 implements expanded pump-and-treat to remediate the groundwater with construction of a new 4,920 L/min (1,300 gpm) pump-and-treat facility.

Tables 9-7 and 9-8 show the numerical components of each alternative (e.g., number of sites evaluated, volume of material treated) for waste sites and groundwater, respectively. The numerical components projections included in Tables 9-7 and 9-8 are based on assumed footprints for remediation and actions based on assumed exceedances developed only for cost estimating purposes for this FS. Numerical components of the selected approach would be refined during the RD/RAWP.

9.3 Remedial Alternative Screening Evaluation

As discussed in EPA guidance (*The Feasibility Study: Development and Screening of Remedial Action Alternatives* [OSWER Directive 9355.3-01FS3]), screening of alternatives is not a required step since only three alternatives are being evaluated. Consequently, they are all carried into the detailed evaluation in Chapter 10.

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
116-KE-1	Site near reactor: Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs); and groundwater/surface water protection risk for other COPCs (carbon-14 and tritium)	1) Surface barrier (area of 418 m^2 [4,500 ft^2]) After 75 years: 2) Confirmation/verification sampling 3) RTD area of 418 m^2 (4,500 ft^2) to 15.2 m (50 ft). Disposal at ERDF or other approved disposal facililty 4) Soil flushing with water 5) Air stripping for the treatment of C-14 while the soil flushing system is operating	1) Surface barrier After 75 years: 2) Minimal design sampling 3) RTD area of 418 m^2 (4,500 ft^2) to 20 m (65 ft) bgs 4) Disposal at ERDF or other approved disposal facililty 5) Air stripping
116-KW-1	Site near reactor: Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs); and groundwater/surface water protection risk for other COPCs (carbon-14 and tritium)	1) Surface barrier (area of 418 m^2 [4,500 ft^2]) After 75 years: 2) Confirmation/verification sampling 3) RTD area of 418 m^2 (4,500 ft^2) to 17 m (55 ft) bgs. Disposal at ERDF or other approved disposal facililty. 4) Soil flushing with water 5) Groundwater monitoring 6) Air stripping for the treatment of C-14 while the soil flushing system is operating	1) Surface barrier (area of 418 m^2 [4,500 ft^2]) After 75 years: 2) Minimal design sampling 3) RTD area of 418 m^2 (4,500 ft^2) to 20 m (65 ft) bgs 4) Disposal at ERDF or other approved disposal facililty 5) Air stripping
100-K-82	Site near reactor: Groundwater/surface water protection risk likely for other COPCs	1) Surface Barrier **After 75 years:** 2) Remove Surface Barrier 3) Minimal Design Sampling 4) RTD area of 884 m^2 (9,520 ft^2) to 20 m (65 ft) bgs 5) Disposal at ERDF or other approved disposal facililty	1) Surface barrier **After 75 years:** 2) Remove surface barrier 3) Minimal design sampling 4) RTD area of 884 m^2 (9,520 ft^2) to 20 m (65 ft) bgs 5) Disposal at ERDF or other approved disposal facililty
UPR-100-K-1	Site near reactor: Groundwater/surface water protection risk likely for other COPCs	1) Surface Barrier **After 75 years:** 2) Remove surface barrier 3) Minimal design sampling 4) RTD area of 4,459 m^2 (48,000 ft^2) to 20 m (65 ft) bgs 5) Disposal at ERDF or other approved disposal facililty	1) Surface Barrier **After 75 years:** 2) Remove surface barrier 3) Minimal design sampling 4) RTD area of 4,459 m^2 (48,000 ft^2) to 20 m (65 ft) bgs 5) Disposal at ERDF or other approved disposal facililty
100-K-101	Human Health Direct Contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI) and/or other COPCs	1) Minimal design sampling 2) RTD area of 4,622 m^2 (49,750 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 4,622 m^2 (49,750 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-73	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI) and/or other COPCs	1) Minimal Design Sampling 2) RTD area of 11 m^2 (120 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal Design Sampling 2) RTD area of 11 m^2 (120 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
116-KE-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI) and/or other COPCs	1) Minimal design sampling 2) RTD area of 35 m^2 (375 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Confirmation/Verification Sampling 2) RTD area of 21 m^2 (225 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
116-KW-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI) and/or other COPCs	1) Minimal design sampling 2) RTD area of 35 m^2 (375 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 35 m^2 (375 ft^2) to 20 m (65 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-55:2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	1) Minimal design sampling 2) RTD area of 267 m^2 (2,870 ft^2) to 5.2 m (17 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 267 m^2 (2,870 ft^2) to 5.2 m (17 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
100-K-56:2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	1) Minimal design sampling 2) RTD area of 267 m^2 (2,870 ft^2) to 4.6 m (15 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 267 m^2 (2,870 ft^2) to 4.6 m (15 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
100-K-57	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	1) Minimal design sampling 2) RTD area of 2,462 m^2 (26,500 ft^2) to 4.6 m (15 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 2,462 m^2 (26,500 ft^2) to 4.6 m (15 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
100-K-98	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
116-K-3	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	1) Minimal design sampling 2) RTD area of 37 m^2 (400 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty 4) Soil flushing with water (outfall) 5) Groundwater Monitoring 6) Supplemental ICs * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 37 m^2 (400 ft^2) to 17 m (55 ft) bgs 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
120-KE-1	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	1) Confirmation/Verification Sampling 2) RTD area of 2,137 m^2 (23,000 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty 4) Soil flushing supplemented with Bioinfiltration 5) Supplemental ICs	1) Minimal design sampling 2) RTD area of 2,137 m^2 (23,000 ft^2) to 26 m (85 ft) 12 m (40 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
120-KE-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
120-KE-3	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
120-KE-6	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
120-KE-9	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
100-K-1	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 9 m^2 (100 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 9 m^2 (100 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-100	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 4,366 m^2 (47,000 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 4,366 m^2 (47,000 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-103	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-104	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 1 m^2 (8 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 1 m^2 (8 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-105	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 3 m^2 (36 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 3 m^2 (36 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-106	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 37 m^2 (400 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 37 m^2 (400 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-107	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 1 m^2 (16 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 1 m^2 (16 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-108	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-13	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 5 m^2 (49 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 5 m^2 (49 ft^2) to 4.6 m (15 ft) bgs. 3) Disposal at ERDF or other approved disposal facililty
100-K-14	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of6 m^2 (63 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of6 m^2 (63 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
100-K-25	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
100-K-27	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
100-K-35	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
100-K-47	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 4807 m^2 (51,750 ft^2) to 9.1 m (30 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 4807 m^2 (51,750 ft^2) to 9.1 m (30 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-48	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Landfarming 2) Supplemental ICs	1) Minimal design sampling 2) RTD area of 84 m^2 (900 ft^2) to 1 m (3 ft) 3) Disposal at ERDF or other approved disposal facililty
100-K-49	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Landfarming 2) Supplemental ICs	1) Minimal design sampling 2) RTD area of 37 m^2 (400 ft^2) to 1 m (3 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-5	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 2 m^2 (25 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 2 m^2 (25 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-50	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 16 m^2 (175 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 16 m^2 (175 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-54	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 414 m^2 (4,459 ft^2) to 2.4 m (8 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 414 m^2 (4,459 ft^2) to 2.4 m (8 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty
100-K-64	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 83,613 m^2 (900,000 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 83,613 m^2 (900,000 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
100-K-80	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 93 m^2 (1,000 ft^2) to 2.4 m (8 ft) bgs 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review	1) Minimal design sampling 2) RTD area of 93 m^2 (1,000 ft^2) to 2.4 m (8 ft) bgs 3) Disposal at ERDF or other approved disposal facililty * Cultural Resource Review
100-K-81	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 7 m^2 (75 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 7 m^2 (75 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
100-K-99	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 4,422 m^2 (47,600 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 4,422 m^2 (47,600 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
120-KE-4	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
120-KE-5	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
120-KE-8	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 16 m^2 (176 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 16 m^2 (176 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
120-KW-6	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 16 m^2 (176 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 16 m^2 (176 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
126-KE-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	Encompassed by alternative for 120-KE-1	Encompassed by alternative for 120-KE-1
130-K-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 22 m^2 (240 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 22 m^2 (240 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
130-KE-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Bioventing 2) Supplemental ICs	1) Minimal design sampling 2) RTD area of 2,694 m^2 (29,000 ft^2) to 15.2 m (50 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
130-KW-1	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 21 m^2 (225 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 21 m^2 (225 ft^2) to 4.9 m (16 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
130-KW-2	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Bioventing 2) Supplemental ICs	1) Minimal design sampling 2) RTD area of 2,694 m^2 (29,000 ft^2) to 15.2 m (50 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
1607-K1	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
1607-K2	Human Health Direct Contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
1607-K5	Human Health Direct Contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty

Table 9-5. Summary of Alternatives for Post-ROD To-Go Evaluated Waste Sites

Site Code (WIDS)	Type of Exceedance (Assumed for Post-ROD To Go Sites)	Alternative 2	Alternative 3
1607-K6	Human Health Direct Contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 347 m^2 (3,740 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-43	Building/Structure	1) Minimal design sampling 2) RTD area of 1,784 m^2 (19,200 ft^2) to 13.7 m (45 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 1,784 m^2 (19,200 ft^2) to 13.7 m (45 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-60	Building/Structure	1) Minimal design sampling 2) RTD area of 650 m^2 (7,000 ft^2) to 6.7 m (22 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 650 m^2 (7,000 ft^2) to 6.7 m (22 ft) bgs (pipeline removal) 3) Disposal at ERDF or other approved disposal facililty
100-K-61	Building/Structure	RTD (Building demolition)	RTD (Building demolition)
100-K-66	Building/Structure	RTD (Building demolition)	RTD (Building demolition)
100-K-67	Building/Structure	RTD (Building demolition)	RTD (Building demolition)
100-K-72	Building/Structure	1) Minimal design sampling 2) RTD area of 23 m^2 (250 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 23 m^2 (250 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-74	Building/Structure	1) Minimal design sampling 2) RTD area of 28 m^2 (300 ft^2) to 1.5 m (5 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 28 m^2 (300 ft^2) to 1.5 m (5 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-75	Building/Structure	1) Minimal design sampling 2) RTD area of 23 m^2 (250 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 23 m^2 (250 ft^2) to 6.1 m (20 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-79	Building/Structure	1) Minimal design sampling 2) RTD area of 53 m^2 (570 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 53 m^2 (570 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-83	Building/Structure	1) Minimal design sampling 2) RTD area of 655 m^2 (7,050 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 655 m^2 (7,050 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
100-K-94	Building/Structure	1) Minimal design sampling 2) RTD area of 2 m^2 (25 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty	1) Minimal design sampling 2) RTD area of 2 m^2 (25 ft^2) to 4.6 m (15 ft) bgs 3) Disposal at ERDF or other approved disposal facililty
132-KW-1	Building/Structure	RTD (Building demolition)	RTD (Building demolition)

Notes: Alternatives for the Pre-ROD To-Go Sites (Table 8-5) were not evaluated because the site is assumed to meet PRGs. If site fails PRGs, the alternative evaluation will follow Post-ROD To-Go decision process. The complete list of sites carried into the FS and additional information on sites included in this table is presented in Appendix J.

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Table 9-6. Summary of Pre-ROD To-Go Waste Sites

Site Code (WIDS)	Known or Suspected Contaminants	Types of Exceedances Assumed
100-K-109	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-110	Based on the results of the sampling and evaluation of the data, the residual contamination levels exceed the groundwater and Columbia River protection remedial action goals for antimony, copper, lead, manganese, mercury, selenium, vanadium, and zinc.	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
100-K-34	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-97	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
116-KE-3	Radionuclides and Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
118-K-1	Zirconium cladding hulls and basin sludge. reactor hardware, incinerator ashes, irradiated nickel plated boron balls	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
120-KW-1	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-2	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-3	Hazardous/dangerous contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-4	Radiological/Hazardous	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-5	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-7	Radiological/Hazardous	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-102	Metals, mercury	Liquid spill/surface release sites
100-K-18	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-19	Hazardous/dangerous contaminants; Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-3	Radiological and chemical contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-30	Mercury	Site exceeds Ecological risk criteria for Mercury (see Chapter 7). Encompassed within footprint of Post-ROD To-GO Waste Site 120-KE-1.
100-K-31	Mercury	Site exceeds Ecological risk criteria for Mercury (see Chapter 7). Encompassed within footprint of Post-ROD To-GO Waste Site 120-KE-1.
100-K-32	Mercury	Site exceeds Ecological risk criteria for Mercury (see Chapter 7). Encompassed within footprint of Pre-ROD To-GO Waste Site 120-KW-1.
100-K-33	Mercury	Site exceeds Ecological risk criteria for Mercury (see Chapter 7). Encompassed within footprint of Pre-ROD To-GO Waste Site 120-KW-1.
100-K-36	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-4	Radionuclides and Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-42	Radionuclides and Metals	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)

Table 9-6. Summary of Pre-ROD To-Go Waste Sites

Site Code (WIDS)	Known or Suspected Contaminants	Types of Exceedances Assumed
100-K-46	Radionuclides and Metals	Pipe/Conveyance sites Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-53	Metals and Ethylene Glycol	Pipe/Conveyance sites Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-6	Radiological/ hazardous contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-62	Radionuclides and Metals	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-63	Co-60, Cs-137, Eu-152/154, Sr-90, Cr+6 * Cultural Resource Review	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs) in culturally sensitive area
100-K-68	Radionuclides, Metals, PCBs, and Asbestos	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-69	Radionuclides, Metals, PCBs, and Asbestos	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-70	Radionuclides and Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-71	Radiological contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-77	Radionuclides and Metals; Creosote	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-84	Arsenic	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-86	Unknown	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-87	Asbestos	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-88	Unknown	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-89	Unknown	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-90	Unknown	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-91	Lead	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-92	Unknown	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-93	PAHs	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-95	PAHs	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
118-KE-2	Information not specified	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
118-KW-2	Radionuclides	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
128-K-2	Metals, PCBs, PAHs, TPH, & asbestos	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
130-KE-1	PAHs, TPH	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
132-KE-1	Metals and PCBs	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
1607-K3	Radiological and chemical contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
600-29	Metals, TPH, PAHs, and asbestos	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)

Table 9-6. Summary of Pre-ROD To-Go Waste Sites

Site Code (WIDS)	Known or Suspected Contaminants	Types of Exceedances Assumed
100-K-109	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-110	Based on the results of the sampling and evaluation of the data, the residual contamination levels exceed the groundwater and Columbia River protection remedial action goals for antimony, copper, lead, manganese, mercury, selenium, vanadium, and zinc.	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
100-K-34	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-97	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
116-KE-3	Radionuclides and Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
118-K-1	Zirconium cladding hulls and basin sludge, reactor hardware, incinerator ashes, irradiated nickel plated boron balls	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for other COCs
120-KW-1	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-2	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-3	Hazardous/dangerous contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-4	Radiological/Hazardous	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-5	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
120-KW-7	Radiological/Hazardous	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs), plus groundwater/surface water protection risk for Cr(VI)
100-K-102	Metals, mercury	Liquid spill/surface release sites
100-K-18	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-19	Hazardous/dangerous contaminants; Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-3	Radiological and chemical contaminants	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-36	Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-4	Radionuclides and Metals	Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-42	Radionuclides and Metals	Building/Structure Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-46	Radionuclides and Metals	Pipe/Conveyance sites Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)
100-K-53	Metals and Ethylene Glycol	Pipe/Conveyance sites Human health direct contact and/or Ecological risk likely in shallow soil (less than 4.6 m [15 ft] bgs)

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Table 9-7. Waste Site Alternative Numerical Components

Alternative	Waste Site Alternative Components																									
	No Action	Groundwater Monitoring		Land Farming		Bioventing		Temporary Surface Barriers		RTD		Biological Infiltration								Soil Flushing—Vadose Zone, Water						
	Number of Sites[a]	Number of MWs Installed (for monitoring of waste site)[a]	Total Number of GW Samples Collected	Number of Sites[b]	Volume of Treated Soil (yd^3)	Number of Sites[b]	Number IW Installed	Number of Sites[b]	Total Surface Cap Area (ha [ac])	Number of Sites[b]	Excavation Volume (m^3[yd^3])	Number of Sites[b]	Total Drip Emitter System Treatment Area ha[ac])	Volume of Biological Substrate (e.g., lactate) (L[gal])	Number of Biosubstrate Mixing Plants	Infiltration Rate (Lpm[gpm])	Number of EWs Installed	Number of MWs Installed	Aboveground Piping (m[ft])	Number of Sites[b]	Total Drip Emitter System Treatment Area (ha[ac])	Total Volume of Water (L[gal])	Infiltration Rate (Lpm[gpm])	Number of EWs Installed	Number of MWs Installed	Aboveground Piping (m[ft])
Alternative 1	116	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alternative 2	50	4	286	2	1,244	2	5	4	2.2 (5)	63	3,784,821 (4,946,558)	15	0.9 (2)	140 million (37 million)	1	530 - 1,100 (140 - 285)	4	4	610 (2,000)	3	0.66 (1.5)	9 million (2 million)	190 - 570 (50 - 150)	3	4	365 (1,500)
Alternative 3	50	8	208	N/A	N/A	N/A	N/A	4	2.2 (5)	66	3,921,000 (5,124,000)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note: The numerical components included above are projected based on assumed footprints for remediation and actions based on assumed exceedances developed only for cost estimating purposes for this FS. The actual approach will be determined following the Decision Logic. Numerical components of the selected approach would be determined during the RD/RAWP.

a. Number of groundwater monitoring wells only applies to new wells installed for specific waste site remediation and does not include the groundwater monitoring wells present in the groundwater remediation network.

b. A number of waste sites are encompassed by the remediation footprint of other waste sites. Additional information is presented in Appendix J.

EW = extraction well
IW = injection well
GW = groundwater well
MW = monitoring well
N/A = not an applicable component of the alternative
RTD = removal, treat, and dispose

Table 9-8. Groundwater Alternative Numerical Components

Alternative	Groundwater Alternative Components																
	Pump-and-Treat								Biological Treatment								Air Stripping
	Number of EWs Operating during Time Frame	Number of IWs Operating during Time Frame	Number of New/Converted EWs Installed	Number of New IWs Installed	Operation Time Frame	Extraction Rate (L/min [gpm])	Ion Exchange Treatment (L/min [gpm])	Above-ground Piping (m[ft])	Number of Bioinjection Wells Operating during Time Frame	Injection Rate (L/min [gpm])	Number of Bioinfiltration Galleries during Time Frame	Infiltration Rate (Lpm[gpm])	Volume of Substrate (L [gal])	Number of Bio Node Mixing Facilities	Number of Biosubstrate Mixing Plants	Aboveground Piping (m [ft])	Treatment Capacity (L/min [gpm])
Alternative 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A
Alternative 2	21 to 62	9 to 17	38	6	2013 to 2037	2,215 to 7,045 (585 to 1,860)	2,215 to 3,500 (585 to 935)	6,400 (21,000)	6 to 8	2,010 to 3,030 (530 to 815)	2	530 to 1680 (140 to 445)	4,080 million (840 million)	2	2	2,896 (9,500)	570 (150)
Alternative 3	34 to 88	17 to 33	57	12	2013 to 2020	3,330 to 9,330 (880 to 2,465)	3,300 to 8,900 (880 to 2,465)	16,760 (55,000)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	570 (150)

Notes: The numerical components included above are projected and were developed for cost estimating purposes for this FS. Numerical components of the selected approach would be determined during the RD/RAWP. Extraction and injection rates include new and existing wells.

N/A = not an applicable component of the alternative

EW = extraction well

IW = injection well

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10 Detailed Analysis of Alternatives

This chapter provides a detailed analysis of the remedial alternatives developed for waste sites and groundwater at 100-K. This analysis follows the development of alternatives presented in Chapter 9 and precedes the Proposed Plan, which includes the selection of a preferred alternative.

This chapter evaluates the remedial alternatives defined in Chapter 9 using seven of the nine CERCLA criteria described in NCP, "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430(e)(9)). The CERCLA evaluation criteria are presented in Section 10.1, and each of the remedial alternatives is evaluated individually and comparatively against the CERCLA criteria in Sections 10.2 and 10.3, respectively. The two remaining criteria, state and community acceptance, will be evaluated after the Proposed Plan goes through public comment and in the responsiveness summary contained in the 100-K decision document. The purpose of the detailed and comparative analysis is to develop the information necessary to recommend a preferred alternative in a Proposed Plan. Following public and stakeholder review of the Proposed Plan, the Tri-Parties will select a final remedial action alternative for 100-K that will lead to a final ROD.

Highlights

- Alternatives developed in Chapter 9 were compared against the seven CERCLA threshold and balancing criteria. The remaining two modifying criteria are formally assessed during preparation of the Proposed Plan (state acceptance) and following review of public and stakeholder comments (community acceptance) on the Proposed Plan.
- Alternative 1: (No Action) does not meet threshold criteria.
- Alternative 2: (RTD and Groundwater P&T Optimized with Other Technologies) meets threshold criteria, and is considered to have the best long-term effectiveness, reduction of TMV, short-term effectiveness, and implementability as compared to the other alternatives. This alternative is implementable, and the costs are lower than for Alternative 3.
- Alternative 3: (RTD and Expanded Groundwater Treatment) meets threshold criteria, and is considered to have the good long-term effectiveness, and moderate reduction of TMV and short-term effectiveness. Implementability challenges could be associated with greater excavation depths; therefore, Alternative 3 has moderate implementability. The costs for this alternative are higher than for Alternative 2.
- The alternative will be implemented over the 100-K OUs (i.e., the 100-KR-1 and 100-KR-2 source OUs, and the 100-KR-4 groundwater OU). The available information is sufficient to select a remedy that will protect human health and the environment and support reasonably anticipated future land use.

10.1 Description of CERCLA Evaluation Criteria

The nine CERCLA evaluation criteria upon which the detailed and comparative evaluations are based are designed to enable the analysis of each alternative to address the statutory, technical, and policy considerations necessary for selecting a final remedial alternative. These evaluation criteria (Table 10-1) provide the framework for conducting the detailed analysis of alternatives and selecting an appropriate remedial action. Table 10-1 provides the more detailed questions that CERCLA guidance recommends to address these criteria. The performance or acceptability of each alternative is first evaluated individually so relative strengths and weaknesses may be identified (Section 10.2). Section 10.3 compares each alternative relative to the CERCLA criteria.

Table 10-1. Summary of CERCLA Criteria

Threshold Criteria	
Overall Protection of HHE	Human health groundwater risk management. Ecological surface water risk management. Human health direct exposure risk management. Ecological risk management from exposure to soil. Soil to groundwater/surface water pathway risk management. Draws on assessments conducted under other criteria, especially long-term effectiveness, short-term effectiveness, and ARARs.
Compliance with ARARs	Chemical-specific ARARs. Action-specific ARARs. Location-specific ARARs. Compliance with other criteria, advisories, and guidance.
Balancing Criteria	
Long-Term Effectiveness and Permanence	Magnitude of residual risk. Adequacy and reliability of controls.
Reduction of TMV through Treatment	Amount of hazardous materials destroyed or treated. Degree of expected reduction in TMV. Degree to which treatment is irreversible. Type and quantity of residuals remaining after treatment.
Short-Term Effectiveness	Protection of community during remedial actions. Protection of workers during remedial actions. Environmental impacts, including sustainability considerations. Time until RAOs are achieved.
Implementability	Ability to construct, operate, and monitor the technology. Reliability of the technology. Ease of undertaking additional remedial action, if necessary. Ability to monitor the remedy's effectiveness. Ability to coordinate and obtain approvals from other agencies. Availability of equipment, specialists, prospective technologies, offsite treatment, storage or disposal services, and capacity.
Cost	Capital costs. Annual O&M costs. Total present worth cost of all capital, annual O&M, and periodic costs (net present value). Total nondiscounted cost all capital, annual O&M, and periodic costs.

Table 10-1. Summary of CERCLA Criteria

Modifying Criteria	
State Acceptance*	Indicates whether the state concurs with, opposes, or has no comment on the preferred alternative.
Community Acceptance*	Assesses the public response to the preferred alternative. Although public comment is an important part of the decision-making process, EPA is required by law to balance community concerns with the above criteria.

* These criteria are not assessed in this report.

The evaluation criteria are divided into three categories (threshold, balancing, and modifying) based on the function of each category in the remedy selection process. The NCP, "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430(f)) states that the first two criteria—protection of HHE, and compliance with ARARs—are "threshold criteria" that must be met by the selected remedial action unless a waiver can be granted under "Degree of Cleanup" (Section 121(d)(4)) of CERCLA.

The five "balancing criteria" represent technical conditions upon which the detailed analysis is primarily based, and include long-term effectiveness and permanence; reduction of TMV through treatment; short-term effectiveness; implementability; and cost. The preferred alternative will be the alternative that is protective of HHE, is ARAR-compliant, and provides the best combination of primary balancing attributes.

The final two criteria—state and community acceptance—are "modifying criteria," which are formally assessed during preparation of the Proposed Plan (state acceptance) and following review of public and stakeholder comments (community acceptance) on the Proposed Plan. Community and state acceptance are not addressed in the FS. Based on information from public participation, the Tri-Parties may modify some aspects of the preferred alternative or decide that another alternative is more appropriate.

10.1.1 Overall Protection of Human Health and the Environment

Overall protection of HHE is the primary requirement that remedial actions must meet under CERCLA. This evaluation criterion is an assessment of whether each alternative achieves and maintains adequate protection of HHE, in both the short-term and the long-term, from unacceptable risks posed by contaminants. Alternatives are protective by eliminating, reducing, or controlling exposure through applicable exposure pathways (NCP, "Remedial Investigation/Feasibility Study and Selection of Remedy" [40 CFR 300.430(e)(2)(i)]. Overall protection of HHE draws on the assessments of the other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

10.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

Compliance with ARARs is the second threshold criterion of remedy selection. This evaluation criterion is used to determine whether an alternative meets the federal, state, and local ARARs identified for the site, as presented in Chapter 8. Alternatives are assessed to determine whether they meet ARARs and other requirements, or if a basis exists for invoking one of the waivers cited in NCP, "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430(f)(l)(ii)(C)).

10.1.3 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence are criteria that evaluate the anticipated ability of an alternative to maintain reliable protection of HHE for the duration of time the risk is above allowable levels. Alternatives are assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful in meeting the RAOs. The following factors are considered in this assessment:

- The magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the remedial action, including the TMV (final risk assessment). Magnitude of residual risk is defined as the risk remaining from untreated waste or treatment residuals after remediation.
- The adequacy and reliability of controls that can be used to manage treatment residuals or residual contamination that remains at the site, such as containment systems or ICs. For example, this factor addresses uncertainties associated with land disposal for providing long-term protection from treatment residuals; the assessment of the potential need to replace technical components of the alternative such as a treatment system; and the potential exposure pathways and risks posed if the remedial action needs to be replaced.

10.1.4 Reduction of Toxicity, Mobility, and Volume through Treatment

This evaluation criterion concerns the statutory preference for remedies that employ treatment to reduce the TMV of the hazardous substances. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction in contaminant mobility, or reduction of the total mass or total volume of contaminated media. This criterion is specific to evaluating how the treatment reduces TMV.

The degree to which the alternative employs treatment that reduces TMV will be assessed. The following factors are considered for the evaluation:

- The treatment process and the materials treated
- The amount of hazardous substances, pollutants, or contaminants that will be destroyed or treated
- The degree of expected reduction in TMV of the waste as a percentage of reduction
- The degree to which the treatment is irreversible
- The type and quantity of residuals that will remain following treatment, taking into consideration the persistence, toxicity, mobility, and propensity of hazardous substances and their constituents to bioaccumulate
- The degree to which treatment reduces the inherent hazards posed by the principal threats

10.1.5 Short-Term Effectiveness

This criterion focuses on short-term impacts of the remedial alternatives by examining the effectiveness of alternatives in protecting HHE during the construction and implementation phase until RAOs are met. As outlined by the CERCLA guidance, this criterion includes four analysis factors:

- Protection of the community during remedial actions (e.g., dust from excavations, transportation of hazardous materials)
- Protection of workers during remedial actions

- Potential adverse environmental impacts (e.g., waste and generation of green house gas emissions) and the effectiveness and reliability of mitigating measures
- Time until RAOs are achieved

10.1.6 Implementability

The implementability criterion relates to the technical and administrative feasibility of executing an alternative and the availability of various services and materials required during its implementation. The ease or difficulty of implementing the alternative is assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including the technical difficulties and unknowns associated with constructing and operating the technology, the reliability of the technology, the ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy
- Administrative feasibility, including activities requiring coordination with other agencies, and the ability and time needed to obtain any necessary approvals and permits for offsite actions
- Availability of required services, personnel, resources, technologies, and materials necessary to construct and operate the alternative

10.1.7 Cost

The cost estimate for each remedial alternative typically includes the following items:

- Remedial design costs including preparation of design drawings and specifications, construction bid documents, RD report, RA work plan, and interim remedial action report; typically calculated as a percent of the capital cost.
- Remedial alternative construction costs including construction management, capital equipment, general and administrative costs, and construction subcontract costs and fees.
- Estimated operating, maintenance, and remedy performance monitoring and reporting costs for the duration of the remedial action.
- Equipment replacement costs.
- Project management.
- Oversight costs and preparation of CERCLA five-year reviews until RAOs are achieved.
- The evaluation of the cost criterion is based on a comparison of the estimated present worth of these costs for each alternative. Actual costs will depend on the final scope and design of the selected remedial action, the implementation schedule, competitive market conditions, and other variables. However, these factors, equally applicable to all alternatives, are not expected to affect the relative cost differences between alternatives.

Life-cycle costs are presented as net present worth values. The net present worth method establishes a common baseline for evaluating costs that occur during different periods, thus allowing for direct cost comparisons between different alternatives. The net present worth value represents the dollars that would need to be set aside today, at the defined interest rate, to ensure that funds would be available in the future, as they are needed to perform the remedial alternative.

Net present worth costs were estimated using the real discount rate published in Appendix C of the *Office of Management and Budget Circular No. A-94, Guidelines, and Discount Rates for Benefit-Cost Analysis of Federal Programs*, effective through October 2011.

The cost estimates are based on specific response action scenarios and assumptions. Sensitivity analyses were not performed to quantify the potential impact of changing key parametric assumptions.

The cost estimates were prepared in accordance with *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 540-R-00-002), along with DOE's *Cost Estimating Guide* (DOE G 430.1-1). The cost estimates are for comparison purposes and are prepared to meet the -30 to +50 percent range of accuracy recommended in CERCLA RI/FS Guidance (EPA/540/G-89/004). The cost estimate details, uncertainties, and supporting information are included in the *Environmental Cost Estimate for 100H/D Area RI/FS* (ECE-100HR311-00001) and *Cost Estimate for 100-K Waste Site and Groundwater* (ECE-100KR4-11-00005).

10.2 Individual Analysis of Alternatives

This section evaluates each of the remedial action alternatives defined in Chapter 9 against the CERCLA threshold and balancing criteria described in Section 10.1. The modifying criteria will be formally addressed during state review of the Proposed Plan and following receipt of public and stakeholder comments on the Proposed Plan. Criteria evaluation details for the remedial alternatives are documented in tabular form. The ratings provided below are based on three levels, as follows:

- ◎ = Expected to perform very well against the criterion with no apparent disadvantage or uncertainty
- ○ = Expected to perform moderately well against the criterion but with some disadvantages or uncertainty
- ● = Expected to perform poorly against the criterion and may have disadvantages or uncertainty

10.2.1 Alternative 1—No Action

The NCP, "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR 300.430(e)(6)) requires consideration of a No Action Alternative to serve as a baseline for evaluating other remediation action alternatives and is retained throughout the FS process. As presented in Chapter 9, all site remedial activities and interim actions (with the possible exception of backfilling any open excavations that are not safe) will be discontinued in December 2012, including ceasing operation of pump-and-treat systems and additional monitoring. Conceptual design details and cost estimates are not prepared for Alternative 1.

The individual analysis of this alternative is presented in Table 10-2. Given that No Action fails the threshold criteria established in "Remedial Investigation/Feasibility Study and Selection of Remedy" (40 CFR300.430(f)) of the NCP, information regarding the performance of this alternative with respect to the balancing criteria is not included.

Table 10-2. Individual Criteria Evaluation for Alternative 1—No Action

Criterion	Rating	Detailed Analysis
Overall Protection of HHE	-	***Not expected to be protective of HHE*** RAOs are not likely to be achieved. Allows unmonitored, potential further migration of groundwater contaminants as well as exposure to groundwater. Potential for exposure to human and ecological receptors and potential of contaminants to leach to groundwater may remain at the waste sites.
Compliance with ARARs	-	***Not expected to be compliant*** Since there is no action, ARARs for waste sites will not be met. Due to unmonitored, potential further migration of groundwater contaminants, DWS and AWQS ARARs may not be achieved in a reasonable time.
Long-Term Effectiveness and Permanence	N/A	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.
Reduction of TMV through Treatment	N/A	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.
Short-Term Effectiveness	N/A	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.
Implementability	N/A	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.
Cost	N/A	A cost estimate for Alternative 1 is not provided because no action is proposed.

10.2.2 Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

The remedial strategy for Alternative 2 relies on optimizing the risk reduction and cost by using a mixture of RTD and groundwater pump-and treat with other technologies. For Post-ROD To-Go sites, the actions will vary depending on the nature and extent of contamination at the waste site, as will be determined following the Decision Logic flowcharts presented in Chapter 9. The actions could include one or more of the following:

- RTD of shallow vadose zone areas. RTD would also include demolition of structures (e.g., buildings) when necessary.
- Biological infiltration.
- Soil flushing with treatment of groundwater.
- Bioventing or land farming for sites with TPH as a COC.
- Temporary surface barriers.
- For groundwater, optimization of the pump-and-treat system with biological infiltration and biological injection, and air stripping for the treatment of carbon-14 in select groundwater extraction wells. The optimized pump-and-treat system would operate until 2037. Remedial process optimization activities will be conducted throughout operational period to assess remedial action

performance. Groundwater modeling simulations are used to support design optimization. Actual performance data is used to update model parameters to reduce model uncertainty. Groundwater simulations are used to modify extraction/injection well field and locations for bioremediation for remediation of remaining contamination.

- Supplemental ICs to mitigate exposure, where potentially required.

Table 9-2 and Figure 9-3 provide additional conceptual design information on Alternative 2. Appendix J presents a summary of the remedial components, areas, and volumes that were assumed for each waste site in development of cost estimates.

Table 10-3 presents the individual analysis of Alternative 2 with respect to the seven CERCLA criteria. Alternative 2 is considered to pass the threshold criteria, since the actions as part of this alternative are likely to achieve RAOs and ARARs. Alternative 2 is expected to have long-term effectiveness and permanence and achieve reduction in TMV because it incorporates active treatment of groundwater and waste sites. Waste site treatment includes RTD plus bioinfiltration and/or soil flushing for sites exceeding surface/groundwater protection criteria for mobile COCs, and bioventing and land farming for sites with TPH as a COC. Alternative 2 also proposes active treatment of carbon-14 in groundwater through air stripping and optimized groundwater treatment through the implementation of biological injection. Alternative 2 is expected to have short-term effectiveness and is implementable at 100-K.

Table 10-3. Individual Criteria Evaluation for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Criterion	Rating	Detailed Analysis
Overall Protection of HHE		***Expected to be protective of HHE*** RAOs are likely to be achieved. This alternative incorporates previous interim action remedies (i.e., soil RTD and groundwater excavation) that have been demonstrated to be effective, plus additional technologies to optimize remedial designs. Monitoring can track progress and compliance with RAOs. RTD mitigates shallow ecological risk and direct contact risk to human receptors through physical removal of contaminated soil. Temporary surface barriers mitigate leaching of contaminants to groundwater and may mitigate direct contact risk to human and ecological receptors for the sites near reactors. Risks from surface/groundwater protection exceedances of mobile COCs (e.g., Cr(VI)) are mitigated through a combination of RTD, biological infiltration (biological reduction), and soil flushing. Risks from sites with TPH as a COC are mitigated through bioventing and land farming. Pump-and-treat limits potential further migration of groundwater contaminants as well as remediates the Cr(VI) plume. Biological injection and air stripping enhance the remediation of Cr(VI) and C-14, respectively. The pump-and-treat enhanced with biological injection achieves risk standards in a reasonable time. Institutional controls prevent exposure to impacted soil and groundwater.
Compliance with ARARs		***Expected to be compliant*** Remedial action/systems will be designed to meet ARARs. DWS and AWQS ARARs are likely to be achieved in a reasonable time.

Table 10-3. Individual Criteria Evaluation for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Criterion	Rating	Detailed Analysis
Long-Term Effectiveness and Permanence		***Expected to have long-term effectiveness and permanence*** *Factors expected to perform very well against the long-term effectiveness and permanence criterion:* - RTD, surface barriers, biological infiltration, soil flushing, bioventing, land farming, pump-and-treat, biological injections, and air strippers are likely to achieve RAGs. - RTD using conventional equipment is reliable and practiced extensively at Hanford. ERDF disposal is assumed effective and reliable. - Adequacy and reliability of pump-and-treat operations are proven at Hanford. - Bioventing and land farming are proven for remediating soils contaminated by petroleum hydrocarbons. - Bioinfiltration and soil flushing provide for areal application of vadose zone remediation to address uncertainty with contamination migration. - Groundwater biological treatment (bioinfiltration and bioinjection) provides additional treatment as pump-and-treat efficiency decreases with decreasing Cr(VI) concentration. - Irrigation restrictions for sites with exceedances of surface/groundwater protection criteria prevent continuous impact to groundwater. Adequacy and reliability of ICs proven at Hanford. - Long-term effectiveness and permanence will be evaluated in CERCLA five-year review process. *Factors that may provide some disadvantages or uncertainty to long-term effectiveness and permanence:* - Biological remediation technologies (bioinfiltration and bioinjection) are proven technologies; however, design testing may be needed to fully develop the system parameters specific for applying at Hanford. - Testing is required to determine the adequacy and reliability of air stripping for the treatment of carbon-14 in groundwater.
Reduction of TMV by Treatment		***Expected to achieve reduction of TMV by treatment*** *Factors expected to perform very well against the reduction of TMV by treatment criterion:* - Reduction of TMV is achieved specifically through treatment via biological reduction (bioinfiltration and bioinjection) and biodegradation (bioventing and land farming). - Significant mass of Cr(VI) in the vadose zone will be removed via contaminant flushing, - Significant mass of carbon-14 will be removed from groundwater via air stripping. - Significant mass of Cr(VI) will be removed through pump-and-treat. - Temporary surface barriers reduce leaching (mobility) of contamination from the vadose zone to groundwater by controlling the vertical entry of water into contaminated media. - Removed soil is treated at ERDF, if needed. *Factors that may provide some disadvantages or uncertainty to the reduction of TMV by treatment:* - None

Table 10-3. Individual Criteria Evaluation for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Criterion	Rating	Detailed Analysis	
Short-Term Effectiveness	●	***Expected to have short-term effectiveness*** *Factors expected to perform moderately well against the short-term effectiveness criterion:* - No adverse risks to the community from implementation of active treatment options due to the remote location and implementation of ICs. - Risks to workers from implementation of active treatment actions are minimized through an HSP and proper PPE. - Nominal short-term risks to workers during installation of groundwater extraction and conveyance piping system, O&M activities, and monitoring. Risks are minimized through HSP and PPE. - RAOs are achieved within 25 years of remedy implementation except at sites near reactors.	
	●	*Factors that may provide some disadvantages or uncertainty to the short-term effectiveness:* - Negative environmental impacts may include: - Generation of GHG from use of excavation equipment; well installation, development, and injection activities. - Waste generation from disposal of contaminated soil and spent ion exchange resin - Achieving RAGs at sites near reactors is limited by time frame for decommissioning (75 years).	
Implementability	●	***Implementable*** Limited technical or administrative challenges are associated with implementation of this alternative. Conventional equipment and vendors for implementation of active treatment options (RTD, surface barriers, biological infiltration, soil flushing, bioventing, land farming, pump-and-treat, biological injections, and air strippers) are readily available. ERDF is proven, reliable, and accessible. Pump-and-treat construction and operations have been previously approved and the ability to construct and operate is proven at Hanford. ICs have been approved and implemented, and are reliable/effective at Hanford. Coupling of multiple technologies for soil and groundwater remediation provides capability to implement effective remediation in varying geophysical setting.	
Cost[a]			
Waste Site Treatment		Capital	$ 348,894,000
		Annual O&M	$ 615,000
		Total Periodic	$ 415,102,000
		Total Nondiscounted	$ 764,611,000
		NPV	$ 422,494,000

Table 10-3. Individual Criteria Evaluation for Alternative 2—RTD and Groundwater Pump-and-Treat Optimized with Other Technologies

Criterion	Rating	Detailed Analysis	
Groundwater Treatment		Capital	$ 13,593,000
		Annual O&M	$ 177,958,000
		Total Periodic[b]	$ 73,990,000
		Total Nondiscounted	$ 265,540,000
		NPV	$ 194,314,000
Total Cost of Alternative		$ 1,030,151,000	
Total Net Present Value of Alternative		$ 616,808,000	

a. Detailed cost estimates are presented in Appendix J. Costs for institutional controls are included under the costs for waste site treatment.

b. Periodic costs include O&M and/or construction activities, including costs to replace an installed remedy or components of an installed remedy, and services that are not included in initial capital costs or annual O&M costs. Periodic costs may be one-time costs or costs that recur at intervals over the life of the remedy.

10.2.3 Alternative 3—RTD and Expanded Groundwater Treatment

Remedial action under Alternative 3 relies almost exclusively on RTD for waste site contamination to achieve the RAOs, as well as aggressive pump-and-treat for groundwater. The remedial action will include the following features:

- RTD for waste sites, with excavation until standards are achieved. RTD includes demolition of structures (e.g., buildings) when necessary.
- Temporary surface barriers.
- For groundwater, aggressive pump-and-treat until 2020, including limited treatment of carbon-14 at select wells using air stripping.
- Supplemental ICs to mitigate exposure, where potentially required.

Table 9-3 and Figure 9-11 provide additional information on this alternative. Appendix J presents a summary of the remedial components, areas, and volumes that were assumed for each waste site in development of cost estimates.

Table 10-4 presents the individual analysis of Alternative 3 with respect to the seven CERCLA criteria. Alternative 3 was considered to pass the threshold criteria, since the actions as part of this alternative are likely to achieve RAOs and ARARs. Given the aggressive RTD approach, Alternative 3 is considered to have good long-term effectiveness and permanence, and reduction of TMV through RTD of contaminated soils and pump-and-treat and air stripping options for treatment of contaminated groundwater. However, a remedy that relies aggressively on RTD could potentially lead to a higher amount of waste generation and GHG emissions from implementation. For this reason, Alternative 3 is not rated as having a high level of short-term effectiveness. Due to the deeper excavation depths than Alternative 2, the implementability

performs moderately well. Limited technical challenges are associated with implementation of this alternative because of competing physical land space for installing new extraction wells in areas of active remediation within the same period.

Table 10-4. Individual Criteria Evaluation for Alternative 3—RTD and Expanded Groundwater Treatment

Criterion	Rating	Detailed Analysis
Overall Protection of HHE	◎	***Expected to be protective of HHE*** RAOs are likely to be achieved. Monitoring can track progress and compliance with RAOs. RTD mitigates risks to human and ecological receptors and soil-to-groundwater/surface water risks encountered at the site through physical removal of contaminated soil. Temporary surface barriers mitigate leaching of contaminants to groundwater and may mitigate direct contact risk to human and ecological receptors for the sites near reactors. Pump-and-treat limits potential further migration of groundwater contaminants as well as remediates the Cr(VI) plume. Carbon-14 contaminant concentrations reduced through air stripping. The enhanced pump-and-treat achieves risk standards in a reasonable time.
Compliance with ARARs	◎	***Expected to be compliant*** Remedial action/systems are likely to meet ARARs. DWS and AWQS ARARs are likely to be achieved in a reasonable time.
Long-Term Effectiveness and Permanence	◎	***Expected to have long-term effectiveness and permanence*** *Factors expected to perform very well against the long-term effectiveness and permanence criterion:* - RTD, surface barriers, pump-and-treat, and air strippers are likely to achieve RAGs. - RTD using conventional equipment is reliable and practices extensively at Hanford. ERDF disposal is assumed effective and reliable. - Adequacy and reliability surface barriers and pump-and-treat are proven at Hanford. - Monitoring and verification sampling, and long-term groundwater monitoring track progress toward compliance with RAOs. - Irrigation restrictions for sites with exceedances of surface/groundwater protection criteria prevent continuous impact to groundwater. Adequacy and reliability of ICs proven at Hanford. - Long-term effectiveness and permanence will be evaluated in CERCLA five-year review process. *Factors that may provide some disadvantages or uncertainty to long-term effectiveness and permanence:* - Testing is required to determine the adequacy and reliability of air stripping for the treatment of carbon-14 in groundwater.

Table 10-4. Individual Criteria Evaluation for Alternative 3—RTD and Expanded Groundwater Treatment

Criterion	Rating	Detailed Analysis
Reduction of TMV by Treatment	◉	***Overall, expected to achieve reduction of TMV by treatment*** *Factors expected to perform very well against the reduction of TMV by treatment criterion:* - Significant mass of Cr(VI) will be removed through pump-and-treat. - Removed soil is treated at ERDF, if needed. - Temporary surface barriers reduce leaching (mobility) of contamination from the vadose zone to groundwater by controlling the vertical entry of water into contaminated media. - Reduction of TMV of carbon-14 in groundwater is proposed through air stripping.
Reduction of TMV by Treatment (cont.)		*Factors that may provide some disadvantage or uncertainty to the reduction of TMV by treatment:* - None
Short-Term Effectiveness	○	***Overall, expected to have moderate short-term effectiveness:*** *Factors expected to perform moderately well against the short-term effectiveness criterion:* - No adverse risks to the community from implementation of active treatment options due to the site's remote location and implementation of ICs. - Risks to workers from implementation of active treatment actions are minimized through an HSP and proper PPE. - Nominal short-term risks to workers during installation of groundwater extraction and conveyance piping system, O&M activities, and monitoring. Risks are minimized through HSP and PPE. - RAOs are achieved within 8 years of remedy implementation except at sites near reactors. *Factors that may provide some disadvantages or uncertainty to short-term effectiveness:* - Negative environmental impacts may include the following: - Generation of GHG from use of excavation equipment and disposal to ERDF, installation of surface barriers, operation of pump-and-treat system - Waste generation from disposal of contaminated soil and spent IX resin - Aggressive RTD could potentially lead to greater environmental impacts as compared to other alternatives from waste generation and generation of GHG from use of excavation equipment and disposal to ERDF. - Achieving RAGs at sites near reactors is limited by time frame for decommissioning (75 years).

Table 10-4. Individual Criteria Evaluation for Alternative 3—RTD and Expanded Groundwater Treatment

Criterion	Rating	Detailed Analysis	
Implementability	○	***Moderate Implementability*** *Factors considered good implementability:* - Limited technical challenges are associated with implementation of this alternative. - ICs have been approved and implemented, and are reliable/effective at Hanford. - Conventional equipment and vendors for implementation of active treatment options (RTD, surface barriers, pump-and-treat, and air strippers) are readily available. - ERDF is proven, reliable, and accessible. - Pump-and-treat construction and operations have been previously approved and the ability to construct and operate is proven at Hanford. *Factors considered low implementability:* - Depths of excavation may present additional technical challenges. Additional RTD will also have a greater impact on the ability to simultaneously implement RTD and construction of groundwater pump-and-treat facility and wells in the 100-K limited working area.	
Cost[a]			
Waste Site Treatment		Capital	$ 399,378,000
		Annual O&M	$ 615,000
		Total Periodic[b]	$ 412,694,000
		Total Nondiscounted	$ 812,687,000
		NPV	$ 467,525,000
Groundwater Treatment		Capital	$ 97,561,000
		Annual O&M	$ 138,488,000
		Total Periodic	$39,761,000
		Total Nondiscounted	$275,810,000
		NPV	$247,129,000
Total Cost of Alternative		$1,088,497,000	
Total Net Present Value of Alternative		$714,654,000	

a. Detailed cost estimates are presented in Appendix J.

b. Periodic costs include O&M and/or construction activities, including costs to replace an installed remedy or components of an installed remedy, and services that are not included in initial capital costs or annual O&M costs. Periodic costs may be one-time costs or costs that recur at intervals over the life of the remedy.

10.3 Comparative Analysis of Remedial Alternatives

The comparative analysis of the proposed alternatives assists in identifying advantages and disadvantages of each alternative relative to the others to identify key tradeoffs that should be noted in the decision making process. The previous sections presented individual evaluations for each alternative. The remedial alternatives proposed for contaminated soil and groundwater at 100-K are compared in Table 10-5, and the analysis follows.

10.3.1 Overall Protection of Human Health and the Environment

Alternative 1 is not protective of HHE because RAOs and ARARs are not achieved in a reasonable time frame.

Alternatives 2 and 3 will achieve the RAOs and meet this threshold criterion. Proposed actions for groundwater are likely to achieve cleanup criteria within a reasonable time frame. For impacted waste sites, treatment alternatives such as RTD, surface barriers, biological infiltration, and others are likely to effectively control or prevent significant risks. Unacceptable risks are also prevented or controlled through implementation of institutional controls as needed.

10.3.2 Compliance with ARARs

Alternative 1 will not comply with groundwater chemical-specific ARARs due to the potential plume migration to the river. Since Alternative 1 neither complies with ARARs nor will be protective of HHE (the two threshold criteria), it was not evaluated for the balancing criteria below.

Alternatives 2 and 3 will comply with ARARs and meet this threshold criterion. Remedial actions and treatment systems proposed under these alternatives would be designed to meet ARARs. For groundwater, proposed remedies will achieve DWS and AWQS ARARs in a reasonable time frame.

10.3.3 Long-Term Effectiveness and Permanence

Alternative 2 and 3 both perform well for this criterion. For groundwater, Alternative 3 aggressively remediates groundwater using pump-and-treat. The adequacy and reliability of pump-and-treat is demonstrated at the Hanford Site through the interim actions. Alternative 2 uses pump-and-treat enhanced with biological treatment. Biological remediation technologies are proven technologies; however, design testing may be needed to fully develop the system parameters specific for applying at Hanford. Alternatives 2 and 3 will achieve DWS and AWQS ARARs in a reasonable time. Testing would be required to determine the adequacy and reliability of air stripping. The adequacy and reliability of institutional controls is also proven at Hanford, but might require long-term enforcement to mitigate risk.

For impacted waste sites, Alternatives 2 and 3 use RTD and disposal at ERDF, which are demonstrated to be adequate, effective, and reliable at the Hanford Site. Alternative 2 optimizes RTD with biological infiltration or soil flushing for waste sites and is coupled with groundwater pump-and-treat systems. Waste site remediation under Alternative 3 is solely by RTD. Maintenance and potential repair of surface barriers in both alternatives may be required for optimal long-term effectiveness.

Alternatives 2 and 3 propose implementation of monitoring and include the CERCLA five-year review process, which would evaluate effectiveness of the proposed actions and track progress toward compliance with RAOs.

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Table 10-5. Comparative Analysis of Alternatives

Criterion	Alternative 1		Alternative 2		Alternative 3	
	Rating	Detailed Analysis	Rating	Detailed Analysis	Rating	Detailed Analysis
Overall Protection of HHE	-	***Not expected to be protective of HHE*** RAOs will not be achieved. The potential for exposure to human and ecological receptors and the potential for contaminants to leach to groundwater may remain at the waste sites.	◉	***Expected to be protective of HHE*** RAOs will be achieved. Multiple technologies are proposed to mitigate exposure and reduce risk through removal and/or treatment. Temporary surface barriers mitigate leaching of contaminants to groundwater for sites near reactors. Remediates Cr(VI) in groundwater through pump-and-treat optimized with biological treatment. Achieves risk standards in a reasonable time. Institutional controls prevent exposure to impacted media.	◉	***Expected to be protective of HHE*** RAOs will be achieved. Alternative relies primarily on RTD to mitigate risks to human and ecological receptors, and soil-to-groundwater/surface water risks. Surface barriers mitigate leaching of contaminants to groundwater for sites near reactors. Remediates Cr(VI) in groundwater through pump-and-treat. Reduces carbon-14 contaminant concentrations through air stripping. Achieves risk standards in a reasonable time.
Compliance with ARARs	-	***Not expected to be compliant*** ARARs will not be met at waste sites above human health or ecological criteria. Due to unmonitored, potential further migration of groundwater contaminants, DWS and AWQS ARARs may not be achieved in a reasonable time.	◉	***Expected to be compliant*** Remedial action/systems will meet ARARs. DWS and AWQS ARARs are anticipated to be achieved in 25 years after start of implementing this alternative.	◉	***Expected to be compliant*** Remedial action/systems will meet ARARs. DWS and AWQS ARARs are anticipated to be achieved in eight years after start of implementing this alternative.
Long-Term Effectiveness and Permanence	NA	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	◉	***Expected to have long-term effectiveness and permanence*** The RAGs for both waste sites and groundwater will be achieved through the range of technologies (RTD, surface barriers, biological infiltration, soil flushing, bioventing, land farming, pump-and-treat, biological injections, and air strippers) in this alternative. The adequacy and reliability of biological remedial technologies is proven; however, design testing may be needed to fully develop system parameters for application at Hanford. Testing is required to determine the adequacy and reliability of air stripping for the treatment of carbon-14 in groundwater.	◉	***Expected to have long-term effectiveness and permanence*** The RAGs for both waste sites and groundwater will be achieved through the RTD and pump-and-treat in this alternative. The adequacy and reliability of proposed remedial technologies is proven. Testing is required to determine the adequacy and reliability of air stripping for the treatment of carbon-14 in groundwater.
Reduction of TMV by Treatment	NA	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	◉	***Expected to achieve reduction of TMV by treatment*** Reduction of TMV in groundwater is achieved through pump-and-treat optimized with biological treatment. For waste sites, TMV will be achieved through biological reduction (bioinfiltration, and bioinjection), biodegradation (bioventing and land farming), or contaminant flushing. Removed soil is treated at ERDF, if needed.	◉	***Expected to achieve reduction of TMV by treatment*** Reduction of TMV in groundwater is achieved through pump-and-treat. Removed soil is treated at ERDF, if needed.
Short-Term Effectiveness	NA	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	◉	***Expected to have short-term effectiveness*** No adverse risks to the community. Risks to workers are minimized through an HSP and proper PPE.	○	***Expected to have moderate short-term effectiveness*** No adverse risks to the community. Risks to workers are minimized through an HSP and proper PPE. Aggressive RTD could potentially lead to greater environmental impacts from GHG and waste generation.
Implementability	NA	Alternative 1 fails threshold criteria. Therefore, an evaluation on balancing criteria is not provided.	◉	***Expected to be implementable*** Limited technical or administrative challenges are associated with implementation of this alternative. Conventional equipment required and vendors readily available. ICs have been approved and implemented, and are reliable/effective at Hanford.	○	***Overall, expected to have moderate Implementability*** Conventional equipment required and vendors readily available. Limited technical challenges are associated with implementation of this alternative. Additional technical challenges on ability to simultaneously implement RTD and construction of groundwater pump-and-treat wells in the 100-K limited working area.
Net Present Value of Alternative (Discounted/ Nondiscounted)	NA	A cost estimate is not provided because no action is proposed.	$616,808,000 / $1,030,151,000		$714,654,000 / $1,088,497,000	

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10.3.4 Reduction of Toxicity, Mobility, and Volume through Treatment

For groundwater, Alternatives 2 and 3 provide substantial reduction of TMV through pump-and-treat. Treatment of carbon-14 in groundwater is also included. These alternatives propose treatment through air-stripping where carbon-14 is extracted from groundwater extraction wells greater than the DWS. Appendix F presents groundwater modeling runs that were performed with this approach to evaluate the fate of carbon-14. Alternative 2 achieves TMV through implementation of additional biological remediation technology to treat groundwater in areas of low permeability and/or low Cr(VI) concentrations. Alternative 3 achieves TMV through aggressive pump-and-treat with construction of a new 1,300 gpm pump-and-treat system.

For waste sites, Alternative 2 proposes the widest range of technologies to achieve reduction of TMV through treatment by physical removal of impacted media (RTD), biological reduction (bioinfiltration and bioinjection), biodegradation (bioventing and land farming), contaminant flushing (soil flushing), and mass transfer (air stripping). Alternative 3 provides reduction of TMV by RTD.

10.3.5 Short-Term Effectiveness

Alternative 2 performs better than Alternative 3. The period to meet RAOs is less in Alternative 3 than in Alternative 2; however, this benefit is offset by the greater environmental impacts under Alternative 3. Alternative 3 aggressively relies primarily on RTD for excavation and disposal of contaminated vadose zone soils at ERDF.

The impact to short term effectiveness on the environment is greatest for Alternative 3 during the construction and implementation phase of the remedy. Many large waste site areas will be exposed to the environment, machinery generated dust, the generation of remediation process waste, and considerably more greenhouse gas (GHG) emissions (from excavation equipment and transportation of material to ERDF) than Alternative 2 would produce. Potential impacts to workers and to the environment from implementing any actions onsite would be controlled and mitigated through effective HSPs and adequate PPE.

Uncertainties with persistent groundwater contamination source from the vadose zone, periodically rewetted zone, or the unconfined aquifer described in the RI/FS Report (DOE/RL-2010-97) could require additional remedial actions to meet the RAOs. Should persistent groundwater contamination or rebound of contamination in the groundwater beneath a previously remediated site indicate a continuing source within the vadose zone, the site would need to be re-excavated to remove the source under Alternative 3. Alternative 2 includes options to implement other technologies (e.g., soil flushing or biological infiltration) to remediate the source with less environmental impacts.

In addition, if persistent groundwater contamination exists within the unconfined aquifer, Alternative 3 may require installation of additional extraction wells to remediate the groundwater effectively. Alternative 2 provides for biological treatment of groundwater, which could be implemented without need for additional wells.

Both alternatives will have some negative environmental impacts as follows:

- Generation of GHG from use of excavation equipment and disposal to ERDF, installation of temporary surface barriers, operation of pump and treat system.
- Waste generation from disposal of contaminated soil and spent IX resin.
- Energy consumption from process equipment.

- Potential cultural resource impacts.

Alternative 3 will have greater negative environmental impacts since it uses both pump-and-treat and RTD exclusively.

10.3.6 Implementability

Alternative 2 performs slightly better than Alternative 3 in that it relies on a broader suite of potential technologies to be employed under the various conditions that will be encountered during the construction phase of the remedy and, therefore, is more likely to be successfully implemented.

Alternative 3 relies only on RTD/excavation and calls for the construction crews to work in and around a large amount of mobile, heavy equipment in a small, consolidated area near the existing reactor buildings. Alternative 3 also involves excavation at depths greater than 4.6 m (15 ft), which presents additional technical challenges relative to Alternative 2. Additional RTD implemented under Alternative 3 will have a greater impact on the ability to implement RTD simultaneously with construction of additional groundwater pump-and-treat facility and wells in the 100-K limited working area.

The required vendors and materials for implementation of Alternative 2 components, such as surface barriers, air stripping, and infiltration/injection activities are readily available, as is the machinery/equipment needed to implement Alternative 3.

For the biological treatment processes, specialized biological reagents would be required, but these are considered readily available. Although biological treatment of hexavalent chromium has been proven, implementation at the Hanford Site would likely require at least laboratory scale treatability testing. While air stripping is a routinely used treatment technology, using it for treating carbon-14 is not routine. Therefore, some amount of laboratory scale treatability testing would be required to determine the adequacy and reliability of air stripping for the treatment of carbon-14 in groundwater.

10.3.7 Cost

Estimated design, construction, O&M, and decommissioning costs were developed for Alternative 2 and 3. Operation and maintenance costs were estimated based on a 75-year remedial time frame. The total estimated net present value is $617 million for Alternative 2 and $715 million for Alternative 3.

Details regarding cost estimates for Alternatives 2 and 3 are provided in Appendix J. These cost estimates have been prepared to meet the -30 to +50 percent range of accuracy recommended in the CERCLA RI/FS Guidance (EPA/540/G-89/004). No capital or O&M costs are associated with Alternative 1.

Overall, estimates indicate that the most cost effective alternative is Alternative 2.

10.4 NEPA Values

This section addresses the incorporation of NEPA values into CERCLA documents. This is consistent with the *National Environmental Policy Act Compliance Program* (DOE O 451.1B Change 2), which requires that CERCLA actions address and incorporate NEPA values such as socioeconomic, ecological, offsite, and cumulative impacts in CERCLA documents to the extent practicable.

Alternatives to address contamination at 100-K are presented in Chapter 9, and include Alternative 1 (No Action); Alternative 2 (RTD and Groundwater Pump-and-Treat Optimized with other Technologies); and Alternative 3 (RTD and Expanded Groundwater Treatment). The No Action alternative would not mitigate the environmental impacts from contaminated waste sites and groundwater. All other alternatives could mitigate the impacts associated with contaminated waste sites and groundwater present at 100-K.

NEPA values associated with remediation are based on the information presented in this RI/FS, including the area and site characteristics (Chapters 1, 2, and 3), final COPCs (Chapter 8), and identification and analysis of remedial actions (Chapter 9). Applying a "sliding scale" of NEPA analysis to 100-K (using *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements: Second Edition* [DOE, 2004]) and considering the CERCLA ARARs (detailed in Section 8.2.2), the principal resource areas of concern include the contaminants in waste sites, contaminants in the groundwater and surface water, solid and liquid radioactive and hazardous waste management, air emissions, potential adverse effects to historic and cultural resources, ecological resources, socioeconomics (including environmental justice concerns), and transportation.

The net anticipated effect from implementation of Alternatives 2 or 3 could be an overall positive contribution to cumulative environmental effects at the Hanford Site. For sites and alternatives with RTD as the selected remedial action, DOE expects that the primary facility to receive contaminated soil will be the Hanford ERDF. NEPA values in the planning for the ERDF operation were explained in detail in the *NEPA Roadmap for the Environmental Restoration Disposal Facility Regulatory Package* (DOE/RL-94-41) for the *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility* (DOE/RL-93-99) as described in the most recent ERDF ROD Amendment (*Amendment to the Record of Decision for the USDOE Hanford Environmental Restoration Disposal Facility* [EPA et al., 2007]).

In addition, DOE has included the combined effects anticipated from ongoing CERCLA/Tri-Party Agreement (Ecology et al., 1989a) response actions as part of the cumulative impact analysis in the *Draft Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington* (DOE/EIS-0391), which includes a sitewide cumulative impact groundwater analysis. This has presented the public with a separate opportunity for comment as part of that NEPA process, and is being used to inform the public concerning ongoing implementing cleanup actions on the Hanford Site. The NEPA values (i.e., resource area and relevant NEPA considerations) most relevant to and potentially affected by the actions taking place under this remedial action are described in Table 10-6.

Table 10-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation*
Transportation	Considers impacts of the proposed action on local traffic (i.e., traffic at the Hanford Site) and traffic in the surrounding region.	Implementation of all action alternatives (except No Action) would be expected to produce short-term impacts on local traffic. A majority of the impact relates to increased truck traffic associated with the aforementioned Alternatives; they would involve transport of contaminated soil moved from a waste site(s) to ERDF. Transportation impacts were considered in the *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Disposal Facility* (DOE/RL-93-99) as part of the evaluation of short-term effectiveness and implementability. NEPA values in the planning for the ERDF operation were explained in detail in the *NEPA Roadmap for the Environmental Restoration Disposal Facility Regulatory Package* (DOE-RL-94-41). Transportation impacts associated with a waste site under Alternative 2 are considerably smaller than for Alternative 3, given the smaller volume of soil to be excavated and transported to ERDF. The discussion of cumulative impacts provides a perspective of transportation to ERDF.
Water Quality	Considers potential water quality concerns associated with the groundwater below the site and the Columbia River.	Performance of excavation of waste sites requires the application of considerable quantities of water for dust control (for air quality). The application of this water may result in migration to groundwater. This impact could be more significant for Alternative 3 than the other alternatives since more excavation is required. Contaminants would be removed from groundwater in all alternatives, which would be expected to cause a net positive effect in water quality both for groundwater below the site and for the Columbia River. Spent ion exchange resin would be generated and managed as solid waste.
Air Quality	Considers potential air quality concerns associated with emissions generated during the proposed action.	Airborne releases associated with Alternatives 2 and 3 could occur due to dust generation during excavation. Alternative 3 requires more excavation, so the potential is greatest with this alternative. A maximum of approximately 5 million tons of contaminated soil would be removed (Alternative 3, over an expected duration of 8 years, or approximately 625,000 tons per year). Alternatives 2 and 3 would also release some carbon-14 to the atmosphere. Any potential of airborne release of contaminants during alternative remedial actions would be controlled in accordance with DOE radiation control and air pollution control standards to minimize emissions of air pollutants at the Hanford Site and protect all communities outside the site boundaries.
		Operation of trucks and other diesel-powered equipment for these alternatives would be expected to introduce quantities of carbon dioxide, sulfur dioxide, nitrogen dioxide, particulates, and other pollutants to the atmosphere. Alternative 3 is expected to have the greatest extent of these emissions since the largest quantity of soil would be excavation and transported. As applicable, vehicular and equipment emissions would be controlled and mitigated in compliance with the substantive standards for air quality protection that apply to the Hanford Site.

Table 10-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation*
Natural, Cultural, and Historical Resources	Considers impacts of the proposed action on wildlife, wildlife habitat, archeological sites and artifacts, and historically significant properties.	Impacts on ecological resources near the remedial actions could result from installation of groundwater wells and excavation of contaminated soil. Such impacts would be mitigated in accordance with the *Hanford Site Biological Resources Management Plan* (DOE/RL-96-32) and *Biological Resources Mitigation Strategy* (DOE/RL-96-88), and with the applicable standards of all relevant biological species protection regulations. Alternative 3 could pose the greatest impact on cultural resources since it would require installation of wells in a potentially culturally sensitive area (36 CFR 800, *National Historic Preservation Act of 1966* [NHPA], Section 106, documentation). However, because many of these sites have already been disturbed and only isolated artifacts would be expected to be encountered during project activities, implementation of the *Hanford Cultural Resources Management Plan* (DOE/RL-98-10) and consultation with area Tribes would help ensure appropriate mitigation to avoid or minimize any adverse cultural or historical resource effects and address any relevant concerns. Impacts to other cultural values will be minimized through implementation of the *Hanford Cultural Resources Management Plan* (DOE/RL-98-10), *Revised Mitigation Action Plan for the Environmental Restoration Disposal Facility* (DOE/RL-2005-27), and consultation with area Tribes, as needed. This will help ensure appropriate mitigation to avoid or minimize any adverse effects to natural and cultural resources and address any other relevant concerns. Potential impacts to cultural and historical resources that may be encountered during the short-term construction activities associated with implementing the action would be mitigated through compliance with the appropriate substantive requirements of NHPA and other ARARs related to cultural preservation.
Socioeconomic Impacts	Considers impacts pertaining to employment, income, other services (e.g., water and power utilities), and the effect of implementation of the proposed action on the availability of services and materials.	The proposed action is within the scope of current DOE-RL environmental restoration activities and would have minimal impact on the current availability of services and materials. This work would be expected to be accomplished largely using employees from the existing contractor workforce. Even if the remedial activities creates additional service sector jobs, the total expected increase in employment would be expected to be less than 1 percent of the current employment levels. The socioeconomic impact of the project would contribute to the continuing overall positive employment and economic impacts on eastern Washington communities from Hanford Site cleanup operations.

Table 10-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation*
Environmental Justice	Considers whether the proposed response actions would have inappropriately or disproportionately high and adverse HHE effects on minority or low income populations.	Per the *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations* (Executive Order 12898), DOE seeks to ensure that no group of people bears a disproportionate share of negative environmental consequences resulting from proposed federal actions. There are no impacts associated with proposed activities associated with 100-K that could reasonably be determined to affect any member of the public; therefore, they would not have the potential for high and disproportional adverse impacts on minority or low income groups.
Cumulative Impacts (Direct and Indirect)	Considers whether the proposed action could have cumulative impacts on HHE when considered together with other activities locally, at the Hanford Site, or in the region.	The environmental concern of 100-K is associated directly with the targeted area. Because of the temporary nature of the activities and their remote location, cumulative impacts on air quality or noise with other Hanford Site or regional construction and cleanup projects would be minimal. When soil at a site in this area is found to be contaminated with hazardous substances in concentrations presenting a material threat to HHE, that threat would be mitigated. The net anticipated effect could be a positive contribution to cumulative environmental effects at the Hanford Site through RTD of such hazardous substances and COCs into a facility that has been designed and legally authorized to safely contain such contaminants, like ERDF. Contaminated soil removed under any alternative would meet the ERDF waste acceptable criteria as described in the *Environmental Restoration Disposal Facility Waste Acceptance Criteria* (WCH-191). As noted earlier, the maximum volume of soil that could be generated for disposal during implementation of the remedial action is approximately 5 million tons over the expected duration of this action (implementation of Alternative 3 is anticipated to occur over an 8-year period, resulting in 625,000 tons per year [and attendant transportation requirements]). Alternative 2 would result in approximately 550,000 tons per year (for 4 years).
		Wastes generated during implementation of the proposed alternatives would be manageable within the capacities of existing facilities. For perspective, ERDF received more than 700,000 tons of waste in CY 2008 and more than 430,000 tons in CY 2007). Radiological contamination is expected to be minimal; by definition, these are waste sites that are believed to be shallow in nature, do not impact groundwater, and have relatively small inventories. ERDF received approximately 22,500 Ci in CY 2008 and approximately 13,000 Ci in CY 2007.

Table 10-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation*
Mitigation	Considers that, if adverse impacts cannot be avoided, response action planning should minimize them to the extent practicable. This value identifies required mitigation activities.	Compliance with the substantive requirements of the ARARs would mitigate potential environmental impacts on the natural environment, including migratory birds and endangered species. DOE has established policies and procedures for the management of ecological and cultural resources when actions might affect such resources (*Hanford Site Biological Resources Management Plan* [DOE/RL-96-32], *Biological Resources Mitigation Strategy* [DOE/RL-96-88], and *Hanford Cultural Resources Management Plan* [DOE/RL-98-10]). Cultural resource and biological species reviews/surveys are undertaken that also provide suggested mitigation activities to assure adverse effects associated with implementing the actions are minimized or avoided. Health and safety methods, documented in the HSPs established by site contractors, would mitigate risks to workers from the remedial activities.
Irreversible and Irretrievable Commitment of Resources	Considers the use of nonrenewable resources for the proposed response actions and the effects that resource consumption would have on future generations. (When a resource [e.g., energy minerals, water, wetland] is used or destroyed and cannot be replaced within a reasonable amount of time, its use is considered irreversible.)	Materials that would be used to backfill waste sites that would be removed under an alternative could be taken, if needed, from the surrounding area to contour the backfill to match the surrounding area. For Alternatives 2 and 3, normal usage of resources during construction activities, such as fuel and water, would be irreversibly used. Potential impacts would be expected to be greatest for Alternative 3, due to the extent of RTD and duration of operation. Restoration of formerly disturbed areas to a more natural state would be expected to result in a net benefit to the ecological and visual resources within the region.

* Includes the evaluation for each alternative.

10.5 Coordination of Interim and Final CERCLA Remedial Activities

A feature of each area is the ongoing implementation of interim action RODs, CERCLA removal actions, RCRA corrective actions, treatability tests, and other activities to remediate contaminated areas or to develop more effective methods that advance remediation, as discussed in preceding chapters.

Implementation of these interim action ROD activities is generating information that allows an improved understanding of site complexity, supports refinement of the CSM, and documents the effectiveness of the remedial actions.

Cleanup of waste sites in accordance with the interim action RODs and focused FSs is ongoing and expected to continue until final action RODs are in place. As remedial actions under interim action RODs are completed, verification sampling and laboratory analyses are performed to document the extent to which RAGs established under the interim action RODs have been met. This information will be essential to supporting final action RODs.

There are many buildings and structures in the 100 Area. The buildings and structures are evaluated for removal, usually using a CERCLA removal action. Once these structures are demolished and decommissioned under CERCLA non-time critical removal actions, samples of the residual soil may be collected for analysis. If the analytical results indicate the area is contaminated, the area is considered a potential waste site. The area is then evaluated and a remedy is selected in accordance with the interim action ROD.

Characterization data and information developed through implementation of remedial actions under interim action RODs and this work plan will be coordinated and evaluated in support of reaching a final action ROD. To support a final action remedy at each OU, the current remedial actions under interim action RODs for the 100 Area OUs will continue until issuance of the final action ROD. While these remedial actions are underway, data will be generated to support final action decision making through the CERCLA process. The 100 Area integrated RI/FS process will be concluded with a data summary for all media (i.e., surface soil, vadose zone, groundwater, and surface water) as documented in Chapters 1 through 7 of the RI report, and has been evaluated through alternative analyses in the FS (Chapters 8 through 10). The final action remedy selection completes the RI/FS process and will be presented in the Proposed Plan. Under CERCLA, five-year reviews continue to be required to evaluate the effectiveness of remedial actions.

10.6 CERCLA and RCRA Corrective Action

The Tri-Party Agreement (Ecology et al., 1989a) states the intent of the Tri-Parties that CERCLA remediation at the Hanford Site will also fulfill the corrective action requirements for Hanford as a facility containing permitted TSD units. The Tri-Party Agreement guides integration and coordination of CERCLA and RCRA at the Hanford Site. The following articles explain the relations of CERCLA remedial actions and RCRA corrective actions:

- Article IV, Paragraph 17, which cites the Tri-Parties' intent "to integrate DOE's CERCLA response obligations, and RCRA corrective action obligations that relate to the release(s) of hazardous substances, hazardous wastes, pollutants and contaminants" covered by the Tri-Party Agreement (Ecology et al., 1989a).
- Article XIV, which applies to the performance of both CERCLA remedial action and RCRA corrective action.

- Article XXIII, which acknowledges the potential for overlap between CERCLA and RCRA cleanup.
- Article XXIV, which specifies the approach for regulatory oversight.

Section 5.4 of the *Hanford Federal Facility Agreement and Consent Order Action Plan* (Ecology et. al., 1989b) addresses the rationale and approach for past practice cleanup. Two key objectives are to "ensure that only one past practice program will be applied at each operable unit," and that "the process selected be sufficiently comprehensive to satisfy the technical requirements of both statutory authorities and the respective regulations."

DOE's corrective action obligation on the Hanford Site is addressed in the RCRA Hanford Facility Permit (*Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion, Revision 8C, for the Treatment, Storage, and Disposal of Dangerous Waste* [WA7890008967]), Condition II.Y.2.a, which provides that DOE corrective action obligations are met through adherence to the Tri-Party Agreement (Ecology et al., 1989a). In particular, "Overview of Cleanup Standards" (WAC 173-340-700) through "Sediment Cleanup Standards" (WAC 173-340-760) functions as ARAR standards for CERCLA remedial actions on the Hanford Site.

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11 References

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