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) signed the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989a), hereinafter called the Tri-Party Agreement (TPA) 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 and active waste management, *Resource Conservation and Recovery Act of 1976* (RCRA) corrective action for solid waste management units, and closure of RCRA treatment, storage, and disposal (TSD) units across the Hanford Site.

This document presents the results of a CERCLA Remedial Investigation (RI)/Feasibility Study (FS) undertaken for 100-D/H (Figure 1-1). The information contained in this RI/FS supports a Proposed Plan, which will go through a public review and provide the basis for a Record of Decision (ROD). The ROD for 100-D/H will apply to the source operable units (OUs) 100-DR-1, 100-DR-2, 100-HR-1, and 100-HR-2 and to the 100-HR-3 Groundwater OU (Figure 1-2).

Much of Chapter 1 is devoted to summarizing the assessment and remediation work, treatability tests, and other relevant studies. This historical information is presented to provide a comprehensive picture of current 100-D/H site conditions and establishes a foundation for the remainder of the RI/FS document.

For the purpose of CERCLA cleanup, four sections of the Hanford Site were placed on the "National Oil and Hazardous Substances Pollution Contingency Plan" (40 CFR 300), Appendix B, "National Priorities List," hereinafter called 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). Because of the large number of waste sites, unplanned releases (UPRs), and extensive groundwater contamination, the 100 Area was further divided into source and groundwater OUs for management of the investigation and remediation.

The list of waste sites for 100-D/H has been refined over time. During operations, waste disposal locations were constructed and operated as needed. Eventually, these locations were assigned an identification number. As technology evolved, computer databases were developed to store and track waste site information. Waste Information Data System (WIDS) is the database of waste site information for the Hanford Site. It assigns standardized identification numbers (site codes) and tracks the status of each waste site. Because of the potential listing on the NPL (40 CFR 300, Appendix B), a preliminary assessment/site investigation (PA/SI) was conducted. This PA/SI identified potential waste sites by geographic area across the Hanford Site. A hazard ranking score resulted in four areas (100, 200, 300, and 1100) to be added to the NPL (40 CFR 300, Appendix B). Waste sites identified within the geographic areas included 100-D and 100-H areas 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-D/H 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 (HHE) are identified through the Nonoperational Area Evaluation process, including the Orphan Site Evaluation and Discovery Site processes.

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. *Hanford Past-Practice Strategy* (DOE/RL-91-40), called Past-Practice 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 clean up waste sites and existing contamination where the need for a remedy was evident.

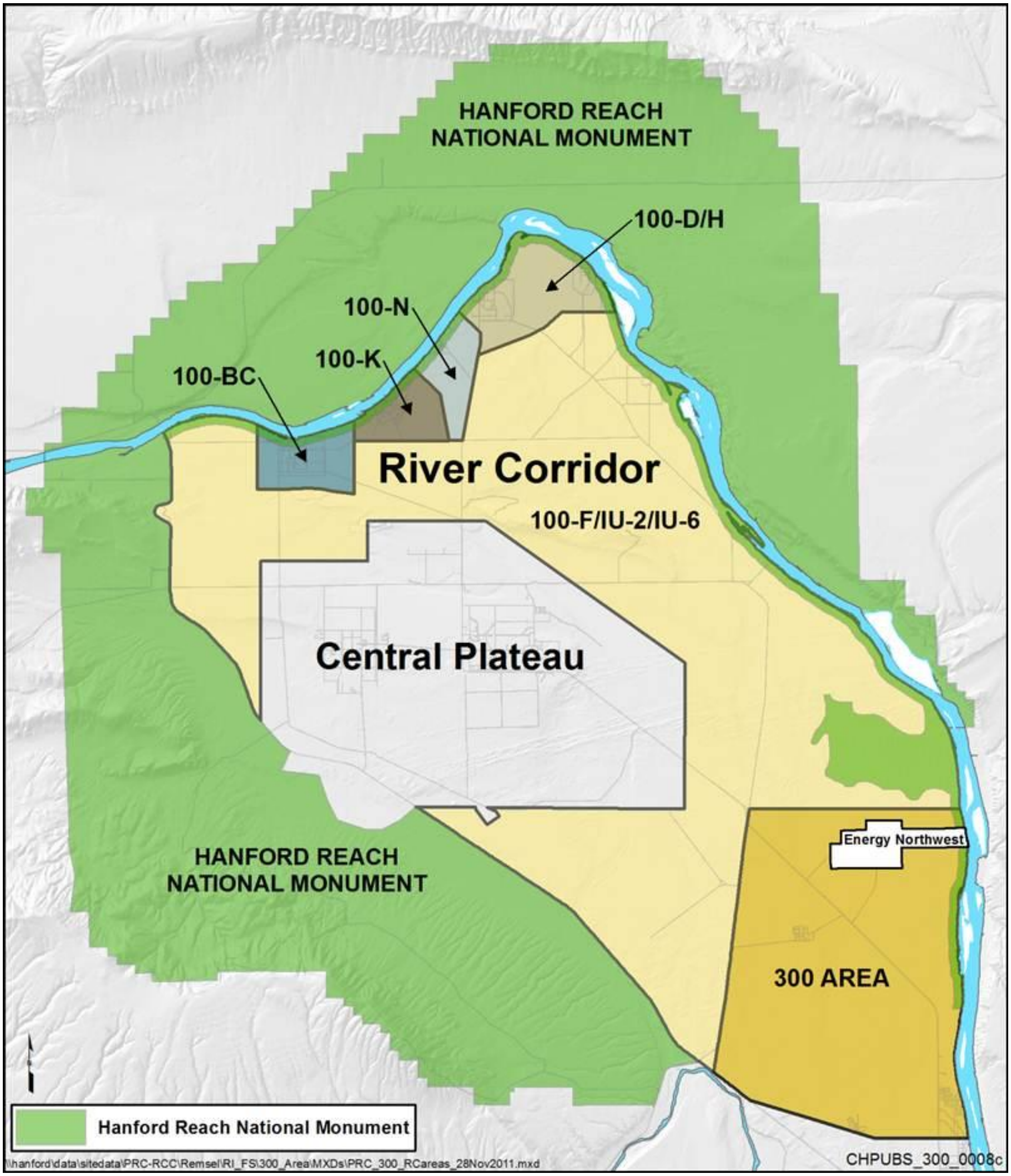

Figure 1-1. Hanford Site Map

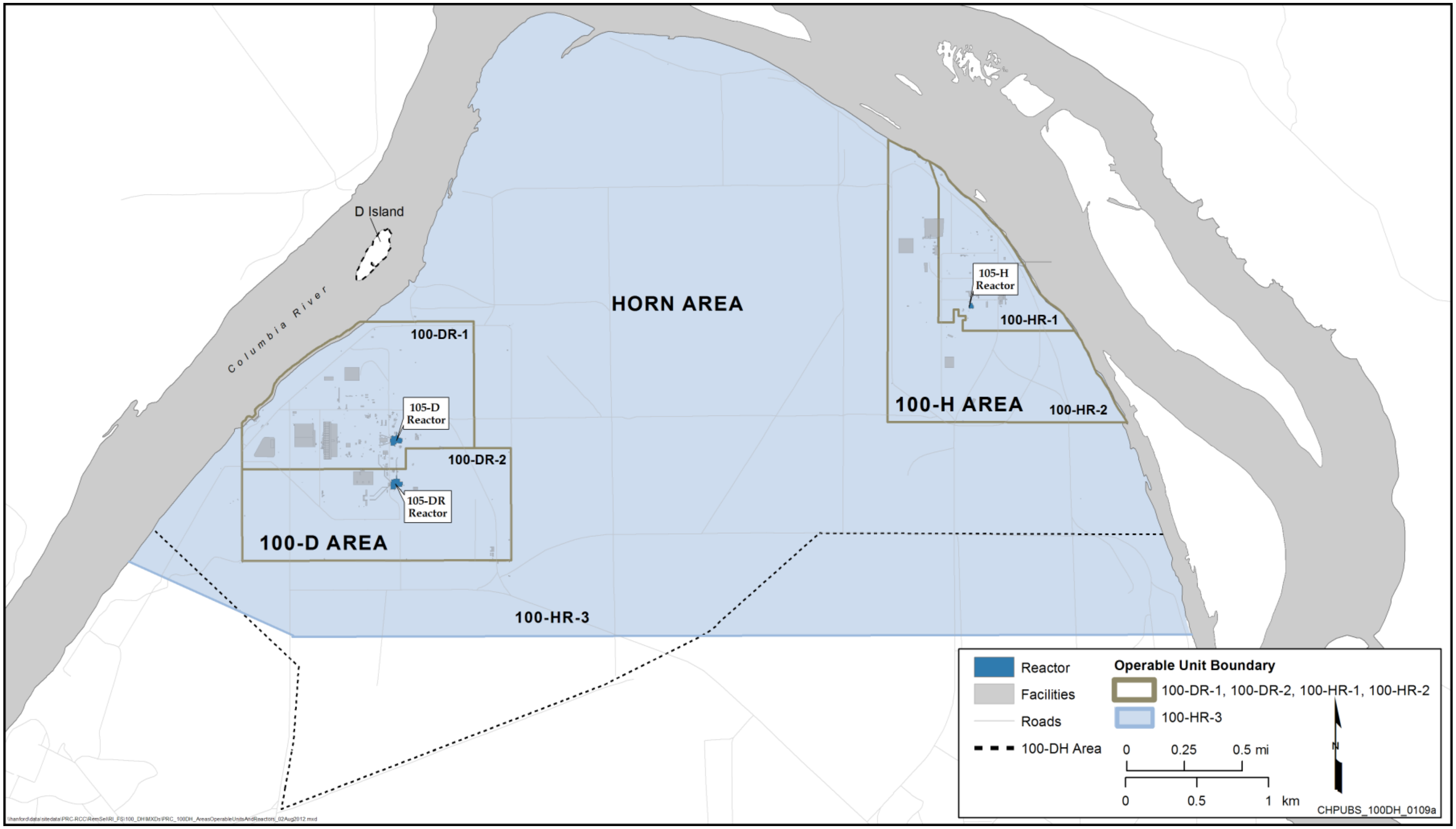

Figure 1-2. Location of 100-D/H Area OUs and Reactors

For 100-D/H, the Past-Practice Strategy (DOE/RL-91-40) resulted in specific actions and priority investigations. Limited field investigations (LFIs) were initiated where liquid waste disposal sites were considered responsible for local groundwater contamination. These LFIs were an initial step in characterizing the nature and extent of contamination in the vadose zone, structures, and debris that received radioactive liquid effluent discharges. Radionuclides, metals, and organics were analyzed in the LFI samples. The following reports document these investigations:

- *Limited Field Investigation Report for the 100-DR-1 Operable Unit* (DOE/RL-93-29)
- *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-DR-2 Operable Unit, Hanford Site, Richland, Washington* (DOE/RL-93-46)
- *Limited Field Investigation Report for the 100-HR-1 Operable Unit* (DOE/RL-93-51)
- *Limited Field Investigation Report for the 100-HR-2 Operable Unit* (DOE/RL-94-53)
- *Limited Field Investigation Report for the 100-HR-3 Operable Unit* (DOE/RL-93-43)

The LFIs indicated that liquid disposal sites in 100-DR-1, 100-DR-2, 100-HR-1, and 100-HR-2 OUs were primarily responsible for the continuing release of hexavalent chromium [Cr(VI)] above established limits to the groundwater. For the 100-HR-3 OU (100-D/H groundwater), 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-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 OUs under the following interim action RODs:

- *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/R10-99/039]), July 1999
- *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/ROD/R10-95/126), September 1995
- *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* (hereinafter called 100 Area Burial Grounds ROD [EPA/ROD/R10-00/121]), September 2000
- *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-H/K ROD [EPA/ROD/R10-96/134]), March 1996

Current River Corridor cleanup work is progressing based on Interim Action RODs. An objective of waste site cleanup is to remove sources of contamination and contaminated environmental media that are close to the Columbia River, and place them in the Environmental Restoration Disposal Facility (ERDF) for final disposal on the Central Plateau. Reducing the concentrations of contaminants entering the Columbia River and restoring the groundwater to beneficial use remain the key objective of groundwater remediation within 100-D/H. Interim Remedial Action Objectives (RAOs) for the cleanup of waste sites within the 100-DR-1, 100-DR-2, 100-HR-1, and 100-HR-2 OUs focused on protecting human health from contaminants in the soil, controlling the sources of groundwater contamination to minimize the effects to groundwater resources, and protecting the Columbia River from further adverse effects. For the

100-HR-3 Groundwater OU, interim action RAOs focused on Cr(VI) as the key effect posed by the site to groundwater and surface water.

DOE is the lead federal agency at Hanford, per CERCLA, *Superfund Implementation* (Executive Order 12580), and the TPA (Ecology et al., 1989a). 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 *Hanford Site Cleanup Completion Framework* (DOE/RL-2009-10), hereinafter called Cleanup Completion Framework, 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.
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 reasonably 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 reasonably 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: *Hanford Site Cleanup Completion Framework* (DOE/RL-2009-10).	

Ecology is the lead regulatory agency for 100-D/H. The lead regulatory agency has the primary responsibility for overseeing all remedial action activities to ensure they meet applicable requirements.

For sites in the River Corridor, remedial actions are expected to restore groundwater to drinking water standards (DWSs) and protect the aquatic life in the Columbia River, by achieving ambient water quality criteria (AWQC) at groundwater discharge points to the river. Unless technically impracticable, the objectives will be achieved within a reasonable time. If cleanup levels 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 or seek an applicable or relevant and appropriate requirements (ARARs) waiver.

To complete cleanup, the River Corridor has been divided into six geographic decision areas, including 100-D/H, to achieve 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. These levels will comply with ARARs and consider the remedial action goals (RAG) previously used in the implementation of interim action RODs for River Corridor OUs. The proposed cleanup levels (preliminary remediation goals [PRGs]) are numeric values that meet ARARs and protect HHE. These PRGs will be used to assess the effectiveness of the selected remedial alternatives.

Chapter 1 summarizes the assessment and remediation work that was completed before preparation of this RI/FS Report. In addition to the 100-D/H specific work, Chapter 1 describes other relevant work that supports remedy selection for 100-D/H. This RI/FS report builds on this body of previous work to provide a comprehensive understanding of current site conditions and evaluate a set of alternatives for addressing the remaining human health and environmental risks at 100-D/H.

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 is evaluated for protection of human health and ecological receptors as well as protection of groundwater and surface water.

- **Deep vadose zone:** from a depth of 4.6 m (15 ft) to the water table. This depth interval is evaluated for protection of groundwater and surface water. Residual contaminant concentrations in this zone are evaluated for human health protection to provide risk management information.

This RI/FS for 100-D/H was undertaken in accordance with *Integrated 100 Area Remedial Investigation/ Feasibility Study Work Plan* (DOE/RL-2008-46), hereinafter called the Integrated Work Plan, for the 100 Area, which contains the planning elements common to all the Hanford Site 100 Area source and groundwater OUs, and *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units* (DOE/RL-2008-46-ADD1), hereinafter called 100-D/H Work Plan, which is specific to 100-D/H. These work plans were developed and approved by Ecology to outline the requirements for an RI/FS supporting cleanup decisions for the OUs within the 100 Area NPL (40 CFR 300, Appendix B).

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 references used in preparing this report (Chapter 11).

- Chapter 2—Study Area Investigation
- Chapter 3—Physical Characteristics of the Study Area
- Chapter 4—Nature and Extent of Contamination
- Chapter 5—Contaminant Fate and Transport
- Chapter 6—Human Health Risk Assessment
- Chapter 7—Ecological Risk Assessment
- Chapter 8—Identification and Screening of Technologies
- Chapter 9—Development and Screening of Alternatives
- Chapter 10—Detailed Analysis of Alternatives
- Chapter 11—References

This RI/FS report includes extensive data used to perform calculations and assessments. Summaries of data are provided in this document and appendices, and clickable links may be used to take 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— Summary of Previous Investigations/Remediation and Annotated Bibliography
- Appendix C— RI Field Sampling Information
- Appendix D—Analytical Data and Text on Data Protocols/Quality Assurance/Quality Control
- Appendix E—Nature and Extent Summaries and Waste Site Table
- Appendix F—Fate and Transport Modeling Documentation
- Appendix G—Summary of Risk Characterization Results with Inclusion of Background Concentrations
- Appendix H—Ecological Risk Assessment Calculation Brief
- Appendix I—Technology Screening—Not Retained Technologies
- Appendix J—Alternative Development Supporting Documentation
- Appendix K—Nonoperational Area Evaluation
- Appendix L—100-D/H Riparian and Nearshore Evaluation
- Appendix M—Data from New Characterization Boreholes and Wells and Development of Geologic Cross Sections
- Appendix N—Summary Statistics
- Appendix O—Crosswalk of WAC Requirements (WAC 173-340-747(8), 2007) for Use of Alternative Fate and Transport Modeling to Modeling Basis of Soil Screening Levels and Preliminary Remediation Goals for 100-D/H Remedial Investigation/Feasibility Study

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, Interim Final* [EPA/540/G-89/004], called CERCLA RI/FS Guidance; *Remedial Investigation/Feasibility Study (RI/FS) Process, Elements and Techniques* [DOE/EH-94007658]). The RI/FS process is the methodology that the *Superfund Amendments and Reauthorization Act of 1986* program has established for characterizing the nature and extent of risks posed by uncontrolled hazardous waste sites and for evaluating potential remedial options.

This RI/FS 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). These documents provide information on the regulations and standards that govern the RI/FS process, as well as an overview of requirements for each chapter of the RI/FS.

This RI/FS has the following objectives:

- Provide information concerning the physical environmental setting and site characterization.
- Draw conclusions concerning the nature and extent of contamination present at the site, the potential for migration of contamination, 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, identifying contaminants of potential concern (COPCs),

evaluating potential migration pathways, and understanding potential effects to receptors, by estimating exposure (dose) effects in consideration of contaminant toxicity.

- Develop and evaluate an appropriate range of remedial action alternatives for the site that address unacceptable risk to human health or the environment.

As a matter of DOE policy, DOE has adopted DOE Order 451.1B at 5.a.(13), which directs DOE field offices to "Incorporate NEPA values, such as analysis of cumulative, off-site, ecological, and socioeconomic impacts, *to the extent practicable*, in DOE documents prepared under the Comprehensive Environmental Response, Compensation, and Liability Act." In a July 11, 2002 policy memorandum from the DOE Office of NEPA Policy and Compliance, it states: "Under DOE's CERCLA/NEPA Policy, established in 1994, DOE relies on the CERCLA process for review of actions to be taken under CERCLA, i.e., no separate NEPA document or NEPA process is ordinarily required. In conducting the CERCLA process, DOE addresses NEPA values (such as analysis of cumulative, off-site, ecological, and socioeconomic impacts) to the extent practicable and includes a brief discussion of impacts in CERCLA documents or other site environmental documents as appropriate."

EPA and DOE-RL will issue a ROD for the 100-D/H OUs that will include responses to the comments received. After the ROD is issued, a remedial design/remedial action will be developed, approved, and then implemented.

The conceptual site model (CSM) is used in this RI/FS report to present what is known about 100-D/H. 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 representation 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-D/H Work Plan (DOE/RL-2008-46-ADD1), the CSM was used to integrate relevant site information, determine whether information or 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 1-3 presents the basic elements associated with a CSM:

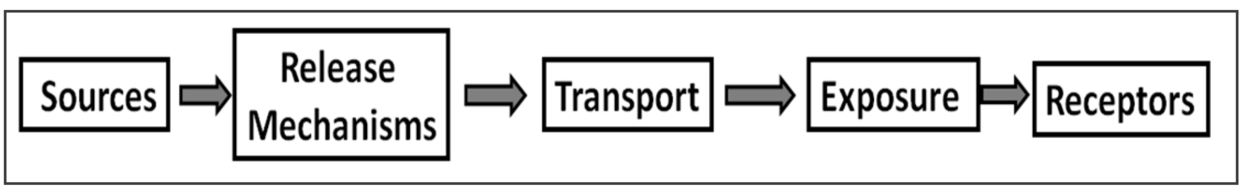

Figure 1-3. Conceptual Site Model

- **Source**—the location where a contaminant enters the physical setting. The primary sources of contaminants were releases related to reactor operations and are described in Chapter 1. Secondary sources are created when contaminants are mixed in the vadose zone and then the groundwater. Reactor operations at 100-D/H have ceased, so remaining primary sources are minimal and are expected to be removed through interim remedial actions; therefore, this document focuses on secondary contaminant sources in the vadose zone and groundwater along with potential risk to human health and the environment. These secondary sources are described in Chapter 4.

- **Release Mechanisms**—the actions necessary to release contaminants to the environment through resuspension of contaminated particulate matter, corrosion, and liquid waste discharges to the vadose zone, plant intrusion, animal burrowing, and erosion. Release mechanisms and relevant physical features are introduced in Chapter 3 and discussed in Chapter 5 in the context of fate and transport modeling.

- **Transport**—movement of a radiological, chemical, or physical agent in the environment from a secondary source, where human or ecological exposure could occur. Contaminants introduced into the environment can be transported between environmental media such as air, vadose zone, groundwater, and surface water because of interconnecting release mechanisms. Transport is discussed in Chapter 5.

- **Exposure**—the process by which a contaminant or physical agent in the environment comes into direct contact with the body, tissues, or exchange boundaries of humans, plants, or animals (for example, ingestion, inhalation, dermal absorption, or root uptake). Contaminants in the environment move from sources to potential receptors via pathways. An exposure pathway is complete when a receptor encounters contaminated environmental media. Potential exposure scenarios are discussed in Chapters 6 and 7.

- **Receptors**—humans and other organisms (for example, plants, animals, and other species) that may come into contact with the contaminants. Chapters 6 and 7 evaluate exposure to receptors.

In Chapters 8 through 10, the refined model is used to identify technologies, develop remedial alternatives, and evaluate the effectiveness of potential remedial actions.

The identification of data needs in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) led to development of a sampling and analysis plan (SAP) that established characterization activities specific to 100-D/H (*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], hereinafter called the 100-D/H SAP). The approved 100-D/H SAP (DOE/RL-2009-40) includes a field sampling plan that provides the sampling strategy and techniques that were used to obtain the RI/FS data presented in this report. The 100-D/H SAP (DOE/RL-2009-40) also provides a Quality Assurance Project Plan (QAPjP) to ensure that data collected meet the appropriate quality assurance (QA) and quality control (QC) requirements.

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 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 of Washington following formation of the Hanford Irrigation and Development Company in 1905.

The River Corridor includes approximately 8,300 acres of historical farmsteads, of which approximately 5,000 acres were orchard lands. Figure 1-4 shows the historical orchard lands within the 100-D/H area. Within the orchard lands, lead arsenate was applied as a pesticide. The farming life at Hanford came to an abrupt halt in 1943 when the U.S. government took possession of the land to produce weapons-grade plutonium as part of the Manhattan Project. Lead arsenate use in Washington State effectively terminated in 1948, when dichlorodiphenyltrichloroethane (DDT) became widely available to the public (*Re-establishing Apples Orchards in the Chelan-Manson Area* [Benson et al., 1969]).

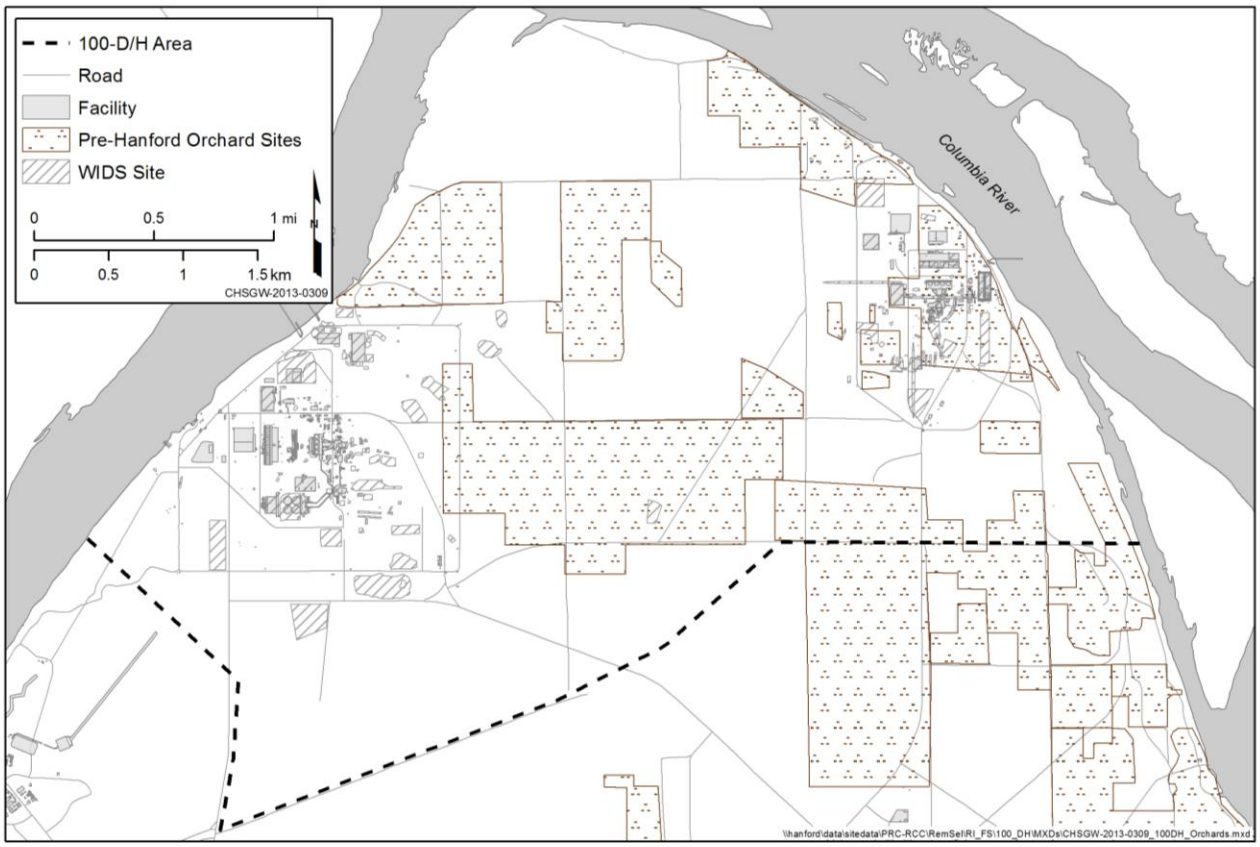

Figure 1-4. Historical Orchard Land Areas in 100-D/H

The persistence of residuals from lead arsenate that was applied as a pesticide before Hanford operations began is a concern that merits an assessment of potential effects to human health and the environment. To address this concern, the Tri-Parties have established the 100-OL-1 orchard lands OU (TPA Change Control Form C-12-02). An RI of the 100-OL-1 OU will be conducted to determine if actions are needed to mitigate potential environmental or human health effects. If results from the RI indicate a need for action, an FS will be conducted to identify and evaluate a range of remedial alternatives for the 100-OL-1 OU.

1.2.1 Site Description

The Hanford Site is divided into numerically designated areas. The areas served as the location for reactor, chemical separation, and related activities for the production and purification of special nuclear materials and other nuclear facilities. The reactors and their ancillary/support facilities were located along the shore of the Columbia River in the 100 Area, because of the need for large quantities of water to cool the reactors. Between 1943 and 1964, nine plutonium production reactors were built along the Columbia River in six areas: 100-BC, 100-K, 100-N, 100-D, 100-H, and 100-F. The areas associated with this investigation are 100-D and 100-H.

The 100 Areas contained all of the reactors used to produce plutonium in fuel slugs irradiated in the reactor. The 100-D/H Area encompasses 20 km^2 (7.8 mi^2) in the northern portion of the Hanford Site in the 100 Area. 100-D/H includes two reactor areas (100-D and 100-H) and adjacent areas, as shown on Figure 1-2. The Columbia River bounds 100-D and 100-H. The area between the reactor areas is commonly referred to as the "Horn." The Horn was used for agricultural purposes until 1943. A few isolated waste sites are located in the Horn, but the area is relatively undisturbed. Appendix A includes detailed site plans of 100-D/H.

1.2.2 Hanford Site and Operational History

This section provides an overview of the history of the Hanford Site and summarizes the history of 100-D/H, including operational and process history. It describes the reactors and support facilities, cooling water systems, and radioactive and nonradioactive waste streams. It also describes the waste disposal facilities that were used during site operations and locations where contaminants were accidentally released. Finally, this section indicates the types of contaminants that are likely to be in various locations at 100-D/H, based on historical information and previous investigations.

Operations in the 100 Area has been described in many reports. The summary in this section draws on information from the following documents:

- DOE/RL-2008-46-ADD1, *Integrated 100 Area Remedial Investigation /Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*
- BHI-00127, *100-H Area Technical Baseline Report*
- WHC-SD-EN-TI-181, *100-D Area Technical Baseline Report*
- PNL-6456, *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford: Volume 2 – Engineered-Facility Sites (HISS Data Base)*
- RL-REA-2247, *Historical Events—Reactors and Fuels Fabrication*
- DUN-4847, *Quarterly Report Contamination Control—Columbia River April – June 1968*
- DUN-4668, *Chemicals Discharged to the Columbia River from DUN Facilities Fiscal Year 1968*
- DUN-6888, *Historical Events—Single Pass Reactors and Fuel Fabrication*

1.2.2.1 Hanford Site History

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 was 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, brought the first three reactors (B, D, and F) 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 and boosted the output of the three Manhattan Project reactors (B, D, and F). The five new reactors were built with the intent of replacing some of the older Manhattan Project reactors, whose graphite blocks were showing signs of deformation, and increasing the plutonium output. Incremental improvements in the basic components of the World War II Manhattan Project reactors and a construction program that incorporated these improvements into the new reactors accounted for doubling the plutonium output at the Hanford Site in 1952 and 1953.

The period from 1956 through 1964 saw the most intense defense production at the Hanford Site, including the construction of a new dual-purpose reactor (N Reactor) capable of generating electricity and producing plutonium. Construction of the N Reactor, which featured a new closed-loop, primary cooling system, was completed in 1963, with plutonium production beginning in 1964. The N Reactor's 800-megawatt 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 the Hanford Site gradually decreased. In 1964, the AEC shut down the H, DR, and F Reactors, followed by the D Reactor in 1967 and B Reactor in 1968. The C, KE, and KW Reactors were shut down in 1971. The N Reactor was shut down in 1986 and transitioned to cold standby in 1989, signaling the close of the Hanford Site'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.

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, WA" [58 FR 48509], hereinafter called Reactor Decommissioning ROD) 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.) Following a period of up to 75 years for radioactive decay of short and intermediate half-life radionuclides, the reactors are planned to be transported to the 200 West Area for disposal (58 FR 48509).

The ISS reactor enclosures at 100-D and 100-H are periodically inspected to ensure that structural integrity and hazardous material confinement is maintained. External inspections are performed annually. Internal inspection of accessible areas are performed at 5-year intervals. Inspections are performed for evidence of damage and degradation caused by corrosion, aging of material, water intrusion, wind damage and animal and insect intrusion. Radiological surveys and inspection of barriers and postings are also performed. Non-routine activities may include repairs.

1.2.2.2 100-D/H Operations

Before beginning reactor construction at 100-D/H, the area supported orchard development, livestock grazing, and irrigated farming. Figure 1-5 is a 1941 aerial photo of the area before reactor construction. By 1947, the D Reactor was thought to be near the end of its life because of the growth and distortion of its graphite core.

Figure 1-5. 100-D/H in 1941 Before Reactor Construction

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The DR Reactor was built from late 1947 to early 1949 as a replacement for D Reactor. However, the D Reactor graphite distortion was controlled, and both reactors operated until 1964 when the DR Reactor was shut down. The D Reactor was shut down in 1967. Construction of H Reactor began in 1948, and the reactor operated from 1949 until 1965.

After reactor shutdown at 100-D/H, the 181-D Pump Station and the 182-D Reservoir were connected to the sitewide Export Water System to provide a backup water supply for the site. This system remains active today. The 182-D Reservoir is discussed in Section 3.8.1.

Fuel rods were placed in the nuclear fission reactors in the 100 Area and irradiated to transmute uranium to plutonium. The fuel was then taken to the 200 Area, where liquid chemical processes were used to separate plutonium and uranium from the fission products. Materials that had passed through the reactors for manufacture, or materials contacting items that had passed through the reactor, were radiologically contaminated with generally short-lived radioisotopes. These materials represented the majority of the waste 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 placement of disposal locations for various waste streams.

Materials Used or Produced in 100-D/H

Many materials were used or produced in the reactor operations and related manufacturing processes in 100-D/H. These materials included 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, chlorine, and sulfuric acid)
  - Materials used for reactor maintenance, such as acids and solvents
- Waste products:
  - Radioactively and chemically contaminated materials (solid and liquid waste)
  - Radioactively and chemically contaminated cooling water

These materials became contaminants when they entered the environment, either through planned release, planned disposal, or through unplanned releases such as spills and leaks. Waste resulting from supporting production operations was disposed of in each area according to phase, quantity, radioactivity, and composition (for example, liquids, solids, high/low mass, or volume, high-level, low-level, strictly chemical, and septic). Thus, liquid and solid disposal locations were constructed and waste management practices were developed to manage these materials consistently among similar facilities at the Hanford Site (although practices changed over time). Liquid wastes from reactor operations and associated facilities were released to the vadose zone and the Columbia River. Solid wastes were disposed of in burial grounds associated with the facilities. More detailed discussions on the nature and extent of the contaminants associated with these processes are provided in Chapter 4. Sites for wastes intentionally or unintentionally released to or buried within 100-D/H included ponds, trenches, cribs, French drains, solid waste burial grounds, and unplanned releases, each of which is described in the following text.

- **Ponds.** Unlined, liquid waste disposal sites that were designed to receive low concentration liquid waste. Two typical 100-D/H Ponds are shown on Figure 1-6.
- **Trenches.** Shallow, narrow, unlined surface liquid waste disposal sites of variable length that received sludge or liquid waste (cooling water, contaminated water and sludge, fuel rupture effluent, and decontamination solutions). 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.
- **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. 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 basin effluent, spent laboratory solutions, and potassium borate solutions.

Figure 1-6. 100-D Area Ponds in 1992

- **French drains.** Subsurface liquid waste disposal sites designed to transport wastewater below the ground. These drains are usually built with a 1 m (3 ft) diameter, open (or gravel filled) pipe that is vertically placed less than 5 m (16 ft) below ground surface (bgs) (Figure 1-7).

- **Solid waste burial grounds.** Landfills (Figure 1-8) used to dispose of radioactive and nonradioactive hazardous substances, construction debris, contaminated equipment and soil, reactor parts, and burnable low-level radioactive materials. The 100 Area burial grounds also received pieces of spent nuclear fuel (*Cleanup Verification Package for the 118-H-1:2, Burial Ground Anomaly Staging Area and Suspect Spent Nuclear Fuel Bunker Area* (CVP-2011-00003)

- **Unplanned release sites.** Waste sites caused by unplanned spills or releases from retention basins, ponds, pipelines (Figure 1-9), or other facilities and equipment (for example, tanks, tanker trucks, and transfer lines) used to handle liquid waste.

Figure 1-7. French Drain at Sodium Dichromate Railcar Unloading Station in 1997 (Waste Site 100-D-12)

1.2.2.3 Reactor Mechanics and Layout

This section describes the mechanics and layout of the reactors and associated facilities. All reactor areas used the same nomenclature for numbering the reactors and associated facilities.

Reactors. The D and H Reactors were graphite-moderated, water-cooled units used to produce weapons-grade plutonium. Each reactor structure (Figure 1-10) includes a concrete foundation, steel base plate, cast iron bottom shield, cubical stack of graphite blocks, cast iron thermal shield walls/top, steel/Masonite® biological shield walls/top, and aluminum process tubes to hold the uranium fuel and carry the cooling water. Each reactor facility (designated as 105-D, 105-DR, and 105-H) includes a reactor block, control rod and safety rod facilities, reactor control room, fuel storage basin and associated fuel handling equipment, fans and ducts for the ventilation and recirculating gas systems, and supporting offices, shops, and laboratories.

Figure 1-8. 118-H-1 Burial Ground Excavation in 2007

1.2.2.4 Cooling Water

This section describes how cooling water was obtained and prepared for use in the reactors. It also describes the fate of the cooling water as it passed through the reactors and was subsequently discharged to the river or to the vadose zone.

A continuous supply of high-quality cooling water was essential to reactor operations to prevent reactor core damage from heat generated by the fission reactions. The D, DR, and H Reactors each used on average (over reactor operating lifetime) about 95,000 L/min (25,000 gal/min) of water obtained from the

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Columbia River. Over the lifetime of D and DR Reactor operations, approximately 4.5 trillion L (1.2 trillion gal) of cooling water were produced and used. At the H Reactor, approximately 2 trillion L (500 billion gal) of cooling water were used.

Figure 1-9. Extensive Excavation to Remove Pipelines near the D and DR Reactors (approximately 1996)

Water Treatment. Water for reactor cooling was treated extensively before passing through the reactors. Figures 1-11 and 1-12 illustrate the general process in the D and H Reactors, respectively. The water treatment process shown is generally applicable to the two water treatment plants in 100-D and the water treatment plant in 100-H. The raw water was pumped from the Columbia River at the 181 River Pump House to the 182 Reservoir and Pump House, and then to the 183 Head House and Water Treatment Plant, where alum, sulfuric acid, sodium hydroxide, and chlorine were added (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]). Sodium dichromate was added as a corrosion inhibitor later in the process at the 190 Process Pump House (100-D and 100-H) and at the 183-DR Water Treatment Plant (100-DR) as discussed below. In the 183 Water Treatment Plant (Figure 1-13), the water was subjected to chemical mixing, flocculation, settling, and filtration (through granular anthracite coal, sand, and gravel), and the treated water was stored in clear wells. Water for filter backwash was supplied from the clear wells by pumps in the 183 Water Treatment Plant. Backwash flowed through the filter media and was subsequently discharged through a waste valve into an "upstream" process sewer that discharged to the river at a 1904 or a 1907 Outfall

(*Hazards Summary Report Volume 3 – Description of the 100-B, 100-C, 100-D, 100-DR, 100-F and 100-H Production Reactor Plants* [HW-74094 VOL3]).

Figure 1-10. D Reactor during Construction (1943 to 1944)

The 100-D upstream process sewers were nonradioactive and discharged at the 1904-D Outfall. The 100-DR and 100-H upstream process sewers received nonradioactive process sewer drains from the 183 and 190 facilities and some of the potentially low contamination work areas at the 105 Buildings and discharged to the 1904 Outfall. The process sewer to the 1907 Outfall also provided emergency DR Reactor cooling water sewers (that is, an alternative downstream [discharged from the reactor process] process sewer in the event of a failure of the primary downstream sewer to the 1904 Outfall).

The 186 Demineralization Plant was constructed as part of the water treatment system for D Reactor to remove dissolved calcium and magnesium salts, but it was never used for this purpose beyond startup tests at the D Reactor because the demineralization step was found to be unnecessary (*Manhattan Project Buildings and Facilities of the Hanford Site: A Construction History* [WHC-MR-0425]). The water from 186-D was sent to the 185-D De-aeration Plant to remove dissolved gases and entrained air (another step that was later found to be unnecessary) and was then pumped at the 190 Process Pump House to the 105 Reactor Building.

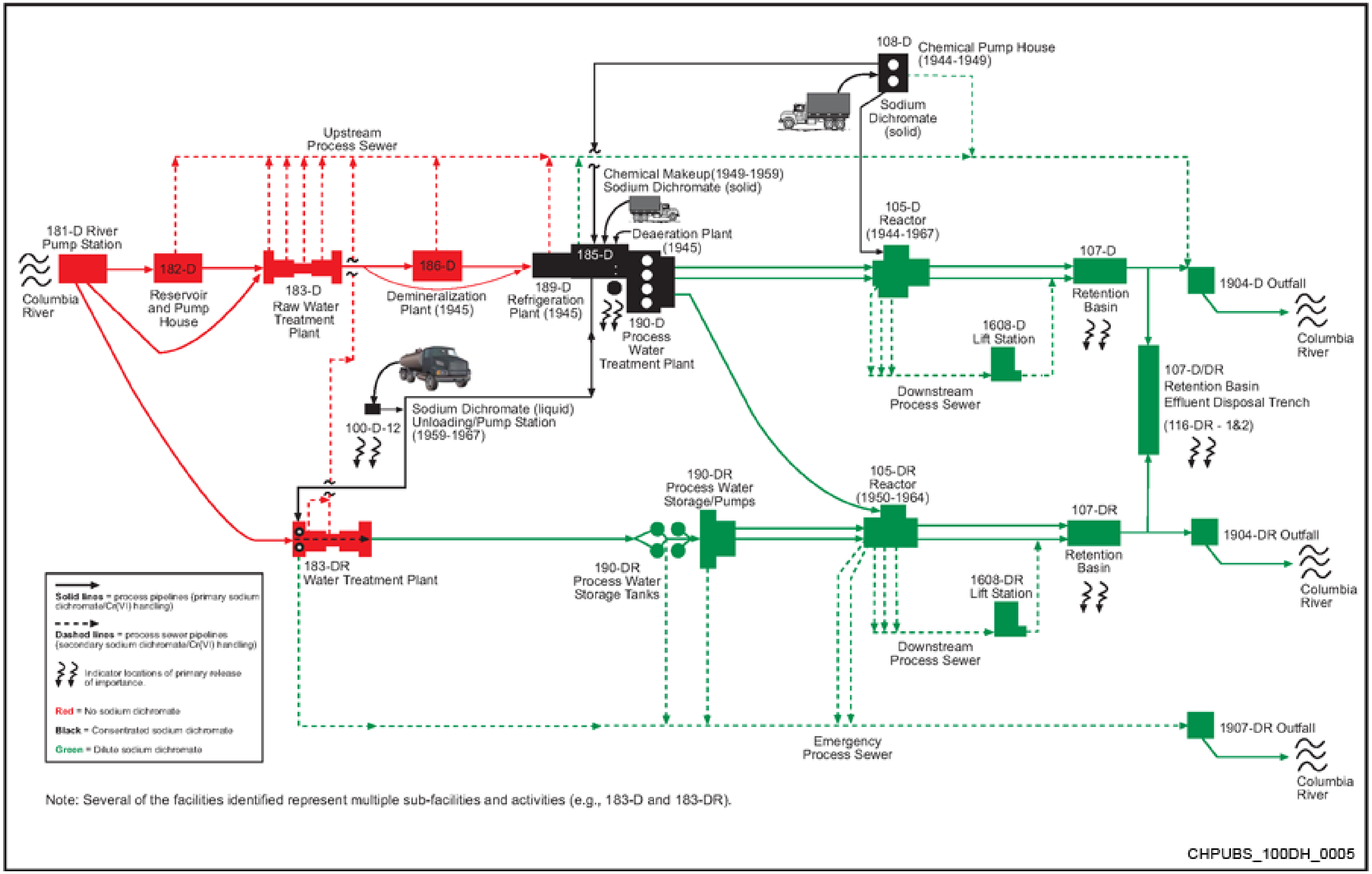
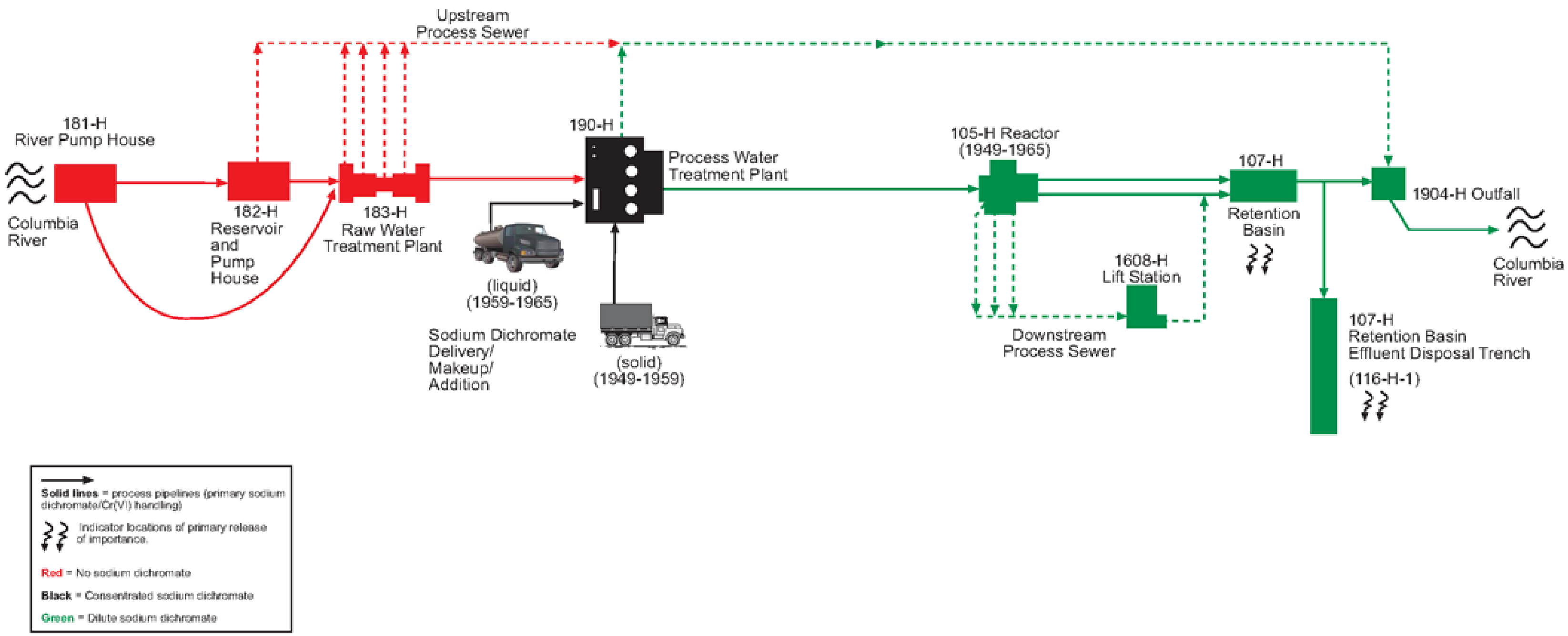


Figure 1-11. 100-D Water Treatment and Sodium Dichromate Use Flow Diagram



Note: Several of the facilities identified represent multiple sub-facilities and activities (e.g., 183-H).

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Figure 1-12. 100-H Water Treatment and Sodium Dichromate Use Flow Diagram

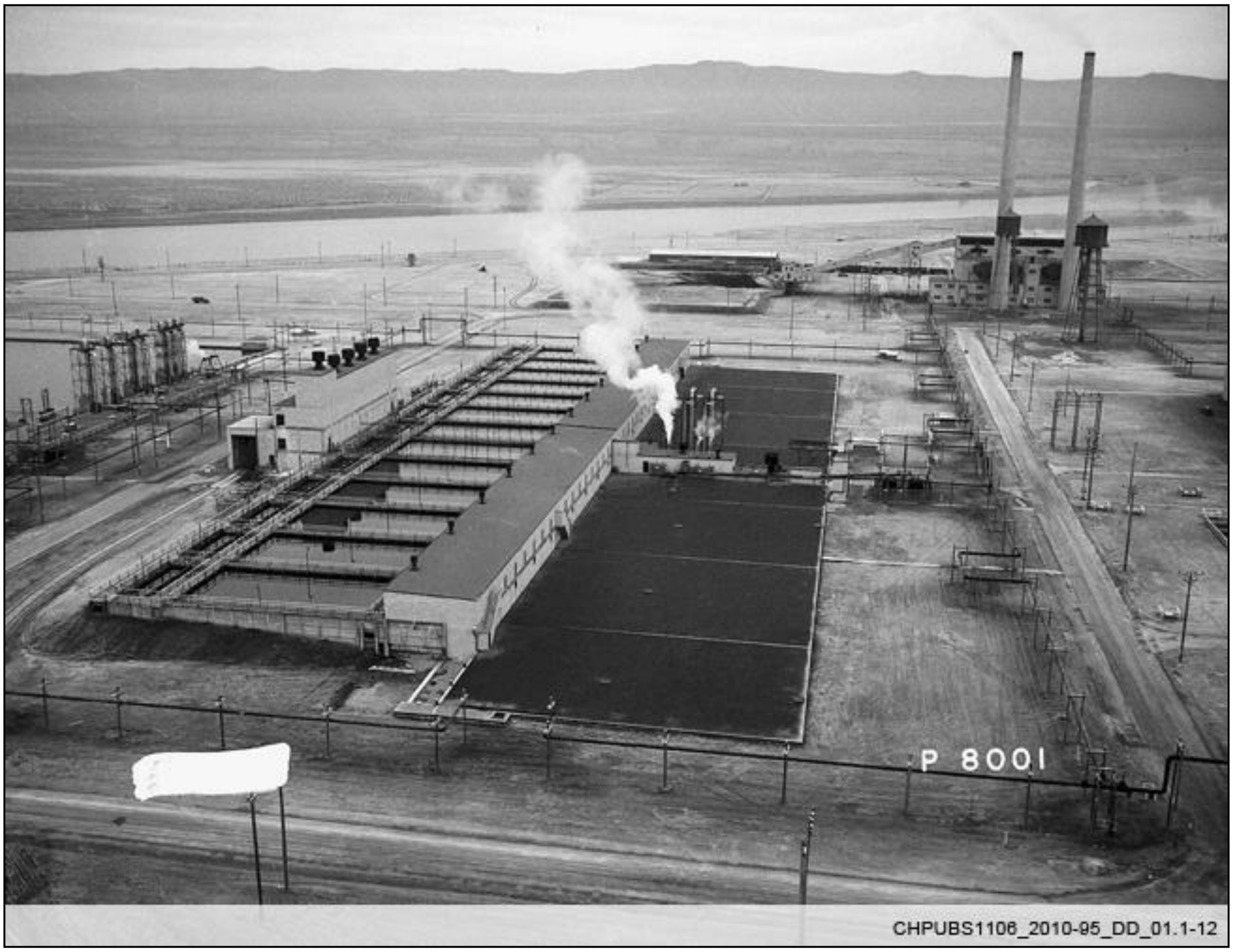

Figure 1-13. Aerial View of 183-D Water Treatment Plant in 1945

1.2.2.5 Sodium Dichromate Use

Sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$), a corrosion inhibitor, was a key additive to cooling water at the 190 Process Pump House (100-D and 100-H) and at the 183-DR Water Treatment Plant (100-DR). Chromium was present in the dichromate anion with a +6 valence state (that is, Cr[VI]). More than 3,000 metric tons (3,300 tons) of Cr(VI) were used in conditioning the cooling water between 1945 and 1967 for the D and DR Reactors and about 1,200 metric tons (1,322 tons) for the H Reactor (100-D/H Work Plan [DOE/RL-2008-46-ADD1]). The reactor coolant had a near neutral pH, with Cr(VI) concentrations averaging 700 µg/L (2,000 µg/L as sodium dichromate).

From the D and H Reactors startup to final shutdown, the cooling water for each reactor contained 2,000 µg/L of sodium dichromate. The cooling water flow rate for each reactor was about 95,000 L/min (25,000 gal/min) from startup until 1955, when production began to increase, and cooling water flow for each reactor increased to about 190,000 L/min (50,000 gal/min) by the time the reactors were shut down. The following text summarizes the process of sodium dichromate preparation and use for reactor cooling water. The 100-D and 100-H facilities are shown in Appendix A.

100-D Area Sodium Dichromate Operations. The facilities and waste sites where sodium dichromate was handled at 100-D, based on process history information, are presented on Figure 1-14.

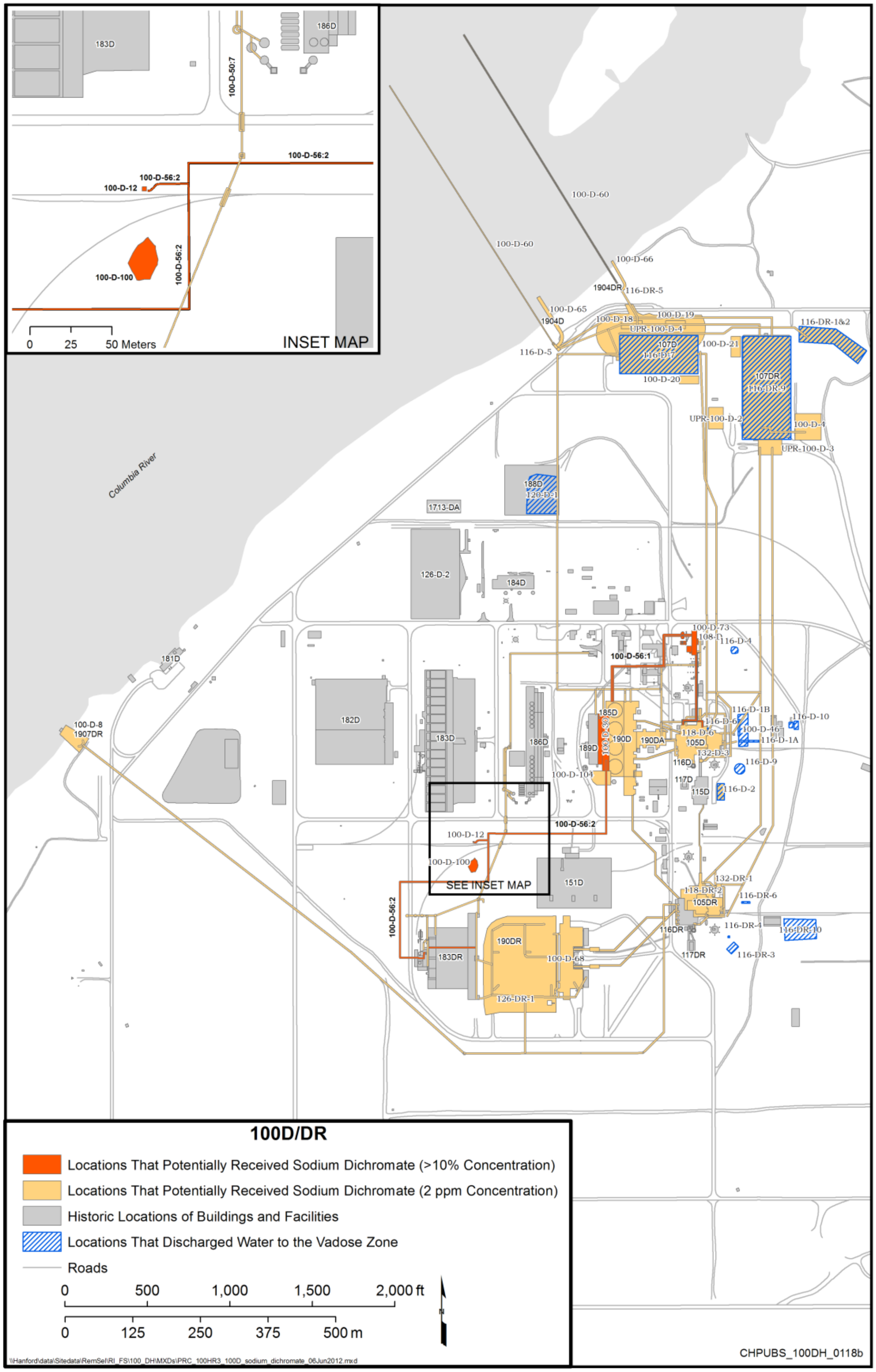

Figure 1-14. Facilities and Waste Sites Where Dichromate Was Handled at 100-D

A 10 wt% sodium dichromate solution was used initially in 1944, which was increased to a 15 wt% sodium dichromate solution as the standard intermediate concentration by 1952 (*A Proposal for Liquid Sodium Dichromate Facilities for the 100-C and 100-D Areas* [HW-27270]). Batches of 10 to 15 wt% sodium dichromate solution were pumped from the 108-D Building via an underground pipeline to storage tanks in the 185-D Building. Batches of 10 or 15 wt% sodium dichromate water solution could also be transferred from the 108-D Building via an overhead pipeline to a storage tank in the 105-D Reactor Building valve pit.

The 10 to 15 wt% sodium dichromate solution was metered into the reactor cooling water stored in the 190-D and 190-DR storage/pump tanks to provide a sodium dichromate concentration of 1,800 to 2,000 µg/L. From there, it was pumped through the reactor facilities from 1944 through 1967. The 2,000 µg/L sodium dichromate reactor cooling water solution had a near neutral pH, with a concentration of Cr(VI) at about 700 µg/L. The sodium dichromate concentration in the reactor cooling water was reduced to 1,000 µg/L during reactor tests from 1964 to 1967 with a corresponding Cr(VI) concentration of 350 µg/L.

Concentrated sodium dichromate materials included solid sodium dichromate dihydrate ($Na_2Cr_2O_7$ -$2H_2O$) and 70 wt% sodium dichromate-water solutions delivered to 100-D. Solid sodium dichromate dihydrate was received (in bags and/or drums) and processed in 100-D from 1944 until 1959. Shipments of 45 kg (100 lb) bags of solid sodium dichromate dihydrate were received at the 108-D Building from 1944 to 1950, then at the 185-D Building until 1955. Shipments of 226.8 kg (500 lb) drums of solid sodium dichromate dihydrate were received and stored at the 185-D Building from 1955 until 1959, when the transition to a liquid sodium dichromate supply system in the 100-D/DR Area was completed (*Monthly Record Report, Irradiation Processing Department August, 1959* [HW-61789]). Based on historical information for the 1713-DA Essential Materials Warehouse, supplies of 45 kg (100 lb) bags of solid sodium dichromate dihydrate also may have been stored at the 1713-DA Essential Materials Warehouse from 1944 until about 1955. It is not known when the 1713-DA Building was removed, but it was not seen in aerial photos after 1955. The shipments of bags and drums of solid sodium dichromate dihydrate were replaced with shipments of 70 wt% sodium dichromate water solutions beginning in 1959 (HW-61789) and continued until D Reactor was shut down in 1967.

In 1959, a tank truck/railroad car Unloading/Transfer Station (100-D-12) was installed adjacent to the railroad spur between the 183-D and the 183-DR Water Treatment Plants. The concentrated sodium dichromate solutions were transferred by hose from railroad cars or tanker trucks to the pumping facility (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]). The 100-D-12 Unloading/Transfer Station included a water dilution/mixing valve and a transfer pump (on a concrete pad) and an underground transfer pipeline (with isolation valves) that tied into the sodium dichromate underground transfer line from 185-D to 183-DR. The water dilution/mixing valve was used to dilute the delivered solutions to 70 wt% sodium dichromate, as necessary.

A 133,000 L (35,000 gal) storage tank was installed outside of the south side of the 185-D Building (Figure 1-14) to store the 70 wt% sodium dichromate solutions received at 100-D-12. A recirculation/transfer pump, valves, and piping connected the outside storage tank to sodium dichromate tanks inside the 185-D Building. The liquid sodium dichromate feed system for the 100-D/DR Area was completed in July 1959 and started up in August 1959 (HW-61789). The isolation valves in the underground line allowed the alternate use of the line for transfers of 70 wt% solutions from the 100-D-12 Unloading/Transfer Station to the 185-D large storage tank, and from 185-D to 183-DR. From 1959 until 1964, the 183-DR Head House received 70 wt% sodium dichromate solutions, which were likely diluted to an intermediate 10 to 15 wt% concentration. From 1959 to 1967, the 70 wt% sodium dichromate solution was diluted to an intermediate concentration (that is, 10 to 15 wt% sodium dichromate solution) in the 185-D Building before feeding to the metering pumps in the 190-D Building.

100-H Area Sodium Dichromate Operations. The facilities and waste sites where sodium dichromate was handled at 100-H, based on process history information, are presented on Figure 1-15. The 100-H facilities are shown in Appendix A. Between late 1949 and early 1965, approximately 2 trillion L (500 billion gal) of reactor coolant containing 2,000 µg/L of sodium dichromate (except for the last year at 1,000 µg/L sodium dichromate) passed through H Reactor. The total amount of sodium dichromate in the reactor coolant volume was approximately 4 million kg (2 million lb), assuming a concentration of 2,000 µg/L, except for the last operating year when the sodium dichromate concentration was reduced to 1,000 µg/L. The residual footprint of the 190-H sodium dichromate handling area is addressed as the 100-H-46 waste site.

Multiple mixing steps to process highly concentrated sodium dichromate solutions to diluted reactor coolant solutions were not used at 100-H. River water was treated for impurities and pumped to the 190-H Building where sodium dichromate was added to make a cooling water solution of approximately 2,000 µg/L sodium dichromate. The bag-mixing process in the 190-H Building used solid sodium dichromate from 1949 to 1959 and 70 wt% sodium dichromate solutions from 1959 to 1965. In 1959, a 56,781 L (15,000 gal) horizontal storage tank was installed in the 190-H Building to receive, store, and supply a 70 wt% sodium dichromate solution to the batch mixing tanks also located in the 190-H Building.

Downstream from Reactors. Cooling water picked up other contaminants during passage through the reactors. These contaminants included activated elements in the water caused by the high neutron flux in the reactor cores (for example, calcium-41, chromium-51, and zinc-65), activation products from reactor components including the graphite reactor cores, steel process tube end pieces, process tubes, fuel cladding (for example, tritium, carbon-14, cobalt-60, nickel-63, europium-152, europium-154, and europium-155), fuel element fission products (for example, cesium-137 and strontium-90), and transmutation products (for example, plutonium-239 and -240). The total radioactivity of the reactor cooling water during normal operation was about 0.2 pCi/L (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]).

Cooling water effluent was near boiling after passing through the reactors (downstream) (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]). During initial reactor operations, the effluent then traveled by pipeline to the 107-D (116-D-7), 107-DR (116-DR-9), and 107-H (116-H-7) Retention Basins where it was held for a short time (hours) to allow thermal cooling and very short-lived radionuclide decay. During the later years of reactor operation, the contaminated effluent was held on one side of a retention basin, then switched to the other side of the basin to provide longer holding times before river discharge. However, this “alternating side” process failed because of thermal stress between the hot and cold sides of the retention basins. Instead, the retention basins were operated as single units (that is, effluent flowed through both basin compartments) before river discharge. In addition, during the later years of operations, the effluent was redirected to nearby Pluto Cribs (replaced in the early 1950s by the 116-DR-1, 116-DR-2, and 116-H-1 liquid disposal trenches), following fuel cladding failures.

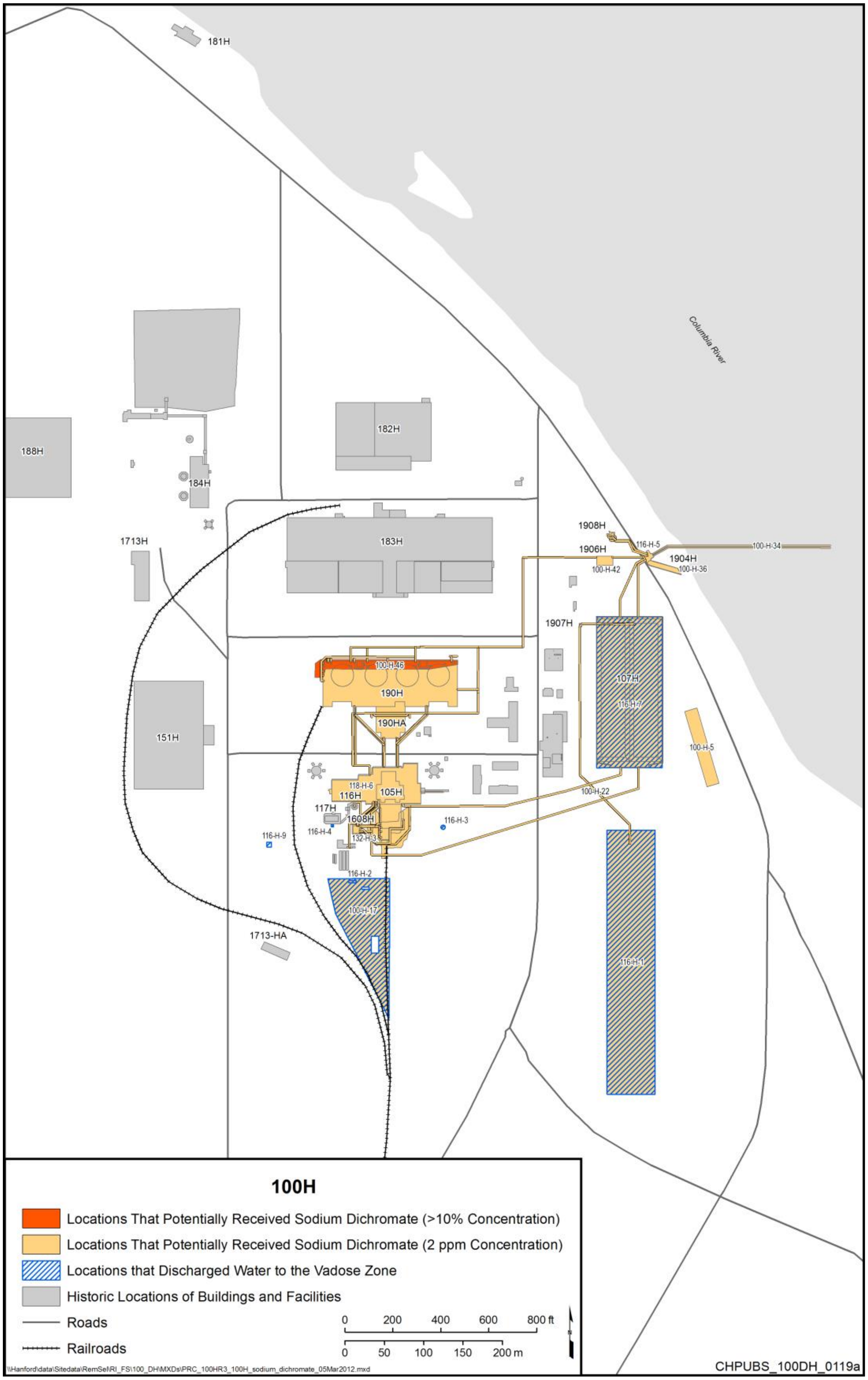

Figure 1-15. Facilities and Waste Sites Where Dichromate was Handled at 100-H

Sludge accumulated in the retention basins from the diatomaceous earth (solid slurry) purges used to clear process tube film buildup and from natural wind-blown sand accumulations. Sludge was removed and placed in 107 Basin Sludge Burial Trenches. The principal radionuclides detected in the Retention Basin Systems included europium-152, europium-154, europium-155, cobalt-60, cesium-137, and strontium-90 (short-lived radionuclides such as chromium-51 and zinc-65 have since decayed away) (*Radiological Characterization of the Retired 100 Areas* [UNI-946]).

The retention basins and effluent lines developed numerous documented leaks likely resulting from the thermal stress produced by the hot water exiting the reactors. The leakage rates at each retention basin were reportedly about 10,000 L/min (2,641 gal/min) (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]; and *Radiological Characterization of the Retired 100 Areas* [UNI-946]). These leaks were not adequately repaired, and coolant loss to the subsurface was sufficient to create long-standing groundwater mounds in that area (*Unconfined Underground Radioactive Waste and Contamination* [HW-27337]; *Tabulation of Radioactive Liquid Waste Disposal Facilities* [HW-33305]; *Unconfined Underground Radioactive Waste and Contamination – 100 Areas* [HW-46715]; *Status of the Ground Water Beneath Hanford Reactor Areas: January, 1962 to January, 1963* [HW-77170]; *Radiological Characterization of the Retired 100 Areas* [UNI-946]).

Significant Releases from Retention Basins and Effluent Lines

Several significant releases from the retention basins and effluent lines have been documented (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]):

- In 1950, a major leak from the northern side of the 107-D (116-D-7) Retention Basin became evident by the presence of water between the road and the fence line.
- In 1951, the 107-DR (116-DR-9) Retention Basin experienced excessive leakage at the inlet. In 1953, some of the contaminated soil from this leak was used as fill material at the southern end of the basin.
- In 1951, leaks were reported along the effluent lines approximately 46 m (150 ft) southeast of the 107-D (116-D-7) Retention Basin, contaminating the immediate vicinity of the basin.
- In 1967, a field test was conducted where the entire reactor effluent volume was discharged to the 116-DR-1/2 Trench for several months.

From the retention basins, the effluent was transferred through large pipes to the 116-D-5 (1904-D), 116-DR-5 (1904-DR), and 116-H-5 (1904-H) Outfall structures and then into pipes that discharged at the bottom center of the Columbia River. The 100-D and 100-DR effluent lines pass through D Island (Figure 1-16) while the 100-H effluent line is further downstream. Overflow from all three-outfall structures could also discharge directly to the shore of the river through nearby spillways.

During production, fuel element and infrastructure failures (for example, pipe leaks) led to releases of radiologically and chemically contaminated materials to the environment (*Unconfined Underground Radioactive Waste and Contamination* [HW-27337], *Tabulation of Radioactive Liquid Waste Disposal Facilities* [HW-33305], *Unconfined Underground Radioactive Waste and Contamination – 100 Areas* [HW-46715]; *Radiological Characterization of the Retired 100 Areas* [UNI-946]). Most fuel-element failures involved natural uranium or enriched uranium fuels. Fuel cladding failures occurred when corrosion or swelling of the aluminum cladding covering a uranium fuel slug caused the cladding to break open, releasing uranium oxide particles that contained plutonium isotopes and fission products (cesium-137 and strontium-90) into the cooling water.

During their years of operation, several hundred fuel cladding failures occurred at each of the D and H Reactors (*Fuel-Element Failures in Hanford Single-Pass Reactors, 1944-1971* [PNWD-2161 HEDR]; *100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]). Fuel cladding failures resulted in highly radioactive cooling water that was released to the soil column or to the Columbia River. Fuel cladding failures also occurred within the fuel storage basins themselves. Some leakage was reported for the 100-D and 100-H fuel storage basins (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; and *100-H Area Technical Baseline Report* [BHI-00127]); however, the leak rate was small, and the leak location was never identified. At D Reactor, however, at least one fuel storage basin leak was documented as being present at the rear of the building in May 1957.

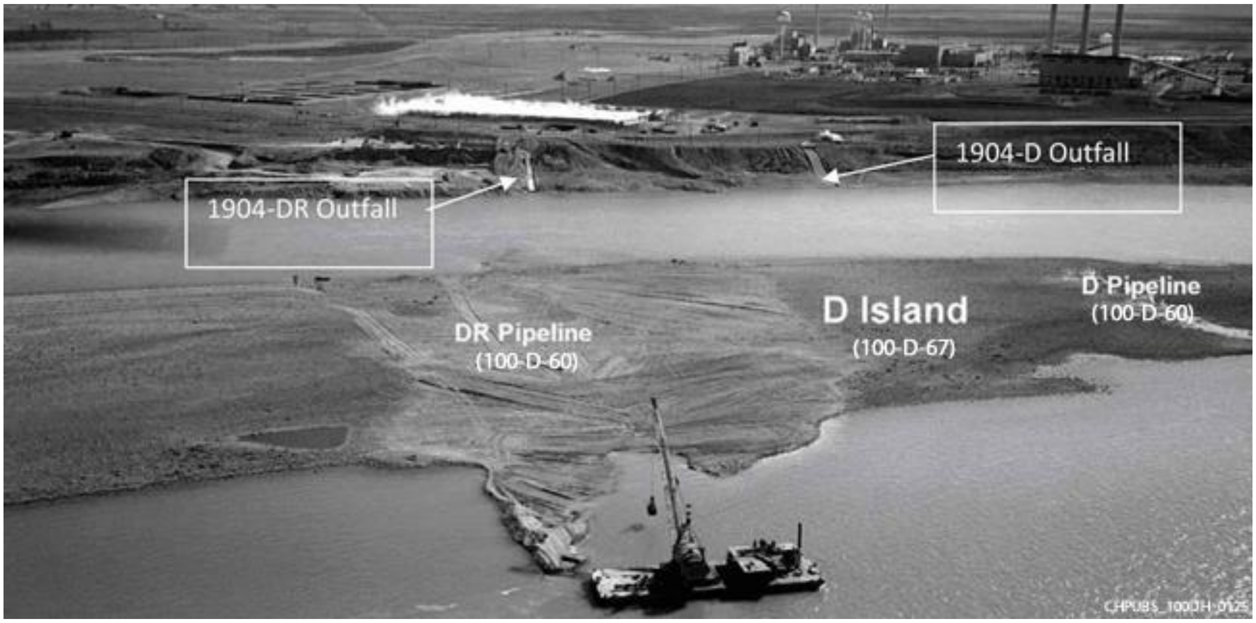

Figure 1-16. Aerial View of D and DR River Effluent Pipelines and Outfalls in 1956

From the early 1950s until the reactors were shut down in the mid-1960s, the highly radioactive water was segregated and drained to the 116-DR-1 Basin Trench (107 Liquid Disposal Trench), 116-DR-2 Basin Trench (107-DR Liquid Waste Disposal Trench), and 116-H-1 Basin Trench (107-H Liquid Waste Disposal Trench). Some other facilities received smaller quantities of radioactively contaminated water from the 105 Fuel Storage Basins and from special maintenance or process tests via the downstream process sewer and the 1608 Pump House (the downstream process sewer lift station), including two trenches east of D Reactor (116-D-1A and 116-D-1B).

From the late 1940s through the late 1960s, the 105 Storage Basin Trenches received water and sludge from the fuel storage basins. The trenches were typically about 30 m (100 ft) long, 3 m (10 ft) wide, and covered with 2 to 5 m (6 to 15 ft) of soil.

1.2.2.6 Other Radioactive Waste Streams

These waste streams included decontamination solutions, sludge, solid waste, and air emissions. Although cooling water was the dominant waste stream at 100-D/H because of the quantities used, other radioactive and chemical waste streams contributed to the contamination observed in 100-D/H soil and groundwater. Figure 1-17 presents the facilities and waste sites where strontium-90 was known to be present at 100-H, based on process history information. One well at 100-D (199-D-5-12) had historical readings of strontium-90 above the DWS until it went dry. Well 199-D-5-132 was drilled in a similar location as 199-D-5-12 and confirmed that the strontium-90 is still above the DWS. This is discussed in Chapter 4.

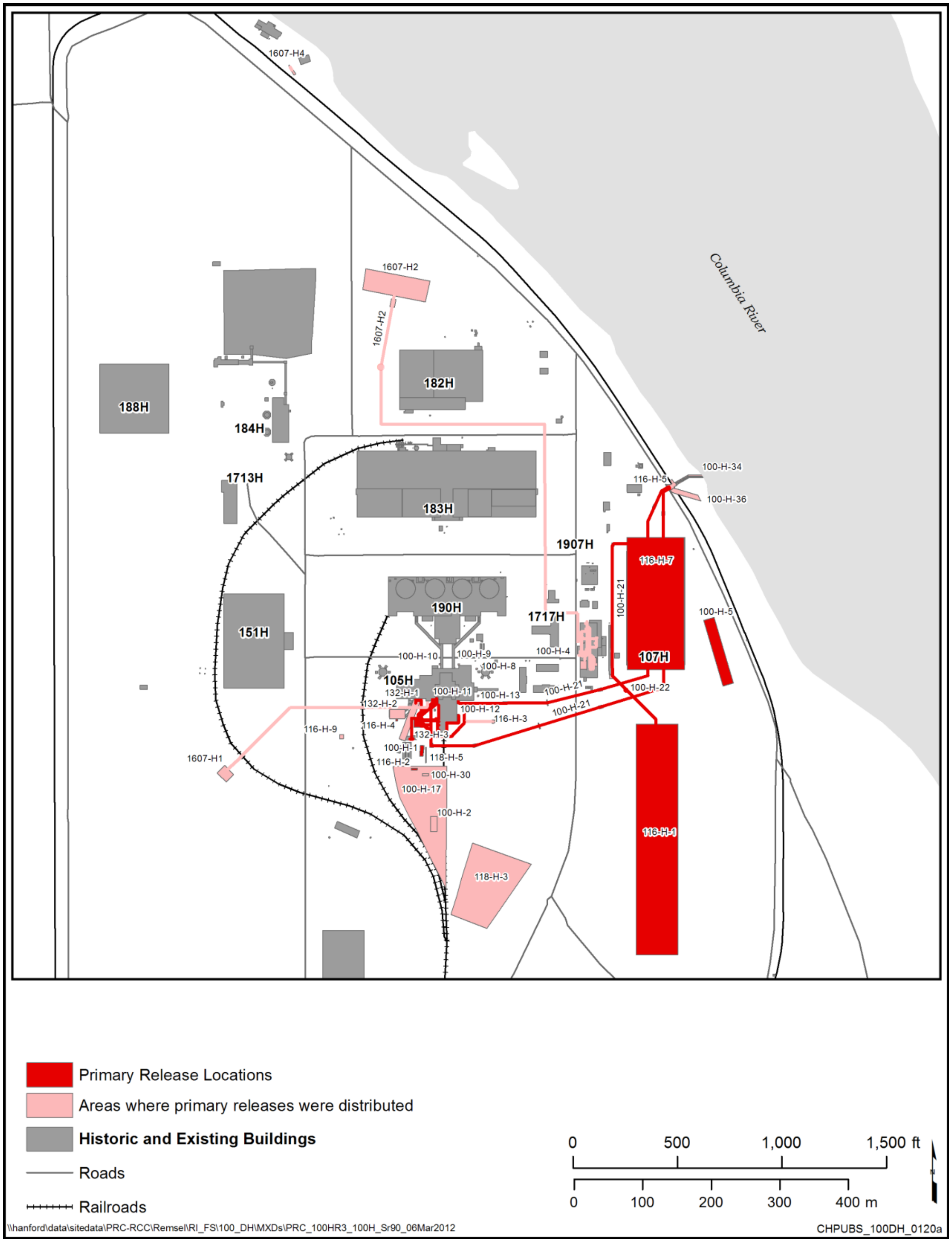

Figure 1-17. 100-H Strontium-90 Potential Sources

The miscellaneous cribs and trenches designation includes facilities (except 107 Liquid Waste Disposal Trenches) within 60 m (200 ft) of the reactor buildings that were used for disposal of liquid waste resulting from fuel failures, decontamination activities, and liquid and sludge from the irradiated fuel storage basins (*Radiological Characterization of the Retired 100 Areas* [UNI-946]). The principal radionuclides associated with these facilities include cobalt-60, cesium-137, strontium-90, europium-152, europium-154, europium-155, carbon-14, and tritium. The 117 Cribs at the D, DR, and H Reactors received low-activity radioactive condensate and water seal water drainage from 117 Building seal pits. The 108 Cribs (116-D-3 and 116-D-4) were underground French drains covered with approximately 2.5 m (8 ft) of soil that received contaminated liquid effluents from the 108-D Building, which housed the 100-D main maintenance shop. The liquid waste included contaminated water, decontamination solutions, solvents, and low-level fission products (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]). The 116-D-3 Crib also received effluent from a cask decontamination pad at the 108-D Building (*Radiological Characterization of the Retired 100 Areas* [UNI-946]).

Decontamination Solutions. Decontamination solutions were used routinely to clean facility equipment and surfaces at 108-D Building, at the reactor fuel slug decontamination facilities decontamination stations in 100-D, and at the H Reactor fuel slug decontamination facility wash pad next to the 105-H Fuel Storage Basin. Known decontamination solutions included chromic, citric, oxalic, nitric, sulfamic, and sulfuric acids (neutralized with sodium carbonate before disposal), and sodium fluoride. Other chemicals, including organic solvents, were used in some decontamination processes at the D and H Reactors at various times and locations (*Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford: Volume 2 – Engineered-Facility Sites (HISS Data Base)* [PNL-6456]; *100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]).

Decontamination solutions contained both radionuclide and chemical contaminants and were generally disposed of in cribs, trenches, or French drains near the buildings in which they were used. Occasionally, decontamination solutions were routed to the downstream process sewer that drained to the 1608 Waste Water Pump House (lift station); the decontamination solutions were combined with the cooling water before being discharged to the river via the retention basins. The 105-DR and 105-H facilities also had process drains to an emergency process sewer that drained to the 1907 Outfall. The process sewer to the 1907 Outfall also received waste from the 183 Water Treatment Plant. The Cr(VI) concentrations in these solutions and volumes discharged to cribs and drains are not known. Near the 108-D Building, decontamination solutions were discharged into two small cribs, 116-D-3 (1951 to 1967) and 116-D-4 (1956 to 1967) (*Technical Activities Report Heat, Water, and Mechanical Studies* [HW-22346]). Laboratory solutions derived from corrosion tests also included Cr(VI) and were disposed of in the 116-D-4 Crib.

Burial Grounds. Burial grounds were used for the disposal of solid waste. The primary radionuclides at these locations were cobalt-60 and europium-152, although europium-154, europium-155, cesium-134, cesium-137, strontium-90, and nickel-63 are present (*Radiological Characterization of the Retired 100 Areas* [UNI-946]). Radioactive solid waste consisted of reactor components, contaminated equipment, tools, air filters, and miscellaneous contaminated items. This waste was primarily disposed of in the 118-D-1, 118-D-2, 118-D-3, 118-D-5, 118-H-1, and 118-H-3 Burial Grounds.

Other radioactive solid waste buried "in place" (that is, not at burial grounds) at 100-D/H included building foundations, belowgrade concrete structures, and other materials from demolished buildings. Starting in the 1970s, most 100 Area solid waste was transferred to the 200 Area burial grounds (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]).

Air Emissions. A carbon dioxide and helium gas atmosphere was maintained around the reactor cores. Facilities supporting air treatment and air handling processes included the 115 and 117 Buildings, the

116 Stacks, and belowgrade tunnels. The reactor buildings were connected to the 115 and 117 Buildings via belowgrade concrete tunnels and ventilation ductwork.

Reactor and support facility ventilation systems first provided fresh air to staff areas, then to zones of increasing contamination, and finally to exhaust stacks. As the air passed through the reactor areas, it became contaminated with carbon-14, iodine-129, and tritium from radioactive gases, contaminated water vapor, and airborne particles. Originally, contaminated ventilation air was released directly to the atmosphere via 61 m (200 ft) tall concrete stacks (the 116 Stacks). However, air filtration systems were installed in 1960 to minimize the release of radionuclides. Two types of filter banks were used: a high efficiency particulate absolute bank and a halogen (activated charcoal) bank (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]). Sections of the 115 and 117 Buildings and their associated tunnels and ductwork were contaminated with cobalt-60, cesium-134, cesium-137, carbon-14, tritium, europium-152, europium-154, europium-155, iodine-129, and strontium-90.

1.2.2.7 Nonradioactive Waste

The types of nonradioactive waste generated at 100-D/H, that had the potential to contribute to soil and groundwater contamination included coal-fired powerhouse waste, septic system waste, a variety of other liquid wastes, and solid waste.

Hydroelectric power and coal were used as sources of energy for the Hanford Site. The D, DR, and H Reactors themselves did not generate electricity. Anthracite coal was stored in coal pits. Ash slurry (water based) from the coal fired 184-D and 184-H Power Houses was transported by pipeline to the 126-D-1 and 126-H-1 Ash Pits (Figure 1-18). Leakage in the pipeline and seepage in the ash pits were potential liquid contamination sources (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]).

Sanitary liquid waste was routed by sewer lines to septic systems. Five septic systems were in 100-D and four in 100-H. There are no records of radiological waste being disposed of to these systems; however, detergents, cleaning compounds, and solvents may have been disposed of that contributed to local nitrate contamination in the vadose zone and groundwater. In addition, fertilizer use on pre-Hanford Site agricultural lands likely contributed to local 100-D/H nitrate contamination. The nitrate plumes are presented on Figures 1-19 and 1-20. The facilities and pre-Hanford Site agricultural lands where nitrate was known to be present at 100-D and 100-H, based on previous historical information, are also presented on Figures 1-19 and 1-20.

Additional nonradioactive liquid waste, including hazardous waste and hazardous substances, were used at various areas and discharged to liquid waste sites (*100-D Area Technical Baseline Report* [WHC-SD-EN-TI-181]; *100-H Area Technical Baseline Report* [BHI-00127]). The areas where liquid waste was handled and disposed of included the following:

- Oil containing polychlorinated biphenyls (PCBs) in electrical transformers and hydraulic machinery
- Boiler water treatment chemicals for the 184-D and 184-H Power Houses (for example, sodium sulfate, tri-sodium phosphate, and chromates) that ended up in boiler sludge (for which disposal methods are not known)
- Zeolite water softener regeneration solutions containing salt were disposed of to the upstream process sewer from the 184-D and 184-H Power Houses

- Fuel oil and diesel stored in underground and aboveground tanks just west of the 184-DR Steam Generating Building, at the confluence of the railroad tracks north of the 184-D Power House, and at 184-H located between 105-H and 190-H (waste sites 100-H-48 and 100-H-52)
- Gasoline and batteries for emergency electrical power (gasoline was stored in an aboveground tank at the rear of the 1621-D Facility)
- Oils, paints, and solvents used and stored in the 1714-D, 1715-D, 1716-D, 1717-D, 1722-D, 1715-H, 1716-H, 1717-H, and 1722-H Buildings
- Fluids from automotive repair and service performed at the 1716-D and 1716-H Buildings
- Additional wastewater generated from various cleaning processes (for which disposal locations are unknown)

Figure 1-18. 184-D Power House with Coal Pit (above) and Ash Pit (to the right) in 1944

Nonradioactive solid waste included paper, trash, metal pieces, and plastic parts. Some combustible waste was disposed of at the 128-D-2, 628-3, and 128-H-1 Burn Pits. Other solid waste consisted of relatively uncontaminated concrete, metal parts, and other materials from decontamination and demolition activities.

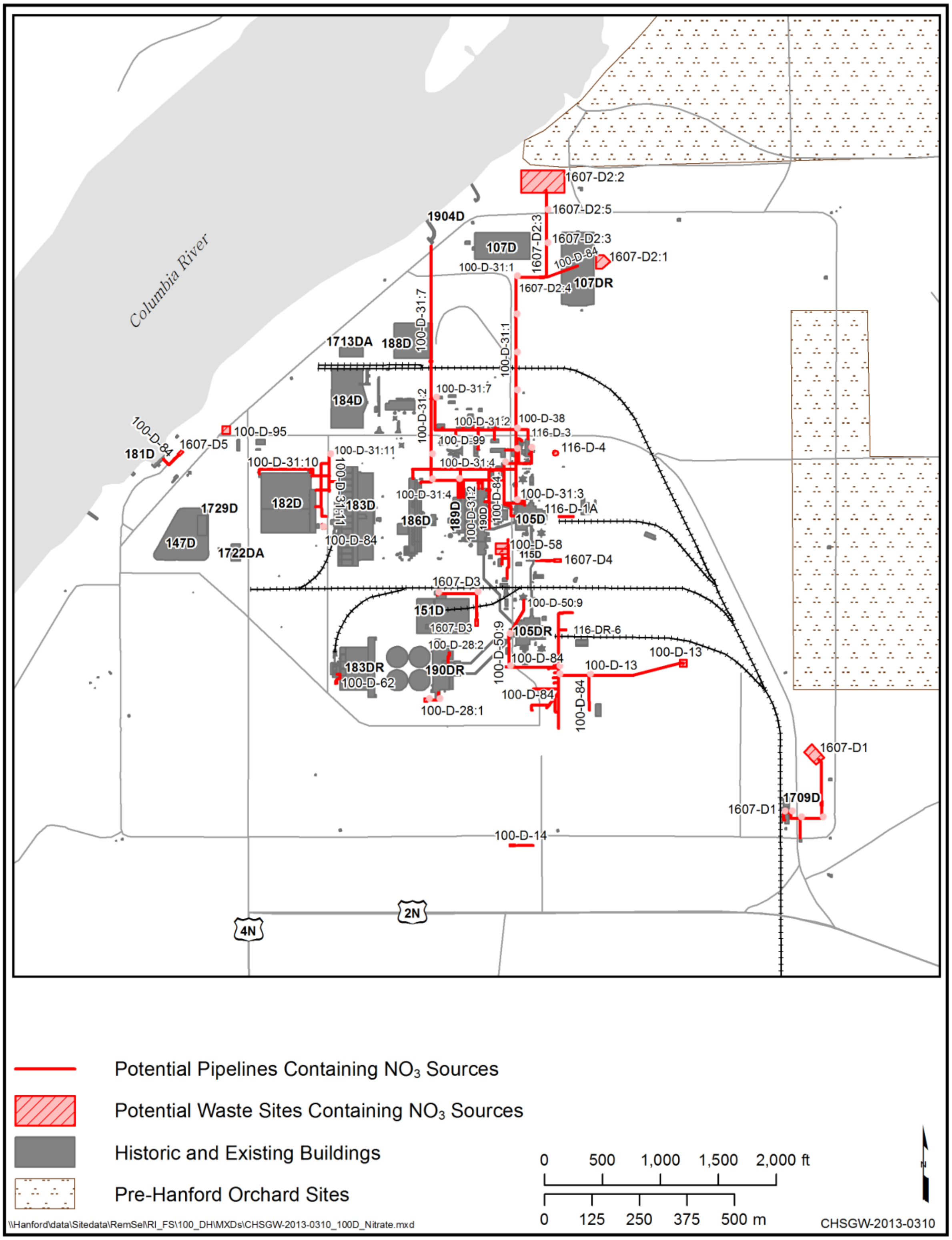

Figure 1-19. 100-D/DR Nitrate Potential Sources

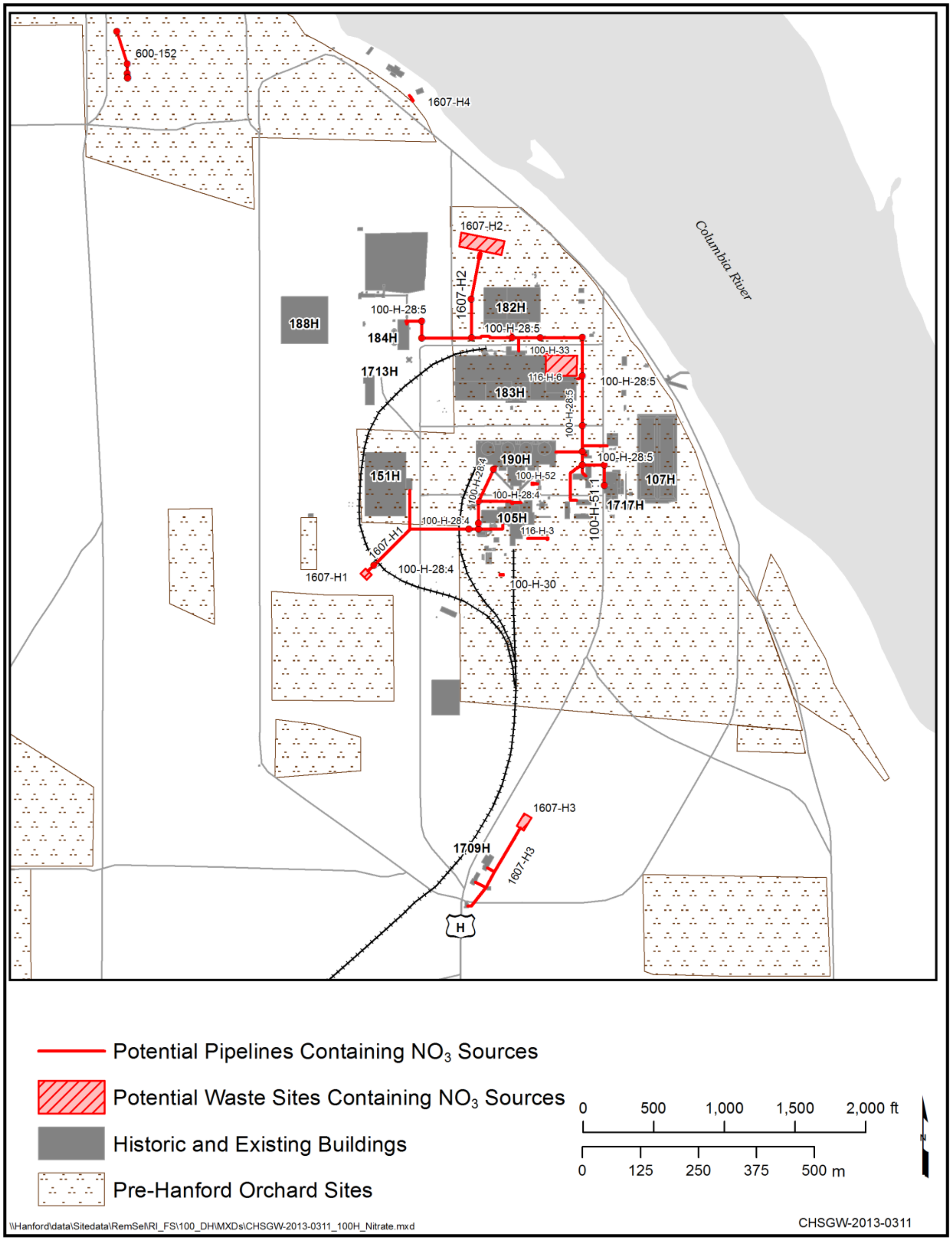

Figure 1-20. 100-H Nitrate Potential Sources

1.2.3 Previous and Ongoing Investigations and Remediation

This subsection summarizes the significant investigation and remediation activities for facilities, waste sites, and groundwater at 100-D/H. Since the beginning of reactor operations, investigations were conducted to determine impacts to the environment, including the Columbia River. With the issuance of the TPA (Ecology et al., 1989a), investigation activities transitioned to CERCLA cleanup activities within the River Corridor including 100-D/H. Investigations and remediation activities were carried out pursuant to various remedial and removal action decision documents for facilities, waste sites, and groundwater.

The relevant data and conclusions from investigations and remediation activities (see Appendix B) provide supporting information that is analyzed and evaluated in this RI/FS. The following are examples of the various data sets used to develop this RI/FS:

- Vadose zone contaminants
- Groundwater contaminants
- Geologic contact information, fate and transport parameters (e.g., 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)

Characterization of the vadose zone and associated waste sites has been an important consideration in Hanford plant operations since the 1940s. Early characterization efforts combined well drilling and geophysical logging to evaluate rates of contaminant migration in the vadose zone and in the aquifer. Little attention was focused on nonradionuclides.

Radiological Characterization of the Retired 100 Areas (UNI-946) presents the results of vadose zone investigations in 1975 at solid and liquid waste sites. Soil samples were collected and analyzed mainly to determine the inventory of radionuclides in retention basins and in the vadose zone. In general, up to 70 percent of the radionuclide inventory was determined to be within the retention basins.

Analytical data used in this RI/FS (provided in Appendix D) include the data reduction protocols and QA reports. Summaries of facility demolition activities, vadose zone investigation and remedial activities, groundwater investigation and remedial activities, and previous risk assessments are provided below.

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

Table 1-2. Summary of Decision Documents for 100-D/H

Decision Document	Summary
Reactors	
Action Memorandum: USDOE Hanford 100 Area National Priorities List, 105-F and 105-DR Reactor Buildings and Ancillary Facilities, Hanford Site, Benton County, Washington (Wagoner et al., 1998), July	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 ISS enclosure over reactor blocks.
Action Memorandum: USDOE Hanford 100 Area National Priorities List, 105-D and 105-H Reactor Facilities and Ancillary Facilities, Hanford Site, Benton County, Washington (Wilson and Klein, 2000), December	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 ISS enclosure over reactor blocks.
Source Operable Units	
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/ROD/R10-95/126), September 1995	Sets forth two approaches to remediation: • **Observational approach**—relies on historical information and LFIs. • **Plug-in approach**—allows for selection and application of remedial actions at similar sites. Selected remedial actions include the following: removal of contaminated soil, structures, and debris using the observational approach; treatment by thermal desorption or soil washing; disposal at the ERDF; and backfill followed by revegetation.
Record of Decision for the 100-IU-1, 100-IU-3, 100-IU-4, and 100-IU-5 Operable Units Remedial Action, Hanford Site, Benton County, Washington (EPA/ROD/R10-96/151), February 1996	This ROD addressed a waste site in the Horn area (identified as 100-IU-4), which was a sodium dichromate barrel landfill. The ROD said no further action was needed following RTD to residential cleanup standards.
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/AMD/R10-97/044), April 1997	Addition of 34 waste sites throughout 100-BC, 100-D, 100-F, 100-H, and 100-K to previous ROD; termination of the soil-washing step for volume reduction; and emphasis on revegetation of remediated waste sites.
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/ROD/R10-99/039), July 1999	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 105-B, 105-D, 105-H, 105-KE, and 105-KW Reactor Buildings consistent with previous CERCLA disposal for areas associated with the 105-C, 105-F, and 105-DR Reactor Buildings.
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 (EPA/ROD/R10-00/121), September 2000	Selected remedies include the following: remove contaminated soil, structures, and associated debris; treat this waste 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-D/H

Decision Document	Summary
Explanation of Significant Differences for the 100 Area Remaining Sites Interim Remedial Action Record of Decision (EPA et al., 2004), April	Addition of 28 waste sites. Addition of "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). Revise institutional controls in accordance with *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41).
Groundwater OUs	
Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington (EPA/ROD/R10-96/134), March 1996	Initiates the use of ion exchange technology to remove Cr(VI) from groundwater using a system of extraction and injection wells.
Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington (EPA/AMD/R10-00/122), October 1999	Alters the selected remedial action by deploying a new technology (in situ oxidation reduction [redox] manipulation [ISRM]) for remediation of the Cr(VI) plume in 100-D.
Explanation of Significant Difference for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington (EPA/ESD/R10-03/606), April 2003	Revises the project schedule and cost estimate associated with the ISRM barrier. Explains that addition of an evaporation pond also invokes an additional ARAR.
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 (EPA et al., 2009)	The cost and schedule for the remedy are revised to reflect the expanded DX and HX groundwater pump-and-treat systems. A total of 15 known waste sites and 47 candidate waste sites are added to the scope. The explanation of significant difference also provides for the reinjection of treated water to downgradient locations to contain plumes.

Note: Chapter 11 provides complete reference citations.

ARAR = applicable or relevant and appropriate requirement
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
ERDF = environmental restoration disposal facility
ISS = interim safe storage
LFI = limited field investigation
ROD = record of decision
RTD = removal, treatment, and disposal

1.2.3.1 Previous Facility Demolition Activities

Since its original construction, 100-D/H has included 128 facilities, including 3 reactors, storage buildings, offices, retention basins, maintenance shops, process plants, an electric substation, storage tanks, pump stations, and outfall structures. Until the structures over a source site have been removed, no soil remediation can be completed. Therefore, the facilities (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. In addition, facility decontamination, demolition and disposal removes contaminants the could potentially be released to the environment as many facilities contain contaminants of concern.

The facilities at 100-D and 100-H were the first to be declared excess after their reactors were shut down starting in 1964 (Figure 1-21). Follow-on housekeeping and decommissioning activities began in 100-D and 100-H as part of a Sitewide initiative in 1973, after deactivation of the reactors. This activity progressed as resources allowed, from 1974 through 1990, with buildings demolished, surplus equipment salvaged or redeployed, and active operations maintained at a minimal level.

D, DR, and H Reactors. As stated in the 1993 Reactor Decommissioning 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 (Ecology et al., 1989a). Since the Reactor Decommissioning ROD (58 FR 48509) in 1993, documentation has been prepared and implemented under CERCLA placing six of the eight surplus reactors (C, D, DR, F, H, and K) into ISS designed to prevent deterioration and release of contamination from the reactors. ISS for the three D/H reactors was complete in 2005 to ensure the safety of the reactors for up to 75 years. Figure 1-22 shows the D and DR Reactors in their ISS configuration. Figure 1-23 shows H Reactor in its ISS configuration.

Figure 1-21. D and DR Reactors following Shutdown, before ISS (2000)

Figure 1-22. D and DR Reactors following ISS (circa 2005)

Figure 1-23. H Reactor after ISS (2005)

DOE decided to broaden the decommissioning approach for these eight surplus reactors, including the D, DR, and H Reactors, retaining the deferred one-piece removal option, as selected in the Reactor Decommissioning ROD (58 FR 48509), and considered an immediate dismantlement option in a Supplemental Analysis. "Amended Record of Decision for the Decommissioning of Eight Surplus Reactors at the Hanford Site, Richland, WA" (75 FR 43158), issued on July 23, 2010, confirms the one piece removal alternative and includes the additional alternative of an immediate dismantlement. The D, DR, and H Reactors removal will be conducted as CERCLA non-time-critical removal actions.

DOE evaluated the coordination of decommissioning actions with the completion of interim field remediation for 100-D/H. Based on October 2012 field remediation information, all waste sites in the immediate vicinity of the reactors are interim closed-out according to the Interim Action ROD. Until reactor removal is complete, DOE will continue to conduct routine reactor maintenance, surveillance, and radiological monitoring to ensure continued HHE protection during the ISS period. It is not anticipated that remedial action will be needed for contaminant releases from the ISS reactor structures before their removal.

Fuel Storage Basins and Facilities. Upon closure of the reactors, the 105-D and 105-DR Fuel Storage Basin shielding water elevations were lowered; and the basins were cleaned out in 1984. Miscellaneous basin equipment and sludge were packaged and disposed in the 200 Area burial grounds (*Fuel Storage Basins Cleanup and Stabilization Project Report* [UNI-3958]). The remaining shielding water was processed and released to two ponds (116-D-10 and 116-D-11) that were excavated specifically to receive the treated shielding water, and an asphalt emulsion was applied to the basin walls and floors in an effort to fix any remaining contamination. The 105-H Fuel Storage Basin was drained to within 1.2 m (4 ft) of the basin bottom and was backfilled with soil, burying the sludge and miscellaneous equipment that remained in the basin (*Radiological Characterization of the Retired 100 Areas* [UNI-946]).

The contaminants in the discharged water included water treatment chemicals and radioactive isotopes dissolved in the cooling water from breached fuel cladding. Primary contaminants in fuel storage basin sludge samples included cesium-137, nickel-63, cobalt-60, and europium-152, -154, and -155, although plutonium-238, plutonium-239/240, tritium, strontium-90, and uranium were also present. Primary contaminants in fuel storage basin water samples were cesium-137 and strontium-90, although plutonium-238, plutonium-239/240, europium-155, and uranium were also present (*Radiological Characterization of the Retired 100 Areas* [UNI-946]).

Remaining building and facility waste exists as contamination in demolished ductwork, concrete, paint, equipment, insulation, and remaining process piping and tanks. Of the 128 facilities, 115 facilities have been demolished or removed from 100-D/H. Table 1-3 summarizes the status of the 100-D/H facilities.

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. Groundwater monitoring began 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 site designs (116-KE-2 and possibly 116-KE-3 and 116-KW-2) sometimes included wells where geophysical logging could assess radionuclide movement. Continued waste site use depended on the vertical migration of contaminants, and sites were shut down when contamination reached certain predetermined concentrations in groundwater at these wells. As such, hydrologic and geochemical processes in the vadose zone were of interest, but were not well understood.

Table 1-3. Summary of Facility Status

Area	Total Number of Facilities	Demolished[a]	Removed[a]	Active[a]	Inactive[a]
100-D	82	63	10	5[b]	4[c]
100-H	46	39	3	3[d]	1[e]
100-D/H	128	102	13	8	5

a. Status:

Active: Facility is occupied and in use (supports Hanford Site missions).

Inactive: Facility is no longer in use and is waiting decommissioning and demolition.

Demolished: Facility has been removed to grade (slab or foundation remains).

Removed: Facility foundation has been removed and any substructure is 0.3 to 0.9 m (1 to 3 ft) below grade.

b. Active facilities in 100-D include the 151-D Primary Substation Switch House, the 181-D River Pump House, the 182-D Reservoir (which supply water to the 200 Area), the 1601-D Transfer Building, and the 6508-S3 Emergency Siren.

c. Inactive facilities in 100-D include the 105-D/DR Safe Storage Enclosures, the 183-D Water Treatment Plant Power Operation Facility, and the 152-D1 Electrical Substation.

d. 100-H active facilities include the 1601-H Transfer Building, the 1713-H Warehouse, and the 6508-S2 Emergency Siren.

e. 100-H inactive facility is the 105-H Safe Storage Enclosure.

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* (PNL-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]). Recharge (sometimes called deep percolation) measurements using lysimetry and other techniques at the Hanford Site have been extensive over the past two decades (*Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates* [PNNL-17841]). Recharge rates applicable to different soil and surface cover conditions at the Hanford Site are listed in *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection* (DOE/RL-2011-50).

During the construction, operations, and remediation years, the native vegetation and topsoil was scraped off a large portion of 100-D/H. Based on results from "Variations in Recharge at the Hanford Site" (Gee et al., 1992), this condition affected a significant change in vadose zone dynamics with a substantial increase in vadose zone water flux since construction. In addition, water was added to historical waste site locations for dust control during remediation activities. Once remediation is complete and native vegetation is reestablished, recharge will decline to pre-construction rates. Recharge rates are discussed in Chapter 5.

Vadose zone contaminant (radiological and nonradiological) characterization studies started at 100-D/H in 1975 to evaluate contaminant inventories, concentrations, and distribution at inactive solid and liquid waste sites, reactors, and associated facilities. In the early 1990s, LFIs assessed the nature and extent of effluent discharges to the vadose zone at high-priority waste sites. Several column leaching studies assessed Cr(VI) transport from contaminated vadose zone material to groundwater. Because of the presence of Cr(VI) in the groundwater, Cr(VI) source identification investigations were performed at 100-D/H.

Key documents applicable to 100-D/H waste site sources (including facilities and groundwater for completeness) are summarized in Table 1-2. Table B-1 (located in Appendix B) provides a brief scope of work, conclusions and implications, and links to the references for key investigations and remediation activities.

Waste Site Remediation. Remediation and characterization of the waste sites in 100 D and 100 H began in 1996 under the authority provided by the interim action RODs and RCRA closure plans, and continues to the present. Remediation consists mainly of (1) RTD of contaminated soil, debris, and waste material; and (2) verification sampling and computer modeling (as needed) to determine whether direct exposure and groundwater protection cleanup requirements have been achieved. After remediation, the excavations are backfilled with approved material, and native shrub steppe flora are planted. Remediation follows the observational approach, including use of radiological field screening data, in-process samples, and direct visual observation. *Remedial Design Report/Remedial Action Work Plan for the 100 Area* (DOE/RL-96-17), called the RDR/RAWP, details the design and implementation of interim remedial actions. The RDR/RAWP (DOE/RL-96-17), Table 2-1 provides interim soil clean-up values that are based on WAC 173-340, “Model Toxics Control Act—Cleanup” (MTCA) 1996. Final direct contact PRGs for human health exposure are based on MTCA (WAC 173-340) 2007 and are summarized in Chapter 8, Table 8-2. Interim cleanup requirements, as described in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) were achieved at all interim closed out and no action waste sites. As indicated in Table 1-4, closed out sites meet applicable 1996 MTCA (WAC 173-340) cleanup standards.

Table 1-4. Summary of Waste Site Status (as of November 2012)

OU	Number of Sites[a]	Closed Out[b]	Interim Closed Out[c]	No Action[d]	Not Accepted[e]	Rejected[f]	Accepted[g]
100-DR-1	154	1	72	19	6	10	46
100-DR-2	61	9	27	3	5	3	14
Total 100-D	**215**	**10**	**99**	**22**	**11**	**13**	**60**
100-HR-1	81	1	32	14	5	3	26
100-HR-2	47	0	13	2	3	4	25
Total 100-H	**128**	**1**	**45**	**16**	**8**	**7**	**51**
Total in 100-D/H	**343**	**11**	**144**	**38**	**19**	**20**	**111**

Notes: Additional information is provided in Appendix E.

a. Total number of sites.

b. **Closed Out:** A historical reclassification status indicating that because of actions taken, a waste management unit meets applicable cleanup standards or closure requirements. This reclassification status is no longer used. An “Interim” reclassification status is used instead.

c. **Interim Closed Out:** A reclassification status indicating that because of 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.

d. **No Action:** A reclassification status indicating that 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 was made that a WIDS site is not a waste management unit and is not within the scope of the *Hanford Federal Facility Agreement and Consent Order Action Plan* (Ecology et al., 1989b), Section 3.1. This classification requires lead regulatory agency approval.

Table 1-4. Summary of Waste Site Status (as of November 2012)

OU	Number of Sites[a]	Closed Out[b]	Interim Closed Out[c]	No Action[d]	Not Accepted[e]	Rejected[f]	Accepted[g]

f. **Rejected:** A reclassification status indicating a waste site does not require remediation under RCRA Corrective Action, CERCLA, or other cleanup standards based on qualitative information such as a review of historical records, photographs, drawings, walkdowns, 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 *Hanford Federal Facility Agreement and Consent Order Action Plan* (Ecology et al., 1989b), Section 3.1.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980

RCRA = Resource Conservation and Recovery Act of 1976

ROD = record of decision

WIDS = waste information data system

There are 215 waste sites in the 100-DR-1 and 100-DR-2 OUs, and 128 waste sites in the 100-HR-1 and 100-HR-2 OUs. Of the 343 sites identified in 100-D/H, 232 have been closed out or interim closed, or given no action, not accepted, or rejected status as shown on Table 1-4. These status categories generally indicate that a site meets the remedial action goals of the interim action RODs. A total of 111 accepted waste sites remain in 100-D/H according to the interim action in 100-D/H as of November 2012.

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 confirming the attainment of interim remedial action goals. This documentation usually includes a description of the interim remedial action conducted, sampling results, disposal information, and a chronology of events.

Tables 1-5 through 1-8 summarize the reclassification of the source OU waste sites and identify Cr(VI) waste sites. Waste site locations are presented in Appendix A. There are two active (operational) sites in 100-D/H. The 100-D-58 Septic System is an accepted waste site, consisting of the modern septic system that supports interim remedial action field facilities, while 100-D-55 (Gravel Pit 21) is classified as a not accepted site.

Table 1-5. 100-DR-1 Operable Unit Waste Sites (as of November 2012)

Reclassification Status	Waste Sites	Total
Closed Out	120-D-1[a]	1
Interim Closed Out	100-D-1, 100-D-2, 100-D-4,[b] 100-D-5, 100-D-6, 100-D-7,[b] 100-D-9, 100-D-18,[b] 100-D-19,[b] 100-D-20,[b] 100-D-21,[b] 100-D-22,[b] 100-D-25, 100-D-29, 100-D-31:1, 100-D-31:2, 100-D-31:3, 100-D-31:4, 100-D-31:5, 100-D-31:6, 100-D-31:7, 100-D-31:8, 100-D-31:9, 100-D-31:10, 100-D-32, [b] 100-D-42, 100-D-45, 100-D-48:1,[b] 100-D-48:2,[b] 100-D-48:3,[b] 100-D-48:4, 100-D-49:1,[b] 100-D-49:2,[b] 100-D-49:3,[b] 100-D-49:4, 100-D-52, 100-D-56:1,[b] 100-D-56:2,[b] 100-D-61, 116-D-1A,[b] 116-D-1B,[b] 116-D-2,[b] 116-D-4,[b] 116-D-5,[b] 116-D-6,[b] 116-D-7,[b] 116-D-9,[b] 116-D-10,[b] 116-DR-1&2,[b] 116-DR-5,[b] 116-DR-9,[b] 118-D-6:2, 118-D-6:3, 118-D-6:4, 120-D-2,[b] 126-D-2, 128-D-2, 130-D-1, 132-D-1, 132-D-2, 132-D-3,[b] 132-D-4, 628-3, 1607-D2:1, 1607-D2:2, 1607-D2:3, 1607-D2:4,1607-D4, 1607-D5, UPR-100-D-2,[b] UPR-100-D-3,[b] UPR-100-D-4[b]	72

Table 1-5. 100-DR-1 Operable Unit Waste Sites (as of November 2012)

Reclassification Status	Waste Sites	Total
No Action	100-D-3, 100-D-24, 100-D-50:5, 100-D-50:10, 100-D-70, 100-D-74, 100-D-75:3, 100-D-80:1, 100-D-82, 100-D-83:4, 100-D-84:1, 100-D-85:1, 100-D-86:2, 100-D-87, 100-D-88, 100-D-90, 116-D-3,[b] UPR-100-D-1, UPR-100-D-5	19
Not Accepted	100-D-10, 100-D-26, 100-D-34, 100-D-38, 100-D-57, 100-D-91	6
Rejected	100-D-33, 100-D-35, 100-D-41, 100-D-59, 100-D-79, 100-D-92, 100-D-93, 100-D-95, 126-D-1,[b] 126-D-3	10
Accepted	100-D-8, 100-D-30,[b] 100-D-31:11, 100-D-31:12, 100-D-50:1, 100-D-50:2, 100-D-50:3, 100-D-50:4, 100-D-50:6, 100-D-50:7, 100-D-50:8, 100-D-50:9, 100-D-60, 100-D-63, 100-D-65,[b] 100-D-66,[b] 100-D-67, 100-D-69, 100-D-71, 100-D-72, 100-D-73,[b] 100-D-75:1, 100-D-75:2, 100-D-76, 100-D-80:2, 100-D-81, 100-D-83:1, 100-D-83:2, 100-D-83:3, 100-D-83:5, 100-D-84:2, 100-D-85:2, 100-D-86:1, 100-D-86:3, 100-D-96, 100-D-97, 100-D-98:1, 100-D-98:2, 100-D-99, 100-D-101, 100-D-102, 100-D-104,[b] 100-D-105, 100-D-107, 118-D-6:1,[b] 1607-D2:5	46

a. The 120-D-1 (100-D Ponds) is a Resource Conservation and Recovery Act Temporary Storage and Disposal unit that has been closed under RCRA.

b. Site associated with sodium dichromate usage.

Waste Site Consideration in the RI/FS. All 100-D/H waste sites were evaluated in this RI/FS to determine if they are protective of HHE.

Table 1-6. 100-DR-2 Operable Unit Waste Sites (as of November 2012)

Reclassification Status	Waste Sites	Total
Closed Out	100-D-27, 122-DR-1:1, 122-DR-1:2, 122-DR-1:3, 122-DR-1:4, 122-DR-1:5, 122-DR-1:6, 122-DR-1:7,[a] 1607-D3	9
Interim Closed Out	100-D-12,[b] 100-D-13, 100-D-15, 100-D-23, 100-D-28:1, 100-D-43, 100-D-46,[b] 100-D-47, 100-D-53, 100-D-54, 100-D-64, 116-D-8, 116-DR-4,[b] 116-DR-6,[b] 116-DR-7, 118-D-1, 118-D-4, 118-D-5, 118-DR-1, 118-DR-2:2,[b] 116-DR-8,[b] 116-DR-10,[b] 126-DR-1, 132-DR-1,[b] 132-DR-2, 1607-D1, 600-30	27
No Action	100-D-68,[b] 100-D-94, 128-D-1	3
Not Accepted	100-D-11, 100-D-36, 100-D-37, 100-D-55,100-D-89	5
Rejected	100-D-17, 100-D-28.2, 100-D-40	3
Accepted	100-D-14, 100-D-58, 100-D-62, 100-D-77,[b] 100-D-78, 100-D-103, 100-D-106, 118-D-2:1, 118-D-2:2,[b] 118-D-3:1,[b] 118-D-3:2 116-DR-3, 118-DR-2:1,[b] 100-D-100[b]	14

a. The 122-DR-1 (105-DR Sodium Fire Facility) is a Resource Conservation and Recovery Act Temporary Storage and Disposal unit that has been closed under RCRA.

b. Site associated with sodium dichromate usage.

Table 1-7. 100-HR-1 Operable Unit Waste Sites (as of November 2012)

Reclassification Status	Waste Sites	Total
Closed Out	116-H-6[a,b]	1
Interim Closed Out	100-H-1,[b] 100-H-3, 100-H-4, 100-H-5,[b] 100-H-9, 100-H-10, 100-H-11, 100-H-12, 100-H-13, 100-H-14,[b] 100-H-17,[b] 100-H-21,[b] 100-H-22,[b] 100-H-24, 100-H-30,[b] 100-H-31, 100-H-41, 116-H-1,[b] 116-H-2,[b] 116-H-3,[b] 116-H-5,[b] 116-H-7,[b] 116-H-9,[b] 118-H-6:2, 118-H-6:3, 118-H-6:4, 118-H-6:5,[b] 118-H-6:6, 132-H-1, 1607-H2, 1607-H3, 1607-H4	32
No Action	100-H-7, 100-H-8, 100-H-28:1, 100-H-28:6, 100-H-28:8, 100-H-33, 100-H-35, 100-H-40, 100-H-45, 100-H-49:2, 100-H-50, 100-H-51:5, 100-H-53, 100-H-54:4	14
Not Accepted	100-H-6, 100-H-18, 100-H-19, 100-H-20, 100-H-26	5
Rejected	100-H-39, 100-H-47, 100-H-49:3	3
Accepted	100-H-28:2, 100-H-28:3, 100-H-28:4, 100-H-28:5, 100-H-28:7, 100-H-34,[b] 100-H-36, 100-H-42, 100-H-43, 100-H-44, 100-H-46, 100-H-48, 100-H-49:1, 100-H-51:1, 100-H-51:2, 100-H-51:3, 100-H-52, 100-H-51:6, 100-H-54, 100-H-56, 100-H-57, 100-H-59, 116-H-4,[b] 118-H-6:1,[b] 126-H-2, 132-H-3	26

a. 116-H-6 (183-H Solar Evaporation Basins) is a Resource Conservation and Recovery Act Temporary Storage and Disposal unit that has been closed under RCRA but is in modified post-closure care.

b. Site associated with sodium dichromate usage.

Table 1-8. 100-HR-2 Operable Unit Waste Sites (as of November 2012)

Reclassification Status	Waste Sites	Total
Closed Out	None	0
Interim Closed Out	132-H-2, 100-H-2,* 100-H-37, 118-H-1:1, 118-H-1:2, 118-H-2, 118-H-3, 118-H-4, 118-H-5, 128-H-1, 1607-H1, 600-151, 600-152	13
No Action	128-H-2, 128-H-3	2
Not Accepted	100-H-15, 100-H-27, 600-258	3
Rejected	100-H-16, 100-H-32, 126-H-1, 100-H-55	4
Accepted	100-H-38, 100-H-58, 600-380, 600-381, 600-382:1, 600-382:2, 600-382:3, 600-382:4, 600-382:5, 600-383:1, 600-383:2, 600-383:3, 600-383:4, 600-383:5, 600-383:6, 600-383:7, 600-383:8, 600-383:9, 600-383:10, 600-384:1, 600-384:2, 600-384:3, 600-384:4, 600-384:5, 600-385	25

* Site associated with sodium dichromate usage.

The Hanford WIDS summarizes information about known and suspected areas of contamination. These areas are defined as locations that may require action to mitigate a potential environmental impact (*Tri-Party Agreement Handbook Management Procedures*, Guideline Number TPA-MP-14, "Maintenance of the Waste Information Data System (WIDS)" [RL-TPA-90-0001]). All 100-D/H waste sites were considered part of this RI/FS process to determine whether the sites are protective of human health and the environment. While the unique factors of each site were considered individually, the overall consideration of waste sites can be described generally based on the following classification/ reclassification status definitions.

- Sites with a "closed out" status were reviewed to confirm that this determination had 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, if available, is consistent with the existing documented basis for rejection or nonacceptance. Where the existing classification/reclassification was appropriate, the site was not considered further within the RI/FS process. Two rejected or not accepted sites at 100-D/H (100-D-10 and 100-D-59) were found to have information that was inconsistent with 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” reclassification status based on confirmatory or verification data are all considered within the overall RI and are quantitatively evaluated against PRGs as described in Chapters 5 through 7 to determine if further action(s) or institutional controls are needed. Sites with a no action or interim closed reclassification with a basis other than direct data (for example, historic decommissioning data) were considered on a site-by-site basis as described in Chapter 8.
- 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 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 a remedial action determination or exclusion from consideration as a formal waste site could be evaluated in order to make this determination. These sites are referred to as “candidate sites” or “confirmatory sites” under the interim action framework. Until such time as the ROD is issued, the candidate process to add these waste sites will be retained under the interim action ROD; and these sites will continue to be dispositioned according to that process, including site-specific evaluation for protection of HHE.

RCRA Treatment, Storage, and Disposal Unit Closure. Three RCRA TSD units (183-H Solar Evaporation Basins, 100-D Ponds, and 105-DR Large Sodium Fire Facility [LSFF]) have undergone closure within 100-D/H as discussed below:

- **183-H Solar Evaporation Basin:** The 183-H Facility was constructed in 1949 and used for 100-H water treatment until mid-1960. This facility consisted of 16 concrete basins that were used in treating Columbia River water for subsequent use as reactor coolant. In 1973, four of these basins were converted for use in evaporation of other mixed waste. Approximately 1.6 million kg (3.6 million lb) of waste per year were treated by solar evaporation. The facility received routine and nonroutine waste, which consisted of spent acid etch solutions, metal constituents in the form of precipitates, and unused chemicals and spent solutions from miscellaneous processes. Most of the water treatment structures, including 12 additional adjoining basins, were demolished in 1974. The four remaining basins were inactive until July 1973, when radioactive and dangerous (mixed) waste from the 300 Area fuel fabrication facilities was shipped to the basins for storage and treatment. The last shipment of waste to the basins took place on November 8, 1985. By the fall of 1996, the basins had been completely demolished, and demolition waste was disposed of in the adjacent 183-H clear wells and at the ERDF. The site was not clean closed under RCRA because fluoride and nitrate concentrations are above the 1996 MTCA (WAC 173-340) Method B cleanup levels. Therefore, the unit was closed in place under the modified closure provisions of the RCRA Hanford permit with post-closure care. The modified closure certification was accepted by Ecology on May 13, 1997 (*183-H Solar Evaporation Basins Postclosure Plan* [DOE/RL-97-48]). Because clean closure was not achieved, dangerous waste constituents remain in the vadose zone beneath the waste site. In addition, RCRA closures do not have authority to address the cleanup of radiological contamination. As such, accepted WIDS site 100-H-33 was created to address the radiological contamination that is within the same footprint as 116-H-6.

- **100-D Ponds (120-D-1):** The 100-D Ponds were approximately 500 m (1,640 ft) northeast of D Reactor and were used from 1977 to 1994 for percolation of effluent. The ponds, which were constructed from the former 188-D Coal Ash Disposal Basin, consisted of two interconnected surface ponds. The original pond was constructed by excavating an area 9 m (30 ft) deep in the eastern half of the 188-D Basin. The site was modified in 1979 to form a two-compartment pond, one overflowing to the other. The modification resulted in a combined surface dimension of 50 by 67 m (160 by 220 ft).

  After the construction of the ponds, all process sewer liquid effluents were diverted to the ponds instead of the Columbia River. The northern pond was a percolation pond and the southern pond was a settling pond. The ponds received corrosive waste from the regeneration of ion exchange columns located in the 185-D/189-D complex. The ponds also received nonhazardous waste from the 183-D sand-filter backwash, small quantities of filtered chlorinated water from hydraulic test loops, and fuel discharge trampoline tests.

  The estimated flow rate was 170,000 L/day (45,000 gal/day). In August 1996, contaminated sediment was removed from the 100-D Ponds as part of a DOE-RL voluntary cleanup action (*100-D Ponds Closure Plan* [DOE/RL-92-71]). On August 27, 1999, Ecology accepted this TSD as clean closed.

- **105-DR Large Sodium Fire Facility (122-DR-1):** The LSFF was in the former supply and exhaust fan wing of the 105-DR Reactor Building (*105-DR Large Sodium Fire Facility Closure Plan* [DOE/RL-90-25]). The LSFF operated from 1972 to 1986 and was used to study the fire and safety aspects associated with sodium and other alkali metal fires for application to liquid metal reactors. It is estimated that 20,000 kg (44,100 lb) of sodium and other alkali metals were used at the facility for the burn tests.

  The facility closure plan divided the facility into seven areas for sampling and closure purposes. Four of the seven RCRA subunits of the LSFF (122-DR-1) were closed out under *105-DR Large Sodium Fire Facility Closure Plan* (DOE/RL-90-25). These subunits included the exhaust fan room, small fire room, large fire room, sodium handling room, and an office area (122-DR-1:1); the gravel scrubber (122-DR-1:3); the 117-DR Seal Pit Crib (122-DR-1:6); and the outdoor storage area (122-DR-1:7). Certification of closure of these LSFF TSD subunits is documented in *105-DR Large Sodium Fire Facility Soil Sampling Data Evaluation Report* (WHC-SD-EN-TI-307), and in an Ecology letter regarding closure certification for the 122-DR-1 Subsites 1, 3, 6, and 7 ("Ecology Acceptance of Closure Certification for the 105-DR Large Sodium Fire Facility (T-1-1)" [Wilson, 1996]). The 122-DR-1:6 Crib closure was based on process knowledge without further sampling. The closure only applies to use of this crib by LSFF operations. This crib and its associated influent piping are also separately identified as the 116-DR-8 and 100-D-50:8 waste sites, respectively, to address residual contamination associated with discharges to the crib.

  The LSFF Closure Plan deferred the remaining three LSFF TSD subunits (122-DR-1:2, 122-DR-1:4, and 122-DR-1:5) to the CERCLA process (TPA [Ecology et al., 1989a]). These three subunits were excavated, and remedial activities are presented in the cleanup verification package (*Cleanup Verification Package for the 105-DR Large Sodium Fire Facility (122-DR-1:2, 100-D-53/122-DR-1:4, 132-DR-2/122-DR-1:5), the 119-DR Exhaust Stack Sampling Building (100-D-64), and the 100-D-23 and 100-D-54 Dry Wells* [CVP-2003-00018]). An Ecology letter ("Ecology Acceptance of Closure Certification for the 105-DR Large Sodium Fire Facility (T-1-1)" [Wilson, 1996]) regarding clean closure certification for the 122-DR-1 Subsites 2, 4, and 5 (*Cleanup Verification Package for the 105-DR Large Sodium Fire Facility (122-DR-1:2, 100-D-53/122-DR-1:4, 132-DR-2/122-DR-1:5), the 119-DR Exhaust Stack Sampling Building (100-D-64), and the 100-D-23 and 100-D-54 Dry Wells* [CVP-2003-00018]) acknowledged receipt and accepted DOE's closure certification and professional engineer's certification of closure for *105-DR Large Sodium Fire Facility Closure Plan* (DOE/RL-90-25), dated June 3, 2004.

In total, 50 waste sites with closed out, rejected, or not accepted classification/reclassification statuses were reconsidered to ensure that each had a sufficient existing basis for these determinations. Those sites with sufficient existing bases are identified in Table 1-9 and will not be addressed further in this RI/FS. Three sites are special cases: Reactor Core Sites 118-D-6:1, 118-DR-2:1, and 118-H-6:1. These sites are discussed in this section. However, all 100-D and 100-H waste sites identified in Appendix C of *Hanford Federal Facility Agreement and Consent Order Action Plan* (Ecology et al., 1989b), hereinafter called TPA Action Plan, will be included in the ROD in order for the remedy decision to be documented, even if no further remedial activities are recommended.

Table 1-9. Sites Not Addressed Further in the RI/FS

Classification/ Reclassification Status	Waste Sites
Closed Out	100-D-27, 116-H-6, 120-D-1, 1607-D3, 122-DR-1:1, 122-DR-1:2, 122-DR-1:3, 122-DR-1:4, 122-DR-1:5, 122-DR-1:6, 122-DR-1:7
Not Accepted	100-D-11, 100-D-26, 100-D-34, 100-D-36, 100-D-37, 100-D-38, 100-D-55, 100-D-57, 100-D-89, 100-D-91, 100-H-6, 100-H-15, 100-H-18, 100-H-19, 100-H-20, 100-H-26, 100-H-27, 600-258
Rejected	100-D-17, 100-D-28:2, 100-D-33, 100-D-35, 100-D-40, 100-D-41, 100-D-79, 100-D-92, 100-D-93, 100-D-95, 126-D-1, 126-D-3, 100-H-16, 100-H-32, 100-H-39, 100-H-47, 100-H-55, 116-H-6, 126-H-1
Accepted*	100-D-58

* Indicates sites with basis for exclusion discussed in text.

Rejected and Not Accepted Waste Sites with Inadequate Existing Bases. Two sites were identified for which the existing basis warrants reconsideration.

100-D-10. The 100-D-10 site was identified to address a reported former outfall in the river embankment upstream from the 100-D-8, 1907-DR Outfall. The site was not accepted on the basis that it received only storm water drainage from the 190-DR Tank Pit. However, storm water drainage from this area was actually routed to the 100-D-50:1 Process Sewer, which discharged to the 100-D-8, 1907-DR Outfall. The 100-D-10 Outfall is visible in pre-Manhattan era aerial photographs, and there is no apparent association with later Hanford Site operations. While this may not warrant consideration of the feature as a waste site, the site should be reconsidered for accepted or not accepted status based on the correct information. For the purposes of the FS, this site will be considered as a candidate site for future evaluation under remedial actions.

100-D-59. The 100-D-59 site consists of a French drain at the former acid transfer station south of the 183-D Head House. This French drain was designed to receive any overflow from sulfuric acid transfer operations. The site was previously reclassified as rejected on the basis that any acids discharged to the drain would rapidly neutralize in alkaline soil. However, this determination was made before it was known that some sulfuric acids used at the Hanford Site were contaminated with mercury that may have accumulated significantly in soil. Because it is not known if the 100-D-59 French drain received mercury-contaminated acids, this site will be considered as a candidate site for future evaluation under remedial actions. However, it should also be noted that the 100-D-59 site is immediately adjacent to the 100-D-72 site and may be incidentally addressed by investigations or remedial activities for the latter site.

Waste Sites Requiring No Further Consideration. Waste sites requiring no further consideration are those that are or will be closed under another regulation, or need to be reclassified using the process in *Tri-Party Agreement Handbook Management Procedures*, Guideline Number TPA-MP-14, "Maintenance of the Waste Information Data System (WIDS)" (RL-TPA-90-0001). The waste sites removed from further consideration in this report are the following:

100-D-58. The 100-D-58 accepted waste site was constructed in 1998 and consists of an active modern septic system servicing 100-D area field remediation facilities. The site receives sanitary sewage from the M0-980 building and restroom trailer. The site was designed for conventional pressure distribution and conforms to the 1993 Department of Health design standard ("Wastewater and Reclaimed Water Use Fees" [WAC 246-272]). There are no radiation zones or known contamination areas in or near this site. For these reasons, this site will not be addressed further under the CERCLA RI/FS process. Following cessation of use, this system will be abandoned in accordance with "Wastewater and Reclaimed Water Use Fees" (WAC 246-272) requirements.

100-D-50:10. The 100-D-50:10 construction camp potable water supply pipelines subsite encompasses residual cast iron pipelines formerly used to supply potable water to the temporary construction camp southeast of the DR Reactor. This subsite was reclassified as no action based on a determination that the potable water supply was not associated with any constituents that would present an adverse risk to human health and the environment. This determination remains appropriate.

116-D-3. The 116-D-3 site was identified as a crib associated with the former 108-D facility. Based on review of historical drawings, geophysical investigation, and excavation, this site was determined to be a duplicate of the 116-D-4 site. The 116-D-3 site was reclassified as rejected in 2000; this reclassification was amended to no action in 2003. Another potential location for this crib has been identified separately as the 100-D-76 waste site. The 116-D-4 and 100-D-76 sites are addressed further in this RI/FS, but the redundant 116-D-3 site will not be considered further.

128-D-1. The 128-D-1 site was identified as a potential burn pit but was determined to be a duplicate of the 128-D-2 or 628-3 burn pit waste sites. The site was reclassified as no action based on this determination. This decision remains appropriate.

1.2.3.3 Nonoperational Area Evaluation Summary

In 2011, an evaluation of the River Corridor nonoperational areas was completed. The nonoperational evaluation considered the five contaminant 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 site evaluations (OSE)
- Air emission 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 also includes specific results and conclusions for 100-D/H.

Orphan Site Evaluation Summary. The OSEs are an important element of the nonoperational area evaluation. The purpose of the nonoperational area evaluation is to increase confidence that waste disposal or releases requiring characterization and cleanup within a given land parcel of the Hanford Site River Corridor are identified. Key elements of the OSEs include a comprehensive review of historical information, aerial photographs, and a field investigation. Results from these activities are reviewed with DOE-RL and the lead regulatory agency. Potential orphan sites are evaluated under *Tri-Party Agreement Handbook Management Procedures*, Guideline Number TPA-MP-14, "Maintenance of the Waste Information Data System (WIDS)" (RL-TPA-90-0001) process. The OSEs were recently completed on the highest potential impact areas of 100-D/H to identify additional waste sites that may require characterization and possibly remediation (*100-D Area Orphan Sites Evaluation Report* [OSR-2006-0001]; *100-H Area Orphan Sites Evaluation Report* [OSR-2008-0002]). The OSE for the remainder of 100-D/H, primarily the Horn area, was completed in 2011 (*100-F/IU-2/IU-6 Area – Segment 4 Orphan Sites Evaluation Report* [OSR-2011-0001]).

The 100-D OSE (OSR-2006-0001) identified 30 new waste sites, and the 100-H OSE (OSR-2008-0002) identified 15 new waste sites. The OSE for the remainder of 100-D/H (OSR-2011-0001) identified six waste sites.

Air Emissions. Two groups of sources of Hanford Site stack air emissions had the potential to affect 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 emissions coming from the 200 Area facilities that separated plutonium and uranium from irradiated reactor fuel. Any hot spots existing in the River Corridor area because of historic stack emission deposition would have decayed or attenuated to negligible levels over the past 40 or more years since the majority of the air emissions occurred. Also, potential fugitive dust from surface waste disposal sites would have similarly decayed and dispersed to less than the allowable annual public exposure levels. Aerial radiation surveys of the Hanford Site and widespread soil 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 investigations were also used to supplement the RI. Contaminant source, meteorological, air, surface water and sediment, and ecological investigations are described in Chapter 2.

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 used established approaches and datasets from the Hanford Site Central Plateau and adapted them to the River Corridor. In addition to the CSM developed for the Central Plateau, the CSM for the River Corridor also addressed the potential for overland flow and potential effects on riparian and near-shore areas. Statistical analysis was used to represent the conceptual models and incorporate the available data to support a quantitative base for the probability that a (undiscovered) waste site might exist in the nonoperational areas. Because of these efforts, no additional waste sites or areas affected by waste site releases were found in the nonoperational areas of 100-D/H that pose a threat to human health and the environment.

1.2.3.4 Previous Groundwater Investigation Activities

Groundwater monitoring projects are established under *General Environmental Protection Program* (DOE Order 5400.1) to meet the requirements of *Radiation Protection of the Public and the Environment* (DOE Order 5400.5), which deals with federal and state regulations. The TPA (Ecology et al., 1989a) is a legally binding document that requires the investigation of groundwater contamination and establishes a process for evaluating and implementing appropriate response actions.

Historical groundwater monitoring results for 100-D/H are presented in Chapter 4, locations of 100-D/H groundwater monitoring wells are illustrated in Appendix A. Groundwater from wells in 100-D/H are sampled for COPCs based on the results of the data quality objectives process. Sampling of groundwater at specific wells is scheduled for collection every quarter to 2 years, depending on the data need. Groundwater data for 100-D/H 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], hereinafter called Hanford Site 2009 Groundwater Report) and are discussed in Chapter 4.

Aquifer Characteristics and Ground-Water Movement at Hanford [HW-60601]) depicted 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 Site operations actively discharged a variety of water and liquid waste to the surface at locations such as B Pond and Gable Mountain Pond in the 200 Area, and retention ponds and trenches in the 100 Area. Groundwater mounds developed at these locations and affected groundwater flow across much of the Site, including 100-D/H. The Hanford Site water table changes over the period from 1950 to 1980 are 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 5-year intervals at a network of wells across the site.

In 1967, the disposal of reactor coolant effluent to trenches was discussed for 100-F and 100-D, with proposed tests at 100-BC and 100-K (*Program Review—Ground Disposal of Reactor Effluent* [DUN-3259]). This report describes the 100-D test conducted at the 116-DR-1&2 Trench. Effluent was initiated from the 107-DR basin on March 7, 1967, and from the 107-D basin on March 9, 1967. Initial flows were 17,034 L/min (4,500 gal/min). On March 17, flows were increased to 104,099 L/min (27,500 gal/min), with liquid levels stabilizing about 3 m (10 ft) above the base of the trench. The test continued at this rate through June 26, 1967, when the D Reactor was shut down. Over this period, approximately 1.3×10^{10} L (3.4×10^9 gal) of effluent were infiltrated through the trench. The estimated infiltration rate was 5,678 L/day (1,500 gal/day) per square foot of trench bottom. Effluent Cr(VI) concentrations of approximately 350 µg/L were estimated. The report provides several figures showing effects to groundwater, including descriptions of the large groundwater mound that developed.
The effluent caused an additional 2.7 to 3 m (9 to 10 ft) of groundwater mounding beyond that caused by ongoing operations. The temperature of effluent exiting the reactor was approximately 95°C (203°F), and groundwater temperatures in excess of 50°C (122°F) were observed near the mound. A portion of this water appears to have migrated into and across the Horn and likely is the source for the large, dilute Cr(VI) plume observed recently in Horn area groundwater.

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]).

By the mid-1980s, routine sampling began to include nonradiological constituents such as nitrate and Cr(VI). By 1984, quarterly groundwater monitoring had identified Cr(VI) at four wells in 100-H. As sampling continued, Cr(VI) continued to be found in various wells in 100-H. Cr(VI) was then reported at 100-D in 1987 at three wells near the D and DR Reactors, which have since been decommissioned. By 1988, it had become clear that action would be needed under CERCLA or RCRA in the 100-HR-3 OU. The initial study work plan was developed under the RCRA corrective action that was compatible with CERCLA (*RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-3 Operable Unit, Hanford Site, Richland, Washington* [DOE/RL-88-36]). This work plan established the OU setting, objectives, procedures, tasks, and schedule for conducting the remedial field investigation and corrective measures study for the 100-HR-3 Groundwater OU. In 1993 and 1994, an LFI report (*Limited Field Investigation Report for the 100-HR-3 Operable Unit* [DOE/RL-93-43]) was completed along with the qualitative risk assessment (QRA) (*Qualitative Risk Assessment for the 100-HR-3 Groundwater Operable Unit* [WHC-SD-EN-RA-007]).

The Tri-Parties decided that all groundwater would be cleaned up under the CERCLA remedial action process that included the 100-HR-3 OU. In 1995, the focused feasibility study (*100-HR-3 Operable Unit Focused Feasibility Study* [DOE/RL-94-67]) and the proposed plan (*Proposed Plan for Interim Remedial Measure at the 100-HR-3 Operable Unit* [DOE/RL-94-102]) were finalized. At the end of 1995, the 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 action ROD followed in April 1996. Table 1-10 summarizes the chronology of reports describing the interim action groundwater monitoring at the 100-HR-3 OU, including the annual monitoring of the pump-and-treat systems and changes that were made to the injection well/extraction well network. Also included in these documents is the In Situ Redox Manipulation (ISRM) barrier monitoring and general groundwater monitoring within 100-D/H. Over time, the understanding of the contaminant distributions has evolved as more monitoring wells have been added to the network.

Table 1-10. Chronology of Groundwater Reports for 100-D/H

Year	Pump-and-Treat System	In Situ Redox Manipulation	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

Table 1-10. Chronology of Groundwater Reports for 100-D/H

Year	Pump-and-Treat System	In Situ Redox Manipulation	Annual Groundwater Monitoring Reports	Aquifer Sampling Tube Data Reports	Annual Environmental Monitoring
1987	—	—	PNL-6315-1, -2	—	PNL-6464
1988	—	—	PNL-6315-3, -4	—	PNL-6886, PNL-7120
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	—	—	PNNL-11141	—	PNNL-11139
1996	EPA/ROD/R10-96/134	—	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	EPA/AMD/R10-00/122	PNNL-13116	—	PNNL-13230
2000	DOE/RL-2001-04	DOE/RL-2000-74	PNNL-13404	—	PNNL-13487
2001	DOE/RL-2002-05	DOE/RL-2001-01	PNNL-13788	BHI-01494	PNNL-13910
2002	DOE/RL-2003-09	DOE/RL-2003-05	PNNL-14187	—	PNNL-14295
2003	DOE/RL-2004-21	DOE/RL-2004-06	PNNL-14548	PNNL-14444	PNNL-14687
2004	DOE/RL-2005-18	DOE/RL-2005-39	PNNL-15070	—	PNNL-15222
2005	DOE/RL-2006-08	DOE/RL-2005-97	PNNL-15670	—	PNNL-15892
2006	DOE/RL-2006-76	DOE/RL-2007-19	PNNL-16346	—	PNNL-16623
2007	DOE/RL-2008-05	DOE/RL-2008-10	DOE/RL-2008-01	SGW-35028	PNNL-17603
2008	DOE/RL-2009-15	DOE/RL-2009-01	DOE/RL-2008-66	—	PNNL-18427
2009	DOE/RL-2010-11	DOE/RL-2010-11	DOE/RL-2010-11	—	PNNL-19445

Note: Complete reference citations are provided in Chapter 11.

As a result of the implementation of these interim remedies and associated monitoring, the extent of the plumes has been mapped. Figures 1-24 and 1-25 depict the Cr(VI) plume in the high river and low river stage during 2011 in the 100-HR-3 OU, respectively. The high river data are from May through July, with low river stage being data from October through December. Data were averaged where multiple samples were collected in that timeframe. Figure 1-26 shows that the 100-D Cr(VI) southern plume splits. Figure 1-27 shows the 100-D northern plume. Figure 1-28 shows the 100-H Cr(VI) plume. The contaminated footprint is approximately 0.8 km^2 (0.31 mi^2). Major features to note are the high concentrations in 100-D, with low values across the Horn into 100-H. The plumes in 100-D are separated by an area of little or no contamination. The most concentrated plume is upgradient from the ISRM

Barrier. These high concentrations appear to be breaking through the barrier. Even though the former HR-3 and DR-5 groundwater pump-and-treat systems were deemed undersized, it is clear from the trend plots accompanying Figures 1-26 through 1-28 that Cr(VI) concentrations in the unconfined aquifer were declining. However, the plume area is sufficiently large that the overall effect of the relatively small systems can be obscured by the sheer size of the groundwater volume being addressed, as well as from the effects of source area remediation. In addition, some wells showed increasing concentrations, which were likely a result of current remediation system causing plume migration, which is further discussed in Chapters 3 and 4. Consequently, the remedial process optimization (RPO) process was initiated and has significantly increased the number of wells involved in the remedy together with increased treatment capacity to accelerate the cleanup of the groundwater plumes.

Columbia River Studies. River Corridor studies involving groundwater (often referred-to in this context as groundwater seeps, pore water, or groundwater upwelling) that are pertinent to Columbia River water quality and ecological risk include the following:

- *Sampling and Analysis of 100 Area Springs* (DOE/RL-92-12)
- *Chromium in River Substrate Pore Water and Adjacent Groundwater: 100-D/DR Area, Hanford Site, Washington* (BHI-00778)
- *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*, hereinafter called Columbia River RI Report (WCH-380)
- *Columbia River Component Risk Assessment, Volume I:Screening Level Ecological Risk Assessment* and *Volume II: Baseline Human Health Risk Assessment* (DOE/RL-2010-117)

Pore Water and Aquifer Tube Studies. In addition to the groundwater investigations, several pore water and aquifer tube studies have been performed that are relevant to 100-D/H and are summarized in Appendix B, Table B-1.

The first (1994) pore water study in the Hanford Reach of the Columbia River was designed to collect substrate water quality and 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 AWQC (since lowered to 10 µg/L), as measured in the river substrate, was the PRG. Embryonic Chinook salmon were selected as the target receptor for the study because they have limited mobility during their early life stages (egg and sac-fry), 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 is in the 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.

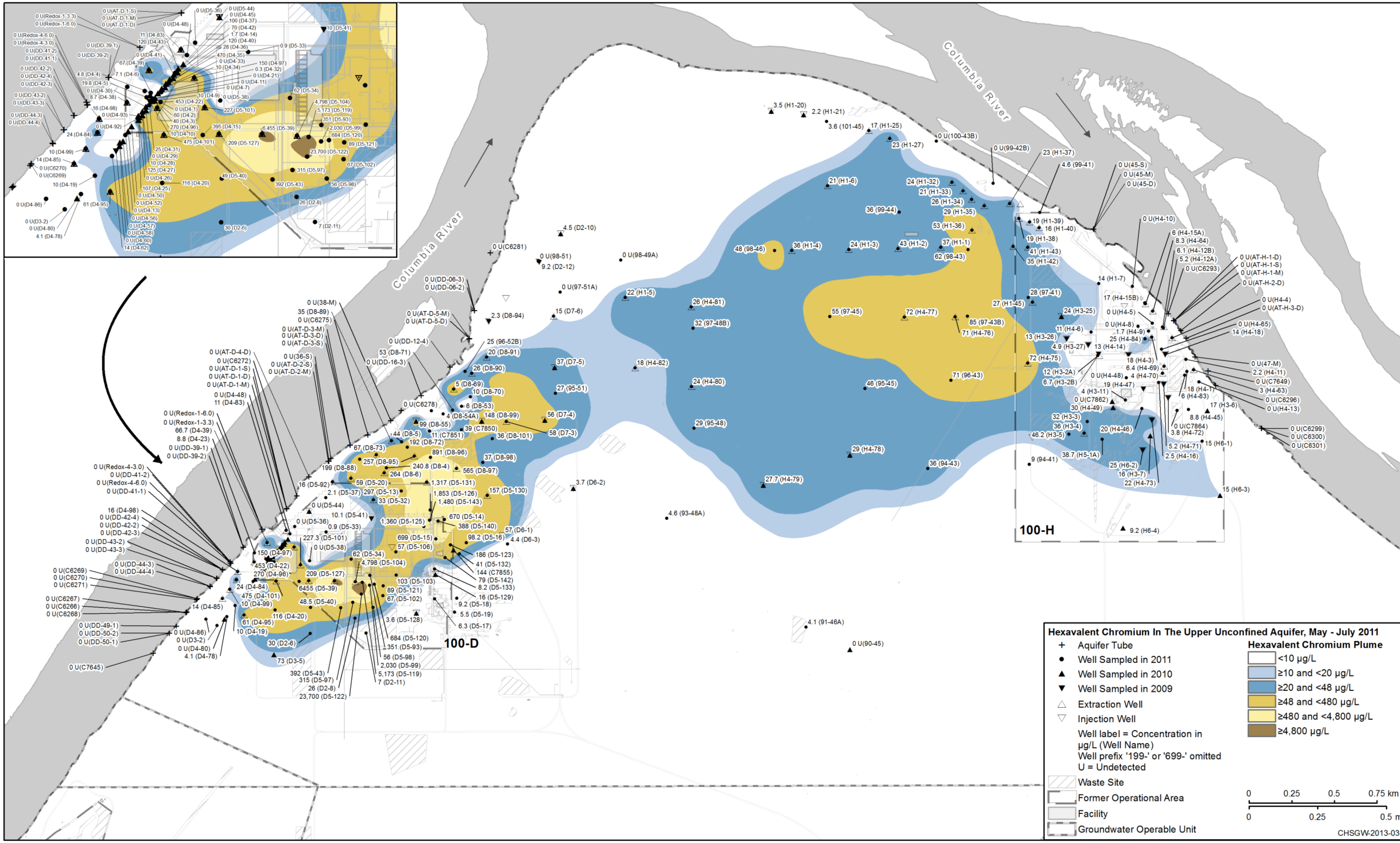

Figure 1-24. 100-HR-3 OU Cr(VI) (High River Stage 2011)

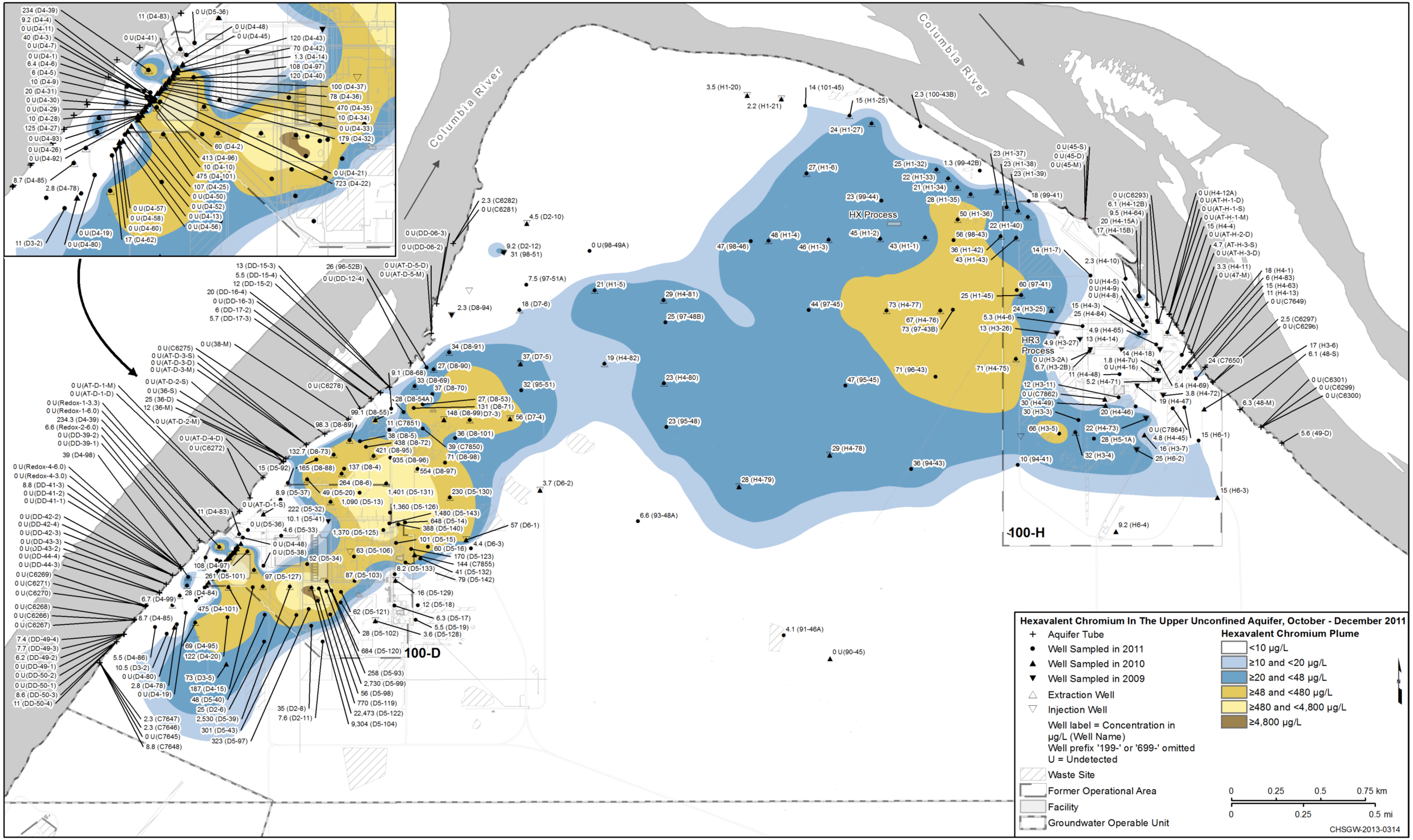

Figure 1-25. 100-HR-3 OU Cr(VI) Map (Low River Stage 2011)

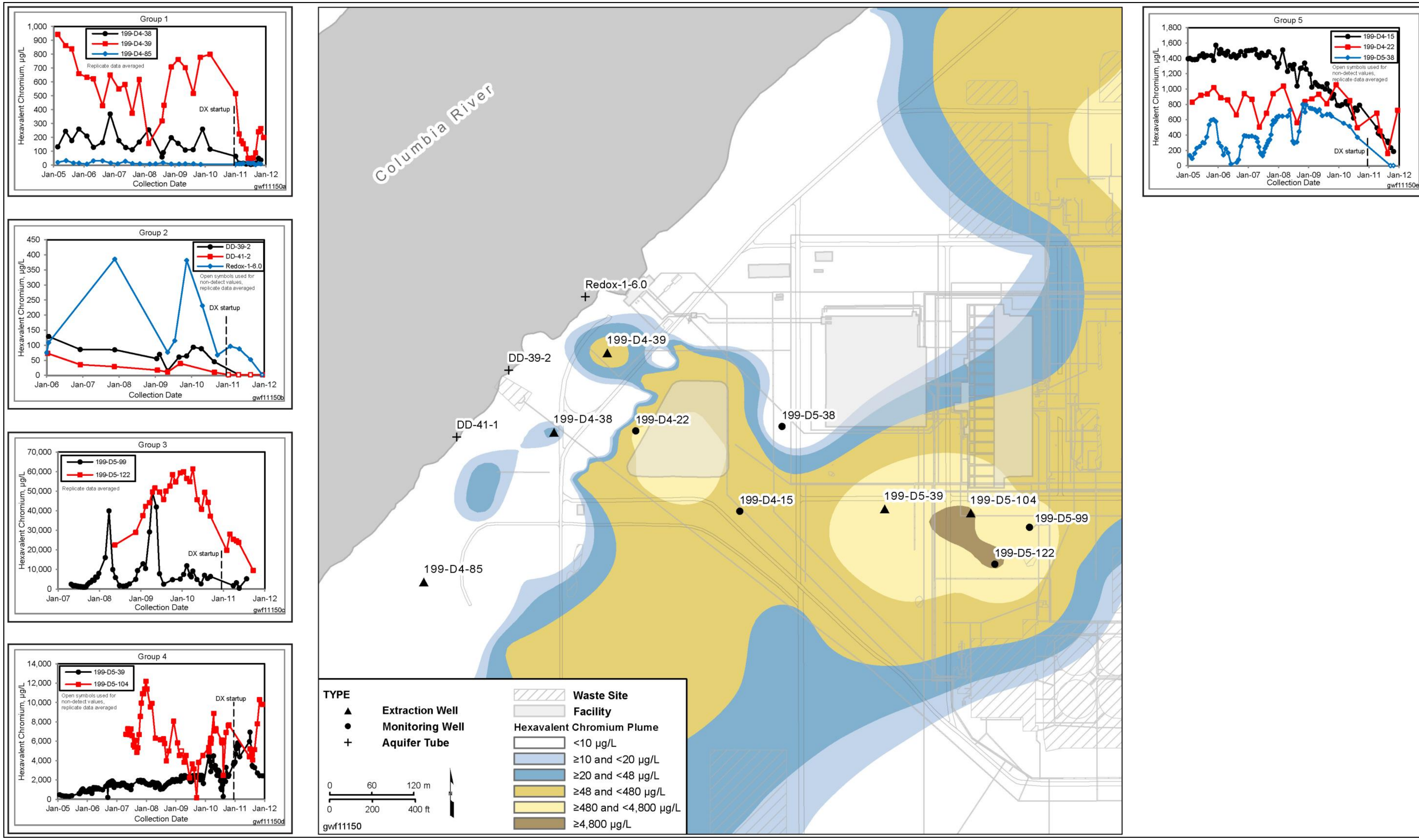

Figure 1-26. 100-D Area Cr(VI) Trend Plots (Southern Plume)

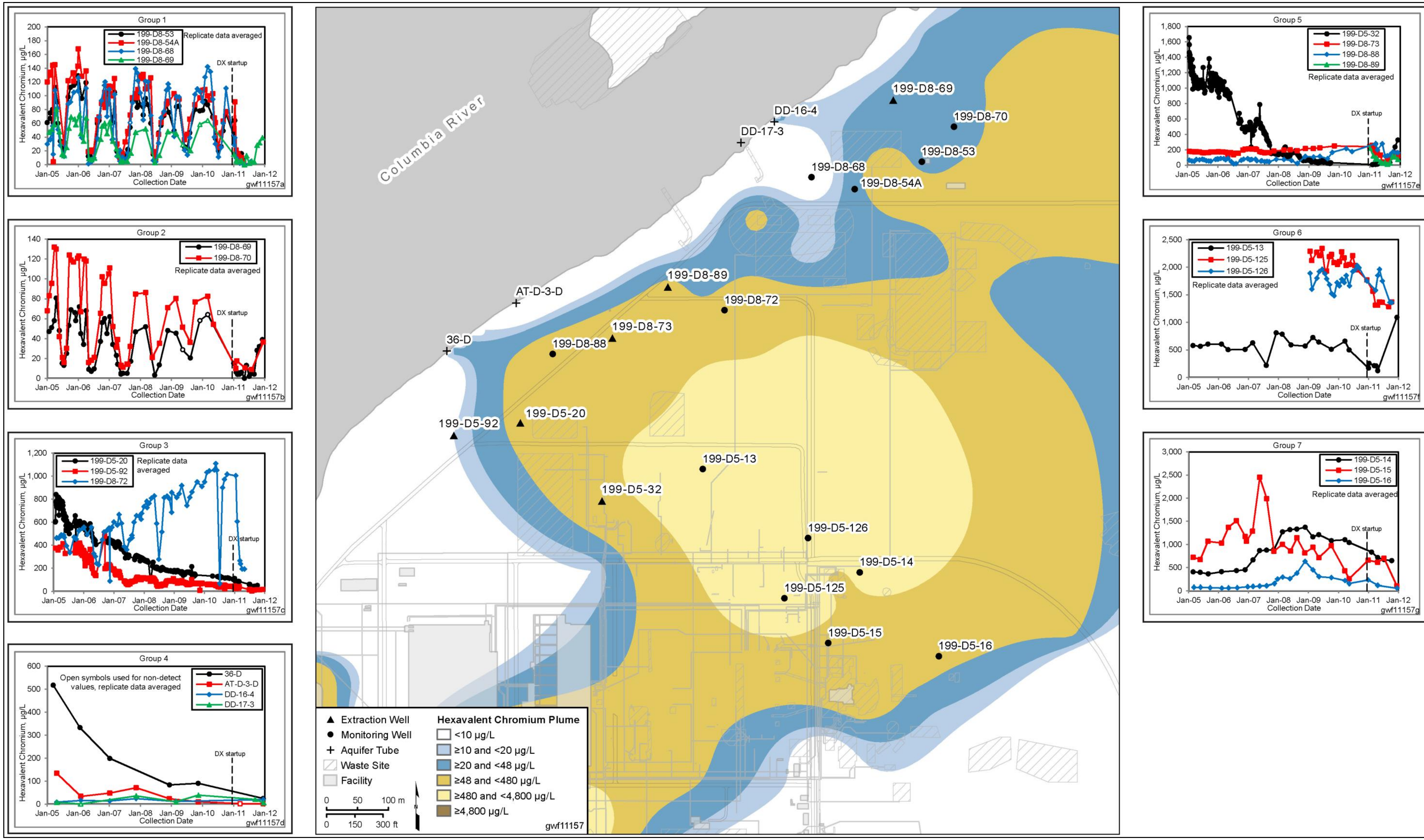

Figure 1-27. 100-D Area Cr(VI) Trend Plots (Northern Plume)

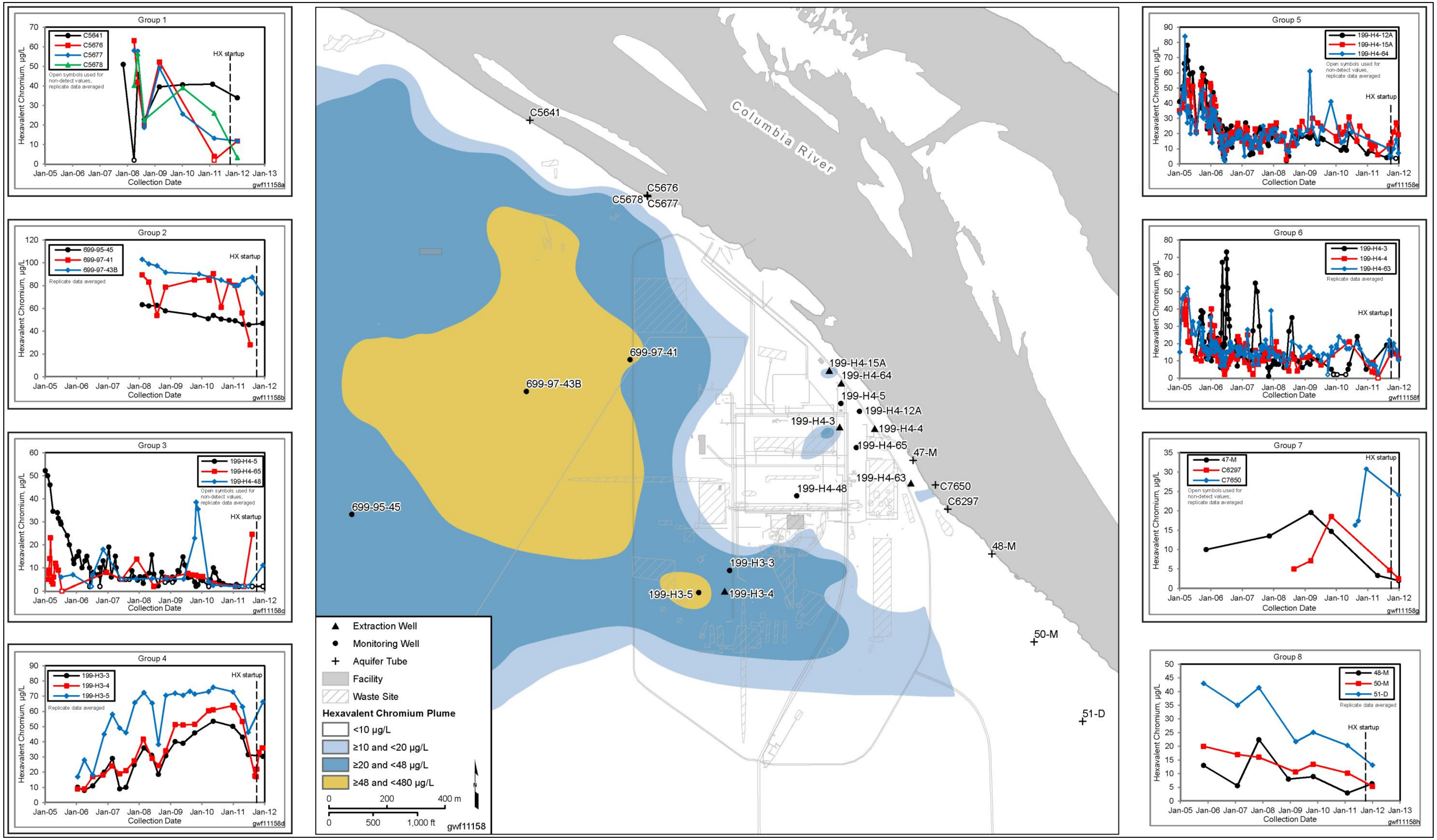

Figure 1-28. 100-H Area Cr(VI) Trend Plots

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The pore water sampling study adjacent to 100-D encompassed 3,100 linear m (10,200 linear ft) of the riverbed offshore of 100-D, corresponding to the mapped extent of Cr(VI) contamination in 100-D (*Chromium in River Substrate Pore Water and Adjacent Groundwater: 100-D/DR Area, Hanford Site, Washington* [BHI-00778]). Cr(VI) concentrations ranged from not being detected at many sample locations to a maximum of 632 μg/L. Results are presented in Table B-1.

Recent pore water studies were conducted from 2008 to 2010 for the entire River Corridor, including 100-D/H (Columbia River RI Report [WCH-380]). These studies showed Cr(VI) values above the AWQC at several river sites opposite the reactor areas during very low river stage. Although the majority of the sites did not show Cr(VI) above detection limits, values up to 331 μg/L and 46 μg/L were observed for the D and H areas, respectively. The sample locations and detailed results for the pore water study are provided in Chapters 2 and 4 of this RI/FS report.

Aquifer tubes have been installed along the Columbia River throughout the River Corridor. Aquifer tubes consist of small, stainless steel screens that are typically driven into the aquifer/hyporheic zone along the riverbank (Figure 1-29) using a percussion method. Data are used to evaluate effectiveness of upgradient treatment systems, such as groundwater pump-and-treat systems and permeable reactive barriers, and to quantify contaminant entry into the river.

The tubes monitor shallow groundwater of the uppermost, unconfined aquifer and typically terminate 1 to 2 m (3 to 6.5 ft) 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* [DOE/RL-2000-59], hereinafter called SAP for Aquifer Sampling Tubes), 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 listed in Table 1-10.

Groundwater/Surface Water Interactions. In April 2008, an expert panel of scientists was convened to provide observations and suggestions intended to improve the current understanding of groundwater-surface water interactions in the 100 Areas (primarily focusing on 100-D Area), and to identify what additional analyses or approaches may provide critical information needed to design and implement effective remediation systems that will minimize impacts to river aquatic systems (*Technical Evaluation of the Interaction of Groundwater with the Columbia River at the Department of Energy Hanford Site, 100-D Area* [SGW-39305]). The panel provided input on the conceptual framework, data acquisition, the role of modeling and current models, and the role of the groundwater-surface water interaction in remedy selection. The resulting suggestions included: the use of three-dimensional modeling, additional evaluation of geologic features of the river, targeted monitoring locations for ecological exposure, evaluation of concentration distribution vertically and horizontally in the aquifer, and additional simulations and various modeling methods.

To date, most of the suggestions and recommendations made by the expert panel have been implemented. However, not all of the recommendations were feasible with current funding or deemed necessary due to the implementation of an upgraded pump-and-treat system.

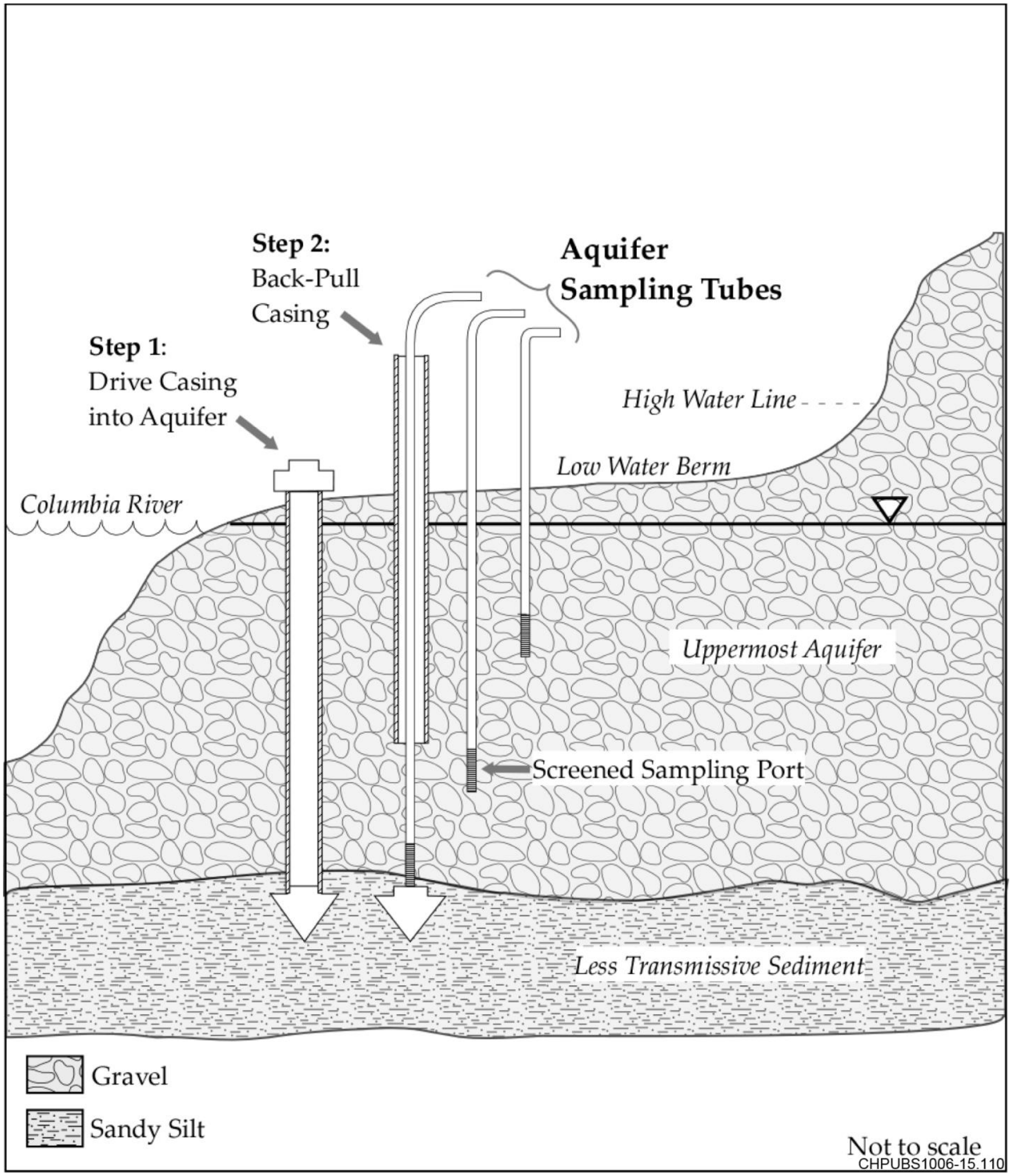

Figure 1-29. Main Components of Aquifer Sampling Tube Installation

Chromium Source Investigation. Three new wells were installed in the northern plume in an attempt to refine the location of the source area. These wells served to better define the high-concentration portion of the northern plume but did not identify a high concentrations similar to that associated with the southern plume where Cr(VI) reached concentrations of 69,700 µg/L in 2010. The shallow and intermediate vadose zone was also sampled in 2009 using innovative drilling technology in an attempt to identify vadose zone chromium sources. This work did not find significant levels of Cr(VI) at depth, but total chromium was elevated beneath waste site 100-D-104, where soil staining is evident.

Chromium in the Ringold Formation Upper Mud Unit. Aquifer tests were performed to gather additional data on the deep chromium contamination. The aquifer tests were performed using existing monitoring wells in 100-H and grouped into three sets of wells, with each set containing three wells. Each of the three-well sets had wells completed at increasing depths in the unconfined aquifer. Some rebound in Cr(VI) concentrations occurred because of the shutdown of the 100-HR-3 pump-and-treat system for a rebound study, but a zone to the north and northeast of H Reactor building was identified as a potential pathway for downward migration of Cr(VI)-contaminated groundwater during reactor operations. Overall, Cr(VI) within the tested zone appears to be of finite extent, which should be amenable to remediation via pump-and-treat.

The results suggest that the most likely explanation for the origin of the Cr(VI) in the RUM unit underlying 100-H is from contaminated cooling water that passed through the H Reactor. The cooling water contained up to 1,000 µg/L of Cr(VI), and was subsequently discharged to the ground. This water formed a mound that provided sufficient hydraulic force to push into the upper RUM unit and mix with existing groundwater in the unit, resulting in concentrations of one-tenth to one-thirtieth of the original cooling water. Concentrations decline inland, consistent with a reactor mound. The areal extent and relatively high continuous concentrations rule out localized contamination during well drilling.

1.2.3.5 Treatability Studies

During the RI/FS process, a range of technologies were identified to mitigate unacceptable risks. However, many of these technologies have little data supporting their performance at a scale comparable to the size of the contaminated site. As such, treatability studies are conducted to fill data gaps on performance characteristics of a promising technology and to reduce uncertainty in the implementation of a technology. One such technology is the passive in-situ reduction of Cr(VI). The various in-situ treatment technologies that have been tested at 100-D/H are described below and shown in Figure 1-30.

In Situ Redox Manipulation. The ISRM system is a passive reactive barrier that started as a single well treatability test. The first ISRM treatment took place in well 199-D4-7 in September 1997, and four additional wells were treated between May and July 1998. The five treated wells created a reducing zone in the unconfined aquifer that was approximately 46 m (151 ft) long by 15 m (49 ft) wide.

The ISRM technology creates a permeable subsurface treatment zone through the injection of sodium dithionite into the aquifer, thus forming a chemically reduced environment. As hexavalent chromium passes through the treatment zone, it is reduced to less toxic and less mobile trivalent chromium.

During the fall of 1999, the treatment zone in the treatability test area was extended by the treatment of a sixth well (199-D4-21), resulting in hexavalent chromium concentrations being reduced from 1,050 µg/L to less than detection in that well. The treatability test ended in calendar year (CY) 1999 after six wells were treated. The success of these six treatment wells provided sufficient additional data to support advancing from treatability testing to emplacement of a large-scale ISRM treatment zone.

The full-scale ISRM treatment zone was installed in three phases. The ISRM reactive treatment zone was created by the injection of a strong reducing agent (Sodium Dithionite) into the aquifer between the river and the southern lobe of the 100-D Area chromium plume. The objective of the ISRM was to form a reactive barrier that would substantially reduce the levels of chromium discharging to the river in this part of the 100-D Area.

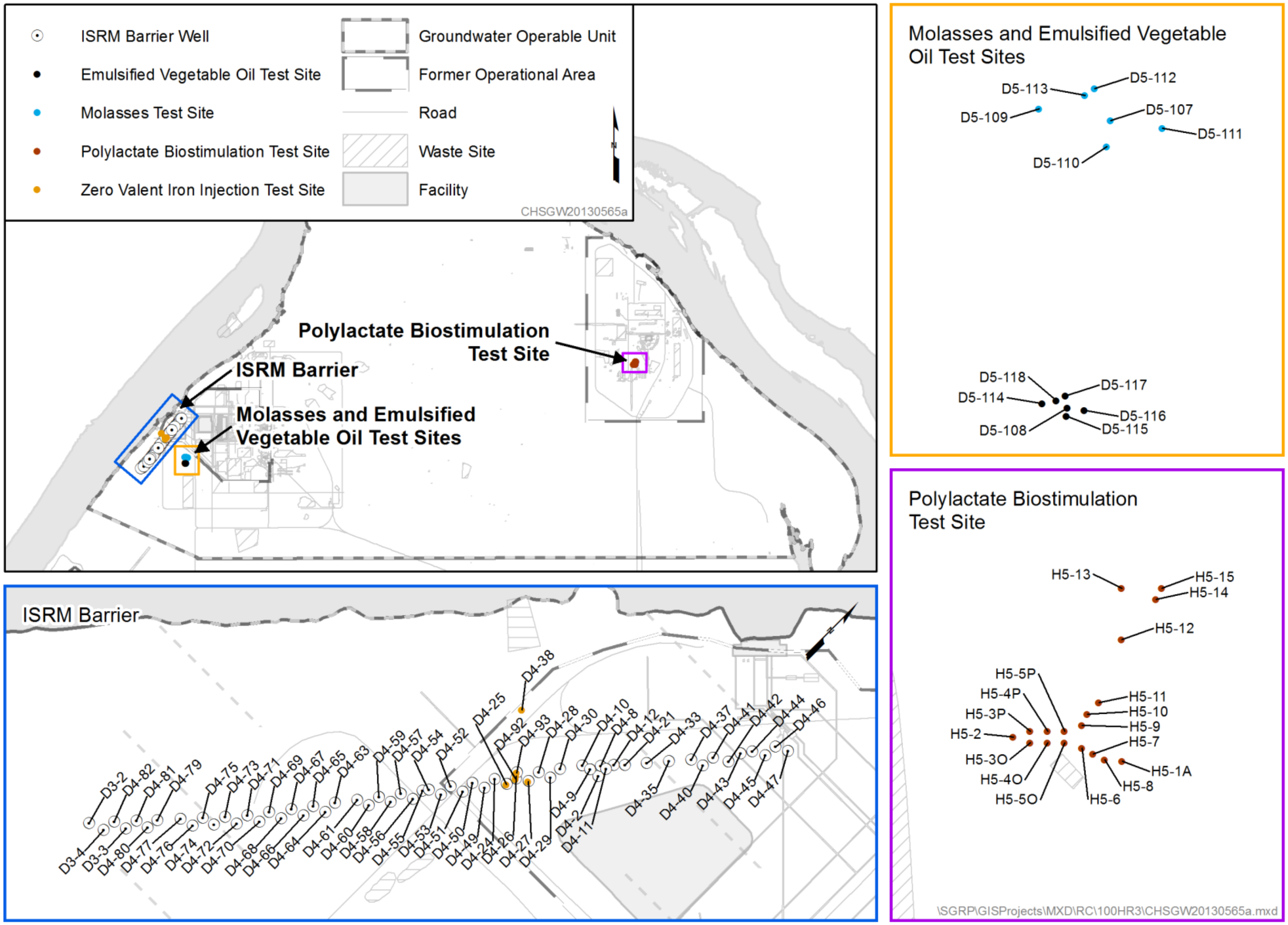

Figure 1-30. Location of In-Situ Treatability Tests at 100-D/H

Phase I of the large-scale deployment of the ISRM technology was initiated in fiscal year (FY) 2000. Sixteen wells were installed (2 compliance wells and 14 treatment zone wells), and chemical treatment was performed in 10 wells. During this phase, the ISRM treatment zone was extended 60 m (197 ft) toward the northeast and 60 m (197 ft) toward the southwest.

In FY 2001, Phase II well construction and treatment zone emplacement activities began. Thirty-two wells were installed (4 compliance wells and 28 treatment zone wells), and chemical treatment was performed in 28 wells. These 28 treatment wells extended the ISRM treatment zone to a length of over 195 m (640 ft).

The ISRM barrier was extended to the west during Phase III drilling in FY 2002. Seventeen ISRM treatment wells and 3 characterization boreholes were drilled, and chemical treatment was performed in 12 of 17 treatment wells. Chemical treatment was subsequently completed in the last five wells during FY 2003, which extended the ISRM treatment zone to a length of 680 m (2,231 ft) and a total of 65 treatment wells and 7 monitoring wells.

The longevity of the treatment zone's capacity to reduce hexavalent chromium within the aquifer, originally estimated to be 23 years (*100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater* [PNNL-13349]), was based on an assessment of the combined effects of chemical and physical characteristics of the aquifer, including the following aspects:

- Quantity and distribution of residual ferrous iron within the aquifer matrix following the treatment process
- Flow rate of untreated groundwater into and through the treatment zone
- Concentration of oxidizing constituents in the incoming groundwater (e.g., DO, nitrate, and hexavalent chromium)

Monitoring of the ISRM indicated that the performance of the barrier was not uniform. By 2007, however, areas in the northeastern portion of the barrier developed loss in reductive capacity and low, but increasing, concentrations of hexavalent chromium were migrating past the southwestern portion of the. Consequently, other in situ approaches or technologies were evaluated that were believed to have the potential to augment (mend) and extend the life of the barrier.

Zero Valent Iron Fortification. The ISRM barrier depends on the presence of naturally occurring iron in the aquifer to create treatment zones that reduce and immobilize Cr(VI). When data indicated that Cr(VI) was breaking through the ISRM treatment zones in several locations, scientists proposed that fortifying the barrier with additional iron could offer a sustainable long-term repair. As such, the Nano-size Iron Injection Test was initiated to evaluate the effectiveness of injecting tiny particles of iron into the aquifer to repair portions of the ISRM barrier, as shown on Figure 1-31.

A two-phase treatability study was initiated to evaluate whether the injection of micron- scale zero valent iron (ZVI) was a feasible approach for augmenting the partially depleted portions of the ISRM barrier. Phase 1 was conducted in FY 2007 and consisted of laboratory testing to identify the optimal ZVI products for injection into the ISRM. A range of candidates were tested for their injectability and their effectiveness at reducing hexavalent chromium in synthesized 100-D Area groundwater. Based on the results of this evaluation, one of the ZVI formulations (RNIP-M2) was selected for field- scale testing (Phase 2).

Field injection testing (Phase 2) was conducted in August 2008 at the 100-D Area. The initial goal was to inject enough ZVI into the more permeable portions of the barrier to ensure that the ZVI would migrate a sufficiently distance (at least 7 m (23 ft)) from the injection well. The second goal was to determine whether the injected ZVI would effectively reduce Cr(VI) concentrations in the groundwater.

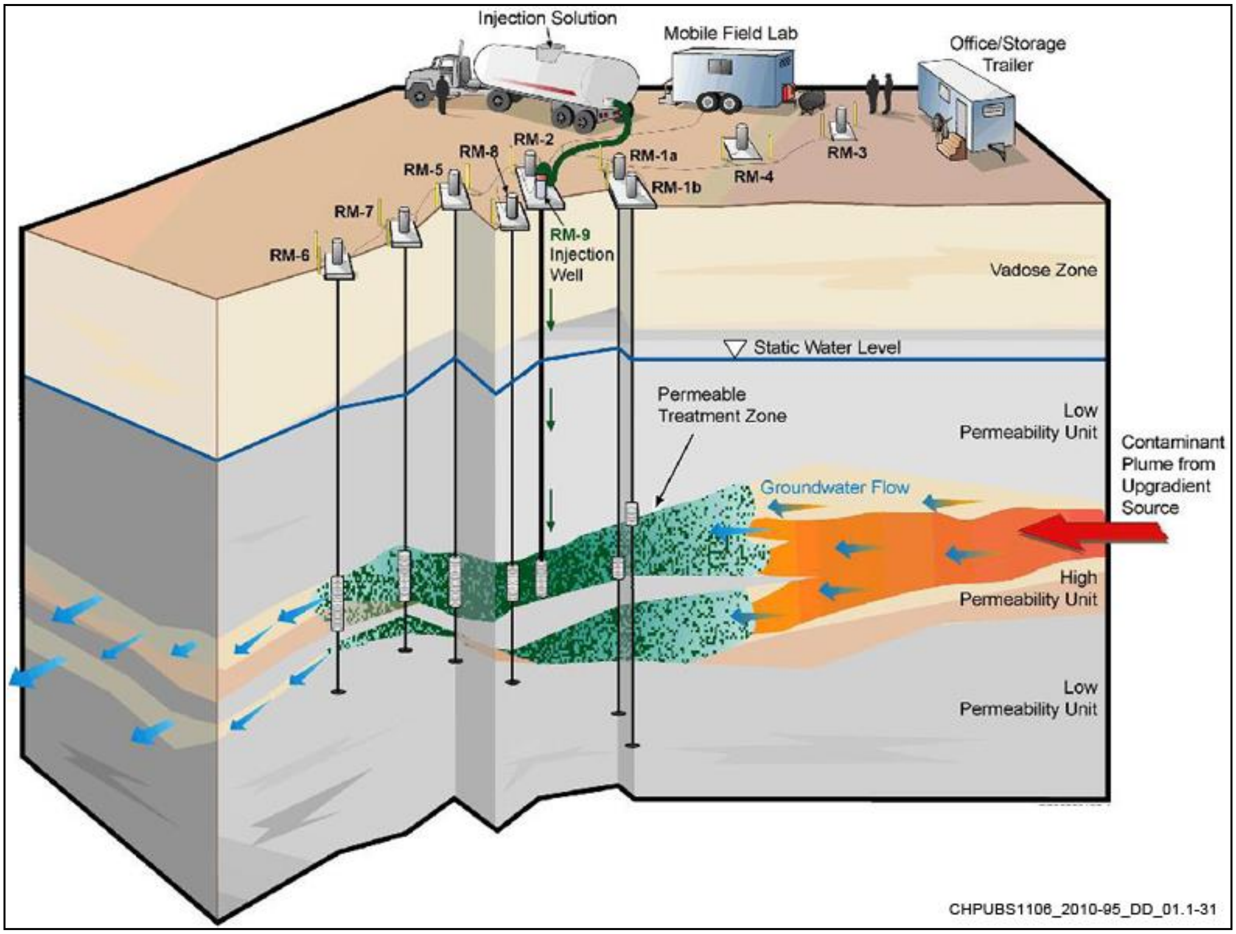

Figure 1-31. Nano-size Iron Injection

Over a period of approximately 5 days, 370,970 L (98,000 gal.) of the RNIP-M2 solution was injected into the Ringold Formation aquifer at a rate of 53 L/min (14 gal/min). Some of the injected ZVI was transported at least 3 m (9.8 ft) away from the injection well. A borehole was drilled 7 m (23 ft) from the injection well in March 2009 to evaluate the radius of influence. Analysis of aquifer materials showed that approximately 4 weight percent (wt%) ZVI was present in the targeted permeable layer near the bottom of the aquifer. Electrical conductivity, electrical resistivity, and induced polarization showed that the injected iron intruded more than 7 m (23 ft) laterally into the formation. Groundwater from the injection and nearby monitoring wells showed that Cr(VI) and total chromium concentrations decreased to near detection limits. Concentrations of dissolved oxygen, nitrate, and uranium also decreased. Sulfate concentrations decreased immediately after treatment but later rebounded to pre-injection levels. Dissolved and total manganese and iron concentrations increased (*Treatability Test Report on Mending the In Situ Redox Manipulation Barrier Using Nano-Size Zero Valent Iron* [DOE/RL-2009-35]). This verified that the goal of emplacing ZVI at least 7 m (23 ft) away from the injection point was successfully accomplished. Monitoring demonstrated that the area near the test was strongly reducing, and Cr(VI) was reduced to immobile Cr(III). The test demonstrated that the injection of the ZVI (RNIP-M2) would be an effective method to replenish those high permeability (high flow) areas of the ISRM barrier where the original reducing power had been partially depleted.

The injection modestly increased hydraulic conductivity and rapidly appeared in wells 3 m (10 ft) downgradient and upgradient. Injection affected the oxidation-reduction potential and dissolved oxygen in wells 3 m (10 ft) away, but no effects were observed in a well 12.8 m (42 ft) away.

One factor in evaluating a treatability test is the cost to implement the technology. The cost of the nano-sized iron was approximately a third of the implementation cost. When the material cost was estimated to implement this technology across 100-D/H, it was considered prohibitive. As such, the technology was judged to not be a cost effective remediation option.

100-D Area Molasses and Vegetable Oil Biostimulation Tests. PNNL completed an in situ biostimulation treatability test at 100-D in CY 2009 (*Hanford 100-D Area Biostimulation Treatability Test Results* [PNNL-18784]). The purpose of biostimulation is to induce the reduction of chromium, nitrate, and oxygen and to remove these compounds from the groundwater. Test data indicated that injected materials were successfully distributed to the target radius from the injection wells. Microbial activity and the ability to reduce the targeted species were observed throughout the monitored zone, and low oxygen, nitrate, and chromium concentrations were maintained for the duration of monitoring. Aquifer permeability reduction within the test zone was moderate while the injected substances and associated organic degradation products persisted for a period of at least 1 year. Further evaluation of this technology is discussed in Chapter 8.

In situ biostimulation can be used to sustain reduction of groundwater species over relatively long periods via slow-release substrates, buildup of biomass, and/or relatively inexpensive reinjection of substrates. Molasses and vegetable oil are two substrates that have been used successfully at other sites to promote the in situ bioremediation of Cr(VI) and other constituents in groundwater. When injected into an aquifer, these common food ingredients stimulate the growth of native bacteria that can, either directly or indirectly, lead to the transformation of redox- sensitive contaminants in groundwater. Owing to the success of in situ bioremediation at other sites, a two-phase treatability study was conducted in the 100-D Area to determine whether in situ bioremediation could be used to extend the life of the ISRM barrier. Conceptually, in situ bioremediation would achieve this goal by reducing the concentrations of oxidizing constituents (e.g., Cr(VI), nitrate, and dissolved oxygen) in the plume upgradient of the ISRM barrier, thereby reducing the concentrations of oxidizing groundwater constituents consuming the reducing power of the ISRM. Field testing of in situ bioremediation using molasses and vegetable oil were conducted separately.

Molasses testing: During FY07, 12 wells were drilled upgradient of the ISRM barrier as part of this test (2 injection wells and 10 monitoring wells). The first phase of testing was initiated in September 2007 with the injection of molasses into the aquifer through a single injection well. The injected molasses successfully formed a treatment zone in the aquifer of about 30 m (100 ft) in diameter. This treatment zone successfully removed oxygen and treated nitrate and Cr(VI) from the groundwater for more than 15 months. The molasses test provided information needed to assess bioremediation in terms of the potential effectiveness, implementability, and cost, of a full-scale system.

Vegetable oil testing: Field testing of the second approach began in August 2008 with the injection of emulsified vegetable oil into the aquifer near the molasses test location. The emulsified vegetable oil was successfully injected through a single injection well, forming a reducing treatment zone about 15 m (50 ft) in diameter that effectively removed dissolved oxygen, nitrate, and Cr(VI). As was the case for the molasses test, sufficient data on equipment and operational requirements were obtained to enable a reliable full-scale cost estimate. Continued monitoring of the site provided information needed to assess the potential effectiveness of a full-scale bioremediation using vegetable oil as a low solubility substrate.

100-H Area Polylactate Biostimulation Test. Biostimulation tests were initiated at the 100-H Area in 2004 by personnel from Lawrence Berkeley National Laboratory (Faybishenko et al., 2009, *In Situ Long-Term*

Reductive Bioimmobilization of Cr(VI) in Groundwater Using Hydrogen Release Compound); see Figure 1-30. In these tests, a commercial polylactate called Hydrogen Release Compound® (HRC)[1] was injected into the aquifer to stimulate microbial activity and transform Cr(VI) to Cr(III). Results from the tests show Cr(VI) concentrations in the treated area decreased to below drinking water standards and remained at that level for nearly 3 years. The principle difference between this test and the tests described in the previous section is the use of polylactate. This is a liquid that is difficult to inject any distance from a well because of its high viscosity; therefore, this substance is limited in its ability to treat large areas of an aquifer. Over several months, polylactate slowly disperses into the aquifer, at which point it acts as a more mobile substrate.

The studies showed that biostimulation by adding safe and relatively inexpensive organic compounds to the aquifer can induce the bacteria in the 100-HR-3 Area groundwater to treat nitrate, dissolved oxygen, and Cr(VI). Success in experiments at the 100-H Area suggests biostimulation is viable broadly within the 100 Areas groundwater. These results provided additional evidence that biostimulation can function as a supplemental technology for groundwater remedies already treating Cr(VI) in the 100-D Area.

Horizontal Directional Drilling. A technology demonstration of horizontal directional drilling was conducted in 100-D to evaluate the capability of this technology in difficult geological conditions and to determine the feasibility of emplacing a horizontal well to intercept a groundwater Cr(VI) plume. The primary goals of this demonstration were to drill through the 25 m (82 ft) thick vadose zone and emplace a 90 m (295 ft) long screen in the unconfined aquifer. Secondary objectives were to minimize the loss of drilling fluid to the vadose zone and aquifer and to place the screen within 1.5 m (5 ft) of the middle of the aquifer. The field demonstration was performed from November 2009 through January 2010.

This test did not result in successful installation of a horizontal groundwater well. The principal impediments to casing installation were difficulty in removing cuttings from the nearly horizontal casing and inability of the downhole hammer to advance through the unconsolidated Hanford formation. The results and analysis of this technology demonstration may be useful to project planners, scientists, and contractors who are considering similar types of projects at the Hanford Site.

Other Studies. Other studies at 100-D/H include radiological and other surveys, and treatability studies to test various technologies with application to cleanup of Cr(VI). Table B-1 (in Appendix B) presents a brief description of these, and Chapter 8 presents the pilot tests and treatability tests reviewed and considered in the FS technology screening.

1.2.3.6 Groundwater Remediation

Three CERCLA interim action remedies were initiated at the 100-HR-3 OU. These include the original 100-HR-3 groundwater pump-and-treat system in 100-H (which treated groundwater from both 100-D and 100-H), the DR-5 pump-and-treat system in 100-D, and the ISRM barrier in 100-D. The Interim ROD for 100-D/H groundwater (100-HR-3 and 100-KR-4 Interim ROD [EPA/ROD/R10-96/134]) required pump-and-treat to address Cr(VI), and an amendment to the interim ROD (100-HR-3 Interim ROD Amendment [EPA/AMD/R10-00/122]) required the ISRM barrier. Following are the RAOs of these systems:

- Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River.

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[1] Hydrogen Release Compound, Regenesis, San Clemente, CA.

- Protect human health by preventing exposure to contaminants in the groundwater.
- Provide information that will lead to the remedy.

For the interim ROD, groundwater in monitoring wells adjacent to the river should contain no more than 20 µg/L of Cr(VI) (100-HR-3 and 100-KR-4 Interim ROD [EPA/ROD/R10-96/134]). Protecting human health means groundwater should meet drinking water standards (for example, no more than 100 µg/L of total chromium [EPA] and no more than 48 µg/L of Cr(VI) [Ecology]), or institutional controls should prevent human consumption of groundwater.

The remedial design report and remedial action work plan (*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]) were issued in September of 1996. Construction was completed by June 30, 1997, and full-time operation of the HR-3 pump-and-treat system began July 1, 1997. In 1996, an amendment to the interim ROD was issued to modify the selected remedial action by deploying a new technology (ISRM) for remediation of the Cr(VI) plume in 100-D.

Concurrently with the startup of the 100-HR-3 pump-and-treat system, *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90), hereinafter called IAMP, established the general monitoring plan for the pump-and-treat systems in the 100-HR-3 and the 100-KR-4 OUs. The major constituents being monitored semiannually are Cr(VI), co-contaminants such as nitrates, and strontium-90. The IAMP (DOE/RL-96-90) was modified by a letter from Ecology to DOE ("Sampling Changes to the 100-HR-3 and 100-KR-4 Operable Units (OU)" [CCN 062039]) and was modified through the TPA (Ecology et al., 1989a) Change Notice process to add wells. With these modifications, the general sampling program was developed and carried forward into the interim ROD.

The 100-HR-3 pump-and-treat system began operation in 1997 with five extraction wells at 100-H and two extraction wells at 100-D using ion exchange resin columns to remove Cr(VI). The treated effluent was discharged into injection wells at 100-H. A series of modifications starting in CY 2000, and ending in CY 2010 added five extraction wells to the HR-3 system. In 2004, the DR-5 pump-and-treat system was installed to treat high Cr(VI) concentrations in groundwater underlying the central part of 100-D. Again through a series of modifications the DR-5 system used five extraction wells and two injection wells to treat the groundwater.

The 100-HR-3 pump-and-treat system was very effective in reducing the size of the Cr(VI) plume beneath 100-H and reducing concentrations to less than the aquatic criteria near the river. However, concentration reductions in the northern plume and central part in 100-D have not been as effective because of the continuing sources of Cr(VI) in the vadose zone and the relatively small size of the DR-5 system.

Figure 1-32 shows the locations of the extraction and injection wells of the former DR-5 and 100-HR-3 system. The 100-HR-3 pump-and-treat system was shut down in May 2011 and removed 405.65 kg (894.3 lb) of Cr(VI) during its period of operation, treating more than 4.2 billion L (1.1 billion gal) of water. The 100-DR-5 pump-and-treat system was shut down in March 2011 and removed 337.58 kg (774.8 lb) of Cr(VI) over its lifetime, treating 384.2 million L (101.5 million gal) of water.

Within the context of the TPA (Ecology et al., 1989a), two target milestones are driving remedial activities at the 100-HR-3 OU: 2012 Columbia River Protection Milestone (M-016-110-T01) and 2020 Groundwater Plume Remediation Milestone (M-016-110-T02) (Ecology et al., 1989a):

> ***M-016-110-T01:*** *DOE shall take actions necessary to contain or remediate Cr(VI) groundwater plumes in each of the 100 Area NPL Operable Units such that Ambient*

Water Quality Criteria for Cr(VI) are achieved in the hyporheic zone and river water column (due date: December 31, 2012)

M-016-110-T02: *DOE shall take actions necessary to remediate Cr(VI) groundwater plumes such that Cr(VI) will meet drinking water standards in each of the 100 Area NPL Operable Units (due date: December 31, 2020).*

Remedial Process Optimization for 100-D/H. In response to the two target TPA (Ecology et al., 1989a) milestones, DOE initiated the RPO framework. The RPO framework provides a systematic approach for evaluating and improving site remediation systems. These activities include refinement of the following five tasks:

1. Review the CSM and implications for site remediation.
2. Review the design and performance of the existing 100-HR 3 OU ex situ remedial systems and treatability actions and identify system or process modifications to improve performance.
3. Identify and screen in situ and ex situ remedial technologies with the potential to improve remedial performance at the site.
4. Develop potential remedial action alternatives for the site based on the screened technologies.
5. Develop pre-conceptual designs and costs for three pump-and-treat technologies that were identified in the screening process for inclusion in one or more of the proposed remedial action alternatives.

Additional information on the RPO efforts is discussed in Chapters 8 and 9 of the FS.

RPO Expansion—DX and HX Pump-and-Treat Systems. Historically, groundwater extraction has focused primarily on protecting the river and extracting groundwater near waste sites. In addition, treated water was injected at quantities and locations that were optimized to minimize discharge of contaminated water to the river and maximize flow of contaminated water toward the extraction wells. However, as a result of actions identified in CERCLA 5-year reviews (Section 1.2.5), the pump-and-treat systems were expanded and improved to increase overall system up-time, reduce individual well down-time, and capture and treat more contaminated groundwater.

In the 100-HR-3 OU, pump-and-treat operations were expanded along the river, including for the first time, the Horn area. Within the unconfined aquifer across the Horn area is a lower concentration, dispersed plume migrating from 100-D toward 100-H. While Cr(VI) concentrations in this region are generally less than 100 µg/L, they still exceed the aquatic criteria, and the contaminated groundwater had previously discharged to the river, near known salmon redds.

Additional extraction and injection wells were installed in the 100-HR-3 OU during system expansion, and two new water treatment plants were installed: 100-DX in 100-D and 100-HX in 100-H (Figure 1-33). DOE expanded the pump-and-treat systems in an effort to protect the river better and to comply with the 100-HR-3 and 100-KR-4 Interim ROD (EPA/ROD/R10-96/134), as amended by *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* (EPA et al., 2009). The location, drilling, installation, and development of 47 new extraction wells and 23 new injection wells are described in *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09). Groundwater data needs were met by collecting one groundwater sample from each new well and analyzing for Cr(VI), anions, metals, tritium, technetium-99, and strontium-90.

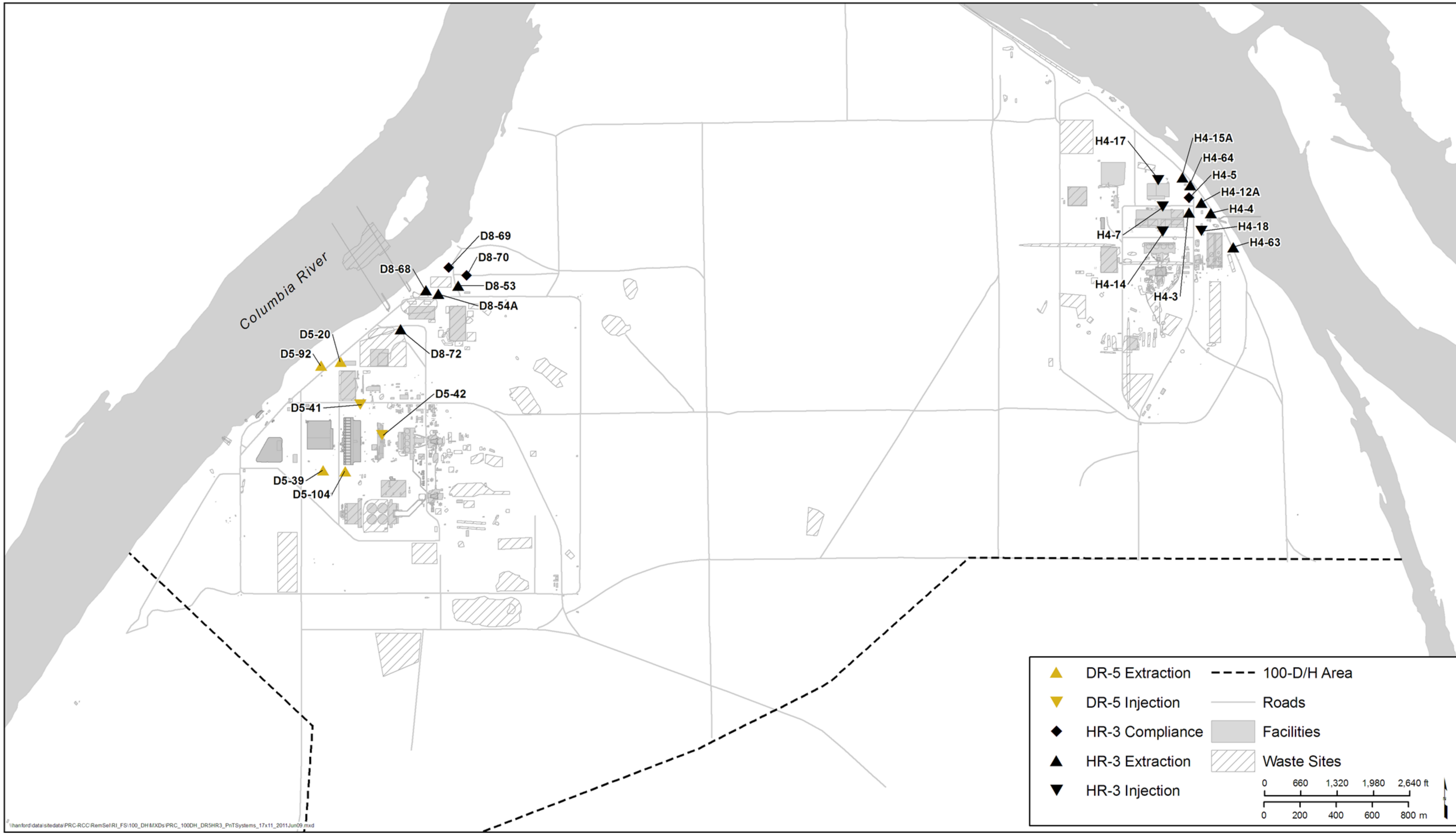


Figure 1-32. Original DR-5 and HR-3 Pump-and-Treat Systems

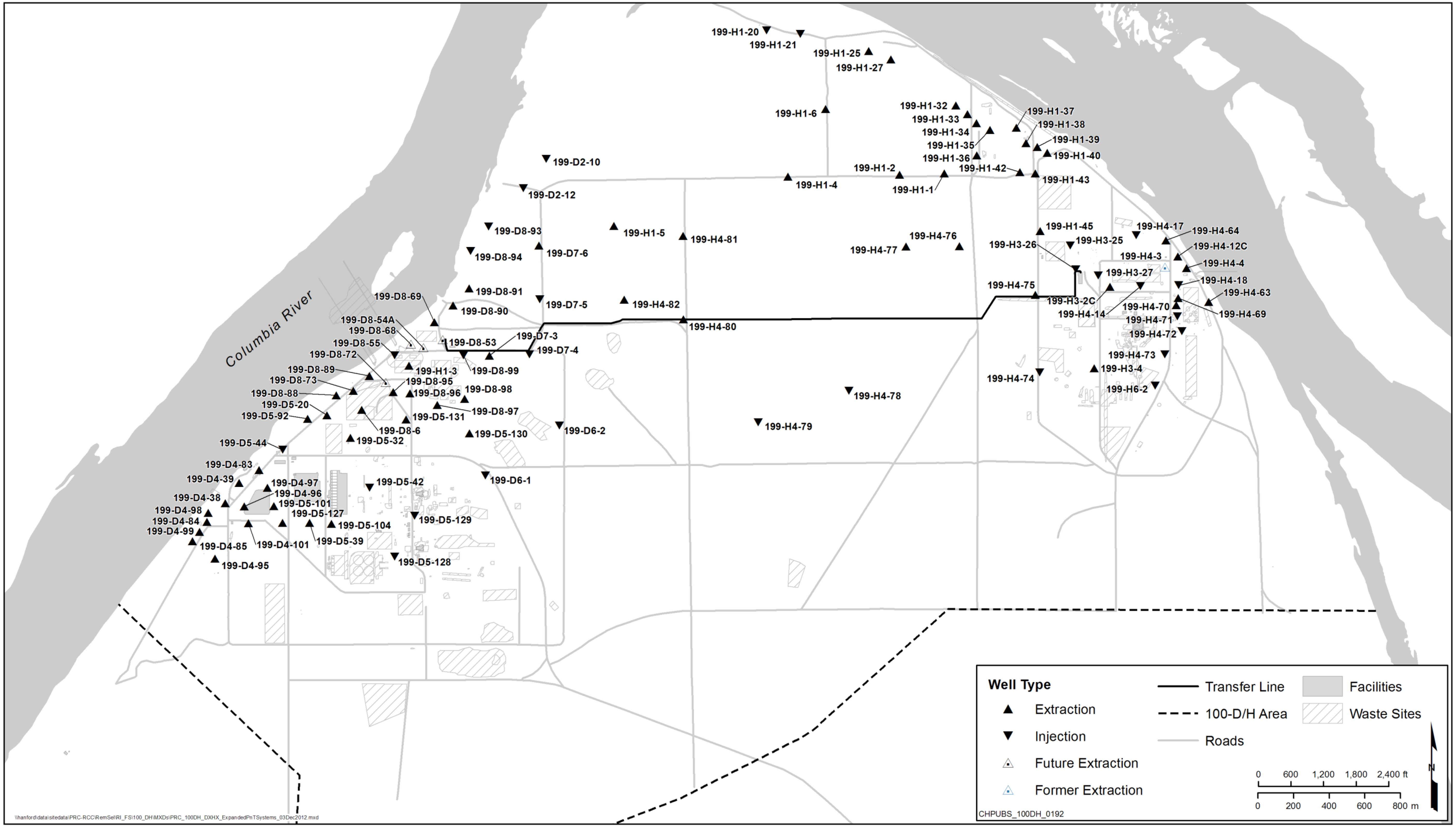


Figure 1-32. Expanded DX and HX Pump-and-Treat Systems

The criteria for operation of the expanded DX and HX pump-and-treat systems will be established in an upcoming revision of *Remedial Design and Remedial Action Work Plan for the 100-HR-3and 100-KR-4 Groundwater Operable Units' Interim Action* (DOE/RL-96-84), which will require regulatory approval. It is anticipated that the DX pump-and-treat system will remove significant mass from the 100-D northern and southern plumes, and operation will remain flexible downstream from the ISRM barrier to enable extraction (initially). The HX system will continue to protect the river with extraction and injection wells in the unconfined aquifer, and is intended to prevent further migration from the Horn area. HX also extracts groundwater from two wells within the first water-bearing unit of the RUM in support of the Interim Action ROD. Both systems have wells located within the Horn to remove contaminant mass from that area and provide hydraulic control to prevent further migration of the Cr(VI) plume towards 100-H.

Groundwater is currently extracted, treated for Cr(VI) by ion exchange, and reinjected into the unconfined aquifer. Other contaminants that may be captured by the pump-and-treat system are not being treated, consistent with interim action ROD expectations. The RI/FS process will identify any additional COCs that would require remedial actions. Total groundwater extraction in 100-D is approximately 2,044 L/min (540 gal/min); however, to afford contingency for system optimization, the remedial design can accommodate a total flow of 2,300 L/min (600 gal/min). Total groundwater extraction in 100-H is approximately 2,763 L/min (730 gal/min); however, to afford contingency for system optimization, the remedial design can accommodate a total flow of 3,000 L/min (800 gal/min). Water from each system is transferred to separate facilities and treated in six ion exchange treatment trains, each of which has four columns (lead, lag 1, lag 2, and polish).

The combined total capacity of the expanded DX and HX pump-and-treat systems is approximately four times the combined total capacity of the former HR-3 and DR-5 pump-and-treat systems. The HR-3 (1,100 L/min [300 gal/min]) and DR-5 (190 L/min [50 gal/min]) ion exchange treatment plants have been placed on "cold standby" status. Table 1-11 summarizes information on schedule, design capacity, and numbers of extraction and injection wells in the pump-and-treat systems.

Table 1-11. Original and Expanded Pump-and-Treat Systems

System	Actual/Scheduled Operation	Design Capacity (L/min [gal/min])	Number of Extraction Wells	Number of Injection Wells
HR-3[a]	June 1997 to May 2011	1,100 (300)	10	4
DR-5[a]	July 2004 to March 2011	190 (50)	5	2
HX[b]	October 2011 to present	3,000 (800)	33	15
DX[b]	December 2010 to present	2,300 (600)	39	16
DX + HX Total by December 2011		**5,300 (1,400)**	**72**	**31**

Notes: Values shown are approximate based on current information and may change as further system improvements and designs occur.

Original and added wells are included in these numbers.

a. HR-3 and DR-5 are not included in the total, as they are no longer operating.

b. DX and HX refer to expanded pump-and-treat systems that focus on remediation of 100-D and 100-H, respectively.

In Situ Redox Manipulation Barrier and Fortification Test. An ISRM permeable reactive barrier continues to treat Cr(VI) in the 100-D southern plume, in conjunction with the DX pump-and-treat system (*Fiscal Year 2008 Annual Summary Report for the In Situ Redox Manipulation Operations* [DOE/RL-2009-01]). The ISRM barrier consists of 65 wells spaced across the width of the 100-D southern plume parallel to the shoreline. The ISRM barrier was established by injecting sodium dithionite, which reacts with iron in the soil, into the aquifer through these wells to create a permeable treatment zone where contaminated groundwater can flow. The treatment zone reduces Cr(VI) to Cr(III). The majority of the remaining chemical reaction byproducts (predominantly sulfate) was then pumped out of the treated portion of the aquifer and transferred to the ISRM Evaporation Pond. The ISRM Pond is no longer used and is scheduled to be decommissioned.

The ISRM barrier continued to convert Cr(VI) to a less-toxic, less-mobile form (Cr[III]) within a portion of the aquifer. Concentrations in some downgradient wells remained above the remedial action goal of 20 μg/L (for interim action ROD) because the northeastern segment of the barrier was not working effectively. Therefore, new DX extraction wells were installed downgradient from the barrier to treat this area, as agreed to by the Tri-Parties. The ISRM barrier will continue to provide a measure of conversion to Cr(III) until the amendments are exhausted.

1.2.3.7 Riparian and Near-shore Areas

The River Corridor has been divided into three environmental zones for purposes of investigation (RCBRA [DOE/RL-2007-21, *River Corridor Baseline Risk Assessment, Volume I: Ecological Risk Assessment*]; Integrated Work Plan [DOE/RL-2008-46]): the upland, riparian, and near-shore aquatic zones. Summary definitions of these environmental zones are presented in Section 3.9. These zones are identified here for describing the investigations in the riparian and near-shore areas.

Riparian and near-shore 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, the riparian zone 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], hereinafter called RCBRA Literature Review). 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 near-shore 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 near-shore 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 near-shore zones.

Investigations historically conducted in the riparian and near-shore areas of 100-D/H are summarized in the RCBRA Literature Review (PNNL-SA-41467). In addition to these historical investigations, other sampling and analytical data have been collected from riparian and near-shore 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 near-shore areas were conducted as part of the RCBRA ecological risk assessment (ERA) (RCBRA [DOE/RL-2007-21, Volume 1]; *100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan* [DOE/RL-2005-42], hereinafter called the RCBRA SAP).

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 in 1983. Contaminant data specific to the 100-D Area riverbank springs indicated slightly elevated concentrations of nitrates, with a maximum concentration of 2,000 µg/L. Tritium and nitrate were detected in riverbank spring water samples in the 100-H Area. The maximum concentration of tritium in spring water samples was 4,000 pCi/L, compared with a maximum of 64,900 pCi/L in a groundwater sample collected from a well. The maximum concentration of tritium in an adjacent surface water sample was 65 pCi/L. The maximum nitrate concentration in a 100-H spring water sample was 5,750 µg/L.

Sampling of riverbank springs and adjacent surface water was performed along the Hanford Reach from the 100-B Area to the Hanford Town Site in 1991. Two springs were sampled at 100-D (*Sampling and Analysis of 100 Area Springs* [DOE/RL-92-12]). Riverbank spring water from these two locations had the highest concentrations of chromium (72 and 124 µg/L) measured during this entire study. In addition, tritium (1,200 and 3,100 pCi/L), strontium-90 (1.8 and 4.5 pCi/L), technetium-99 (0.3 to 4.9 pCi/L), and total uranium (0.9 and 1 pCi/L) were detected in riverbank spring water. Columbia River water samples collected near these riverbank spring sampling locations were below detectable limits, except for total uranium; total uranium concentrations in surface water were judged to be similar to concentrations in background locations. Samples of riverbank sediments had the highest concentrations of chromium (maximum of 122 mg/kg) for all sediment sampling locations. Gross beta concentrations in sediments ranged from 18 to 19 pCi/g. Concentrations of all of radionuclides were below detection or similar to concentrations in background locations. Five springs were sampled at 100-H. Riverbank spring water from these locations contained detectable levels of chromium (16 to 52 µg/L), tritium (400 to 3,800 pCi/L), strontium-90 (0.4 to 13 pCi/L), and total uranium (0.7 to 1.2 pCi/L). River water samples collected in the vicinity of these riverbank springs had concentrations below the detectable levels for chromium, strontium-90, and technetium-99. Total uranium levels in river water samples at 100-H were detected but were similar to levels in background locations. In addition to elevated chromium concentrations (maximum of 122 mg/kg), riverbank spring sediment from 100-H had detectable levels of strontium-90, cesium-137, potassium-40, radium-226, thorium-228, and thorium-232 (*Sampling and Analysis of 100 Area Springs* [DOE/RL-92-12]).

Also in 1991, six sediment samples were collected from four locations in the vicinity of 100-D (*100 Area Columbia River Sediment Sampling* [WHC-SN-EN-TI-198]). Maximum concentrations of potassium-40, radium-226, uranium-233/234, uranium-238, thorium-228, and thorium-232 were no different than concentrations in upstream background samples. Two other radionuclides, cesium-137 and europium-152, had concentrations higher than those of the background samples (cesium-137, maximum 1.3 pCi/g; europium-152, maximum 0.9 pCi/g). Nine radionuclides were detected in the 100-D Area, but they were not detected in the background samples or in samples from the 100-B/C or the 100-K Areas. These radionuclides were cobalt-60 (maximum 0.41 pCi/g), europium-154 (maximum 0.04 pCi/g), europium-155 (maximum 0.04 pCi/g), radium-228 (maximum 0.54 pCi/g), thorium-231 (maximum 0.29 pCi/g), thorium-234 (maximum 0.69 pCi/g), uranium-235 (maximum 0.02 pCi/g), neptunium-237 (maximum 0.48 pCi/g), and americium-241 (maximum 0.24 pCi/g). Sediment samples were collected from four locations near the 100-H Area. Concentrations of most radionuclides detected (potassium-40, radium-226, thorium-228 and thorium-232) were similar to sediment concentrations from a reference site at Vernita, upstream from the Hanford Site. Sediment concentrations of europium-152 and uranium isotopes that were detected were above the reference level at Vernita. The maximum concentration for europium-152 was 1.8 pCi/g; for uranium-233/234, the maximum concentration was 2.3 pCi/g; and for uranium-238, the maximum concentration was 2.3 pCi/g. Plutonium-239/240 was detected in a single sediment sample, with a concentration of 0.07 pCi/g.

The SESP project does not routinely monitor Columbia River water near 100-D and 100-H. The nearest routinely monitored locations are the annual cross-river transects at 100-N and 100-F. Riverbank spring locations near 100-D and 100-H 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-D and 100-H 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-D and 100-H sediments were similar to levels detected in previous years (*Hanford Site Environmental Report for Calendar Year* 2009 [PNNL-19455], hereinafter called 2009 Sitewide Environmental Report).

Investigations of riparian and near-shore areas were conducted in support of the RCBRA. Riparian and near-shore 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 near-shore study sites in 100-D/H (RCBRA SAP [DOE/RL-2005-42], Table C-1). Eight near-shore (aquatic) study sites were near 100-D/H. Eight riparian study sites were also upstream and downstream from 100-D/H, and between the 100-D and 100-H operational areas.

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

Media collected in the upland and riparian zones included soil, vegetation, invertebrates, small mammals, and kingbirds (kingbirds in the riparian zone only). Near-shore 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 in riparian and near-shore areas is presented in Chapter 4 of this RI/FS report.

1.2.4 Risk Assessments

Risk assessments have been conducted for the 100 Area to provide the foundation for establishing the need for remedial action to protect HHE. Three key risk assessments, i.e., the QRAs performed in the early 1990s, RCBRA (DOE/RL-2007-21), and CRC (DOE/RL-2010-117), are summarized below. The results of RCBRA and the CRC are described in more detail (and used) in Chapters 4, 6, and 7 of this RI/FS.

Qualitative Risk Assessments. QRAs were conducted to define the basis for remedial actions under Interim Action RODs (Past-Practice Strategy [DOE/RL-91-40]). Assessment of human health risks in the QRAs was based on frequent use and occasional use scenarios, which reflected current guidance for that time. 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 the 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.

River Corridor Baseline Risk Assessment. The RCBRA (DOE/RL-2007-21, Volume I, and *River Corridor Baseline Risk Assessment, Volume II: Human Health Risk Assessment*) has been conducted to characterize current and potential future risks to human health and the environment that may be posed by releases of contaminants in the River Corridor. The RCBRA supports the current remediation decisions and consists of a human health risk assessment (HHRA) and an ERA.

The HHRA (DOE/RL-2007-21, Volume II) provides as assessment of residual risks for remediated waste sites using the residential land use exposure scenario that was the basis for the cleanup values for the interim action ROD cleanup. In addition, the HHRA provides an assessment of residual risks for remediated waste sites and broad areas using a broad range of hypothetical receptors, including adults and children living in the River Corridor, Tribal members, recreational users, and adults working on the site. A screening level groundwater risk assessment is also completed to evaluate potential risks associated with potential exposure to contaminated groundwater.

One of the objectives of the RCBRA is to determine if the interim actions were protective of ecological receptors, which is achieved through the evaluations conducted in the ERA (DOE/RL-2007-21, Volume I). The scope of this ERA addresses upland areas, including remediated CERCLA waste sites, the White Bluffs and Hanford Townsites, and the 300 Area. In addition, the ERA evaluates the riparian and near-shore aquatic zones as well as areas of groundwater emergence on the south and west shoreline of the Columbia River. The ERA approach is based on an overall CSM that summarizes what is known about site conditions (including the location of contamination sources) and describes transport and exposure pathways through various environmental media that may be important in evaluating potential exposure to ecological receptors. Where possible, multiple lines of evidence were employed to comprehensively evaluate the potential for adverse effects on plants, invertebrates, and wildlife.

Columbia River Component Risk Assessment. The CRC (DOE/RL-2010-117) provides a comprehensive HHRA (Volume II) and a screening-level ERA (Volume I). The intent of the CRC HHRA was to complete the assessment of the "bank-to-bank" Hanford Reach and downstream areas (i.e., Lake Wallula) of the Columbia River, characterizing risk in areas not previously addressed under the RCBRA (DOE/RL-2007-21). Human exposure scenarios include an avid angler, casual user, subsistence farmer, and a Native American (Yakama Nation) subsistence fisher. The CRC HHRA identifies fish consumption as the largest potential contribution to overall human health risks.

The CRC ERA(DOE/RL-2010-117, Volume I) also uses analytical chemistry collected from surface water, sediment, pore water, island soils, and fish to evaluate the potential for risk to ecological receptors including aquatic life living within the Columbia River and wildlife frequenting or inhabiting the islands within the river. Based on a screening-level ecological risk assessment, the CRC ERA(DOE/RL-2010-117, Volume I) identifies some contaminants as contaminants of potential ecological concern (COPEC); mostly metals. The CRC further considered whether COPECs are attributable to Hanford Site-related sources.

Conclusions from the CRC HHRA (DOE/RL-2010-117, Volume II) are discussed in Section 6.4.2, and the CRC ERA (DOE/RL-2010-117, Volume I) are reviewed in Section 7.6.2.

1.2.5 CERCLA Five-Year Review

Effectiveness of the interim actions discussed previously is evaluated through the CERCLA 5-year review process. This review determines whether the selected remedy remains protective of HHE. Since the issuance of the first interim ROD, there have been three 5-year reviews for the 100 Area NPL (40 CFR 300, Appendix B) Site. *USDOE Hanford Site First Five Year Review Report* (EPA, 2001) recommended system enhancements to the 100-HR-3 groundwater pump-and-treat system for chromium that have been implemented. *The Second CERCLA Five-Year Review Report for the Hanford Site* (DOE/RL-2006-20) listed five issues and recommended six actions for 100-D/H:

- **Issue 8.** Groundwater monitoring data indicate there is an unidentified chromium vadose source in the 100-D Area near the demolished 190-DR clear wells.
  - **Action 8-1.** Complete a field investigation to investigate additional sources of chromium groundwater contamination within the 100-D Area. Perform additional geologic and geochemical investigations of the vadose zone in the 100-D Area. Investigations were conducted for both the southern and northern plume (*Investigation of Hexavalent Chromium Source in the Southwest 100-D Area* [SGW-38757]; *Report on Investigation of Hexavalent Chromium Source in the Northern 100-D Area* [DOE/RL-2010-40]). In addition, several boreholes and wells have been installed as part of the RI/FS (100-D/H Work Plan [DOE/RL-2008-46-ADD1]). This completed the required action.
- **Issue 9.** There is less than adequate data to characterize potential chromium groundwater contamination between the 100-D and 100-H Area, in the area known as the "Horn."
  - **Action 9-1.** Perform additional characterization of the aquifer for chromium contamination between the 100-D and 100-H Area, in the area known as the "Horn," and evaluate the need to perform remedial action to meet the RAOs of the 100-D ROD for interim action. This issue will also be addressed in the record of decision. This action was previously completed and is summarized in *Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* (DOE/RL-2008-42).
  - **Action 9-2.** Incorporate the "Horn" area into the 100-HR-3 interim ROD treatment zone if Action 9-1 indicates the "Horn" contains a groundwater chromium plume that needs immediate remediation. DOE has completed the RPO evaluation of the pump-and-treat system and is currently implementing the results (*100-HR-3 Remedial Process Optimization Modeling Technical Memorandum* [SGW-40044]). DOE installed additional extraction and injection wells throughout the Horn area in FY 2009 and FY 2010 as part of RPO. This completed the required action.
- **Issue 10.** Some of the groundwater wells near the 182-D reservoir show conductivity values similar to values expected for raw water, indicating some leakage from the reservoir.
  - **Action 10-1.** Issue direction to the operating contractor to change operations to minimize leakage from the 182-D reservoir further. Direction was given to the contractor, and the action was completed. The leaks and their effect on groundwater flow have significantly diminished since the reduction of storage volume in the reservoir in 2004, to the point that influences on groundwater flow from reservoir leakage are indistinguishable from those created by nearby

pump-and-treat activities (*Project Work Plan: Hanford 100-D Area Treatability Demonstration: Accelerated Bioremediation through Polylactate Injection* [PNNL-SA-50369]).

- **Issue 11.** A few wells within the ISRM barrier have shown break through much sooner than expected.
  - **Action 11-1.** Perform initial limited iron amendments to the ISRM barrier to evaluate whether this enhances performance. Results of the iron amendment tests are documented in *Treatability Test Report on Mending the In Situ Redox Manipulation Barrier Using Nano-Size Zero Valent Iron* (DOE/RL-2009-35). This completed the required action.
- **Issue 12.** Groundwater samples from deeper wells extending below the aquitard exceed the drinking water standard (100 µg/L) for chromium. The extent of chromium contamination in this zone is not well understood.
  - **Action 12-1.** Perform additional characterization of the aquifer below the initial aquitard. DOE installed three wells in the Horn area, screened in the RUM unit (*Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* [DOE/RL-2008-42]), and continued to monitor three wells in the 100-H Area. Five wells (three in 100-H and two in 100-D) were installed as part of the 100-D/H Work Plan (DOE/RL-2008-46-ADD1). The wells have been drilled through the RUM and screened within the first water-bearing unit encountered. This completed the required action.

The third 5-year review was published in March 2012 (*Hanford Site Third CERCLA Five-Year Review Report* [DOE/RL-2011-56]). There were two issues and two actions identified for the 100-D/H Area.

- **Issue 2.** Recent data indicates a low spot in the surface of the Ringold Upper Mud in the 100-HR-3 OU that may trap hexavalent chromium in the aquifer, which in combination with a likely continuing vadose source of hexavalent chromium at the adjacent 100-D-100 waste site results in persistent hexavalent chromium concentrations in groundwater southeast of the 182-D Reservoir.
  - **Action 2.1.** Remove, treat, and dispose of the chromium source discovered in the deep vadose zone at 100-D-100. Remediation of the 100-D-100 site to remove the chromium source in the vadose zone is ongoing.
- **Issue 3.** Leakage and spills from the 182-D Reservoir and export water system may contribute to movement of contaminants into the vadose zone.
  - **Action 3.1.** Complete the engineering export water scoping study to evaluate whether the 182D Reservoir and export water system is necessary to support the Hanford Cleanup Mission. *Hanford Site Water System Master Plan* (HNF-5828), called the Water System Master Plan, indicates that the 182D reservoir will be closed following installation of pumps to bypass the reservoir.

1.2.6 Summary

Chapter 1 summarized historical information, prior assessments and remediation work, treatability tests, and other relevant studies. This information provides a picture of current 100-D/H site conditions and establishes a foundation for the remainder of the RI/FS document.

Hanford-related contamination of the 100-D/H Area began with reactor construction in 1943 and continued until related operations ceased. Radiological and chemical contamination of soil and groundwater resulted that remains to date. Characterization efforts have delineated the nature and extent of groundwater and vadose zone contamination. Risks to HHE were recognized early, resulting in operational actions to limit transport of contaminants to potential receptors. Despite those actions, contamination levels exceeding standards have resulted. Interim remedial actions, including groundwater pump-and-treat and in situ treatments have been deployed to address groundwater contamination. Similarly, demolition of surface facilities and excavation of contaminated soil have been performed to begin the process of restoring the land and groundwater to beneficial use.

2 Study Area Investigation

> ***Highlights***
> - The investigation addressed the data gaps identified in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1).
> - Ten soil boreholes (five of which were converted to temporary wells), five test pits, twelve unconfined aquifer monitoring wells, and five RUM wells were installed.
> - Seventy wells were installed as part of the RPO. Data from that effort were incorporated into the analysis.
> - Fifty-two wells were sampled for the spatial and temporal groundwater sampling.

The study area investigation included the vadose zone and groundwater in 100-D/H, as guided by an approved work plan. Development of the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) was based on review and evaluation of relevant documented information and data. The work plan identified additional information to support a remedial alternative evaluation and decision. This chapter describes the data needs (Table 2-1), the data collected to fill them, and the corresponding scope of work (including field activities, tests, analyses, and data sources) that was designed and carried out in the RI/FS. Chapters 3, 4, and 5 present results of the RI/FS activities. These chapters include data collected pursuant to the work plan referenced above as well as from previous studies and historical information to identify the nature and extent of contamination. The scope of work is outlined in the Integrated Work Plan (DOE/RL-2008-46), 100-D/H Work Plan (DOE/RL-2008-46-ADD1), and the 100-D/H SAP (DOE/RL-2009-40).

The following sections of this chapter describe the field activities, other investigations and ongoing activities that contributed to this RI/FS. These sections summarize the scope of work, document any deviations from the work plan, 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 remedial action alternatives, including *Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River* (DOE/RL-2008-11), hereinafter called Columbia River RI Work Plan, the RCBRA (DOE/RL-2007-21), and ongoing groundwater and aquifer tube monitoring.

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

2.1 Remedial Investigation Activities

The RI field activities included boreholes, test pits, groundwater monitoring well installation, spatial and temporal groundwater monitoring, and associated sampling and analysis for each activity. Table 2-1 presents the relationship of the field efforts and the data needs that were identified in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1). Table 2-2 includes the supplemental investigations identified in the work plan and other investigations that may affect cleanup decisions for 100-D/H. Table 2-3 summarizes the field program and Table 2-4 shows the field samples collected. Figures 2-1, 2-2, and 2-3 present the locations where field sampling was conducted for 100-D, 100-H, and the Horn, respectively.

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to 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 nature and extent of contamination in the vadose zone.	Continue interim remedial actions as they have demonstrated to be efficient in obtaining the necessary data during remediation. Obtain data documenting the remaining residual contamination following completion of the interim remedial action.	Interim remedial action and sampling have continued at 100-D/H waste sites. Data for sites that were reclassified before June 2012 have been evaluated through the risk evaluation process presented in this report. The verification data collected during the interim remedial actions are presented in Appendices D and E and evaluated in Chapters 5, 6, and 7. Knowledge and experience from the implementation of interim remedial actions is also used in the evaluation of technologies in Chapter 8.	Yes
2. Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath remediated waste sites.	Characterize beneath and adjacent to remediated waste sites to assess the nature and extent of contamination in the vadose zone.	Drill 10 boreholes and install 2 groundwater monitoring wells; also excavate 5 test pits. Collect and analyze samples to assess vertical extent of contamination in the vadose zone. Excavate test pits to assess potential Cr(VI) sources and contaminant concentrations to maximum depths of 6.1 to 7.6 m (20 to 25 ft).	Ten boreholes drilled for waste site characterization were located as follows (borehole ID): • 116-D-1B Trench (C7855) • 116-D-7 Retention Basin (C7851) • 116-DR-1&2 Trench (C7852) • 116-DR-9 Retention Basin (C7850) • 116-H-1 Trench (C7864) • 116-H-4 Crib (C7862) • 116-H-6 Solar Evaporation Basin (C7860) • 116-H-7 Retention Basin (C7861) • 118-D-6:3 Reactor Fuel Storage Basin (FSB) (C7857) • 118-H-6:3 Reactor FSB (C7863) Groundwater monitoring wells were installed at the following waste sites (Well ID; borehole ID; SAP Reference number): • 100-D-56:1 Pipeline (Well 199-D5-143; C8375; Well 9 redrill) • 100-D-12 French Drain (Well 199-D5-144; C8668; Well R5 redrill) • 116-D-1A Trench (Well 199-D5-132; C7622; Well 4) A test pit was excavated at each of the following waste sites: • 100-D-12 French Drain (site has a well also) • 100-D- 4 Trench • 116-D-4 Crib • 116-H-2 Trench • 1607-H4 Septic System	Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion	Data Gap Filled?
			Samples were collected in boreholes through the vadose zone, including at the Hanford formation/Ringold Formation contact (where present). Soil samples from boreholes and test pits were analyzed for location specific target analytes, field screening parameters, and batch leach testing. Borehole information and analytical data are presented in Chapters 3 and 4, and Appendices C, D, and M.	
3. Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath and around reactor structures.	Characterize beneath and around the reactor structures to assess nature and extent of contamination in the vadose zone.	Drill two boreholes near the reactor structures in areas most likely to contain soil contamination. Collect and analyze samples to assess vertical extent of contamination in the vadose zone.	Soil boreholes were drilled at two FSBs. (These boreholes also meet the data needs in Data Gap 2.) • 118-D-6:3 Reactor FSB (C7857) • 118-H-6:3 Reactor FSB (C7863) Samples were collected through the vadose zone, including at the Hanford formation/ Ringold Formation contact (where present). Samples were analyzed for location specific target analytes, field screening parameters, and batch leach testing. Analytical results from these two boreholes are presented in Chapter 3 (Section 3.4.3),Chapter 4 (Sections 4.3.1) and Appendix D.	Yes
4. Unidentified waste sites (orphan/discovery sites) may exist in 100-D/H. Unidentified sites may include chromium contamination in surface soil because of undocumented spills.	Identify new waste sites and potential sources of contamination.	Complete the OSE process in the Horn and conduct a supplemental survey of 100-D Operational Area.	The OSE process was completed in the Horn area (*100-F/IU-2/IU-6 Area – Segment 4 Orphan Sites Evaluation Report* [OSR-2011-0001]). The evaluation identified six additional waste sites (600-380, 600-381, 600-382, 600-383, 600-384, and 600-385). A supplemental survey will be conducted at 100-D when remediation has been completed.	Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion	Data Gap Filled?
5. The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in selected areas.	Define the extent of groundwater contamination above cleanup standards in select areas of the unconfined aquifer.	Install three new aquifer tubes and five new wells at approved locations in 100-D. Install three new aquifer tubes and five new wells at approved locations in 100-H. Sample the wells for groundwater COPCs presented in the 100-D/H SAP (DOE/RL-2009-40).	**100-D:** A cluster of new aquifer tubes and seven new wells were installed. One additional aquifer tube was added to the cluster of three planned and represents a second deep zone. The aquifer tubes and wells were placed and sampled according to the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) to define the strontium-90 and Cr(VI) plumes, with one additional aquifer tube installed. Samples were collected and analyzed from the Hanford/Ringold lithologic change and from groundwater. The analytical data from the aquifer tubes are presented in Chapter 4 (Section 4.4) and in Appendix D. The groundwater data are presented in Chapter 4 and Appendix D.	Yes[a]
			Aquifer tubes (Sampling point 1) identifiers are: • C7645 • C7646 • C7647 • C7648 The well identifiers are: • 199-D3-5 (C7620; Well 2) • 199-D5-133 (C7621; Well 3) • 199-D5-132 (C7622; Well 4–also for Data Gap 2) • 199-D6-3 (C7623; Well 5) • 199-D5-143 (C8375, Well 9 redrill) • 199-D5-140 (C7866, mislocated Well 9) • 199-D5-144 (C8668, Well R5 redrill- also for Data Gap 2	
			100-H: A cluster of two new aquifer tubes and five new wells were installed. The deep locations for the aquifer tube cluster were not installed because of encountering the RUM at a shallow depth. There was insufficient water at the deep locations for aquifer tube installation. The installed aquifer tubes and wells were placed and sampled according to the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) to define the strontium-90, Cr(VI), and nitrate plumes as outlined in the work plan. Samples were collected and analyzed at the Hanford/Ringold lithologic change and from groundwater. The analytical data from the aquifer tubes are presented in Chapter 4 (Section 4.4) and in Appendix D. The groundwater data are presented in Chapter 4 and Appendix D.	

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion		Data Gap Filled?
			Aquifer tube (Sampling point 8) identifiers are: • C7649 • C7650	The well identifiers are: • 199-H3-6 (C7626; Well 6) • 199-H3-7 (C7627; Well 7) • 199-H6-3 (C7628; Well 10) • 199-H6-4 (C7629; Well 11) • 199-H1-7 (C7630; Well 12)	
6. The level of groundwater contamination entering the Columbia River (in particular, the hyporheic zone) is not well known.	Evaluate the utility and adequacy of aquifer tubes in supporting the understanding of groundwater contamination entering the Columbia River. Collect groundwater upwelling data.	Continue collecting aquifer tube sampling data and information per the existing program. Collect groundwater upwelling samples in the Columbia River (Columbia River RI Work Plan [DOE/RL-2008-11]). A task was included in the Integrated Work Plan (DOE/RL-2008-46) for evaluating and developing an approach to obtain data that will demonstrate compliance with ambient water quality criteria in the river, for proposed new ROD.	Four new aquifer tubes (two at 100-D and two at 100-H) were installed and data collection continues from the existing aquifer tube sampling program. The aquifer tube data are presented and discussed in Chapter 4 (Section 4.5.1.4 and Sections 4.5.2 through 4.5.8). Upwelling samples were collected as per the Columbia River RI Work Plan (DOE/RL-2008-11). Results are presented in *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) and discussed in Section 2.1.7.2 and Chapter 4. Approaches to obtain and assess data to demonstrate groundwater compliance with AWQC in the Columbia River (e.g., monitoring wells, aquifer tubes, and pore water sampling) were evaluated during the remedial investigation. The results of this task are discussed in Section 2.1.7.1 along with summaries of the additional investigations associated with this task.		Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion	Data Gap Filled?
7. The nature and extent of contaminants beneath the unconfined aquifer has not been evaluated.	Collect physical and hydrogeologic information to further support the evaluation of contaminant fate and transport beneath the unconfined aquifer.	100-D: Drill and sample soil and groundwater from two new boreholes (R4 and R5) drilled through the RUM and into the Ringold unit B. 100-H: Drill and sample soil and groundwater from three new boreholes (R1, R2, and R3) drilled through the RUM and into the Ringold unit B. Collect soil samples at 1.5 m (5 ft) into the RUM at the eight wells installed during the pump-and-treat system expansion. Collect samples in the 100-D wells at the Hanford/Ringold geologic contact.	**100-D:** Two new boreholes (R4 and R5) were planned to extend into the RUM, down to the Ringold Formation unit B (presumed) aquifer. These were completed as wells screened in the first water-bearing unit of the RUM. The well identifiers are as follows: • 199-D5-134 (C7624; Well R4) • 199-D5-141 (C7625; Well R5 – mislocated) **100-H:** Three new boreholes (R1, R2, and R3) were drilled through the RUM and into the Ringold Formation unit B (presumed) aquifer. These were completed as wells screened in the first water-bearing unit of the RUM. The well identifiers are as follows: • 199-H3-9 (C7639; Well R1) • 199-H3-10 (C7640; Well R2) • 199-H2-1 (C7631; Well R3) Results from the boreholes are presented in Chapter 3. **Soil Samples:** Split-spoon soil samples at 1.5 m (5 ft) total depth into the RUM were collected from eight wells that were installed as part of the expansion of the 100-D/H pump-and-treat system. Samples were collected in 100-D wells at the Hanford/Ringold lithologic change. For new wells near waste sites, additional split-spoon samples were collected above and below the Hanford formation/Ringold Formation unit E contact. For deep wells, split-spoon soil samples were collected from above the water table; within the unconfined aquifer; within the deep unconfined aquifer at the top of the RUM; at two depths within the RUM (outside of any water producing zone); and within the Ringold Formation unit B (presumed), per the 100-D/H SAP (DOE/RL-2009-40). Analytical results from the soil boreholes are summarized in Chapter 4 (Section 4.3) and presented in Appendix D. Groundwater samples were collected during drilling of R1 through R5 from the unconfined aquifer, water-bearing units of the RUM, and the Ringold Formation unit B aquifer (presumed) for field screening parameters and COPC analysis. Groundwater results for the RUM wells are presented in Chapter 4 (Section 4.4) and in Appendix D.	Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion	Data Gap Filled?
8. It is unknown if contamination within the RUM will adversely affect aquatic receptors in the Columbia River.	Update bathymetric data for the river within 100-D/H to support calculations of contaminant transport to the river and ecological receptors.	Evaluate digital bathymetric data recently compiled by PNNL.	The data were evaluated to provide a better understanding of the relationship between the riverbed and the groundwater flow in the adjacent aquifer. A summary of the bathymetry is included in Section 2.1.7, and the data are incorporated into geologic cross sections in Appendix M. The groundwater upwelling sample results were used to determine if 100-D/H ecological receptors are adversely affected by unconfined aquifer or RUM contamination.	Yes
9. The rate of chemical and hydraulic exchange between the aquifer and the river in the nearshore is unknown.	Collect geochemical and hydrogeologic data to evaluate nearshore area groundwater contaminant fate and transport.	The nearshore area is directly affected by river stage. Available data to provide adequate understanding of groundwater flow paths, contaminant migration, and mixing in the nearshore area have been limited. TPA (Ecology et al., 1989a) milestones state that compliance with cleanup standards in this area is a target.	No specific data collection activities were proposed in this RI. Data from other efforts were used in the RI/FS as defined in *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) and associated *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90), the SAP for Aquifer Sampling Tubes (DOE/RL-2000-59), and the *Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River* (DOE/RL-2008-11). Relevant results from these activities are discussed in Chapters 3, 4, and 5.	Yes
10. The mechanism to explain the persistence of the Cr(VI) plume is unknown.	Collect soil and water samples from the following units: (1) vadose zone, (2) deep vadose zone, (3) rewetted zone, (4) unconfined aquifer, (5) above the RUM, and (6) within the RUM.	Soil and water analyses were needed to determine the potential for each unit to contain sufficient contamination to be a continuing source of groundwater contamination.	Soil and water samples were collected and analyzed per the 100-D/H SAP (DOE/RL-2009-40). Sample locations are identified under Data Gaps 5 and 7, and summarized in Appendix C. Analytical results are presented in Chapter 4 (Section 4.3) and in Appendix D.	Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to 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 maximum contaminant levels had been detected in 100-D, 100-H, and the Horn area. Interim remedial actions are currently operating to address contaminated areas in 100-D, 100-H, and the Horn area. The RI collected data necessary for comparison of potential final remedies in the FS.	Data were collected during the RI and incorporated into the evaluation of technologies presented in Chapter 8 and Appendix I.	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 confirm contaminant distribution coefficients (K_d) to support modeling.	On selected soil samples, physical properties, hydraulic properties, contaminant concentrations, and leaching behavior were evaluated.	Soil samples from each of the deep boreholes, the eight monitoring wells installed during expansion of the pump-and-treat system, seven boreholes drilled through remediated waste sites, and one test pit were collected and analyzed per the 100-D/H SAP (DOE/RL-2009-40). Fate and transport modeling results are presented in Chapter 5 and Appendix F.	Yes
13. Data are needed to better define the spatial and temporal distribution of groundwater contamination.	Collect and analyze groundwater samples from select groundwater monitoring wells.	Additional groundwater data were needed that are spatially representative of 100-D/H, reflect river stage influence, and include groundwater COPCs.	A total of 53 existing wells were scheduled for sampling and analysis for the temporal and spatial analysis. Of these, 52 were included in the analysis. Well 199-D5-41 was sampled once, and then converted to an injection well per *Tri-Party Agreement Change Notice Form: DOE/RL-2009-40, 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, Rev. 0* (TPA-CN-368). The data from this well were not used in the spatial and temporal analysis because the well was sampled only once and did not provide the statistical basis needed. Groundwater results from this sampling effort are presented in Chapters 4 and 6 and Appendix D.	Yes

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

Data Gap	Data Need	Scope of Work	Work Conducted with reference to Section with Discussion	Data Gap Filled?
14. Leakage (current and future) from the 182-D Reservoir and export water lines may affect groundwater flow, contaminant transport, and effectiveness of remedies.	Evaluate future needs for the 182-D Reservoir.	Future operation needs for the 182-D Reservoir may require maintenance of higher water levels.	The water system master plan (*Hanford Site Water System Master Plan* [HNF-5828]) evaluates the future needs and infrastructure solutions for the 182-D Reservoir and export water lines.	Yes
	Collect water level and contaminant concentration data near the 182-D Reservoir.	Data are needed to monitor leakage, effects on groundwater flow and contaminant transport, and potential effects to remedies.	Automated water level monitoring and quarterly sampling at Wells 199-D5-38, 199-D5-33, and 199-D5-34 will continue as part of standard remedy performance evaluation. The Export Water System, including the 182-D Reservoir, is discussed in Chapter 3 (Section 3.7.1).	

a. Cr(VI) was identified in Well 199-D3-5 resulting in greater confidence regarding the location of contamination in 100-D. The edge of the plume was defined using quantile kriging methods described in *Hanford Site Groundwater Monitoring for 2011* (DOE/RL-2011-118). The Cr(VI) results will guide the remedial action design but should not affect the selection of a remedy.

AWQC = ambient water quality criteria
COPC = contaminant of potential concern
ID = identification
OSE = orphan site evaluation
PNNL = Pacific Northwest National Laboratory
RI/FS = remedial investigation/feasibility study
ROD = record of decision
RUM = Ringold Formation upper mud
SAP = sampling and analysis plan
TPA = Tri-Party Agreement

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 AWQC in the river for the ROD. In April 2008, a technical review panel was convened to evaluate groundwater interactions with the Columbia River (*Technical Evaluation of the Interaction of Groundwater with the Columbia River at the Department of Energy Hanford Site, 100-D Area* [SGW-39305]). The panel suggested that the current mixing/dilution conceptual model should be reevaluated. 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.	Table 2-1, Data Gap 6, Work Conducted/Section with Discussion Section 2.1.13, River Corridor Supplemental Investigation Section 4.9.8.4 "Hyporheic Zone"
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 cleanup 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 2.1.13, River Corridor Supplemental Investigation
Reevaluating 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 2007 MTCA ("Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)]) 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 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 soil cleanup value.	Section 2.1.13, River Corridor Supplemental Investigation
Determining a site-specific soil-partitioning value for antimony. This value is necessary for calculation of the 2007 MTCA ("Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)] 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 2.1.13, River Corridor Supplemental Investigation
Reevaluate soil cleanup levels for arsenic to support the ROD. The soil RAG for arsenic under the interim RODs is 20 mg/kg, based on the TPA (Ecology et al., 1989a) to use the1996 MTCA ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740(2)] Method A value (*Remedial Design Report/Remedial Action Work Plan for the 100 Area* [DOE/RL-96-17]). The 2007 MTCA ("Unrestricted Land Use Soil Cleanup Standards" [WAC-173-340-740(2)]) Method A value is also 20 mg/kg. The 2007 MTCA ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740(3)] Method B and "Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)]) soil values for arsenic are below the site arsenic background of 6.5 mg/kg. Selection of a soil cleanup level for arsenic in the River Corridor will be accomplished through development of RODs.	Section 2.1.13, River Corridor Supplemental Investigation
Other Primary Investigations that Potentially Affect Feasibility Study Decisions for Waste Sites and Groundwater Contamination	
Columbia River RI Work Plan (DOE/RL-2008-11).	Section 2.1.7, Surface Water and Sediment Investigation

Table 2-2. Supplemental Investigations and Other Primary Investigations

Scope of Work Identified	Section with Discussion
River Corridor Baseline Risk Assessment (DOE/RL-2007-21).	Chapter 6, Human Health Risk Assessment Chapter 7, Ecological Risk Assessment Section 3.9, Demography and Land Use
Annual Groundwater Monitoring.	Section 2.1.10, Groundwater Investigations Section 4.4, Groundwater Contamination Section 4.5, Distribution of Contaminants
Ongoing Aquifer Tube Sampling.	Section 2.1.10, Groundwater Investigations Section 4.4, Groundwater Contamination Section 4.5, Distribution of Contaminants
Columbia River Component Risk Assessment (DOE/RL-2010-117, Vol. 1 [*Screening-Level Ecological Risk Assessment*] and Vol. II [*Baseline Human Health Risk Assessment*]).	Section 7.5.2, Results and Conclusions of the CRC Section 3.9, Demography and Land Use
Data Summary Report for Hanford Site Coal Ash Characterization (WCH-506).	N/A

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

DOE/RL-2007-21, *River Corridor Baseline Risk Assessment, Volume I: Ecological Risk Assessment*.

DOE/RL-2008-11, *Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River*.

DOE/RL-2010-117, *Columbia River Component Risk Assessment, Volume I: Screening-Level Ecological Risk Assessment*.

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, "Model Toxics Control Act—Cleanup," "Deriving Soil Concentrations for Groundwater Protection."

WCH-506, *Data Summary Report for Hanford Site Coal Ash Characterization*.

AWQC = ambient water quality criteria
CRC = Columbia River Component
HHRA = human health risk assessment
N/A = not applicable
MTCA = Model Toxics Control Act
RAG = remedial action goal
ROD = record of decision
TPA = Tri-Party Agreement

Table 2-3. Summary of 100-D/H Remedial Investigation Field Program

Type	100-D	100-H	Total
New boreholes that have been decommissioned	3	2	5
New boreholes converted to temporary wells	2	3	5
New test pits	3	2	5
New permanent wells (screened in the unconfined aquifer)	7	5	12
New permanent wells (screened in the first water-bearing unit in the RUM)	2	3	5
New aquifer tubes per location	4	2	6
Spatial and Temporal Uncertainty Monitoring Wells			52

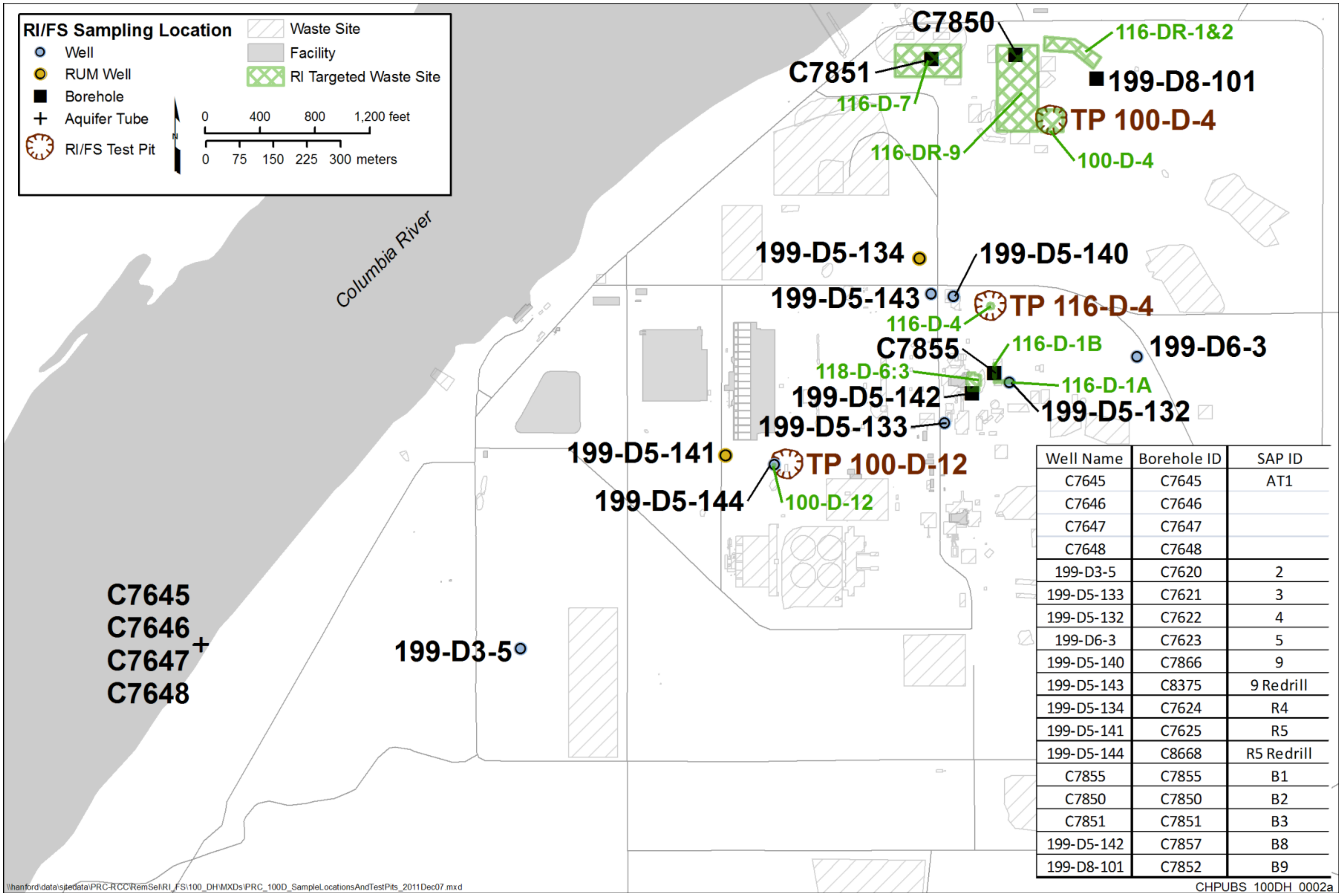
Table 2-4. Number of Field Samples Collected for 100-D/H Remedial Investigation

Source	Soil Samples*	Groundwater Samples*
New boreholes (decommissioned)	70	5
New boreholes (converted to temporary monitoring wells in unconfined aquifer)	57	5
New test pits	27	N/A
New permanent wells (screened in the unconfined aquifer)	154	41
New permanent wells (screened in the first water-bearing unit in the RUM)	63	30
New aquifer tubes	N/A	18
Spatial and Temporal Uncertainty Monitoring Wells	N/A	156

* The number of samples taken reflects the number of intervals sampled (*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]). The samples from each interval were then split amongst several laboratories for different analyses.

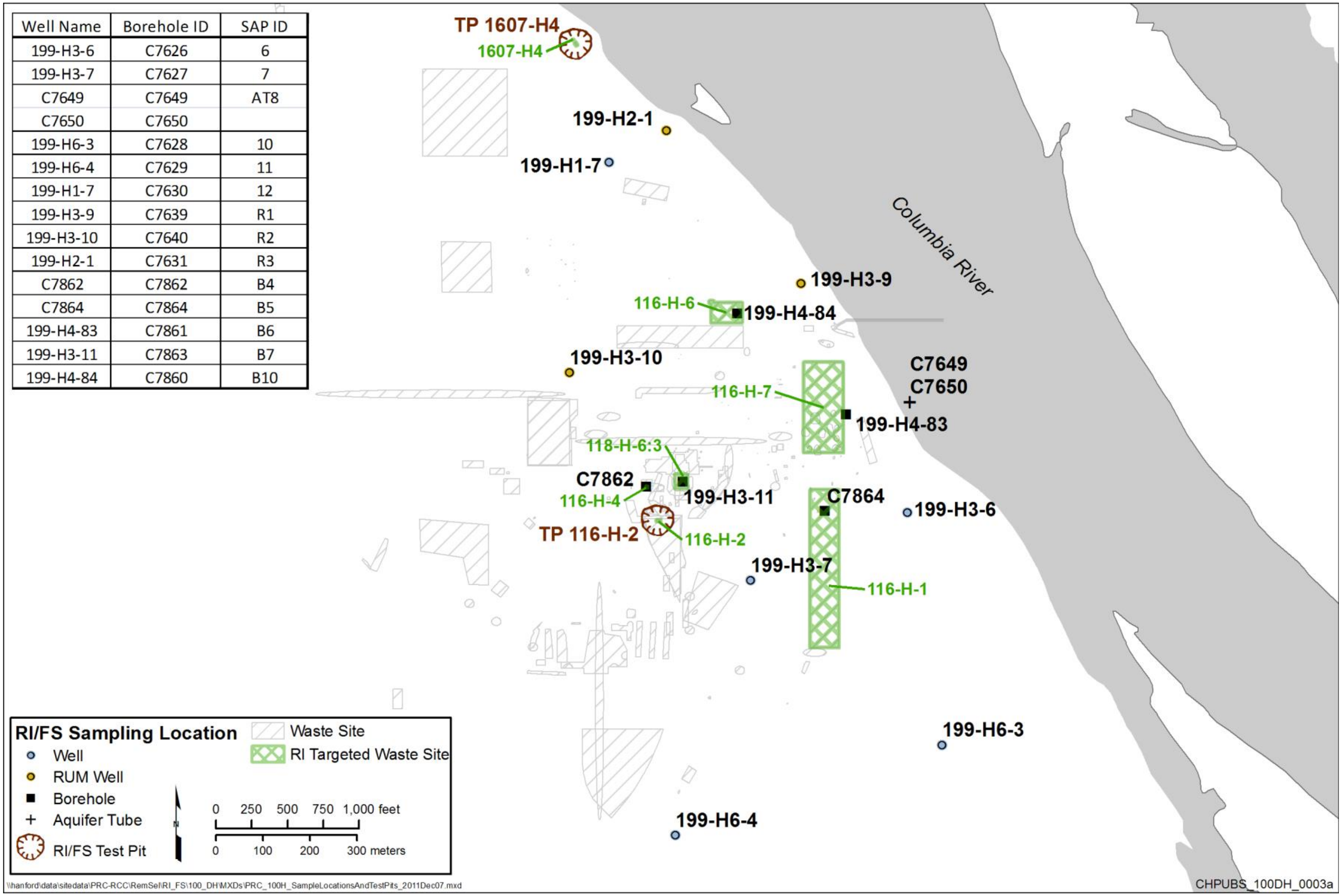
RUM = Ringold Formation upper mud unit

N/A = not applicable



Well Name	Borehole ID	SAP ID
C7645	C7645	AT1
C7646	C7646	
C7647	C7647	
C7648	C7648	
199-D3-5	C7620	2
199-D5-133	C7621	3
199-D5-132	C7622	4
199-D6-3	C7623	5
199-D5-140	C7866	9
199-D5-143	C8375	9 Redrill
199-D5-134	C7624	R4
199-D5-141	C7625	R5
199-D5-144	C8668	R5 Redrill
C7855	C7855	B1
C7850	C7850	B2
C7851	C7851	B3
199-D5-142	C7857	B8
199-D8-101	C7852	B9

Figure 2-1. Map Showing 100-D RI Sampling Locations



Well Name	Borehole ID	SAP ID
199-H3-6	C7626	6
199-H3-7	C7627	7
C7649	C7649	AT8
C7650	C7650	
199-H6-3	C7628	10
199-H6-4	C7629	11
199-H1-7	C7630	12
199-H3-9	C7639	R1
199-H3-10	C7640	R2
199-H2-1	C7631	R3
C7862	C7862	B4
C7864	C7864	B5
199-H4-83	C7861	B6
199-H3-11	C7863	B7
199-H4-84	C7860	B10

Figure 2-2. Map Showing 100-H RI Sampling Locations

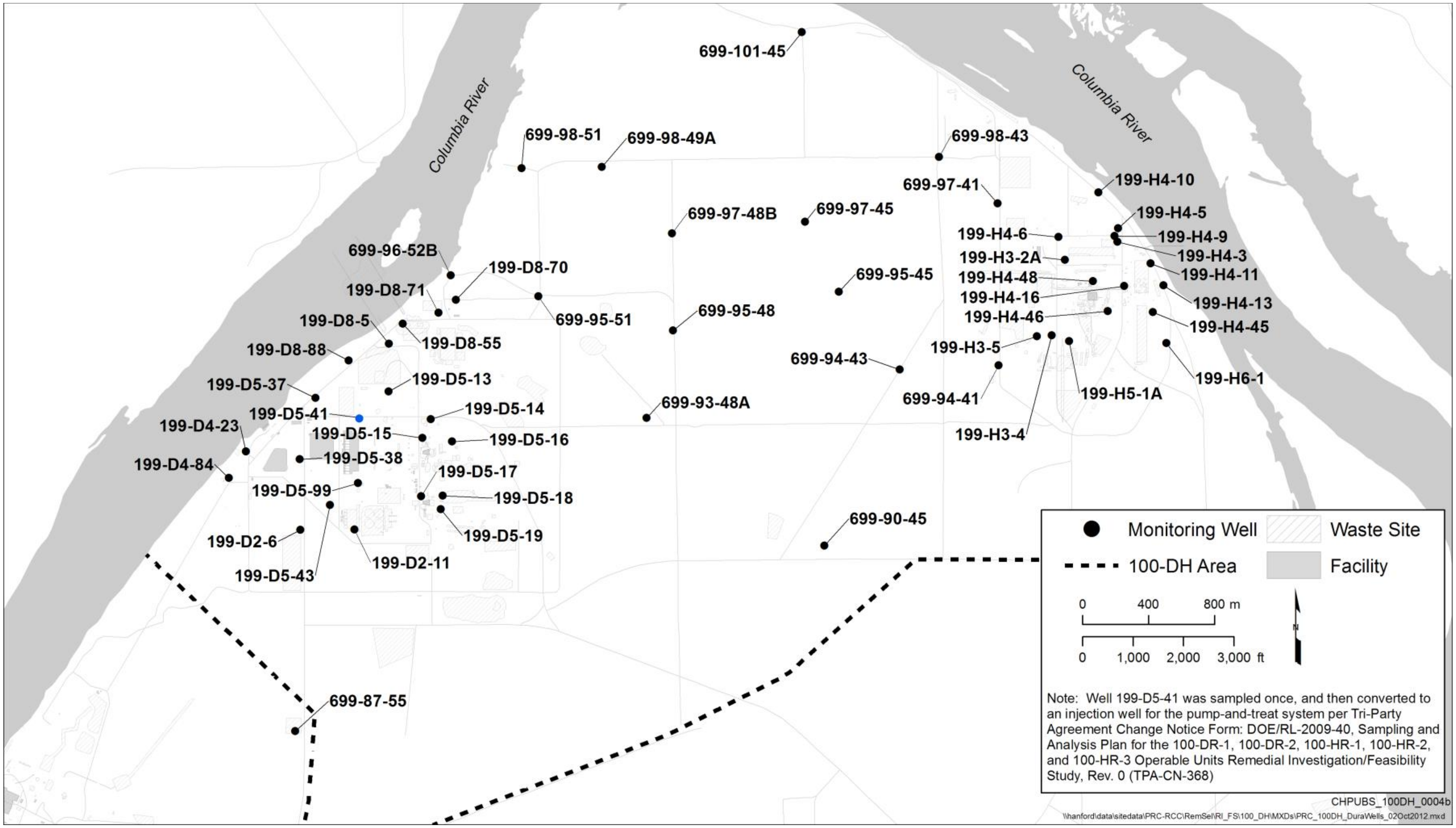


Figure 2-3. 100-D/H RI Spatial/Temporal Groundwater Monitoring Well Locations

The 100-D/H SAP (DOE/RL-2009-40) provides additional details, such as specific sample intervals, sampling and analytical methodology, and technical memorandums that summarize each field activity. Appendix C includes specific information for each borehole and sampling interval, including details of the field effort for soil and groundwater sampling, respectively. Soil samples were typically collected at 1.5 m (5 ft) depth intervals during drilling. Actual soil and groundwater sample depths may have some minor variability from the depths planned in the 100-D/H SAP (DOE/RL-2009-40) because of 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-D/H SAP (DOE/RL-2009-40).

The following sections present details of investigations conducted under the 100-D/H Work Plan (DOE/RL-2008-46-ADD1), 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 (DOE/RL-2007-21).

Variations of the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) typically resulted in additional data collection and were as follows:

- Well Drilling
  - Well 199-D5-141 (C7625; Well R5) was incorrectly located. A replacement well, Well 199-D5-144 (C8668, Well R5 redrill), was drilled in the originally planned location. Samples were collected and analyzed during drilling from both of these wells. Drilling depth and sampling for Well 199-D5-144 (C8668, Well R5 redrill) was conducted under *Tri-Party Agreement Change Notice Form: DOE/RL-2009-40 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, Rev. 0* (TPA-CN-460).
  - Well 199-D5-140 (C7866, Well 9) was incorrectly located and not placed beneath the 100-D-56 sodium dichromate pipeline. A replacement well, Well 199-D5-143 (C8375; Well 9 redrill), was drilled in the originally planned location. Samples were collected and analyzed during drilling from both of these wells.
- Aquifer Tubes
  - One additional aquifer tube was added to the cluster of three planned at 100-D and represents a second deep zone.
  - The deep zone aquifer tubes at the 100-H cluster location were not installed as a result of encountering the Ringold Formation upper mud (RUM) at a shallow depth. There was insufficient water at the deep locations for aquifer tube installation.

Other approved deviations include the following:

- **Spatial and Temporal Sampling.** Well 199-D5-41 was sampled once and then converted to an injection well for the pump-and-treat system per *Tri-Party Agreement Change Notice Form: DOE/RL-2009-40, 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, Rev. 0* (TPA-CN-368).
- **Temporary Well Installation in 5 of 10 Boreholes.** Five boreholes were drilled into waste sites and completed as 10 cm (4 in.) temporary wells: 116-DR-1&2 (Trench), 118-D-6:3 (FSB), 116-H-6 (Solar Evaporation Basin), 116-H-7 (Retention Basin), and 118-H-6:3 (FSB). The well names and

associated borehole IDs are as follows: 199-D5-142 (C7857), 199-D8-101 (C7852), 199-H4-83 (C7861), 199-H4-84 (C7860), and 199-H3-11 (C7863).

2.1.1 RI Datasets Used in RI/FS

Historical and RI data are evaluated in this report. Appendix D provides additional details on the dataset along with data. Appendix D Table 1 is a key to the data tables contained within the Appendix. Appendix D Tables 2 through 9 provide sample identifiers and analytical results from both historical and RI sampling. 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 before initiation of the current RI/FS field investigation activities. Data sources include the 70 RPO wells, existing monitoring wells, decommissioned well geologic data, aquifer test and rebound study, the Horn study, and the northern and southern plume investigations, among others:
  - Waste site remedial action soil analytical data (Cleanup Verification Package [CVP] and Remaining Site Verification Packages [RSVP] data) for the 17 waste sites investigated in the RI. This dataset was used in the CSM evaluation of the nature and extent of soil contamination (Chapter 4, Section 4.9), groundwater protection (Chapter 5), HHRA (Chapter 6), and ERA (Chapter 7). Other CVP and RSVP data are presented in Appendices D and E.
  - Field investigation soil analytical data (LFI data). This dataset was used in the evaluation of the nature and extent of soil contamination (Chapter 4), groundwater protection (Chapter 5), HHRA (Chapter 6), and ERA (Chapter 7).
  - Groundwater analytical data (January 1, 2006 to December 31, 2011). This dataset was used in evaluating the nature and extent of groundwater contamination (Chapter 4) and provides the basis for the initial plumes for groundwater modeling (Appendix F). Historical groundwater data was included to add to the understanding of the nature and extent of contamination, especially as it relates to the sources of contamination.
  - Well and borehole drilling and well construction information. This dataset was used in the development of hydrogeologic cross sections, aquifer isopach map, and RUM surface contour map (Chapter 3 and Appendix M) and groundwater model development (Chapter 5 and Appendix F).
  - Fate-and-transport parameters (for example, geochemical parameters, hydrogeologic parameters, and soil physical properties). This dataset was used in the development of the groundwater model and fate-and-transport evaluations (Chapter 5 and Appendix F).
  - Geologic information. This dataset was used in the development of the hydrogeologic cross sections, aquifer isopach map, and RUM surface contour map (Chapter 3 and Appendix M) and groundwater model development (Chapter 5 and Appendix F).
  - Groundwater levels and river stage. This dataset was used in the development of groundwater flow maps and groundwater model developments (Chapter 5 and Appendix F).
  - CVP data collected for the 144 interim closed-out waste sites per the interim action ROD as part of the ongoing interim waste site remediation are used to develop and refine the CSM (Section 4.9), are qualitatively discussed for the interim closed-out waste sites further characterized in the RI (Chapter 4,Sections 4.3.2 to 4.3.18), and are used in surface and groundwater protection, the human health risk assessment, and the ERA in Chapters 5, 6, and 7.

  - Data collected during the RI/FS field investigation activities.
  - Soil analytical data. Depth specific soil samples collected during RI borehole and well installation are used to evaluate contaminant distribution in the vadose zone and to develop/refine the CSM (Chapter 4), groundwater protection (Chapter 5), and HHRA (Chapter 6).
- Groundwater analytical data:
  - Spatial and temporal groundwater monitoring data. This dataset was used in the HHRA (Chapter 6) and understanding of spatial and temporal distribution of groundwater contaminants (Chapter 4).
  - Groundwater samples collected from RI boreholes and monitoring wells. Depth discrete groundwater samples were used to establish the vertical distribution of contaminants in groundwater (Chapter 4) and to develop/refine the CSM.
- Soil physical properties (grain size, moisture content, and porosity). These data were used in the groundwater model development (Appendix F), fate and transport modeling, and preliminary remediation goal (PRG) development.
- Hydraulic conductivity. These data were used in the groundwater model development (Appendix F).
- Geophysical logging. The geophysical logs from RI boreholes are presented in Appendix M. These data help with the understanding of the CSM and transport of contaminants through the vadose zone.
- Distribution coefficient data for metals. This dataset is used in the evaluation of fate-and-transport of metals (Chapter 5).

Analytical data used in the RI/FS (Appendix D) were collected and analyzed in a fixed laboratory using approved methods with specific quality assurance/quality control (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 quantity to support regulatory decision making.

2.1.2 Historical Information Review

Historical information for 100-D/H was researched and considered during the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) development and in the preparation of this report. Section 1.2.3 and Appendix B summarize those reports containing relevant or significant information. In addition, a summary of site history and 100-D/H operational and process history is presented in Section 1.2.2.

2.1.3 Surface Features

Surface feature mapping, such as high-resolution topography, was conducted using Light Detection and Ranging (LIDAR) technology for 100-D/H in 2008. 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 mapping is estimated at 0.11 m (4.3 in.). LIDAR data were used to create a topographic map of 100-D/H for defining surface relief/elevation differences. Surface topography (Section 3.1) establishes part of the framework needed to evaluate contaminant fate and transport. LIDAR was also used in conducting the non-operational area evaluation, discussed in Appendix K.

2.1.4 Contaminant Source Investigations

The OSE is a systematic approach to review land parcels and identify potential waste sites within the River Corridor that are not currently listed in existing CERCLA decision documents (RODs). The OSE is discussed as part of the nonoperational area evaluation in Chapter 1 and is included in Data Gap 4 (Table 2-1).

The OSE process in 100-D was completed in February 2009 and identified 30 new waste sites (*100-D Area Orphan Sites Evaluation Report* [OSR-2006-0001]). In 100-H, the OSE was also completed in February 2009 (*100-H Area Orphan Sites Evaluation Report* [OSR-2008-0002]) and identified 15 new waste sites. The OSE for the remainder of 100-D/H, primarily the Horn area, was completed in 2011 (*100-F/IU-2/IU-6 Area – Segment 4 Orphan Sites Evaluation Report* [OSR-2011-0001]) and identified six new waste sites. The waste site numbers for these orphan sites are 600-380, 600-381, 600-382, 600-383, 600-384, and 600-385. Evaluation of these new waste sites will be conducted to determine their status (that is, “no action,” “not accepted,” “rejected,” or “accepted”) and remediation will be carried out as appropriate. In addition, discovery site identification continues during ongoing remedial actions.

2.1.5 Meteorological Investigations

The Hanford Meteorological Station (HMS) is operated by Mission Support Alliance (MSA) for DOE (http://www.hanford.gov/hms/). HMS provides a range of Hanford Site weather forecast products and real-time meteorological data, and currently maintains an extensive historical database of meteorological and climatological data. Meteorological 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 to determine compliance with state and federal regulatory requirements. These regulations include a radiological standard, which requires that Hanford Site emissions will 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 the 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 generate actual or potential pollutants of concern. DOE provides information to Washington State and EPA clean air offices describing the emissions. The following text summarizes the most recent information regarding Hanford Site air monitoring activities (2009 Sitewide Environmental Report [PNNL-19455]).

2.1.6.1 Air Monitoring Near Facilities and Operations

Ambient air is monitored at locations on the Hanford Site near facilities and operations. Samplers are located primarily within approximately 500 m (1,640 ft) of projects or facilities having a known potential for, or history of, environmental radiation releases. This ambient monitoring is termed near-facility environmental monitoring. Monitoring locations are associated largely with major nuclear facilities and waste storage, disposal, or cleanup activities. Occasional adjustments are made in the number or location of the monitoring stations as changes in the sources of emissions may occur.

2.1.6.2 Air Monitoring at Hanford Sitewide and Offsite Locations

As part of the Hanford Site Environmental Surveillance Program, near facility ambient air samples are collected at four continuously operating locations associated with 100-D and four locations associated with 100-H (Figure 2-4). In addition, 11 ambient air monitors are operated at locations representing the Hanford Site perimeter, along with seven monitoring stations in nearby communities of Basin City, Benton City, Kennewick, Mattawa, Othello, Pasco, and Richland, Washington, and one in a distant community (Yakima, Washington).

Samples are 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 are collected at each station biweekly and monitored for gross alpha and gross beta concentrations. Biweekly samples are combined into quarterly composite samples and analyzed for gamma emitting radionuclides. Samples of atmospheric water vapor are collected every 4 weeks and analyzed for tritium at approximately 20 locations. All air sample results showed very low radiological concentrations in 2010, with resultant exposure to any public individual remaining well below the dose standard of 10 mrem/yr total effective dose equivalent. A detailed discussion of the air sampling and results are presented in the 2009 Sitewide Environmental Report (PNNL-19455) in Section 8.2. Table 8.2.3 of the same report provides sample locations and a list of analyses collected at each location.

Ambient air sampling is the primary method used in monitoring fugitive emissions. Hanford Site contractors also monitor for other effects from airborne emissions or other releases from site facilities. This is done through sampling of various environmental media besides the air, as part of the Surface Environmental Surveillance Program. Routine monitoring includes sampling of surface contamination, external radiation doses, soil, vegetation, and animals. All estimated and measured environmental doses from Hanford Site activities remain much lower than EPA and DOE standards. While not a required action for the CERCLA remedial action, the Washington State 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 the Hanford Site's most closely controlled work areas. A discussion of the nature and extent of air contaminants is presented in Section 4.8. Historic fugitive dust emissions or stack emissions have been evaluated as a potential fate-and-transport pathway for contaminants in non-operational areas. The nonoperational area evaluation discussed in Chapter 1 and presented in Appendix K, summarizes different surveillance programs, including the OSE, and provides different statistical analyses to identify the potential for effects in nonoperational areas.

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

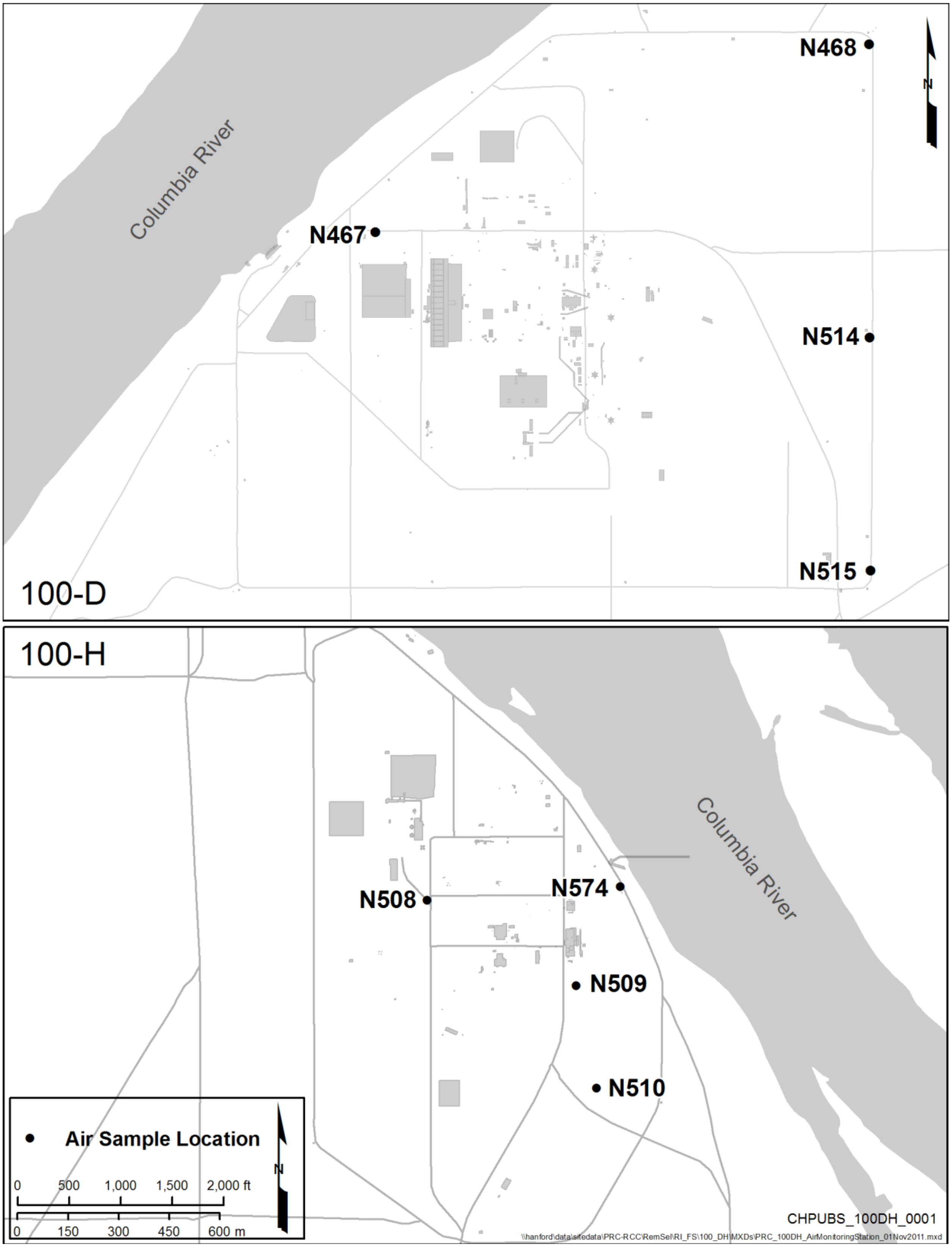


Figure 2-4. Collection of Ambient Air Samples Associated with 100-D and 100-H

2.1.7 Surface Water and Sediment Investigations

Pore water, surface water, and sediment investigations were 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). These data were integrated with the RI data to evaluate groundwater discharge to surface water and presented in the CRC (DOE/RL-2010-117). The data evaluation is presented in Appendix L.

2.1.7.1 Approaches to Demonstrate Compliance at the Columbia River

To address Data Gap 6 approaches to obtain and assess data to demonstrate groundwater compliance with AWQC in the Columbia River (e.g., monitoring wells, aquifer tubes, and pore water sampling) were evaluated during the remedial investigation. This task included an extensive literature search for data collection and data analysis strategies, re-assessing the 1:1 dilution assumption for groundwater entering the river, and reevaluating the current mixing/dilution conceptual model for groundwater and surface water in the hyporheic zone. The pertinent findings from this evaluation included:

- Although aquifer tubes may not be suitable for compliance monitoring (Chapter 4, Section 4.5.1.4), they are a reliable tool for collecting hyporheic zone data and are useful in tracking groundwater contaminants through shoreline areas.
- Pore water (groundwater upwelling) sampling is not suitable for compliance monitoring. Hanford Site groundwater upwells into the river during low river stage conditions. The upwelling groundwater quality is variable due to flow reverses several times per day due to Priest River Dam operations. (Chapter 4, Section 4.9.8.5).
- The literature review produced some new thoughts on the mixing/dilution conceptual model for groundwater and surface water in the hyporheic zone (Chapter 4, Section 4.9.8.4). However, the review did not produce analytical tools useable to evaluate the 1:1 dilution theory.
- No strategies were identified to collect data that could support the Interim ROD 1:1 dilution assumption for groundwater entering the river. The approach adopted in the feasibility study (Chapter 9) is to treat groundwater to achieve AWQC at the groundwater-surface water interface in the hyporheic zone (Chapter 9, Section 9.2.2.4). This also takes into account that diffusion and dispersion may still be considered contributors to attenuating processes for groundwater contaminants (Chapter 8, Section 8.3.1.2).

DX and HX pump-and-treat systems are in operation and the objective of these systems is to provide hydraulic containment of Cr(VI) to protect the Columbia River. Capture zone analysis is another tool that will assist in demonstrating remediation effects. Capture zone analysis indicates that hydraulic containment is being achieved in most locations along 100-D/H. Realignment of the system for optimizing plume capture is ongoing, with the objective of protection of the river (*Calendar Year 2012 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation* [DOE/RL-2013-13]).

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

Groundwater beneath the Hanford Site discharges to the Columbia River through seeps and upwelling to the riverbed. This flow path provides a means to transport Hanford Site contaminants that may have leached into groundwater to reach the Columbia River.

The availability of historical data to understand preferential groundwater flow paths, contaminant migration restrictions, and groundwater and river water mixing in the nearshore area is limited. Groundwater discharges into the Columbia River along the Hanford Reach. Mostly laminar flow results in a complex flow regime (*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 groundwater upwelling at the bottom of the river, and between river water and groundwater seeps at shoreline locations. Data were collected near 100-D/H in 2009 and 2010 to address the uncertainty related to the level of contaminants entering the Columbia River, 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 Work Plan (DOE/RL-2008-11) pore water sampling was a technology demonstration to verify that proposed equipment was usable in the variable conditions found in the Hanford Reach section of the Columbia River. The second phase consisted of two subphases. Phase IIa focused on identifying riverbed areas where groundwater was entering the Columbia River, as evidenced by variations in conductivity and temperature measurements. In Phase IIb, a subset of the Phase IIa locations that showed evidence for groundwater entering the river were revisited in order to collect and analyze pore water samples for Cr(VI) as an indicator contaminant. Phase III sampling 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.

Pore water data (conductivity and temperature) were collected in Phase IIa using a multi-sensor water sampling probe capable of being inserted approximately 30 cm (12 in.) into the riverbed at five cross-river transects in 100-D and six in 100-H. Each transect had five sample locations. Additionally, 10 locations surrounding the established transects were sampled.

Pore water sampling for Phase IIb was conducted at a subset of the Phase IIa locations that indicated groundwater upwelling based on conductivity and temperature variances between the river and pore water, and were deemed most likely to show contamination. These sample locations were approved by the Tri-Parties and are shown on Figures 2-5 and 2-6 (Columbia River RI Report [WCH-380]).

Pore water samples for Phase III (Figures 2-7 and 2-8) 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. For Phase III sampling, the Tri-Parties selected six sample locations each near 100-D and 100-H for collection of pore water, surface water, and sediment. The Tri-Parties also chose one additional pore water sample location in 100-D, and two additional pore water sample locations for Cr(VI) only in 100-H. Phase III characterization samples were analyzed for a range of radiological and nonradiological analytes as shown in Table 2-5.

Pore water and sediment samples were successfully obtained from these locations and analyzed for a range of radiological and nonradiological analytes (listed in Table 2-5). Because of volume limitations, not all media and/or analyses could be collected or conducted. Chapter 4 presents the results from the sampling efforts. Table 2-6 provides information on the number of pore water samples collected during each sampling phase and the collection period.

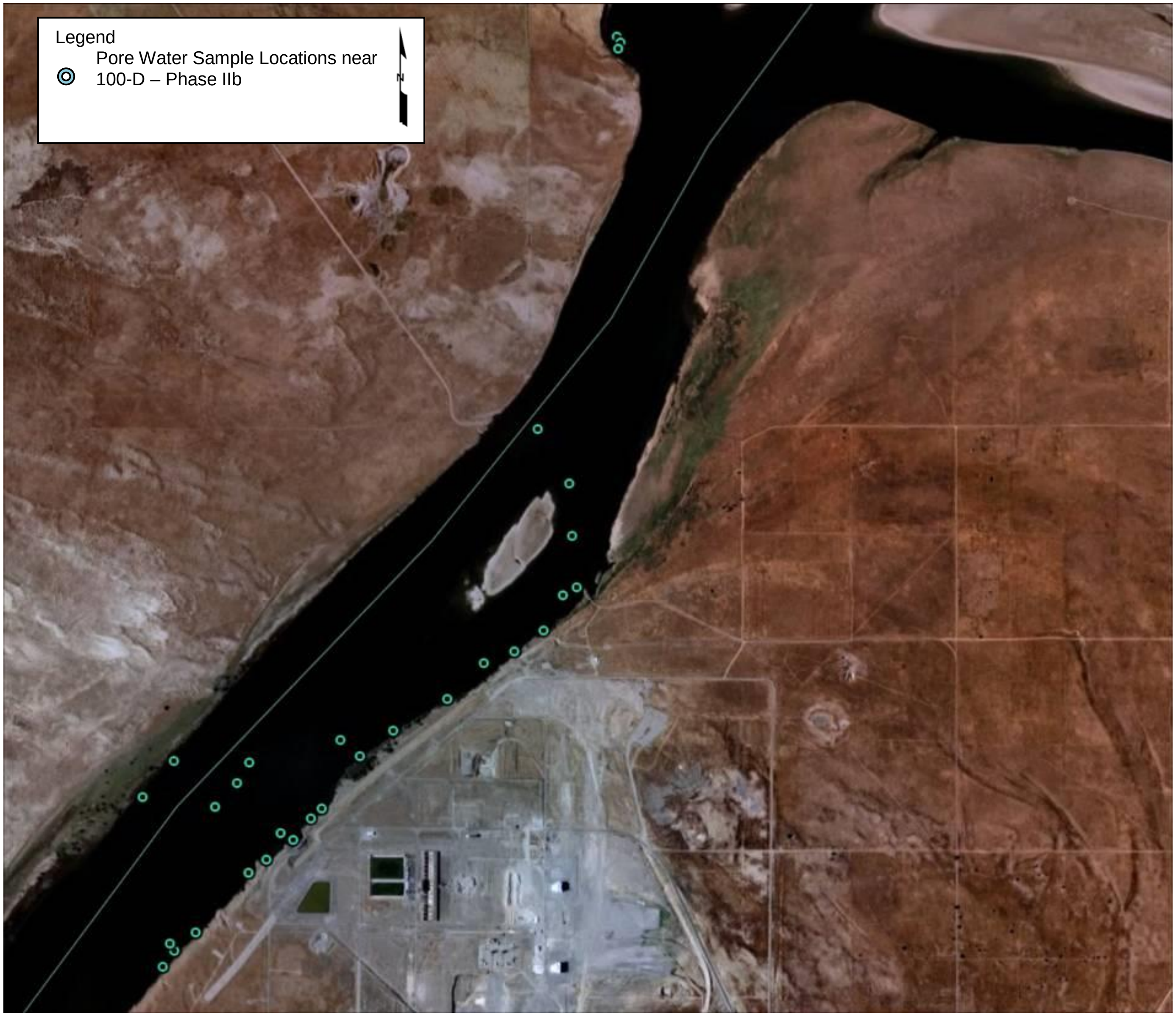


Figure 2-5. Remedial Investigation for Hanford Site Releases to the Columbia River— Phase IIb Indicator Contaminant Sample Locations at 100-D

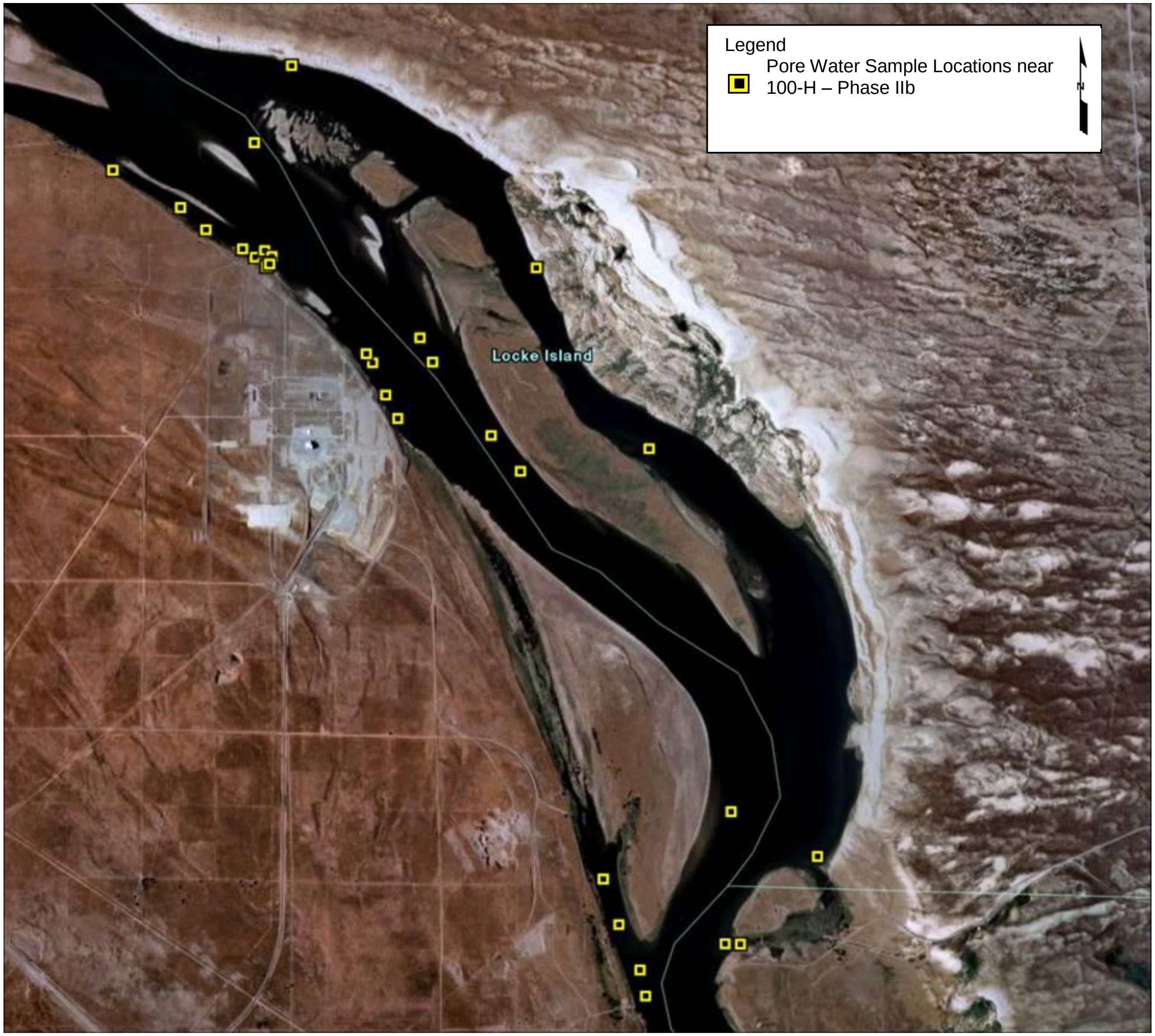


Figure 2-6. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase IIb Indicator Contaminant Sample Locations at 100-H

Figure 2-7. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase III Characterization Sample Locations for 100-D

Figure 2-8. Remedial Investigation for Hanford Site Releases to the Columbia River—Phase III Characterization Sample Locations for 100-H

Table 2-5. Summary of Analyses Requested for Surface Water, Sediment, and Pore Water Sampling during Columbia River Remedial Investigation

Analytical Parameter	EPA Method	Surface Water	Sediment	Pore Water
Metals (filtered)	6010/7470	X	--	X
Metals (unfiltered)	6010/7470	X	--	X
Metals (solid)	6010/7471	--	X	--
Cr(VI)	7196A	X	X	X
VOCs	8260B	X	X	--
SVOCs	8270C	X	X	--
Pesticides	8081	X	X	--
PCBs	8082	X	X	--
Petroleum hydrocarbons	8115	--	X	--
Thorium isotopes	Isotopic Th	X	X	--
Plutonium isotopes	Isotopic Pu	X	X	--
Tritium	LSC	X	--	X
Total beta radiostrontium	GPC	X	X	X
Uranium isotopes	Isotopic U	X	X	--
Carbon-14	LSC	X	X	--
Gamma-emitting radionuclides	GEA	X	X	--
Technetium-99	LSC/GPC	X	X	--
TOC/DOC	415.1 & 415.1 M	X	X	X
Grain Size	ASTM D422-63	--	X	--
AVS/SEM[a]	N/A	--	X	--
Nitrate and anions	300.0 & 353.2	X	--	X
Hardness	130.1	X	--	--
Alkalinity	310.1	X	--	--
Field parameters[b]	Field instruments	X	--	X

Source: 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. Sediment samples were extracted and analyzed for acid volatile sulfides (AVS) (*Draft Analytical Method for Determination of Acid Volatile Sulfide in Sediment, Determination of Acid Volatile Sulfide and Selected Simultaneously Extractable Metals in Sediment* [EPA-821-R-91-100]). The simultaneously extracted metal (SEM) extracts were analyzed for all other metals by ICP-MS in accordance with PNNL standard operating procedures.

b. 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 consisted of temperature and conductivity.

DOC = dissolved organic carbon
GEA = gamma energy analysis
GPC = gas proportional counting
ICP-MS = inductively coupled plasma mass spectroscopy
LSC = liquid scintillation counting
N/A = not applicable
PNNL = Pacific Northwest National Laboratory

Table 2-5. Summary of Analyses Requested for Surface Water, Sediment, and Pore Water Sampling during Columbia River Remedial Investigation

Analytical Parameter	EPA Method	Surface Water	Sediment	Pore Water

RI = remedial investigation
SVOC = semivolatile organic compound
TOC = total organic carbon
VOC = volatile organic compound

Table 2-6. Summary of 100-D and 100-H Sample Collection during the Columbia River Remedial Investigation

Sample Phase	Sample Dates	Parameters of Interest	Number of Samples/Stations
100-D: Phase IIa	January/February/March 2009	Conductivity Mapping	77
100-D:Phase IIb	September/October 2009	Indicator Contaminant Screening	30
100-D:Phase III	February 2010	Groundwater Upwelling Characterization	6 (1)*
100-H:Phase IIa	January/February/March 2009	Conductivity Mapping	91
100-H:Phase IIb	October 2009	Indicator Contaminant Screening	30
100-H:Phase III	January/February 2010	Groundwater Upwelling Characterization	6 (2)*

* The number in parentheses represents the count of sample sites sampled only for Cr(VI) in pore water during Phase III sampling.

2.1.7.3 Surface Water Sampling

During Phase III, the influence of contaminants on the water immediately above groundwater upwelling locations was determined by taking surface water samples. River water and pore water samples were collected concurrently approximately 0.3 m (12 in.) above the riverbed. Table 2-6 provides information on the number of surface water samples and the collection period at 100-D and 100-H.

2.1.7.4 Sediment Sampling

Sediment samples collected during Phase III of the study were from the locations shown on Figures 2-7 and 2-8. Samples were analyzed for a range of radiological and nonradiological analytes, as listed in Table 2-5. Sediment samples were obtained as close to the pore water sample locations as reasonably possible, with a preference given to locations with sediment deposits. Sample volume was limited in some locations because of the dominance of cobbles on the riverbed. Sediment samples could be collected at only five of the six specified sample locations at each of 100-D and 100-H. In locations where sediment sample volume was limited, not all analyses could be performed. Table 2-6 presents information on sediment samples and the collection period.

2.1.7.5 Additional Surface Water, Sediment, and Island Soil Sampling

In addition to the CRC sampling described in the preceding sections, supplemental samples of surface water, sediment, and island soil samples were collected through the CRC effort to identify the nature and extent of potential releases of contaminants associated with operations at the Hanford Site 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 Soil* (WCH-352)

- *Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington: January 2011* (WCH-398), hereinafter called Hanford Site Releases Data Summary.

Figures 5-10a through 5-11c in Hanford Site Releases Data Summary (WCH-398) show these sample locations near 100-D and 100-H. Table 2-7 provides a summary of the number of additional samples collected. The CRC also planned to collect samples from D-Island, but because of high Columbia River conditions that restricted access to D-Island, no soil samples were collected during the 2009 and 2010 CRC sampling efforts.

Table 2-7. Summary of Additional Samples Collected in the Vicinity of 100-D/H

Media Collected	Number of Samples	
	100-D	100-H
Island Soil	9	10
Surface Water	2	1
Sediment*	13	22

* Includes shoreline, shallow, and core samples.

However, over the past 23 years, D-Island was characterized three times:

- In the early 1990s, the upstream half (12.5 acres) of 100-D Island (100-D-67) was surveyed using the Ultrasonic Ranging and Data System (USRADS) (*100-D Island USRADS Radiological Surveys Preliminary Report – Phase II* [BHI-00134]). Areas of elevated radiation readings were found to be discrete radioactive particles (specks) that were in the silt 10.1 to 25.4 cm (4 to 10 in.) beneath the surface and between the 4 to 6 inch diameter cobbles that make up the bulk of the soil on 100-D Island. During the USRADS surveys in April 1992, the specks that were found were removed and portions of them were counted in the laboratory. The only radionuclide found in the majority of the specks was cobalt-60. In 1992, the highest activity speck contained 22 micro-Curies of cobalt-60 with the average specks containing 2.5 micro-Curies. Calculations based on the maximum number of specks found in a volume of soil show that the soil activity due to cobalt-60 in 1992 was 0.45 pCi/g.

- The Washington State Department of Health (WDOH) conducted a risk assessment on cobalt-60 present in particulates on 100-D Island (*100-D Island Radiological Survey* [WDOH/ERS-96-1101]). The carcinogenic risk associated with the cobalt-60 particles was stated to be the result of two pathways: external exposure and ingestion. The maximum potential dose rate from external exposure was estimated to be 0.04 mrem/year based on a recreational scenario. The WDOH study (*100-D Island Radiological Survey* [WDOH/ERS-96-1101]) also reported the carcinogenic risk from external exposure and ingestion of soil to be 2.7×10^{-8} and 2.3×10^{-11}, respectively, and concluded that the risks from radioactive specks were not sufficient to justify further surveys to locate and remove them. Since 1993, cobalt-60 has decayed through almost four half-¬lives resulting in present day risks that are considerably less than these values.

- In 2004, the 100-D Island was surveyed using Laser-Assisted Ranging and Data System (LARADS). The results of the survey showed that levels of gamma-emitting radionuclides were present at or slightly above background levels, with maximum readings between background and 5,000 counts per minute.

The information and data derived from these three characterization efforts is used in the human health risk assessment (Chapter 6, Section 6.4.2) to establish if remedial actions are required at D-Island, which is included in the 100-DR-1 operable unit.

2.1.8 Geological Investigations

Geological investigations were conducted to address Data Gaps 2, 3, 5, 7, 10, and 12 listed in Table 2-1. Geological characterization and physical and hydraulic property data needs were identified to support development/refinement of the CSM and performance of analytical and numerical modeling within 100-D/H. 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 within the unconfined and semi-confined aquifers. To address these data needs, the following wells were installed (Appendix C provides a crosswalk):

- Twelve permanent wells were installed in the unconfined aquifer: Wells 199-D3-5 (C7620, Well 2), 199-D5-133 (C7621, Well 3), 199-D5-132 (C7622, Well 4), 199-D6-3 (C7623, Well 5), 199-D5-140 (C7866, Well 9), 199-D5-143 (C8375, Well 9 redrill), 199-D5-144 (C8668, Well R5 redrill), 199-H3-6 (C7626, Well 6), 199-H3-7 (C7627, Well 7), 199-H6-3 (C7628, Well 10), 199-H6-4 (C7629, Well 11), and 199-H1-7 (C7630, Well 12).

- Five wells were installed in the first water-bearing unit in the RUM: Wells 199-D5-134 (C7624, Well R4), 199-D5-141 (C7625, R5), 199-H2-1 (C7631, Well R3), 199-H3-9 (C7639, Well R1), and 199-H3-10 (C7640, Well R2).

- Five boreholes were drilled into waste sites and subsequently decommissioned: 116-DR-9 (Retention Basin), 116-D-7 (Retention Basin), 116-D-1B (Trench), 116-H-4 (Pluto Crib), and 116-H-1 (Trench).

- Five boreholes were drilled into waste sites and completed as 10 cm (4 in.) temporary polyvinyl chloride (PVC) wells: 116-DR-1&2 (Trench), 118-D-6:3 (FSB), 116-H-6 (Solar Evaporation Basin), 116-H-7 (Retention Basin), and 118-H-6:3 (FSB).

- Seventy RPO wells were installed per *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09). Geologic and characterization data from those wells were incorporated into the evaluation of site conditions. Well construction details, geologic information, and other data for the RPO wells are included in *Borehole Summary Report for the Installation of 70 Remedial Process Optimization, Pump-and-Treat Expansion Wells, For the 100-HR-3 Operable Unit* (SGW-48612), hereinafter called the Borehole Summary Report for RPO Wells.

Five boreholes were converted to temporary monitoring wells during installation activities to obtain a representative water sample from the unconfined aquifer. These wells had 3 m (10 ft) PVC screens installed to straddle the water table. The use of temporary monitoring wells is consistent with the 100-D/H SAP (DOE/RL-2009-40). Table C-4 (Appendix C) includes pertinent well location information while Table C-4 identifies samples collected in accordance with the 100-D/H SAP (DOE/RL-2009-40) requirements. Deviations in the number and depth of a particular sample are generally due to insufficient sample recovery. Other conditions that may cause a minor deviation include differences in planned depth for the water table, and differences in the expected geologic material changes. These deviations are identified in Table C-4 (Appendix C).

Well 199-D5-140 (C7866, Well 9) was intended to characterize the location of the 100-D-56 sodium dichromate pipeline at a 90 degree bend where a hole in the pipe was observed. However, the well was drilled at the wrong location because of coordinate issues. No change notice was needed for drilling, sampling, and installing the “replacement” well in the correct location because it was done per the SAP requirements. The new well number 199-D5-143 (C8375) was located as specified in the 100-D/H SAP (DOE/RL-2009-40).

Well 199-D5-141 (C7625, R5) was drilled at a location west of the planned location to avoid overhead power lines and the 100-D-100 remediation activities scheduled for summer 2011. Sampling was conducted in Well 199-D5-141 (C7625, Well R5) as planned in the 100-D/H SAP (DOE/RL-2009-40), which filled Data Gap 7. A shallower borehole was drilled at the original planned location. This 10 cm (4 in.) temporary PVC well was drilled approximately 3 m (10 ft) into the RUM. The new well number is 199-D5-144 (borehole C8668). Sampling from Well 199-D5-144 (C8668, Well R5 redrill) was conducted per *Tri-Party Agreement Change Notice Form: DOE/RL-2009-40 Sampling and Analysis Plan for the 100DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units Remedial Investigation Feasibility Study, Rev. 0* (TPA-CN-460).

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 RUM surface using near river wells was sufficient to indicate that the RUM 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. Bathymetry of the Columbia River near 100-D/H is shown on Figures 2-9 and 2-10.

Cr(VI) and other contaminants have been detected in the RUM unit and deeper Ringold units in 100-H groundwater. Additional information on the topography of the RUM unit surface relative to the topography of the river bottom was needed to evaluate the discharge locations of RUM unit groundwater

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 needed to be collected over a 30 km (19 mi) section to supplement existing bathymetric and topographic data to fill significant data gaps in the central portion of the Hanford Reach. The hydrographic surveys were conducted in 2010 and the resulting data were merged to produce a single high-resolution (1 m [3.3 ft]) dataset for the Hanford Reach. Bathymetry data are incorporated in geologic cross sections presented in Appendix M while Chapter 4 presents a discussion of the updated bathymetric results.

2.1.8.2 Geophysical Logging

To gain a better understanding of the area geology, geophysical logging was conducted at each RI borehole (27 total). Logging was conducted using S.M. Stoller Corporation's Spectral Gamma Logging System and Neutron Moisture Logging System 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 temporary casing to produce a geophysical log of the entire length of the borehole. The log reports are located in the borehole summary reports (*Borehole Summary Report for the Installation of 16 Resource Protection Wells in the 100-HR-3 Groundwater Operable Unit in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit* [SGW-49912]; *Borehole Summary of Ten Characterization Boreholes in the 100-DR-1, 100-DR-2 and 100-HR-1, 100-HR-2 Source Operable Units in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit* [SGW-50131]). The geophysical logging results are presented in Chapter 4, with the logs included in Appendix M.

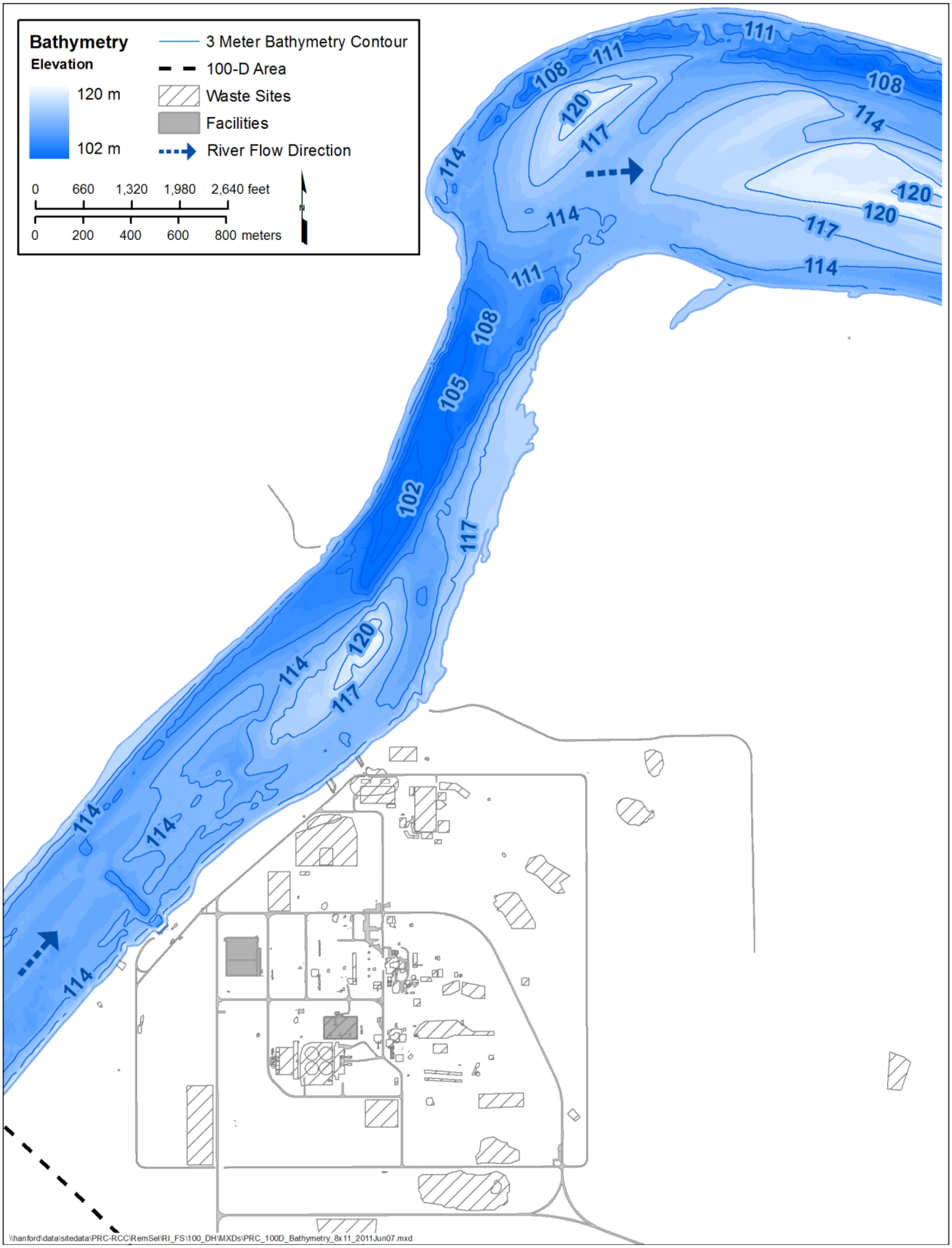


Figure 2-9. Bathymetry of the Columbia River near 100-D

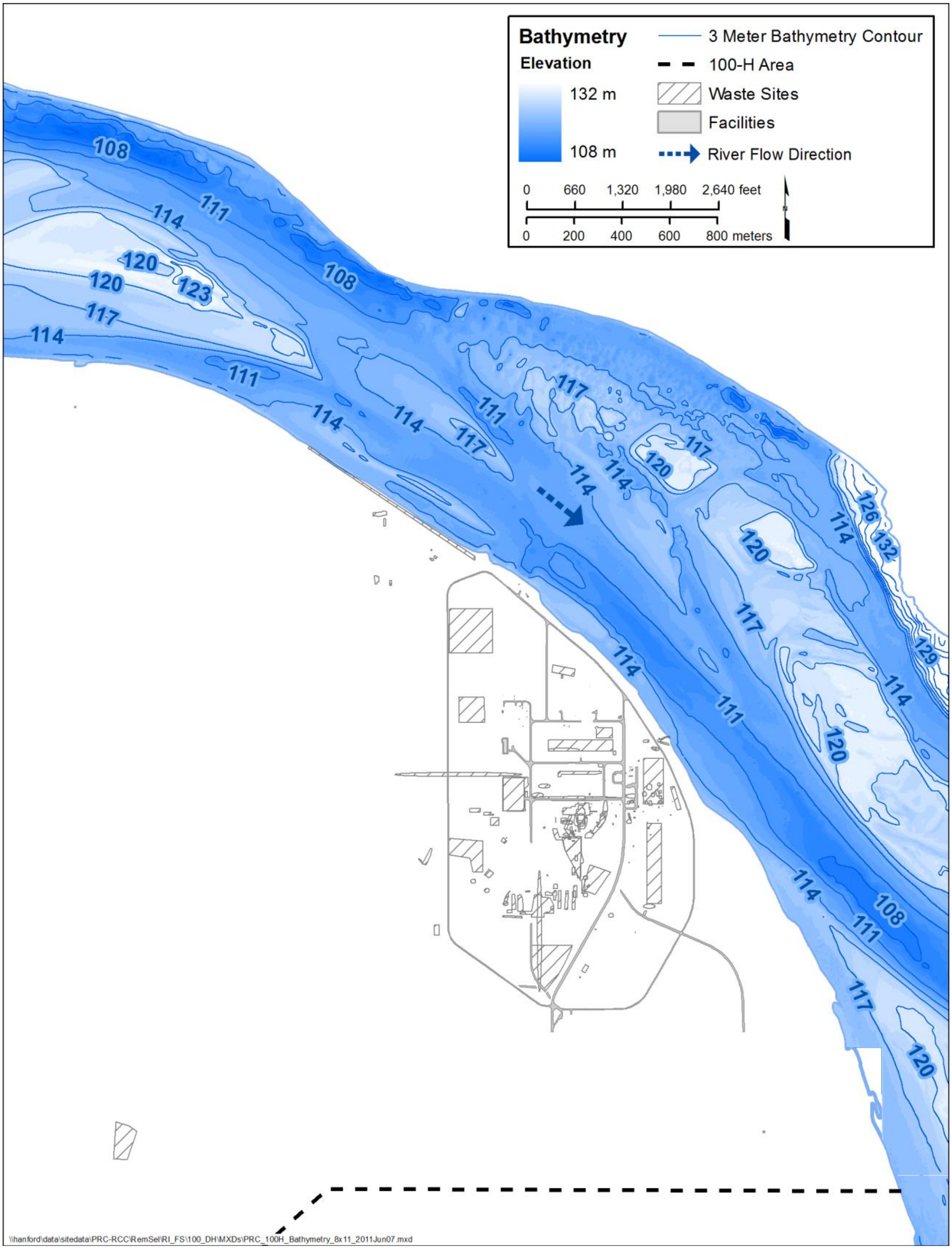


Figure 2-10. Bathymetry of the Columbia River near 100-H

2.1.8.3 Remedial Process Optimization Wells

Seventy RPO wells were installed in 100-D/H as part of an expansion for the pump-and-treat system. This expansion was conducted to meet the remedial objectives set forth in *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington* (EPA/ROD/R10-96/134), hereinafter called 100-H/K ROD. Figure 2-11 shows the locations of these wells. Drilling and sampling of these RPO wells were conducted as per the following control documents, and amended by the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) and 100-D/H SAP (DOE/RL-2009-40):

- *ARRA Description of Work for the Installation of Fourteen Remedial Process Optimization Wells for the 100-D Area of the 100-HR-3 Operable Unit, FY2009* (SGW-41535)
- *Description of Work for the Installation of 35 Remedial Process Optimization Wells in the 100-H Area for the 100-HR-3 Operable Unit, Fiscal Year 2009* (SGW-41534)
- *ARRA FY2010 Description of Work for the Installation of 18 Scenario 5 Remedial Process Optimization Wells for the 100-D Area, 100-HR-3 Operable Unit* (SGW-44089)
- *ARRA FY2010 Description of Work for the Installation of 15 Scenario 5 Remedial Process Optimization Wells for the 100-H Area, 100-HR-3 Operable Unit* (SGW-44142)
- *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09, Rev. 0)
- *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09, Rev. 1)
- *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09, Rev. 2) for Scenario 5 wells project expansion

Table 2-8 presents the vadose zone soil matrix, aquifer soil matrix, and RUM sampling analytes and physical property tests (nine wells only) that were conducted at the selected RPO wells specifically for the RI. Samples were collected from the RUM for the purpose of determining vertical hydraulic conductivity and the possible presence of contaminants.

Results from these data are discussed in Chapter 4. The geologic interpretation from soil borehole logs is discussed in general in Chapter 3, and in detail in the Borehole Summary Report for RPO Wells (SGW-48612). The geology encountered in the new wells is generally consistent with previous reports.

2.1.9 Vadose Zone Investigations

The RI work is intended to develop and refine the CSM. One important aspect of the characterization is to provide information on the nature and extent of contaminant distribution in the vadose zone. As part of this effort, characterization wells, boreholes, and test pits were conducted at the locations described in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) and 100-D/H SAP (DOE/RL-2009-40).

Data needs specific to sources (soil) identified in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) and summarized in Table C-4 (Appendix C) are described in this section. Data needs were addressed in accordance with the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) and 100-D/H SAP (DOE/RL-2009-40), except where noted, relative to unremediated and remediated waste sites and reactor areas (Data Gaps 1, 2, and 3, respectively). In addition, soil investigations were undertaken to evaluate the persistence of Cr(VI) (Data Gaps 7 and 10, respectively). The data collected were also used for development of fate and transport modeling (Data Gap 12).

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-D/H Work Plan (DOE/RL-2008-46-ADD1). Waste sites with a high potential to affect groundwater are considered "high priority." At 100-D/H, those waste sites primarily handled high concentrations of sodium dichromate liquid. The waste sites identified in Chapter 1include 100-D-100, 100-D-12, 100-D-56, and 100-D-30, among others. 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 are used as a component of the CSM and in evaluating the nature and extent of contamination. CVP data collected during ongoing remediation are generally discussed in Chapter 4.

Remedial actions in 100-D/H began in 1996 under the authority of an interim ROD (*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/ROD/R10-95/126]) and continue today. Cleanup has primarily consisted of RTD, which generates additional characterization data to address many of the vadose zone data gaps and helps refine overall site knowledge. Contaminated soil and debris are removed and disposed to the ERDF or another offsite facility (as appropriate) until the interim cleanup levels are met. Activities are guided during excavation using data obtained through field measurements or quick turnaround laboratory analyses. Sequencing of waste site cleanup is based on the TPA (Ecology et al., 1989a) milestone framework. Within this framework, knowledge of operational processes and past releases was used to target and prioritize specific waste sites or areas with contaminants that presently exist in groundwater or that could adversely affect it. Effective implementation of waste site cleanup prevents human and environmental exposure to soil contamination and further degradation of groundwater, thereby increasing the likelihood for success of groundwater cleanup actions (such as pump-and-treat).

As of November 2012, there were 343 waste sites, including subsites, identified in 100-D/H. Data needs associated with soil remedial actions were met by completing the remedial actions, collecting data to verify interim cleanup of waste sites, and obtaining concurrence from regulators on the achievement of interim RAGs for direct exposure, groundwater protection, and Columbia River protection. Appendix E (Table E-1) documents data from "Interim Closed Out" and "No Action" sites that were incorporated into this RI/FS report.

2.1.9.2 Characterize Beneath and Beside Remediated Waste Sites

The need to provide additional characterization beneath and beside remediated waste sites (Data Gap 2) was addressed by installing 14 boreholes in 100-D, 13 boreholes in 100-H (Appendix C, Tables C-5 and C-6), and 5 test pits (Appendix C, Table C-7) to assess the vertical extent of contamination in the vadose zone. Characterization data were used to develop/refine the current CSM, including model input parameters and assumptions addressed in Chapter 5.

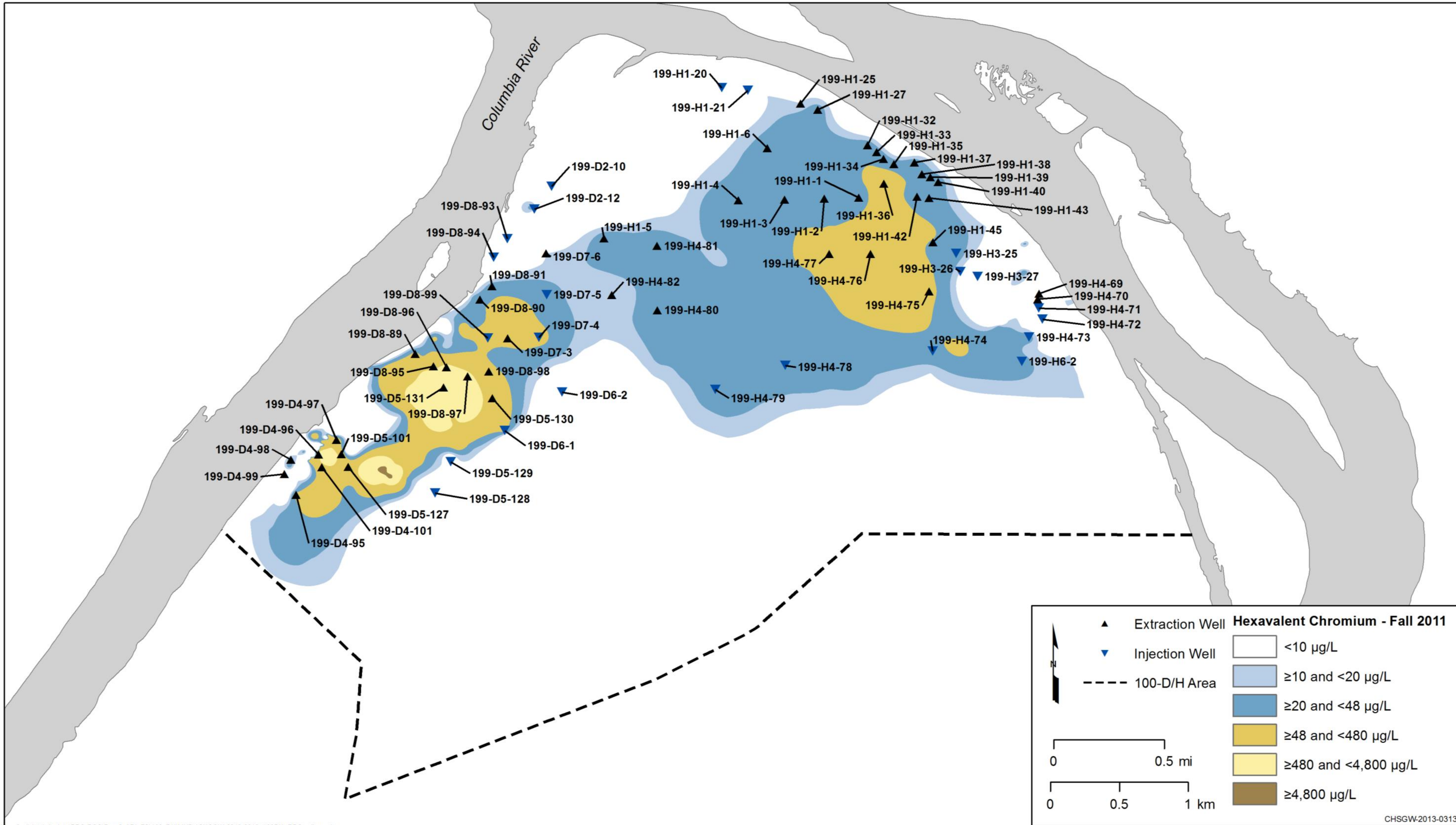


Figure 2-11. Remedial Process Optimization Well Locations

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Table 2-8. Soil Sample Chemical Analyses and Physical Property Tests for Nine RPO Boreholes

Radionuclides	Nonradionuclides*		Physical Properties
Barium-133	Antimony	Lithium	Grain size (sieve analysis)
Cesium-137	Arsenic	Manganese	
Cobalt-60	Barium	Molybdenum	
Europium-152	Beryllium	Nickel	
Europium-154	Boron	Selenium	
Europium-155	Cadmium	Silver	
Strontium-90	Cr(VI)	Thallium	
	Chromium (Total)	Vanadium	
	Copper	Zinc	
	Lead		

* Includes geochemical analyses for K_d and batch leach testing (see Chapter 5).

RPO = remedial process optimization

To fill the data need, boreholes and test pits were identified and sampled to refine the CSM, confirm modeling inputs, and provide data on the vertical distribution of contaminants. The RI activities required to address the data needs for Data Gap 2 involved drilling 10 boreholes, installing 2 permanent monitoring wells, excavating 5 test pits, and collecting and analyzing soil samples to assess the vertical extent of contamination in the vadose zone. Boreholes were drilled and sampled, and all but five boreholes were converted to 10 cm (4 in.) temporary PVC wells or permanent stainless steel wells (Appendix C, Table C-5). Characterization data collected beneath remediated waste sites were used to develop/refine the current CSM, including model input parameters and assumptions. Input parameters and assumptions used for remediated waste sites were compared against field data to identify the accuracy of model inputs and assumptions that affect contaminant migration predictions.

To determine which interim closed sites required additional characterization, all accepted waste sites having undergone an interim remedial action were evaluated with consideration of the following:

- Depth of remedial action relative to depth of the site's engineered structure
- Depth of contamination reported in historical documents relative to depth of remedial action
- Omission of historically reported contaminants during closure sampling analysis
- Closure sample concentrations relative to current 2007 MTCA (WAC 173-340) Method B cleanup levels
- Trends indicating contaminant concentration increases with depth
- Proximity to groundwater contaminant plumes
- Historically documented effects to groundwater
- Type of waste site (for example, high volume liquid effluent site, low volume liquid effluent site, or sludge trench)

Sites selected for characterization were identified during the work plan process in coordination between Ecology and DOE. Vadose zone soil samples were collected for characterization purposes during the field activities in locations as outlined in Table 2-1. Five boreholes were completed as 10 cm (4 in.) temporary PVC wells in order to obtain representative groundwater samples. Table C-8 (Appendix C) identifies the waste sites that were investigated and provides justification for selection, which was documented in Section 4.8.1 of the 100-D/H Work Plan (DOE/RL-2008-46-ADD1). Drilling of boreholes and wells, as outlined in Table 2-1, was conducted to address Data Gap 2.

Table C-5 (Appendix C) summarizes borehole and monitoring well sampling and location information, and Table C-7 (Appendix C) summarizes test pit information. Sampling and location information for the five boreholes completed as temporary monitoring wells (199-D8-101, 199-D5-142, 199-H4-84, 199-H4-83, and 199-H3-11) is presented in Section 2.1.

Samples were screened in the field for radiological contamination using field instruments and visually inspected for Cr(VI), as indicated by soil staining. Soil samples were generally collected from boreholes for analytical testing, field screening, and batch leach testing according to the 100-D/H SAP (DOE/RL-2009-40). Sampling typically was conducted at 4.5, 3, 1.5, and 0.6 m (15, 10, 5, and 2 ft) above the water table, at the water table, and 1.5 m (5 ft) into the aquifer. Location-specific target analytes specified in the 100-D/H SAP (DOE/RL-2009-40) include both a subset of the master list of target analytes (presented in Table 2-9) and additional analytes selected based on previous investigations and history of the waste site.

Table 2-9. Master List of Soil Target Analytes from 100-D/H Work Plan

Radionuclides	Nonradionuclides		
Americium-241	1,1-Dichloroethene	Beta-BHC	Manganese
Barium-133	4,4'-DDT	bis(2-ethylhexyl)phthalate	Mercury
Carbon-14	Acetone	Boron	Molybdenum
Cesium-137	Antimony	Cadmium	Nickel
Cobalt-60	Aroclor-1016 (PCB)	Carbon Tetrachloride	Nitrate (as N)
Europium-152	Aroclor-1221 (PCB)	Chloroform	Nitrite (as N)
Europium-154	Aroclor-1232 (PCB)	Chromium (Total)	Pyrene
Europium-155	Aroclor-1242 (PCB)	Chrysene	Selenium
Neptunium-237	Aroclor-1248 (PCB)	Cobalt	Silver
Nickel-63	Aroclor-1254 (PCB)	Copper	Strontium
Plutonium-238	Aroclor-1260 (PCB)	Di-n-butyl phthalate	Sulfate
Plutonium-239/240	Arsenic	Dibenz[a,h]anthracene	Thallium
Strontium-90	Barium	Dieldrin	Tin
Technetium-99	Benzene	Fluoranthene	Trichloroethene
Tritium	Benzo(a)anthracene	Fluoride	Uranium (Total)
Uranium-233/234	Benzo(a)pyrene	Cr(VI)	Vanadium
Uranium-235	Benzo(b)fluoranthene	Indeno(1,2,3-cd)pyrene	Vinyl Chloride
Uranium-238	Benzo(k)fluoranthene	Lead	Zinc
	Beryllium	Lithium	

Source: *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units* (DOE/RL-2008-46-ADD1).

Additional samples were collected, including at major formation and lithology changes, at the discretion of the geologist or sampler based on soil characteristics and field screening results; these samples were analyzed for physical properties (such as, grain size, porosity, moisture content, and bulk density, and for saturated samples, saturated hydraulic conductivity).

The split-spoon soil samples were collected in 0.76 m (2.5 ft) long (including shoe), 10 cm (4 in.) diameter split-spoon samplers lined with four 15 cm (6 in.) long Lexan® or stainless steel liners. The sampler was driven the full 0.76 m (2.5 ft) or until refusal (as determined by the onsite field geologist), whichever came first.

Groundwater samples were collected from open boreholes using a submersible pump with rates ranging from 3.29 L/min (0.87 gal/min) in C7851 to 38 L/min (10 gal/min) in C7864. Boreholes C7850 and C7855 were pumped at 22.7 and 7.6 L/min (6.0 and 2.0 gal/min), respectively. Before sampling, each borehole was purged long enough to provide stabilized field readings, but not necessarily three casing volumes. If significant drawdown occurred to where pumping could not be sustained, and a sample could not be collected, an alternative means of sampling was followed. A submersible pump was used for each of the boreholes, with the exception of C7862, which had inadequate recharge. Borehole C7862 was sampled using a “Kabis” sampler.

Boreholes C7852, C7857, C7860, C7861, and C7863 did not produce adequate water for sampling. Because of the difficulty of obtaining water samples, these five boreholes were completed as 10 cm (4 in.) temporary PVC wells. The temporary wells were developed before sampling. The field filtered water samples were analyzed for Cr(VI) and other metals to support K_d determination.

Boreholes C7850, C7851, C7855, C7862, and C7864 were not completed as monitoring wells and were decommissioned with DOE, Ecology, and EPA approval, in accordance with “Minimum Standards for Construction and Maintenance of Wells” (WAC 173-160), after geophysical logging and sampling were completed. The boreholes were backfilled to 0.6 m (2 ft) above static water level (to account for variability of the water table) with 10 to 20 mesh Colorado Silica Sand. The remaining borehole was filled with granular bentonite to within 0.9 m (3 ft) of ground surface. A cement seal was then placed from 0.9 m (3 ft) bgs to ground surface and marked with the name and date of the decommissioned borehole.

One test pit each was excavated and sampled at the100-D-12 Pump Station/French Drain, 100-D-4 Sludge Trench, 116-D-4 Liquid Waste Trench/Crib, 1607-H4 Septic Tank and Drain Field, and 116-H-2 Liquid Waste Trench/Crib waste sites (Appendix C, Table C-7). Table C-8 (Appendix C) provides justification for selection of these waste sites for sampling, as developed in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1).

The 100-D-12 French Drain trench was excavated and sampled to a depth of 7.6 m (25 ft). The test pits at 100-D-4, 116-D-4, 116-H-2, and 1607-H-4 were excavated and sampled to a depth 6.2.m (19 ft). In addition to collection and submittal for laboratory analysis, samples were screened in the field for radiological contamination (using field instruments) and Cr(VI) (by visual observation).

Sampling commenced at the maximum depth of remedial action. The maximum depths of remedial action at waste sites are presented in Table 2-10.

Samples were generally collected at 0.6 m (2 ft) intervals at the discretion of the geologist/sampler based on field screening results. One sample was also collected at the bottom of each excavation. Samples were collected for location-specific target analyte analysis, field screening, and batch leach testing. Excavations were backfilled immediately on completion of sampling.

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Table 2-10. Maximum Depth of Remedial Action at Select Waste Sites

Waste Site	Depth m (ft) bgs	Waste Site	Depth m (ft) bgs
100-D-12	2.4 (8.0)	116-H-2	2.6 (8.3)
100-D-4	2.9 (9.5)	1607-H4	3.6 (11.0)
116-D-4	2.9 (9.5)		

bgs = below ground surface

2.1.9.3 Characterize beneath and around Reactor Structures

Additional characterization was needed for interim closed areas adjacent to the 105-D and 105-H Reactor facilities and soil underlying these reactors (Data Gap 3). Justification for characterization at these two reactors includes reports of leakage from FSBs during reactor operations, reports of contamination beyond the depth of remedial actions, the quantity of liquids managed, and the lack of sampling performed beneath the FSBs and around/beneath the reactors (Appendix C, Table C-8). To address Data Gap 3, boreholes were drilled adjacent to the 118-D-6:3 FSB (105-D Reactor) and through the118-H-6:3, FSB (105-H Reactor). The 118-H-6:3 FSB is also collocated with waste subsites 118-H-6:2; 105-H Reactor Ancillary Support Areas, Below-Grade Structures, and Underlying Soils, and 118-H-6:6 FSB Deep Zone Side-Slope Soils. One borehole was drilled within the boundary of each of the two reactor FSBs, and samples were collected and analyzed to assess the vertical extent of contamination and to refine the 100-D/H CSM.

Remediation of the 118-H-6:3 FSB included removing the below grade structure because of documented leaks and disposing of contaminated materials, including the soil underlying the former FSB floor and the side slopes. The 118-D-6:3 below grade structure remains in place because the FSB did not have a history of leaking; thus, the borehole was drilled as close as possible to the FSB. Copies of the borehole logs, detailed sampling summaries, well construction summaries, well summary sheets, geophysical logs, and final surveys are located in the borehole summary reports.

Additional characterization was not required for the 105-DR ISS reactor facilities, per the 100-D/H Work Plan (DOE/RL-2008-46-ADD1), because there was no historical evidence that the FSB leaked, and soil samples collected beneath the FSB floor indicated no contamination was present.

2.1.9.4 Evaluate Reasons for the Persistence of Cr(VI)

During the RI, data were collected to evaluate the potential for contaminants to be entrained within the soil matrix and be a continuing source of groundwater contamination (Data Gap 10). Samples were targeted within the upper and lower vadose zone, periodically rewetted zone, unconfined aquifer, RUM surface, and the first water-bearing unit of the RUM (Chapter 4). The soil data obtained during RI sampling and analysis activities, along with data from the RPO wells, were evaluated at the specified locations to decrease uncertainty about contaminant sources.

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 site contaminants in the environment is highly dependent on the effluent volume discharge and contaminant specific K_d, which quantifies the partitioning of a contaminant between a solid phase and an aqueous phase. Data needed to develop a K_d and to conduct accurate fate and transport modeling include: physical properties, hydraulic conductivity, batch leach test results, contaminant concentrations, and field screening parameters. Data to support contaminant fate and transport modeling were collected during the RI. Results of batch leach testing are discussed in Section 5.5, with details on sampling provided in the 100-D/H SAP (DOE/RL-2009-40).

Data to support contaminant fate and transport modeling were developed for selected RI soil samples as described in Chapter 5, including information on physical properties, hydraulic conductivity, batch leach test results, and field screening parameters, presented in Chapter 3.

2.1.10 Groundwater Investigations

Although considerable groundwater data have been gathered for 100-D/H, some additional data from monitoring wells and aquifer tubes were needed to support remedy decision making, as described below. This included additional investigation of selected waste sites. The rationale for selection of waste sites for additional groundwater characterization is summarized in Table C-8 (Appendix C).

Data needs specific to groundwater, as identified in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1) and summarized in Table 2-1, are described in this section. Data collected to fill data gaps included sampling during drilling of the RPO wells within 100-D/H. Table 2-2 includes the supplemental investigations identified in the Integrated Work Plan (DOE/RL-2008-46), and other investigations that may potentially affect the remedy decision for 100-D/H.

2.1.10.1 Characterize Beneath the Unconfined Aquifer

The unconfined aquifer in 100-D is primarily within the Ringold unit E. At 100-H, the Ringold unit E is not present and the unconfined aquifer is within the Hanford formation. The Horn represents a transitional area where the unconfined aquifer is present in pockets of Ringold unit E or in the Hanford formation where the Ringold unit E is not present. The surface of the RUM is considered the base of the unconfined aquifer in 100-D/H, with the presence of silt and clay layers acting as a hydraulic barrier.

Several confined water-bearing sandy gravel units are present within and below the RUM. These water-bearing units may provide pathways for Cr(VI) to migrate between stratigraphic units under certain hydrogeologic conditions. Cr(VI)-contaminated groundwater from the RUM may discharge to the river, adversely affecting aquatic resources, and/or affecting portions of the RUM that have the potential for future use as a drinking water resource. As presented in *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* (SGW-47776), the first water-bearing unit in the RUM appears to be connected to the Columbia River in some locations and connected to the unconfined aquifer in other portions of 100-H. Previous investigations identified Cr(VI) within the first water-bearing unit of the RUM at 100-H, with concentrations ranging from below detection on the western side of 100-H to levels approaching 200 µg/L in one location, where extraction is currently occurring. Previous investigations of the RUM in other locations of 100-D/H were limited to one well location in 100-D and three wells across the Horn, with low Cr(VI) levels identified in one of the Horn area wells. Additional data were collected to further define the extent of contamination in the RUM and to support contaminant fate-and-transport evaluation.

Before the RI, only Well 199-D8-54B was completed in the first water-bearing unit of the RUM underlying 100-D. This well is located in an area of relatively low Cr(VI) concentrations in the northern plume. Data had not been collected beneath the 100-D southern plume, where the highest Cr(VI) concentrations are present in the unconfined aquifer. Cr(VI) concentrations in the southern plume are an order of magnitude greater than encountered in the northern plume. In 100-H, two wells (199-H3-2C and 199-H4-12C) and one piezometer (199-H4-15CS) are screened in the first water-bearing unit of the RUM. Cr(VI) concentrations in these wells/piezometer range from 55 to 153 µg/L during 2011. Piezometer host 199-H4-15 has three other screens (R, Q, and P) below the RUM at 59.1 to 59.7 m (194 to 196 ft), 89.9 to

90.5 m (295 to 297 ft), and 99.1 to 99.7 m (325 to 327 ft) bgs respectively. Cr(VI) has not been detected at concentrations above the AWQC in groundwater samples collected from these deeper sampling points.

Five deep boreholes were drilled as part of the RI to address the need for additional deeper characterization data. Two wells were placed at 100-D and three at 100-H. In 100-D, monitoring well 199-D5-134 (C7624, Well R4) was drilled slightly downgradient of the northern plume hot spot. Well 199-D5-141 (C7625, Well R5) was drilled near the 100-D-12 Pump Station/French Drain. In 100-H, groundwater monitoring well 199-H3-9 (C7639, Well R1) was drilled near the 116-H-7 Retention Basin. Well 199-H3-10 (C7640, Well R2) was drilled near the 183-H Clearwells/Disposal Pit. Well 199-H2-1 (C7631, Well R3) was drilled adjacent to the river, not bordering any known waste sites.

Well locations were selected to augment the existing well coverage in 100-H and to perform general characterization in 100-D in areas where deep investigations had not yet been carried out. Methods for collecting soil and groundwater samples during RUM drilling are described in Section 2.1.8. Table C-5 (Appendix C) summarizes borehole/well locations, depth to the Hanford formation/Ringold Formation unit E contact (if present), RUM surface contact, and well construction information. Table C-6 (Appendix C) summarizes the samples planned in the 100-D/H SAP (DOE/RL-2009-40) versus those actually collected during drilling.

Groundwater samples were collected at discrete depth intervals during drilling. Samples were collected from the unconfined aquifer, water-bearing units in the RUM, and deeper water-bearing units (presumed to be the Ringold Formation unit B). Laboratory analysis was conducted for analytes listed in Table 2-11. In addition, one field filtered groundwater sample was collected for analysis of Cr(VI) and other metals to support K_d determination and to refine the nature and extent of Cr(VI) contamination. The sampling methodology used is described in Section 2.1.8. The deep boreholes were completed as monitoring wells in the first water-bearing unit of the RUM.

Split-spoon soil samples were collected at various depth intervals in the vadose zone and unconfined aquifer, at the aquifer/RUM contact, at additional depth intervals within the RUM, and within the Ringold Formation unit B. Soil samples were screened in the field for radiological and Cr(VI) contamination and laboratory analyzed for target analytes. 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 vertical hydraulic conductivity). Samples were also collected at approximately 1.5 m (5 ft) intervals throughout the entire borehole intervals for field screening and geologic logging.

Table 2-11. Groundwater Contaminants of Potential Concern and Additional Analytes for 100-D/H

Contaminants of Potential Concern				
Radionuclides	**Nonradionuclides**			
Strontium-90 Technetium-99 Tritium	1,1-Dichloroethene Antimony Arsenic Benzene Beryllium Cadmium Carbon Tetrachloride	Chloroform Chromium (Total) Cobalt Copper Fluoride Cr(VI)	Lead Manganese Mercury Nickel Nitrate (as N) Nitrite (as N) Selenium	Silver Sulfate Thallium Trichloroethene Uranium Vanadium Vinyl Chloride Zinc

Table 2-11. Groundwater Contaminants of Potential Concern and Additional Analytes for 100-D/H

Contaminants of Potential Concern	
Additional Analytes	
Radionuclides	**Nonradionuclides***
Gross alpha Gross beta Cesium-137 Cobalt-60 Europium-152 Europium-154	Cyanide Pesticides Polychlorinated Biphenyls Polycyclic Aromatic Hydrocarbons Semivolatile Organic Compounds

Source: *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).

* Semivolatile organic compounds, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, and cyanide were analyzed for select wells and sampling events, as identified in Table 2-19 of DOE/RL-2009-40.

Figure 2-12 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. Table C-5 (Appendix C) summarizes the well construction, locations, and depth to the upper contact of the Ringold Formation unit E and the RUM encountered during drilling of each borehole.

Following construction, wells were developed by pumping at sustainable flow rates up to 4.2 L/sec (55 gal/min). Development was continued until the well produced clear water consisting of low turbidity (less than or equal to 5 nephelometric turbidity units) and stabilized (at least three consecutive measurements within 10 percent of each other) temperature, pH, and specific conductance measurements were obtained. Water level drawdown and recovery was monitored with pressure transducer and datalogger equipment. These deep wells were not sampled further for the RI, but will be incorporated into the monitoring well network that is sampled periodically and included in annual reports (such as *Hanford Site Groundwater Monitoring Report for 2010* [DOE/RL-2011-01]).

Remedial Process Optimization Wells. As discussed in Section 2.1.8, 70 RPO wells were installed in 100-D/H as part of an expansion for the pump-and-treat system. Data were collected from these wells to support the RI effort in addition to the primary purpose of increasing efficiency of the pump-and-treat system. Groundwater samples collected specifically for the RI were from the unconfined aquifer. Results from these data are discussed in Chapter 3 and Chapter 4.

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] and strontium-90) at concentrations above cleanup standards (e.g., PRGs) in select locations in the unconfined aquifer in 100-D and 100-H (Data Gap 5). To address Data Gap 5, groundwater monitoring wells and aquifer tubes were installed at 100-D/H. Table 2-1 lists the wells and aquifer tubes installed to address this data gap. Information about the construction of these wells and aquifer tubes is summarized in Appendix C.

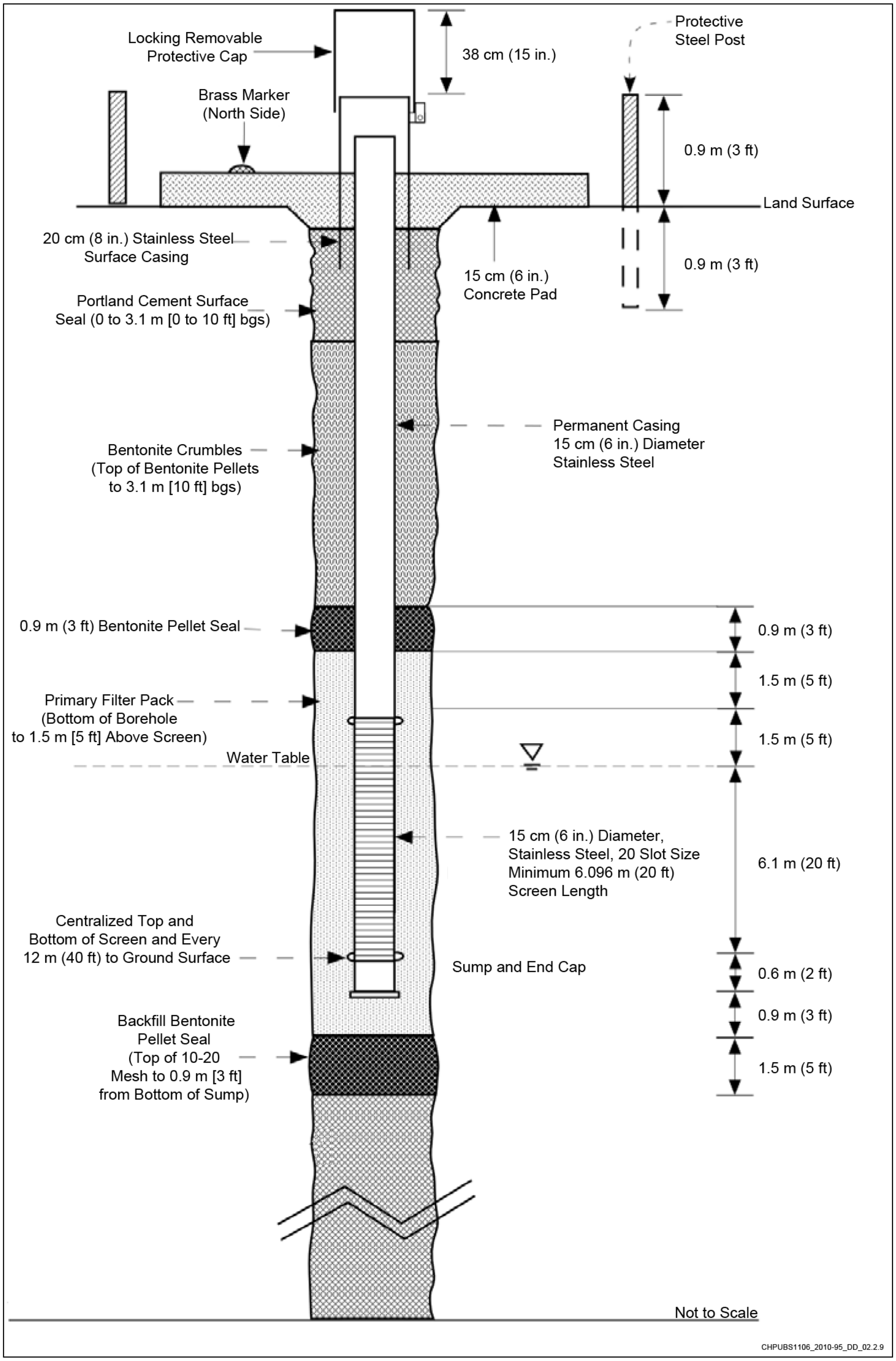

Figure 2-12. General Well Design

Each well was drilled to the top of the RUM and screened across the entire saturated thickness to characterize the unconfined aquifer. Soil samples were typically collected at 1.5 m (5 ft) intervals for geologic archive samples and field screening. Additionally, soil samples for each well were generally collected at 4.6, 3, 1.5, and 0.6 m (15, 10, 5, and 2 ft) above the water table, at the water table, 1.5 m (5 ft) below the water table, and at the bottom of the unconfined aquifer for analysis for location-specific target analytes, field screening parameters, and batch leach testing. Split-spoon samples were also collected from each borehole at major formations and lithology changes to provide site-specific physical property data (grain size, porosity, moisture content, bulk density, and vertical hydraulic conductivity) to support modeling efforts.

During the drilling of each well, groundwater samples were collected at 1.5 m (5 ft) intervals through the unconfined aquifer, beginning at approximately 1.5 m (5 ft) into the unconfined aquifer, for information on the vertical distribution of contaminants. Depth discrete groundwater samples were collected in each of the permanent wells during drilling starting at a depth of approximately 27 m (88 ft) in 100-D and starting at approximately 9 to 13 m (29 to 43 ft) in 100-H. Groundwater sampling continued to either the RUM contact for shallow wells or to the bottom of the borehole for deep (RUM) wells. All water samples from the wells were analyzed for groundwater COPCs (Table 2-11).

Wells were constructed and developed as described in Section 2.1.10.1. The wells were equipped with 3.1 to 4.6 m (10 to 15 ft) long screens, with construction details included in the borehole summary reports. In addition, copies of the borehole logs, detailed sampling summaries, geophysical logs, and final surveys are located in the borehole summary reports (Section 2.2). Table C-5 (Appendix C) summarizes borehole/well locations, depth to the Hanford formation/Ringold Formation unit E contact (if present), RUM surface contact, and well construction information.

At 100-D, Monitoring Well 199-D3-5 (C7620, Well 2) and Wells 199-D6-3 (C7623, Well 5), 199-D5-140 (C7866, Well 9), and 199-D5-144 (C8668, Well R5 redrill) were installed to define the extent of the Cr(VI) plume to the south, southeast, and east, along with aquifer tubes (C7645, C7646, C7647, and C7648). The aquifer tubes were used in this area in lieu of installing monitoring wells to protect cultural resources. Monitoring Well 199-D3-5 (C7620, Well 2) was intended to define the extent of the Cr(VI) plume to the south; however, Cr(VI) was detected at that location, and therefore the edge of the plume has not been identified. If needed, additional wells may be installed during remedial design to address this data gap. In addition to defining the Cr(VI) plume, Monitoring Well 199-D6-3 (C7623, Well 5) was installed to define the extent of the strontium-90 plume, and to determine if potential sources of contamination are present in groundwater southeast of the 105-D Reactor. Monitoring Well 199-D5-133 (C7621, Well 3) was also installed to define the extent of the strontium-90 plume.

During the northern plume investigation (*Report on Investigation of Hexavalent Chromium Source in the Northern 100-D Area* [DOE/RL-2010-40]), a borehole had been drilled near the 100-D-56 Pipeline and had not identified high concentrations of Cr(VI) in soil. Therefore, during the RI, Monitoring Well 199-D5-140 (C7866, Well 9) was installed to investigate Cr(VI) sources near the 100-D-56 Pipeline where a hole in the pipeline, as a result of corrosion, was noted during remediation activities. However, because of an initial incorrect location of Well 199-D5-140 (C7866), a replacement well, Well 199-D5-143 (C8375, Well 9-redrill) was drilled in the planned location and sampled in accordance with the 100-D/H SAP (DOE/RL-2009-40). Since the northern plume investigation did not identify a Cr(VI) source, this well location was also selected to evaluate whether Cr(VI) concentrations in groundwater are higher near the pipeline than in nearby Wells 199-D5-125 and 199-D5-126, which have Cr(VI) concentrations between 1,500 and 2,000 µg/L.

From 1987 to 1999, groundwater samples from Monitoring Well 199-D5-12 (located east of the 105-D Reactor) had the highest strontium-90 concentrations identified in the unconfined aquifer underlying 100-D. This well was decommissioned in late 1999, with the last groundwater sample collected having strontium-90 concentrations exceeding the DWS of 8 pCi/L by approximately five times. Since that time, no wells have been available for sampling near this former well location. During the RI, Monitoring Well 199-D5-132 (C7622, Well 4) was installed as a replacement through the 116-D1-1A Trench to monitor both strontium-90 and Cr(VI). Well 199-D5-132 is located approximately 46 m (150 ft) and hydraulically downgradient from former Well 199-D5-12 and, therefore, monitors contaminants that may have sources located near the former well.

A cluster of two new aquifer tubes (C7649 and C7650), Monitoring Well 199-H3-6 (C7626, Well 6), and Wells 199-H3-7 (C7627, Well 7) and 199-H6-3 (C7628, Well 10) were installed in 100-H to define the extent of strontium-90 and to monitor nitrate concentrations. Specifically, the strontium-90 plume near waste sites 116-H-1 and 116-H-7, and along the river, had not been well defined.

Monitoring Wells 199-H6-3 (C7628, Well 10) and Well 199-H6-4 (C7629, Well 11) were installed to evaluate the southern extent of the strontium-90 plume, south of Well 199-H6-1 (and the former 107-H Liquid Disposal Trench [Waste Site 116-H-1]) in 100-H. In addition, the wells were placed to allow further evaluation of potential effects related to the 1607-H3 Septic System near a former guardhouse location (Facility 1720-H).

Monitoring Well 199-H1-7 (C7630, Well 12) was installed to assess groundwater effects north of the 1607-H3 Septic System where sufficient well coverage had not been available. Monitoring Well 199-H1-7 was also placed to monitor for polychlorinated biphenyls (PCBs), specifically Aroclor-1254), which was detected in an unfiltered groundwater sample from Well 199-H4-10 at a concentration of 8.3 µg/L in November 2005. Aroclor-1254 was also detected in CVP samples collected during remediation of the 1607-H2 waste site.

The aquifer tubes installed to address Data Gap 5 are 0.64 cm (0.25 in.) outer diameter (0.43 cm [0.17 in.] inner diameter) polyethylene tubes that have a 15 cm (6 in.) long screen at the lower end. The tubes were implanted into the aquifer by driving a temporary steel casing into the ground and inserting a tube into the casing. The end of each tube was fitted with a screened section, which acts as the sampling port. The temporary steel casing was driven either by a hydraulic ram attached to a vehicle or by a hand-carried pneumatic air hammer. The steel casing was then backpulled, leaving the tube (and the stainless steel drive point) in place. Water is withdrawn from the tube using a peristaltic pump. The tubing exposed at ground surface is of minimal length (several feet) and is protected from wildlife and the elements by PVC conduit. Figure 2-13 shows the main components of aquifer tube installation. Each individual tube was driven to a different depth. 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. Table C-10 summarizes information on the two new aquifer tube clusters that were installed as part of the RI.

2.1.10.3 Evaluate Reasons for the Persistence of Cr(VI)

Groundwater samples were analyzed for COPCs as specified in the 100-D/H Work Plan. In addition, for the low and transition river stage sampling rounds, groundwater samples from select wells were analyzed for cyanide, pesticides, PCBs, polycyclic aromatic hydrocarbons (PAHs), and/or semivolatile organic compounds (SVOCs), as in the 100-D/H Work Plan (DOE/RL-2008-46-ADD1).

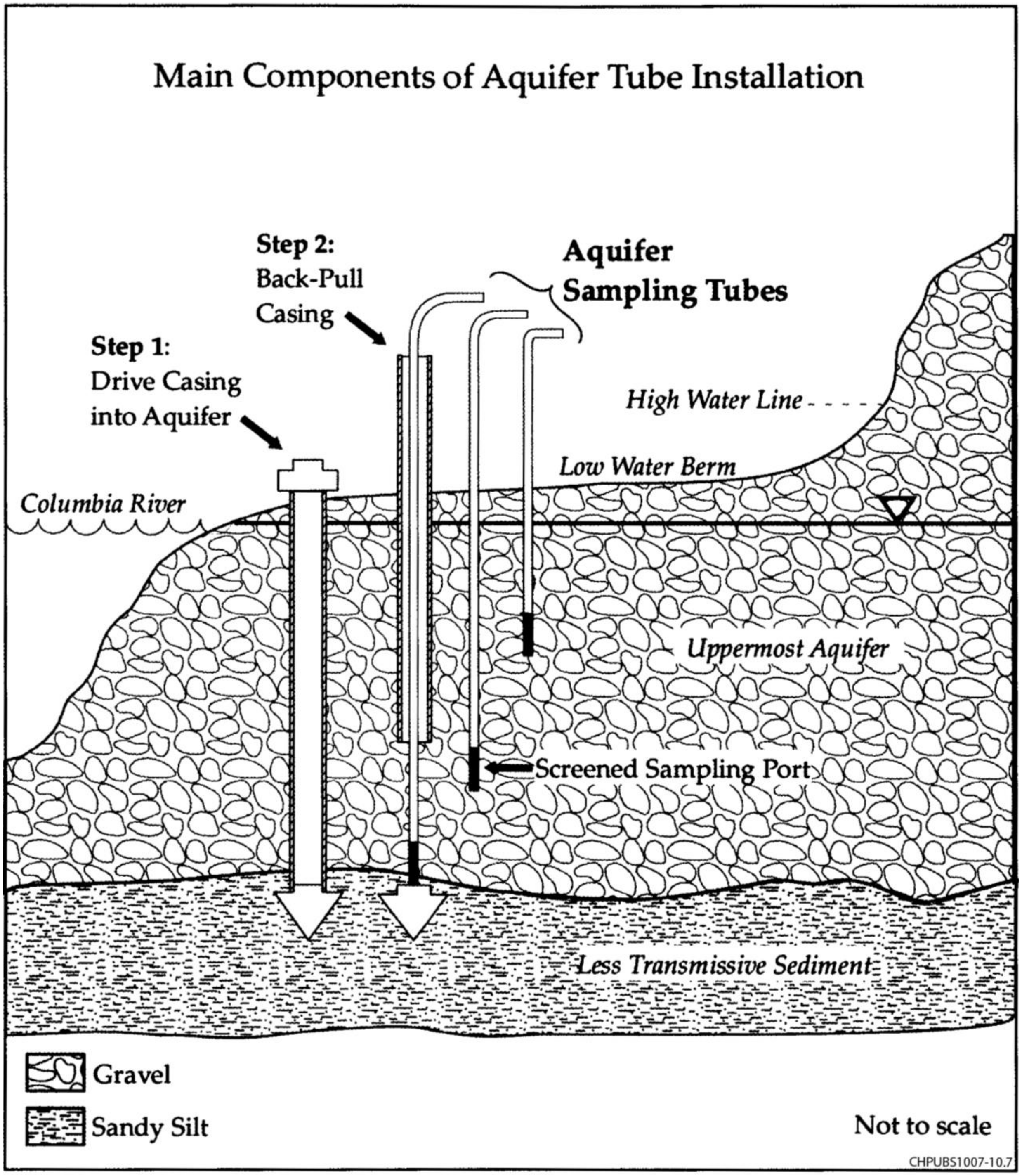

Figure 2-13. Main Components of Aquifer Tube Installation

2.1.10.4 Evaluate the 182-D Reservoir

The Export Water System, originally installed in the mid-1940s, provides redundant water supply capability using pumps located in 181-B/182-B Buildings as the primary source, with pumps in 181-D/182-D Buildings and 182-B Building diesel pumps as backup sources. Concerns over leakage from the 182-D Reservoir and the potential for any leakage to affect remedial actions led to a need to evaluate the reservoir uses (Data Gap 14). The current Water System Master Plan (HNF-5828) evaluates the future needs and infrastructure for the reservoir and export water lines and considers future operation needs for the 182-D Reservoir (Data Gap 14).

The 182-D Reservoir has a capacity of 94.6 million L (25 million gal); however, this has been administratively reduced to about 18.9 million L (5 million gal). Both operational and out-of-service pumps are present at 100-D/H. Use of the 182-D Reservoir is scheduled to continue for several years. Improvements to the 100-BC Export Water System, proposed for mid-2014, may facilitate some additional use of the system at 100-D/H during upgrades at 100-BC, depending on the status of use and water system expansion of operations at the 200 East and 200 West Areas. The current schedule has the 182-D Reservoir and associated pump stations closed by mid-2016, dependent on funding and other site priorities (Water System Master Plan [HNF-5828]). Automated groundwater elevation monitoring has been conducted historically near the reservoir. Quarterly sampling at selected wells near the reservoir will continue as part of standard remedy performance evaluation.

2.1.10.5 Ongoing Groundwater Monitoring

The 100-D/H RI groundwater data were evaluated with groundwater data from ongoing sampling of monitoring wells and aquifer tubes (Chapter 4). Monitoring wells and aquifer tubes in 100-D/H are sampled according to an established schedule and analyzed for specified constituents. The RI/FS unconfined aquifer wells, RUM wells, and aquifer tubes will be included in future groundwater sampling events to aid in monitoring the presence of selected COPCs in groundwater.

The following list presents the main guiding documents governing monitoring well and aquifer tube sampling and analysis in 100-D/H. Numerous TPA Change Notices have been issued to update these documents as wells have been added or decommissioned and are available in the Administrative Record:

- *Sampling and Analysis Plan for In Situ Redox Manipulation Project* (DOE/RL-2003-63)
- 100-D/H SAP (DOE/RL-2009-40), as amended
- SAP for Aquifer Sampling Tubes (DOE/RL-2000-59)
- RCBRA SAP (DOE/RL-2005-42)
- *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* (DOE/RL-2006-75)
- IAMP (DOE/RL-96-90), as amended
- *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)
- *Data Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington* (WCH-398)

2.1.11 Dense Chrome Theory Evaluation

Historical handling activities of sodium dichromate at 100-D (100-D-12 and former Railcar Unloading Station) have led to a theory regarding the potential presence of a dense Cr(VI) plume at the base of the unconfined aquifer, at the Ringold Formation unit E/RUM contact. This theory relates to Data Gaps 5 and 10, nature and extent of contamination in the unconfined aquifer and reasons for the persistence of the Cr(VI) plume, respectively. Concentrated solutions at 3,340 g/L being transferred off the rail car that leaked into the ground would have migrated through the vadose zone and entered the groundwater with relatively little dilution. Once in the groundwater, the density of the concentrated solution may have been sufficient to cause that solution to drop through the unconfined aquifer and collect on the RUM surface, because of the presence of silts/clays. Subsequently, this mass would diffuse and advect over the years within the groundwater flow regime to the current distribution. The maximum distribution observed at 199-D5-122 is about 69,700 µg/L, approximately 10,000 times less than the concentrated solution.

The vertical distribution of Cr(VI) in the unconfined aquifer was investigated previously (*Report on Investigation of Hexavalent Chromium in the Southwest 100-D Area* [DOE/RL-2009-92]). The investigation plan is described in *Field Investigation Plan for the Source of the Southwestern Chromium Plume in the 100-D Area* (DOE/RL-2006-74). Six wells near the 100-D South Plume "hot spot" were investigated using both Kabis and Solinst sampling devices. The only stratification in concentration was observed in Well 199-D5-99 at the base of the aquifer. Since that time, no additional work had been conducted to investigate Cr(VI) concentration stratification and determine if there are remnants in the current concentration distribution that support this theory. Therefore, passive samplers were used within four existing monitoring wells in 100-D/H to provide additional vertical stratification data. This additional work was performed outside the scope of the 100-D/H RI under a sample instruction. Results of the analyses are presented and discussed in Section 4.5.2.

2.1.12 Ecological Investigations

Ecological investigations have been conducted within or as part of the RI/FS for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and HR-3 OUs. These investigations have included work completed in support of the RCBRA (DOE/RL-2007-21), specifically Volume 1; the CRC (DOE/RL-2010-117), specifically Volume 1; and the Surface Environmental Surveillance Program (SESP) operated by Pacific Northwest National Laboratory (PNNL).

Ecological investigations for the RCBRA were identified through the data quality objective (DQO) process (*DQO Summary Report for the 100 Area and 300 Area Component of the RCBRA* [BHI-01757]) and as specified in the RCBRA SAP (DOE-RL-2005-42). Data collection consisted of sampling biotic media (e.g., plant, invertebrate, small mammal, bird egg, and fish tissue) and co-located abiotic media (e.g., soils, pore water, and sediment) for various contaminants of potential concern. Various field measures (e.g., species density and abundance) and biological assays (laboratory toxicity tests conducted on biota introduced to Hanford abiotic media) were also conducted. These data were included as appropriate as part of the ecological risk assessment presented in Chapter 7 and the riparian and nearshore evaluation in Appendix L of this report.

Ecological investigations for the CRC were identified through the DQO process (*DQO Summary Report for the Remedial Investigation of Hanford Site Releases to the Columbia River* [WCH-265]) and as specified in the Columbia River RI Work Plan and its corresponding SAP (DOE/RL-2008-11, Appendix A). Biota data collection focused on collecting fish tissue samples in 2009 and 2010. Associated abiotic media (surface water, sediment, and a groundwater upwelling study) were also collected to use in conjunction with the fish tissue samples. These data were included as appropriate as part of the ecological risk assessment presented in Chapter 7 and the riparian and nearshore evaluation in Appendix L of this report.

Through the SESP, PNNL monitors and surveys the Hanford Site plant and animal resources to establish potential radiological exposures as a result of 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]). Section 3.9 summarizes the ecology of the Hanford Site and Section 4.2.5 summarizes the results of the biota monitoring.

2.1.12.1 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.

2.1.12.2 Fish and Wildlife Monitoring

Fish and wildlife on the Hanford Site are monitored for Site-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 strontium-90 and gamma emitters, including cesium-137. Since the 1990s, strontium-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.

2.1.12.3 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.

2.1.12.4 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. In addition, two aerial surveys were conducted to identify possible steelhead trout spawning areas. 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.

2.1.12.5 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. Burrowing owl distributions and nesting habitats were evaluated.

2.1.12.6 Contaminated Biota

Radiological surveys are conducted around active and inactive waste sites at the Hanford Site to detect surface radiological contamination, including biointrusion, from plants and animals (including insects). The results from these surveys are used to determine trends, assess environmental impacts, and identify corrective actions, as appropriate. None of the 100 Area sites falls within the priority ranking for contamination incidents at the Hanford Site (most incidents are reported in the 200 Area). A total of 18 contamination episodes, mostly animal-related, were reported across the entire 100 Area in 2010 (*Quarterly Environmental Radiological Survey Summary, Fourth Quarter Calendar Year 2010* [HNF-SP-0665]).

2.1.13 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:

- **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 the river is cyclical in response to the diurnal river stage cycles, which typically include two high and low stages in response to upstream hydroelectric dam power peaking demands. Review of modeling suggests there is a significant back-and-forth motion in the groundwater near the river that results in a substantial reduction in the groundwater flow velocity in the aquifer. It will experience numerous changes in flow direction before it eventually reaches the water column in the river. This concept is further discussed in Chapter 4 (Section 4.9.8.4, "Hyporheic Zone").

- **Analyzed samples to determine River Corridor background concentration values for antimony, boron, cadmium, lithium, mercury, molybdenum, selenium, silver, and thallium.** Site-specific background values for these constituents were needed to determine soil cleanup values because calculated risk based concentrations and/or ecological protection concentrations were less than Washington State or expected site-specific background values. Provisional data have been calculated and are presented in *Soil Background for Interim Use at the Hanford Site* (ECF-HANFORD-11-0038). 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 action RODs is 2.0 mg/kg.

- 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.** Different K_d values have been identified at the Hanford Site for antimony. A site-specific value is needed to calculate soil RAG values (2007 MTCA, "Deriving Soil Concentrations for Groundwater Protection" [WAC 173-340-747(3)(a)]). The summary of a scientific literature review conducted for this task 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 Site 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 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 "Cleanup Levels and Risk Calculations" (CLARC) database (Ecology, 2009), hereinafter called CLARC database.

  - 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 Site soil types. This value is based on sorption, not desorption.

  - Based on this review, a K_d value of 3.76 mL/g was used in the groundwater modeling presented in Chapter 5. This is 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 a maximum concentration of antimony reaching groundwater at a peak year greater than 1,000 years, and the elimination of antimony as a groundwater COPC. A higher K_d value would have no effect on this result.

- **Reevaluated 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 TPA (Ecology et al., 1989) stipulation to use the 1996 MTCA ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740(2)]) Method A value (*Remedial Design Report/Remedial Action Work Plan for the 100 Area* [DOE/RL-96-17]). The 2007 MTCA ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740(2)]) Method A value is also 20 mg/kg. In accordance with Ecology guidance (Ecology memo dated June 11, 2013, "Issues Associated with Establishing Soil Cleanup Levels for Arsenic" [Bradley, 2013]), the Method A arsenic soil cleanup level (20 mg/kg) can be used to define natural background levels when developing Method B soil cleanup levels for the Hanford site. 2007 MTCA (WAC 173-340) is not intended to address health risks from other sources, including natural background.

2.2 Field Activity Documentation

As discussed in previous sections, field investigations have been conducted in 100-D/H to address the concerns discussed in the Data Needs Table 2-1, to supplement information received from the LFIs, and in response to results from ongoing remedial actions (for example, CERCLA 5-year reviews). The results of these field investigations are summarized in a variety of documents and tables. The following three borehole summary reports contain the borehole logs, detailed sampling summary, well summary sheets, and the final survey data:

- *Borehole Summary Report for the Installation of 16 Resource Protection Wells in the 100-HR-3 Groundwater Operable Unit in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit* (SGW-49912)
- *Borehole Summary of Ten Characterization Boreholes in the 100-DR-1, 100-DR-2 and 100-HR-1, 100-HR-2 Source Operable Units in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit* (SGW-50131)
- Borehole Summary Report for RPO Wells (SGW-48612)

The additional field data not contained within these reports are located in Appendix C.

3 Physical Characteristics of the Study Area

This chapter describes the physical and environmental characteristics of 100-D/H, including the information obtained during the RI and ongoing monitoring activities. Physical characteristics are important components of the CSM because they help in presenting and understanding the nature and extent of contamination (as described in Chapter 4) and contaminant fate and transport (described in Chapter 5). The topics of this chapter include important surface features, meteorology, hydrology, geology, soil, hydrogeology, artificial water systems, demography and land use, ecology, and cultural resources. Some topics, such as regional geology and meteorology, concern the Hanford Site as a whole, while others are more specific to 100-D/H.

Highlights

- The topography in 100-D/H is relatively flat inland from the Columbia River, with a break in slope on the east side of 100-D and changes are greatest near the Columbia River where the riverbank slopes steeply.
- 100-D/H is characterized by a semiarid climate, shrub-steppe community with occasional high winds.
- The vadose zone consists of the highly transmissive and heterogeneous Hanford formation, underlain by the slightly less transmissive Ringold Formation unit E in 100-D. The less transmissive RUM unit underlies the Ringold Formation unit E and serves as an aquitard forming the base of the unconfined aquifer. The RUM contains poorly defined water-bearing layers.
- At 100-H, the Ringold Formation unit E is largely absent with the Hanford formation constituting both the vadose zone and unconfined aquifer.
- The unconfined aquifer is predominantly within Ringold Formation unit E at 100-D and predominantly within the Hanford formation in the Horn and 100-H.
- Groundwater flows more readily across the Horn and 100-H because of the difference between the geologic units.
- The vadose zone is thicker at 100-D than at 100-H.
- River stage affects groundwater near the river, influencing groundwater elevations over 700 m (2,300 ft) inland at 100-D and over 640 m (2,100 ft) inland at 100-H. When river stage is low (October), groundwater flow is from 100-D/H toward the river. When river stage is high, water can enter the near-river aquifer and mix with 100-D/H groundwater.

3.1 Surface Features

Natural and manmade forces have modified the surface topography of the Hanford Site (*200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program* [DOE/RL-98-28]). The Columbia River, Pleistocene catastrophic flooding, Holocene eolian forces, interim remedial actions, and the construction of roads and buildings to support Site missions have modified the Hanford Site topography. Basalt ridges and low-relief plains dominate the land surface of the Hanford Site. East-west trending anticlinal ridges are present south of 100-D/H. The surface topography of 100-D/H (Figure 3-1) was updated in FY 2010 using LIDAR, as described in Section 2.1.3.

The topography in 100-D/H consists of relatively steep banks rising up from the Columbia River and then generally flat to slightly undulating inland. Surface outburst channel features from ice age flooding events (discussed in Section 3.4) can be seen on Figure 3-1. The east side of 100-D slopes significantly and is several meters lower in elevation extending across the Horn area into 100-H. This break in slope appears to coincide with the eastern edge of the Ringold Formation unit E, which is not present across the Horn or at 100-H. Surface elevations range from approximately 154 m (505 ft) along the western boundary of 100-D/H to 115 m (377 ft) south of H Reactor.

3.2 Meteorology

The Hanford Site is located in a structural and topographic depression of the Columbia Plateau called the Pasco Basin. The area has a semiarid climate with dry and warm conditions. 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* [PNNL-6415], hereinafter called the NEPA Characterization Report). The Cascade Range to the west creates a rain shadow effect over eastern Washington State, minimizing precipitation at 100-D and 100-H, while the Rocky Mountains and ranges in southern British Columbia protect the sites from the more severe polar air masses from Canada (*Hanford Site Climatological Summary 2004 with Historical Data* [PNNL-15160]).

Climatologic data are monitored at the HMS near the 200 Area southwest of the 100-D/H boundary and other locations throughout the Hanford Site. Data gathered at the station are representative of conditions in 100-D/H. The station is approximately 12.9 km (8 mi) southwest of the 100-D/H boundary. From 1945 through 2009, the recorded maximum temperature was 45°C (113ºF) during 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 54 percent (NEPA Characterization Report [PNNL-6415]). 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 minimum and maximum temperatures, respectively, at the Hanford Site from 1945 through 2009.

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 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.

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 km/h (6 to 7 mi/h) (Table 3-4). The highest average wind speeds, ranging from 14 to 16 km/h (8 to 10 mi/h), have been reported during summer. The fastest wind speeds recorded at HMS are usually associated with flow from the southwest. However, the summertime drainage winds from the northwest frequently exceed speeds of 47 km/h (30 mi/h).

Strong winds occasionally create blowing dust, and dust suppression measures are necessary during construction, demolition, and remedial actions to prevent the spread of contamination during periods of high winds. Methods used to minimize wind-related concerns in 100-D/H include applying dust suppression water and soluble adhesives. Wind and dust can limit the progress of work, and at times, it is necessary to stop work.

The wind speed class with the highest frequency of occurrence at HMS is 6.5 to 11 km/h (4 to 7 mi/h). Winds in that category occur 37 percent of the time. The speed class with the second highest frequency of occurrence is 13 to 19 km/h (8 to 12 mi/h), at 25 percent. Winds averaging over 40 km/h (25 mi/h) only occur 1 percent of the time on an annual basis, with the highest frequency (1.6 percent) in March (*Hanford Site Climatological Summary 2004 with Historical Data* [PNNL-15160]).

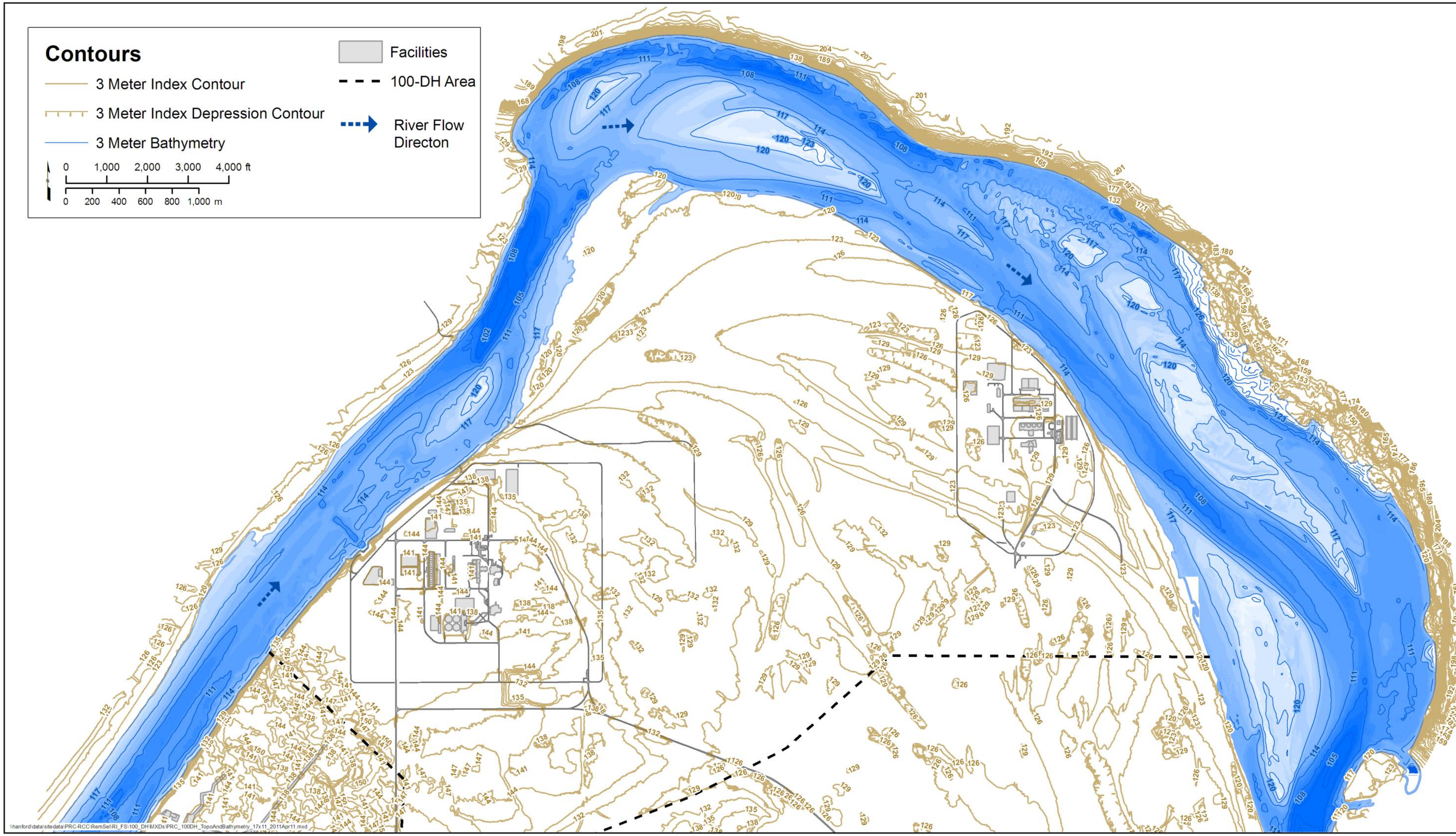

Figure 3-1. 100-D/H Topography and Columbia River Bathymetry (2010)

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

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

Source: http://www.hanford.gov/page.cfm/hms/products/minmonth.

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

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

Source: http://www.hanford.gov/page.cfm/hms/products/maxmonth.

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

1947–2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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
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
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
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
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
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

Source: http://www.hanford.gov/page.cfm/hms/products/totprcp.

Table 3-4. Monthly Extremes for Prevailing Wind Directions, Average Speeds, and Peak Gusts at 15.2 m (50 ft) Level 1945 through 2004

Month	Prevailing Direction	Average Speed (km/h [mi/h])	Highest Average		Lowest Average		Peak Gusts		
			km/h (mi/h)	Year	km/h (mi/h)	Year	Speed (km/h [mi/h])	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 (8.2)	17.2 (10.7)	1977	9.5 (5.9)	1958	113 (70)	SW	1956
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	January 1972

Source: *Hanford Site Climatological Summary 2004 with Historical Data* (PNNL-15160), Table 5.1.

3.3 Surface Water Hydrology

The Columbia River is the only perennial surface water feature associated with 100-D/H. The Columbia River influences Site hydrogeology and contaminant migration, and is used as an onsite and regional water supply.

3.3.1 Columbia River

The Columbia River is the only natural surface water feature near 100-D/H and the study area to the west, north, and east (Figure 3-1). 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 stretch of Columbia River along the 100 Areas is referred to as the Hanford Reach. The Hanford Reach extends from river mile 396 approximately 1.6 km (1 mi) below Priest Rapids Dam downstream 81.6 km (51 mi) to river mile 346.5 north of the 300 Area north of the city of Richland, Washington (Figure 1-1). In May 2000, the Hanford Reach was incorporated into the 70,820 ha (175,000 ac) Hanford Reach National Monument ("Establishment of the Hanford Reach National Monument" [65 FR 37253]). River flows here are managed by controlling discharges from Priest Rapids Dam for generating power, controlling floods, and promoting salmon egg and embryo survival.

The Columbia River is noted for its very high quality water, exhibiting low suspended and dissolved solids load, 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 run-off from regional and high-elevation snowmelt. Flows are lowest from September through October. 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. It has an average flow rate of approximately 3,250 m^3/s (115,000 ft^3/s).

Construction of the Priest Rapids Dam began in 1956, with power generation starting 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 from 100-D/H is McNary Dam. Construction of the McNary Dam began in 1947 with power generation starting 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 and width of the Columbia River varies with changes in discharges and flow rates. River width within the Hanford Reach 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 measured and recorded hourly at both 100-D and 100-H. Both the D and H River Stage gauges are maintained by DOE. As previously discussed, the river stage fluctuates throughout the year, depending on season. The Priest Rapids Dam, which is upstream from the 100 Area, ultimately controls the volume of river water flowing through the Hanford Reach. Figure 3-2 shows the daily average and annual river discharge rates at Priest Rapids Dam from 2005 through 2009. The river responses at the 100-D and 100-H gauge stations are similar. The highest discharge rates generally occur in May and June, when snowmelt is contributing to surface runoff into the river. Fluctuations in river stage directly influence groundwater levels, as described in Section 3.7.2.

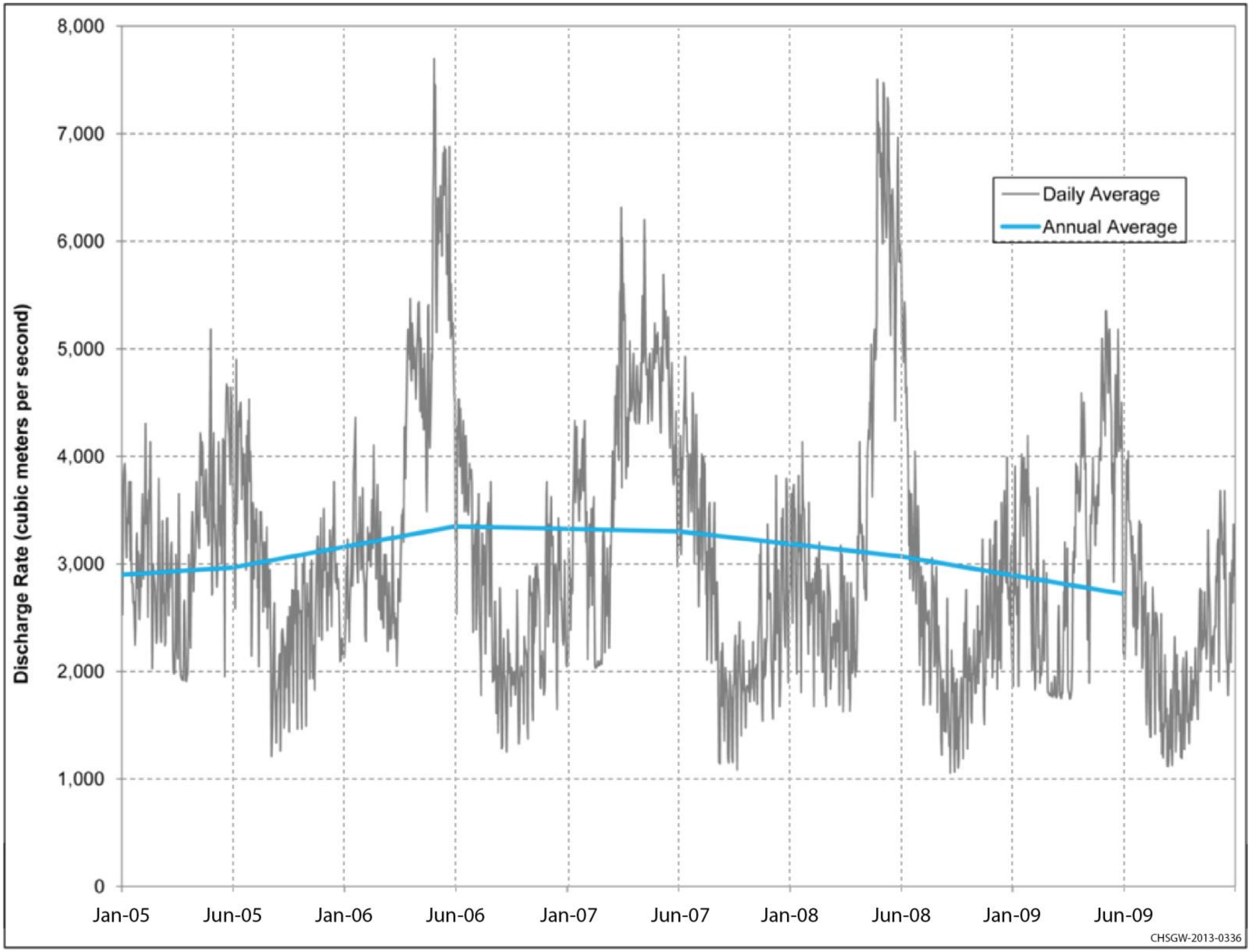

Figure 3-2. Daily Average and Annual Average Discharge Rates at Priest Rapids Dam (2005–2009)

3.3.2 Surface Water Use

Surface water from the Columbia River is withdrawn at 100-D for Hanford Site water use (*Hanford Site Environmental Report for Calendar Year 2006* [PNNL-16623]). The 182-D Reservoir was constructed and was put into use in 1945. The reservoir provided cooling water to D Reactor and a secondary supply of raw water to the rest of the Hanford Site. Section 3.8 provides additional details regarding the water supply system on the Site. The Columbia River also provides the primary source of drinking water for the downstream municipalities of Richland, Kennewick, and Pasco, Washington. Numerous agricultural production operations downstream of the Hanford Site also withdraw water from the Columbia River for irrigation.

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]). Unconsolidated sediments of the late Miocene, Pliocene, and Pleistocene ages (suprabasalt sediments) 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 (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

During the Ice Age (Pleistocene epoch), massive cataclysmic floods repeatedly occurred, interrupted by interglacial periods of several tens of thousands of years. Three episodes of cataclysmic flooding are recognized in the Pasco Basin. The oldest ice age floods were at least 770,000 years ago (±20,000 years); however, the first floods may have occurred closer to the beginning of the Ice Age, 2.6 million years ago. Gravels associated with the last (most recent) episode of flooding are found throughout the Pasco Basin. Fine-grained deposits associated with that flood event contain volcanic material dating between 13,000 and 15,000 years ago (*Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports* [WHC-SD-ER-TI-003]).

3.4.1 Geologic Setting

100-D/H lies on the northern flank of the Wahluke Syncline where the Columbia River winds around the north end of the Hanford Site and flows to the southeast towards Wallula Gap. The suprabasalt sediments at 100-D/H are as much as 108 m (355 ft) thick (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

Numerous investigations have been conducted in 100-D/H that contributed to the understanding of the geology of the area. As part of the RI, data from recently drilled wells were evaluated and combined with historical information and data from wells drilled since 1996 to support the interim actions. The information has been integrated to form an updated interpretation of 100-D/H geology. The general stratigraphic relationships of the units have remained unchanged, but the local geometry and thickness relationships are more detailed.

Geologic units from shallowest to deepest are Holocene sediments, Hanford formation, Ringold Formation, and the Columbia River Basalt Group. *100 Area Stratigraphic Database Development*

(ECF-100NPL-11-0070) describes the process used to create geologic maps and cross sections presented in Appendix M.

A partial listing of previous reports used to supplement the RI data include (but are not limited to) the following documents.

- *Limited Field Investigation Report for the 100-HR-3 Operable Unit* (DOE/RL-93-43)
- *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South Central Washington* (WHC-SD-EN-TI-132)
- *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)
- *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (DOE/RL-99-51)
- *Description of Work for the Installation of Two NABIR Wells at the 100-H Area, FY2006* (WMP-29720)
- *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09)
- *Borehole Summary Report for the Installation of 70 Remedial Process Optimization, Pump-and-Treat Expansion Wells, for the 100-HR-3 Operable Unit* (SGW-48612), which describes 70 new wells drilled to support the DX and HX interim action pump-and-treat expansions and included specific data collected in support of the RI/FS
- *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* (SGW-47776)
- *Report on Investigation of Hexavalent Chromium Source in the Northern 100-D Area* (DOE/RL-2010-40)
- *Report on Investigation of Hexavalent Chromium Source in the Southwest 100-D Area* (DOE/RL-2009-92)
- *Hydrogeological Summary Report for the 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* (DOE/RL-2008-42)
- *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2 and 100-HR-3 Operable Units* (DOE/RL-2008-46-ADD1)
- *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)

Appendix B provides a bibliography of additional documents related to 100-D/H.

Geologic data obtained from the recent drilling of RI and RPO boreholes have considerably improved the knowledge of 100-D/H stratigraphic relationships. Before drilling these boreholes, the geographic location of where the unconfined aquifer matrix transitions from the Ringold Formation unit E to the Hanford formation was not as well defined. The location of this lithologic transition, particularly to the east of 100-D, is important because the Hanford formation is more transmissive than the Ringold Formation unit E, which influences groundwater flow (Section 3.7). Data from the new boreholes also provides better delineation of the RUM surface.

3.4.2 Stratigraphy

Stratigraphic units at 100-D/H are listed below, and shown on the left side of Figure 3-3. Three of these units are most important to understanding groundwater contamination effects, the Hanford formation, Ringold Formation unit E, and the RUM. The cataclysmic flood deposits that form a major portion of the sediment present in the Pasco Basin are not formally named in the stratigraphic nomenclature. Therefore, this unit is informally referred to as the Hanford formation. Figure 3-3 presents the generalized stratigraphic column for 100-D/H, and includes the general lithostratigraphy and hydrostratigraphy, which provide a more detailed description of the geologic material and the locations of the various water bearing units, respectively. It should be noted that the connectivity of the transmissive units within the RUM has not been determined.

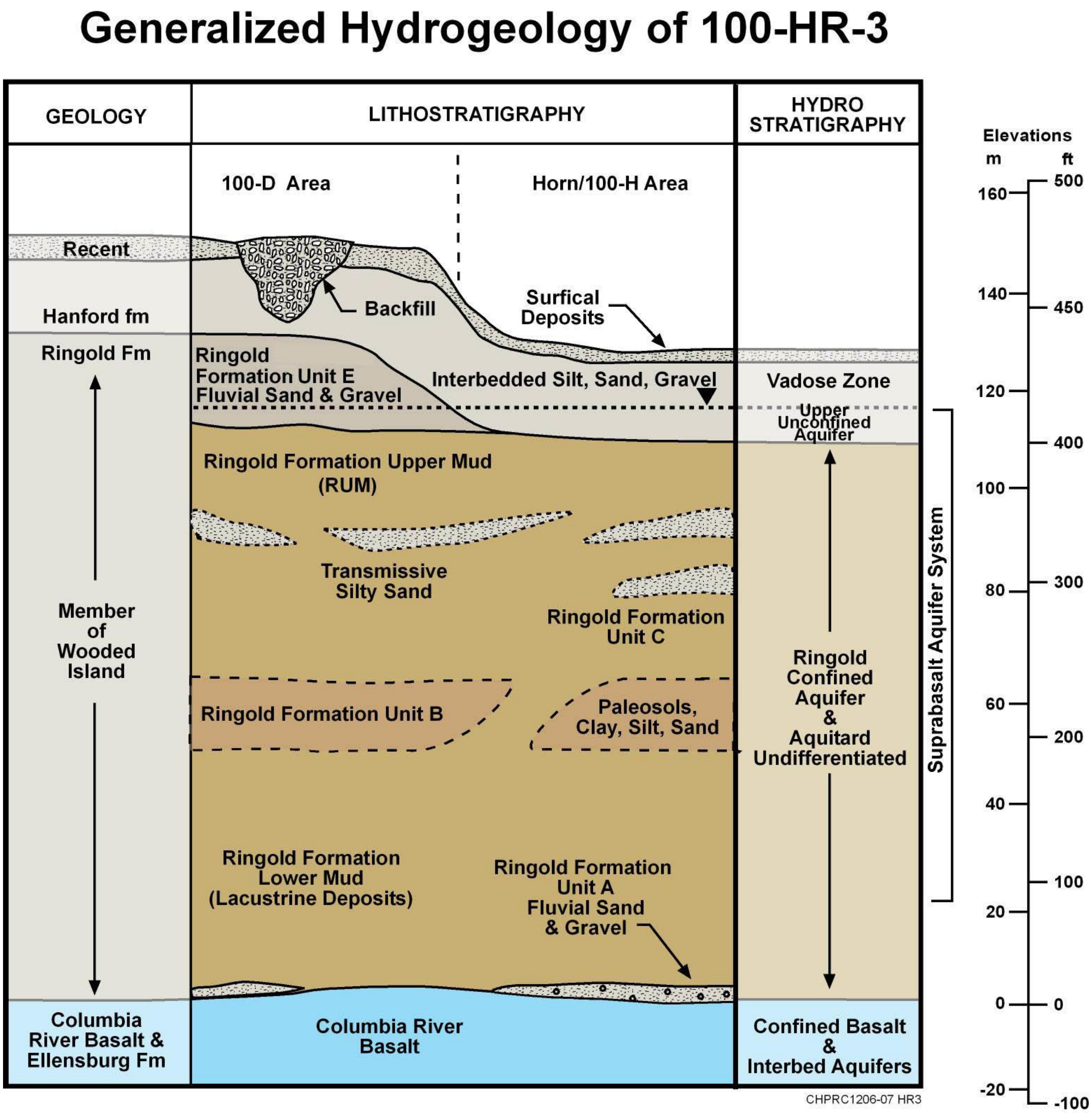

Figure 3-3. Generalized Geology and Hydrostratigraphy of 100-D/H

Specific stratigraphic units are listed below (from youngest to oldest) and described in more detail in the sections that follow:

- Recent eolian or anthropogenic deposits (sand or sand and gravel)
- Hanford formation (sand and gravel)
- Ringold Formation unit E (sand and gravel)
- RUM (silt, fine sand, and clay—includes water-bearing gravely to sandy layers)
- Ringold Formation unit C (sand and gravel)
- Ringold Formation lower mud (RLM) unit (silt and clay)
- Ringold Formation unit B (sand within RLM)
- CRBG (Columbia River Basalt Group flows interlayered with Ellensburg Formation sediments)
- Ellensburg Formation (sedimentary interbeds [tuff, paleosols, and sand] between CRBG basalt flows, including the Rattlesnake Ridge Interbed)

The sediments that overlie the basalts are divided into two primary units. The Ringold Formation is of late Miocene to middle Pliocene age (approximately 10.5 to 3 million years before present [B.P.]) (*Sedimentology and Stratigraphy of the Miocene-Pliocene Ringold Formation, Hanford Site, South-Central Washington* [WHC-SA-0740-FP]). The Ringold Formation 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* [Newcomb et al., 1972]). 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]).

The unconsolidated deposits at 100-D/H are underlain by Miocene-aged (approximately 17 to 8.5 million years B.P.) basalt of the CRBG that is interbedded with the Ellensburg Formation (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]). 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 contaminants in the subsurface. The Ringold Formation at 100-D/H includes several formational units including the Ringold Formation unit E, the RUM, the Ringold unit C (potentially), Ringold unit B, and the RLM. The Hanford formation comprises most of the vadose zone throughout 100-D/H. In addition, the Ringold Formation unit E is present in 100-D, where it comprises the unconfined aquifer and part of the vadose zone. Elsewhere in 100-D/H, the unconfined aquifer is composed almost entirely of Hanford formation sediments, including the area across the Horn. Aquifer testing and slug testing data indicate that the horizontal hydraulic conductivity of the Hanford formation is generally three times greater than the Ringold Formation unit E; although a variable degree of cementation can influence the transmissivity in both units (Tables 3-9 through 3-14; Appendix M). The RUM is present throughout 100-D/H, forming the base of the unconfined aquifer. The RUM appears to be thinnest near 100-H where the overlying Ringold Formation unit E has been eroded. The RUM includes interbedded sandy zones that form semiconfined (100-H only) to confined water-bearing units. These relationships are shown on Figure 3-3.

3.4.2.1 Surface Deposits

Recent deposits include eolian sands and river alluvium, which were placed over the past 10,000 years, and backfill materials deposited by humans. Construction backfill 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 because of extensive grading in the 1950s. Outside of those areas, the Holocene deposits are relatively thin (0.3 m [1 ft]) (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]). Holocene surficial deposits consist of silt, sand and gravel.

3.4.2.2 Hanford Formation

The Hanford formation consists predominantly of unconsolidated sediments that cover a wide range of grain sizes, from boulder-sized gravel to sand, silty sand, and silt. The Hanford formation is an informal name used to describe these Pleistocene-age cataclysmic flood deposits. The Hanford formation facies consists of moderately to very poorly sorted, large to very large, cobble- to boulder-sized clasts in open framework gravels that include discrete sand lenses, with little, or no, silt and clay-sized material. The gravel-dominated Hanford formation is highly basaltic, ranging from approximately 50 to 80 percent basalt (*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 sand fractions are also high in basalt content, with the remaining portion composed of feldspar, quartz, and traces of mica. The grains typically are subround to round gravel and subangular to subround in the sand grain fraction. The gravel-dominated facies typically are well stratified and contain little to no cementation (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]). Discrete sand lenses are present in 100-D/H, which may serve as preferential flow paths or collection zones for vadose zone contaminants. Caliche (calcium carbonate crust) is occasionally observed on Hanford formation gravels.

The Hanford formation has traditionally been classified into three separate lithofacies: gravel-dominated, sand-dominated, and interbedded sand and silt-dominated (*Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin* [DOE/RL-2002-39]). Beneath 100-D/H, only the gravel and sand dominated facies are present to depths of approximately 17 m (55 ft) bgs. Thicknesses range from 5 to 22 m (17 to 73 ft), with greatest thickness underlying the southwest-central part of 100-D/H. The unit generally thins to the north and east (Integrated Work Plan [DOE/RL-2008-46]). The gravel and sand dominated units are difficult to differentiate since a range of sediment types may be present in either unit.

The gravel dominated facies (H1) generally consists of coarse grained sand and small to boulder sized gravel, often displaying large scale cross stratification. This unit is typically uncemented with an open framework. Basalt lithology dominates, with some quartz and feldspar present (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

Sand dominated facies (H2) are generally well stratified, and consist of fine to coarse grained sand with small grained gravel. Silt is also present, being common in the well sorted and open framework, but the amount of silt is highly variable elsewhere. The sand dominated unit may contain small pebbles and rip-up clasts in addition to lenticular, pebble-gravel interbeds and silty interbeds less than 1 m (3 ft) thick.

Some laterally continuous interbeds are present (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

3.4.2.3 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". Hydrologic property differences exist across the Hanford/Ringold contact because of differences in the physical nature of the two units and actions of scouring by the paleofloods. Pleistocene-age cataclysmic glacial outburst floods have eroded into the older Ringold Formation sediment and removed and/or reworked some of the Ringold sediments.

Ringold Formation 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 locations 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, and to some degree, in the surface topography.

To the east of 100-D, the Ringold Formation unit E is eroded away over much of the area, resulting in the Hanford formation laying unconformably on the RUM. There are locations where Ringold Formation unit E is present across the Horn into 100-H, which indicates uneven erosion of that unit. Hanford formation material that was deposited over the Ringold Formation erosional surface formed a contact surface (disconformity) between the two stratigraphic units. Since these two stratigraphic units have different lithologies, they also have unique hydraulic properties, which influence groundwater flow pathways and contaminant distribution as the contact is encountered. Because the overlying Hanford formation exhibits substantially greater hydraulic conductivity that the Ringold unit E or RUM Formations, 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 3.6.1, indicates that the saturated hydraulic conductivity of the Hanford formation is greater than that of Ringold Formation unit E, with substantial local variability. In 100-D, the water table is generally below this contact. However, where the Hanford formation - Ringold Formation contact occurs below the water table, groundwater flows will tend to have a greater velocity within the Hanford formation portion with water migrating more slowly through Ringold Formation unit E. This condition may occur in areas of the Horn. At 100-H, the Ringold Formation unit E is essentially absent.

The Hanford/Ringold contact may also affect groundwater discharge to the Columbia River. During operation of the reactors at 100-D and 100-H, groundwater elevations were substantially raised because of leakage and intentional discharges of reactor cooling water to the ground near the reactors. Seepage of groundwater along the Columbia River shoreline was documented at 100-D and 100-H as early as 1963 (*Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January, 1963* [HW-77170]). At 100-D, thermal springs were present along 609.6 m (2,000 ft) of riverbank, indicating a preference for horizontal flow instead of vertical flow where the hydraulic conductivity of the stratigraphic units changed. Thermal springs were also present at 100-H, extending 914.4 m (3,000 ft) along the riverbank. The groundwater at 100-D/H (as well as at the other 100 Area reactors) exhibited substantially elevated temperature because of the releases of near-boiling spent cooling water from the reactors. Groundwater seepage in these locations was still observed in 1991 (*Riverbank Seepage of Groundwater Along the 100 Areas Shoreline, Hanford Site* [WHC-EP-0609]) near both 100-D and 100-H, although less common. The recent groundwater seepage conditions are associated with re-equilibration of groundwater elevations following periods of seasonal high river state and temperatures have returned to typical background conditions.

Where the Hanford formation/Ringold Formation unit E contact occurs below the river level (approximately 115 m [364 ft] average elevation in 100-D/H) 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-D, where substantial deposits of the Ringold Formation unit E are present, the Hanford formation - Ringold Formation unit E contact is predominantly above the water table.

3.4.2.4 Ringold Formation

The Miocene- to Pliocene-age (8.5 to 3.4 m.y. B.P.) Ringold Formation is a combination of alluvial and lacustrine deposits produced by the ancestral Columbia River and other regional river systems. Across the Hanford Site, the Ringold Formation is as much as 185 m (606 ft) thick. The Ringold Formation consists of nonindurated and semi-indurated clay, silt, fine- to coarse-grained sand, and variably cemented, multilithic, granule to cobble gravel. Ringold Formation sediments have been classified into five sediment facies associations, including fluvial gravel, fluvial sand, overbank deposits, lacustrine deposits, and alluvial fan deposits (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]; *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 typical stratigraphic units within the Ringold Formation are generally identified, from shallowest to deepest, as: unit E, RUM (confining layer), units B and C, Ringold lower mud, Ringold Formation gravel unit A. Beneath 100-D/H, the Ringold Formation does not contain all of the commonly encountered stratigraphic units found elsewhere across the Hanford Site. At 100-D, Ringold Formation units A and C are described as either thin or absent (*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]), but have not been identified in borehole logs in that area. At 100-D, Ringold Formation unit E is present in some locations, but not in others. The only gravel unit that thickens northward towards 100-D is Ringold Formation unit B, which is up to 25 m thick (*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]).

Ringold Formation unit E. The Ringold Formation unit E is the youngest Ringold-age sediment present in the area; it occurs consistently in the 100-D Area and directly overlies the RUM. In the Horn and 100-H Area, the presence of Ringold Formation unit E sediment is limited. The Ringold Formation unit E is composed of fluvial matrix-supported gravels and sands with intercalated fine- to coarse-grained sand and silt layers. Ringold Formation unit E lithology is between 35 and 90 percent felsic consisting mainly of metamorphic, intermediate volcanic, and felsic volcanics (*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]). Micaceous sand is occasionally encountered. Grain-size distributions tend to be bimodal, with granule and coarse-sand fractions generally absent. Cementation of the Ringold Formation unit E increases to the south and west in 100-D. The Ringold Formation unit E generally pinches out between the northeast portion of 100-D and the Horn, with occasional sporadic occurrences identified in the Horn, but is generally not present beneath 100-H.

Ringold Formation upper mud unit. The RUM underlying Ringold Formation unit E gravels is dominated by a fine-grained overbank paleosol facies association that is up to 61 m (200 ft) thick (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]). Regionally, the RUM is essentially continuous with an undulating surface with depressions and topographic highs that locally affect aquifer thickness. It appears to dip to the north or be partly eroded in the most northwestern portion of the Horn area. The top of the RUM ranges between elevation 104.5 and 115 m (342.8 and 377.3 ft) (*North American Vertical Datum of 1988* [NAVD88]). Boreholes drilled to basalt in 100-N and 100-H suggest that about 61 m (200 ft) of overbank-paleosol strata and 23 to 30.5 m (76 to 100 ft) of lacustrine deposits lie beneath the Horn area (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

The upper part of the RUM sometimes contains gravel in a silt/clay matrix that represents a transition zone (reworked interval) above the more massive silt or clay. The silt- and clay-rich RUM has low hydraulic conductivity values relative to the Hanford formation and Ringold Formation unit E. The RUM is considered an aquitard and forms the base of the unconfined aquifer. Within the RUM, thin sand-to-gravel layers form zones with variable hydraulic conductivities that range from low to high (K_H of 0.00012 to 0.0019 cm/sec [0.34 to 5.39 ft/day]; K_V of 1.4×10^{-8} to 5.0×10^{-3} cm/sec [4×10^{-5} to 14.17 ft/day]) and form confined or semiconfined aquifers (Section 3.6.2). The connectivity of the first water bearing unit of the RUM across the site has not been determined. Beneath a localized area of 100-H inland from the reactor, a shallow water-bearing unit within the RUM has been shown to be potentially hydraulically connected to the unconfined aquifer (Section 3.6.1), which could provide a pathway for contaminants to migrate. The top surface of the RUM is found between 28 and 33 m (91 and 109 ft) bgs near 100-D and between 11 and 40 m (37 and 66 ft) bgs near 100-H.

The surface topography of the RUM is presented on Figure 3-4. This map was constructed using historical borehole data and includes RUM surface data obtained from the RPO and RI boreholes/wells. The map displays the RUM surface elevation in 1 m (3.3 ft) contour intervals. Individual RI borehole RUM elevation data points are listed in Table C-5 of Appendix C. These data were also used to develop hydrogeologic cross sections and surface contour maps (see Sections 3.6 and 4.5.2, and Appendix M). The maps and cross sections identify scour features in the RUM surface that are the result of river channel migration and/or glacial floods that ultimately laid down the Hanford formation. These scour features are also expressed east of the abrupt drop in surface elevation at the eastern edge of 100-D, coincident with the Ringold Formation unit E pinchout/erosional truncation zone (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]). The subsurface structure indicates north to northeast trending channel scouring in the RUM unit that is roughly parallel to the modern Columbia River.

The RUM surface exhibits varying complexity, which may be related to the amount of available information. The higher density of boreholes near 100-D and 100-H provide for a more detailed delineation of channels and surface undulations in comparison to the Horn. There are 3 to 4 m (10 to 13 ft) deep scour channels eroded into the surface at 100-D and 100-H that indicate the migration of the main channel of the Columbia River to the east over time. The northern tip of the Horn area exhibits significant erosion of the RUM in the nearshore area where the Columbia River bends to the southeast.

Other characteristics of the RUM surface (Figure 3-4) include the undulating surface and localized depressions, which exhibit a horseshoe-like feature at 100-D. Higher elevations in the RUM surface are present close to the Columbia River, trending parallel and adjacent to the river. This ridge feature can be seen in cross section B to B' (Appendix M, Figure M-6) where the rise in the RUM surface is apparent at Well 199-D8-89, with the corresponding depression farther inland at Wells 199-D5-134 and 199-D5-140.

A high RUM surface also appears to be northeast of 100-D. Depressions are at several locations. One depression is north of the 100-D Area, and another appears to circle the inland side of the D/DR Reactors. A third, less noticeable but possibly more important depression is between the river and the Cr(VI) plume hot spots. A portion of the third depression extends from near the 100-D south plume hot spot toward the north end of the in situ redox manipulation (ISRM) barrier. The depression in the RUM surface, near the hot spot, is shown in Appendix M, Figure M-5, at Well 199-D5-141. This depression may have some effect on the shape of the south plume, contributing to the extension of the Cr(VI) plume to the south and west at Well 199-D3-5 as shown in Figures 4-66 and 4-67, which present the Cr(VI) plume. In addition, Appendix M Figure M-7 provides an indication of the change in vertical relief that is present at the south end of 100-D, as indicated by the depth to RUM shown in Well 199-D4-81 and other surrounding wells.

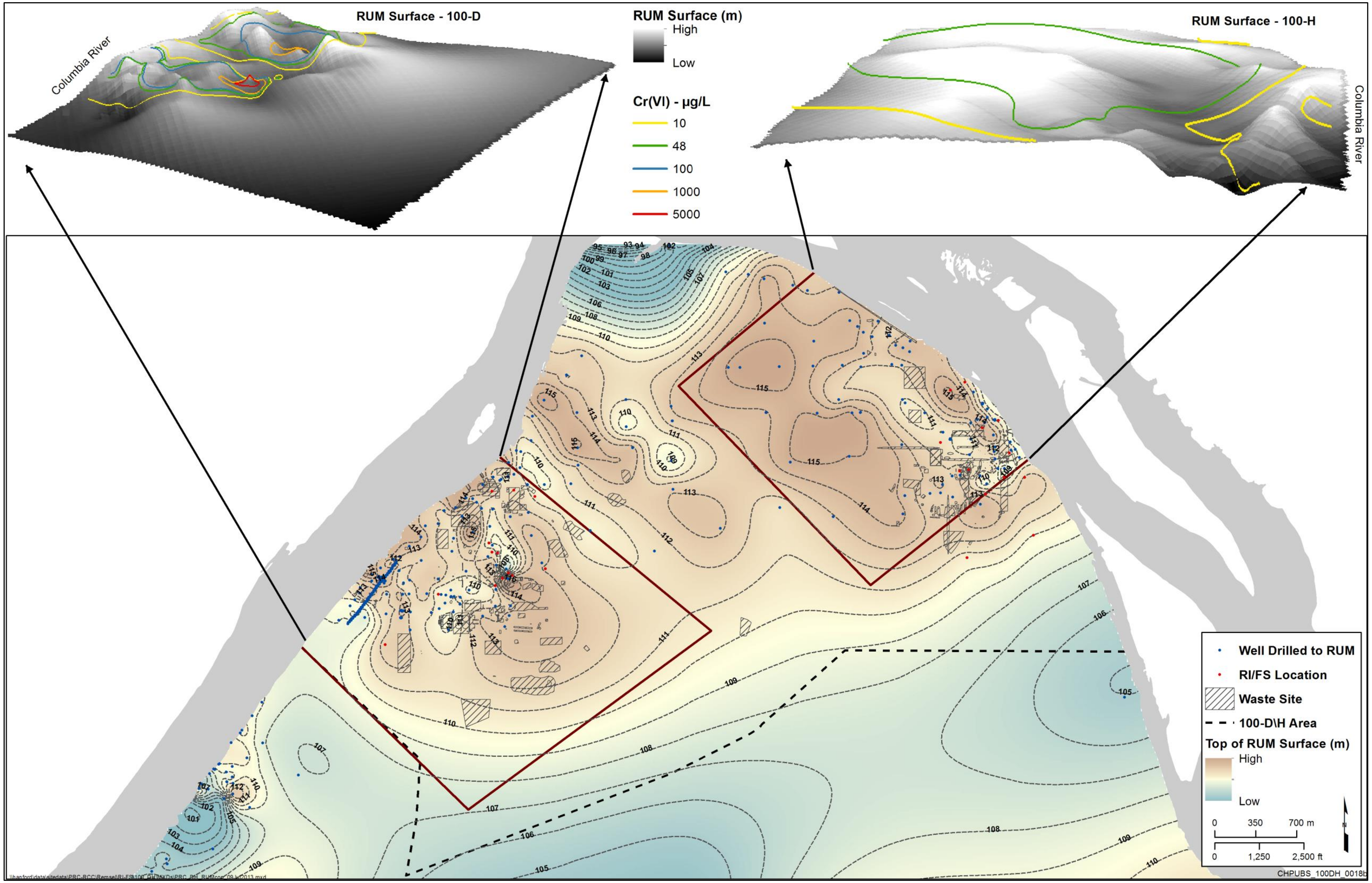

Figure 3-4. 100-D/H RUM Surface Elevation

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In the central Horn area, a broad high area of RUM is observed, corresponding to an area of relatively thin aquifer. Two low areas can be seen at 100-H, both trending from the northwest to the southeast. One shallow channel in the RUM extends northwest just west of H Reactor, and can be seen near 100-H (cross section D to D'; Appendix M, Figure M-8). The second depression, which may be related to the Cr(VI) distribution in the first water-bearing unit of the RUM, parallels the river along the shoreline.

Localized topographic highs and lows are identified on the RUM surface based on borehole data. Of particular interest in 100-D is the RUM depression just west of the D and DR Reactors that is approximately 2 m (6 ft) deep, which may provide a preferential groundwater flow path in a direction nearly parallel to the river.

Ringold Formation unit B and Ringold Formation lower mud unit. The Ringold unit B separates and differentiates the fine-grained sediment of the RUM from the underlying fine-grained sediment of the RLM. Fine sand to silty sand deposits of the Ringold unit B overlie the RLM unit and are approximately 15 to 24.5 m (50 to 80 ft) thick beneath 100-D/H. These Ringold unit B sands are inferred to be equivalent to fluvial gravel deposits of unit B (and possibly unit D) to the south in the Cold Creek Syncline. Ringold units A and C, which are present in other parts of the Cold Creek Syncline to the south of Gable Mountain, have not been found beneath 100-D/H. The RLM consists of fine-grained (silt- and clay-dominated) deposits (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]) that are approximately 23 to 30.5 m (75 to 100 ft) thick beneath 100-D/H.

3.4.2.5 Columbia River Basalt Group and Ellensburg Formation

The identified basalt flows of the CRBG number approximately 300 and maximum total thickness is approximately 4,600 m (15,000 ft) in the Pasco Basin. The CRBG erupted in the Miocene Epoch (17 to 8.5 million years ago) and has been divided into four formations from youngest to oldest: Saddle Mountain Basalt, Wanapum Basalt, Grand Ronde Basalt, and Imnaha Basalt (*Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports* [WHC-SD-ER-TI-003]).

Sedimentary interbeds of the Ellensburg Formation occur between basalt flows. These interbed sediments (tuffaceous sands, silts, and clays) and the porous/fractured basalt flow tops and flow bottoms form confined "interflow" aquifer zones that may extend across the Pasco Basin (*Site Characterization Plan: Reference Repository Location, Hanford Site, Washington* [DOE/RW-0164]).

The Elephant Mountain Member of the Saddle Mountain Basalt Formation is the upper basalt unit beneath 100-D/H (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

3.4.3 Hydrogeologic Cross Sections

Geological characterization and physical and hydraulic property data needs were identified to support development and refinement of the CSM and modeling for 100-D/H. Soil and groundwater data obtained from 27 RI boreholes were incorporated with existing data to further the understanding of the stratigraphy, hydrogeology, and contaminant mobility through the vadose zone and within the unconfined and semiconfined aquifers. Characterization data collected for the RI are described in Chapter 2.

Hydrogeologic cross sections, surface contour maps, and isopach maps of 100-D/H provide representations of the 100-D/H geology (See Figures 3-1, 3-4, 3-7, and Appendix M). Sufficient information exists to define the unconfined aquifer system in 100-D/H, as the majority of boreholes were drilled to confirm the depth to the RUM that forms the base of the unconfined aquifer. Figure 3-5 presents the trend lines used to construct five hydrogeologic cross sections, and includes the locations of the 17 RI wells. Hydrogeologic cross sections are presented in Appendix M, with analytical data presented on cross sections in Section 4.5.2.

Hydrogeologic information about the Ringold units below the RUM is far more limited than for the Hanford formation and Ringold unit E sediments. Several wells at 100-H drilled in the 1990s were deep enough to provide information on the RUM and a deeper water-bearing zone, presumed to be Ringold Formation unit B. The Horn study (*Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* [DOE/RL-2008-42]), RPO effort (*Sampling and Analysis Plan for Installation of 100-HR-3, Groundwater Operable Unit Remedial Process Optimization Wells* [DOE/RL-2009-09]), and the RI characterization improved understanding of the relationships and properties of these units.

Cross section A to A' (Figure M-5) is located in the southern portion of 100-D and trends from the Columbia River inland toward the east. The cross section shows the unconfined aquifer being present within the Ringold Formation unit E, and relatively thin. The undulating surface of the RUM is also evident, with a scour depression in the RUM surface present at Wells 199-D5-141 and 199-D5-104. The RUM surface rises slightly toward the river in this area, which may act as an impediment to contaminant migration. Not evident in the cross section, but shown in plan view in Figure 3-4, is the dip in the RUM surface in the southern portion of 100-D (coinciding with Well 199-D3-5), where the surface has a downward slope toward the south.

Cross section B to B' (Figure M-6) begins at the Columbia River and extends to the east, through northern 100-D. Several depressions occur in the RUM surface along this cross section. The dip in the RUM extends across a wider area in cross section B to B’ and is more pronounced than in cross section A to A'. As in cross section A to A', the RUM surface rises as it gets closer to the river.

Hydrogeologic cross section C to C' (Figure M-7) runs parallel to the Columbia River from the ISRM well locations towards the Horn area in the north. Cross section C to C' shows the unconfined aquifer completely within the Ringold Formation unit E near 100-D, with the RUM forming the bottom of the unconfined aquifer. As the cross section extends to the north, the Ringold Formation unit E is no longer identified in boring logs, with the aquifer being present entirely in Hanford formation material, which is more conductive than the Ringold Formation unit E. The abrupt change in geology near Well 199-D8-55 and Well 199-D8-68 aligns roughly with the southern edge of surface outburst channels during historic flood events (Figure 3-1) that crossed the Horn, eroding the Ringold Formation unit E. In addition, the outburst channels may have developed preferential pathways across the Horn, resulting in the wide distribution of Cr(VI) during reactor operations through this zone. This cross section also shows the undulation of the RUM surface through the area, and a significant drop in elevation at the Horn.

Cross section D to D' (Figure M-8) spans 100-D/H, beginning just north of 100-D and extending across the Horn to 100-H. The RUM surface across the Horn has a slight rise near 100-H but otherwise unremarkable. The unconfined aquifer occurs within the Ringold Formation unit E at 100-D, but transitions to the Hanford formation across the Horn and at 100-H, with some few exceptions. The transition of the aquifer matrix from Ringold Formation unit E to the Hanford formation likely facilitated the lateral spread of Cr(VI) across the Horn area and 100-H, because of greater hydraulic conductivity values of the Hanford formation. The spreading would have dramatically increased with the significant groundwater mounding that was caused by reactor operations and the 1967 cooling water injection test.

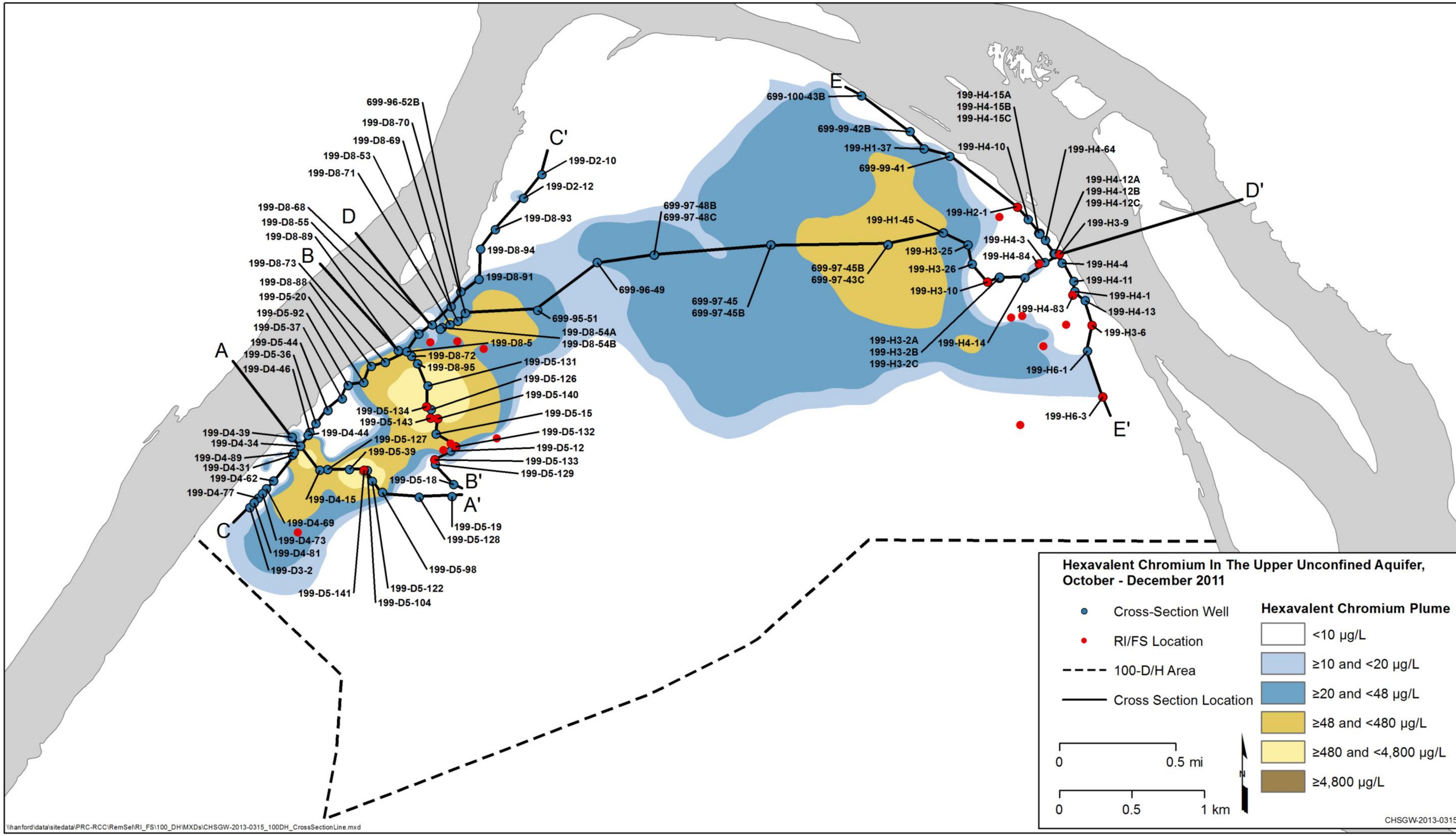

Figure 3-5. Trendline Location Map for 100-D/H Hydrogeologic Cross Sections and RI Wells

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Running parallel to the Columbia River at 100-H is cross section E to E' (Figure M-9). Consistent with the 100-H portion of cross section D to D', the unconfined aquifer is present in the Hanford formation. This cross section shows several wells with screens completed in a confined transmissive lens (fine sand) that occurs within the RUM unit. The cross section also indicates that the unconfined aquifer is very thin at 100-H.

3.4.4 Remedial Process Optimization Wells

Seventy wells were drilled in 2009 and 2010 to enhance efficacy of the remedial action following the 2008 RPO analysis of the HR-3 and DR-5 interim action pump-and-treat systems. The RPO identified the systems as undersized relative to the extent of the Cr(VI) plumes. The 70 wells were drilled within 100-D, across the Horn, and in 100-H. The sampling and analysis plan is described in *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells* (DOE/RL-2009-09). The RPO sampling is briefly summarized in Section 2.1.8. Physical and chemical data collected from RPO boreholes and wells are incorporated into isopach maps, surface contour maps, hydrogeologic cross sections, and modeling.

3.5 Vadose Zone

This section describes the general characteristics of the vadose zone underlying 100-D/H. The vadose zone (unsaturated zone) extends from ground surface to the water table of the uppermost aquifer. The hydraulic and chemical properties of this region control the downward movement of liquids and contaminants released near ground surface. Also called the zone of aeration, it includes the soil at the surface, the capillary fringe zone above the principal water-bearing zone, the periodically rewetted zone, and the combined rock, soil, air, and moisture interface linking the two. As the water table fluctuates in response to river stage and changes in recharge rates, the periodically rewetted zone experiences either wet or drying conditions. The capillary fringe is the edge of that wetted surface where water seeps into the vadose zone material because of tension saturation. The thickness of the capillary fringe is typically small in sand and gravel formations (e.g., a centimeter or two), whereas the periodically rewetted zone in areas near the river at 100-D/H may be as much as 2 m (6 ft) thick.

The dominant stratigraphic unit in the vadose zone underlying 100-D/H is the Hanford formation. In 100-D/H, the upper part of the vadose zone to depths from 0.3 to 13.7 m (1 to 45 ft), has been disturbed in a nonuniform fashion by site grading and construction activities in the mid to late 1940s, by site operations between 1945 and 1967, and by waste site remediation and facilities decommissioning activities since reactor shutdown. The D, DR, and H Reactor areas were cleared of vegetation and regraded. Select areas away from the reactors were stripped and graded to support specific facilities, but outside the construction areas the existing plant community and soil profiles were not disrupted, especially within the Horn area.

The vadose zone at 100-D includes surficial soil, Hanford formation sediments, and Ringold Formation unit E sediments. In 100-H, the Ringold Formation unit E is absent. There are pockets of Ringold Formation unit E across the Horn. An investigation of the physical and geochemical properties of the vadose zone in the 100 Area is presented in *Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site* (PNNL-17674).

Vadose zone thickness, which also represents the depth to groundwater, ranges from 0 to 27 m (0 to 89 ft), with an average thickness of 20 m (65.4 ft) in 100-D and an average thickness of 11.3 m (37.1 ft) in 100-H. Across 100-D/H, the vadose zone is typically thinner near the Columbia River and has extensive topographic variability. The surface topography has a significant drop in the north, closer to the Horn, consistent with the locations of the outwash channels.

Water that infiltrates the ground surface is either retained by capillary forces or passed downward toward the water table, as gravitational flow. Movement of moisture in the vadose zone is influenced by overall soil moisture content, the hydraulic properties of soil, vegetation cover, and timing of precipitation events.

3.5.1 Soil Types

Holocene deposits of eolian loess, silt, sand, and gravel form surficial deposits across 100-D/H. These deposits overlie the Hanford formation in a relatively thin (less than 1 m [3 ft] thick) veneer in most locations. During the past 10,000 years, a mix of eolian and alluvial processes deposited this soil. In some portions of 100-D/H, the surface is reworked construction backfill. This backfill material typically consisted of Hanford formation gravel, sometimes mixed with construction debris. Debris pits and piles created during construction have generally been addressed as waste sites. Recent (1995 to present) backfill practices rely almost exclusively on excavated Hanford formation gravel or fill imported from local or offsite borrow pits. This backfill is generally located near existing or former manmade structures and varies in depth, depending on the excavation depth of waste sites and building foundations. Additionally, backfill may cover larger graded areas to a depth up to 0.3 m (1 ft). Because of human activities associated with construction of the reactors and supporting facilities, the Holocene deposits may have been removed or altered. The key waste sites in the operational areas are shown on Figures 2-1 and 2-2 and the extent of disturbed soil is visible in the areal views shown on Figures 2-5, 2-6, 2-7, and 2-8.

Soil Survey Hanford Project in Benton County Washington (BNWL-243) describes 15 soil series on the Hanford Site, which consist of sand, sandy loams, and silty loams. The following five soil series are present within 100-D/H (Figure 3-6):

- **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 feet.

- **Ephrata Stony Loam.** Ephrata stony loam is similar to Ephrata sandy loam. It differs by the presence of many large hummocky ridges that consist of debris from melting glaciers. Areas between hummocks may contain many boulders several feet in diameter.

- **Riverwash.** Riverwash consists of the wet and periodically flooded areas of sand, gravel, and boulders adjacent to the Columbia River.

- **Rupert Sand.** Rupert sand is brown to grayish brown coarse sand. The color grades to dark grayish-brown at a depth of about 90 cm (35 in.). Rupert soil typically develops under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that are mantled by windblown sand. The relief characteristically consists of hummocky terraces and dune-like ridges. The soil is correlated as Quincy sand from an earlier survey.

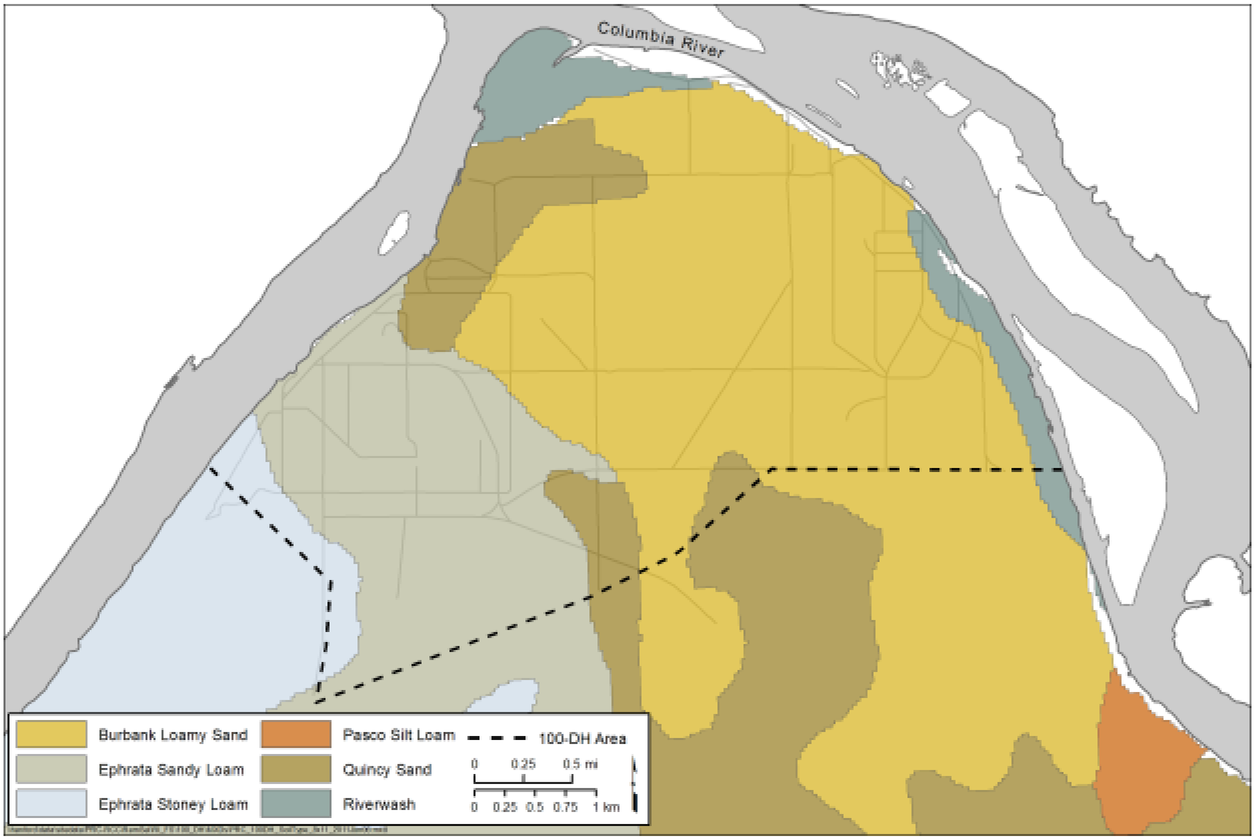


Figure 3-6. Soil Series in the Vicinity of 100-D/H Areas

The Burbank Loamy Sand and the Ephrata Sandy Loam cover around 70 percent of 100-D/H. Ephrata Sandy Loam covers the majority of 100-D, with an area of Ephrata Stony Loam along the west boundary and areas of Rupert (Quincy) Sand near the northeast and southeast boundary. 100-H is primarily Burbank Loamy Sand, with an area of Riverwash along the east boundary. The Horn is primarily Burbank Loamy Sand, with an area of Rupert (Quincy) Sand along the northwest boundary and an area of Riverwash along the north boundary. Many small areas of backfill exist where construction activities and interim remedial actions have been completed. Each of these soil types has different characteristics.
The characteristics of the soil, such as permeability, are critical to modeling and understanding the effects of infiltration and subsequent recharge to the aquifer. Tables 3-5 and 3-6 present recharge estimates applicable to different conditions for 100-D/H surface soil. For comparison, "Hanford Site Vadose Zone Studies: An Overview" (Gee et. al., 2007) notes a range from nearly zero to 100 mm/yr depending on the soil type and vegetation cover.

Table 3-5. Estimated Recharge Rate

Major Soil Type	Estimated Recharge Rate (mm/yr)			
	No Vegetation	Cheatgrass	Young Shrub-Steppe	Mature Shrub-Steppe
Rupert Sand	44	22	8	4.0
Burbank Loamy Sand	52	26	6	3.0
Ephrata Sandy Loam	17	8.5	3.0	1.5

Table 3-5. Estimated Recharge Rate

Major Soil Type	Estimated Recharge Rate (mm/yr)			
	No Vegetation	Cheatgrass	Young Shrub-Steppe	Mature Shrub-Steppe
Ephrata Stony Loam	17	8.5	3.0	1.5
Riverwash	92	46	N/A	N/A

Source: PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, Table 4.15.
NA = not applicable

Table 3-6. Estimated Recharge Rates and Variation—Disturbed Conditions

Condition	Best Estimate (mm/yr)	Estimated Standard Deviation (mm/yr)	Minimum (mm/yr)	Maximum (mm/yr)
Rupert Sand	44	22	22	88
Burbank Loamy Sand	52	26	26	101
Ephrata Sandy Loam	17	8.5	8.5	34
Ephrata Stony Loam	17	8.5	8.5	34
Riverwash	92	46	46	101

Source: PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*.
NA = not applicable

3.5.2 Soil Moisture Variations

Unsaturated flow of moisture/liquid in the vadose zone is highly complex and influenced by the hydraulic properties of soil and vegetation cover. 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 (that is, hydraulic gradient). In 100-D, the moisture content in the Hanford formation or Ringold Formation unit E vadose zone ranges from 1.0 to 10.0 percent. The soil moisture content in the vadose zone of the Hanford formation in 100-H ranges from 1.8 to 6.0 percent. The moisture content in the vadose zone is largely dependent upon the grain size distribution, with finer grained zones able to retain more moisture because of their smaller pore size and greater number of pores available.

The Hanford formation comprises the majority of the vadose zone beneath 100-D/H, although a lower water table in 100-D results in the Ringold Formation unit E also becoming unsaturated. Unsaturated flow through the Hanford formation may be influenced by the depositional environment. The flood deposits that constitute the Hanford formation tend to fine upward within each depositional sequence, resulting in alternating coarser and finer grains vertically. Cross beds found in the Hanford formation may also locally influence vertical migration of soil water, though the magnitude and extent of influence is not known.

Much of the operational area within 100-D/H was denuded of the native plant and soil cover, optimizing conditions for deep percolation of precipitation through the vadose zone. During historical operations, water was intentionally discharged to the ground surface, and under both historical and ongoing remedial actions, water may be applied to the ground surface for dust control. Under current conditions, low-moisture conditions dominate vadose zone with the majority of moisture resulting from infiltration of natural precipitation. However, periodic elevation of the water table because of fluctuations in river stage, leaks from site infrastructure (for example, 181-D River Pump House, 182-D Reservoir, and pipelines), and local application of dust suppression water during remedial actions can also contribute to increased soil moisture.

Within 100-D/H, vadose zone thickness varies because of natural and anthropogenic influences, such as changes in Columbia River stage as well as changes in topography. If groundwater is contaminated, mobile contaminants may be introduced into the basal vadose zone over large areas with the rising water table. With reduction in artificial recharge, precipitation is the main source of recharge; however, fluctuations in river stage and the flux from artificial recharge may affect 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 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 is less than 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, transpiration is essentially zero because of lack of vegetation; consequently, a larger percentage of precipitation and any anthropogenic water are able to infiltrate into the vadose zone readily and, if a sufficient volume is present, migrate to the water table. Physically, as additional water is added to the vadose zone, it will migrate vertically under the force of gravity when the moisture content exceeds that which can be retained by the soil capillary forces.

3.5.3 Physical Soil Properties

During the RPO and RI/FS field investigations, numerous soil samples were collected within the Hanford formation, Ringold Formation unit E, RUM, first water-bearing unit in the RUM, and Ringold Formation unit B for evaluation of physical properties such as particle size, percent moisture, bulk density, and calculated porosity. Sample details are included in Appendix M. Samples included were collected from the vadose zone, aquifer matrices, and aquitard(s), with each stratigraphic formation clearly identified. Samples are listed in order, from shallow to deep, in order to show the variance in physical properties over the soil profile.

Particle size analysis was performed in accordance with *Standard Test Method for Particle-Size Analysis of Soils* (ASTM D422-63). Sediment moisture content was determined in accordance with *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass* (ASTM D2216-05). Density was determined in accordance with *Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method* (ASTM D2937-04) and is reported both as wet density and as dry density. Porosity is a calculated value determined by the following equation and reported as a percent.

$$Porosity = 1 - \frac{Bulk\ Density}{Particle\ Density}$$

For purposes of calculating porosity, normal particle density is assumed to be 2.65 g/cm^3 (165.434 lb/ft^3), the approximate particle density of quartz.

The results of physical testing of the vadose zone samples showed that for grain size the majority of the vadose zone consists of sandy gravels. However, grab samples collected from test pits at depths less than

6.1 m (20 ft) bgs often have more sand content than deeper soil. These samples may represent reworked soils with backfill, considering samples were collected in waste sites that had limited excavations conducted. Occasionally, sand layers are present in the vadose zone at greater depths (for example, Wells 199-D5-134 and 199-D5-132 had 67 to 70 percent sand at depths from 16.8 to 17.7 m [55 to 58 ft] bgs).

PNNL conducted a historical study (*Vadose Zone Hydrogeology Data Package for Hanford Assessments* [PNNL-14702]) on bulk densities in the Hanford formation versus the Ringold Formation unit E, which are used for comparison to recent RI and RPO physical property data (Table 3-7). Size classifications for the RI and RPO data sets were primarily based on the borehole log descriptions. Bulk density is used in vadose zone fate and transport calculations. The site wide statistical mean values were essentially identical for the Hanford formation and the Ringold Formation unit E, with the RI/RPO data also comparable within the data set. Appendix D (Table D-68) contains the sieve analysis reports for the RPO data set.

3.6 Hydrogeology

The understanding of the hydrogeologic framework of 100-D/H is based on subsurface investigations conducted during the operational phase of the reactors up through the interim remedial actions and the current RI/FS. The three main hydrogeologic units include the following:

- Vadose zone (discussed in Section 3.5)
- Suprabasalt aquifer system
- Confined basalt aquifer system

This section describes the saturated hydrogeology of 100-D/H, 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 basalt. The structure of the aquifer system is one of the controlling factors for groundwater flow between the various aquifers, aquitards, and the Columbia River, which forms a regional discharge boundary for shallow groundwater beneath the Hanford Site.

At 100-D/H, the unconfined aquifer is the zone between the water table and the surface of the RUM. At 100-D, the unconfined aquifer is present in the Ringold Formation unit E, and at 100-H, it is present in the Hanford formation, since the Ringold Formation unit E is absent. Within the RUM, there are several zones of sand and gravel which are water-bearing units. (Specific properties of these zones are described in Section 3.4.2.4 and Section 3.6.2). These water-bearing units may be connected to each other, to the unconfined aquifer, or to the Columbia River. The extent of this aquifer interconnection varies spatially across 100-D/H and may have been temporally dependent on the overlying hydrologic conditions, such as elevated head pressures that existed during operations because of high-volume cooling water discharges.

As presented in Section 3.4.1, the stratigraphic units identified within the Ringold Formation include the Ringold Formation unit E, the RUM, the Ringold unit B, and the RLM. Aquifers found below the upper surface of the RUM are typically confined or semiconfined, but leakage between the units may also occur. In addition, these various units may not be continuous in all locations, making them difficult to differentiate during drilling activities. The hydrostratigraphy of the suprabasalt aquifer system underlying 100-D/H is summarized in Table 3-8.

Table 3-7. Statistical Mean Values for Site Wide Sample

	Site Wide Values					RI/ RPO Values				
				Bulk Density					Bulk Density	
Soil Class	**Sample Size**	**K_s (cm/sec)**	**% gravel**	**g/cm^3**	**kg/m^3**	**Sample Size**	**K_s (cm/sec)**	**% gravel**	**g/cm^3**	**kg/m^3**
Hanford silty sand	38	8.58E-05	0.2	1.61	1610	NA	NA	NA	NA	NA
Hanford fine sand	36	3.74E-04	0.6	1.60	1600	NA	NA	NA	NA	NA
Hanford coarse sand	81	2.27E-03	2.6	1.67	1670	NA	NA	NA	NA	NA
Hanford gravelly sand	16	6.65E-04	25.8	1.94	1940	NA	NA	NA	NA	NA
Hanford sand	NA	NA	NA	NA	NA	27	1.29E-02	25.79	1.72	1717
Hanford gravel	40	1.46E-03	67.6	1.97	1970	2	NA	98.55	1.80	1803
Hanford sandy gravel	28	3.30E-04	51.4	1.93	1930	29	8.51E-03	51.90	2.00	2003
Ringold Formation gravel	18	4.13E-04	46.1	1.90	1900	13	1.66E-02	55.54	1.95	1946
Ringold unit E sand	NA	NA	NA	NA	NA	6	3.58E-02	12.31	1.74	1735
RUM silt or clay	NA	NA	NA	NA	NA	63	1.74E-04	24.21	1.43	1430
RUM silty or clay with sand	NA	NA	NA	NA	NA	16	3.24E-04	17.76	1.50	1498
RUM silt or clay with gravel	NA	NA	NA	NA	NA	17	2.40E-05	28.28	1.40	1397

Source: PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*.

NA = data not available or calculated

RI = remedial investigation

RPO = remedial process optimization

Note: not all RI and RPO data were size classified, some size classification is based on borehole logs. Sampling information is provided in Appendix C.

The hydraulic properties of an unconsolidated water-bearing unit are greatly influenced by the lithology of the aquifer matrix, with sand and gravel deposits generally being more transmissive than silt and clay units. However, poorly sorted sand and gravel deposits that contain intercalated silts and clays will see a significant reduction in hydraulic conductivity over well-sorted sand and gravel deposits because the pores are filled with fines, thereby reducing the interconnectedness of pores. Hydraulic conductivity is generally defined as the flow volume over time through a cross-sectional area (presented in cm/sec, m/day, or ft/day). Variations in the hydraulic conductivity of the aquifer matrix directly affect the ease with which groundwater flows through the unit, which affects the ability of contaminants to migrate (see Chapter 5). Because of the lower energy depositional environment, the RLM has the lower vertical hydraulic conductivity of the two aquitards (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]).

Table 3-8. Hydrostratigraphy of the Suprabasalt Aquifer System at 100-D/H

Geologic Unit	Hydrostratigraphic Description	Principal Facies/ Principal Sediment Type	Approximate Range of Saturated Thickness (m [ft])
Hanford formation	Unconfined aquifer in 100-H and the eastern portions of the Horn	Cataclysmic flood deposits/sandy gravel, loose	0 to 9 (0 to 30)
Ringold Formation unit E	Unconfined aquifer in 100-D and the western portion of the Horn	Medium to high energy fluvial deposits/sandy gravel to sand, weakly to semiconsolidated	0 to 18 (0 to 60)
RUM	Aquitard defining the base of the unconfined aquifer	Paleosol and overbank deposits/sandy silt and silty clay, well-compacted	40 to 49 (130 to 160)
RUM, "first water-bearing unit"	First water-bearing unit (a confined to semiconfined water-bearing zone)	Low energy alluvial and paleosols/silty sand to fine sand, single-grained structure forming an interbed within the otherwise compact, fine-textured RUM	1 to 9 (3 to 30)
Ringold Formation unit B	Confined aquifer	Low energy alluvial deposits and paleosols/sand, loose	15 to 24 (50 to 80)
RLM	Aquitard	Lacustrine deposits/silt and clay, massive and compact	23 to 38 (75 to 125)

RUM = Ringold Formation upper mud unit

RLM = Ringold Formation lower mud unit

3.6.1 Unconfined Aquifer

Deposits making up the unconfined aquifer at 100-D/H include the Hanford formation and Ringold Formation unit E. The thickness of the unconfined aquifer is determined by the difference between the water table elevation and the surface of the RUM, which forms the base of the unconfined aquifer. Aquifer thickness is greatest where deep scour channels occur in the RUM. Two isopach maps (showing aquifer thickness) are presented on Figure 3-7 and 3-8, using 1 m (3.3 ft) contour intervals. These maps were created by subtracting RUM surface elevations from water table elevations measured during the high and low river periods, as indicated on the figures, and include water table elevations from recent RI and

RPO wells. Areas of darker blue indicate places where aquifer thickness is greatest and generally correspond to channels in the RUM surface.

The unconfined aquifer thickness at 100-D/H generally thins from west to east from 100-D toward 100-H (Figures 3-7 and 3-8). Thickness of the unconfined aquifer ranges from near 0 to 12 m (39 ft) across the area. The thickness of the unconfined aquifer mimics the topography of the RUM (*Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* [DOE/RL-2008-42]). Aquifer thickness is greater beneath 100-D, where the unconfined aquifer matrix consists solely of Ringold Formation unit E sediments. The unconfined aquifer matrix in the Horn and 100-H Areas consists of Hanford formation sediments where Ringold Formation unit E sediments are typically absent because of erosion. The aquifer is also influenced by the river stage, which causes fluctuations in the water table. Areas closest to the river are most affected by these fluctuations, with the effect muted farther inland.

The location for the transition of the aquifer matrix from Ringold Formation unit E to the Hanford formation has been updated based on information collected during drilling of the 70 RPO wells and RI boreholes and wells. As shown on Figure 3-9, pockets of Ringold Formation unit E have been identified farther east and south than previously identified in *100-HR-3 Remedial Process Optimization Modeling Data Package* (SGW-40781). In addition, the location of isolated pockets of Ringold Formation unit E across the Horn provides further evidence that this transition is an erosional feature.

Recent RI drilling generally supports earlier observations that the more transmissive Hanford formation is the dominant aquifer matrix in most of the Horn area and 100-H. As indicated by Figure 3-10, a portion of the Ringold unit E is present above the water table, with some differences depending on seasonal variations. On the north end of 100-D, where the retention basins and cooling water trench were located, the Ringold unit E tapers off, resulting in a preferential pathway for water discharged in that area to migrate to the north and then easterly where Hanford formation is dominant. The change in aquifer matrix from 100-D toward the Horn and 100-H is important hydrogeologically because Hanford formation sediments typically have higher horizontal hydraulic conductivity values than Ringold Formation unit E sediments. During reactor operations, the groundwater mound beneath the retention basins and cooling water trench at 100-D pushed water to the north and east into the Hanford formation. Once groundwater entered the Hanford formation, it would be less likely to move back south into the less transmissive Ringold Formation unit E, since groundwater movement through the more transmissive unit (with a higher hydraulic conductivity) would be preferential for flow since groundwater follows the path of least resistance.

3.6.1.1 Horn Horizontal Hydraulic Conductivity – Unconfined Aquifer

Saturated horizontal hydraulic conductivity data from wells drilled before 2009 as part of the interim remedial actions are provided in *100-HR-3 Remedial Process Optimization Modeling Data Package* (SGW-40781) and are listed in Table M-5 (Appendix M). The data provided in the model data package are grouped by geologic unit and include information on the data source and method of analysis. Well locations with estimates for hydraulic conductivity cover a broad area at 100-D, but are limited at 100-H to the area around H Reactor. Among the listed well locations are three wells in the Horn area for which hydraulic conductivity values were available at the time.

Hydraulic conductivity values corresponding to the Hanford formation and the Ringold Formation unit E provided the basis for the development of the hydraulic conductivity distribution in the 100-D/H and across the Horn that is described in *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model* (SGW-46279). Slug test data and analysis from RI wells is included (*Analysis of Slug Test Data at the 100-HR-3 Operable Unit* [ECF-100HR3-12-0011]) in Table

D-67 of Appendix D. Variability of the horizontal hydraulic conductivity in the unconfined aquifer reflects the variable cementation and sediment heterogeneity of the Ringold Formation unit E and the Hanford formation.

Based on this dataset, approximate ranges of hydraulic conductivity for each area are summarized in Table 3-9, assuming an average value where multiple entries are provided for the same well location. It should be noted that the values for Wells 199-D8-3 and 199-H4-10 are well outside the range of available hydraulic conductivity estimates from all other wells and for that reason two sets of ranges were calculated for 100-D and 100-H, including and excluding those data points, respectively. Also, one of the hydraulic conductivity estimates available in the Horn was an order of magnitude higher than the other two.

The distribution of hydraulic conductivity values in each area is illustrated in the cumulative frequency plot shown in Figure 3-11. Summary statistics were calculated based on data obtained from wells screened within those geologic units, and located in certain areas of the Hanford site, as provided in *100-HR-3 Remedial Process Optimization Modeling Data Package* (SGW-40781) and tabulated in Table M-4, Appendix M. The hydraulic conductivity frequency plot suggests that the distributions in 100-D and 100-H are not significantly different. Both datasets are characterized by some extreme (and potentially suspect) values, resulting in higher mean values that differ by a factor of three between the two areas. When those extreme values are excluded, the mean hydraulic conductivity in the Hanford formation of 100-H is about two times higher than that in the Ringold Formation unit E of 100-D. Similarly, the median hydraulic conductivity value is 0.026 cm/s for the Ringold Formation unit E and 0.039 cm/s for the Hanford formation. It is important to note that in localized areas where horizontal conductivity is higher, preferential flow pathways may exist.

A field investigation of the Horn area between 100-D and 100-H was conducted in 2007 and 2008 to characterize the extent, concentration, and movement of Cr(VI) in groundwater (*Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit* [DOE/RL-2008-42]). As part of this study, new wells were drilled and development data were analyzed to calculate hydraulic conductivity estimates in the unconfined aquifer. As no aquifer tests were performed for this characterization effort, the well development data could provide the basis only for rough estimates of hydraulic conductivity, especially considering that well development data reflect short-term aquifer response and can largely overestimate the specific capacity of the well. The estimated hydraulic conductivities varied between 0.013 and 2.242 cm/s (36 and 6,354 ft/d).

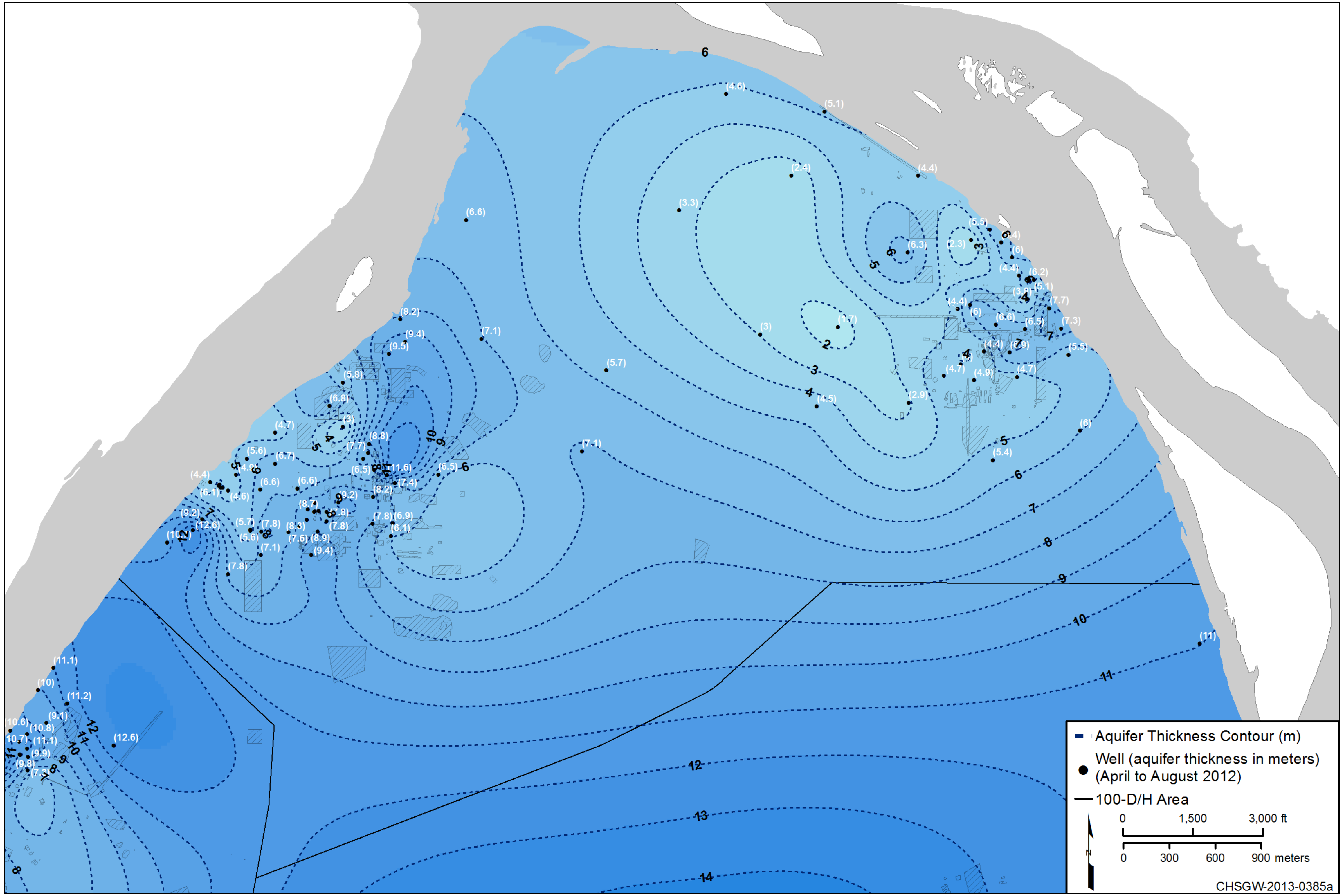


Figure 3-7. Unconfined Aquifer Thickness at 100-D/H for April to August 2012

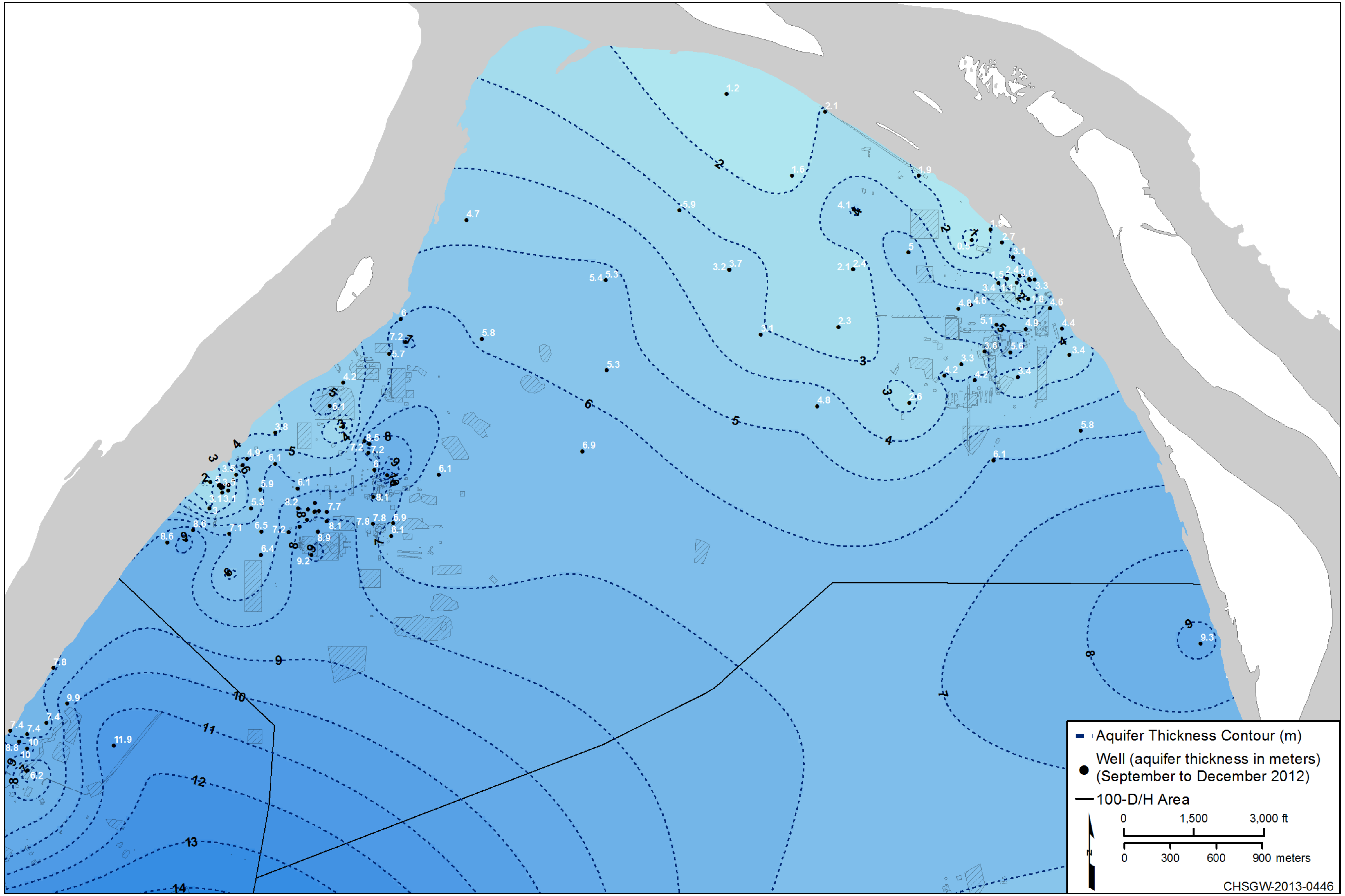


Figure 3-8. Unconfined Aquifer Thickness at 100-D/H for September to December 2012

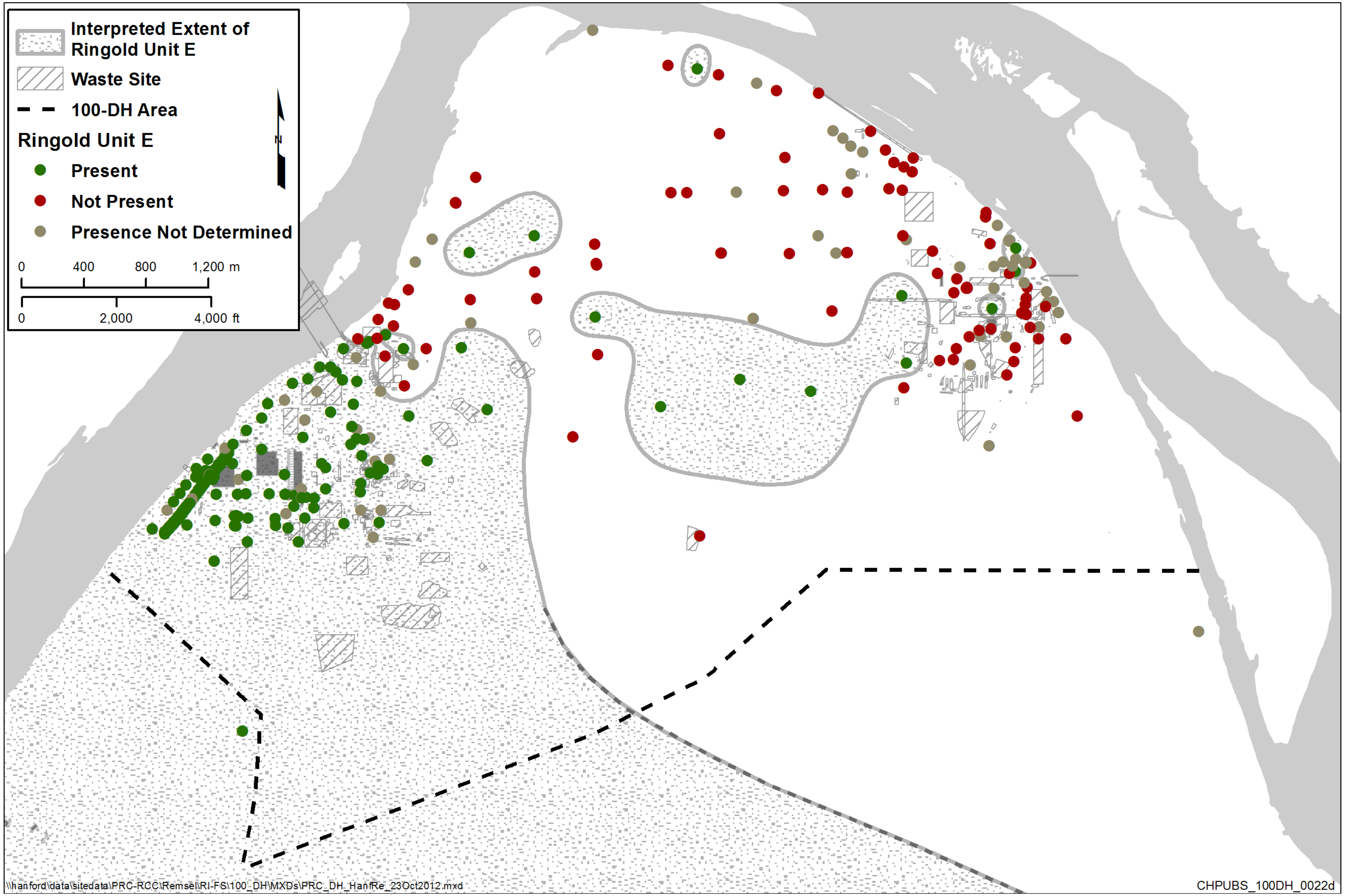


Figure 3-9. Hanford/Ringold Formation Unit E Presence at 100-D/H

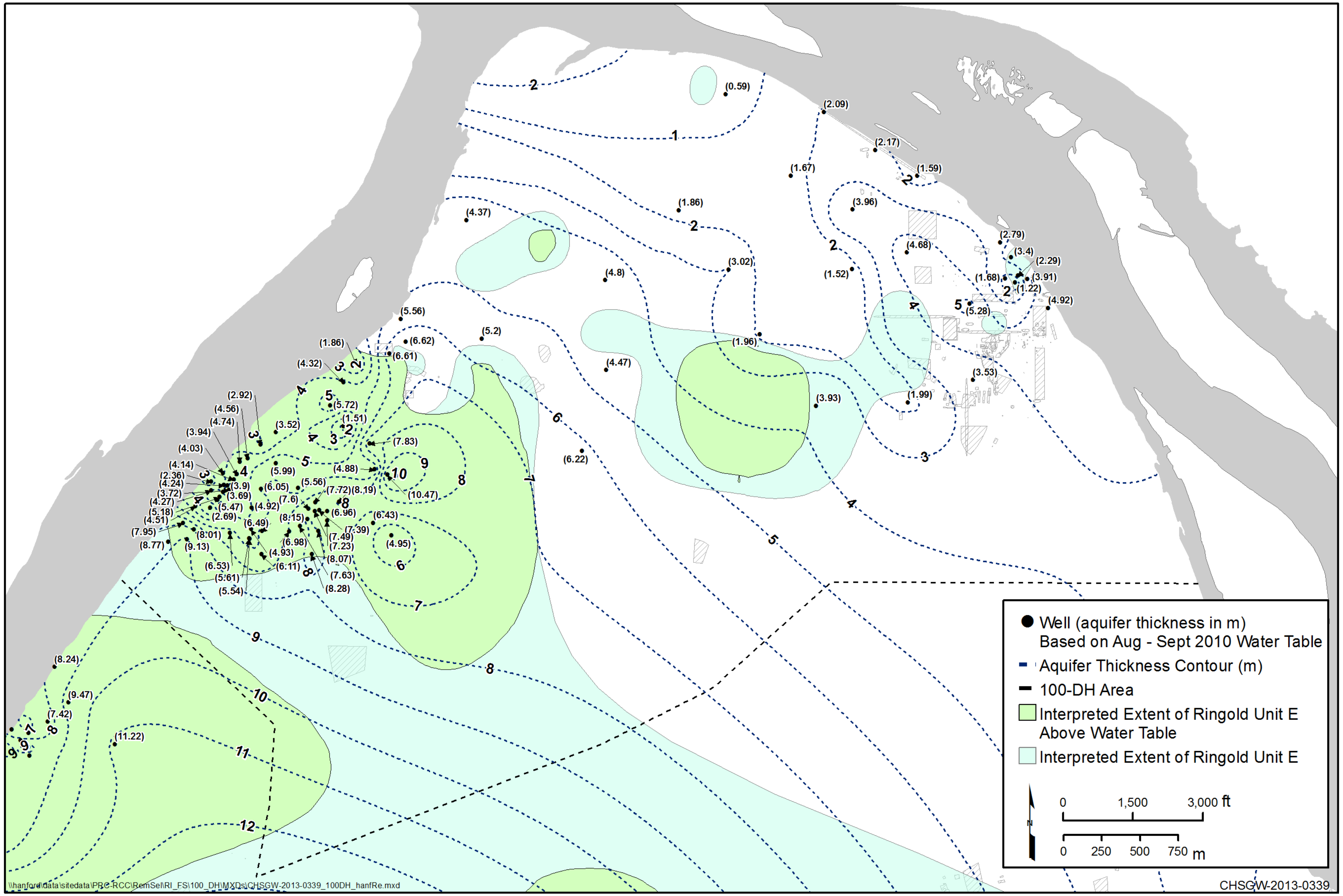


Figure 3-10. Unconfined Aquifer Thickness and Geologic Unit Distribution

Table 3-9. 100-D/H Estimated Ranges of Horizontal Hydraulic Conductivity Values Using Model Data Package Data

Area	Formation	Horizontal Hydraulic Conductivity K_H	Average Horizontal Hydraulic Conductivity K_H
100-D	Ringold unit E	0.004 to 0.648 cm/s (10.0 to 1837.0 ft/d)	0.059 cm/s (167.0 ft/d)
100-D (excluding outliers)	Ringold unit E	0.004 to 0.187 cm/s (10.0 to 530.0 ft/d)	0.040 cm/s (114.8 ft/d)
100-H	Hanford	0.018 to 1.863 cm/s (50.0 to 5,290.8 ft/d)	0.170 cm/s (483.0 ft/d)
100-H (excluding outliers)	Hanford	0.018 to 0.670 cm/s (50.0 – 1,900.0 ft/d)	0.086 cm/s (242.6 ft/d)
Horn	Hanford	0.018 to 0.279 cm/s (50.0 to 790.0.0 ft/d)	0.106 cm/s (300.0 ft/d)

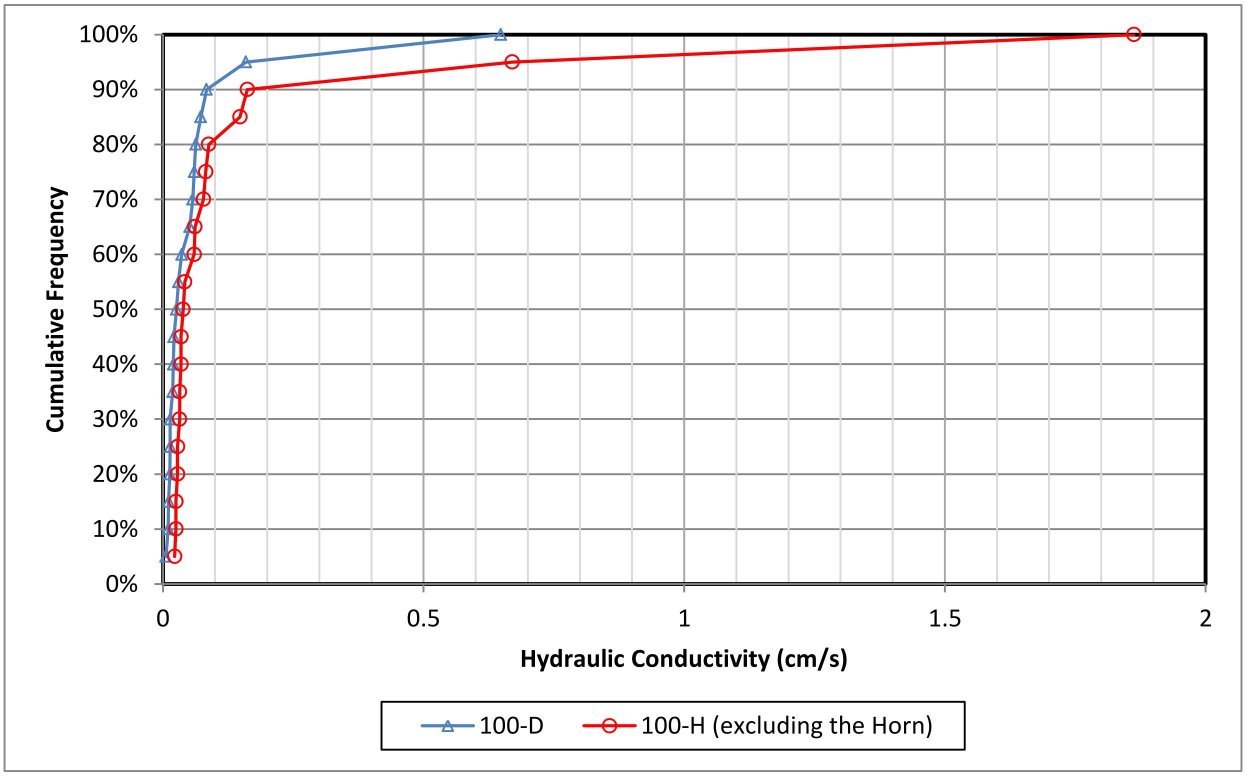


Figure 3-11. Cumulative Frequency of Hydraulic Conductivity Estimates in 100-D/H

Slug test data from 16 RI wells in 100-D and 100-H were analyzed to estimate hydraulic conductivity and specific storage of the water-bearing unit at each well as described in *Analysis of Slug Test Data at the 100-HR-3 Operable Unit* (ECF-100HR3-12-0011), included in Table D-67 of Appendix D. Calculated hydraulic conductivity values for wells in 100-D and 100-H screened in the Hanford formations and the Ringold Formation unit E are tabulated on Table 3-10.

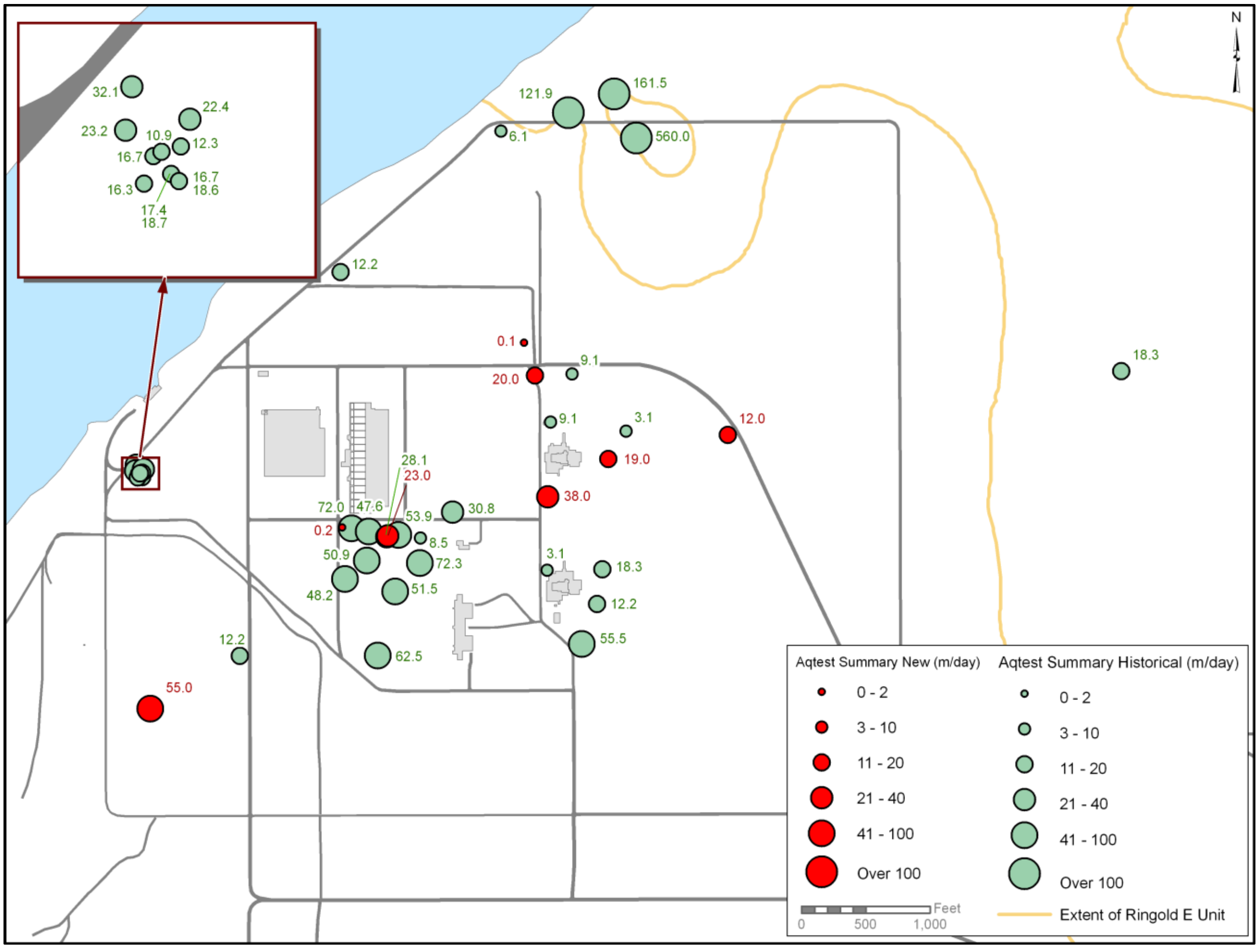
Table 3-10. Estimated Hydraulic Conductivity Values from Slug Tests in 100-D and 100-H Area Wells

Well Name	Area	Geologic Unit	Horizontal Hydraulic Conductivity K_H (cm/s)	Horizontal Hydraulic Conductivity K_H (ft/d)	Vertical Anisotropy Ratio (K_V/K_H)
199-D3-5	100-D	Hanford and Ringold E	0.064	181.4	0.1
199-D5-132	100-D	Ringold E	0.022	62.4	0.1
199-D5-133	100-D	Ringold E	0.044	124.7	0.1
199-D5-143	100-D	Ringold E	0.023	65.2	0.1
199-D5-144	100-D	Ringold E	0.027	76.5	0.1
199-D6-3	100-D	Ringold E	0.014	39.7	0.1
199-H3-6	100-H	Hanford	0.044	124.7	0.01
199-H3-7	100-H	Hanford	0.031	87.9	0.1
199-H6-3	100-H	Hanford	0.031	87.9	0.1
199-H6-4	100-H	Hanford	0.140	396.9	0.1

Source: ECF-100HR3-12-0011, *Analysis of Slug Test Data at the 100-HR-3 Operable Unit*.

Hydraulic conductivity estimates for the Ringold Formation unit E based on the analysis of slug test data in 100-D varied between 0.014 and 0.044 cm/s (40.0 to 124.7 ft/d) with an average value of 0.026 cm/s (73.7 ft/d). The range of hydraulic conductivity estimates for the Hanford formation in 100-H was 0.031 to 0.140 cm/s (87.9 to 396.9 ft/d) with an average value of 0.062 cm/s (174.3 ft/d). These estimates are within the range of values historically reported in these areas and geologic units, and within the ranges reported in the literature for the particular soil types (e.g., *Groundwater* [Freeze and Cherry, 1979], Table 2.2).

Figures 3-12 and 3-13 illustrate the relative magnitude of the hydraulic conductivity estimates in 100-D and 100-H, respectively, distinguishing between older and recent aquifer tests (RI slug tests). These illustrations suggest that hydraulic conductivities in the Hanford formation are higher than those in the Ringold Formation unit E in this part of the River Corridor; however, the difference is not as significant as seen in other areas across the Hanford Site (e.g., the Central Plateau). In addition, hydraulic conductivities in 100-H are relatively uniform, unlike those in 100-D where a higher degree of variation is identified, although a spatial pattern of those variations is not evident in those plots.

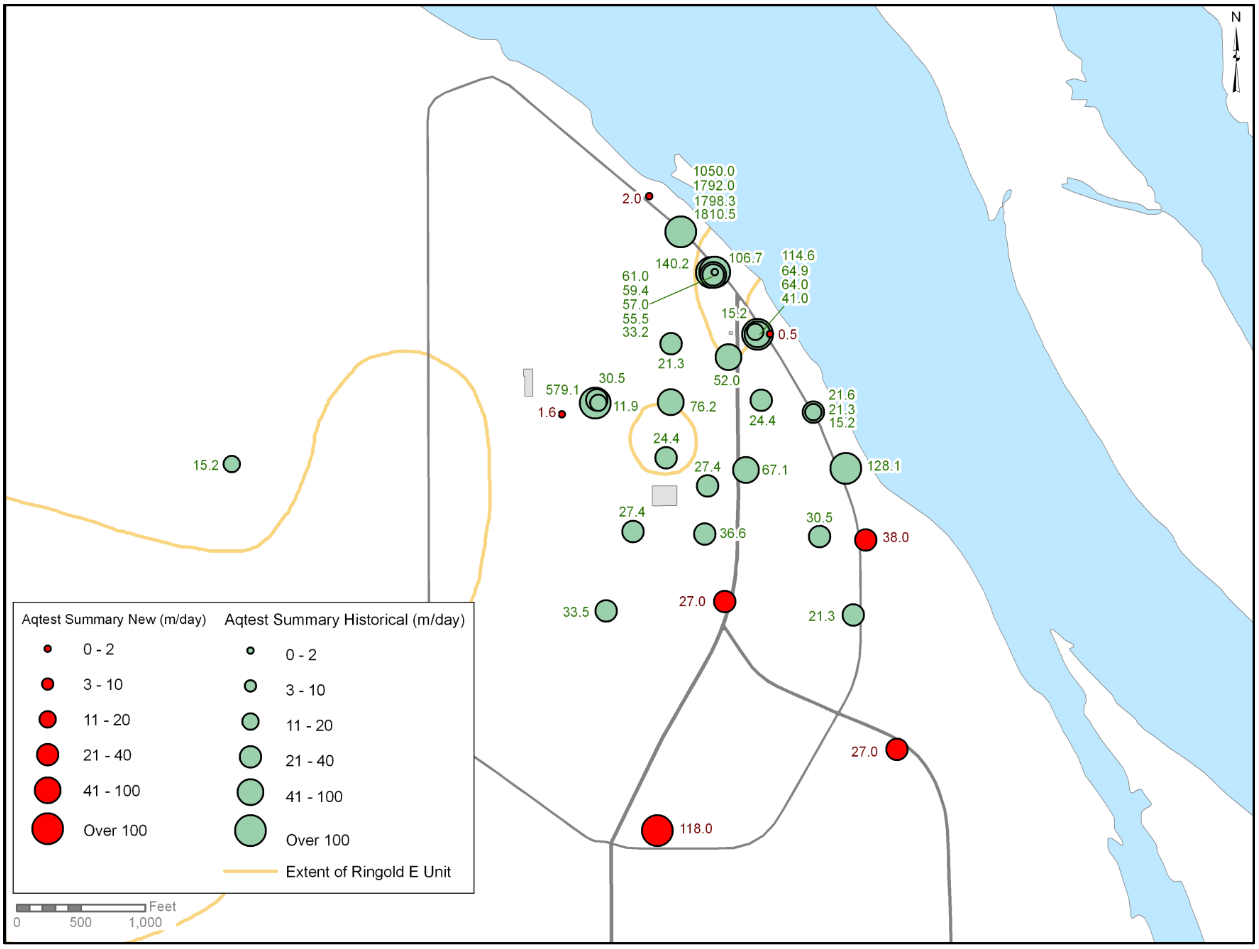


Source: ECF-100HR3-12-0011, *Analysis of Slug Test Data at the 100-HR-3 Operable Unit*.

Figure 3-12. Hydraulic Conductivity Estimates by Magnitude in 100-D

3.6.1.2 Vertical Hydraulic Conductivity – Unconfined Aquifer

Aquifer characterization activities were performed before the treatability test and subsequent installation of the ISRM barrier in 100-D (*100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater* [PNNL-13349]). As part of the characterization effort, two constant-rate aquifer tests were conducted to provide information that could be used to evaluate possible changes in the subsurface hydrologic conditions. The pumping tests were conducted before and following the treatability test, with aquifer responses at seven observation wells analyzed individually. The results of this analysis included estimates of the horizontal hydraulic conductivity in the unconfined aquifer, vertical anisotropy, storativity, and specific yield. Horizontal hydraulic conductivity estimates were included in *100-HR-3 Remedial Process Optimization Modeling Data Package* (SGW-40781) as presented earlier. Evaluation of the vertical anisotropy in the vicinity of the tested wells resulted in a range of vertical-to-horizontal ratios of 0.006 to 0.031 with a mean value of 0.015 (±0.010), with the second term corresponding to one standard deviation.



Source: ECF-100HR3-12-0011, *Analysis of Slug Test Data at the 100-HR-3 Operable Unit*.

Figure 3-13. Hydraulic Conductivity Estimates by Magnitude in 100-H

Soil samples were collected during the RI from the vadose zone, unconfined aquifer, RUM, and Ringold Formation unit B for vertical hydraulic conductivity analysis. The results from the sieve analyses and permeameter tests are tabulated on Table M-4 (Appendix M). Vertical hydraulic conductivity estimates are summarized in Table 3-11.

Based on these values, the vertical hydraulic conductivity in the Hanford formation ranges between 2.1×10^{-6} cm/s and 3.94×10^{-2} cm/s with a mean value of 1.16×10^{-2} cm/s. Vertical hydraulic conductivities in the Ringold Formation unit E vary between 2.45×10^{-4} cm/s to 8.01×10^{-2} cm/s with a mean value of 3.24×10^{-2} cm/s. It should be noted that there is considerable variation within both units.

The vertical anisotropy ratio is defined as the ratio of vertical to horizontal hydraulic conductivity. *Groundwater Hydrology* (Todd, 2005) reports values of the anisotropy ratio ranging from 0.1 and 0.5 for alluvium and as low as 0.01 when clay layers are present. Assumed vertical anisotropy ratios that were used for the analysis of the RI well slug test data are listed in Table 3-10. In all cases, the vertical anisotropy ratio was 0.1, except for Well 199-H3-6 in 100-H. In Well 199-H3-6, the late-time response to the slug test was a better match with an anisotropy value of 0.01, which was used for this well. However, it should be noted that slug tests are known to have limited reliability in estimating vertical hydraulic conductivities, and that estimates of horizontal hydraulic conductivity obtained from the slug tests are relatively insensitive to the value of the vertical hydraulic conductivity used (horizontal hydraulic conductivity of 33 m/d versus 38 m/d); therefore, a ratio of 0.01 was considered reasonable for Well 199-H3-6.

Table 3-11. Estimated Vertical Hydraulic Conductivity Values from Soil Samples in 100-D and 100-H Area Wells

Well ID	Vertical Hydraulic Conductivity, K-sat (cm/sec)	Depth (m)	Depth (ft)	Stratigraphic Unit (based on geologic log)[a]	Lithologic Description[b]
199-H3-9	2.89×10^{-2}	14.40	47.24	Hanford	Gravelly sand
	3.8×10^{-5}	15.93	52.26	RUM	Silty sand
	4.24×10^{-3}	23.23	76.21	RUM	Sand
	5.7×10^{-6}	30.79	101.0	RUM	Silty sand
199-H3-10	3.64×10^{-3}	16.54	54.27	Hanford	Sandy gravel
	1.80×10^{-6}	17.36	56.96	RUM	Silty sand
	2.42×10^{-3}	68.15	223.6	Lower water bearing unit (presumably unit B)	Sand with silt
199-H2-1	2.20×10^{-6}	11.61	38.09	RUM contact	Silty sand
	1.30×10^{-4}	11.90	39.04	RUM contact	Sand with silt
	5.0×10^{-3}	48.63	159.5	RUM	Sand with silt
199-D5-133	9.33×10^{-3}	15.8	51.84	Hanford	Gravelly sand
	5.21×10^{-2}	31.62	103.7	Unit E	Sand
199-D5-141	8.99×10^{-4}	23.30	76.44	Unit E	Sandy gravel
	2.45×10^{-4}	24.77	81.27	Unit E	Sandy gravel
	8.01×10^{-2}	32.54	106.8	Unit E	Sand
	1.4×10^{-8}	34.98	114.8	RUM	Silty sand
	9.54×10^{-3}	96.15	315.5	Lower water-bearing unit (presumably unit B)	Sand
199-D5-143	3.64×10^{-3}	11.62	38.12	Hanford	Gravel with sand
	3.94×10^{-2}	13.11	43.01	Hanford	Sandy gravel
	1.23×10^{-2}	14.66	48.10	Hanford	Sandy gravel
	2.1×10^{-6}	16.35	53.64	Hanford	Sandy gravel
	5.73×10^{-2}	17.70	58.07	Unit E	Gravel with sand
	3.64×10^{-3}	30.86	101.2	Ringold Unit E	Gravel with sand
	2.7×10^{-8}	33.19	108.9	RUM	Silt with sand

Table 3-11. Estimated Vertical Hydraulic Conductivity Values from Soil Samples in 100-D and 100-H Area Wells

Well ID	Vertical Hydraulic Conductivity, K-sat (cm/sec)	Depth (m)	Depth (ft)	Stratigraphic Unit (based on geologic log)[a]	Lithologic Description[b]
C7850	5.06×10^{-4}	12.42	40.75	Hanford	Gravel with sand
	6.93×10^{-3}	19.37	63.55	Ringold Unit E	Gravelly sand

Notes: Values are based on data tabulated in Table M-4, Appendix M; hydraulic conductivity was calculated in the laboratory by Method D2434 Permeability.

a. Samples indicated as RUM are from the first water bearing unit in the RUM.

b. Lithology based on sieve analysis.

RUM = Ringold Formation upper mud

3.6.2 Confined Aquifer Zones within the Ringold Formation

The RUM contains near-horizontal sandy water-bearing units between the RUM surface and Ringold Formation unit B, a deeper water-bearing unit. These units represent confined or semiconfined units with variable conductivity and interconnectivity. The recognized aquifer units within the RUM are identified as the Ringold Formation unit C, generally the first water-bearing unit, and the lower water-bearing unit, which is presumed to be the Ringold Formation unit B (Figure 3-3). Other water-bearing units may also be present; however, these discontinuous units are not formally recognized in the nomenclature.

At 100-D, the first water-bearing unit in the RUM is typically identified as Ringold Formation unit C. This unit may be absent at 100-D, with the first water-bearing unit at 100-D being the Ringold Formation unit B (*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]).

Three wells are currently completed within the RUM in the vicinity of the Horn. The first water-bearing unit within the RUM is semiconfined to confined, based on its observed piezometric head being higher than the overlying shallow unconfined unit in some areas, but otherwise not well defined in this area.

At 100-H, the RUM first water-bearing unit is confined to semiconfined and described as a very fine-to-fine-grained sand unit in RI borehole logs. The unit may occur as a discontinuous sand layer. Observations of the piezometric head in this unit during local pumping and during injection into the shallow unit indicate that it is not fully isolated from the overlying unconfined unit in the area inland of the H Reactor; near the river, however, it appears to be semiconfined to confined and isolated from the overlying unit. In wells completed in this unit near the river, the groundwater exhibits rapid, nearly simultaneous head changes that coincide directly with river stage fluctuations. The inland wells do not exhibit simultaneous responses to river stage changes, but are responsive to head changes in the overlying unconfined unit; this indicates that the unit identified as the first water-bearing unit of the RUM in the inland area of 100-H may not be in direct hydraulic communication with the similar unit near the river. The first water-bearing unit is approximately 0.5 to 7 m (1.6 to 23 ft) thick and occurs at elevations ranging from approximately 95 to 105 m above mean sea level (amsl) (312 to 345 ft amsl) (*North American Vertical Datum of 1988* [NAVD88]). Groundwater levels in this unit respond to changes in river stage, and when the river stage is moderate to low, this unit shows slightly higher pressure head than the unconfined aquifer near the river. In addition, the lack of lag time between Columbia River stage changes and the water table fluctuations in the nearby wells completed in the RUM indicates a hydraulic connection between these units.

The lower sand unit is approximately 6 to 10 m (20 to 33 ft) thick and occurs at elevations ranging from approximately 20 to 30 m amsl (66 to 98 ft amsl) (*North American Vertical Datum of 1988* [NAVD88]). When first encountered during drilling Well 199-H3-9, the lower water-bearing unit sands caused a sand heave of more than 15 m (50 ft) into the borehole, indicating good water production in that unit.

Five of the RI well boreholes were drilled to the lower water-bearing unit in the RUM, presumed to be Ringold Formation unit B. These are Wells 199-D5-134 (C7624, Well R4), 199-D5-141 (C7625, Well R5), 199-H2-1 (C7631, Well R3), 199-H3-9 (C7639, Well R1), and 199-H3-10 (C7640, Well R2). Laboratory results (presented in Chapter 4) did not indicate contamination in the lower water-bearing unit encountered during drilling. As a result, the lower half of each borehole was sealed and the five deeper RI boreholes were completed with each well screened across the first water-bearing unit within the RUM. Piezometer 199-H4-15CR indicates the pressure head for this confined water-bearing zone is 1 to 2 m (3 to 7 ft) higher than for the unconfined aquifer near the Columbia River in 100-H.

3.6.2.1 Horizontal Hydraulic Conductivity – Water-Bearing Units within the RUM

Slug tests were completed on five RI wells installed in the first water-bearing unit of the RUM (*Analysis of Slug Test Data at the 100-HR-3 Operable Unit* [ECF-100HR3-12-0011]). In 100-D, hydraulic conductivity values estimated for the sandy unit at wells 199-D5-134 and 199-D5-141 were 1.2×10^{-4} cm/sec (0.66 ft/day) and 2.3×10^{-4} cm/sec (0.34 ft/day), respectively. In 100-H, three wells were screened in the first water-bearing unit of the RUM with hydraulic conductivities ranging from 6.9×10^{-4} cm/sec (1.96 ft/day) to 2.3×10^{-3} cm/sec (6.52 ft/day). The higher value at 199-H3-2C may be related to leaky aquifer conditions identified at this location. The 100-D RI results had hydraulic conductivity values that were two orders of magnitude less than those at Well 199-H3-2C. Table 3-12 summarizes the estimated hydraulic conductivities from the slug test data.

Table 3-12. Estimated Hydraulic Conductivity Values from Slug Tests

Well Name	Area	Geologic Unit	Horizontal Hydraulic Conductivity, K_H (cm/s)	Horizontal Hydraulic Conductivity, K_H (ft/d)	Vertical Anisotropy Ratio (K_V/K_H)
199-D5-134	100-D	First water-bearing unit in RUM	1.2×10^{-4}	0.34	0.1
199-D5-141	100-D	First water-bearing unit in RUM	2.3×10^{-4}	0.65	0.1
199-H2-1	100-H	First water-bearing unit in RUM	2.3×10^{-3}	6.52	0.1
199-H3-9	100-H	First water-bearing unit in RUM	6.9×10^{-4}	1.96	1.0
199-H3-10	100-H	First water-bearing unit in RUM	1.9×10^{-3}	5.39	0.1

Source: ECF-100HR3-12-0011, *Analysis of Slug Test Data at the 100-HR-3 Operable Unit.*

RUM = Ringold Formation upper mud

3.6.2.2 Vertical Hydraulic Conductivity – Water-Bearing Units within the RUM

During installation of the 70 DX/HX RPO wells across the 100-HR-3 OU, efforts were made to collect RUM surface samples at each borehole location for permeameter tests. Tests were not conducted when poor sample recovery occurred (e.g., Well 199-D7-5). In addition, soil samples were collected from 14 boreholes during the RI to evaluate the physical properties of the RUM. Each borehole log was conducted to verify the lithology of the depth interval that is representative of the first water-bearing unit of the RUM. The vertical hydraulic conductivity estimates are tabulated in Table 3-11.

The estimated vertical hydraulic conductivity values in the first water-bearing unit of the RUM varied between 1.40×10^{-8} and 5.0×10^{-3} cm/sec. However, samples from two of the locations (Well 199-H2-1 and 199-H3-9) had hydraulic conductivity values of 4.24×10^{-3} and 5.0×10^{-3} cm/s, respectively. The results from these two locations skew the results for the remainder of the sample set. The hydraulic conductivity values without including those results range from 1.4×10^{-8} to 3.8×10^{-5} cm/s, which is consistent with expected results.

Samples from two different depths were collected in 199-H1-35 and 199-H1-36. The second sample from Well 199-H1-35 was collected 1.5 m [5 ft] into RUM and it had a vertical hydraulic conductivity value of about 1.0×10^{-6} cm/sec, approximately one order of magnitude lower than the value estimated from the sample collected from the RUM surface. The 199-H1-36 sample (1.5 m [5 ft] into the RUM) appears to have greater sand content than the sample collected at the RUM surface. The vertical hydraulic conductivity value for the 199-H1-36 RUM surface sample was at 1.0×10^{-6} cm/sec. The 199-H4-71 and 199-H4-73 samples have a greater percentage of sand/gravel than RUM samples with low vertical hydraulic conductivity values.

Analysis of an aquifer test performed at Well 199-H3-2C, as part of the deep chromium investigation in 100-H (*Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* [SGW-47776]), suggests that there is hydraulic connection between the unconfined aquifer and a shallow water-bearing unit in the RUM at that location. The borehole log of this well shows higher permeability sediments above its screened interval. Vertical hydraulic conductivity estimates for neighboring Wells 199-H4-71 and 199-H4-73 are more than one order of magnitude higher than those of other RUM wells nearby. On the other hand, the aquifer test data at Well 199-H4-12C did not allow for similar inferences, because of its proximity to the Columbia River and the river's effect on water levels in the aquifer. Other nearby wells such as 199-H4-70 and 199-H3-27, have estimated vertical hydraulic conductivities consistent with typical RUM values (1.0×10^{-6} cm/sec, or 0.0028 ft/day), which suggests that the extent of a higher vertical conductivity zone could be limited in that area.

3.6.3 Columbia River Basalt Group Hydrogeology

The basalt confined aquifer system extends throughout the Pasco Basin. The upper basalt confined aquifer is an interflow zone consisting of fractured Elephant Mountain Member basalt flow-bottom, Rattlesnake Ridge interbed sediments, and underlying fractured Pomona Member basalt flow-top (see Figure 3-3). Piezometer 199-H4-15CP monitors a fracture zone in the Elephant Mountain Member basalt and consistently exhibits an artesian head, with water flowing from the well when the well cap is opened. Well 199-H4-2 monitors the upper basalt confined aquifer and also exhibits an artesian condition. It should be noted that the pressure differential exhibited between the basalt aquifer unit and the aquifers within the overlying unconsolidated units is not a demonstration of an actual upward gradient (i.e., flow of groundwater from the deeper units to the shallower units) in the absence of defined flow paths.

Early groundwater maps of the upper confined basalt aquifer system show groundwater flow to the southwest under 100-D/H, based on very limited hydraulic head data between the Columbia River and Gable Mountain – Gable Butte (*Hydrochemistry and Hydrogeologic Conditions Within the Hanford Site*

Upper Basalt Confined Aquifer System [PNL-10817]). Recent Hanford Site groundwater maps for the upper basalt confined aquifer (*Hanford Site Groundwater Monitoring and Performance Report for 2009* [DOE/RL-2010-11]) have not portrayed the piezometric surface for the upper basalt confined aquifer in the 100 Area because of the limited dataset.

3.7 Groundwater Flow Regime

The understanding of groundwater movement at the100-D/H Area and its effects on migration of associated contaminants is based on knowledge of historical conditions as well as current operating conditions that affect groundwater elevation, flow direction, and velocity. Hydrogeologic characterization of aquifer material at 100-D/H presented in preceding subsections provides part of the picture, with understanding of the dramatic effects of water management related to reactor operations and recent operation of groundwater remedial actions providing the rest of the story. This section focuses on groundwater flow patterns and rates under historical (predevelopment and operational) and recent conditions. Natural and artificial hydrologic processes influenced groundwater flow patterns and contaminant distribution at 100-D/H.

The groundwater regime at 100-D/H can be separated into the following phases:

- Historical conditions, including the following:
  - Predevelopment (pre-1862) conditions, during which time there was little to no anthropogenic activity
  - Pre-Hanford Site (pre-1900) operations, when irrigated agriculture was implemented at numerous locations near the river, including operation of a substantial irrigation canal across the Site to transport irrigation water
  - Operational (1943 to 1970’s) conditions, during which time reactors were constructed and operated at the 100-D/H Areas, and substantial artificial recharge occurred because of disposal of wastewater into the vadose zone
  - Post-operational (post 1970’s) conditions, during which time effects from reactor and related operations ceased, and groundwater conditions commenced recovery to conditions showing many of the features of the pre-Hanford time frame
- Current (recent) conditions, during which time interim remedial actions have been undertaken. These remedial actions include waste site remediation in the vadose zone (source control), and groundwater pump-and-treat systems for the groundwater.

The following section describes the groundwater flow regime in terms of these historical and current (recent) conditions. It focuses on conditions in the unconfined aquifer caused by groundwater contamination and related remedial activities within the Ringold Formation unit E and Hanford formation, and concludes with discussion of the underlying RUM and interactions between the RUM and the unconfined aquifer.

3.7.1 Historical Groundwater Flow Conditions

General patterns of groundwater flow before the commencement of operations at 100-D/H can be inferred from early maps of groundwater levels and from the distribution of natural recharge and discharge boundaries at 100-D/H. Together, these indicate that groundwater flow directions and rates in the area of the D, DR, and H Reactors were dictated by the natural locations of recharge and discharge, leading to general patterns of flow from the south-southeast toward the Columbia River near the D and

DR Reactors, and from the south-southwest toward the Columbia River near the H Reactor. Groundwater ultimately discharged to the Columbia River and fluctuations in groundwater levels within the unconfined aquifer resulted from natural changes in the stage of the Columbia River.

During the period of irrigated agriculture operations on the Hanford Site area, some undefined amount of artificial recharge likely occurred. This recharge would have been mostly related to local conditions beneath fields irrigated using flood or rill distribution techniques, and from leakage from the Hanford Ditch (an irrigation canal used to convey water from the vicinity of 100-K Area on the upstream side to the vicinity of the former Hanford Townsite on the downstream side). The hydrogeologic effects of the period of irrigated agricultural operations at Hanford are not defined quantitatively.

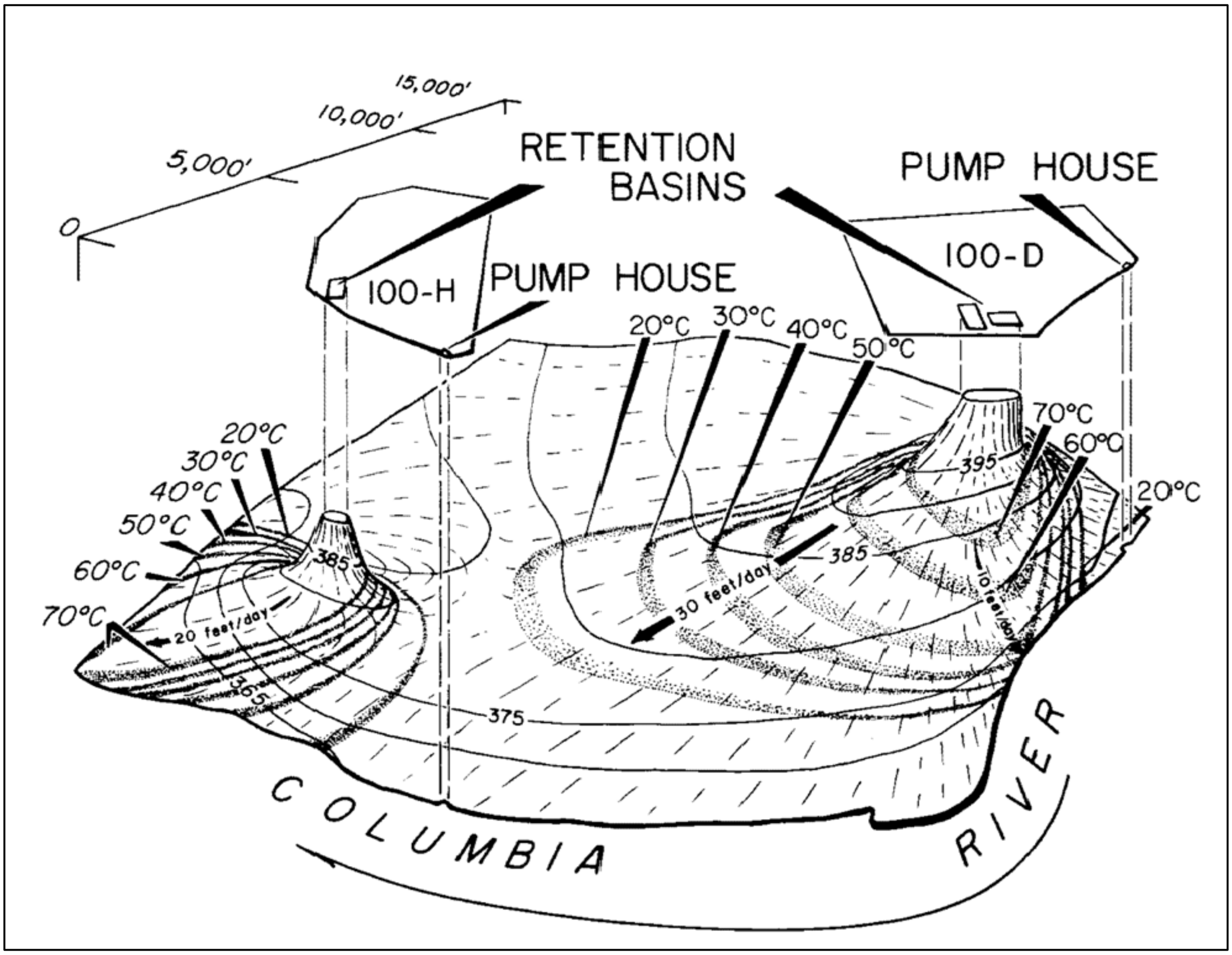
With the industrial development of the Hanford Site, various anthropogenic influences have dominated the directions and rates of groundwater flow. During operation of the D, DR, and H Reactors, large volumes of spent cooling water (high-temperature effluent from the reactors, containing Cr(VI) and other chemicals used to maintain water quality) were discharged to the retention basins where the water was held up, allowing the water to cool somewhat and short-lived radionuclides to decay. After the holding period, the contaminated cooling water was discharged directly into the Columbia River. Reactor cooling water entered the vadose zone in the vicinity of the reactor operations under two common conditions. First, leaks developed in the retention basins as a result of thermal expansion and contraction, allowing cooling water to leak from the basins into the underlying vadose zone. This contributed substantial quantities of localized artificial recharge to the underlying groundwater. Secondly, episodic fuel element failures also contaminated the cooling water with radioactive fission products and fuel residues; under these upset conditions, the cooling water stream was discharged directly to the vadose zone via engineered infiltration trenches instead of to the river. The discharge of contaminated cooling water to the vadose zone reduced the amount of radioactive contaminants that ultimately reached the river. The local artificial recharge conditions caused by discharges of contaminated cooling water from these trenches, and leaks from the retention basins, resulted in the buildup of extensive groundwater mounds in the unconfined aquifer beneath the reactor operating areas at 100-D and 100-H. Monitoring well hydrographs from 100-D and 100-H indicate that wastewater infiltration elevated groundwater levels as much as 10 m (33 ft) at 100-D and 7 m (21 ft) at 100-H. These extensive mounds altered groundwater flow patterns and groundwater velocity for years and account for the observed current distribution of groundwater contaminants across the entire width of the Horn area from 100-D to 100-H. Operation of the three reactors ceased in 1964 (DR Reactor), 1967 (D Reactor), and 1965 (H Reactor). The artificial recharge mounds dissipated fairly quickly and groundwater flow began to return to pre-Hanford conditions.

A contemporary report of observations of the groundwater mounding effects of discharges of reactor cooling water to the vadose zone in the Hanford 100 Areas during reactor operations is presented in *Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January, 1963* (HW-77170), which presents detailed descriptions of the groundwater mounds observed at all of the Hanford reactor areas, including detailed description of the groundwater temperature effects caused by discharge of high volumes of near-boiling cooling water.

3.7.1.1 Groundwater Mounding at 100-D

Groundwater mounding beneath the 107-D and 107-DR Retention Basins began shortly after reactor operations started in 100-D. By 1963, both basins had developed contraction/expansion cracks that allowed a large fraction of the conveyed cooling water to leak from the basins into the underlying vadose zone. The study of thermal and hydraulic effects, published in *Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January, 1963* (HW-77170), clearly indicate the evolution of a groundwater mound, consisting largely of reactor cooling water, that extended all the way from 100-D to 100-H, with a peak elevation of greater than 122 m (400 ft) amsl beneath the 107-D and

107-DR Retention Basins. The thermal effects of the 100-D cooling water recharge were measured in the intake water for 100-H. The calculated groundwater velocity between 100-D and 100-H was 9.1 m/day (30 ft/day). Groundwater temperature had been raised between 10°C and 50°C (50°F and 122°F) by 1963. The inferred extent of the groundwater mound associated with operation of the D and DR Reactors, along with the associated measured thermal effects, is shown in Figure 3-14. Thermal springs, caused by discharge of reactor cooling water from the exposed aquifer face near the river, were observed to extend over 600 m (2,000 ft) along the river shore downstream from the 100-D cooling water retention basins.



Source: HW-77170, *Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January,1963*.

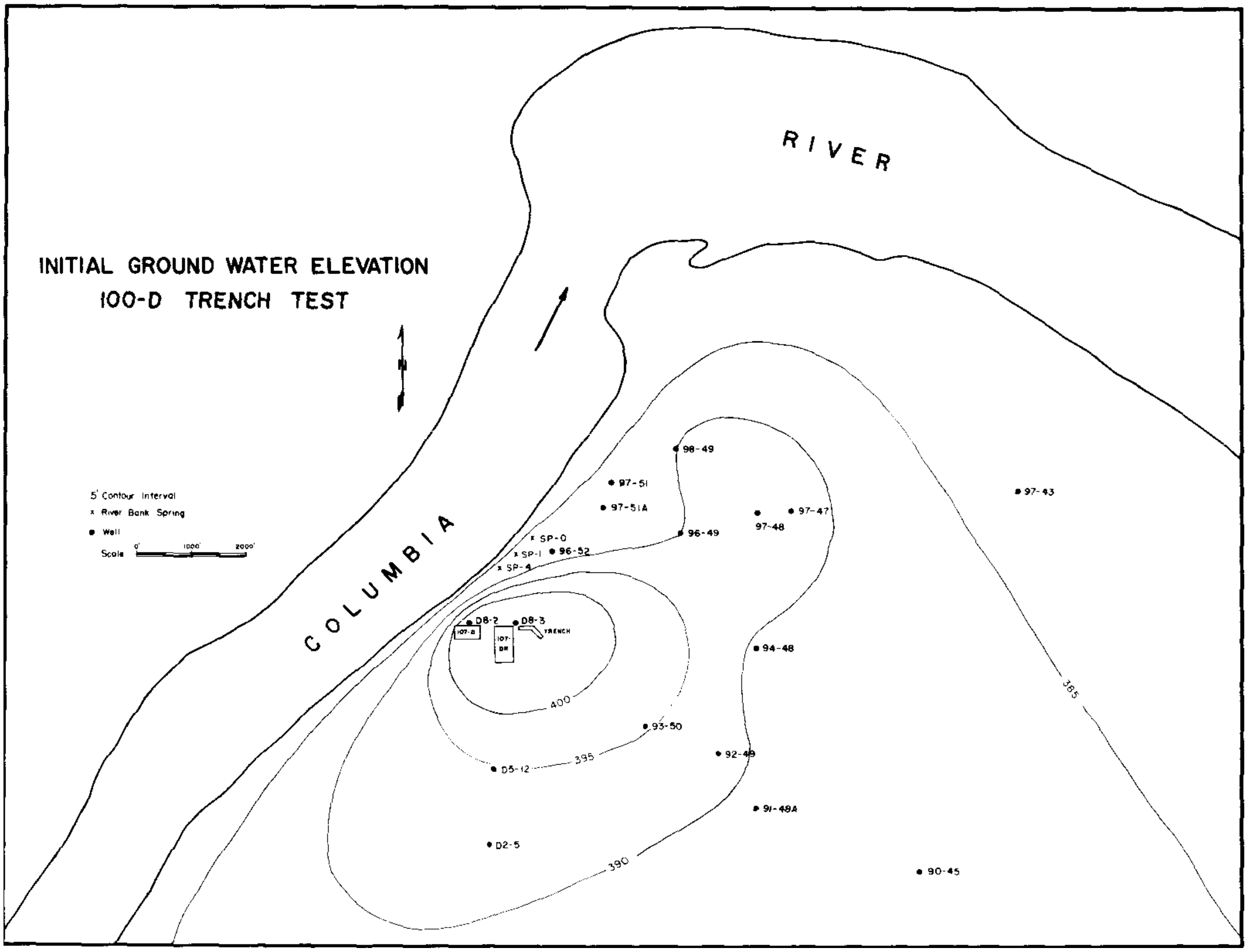
Figure 3-14. Perspective Drawing of the Water Table at the 100-D and 100-H Areas in 1962

Continuing releases of fission and activation products in cooling water into the adjacent Columbia River was a concern for reactor operations by the 1960s. In order to assess some alternatives to continued release of cooling water directly to the river, a series of tests involving continuous discharge of reactor cooling water streams directly to the vadose zone was developed. One such test was conducted at 100-D during the last 4 months of operation of the D Reactor and is described in *Ground Disposal of Reactor Coolant Effluent* (BNWL-CC-1352). This test was performed from March to June 1967 and involved directing the entire cooling water discharge from operation of D Reactor (DR Reactor having been shut down in December 1964) into the 116-DR-1 and 116-DR-2 Waste Water Trenches. The objective of the test was to observe the reduction in fission and activation product activity concentrations produced by the increased time of travel for cooling water to enter the river, compared to the historical practice of direct discharge of cooling water. The test involved monitoring the nuclide activity concentrations in the effluent cooling water and comparing those measurements to the activity concentrations observed in samples collected from the thermal springs that emerged at the river shore. Measurements of changes in groundwater temperature and elevation were also conducted to document the effects of the discharge on the physical groundwater system. The test was found to be effective at reducing activity concentrations of target nuclides (e.g., iodine-131, chromium-51, and zinc-65). During the test, a large volume of reactor coolant effluent was discharged to the 116-DR-1 and 116-DR-2 Trenches at a constant rate of 104,100 L/min (27,500 gal/min). This resulted in a total subsurface discharge of more than 13 billion L (3.4 billion gal) of cooling water effluent over the course of the test.

Groundwater elevations and temperatures increased beneath 100-D, with no significant decrease in the infiltration rate over time. Approximately 25 percent of the discharged volume was accounted for in the groundwater mound that formed. Detectable increases in groundwater elevation were measured as far as 1.6 km (1 mi) from the trenches.

Figures 3-15a, 3-15b, and 3-15c illustrate water table conditions before, during, and after the 4-month field test in 1967. The effect of the groundwater mound on groundwater lateral flow shows the radial flow from the groundwater mound created with the discharge. This large effluent discharge increased the groundwater gradient of the already-established mound and accelerated groundwater flow to the northeast and east away from the trenches. In addition, the resulting increased head of the enlarged groundwater mound would have applied additional vertical pressure on the underlying aquitard (RUM). This potentially resulted in some water migrating vertically into the underlying RUM, resulting in contamination in that unit, such as at Well 699-97-48C. However, the anisotropic nature of the contact between the RUM and the overlying unconsolidated formations (i.e., either Ringold Formation unit E or Hanford formation), as well as the anisotropic contact between the Hanford formation and the Ringold unit E would have made lateral flow away from the mound the preferential pathway; rapidly in the Hanford, and slightly slower in the Ringold unit E. In addition, the relatively low hydraulic conductivity of the RUM and the relatively short duration of the injection test (i.e., 4 months) would tend to minimize the vertical distribution effects of this test condition. This scenario is discussed further in Chapter 4.

Hydrographs from wells near the infiltration trench indicate that extensive groundwater mounding that occurred in response to the infiltration persisted for the duration of the test; the mound did not fully dissipate until about 1968 or 1969, although it was largely gone by September 1967 (Figure 3-16). During the test, groundwater elevation rose to nearly meet the ground surface in the immediate vicinity of the disposal trench, with a water table elevation of 129 m (415 ft) and a ground surface elevation of approximately 133 m (436 ft). The effects of the artificial recharge were compounded by the fact the Columbia River exhibited substantially higher than average annual peak river stages during the period of 1961 through 1972; this condition would have prolonged the decay of the groundwater mound established by artificial recharge at 100-D/H. By June 1967, the researchers were no longer able to clearly discern changes in groundwater elevation related to the cooling water discharge from the effects of the annual peak river stage, which occurred that month and reached an elevation of 134 m (440 ft) amsl at Priest Rapids Dam.

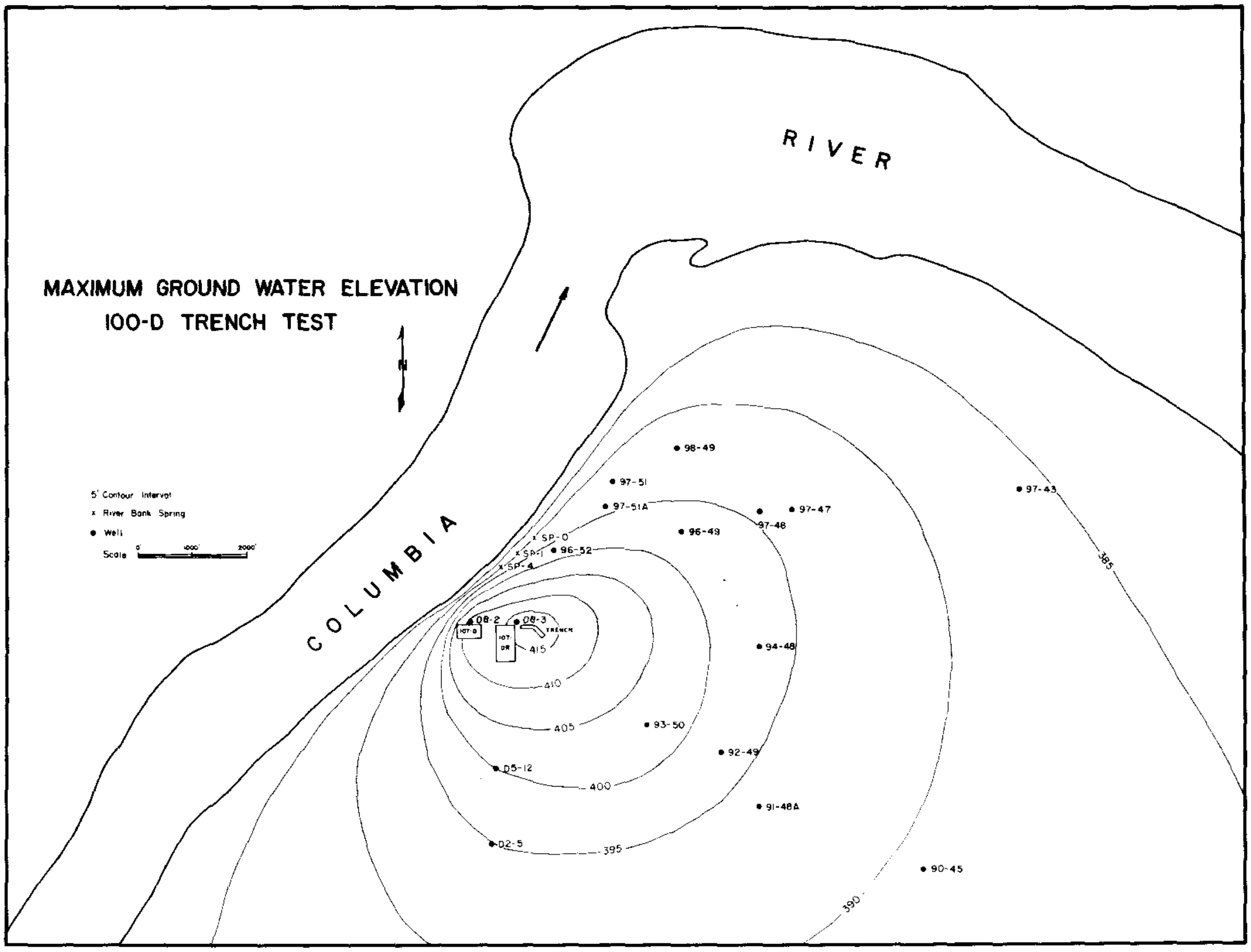


Source: BNWL-CC-1352, *Ground Disposal of Reactor Coolant Effluent*.

Figure 3-15a. Hydrologic Effects of the 1967 Infiltration Test

In addition to the reactor cooling water discharges at the100-D/H Area, other anthropogenic activities have produced local artificial recharge to the shallow unconfined aquifer. In particular, chronic leakage from the 182-D Reservoir has produced a local groundwater mound beneath the footprint of the reservoir. This presence of this mound is apparent in two sets of observations:

- The Cr(VI) plume in the general 100-D Area has been divided by a body of uncontaminated water that is generally centered on the 182-D Reservoir. This condition does not appear to be related to natural groundwater flow.
- The basic geochemistry of groundwater samples collected from monitoring wells immediately adjacent to the reservoir is substantially different from the surrounding groundwater and exhibits characteristics consistent with the geochemistry of the Columbia River.

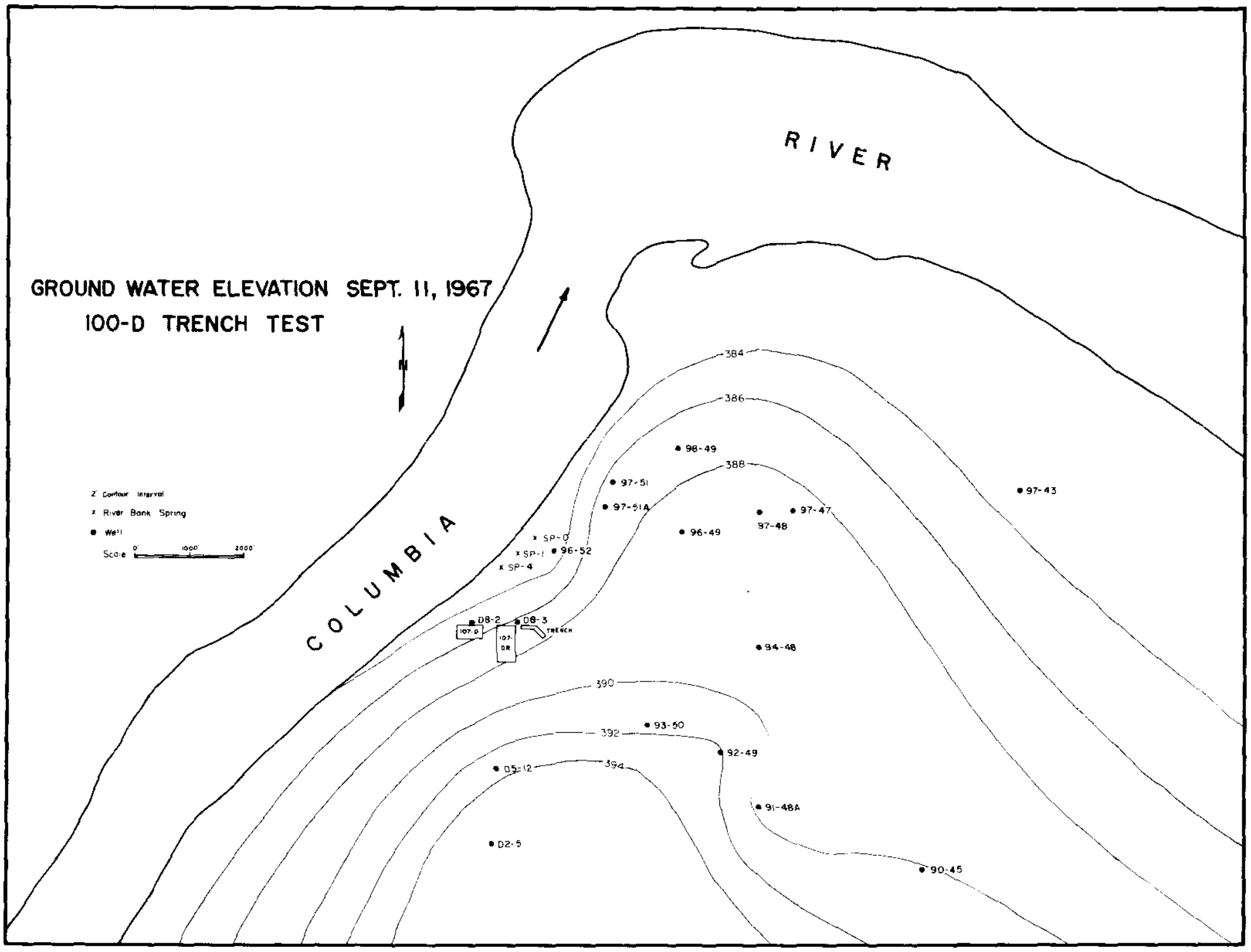


Source: BNWL-CC-1352, *Ground Disposal of Reactor Coolant Effluent*.

Figure 3-15b. Hydrologic Effects of the 1967 Infiltration Test

The 182-D Reservoir was constructed as part of the D Reactor cooling water treatment system and has also been used to store raw river water for Site use, including export to the 200 Areas of the Central Plateau. The reservoir is still used as one of two sources of untreated, nonpotable water to supply the Hanford Site. Up until the last few years, the 182-D Reservoir chronically leaked enough to sustain a local groundwater mound. In recent years, the reservoir has been operated under administrative controls that limit the operating head within the reservoir to a predetermined water level. This has reduced the apparent leakage from the reservoir substantially. Although the reservoir is expected to continue to leak, the effects on the underlying shallow unconfined aquifer are becoming apparent as the inferred distribution of the uncontaminated water that divides the two Cr(VI) plume segments appears to the shrinking. An area of very low Cr(VI) concentration is still observed associated with Wells 199-D5-33 and 199-D5-44, located near the reservoir.

Recent efforts to address the leakage have included reducing the operating water level in the reservoir and attempting to seal concrete cracks and construction joints. As presented in Chapter 4, the result has been a reduction in leakage and diminished effects on the local groundwater flow, which is seen by the merging of the northern and southern Cr(VI) plumes at 100-D.



Source: BNWL-CC-1352, *Ground Disposal of Reactor Coolant Effluent*.

Figure 3-15c. Hydrologic Effects of the 1967 Infiltration Test

3.7.1.2 Groundwater Mounding at 100-H

In 100-H, a substantial groundwater mound formed under conditions similar to those at 100-D; however, the overall magnitude of the mound was smaller, both in its height (which still approached local ground surface) and in areal extent. Again, similar to 100-D and the other Hanford reactors, cooling water was stored before treatment in the 182-H Reservoir, which may have leaked unspecified quantities of water during operation. Spent cooling water left the reactor and was held up in the 116-H-7 (107-H) Retention Basin before being discharged to the Columbia River. Retention basin leaks at 100-H developed and substantial quantities of water were inadvertently released to the vadose zone beneath the basin. In addition, contaminated cooling water generated during upset conditions (e.g., fuel ruptures) at H Reactor was diverted from the retention basin to the 116-H-1 Trench and allowed to infiltrate into the vadose zone soil. Cooling water leaking from the retention basin and discharged to the trench was the source of the observed groundwater mound at 100-H.

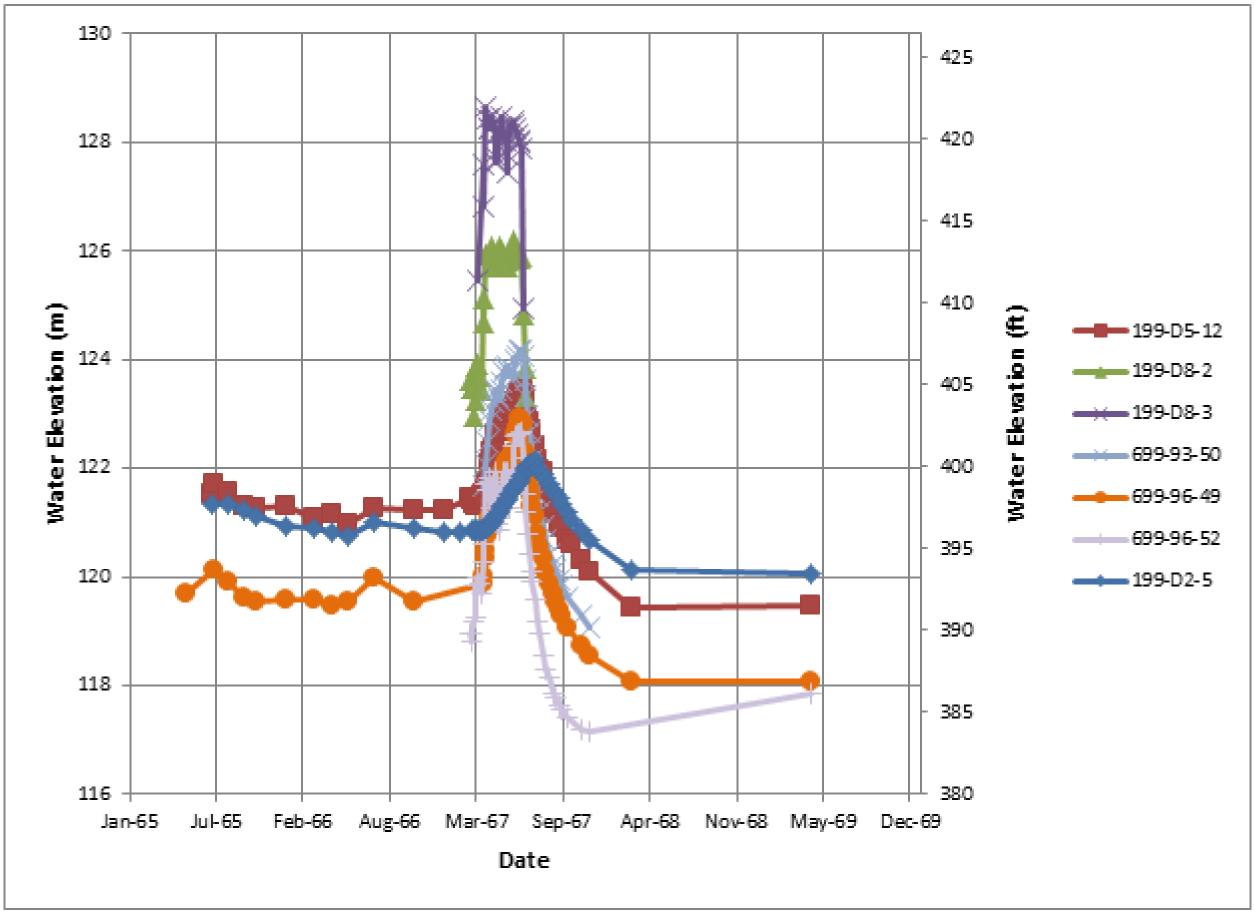


Figure 3-16. Hydrographs of Selected Wells near the 116-DR-1&2 Infiltration Trench

The groundwater mound at 100-H reached nearly to the ground surface and, like the mound observed at 100-D, exhibited elevated temperature greater than 70°C (157°F). The groundwater mound at 100-H would also have consisted largely of spent reactor cooling water, which would have displaced most of the naturally flowing groundwater in the aquifer during the operations period of the reactor. The 100-H mound formed within the coarse-textured Hanford formation that underlies the reactor area and sits directly atop the underlying RUM; the shallow unconfined aquifer at 100-H is found entirely within the Hanford formation. Groundwater beneath 100-H flowed rapidly toward the adjacent river where it discharged. Thermal springs were observed for about 1,000 m (3,000 ft) downstream from 100-H during reactor operations. Because of the 100-H facilities' proximity to the river and the high hydraulic conductivity of the underlying Hanford formation, the groundwater of the 100-H mound flowed rapidly toward the river at a velocity of about 6.1 m/day (20 ft/day) and did not develop the broad extent observed at 100-D. The mounding quickly dissipated after H Reactor operations ceased in 1965.

During the early to mid-1960s, the reactor cooling water mound from 100-D operations extended all the way across the Horn to 100-H, and temperature increases in cooling water withdrawn for 100-H operations were partially attributed to the elevated groundwater temperature because of the 100-D contribution.

3.7.1.3 Pump and Treat System Influences

In 1997 and 2004, two interim groundwater pump-and-treat systems (HR-3 and DR-5, respectively) were installed in 100-D/H. Although these systems worked effectively at reducing contaminant concentrations in the unconfined aquifer and the first water-bearing unit in the RUM, the systems had only localized influence on the groundwater flow regime. The DR-5 and HR-3 systems were shut down in April and May 2011, respectively. The new 100-DX and 100-HX systems came on line December 17, 2010, and October 1, 2011, respectively.

3.7.1.4 Horizontal Hydraulic Gradients and Flow Velocities

While reactor-related activities took place (including disposal of wastewater to the subsurface), groundwater flow velocities between the wastewater disposal areas and the Columbia River increased considerably from predevelopment rates. Several years after operations started in the 100-D and 100-H Areas, it was discovered that leaks from the retention basins and associated pipelines caused significant groundwater mounding under the retention basins, greatly increasing the gradients and groundwater velocities between the basins and the Columbia River. The gradients formed were sufficient to cause riverbank thermal springs near the retention basins in both areas.

In 1962, a study was undertaken to determine the effects that the thermally hot groundwater might have on reactor operations (*Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January, 1963* [HW-77170]). At that time, groundwater velocities near the 100-D and 100-H Retention Basins were estimated to range from about 3.5×10^{-3} cm/sec (10 ft/day) to about 1.06×10^{-2} cm/sec (30 ft/day). Figure 3-14 depicts approximate groundwater elevations in 1962. Groundwater velocity at 100-D exhibited the greatest variation; velocity directly toward the river from the retention basins was about 3.5×10^{-3} cm/sec (10 ft/day), somewhat moderated by the presence of the Ringold unit E material in the aquifer. The velocity of groundwater flowing across the Horn toward 100-H was substantially greater at about 1.06×10^{-2} cm/sec (30 ft/day). The velocity at 100-H, flowing from the vicinity of the retention basin toward the river was about 7.0×10^{-3} cm/sec (20 ft/day). Given the period of reactor operations in both areas, the groundwater elevation contours presented on Figure 3-14 likely represent the approximate size and configuration of the groundwater mounds at their peaks, although the mound beneath 100-D would have grown substantially during the cooling water injection test conducted in 1967. The calculated groundwater velocity during the 100-D injection test was 1.75×10^{-2} cm/sec (50 ft/day) based on reduction of measured iodine-131 activity concentrations in the cooling water and in the groundwater subsequently discharged at thermal springs along the river (*Ground Disposal of Reactor Coolant Effluent* [BNWL-CC-1352]).

Discharges of wastewater to the various trenches and basins declined with the sequential cessation of reactor operations in 1964 (DR Reactor), 1965 (H Reactor), and in 1967 (D Reactor). Water level data obtained since 1967 suggest that conditions approaching predevelopment horizontal hydraulic gradients were largely restored by about 1968 or 1969 (Figure 3-16).

The effects of wastewater infiltration on patterns of groundwater flow and contaminant migration near the 100-D and 100-H Area reactors and associated trenches and basins are detailed further in Chapter 5. Water level maps are used to depict patterns of flow inland from the reactors and associated wastewater disposal areas and the likely effect of these groundwater flow patterns on contaminant migration.

3.7.1.5 Vertical Gradients

During operation of the reactors, infiltration and overland flow of contaminated cooling water from surface features and from leaks at the 100-D and 100-H Area retention basins created significant vertical (downward) fluxes within the vadose zone that would have increased the potential for vertical migration of contaminants released to the aquifer. Although historical water level data from River Corridor reactor areas during this period are from wells with similar screened intervals (making direct assessments of vertical gradients difficult), qualitative evaluation of the mounding conditions suggests that vertical hydraulic gradients exerted by the intense artificial recharge must have been significant.

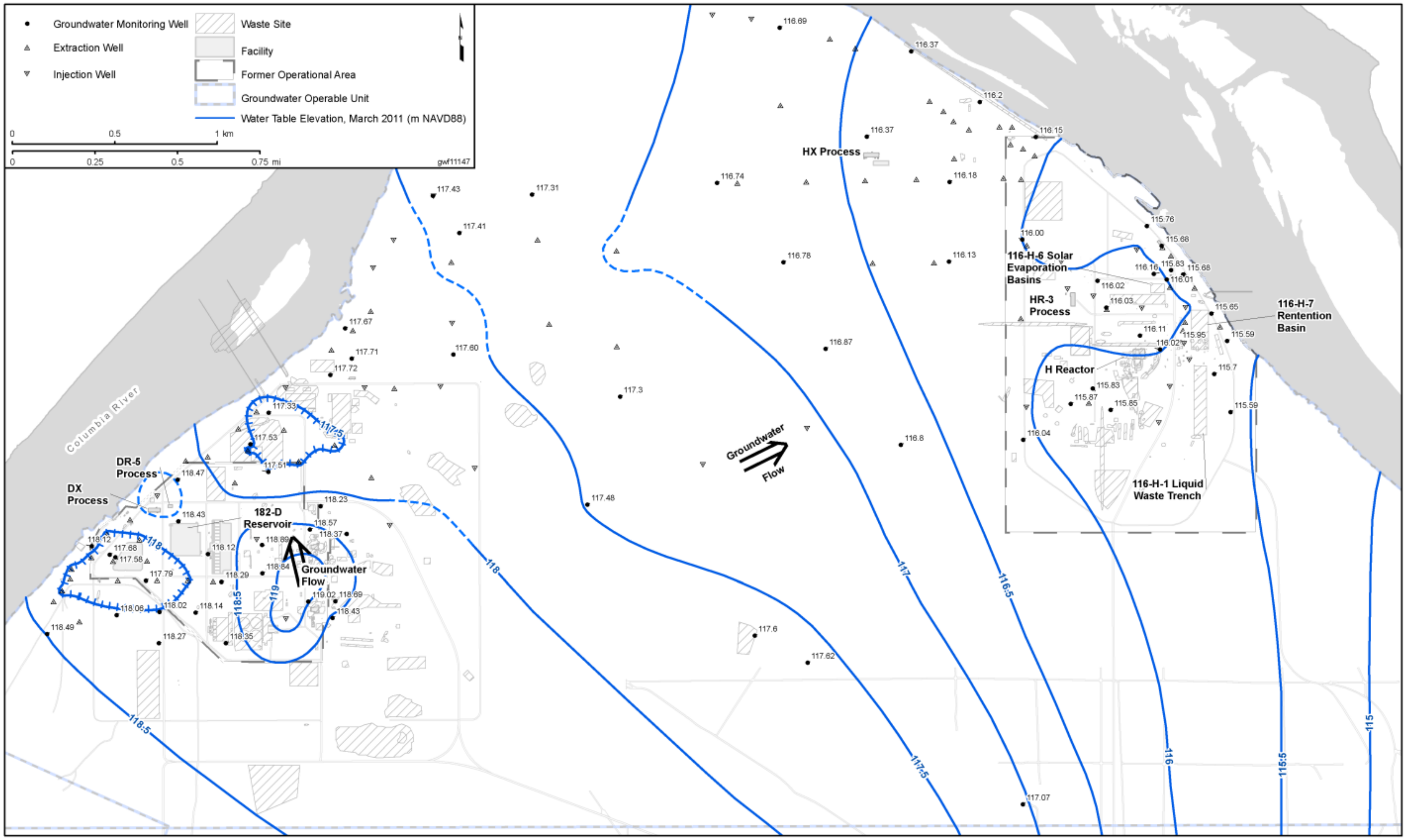
3.7.2 Current Groundwater Flow Conditions

Since the cessation of reactor operations and associated wastewater disposal, hydraulic gradients and groundwater flow have largely returned to their predevelopment direction toward the Columbia River, with variations in response to changes in the stage of the now actively managed Columbia River, which are dictated by the spring snowmelt, summer season, and controlled releases at the Priest Rapids Dam. Throughout the year, hydraulic gradients steepen toward the river during low river stage (fall and winter), and flatten or may reverse near the shoreline during high river stage. Superimposed on these longer term fluctuations are daily and weekly fluctuations arising from controlled releases at the Priest Rapids Dam. Historically, the water table elevation ranges from approximately 117 m (384 ft) in the 100-D and central Horn areas to approximately 115 m (377 ft) in 100-H (*North American Vertical Datum of 1988* [NAVD88]). The seasonal high river stage on the Hanford Reach of the Columbia River coincides with the spring snowmelt and typically extends from May through July and seasonal low river stage is generally from September through the early winter. Data used for development of the water level maps are presented in Appendix D, Tables 10 through 64.

Data obtained from river gauges along the Hanford Reach indicate that high river stage 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 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]). Groundwater elevations have varied by up to 1.0 m/day (3.3 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]).

Water table maps are presented to illustrate groundwater elevations and groundwater flow under three different seasonal conditions: when the average river stage is at the annual low (September), when the river stage is intermediate (March), and when the river stage peaks (June). Groundwater elevation data displayed on the June 2010 and September 2010 contour maps represent pre-DX/HX pump-and-treat system groundwater elevations. However, the DR-5 and HR-3 pump-and-treat systems were still operating. The March 2011 contour map represents conditions where only the DX system was on line.

The March 2011 groundwater contour map represents flow conditions during intermediate river stage (i.e., average conditions; Figure 3-17) over the 100-HR-3 OU. Figure 3-17 illustrates that under current conditions, groundwater enters the 100-HR-3 OU from the south and generally flows toward the Columbia River. Much of the regional flow is toward the northeast and 100-H. A lesser portion flows north/northwest toward 100-D, which is now influenced by pumping and injection. From the area northeast of 100-D, groundwater flows across the Horn to the east-northeast and toward 100-H. Evidence indicates that the DX pump-and-treat system is influencing the groundwater flow regime beneath 100-D. Two groundwater depressions near the river are caused by DX extraction wells. In addition, a groundwater mound is nearly centered beneath the reactors, which is caused by DX injection wells. Flow away from the injection wells is designed to push contaminants toward the extraction wells.



Reference: NAVD88, *North American Vertical Datum of 1988*.

Figure 3-17. 100-D/H Water Table Map – March 2011

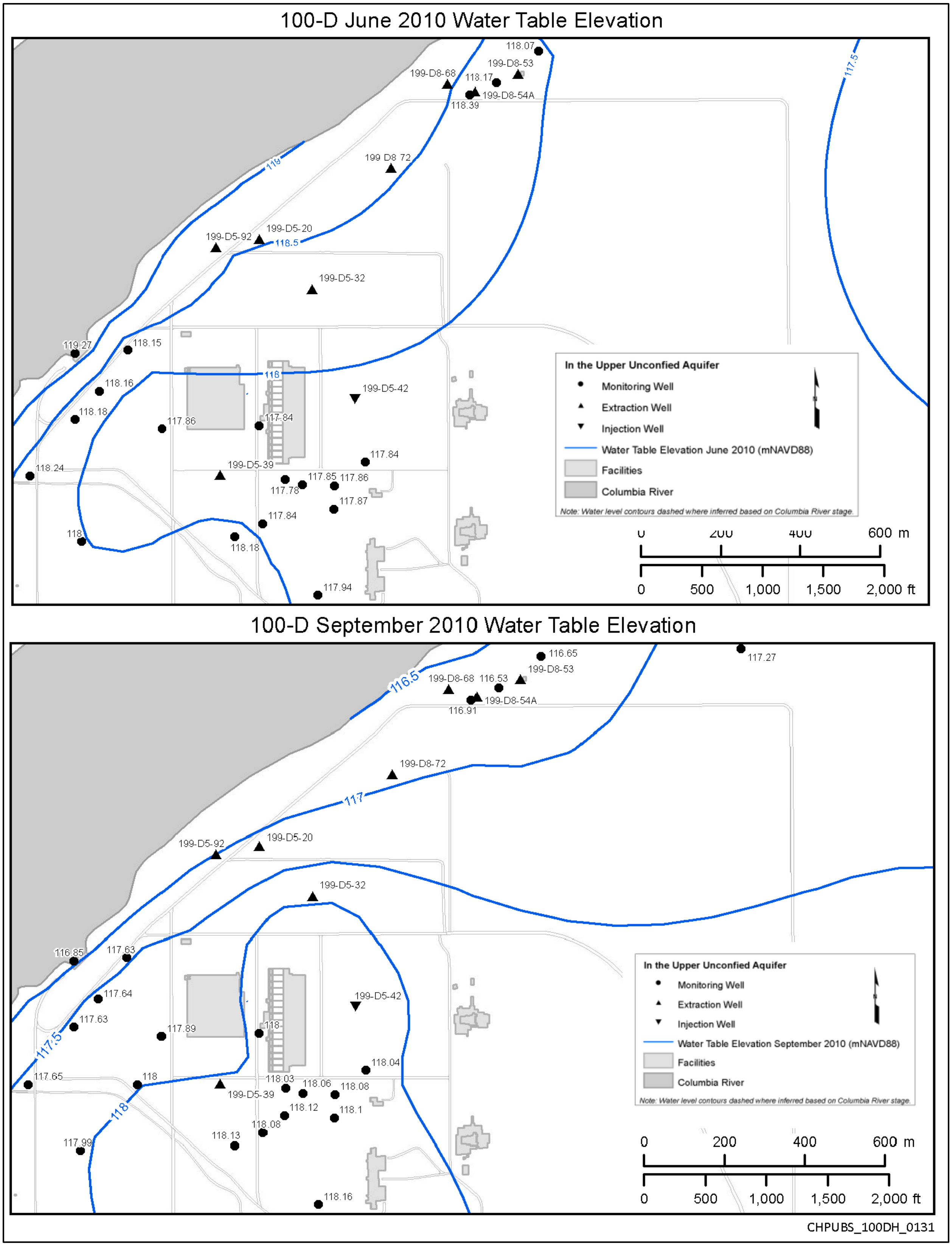
Two additional groundwater contour maps were constructed to show close-up profiles of 100-D (Figure 3-18) and 100-H (Figure 3-19) during high and low river stages. These maps show the effects of river stage on the groundwater flow regime near the river, where the effect is more pronounced than it is inland or in the Horn area. The map shows high river stage conditions at 100-D in June 2010, where the 119 m (390 ft) equipotential line is near the river, and the next two consecutive equipotential lines decrease inland to 118.5 and 118 m (388.8 and 387 ft). This decrease indicates the river is flowing into the aquifer, so the river is referred to as a "losing stream." The flow is generally southeast, away from the river. The 118 m (387 ft) equipotential line is distorted around extraction Well 199-D5-39, which was extracting groundwater for the former DR-5 pump-and-treat system. In 100-D, the September 2010 map on Figure 3-18 shows low river stage conditions, where the 118 m (387 ft) equipotential line is inland; then, the next three consecutive equipotential lines decrease from 117.5 to 116.5 m (385 to 382 ft) at the river. This decrease indicates groundwater is discharging to the river. The general flow direction is northwest, north, and northeast depending on the location in 100-D. The influence of the former DR-5 pump-and-treat system is observed with the 118 m (387 ft) equipotential line.

The June 2010 map on Figure 3-19 represents high river stage conditions in 100-H, where the 117 m (383.8 ft) equipotential line is near the river, with the next equipotential line decreasing inland to 116 m (380.5 ft). This potentiometric head difference indicates that during period of high river stage, water enters the aquifer from the river and may migrate some distance inland at a velocity determined by the head difference. The oval-shaped 116 m (380.5 ft) equipotential line is likely a combination of effects from high river stage and the former HR-3 pump-and-treat extraction wells that were operating. The September 2010 map on Figure 3-19 represents low river stage conditions in 100-H, where equipotential lines converge toward the river from high to low elevation. This indicates groundwater is discharging to the river. The general flow direction is northeast and east depending on the location in 100-H. The influence of the former HR-3 pump-and-treat system is evident near Well 199-H4-3, which causes a steeper hydraulic gradient.

Groundwater flow direction reversals have been documented in 100-D and 100-H (*Conceptual Site Models for Groundwater Contamination at 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units* [BHI-00917]; *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins* [PNL-6728]). Over the course of each year, however, groundwater exhibits a net discharge to the Columbia River from 100-D/H.

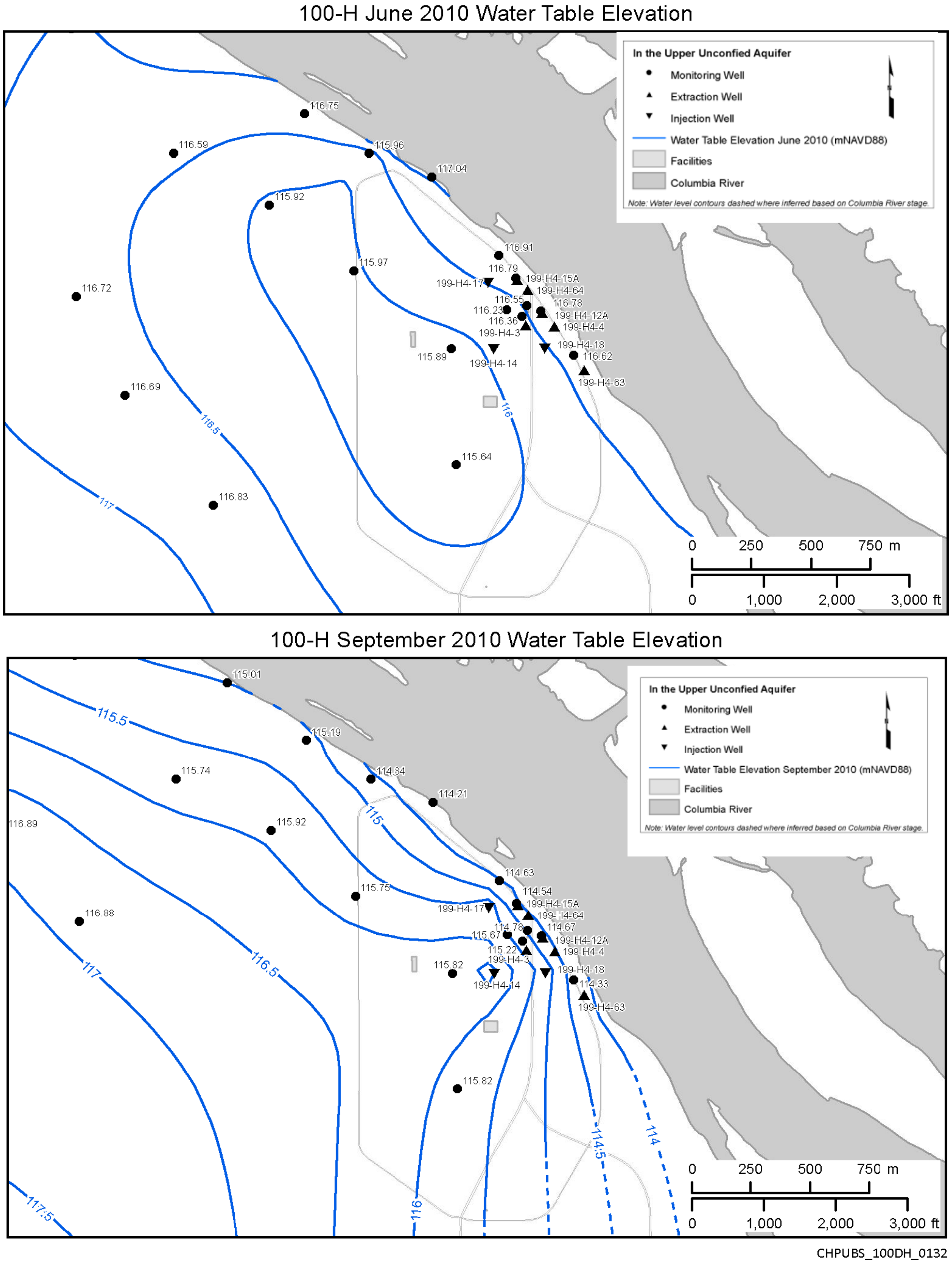
Figures 3-20 and 3-21 show river stage elevation at 100-D and 100-H river gauges versus groundwater elevations in selected wells in each area, respectively. Figures 3-20 and 3-21 show the annual and diurnal cycles in river stage fluctuations and the translation of those stage changes into the adjacent aquifer. The river stage fluctuates as much as 4.6 m (15 ft) during the year and some days by as much as 2.7 m (9 ft) (*Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River* [PNL-9437]), depending on how water is released from Priest Rapids Dam upstream from the Hanford Site. The fluctuations in river stage create a cyclic rise and fall of the water table in the aquifer adjacent to the river, the effects of which can be observed hundreds of meters inland. This zone between the high and low water table is termed the periodically rewetted zone.

Figure 3-17 shows that the 100-DX pump-and-treat system has a significant influence on groundwater flow at 100-D. With the startup of the 100-HX pump-and-treat system, which includes pumping of the RUM first water-bearing unit from Wells 199-H4-12C and 199-H3-2C in fall 2010, hydraulic gradients are now altered. Operation of the DX and HX pump-and-treat systems will result in gradient effects caused by extraction and injection wells.



Reference: NAVD88, *North American Vertical Datum of 1988*.

Figure 3-18. 100-D Water Table Maps – June and September 2010



Reference: NAVD88, *North American Vertical Datum of 1988*.

Figure 3-19. 100-H Water Table Maps – June and September 2010

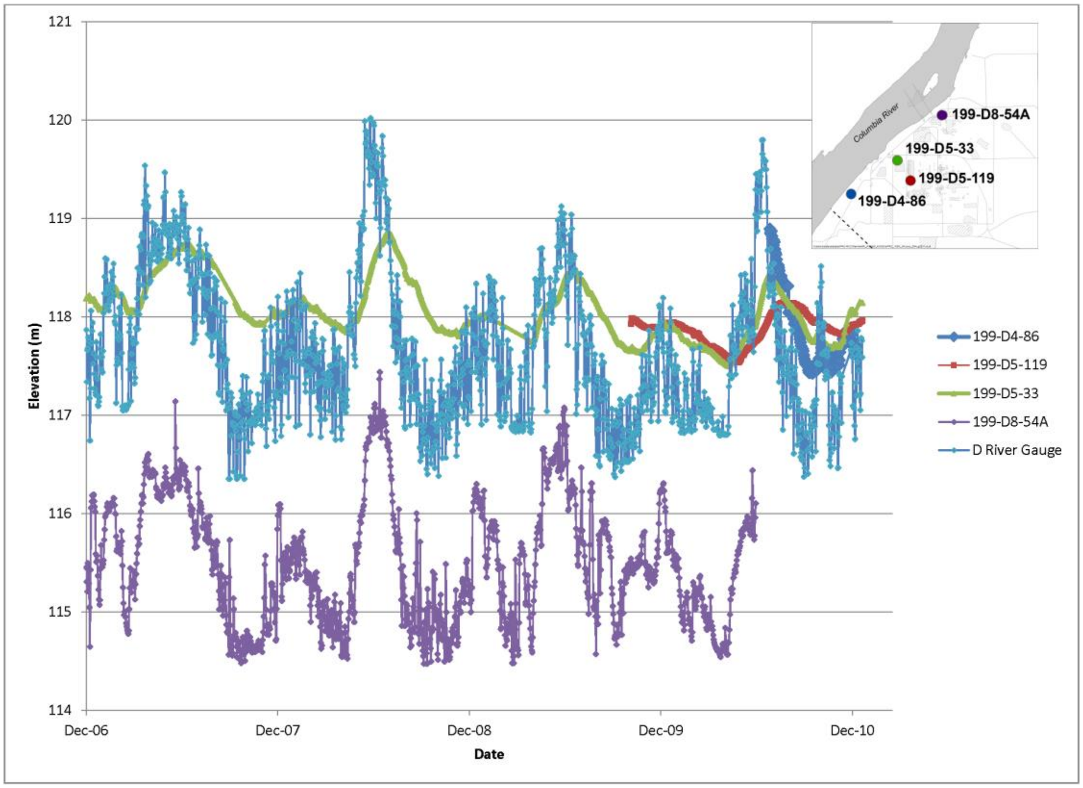


Figure 3-20. River Stage at 100-D Compared to Water Elevations in Selected Wells

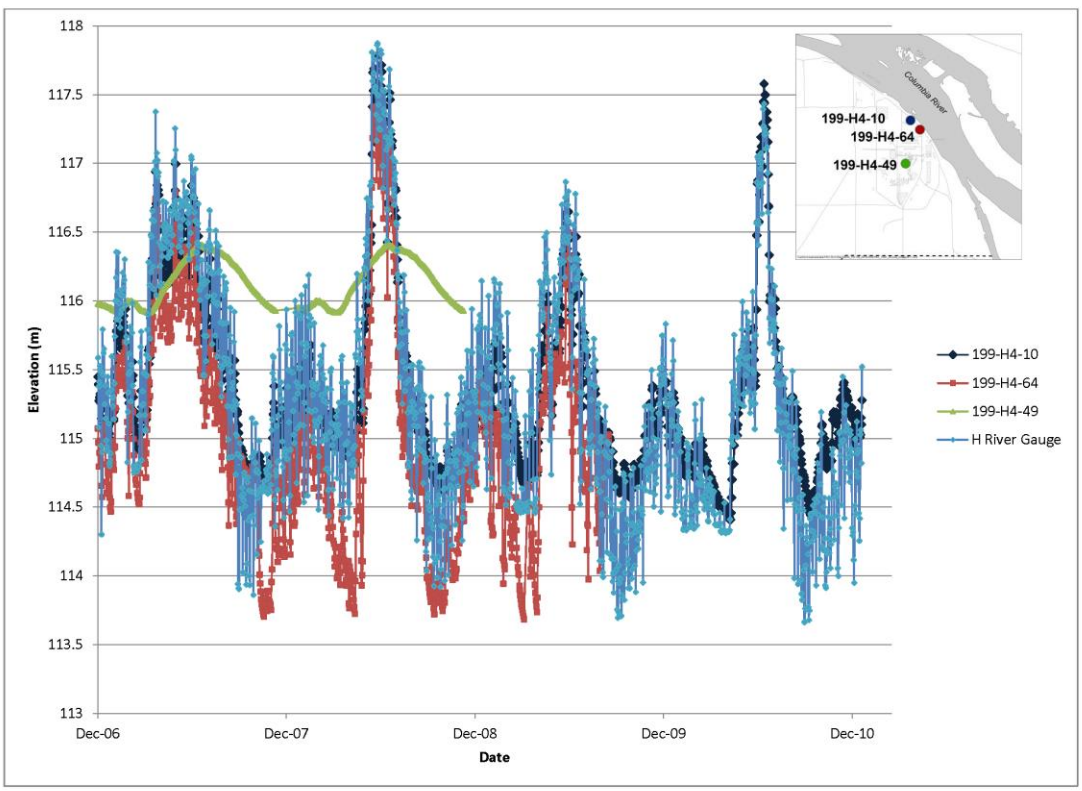


Figure 3-21. River Stage at 100-H Compared to Water Elevations in Selected Wells

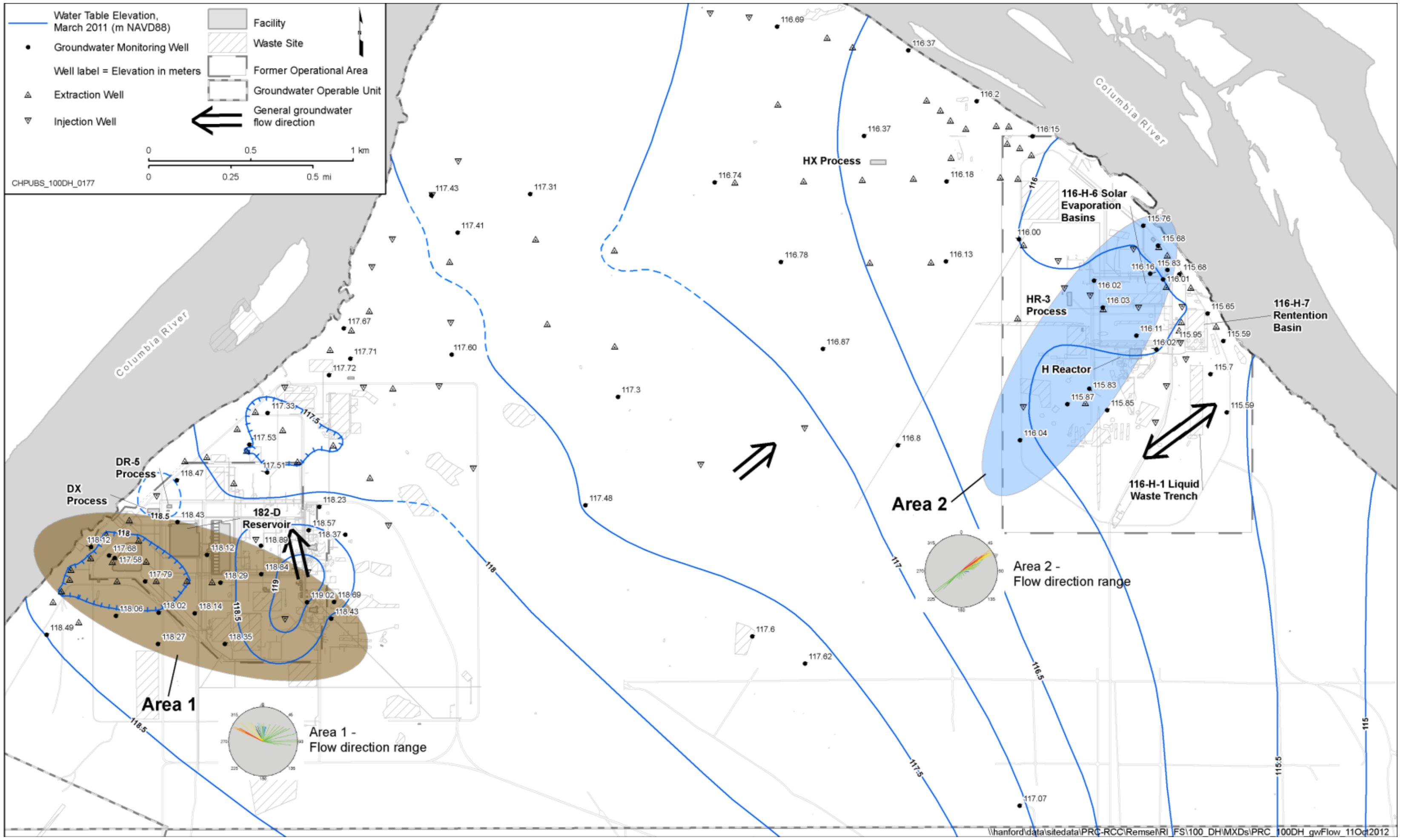
3.7.2.1 Horizontal Gradients and Groundwater Velocities

Current hydraulic gradients within the unconfined aquifer are generally toward the Columbia River, but the gradients show some seasonal variation in response to changes in river stage. Gradients steepen toward the river during low river stage (fall and winter), and flatten or may reverse near the river shoreline during high river stage (spring). Local gradients are also influenced by the operation of the pump-and-treat systems in 100-D/H.

The 100-HR-3 groundwater pump-and-treat systems were reconfigured and expanded in 2011 following RPO activities. Four groundwater pump-and-treat systems operated for all or part of 2011:

- In the 100-D Area, the DX system operated for the entire calendar year, while the DR-5 system operated from January to April.
- In the 100-H Area, the HR-3 system operated from January to May, while the HX system operated from late September to December.
- To evaluate the variation in the groundwater gradient direction and magnitude at 100-D/H, as influenced by current pump-and-treat operations, a three-point gradient analysis was performed using groundwater levels measured during 2011. A "mesh" of triangles was created between monitoring wells that are outfitted with dataloggers and transducers that record groundwater levels continuously. With some exceptions (detailed below), each triangle in the mesh, referred to as an element, is defined by three monitoring wells. A gradient vector consisting of a magnitude and azimuth (direction) is calculated for each element, using groundwater levels measured in the three wells (Figure 3-22). For this analysis, weekly gradients were calculated for each element, using weekly average groundwater elevation measurements in monitoring wells. The presence of extraction or injection wells within any one three-point element introduces some degree of uncertainty in the net calculated gradient. Injection and extraction wells may exert effects on the direction or magnitude of gradient within the element.

The three-point gradient method is most effective if water levels vary linearly between the three wells used to define the triangular element. If an injection or extraction well lies inside an element, however, water level mounding or depression generated by the injection or extraction well will result in a different gradient than would be calculated assuming a planar water table passing through the three monitoring wells. Element triangles were, therefore, drawn such that injection wells lie outside of the triangles. If it was not possible to draw appropriate triangles using existing monitoring wells, water levels at the triangle vertices were inferred from weekly average water level maps prepared for *Calendar Year 2010 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and 100-NR-2 Groundwater Remediation* (DOE/RL-2011-25). These water level maps were calculated using a universal kriging technique that explicitly accounts for the effects of injection or extraction on groundwater levels (*Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance* [SGW-42305]).



Reference: NAVD88, *North American Vertical Datum of 1988*.

Figure 3-22. Water Table Elevation Map for 100-D/H (March 2011) Indicating Inferred Groundwater Flow Directions

Results of the three-point gradient analysis suggest geographic variations in average hydraulic gradients that can be broadly grouped in three general areas (shown in Figure 3-22) as follows:

- **Area 1:** The area near the 100-D southern plume that is now the target of the 100-DX remedy (example Element 7).
- **Area 2:** The area near 100-H that is now the target of the 100-HX remedy (example Element 76).
- **Area 3:** The area between 100-D and 100-H, referred to as the Horn. Because of relatively sparse data during 2011, a hydraulic gradient rose diagram is not presented for the Horn area.

Radial diagrams illustrating gradient magnitude and direction in Areas 1 and 2 are presented on Figures 3-23 and 3-24. At 100-D, an azimuth direction of approximately 310 degrees would indicate a flow direction perpendicular to the Columbia River. At 100-H, an azimuth direction of approximately 45 degrees would indicate a flow direction perpendicular to the Columbia River. The radial diagrams illustrate the variations in weekly average gradient for representative elements in the two general areas identified above. The direction that the lines point indicates the calculated azimuth direction (that is, the flow direction). The length of the line indicates the relative magnitude of the groundwater gradient. The line colors reflect the general seasonality of the observations: blue indicating spring, green indicating summer, yellow indicating fall, and red indicating winter.

In Area 1, hydraulic gradients during 2011 varied in magnitude from approximately 0.0014 to 0.0023 for the period May through August, and from approximately 0.0017 to 0.0031, for the period September through April. The gradient direction was to the north/northwest toward the Columbia River for most of the year; however, gradients shifted to the north/northeast for a brief period from May through August 2011, coinciding with high stage in the Columbia River. The flow direction in this area exhibited a range of approximately 200 degrees azimuth over the high river-stage period of May to August, but only a range of 70 degrees azimuth during the period of September through April. Time-series and radial graphics showing the weekly gradients for Area 1 are presented on Figure 3-23.

In Area 2, hydraulic gradients varied in magnitude from about 0.0014 to 0.0036 for the period of May through August, and from approximately 0.0015 to 0.0046 for the period of September through April. The gradient direction was generally north/northeast toward the Columbia River; however, gradients shifted to the south/southeast for a brief period from May through August 2011, coinciding with high stage in the Columbia River. The flow direction in this area exhibited a range of approximately 128 degrees azimuth over the high river-stage period of May to August, but only a range of 70 degrees azimuth during the period of September through April. Time-series and radial graphics showing the weekly gradients for Area 2 are presented on Figure 3-24.

During 2011, hydraulic gradients in Area 3, consisting of the Horn, are difficult to enumerate because of widely varying monitoring frequencies at the wells that form the boundaries of the gradient elements. Available data indicate that areas relatively close to the shore of the Columbia River varied in azimuth from north/northwest during times of very low river stage (that is, toward the Columbia River at the northern side of 100-D), to south/southeast (that is, away from the Columbia River) during times of very high river stage, with periods of relatively flatter gradients to the west and west-southwest at times of intermediate river stage. At locations more distant from the Columbia River, gradients appear to be more systematically to the west across the Horn.

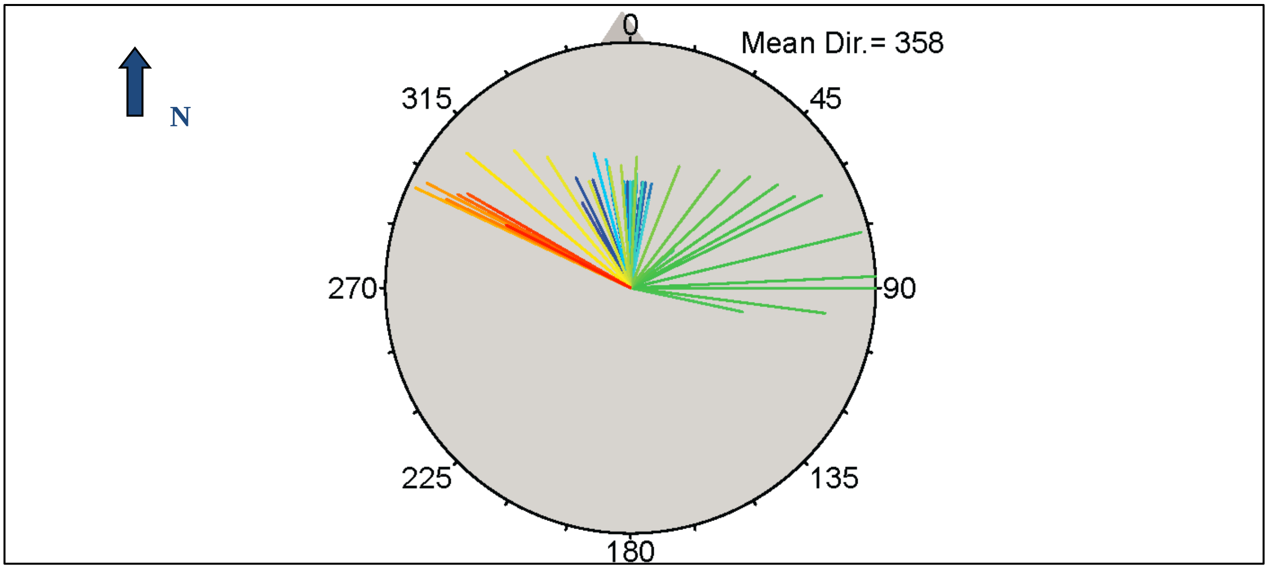


Figure 3-23. Weekly Average Gradient in 2011 for a Representative Element in Area 1

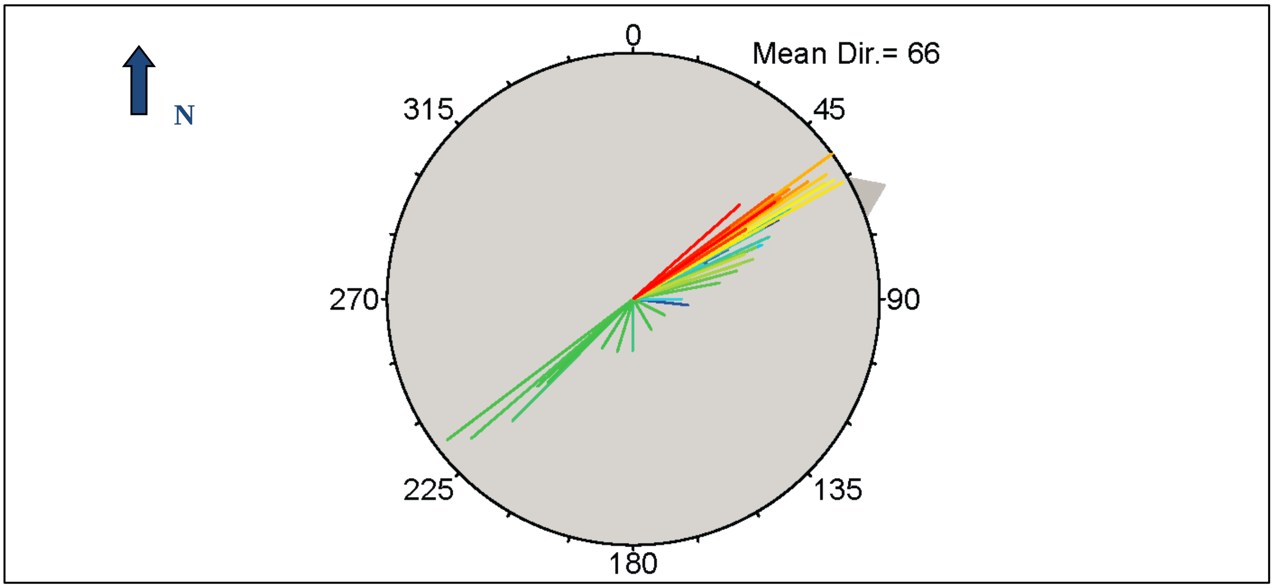


Figure 3-24. Weekly Average Gradient in 2011 for a Representative Element in Area 2

Representative ranges of average gradient magnitude and direction, hydraulic conductivity, and groundwater velocity for Areas 1 and 2 are summarized in Table 3-13. The tabulated range of values for gradient direction in Table 3-13 has the following limitations:

- Excludes eccentric elements
- Excludes elements with limited temporal coverage
- Does not reflect complete reversal that occurred at some wells primarily in response to groundwater pump-and-treat operations at nearby wells and in response to the changes in the Columbia River stage

Table 3-13. Typical Hydraulic Gradients and Groundwater Velocities for 2011

Area	Typical Hydraulic Gradient Magnitude	Typical Flow Direction (Azimuth)	Hydraulic Conductivity in Corresponding Formation (cm/sec)	Groundwater Flow Velocity in Corresponding Formation (cm/sec)
1	0.001 - 0.005	223 - 358	2.31×10^{-4}	1.29×10^{-6} - 6.43×10^{-5}
2	0.0008 - 0.003	23 - 106	6.94×10^{-4}	3.09×10^{-6} - 1.16×10^{-5}

3.7.2.2 Vertical Gradients

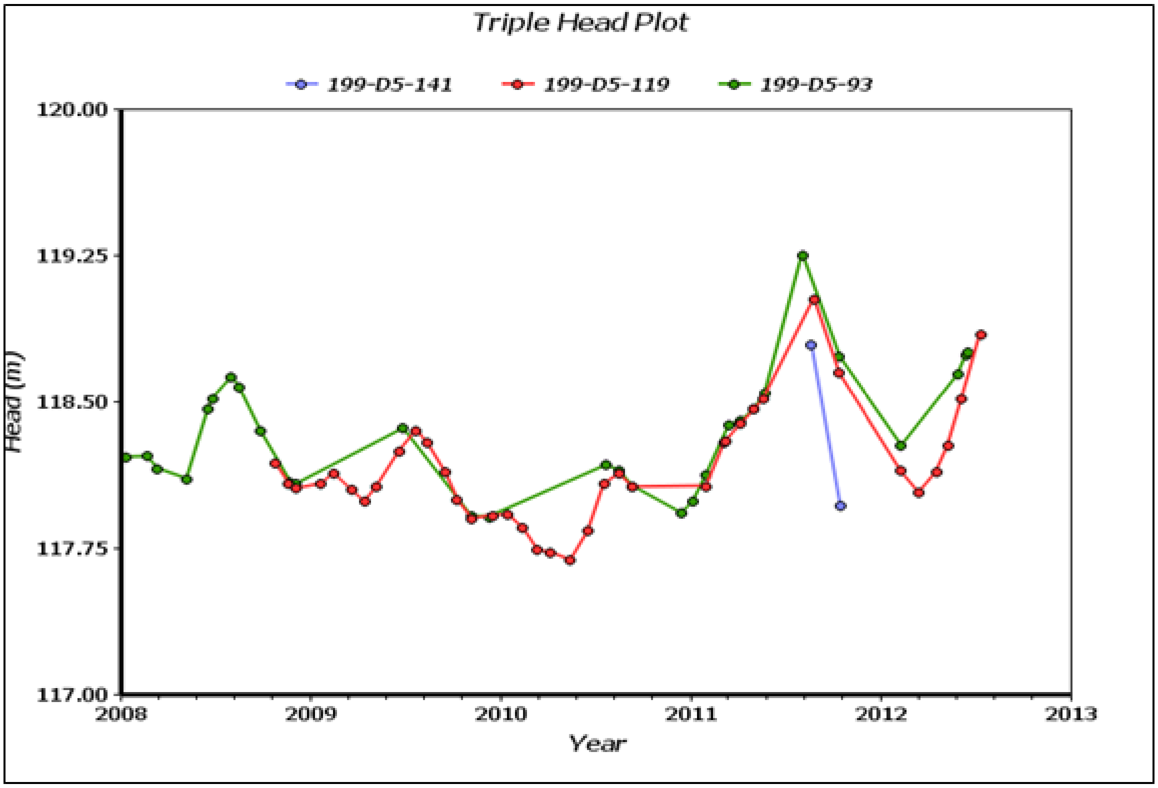
Four factors influence the evaluation of vertical hydraulic gradients across 100-D/H, making a detailed evaluation of vertical hydraulic gradients difficult:

- Throughout much of 100-D/H, the thickness of the unconfined aquifer is quite small, ranging from 2 to 3 m (6.6 to 9.9 ft) in areas of 100-H and the Horn, up to about 8 to 10 m (26.2 to 32.8 ft) in areas of 100-D.
- The current monitoring well network consists mainly of wells screened within the Ringold Formation unit E within 100-D and in the Hanford formation in 100-H and most of the Horn. Although screened intervals vary between wells, the screened intervals of neighboring wells often overlap because of the desire to monitor certain intervals within the aquifer.
- Natural stresses, such as recharge, that would result in significant vertical gradients are limited, except close to the Columbia River where three-dimensional flow occurs in response to stage-driven recharge-discharge cycles.
- Operation of the extensive pump-and-treat extraction and injection wells, which by design, generates vertically and horizontally convergent/divergent flow, and overwhelms ambient vertical gradient patterns.

During the RI, groundwater levels were measured in boreholes drilled to the lower water-bearing units (199-D5-134, 199-D5-141, 199-H2-1, 199-H3-9, and 199-H3-10) to supplement the existing dataset. In addition, static potentiometric groundwater surface levels were measured in completed wells, which were all screened in the first water-bearing unit of the RUM. Water levels were collected during drilling and subsequently collected from the completed well.

At 100-D, there are three wells completed in the first water-bearing unit of the RUM. These are 199-D5-134, 199-D5-141, and 199-D8-54B. Of these wells, only Well 199-D8-54B was installed as a nested well pair with its sister Well 199-D8-54A, which is completed in the unconfined aquifer. Initial evaluation of the water levels during drilling for the RI wells indicates the potential for a slight upward gradient in both 199-D5-134 and 199-D5-141. However, water level information collected during drilling can be misleading because raising and lowering of drill casing during drilling activities can open up or seal off various water bearing units. A more reliable evaluation can only be conducted following well completion and development.

Both RI wells at 100-D have had a minimal number (one to two) of water level measurements taken since the well was completed and developed. RI Well 199-D5-134 is located near both extraction and injection wells, which influence the water table. Cross gradient Well 199-D5-131 is currently an extraction well, and cross gradient Well 199-D5-42 is an injection well. As shown in Figure 3-25 top, the water levels at Well 199-D5-134 track closely to the nearest downgradient Well 199-D5-13.



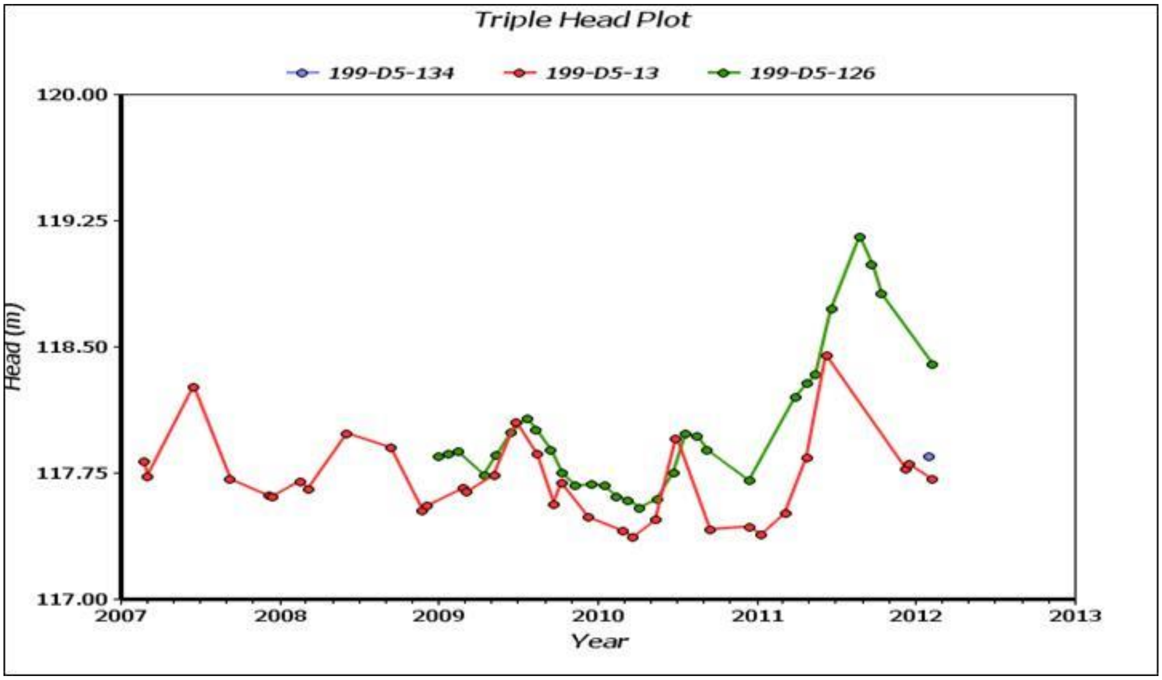


Figure 3-25. Comparison of Piezometric Head Observed in Selected Wells Completed Within the Shallow Unconfined Aquifer and the Uppermost Water-Bearing Unit of the RUM at 100-D

Nearby Well 199-D5-126 also tracked closely with that well until mid-2010, which correlates with the startup of the DX pump-and-treat system, indicating that this well is being influenced by that system. At Well 199-D5-141, water levels in the nearby Wells 199-D5-119 and 199-D5-93 both track closely with the RI well (Figure 3-25; bottom). While this interpretation is based on limited data, it suggests that the vertical gradient between the first water-bearing unit of the RUM (as exhibited in Well 199-D5-93) and the unconfined aquifer at Well 199-D5-134 is near zero, with a slightly downward vertical gradient at Well 199-D5-141.

Only one well pair is present at 100-D. These are Wells 199-D8-54A and 199-D8-54B. Typically, well pairs are constructed close together and provide excellent information when evaluating the vertical gradient between aquifers. As shown in Figure 3-26, water levels in these two wells are essentially identical, with the head difference being consistently lower by 0.01 to 0.35 m (0.03 to 1.2 ft) in the unconfined aquifer as compared to the RUM. This indicates that there is a small, but consistently upward, gradient between the unconfined aquifer and the first water-bearing unit of the RUM. None of the wells at 100-D were screened in the lower water-bearing units, since contamination was not found in these lower units, therefore the vertical hydraulic gradient associated with those lower units cannot be determined. A discussion on the contaminant concentrations found in the lower water bearing units is included in Section 4.5.2 Vertical Distribution of Contaminants.

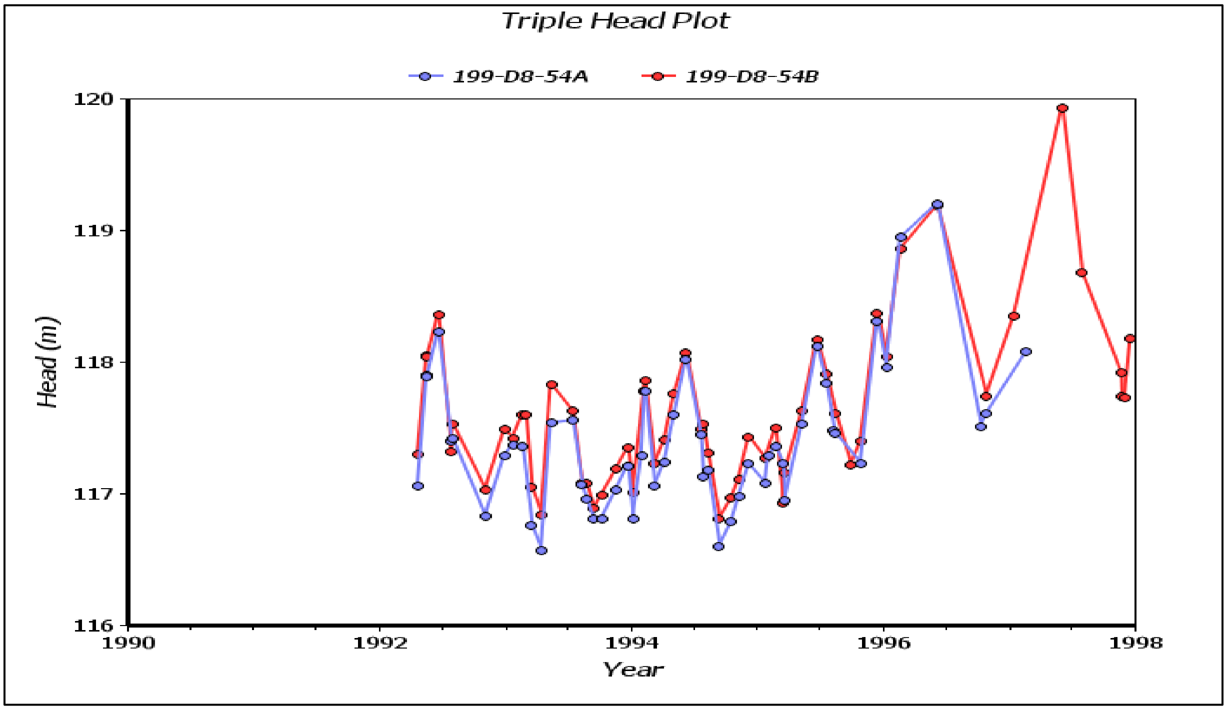


Figure 3-26. Comparison of Piezometric Head Observed in Selected Wells Completed Within the Shallow Unconfined Aquifer and the Uppermost Water-Bearing Unit of the RUM at 100-D

At 100-H, there are six wells that are screened within the first water-bearing unit of the RUM. Three of the older RUM wells are paired with wells screened within the unconfined aquifer, as shown in Table 3-14. Since Wells 199-H3-2C and 199-H4-12C are currently being used as extraction wells, current data from those well sets are not suitable for evaluation of the vertical hydraulic gradient and older information must be used.

Table 3-14. Paired Wells at 100-H Area Completed Within the Shallow Unconfined Aquifer and the First Water-Bearing Unit of the RUM

Stratigraphic Unit Monitored	Well Pairs		
Screened in unconfined aquifer	199-H3-2A 199-H3-2B	199-H4-12A 199-H4-12B	199-H4-15A 199-H4-15B
Screened in first water-bearing unit of the Ringold Formation upper mud	199-H3-2C (extraction well)	199-H4-12C (extraction well)	199-H4-15CS

Figure 3-27 shows the water levels for the H-River Gauge along with Wells 199-H4-12A and 199-H4-12C, which are located adjacent to the Columbia River. Before connection of the pump-and-treat system, water levels in both wells tracked closely with the river stage changes. Well 199-H4-12A, however, has considerably lower hydraulic head than either the river or Well 199-H4-12C, which is completed in the RUM. This indicates an upward vertical gradient in this area, opposite of that found inland. It should also be noted that the RUM well hydraulic head falls in the mid-range of the river gauge measurements, with apparently instantaneous response to river stage change. This indicates a hydraulic connection between the aquifer in the RUM and the river (discussed further in Section 3.7.4, Section 3.7.6, and Section 4.5.1).

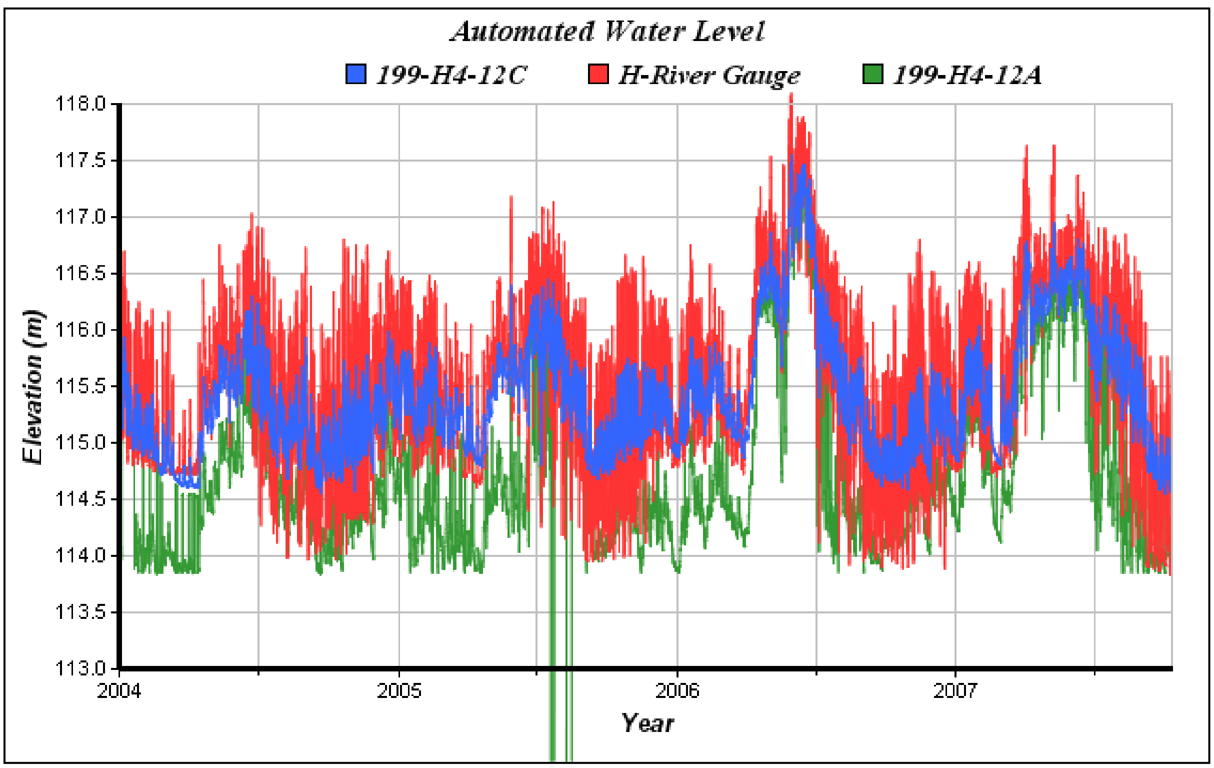


Figure 3-27 Comparison of Piezometric Head Observed in Selected Wells Completed Within the Shallow Unconfined Aquifer and the Uppermost Water-Bearing Unit of the RUM at 100-H

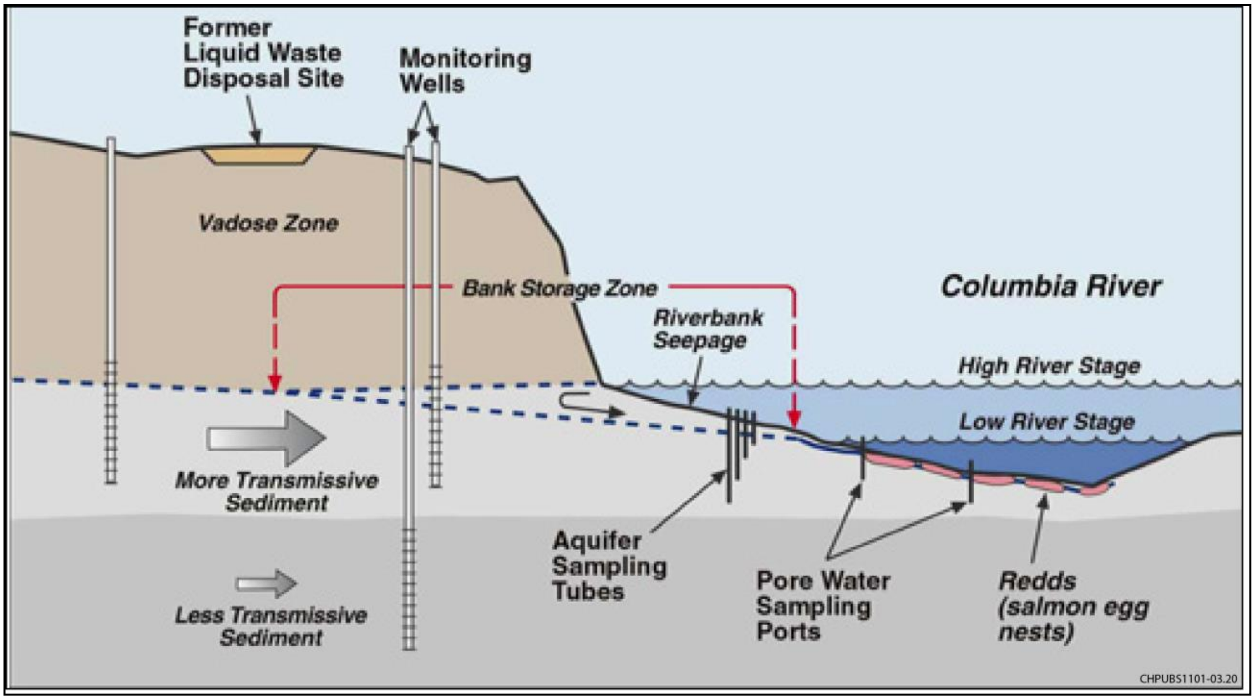
RI Wells 199-H3-9, 199-H3-10, and 199-H2-1 were not nested with adjacent wells, making evaluation of the vertical gradient difficult. Water level data for these wells is also limited to a single point, which does not allow for trend analysis. In addition, under current conditions, groundwater levels in Wells 199-H3-9 and 199-H3-10 are likely influenced by the extraction pumping at Wells 199-H3-2C and 199-H4-12C, which are screened in the first water-bearing unit of the RUM. The hydraulic head differences of Wells 199-H4-15A (unconfined), 199-H4-15B (unconfined), 199-H4-15CS (first water-bearing unit in the RUM), 199-H4-15CR (Ringold unit B), 199-H4-15CQ (water-bearing unit in the RLM), and 199-H4-15CP (basalt unit) are considerable. Hydraulic head of the first water-bearing unit in the RUM is occasionally lower than the head in the unconfined aquifer, but has been as much as 0.5 m (1.6 ft) higher. The well completed in the Ringold unit B (199-H4-15CR) has similar head values to that of the RUM well (199-H4-15CS). Well 199-H4-15CQ, completed in the RLM, has a higher head and therefore upward gradient when compared to the shallower aquifers, but there is considerable variation in the amount of head present. The hydraulic head of the basalt is consistently about 4 m (13 ft) higher than the other wells, indicating a strong upward gradient in the basalt aquifer. The presence of a demonstrable piezometric head difference between aquifer units is not evidence of the movement of groundwater upward or downward between the units. The movement of water in response to the observed head differences is dependent upon the existence of hydraulic conduit that would allow the movement of water. In most instances where substantial piezometric head differences are identified, the sustained pressure differential is indication of the absence of a direct hydraulic communication between the units.

3.7.3 Groundwater and Surface Water Interactions

Groundwater and surface water interactions are important for understanding the flux of contaminants 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 occurs as seeps or springs release groundwater that flows across the riparian zone to the river, and via direct subsurface discharge of groundwater into the river channel substrate. Section 4.5 discusses recent pore water, surface water, and sediment sampling results, and Figure 3-28 illustrates the zone of interaction and riverbank seepage.

Groundwater flow, especially near the river, is strongly influenced by river stage, which varies seasonally and is directly controlled by the upstream Priest Rapids Dam. The rise and fall of river stage creates a dynamic zone of interaction between groundwater and river water; river stage influences 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 (for example, changes in gradient and physical mixing of river water with groundwater) are the primary influences on contaminant concentrations and fluxes where groundwater discharges into the river. Chemical processes (for example, precipitation reactions involving varying concentrations of calcium carbonate, pH, or reduction-oxidation conditions) may render contaminants less mobile as they adsorb to sediments, more mobile as they desorb from sediment under specific conditions or precipitate out of solution.



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 3-28. Zone of Interaction and River Bank Seepage

Riverbank seepage to the river, as shown on Figure 3-28, is visible as the river stage declines following seasonal periods of high water. Conversely, during high river stage, these seep areas are submerged as river water enters the riverbanks and forms a layered system or a mixture during interaction with approaching groundwater. Data concerning the seeps and the riverbank indicate that the riverbank storage water composition varies 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]). A cross-sectional depiction of groundwater flow towards the river is presented in Figure 3-28 and Figure 3-29. Figure 3-29 presents actual water table relationship at 100-D relative to the elevation of the Columbia River.

Along the 100 Area, 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* [PNL-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]).

3.7.4 Aquifer Intercommunication

Aquifer intercommunication occurs when groundwater moves vertically between aquifers, such as the unconfined aquifer and first water-bearing unit of the RUM, or between the first water-bearing unit of the RUM and lower water-bearing units.

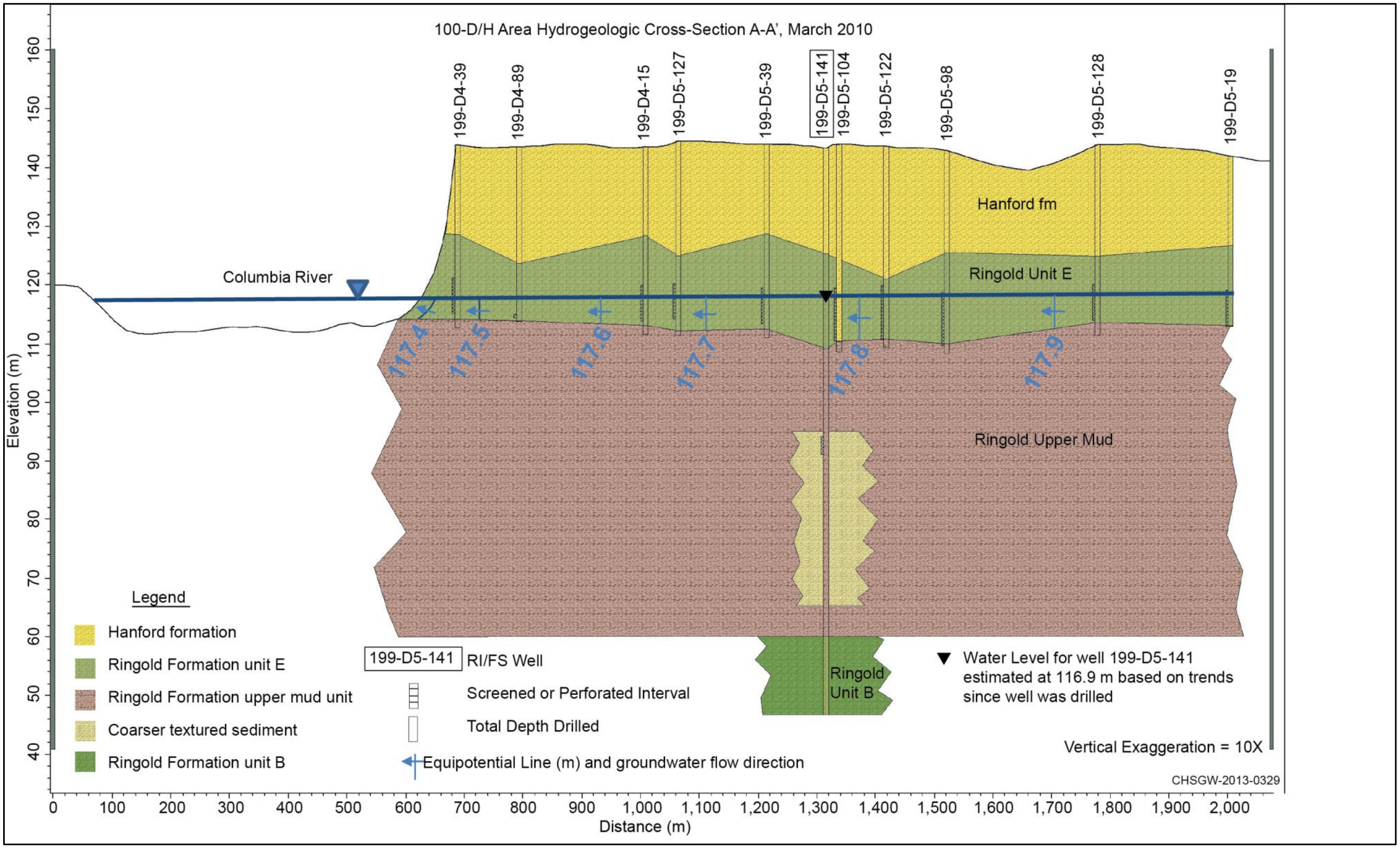


Figure 3-29. Groundwater Equipotential Lines and Streamflow Lines at 100-D

For groundwater movement to occur between aquifers, a difference in each aquifer's potentiometric head must exist and a permeable flow path must exist between the two through which water can flow. Intercommunication between aquifers can occur by one mechanism or a combination of several mechanisms:

- Natural vertical head differences between aquifers push water through the intervening aquitard.
- Differences in head resulting from anthropogenic activities provide a driving force that pushes 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 shallow water-bearing sands to the unconfined aquifer).
- Erosional unconformities are considered the most likely significant mechanism for direct physical interconnection between the unconfined aquifer and water-bearing units within the upper RUM.
- The potential for pathways along poorly constructed wells or boreholes also exists; however, older wells suspected of having poor construction have been decommissioned.

Although vertical head differences offer one line of evidence of intercommunication between aquifer (and aquitard) units, another line of evidence is groundwater quality data. The presence of groundwater contaminants in underlying units provides evidence of communication with overlying units. The aquifer interconnections at 100-D have not been evaluated primarily because contamination has not been identified in the lower aquifers.

At 100-H, wells completed in the first water-bearing unit of the RUM currently exhibit concentrations of Cr(VI) at levels above 100 µg/L (see Section 4.5.1). These data indicate that in the past, most likely under operational conditions when vertical head gradients were elevated, aquifer intercommunication occurred. This aquifer intercommunication is indicated by the close similarity in measured piezometric heads in Wells 199-H3-2A, 199-H3-2B, and 199-H3-2C in years before initiating pump-and-treat activities at 100-H (Figure 3-30). The measured heads in these three wells from 1986 to 1997 were nearly identical and exhibited seasonal transients of the same timing and magnitude. This condition indicates that these aquifer units are not hydraulically isolated, and there continues to be either intercommunication between the wells or between individual wells and the river. As part of *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* (SGW-47776), aquifer intercommunication was tested at groundwater monitoring Wells 199-H3-2C, 199-H4-12C, and Piezometer 199-H4-15CS. Both step tests and constant-rate pumping tests were conducted and nearby wells were monitored for response. During the constant rate pump test of Well 199-H3-2C, the unconfined aquifer was found to exhibit characteristics of a leaky aquifer, with groundwater levels in adjacent wells showing drawdown in response to pumping of the first water-bearing unit in the RUM (Figure 3-31). This is further supported by the almost immediate rising of groundwater levels in these wells after the pump was turned off. The lithologic description in the borehole log suggests that the shallow portion of the RUM unit at Well 199-H3-2C contains a greater percentage of sand, which is the likely cause of the hydraulic connection. This indicates intercommunication between the unconfined aquifer and the first water-bearing unit of the RUM at the nested well set 199-H3-2A, 199-H3-2B, and 199-H3-2C.

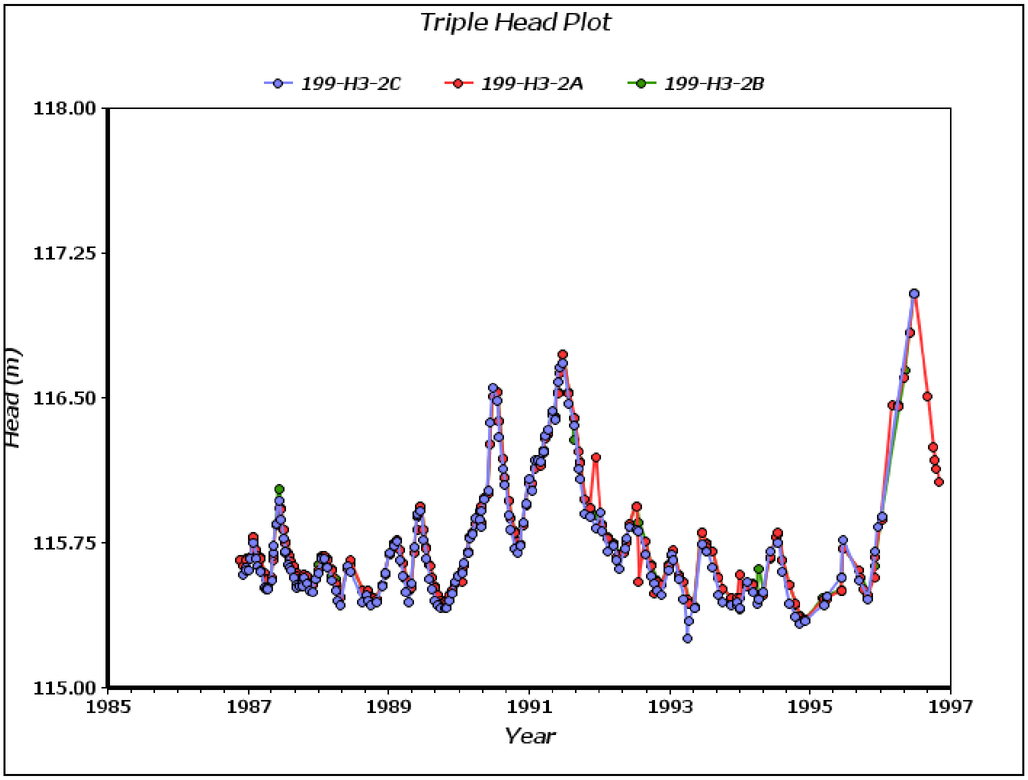


Figure 3-30. Piezometric Head Trends in Three Paired Wells at 100-H

The pump test also shows a response to river stage in RUM Well 199-H4-12C and Piezometer 199-H4-15CS, indicating communication with the Columbia River. The communication to the river is also discussed in Section 3.7.2, Section 3.7.6, and Section 4.5.1. The associated nested wells, however, did not indicate intercommunication between the unconfined aquifer and the RUM at those locations during testing. To confirm that the response was not related to leakage of the bentonite seal between the screened zones, the nested well completion of Well 199-H4-15 was evaluated in *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* (SGW-47776). The data from the nested wells (199-H4-15A, 199-H4-15CS, 199-H4-15CP, 199-H4-15CQ, and 199-H4-15CR) showed no evidence that the pumping well boreholes were acting as conduits for the exchange of groundwater between different water-bearing zones, which had previously been a concern.

An evaluation of the differences in hydraulic head (Section 3.7.2) indicates that the lower aquifer does not consistently have an upward vertical gradient, but can exhibit different gradients at different locations. This is due to the heterogeneity of the aquifer material and the overlying mud unit. As a result, wells screened in the first water-bearing unit of the RUM have nearly the same water table elevation as the wells in the unconfined aquifer in completed wells, with only slight differences. A head difference is present in Well 199-H4-12C as compared to 199-H4-12A; but not evident at Well 199-H3-2C as compared to 199-H3-2A, as discussed previously.

Upward gradients will respond to increased downward pressure such as the increased hydraulic pressure created during reactor operations that resulted in a groundwater mound in both 100-D and 100-H, and may be reversed under such operational conditions. Evidence for these overwhelming conditions includes the river response in RUM wells and the thermal response noted during reactor operation. During reactor operations, thermal springs at the edge of the Columbia River at 100-H were measured with temperatures up to 74°C (165°F) (*Status of the Ground Water Beneath Hanford Reactor Areas January, 1962 to January, 1963* [HW-77170]).

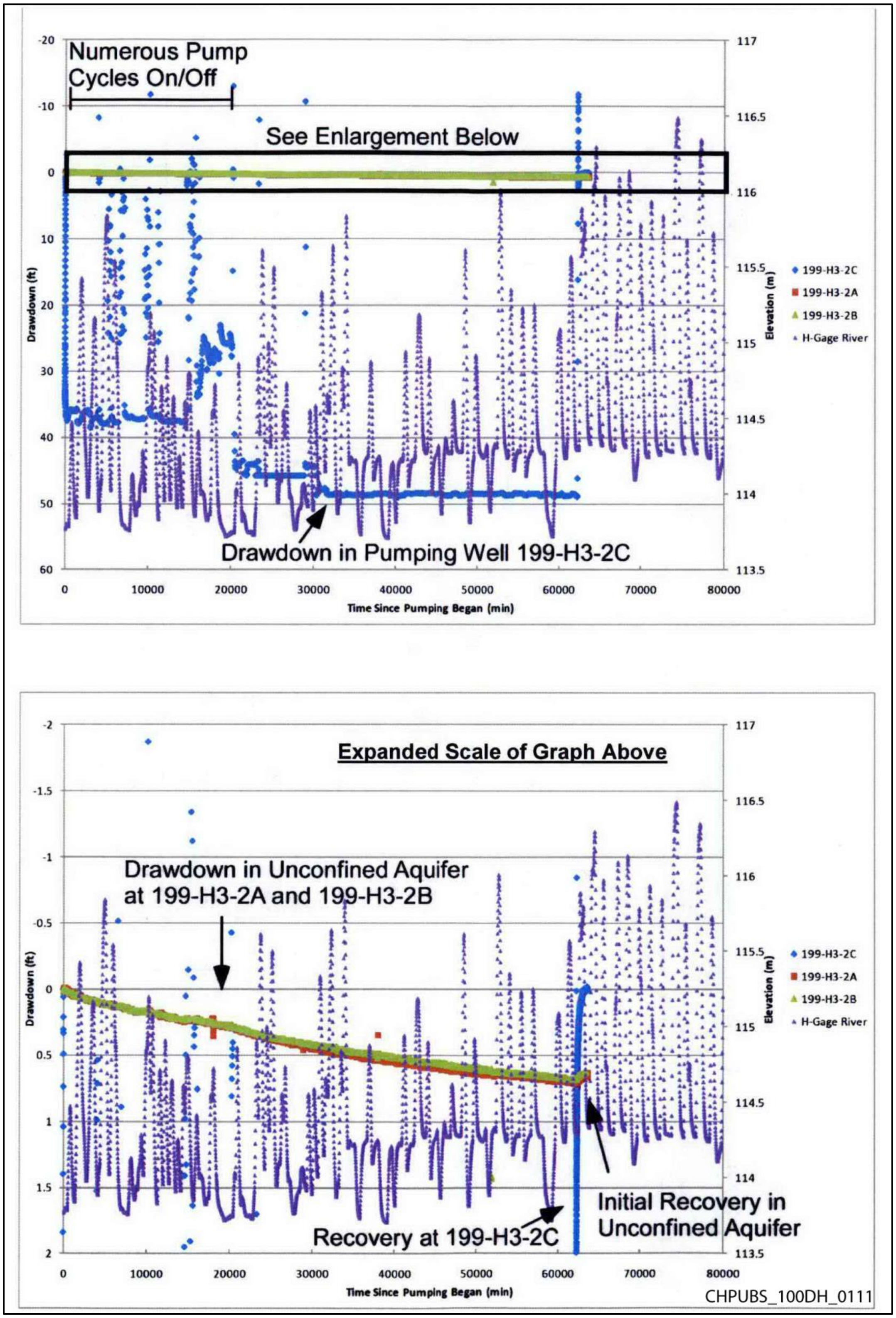


Figure 3-31. Hydrographs for Constant Rate Pump Test at Well 199-H3-2C

Further evidence of a hydraulic connection between the unconfined aquifer and first water-bearing unit in the RUM at a localized area of 100-H includes the results of a comparison of the geochemistry of groundwater from the unconfined aquifer, first water-bearing unit in the RUM, and river water. First, analysis of groundwater geochemistry from the first water-bearing unit in the RUM (Section 3.7.6) indicates that groundwater from RUM wells near the river have a chemical signature similar to that of river water. Second, the chemical signature of groundwater from RUM Well 199-H3-2C is similar to groundwater from nested Wells 199-H3-2A and 199-H3-2B, which are completed in the unconfined aquifer. Third, in addition to having similar chemical signatures between groundwater and river water, the ability of Well 199-H4-12C to sustain about 38 L/min (10 gal/min) pumping provides further supporting evidence that the RUM aquifer is drawing water from another source, such as the river or other aquifers.

3.7.5 Additional Effects to the Groundwater Flow Regime

The current interim remedies for 100-HR-3 OU groundwater contaminated with Cr(VI) consist of in situ chemical treatment and pump-and-treat. These interim remedies are intended to prevent Cr(VI) from reaching the Columbia River at concentrations exceeding the State of Washington Surface Water Quality Standard of 10 µg/L. These remedial systems (discussed in Chapter 1) have a significant effect on the groundwater flow regime in the 100-HR-3 OU.

The updated remediation systems will drastically alter hydraulic gradients and flow in the unconfined aquifer beneath 100-D/H. The 100-DX/HX system is designed to effectively capture and treat Cr(VI)-contaminated groundwater before it enters the Columbia River at concentrations exceeding the State Surface Water Quality Standard. This system will continue to evolve as extraction and injection wells are turned on and off to account for seasonal river stage variations and plume configuration changes.

Another aspect of soil remedial activities potentially affecting groundwater is dust control. During remedial action, it is important to control fugitive dust (and the contamination it may contain). Water is applied to control airborne dust on haul roads, at excavation sites, and at soil stockpiles. If the water volume applied exceeds the holding capacity of vadose zone soil, it could move deeper into the vadose zone and eventually serve as a source of groundwater recharge. As a result, water is applied only to the extent needed to control dust to meet worker protection needs, and mitigate airborne contamination concerns for that day’s planned excavation activities.

3.7.6 Groundwater Geochemistry

Groundwater data were evaluated for the distribution of the major ions in various wells within 100-D/H. The major ions evaluated include the common positively charged cations [calcium (Ca^{+2}), sodium (Na^{+}), potassium (K^{+}), and magnesium (Mg^{+2})] and the common negatively charged anions [chloride (Cl^{-}), sulfate (SO_4^{-2}), carbonate (CO_3^{-2}) and bicarbonate (HCO_3^{-})]. The relative equivalent concentrations of these ions were compared in wells with different geology, various levels of contamination, and the water of the Columbia River. To compare the concentrations of the ions, laboratory analytical results are collected. The concentrations are then converted from micrograms per liter or milligrams per liter into the milliequivalents per liter of the ion, based on its atomic weight.

The equivalent ionic concentrations vary greatly across 100-D/H (Appendix M), but when the distribution is plotted as a graphic diagram, patterns develop. Radial plot diagrams showing relative ion concentrations for various wells, based on the data in Table M-6 (Appendix M), and for the Columbia River, are presented on Figures 3-30 and 3-31. Groundwater monitoring wells were evaluated from various geologic units and locations at 100-D (Figure 3-32), across the Horn (Figure 3-33), and from 100-H (Figure 3-33).

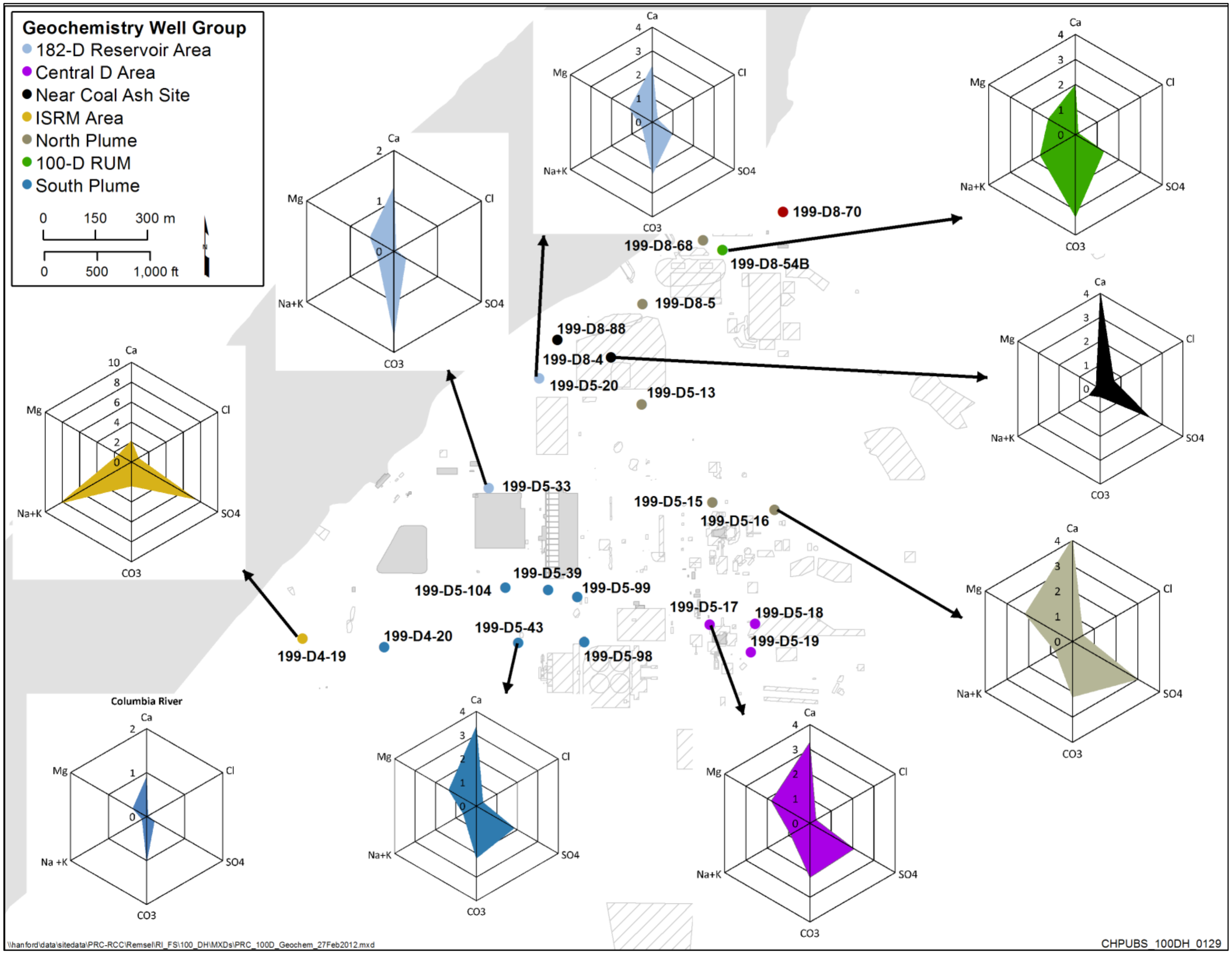


Figure 3-32. Major Ion Chemistry of 100-D Groundwater

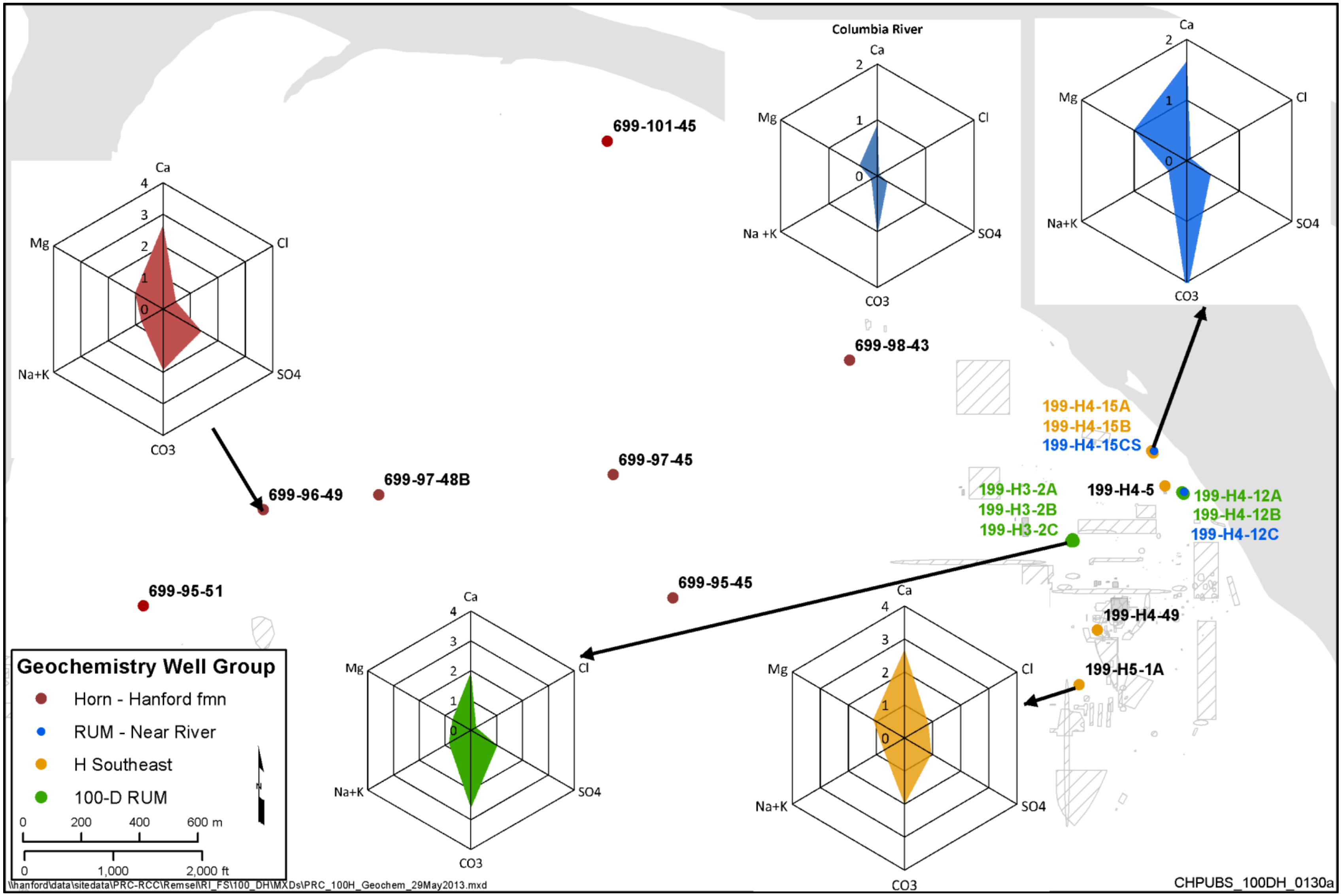


Figure 3-33. Major Ion Chemistry of 100-H and Horn Groundwater

Not all wells had adequate data for conducting a geochemical analysis; however, based on the available data, several groups with a similar chemistry, ion pattern, or distribution emerged during the evaluation. At 100-D/H, the primary patterns correlate with the geologic unit in which the well is completed. There are differences between wells completed in the Hanford formation, those completed in the Ringold Formation unit E, and those completed in the RUM or lower Ringold Formation units that are apparent in the chemical pattern moving west to east across the Horn. The other controlling factors are the contaminant levels and various sources.

Groundwater monitoring wells with similar geochemical signatures are shown in Figures 3-32 and 3-33 with similar colored dots. A detailed description of the geochemistry similarities and the data used to develop the radial plot diagrams are included in Appendix M.

Wells in 100-D are generally completed and screened within the Ringold Formation unit E, and the geochemical signature is similar in most wells within that formation. Slight variations in the pattern are evident in areas with higher levels of Cr(VI), with slightly higher levels of magnesium, sodium, and potassium changing the pattern in the Stiff diagram. At Well 199-D5-33, the geochemical pattern is most similar to that found in river water. This is likely due to some continued leakage of the 182-D Reservoir, which holds raw river water.

Other areas with variation include the ISRM barrier, as seen in Well 199-D4-19. The reducing agent used in the barrier consists of sodium dithionite ($Na_2S_2O_4$). As expected, the sodium and sulfate levels in the groundwater at the ISRM well are much higher than levels in other wells within 100-D/H. This pattern indicates the continued presence of reaction products from the placement of the ISRM barrier.

Also in 100-D is waste site 126-D-1 Coal Ash Pit. The relatively high calcium and sulfate concentrations exhibited in Well 199-D8-4 are consistent with effects from deposition of fly and bottom ash, as well as flue-gas desulfurization residues. Flue gas desulfurization residue consists primarily of gypsum (calcium sulfate) and is frequently combined with fly ash. The chemical distribution found in flue gas desulfurization is consistent with the geochemical pattern identified in the wells downgradient from waste site 126-D-1, including Wells 199-D8-88 and 199-D8-4. No metals were identified in association with these wells, with the exception of a reported value of 60 µg/L of zinc in Well 199-D8-4, which is lower than the ambient water quality criterion of 91 µg/L but higher than typical concentrations in that well.

North of 100-D toward the Horn are Wells 199-D8-70 and 699-95-51. The chemical signature in these wells is less distinct. The wells in the northern 100-D/Horn transitional area have lower levels of carbonate than in other areas. Well 699-101-45, located to the far north of the Horn, is also considered transitional and has the same pattern. The higher levels of sodium plus potassium in these wells are consistent throughout the Horn and are coupled with lower magnesium levels than those found in 100-D. The wells in the Horn also tend to have lower chloride levels than wells in 100-H, which are associated with the Hanford formation.

Wells completed in the Hanford formation at 100-H have a similar chemical pattern. The concentrations of magnesium, chloride, and sodium plus potassium give the Stiff diagram a distinct shape, as represented by Well 199-H4-49 on Figure 3-33.

Well 199-D8-54B shows a significantly different geochemical pattern than other wells at 100-D. This well is completed in the first water-bearing unit of the RUM; therefore, the groundwater chemistry reflects the chemistry within that aquifer. As shown in the other RUM wells within 100-H and the Horn, most of the wells completed in this aquifer have a similar pattern, with much higher carbonate, sodium, and potassium levels. However, Well 199-D8-54B is unexpectedly similar in chemical pattern to a group of nested wells (199-H3-2A, 199-H3-B, and 199-H3-C). It is also similar to nested Wells 199-H4-12A and 199-H4-12B, which are completed in the Hanford formation. However, the RUM Well 199-H4-12C has a different signature. It is undetermined why wells with such different geology would present such similar patterns in groundwater chemistry.

Three sets of nested wells are in 100-H. The nested wells consist of at least three wells or piezometers completed in multiple aquifers and within a few feet of each other. The nested groups are 199-H3-2, 199-H4-12, and 199-H4-15. Wells with the suffix of "A" and "B" are completed in the unconfined aquifer at 100-H. Wells 199-H3-2C, 199-H4-12C, and 199-H4-15CS are completed in the RUM. The remaining piezometers associated with 199-H4-15 are completed in the Ringold Formation unit B (-15CQ), the RLM (-15CR), and the basalt (-15CP) units, which all have distinct geochemistry.

Monitoring Wells 199-H3-2A, 199-H3-2B, 199- H3-2C, 199-H4-12A, and 199-H4-12B have a similar chemical pattern. The consistency of the chemical pattern is expected for the "A" and "B" wells because they are completed in the same geologic unit. The deep well, 199-H3-2C, was completed in the RUM. Monitoring Well 199-H3-2C was shown to be connected to the overlying unconfined aquifer wells (199-H3-2A and 199-H3-2B) during the aquifer rebound test (*Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* [SGW-47776]).

The other two RUM well/piezometers at 100-H (199-H4-12C and 199-H4-15CS) are near the Columbia River. Both of these wells have a geochemistry that is similar to river water, and different from the chemistry found in the associated nested wells. The water levels in these wells also respond to changes in river stage (*Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* [SGW-47776]). The observation of similar geochemistry supports the theory that the RUM is hydrologically connected to the river in that location. It also supports the theory that the RUM wells near the river are not connected to the inland RUM wells.

3.7.7 Time Series Evaluation

The geochemistry of four wells was also evaluated over a time series with data from 1988 through 2010: 199-D4-15 (southern 100-D), 199-D5-14 (northern 100-D), 199-H4-48 (central 100-H), and 199-H4-6 (northern 100-H). These wells were chosen for time series evaluation based on their geographic location and the availability of sufficient data to produce stiff diagrams, while providing data from a variety of geologic formations, site conditions (such as the ISRM barrier), and a spatial distribution. Time periods used for the evaluation were limited to those periods when data were analyzed for a specific well. Stiff diagrams for each well over time, with the corresponding Cr(VI) concentrations are presented in Figures 3-34 and 3-35.

The wells in 100-D showed no significant change over time, with geochemical patterns consistent with other wells in the geographic area. Some slight changes were present in 100-D area wells in the sulfate, calcium, and magnesium levels; however, these were relatively stable over time. Well 199-D5-14 had the greatest change at 100-D (Figure 3-32) from 1992 and 2003, however no apparent correlation to Cr(VI) concentrations was possible due to lack of data during that timeframe.

In 100-H, Well 199-H4-48 had little change from 1999 through 2010 (Figure 3-35). The pattern for 1992 had very little chloride in the geochemical signature, which is quite different from the pattern in all of the later years. This change corresponds with a drop in Cr(VI) concentrations from 150 µg/L in 1996 to 20 µg/L in 1999 in Well 199-H4-48.

The other well in 100-H that was evaluated over time is 199-H4-6 (Figure 3-35). Well 199-H4-6 showed little change over time, with small fluctuations of sulfate from 1988 through 1996. In 2010, the chloride levels in 199-H4-6 increased, thus changing the pattern, but there was no apparent corresponding change in Cr(VI) levels, and the cause of this fluctuation has not been determined.

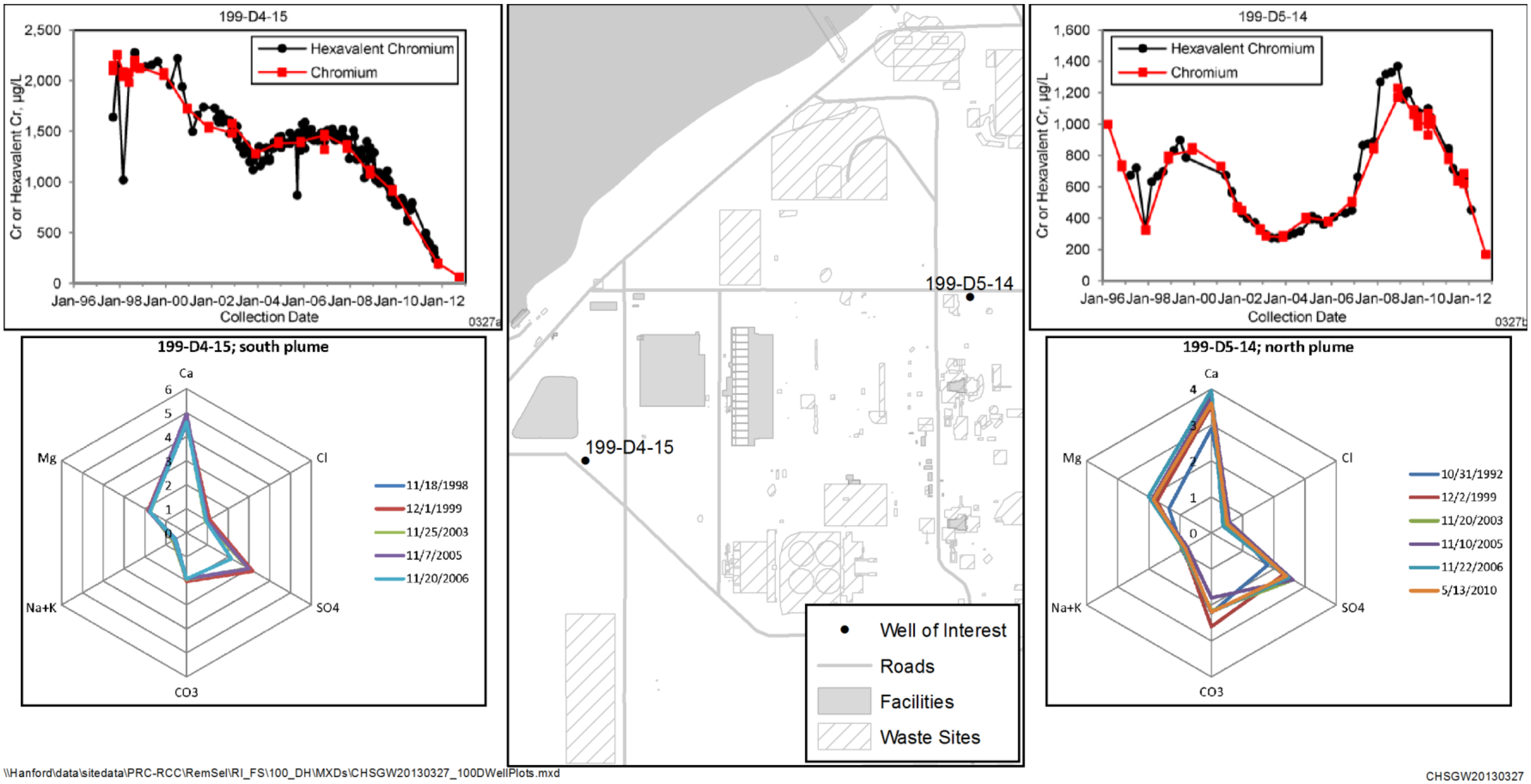


Figure 3-34. Stiff Diagrams and Cr(VI) Concentrations over Time for Select Wells in 100-D

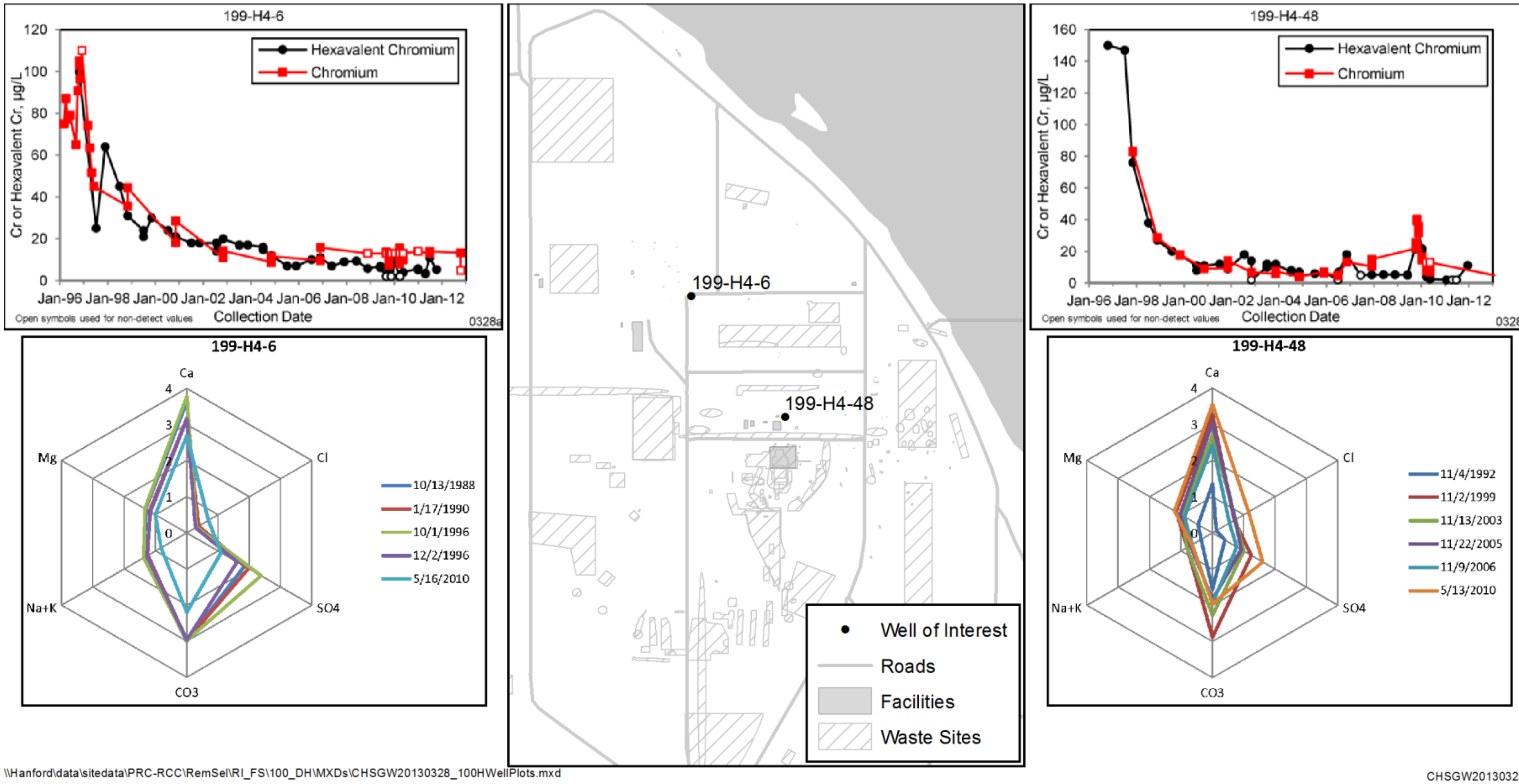


Figure 3-35. Stiff Diagrams and Cr(VI) Concentrations over Time for Select Wells in 100-H

Review of geochemical data suggests the following:

- Groundwater chemistry at the ISRM barrier (Well 199-D4-19) has been altered, showing high sulfate levels.
- Groundwater downgradient of the coal ash pit is consistent with the chemistry of fly ash; however, no other contamination has been linked to it.
- It is likely that the 182-D Reservoir continues to leak, affecting the groundwater. This is supported by the chemistry of Well 199-D5-33 and other nearby wells, which is similar to that of River water (Figure 3-32).
- RUM Well 199-H3-2C is hydrologically connected to the overlying unconfined aquifer.
- RUM wells near the Columbia River at 100-H appear to be hydrologically connected to the Columbia River.
- RUM wells inland at 100-H do not appear to be connected to the river based on the geochemistry (Section 3.7.6), and the results of aquifer tests (Section 3.7.4).

3.8 Artificial Water Systems

This section describes the water systems at 100-D/H that affect the groundwater flow regime.

3.8.1 Export Water System

The Export Water System provides water service within the 100 and 200 Areas of the Hanford Site, as well as certain facilities in the 600 Area (Figure 3-36) for process water, fire protection, dust suppression, and other nonpotable uses. At 100-BC and 100-D, river pumping stations draw raw water from the Columbia River and feed it into two large-capacity reservoirs (182-B and 182-D). In turn, pump stations at the reservoirs move water into a network of pipelines traversing the 100 Area and connecting to moderately sized distribution reservoirs on the Central Plateau. The Export Water System was originally installed in the mid-1940s and has been in constant use for more than 60 years. By 2004, the majority of the water lines in 100-D were removed from service. The only remaining active lines are the 1.1 m (3.5 ft) diameter export water line and one 0.3 m (1 ft) diameter fire suppression water line.

The 182-D Reservoir is one of two remaining structures at the Hanford Site that stores large quantities of untreated raw water. Chapter 2 discusses the current plans for the 182-D Reservoir and export water lines. Currently, the 182-D Reservoir serves two roles:

- Rarely needed emergency backup facility to the primary reservoir in 100-BC
- Source of water operated during 242-A Evaporator campaigns to reduce waste volumes in the single- and double-shell tanks in the 200 Area

Leaks from the 182-D Reservoir occurred chronically from the beginning of reactor operations, potentially influencing the local groundwater flow regime. It has been demonstrated that historically the reservoir may have leaked several hundred gallons per minute. Leakage from the reservoir and export water lines could affect groundwater flow, contaminant mobility, and the effectiveness of groundwater cleanup at 100-D. Low specific conductance readings in groundwater and historically elevated groundwater levels in monitoring wells near the reservoir confirm that significant leakage had occurred and was an ongoing, chronic condition.

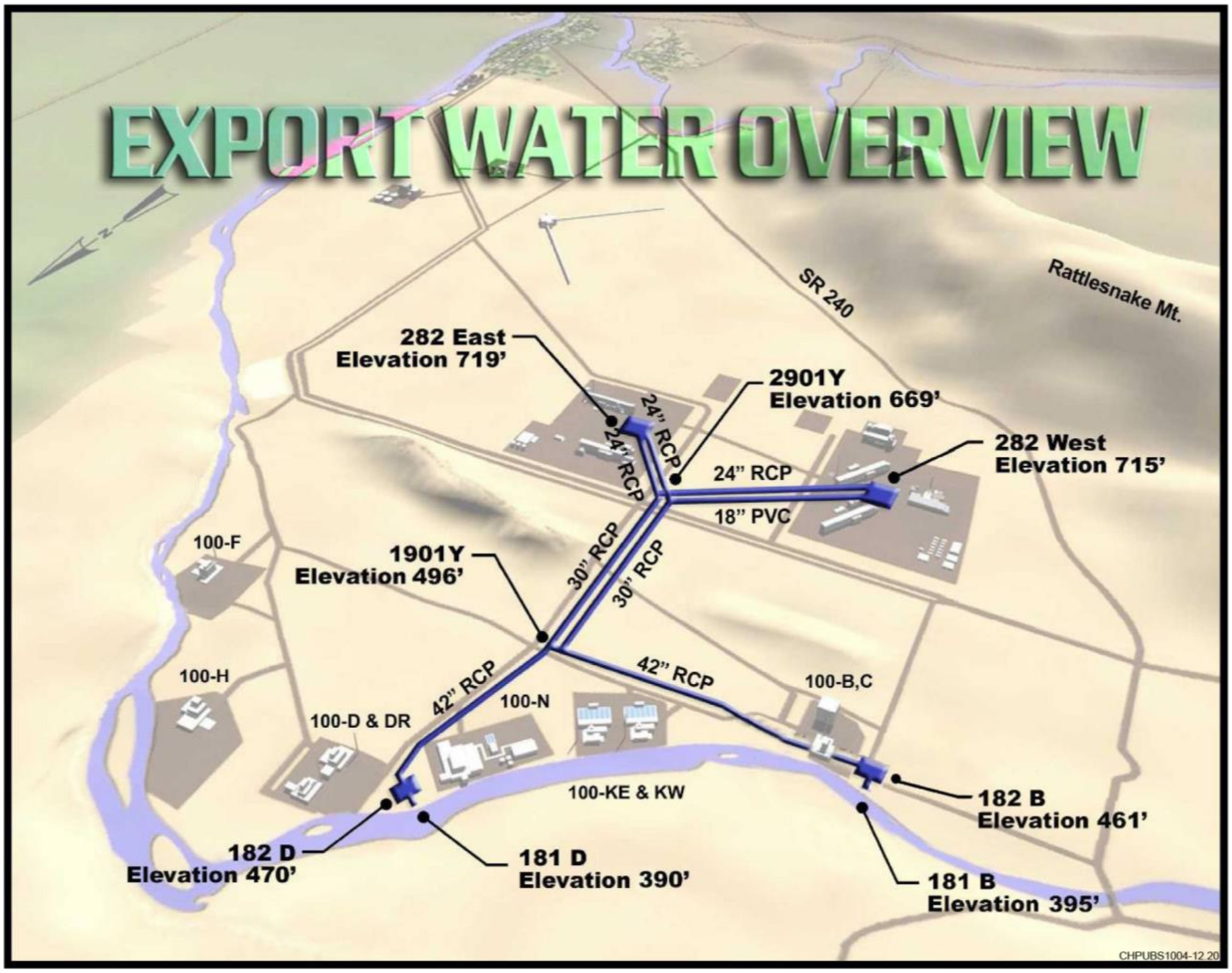


Figure 3-36. Export Water Distribution Piping

Until 2004, the 182-D Reservoir chronically leaked enough to sustain a local water table mound that created a "clean zone" between the northern and southern plumes in 100-D (see Chapter 4). This mound appears to have diverted groundwater flow north and south of the 182-D Reservoir, with corresponding diversion and local dilution of contaminants in groundwater. However, these leaks and their effect on groundwater flow have diminished since the reduction of storage volume in the reservoir in 2004 (from 95 million L [25 million gal] to 19 million L [5 million gal]) (Water System Master Plan [HNF-5828]). The current level of leakage has localized influences on groundwater flow which are partially masked by flow changes created by nearby pump-and-treat activities (*Calendar Year 2010 Annual Summary Report for the 100-HR-3and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater Remediation* [DOE/RL-2011-25]).

Monitoring of water levels in the reservoir and groundwater levels in nearby monitoring wells (199-D5-33, 199-D5-38, and 199-D5-34) is conducted automatically via pressure transducers to coordinate reduced operation consistent with the Water System Master Plan (HNF-5828).

In response to the reservoir leakage information, a specific issue (Issue 10) was included in *The Second CERCLA Five-Year Review Report for the Hanford Site* (DOE/RL-2006-20) for DOE to provide direction to its operating contractor to conduct changes to the operation of the reservoir to minimize leakage.

Those actions were completed and documented in the closeout of the Five-Year Review issue. Specific actions implemented include the following:

- The 182-B Reservoir is designated as the primary export water source for the Hanford Site and is used for emergency backup (maintained in a standby configuration).
- The original design water level for the 182-D Reservoir was a depth of 4.6 m (15 ft) with 0.3 m (1 ft) of freeboard; however, while in standby operations, the water levels within the182-D Reservoir have been reduced via operating controls over the past 7 years using a graded approach. Water levels are now maintained at depths of 0.3 to 0.9 m (1 to 3 ft).
- During emergency operations, the water levels within the 182-D Reservoir are allowed to rise from 0.6 to 1.8 m (2 and 6 ft).
- Flow from the 182-D Reservoir is required infrequently for emergency operation, most recently to support 242-A Evaporation operations during a pump maintenance shutdown at the 182-B Reservoir.
- The floor of the reservoir was cleaned and caulked.

DOE recently evaluated various options for the Export Water System, including whether the 182-D Reservoir was necessary to support the continued Hanford Site cleanup mission. The Water System Master Plan (HNF-5828) identified the preferred infrastructure solution for the Export Water System and included monitoring requirements for the 182-D Reservoir and export water lines. The Water System Master Plan (HNF-5828) calls for maintaining the present Export Water System for the next 10 years while a new export water system is designed, permitted, and constructed in 100-K. Ultimately all Export Water System-related facilities in 100-D would be demolished. The 182-D Reservoir and pump station will be removed and the area brought to grade with clean fill. In the meantime, monitoring of the 182-D Reservoir will continue, as specified in the Water System Master Plan (HNF-5828).

3.8.2 Reactor Cooling Water Systems

Other facilities that released large quantities of fluid over long periods included the 107-D and 107-DR Retention Basins, the 116-DR-1 and 116-DR-2 Trenches, and the 120-D-1 Ponds. These long-term discharges created groundwater mounds under the discharge facilities that overwhelmed the natural hydraulic gradient for some distance away from the discharge site and had substantial effects on contaminant migration patterns in the unconfined aquifer. A substantial groundwater mound beneath the entire 100-D Area, centered beneath the retention basins, had a maximum observed height of about 5 m (15 ft) above the natural static water table (*100-HR-3 Remedial Process Optimization Modeling Data Package* [SGW-40781]).

These long-term releases created a radial flow regime that was established early in the operations period and sustained until operations ceased. Groundwater mounding dissipated quickly (that is, within weeks or a few months) after reactor operations ceased at DR Reactor (1964) and D Reactor (1967); however, the groundwater mound from the 1967 infiltration test did not fully dissipate until about 1968 or 1969 (as discussed in Section 3.7.1.1 Groundwater Mounding at 100-D).

In 100-H, the opportunities for groundwater mounding that formed from liquid discharges were much less complex. The 116-H-7 (107-H) Retention Basin, held-up spent reactor cooling water before discharged to the river; it leaked chronically throughout the operations period. In addition, contaminated cooling water was discharged from the retention basin to the 116-H-1 Trench and was allowed to infiltrate into the vadose zone. As previously described, a slightly smaller groundwater mound persisted beneath the 100-H Area until cessation of operations in 1965, after which the mound quickly dissipated (see Section 3.7.1.2 Groundwater Mounding at 100-H).

3.8.2.1 Demography and Land Use

Demographics. 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 ethnic minorities. Native American descendants living near the Hanford Site include members of the following federally recognized groups: Confederated Tribes and Bands of the Yakama Nations, Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Nez Perce Tribe, and Confederated Tribes of the Colville Reservation. Members of other unrecognized Tribes, such as the Wanapum, also live in the area. There is no continuous human inhabitation immediately adjacent to 100-D/H.

The economy in the region near the Hanford Site is driven by three major sectors: DOE and its contractors operating the Hanford Site; Energy Northwest, which operates the nuclear-powered Columbia Generating Station on land leased from DOE; 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, tourism, and health care.

Land Use. The Columbia River is a critical resource for the people and ecology of the Pacific Northwest. The 80.5 km (50 mi) stretch of the Columbia River flowing through the Hanford Site is referred to as the Hanford Reach. It is a non-tidal, free-flowing stretch of the Columbia in the United States. 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. As one of the largest rivers in North America, its waters support a multitude of uses that are vital to the economic and environmental well-being of the region. The river is particularly important in sustaining the culture of Native Americans.
The Columbia River downstream of the Hanford Site is the primary source of municipal drinking water for cities of Richland, Pasco, and Kennewick; river water is withdrawn for irrigation at numerous locations below the Hanford Reach.

Land use in the River Corridor is currently controlled by the DOE and the U.S. Fish and Wildlife Service (USFWS), which jointly manage this federally owned land to protect natural and cultural resources while conducting cleanup activities. Such management is consistent with the *Final Hanford Comprehensive Land Use Plan Environmental Impact Statement* (DOE/EIS-0222-F), hereinafter called Hanford CLUP, and *Supplement Analysis: Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE/EIS-0222-SA-01) for the Site, and reflects the requirements of *Hanford Reach National Monument: Final Comprehensive Conservation Plan and Environmental Impact Statement Adams, Benton, Grant and Franklin Counties, Washington* (USFWS, 2008) for the Hanford Reach National Monument. It is both the DOE and the USFWS expectation that this joint management of the Hanford Site will continue for many years into the future and that the property will remain under federal ownership.

Interim RODs for CERCLA cleanup activities in the River Corridor recognized that the reasonably anticipated future land use in the River Corridor had not been well defined. Since that time, DOE has issued the Hanford CLUP (DOE/EIS-0222-F), the Hanford Reach National Monument has been established, and those documents define conservation and preservation as the future use of the lands along the river. In a memorandum (*Hanford Reach National Monument* [Clinton, 2000]), the President directed the Secretary of Energy to consult with the Secretary of the Interior on how best to protect the lands around the Hanford Reach National Monument permanently. Much of the area contains shrub-steppe habitat and other areas of scientific and historic interests. The President specifically included the possibility of adding lands to the Hanford Reach National Monument as they are remediated. EPA and the state of Washington believe that the cleanup actions in the River Corridor should also support the potential for future residential use.

When soil cleanup goals were initially established for the River Corridor, the TPA (Ecology et al., 1989a) 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. Such a goal addressed the interests of a number of Hanford Site stakeholders, including the Future Site Uses Working Group. Interim action cleanup requirements were based upon consideration of 1997 MTCA (WAC 173-340) cleanup requirements for unrestricted surface use for chemical contaminants and a dose based standard of 15 mrem per year for radiological constituents based on DOE guidance for a residential exposure. For the purpose of establishing final cleanup requirements for the River Corridor cleanup, the Tri-Party agencies believe it is appropriate to continue to use the interim action ROD cleanup requirements, updated to reflect revised 2007 MTCA (WAC 173-340) values and excess cancer risk for radiological constituents. Final cleanup values will also be established to protect groundwater and surface water resources and address ecological risk considerations.

Because the interim action cleanup values in River Corridor RODs were developed to accommodate a variety of future land use options the resultant cleanup actions will be protective of the reasonably foreseeable land uses that DOE and the USFWS anticipate for the River Corridor.

Tribal Interests. Tribal fishing rights are recognized on rivers within the lands ceded by treaty, including the Columbia River, which flows through the Hanford Site. In addition to fishing rights, the Tribes retain 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 the Hanford Site, which was assembled from lands acquired from private owners and lands withdrawn from the public domain into a federal enclave with no public entry, 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.

3.9 Ecology

The Hanford Site is located in a mid-latitude area with a semiarid climate. This portion of the Columbia Basin provides a unique habitat, having the last free-flowing section of the Columbia River passing 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 relatively undisturbed. Only about 6 percent of Hanford Site land has been disturbed or is actively used by DOE for waste disposal and storage. The native terrestrial and aquatic ecological resources found on the Hanford Site are becoming increasingly rare throughout the Columbia Basin region.

Three key ecological study zones have been identified for purposes of investigation in the River Corridor: the upland, riparian, and nearshore river zones (RCBRA Literature Review [PNNL-SA-41467]; RCBRA [DOE/RL-2007-21, Volume I]).

- **Upland zone**—Consists of land adjacent to the main channel of the Columbia River above the high-water mark of the Columbia River. Terrestrial and generally dry, the upland zone is not influenced by river flow and depends on precipitation for its water supply.

Within the operational areas, most of the upland zone is highly disturbed, consisting of barren or gravel areas or non-native annual species. The upland environment outside the operational areas is relatively undisturbed and consists of relatively native shrub-steppe vegetation habitat.

- **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 Report [DOE/RL-2007-21, Volume I]).

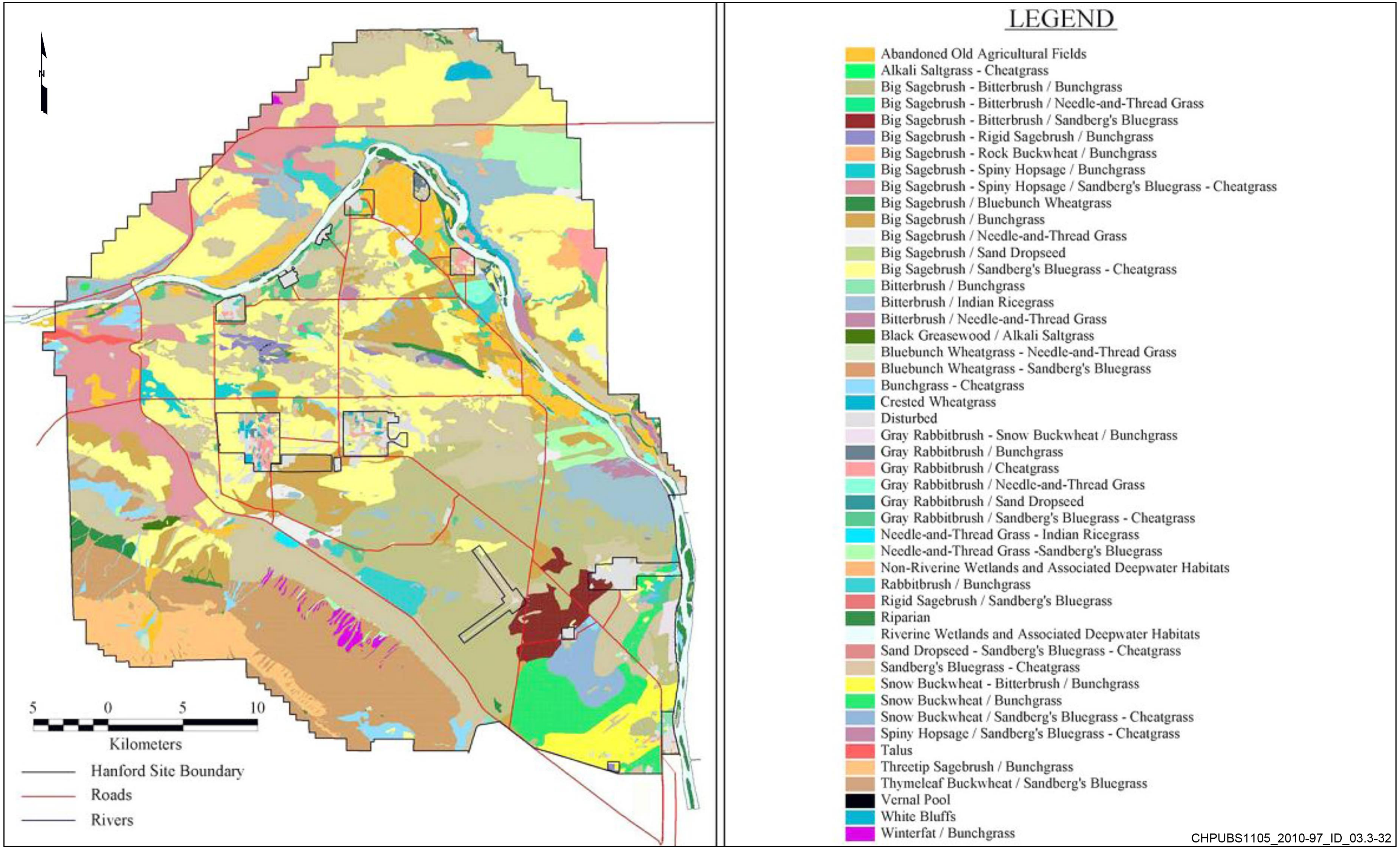
- **Nearshore aquatic zone**—Consists of a narrow band of the Columbia River adjacent to the shoreline. The nearshore aquatic zone evaluated in this report extends from the low water mark on the shoreline into the river channel to a water depth of roughly 1.8 m (6 ft). The CRC (DOE/RL-2010-117, Volume I) evaluates environmental conditions for depths greater than 1.8 m (6 ft). 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 45 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 Report [DOE/RL-2007-21, Volume I]).

Large-scale distribution of vegetation types within the upland zone and surrounding the riparian and nearshore zones before the 2000 wildfire is presented in Figure 3-37. Table H-1 (Appendix H) presents a description and list of species known or potentially occurring on the Hanford Site classified by habitat type.

3.9.1 Threatened and Endangered Species

Several 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 or 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 (Table 5-1 of *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* [DOE/RL-2004-37]; Chapter 7 of this report). 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 (RCBRA Literature Review [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 they 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]).



Source: PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*.

Figure 3-37. Distribution of Vegetation Types and Area before the 2000 Fire

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Table H-22 provides flora and fauna species listed by the State of Washington as threatened or endangered, including candidate, sensitive, and monitored species thought or known to occur on the Hanford Site.

3.9.2 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, *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments: Interim Final* (EPA-540-R-97-006), hereinafter called ERAGS, 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, pollen-feeding animals may be relatively unimportant in terms of nutrient and energy transfer through the food web, but they are important as plant pollinators. The same generalities are applicable to considerations of trophic linkages in the aquatic environment (for example, 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 Report [DOE/RL-2007-21, Volume I]).

This trophic framework is used to describe a simplified structure for the ecological community of the RCBRA (DOE/RL-2007-21) (Figure 3-37). 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 habitats. 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.

Hanford Site-specific receptors are recommended as surrogates for the 2007 MTCA ("Terrestrial Ecological Evaluation Procedures" [WAC 173-340-7490]) feeding guilds because they represent relevant ecological 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, animals do not typically restrict themselves to narrowly defined 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 (for example, strict herbivory) is done to set the exposure bounds in trophic-transfer analyses.

3.9.3 Post-remediation Restoration

After demonstrating that a waste site cleanup achieves cleanup criteria and RAOs, it is backfilled with approved material and revegetated in accordance with *Hanford Site Biological Resources Management*

Plan (DOE/RL-96-32), hereinafter called BRMaP, which outlines that the end goals of restoration are to be developed in the context of future land use. The goal of most post-remediation waste site restoration efforts, where habitat is to be restored, is to establish the necessary species composition, structural components and ecological processes at a site such that it can support native plants, fish and/or wildlife. Utilizing varying restoration methods and natural processes at a site-by-site level will enhance biodiversity and strengthen the ecosystem and thus meet the expectations set forth by BRMaP (DOE/RL-96-32).

DOE and contractors will continue to consider biological resource values in planning to minimize or avoid adverse impacts, and plan for appropriate mitigation and restoration where impacts can not be avoided. For example, native plants and wildlife prefer to utilize sloped topography, whether existing naturally or through man-made occurrences such as waste sites that are not backfilled to grade. Micro-habitats created through varied topography provide native plants and wildlife with many benefits, such as relief from climatic extremes (wind and temperature), shade relief, shelter from predation, and burrowing opportunities. Therefore, restoration of remediated areas may include varying backfilled grades to optimize conditions for plants and wildlife.

High quality riparian habitat remains low throughout the Hanford Reach, representing only a small fraction in proportion to upland terrestrial habitats. BRMaP (DOE/RL-96-32) describes these areas as Level IV Resources and as such, are to be rectified at a 2:1 ratio, by area or quality. With regard to shoreline waste sites 100-D-8, 100-D-65, and 100-D-66 for example, DOE restored shoreline Level IV habitat to meet the expectations outlined in BRMaP (DOE/RL-96-32) guidance. It is expected that DOE would continue to restore shoreline areas impacted by remediation in accordance with BRMaP (DOE/RL-96-32) guidelines.

3.10 Cultural Resources

The Hanford Site contains some of the most important archaeological sites in the region. Many of these sites are eligible for listing on the "National Register of Historic Places" (36 CFR 60). In addition, other natural resources and sacred sites important to the cultures of the regional Tribal Nations are preserved at the Hanford Site (*Data Compendium for the Columbia River Comprehensive Impact Assessment* [PNL-9785]). Long-term (that is, more than 50 years) restricted access has minimized looting and vandalism of historic, cultural, and archaeological sites. Furthermore, hydroelectric and agricultural development have not destroyed these culturally significance sites, as has been experienced elsewhere in the Columbia River Basin.

While rapid Hanford Site development did not accommodate protection of important Native American locations, 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 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 three suitable categories for chronicling historic, archaeological, and traditional cultural properties of the Hanford Site:

- Prehistoric era (10,000 years 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 before 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 uses (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 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 CTUIR, Yakama Indian Nation, the Nez Perce Tribe, and the Wanapum. A cultural resources review process was followed for any data collection activities. As with other areas across the Hanford Site, disturbance maps and reports have been prepared for many areas. Tribal Nation leaders review the locations and potential effects to these resources before site activities begin (*Hanford Cultural Resources Management Plan* [DOE/RL-98-10]).

3.10.1 Prehistoric Era

Approximately a dozen prehistoric sites are in 100-D/H, most of which are within 0.4 km (0.25 mi) of the Columbia River. In addition, numerous historic sites are associated with the pre-Hanford Site agricultural period. In general, archaeological sites on the Hanford Reach, including 100-D/H, 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, 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 pre-contact 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 pit houses and tool assemblages used for stone tool manufacture and plant and animal preparation. In contrast, short-term, seasonal-use sites have no pit houses; however, they contain artifacts similar to long-term-use sites. Seasonal use of the area centered on the fall fish migrations and winter villages. Seasonal rounds began in the spring with the maturing of plants in the lowland areas and gradually moved to the higher elevations as plant maturation continued into the early fall. Fishing continued from April through September, and hunting occurred 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 years B.P.) represents the oldest known Paleo-Indian culture in the Columbia Plateau region. Although archaeological evidence is limited, the people of this period are believed to have been highly mobile hunters and foragers. The food source was primarily large mammals, supplemented with small mammals and fish. Population numbers were low. Living areas are believed to have been in rock shelters and caves. No evidence of constructed dwellings or storage features exists, which further supports the theory of a highly mobile culture. Artifacts from this phase include projectile points, cobble tools, scrapers, gravers and burins, hammer stones, grooved stones, used flakes, bone awls, ocher beads, and antler wedges. Supporting evidence of a Paleo-Indian culture on the Hanford Reach includes a Windust-style projectile point, which was discovered near 100-K in 2001. This projectile point is the oldest known Paleo-Indian point discovered to date at the Hanford Site.

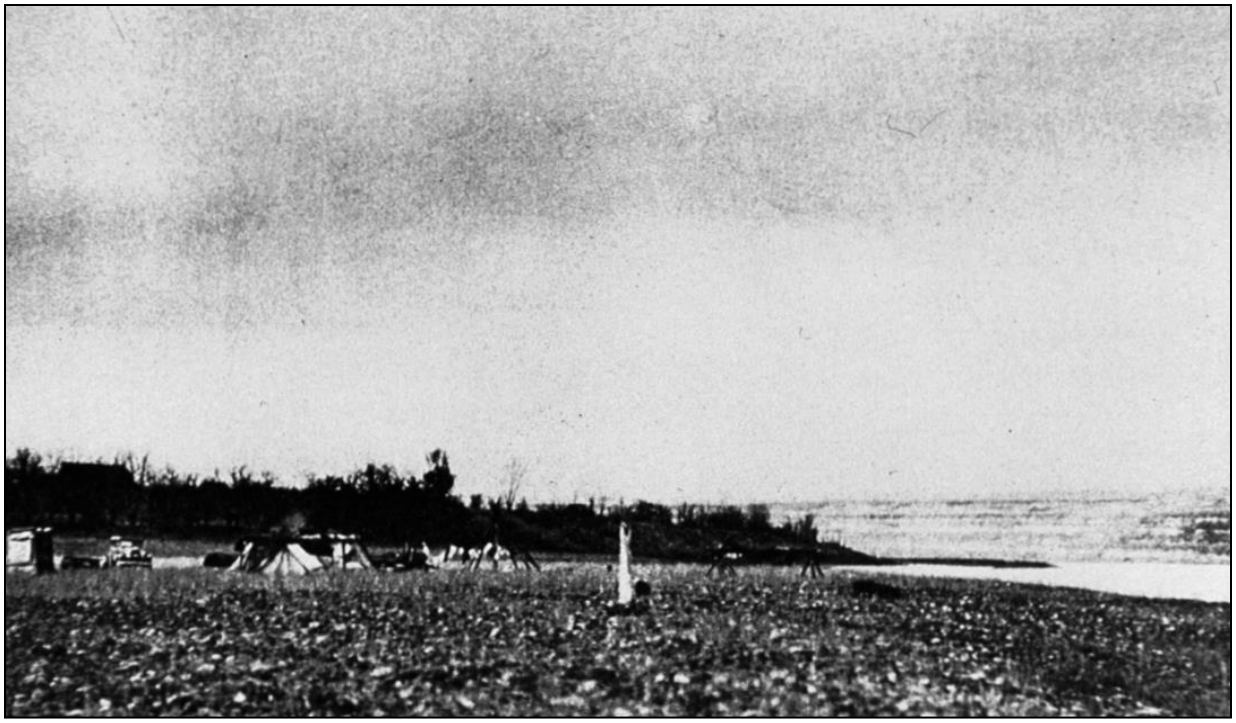
The Cascade/Vantage Phase (8,000 to 4,500 years B.P.) sites include leaf-shaped Cascade projectile points, stemmed projectile points, ovate knives, edge-ground cobble tools, microblades, hammer stones, core tools, and scrapers. The people of this period are believed to have been mobile foragers who relied in part on fish, mussel shells, seeds, and animals. Generally, Vantage Phase sites are 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 years B.P.) are believed to have been more dependent than 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 silica and petrified wood, probably the result of increased upland exploitation. During this period, a shift from chipped stone to ground stone and cobbled 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 years B.P.) is characterized by the use of pit houses. The pit houses had level floors, vertical walls with step-like benches, and basal-notched and corner-notched projectile points. The Cayuse II Phase (1,200 to 900 years B.P.) differs only slightly from the earlier phase in that it contains a different pit house design. These pit houses lack the wall benches that characterize the previous phase. Projectile points remain very similar. In the Cayuse III Phase (900 to 250 years B.P.), the number of corner-notched projectile points decreases, and the use of stemmed and side-notched points increases. The number of trade goods also increases 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. During the Cayuse period, populations increased their reliance on fish and root collecting and reduced their reliance on hunting. Horses were introduced in about 1730, increasing the hunting and transportation capabilities. The Cayuse III Phase was also the period with the largest pre-contact populations.

Sahaptin-speaking Wanapum occupied the region of the Columbia River between the Wenatchee and Snake Rivers. Pre-contact population numbers were estimated to be as high as 10,000 before the beginning of the 1800s. By the early to middle 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 Wanapum 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 Wanapum would return to the river to pursue the fall fish migrations and prepare for the upcoming winter. Figure 3-38 shows a temporary camp, and Figure 3-39 shows a dugout canoe.



Note: Building in background and car to the left.

Figure 3-38. Native American Temporary Camp in 1945

3.10.2 Homestead and Townsite Era

The Lewis and Clark expedition of 1805 was the initial group of explorers and 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 industries. Numerous locations with gold mining features believed to be created by Euro-American and Chinese people 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.

Figure 3-39. Dugout Canoe in 1945

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 that supported 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. Agriculture 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 passage of 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 5 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 & Pacific Railroad) to the Columbia Basin area. Local transportation systems in the Columbia Valley were very limited at that time, so 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. The earliest known ferry service began at White Bluffs in 1859. A ferry service began operation in 100-D in 1880 to transport Chinese gold miners across the Columbia River; Native Americans had previously used this location for a canoe crossing. A store and hotel were established near the crossing. A ferry operated at this location until the Manhattan Project took control of the area in 1943 and closed the ferry after 63 years of operation. Figure 3-40 shows a ferry crossing in the Horn area. 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 crop yields. Irrigation projects were under construction throughout eastern Washington shortly after the turn of the 20th century.

Note: Ferry boat in approximate center of photograph.

Figure 3-40. Ferry Crossing in Horn Area in 1941

Many irrigation projects began as small-scale, privately funded projects, usually with insufficient funding, and the Hanford Site area was no exception. The Hanford Site area was sought after by developers and producers for its unique geographical ability to produce agricultural crops, especially fruit, 2 to 3 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. Various irrigation techniques were initiated to produce the most affordable irrigation system, which included pumping from wells and 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 removed 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 that 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

Within this chapter, the key elements of potential contaminant pathways within the environment are discussed. These include a number of important elements for the CSM such as the interrelationships between the geology, the ecology, and the hydrologic cycle. The relationship between these elements and the vadose zone, groundwater, riparian zone, and Columbia River are discussed. The discussion also includes a description of the plants and animals that need to be considered as part of the remedy selection. Historical use of the land by various Native American tribes has resulted in the designation of culturally sensitive sites within 100-D/H. Mitigative or evasive measures may be required to protect these sites during remedial actions, which are proposed at the culmination of this report.

The study area is in the Pasco Basin of Washington. 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. Surface winds are predominantly from the northwest and are frequently the result of cooler air draining from the mountains to the northwest. On average, the highest wind speeds occur in March. Average annual precipitation is 17.2 cm (6.8 in.) with most of this occurring during the late fall and winter months when evapotranspiration is lowest. Natural recharge rates to groundwater from precipitation vary from approximately 0 to 100 mm/yr (0 to 3.94 in./yr), depending on plant cover and soil type. In operational areas where the vegetation and topsoil have been removed, a large fraction of this water travels down through the vadose zone, leaching any available contaminants as it drains. The Columbia River is the dominant surface water feature at the Site. Columbia River flows typically peak from May through July during spring runoff because of regional and high elevation snowmelt. Flows are lowest from September through October. 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. At high river stage, the river water can impact groundwater flow some distance inland within the aquifer. The degree of impact is very site specific and depends heavily on the stratigraphy of the location.

At 100-D/H, the stratigraphy varies considerably from 100-D, across the Horn to 100-H. Basalts are overlain by Ringold Formation material across the entire Site. The Ringold Formation consists of Miocene-Pliocene age sediments with several identified units, with both semiconfined and confined aquifers; however not all units exist in all areas across 100-D/H. Ringold Formation unit E is primarily present at 100-D, but is only identified in small pockets across the Horn, and has not been identified at 100-H. As a result, the unconfined aquifer is present within the Ringold Formation unit E at 100-D, and in the overlying Hanford formation at 100-H. This difference has a significant effect on groundwater movement in the area, and subsequently on the contaminant distribution, because of a higher hydraulic conductivity within the Hanford formation materials allowing faster groundwater movement in that formation.

Another feature of the geology that is important to groundwater flow is the surface of the Ringold Formation upper mud unit, the RUM. The RUM is a low transmissive confining aquitard consisting predominantly of silt, with some interbedded sandy zones. Results of recent geologic investigations indicate that the RUM surface has an undulating topography with relief up to several meters. The undulating surface potentially slows groundwater flow with downward dips in the surface potentially controlling flow direction.

The Ringold Formation unit E has been eroded over much of the area east of 100-D, although occasional pockets remain beneath the Horn and 100-H. The upper part of the RUM sometimes contains gravel in a silt/clay matrix that may be a transition zone (reworked interval) above the more massive silt or clay. Within the RUM, thin sand-to-gravel lenses form zones with variable hydraulic conductivities that range from low to high.

Across 100-D/H, the vadose zone is composed of Hanford formation material, although a lower water table in 100-D results in the Ringold Formation unit E also becoming unsaturated. Cross-beds found in the Hanford formation also may locally influence vertical migration of contaminated liquids, although 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.

Vadose zone thickness (and depth to groundwater) ranges from 0 to 27 m (0 to 89 ft), with an average thickness of 11.3 m (37.1 ft) in 100-H and an average thickness of 20 m (65.4 ft) in 100-D. Average vadose zone thickness within 100-D/H is estimated to be 15.6 m (51.3 ft). The vadose zone in 100-D consists of a thin veneer of permeable surface soil, underlain by Hanford formation sediments and Ringold Formation unit E sediments. The vadose zone in 100-H consists of a thin veneer of permeable surface soil underlain by Hanford formation sediments, with the Horn being a transitional area geologically.

The Hanford Site’s arid climate keeps the vadose zone soil moisture relatively low. Historically, effluent discharge to the soil column increased soil moisture beneath waste sites. Soil moisture ranged from less than 2 percent to 10 percent, with one sample slightly exceeding 10 percent. Samples collected from near the water table generally had higher moisture content than those samples collected higher in the vadose zone, the exception being those samples near the surface that occasionally exhibit higher moisture content because of precipitation. Vadose zone soil data show that the Ringold Formation unit E has similar grain size, porosity, and bulk densities as those of the Hanford formation, yet the Ringold Formation unit E has greater moisture content (at 100-D) than that of the Hanford formation.

During reactor operations at 100-D/H, the rates and direction of groundwater flow in the unconfined aquifer were controlled by the underlying geology, while being strongly influenced by surface and subsurface discharge of cooling water effluent and operation of the water/wastewater infrastructure.

Infiltration and overland flow of contaminated cooling water from surface features and from leaks at the 100-D and 100-H Area retention basins created significant vertical (downward) fluxes within the vadose zone that would have increased any potential for vertical migration of contaminants released to the aquifer. Since reactor operations ceased, 100-D/H hydrogeology has primarily been influenced by the following:

- Natural precipitation events and snow melt
- Groundwater remediation activities
- Operation of the Export Water System and other water/wastewater infrastructure
- Application of dust suppression water during waste site remediation
- Annual and diurnal fluctuations in Columbia River stage

Groundwater flows into 100-D/H from the south and then regionally bends toward the lower hydraulic heads at 100-H. At 100-D, some groundwater discharges to the Columbia River; however, most of the groundwater flows from 100-D across the Horn to 100-H. River stage affects groundwater near the river, influencing groundwater elevations more than 700 m (2,300 ft) inland at 100-D, and more than 640 m (2,100 ft) inland at 100-H. When river stage is low, natural groundwater flow is from 100-D/H toward the river. When river stage is high, water can flow from the river inland and mix with 100-D/H groundwater.

Current hydraulic gradient magnitudes and directions within the unconfined aquifer are generally toward the Columbia River, but they show some seasonal variation in response to changes in river stage. Gradients steepen toward the river during low river stage (fall and winter), and flatten or may reverse near the river shoreline during high river stage (spring). Local gradients are also heavily influenced by the operation of the pump-and-treat systems in the 100-D and 100-H Areas. During 2011, groundwater pump-and-treat remedies were reconfigured and expanded following RPO activities. Four groundwater pump-and-treat systems operated for all or part of 2011:

- In the 100-D Area, the DX system operated for the entire year, while the DR-5 system operated from January to April.

- In the 100-H Area, the HR-3 system operated from January to May, while the HX system operated from late September to December.

Because of the operation of these remedies, and the influence of the Columbia River stage, groundwater levels and hydraulic gradients within the unconfined aquifer varied widely during 2011.

Near the 100-D southern plume, the hydraulic gradients during 2011 varied in magnitude from about 0.0002 to about 0.008. The gradient direction was generally north/northwest toward the Columbia River; however, gradients shifted to the north/northeast for a brief period from May through August 2011, coinciding with high stage in the Columbia River. The flow velocity ranged from 0.0000013 to 0.000064 cm/sec (0.004 to 0.181 ft/day). Near 100-H, the gradient direction was generally north/northeast toward the Columbia River; however, gradients shifted to the south/southeast for a brief period from May through August 2011, coinciding with high stage in the Columbia River. The flow velocity ranged from 0.0000031 to 0.000012 cm/sec (0.009 to 0.034 ft/day).

Intercommunication between different aquifers is indicated at nested Wells 199-H3-2A, 199-H3-2B, and 199-H3-2C within 100-H. During a step test and constant-rate pump test of Well 199-H3-2C, the unconfined aquifer exhibited characteristics of a leaky aquifer, with groundwater levels in nearby water table wells showing drawdown in response to pumping in the first water-bearing unit in the RUM. Geochemical data evaluated during this RI also indicate a connection between the aquifers at

Well 199-H3-2C. Aquifer connectivity was not identified in the nested well sets at Wells 199-H4-15CS and 199-H4-12C.

An examination of the vertical hydraulic gradient between the various aquifers indicated that a weak upward gradient is present in some locations in 100-D/H, with other areas showing either a downward or equipotential gradient. These conditions, combined with a less cemented and thinner zone between the surface of the RUM and the first water-bearing unit of the RUM are conducive to allowing transmission of contaminated groundwater from the unconfined aquifer to the first water-bearing unit in the RUM. Under operating conditions, the groundwater mound formed at both the D and H Reactors would have allowed migration to the lower aquifer.

Groundwater monitoring wells in the southern Cr(VI) plume in 100-D, with a few exceptions, have similar geochemical pattern. Wells in the southern plume have higher relative levels of calcium, with high levels of carbonate and sulfate. The geochemical signature in the northern plume is similar to that found in the southern plume, with the exception of higher sodium plus potassium, sulfate, and magnesium levels. Wells with a different geochemical pattern are those affected by local contamination or other groundwater additives. The reducing agent used in the barrier consists of sodium dithionite ($Na_2S_2O_4$). As expected, the sodium and sulfate levels in the groundwater at the ISRM well are much higher than levels in other wells within 100-D/H. The wells in the Horn have a similar geochemical signature to each other.

Monitoring Wells 199-H3-2A, 199-H3-2B, 199- H3-2C, 199-H4-12A, and 199-H4-12B have a similar geochemical pattern. Of these wells, only one (Well 199-H3-2C), was completed in the RUM. The other two RUM wells with adequate geochemical data are Well 199-H4-12C and 199-H4-15CS. These wells are located near the Columbia River, and have a geochemistry similar to river water but different from the chemistry found in the associated nested wells. The water levels in these wells also respond to changes in river stage (*Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation* [SGW-47776]). The observation of similar geochemistry supports the theory that the RUM is hydrologically connected to the river in that location.

The Hanford Site area was a seasonal home to human inhabitants dating back at least 11,000 years. For hundreds of years before the end of the Frontier Period in 1890, the Wanapum and other tribes used the area as a seasonal homeland. These peoples would take advantage of the fish runs in the fall and winter along the river before returning to higher ground in the spring and summer. European settlement followed before the taking of the land by the federal government in 1943.

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