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Revision 0

Integrated 100 Area Remedial Investigation/ Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units

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

U.S. DEPARTMENT OF ENERGY

Richland Operations Office

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Richland, Washington 99352

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Title: *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units*

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Executive Summary

This document is Addendum 5 of DOE/RL-2008-46.[1] The purpose of a work plan is to explain the Remedial Investigation/Feasibility Study (RI/FS) project background and rationale, and to present detailed plans for investigation of a contaminated site under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*[2] (CERCLA). It should be noted that the CERCLA RI/FS results are intended to address the *Resource Conservation and Recovery Act of 1976*[3] (RCRA) corrective action requirements for areas of RCRA concern. The characterization results from the RI are intended to support final remedy selection under CERCLA for 100-N at the Hanford Site. Five areas (Figure ES-1) have been defined for the River Corridor 100 Area: 100-BC, 100-K, 100-D and 100-H, 100-N, and 100-F combined with 100-IU-2/6. Planning for the 300 Area will be addressed separately. These areas combine groundwater contamination, soil contamination sites, and facilities in geographic areas that encompass the 100 Area "National Priorities List"[4] sites.

The work plan implements an approach designed to reach final remediation decisions, describes key features of the planning process to support implementation of this approach, and provides important key regulatory and risk assessment assumptions common to 100 Area. This document, Addendum 5 to the Integrated Work Plan, provides information for 100-N. 100-N includes the 100-NR-1 Source Operable Unit (OU), and the 100-NR-2 Groundwater OU. Figure ES-1 shows the location of 100-N and proximity to other 100 Areas.

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[1] DOE/RL-2008-46, 2010, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1002260412.

[2] *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 42 USC 9601, et seq. Available at: http://uscode.house.gov/download/pls/42C103.txt.

[3] *Resource Conservation and Recovery Act of 1976*, 42 USC 6901, et seq. Available at: http://epw.senate.gov/rcra.pdf.

[4] 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan," Appendix B, "National Priorities List," *Code of Federal Regulations*. Available at: http://edocket.access.gpo.gov/cfr_2009/julqtr/40cfr300AppB.htm.

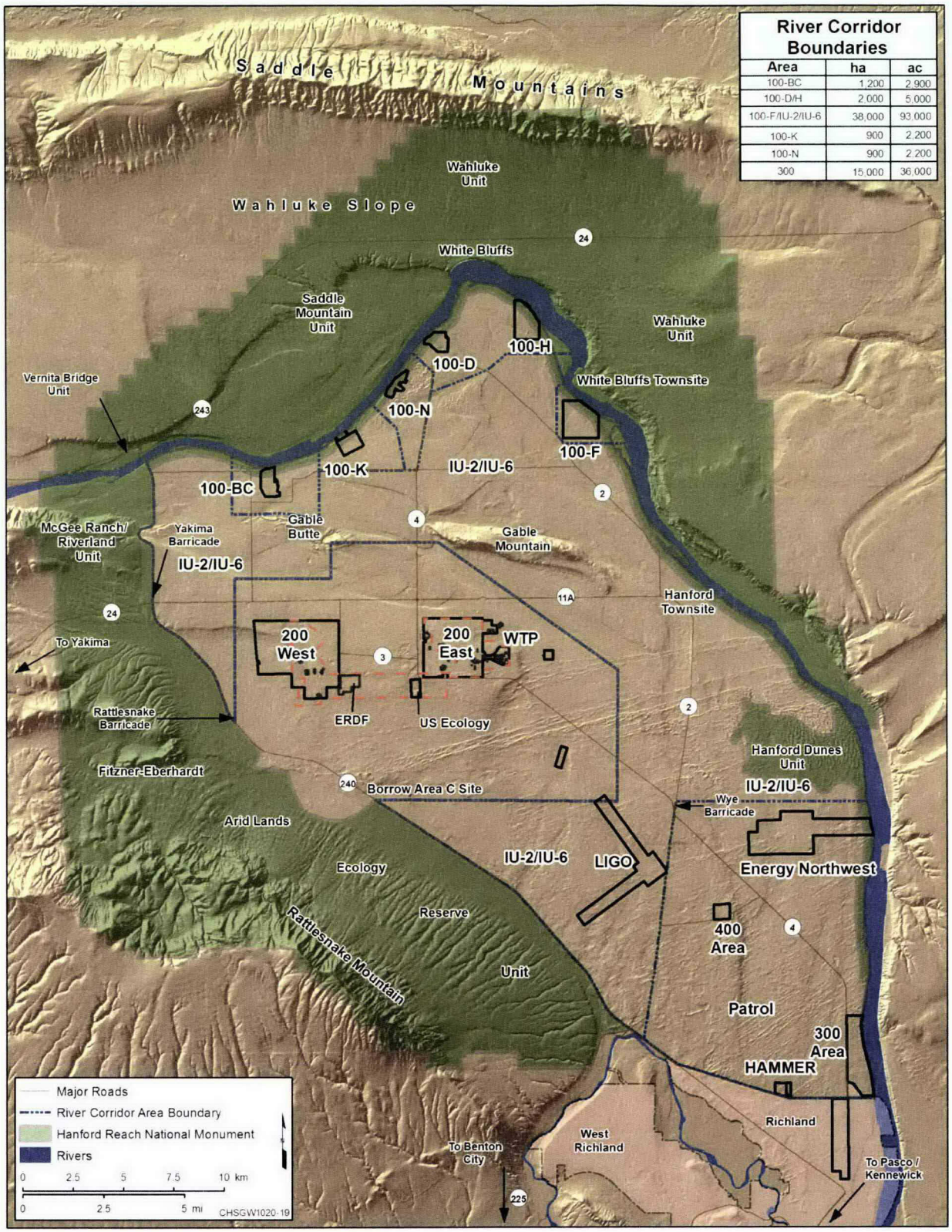

Figure ES-1. River Corridor Boundaries

A planning process meeting was conducted in September 2009 to identify data collection and analysis needs to support final remediation decisions at 100-N. The following key elements were identified during this planning process:

- **Information was identified and collected on the existing site conditions.** Information includes the operational history of the facilities (with an emphasis on disposal operations), the known nature and extent of groundwater and soil contamination, geohydrologic information, source and groundwater remedial actions, the results of treatability and characterization studies, and the results of environmental media monitoring.

  Strontium-90 contamination is the primary risk driver through the groundwater pathway. Less extensive and concentrated plumes of other contaminants have been identified (e.g., petroleum, nitrate, and tritium) at 100-N. Appendix C presents maps of the facilities source sites and the strontium-90 groundwater plume from the 2008 Annual Report on Groundwater (DOE/RL-2008-66).[5] The plume has remained consistent in concentration and shape (as measured at the uppermost portion of the unconfined aquifer) over the last few years, with the cessation of reactor operations. Through July 2010, 17 waste sites have been interim closed per EPA/ROD/R10-990112,[6] the 100-N CERCLA 1999 Interim Record of Decision (ROD) and the soil portions of three waste sites (1324-N [120-N-1], 1324-NA [120-N-2], and 100-N-58) have been clean-closed per RCRA. However, due to groundwater contamination, post-closure groundwater monitoring is required for the 1324-N and 1324-NA sites. While the interim closed out remedial actions satisfied the interim RODs, they may not satisfy final CERCLA remediation and/or RCRA corrective action requirements as CERCLA applicable or relevant and appropriate requirements and risks will be re-assessed. There are 129 accepted waste sites remaining for remedial action.

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[5] DOE/RL-2008-66, 2009, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0905131281. http://www2.hanford.gov/arpir/?content=findpage&AKey=0905131282.

[6] EPA/ROD/R10-990112, 1999, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.epa.gov/superfund/sites/rods/fulltext/r1099112.pdf.

- **A conceptual site model was developed.** A conceptual site model (CSM) is a description of a site representation that organizes the information available and summarizes the site conditions. Known contamination levels and location(s), as well as information needed to support 100-N remediation decisions for the final ROD, were used to develop the CSM. In turn, the CSM was used to identify data and information gaps, establish data needs, and design a field program to address those needs.

  An important feature of the CSM was identifying potential sources of contaminants, primarily strontium-90, and providing theories regarding the persistence of the contaminant plumes and mass distribution in soil. Based on reactor operations process knowledge, reactor process water discharges contained levels of strontium-90 in excess of 600 pCi/L (Table 4-1). The effluent infiltration and migration to groundwater in 100-N produced strontium-90 concentrations of about 6,000 pCi/L in a monitoring well during the mid-1980s (WHC-SR-0377).[7] As of 2008, strontium-90 concentrations above the maximum contaminant level extend inland from the river approximately 1.2 km (0.76 mi) in 100-N with an overall plume area estimated as 0.58 km^2 (0.22 mi^2) (100-N Area Map, Appendix C).

- **Data gaps, or uncertainties, were identified as part of the conceptual site model development process.** A list of data gaps, or statements of uncertainty, was identified as part of the planning process. The following data gaps that recognize the need for additional information to better define and/or understand conceptual site model factors were identified:

  - Risk for direct exposure, protection of groundwater, and protection of the Columbia River at unremediated waste sites
  - Risk of residual soil contamination following interim remedial action on human health, groundwater, surface water, and the environment
  - Extent of contamination in the unconfined aquifer
  - Extent of contamination in the Ringold Formation upper mud (RUM) unit
  - Continued persistence of strontium-90 contamination in the groundwater

[7] WHC-SP-0377, 1988, *Assessment of Westinghouse Hanford Company Methods for Estimating Radionuclide Release from Ground Disposal of Waste Water at the N Reactor Sites*, Westinghouse Hanford Company, Richland, Washington. Available at: http://www.osti.gov/energycitations/purl.cover.jsp?purl=/6492544-NRpLNd/.

- Hydraulic properties of the RUM unit
- Effectiveness of groundwater contamination remediation activities

Chapter 4 presents the data gaps defined during the planning process.

- **Data needs were defined to address each of the data gaps or uncertainties.** Each of the gaps is defined by a data need that, when filled, provides information to reduce or eliminate the associated uncertainty. Table 4-7 and DOE/RL-2009-42,[8] present the data needs and describe how they will be filled for 100-N. An important consideration in Table 4-7 is that several ongoing programs (e.g., facility demolition, waste site evaluation, characterization, and remediation of the remaining 129 sites, and treatability testing) will provide data and resolve many of the uncertainties identified for 100-N. The Sampling and Analysis Plan (DOE/RL-2009-42) identifies only those data collection activities associated with this addendum. The RI/FS report prepared for 100-N will use data and information obtained from ongoing remediation programs that become available during development of the report. The results of ongoing deactivation, decontamination, decommissioning, and demolition, and from waste site and groundwater interim remediation actions plus the proposed investigations, will be used in the selection of final remedies and incorporated into a proposed plan leading to a ROD. Table ES-1 summarizes the field characterization program proposed under this addendum. Table ES-2 presents the number of field samples and analytes that will be collected.

Table ES-1. Proposed 100-N Characterization

Type	100-N Area
New boreholes/test pits (vadose zone)	0
New wells (unconfined aquifer)	6
Aquifer Tube arrays (2 new and 2 existing arrays)	4
New wells into the RUM	2
Sampling of monitoring wells (to support groundwater spatial/temporal uncertainty)	18
Sampling of monitoring wells (site specific)	7

Note: For a complete description of work scope, see Table 4-7 and the Sampling and Analysis Plan.

[8] DOE/RL-2009-42, *Sampling and Analysis Plan for the 100-NR-1 and 100-NR-2 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Table ES-2. Number of Field Samples and Analytes Proposed for 100-N

Source	Soil Samples*	Groundwater Samples	Analytes
New boreholes/test pits (vadose zone)	0	0	0
New wells (unconfined aquifer)	131	32	8,747
Aquifer Tube arrays (2 new and 2 existing arrays)	0	27	765
New wells into Ringold unit B	17	10	1,687
Sampling of monitoring wells (to support groundwater spatial/temporal uncertainty)	0	54	5,841
Sampling of monitoring wells (site-specific)	0	21	2,334

Notes: Table does not include field quality control or archive samples.

* Includes both chemical and physical property analyses.

- **A sampling and analysis plan was developed as the implementing document for the field program.** The sampling and analysis plan identifies the soil and groundwater characterization scope needed to address the remaining data gaps. Additionally, this information is collected to aid in addressing groundwater risk uncertainty.

- **Considerable progress has been made at 100-N.** In 100-N, considerable work remediating groundwater contamination, removing facilities, and remediating/evaluating waste sites has been completed over the past decade:

  - Evaluated/initiated strontium-90 and petroleum remediation in groundwater
  - 178 facilities demolished or removed
  - 55 sites interim closed, not accepted, or required no action

  Through the end of September 2012, additional work is planned that will provide valuable information for the RI/FS Report, Proposed Plan, and ROD:

  - Groundwater remediation of petroleum and strontium-90 to continue
  - 80 percent completion of facility demolition and 75 percent completion of reactor interim safe storage
  - Remediation of remaining waste sites

  Results of these activities provide the basis for identifying the remaining uncertainties needed to make final remediation decisions. Section 1.2 provides the completed and planned work for 100-N.

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Terms

AWQC	Ambient Water Quality Criteria
bgs	below ground surface
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COC	contaminant of concern
COPC	contaminant of potential concern
COPEC	contaminant of potential ecological concern
CSM	conceptual site model
CVP	cleanup verification package
CY	calendar year
D&D	decontamination and decommissioning
D4	deactivation, decommissioning, decontamination, and demolition
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office (also known as RL)
DOS	design optimization study
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EMA	elevated metals area
ENU	Elementary Neutralization Unit
EPA	U.S. Environmental Protection Agency
ERA	Expedited Response Action
ERDF	Environmental Restoration Disposal Facility
ESD	Explanation of Significant Differences
FS	feasibility study
FSB	fuel storage basin
FY	fiscal year
H_2SO_4	sulfuric acid
HGP	Hanford Generating Project
IROD	interim record of decision

ISS	interim safe storage
ISTZ	in situ treatment zone
ITRD	Innovative Treatment and Remediation Demonstration
K_d	distribution coefficient
LFI	limited field investigation
LTS	Long Term Stewardship
LWDF	Liquid Waste Disposal Facilities
MCL	maximum contamination limit
MNA	monitored natural attenuation
msl	mean sea level
NAPL	nonaqueous phase liquid
NPDES	National Pollutant Discharge Elimination System
OSE	orphan site evaluation
OU	operable unit
PAH	polynuclear aromatic hydrocarbons
PCB	polychlorinated biphenyl
PNNL	Pacific Northwest National Laboratory
PRB	permeable reactive barrier
PRG	preliminary remedial goal
QRA	qualitative risk assessment
RAO	remedial action objective
RCRA	*Resource Conservation and Recovery Act of 1976*
RI	remedial investigation
ROD	record of decision
RTD	removal, treatment, and disposal
RUM	Ringold Formation upper mud
SAP	sampling and analysis plan
SDA	suspected diesel contaminated area
SPA	strontium plume area
SVOC	semivolatile organic compound

TAG	Technical Advisory Group
TPA	Tri-Party Agreement
TPH	total petroleum hydrocarbons
TPH-DR	total petroleum hydrocarbons – diesel range
Tri-Parties	U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TSD	treatment, storage, and disposal
UCL	upper confidence limit
UPR	unplanned release
VOC	volatile organic compound
WCA	Washington Closure Hanford
WIDS	Waste Information Data System

1 Introduction

This document is Addendum 5 to *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan* (DOE/RL-2008-46). This addendum describes the 100-N Operable Units (OUs) and planned efforts to conduct a remedial investigation (RI) in support of a final record of decision (ROD). The 100-N includes the 100-NR-1 Source OU and the 100-NR-2 Groundwater OU. The integrated work plan contains the planning elements common to the Hanford Site 100 Area source and groundwater OUs and a summary of the RI/feasibility study (FS) tasks. Figure 1-1 shows the relationship between the RI/FS work plan and this addendum.

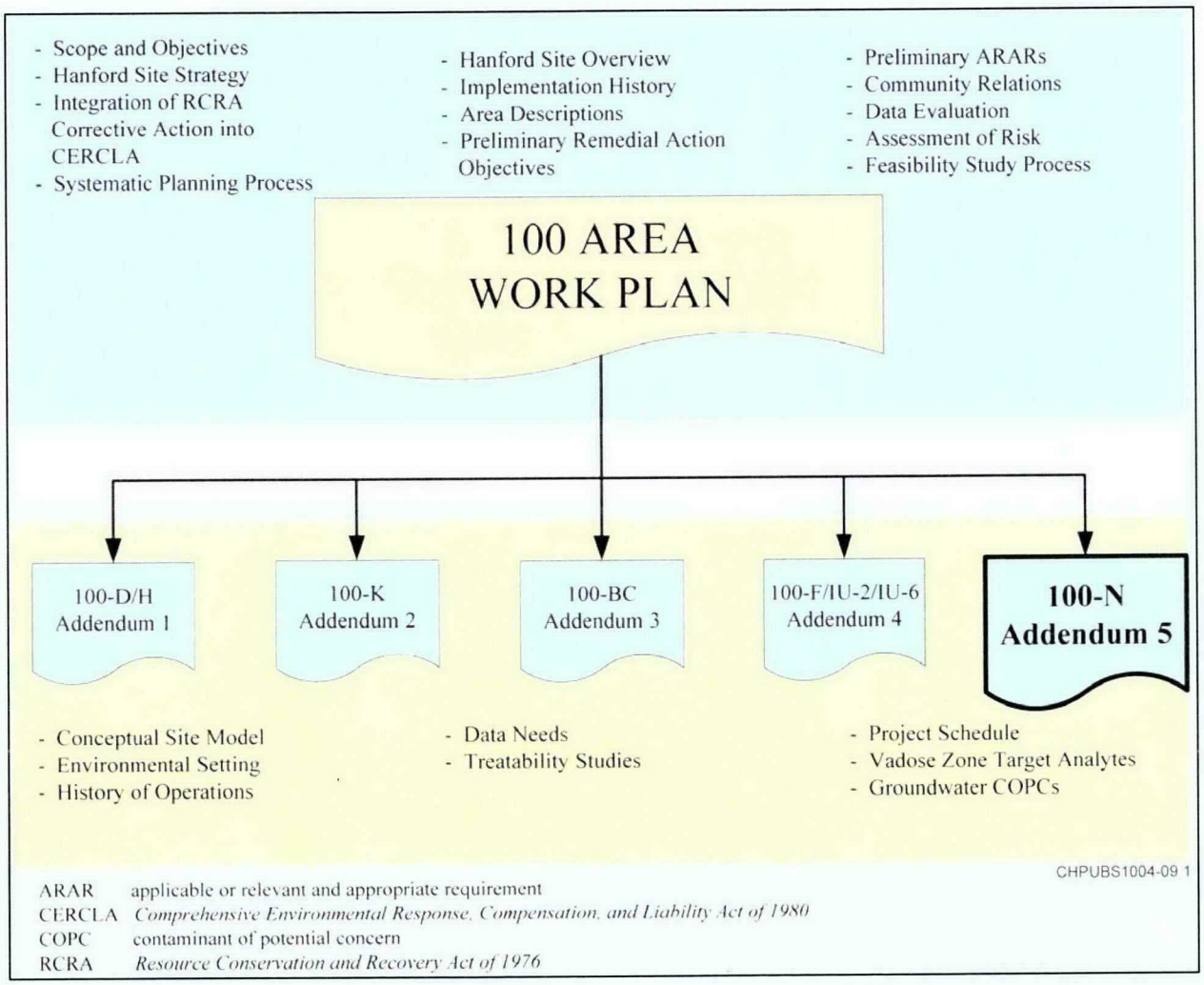


Figure 1-1. Relationship between the Work Plan and Addenda

This addendum describes key data collection and analysis elements that will support final remediation decisions for the 100-N OUs.

The planning process followed to develop this addendum included evaluating the results of past and ongoing remediation activities; describing the remaining uncertainties in the context of a conceptual site model (CSM)[1] to support remedial decisions; and justifying the type, location, and quantity of data needed to reduce or eliminate the identified uncertainties. A component of the planning process involved developing "plates" presenting the CSM components for identifying principal study questions, with supporting information, and resulting data gaps that may require further evaluation. These plates were provided to the U.S. Department of Energy (DOE), Richland Office (also known as RL) (DOE-RL), and the State of Washington Department of Ecology (Ecology) for review and comment. A working session was held to discuss the CSM plates. Although full resolution was not achieved on the CSM plates, the contractors developed the data needs and proposed the sampling approaches outlined in this addendum.

1.1 Scope

This addendum addresses the data and information needed to support groundwater and waste site remediation investigations associated with 100-N, which consists of the 100-N Reactor area, portions of the adjacent 600 Area, and associated waste sites. Figure 1-2 shows the location of 100-N and its proximity to other 100 Areas.

This addendum identifies data gaps and processes to address the gaps whose resolution is significant to making informed remediation decisions. The CSM is a useful tool to guide characterization and identify data gaps. A CSM is a representation of the site that organizes the information available and summarizes the site conditions. More importantly, a CSM can be used to establish programmatic priorities for sampling and testing hypotheses.

Additional data collection and other investigations will be used to address data gaps significant to making remediation decisions. The CSM addresses contaminant sources (i.e., process history), nature and extent of contamination, fate and transport, and exposure assessment (DOE/RL-2007-21, Draft C, *River Corridor Baseline Risk Assessment Volume II: Human Health Risk Assessment*); it supports risk characterization, remedial action selection, remedial action adequacy evaluation, performance monitoring, and site closure. Chapter 2 provides the background and environmental setting information necessary to support the development of the 100-N CSM.

CSM component summaries fostered discussions on issues and concerns. This information was used to solicit input from regulators, agencies, and subject matter experts. Chapter 4 presents the CSM and data gaps/needs table for 100-N.

Most importantly, data needs identification led to development of a sampling and analysis plan (SAP) that establishes characterization activities specific to 100-N. The SAP (DOE/RL-2009-42) includes a field sampling plan with the sampling strategy and techniques to obtain the data required for the RI/FS. The SAP provides a quality assurance project plan to ensure data collected meet the appropriate quality assurance and quality control requirements.

[1] A conceptual site model is a set of hypotheses and assumptions about the physical characteristics (e.g., media properties) and phenomena (e.g., model of fluid flow) that describe and postulate the behavior of contamination. The CSM, which describes contaminant sources and receptors, and the interactions linking them, is used to identify uncertainties and provide a framework to identify data and information needed to resolve each uncertainty. The CSM evolves as new data and information are developed.

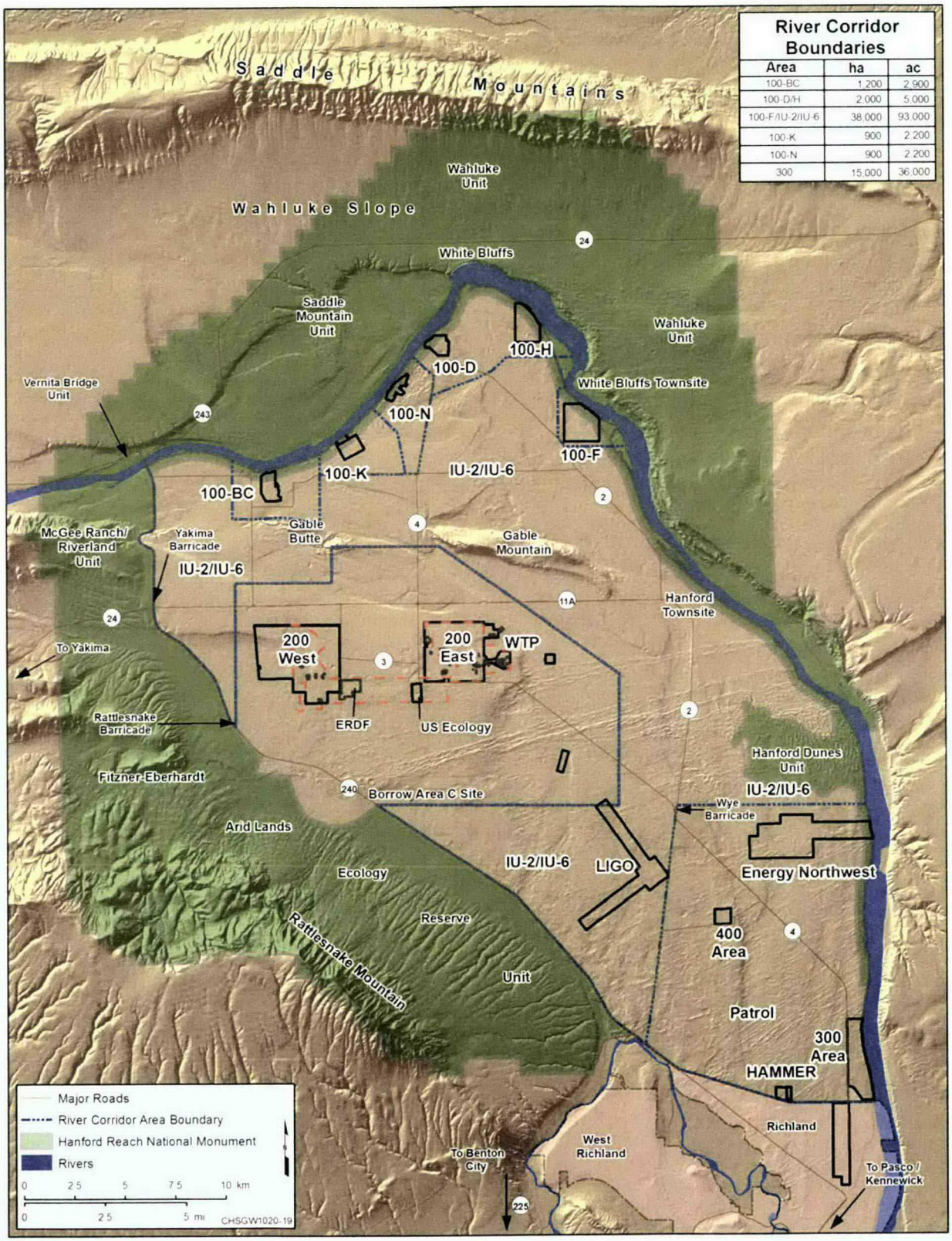


Figure 1-2. River Corridor Boundaries

1.2 100-N Remediation Accomplishments

A considerable amount of environmental remediation and restoration is already completed or planned at the Hanford Site. These remediation activities, many of which are ongoing, have achieved significant cleanup progress across the site. These activities include characterizing groundwater plumes and their potential sources, cleaning up the groundwater and soil, and testing new and alternative treatment methods specific to the issues and contaminants on the Hanford Site.

The following subsections provide information on the cleanup progress already undertaken in 100-N.

1.2.1 100-N Deactivation, Decommissioning, Decontamination, and Demolition Actions

100-N includes 232 former and remaining facilities, including the reactor, water treatment plants, a generating plant, storage buildings, offices, maintenance shops, process plants, an electric substation, storage tanks, pump stations, and outfall structures. The definition of facility (as applied to the Facility Decommissioning Process) is "a freestanding building, plant, laboratory, or other enclosure and associated building that fulfills, or fulfilled, a specific purpose, and is owned by or otherwise under the responsibility of DOE." (Note: this usage differs substantially from that in the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* [CERCLA] and the *Resource Conservation and Recovery Act of 1976* [RCRA].) Until the structures located over a source site are removed, soil remediation cannot be completed. The facilities are—and have been—undergoing removal to clear the way for remedial work focusing on underlying soil contamination. Table 1-1 shows the status of the 232-100-N facilities.

Starting in April 2009, the 100-N Reactor began undergoing the final stage of stabilizing and enclosing the highly radioactive reactor core in an upgraded, weather resistant shell for potentially 75 years, per the plan as presented in "105-N Reactor Building and 109-N Heat Exchanger Building Action Memorandum" ("105-N Reactor Building and 109-N Heat-exchanger Building Action Memorandum" [Wilson, 2005]). This stabilization, interim safe storage (ISS), will prevent environmental degradation of the structure and prevent the spread of contamination. The ISS shell is intended to minimize the spread of any potential contamination from and beneath the reactor. ISS completion is scheduled for September 2011. These actions minimize the facility footprint by removing peripheral reactor buildings and equipment and disposing of the debris. The principal structures remaining as of January 2010 are the 105-N Reactor and the 109-N Heat Exchanger Building. The 100-N facilities (including the pipelines near the 105-N Reactor and other 100-N locations) have been removed already or will be removed so they meet the cleanup goals and objectives of the interim RODs.

Along with ISS activities, 100-N is undergoing continued deactivation, decommissioning, decontamination, and demolition (D4). Figures 1-3 through 1-5 illustrate 100-N D4 actions and progress. Appendix A provides the complete status of facilities in 100-N.

Table 1-1. Summary of Facility Status in 100-N (March 2010)

Status (Total Number of Facilities)	Facility				
Active (34)	609	1120-N	1904-NA	MO-801	MO-808
	610	1143-N	1904-NB	MO-802	MO-865
	613	1158-NB	1904-NC	MO-803	MO-866
	676	1158-NC	6508-S8	MO-804	TC1301-N
	1103-N	155-N	MO-085	MO-805	TC1301-NA
	1110-N	186-N	MO-088	MO-806	TC1301-NB
	1119-N	1902-N	MO-765	MO-807	
Demolished (98)	104-N	119-N	13-N	1707-N	183-ND
	105-NB	119-NA	1515-N	1712-N	184-N
	105-NC	11-N	1516-N	1714-N	184-NA
	107-N	1300-N	1517-N	1714-NA	184-NB
	108-N	1301-N	1518-N	1714-NB	184-NC
	109-NA	1304-N	1519-N	1715-N	184-ND
	1100-N	1312-N	151-N	1715-NA	184-NE-1
	1101-N	1313-N	1524-N	1716-NA	184-NE-2
	1102-N	1314-N	1525-N	1716-NE	184-NF
	1112-N	1315-N	153-N	1723-N	185-N
	1112-NA	1316-N	1614-N	1723-NA	1900-N
	1112-NB	1316-NA	163-N	1723-NX	MO-390
	1114-N	1316-NB	166-N	1734-N	MO-544
	1114-NA	1316-NC	1701-N	1802-N	MO-545
	1115-N	1317-N	1701-NE	181-N	MO-864
	1116-N	1325-N	1703-N	181-NC	MO-870
	1116-NB	1327-N	1705-N	183-N	MO-950
	1124-N	1330-N	1705-NA	183-NA	MO-999
	1158-N	1331-N	1706-N	183-NB	
	1158-NA	1332-N	1706-NA	183-NC	

Table 1-1. Summary of Facility Status in 100-N (March 2010)

Status (Total Number of Facilities)	Facility				
Inactive (25)	105-N[a]	117-N	1323-N	181-NE	1926-N
	105-NA	117-NVH	1605-NE	182-N	MO-868
	105-ND		1722-N	1908-N	
	105-NE	1303-N	1724-N	1908-NE	
	109-N[a]	1310-N	181-NA	1909-N	
	116-N[b]	1322-N	181-NB	1914-N	
Removed (75)	109-NB	1129-N	1143-NC	1156-N	1523-N
	1104-N	1130-N	1144-N	1157-N	1526-N
	1105-N	1131-N	1145-N	1157-NA	1702-N
	1107-N	1132-N	1145-NA	1159-N	MO-230
	1109-N	1133-N	1145-NB	1160-N	MO-231
	1111-N	1134-N	1146-N	1161-N	MO-374
	1113-N	1134-NA	1147-N	1162-N	MO-383
	1116-NA	1135-N	1148-N	1163-N	MO-391
	1117-N	1135-NA	1149-N	1510-N	MO-423
	1118-N	1137-N	1150-N	1512-N	MO-740
	1123-N	1140-N	1151-N	1513-N	MO-767
	1125-N	1141-N	1152-N	1514-N	MO-768
	1126-N	1142-N	1153-N	1520-N	MO-827
	1127-N	1143-NA	1154-N	1521-N	MO-846
	1128-N	1143-NB	1155-N	1522-N	MO-957
Total: 232 Facilities					

a. Facility being placed in ISS.

b. The 116-N Stack is considered Inactive because the below grade structure is still in place, even though the above grade structure has been demolished.

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

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

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

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

100-N Area D4 Progress

Facility D4* Status

- Initial Characterization in Progress
- Ready for Deactivation / Deactivation in Progress
- Ready for Demolition / Demolition in Progress
- Demolition & Loadout Complete
- Demolished prior to RCCC

Status Description

Initial Characterization in Progress
Historical site assessment and scoping surveys in progress.

Ready for Deactivation / Deactivation in Progress
Historical site assessment and scoping surveys complete. Work packages in place.

Ready for Demolition / Demolition in Progress
Haz. mat removal and equipment stripout complete. Sample analysis and waste profile complete.

* Deactivation, Decontamination, Decommissioning & Demolition

Demolition Progress

105N	181NE	1143N	~~1516N~~	~~1802N~~
105NA	~~181NC~~	~~1300N~~	~~1517N~~	~~1900N~~
~~105NB~~	182N	~~1301N~~	~~1518N~~	1902N
~~105ND~~	~~183N~~	1303N	~~1519N~~	1908N
105NE	~~183NA~~	~~1304N~~	~~1701N~~	1908NE
107N	~~183NB~~	1310N	~~1703N~~	~~13N~~
~~107N-105N~~	~~183NC~~	~~1312N~~	~~1705N~~	~~MO013~~
~~108N~~	~~183ND~~	~~1313N~~	~~1705NA~~	~~MO050~~
~~109N~~	~~184N~~	~~1314N~~	~~1706N~~	~~MO055~~
~~116N~~	~~184NA~~	~~1315N~~	1706NA	MO100
117N	~~184NB~~	~~1316N~~	~~1707N~~	~~MO358~~
117NVH	~~184NC~~	~~1316NA~~	~~1712N~~	MO403
~~119N~~	~~184ND~~	1322N	~~1714N~~	MO415
~~119NA~~	~~184NE~~	1322NA	~~1714NA~~	MO425
~~151N~~	~~184NF~~	1322NB	~~1714NB~~	MO426
~~153N~~	~~185N~~	1322NC	~~1715N~~	MO427
~~163N~~	186N	~~1330N~~	~~1716NE~~	~~MO900~~
~~166N~~	~~1112N~~	~~1331N~~	1722N	~~MO911~~
181N	1112NA	~~1332N~~	~~1723N~~	~~MO913~~
181NA	1120N	~~1515N~~	~~1723NX~~	~~MO992~~
181NB				

Note: Does not include status for all facilities in 100-N.

Figure 1-3. 100-N D4 Progress Demolition as of February 2010

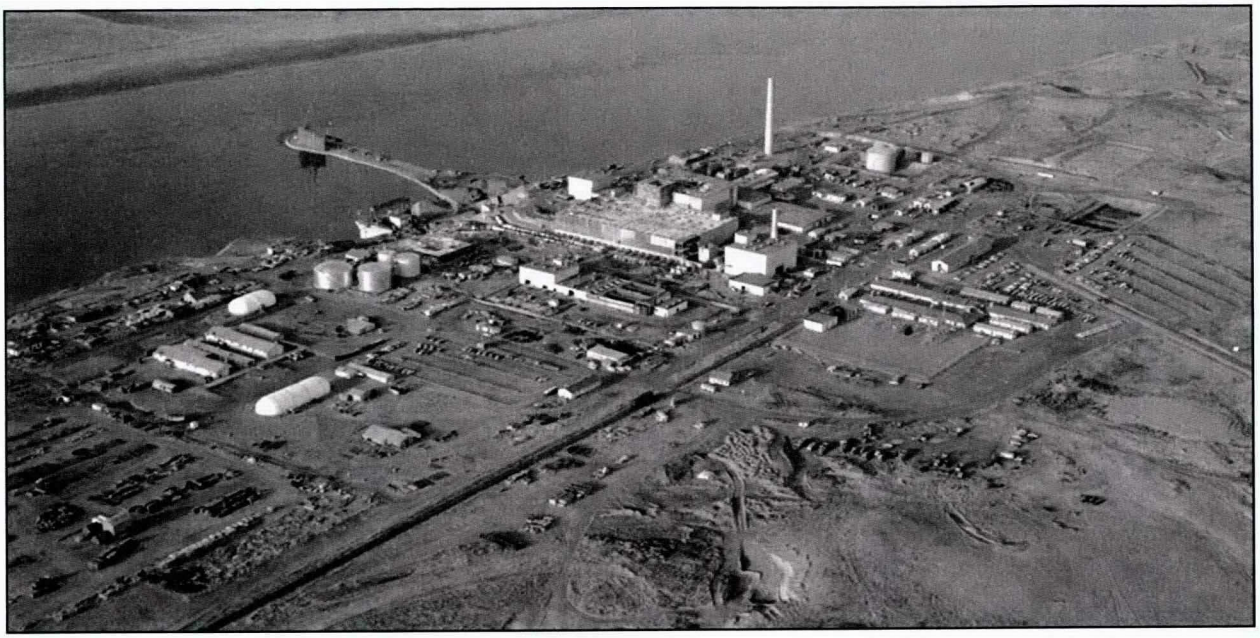


Figure 1-4. Aerial Photos of 100-N in 1962

Figure 1-5. Aerial Photos of 100-N in 2008 Displaying D4 Progress

1.2.2 100-N Waste Site Remediation

In 1996, the overall pace of the Hanford Site cleanup along the river accelerated. An expedited response action to address strontium-90 (Sr-90) groundwater contamination was implemented at N-Springs ("Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Richland, WA" [Butler and Smith, 1994]) and several interim action RODs were adopted for source and groundwater OUs in the various reactor areas. The primary focus for source OUs was former liquid effluent sites for which removal, treatment (as necessary), and disposal (RTD) is the standard remedy. The RTD was designed to achieve the remedial action objectives (RAOs) and goals specified in interim action RODs for direct exposure 0 to 4.6 m (0 to 15 ft) below ground surface (bgs)

and protection of groundwater and the Columbia River. However, the interim action RODs for the OUs located at 100-N were not adopted until 1999 and after (*Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington* [EPA/ROD/R10-99/112]; *Interim Remedial Action Record of Decision for the 100-NR-1 Operable Unit of the Hanford 100-N Area, Hanford Site, Benton County, Washington* [EPA/ROD/R10-00/120]; and *Explanation of Significant Difference for the 100-NR-1 Operable Unit Treatment, Storage, and Disposal Interim Action Record of Decision and 100-NR-1/NR-2 Operable Unit Interim Action Record of Decision, Hanford Site, Benton County, Washington* [EPA/ESD/R10-03/605]).

In accordance with the interim action ROD, each excavation has soil sampling and modeling (if needed) conducted to assess the potential impact to human health, groundwater, and the Columbia River from residual contamination. Every remediated waste site is sampled and analyzed as part of cleanup verification to demonstrate that remedial actions achieved the RAOs. Where remedial action goals and objectives are achieved, the waste site is considered interim closed.

Roughly, 474,000 metric tons (522,200 tons) of contaminated soil and debris have been removed from 100-N waste sites and more than 650 soil samples have been collected to verify cleanup and document interim closure status. Figures 1-6 and 1-7 show the excavations for two sites—the 116-N-1 (1301-N) and 116-N-3 (1325-N) Cribs and Trenches. These two liquid disposal facilities were the major sources of groundwater contamination.

Note: Picture taken in 2004.

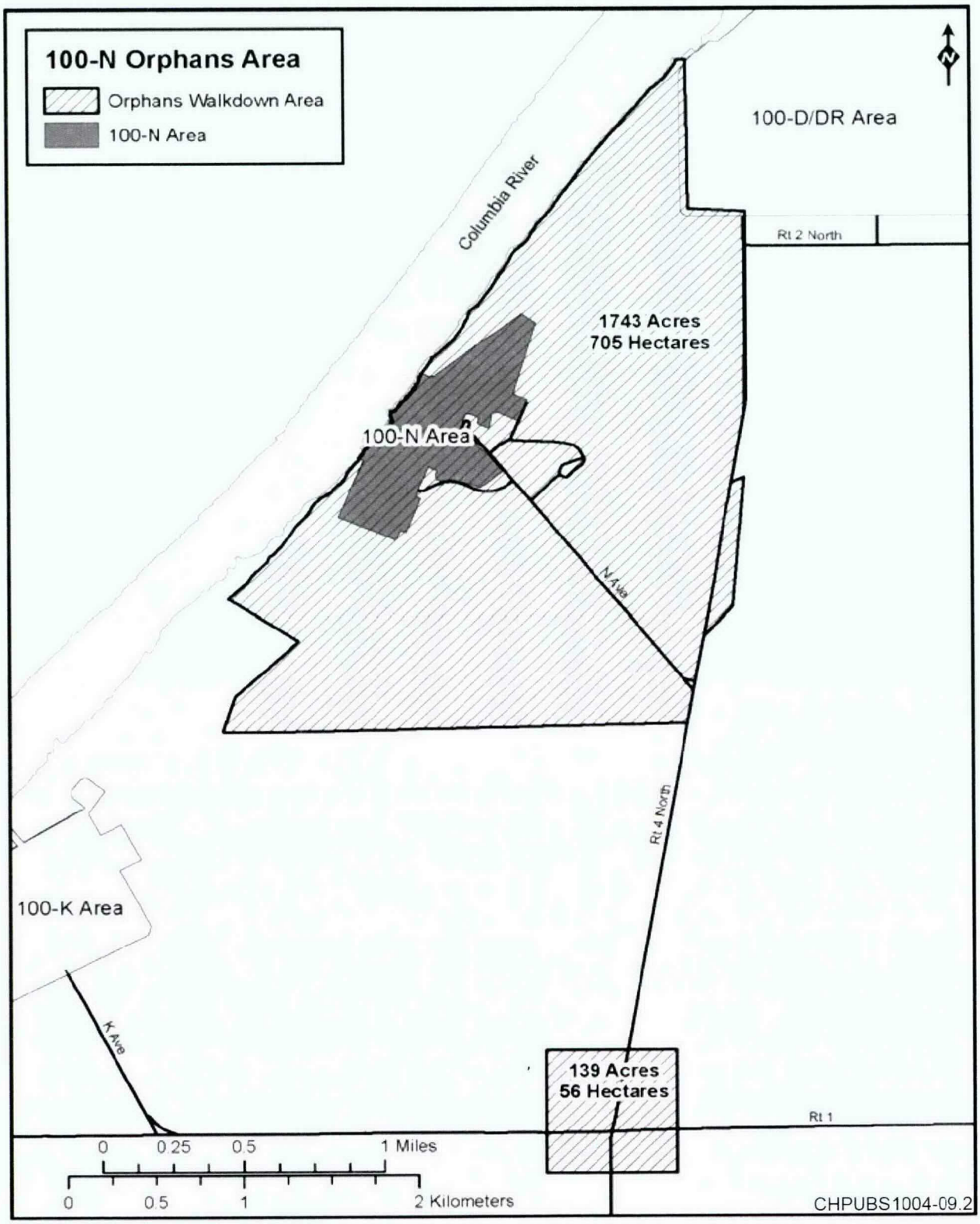
Figure 1-6. Excavation to Remove Contaminated Soil at 116-N-1 Crib and Trench

Figure 1-7. Excavation of Contaminated Soil at 116-N-3 Crib and Trench that Occurred 2000 to 2002

A total of 185 waste sites were identified in 100-N through March 2010 (Chapter 2, Table 2-3). The waste sites are categorized by their remediation status. These status categories generally indicate whether a site meets the cleanup goals and objectives of the interim action RODs. There were 17 interim closed waste sites and one closed waste site. As of March 2010, 129 accepted waste sites remain to be cleaned up in 100-N. Interim remedial actions are scheduled for completion by the end of 2011.

1.2.3 100-N Orphan Site Evaluation

An orphan site evaluation (OSE) was conducted on the highest potential impact areas of 100-N to identify unknown waste sites that may require additional characterization and possibly remediation (*100-NR-1 Area Orphan Sites Evaluation Report* [OSR-2009-0001, Rev. 0]). The OSE in the 100-NR-1 OU was conducted between August 2006 and March 2007. Chapter 2 provides a detailed description of the OSE process. The scope, shown in Figure 1-8, covered a total area of approximately 7.62 km^2 (2.94 mi^2) where 23 orphan sites were identified. These sites will follow the TPA-MP-14 process (*Tri-Party Agreement Handbook Management Procedures* [RL-TPA-90-0001]) and be addressed according to RODs or ROD amendments.



Source: OSR-2009-0001, Rev. 0

Figure 1-8. Area Addressed by 100-N Orphan Sites Evaluation Process

1.2.4 100-N Pump-and-Treat System

The widespread Sr-90 plume originated from two liquid waste disposal facilities (1301-N and 1325 N). The discharges to these two facilities resulted in riverbank seeps almost immediately after N Reactor operations began; the seeps were called N-Springs. The effect of releases at N-Springs to the Columbia River was initially monitored using 13 short, perforated, carbon steel casings located at the edge of the riverbank below the seepage face. Sr-90 levels as high as 9,100 pCi/L were recorded at N-Springs-3 in 1988, with the majority of the releases found between locations N-Springs-1 and N-Springs-6. *Technical Reevaluation of the N-Springs Barrier Wall* (BHI-00185) presents the groundwater conditions at N-Springs (circa 1994) that required the Expedited Response Action (ERA) described in the following paragraphs.

In January 1994, RL submitted to U.S. Environmental Protection Agency (EPA) and Ecology an engineering evaluation/cost analysis entitled the *N-Springs Expedited Response Action Proposal* (DOE\RL-93-23). The ERA Proposal evaluated multiple alternatives (reviewed and screened 5 technologies and 20 process options) to reduce the Sr-90 flux to the Columbia River. The ERA proposal recommended a vertical barrier composed of an 853.4 m (2,800 ft) long slurry wall constructed by a deep soil mixing method, to cut off Sr-90 contamination flux to the river. The ERA Proposal established a primary objective of eliminating, or significantly reducing, the flux of Sr-90 to the Columbia River through the N-Springs.

On February 22, 1994, an independent technical review report was made available for review and comment as part of the ongoing public comment period on the ERA Proposal (*Independent Technical Review of N Springs Expedited Response Action Proposal Hanford Site, Final Report* [ASI, 1994]). This report presented the conclusions of the panel of independent, third-party technical experts regarding the technical adequacy and conclusions of the N-Springs ERA Proposal. The independent review board expressed concern with many of the findings and conclusions in the ERA Proposal, including the assumed effectiveness of the pump-and-treat remedy, and noted uncertainty that the methods could achieve the estimated Sr-90 removal levels. A recommendation was made to reassess the potential constructability of a grouted, interlocked sheet pile wall, and the feasibility of constructing a barrier within 15.24 m (50 ft) of the Columbia River. These discussions were followed by "Action Memorandum: N-Springs Expedited Response Action Cleanup Plan" (Butler and Smith, 1994).

The Action Memorandum, dated September 23, 1994, required installing and operating a 189 L/min (50 gpm) pump-and-treat system by September 1995, and a grouted-hinge sheet pile wall at the edge of the river.

The Action Memorandum presented and recommended a new alternative based on the combination of public comments, the conclusions reached in the Independent Technical Review, and the information in the historical documents. In March 1995, Ecology and EPA concurred with RL that installing the sheet pile wall could not be achieved in the manner specified ("Re: USDOE Request to Change N Springs Action Memorandum" [Stanley and Sherwood, 1995]). Ecology and EPA subsequently directed RL to proceed with installing a pump-and-treat system as an ERA. The N-Springs pump-and-treat system was completed by August 1995 and in full operation by September 1995, meeting the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement [also known as TPA]) Milestone M-16-12D. Based on recommendations in *N-Springs Expedited Response Action Performance Evaluation Report* (DOE/RL-95-110) and *N-Springs Pump and Treat System Optimization Study* (DOE/RL-97-34), the system was upgraded to operate at 227 L/min (60 gpm) beginning on December 17, 1996. Under this configuration, the network consisted of four extraction wells (199-N-75,199-N-103A, 199-N-105A, and 199-N-106A) and two injection wells (199-N-29 and 199-N-104A), as depicted in Figure 1-9. The optimized extraction wells were located to reduce the flux of Sr-90 to the Columbia River along this seepage face. The Sr-90 was removed from groundwater by passage through vertical tanks containing clinoptilolite. When the tank(s) outflow indicated Sr-90, the compromised clinoptilolite medium was removed and replaced, then later disposed in the Environmental Restoration Disposal Facility (ERDF).

The pump-and-treat system captured water along the entire length of the 1301-N Trench and performed as designed during the optimization study. However, the system demonstrated a limited capability to remove Sr-90 from the aquifer and was terminated in March 2006 (*Hanford Federal Facility Agreement and Consent Order* [Ecology et al., 1989a]).

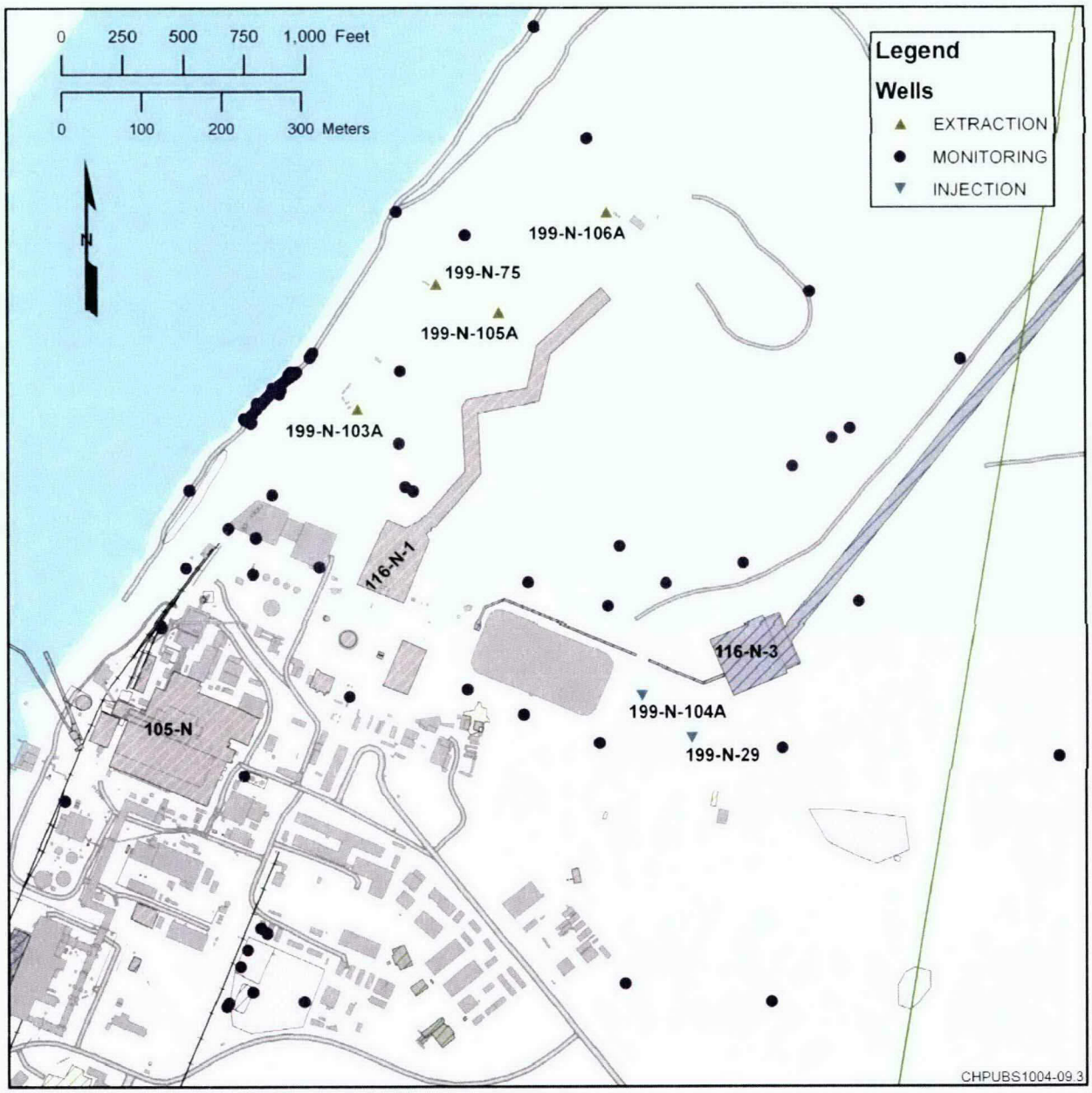


Figure 1-9. Location of the 100-NR-2 Pump-and-Treat System Wells (2008) Capture Zone Map

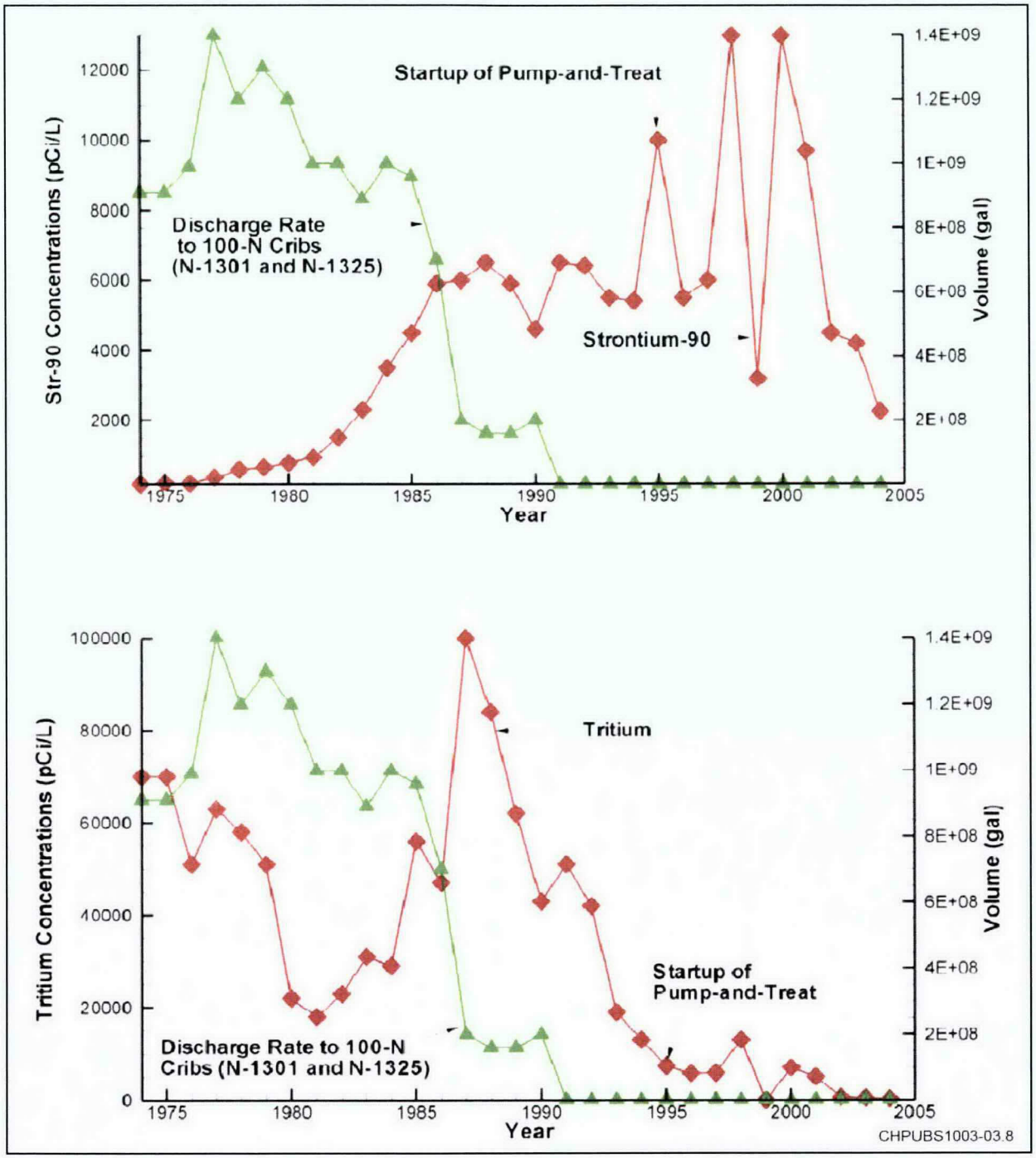
From September 1996 through March 2006, the pump-and-treat system in 100-N treated more than 1.1 billion L (305 million gal) of groundwater and removed approximately 1.8 Ci of Sr-90 from the aquifer in the 100-NR-2 OU (DOE/RL-2008-66). In 100-N, between 72 and 85 Ci of Sr-90 remain in the saturated sediment and 0.8 Ci in groundwater (*Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization* [PNNL-17429], and EPA/ROD/R10-99/112). *Strontium-90 Adsorption-Desorption*

Properties and Sediment Characterization at the 100 N-Area (PNL-10899) estimated that approximately 1,700 Ci remained in the vadose zone.

Despite the hydraulic containment provided by the pump-and-treat system, elevated Sr-90 concentrations near the shoreline have persisted since the beginning of pump-and-treat operations. Figure 1-10 illustrates the pump-and-treat system impact on groundwater Sr-90 concentrations at the riverbank. The green line shows that cribs discharges terminated in 1991. The red lines show the concentration history of Sr-90 and tritium in groundwater in Wells 199-N-8S and 199-N-46. These wells are adjacent, above the riverbank, and near the center where the Sr-90 plume intersects the river. This monitoring location reported estimated annual flux of Sr-90 and other contaminants to the river to comply with a National Pollutant Discharge Elimination System (NPDES) discharge permit (1301-N/1325-N cribs). During the operating years, water pumped from Well 199-N-8S was sampled continuously and composited for monthly analysis. After 1990, when water was no longer discharged to the soil column from N Reactor operations, periodic grab samples were collected from adjacent Well 199-N-46 (*CY 2004 Annual Summary Report for 100-HR-3, 100-KR-4 and 100-NR-2 Operable Unit Pump-and-Treat Operations* [DOE/RL-2005-18]). Concentrations steadily increased from 1980 until about 1989. Since that time, concentrations have fluctuated widely, presumably in response to river stage, sampling time, and/or date relative to water level. Nevertheless, near-shore pore fluid Sr-90 concentrations remain elevated. This observation confirms modeling results indicating that Sr-90 in the near-shore aquifer or stream bank storage zone will decline, primarily by radioactive decay. This observation can be illustrated by reviewing extraction rates for Well 199-N-103A (nearest the 100-N shoreline); pumping groundwater from this well did not cause a reduction in near-shore contaminant concentrations.

Tritium, a non-adsorbing co-contaminant, declined rapidly from the beginning of pump-and-treat operations through 2005, and remained at or below the detection limit (~200 pCi/L) in near-shore groundwater samples. Tritium remains elevated (average of about 20,000 pCi/L) in the pump-and-treat capture zone (*Calendar Year 2005 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operations* [DOE/RL-2006-08]). However, near-shore tritium concentrations have fluctuated much less within the capture zone than outside of it, providing some evidence that the predicted hydraulic containment functioned as designed. The tritium data for a near-shore well outside the capture zone (199-N-46) indicates significant tritium fluctuation until year 2000, after which observed tritium values have consistently decreased. Because the pump-and-treat began in 1995, the tritium decline beginning in year 2000 may not be entirely attributed to the pump-and-treat system operations.

Although the pump-and-treat system may have met the objective of reducing groundwater flow (and non-adsorbing co-contaminants) in the Sr-90 plume area to the river, it has not met the objective of reducing Sr-90 concentrations in aquifer pore fluid at the shoreline or in the stream bank storage zone. Minimizing exposure of eco-receptors in the near-shore aquatic and riparian zone to Sr-90, the primary 100-NR-2 contaminant of potential ecological concern (COPEC) (*Strontium-90 Treatability Test Plan for 100-NR-2 Groundwater Operable Unit* [DOE-RL 2005-96, Rev. 0, Reissue]), requires a different approach.



Note: Well 199-N-8S data were used until about 1995 when 199-N-46 sampling began (DOE/RL-2005-18, p. 4-25); operational discharge data are not included in the appendices.

Figure 1-10. Strontium-90 and Tritium in Near-Shore Monitoring Wells 199-N-8S and 199-N-46

1.2.5 Hanford N-Springs Sheet Pile Program Summary

Between December 2 and December 30, 1994, DOE-RL conducted a sheet pile installation test program. The objective was to evaluate the ability to drive sheet pile to a depth of 15 m (50 ft) along the proposed 914.4 m (3,000 ft) barrier wall alignment. Initial subcontractor attempts used vibratory hammers to install piling. After several failed efforts, a diesel impact hammer was attempted without success. It became

obvious that larger hammers would be required if the cobble and boulder laden soil was to be penetrated. Test pits confirmed that the formation consisted of cobble- and boulder-sized material that prevented penetration. A more powerful, variable energy hydraulic hammer was obtained and tested. Early indications appeared successful; however, after extraction, it was determined that the pile had reached only ~9 m (~30 ft) bgs. The high-energy impact hammer resulted in destroying the bottoms of the test piles. Three drive tests were completed with similar results: sheet pile destruction after penetrating ~9 m (~30 ft), yet 3 to 6 m (10 to 20 ft) short of the target depth objective clay unit. Adequate testing was performed to demonstrate that interlocking piling could not be driven to the clay layer and severe damage occurred at lesser depths. It was concluded that the Ringold Formation was not penetrable with standard sheet piling installation methods and a sheet pile barrier could only be installed after the in situ material was broken up and loosened prior to pile driving.

1.2.6 In Situ Treatability Test Planning Workshop Report

The following text is paraphrased from the planning workshop (*In Situ Treatability Test Planning Workshop Report* [BHI-00787]).

> *On May 1 and May 2, 1996, the U.S. Department of Energy (DOE), Richland Operations Office (RL) conducted a planning workshop for the In Situ Treatment Zone (ISTZ) treatability test. The proposed ISTZ was a 9 m 30 (ft) deep by 1 m (3 ft) wide by 30 m (100 ft) long trench filled with clinoptilolite, a naturally occurring zeolite mineral. The proposed location of the treatability test was along an access road, approximately parallel to the Columbia River at the shoreline. The ISTZ would be constructed by either conventional trench excavation with shoring systems, or by auger drilling with steel casings to provide the excavation and earth-support systems. The purpose of the ISTZ test was to provide an innovative, long-term remedial treatment for groundwater contaminated with Sr-90.*
>
> *The objectives of the treatability test were to demonstrate the feasibility of using ISTZ to accomplish the following:*
>
> - *Cause the Sr-90 to be adsorbed from the groundwater that passes through the zone*
> - *Delay Sr-90 from reaching the Columbia River*
>
> *The objective of the groundwater remediation alternative was to reduce the flux of Sr-90 to the Columbia River. In the short term, Sr-90 concentrations would be reduced as groundwater leaves the ISTZ and enters the Columbia River. In the long term, the delay would be sufficient for natural decay to occur so that the concentration levels would be below regulatory concern when the Sr-90 finally breaks through the ISTZ.*
>
> *Secondary objectives of the treatability test were to demonstrate:*
>
> - *Constructability*
> - *That the ISTZ test can be accomplished while preserving Native American cultural and religious values*
>
> *The workshop was attended by regulators, stakeholders, and several Native American tribes. Concerns centered on the following:*
>
> - *Constructability of the ISTZ*

- *ISTZ performance in preventing migration of Sr-90 to the Columbia River*
- *Native American Tribal cultural and religious values*
- *Applicability of an ISTZ in the 100-N Area*

Agreements reached and documented at the conclusion of the workshop included:

- *All parties agreed that the ISTZ could be constructed.*
- *All parties agreed that improved shoring would not be needed for the short-term ISTZ test.*
- *No riprap will be left along the Columbia River bank after the test.*
- *All parties agreed that the treatability test plan would be updated to reflect the results of the discussions associated with concerns noted during the workshop and in an earlier questionnaire.*
- *All parties agreed that a proposed upcoming CMS would address specific issues related to long-term implementation of the ISTZ, which are outlined in the concerns.*
- *All parties agreed that the ISTZ would be removed at the end of the test.*

Implementation of workshop agreements were deferred in deference to cultural and engineering concerns raised after completion of the workshop reports to DOE.

1.2.7 Innovative Treatment and Remediation Demonstration Program

In 1993, DOE initiated the Innovative Treatment and Remediation Demonstration (ITRD) Program in cooperation with EPA's Technology Innovation Office. The following text describing the results of that effort is paraphrased from the summary ITRD final report (*Hanford 100-N Area Remediation Options Evaluation Summary Report* [ITRD Program, 2001]).

> *In January 1998, the DOE Hanford Field Office requested ITRD technical assistance to evaluate innovative technologies to address strontium-90 (Sr-90) contamination in the vadose zone and in the groundwater at the 100-N site. The Hanford Environmental Restoration program asked that the ITRD project focus on identification of technologies for long-term implementation to enhance or improve the baseline design for groundwater remediation (pump-and-treat), and support the assessment of innovative approaches needing further evaluation for site-specific implementation.*
>
> *The ITRD formed and coordinated a Technical Advisory Group (TAG) with technology experts and participants from site-specific government, industry, and regulatory groups. At the beginning of the ITRD, contaminated soil had been removed to 4.6 m (15 ft) below average grade in the 1301-N and 1325-N liquid waste disposal facilities and disposed at ERDF, the pump-and-treat system at N-Springs was operational, and groundwater monitoring was continuing.*

The strength of the ITRD process rested in its review and evaluation of approximately 40 technologies, as shown in Table 1-2.

Table 1-2. Technologies Considered for 100-N Area through the ITRD Process

Technology	Type or Source
Electrokinetic shoreline w/surfactant	In situ
Soil flushing—aquifer/shoreline w/amendments	In situ
Permeable treatment wall—funnel and gate	In situ
Permeable treatment wall—zeolite/$CaSO_4$/phosphate/apatite	In situ
Permeable treatment wall—Fe^0	In situ
Chemical fixation—apatite/phosphate/sulfite/carbonate	In situ
Chemical fixation—modification of aquifer materials	In situ
Natural attenuation	In situ
Pump-and-treat	In situ
Passive hydraulic—barrier/hydraulic control	In situ
Contaminated zone—freezing with excavation	In situ
Phytoremediation	In situ
In situ vitrification	In situ
Oxidation of manganese	In situ
Injectable barrier—300-year flow path	In situ
Bioaccumulation (shellfish, oysters)	In situ
Impermeable barrier (chromium, sulfite, nitrate)	In situ
Chemical process	In situ
Recirculation wells	In situ
Jet grouting	In situ
Gel technology to form impermeable barrier	In situ
Slurry walls/grout curtains/sheet pile	In situ
Cryogenic barrier	In situ
Biologic barrier	In situ
Cryosweep	In situ
Total excavation	In situ
Mandrel	In situ
Jet grouting with reactive materials	In situ
Vibratory membrane filtration	Ex situ
Chemical process	Ex situ

Table 1-2. Technologies Considered for 100-N Area through the ITRD Process

Technology	Type or Source
Reverse osmosis/electrodialysis	Ex situ
Electrically switched ion exchange	Ex situ
3M filters	Ex situ
Hydrofracturing/pneumatic fracturing	Enabling Technologies
Cassette emplacement for barrier material	Enabling Technologies
Horizontal wells	Enabling Technologies
Cryogenic removal	Enabling Technologies
Monitored natural attenuation	Identified by TAG members
Phytoremediation	Identified by TAG members
Permeable clinoptilolite barrier	Identified by TAG members
Impermeable sheet pile/cryogenic barrier	Identified by TAG members

The TAG identified the general areas where more information was needed: aquifer geochemistry, desorption distribution coefficient (K_d), and fluctuating Columbia River stage impacts on contaminant flux to the river. The following reports describe the results of these studies:

- Bank Stability Evaluation (*Technical Memorandum for the 100-N Area ITRD Bank Stabilization Evaluation* [BHI—01324])
- Groundwater-River Interaction in the Near River Environment at 100-N (*Groundwater-River Interaction in the Near River Environment at the 100-N Area* [HydroGeoLogic, Inc., 1999])
- Use of Phosphatic Materials for Sr-90 Stabilization (*The Use of Phosphatic Materials for Hanford N-Springs 90-Sr Stabilization, Phase I* [Moody, 1999])
- Strontium Mobilization using Chemical Lixivants (*Report on Strontium Mobilization Using Potential Chemical Lixiviants at the Hanford 100-N Site* [MSE-49, 2000])

The treatment technologies evaluations led to the development of the following six remediation scenarios:

1. Monitored natural attenuation (MNA).
2. Permeable clinoptilolite barrier.
3. MNA on the river side of the barrier.
4. MNA and phytoremediation on the river side of the barrier.
5. Apatite seeds/liquid phosphate stabilization with impermeable barrier. Apatite on the river side of barrier, phosphate on inland side of barrier.
6. Soil flushing with impermeable barrier, phytoremediation on the river side of barrier, phosphate stabilization, and soil flushing on inland side of barrier.

7. Soil flushing with impermeable barrier, natural attenuation on the river side of barrier, liquid phosphate stabilization, and soil flushing on inland side of barrier.

The evaluation process narrowed the above field to five potentially useful technologies: a Clinoptilolite Permeable Barrier, a Sheet Pile/Cryogenic Impermeable Barrier, MNA, Phytoremediation, and Soil Flushing. The two barrier technologies, permeable and impermeable, would be constructed along the riverbank and used in conjunction with the other three technologies. The TAG evaluated the other four technologies in detail and made the following conclusions and recommendations:

- **Monitored Natural Attenuation.** The short half-life and strong sorption of Sr-90 make this an attractive option. Hydrogeologic modeling provides the basis for predicting that movement of Sr-90 is slow and flushing by interaction with fluctuating river stages will not remove substantial amounts of Sr-90 from the riverbank. This remediation method may be appropriate for the portion of the plume far from the river but will do little to limit the current discharges of Sr-90 at the N-Springs that are currently in excess of the regulatory limit. Long-term monitoring strategies are needed; these may emerge as part of DOE efforts to establish protocols for Long-Term Stewardship (LTS). The site meets the criteria established by DOE for MNA. We recommend that, when LTS protocols are established, this option should be examined in more detail.

- **Soil Flushing.** This remediation option is likely to be effective in removing both radioactive and nonradioactive Sr-90 from the site in the least amount of time. Modeling calculations indicate it is possible to build a wellfield, then detect and control potential excursions. Long-term monitoring may still be required after the flushing is nominally completed; it is recommended that this issue be examined in more detail in consultation with regulators.

- **Phytoremediation.** The technology did not receive a detailed analysis in this study. However, it may be the best option for controlling current releases of Sr-90 at the river. Leaf litter control may be an issue; however, it may be suitable for a 30-year period to control the riparian zone while MNA or stabilization is used to control those portions of the plume further from the river.

- **Stabilization of Sr-90 by Phosphate Injection.** This option was examined in this study but removed from further consideration by a TAG subcommittee. The work done at the time under contract to ITRD to design a stabilization system was insufficient to support recommendation of this option. Phosphate solid injection and co-precipitation were found to remove Sr-90; however, the vendor did not provide sufficient design information or explain inconsistent results for contrasting behavior of radiogenic and stable strontium.

The TAG did not conclude the method should be abandoned. It was recognized that it might be possible to create a long-term barrier in areas of the plume using phosphate stabilization. Current work in the DOE Tanks Focus Area provided new data that encouraged re-examination of this option, which occurred subsequently, as described in the following paragraphs.

1.3 Current Groundwater Remediation Approach

Since the completion of the ITRD Report, several important developments have occurred (*Evaluation of Strontium-90 Treatment Technologies for the 100-NR-2 Groundwater Operable Unit* [CH2M HILL, 2004]). The TAG determined that soil flushing was not a feasible option, primarily because of the massive volumes of lixiviant required for injection and removal, and the problems inherent in treating and disposing large volumes of radioactive wastewater.

Interest was renewed in strontium stabilization by phosphate injection (chemical injection) based on reports of successful bench testing at Sandia National Laboratory. Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratory scientists presented the merits of apatite sequestration and phytoextraction at a workshop in August 2003. Because of the potential for these technologies to remove or sequester Sr-90 from the riverbank sediments, DOE funded two laboratory studies at PNNL in fiscal year (FY) 2004 to determine their appropriateness for the 100-NR-2 OU:

- Phytoextraction of Sr-90 at Hanford 100-N
- Sr-90 sequestration by apatite at Hanford 100-N

Currently, a chemical barrier composed of apatite is being tested as a primary treatment technology and phytoextraction as a secondary treatment or "polishing" step.

1.3.1 Apatite Barrier Installation

At 100-N, innovative technology is being tested to fix mobile Sr-90 in a chemical barrier formed in situ after injected into the aquifer. The description of the apatite barrier provided is from *Hanford 100-N Area Apatite Emplacement: Laboratory Results of Ca-Citrate-PO4 Solution Injection and Sr-90 Immobilization in 100-N Sediments* (PNNL-16891). This technology reduces the disruption that would be caused by installing slurry or clinoptilolite barriers. The method creates a chemical filter allowing groundwater to pass unimpeded while providing dissolved Sr-90 access to the mineral apatite. Apatite (a stable mineral found in rocks, teeth, and bone) contains calcium and phosphate and has a strong affinity for substituting strontium into its mineral structure. Scientists proposed injecting apatite-forming elements directly in groundwater (DOE/RL-2005-96, Rev. 0, Reissue). The apatite incorporates the Sr-90 in the mineral matrix, thereby preventing further migration. Figure 1-11 shows the test site where the apatite barrier technology is being developed. Because initial testing proved successful, the full scale expansion was implemented.

The apatite barrier in subsurface sediments at 100-N is constructed by injecting an aqueous solution containing a Ca-citrate complex and Na-phosphate into the groundwater. Citrate is needed to keep Ca in solution long enough (days) to allow the injected solution to spread through the Sr-90 contaminated aquifer. The relatively slow biodegradation of the Ca-citrate complex (days) allows sufficient time to disperse the reagents through the aquifer where treatment is required. As Ca-citrate degrades, the free Ca and phosphate ions combine to form amorphous apatite, as shown in Figure 1-12. Amorphous apatite formation occurs within one week and crystalline apatite within a few weeks. Apatite minerals are very stable and practically insoluble in water. The Sr-90 rapidly adsorbs onto the mineral surfaces and then slowly substitutes for Ca in the mineral matrix over a period of months.

The timing of injections is very important to achieving the residence times needed for apatite formation in the aquifer. The rate of water movement in the Hanford formation can be up to 10 times faster than observed in the Ringold Formation, and flows in both formations respond to water elevations related to Columbia River stage. To address this problem, the current plan is to inject the Ca-citrate-phosphate solution separately into the Hanford formation and Ringold Formation unit E sediments. Simulations of injections into the lower (less transmissive) Ringold Formation at sustained low and high river stage reveal the river stage does not move the Ca-citrate-phosphate injection plume a significant distance before apatite is precipitated. Therefore, injections into the Ringold Formation unit E are best at lower river stages (late fall) to get apatite movement toward the river, but the effort is not time dependent.

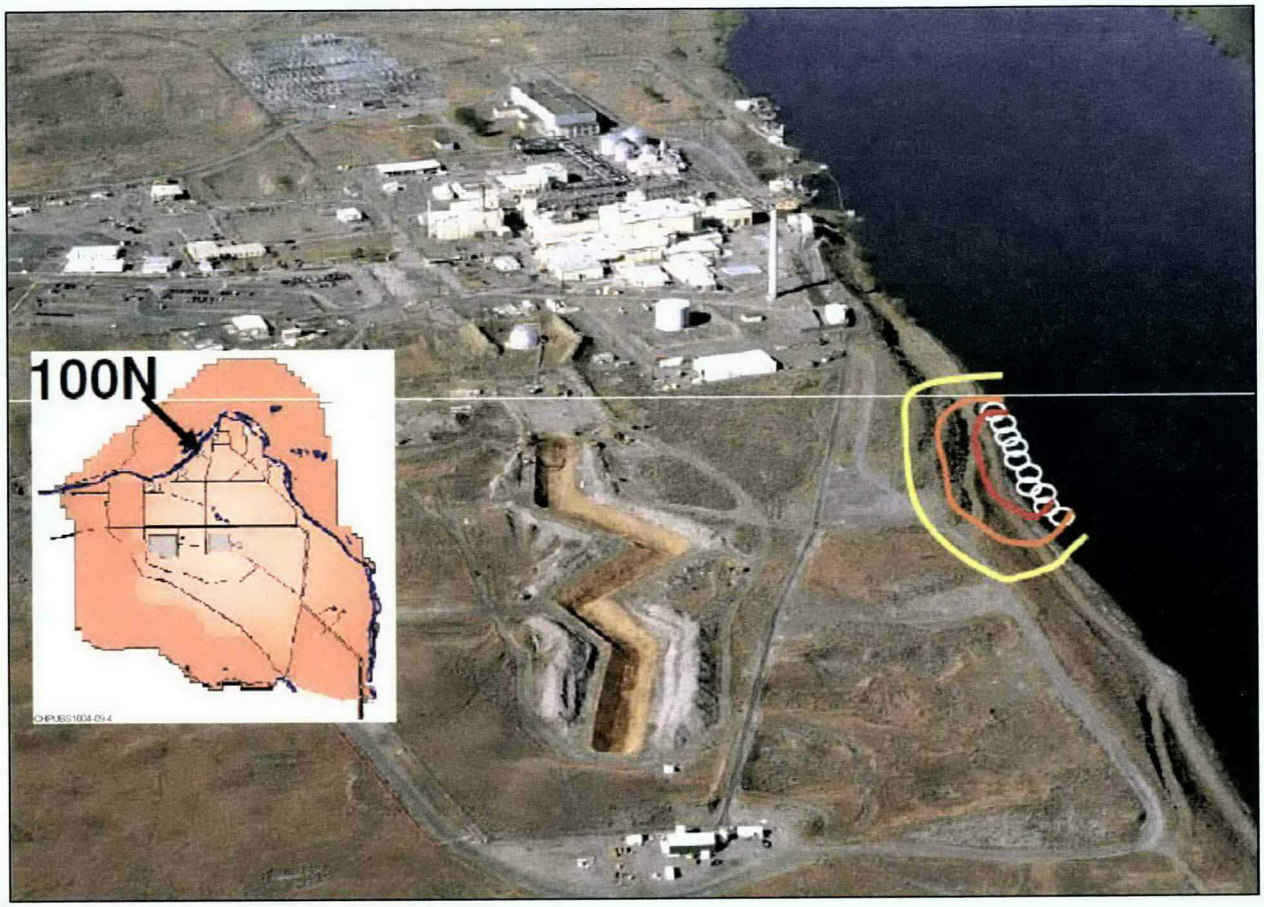


Figure 1-11. Apatite Barrier Technology Test Site Adjacent to the Columbia River at 100-N

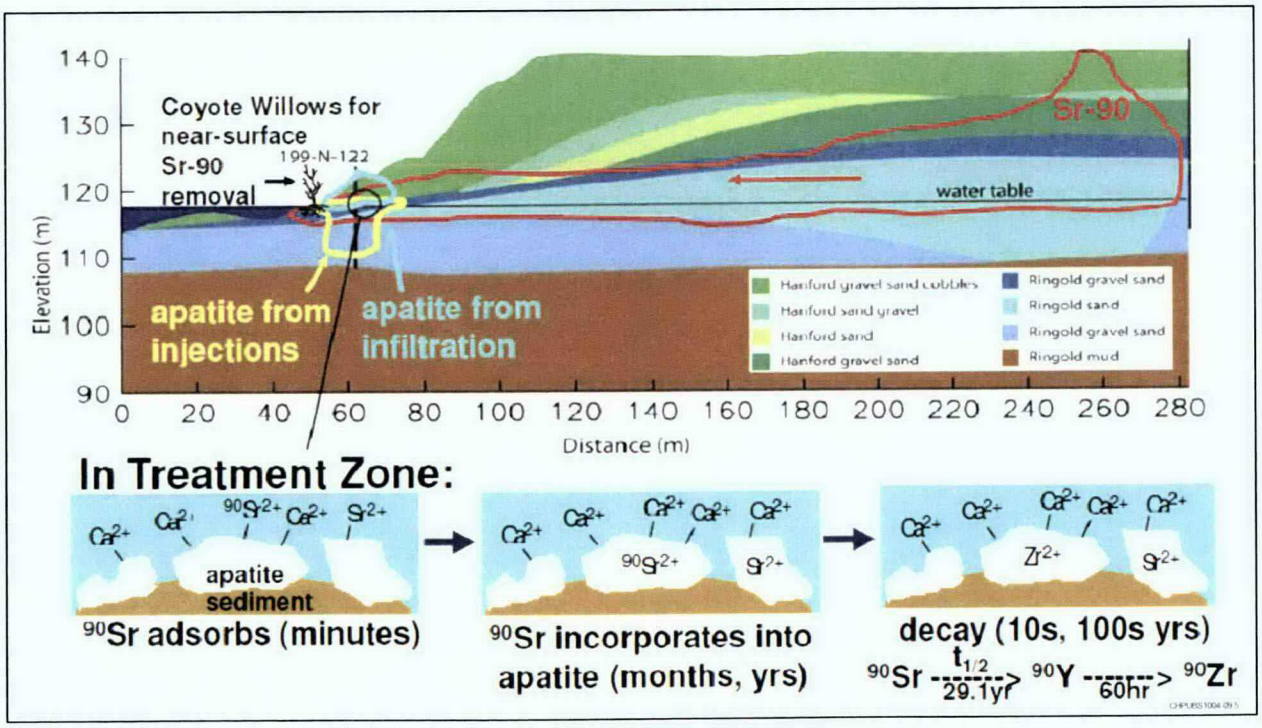


Figure 1-12. Theoretical Formation of an Apatite Chemical Barrier for Sr-90 Removal

In contrast, apatite-forming solution injection into the Hanford formation rewetted zone needs to be done during high river stage (late spring) so the formation is water saturated. In addition, because solution movement toward the river is desired, it would be advantageous for the injection to occur at a high river stage (saturating as much of the intermittently rewetted zone as possible) followed by a moderate river stage, to get slow flow toward the river.

In July 2005, the plan to inject apatite-forming chemicals into the soils beneath selected closed waste sites was completed. The plan focused on soil and groundwater along approximately 91 m (300 ft) of the Columbia River. This 91 m (300 ft) represented the area of highest Sr-90 concentration along the bank of the Columbia River. Testing was launched in 2006.

Throughout 2006 and 2007, a low-concentration, apatite-forming solution was injected through 10 wells into the test area shallow groundwater. The objective of the low concentration, Ca-citrate-phosphate injections was to stabilize Sr-90 in the aquifer at the test site. The results and experience from the low concentration injections led to the design for higher concentration injections (PNNL-17429). During summer 2008, 16 wells were injected using adjusted techniques and chemical mixes. Apatite is slow to incorporate Sr-90 under field conditions. The apatite barrier was extended during 2010 based on the monitored results. The high chemical mixture concentration has been decreasing slowly in some areas (*100-NR-2 Apatite Treatability Test FY09 Status: High Concentrations Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization: Interim Report* [PNNL-SA-70033]).

Despite these challenges, the monitoring data are encouraging, revealing that apatite is forming and Sr-90 is being adsorbed as designed. Sr-90 concentrations, based on gross beta, fell below baseline levels in 19 of 20 wells. Data indicate Sr-90 in the remaining well, while exhibiting levels above baseline minimum values, is on a downward trend.

The average reduction in Sr-90 concentrations at four compliance monitoring wells was 95 percent relative to the high end baseline range, and 84 percent relative to the low end, indicating the performance objective specified in the treatability test plan (90 percent reduction in Sr-90 concentration) after one year of treatment (PNNL-SA-70033 and *100-NR-2 Apatite Treatability Test: high-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization* [PNNL-19572]).

An evaluation of sediment core samples that were collected in November 2009, approximately one year after the high-concentration treatments, was used to quantify the amount of apatite formation resulting from the sequential low- followed by high-concentration treatments performed to date. Average phosphate for three boreholes (both Hanford and Ringold formations) was 68 percent of the injected mass (*Hanford 100-N Area In Situ Apatite and Phosphate Emplacement by Groundwater and Jet Injection: Geochemical and Physical Core Analysis* [PNNL-19524] and PNNL-19572).

An additional pilot-scale test was conducted in December 2009 to evaluate potential strategies for using jet injection technology to emplace an apatite permeable reactive barrier (PRB) in the vadose zone and upper unconfined aquifer. The test consisted of three distinct treatment zones using three different media: a phosphate-only solution, preformed apatite, and the same phosphate solution with preformed apatite. The pilot-scale test was conducted upstream of the existing apatite PRB. The objective of the jet injection pilot-scale demonstration was twofold: evaluate the ability of the technology to deliver the different material/chemical solutions into the vadose zone and upper unconfined aquifer within three distinct treatment zones in the 100-N shoreline, and evaluate the ability of the methods to install a PRB in the vadose zone containing a specific amount of apatite (4 mg apatite/g sediment) (*Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit* [SGW-47062]).

Both objectives of the test were met. Jet injection technology was successfully used to emplace three different media in the vadose zone and upper unconfined aquifer. Collection and analysis of post-injection sediment cores enabled evaluation of apatite emplacement within the vertical sediment column. Apatite emplacement at concentrations equal to or greater than 4 mg apatite/g sediment was observed.

The apatite technology treatability testing results are showing great promise as a remediation option. As a result, DOE proposed in June 2009 to amend the existing interim remedial action ROD for the 100-NR-1 and 100-NR-2 OUs (IROD) (EPA/541/R-99/112) to include as an interim remedial action the expansion of the existing apatite PRB to a total length of approximately 762 m (2,500 ft) in the aquifer and the vadose zone. The resulting Amendment to the IROD (IROD Amendment) was issued in September 2010 and allows for this proposed expansion.

The implementation of the interim remedy apatite barrier expansion will be conducted under a revision to the 100-NR-2 OU interim action remedial action/remedial design work plan (Interim RD/RA Work Plan) (*Remedial Design/Remedial Action Work Plan for the 100-NR-2 Operable Unit* [DOE/RL-2001-27]) that is under development and due to be submitted as a draft to Ecology by March 2011.

Immediate plans to optimize this apatite barrier technology prior to full-scale expansion will initially move forward under two approved design optimization studies (DOS), the barrier expansion DOS (*Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit* [DOE/RL-2010-29]) and the jet injection DOS (*Jet Injection Design Optimization Study for the 100-NR-2 Groundwater Operable Unit* [DOE/RL-2010-68]).

1.3.2 Phytoextraction

Phytoextraction is a managed remediation technology in which plants are used to extract or bind soil contaminants. The coyote willow is the most suitable plant to use along the Columbia River shore due to its rapid and robust regrowth abilities. The coyote willow is extensively used for bank stabilization and revegetation purposes along the Columbia and Yakima Rivers.

Coyote willows were successfully cultivated along the Columbia River shoreline during the past three years. In the remedial technologies chain aimed at treating Sr-90, phytoextraction using coyote willow is a polishing step in these multiple processes protecting the river.

A phytoextraction technology test conducted at an uncontaminated area at 100-K (Figure 1-13) is now complete. The next step develops methods for safely planting, tending, and harvesting the willows along the riprap covering the 100-N Sr-90 contaminated shoreline. These shrubs will help restore the environment by removing Sr-90 from groundwater and the vadose zone through the riparian zone (the interface between land and a stream).

An extended apatite barrier (previously described) is constructed and designed to immobilize Sr-90 near the river or expected to move toward the river over the next 300 years. The phytoextraction treatment system along the riparian zone of the Columbia River may be constructed to address Sr-90 in the vadose and saturated zones. With the apatite barrier fully functional, the coyote willow would extract Sr-90 from the riparian zone, and then would be discontinued.

The key to using phytoextraction as part of the treatment, besides the treatable sediment volume, is biomass production. The focus determined whether the technology is usable, and involved two major objectives:

1. Determine the most efficient fertilization method for coyote willow to generate the greatest possible biomass while protecting the Columbia River from excess nutrient runoff.
2. Demonstrate coyote willow efficacy as a phytoextraction tool along the riparian zone.

Figure 1-13. Coyote Willows Growing in the Test Plot in 100-K

The study began in late spring 2007, with 50 coyote willow starts planted in a fenced area at 100-K. This part of the study targeted plant growth rather than phytoextraction capabilities, so 100-K, which was not contaminated with Sr-90, was well suited as a host location. Often flooded by the annual high Columbia River stage well into June, this site is a severe test for the ability of the willow shrubs to survive realistic field conditions.

During the first year of the test, relatively little growth occurred while the plants became established and developed root systems. In October 2007, the plants were pruned down to the trunk plus primary branches. Forty-nine of the 50 plants survived the winter. In May and June 2008, the site was once again flooded and serious growth began in July. The second year harvest was completed in October 2008. The average biomass was 369 percent greater than the first year at about 340 kg (750 lb) per acre, which was in line with predictions.

The stem and foliage of coyote willows accumulating Sr-90 will present not only a mechanism to remove the contaminant but also will be viewed as a source of nutrition for natural herbivores and, therefore, a potential pathway for the isotope to enter the riparian food chain. Management of the willows will include a series of engineered barriers: large and small animal fencing will control herbivores intrusion such as deer and rodents, bird intrusion will be minimized by placing netting over the top of the enclosure, and detritus (leaves and twigs) will be retained by fencing and removed on a regular basis. A recent study concluded the risk for detectable transfer of Sr-90 from willow trees growing in the contaminated soil along the 100-N shoreline through the food chain of herbivorous insects is slight to

nonexistent (*100-N Area Strontium-90 Treatability Demonstration Project: Food Chain Transfer Studies for Phytoremediation Along the 100-N Columbia River Riparian Zone* [PNNL-18294]).

If the coyote willow continues to perform over the coming year, the next step may be testing at 100-N in actual Sr-90 contaminated soil through a stand-alone treatability test plan. Methods for safely planting, tending, and harvesting the willows along the riprap covering the shoreline will need to be developed.

1.3.3 Petroleum Removal

Soil and groundwater petroleum contaminant removal in 100-N is being performed to protect the Columbia River, currently within a limited scope, with the majority of petroleum removal planned for 2011. Petroleum in the vadose zone and groundwater is primarily from a 1966 diesel fuel leak of more than 302,833 L (80,000 gal) (DOE/RL-95-111) associated with the 166-N Tank Farm (Figures 1-14, 1-15, and 1-16). Other petroleum releases consisting of significantly smaller volumes occurred over time. Because of these leaks, petroleum is present in soil and groundwater as free product. Free product petroleum contamination consists of a fraction that floats on groundwater, in addition to a dissolved fraction.

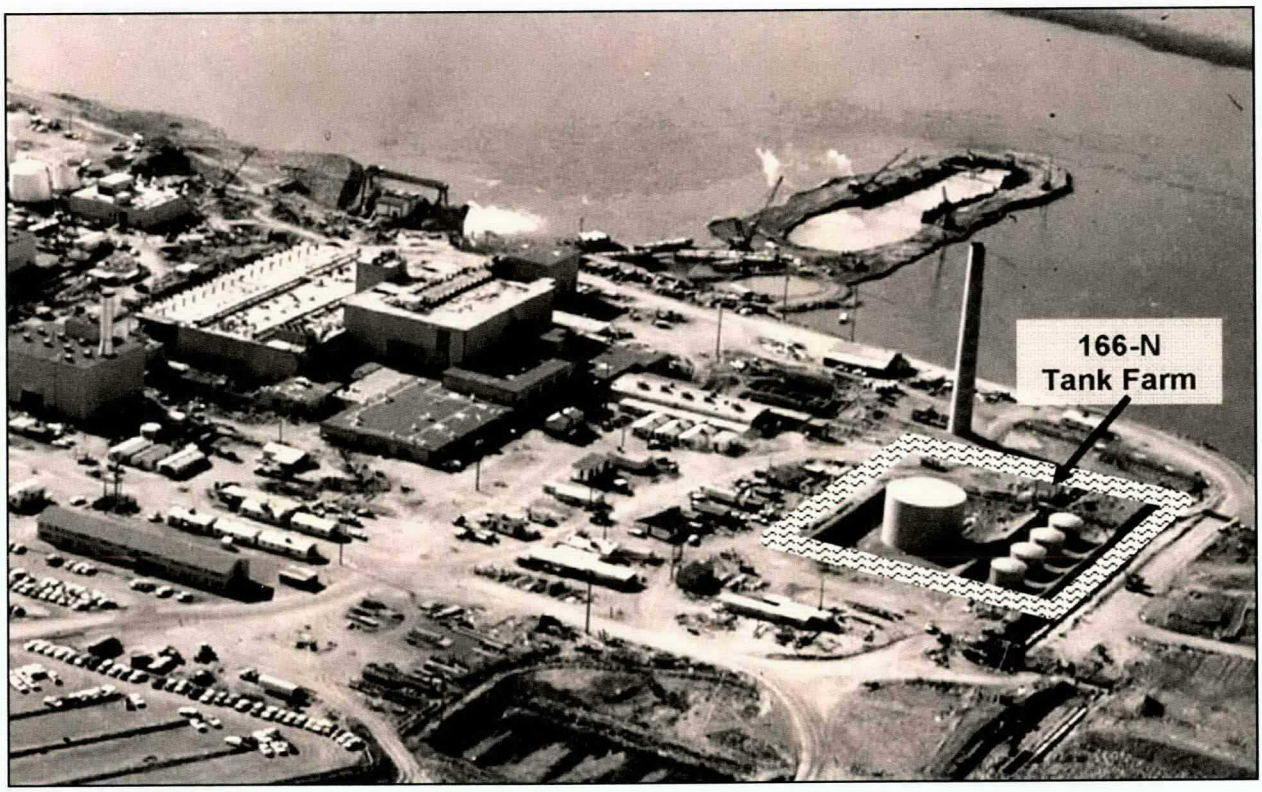


Figure 1-14. 166-N Tank Farm Facility (Early 1960s)

The petroleum hydrocarbon (diesel) plume is shown in Figure 1-15. It is confined to a relatively small area in 100-N, centered on Well 199-N-18 (16,000 µg/L), with detections of total petroleum hydrocarbon-diesel range (TPH-DR) found in seven other nearby Wells—199-N-167 (3,100 µg/L), 199-N-169 (1,100 µg/L), 199-N-170 (360 µg/L), 199-N-171 (2800 µg/L), 199-N-172 (2,400 µg/L), 199-N-173 (2,100 µg/L), and 199-N-96A (260 µg/L).

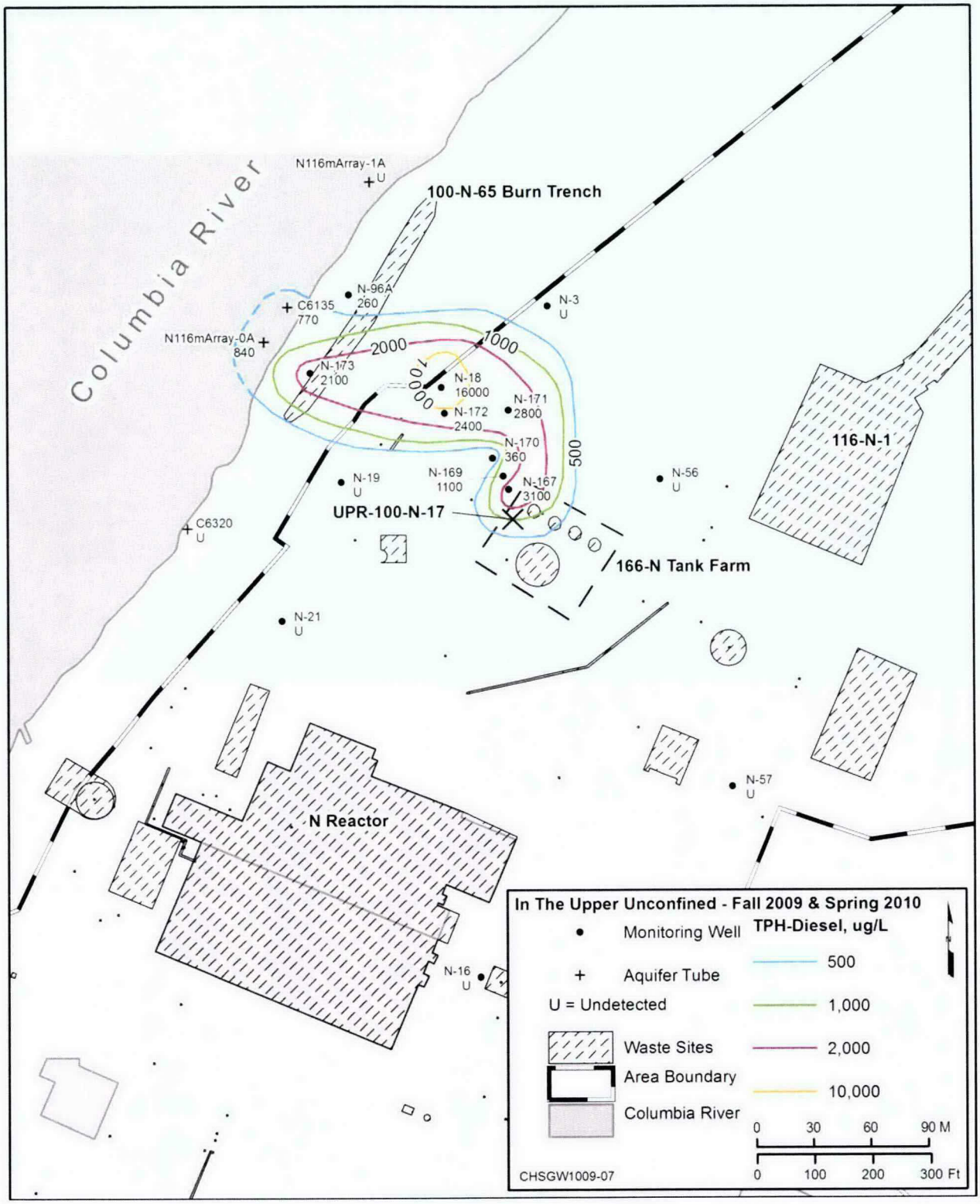


Figure 1-15. Petroleum Concentrations near the 166-N Tank Farm Facility

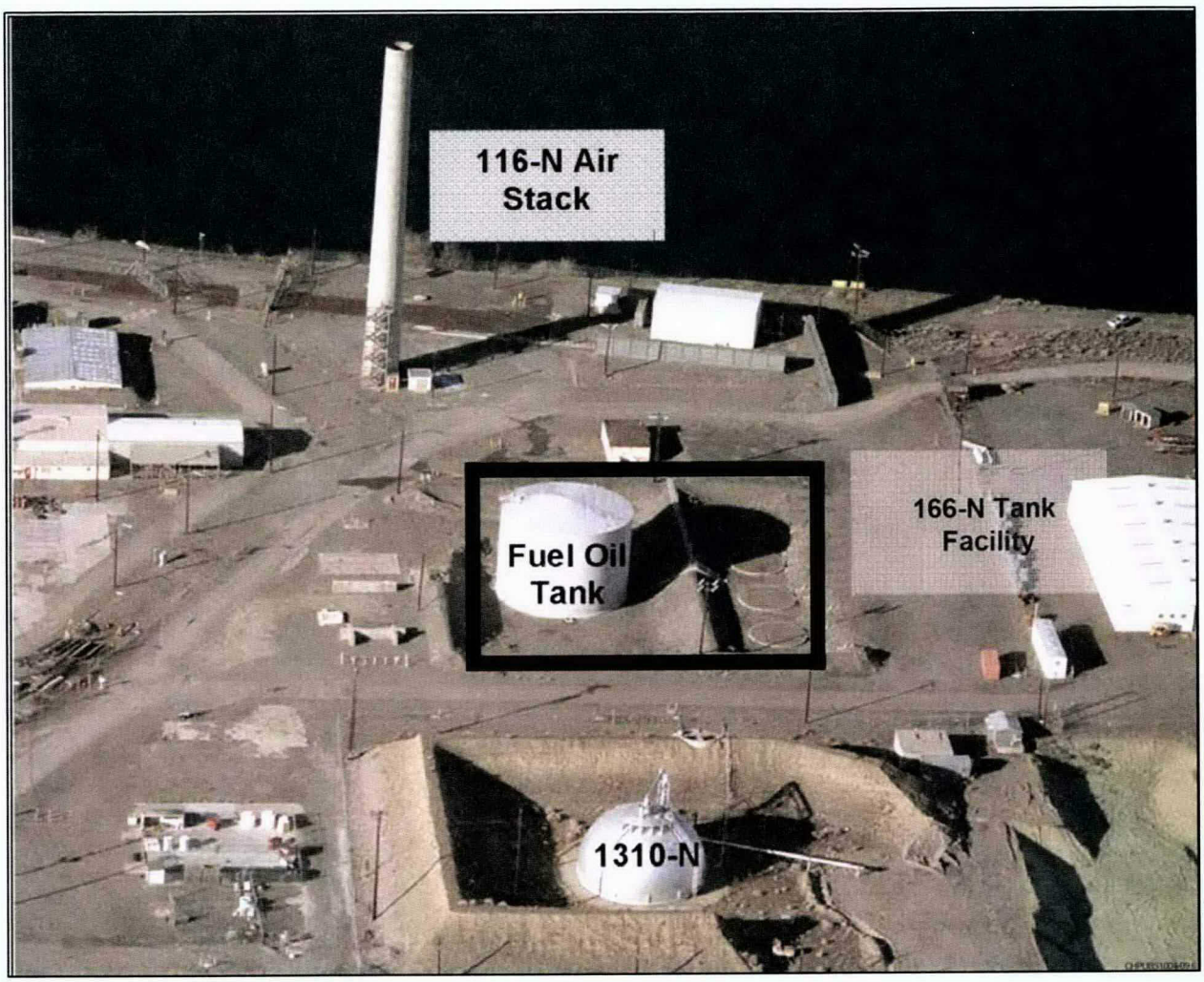


Figure 1-16. 100-N Tank Farm Facility (1990s)

DOE continued a remedial action to remove free product (diesel) from Well 199-N-18. The passive remediation involves the use of a polymer "Smart Sponge®" that selectively absorbs petroleum products off the surface of water. Every two months, two of the sponges are lowered just into the water table, in Well 199-N-18. The sponges are weighed prior to emplacement in the well and when they are removed from the well. The difference in weight between the two measurements is the amount of "product" or diesel fuel contamination removed from the well. Table 1-3 shows the results of this remediation activity since it was started in 2003. Removal of product from Well 199-N-18 will continue, per requirements in the interim ROD for 100-N (EPA/ROD/R10-99/112).

Evidence of low levels of hydrocarbon contamination has been observed in other wells in the past, including 199-N-3, 199-N-16, and 199-N-19 (*Hanford Site Groundwater Monitoring for Fiscal Year 2002* [PNNL-14187]). These wells had no detectable TPH-DR in 2009. Other wells near the plume also had no detectable TPH-DR in 2009 (199-N-21, 199-N-56, 199-N-57, and 199-N-64).

® Smart Sponge is a registered trademark of AbTech Industries, Inc., Scottsdale, Arizona.

Table 1-3. Hydrocarbon Product Removed from Well 199-N-18 (2003 to 2009)

Year	Product Removed (g)	Notes
2003	~1,200*	Estimate provided per information given in note below; data records lost when original work package was lost in the field
2004	3,475	Changed out twice a month
2005	780	Changed approximately every two months
2006	1,370	Changed every two months
2007	1,294	Changed every two months
2008	920	Changed every two months
2009	1,380	Changed approximately every two months
Total	**10,419**	**Total removed through end of 2009**

* *Calendar Year 2003 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit (OU) Pump & Treat Operations* (DOE/RL-2004-21) reports product removal started in October 2003. DOE/RL-2005-18 states that the average mass removal for FY 2004 (10-2003 to 10-2004) was approximately 0.4 kg/month, so an estimate is provided for the three months missing in CY 2003.

Aquifer tubes near the southern portion of 100-N shoreline are sampled for TPH-DR. In 2009, only tubes C6135 and N116m Array-0A had detections of TPH-DR, with values of 770 µg/L and 840 µg/L, respectively.

Chapter 2, Section 2.3.1, provides additional discussion of the diesel plume.

Data from historical work and other ongoing efforts (*Bioremediation Well Borehole Soil Sampling and Data Analysis Summary Report for the 100-N Area Bioremediation Project (UPR-100-N-17)* [WCH-370]) will be used in the RI/FS when available in time to support the schedule for completion of the RI/FS.

A Phase I Bioremediation pilot system, which was installed in FY 2009 to address petroleum in the soil, is operational in 100-N. Bioremediation is the breakdown of petroleum to innocuous byproducts by naturally occurring bacteria in the environment, a well-established remedial method for petroleum. The form of bioremediation elected for this pilot testing is bioventing, injecting air into the vadose zone to facilitate bioremediation by native biota. Bioventing increases oxygen in the subsurface, which stimulates the growth of bacteria that survive in an oxygen-rich environment. These bacteria are highly effective in breaking down the petroleum compounds into innocuous byproducts.

The pilot study includes seven bioremediation vadose wells conducting bioventing tests. Data collected from this study will be used to evaluate the potential applicability of bioremediation to meet cleanup goals for the petroleum waste sites at 100-N and support design of a possible large-scale bioventing system to address vadose zone petroleum.

Additional characterization of petroleum in the 100 Area is ongoing, including a well installation between the tank farm and the river in March 2009 (199-N-173). Several wells are being sampled to gather more information on the nature and extent of the petroleum hydrocarbon plume. These include 199-N-173, 199-N-96A, 199-N-18, 199-N-19, 199-N-21, 199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172. Seventeen 7.6 m (25 ft) injection well and four 7.6 m (25 ft) monitoring well completions installed for the upriver extension of the apatite PRB were sampled in the spring of 2010 for diesel and

diesel-degradation products. The additional characterization results will provide data to support assessments for ecological risk and other remedial technologies.

Should the apatite barrier, phytoextraction, or petroleum removal actions discussed in these subsections be incorporated into the next ROD for 100-N, they would be managed and maintained through the *Hanford Long-Term Stewardship Program Plan* (DOE/RL-2010-35, Rev. 0). This program responsibility begins for a geographic area (e.g., 100-N and 100-D/H) when remedy cleanup objectives and goals are met, as defined by applicable CERCLA and RCRA decision documents. The program includes post-cleanup obligations such as the maintenance of remedies and institutional controls, the conduct of CERCLA five-year reviews, and the operation and maintenance of groundwater treatment systems that are operational and functional. In addition, the program includes managing the site's cultural, biological, and natural resources. The *Hanford Long-Term Stewardship Program Plan* presents detailed information about this program.

1.3.4 Aquatic and Riparian Impact Assessment

An initial assessment of the current impacts of contaminated groundwater plumes on aquatic and riparian zones within the 100-NR-2 OU was conducted in 2005. This summary is based on information described in DOE/RL-2006-26.

This assessment was one component of the selected remedy described in the Interim Remedial Action ROD for the 100-NR-1 and 100-NR-2 OUs (EPA/ROD/R10-99/112). Historical data and new data obtained during 2005 were used for this impact assessment. For the evaluation, water, sediment, soil, and aquatic and terrestrial biota were collected during calendar year (CY) 2005 and analyzed for COPECs, including Sr-90, uranium, technetium-99 (Tc-99), heavy metals, polychlorinated biphenyls (PCBs), and petroleum hydrocarbons.

The impact assessment parameters and data used during the assessment consisted of the following:

- Whole body and tissue dose calculations for radionuclides (primarily Sr-90)
- Chemical effects modeling (Ecological Contaminant Exposure Model) for tissue and environmental media
- Visual and microscopic examination of whole animal and tissue samples for abnormalities
- Presence (or absence) and abundance of key species
- Habitat evaluations
- Comparisons with upstream reference area (Vernita), background concentrations of COPECs, and state and federal criteria for the protection of aquatic and terrestrial organisms

The additional characterization results will provide data supporting remedial technology assessments. Table 1-4 presents a summary of findings for the assessment.

Table 1-4. Summary of Preliminary Findings for the 100-NR-2 Ecological Impact Assessment

					Health Status Indicators		
Plume Area	**Guild Species Present?**	**Contaminant Exposure Pathway?**	**Evidence of Contamination in Biota?**	**Dose or Media Concentration Exceeded?[a]**	**Body Condition**	**Histology**	**Population/ Community**
SPA	Yes	Yes	Yes	Yes	Normal	Abnormal[b]	Normal[c]
SDA	Yes	Yes	No	Yes	Normal	Not Available	Normal[d]
EMA	Yes	Yes	Yes	Yes	Normal	Normal	Normal[d]

Source: *Aquatic and Riparian Receptor Impact Information for the 100-NR-2 Groundwater Operable Unit* (DOE/RL-2006-26)

a. Refers to dose calculations based on soil, sediment, or water and related exposure pathways and tissue concentrations or threshold concentrations for soil, sediment, or water protective of aquatic and riparian biota.

b. A greater percentage of abnormal oocytes and cell shapes was reported for clam tissue than at the reference area. However, the sample size may be too small to make a definitive conclusion.

c. Higher river stage during the survey and presence of riprap prevented access to the central portion of the SPA; overlap from the EMA and SDA covered the sides of the SPA.

d. Population/community indicators primarily based on mollusk survey indicating a normal age class structure of *Corbicula* in the study areas and presence of snail species indicative of north temperature streams with high water quality.

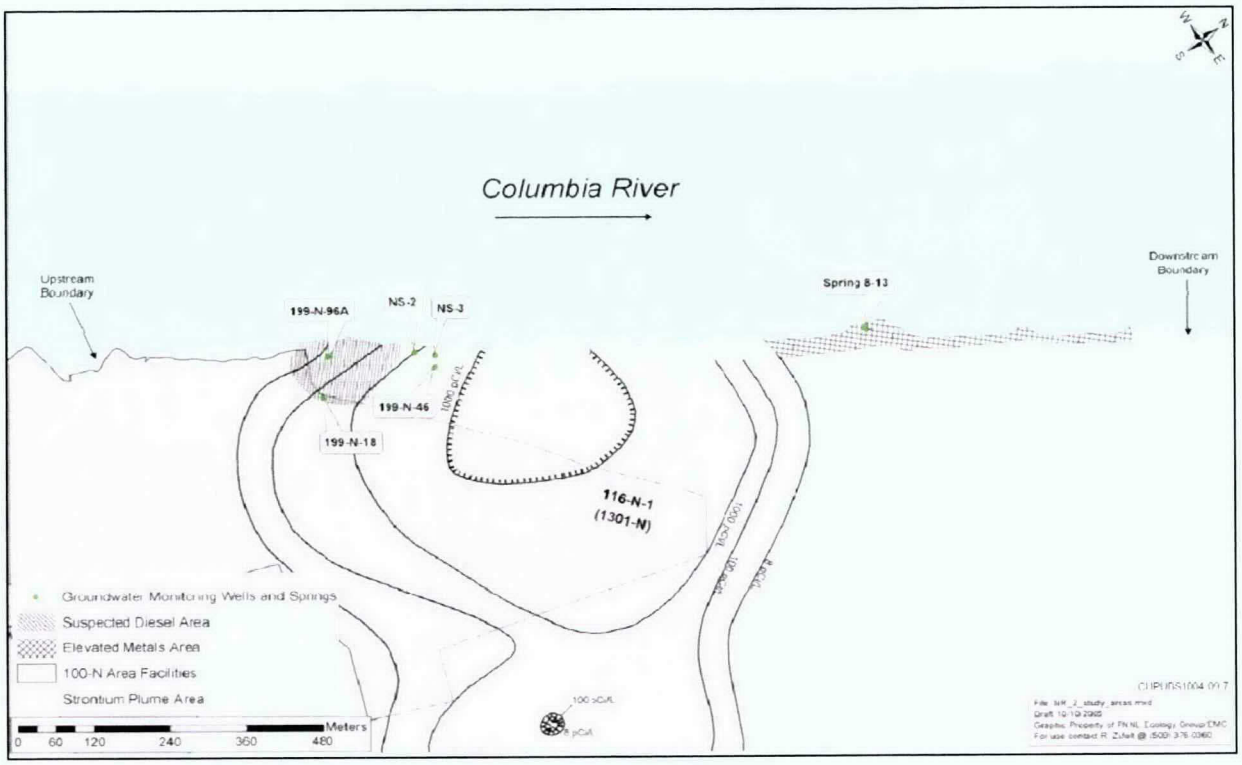
EMA = elevated metals areas

SDA = suspected diesel contaminated area

SPA = strontium plume area

Strontium Plume Area. Levels of Sr-90 were elevated in Asiatic clams compared with Vernita (Figure 1-17); however, estimated radiological doses for all biota evaluated were well below U.S. and international thresholds. Minimal indication of adverse effects of Sr-90 contamination was found in health status indicators surveyed in these sampling efforts. The exception was a slightly higher frequency of abnormal oocytes and an apparent increase in the frequency of digestive tract cellular abnormalities and digestive gland hemocytosis in clam tissue samples from the strontium plume area compared to the reference area. In addition, barium, cadmium, nickel, vanadium, and zinc were detected at levels above ecological benchmarks in the strontium plume area.

Suspected Diesel Contaminated Area. Indications of potential adverse effects were identified for the section of shoreline (approximately 150 m [492 ft]) near the suspected diesel contaminated area (SDA) from a spill that occurred in the 1960s. Data for shallow aquifer tubes (10 cm [3.9 in.] beneath the riverbed) indicate the impacted area is anoxic with elevated dissolved iron and manganese concentrations that exceed water quality benchmarks for the protection of aquatic life. The occurrence of elevated iron and manganese concentrations is consistent with anaerobic microbial decomposition of petroleum hydrocarbons, suggesting that this diesel related contaminant plume would decline by natural biodegradation processes. Sampling recommended by this study is being performed on wells installed along the 100-N shoreline (*100-NR-2 Groundwater Operable Unit Sr-90 Plume Rivershore Sampling and Analysis Plan* [DOE/RL-2009-32]).



Source: DOE/RL-2006-26

Figure 1-17. Sampling Regions Located Along the Shoreline at the 100-NR-2 Groundwater Operable Unit Study Area

Elevated Metals Area. Barium, manganese, lead, and zinc in water; arsenic, barium, cadmium, lead, and nickel in soil; and cadmium and zinc in biota exceed benchmarks for wildlife in the elevated metals area (EMA), SDA, and the strontium plume area (SPA). Threshold exceedances of some of these metals may not be attributable to 100-N operations. For example, metals from upstream sources (lead/zinc mining and refinery operations in Canada and Idaho, and uranium mining near Spokane, Washington) may account for above background concentrations of lead, cadmium, and zinc (and possibly barium and other metals) in environmental media and selected biota. Chromium was detected in clam tissue in the EMA and SPA, but pore fluid concentrations of hexavalent chromium (Cr(VI)) for springs and aquifer tubes did not exceed the aquatic standard for chromium, a ubiquitous contaminant in the plutonium production reactor areas. Lead was detected at elevated levels in two of the deer mice sampled in this area, and maximum lead concentrations in soil in the EMA were above the most relevant screening criteria for birds and mammals. Maximum concentrations of arsenic, chromium, and uranium are also slightly greater in the EMA than the soil screening criteria. The highest concentrations of soil uranium were found at Vernita. Soil data are given in Section 2.3.4 of this report. The assessments are based on maximum observed values compared against the most sensitive benchmarks. Modeling using the Ecological Contaminant Exposure Model (based on median soil, water, and sediment concentrations of metals) did not indicate unacceptable risk from these metals.

Polychlorinated Biphenyls. Some congeners of PCBs were detected in samples at the 100-NR-2 study area, but concentrations were well below current ecological benchmarks and were comparable to concentrations observed at Vernita.

Weight-of-Evidence Information. In addition to contaminant concentrations and histological data, general habitat conditions were evaluated. A principal finding of the present study was a normal distribution of

aquatic mollusk species indicative of high water quality conditions in the 100-NR-2 OU contaminant plume study areas. In addition, a normal age distribution of Asiatic clams was noted throughout the study area, indicating favorable habitat conditions. A survey of aquatic invertebrates conducted in September and October 2005 indicated a normal distribution of aquatic insects and other invertebrates in the study area. Evaluations of terrestrial or riparian habitat indicators were less clear. This was primarily a result of prior large physical disturbances in the study area and the use of herbicides to prevent the growth of mulberry and other nuisance vegetation in the SPA. However, the small mammal population was found to be reproductively active in the study area.

1.4 Remedial Investigation for Hanford Site Releases to the Columbia River

As described in the Integrated 100 Area Work Plan (*Integrated 100 Area Remedial Investigation/ Feasibility Study Work Plan* [DOE/RL-2008-46]), a remedial investigation of Hanford Site releases to the Columbia River is being conducted. A remedial investigation work plan was issued in 2008 (DOE/RL-2008-11) to establish the approach for characterizing the nature and extent of Hanford Site-related contaminants that have come to be located within the Columbia River and assessing the current risk to ecological and human receptors posed by site-related contaminants. A technology that provides the capability of in situ conductivity and temperature measurements as well as sample collection for pore water and surface water is being used to support this task. Preliminary results from sampling conducted adjacent to the 100-N Reactor site detected Sr-90 at four locations. Chapters 2 and 4 describe the relationship of these sample results to the Sr-90 nature and extent in groundwater.

2 Site Background and Environmental Setting

Between 1943 and 1963, nine nuclear reactors were built along the Columbia River with the core function of producing special nuclear materials for national defense. 100-N includes the N Reactor and its ancillary production and waste disposal facilities. This chapter describes the background and environmental setting of 100-N and includes information on waste generated and contamination, both known and potential.

The 100 Area is located in the northern part of the Hanford Site along the south shore of the Columbia River (Figure 1-2). The five separate divisions of the 100 Area are composed of source OUs and groundwater OUs. Source OUs address liquid, solid, radioactive, and past practice waste sites; groundwater OUs address groundwater contamination. The 100-N area source OU is 100-NR-1; the groundwater OU is 100-NR-2, and between the OUs, all suspect media are captured—the vadose zone, intermittently re-wetted zone, wetted zone, groundwater-vadose interface, and any contaminated surface water areas. Table 2-1 summarizes 100-N site information.

Table 2-1. 100-N Site Location Information

	Site Information
100-N	100-N is located upstream of the northwest bend of the Columbia River, between 100-D-H and 100-K. There is one production reactor, 105-N, and its associated infrastructure. The source area OU is 100-NR-1.
Groundwater	The 100-NR-2 OU encompasses the groundwater beneath 100-N.
OU = operable unit	

D4 activities are ongoing at 100-N and ISS activities are in progress for the 105-N Reactor Building. The ISS of the N Reactor is scheduled for completion by 2012. Figures 2-1 and 2-2 provide aerial views of 100-N before the start of D4 and ISS activities.

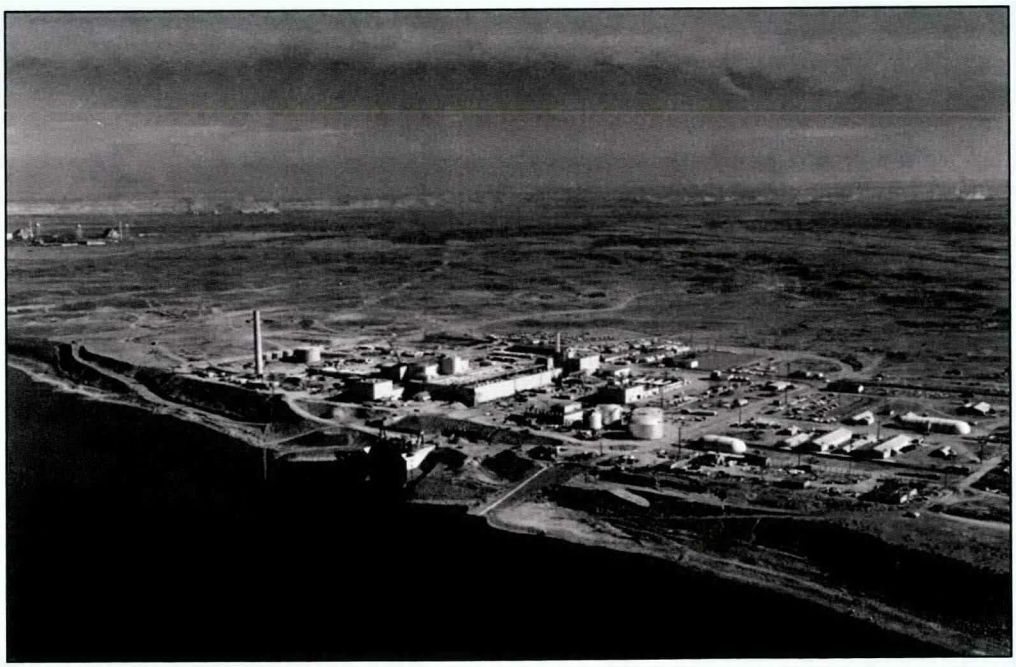


Figure 2-1. Aerial View of 100-N (1968)

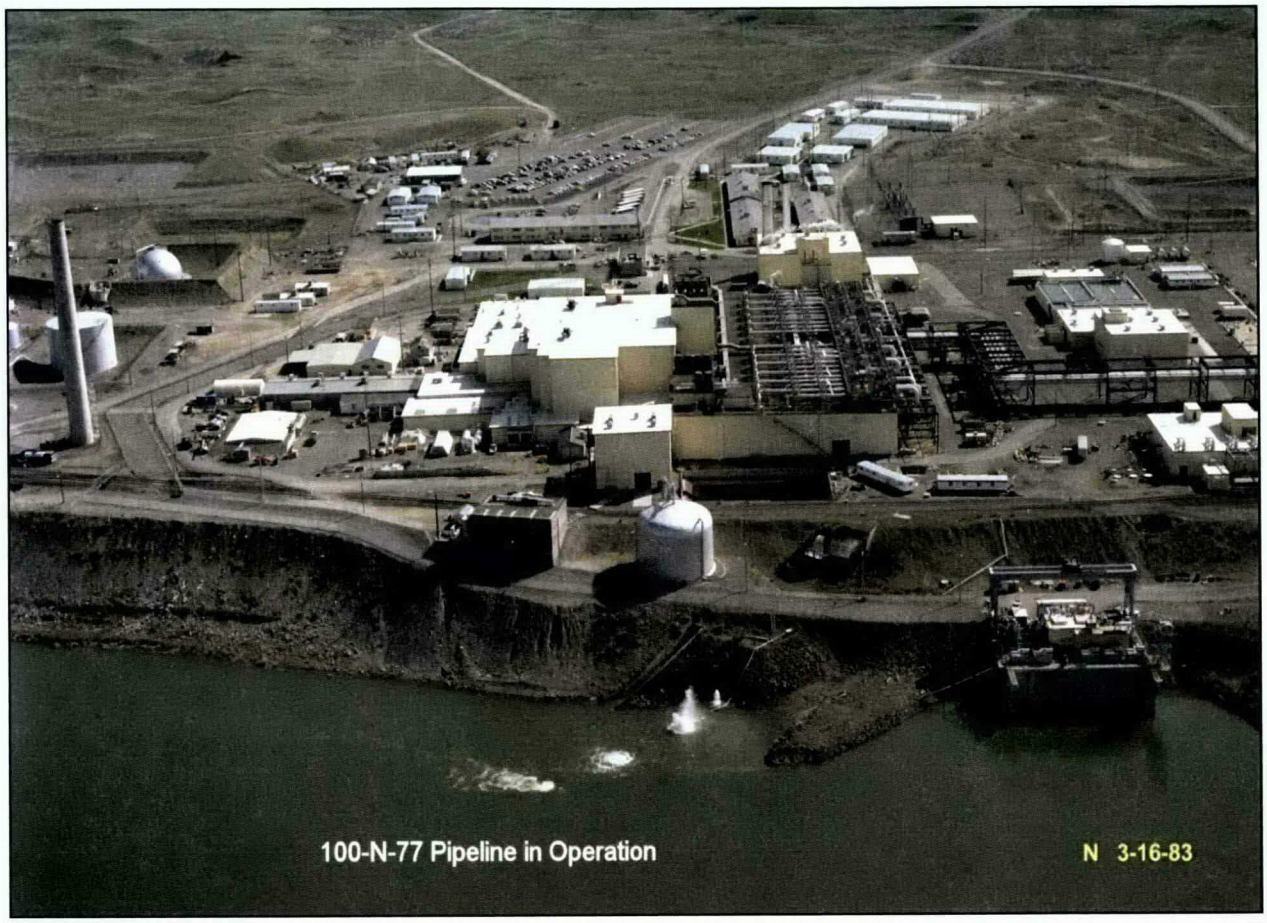


Figure 2-2. Aerial View of 100-N and the Hanford Generating Plant (1983)

2.1.1 Process History Description

The Hanford Site's ninth defense materials production reactor, N Reactor, operated from 1964 to 1986. Although there were many differences between this last reactor and the previous eight, the primary difference was that N Reactor had two separate cooling loops: the primary loop provided cooling to the fuel elements and the secondary loop provided water to remove heat from the primary system and release heated water to the Columbia River. This two-loop cooling system released significantly less radioactive effluent (wastewater) on a daily basis as compared to the eight previous reactors. N Reactor's primary coolant system used from 380 to 5,700 L (100 to 1,500 gal) per minute of fresh, treated water, a vast decrease from the 132,000 to 397,000 L (35,000 to 105,000 gal) per minute consumed by Hanford's single pass reactors (WHC-MR-0521). Table 2-2 summarizes significant milestones in N Reactor operations.

Table 2-2. Significant Dates for 100-N Reactor Operation

Date	Milestones
May 13, 1959	Construction of N Reactor began
September 1963	Construction of the Hanford Generating Plant began
December 1963	N Reactor went into production
March 1964	Construction of N Reactor was completed

Table 2-2. Significant Dates for 100-N Reactor Operation

Date	Milestones
November 1964	N Reactor reached 4,000 MW (thermal)
April 1966	HGP construction was completed
December 1966	N Reactor reached 800 MW (electrical) (combined with HGP output)
1975	N Reactor irradiated fuel storage began in KE Reactor fuel storage basin
1981	N Reactor irradiated fuel storage began in KW Reactor fuel storage basin
December 12, 1986	N Reactor placed in stand-down status
February 1988	N Reactor placed in cold standby
1989	Shipment of N Reactor irradiated fuel to 100-K was completed
1990	N Reactor dewatered
October 1991	N Reactor ordered shut down

Source: *RCRA Facility Investigation-Corrective Measures Study Work Plan for the 100-NR-1 Operable Unit*, Hanford Site, Richland, Washington (DOE-RL-90-22)

HGP = Hanford Generating Plant

MW = mega watt

Materials that passed through the reactor for the manufacturing of special nuclear materials or that contacted items passing through the reactor were considered radiologically contaminated and represented the majority of the wastes produced. Contaminant categories from the manufacturing process include, but are not limited to, the following:

- Process inputs
  - Raw materials to be processed through the reactor, such as uranium fuel and cooling water.
  - Process chemicals for water conditioning and inhibiting corrosion were added because water management was crucial to reactor operations and represented a major input subsystem; sodium dichromate was used from 1963 to 1965, then in lesser amounts from 1965 to 1967 when hydrazine became the primary conditioner and continued until the 1986 stand-down order. (Rev. 0, *RCRA Facility Investigation-Corrective Measures Study Work Plan for the 100-NR-1 Operable Unit, Hanford Site, Richland, Washington* [DOE-RL-90-22]; and *Closure-Post-Closure Plan for 1301-N and 1325-N Liquid Waste Disposal Facilities* [UNI-3533]).
  - Materials used for reactor maintenance (acids, solvents, and heavy metals).
- Process outputs
  - Isotopes and byproducts, such as plutonium-239 (Pu-239), Sr-90
  - Radioactive and chemically contaminated materials (solid and liquid wastes)
  - Radioactive and chemically contaminated cooling water
  - Uncontaminated waste materials (construction debris)

The irradiated fuel elements were shipped to the 200 Area for chemical processing. Unlike the single-pass reactors, N Reactor decontamination solutions were often piped to storage facilities before being transported to the 200 Area for disposal. During production, fuel element failures and infrastructure failures (e.g., pipe leaks) resulted in contaminated materials released to the environment. Descriptions of these release types are provided in Appendix B (for 100-N waste sites) and Appendix A (for 100-N facilities).

Burial grounds at 100-BC, 100-K, and 100-D were used to dispose contaminated solid wastes generated at 100-N (*Corrective Measures Study for 100-NR-1 and 100-NR-2 Operable Units* [DOE-RL-95-111]; *100-K Area Technical Baseline Report* [WHC-SD-EN-TI-239]; and *Underground Radioactive Materials at 100-D Plant* [DUN-3063]); K Basins were used for long-term N Reactor spent fuel storage (WHC-MR-0521). There are no known burial grounds at 100-N (*The Plutonium Production Story at the Hanford Site: Processes and Facilities History* [WHC-MR-0521]). Wastes resulting from supporting reactor operations were similarly disposed in each area according to phase, quantity, radioactivity, and composition (liquids, solids; high-low mass or volume; high-level, low-level; strictly chemical; septic, and so forth).

2.1.1.1 Liquid Discharges

The 100-NR-1 OU includes liquid and solid waste disposal sites and unplanned release sites related to operations associated with the 100-N Reactor.

Liquid wastes were disposed to 100-N soil column and to the Columbia River through a variety of disposal facilities including outfalls, spillways, cribs, ponds, pits, French drains, and septic systems. Two Columbia River outfall structures were built in 100-N: 1908-N and 1908-NE.

The 1908-N Outfall (Figures 2-3 and 2-4) was designed primarily to return raw river water used to remove heat from the secondary cooling system. It also provided an emergency disposal method for primary cooling water and fuel storage basin water, should it be needed. The outfall was permitted under NPDES permit number WA-000374-3. The permit specified maximum daily average flow to be 1,718,000 m^3 (48,668.5 ft^3) with a daily maximum flow rate of 2,290,000 m^3 (64,872.5 ft^3). The daily maximum discharge temperature was specified a 77° F. The daily average free available chlorine was 29 kg/day with a daily maximum of 96 kg. The pH was specified between 6.0 and 9.0. The outfall was built in 1963 and operated until the Hanford Generating Project (HGP) closed in 1986. The outfall structure includes a reinforced concrete weir box that discharged to the bottom of the Columbia River through a 102 in. diameter steel pipeline.

The 1908-NE Outfall served the same purpose as the 1908-N Outfall, but serviced only the HGP facilities. Because the HGP was physically isolated from the reactor facilities, this outfall did not provide for emergency water disposal. The 1908-NE Outfall operated under NPDES permit number WA-002487-2. It was built in 1966 and operated until discharge terminated in 1988. The pollutants include strontium-90, cobalt-60, cesium-137, arsenic, barium, cadmium, chromium, lead, selenium, silver, mercury, and PCBs. The outfall received single-pass raw river water from the HGP condensers, as well as wastewater from the 100-N-1 Settling Basin. The 1908-NE Outfall consisted of a seal well located on the riverbank and a pipeline extending 1,000 ft into the Columbia River. Effluent from the nearby N Reactor did not enter into the HGP system or the 1908-NE Outfall.

Wastewater collected from sumps and drains designed to manage radioactive wastes within the facility was discharged to the crib and trench facilities. These drains contained effluent from water quality testing laboratories, personnel decontamination stations, waste transfer stations, and from floor drains located in controlled areas of the reactor building.

Figure 2-3. Construction of 1908-N Outfall and 100-N-79 Emergency Spillway (1961)

Figure 2-4. 100-N-79 Emergency Spillway (2005)

Settling and percolation ponds were used in 100-N to settle out solids from filter backwash, treat corrosive regeneration effluent, and dispose of backwash effluents. The ponds were generally unlined trenches and relied on infiltration of the liquid into the soil.

The 163-N Demineralization Plant provided demineralized water for N Reactor primary coolant systems. Large ion exchange columns were located in the plant to remove minerals from the filtered water. The plant demineralized, filtered, and treated water from the 183-N Water Treatment Facility; degassed it; and pumped it to a water storage tank. This water was used in the primary, secondary, and fuel storage basin cooling water systems. Sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) were used to regenerate the ion exchange columns. Following regeneration, the NaOH and H_2SO_4 were discharged to the 163-N Neutralization Pit and a French drain.

In November 1988, the 120-N-2 Surface Impoundment was discontinued when the newly constructed Elementary Neutralization Unit (ENU) was put online inside the 163-N Demineralization System facility. The ENU neutralized the spent regenerant before discharge to the 120-N-1 Percolation Pond, and did so with greater efficiency and operator control than was possible in the 120-N-2 Surface Impoundment facility (*100-N Area Technical Baseline Report* [WHC-SD-EN-TI-251]; and DOE-RL-90-22).

Primarily, radioactive effluents and wastes were generated within the 105-N Reactor Building and the 109-N Heat Transfer Building. The radioactive process effluent and waste streams ultimately were sent to the 116-N-1 Crib and Trench (1301-N Facility), the 116-N-3 Crib and Trench (1325-N Facility), or the 1314-N Liquid Waste Loadout Station. In order to maintain low dose rates and an efficient cooling system associated with the reactor core, the steam generator, and the fuel storage basin work areas, fresh demineralized water was added to these independent systems, and the wastewater (bleed off) was discharged to the 116-N-1 (1301-N) and 116-N-3 (1325-N) cribs and trenches.

Water released to the 116-N-1 and 116-N-3 Cribs eventually reached the Columbia River through the groundwater system. The 100-N Reactor contains additional alloys and materials not present in the older reactors. These materials were protected from corrosion and the heat transfer surfaces protected against fouling by suitable water treatment, resulting in a reduced need for the addition of chemical corrosion inhibitors such as sodium dichromate. Although not substantially used in the reactor cooling water system, the historical record indicates 6.3 to 8.2 m tons (7 to 9 tons) of sodium dichromate were used per year at 100-N for several years after startup for the rod cooling water system that discharged to the crib (*Chemicals Discharged to the Columbia River from DUN Facilities Fiscal Year 1968* [DUN-4668], *Chemicals Discharged to the Columbia River from DUN Facilities FY 1969* [DUN-6205], and *Chemicals Discharged to the Columbia River from DUN Facilities, FY 1970* [DUN-7162]). Thus, approximately 63 m tons (70 tons) of sodium dichromate were documented as discharged (see Table 4.3).

A major oil release (302,833 L [80,000 gal]) of No. 6 fuel oil occurred in 1966 when a 4 in. line lost integrity through external corrosion in the 166-N Tank Farm. The diesel oil drained through the soil to the Columbia River. A trench was excavated along the riverbank to intercept the oil before it could reach the river. Oil exposed at the trench was burned periodically through 1967 (DOE-RL-90-22). Remediation of this spill continues (see Section 2.3.3.3).

2.1.2 Secondary Mission: Isotope Production and Electrical Power Generation at the Hanford Generating Plant

Secondary missions besides the production of special nuclear material at N Reactor included tritium production and electrical power generation (WHC-MR-0521; WHC-SD-EN-TI-251). From 1965 to 1967, a "co-product" demonstration campaign took place, in which tritium was produced in the reactor from special lithium aluminate fuel elements. Beginning in 1966, N Reactor steam for electrical production was

harnessed at the HGP, which was constructed west of the N Reactor facilities by the Washington Public Power Supply System.

The Atomic Energy Commission order issued in 1971 to close the KE Reactor included closure of N Reactor. An agreement reached later in 1971 allowed the N Reactor to continue operations to produce steam for the HGP and to pre-produce fuel grade (not weapons grade) plutonium for the breeder reactor program. The spent fuel produced at the N Reactor was never used by the breeder reactor program and was stored at the 100-K Basins (*History of the Plutonium Production Facilities at the Hanford Site Historic District, 1943-1990* [DOE-RL-97-1047]). The continued operation of N Reactor resulted in modifications and upgrades to waste management treatment systems at these facilities (WHC-MR-0521).

2.1.2.1 Tritium Production

Waste products associated with tritium production were mainly in the forms of irradiated lithium targets, and tritium concentrations in the process waters released to the 1301-N and 1325-N Liquid Waste Disposal Facilities (LWDFs) (116-N-1 and 116-N-3 Cribs and Trenches). A description of the process water released to the 1301-N and 1325-N LWDFs is provided in this work plan (see Section 4.1.6). The tritium production lithium targets were considered a product and not a waste product at the time of production. Much effort would have been spent trying to preserve the irradiated lithium targets. Nevertheless, some lithium targets or fragments, and other fuel element fragments, were discharged to the 105-N Fuel Storage Basin (N-Basin). Fuel elements were removed from the N-Basin in 1989 (*N Area Final Project Program Plan* [BHI-01130, Rev. 0]) and moved to the 100-K Basins. The N-Basin sediment was removed and consolidated with other 100-N sediments in the North Cask Pit located in the 105-N Building (BHI-01130, Rev. 0) in 1998. These North Cast Pit sediments were eventually removed and transported to ERDF (Pak, 1998). Based on available documentation, it appears the tritium production activities resulted in the only known source being the tritium in the process waters released to 116-N-1 (1301-N) and 116-N-3 (1325-N).

2.1.2.2 Hanford Generating Plant

From 1966 through 1986, HGP imported steam from the adjacent 100-N production reactor to power two 430-megawatt turbine generators. The primary waste stream associated with HGP operations was steam condensate. Secondary waste streams (and potential contaminant sources) derived from numerous sources, including a water chemistry laboratory, instrument shop, maintenance and machine shops, and water treatment (four mixed resin bed ion exchangers, a hydrazine and morpholine station). Other streams include an emergency diesel generator room with a 75,708 L (20,000 gal) buried fuel tank, six large facility transformers, a river water bus duct cooler (Phase A transformer containing PCBs), battery rooms containing 60 large batteries and an annunciator battery bank, turbine lubricating oil storage and oil filtering tanks with a combined capacity of 52,995 L (14,000 gal) including 10,221 L (2,700 gal) of new oil, and a sanitary sewer system (*Scoping Document for the Hanford Generating Plant in the 100-N Area* [WHC-SD-DD-AP-016, Rev. 0]). A support facility, the 1716-NE Maintenance Garage, included an underground gasoline storage tank and three vehicle maintenance bays with floor drains that led to a French drain.

The HGP steam condensate, liquid effluent from the HGP service water pumps, HGP floor drains and sumps, demineralizer backwash, and runoff from the 185-N roof and parking lot, were discharged to the 100-N-1 Settling Pond that drained to the 1908-NE Outfall, which discharged directly to the river bottom. Imported 100-N reactor steam would occasionally contain radionuclides (e.g., tritium and Co-60) and trace contaminants (e.g., metals) from the 105-N primary cooling loop, due to leaks (cross-communication) between the primary and secondary cooling loops. These contaminants would be present in the condensate discharged to the 100-N-1 Settling Pond. The process effluents also contained trace oxygen

scavenging conditioners such as morpholine, hydrazine, and ammonia according to RCC Stewardship Information System Site Summary for 100-N-1.

The 100-N-4 Drain Field received HGP sanitary sewage and laboratory waste. Corrosion inhibitors hydrazine and morpholine tests were performed in the laboratory, and reagents used for these tests were discharged to 100-N-4 according to RCC Stewardship Information System Site Summary for 100-N-4. The 100-N-3 French drain received effluent from the 1716-NE Maintenance Garage bay floor drains (*Cleanup Verification Package for the Hanford Generating Plant 100-N-4 Tile Field (SWMU #5); 100-N-1 Settling Pond (SWMU #6); 1908-NE Outfall (SWMU #7); 1716-NE Maintenance Garage (SWMU #8) and 100-N-52 Underground Storage Tank; 100-N-3 Maintenance Garage French Drain, 100-N-41 Gate House Septic Tank, and 100-N-45 Office Building Septic Tank (SWMU #9); 100-N-5 Bone Yard (SWMU #10); and 100-N-46 Underground Storage Tank* [HGP-CVP-SWMUs 5, 6,7, 8, 9, & 10]).

Washington Public Power Supply System (now Energy Northwest) operated HGP. No documentation was found addressing non-aqueous liquid wastes or hazardous and/or radioactive nonliquid waste disposal. A small number of 100-N waste sites (i.e., dumping sites and burn pits) show there were rare instances where inappropriate wastes (e.g., oil filters, vehicles batteries) were disposed onsite.

Chapter 4 of this work plan provides details of HGP associated waste products; Table 4-1 lists Closed and Interim Closed waste sites and applicable Cleanup Verification Packages and Table 4-8 characterizes data summary generated for each Interim Closed HGP waste site.

2.1.3 Waste Sites Description and History

The two primary liquid waste disposal sites in 100-N are the 116-N-1 and 116-N-3 Crib and Trenches, also known as the 1301-N and 1325-N LWDF, respectively. The oldest is the 116-N-1 Crib, used from the time the reactor went online in 1963 until September 1985. The trench was extended in 1965 because the wastewater volume exceeded the capacity of the crib. The 116-N-3 Crib, built in 1983, was to augment the original 116-N-1 Crib (1301-N LWDF). In 1985, a covered extension trench was added to the 116-N-3 Crib (1325-N LWDF) to increase the capacity of that facility. To enhance percolation, the 116-N-3 Crib and Trench were sited where borehole geophysical logs and data (WHC-SP-0377) indicated relatively high permeability. The newer facility was located approximately twice the distance from the river as the old facility, and was completely covered. Remedial action goals were achieved during remediation of the 116-N-3 Crib and Trench (*Cleanup Verification Package-Clean Closure Report for the Soil Column of the 116-N-3 Trench and 100¬N-63:1 Pipeline* [CVP-2002-00002], and *Cleanup Verification Package-Clean Closure Report for the Soil Column of the 116-N-1 Crib and Trench* [CVP-2006-00004]). An Explanation of Significant Differences (ESD) (*Explanation of Significant Difference for the 100-NR-1 Operable Unit Treatment, Storage, and Disposal Interim Action Record of Decision and 100-NR-1-NR-2 Operable Unit Interim Action Record of Decision, Hanford Site, Benton County, Washington* [EPA-ESD-R10-03-605]) published in 2003 for 116-N-1 addresses contamination left behind that exceeds the RAOs in the Interim ROD for groundwater protection. Both permitted RCRA facilities waste sites were classified as "interim closed out" in accordance with the CERCLA Record of Decision, and the waste site reclassification guideline TPA-MP-14 (RL-TPA-90-0001).

As of March 25, 2010, 185 waste sites (including 23 orphan sites) are located within 100-N (Table 2-3). These waste sites are inactive, past practice disposal sites described as trenches, ditches, cribs, ponds, and unplanned releases.

Table 2-3. Summary of Waste Sites in 100-N (March 2010)

Status (Total Number of Waste Sites)	Waste Site				
Accepted (129, all slated for remediation in FY10 and 11)	100-N-13	100-N-6	100-N-86	124-N-1	UPR-100-N-20
	100-N-14	100-N-60	100-N-87	124-N-10	UPR-100-N-21
	100-N-16	100-N-61	100-N-88	124-N-2	UPR-100-N-22
	100-N-17	100-N-62	100-N-89	124-N-3	UPR-100-N-23
	100-N-18	100-N-63	100-N-90	124-N-4	UPR-100-N-24
	100-N-22	100-N-63:2	100-N-91	124-N-9	UPR-100-N-25
	100-N-23	100-N-64	100-N-92	128-N-1	UPR-100-N-26
	100-N-24	100-N-65	100-N-93	130-N-1	UPR-100-N-29
	100-N-25	100-N-66	100-N-94	1908-N	UPR-100-N-3
	100-N-26	100-N-68	100-N-95	2607-FSM	UPR-100-N-30
	100-N-28	100-N-77	100-N-96	600-339	UPR-100-N-31
	100-N-29	100-N-77:1	100-N-97	600-340	UPR-100-N-32
	100-N-30	100-N-79	100-N-98	600-347	UPR-100-N-35
	100-N-31	100-N-80	100-N-99	600-348	UPR-100-N-36
	100-N-32	100-N-81	100-N-100	600-35	UPR-100-N-39
	100-N-33	100-N-82	100-N-101	628-2	UPR-100-N-4
	100-N-34	100-N-83	100-N-102	UPR-100-N-1	UPR-100-N-42
	100-N-36	100-N-84	100-N-103	UPR-100-N-10	UPR-100-N-43
	100-N-37	100-N-84:1	116-N-2	UPR-100-N-11	UPR-100-N-5
	100-N-38	100-N-84:2	116-N-4	UPR-100-N-12	UPR-100-N-6
	100-N-47	100-N-84:3	118-H-1:1	UPR-100-N-13	UPR-100-N-7
	100-N-53	100-N-84:4	118-H-1:2	UPR-100-N-14	UPR-100-N-8
	100-N-54	100-N-84:5	118-N-1	UPR-100-N-17	UPR-100-N-9
	100-N-55	100-N-84:6	120-N-3	UPR-100-N-18	UPR-100-N-23
	100-N-57	100-N-84:7	120-N-4	UPR-100-N-19	UPR-100-N-24
	100-N-59	100-N-85	120-N-7	UPR-100-N-2	
Closed Out (3)	100-N-58	120-N-1	120-N-2		
Interim Closed Out (17)	100-N-1	100-N-45	100-N-51	100-N-78	UPR-100-N-37
	100-N-3	100-N-46	100-N-51B	116-N-1	
	100-N-4	100-N-5	100-N-52	116-N-3	
	100-N-41	100-N-50	100-N-63:1	1908-NE	
No Action (1)	100-N-67				

Table 2-3. Summary of Waste Sites in 100-N (March 2010)

Status (Total Number of Waste Sites)	Waste Site				
Not Accepted (10)	100-N-12	100-N-7	100-N-71	100-N-73	UPR-100-N-41
	100-N-69	100-N-70	100-N-72	UPR-100-N-40	100-N-35[a]
Rejected (27)	100-N-10	100-N-40	100-N-9	124-N-6	UPR-100-N-34
	100-N-11	100-N-56	116-N-8	124-N-7	UPR-100-N-38
	100-N-19	100-N-74	120-N-5	124-N-8	UPR-600-17
	100-N-21	100-N-75	120-N-6	600-32	
	100-N-27	100-N-76	120-N-8	UPR-100-N-15	
	100-N-39	100-N-8	124-N-5	UPR-100-N-33	
Total[b]	**185 sites**				

a. 100-N-35 is listed as Not Accepted (Proposed).

b. Total number of sites includes discovery sites.

Closed Out: A waste site meets applicable cleanup standards or closure requirements (as a request of failing cleanup actions).

Interim Closed: A waste site meets the cleanup standards specified in an interim record of decision (as a request of failing cleanup actions).

No Action: A waste site does not require remedial action based on quantitative data collected from the site.

Not Accepted: Based on an assessment, a WIDS site is determined not to be a waste site and is, therefore, not within the scope of the *Hanford Federal Facility Agreement and Consent Order Action Plan*, as amended (Ecology et al., 1989b). This classification requires lead regulatory agency approval.

Accepted: Based on an assessment, a WIDS site is determined to be a waste site as defined by Ecology et al. (1989b).

Discovery: A newly discovered WIDS site, with evidence of a potential waste site, but the assessment is not yet complete.

As of 2010, at least 474,000 m tons (521,400 tons) of contaminated soil and debris have been removed from 100-N to mitigate and reduce impacts to human health and the environment. Of this, 334,000 m tons (367,400 tons) went to ERDF during the 116-N-1 Trench and Crib remediation activities (CVP-2006-00004, Section 3.1). The other 140,000 m tons (154,000 tons) were transported to ERDF during the 116-N-3 Trench, Crib, and 100-N-63:1 remediation (CVP-2002-00002, Section 4.2). An undetermined amount of contaminated materials was removed and disposed to ERDF from nine additional 100-N waste sites (Appendix B provides additional details). There are 129 accepted waste sites remaining in 100-N to be cleaned up/evaluated, which are tentatively on the path for interim remedial action as of March 25, 2010. Table 2-3 summarizes and defines classifications for the individual waste sites in 100-N. These Waste Information Data System (WIDS) classifications are defined in the integrated work plan (DOE-RL-2008-46). Appendix B provides a description and history for each waste site, and lists the contaminants of concern (COCs) for each interim closed or closed waste site. Appendix C provides maps that include the locations of 100-N waste sites and distinguishes those that received Sr-90.

The use of 100-N facilities and their operational roles are described in other technical documents (such as WHC-SD-EN-TI-251 and DOE-RL-95-111). The uses and/or development of facilities and waste sites can affect remedial actions (e.g., using the ENU, rather than the 120-N-1 and 120-N-2 settling ponds for waste management). If residual contamination remains at a facility location (foundations, pads, and

subgrade piping) after the completion of D4, the location is reclassified as a waste site. However, if a facility is completely removed and no residual contamination remains, the location is not reclassified as a waste site.

There are four RCRA permitted waste sites within the 100-NR-1 OU: 116-N-1 and 116-N-3 (1301-N and 1325-N LWDF), 120-N-1 (1324-NA percolation pond), and 120-N-2 (1324-N surface impoundment). RCRA, Part A, Permit Application forms for these units were initially submitted in 1986 and 1987, and have been revised since (e.g., to add associated pipelines and modify waste codes).

In order to ensure all CERCLA hazardous substances (including radionuclides) were addressed during closure and to make disposal of closure wastes in the ERDF (a CERCLA facility), DOE, EPA, and Ecology (Tri-Parties) subsequently developed an integrated CERCLA remedial action and RCRA closure approach for these units. Under this approach, 120-N-1 and 120-N-2 were included in the 100-NR-1 Corrective Measures Study and Proposed Plan. The waste site reclassification form for 100-N-58 was approved by Ecology in 2002. 120-N-1 and 120-N-2 were included in the 100-NR-1 Corrective Measures Study and Proposed Plan; however, because these documents indicated no soil contamination was present, EPA did not include them in the 100-N CERCLA ROD. Closure activities for 120-N-1 and 120-N-2 have been completed and approved as provided in 03-RCA-0236 (Ecology letter dated February 7, 2003 [see Appendix D]). Post-closure groundwater monitoring is performed for sulfates.

2.1.4 Orphan Sites Process

DOE has implemented a number of processes to identify new waste sites (Integrated Work Plan, Chapter 3). The process of identifying new waste sites increases confidence that waste disposal and releases requiring characterization and cleanup within a given land parcel on the Hanford Site are addressed.

In addition to the previously described waste sites, other locations are categorized as orphan sites. Orphan sites are considered man-made features, items, or activity areas within the River Corridor that share the following characteristics:

- Meet the TPA-MP-14 criteria for waste site identification.
- Are not identified for characterization or cleanup within the regulatory decision documents (e.g., Interim Action ROD).
- Have been presented to and accepted by the Washington Closure Hanford (WCH) Field Remediation Closure Project, U.S. Department of Energy, Richland Operations Office, and the regulators (*Orphan Sites Evaluation Project Execution Plan* [WCH-218]).

The orphan site evaluation of the 100-NR-1 OU was conducted between August 2006 and March 2007. Documentation of this investigation of 100-NR-1 is completed (OSR-2009-0001, Rev. 0). The scope covered an area of approximately 762 ha (1,882 ac), as shown on Figure 1-8. Twenty-three orphan sites were identified during the evaluation process. These orphan sites, which will follow the TPA-MP-14 process, will be addressed according to current or future RODs or ROD amendments.

Orphan sites are considered known or suspected sources of contamination. These sites are newly discovered potential waste sites that will be evaluated to determine their impact (if any) to the environment, with potential changes to work planning and execution administered through established project management channels.

2.1.5 Decommissioning Activities

In April 1986, an accident at the Chernobyl nuclear plant in the former Soviet Russia initiated a stand-down for safety evaluations at the N Reactor. After the stand-down, DOE ordered the N Reactor to cold standby in

February 1988, and a large decontamination and decommissioning (D&D) project that led to its final disposition began in 1994 (*N Reactor Deactivation Program Plan* [WHC-SP-0615]). Figure 2-5 shows the D4 success through 2002.

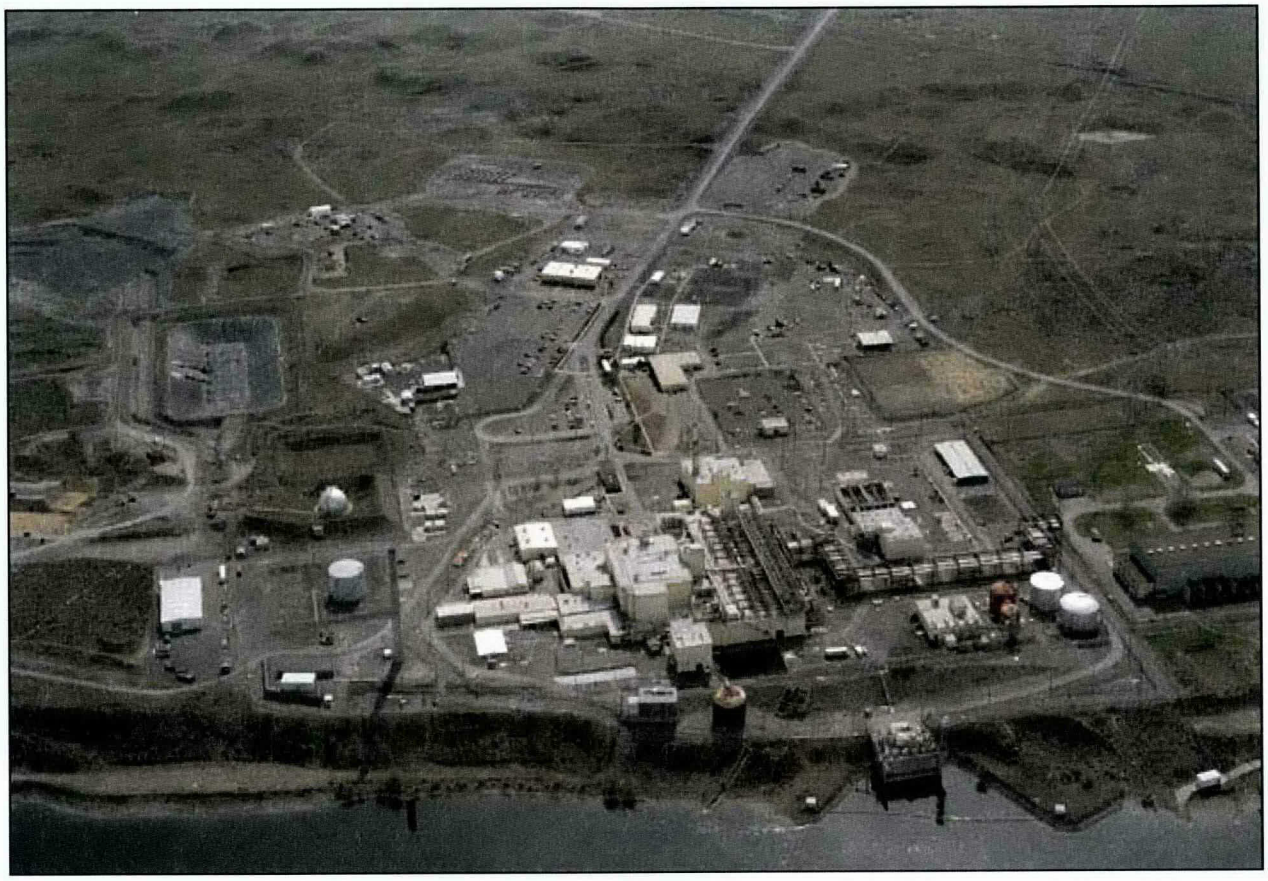


Figure 2-5. 100-N Area (2002)

Table 1-1 in Chapter 1 shows the status of facilities. The description and history of each facility is summarized in Appendix A.

In 1995, a CERCLA action memorandum was issued, directing the N Reactor to be placed in ISS condition (Wilson, 2005). ISS represents a series of actions taken to protect the reactor from environmental degradation and prevent the spread of contamination by "cocooning," or providing an upgraded, weather resistant shell to isolate the reactor core until final remedial activities are conducted. The action minimizes the facility footprint by removing peripheral reactor buildings and equipment, and disposing of that debris properly. Completion of ISS activities at the N Reactor is projected for 2012.

2.2 Environmental Setting

The 100 Area environmental setting is provided in detail in the integrated work plan (DOE-RL-2008-46, Section 2.3), with specific 100-N information included here.

2.2.1 Topography

100-N topography is relatively flat inland from the Columbia River (Figure 2-2). The area has been graded extensively from the time reactor construction began in the 1960s through the present waste site remedial activities. The elevation of 100-N ranges from approximately 120 m (390 ft) above mean sea level (msl) at the

Columbia River to approximately 140 m (459 ft) above msl on the east side (*Limited Field Investigation Report for the 100-NR-2 Operable Unit: Hanford Site, Richland, Washington* [DOE-RL-93-81]). The slope along the riverbank has gradients of at least 15 percent. Bluff heights above the river surface range to approximately 21 m (70 ft) at 100-N. The surrounding terrain is the result of catastrophic flooding associated with Pleistocene glaciation (DOE-RL-93-81), and is characterized by low hills and mounds. Several geologic terraces and levees are located along both sides of the river channel in 100-N. Geological carbon-14 dating of organic material contained in soil samples taken from an older terrace near the N-Springs area, and several other locations along this section of the river indicate this section of the river has been in its present position for several thousand years (BHI-01324). In addition, an archeological study excavated into the second terrace levee above the river immediately north of the HGP and mussel shells found in the sands near the base of the terrace were collected for radiocarbon analysis. The radiocarbon date calculated for the shells was 7,880 +/− 110 years. This terrace is present under the fill at the HGP, based on aerial photographs taken prior to construction at 100-N. Based on the system of terraces and levees correlative to the second terrace (discussed previously), the Columbia River has occupied the same channel from 100-BC to 100-D for at least the past ~8,000 years (*Final Report for Interim Stabilization of 211-U and 211-UA Contamination Areas* [BHI-01628] and *Late Pleistocene and Holocene-Age Columbia River Sediments and Bedforms: Hanford Reach Area, Washington, Part 2 – Geologic Atlas Series* [WCH-46]). Therefore, despite the tremendous volumes of water flowing past the 100-N shoreline, the shoreline itself is stable (shoreline riprap was added to reduce exposure, not shoreline stability).

The landscape is a semiarid (steppe) environment with a sparse covering of cold desert shrubs and drought resistant grasses. This landscape supports occasional small, wetland-like features affected by infrastructure drainage, facilities, and past development. Numerous infrastructure features include pipelines, reactor buildings, former waste sites, and groundwater remediation systems and equipment.

2.2.2 Geology

100-N is underlain by the Miocene age (approximately 17 to 8.5 million years) Columbia River Basalt Group and late Miocene to Pleistocene age sediments (approximately 10.5 million to 12,000 years) that overlie the basalts.

The sediments are divided into two main units: the Ringold Formation of late Miocene to middle Pliocene age (approximately 10.5 to 3 million years) and the Hanford formation of Pleistocene age (approximately 1 to 12,000 million years). Holocene deposits of silt, sand, and gravel form a relatively thin veneer at the surface. The water table is in the Ringold Formation unit E, as is the unconfined aquifer. Based on limited borehole information, the Ringold Formation upper mud unit (RUM) underlies the entire area, is a relatively low permeability unit, and forms the base of the unconfined aquifer. Table 2-4 shows the elevations and thicknesses of the Ringold Formation and Hanford formation in 100-N.

The properties of these formations influence the distribution and behavior of contamination in the subsurface. Within 100-N, the vadose zone is composed mainly of the Hanford formation with portions of the Ringold unit E locally. Figure 2-6 provides a generalized geologic stratigraphic section of 100-N. Five new cross sections were constructed to show the geology throughout 100-N, shown in Figures 2-7 through 2-13. Data from several previous geologic reports, existing and decommissioned wells, and data from new well installations were used to present the best depiction of 100-N geology.

Table 2-4. Elevation and Thickness of Major Geologic Units Beneath 100-N

Geologic Unit	Top Elevation (m)	Thickness Range (m)	Description
Hanford formation	122–145	6–23	Uncemented pebble-cobble gravel
Ringold unit E	118–128	5–20	Pebble-cobble gravel; variably cemented
RUM	105–110	17–29	Silt and clay with minor sandy layers
Ringold unit C	80	3–5	Sand
Ringold Paleosol Overbank Interval	75	38–43	Silt and sand
Ringold unit B	40	20–22	Sand
Ringold lower mud	10	30	Clay and silt
Ringold unit A	-20	4–8	Gravel
Elephant Mountain	-30	40–50	Basalt

Sources: *Hydrogeology of 100-N Area, Hanford Site, Washington* (WHC-SD-EN-EV-027) and Well Information and Document Lookup database.

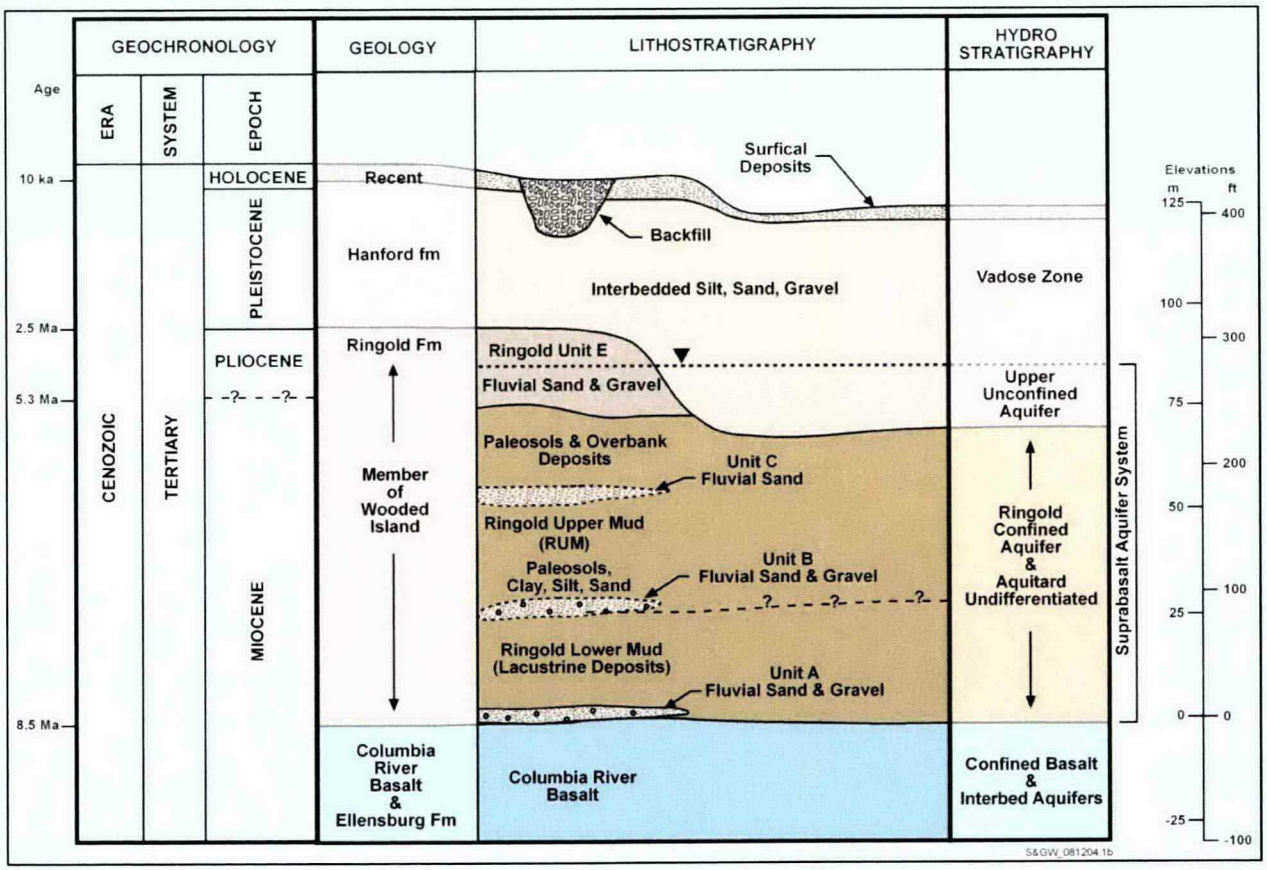


Figure 2-6. Generalized Geologic Stratigraphic Section of 100-N

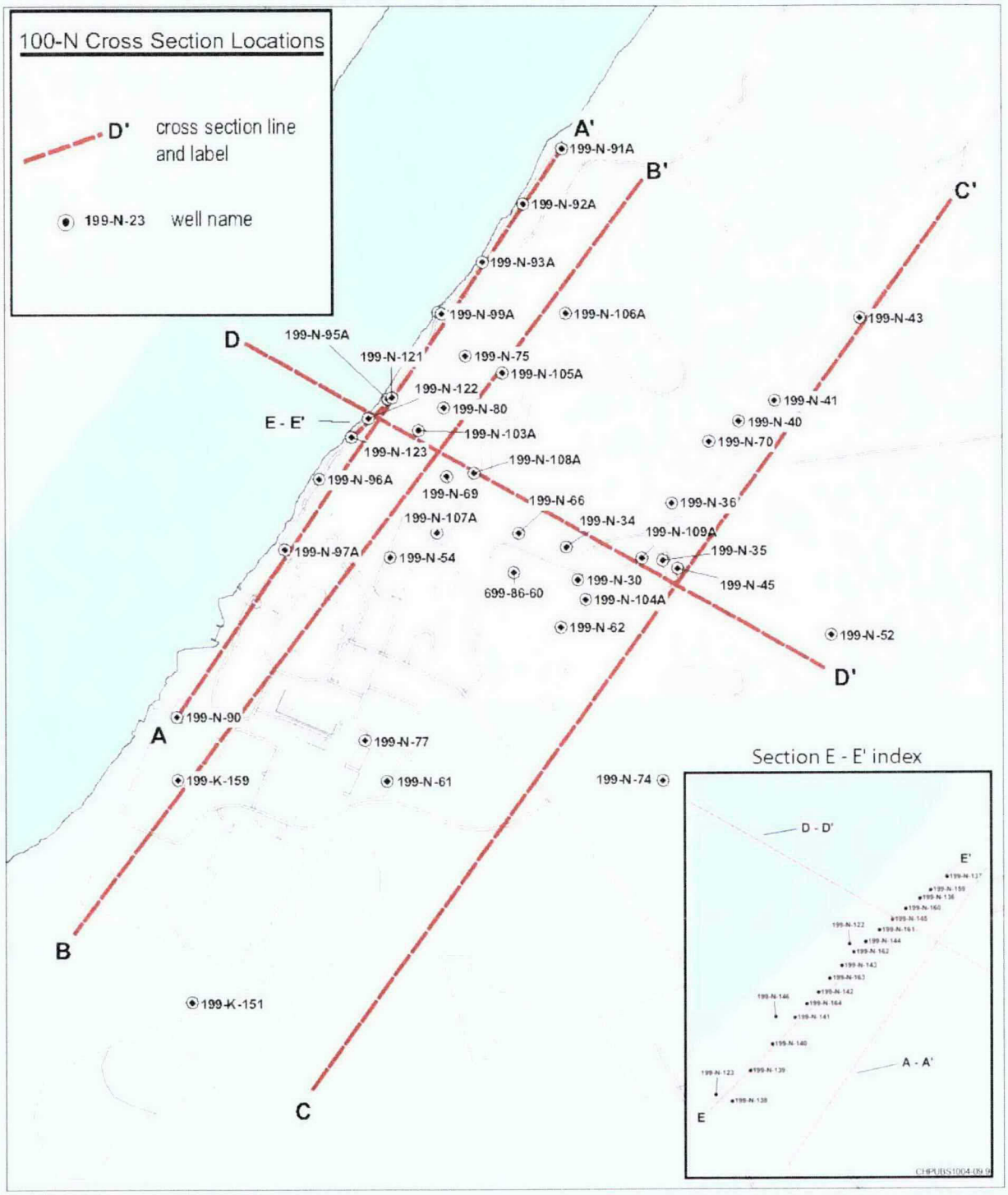


Figure 2-7. Locations of Cross Sections within 100-N

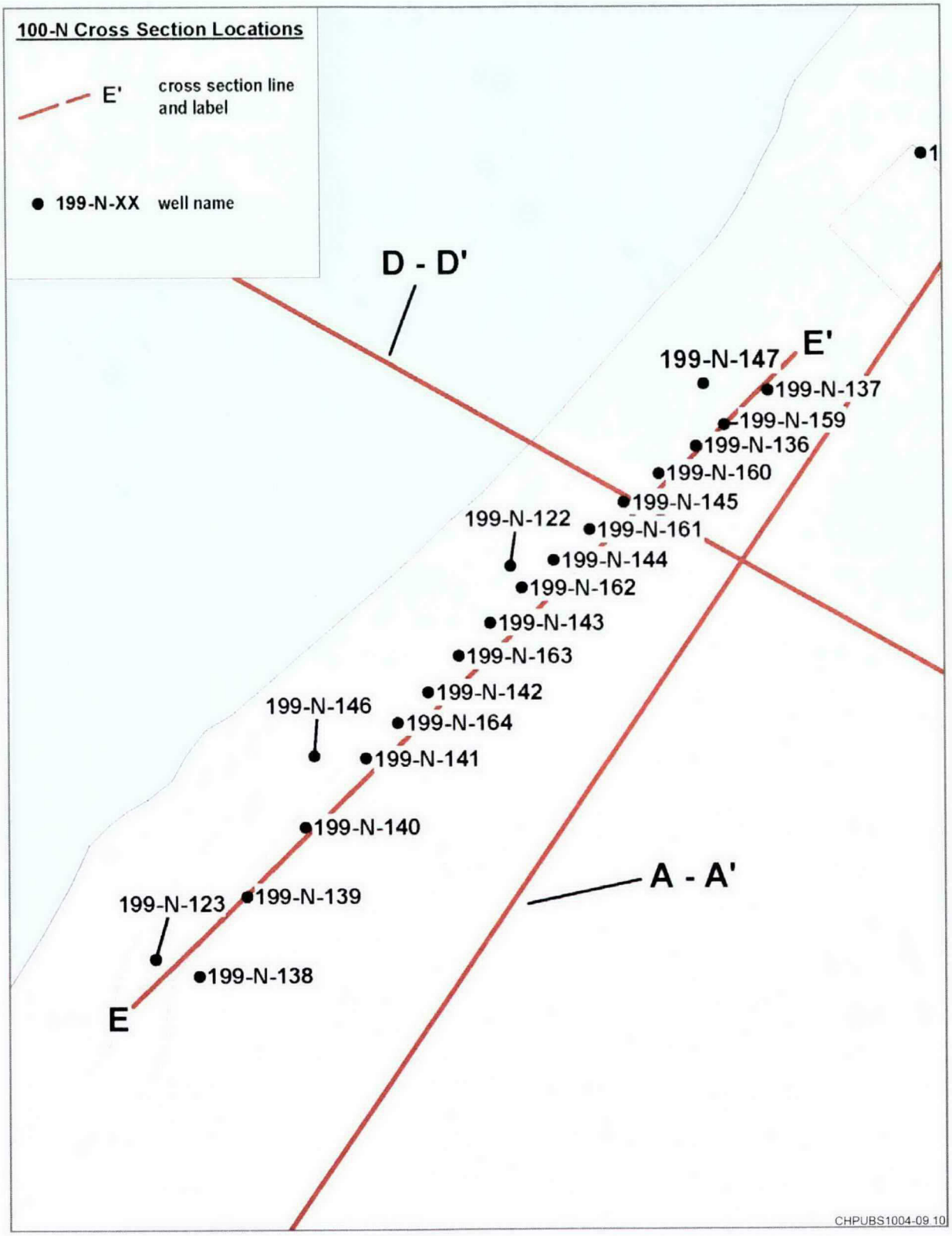


Figure 2-8. Detailed View of Cross Section E to E'

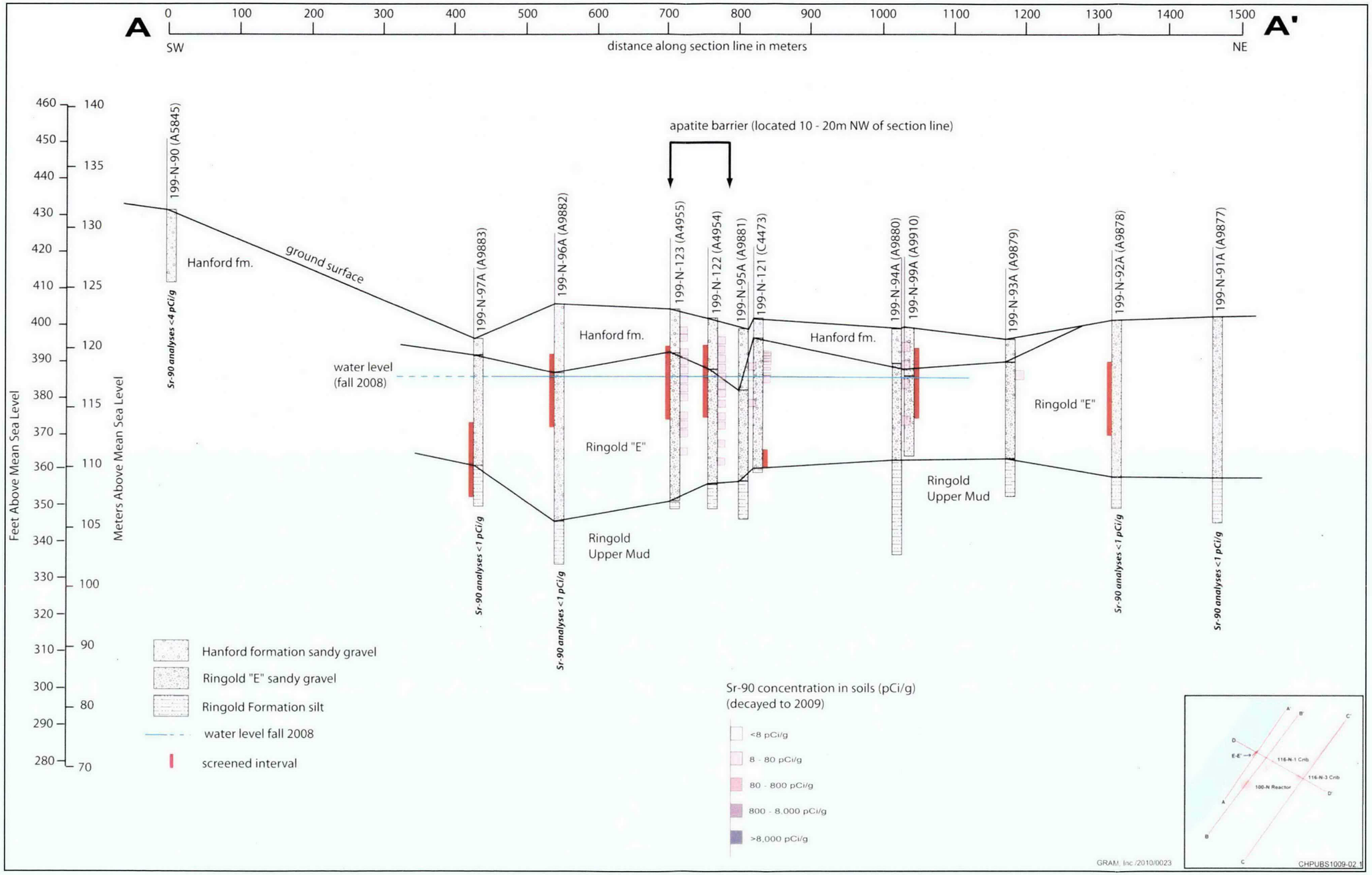


Figure 2-9. Geologic Cross Section A to A'

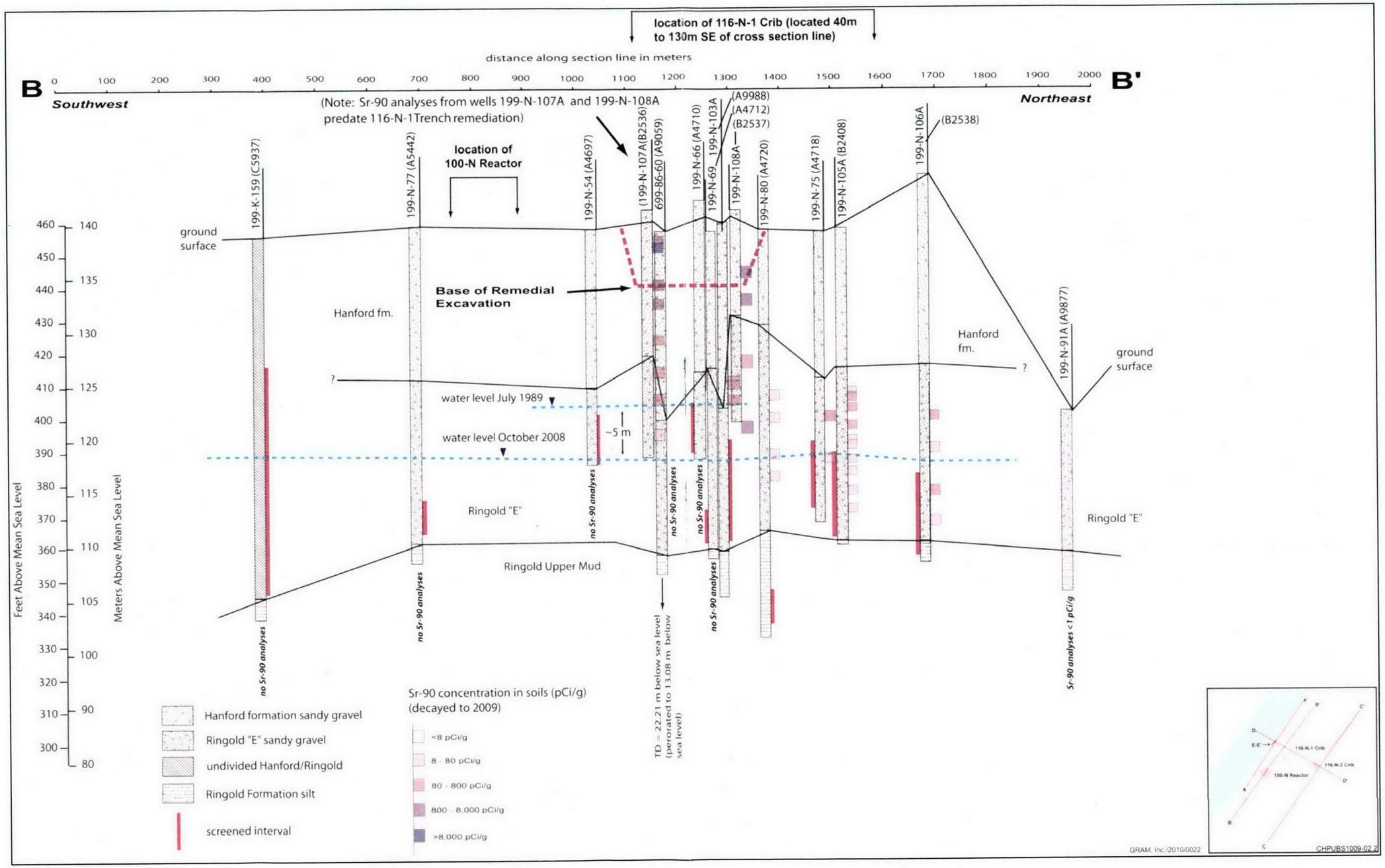


Figure 2-10. Geologic Cross Section B to B'

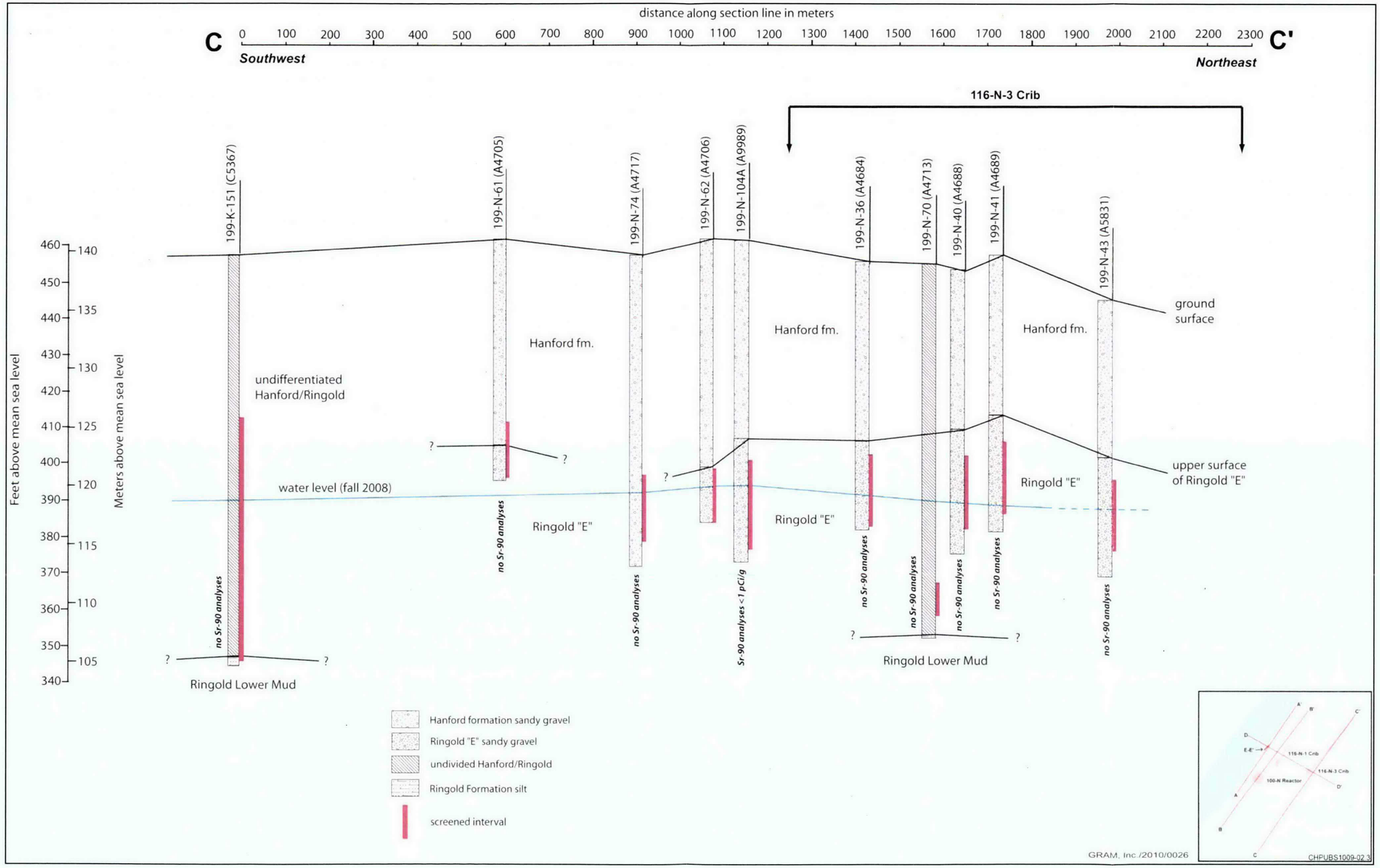


Figure 2-11. Geologic Cross Section C to C'

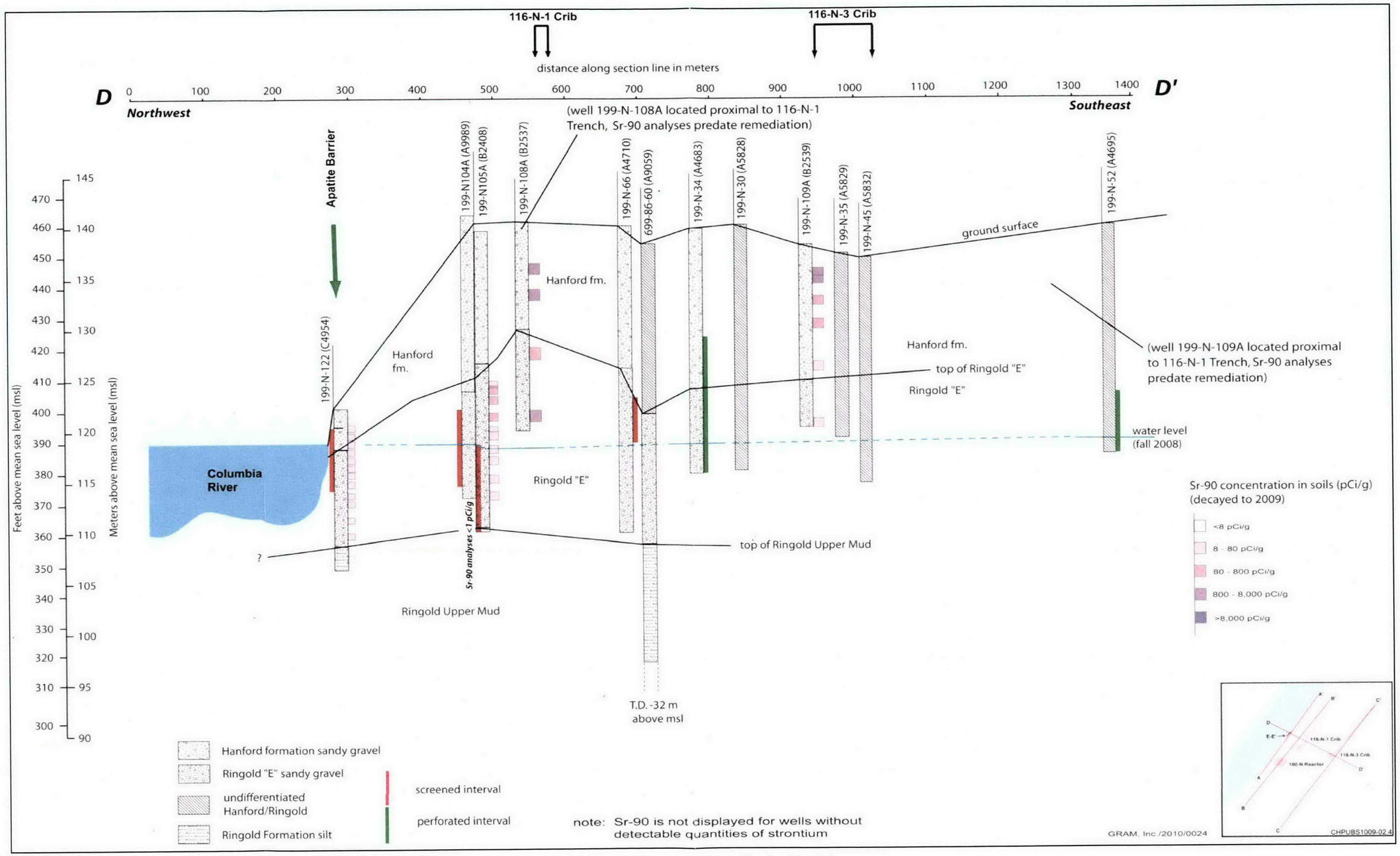


Figure 2-12. Geologic Cross Section D to D'

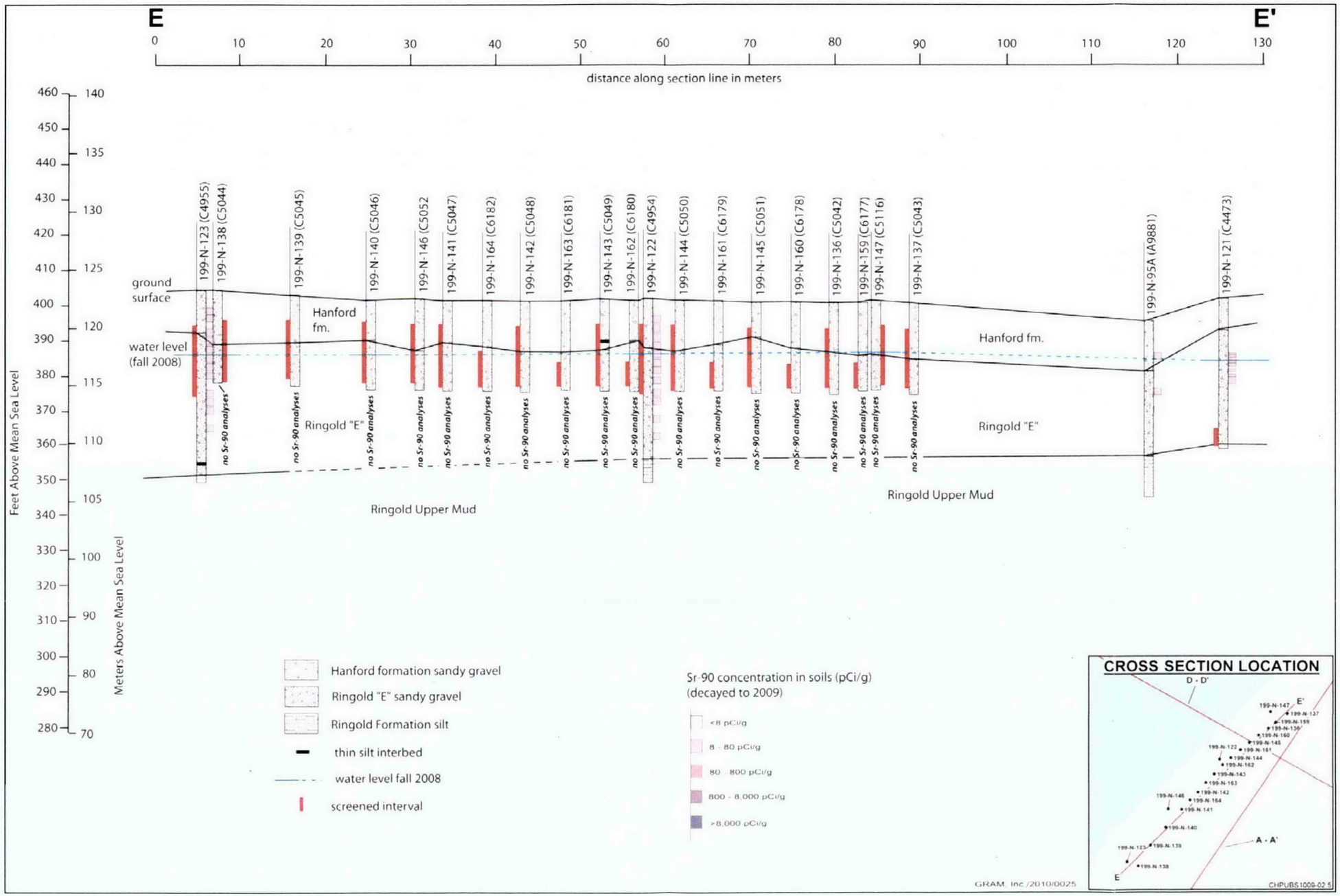


Figure 2-13. Geologic Cross Section E to E'

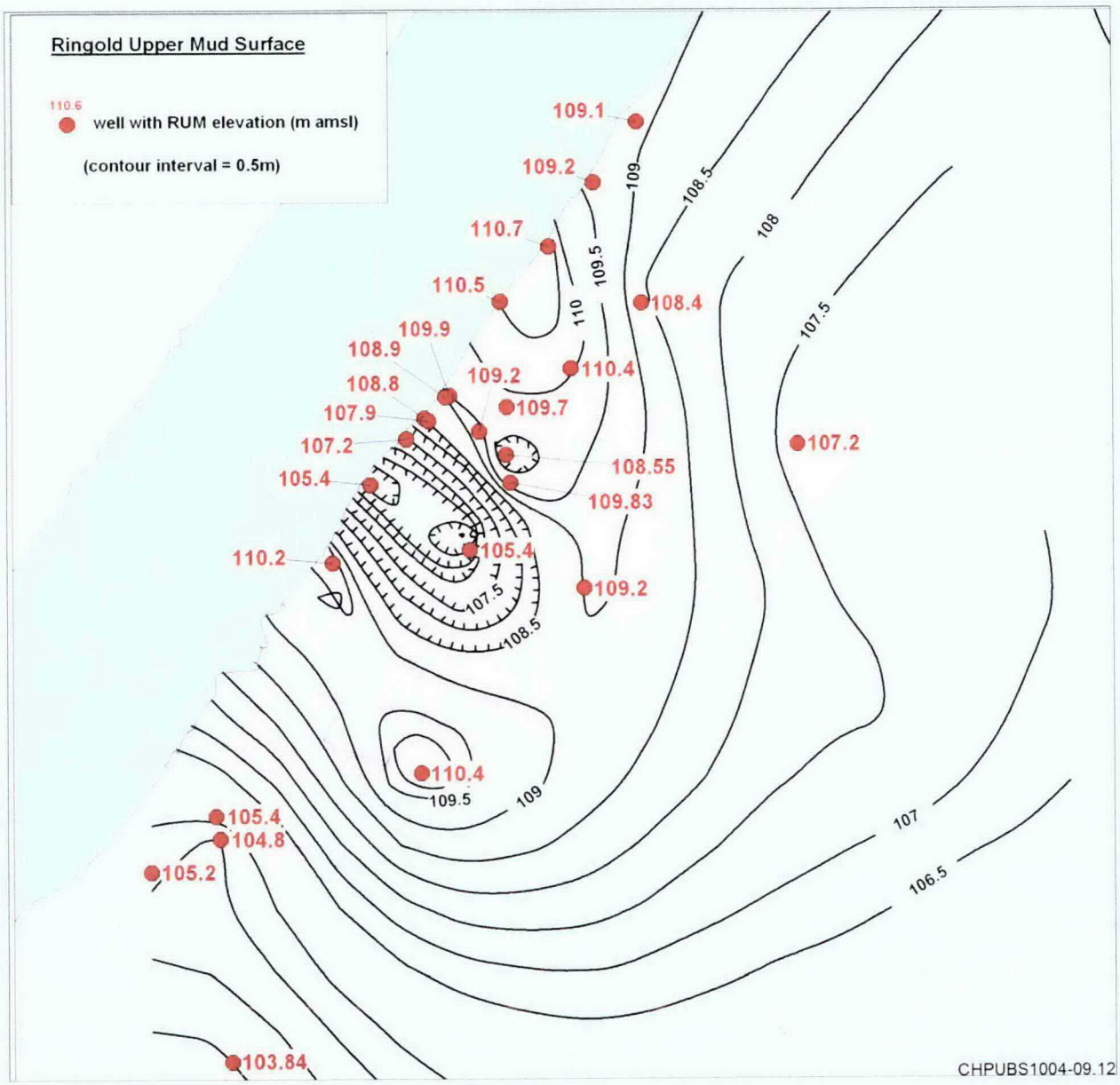


Figure 2-15. RUM Elevations in 100-N

2.2.2.3 Hanford-Ringold Contact

The Hanford formation is more transmissive and permeable than the Ringold Formation and the contact between the two potentially affects vadose zone and groundwater contaminant transport. Several criteria differentiate the two units. The sand fraction in Hanford gravels generally contains 40 to 70 percent basalt as compared to Ringold deposits that generally contain less than 25 percent basalt (*Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]; WHC-SD-EN-EV-027; and BHI-00135). Hanford gravels may display salt-and-pepper and gray coloring, while Ringold gravels are generally oxidized and reddish-brown to yellow-red in color. Hanford gravels tend to be less consolidated or cemented than Ringold gravels. Drilling rates are slower in the Ringold Formation, which exhibits decreased hydraulic conductivity. Consequently, this contact may support contaminant spreading because of hydrologic differences.

Studies done at the apatite PRB, installed along approximately 91.44 m (300 ft) of the Columbia River shoreline at 100-N, have shown significant hydrologic differences between the Hanford formation and the Ringold Formation. The Hanford formation is much more transmissive than the underlying Ringold unit E is; however, due to hydrologic heterogeneity, the hydraulic conductivity in both units is highly variable. Typical values of 15.2 and 182 m/day (50 and 597 ft/day) have been used for modeling purposes for the Ringold and Hanford units, respectively (HydroGeoLogic, Inc., 2004). A further example of the differences that can occur between the Hanford formation and Ringold unit E was demonstrated when development data from apatite PRB injection wells were used to determine the specific capacity for each well. Specific capacity—the quantity of water a well can produce per unit drawdown—provides a method for comparing the relative transmissivity of the aquifer. While specific capacity is not directly proportional to hydraulic conductivity, it is an indicator of both hydraulic conductivity and well efficiency. The specific capacity on the downstream half of the PRB is 10 to 30 times higher than the upstream portion of the barrier (PNNL-17429).

The Hanford-Ringold contact, which is irregular in 100-N, was affected by post-Ringold erosion (e.g., Pleistocene flooding). Figure 2-14 shows the elevation of the Hanford-Ringold contact (WHC-SD-EN-TI-011).

2.2.2.4 Surface Deposits

The Holocene deposits consist of silt, sand, and gravel that form a relatively thin (up to 5 m [16 ft]) veneer across 100-N. The sediments, which were deposited by a mix of windblown and alluvial processes during the past 10,000 years, consist of very fine to medium-grained angular to sub-angular sand with minor silt and gravel. In some portions, the surficial sediments consist of reworked backfill material from the Hanford formation (WHC-SD-EN-TI-011).

2.2.3 Hydrogeology

Liquid waste, including radionuclides and hazardous chemicals, has been discharged to the surface in 100-N. Some of the contaminants reached groundwater. Understanding groundwater flow and aquifer properties is necessary to properly monitor groundwater and track the spread of contaminants.

2.2.3.1 Aquifer Properties

The uppermost aquifer in 100-N is unconfined and comprises the sands and gravels of Ringold Formation unit E. During high river stage, the water table rises temporarily into the lower portion of the Hanford formation near the river. The unconfined aquifer is approximately 9 to 12 m (30 to 40 ft) thick. Fine-grained units of the RUM unit form the base of the unconfined aquifer.

Most of the monitoring wells in 100-N are screened in the top 6 m (20 ft) of the unconfined aquifer. A few wells (e.g., 199-N-69, 199-N-70, 199-N-77, and 199-N-121) are screened at the bottom of the aquifer, immediately above the RUM unit. Former extraction wells (199-N-103A, 199-N-105A, and 199-N-106A) are screened across the entire thickness of the aquifer.

Transmissivity of the unconfined aquifer ranges from 93 to 560 m^2-d (1,000 to 6,000 ft^2/day) throughout most of 100-N (WHC-SD-EN-EV-027). Wells in the northwest seem to show a higher transmissivity (up to 1,900 m^2-d [20,000 ft^2/day]). These values correspond to horizontal hydraulic conductivity of 15 to 91 m/day (50 to 300 ft/day), and 300 m/day (1,000 ft/day) in the northwest. Vertical hydraulic conductivity is 0.03 to 21 m/day (0.1 to 70 ft/day).

In 2006, as part the PRB siting investigations, DOE conducted a tracer injection test and two pilot injection tests in wells on the 100-N shoreline (PNNL-17429). Hydraulic and transport response data were evaluated at two pilot test sites. Researchers determined there was a greater contrast in permeability

2.2.2.1 Ringold Formation

The Ringold Formation unconformably overlies the Columbia River Basalt Group. The Ringold units identified from oldest to youngest in 100-N include unit A, Ringold lower mud, unit B, paleosol overbank interval, unit C, RUM, and unit E. Within 100-N, the top of the Ringold Formation ranges from 6 m (19 ft) to approximately 23 m (77 ft) bgs. Deposited by fluvial-lacustrine (stream-lake) processes, it is composed of a mix of fluvial gravels, fluvial sands, overbank deposits, paleosols, and lake deposits (*Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington* [WHC-SD-EN-EE-004]; *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas* [WHC-SD-EN-TI-011]). The Ringold Formation ranges from 137.2 to 150.5 m (450 to 494 ft) in thickness in 100-N, based on two wells (699-81-62 and 699-84-59) drilled to the top of basalt (WHC-SD-EN-EV-027).

The Ringold unit A consists of fluvial gravel dominated deposits. The lower mud consists of a lower paleosol-dominated interval and an upper lake deposit-dominated interval. Units B and C are characterized by fluvial sands with lesser, but still common overbank deposits and minor fluvial gravels. The paleosol-overbank interval between units B and C is a silt-rich deposit that locally contains abundant pedogenic carbonate development and minor sand interbeds (generally less than 3 m [10 ft] thick). The fine-grained upper mud deposits are typical overbank and paleosol facies. Unit E is composed of pebble to cobble fluvial gravels in a fine to coarse grained sand matrix with localized, discontinuous cementation. Figure 2-14 shows the top of the Ringold unit E. The base of the unconfined aquifer is defined by the top of the RUM, which is considered an aquitard rather than an impermeable unit. The hydraulic conductivity of the RUM within 100-N is not known. Channels were eroded into the top of the RUM, which established an undulating surface throughout the 100 Area. Figure 2-15 shows RUM elevations within 100-N. The Ringold unit E overlies the RUM and typically consists of fluvial gravels with lesser amounts of sand, silt, and clay, with variable and locally discontinuous cementation. The unconfined aquifer in 100-N is primarily within the Ringold unit E except during high river stage when the water table is within the Hanford formation near the river. The Ringold unit E ranges in thickness from 5 to to 20 m (17 to 65 ft) in 100-N (WHC-SD-EN-EV-027; *N-Springs Barrier Wall Drilling Program Data Package* [BHI-00135]), and is overlain by the Hanford formation.

2.2.2.2 Hanford Formation

In 100-N, the Hanford formation is present to depths of approximately 23 m (77 ft) bgs. It is an open framework with boulder-cobble gravel, sand, and silt deposited by cataclysmic floodwaters from glacial Lake Missoula during the Pleistocene epoch (*Draft Environmental Assessment: Reference Repository Location Hanford Site, Washington* [DOE-RW-0017]). The Hanford formation is divided into three facies: gravel dominated, sand dominated, and silt dominated (*Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin* [DOE-RL-2002-39]). The grains typically are sub-round to round gravel and sub-angular to round in the sand grain fraction. The gravel dominated facie typically is well stratified and contains little to no cementation (WHC-SD-EN-EV-027 and *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington* [WHC-SD-EN-TI-132]), but may contain discreet sand lenses.

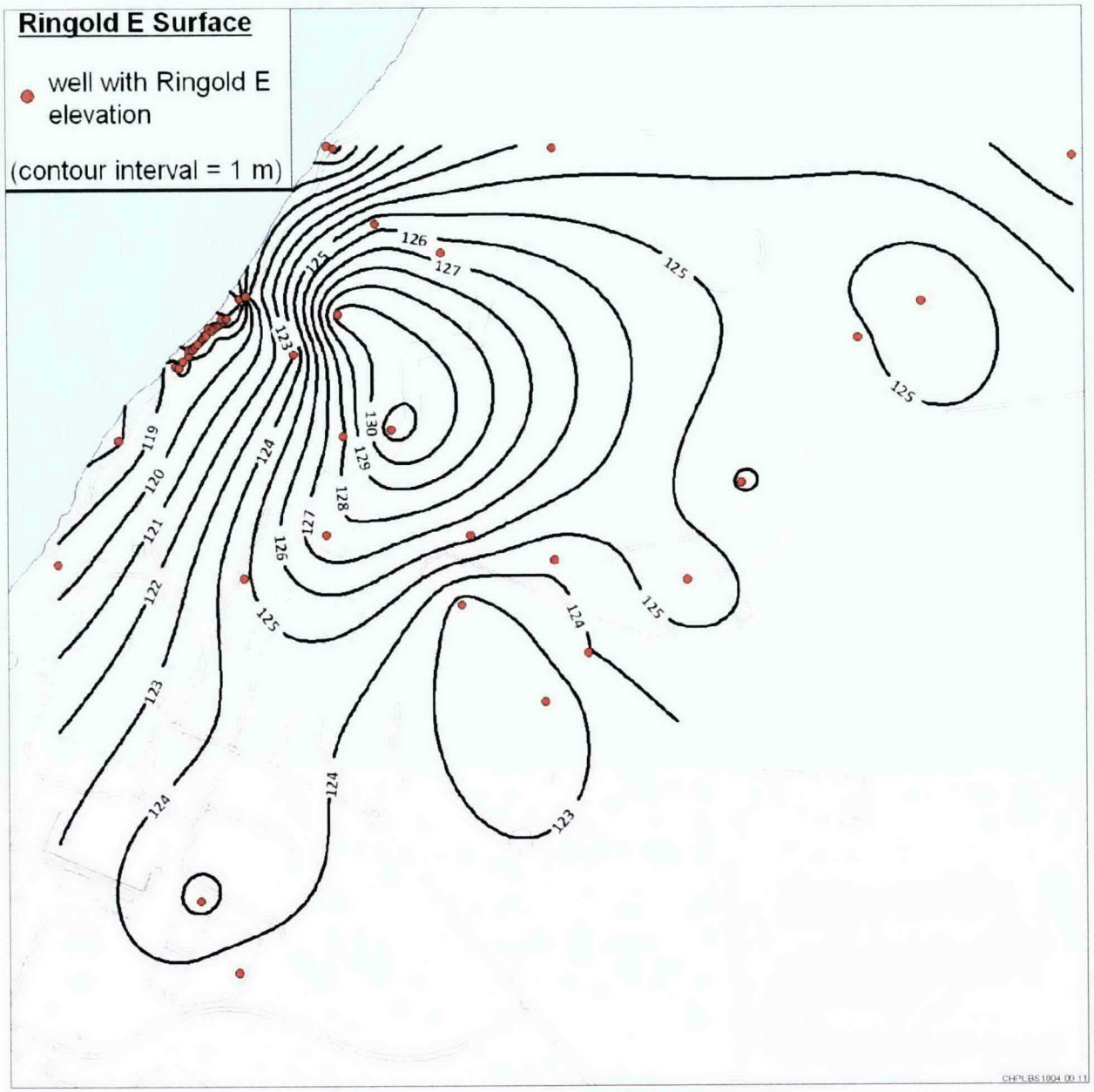


Figure 2-14. Ringold Unit E Elevations in 100-N

between the Hanford and Ringold sediments at the downstream site (near Well 199-N-137) than at the upstream site (near Well 199-N-138). Permeability of the Hanford formation was more variable than that of the Ringold Formation.

Deeper, confined aquifers occur within the Ringold Formation and in the basalt-interbed system (Figure 2-6). Wells 199-N-80 and 199-N-8P are screened in sandy layers within the RUM unit. No wells in 100-N are screened in the basalt-confined aquifers. The confined aquifers are isolated from the overlying aquifers by low permeability strata.

2.2.3.2 Groundwater Flow and Groundwater River Interaction

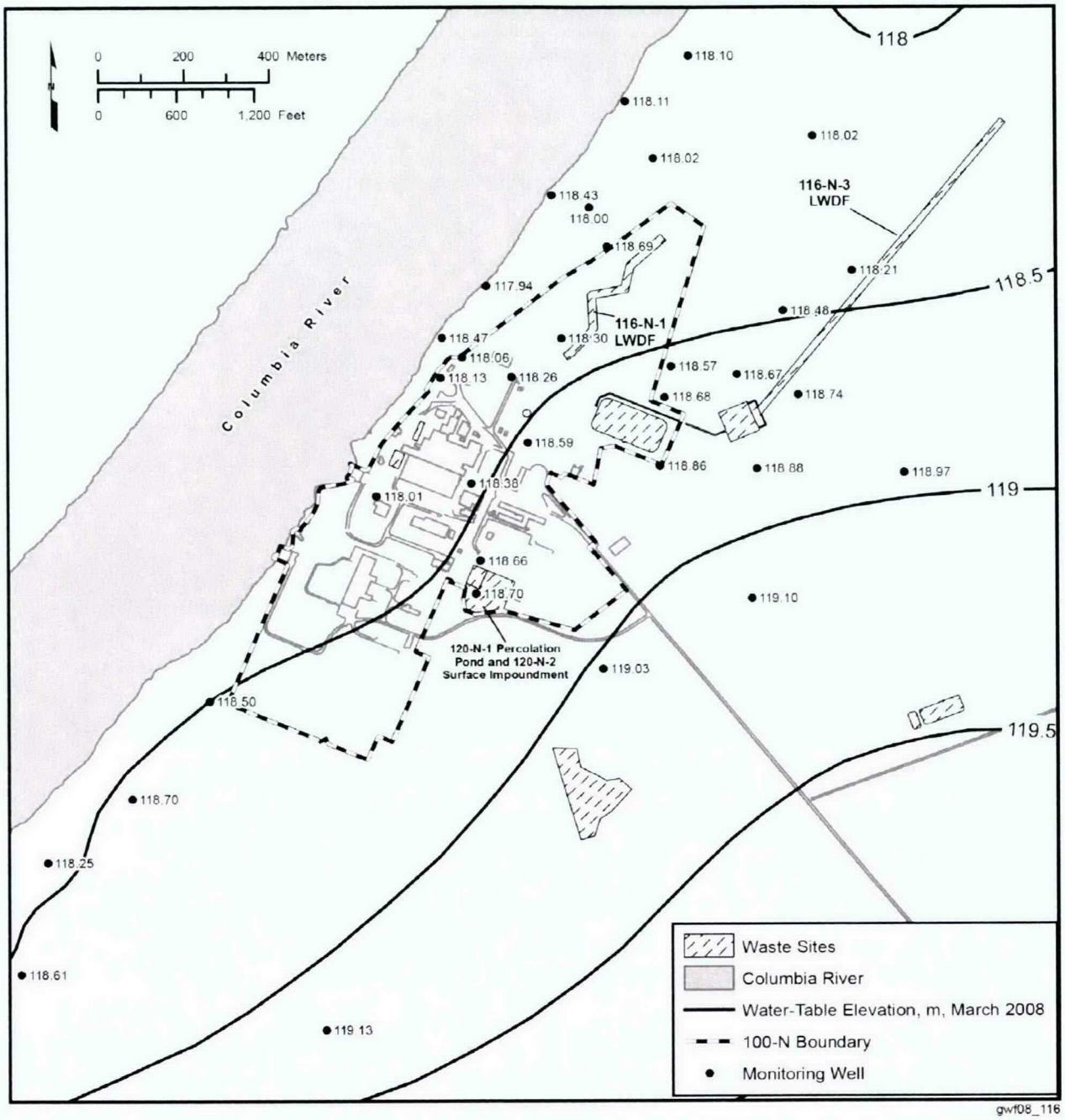
Both natural and artificial hydrologic processes have influenced subsurface contaminant distribution. Ongoing natural processes include natural recharge and river stage changes. Artificial recharge from liquid waste discharged to cribs and ponds in the 1960s through 1980s influenced groundwater flow and contaminant distribution.

Beneath 100-N, groundwater flows primarily toward the northwest, toward the Columbia River (Figure 2-16). Groundwater discharges to the river primarily below the low water line. There are currently two riverbank springs discharging above the low water line.

Daily and seasonal changes in the Columbia River stage are controlled by the Priest Rapids Dam, located upstream of the Hanford Site. During spring, the river level rises because snowmelt runoff is allowed to flow through the dam. During these periods of high river stage, river water flows into the aquifer along the Hanford Reach, causing the water table to rise throughout the 100 Area. High river stages can be more than 3 m (10 ft) higher than low river stages. River stage may fluctuate several feet over short time intervals (i.e., hours to days) based on Priest Rapids Dam operations (*Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*, [DOE-RL-96-84]). Changing river stage influences groundwater elevations over 1 km (3,000 ft) inland from the river.

In 2007, a series of three-point problems were solved to calculate gradient in various well triangles in 100-N (*Calendar Year 2007 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operation* [DOE-RL-2008-05]). For selected wells equipped with transducers, net annual gradient and flow were calculated. The following are general observations:

- Net groundwater flow during the year was northwest beneath the overall 100-N area. Net flow was north-northwest beneath 116-N-1 and toward the northwest farther inland.
- Net flow velocity during CY 2007 was approximately 0.04 m/day (0.13 ft/day) or approximately 15 m/year [49 ft/year].
- When the river stage was low, groundwater flow direction was toward the river (northwest), which was also the net flow direction.
- When the river stage was high, groundwater flow direction was away from the river (southeast) overall, and east-northeast in inland areas.
- The water table gradient and velocity are as much as an order of magnitude larger during low river stage than during high river stage.



Source: *Hanford Site Groundwater Monitoring for Fiscal Year 2008* (DOE-RL-2008-66)

Figure 2-16. 100-N Water Table Map, March 2008

From the 1960s through the 1980s, effluent discharged to liquid waste disposal facilities created groundwater mounds that influenced groundwater flow and the distribution of contaminants. The 116-N-1 site (1301-N liquid waste disposal facility) operated from 1963 through 1985. The 116-N-3 site (1325-N liquid waste disposal facility) operated from 1983 through 1991. The 120-N-1 site (1324-NA percolation pond) operated from 1977 to 1991. The long-term discharges created groundwater mounds under the disposal facilities. These mounds had substantial impacts on contaminant migration patterns in the unconfined aquifer, which are discussed further in Chapter 4. Similar mounds in each of

the 100 areas raised the water table regionally through the entire northern portion of the Hanford Site (*Hydrologic Information Summary for the Northern Hanford Site* [WCH-SD-EN-TI-023]). While the groundwater mounds existed, the water table was in the Hanford formation in some parts of 100-N. At that time, groundwater discharged to the Columbia River through a series of riverbank springs above the water line, known as the N-Springs.

Figure 2-17 shows the trends in water levels in four wells in 100-N. The elevated water table was evident 1.7 km (1.1 mi) inland at upgradient well 699-81-58. The groundwater mounds in 100-N dissipated rapidly in the early 1990s after liquid effluent disposal ceased. The regional water table (699-81-58) appeared to be still declining in 2009. The bump in water levels in the mid-1990s was caused by higher than average river stage.

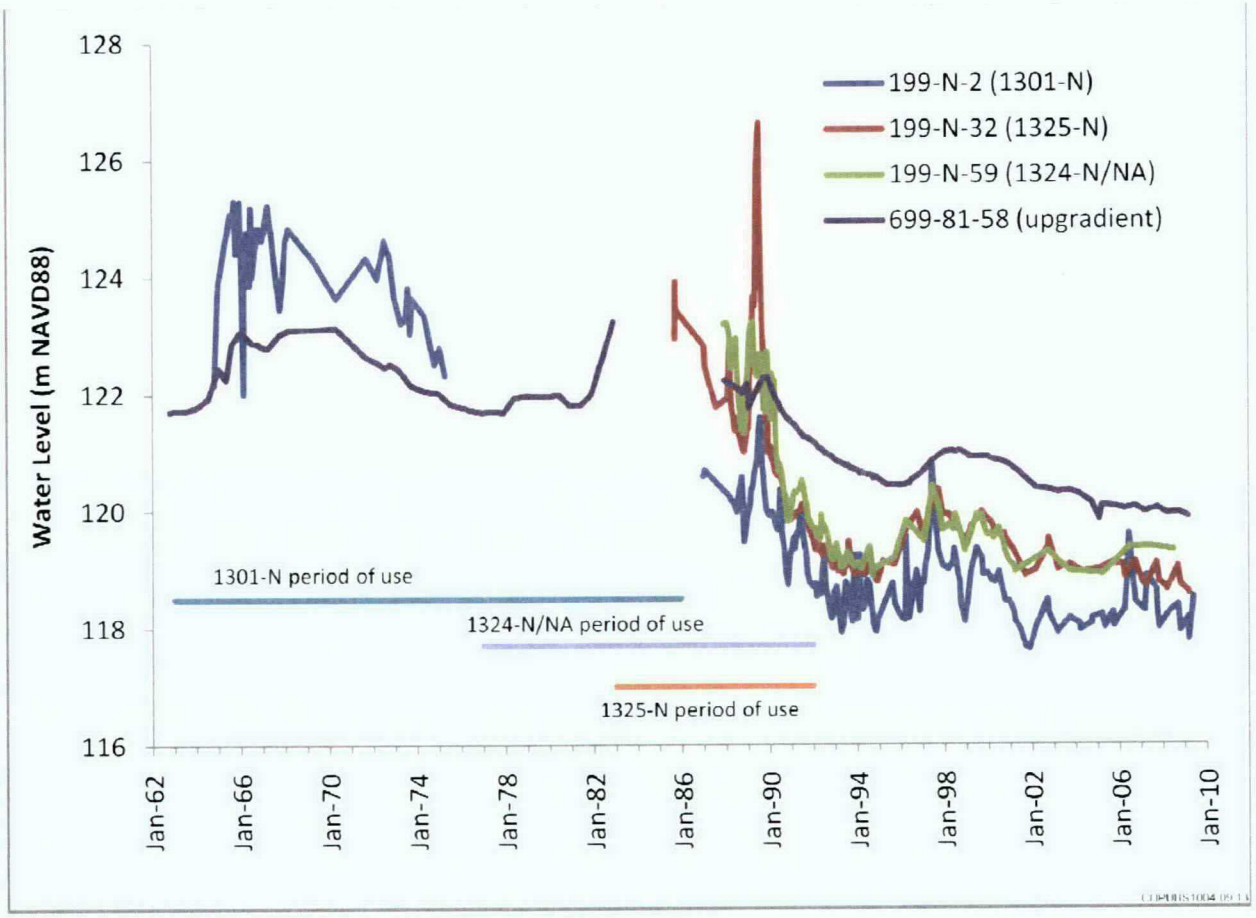


Figure 2-17. Water Levels in 100-N Wells, 1962 through 2009

2.3 Known and Potential Contamination

This section summarizes previous investigations and the current understanding of the nature and extent of vadose zone and groundwater contamination. Investigation, characterization, and remediation results for 100-N, which are discussed in this section, were considered in the development of the CSM (Chapter 4).

The compact disk located in Appendix E contains vadose and groundwater data. It contains data for soil, groundwater, and aquifer tubes. Included on this disc is explanatory text for these datasets. For comparison with cleanup levels, soil background, and groundwater background, see "Model Toxics Control Act—Cleanup" (WAC 173-340); *Hanford Site Background: Part 1, Soil Background for*

Nonradioactive Analytes (DOE-RL-92-24); and *Hanford Site Background: Part 3, Groundwater Background* (DOE-RL-96-61), respectively.

2.3.1 Nature and Extent of Vadose Zone Contamination

Initial characterization of the vadose zone consisted of limited field investigations (LFIs) performed in the early 1990s. Additional information and data from the vadose zone has been gathered through wells drilled for the groundwater monitoring program, remediation, and characterization of waste sites that began in 1996 under the authority provided by interim action RODs, and through implementation of interim groundwater remediation technologies. The results from these investigations and activities provide information about where contamination was detected in 100-N. However, vadose zone characterization beneath remediated waste sites is addressed in Chapter 4 of this addendum.

2.3.1.1 100-N Area Source Operable Unit Field Investigations (1992 and 1995)

To assess impacts associated with discharging effluent to the soil column at various waste sites, LFIs were conducted for the 100-NR-1 OU in 1992 and 1995. The following documents (or their precursors) were used in planning for these two LFIs: DOE-RL-90-22, Rev. 0; UNI-3533; and *N Reactor Effluent Stream-Specific Report* (WHC-EP-0342 Addendum 3). With the exception of *Closure/Post-Closure Plan 1301-N Liquid Waste Disposal Facility* (DOE/RL, 1987), the documents listed were used by Ecology to evaluate the 100-N master target analyte list during July 2010, and the master list was revised per Ecology's findings and recommendations (see Appendix F, 100-N Contaminants of Potential Concern Memo and Master List for Vadose Zone Target Analytes). The results (documented in *Limited Field Investigation Report for the 100-NR-1 Operable Unit Abatement Assessment* [DOE-RL-93-80] and *1301-N and 1325-N Liquid Waste Disposal Facilities Limited Field Investigation Report* [DOE-RL-96-11]) indicate radiological contamination is the primary concern and assumed to be the main contributor to overall risk within vadose zone soils. In addition, metals are present at several sites, with some concentrations exceeding Hanford Site background values (DOE-RL-92-24). Other contaminants (e.g., volatile organic compounds [VOCs], semivolatile organic compounds [SVOCs], and PCBs) were detected in relatively few samples at low concentrations.

As part of the LFIs, soil sampling and analyses were performed at nine high priority waste sites. Seven waste sites were intrusively investigated during the 1992 LFI (Table 2-5): 116-N-2 Treatment and Storage Facility, 119-N Cooling Water Drain Line, 120-N-2 Surface Impoundment, 1322-N Sampling Building, South Settling Pond, and 166-N Tank Farm (UN-100-N-17), as well as a test pit excavated at the 120-N-1 Percolation Pond. Data collection and analyses were conducted in accordance with DOE-RL-90-22. Contaminants of potential concern (COPCs) and sampling requirements were identified in BHI-00368, *Data Quality Objectives Workshop Results for 1301-N and 1325-N Characterization*. Two waste sites—the 1301-N (116-N-1) and 1325-N (116-N-3) Liquid Waste Disposal Facilities (DOE-RL-96-11)—were intrusively investigated in 1995.

Other investigation methods conducted as part of the LFIs include surface sediments sampling, field screening for VOCs, metals, and radionuclides; sampling for geological and physical properties; radiological and chemical constituents sampling; and borehole geophysical logging.

Samples were collected as part of the 1992 LFI (DOE-RL-93-80) to a maximum depth of 30.2 m (99 ft) and were analyzed for various chemicals, radionuclides, and soil properties (including bulk density, particle size distribution, moisture content, saturated hydraulic conductivity, and unsaturated hydraulic conductivity). Table 2-5 presents summary information describing the LFI investigations. The maximum extent of remedial action (i.e., remove, treat, and dispose) provides an indication of contamination removed after completion of the LFI.

Table 2-5. Summary of 100-N Limited Field Investigation (Vadose)

Waste Site or Facility	Number of Boreholes	Media	Maximum Depth of Investigation (m [ft])	Maximum Extent of Contamination (m [ft])	Maximum Extent of Remediation (m [ft])	LFI
116-N-1	5[a]	Soil	22.9 (75)[b]	21.0 (69)[b]	6.5 (21.3)	DOE-RL-93-80, DOE-RL-96-11
116-N-2	1[c]	Soil	7.2 (23.5)	6.4 (21)	Accepted[d]	DOE-RL-93-80
116-N-3	1	Soil	19.7 (64.6)	18.7 (61.5)	5.2 (17)	DOE-RL-96-11
119-N		Soil	7.6 (25)	7.3 (24)	Accepted[e]	
120-N-1	1 test pit	Soil	21.3 (70)	21.3 (70)	0[f]	DOE-RL-93-80
120-N-2	1	Soil	23.5 (77)	23.2 (76)	0[f]	DOE-RL-93-80
100-N-58	1	Soil	23.8 (78)	23.8 (78)	0[g]	DOE-RL-93-80
1322-N-NA	1	Soil	7.5 (24.5)	6.9 (22.5)	Accepted[g]	DOE-RL-93-80
166-N	1	Soil	22.9 (75)	22.6 (74)	Accepted[h]	DOE-RL-93-80

a. 4 of the 5 boreholes (199-N-75, N-76, N-108A, and N-80) were not completed within the 116-N-1 footprint (engineered structure outline).

b. Maximum value for boreholes completed within the 116-N-1 boundary.

c. Borehole is located adjacent to the "Golf Ball" storage tank.

d. 116-N-2 accepted for remediation, but it is not yet complete.

e. UPR-100-N-14 and UPR-100-N-9 are accepted for remediation, contaminated soil was removed and sent to the 200 Area for disposal, and the area was filled with clean soil.

f. 120-N-1 and 120-N-2 were included in the 100-NR-1 Corrective Measures Study and Proposed Plan; however, because these documents indicated no soil contamination was present, EPA did not include them in the 100-N CERCLA ROD. Closure activities for 120-N-1 and 120-N-2 have been completed and approved as provided in 03-RCA-0236 (Ecology letter dated February 7, 2003). Samples were collected from site soil and from pipeline scale. None of the 95 percent upper confidence level (UCL) soil concentrations for COCs exceeded Hanford Site or Washington State soil background concentrations. Remedial/corrective action included the removal of miscellaneous site structures only.

g. UPR-100-N-4 and UPR-100-N-8 accepted for remediation, but remediation is not yet complete.

h. UPR-100-N-17, UPR-100-N-18, UPR-100-N-20, UPR-100-N-24, and UPR-100-N-43 accepted for remediation, but remediation is not yet complete.

The 1995 LFI was performed at the 1301-N (116-N-1) and 1325-N (116-N-3) Liquid Waste Disposal Facilities (DOE-RL-96-11). The purpose, as established by the Tri-Parties, was to supplement previous field investigations, verify historical information, and provide necessary information so the Tri-Parties could address the following issues:

1. Determine if immediate action is required on soil at 116-N-1 (1301-N) and 116-N-3 (1325-N) to protect groundwater.
2. Determine if, for the long term, soil remediation is required to protect groundwater from a future potential impact and, if so, when remediation should be performed.

The LFI field activities included borehole drilling, sampling, and geophysical logging to investigate both contaminant and moisture distribution in soil(s) beneath the 1301-N and 1325-N facilities. The 1993 LFI

(DOE-RL-93-80) provided considerable information on near surface contamination and subsurface conditions at some distance from the facilities, but not within the facility footprints. Three new boreholes (199-N-107A, 199-N-108A, and 199-N-109A) were drilled as part of the 1995 LFI. Borehole 199-N-107A was drilled within the 1301-N Crib, while boreholes 199-N-108A and 199-N-109A were drilled immediately adjacent to the 1301-N Trench and 1325-N Crib, respectively. Soils from the boreholes were surveyed in the field for radioactivity. Vadose zone soils were sampled and subjected to physical, chemical, and radiological laboratory analyses. Downhole geophysical techniques measured gamma ray emitting contaminants, soil density, and moisture distribution. In addition to the new boreholes, four existing wells were geophysically logged.

RCRA permit parameters apply to 1301-N and 1325-N facilities (Part V, Closure Unit 2 [WA7890008967]), and 1324-N Surface Impoundment and 1324-NA Percolation Pond (Part V, Closure Unit 3 [WA7890008967]). Closure certificates for these sites are provided in Appendix D. LFI data are not available for all constituents listed in the RCRA permit. Of the available data set from the 1992 and 1995 LFIs, only one exceedance is identified. Per the RCRA permit parameter list, the maximum chromium (total) values exceeded the Groundwater Protection limit based on values in Table 2-1 of DOE-RL-96-17, Rev. 6, at each of the boreholes 199-N-75 (17 to 17.7 m [56 to 58 ft] bgs pre-excavation) and 199-N-76 (16.8 to 17.3m [55 to 57 ft] bgs pre-excavation). Supplemental parameters, not listed in the RCRA Permit, were analyzed during the LFI investigations. However, not all information is available for all potential waste constituents directed to the liquid waste disposal facilities (LWDFs) through drains and piping from the 105-N Reactor and the 109-N Heat Exchange Buildings.

2.3.1.2 100-N Limited Field Investigation Radiological Results for Vadose Soils

Table 2-6 summarizes the LFI sampling results. Based on the field investigation results, radiological contamination is the primary concern and assumed the main contributor to overall risk within the vadose zone. Radionuclides detected above background included Co-60, Sr-90, K-40, Eu-154, Eu-155, Pu-238, Pu-239-240, Cs-137, radium-226 (Ra-226), thorium-228 (Th-228), thorium-232 (Th-232), and uranium-238 (U-238). Uranium 233-234 and uranium 234 are presented independently because the analyses were performed by different laboratories. The following constituents were reported above detection limits but do not have established background values: Am-214, Cs-134, Mn-54, and Ra-228 (DOE-RL-96-11, Rev. 0).

The highest radiological concentrations were generally found in soils near the bottom of the 116-N-1 and 116-N-3 waste sites. In general, radiological contamination is highest immediately beneath the former waste site engineered structure, and decreases with depth within the vadose zone to the historical high water table established during facility operations. Radionuclides were transported to the depth of the former water table, and radiological contaminant concentrations increase from that depth to the current water table depth. Table 2-6 summarizes LFI sampling results.

Figures 2-18 through 2-26 present borehole locations and cross sections of select radiological analytes from the three 1992 LFI boreholes (199-N-107A, 199-N-108A, and 199-N-109A) and the three boreholes drilled as part of the 1995 LFI (199-N-75, 199-N-76, and 199-N-80). The boreholes have been removed, but 199-N-107A was located within the engineered structure and boreholes 199-N-108A and 199-N-109A were located immediately adjacent to the 116-N-1 (1301-N) and 116-N-3 (1325-N) waste sites, respectively. Boreholes 199-N-75, 199-N-76, and 199-N-80 are outside the 116-N-1 (1301-N) excavation footprint. All six of these boreholes are part of the groundwater monitoring network. Of particular note, Borehole 199-N-107A had eight radionuclide constituents (Am-241, Cs-137, Co-60, Eu-154, Eu-155, Pu-238, Pu-239-240, and Sr-90) above the Direct Exposure limit, based on soil cleanup concentration values in Table 2-1 of DOE-RL-96-17, Rev. 6, within the top 4.6 m (15 ft) of soil, including Am-241, Cs-137, Co-60, Eu-154, Eu-155, Pu-238, Pu-239-240, and Sr-90. This material was removed as part of 116-N-1 (1301-N) remediation that concluded in 2005.

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
116-N-1 Crib and Trench (1301-N) Depth: 3.66 m (12 ft) Number of boreholes: 2 Crib borehole 199-N 107A: 22.8 m (75 ft) depth Trench borehole 199-N-108A: 22 m (72 ft) depth	Am-241 Cs-134 Cs-137 Co-60 Eu-154 Eu-155 Manganese-54 Pu-238 Pu-239-240 K-40 Ra-226 Ra-228 Sr-90 Th-228 Th-232 U-234 U-238	Cadmium Chromium Lead Fluoride Sulfate Nitrate	Acetone Carbon disulfide Methylene chloride Toluene 4-methyl 2-pentanone 2-butanone Bis(2-ethylhexyl) phthalate di-n butylphthalate N-nitrosodiphenylamine	Radiological and metal contaminants were obtained from two boreholes within the waste site in 1995 (1301-N and 1325-N LFI). Organic analyses were not performed on these samples. Reported organic contaminants were from the three boreholes (199-N-75, 199-N-76, and 199-N-80) located more than 91.5 m (300 ft) away from 1301-N, toward the Columbia River. The boreholes support the 100-NR-2 LFI. Chemical analyses from these three wells were part of the 100-NR-1 LFI scope. PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for toxaphene only). VOAs were found with the highest concentration at depths greater than 15 m (50 ft). The highest levels of phthalate compounds were detected at depths greater than 4.6 m (15 ft). The highest concentrations of radionuclide contaminations occur at the crib base to a few feet below the crib base. This interval is referred to as the concentrated layer. Sr-90 has been detected throughout the soil column from the crib base to the water table. The concentrated layer also contains chromium and lead at above background concentration. Nickel and cadmium were detected at background concentrations. Contamination is present to groundwater and extends laterally towards the river.

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
116-N-3 Crib and Trench (1325-N) Crib Depth: 3.6 m (12 ft) Trench depth : 2.1 m (7 ft) Number of boreholes: 1 Crib borehole 199-N 109A: 19.5 m (64 ft) depth	Actinnum-228 Am-241 Bismuth -214 Cs-134 Cs-137 Co-60 Eu-154 Eu-155 Lead-214 Manganese-54 Pu-238 Pu-239-240 K-40 Ra-224 Ra-226 Ra-228 Sr-90 Th-228 Th-232 U-234 U-235 U-238		No organic analyses were performed.	All cadmium results were reported as detected in this file (some, but not all, with flags for blank contamination). Chromium, lead, and nickel results were less than background. The highest concentrations of radionuclide contaminations were found in the zone 2 m (6.6 ft) below the excavation floor, and decreased with depth.

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
120-N-1 Percolation Pond Depth: 4.6 m (15 ft) Number of test pits: 1	NA	Copper Zinc	Acetone Benzene Chloroform Methylene chloride Toluene Bis(2-ethylhexyl) phthalate di-n butylphthalate Fluoride Sulfate	Radionuclide contamination was not expected at this waste site, and none was detected via field screening. Laboratory analyses for radionuclides were not performed. PCBs non-detect at reporting limits from 33 to 74 µg/kg. Pesticides non-detect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for toxaphene only).
120-N-2 Surface Impoundment (1324-N) Depth: 4.6 m (15 ft) Borehole depth: 23.5 m (77 ft)	NA	Copper	2-butanone (MEK) 2-hexanone Acetone Chloroform Methylene chloride Toluene Xylene Bis(2-ethylhexyl) phthalate di-n butylphthalate Diethylphthalate Fluoride Sulfate	Radionuclide contamination neither was expected at this waste site, nor was it found, except for one elevated beta gamma detection from the 12.2 to 14 m (40 to 46 ft) interval. Laboratory analyses for radionuclides were not performed. PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for toxaphene only).

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
100-N-58 South Settling Pond Depth: 4.6 m (15 ft) Number of boreholes: 1 Borehole depth: 24 m (78 ft)	NA	Manganese	Acetone Methylene chloride Toluene Bis(2-ethylhexyl) phthalate di-n butylphthalate Diethylphthalate Fluoride Sulfate	Radionuclide contamination was not expected at this waste site. Field screening showed radioactivity levels to be either nondetected or below background. Laboratory analyses for radionuclides were not performed. PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for only).
1322-N and 1322-NA Sampling Buildings Number of boreholes: 1 Borehole depth: 7.5 m (24.5 ft)	Am-241 Cs-137 Co-60 Pu-239-240 K-40 Ra-226 Sr-90 Th-228-232 U-233-234 U-238	Copper Lead Zinc	Methylene chloride Toluene Aroclor 1260 Benzo(a)anthracene Benzo(b)fluoranthene Bis(2-ethylhexyl) phthalate Chrysene Dimethylphthalate di-n butylphthalate Fluoranthene Phenanthrene Pyrene Fluoride Sulfate	PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for toxaphene only). SVOCs were detected in one surface sample, and may be associated with creosote, a wood preservative.

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
116-N-2 Treatment and Storage Facility Number of boreholes: 1 Investigation depth: 7.2 m (23.5 ft)	Am-241 Cs-137 Co-60 Pu-239-240 K-40 Ra-226 Sr-90 Tc-99 Th-228 Th-232 U-233-234 U-238	Lead	1,1,1 trichloroethane 2-butanone Methylene chloride Toluene 1,4-dichlorobenzene Anthracene Aroclor 1254 Aroclor 1260 Benzo(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Chrysene Diethylphthalate di-n butylphthalate Fluoranthene Phenanthrene Pyrene Fluoride Nitrate Sulfate	Sr-90 was not detected above minimum detectable activities (0.8 to 1.0 pCi/g) in any samples (laboratory conducted liquid scintillation counting). PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for only). SVOCs were detected from two surface samples, and may be associated with creosote, a wood preservative.
119-N Cooling Water Drain Line Number of boreholes: 1 Borehole depth: 7.6 m (25 ft)	NA	NA	Acetone Methylene chloride Fluoride Sulfate Nitrate	Radionuclide contamination was not expected at this waste site. No radionuclide analyses were performed. No inorganic compounds were detected above background. No SVOCs were detected above background. PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for only).

Table 2-6. Summary of the Limited Field Investigation Analytes Detected

Waste Site	Radiological	Inorganic (exceeded HSB)	Organic	Relevant Information
166-N Tank Farm Number of boreholes: 1 Borehole depth: 22.8 m (75 ft)	Co-60 K-40 Ra-226 Sr-90 Th-228 Th-232 U-238 U-233-234		2-butanone Acetone Benzene Ethylbenzene Toluene Xylene 2-methylnaphthalene Anthracene di-n-butylphthalate Fluorene Naphthalene Phenanthrene Pyrene Fluoride Sulfate Nitrate	The highest VOA concentration(s) were found at depths from 16.5 to 21.6 m (54 to 71 ft). The source of these potential contaminants is likely related to the UN-100-N-17 unplanned release. PCBs nondetect at reporting limits from 33 to 74 µg/kg. Pesticides nondetect at reporting limits from 1.7 to 19 µg/kg (170 to 190 µg/kg for only). No inorganic compounds were detected above background. All radionuclides were detected at greater than 4.6 m (15 ft) depth.

Source:

DOE-RL-93-80, *Limited Field Investigation Report for the 100-NR-1 Operable Unit.*

DOE-RL-93-81, *Limited Field Investigation Report for the 100-NR-1 Operable Unit.*

DOE-RL-96-11, *1301-N and 1325-N Liquid Waste Disposal Facilities Limited Field Investigation Report.*

Note: Reporting limits provided where available. Where reporting limits are not provided, the information was not available.

HSB = Hanford Site Background, 90 percent threshold level (DOE-RL-92-24, Rev. 3)
LFI = limited field investigation
NA = not available
PCBs = polychlorinated biphenyls
SVOC = semivolatile organic compound
VOA = volatile organic analyte

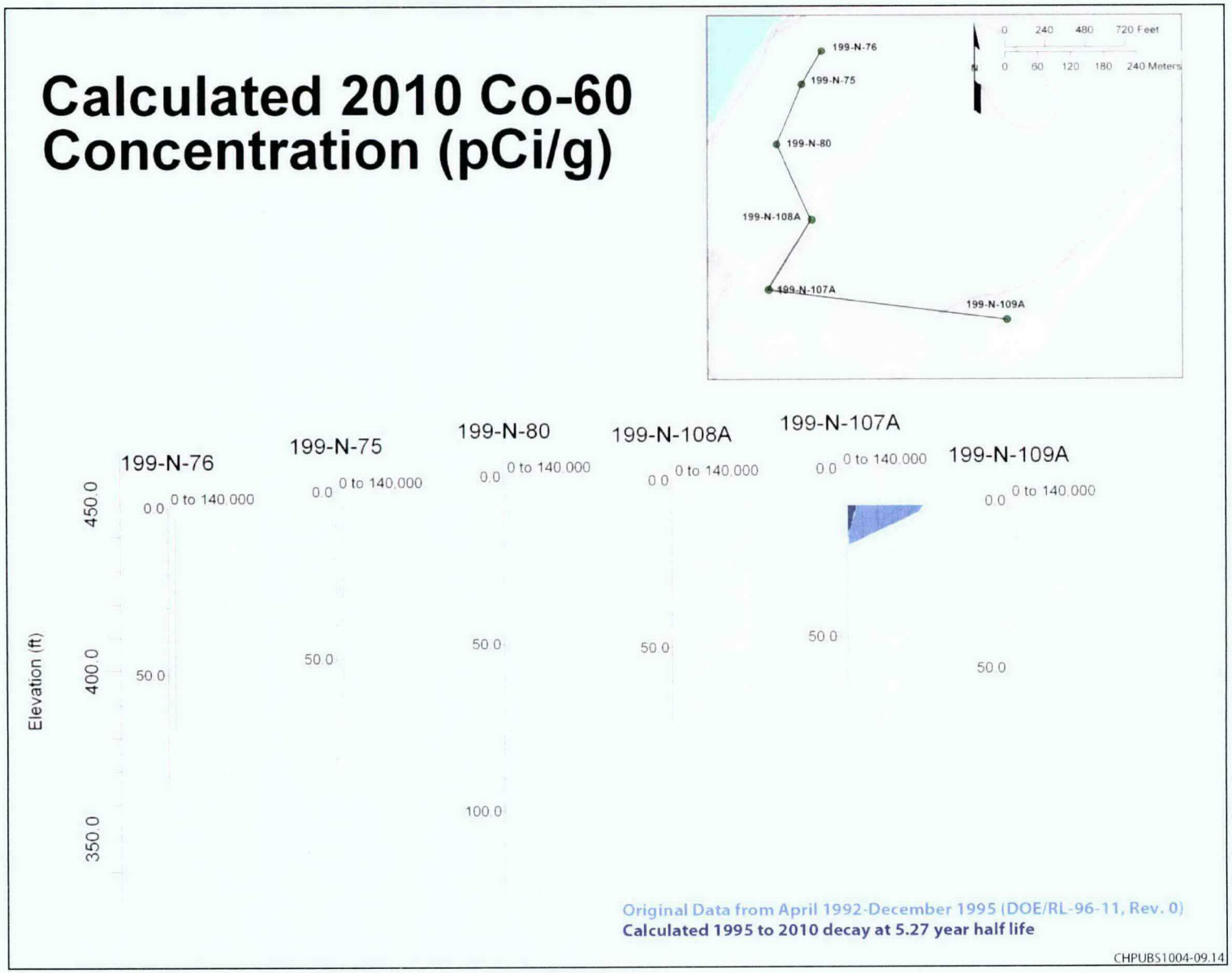


Figure 2-18. Co-60 Calculated to 2010 Concentrations at Select 100-N LFI Boreholes

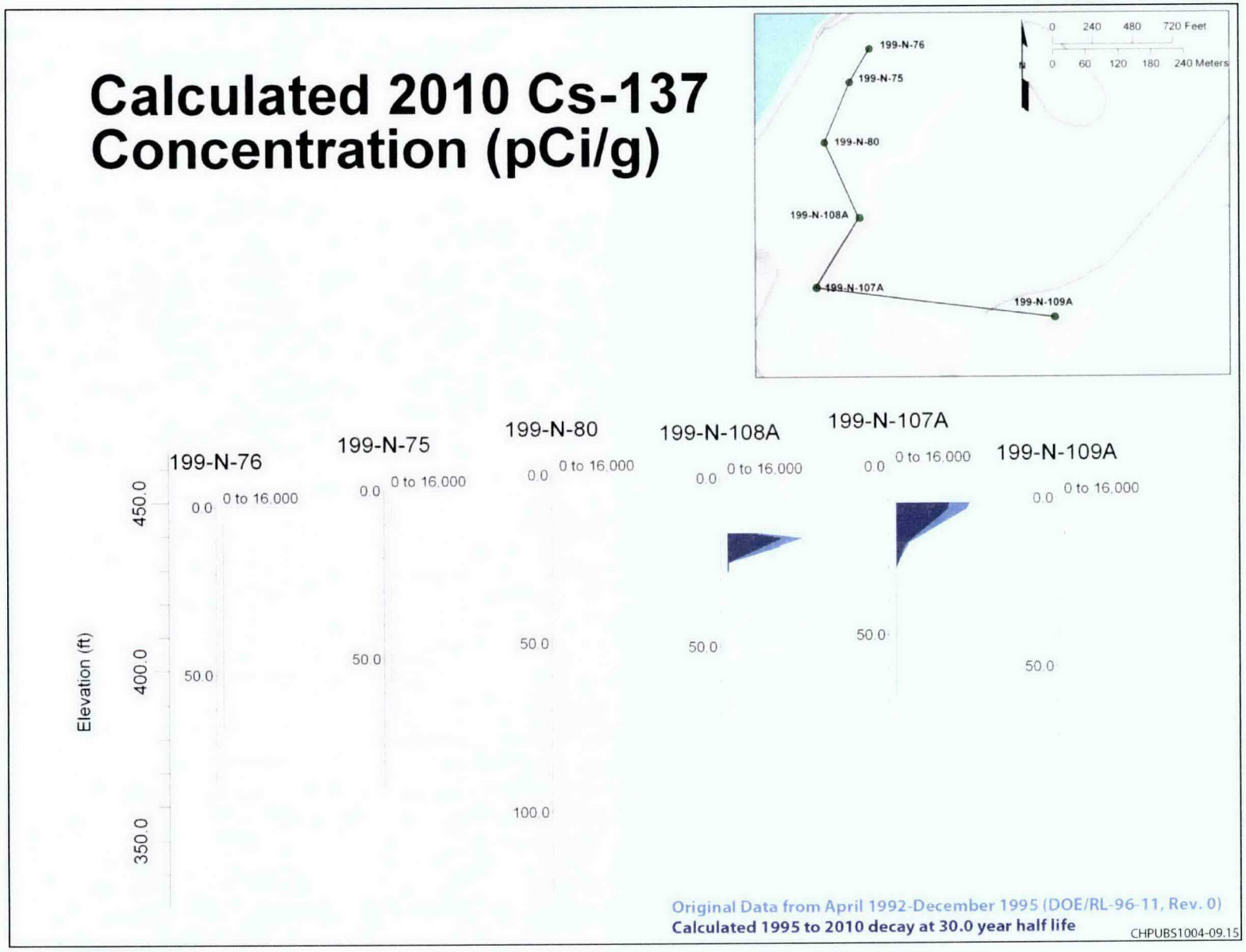


Figure 2-19. Cs-137 Calculated to 2010 Concentrations at Select 100-N LFI Boreholes

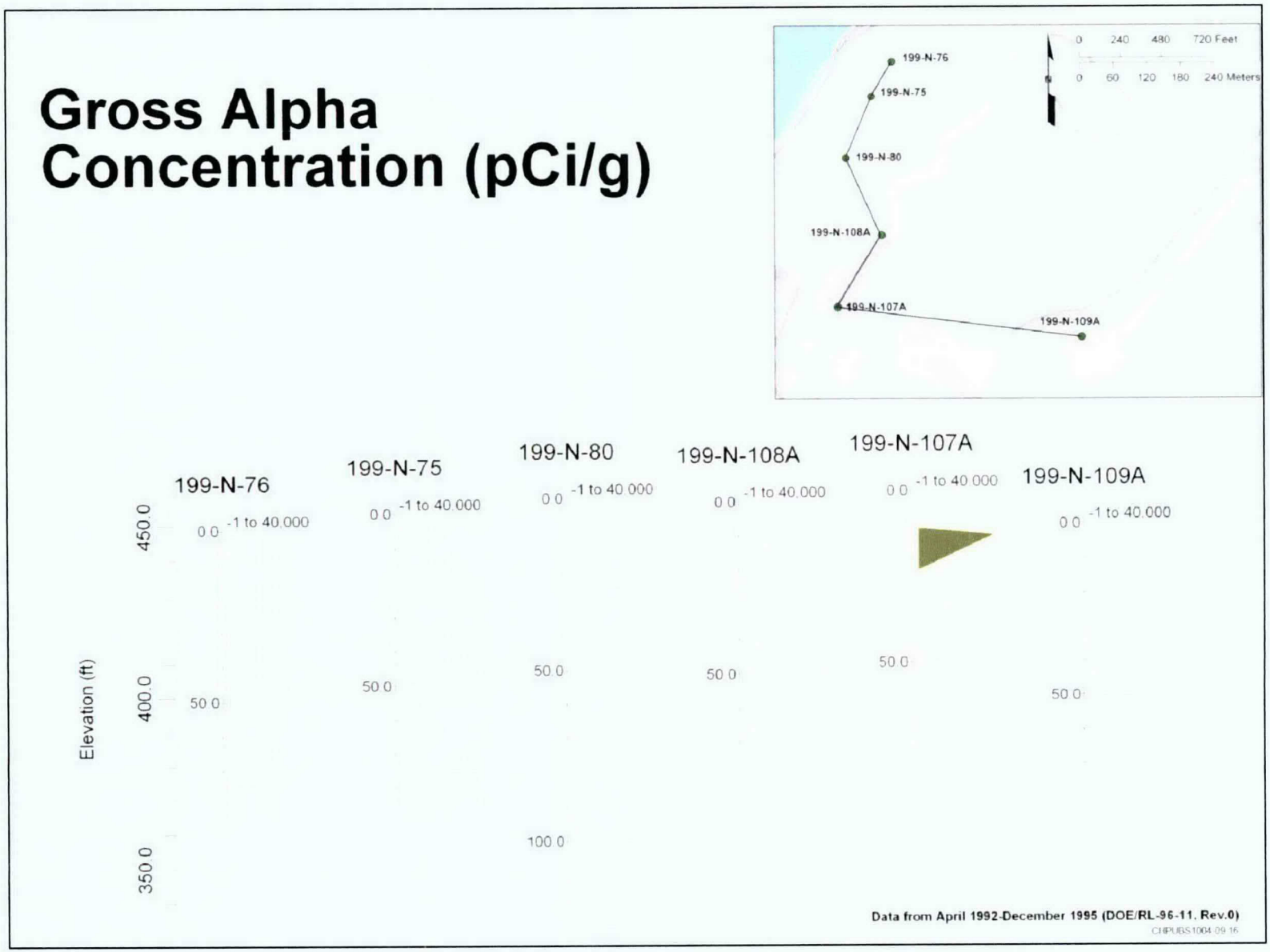


Figure 2-20. Gross Alpha Concentration at Select 100-N LFI Boreholes

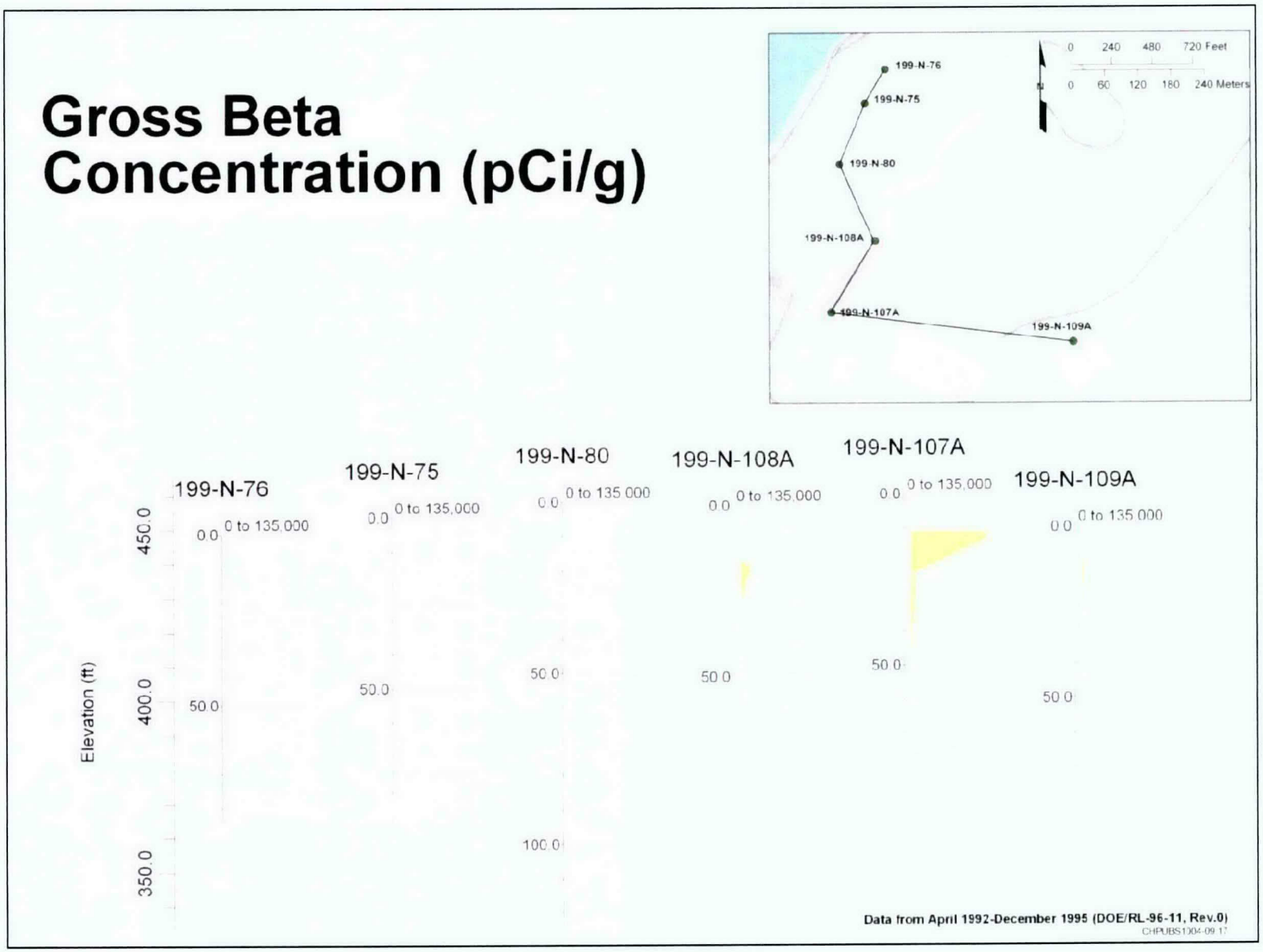


Figure 2-21. Gross Beta Concentration at Select 100-N LFI Boreholes

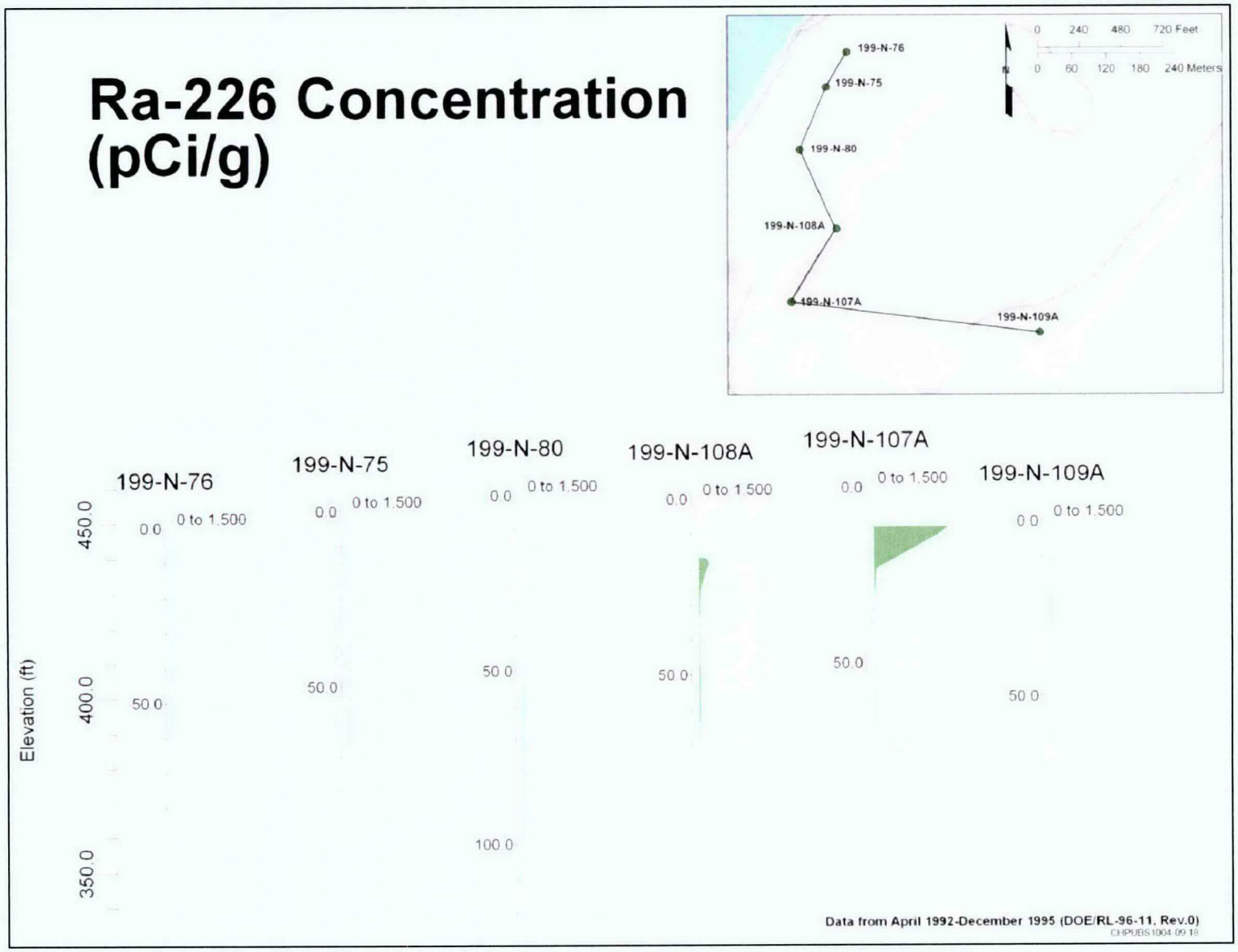


Figure 2-22. Ra-226 Concentration at Select 100-N LFI Boreholes

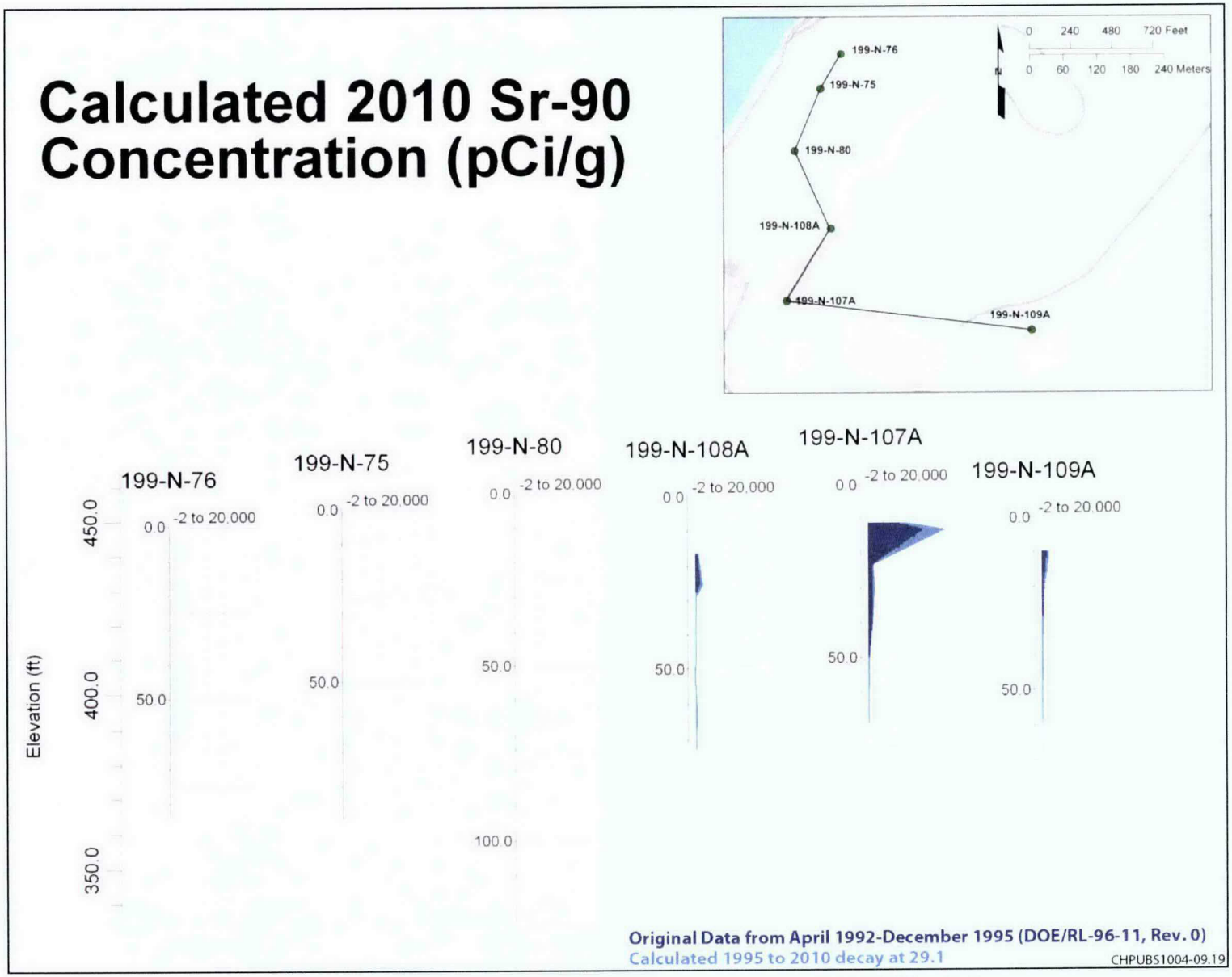


Figure 2-23. Sr-90 Calculated to 2010 Concentrations at Select 100-N LFI Boreholes

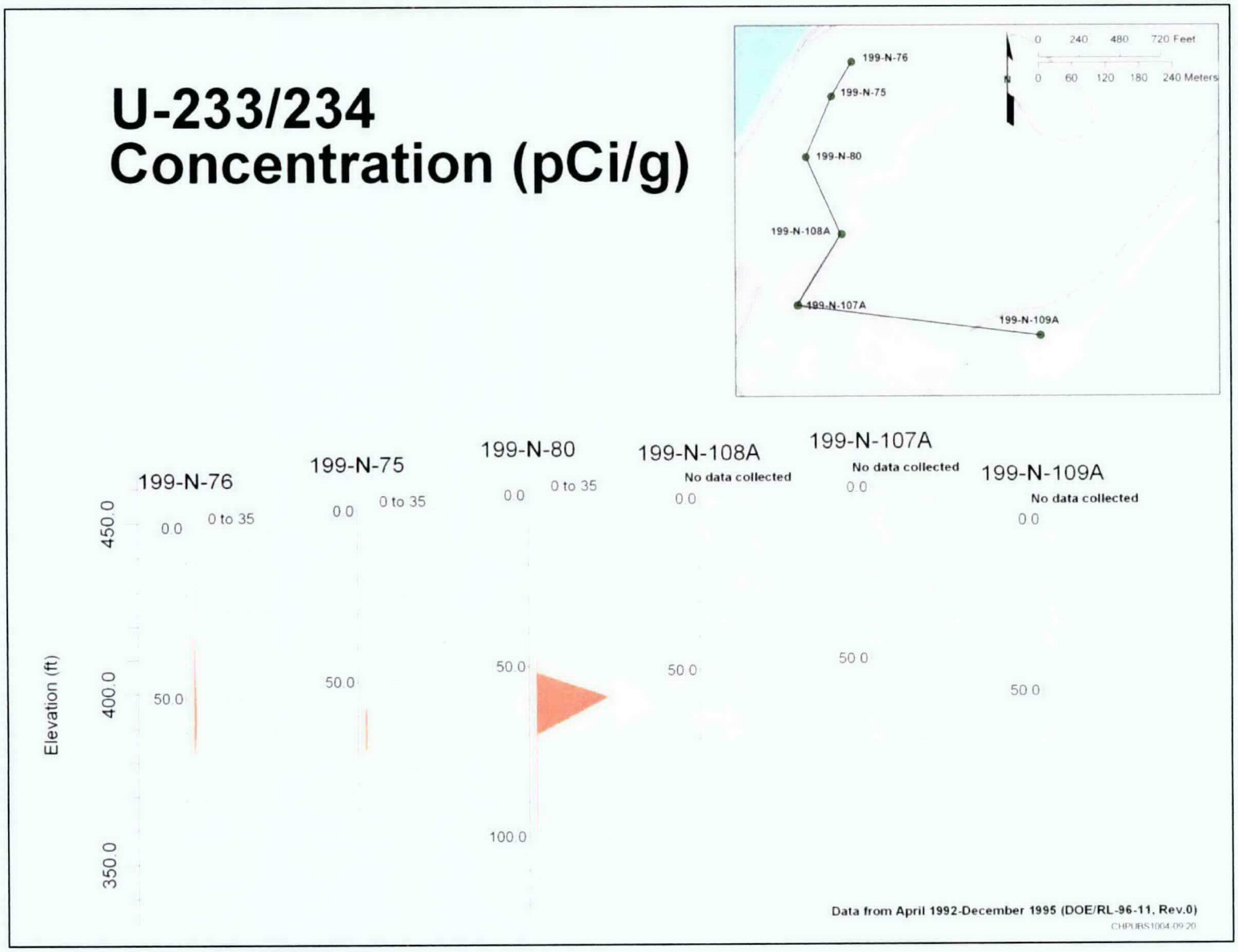


Figure 2-24. U-233-234 Concentration at Select 100-N LFI Boreholes

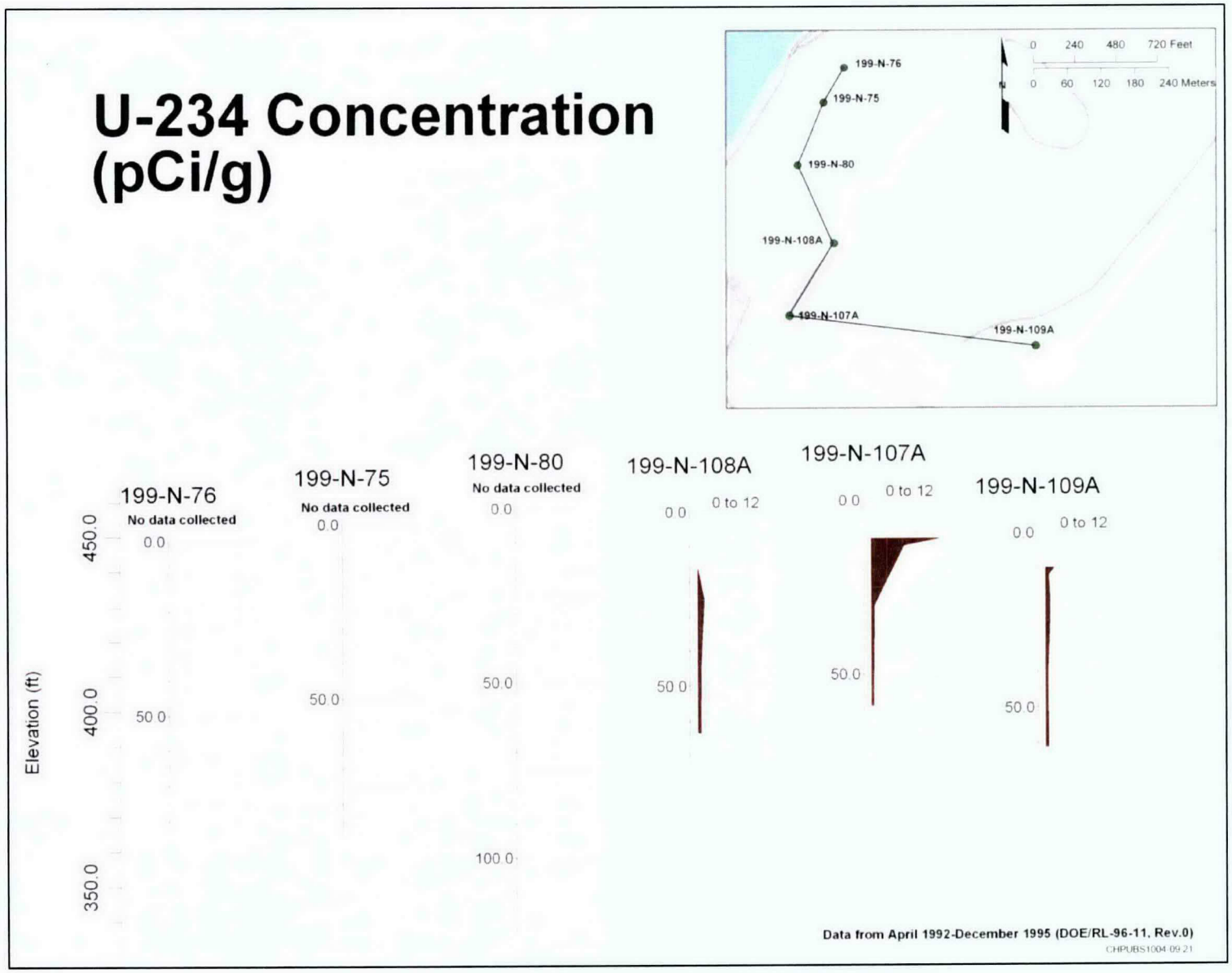


Figure 2-25. U-234 Concentration at Select 100-N LFI Boreholes

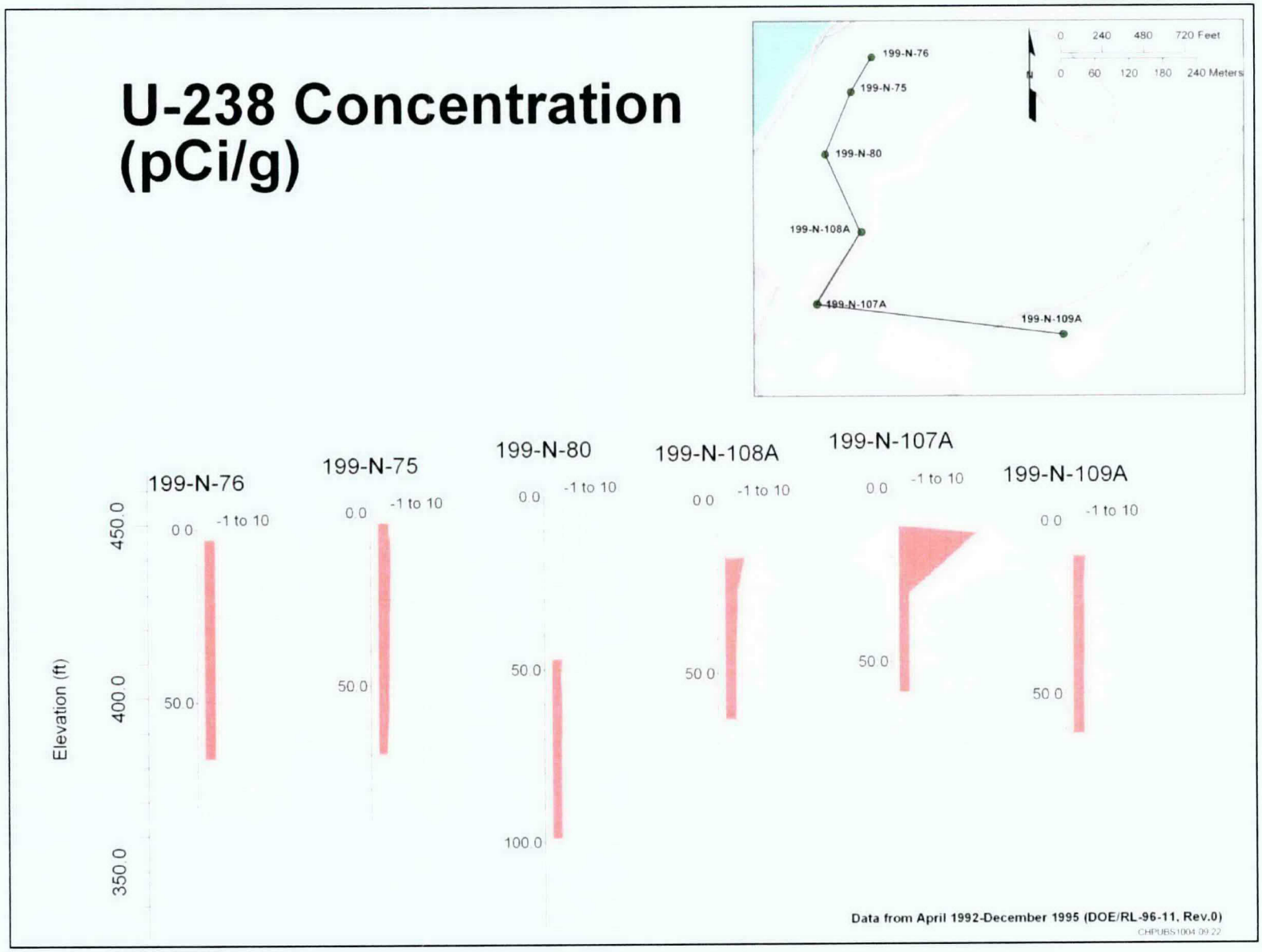


Figure 2-26. U-238 Concentration at Select 100-N LFI Boreholes

Fewer depth discrete samples were taken at boreholes 199-N-75, 199-N-76, and 199-N-80 in the 1995 LFI investigation, but results exceeding the groundwater protection limit for radiological constituents were deeper than 16.8 m (55 ft) bgs.

The highest Co-60, Cs-137, and Pu-239-240 concentrations detected in 100 Area soils were from 100-N. The highest Co-60 concentration (18 ± 1.80 pCi/g) was detected west of the head end of the 116-N-1 Crib (1301-N). Additionally, soil at the head end but southwest of the 116-N-1 Crib and Trench contained the highest Cs-137 concentration (2.2 ± 0.223 pCi/g). The highest Pu-239-240 concentration (0.06 ± 0.008 pCi/g) was detected at the same location as the highest Co-60 concentration (WHC-SD-EN-TI-251).

2.3.2 Nature and Extent of Contamination in the Groundwater

Strontium-90 was sampled from 23 boreholes in 100-N (Figure 2-27) and soil samples collected during waste site interim action remedial activities. Post remediation Sr-90 soil sample results are shown for 116-N-1 (1301-N), 116-N-3 (1325-N), and 100-N-63:1 in Figures 2-28, 2-29, and 2-30 respectively.

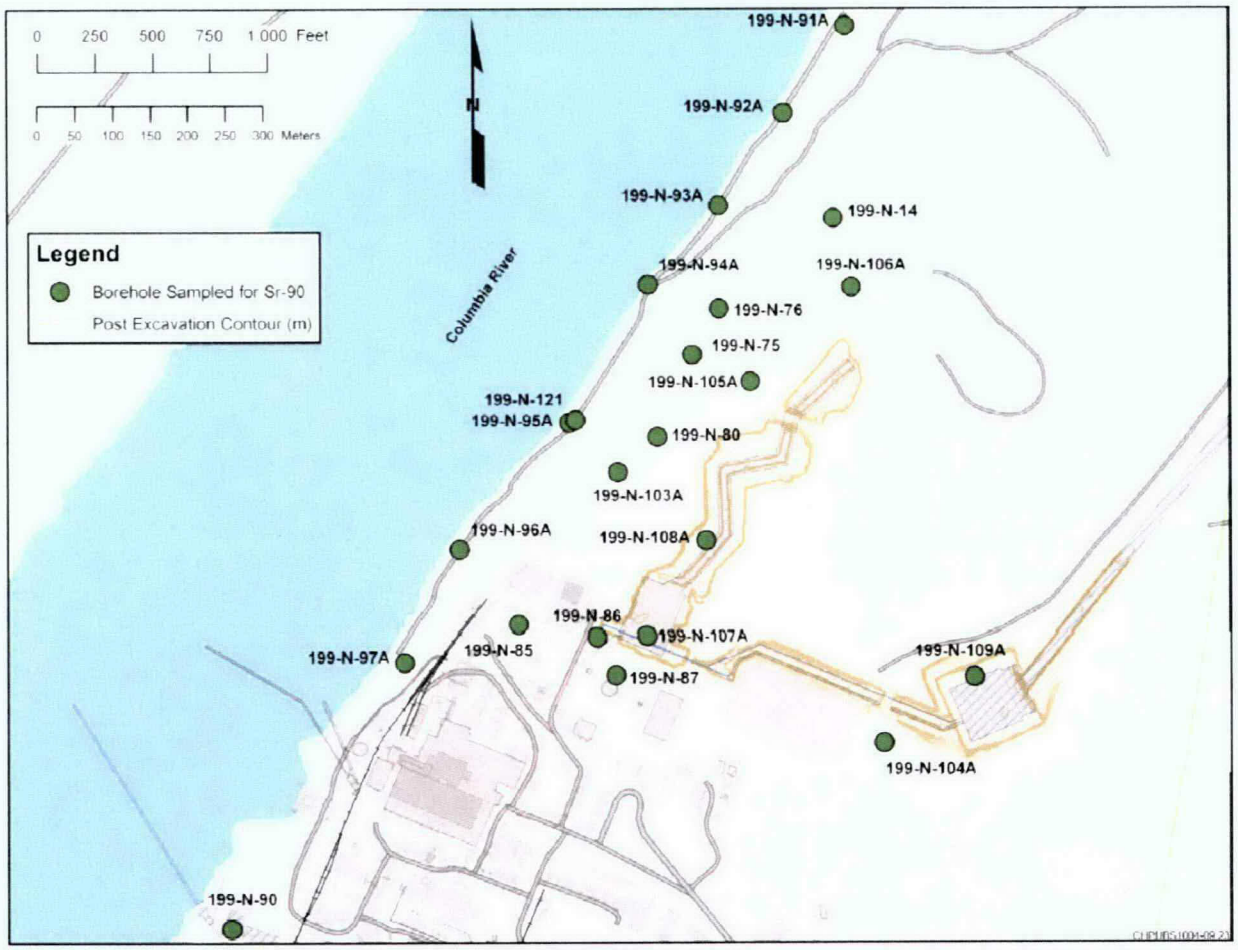
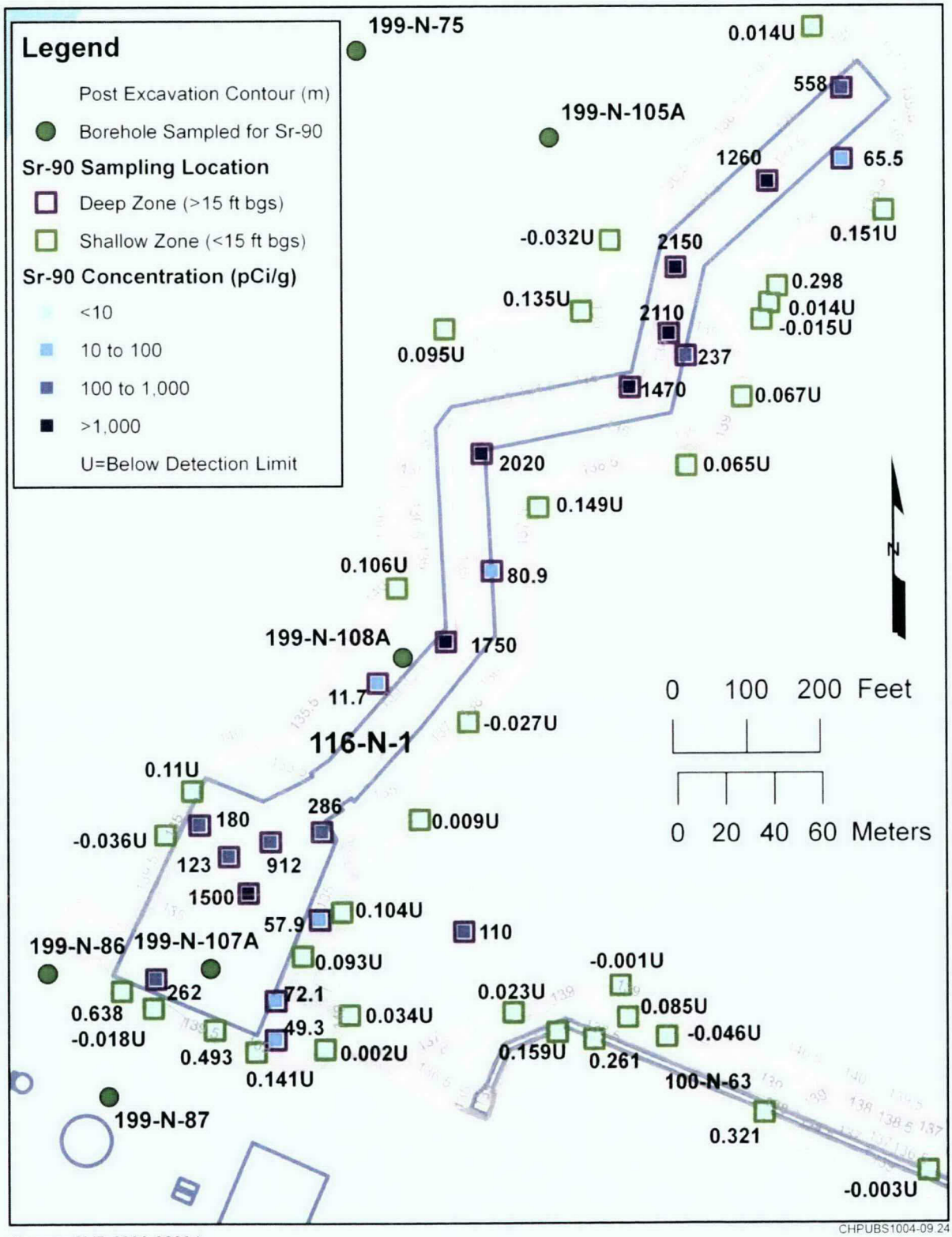
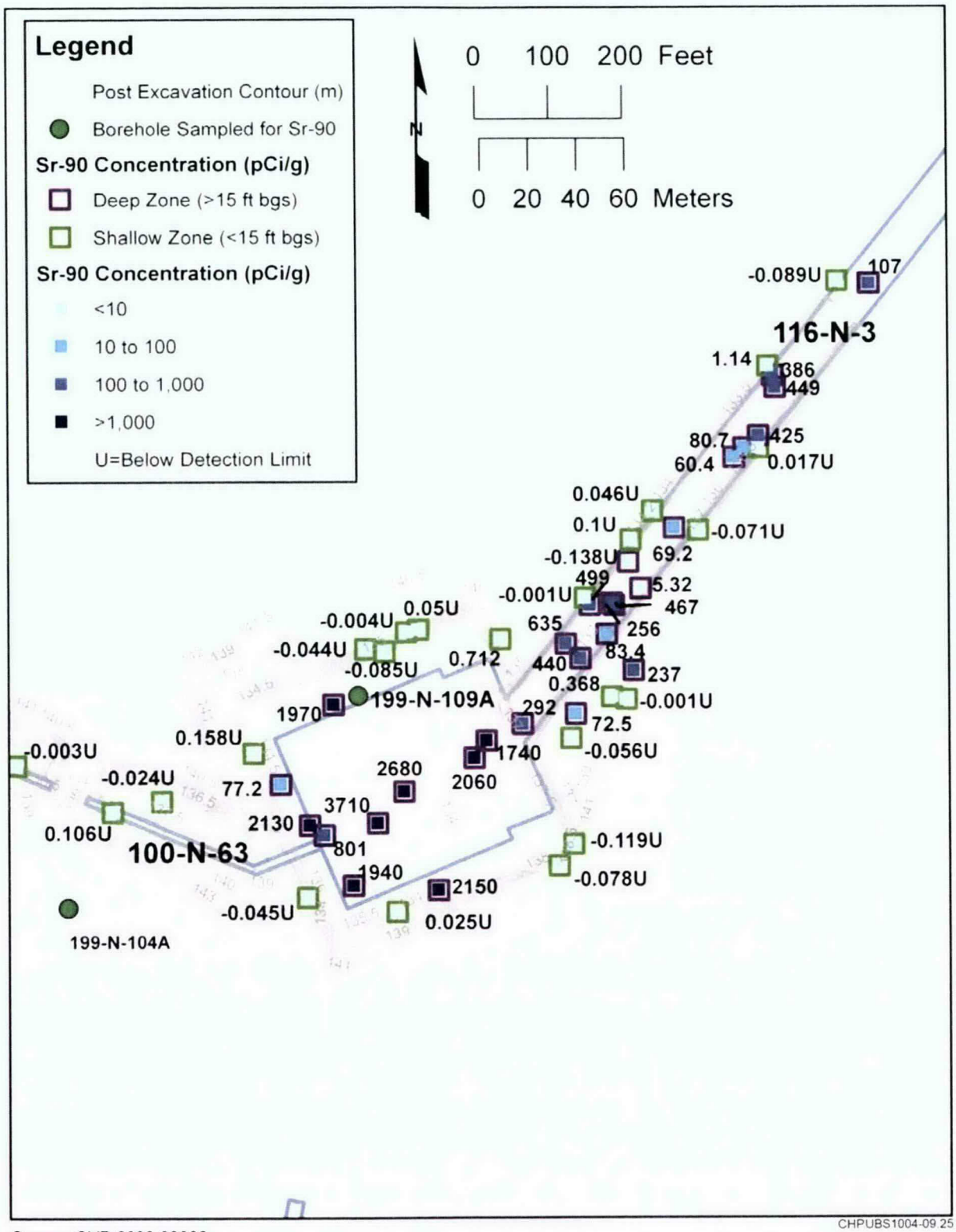


Figure 2-27. Vadose Zone Boreholes Sampled for Strontium-90 within 100-N



Source: CVP-2006-00004

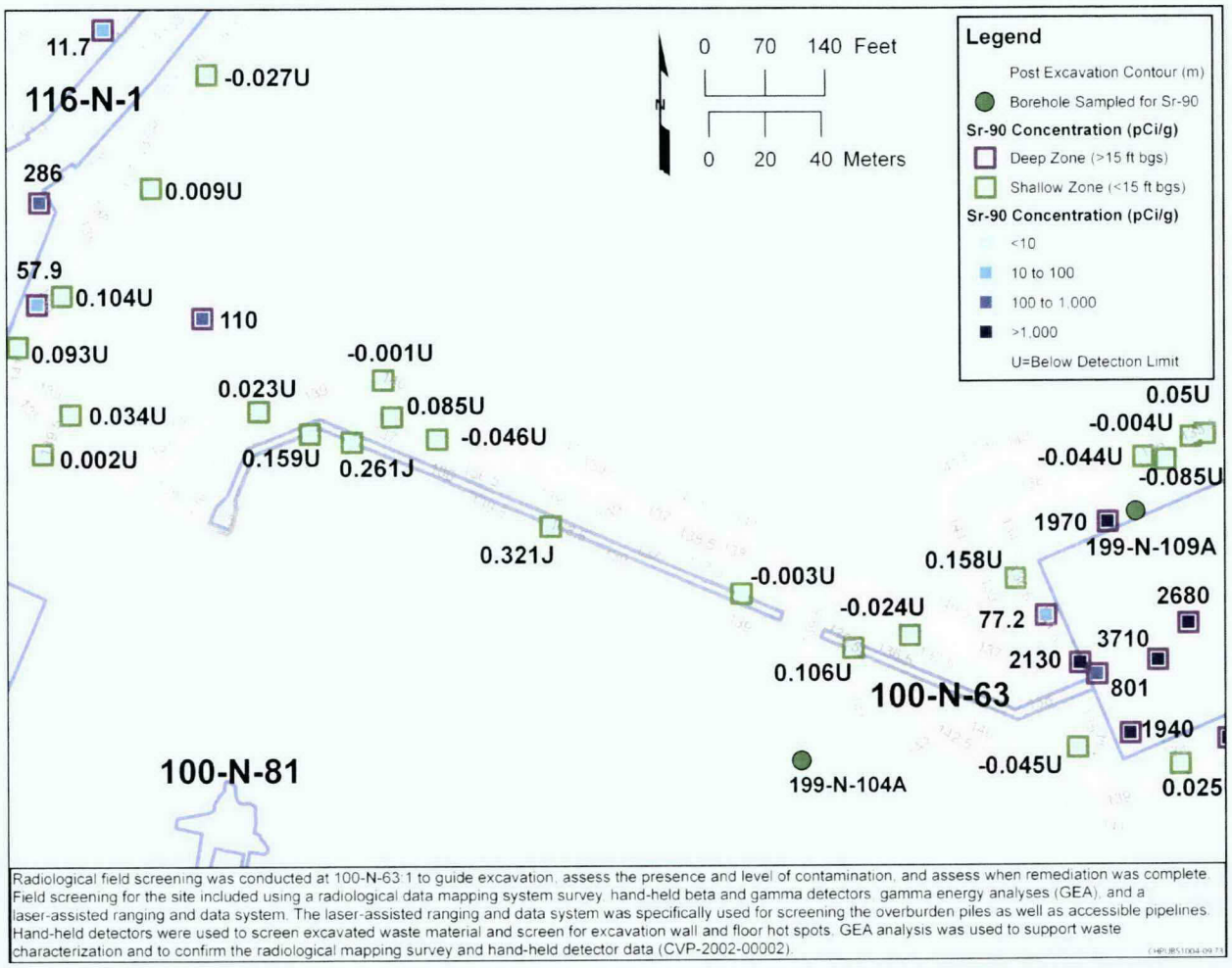
Figure 2-28. 1301-N (116-N-1) Vadose Zone Strontium-90 Post Remediation Sampling Results



CHPUBS1004-09 25

Source: CVP-2002-00002

Figure 2-29. 1325-N (116-N-3) Vadose Zone Strontium-90 Post Remediation Sampling Results



Radiological field screening was conducted at 100-N-63:1 to guide excavation, assess the presence and level of contamination, and assess when remediation was complete. Field screening for the site included using a radiological data mapping system survey, hand-held beta and gamma detectors, gamma energy analyses (GEA), and a laser-assisted ranging and data system. The laser-assisted ranging and data system was specifically used for screening the overburden piles as well as accessible pipelines. Hand-held detectors were used to screen excavated waste material and screen for excavation wall and floor hot spots. GEA analysis was used to support waste characterization and to confirm the radiological mapping survey and hand-held detector data (CVP-2002-00002).

Figure 2-30. 100-N-63:1 Vadose Zone Strontium-90 Post Remediation Sampling Results

The following are key observations about the nature and extent of Sr-90 in the 100-N vadose zone prior to remediation.

- The highest Sr-90 concentrations measured in the LFI investigations were not from the vadose zone but at two locations in the 116-N-1 (1301-N) Crib (*1301-N and 1325-N Liquid Waste Disposal Facilities Limited Field Investigation Report* [DOE-RL-96-11]) prior to remediation. One soil sample was taken from Well 199-N-107A about 0.3 to 1 m (1 to 3 ft) above the crib bottom (19,700 pCi/g); the second soil sample was attached to a crib boulder (92,300 pCi/g).

- These measurements are also consistent with analyses of in-trench samples taken at locations TS-01 through TS-09 during operations where average Sr-90 concentrations per sampling location ranged between 33,000 and 210,000 pCi/g (BHI-00368). Similar high LFI concentration measurements were not observed at 116-N-3 (1325-N), which may be because no sampling took place in the crib very close to the pipe outlet. However, analyses of crib sediment samples taken at locations CS-01 through CS-12 during operations provided Sr-90 concentrations ranging between 3,000 and 630,000 pCi/g (BHI-00368).

- Directly beneath the cribs and trenches, a concentrated contaminant zone that extends deep into the vadose zone is indicated. At 116-N-1 (1301-N), the vertical distribution of this zone is best shown by the Sr-90 profile at Well 199-N-107A (Figure 2-31) where higher concentrations occur down to the

Hanford formation/Ringold Formation interface. The horizontal distribution along the axis is inferred from the deeper soils analyzed post remediation near the sides of the trench at greater than 4.6 m (15 ft) bgs (Figure 2-30). Although the horizontal distribution perpendicular to this axis is not well defined by boreholes constructed to date, it is best suggested by the 199-N-108A profile (Figure 2-31). Here the higher concentration zone does not extend as deeply into the vadose zone, although the concentrations are similar to those at 199-N-107A. These data suggest that the average concentration in this zone is relatively even along the axis and between 1,000 and 2,000 pCi/g. Concentrations underneath the bends in the trench tend to be at the high end of the range (Figure 2-31). The soil concentrations generally decrease with distance from the 1301-N toward the Columbia River (Figure 2-32).

- Similarly, at 116-N-3 (1325-N), the vertical distribution is best illustrated at borehole 199-N-109A (Figure 2-33) and horizontal distribution is illustrated by the 4.6 m (>15 ft) bgs post remediation samples along the trench (Figure 2-29). In this borehole, both vertical and horizontal concentrations appear to decrease sharply away from the pipe outlet in the crib. For example, horizontal concentrations in post remediation samples along the trench axis (Figure 2-29) decrease from about 4,000 at the pipe outlet to 500 pCi/g at the end of the trench.

- Outside the concentrated zones beside and beneath 116-N-1 (1301-N) and 116-N-3 (1325-N), the existing data (e.g., in Well 199-N-105A in Figure 2-31 and Well 199-N-109A in Figure 2-33) suggest the average concentrations are much lower. However, differences are apparent between the upper and lower vadose zone where the upper zone has always been above the water table and the lower comprised the upper unconfined aquifer until the groundwater mounding from operations subsided. In the upper vadose zone, Sr-90 concentrations are less than 5 pCi/g, but in the lower vadose zone, Sr-90 concentrations are frequently greater than 100 pCi/g up to about 900 pCi/g.

2.3.2.1 Other Vadose Contaminants

Metals above Hanford Site background values (90th percentile, DOE-RL-92-24, Rev. 4) were detected during the 1992 and/or 1995 field investigations in soil samples associated with the 100-N-1 (total chromium, lead, copper, and zinc), 100-N-58 (manganese), 116-N-1 (cadmium, total chromium, and lead), 116-N-2 (lead), 120-N-1 (copper and zinc), 120-N-2 (copper), and 1322-N (copper, lead, and zinc) sites. In addition, the following metals were detected in select soil samples for which no Hanford background values are published: antimony, boron, cadmium, selenium, and thallium. It should be noted that in the years since these field investigations were conducted, all the sites listed in the first sentence of this paragraph have been interim closed through Cleanup Verification Package (CVP) and/or WSRF documentation (see Appendix B for document numbers). Figures 2-34 and 2-35 present post remediation total chromium and hexavalent chromium at the 116-N-1 Trench . Similar figures were not developed for the 116-N-3 Trench because during its operational life, Cr(VI) was not in use at the 100-N as a corrosion inhibitor, so total chromium and Cr(VI) were not included as COCs for the 116-N-3 site. As a result, no verification samples were collected or analyzed for total chromium and Cr(VI) as part of CVP efforts at 116-N 3.

Chromium in soil samples originated from reactor coolant water discharges to the 1301-N LWDF that contained sodium dichromate. Vadose zone characterization beneath the 1301-N LWDF and 1325-N LWDF (DOE-RL-96-11, Rev. 0) identified three zones with varying chromium concentrations (Figure 2-36). Zone A was the shallowest zone (elevation above 255 m [430 ft] above msl) and contained chromium concentrations ranging from 32 to 57.7 mg/kg. In the data quality objective workshop (BHI-00368 rev 0), previous study WHC-SD-EN-DP-056, rev 0-A identified total chromium in 2 occurrences of 13 samples in 1325-N sediments. Many of these results appear to have quality concerns.

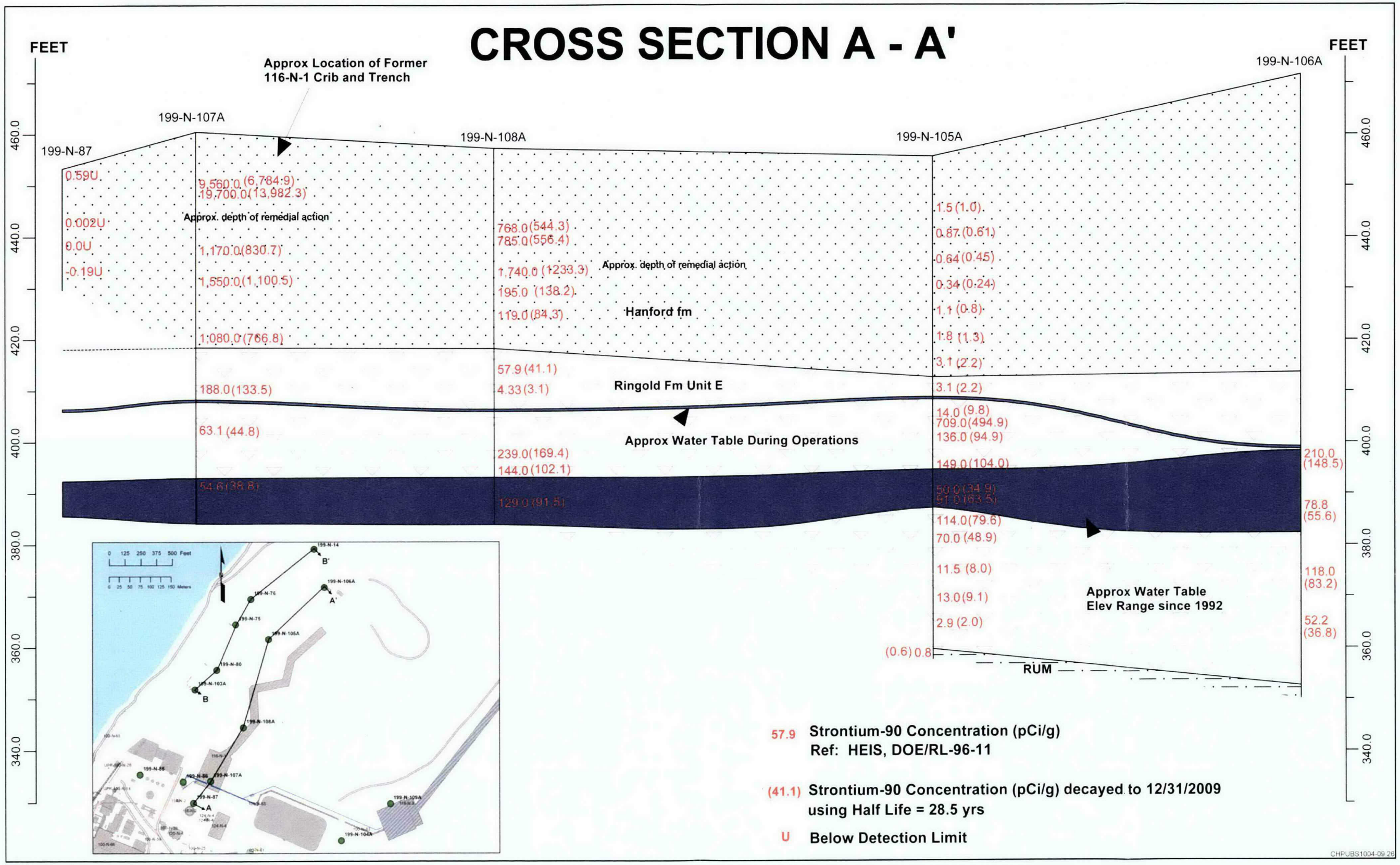


Figure 2-31. Strontium-90 Concentrations, by Depth, at Five Boreholes along the Long Axis of 1301-N (116-N-1)

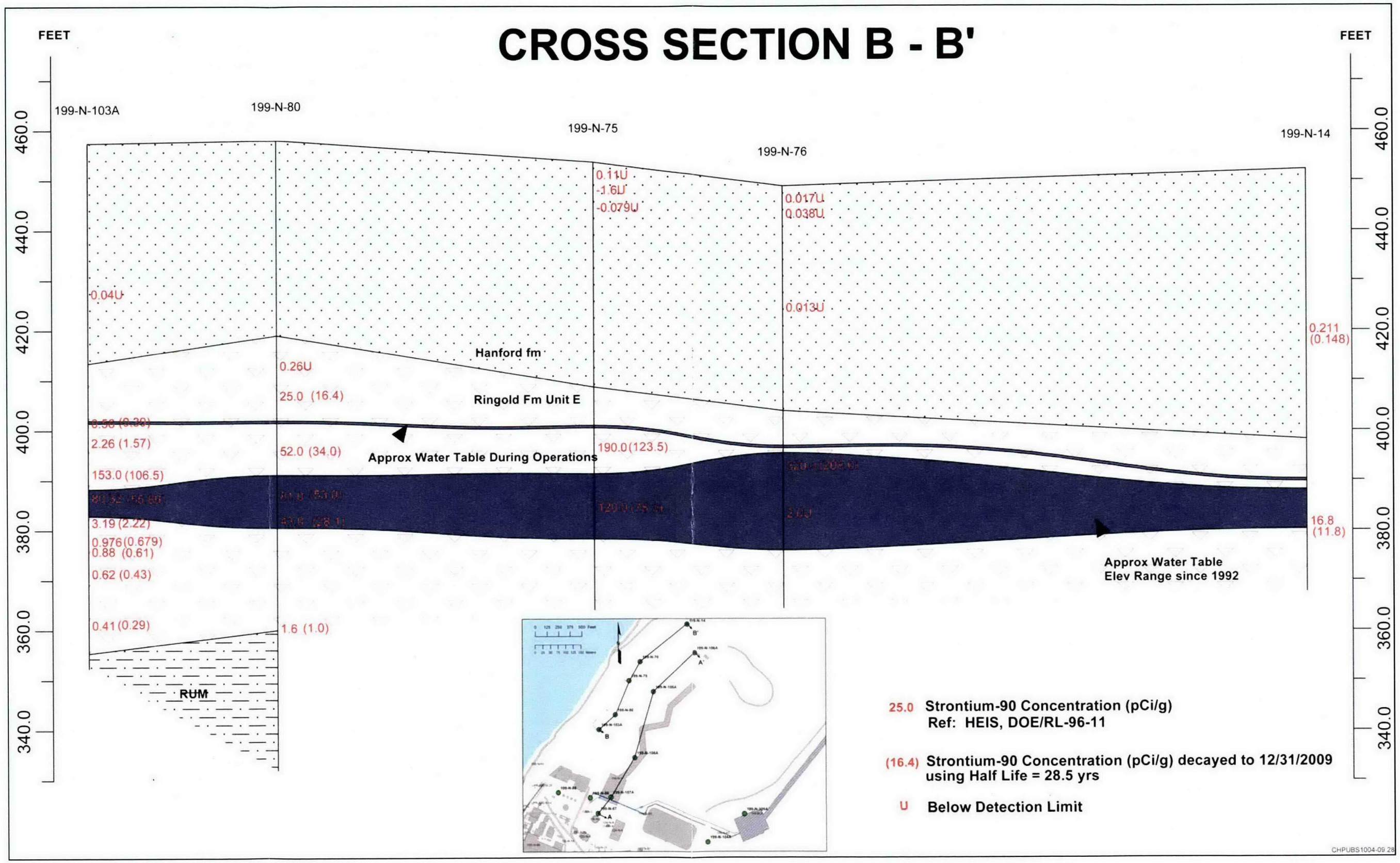


Figure 2-32. Strontium-90 Concentrations, by Depth, at Five Boreholes Downgradient of 1301-N (116-N-1)

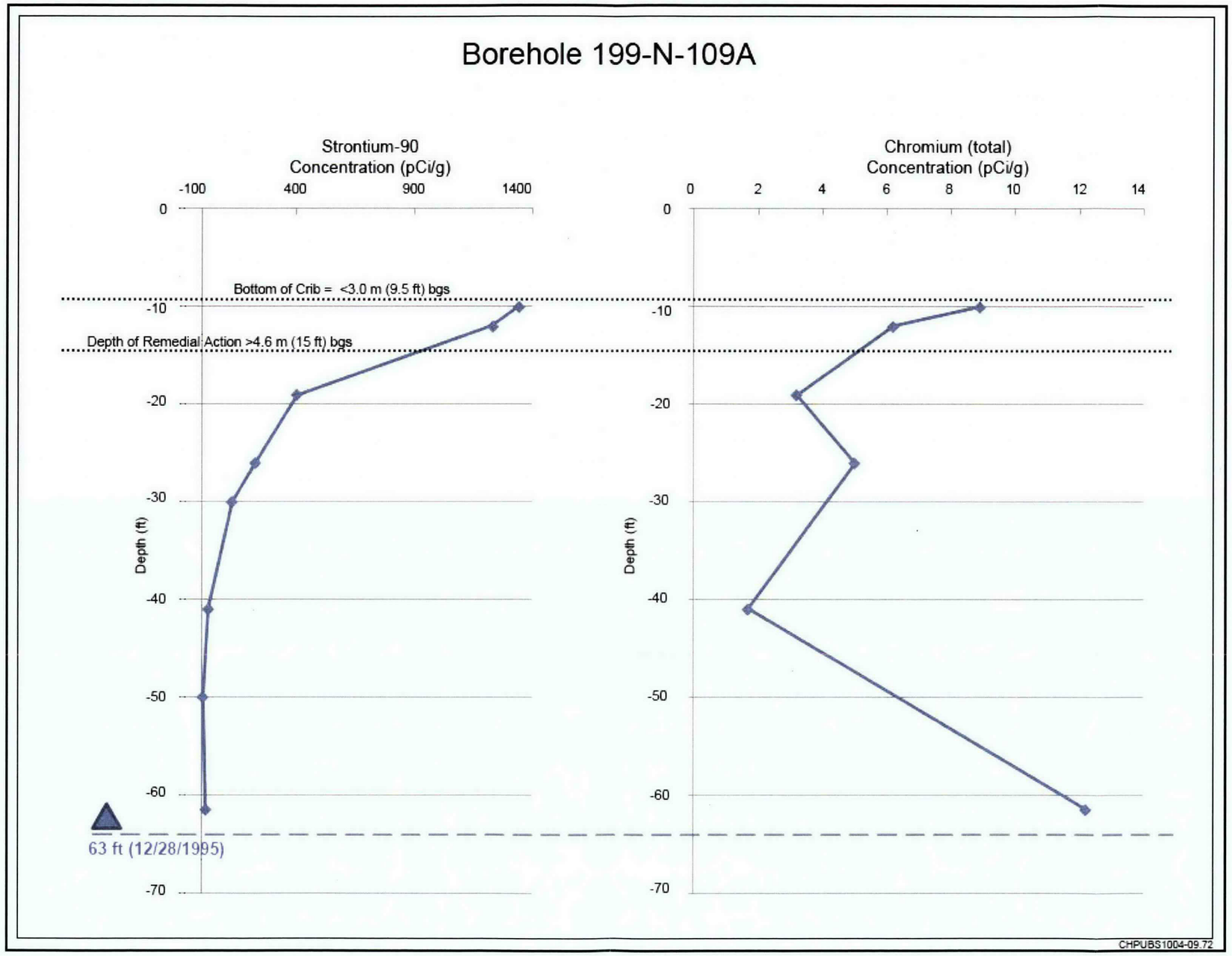


Figure 2-33. A Strontium-90 and A Chromium Profile for Borehole 199-N-109A (1325-N LWDF)

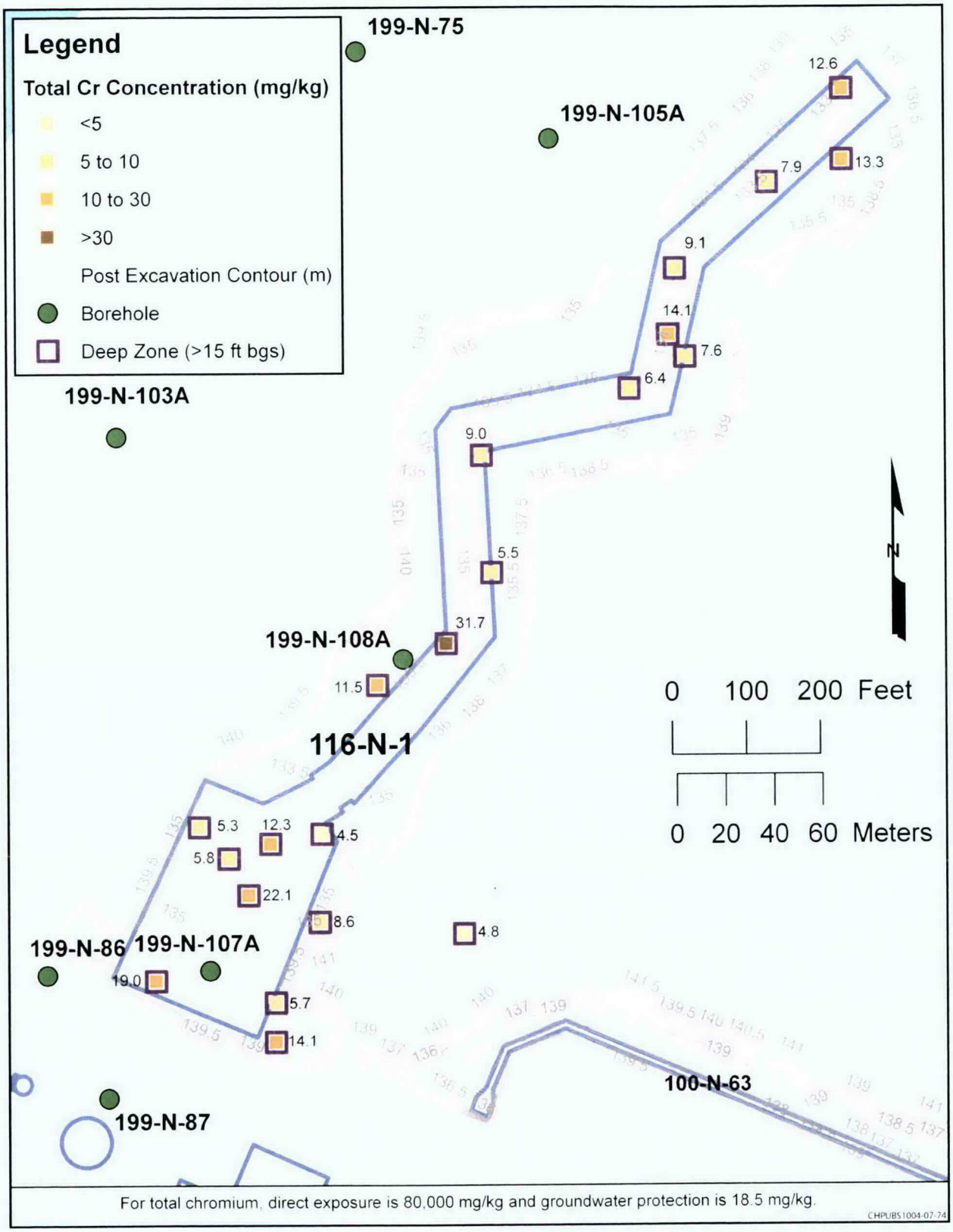


Figure 2-34. Post-Remediation Total Chromium Sampling Results At 16-N-1 Trench

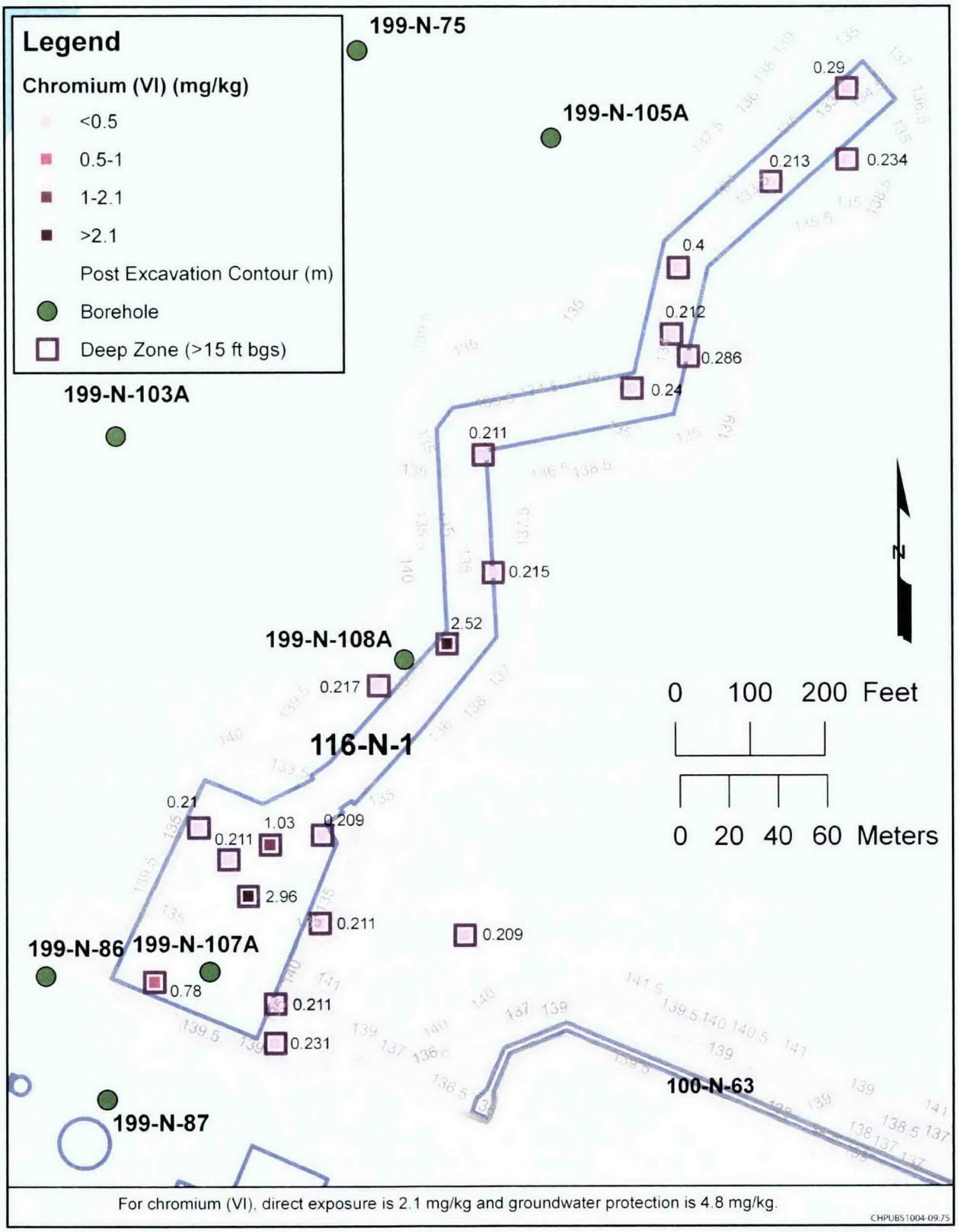
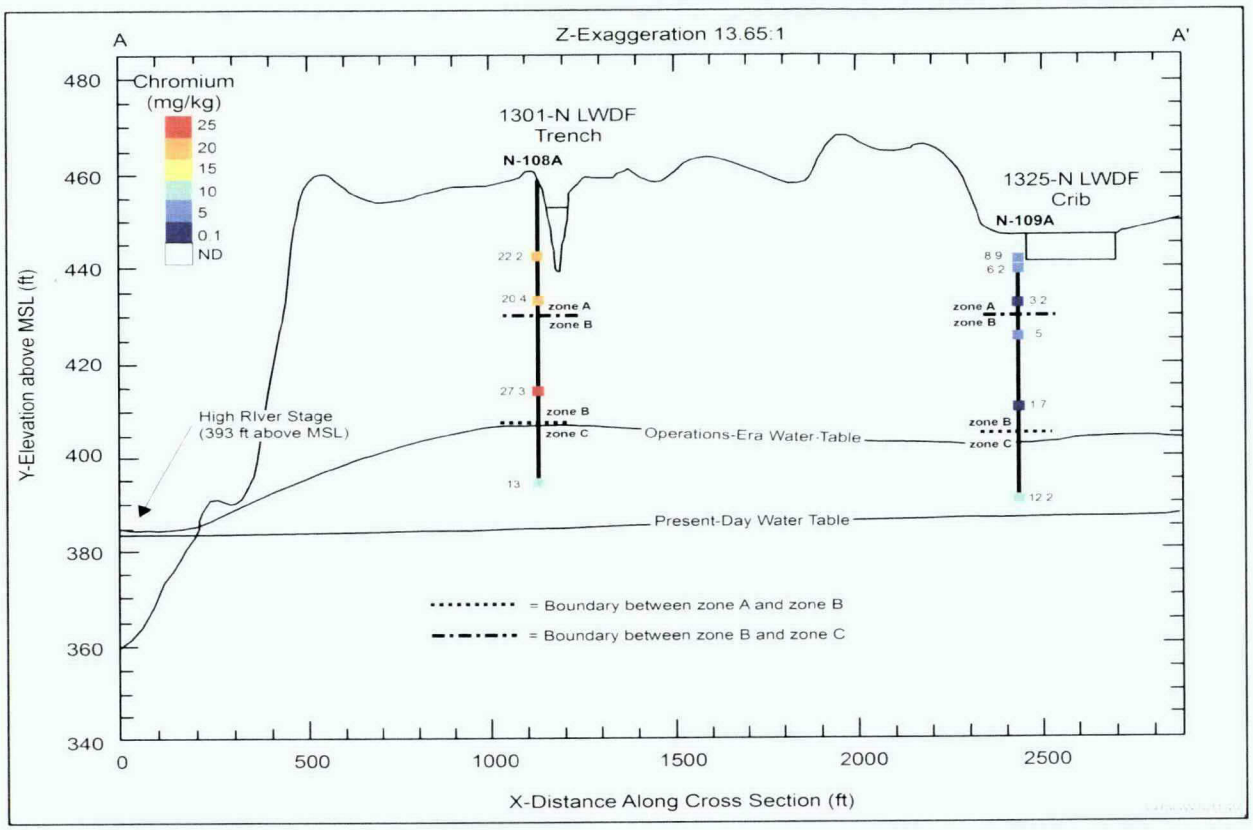


Figure 2-35. Post-Remediation Hexavalent Chromium Sampling Results at 116-N-1 Trench



Source: DOE-RL-96-11

Figure 2-36. Chromium Concentrations by Zone

These data will be further evaluated in the RI report. The soil horizon containing these samples has been excavated and removed to ERDF. Beneath Zone A, Zone B extended down to an elevation of 123.5 m (405 ft) above msl and contained chromium concentrations ranging from 1.7 to 273 mg/kg, which were the highest concentrations recorded in the area. The deepest zone, Zone C, extended from 123.5 m (405 ft) above msl to the water table and contained chromium concentrations that ranged from 12.2 to 13 mg/kg. Chapter 4 provides additional vadose zone metals contamination discussion, particularly Cr(VI).

Most inorganic analytes found in 100-N soils occur at levels well below health based cleanup standards and guidelines. Concentrations of inorganic analytes in soil are highly variable depending on soil type, however, and in some instances due to their genesis, may naturally exceed health based cleanup standards recommended by Ecology. The highest measured background concentrations occur in three volumetrically minor soil types, the most important of which is the topsoil adjacent to the Columbia River that is rich in carbon. The sediment arsenic concentrations, in particular, are likely from the near-river topsoil component of the EMA data summarized in Table 2-6. Note that 104 samples were collected in establishing an arsenic background value. The concentrations in this sample group ranged from a low of 3 mg/kg to a high of 11.4 mg/kg. As noted, the 90th percentile value for arsenic (6.47 mg/kg) is the background value.

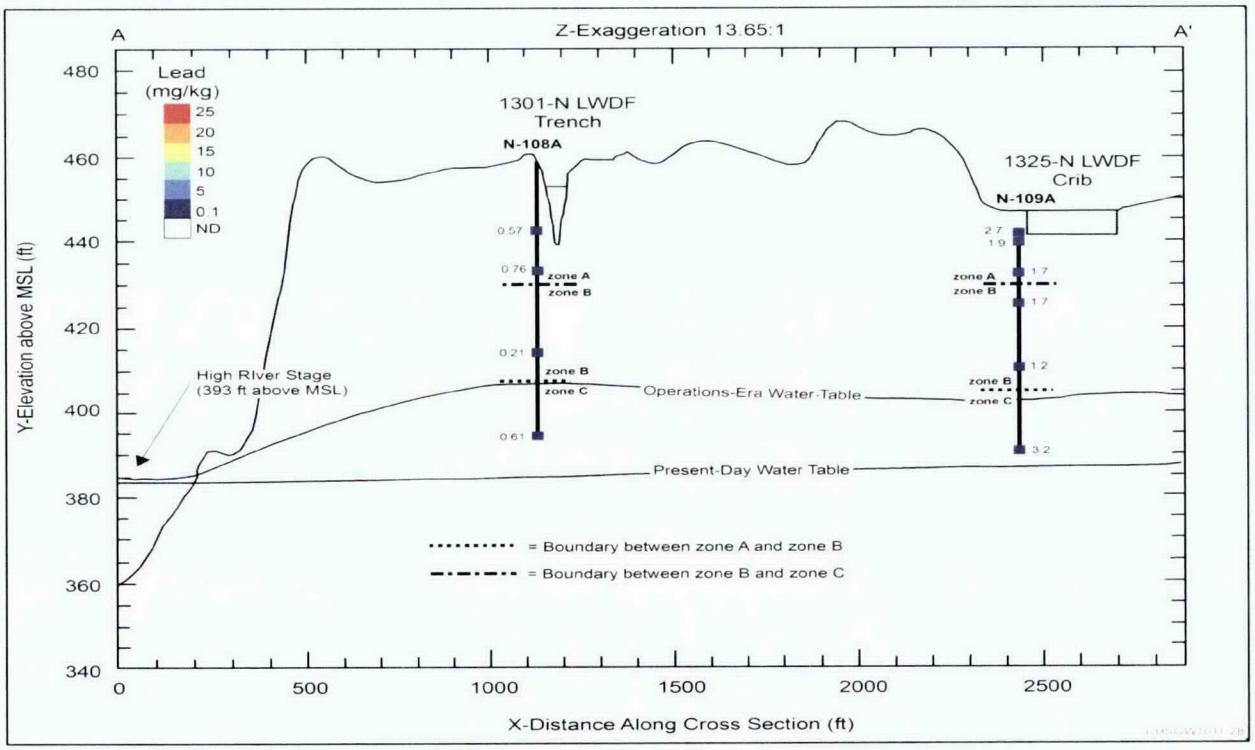
Therefore, to put the 100-N near-shore EMA data in perspective:

- The samples collected were likely near-river topsoil samples, which had the highest measured background concentrations in the *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes* (DOE-RL-92-24).

- The sediments collected in this effort were likely affected by Columbia River stage and suspended sediments, which are known to be affected by upstream activities (e.g., agriculture, mining, paper mills). This effect is illustrated by the Priest Rapids sample median arsenic concentration (6.9 mg/kg), which is higher than three of the near-shore concentrations (3.5, 4.2, and 1.8 mg/kg) and the background value (6.47 mg/kg).

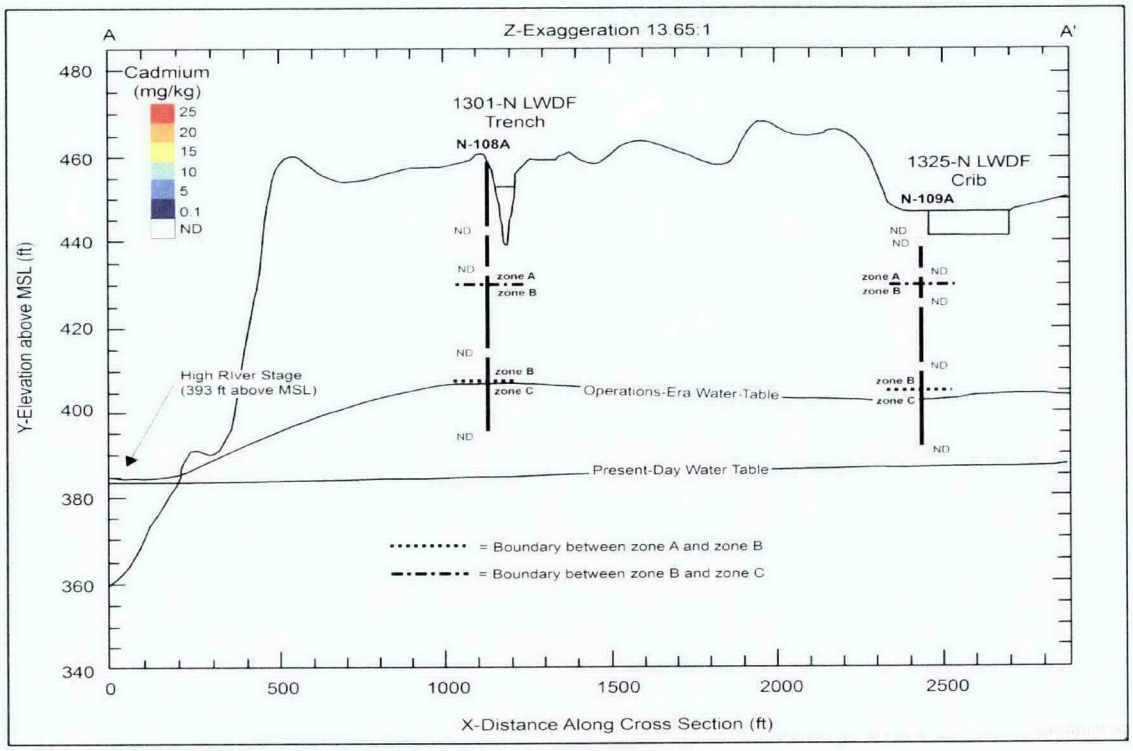
Figures 2-37, 2-38, and 2-39 show the lead, cadmium, and nickel concentrations, respectively, in the same A, B, and C zones as chromium is depicted in Figure 2-36. These elements measured at elevated level(s) are generally retained or sequestered in the vadose zone, and the concentrations decrease with depth.

Anions were detected in soil samples associated with the 100-N-1, 100-N-4, 100-N-58, 116-N-1, 116-N-3, 120-N-1, and 120-N-2 waste sites. The 100-N-4 Tile Field and the 199-N-87 borehole near the 116-N-1 Crib and Trench had anions detected above Hanford Site background (95 percent upper contaminant level [UCL], DOE-RL-92-24, Rev. 4). 100-N-4 had four samples of ammonia that exceeded background and the 199-N-87 borehole had one sample of sulfate that exceeded background. Hanford Site background for ammonia is 32.5 mg/kg and the maximum concentration detected was 75 mg/kg. Hanford Site background for sulfate is 1,360 mg/kg and the maximum concentration detected was 2,040 mg/kg.



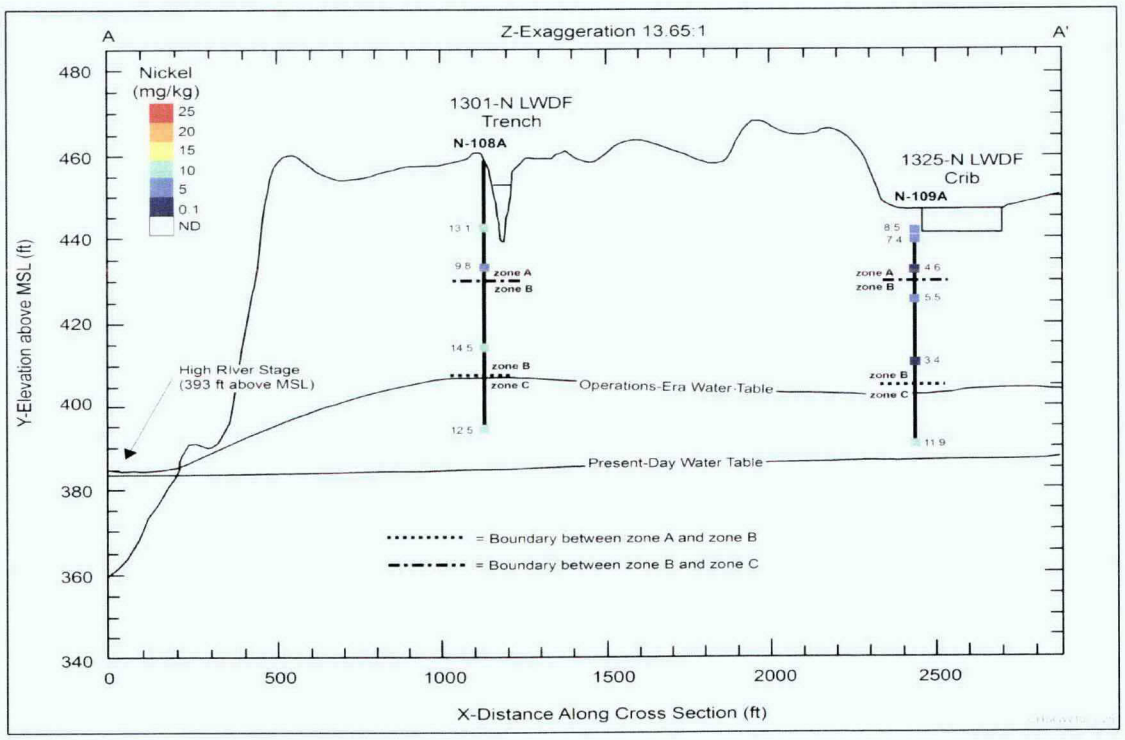
Source: DOE-RL-96-11

Figure 2-37. Lead Concentrations by Zone



Source: DOE-RL-96-11

Figure 2-38. Cadmium Concentrations by Zone



Source: DOE-RL-96-11

Figure 2-39. Nickel Concentrations by Zone

Petroleum contamination was primarily investigated by collecting samples from wells drilled (199-N-85) and/or located near the subsurface contamination caused by the diesel fuel line leak 302,833 L (80,000 gal) on the west side of the 166-N Tank Farm in 1966. Characterization Well 199-N-85 is located proximal to the leak location. Ten samples were collected over the vadose zone between 4.6 and 22.5 m (15 and 74 ft) bgs. A suite of volatile and semivolatile compounds were analyzed (DOE-RL-93-80) that are considered species present in diesel fuel or degradation products (e.g., xylene, anthracene, 2-methylnaphthalene). These contaminants were identified between 18 and 22.5 m (59 and 74 ft) bgs. Several wells are being sampled to gather more information on the nature and extent of the petroleum hydrocarbon plume. These include 199-N-173, 199-N-96A, 199-N-18, 199-N-19, 199-N-21, 199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172. A passive bioremediation technology is being installed to remediate petroleum hydrocarbons in the vadose zone (*Sampling and Analysis Instruction for Installation of UPR-100-N-17 Bioremediation Wells and Performance of Bioventing Pilot Tests* [WCH-323]). For site 100-N-5, the CVP states the polynuclear aromatic hydrocarbons (PAHs) most likely resulted from in situ materials combustion or combusted materials disposal. However, PAHs were not detected COCs through confirmatory sampling in the CVP. PAHs were found in two samples from boreholes at the 116-N-2 site in the LFI. Chapter 4 discusses petroleum contamination details at 100-N.

VOCs, SVOCs, PAHs, and PCBs (Aroclor 1254 and Aroclor 1262) were detected in subsurface samples but generally at low concentrations, often below quantitation limits, and in a relatively few samples.

2.3.3 Nature and Extent of Contamination in the Groundwater

This section describes the nature and extent of groundwater contamination (100-NR-2 Groundwater OU) within 100-N. The detailed groundwater information within 100-N is found in the annual Hanford Site groundwater monitoring reports (e.g., *Hanford Site Groundwater Monitoring Report for Fiscal Year 2007* [DOE-RL-2008-01]) and the annual groundwater pump-and-treat reports (e.g., DOE-RL-2008-05). 100-N groundwater monitoring wells locations are shown in Appendix C.

2.3.3.1 Strontium-90

The primary groundwater contaminant is Sr-90. The area where the highest concentrations of Sr-90 reach the Columbia River is of special concern for remediation and monitoring. A pump-and-treat system was operated at 100-N from fall 1996 through spring 2006. During its operation, it removed only 1.8 Ci of Sr-90 from the groundwater, which is less than the amount eliminated by radioactive decay. As of 2008, an estimated 72 Ci of Sr-90 are contained in the saturated sediments, and approximately 0.8 Ci are retained in the groundwater; this equates to a Sr-90 retardation factor of approximately 100 (PNNL-17429). Because Sr-90 has a much greater affinity for sediment than for water (high K_d), its rate of transport in groundwater to the river is considerably slower than the actual groundwater flow rate. The relative velocity of Sr-90 transport to groundwater flow is approximately 1:100 (PNNL-SA-70033). In FY 2008, Sr-90 concentrations above the 8 pCi/L maximum contamination limit (MCL) extend inland from the river approximately 1.2 km (4,000 ft) in 100-N (*Hanford Site Groundwater Monitoring for Fiscal Year 2008* [DOE-RL-2008-66]). The overall plume area is estimated at 0.58 km^2 (0.22mi^2) (Figure 2-40). Near the apatite barrier, the Sr-90 concentrations have decreased. Figure 2-41 shows Sr-90 concentrations in the area along the shoreline where the apatite PRB was installed.

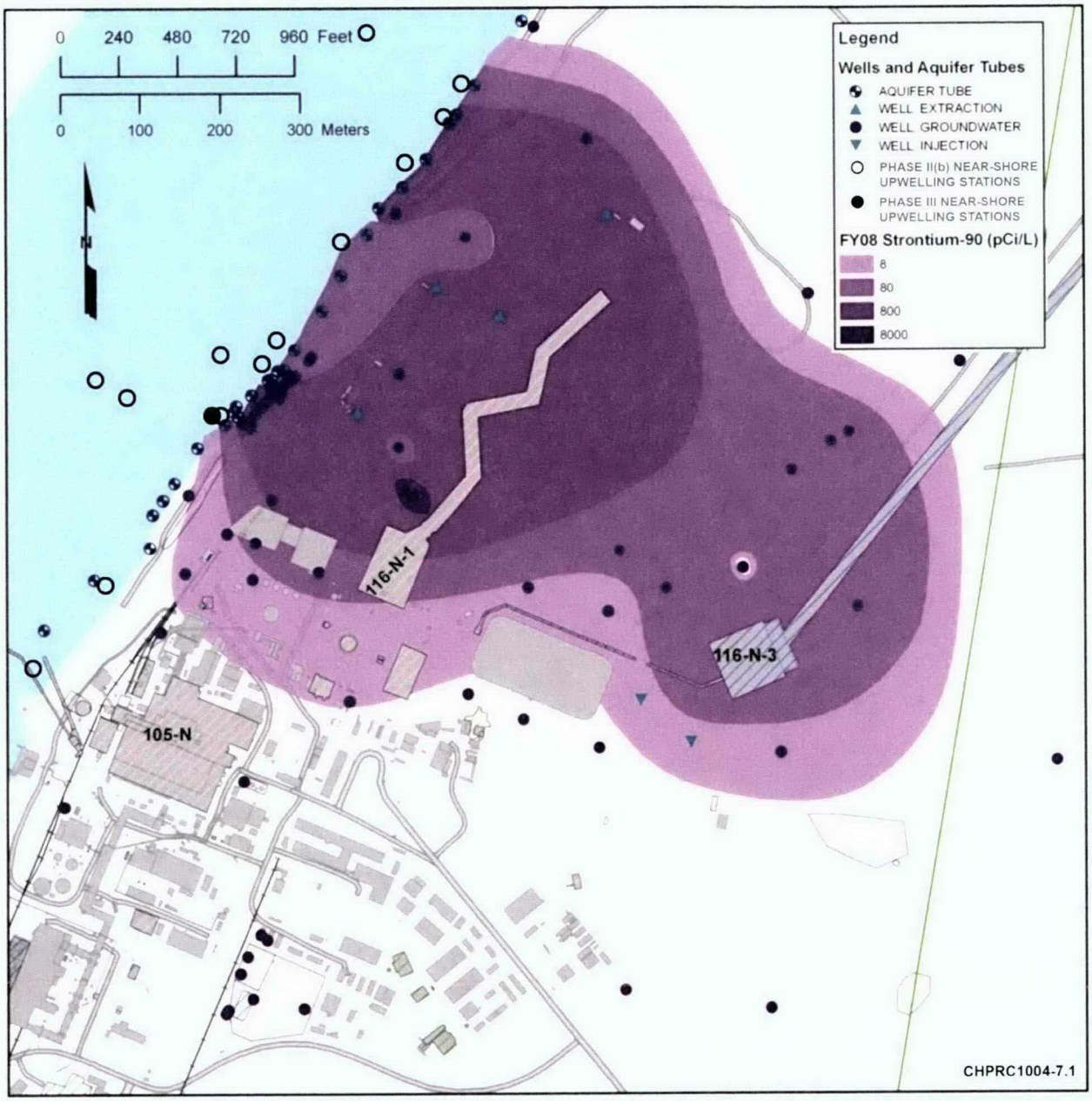


Figure 2-40. 100-N Average Strontium-90 Concentrations in 100-N, Unconfined Aquifer

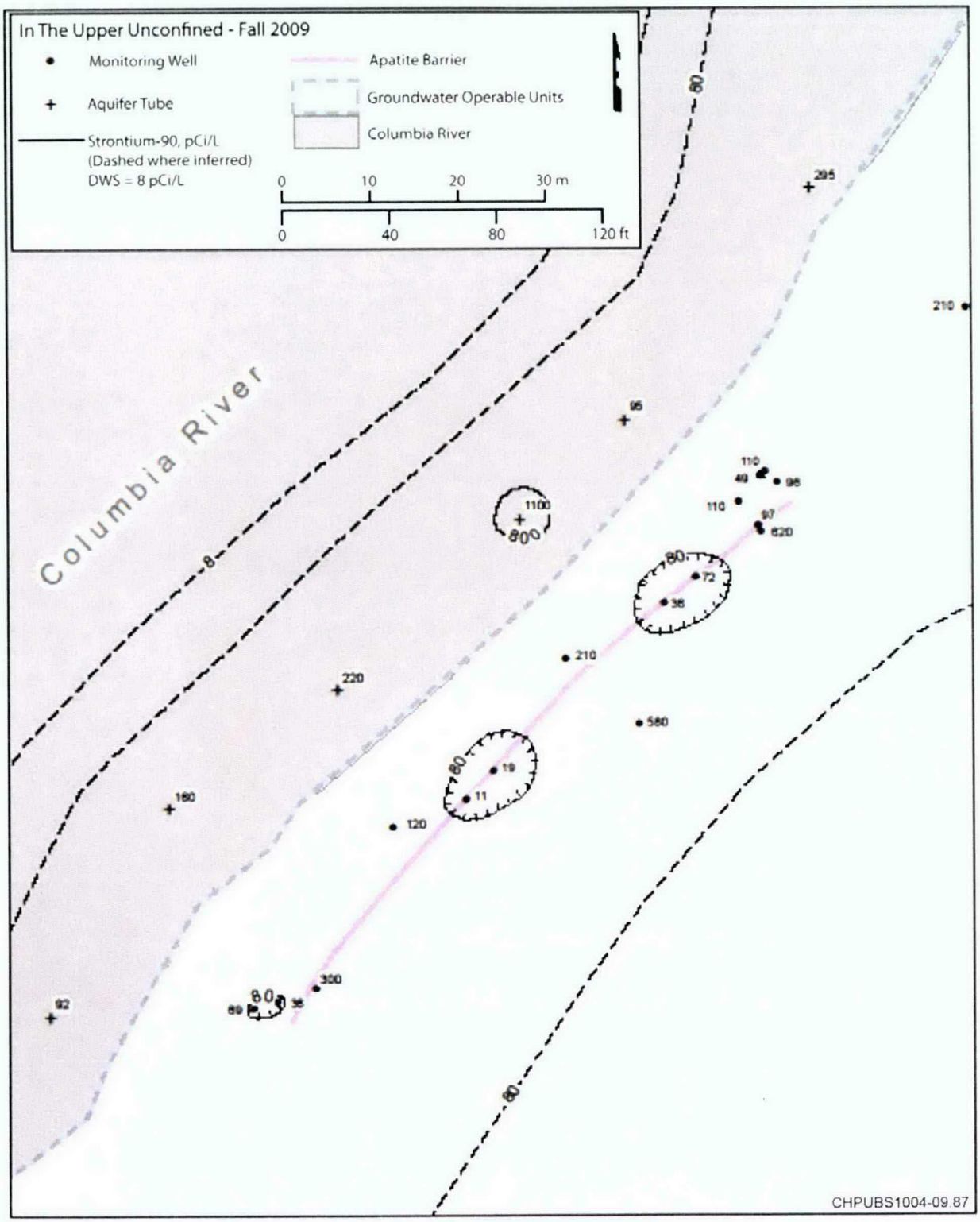


Figure 2-41. Strontium-90 Concentrations along the Apatite PRB—Fall 2009

Over the years, many 100-N wells have been monitored to track groundwater contamination. Starting in the 1970s, several wells around the 1301-N Crib were monitored for Sr-90 contamination. In the 1980s, Sr-90 contamination showed up at the river in several seeps and springs resulting from effluent disposal to the 1301-N Crib. Additional wells were installed in the 1980s and 1990s to further track Sr-90 and other contaminants of interest. During pump-and-treat operations, Sr-90 concentrations in the extraction wells (199-N-75, -103A, -105A, and -106A) were trending down, but most of the wells showed a rebound effect after operations stopped in 2006. As of 2009, two of the four wells exceeded all prior measurements (199-N-75 and 199-N-105A), one may be trending down (199-N-106A), and one is remaining the same (199-N-103A). Wells that exist outside the plume (as shown in Figure 2-40) have shown detectable concentrations of Sr-90 in the past (late 1980s through early 2000s). The wells are 199-N-22 (2004), 199-N-23 (1993), 199-N-24 (1993), 199-N-25 (1993), and 199-N-47 (2003). These wells were located between the reactor or associated support buildings and the river, but have all been decommissioned (the year the well was decommissioned is shown in parentheses). Although these wells had detectable amounts of Sr-90, they were all at or below the detection limit before they were decommissioned. Figure 2-42 shows the trend plot of Sr-90 concentrations for these wells when they were still in service.

The historical presence of Sr-90 the groundwater could have affected the environment along the river shore or out into the river sediments. Areas of groundwater upwelling exist in the near-shore river sediments. Water temperature and conductivity measurements were used to identify locations along the 100-N reach of the Columbia River where groundwater upwelling might be expected. Preliminary results from 2009 to 2010 pore water samples taken from the locations identified (see Figure 2-40) indicate detectable amounts of Sr-90 in a number of locations, although the Sr-90 results from most of the 100-N locations were below detection. Five samples detected Sr-90 ranging from 11 to 72 pCi/L, with measurements of 11 and 17 pCi/L at two locations just downriver from the 100-N outfall and spillway, which is outside of known Sr-90 plume contours.

Strontium-90 is found primarily adsorbed to sediments by ion exchange (99 percent adsorbed, less than 1 percent in groundwater) in the upper portion of the unconfined aquifer and lower vadose zone. Strontium-90 is limited to the upper portion of the unconfined aquifer. Strontium-90 is not detected in Wells 199-N-69 and 199-N-70, which are screened at the bottom of the unconfined aquifer, while relatively high concentrations are noted for adjacent, shallow Wells 199-N-67 and 199-N-81. In FY 2008, maximum Sr-90 concentrations were measured between 115.7 and 116.3 m (379.6 and 381.5 ft) elevation in the Ringold Formation within aquifer tubes, while lower concentrations were reported for the deeper tubes. Concentrations were much lower in the shallowest aquifer tubes, which monitor the Hanford formation (DOE-RL-2008-66).

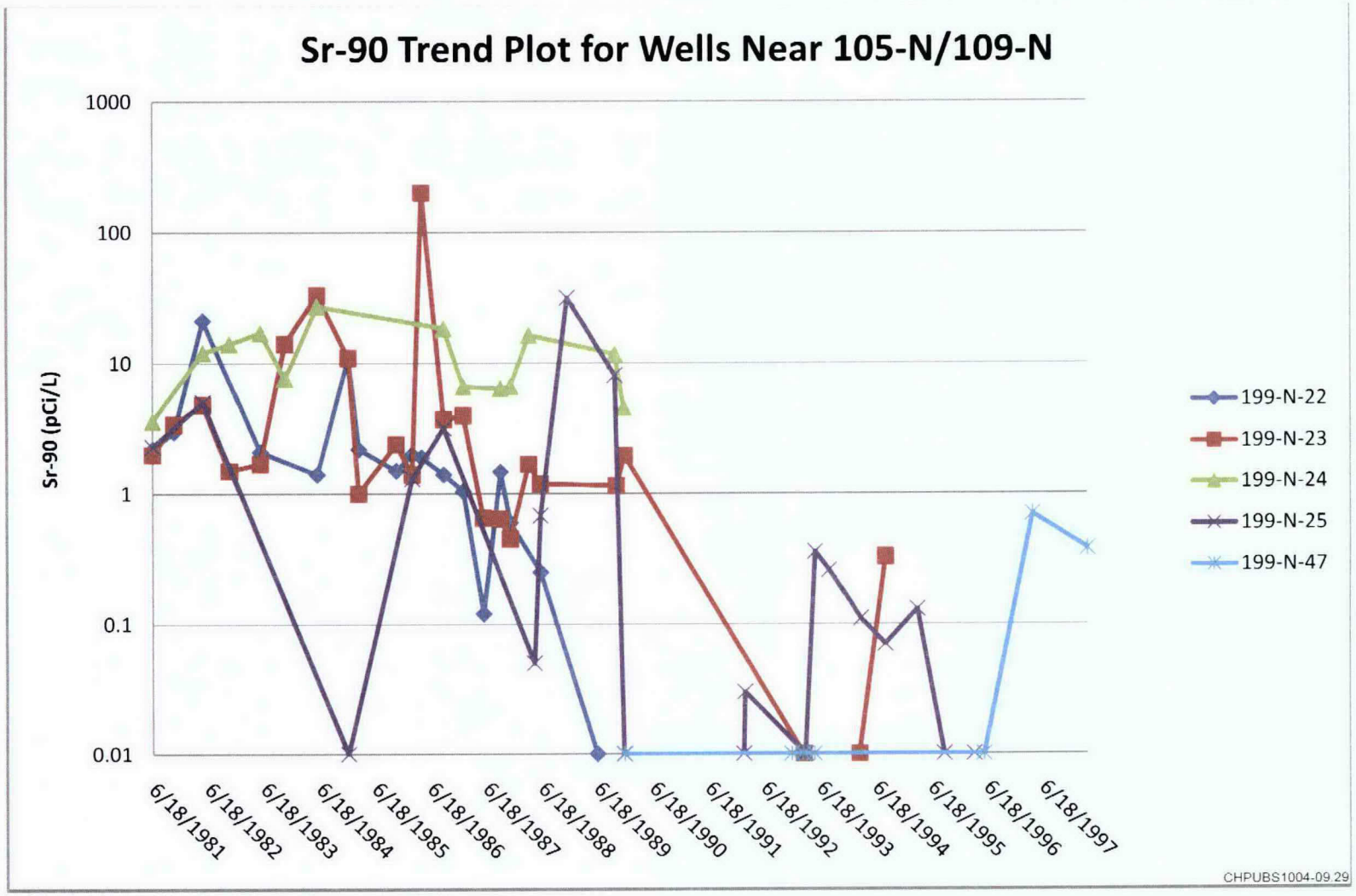


Figure 2-42. Sr-90 Trend Plots for Wells outside the Current Sr-90 Plume

Plume maps (Figure 2-43) are shown for 1996 (pre-pump-and-treat) and fall 2006 (several months after pump-and-treat operations ceased) to illustrate that the extent and magnitude of the Sr-90 plume at the 8 pCi/L (MCL) has not changed significantly during the years from monitoring the single well closest to the source. Comparing the 1996 map to the one shown in Figure 2-40, there is very little difference in the size and shape of the plume. Even when the pump-and-treat was operational, the basic shape of the plume was the same.

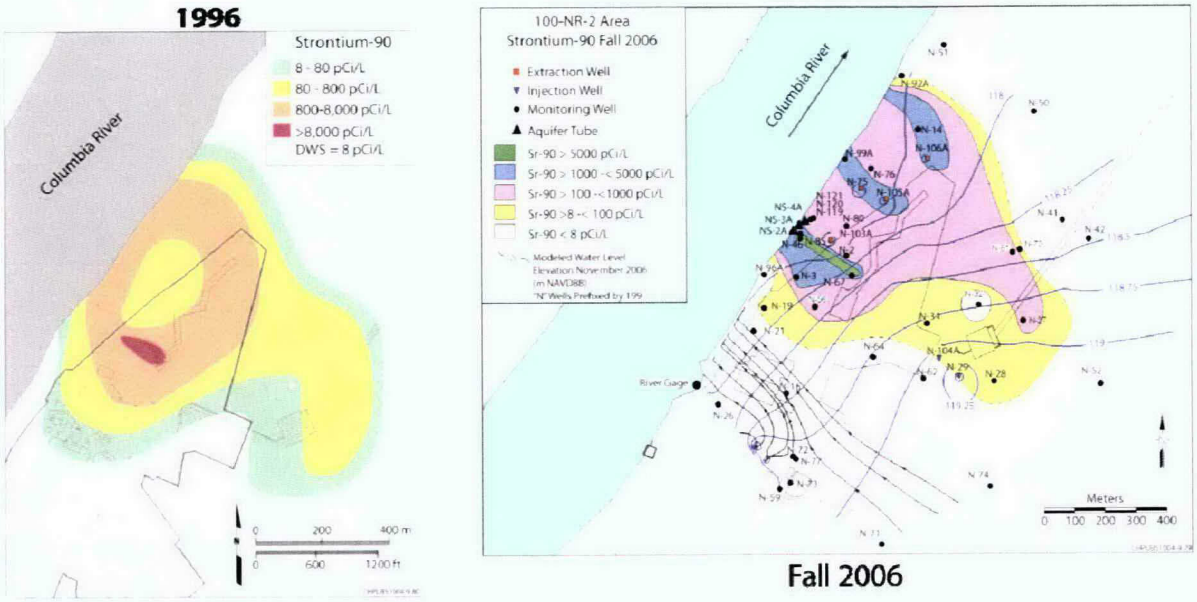


Figure 2-43. Historic Sr-90 Plume Maps

The only flowing 100-N seep is located downgradient of the Sr-90 plume and it was removed from the NPDES in 1999 (HNF-EP-0527-9, *Environmental Releases for Calendar Year 1999*) and has not exceeded the MCL for Sr-90 since 2003 (DOE-RL-2008-66). Strontium-90 has historically been detected in seeps and aquifer tubes at concentrations greater than the MCL along the length of the approximately 670 m (2,200 ft) 100-N shoreline. The highest Sr-90 concentration at the shoreline was 75,000 pCi/L in aquifer tube NVP2-116.0 (calculated from a gross beta measurement in 2008). This represented a spike in concentration caused by injections into the apatite barrier (DOE-RL-2008-66). Baseline concentrations (pre-treatment) at the injection well locations ranged from approximately 400 to 2,800 pCi/L (PNNL-17429). Since shoreline monitoring began in 1985, the highest Sr-90 concentration detected has been 15,700 pCi/L from Well 199-N-46 (1988).

The RI-FS report will include an evaluation of the expected accumulation of Sr-90 within the apatite barrier and associated risk to human health and the environment. This accumulation over the expected life span of the barrier is one of the factors necessary to choose the best possible remedial alternative(s), including the need to require institutional controls.

2.3.3.2 Nitrate

Nitrate concentrations exceed the drinking water standards (DWSs) (45 mg/L) beneath a portion of 100-N (Figure 2-44). Sources for nitrate groundwater contamination include both pre-Hanford (e.g., agriculture) and Hanford activities.

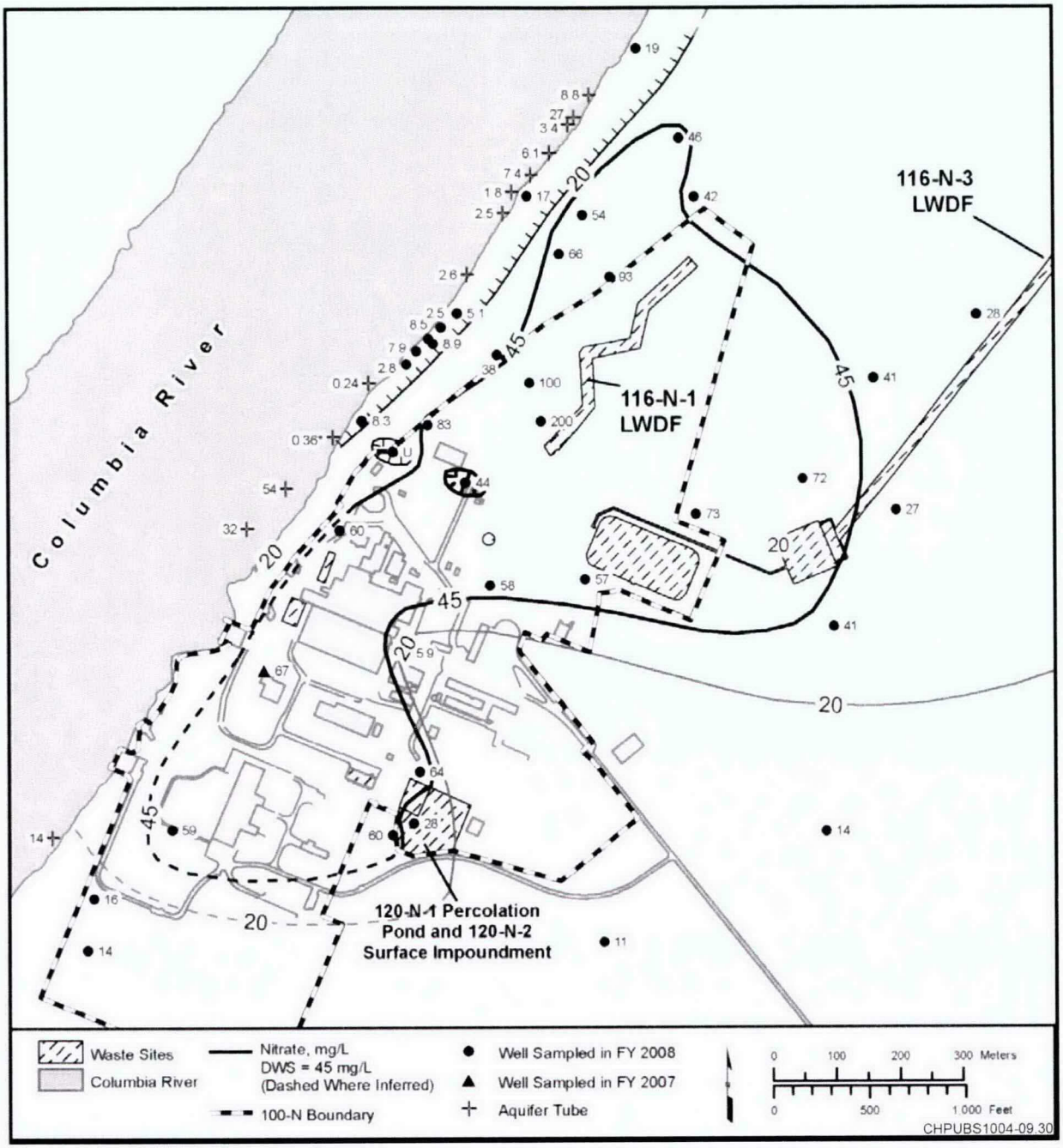


Figure 2-44. Average FY 2008 Nitrate in Groundwater within 100-N, Unconfined Aquifer

In FY 2008, the maximum concentration detected within 100-N was 6,680 mg/L from Well 199-N-143. This high nitrate concentration is an artifact of Apatite Barrier Technology performed in this area, as evidenced by this high concentration observed in only one sampling round shortly after injection of apatite solution, while the concentration is greater than an order of magnitude higher than upgradient wells. Nitrate concentrations exceeding DWSs were detected in 31 wells in 100-N in FY 2008. The nitrate plume above the DWSs covers an area of approximately 0.54 km^2 (0.21 mi^2). A list of the potential 100-N nitrate sources was assembled and incorporated into Section 4.1.6 as a table (including the HGP Tile Field [100-N-4]).

In addition to the previously noted contaminants in this subsection, VOCs, SVOCs, PCBs (Aroclor 1254 and Aroclor 1262), and anions (ammonia, alkalinity, chloride, fluoride, nitrate, o-phosphate, and sulfate) were detected in subsurface samples but generally at low concentrations, often below quantitation limits, and in relatively few samples.

2.3.3.3 Petroleum

Petroleum hydrocarbons from a 1960s diesel fuel leak (DOE-RL-95-111) associated with the 166-N Tank Farm reached groundwater. Petroleum has been detected in groundwater since 1987, when petroleum related constituent sampling in monitoring wells was initiated. Petroleum compounds have been detected in wells near and downgradient of the former tank farm (Figure 4-3). Figure 1-15 shows the current extent of the TPH-DR plume in 100-N and a clear relationship to the source of the contamination, the 166-N Tank Farm. The water table has petroleum free product in Well 199-N-18, which is closest to the former leak site and exhibits the highest levels of groundwater contamination for TPH-DR. Measured values in 2009 were 67 mg/L (March) and 16 mg/L (September). WCH had seven wells installed in late 2008 and early 2009, as part of a bioventing technology demonstration. Five of the seven wells were completed in groundwater (199-N-167, -169, -170, -171, and –172), with the other two as vadose completions (199-N-166 and -168). Groundwater samples have been collected from all five of these wells and the results are shown in Table 2-7.

Table 2-7. WCH Bioventing Well Groundwater Sample Results (2009 to 2010)

Well Name	8-20-2009	9-16-2009	4-23-2010
199-N-167	3,100 µg/L	1,900 µg/L	4,600 µg/L
199-N-169	Not sampled	Not sampled	1,100 µg/L
199-N-170	Not sampled	Not sampled	360 µg/L
199-N-171	Not sampled	Not sampled	2,800 µg/L
199-N-172	2,400 µg/L	2,200 µg/L	25,000 µg/L

During Well 199-N-173 installation in early 2009, soil and groundwater samples were collected to characterize the TPH contamination extent immediately downgradient of the spill area and Well 199-N-18. It was known that TPH-DR had been detected in two aquifer tubes along the shoreline, and this well was installed to determine the level of adjacent groundwater contamination. TPH-DR was detected in the vadose zone soil above the water table starting at 4.12 m (13.5 ft) bgs. The highest level was immediately above and at the water table (5.72 m [18.8] bgs). At 7.77 m (25.5 ft) bgs and to total depth 13.98 m (45.9 ft) bgs), there was no detectable TPH-DR. Figure 2-45 shows the vertical distribution plot of soil data for this well.

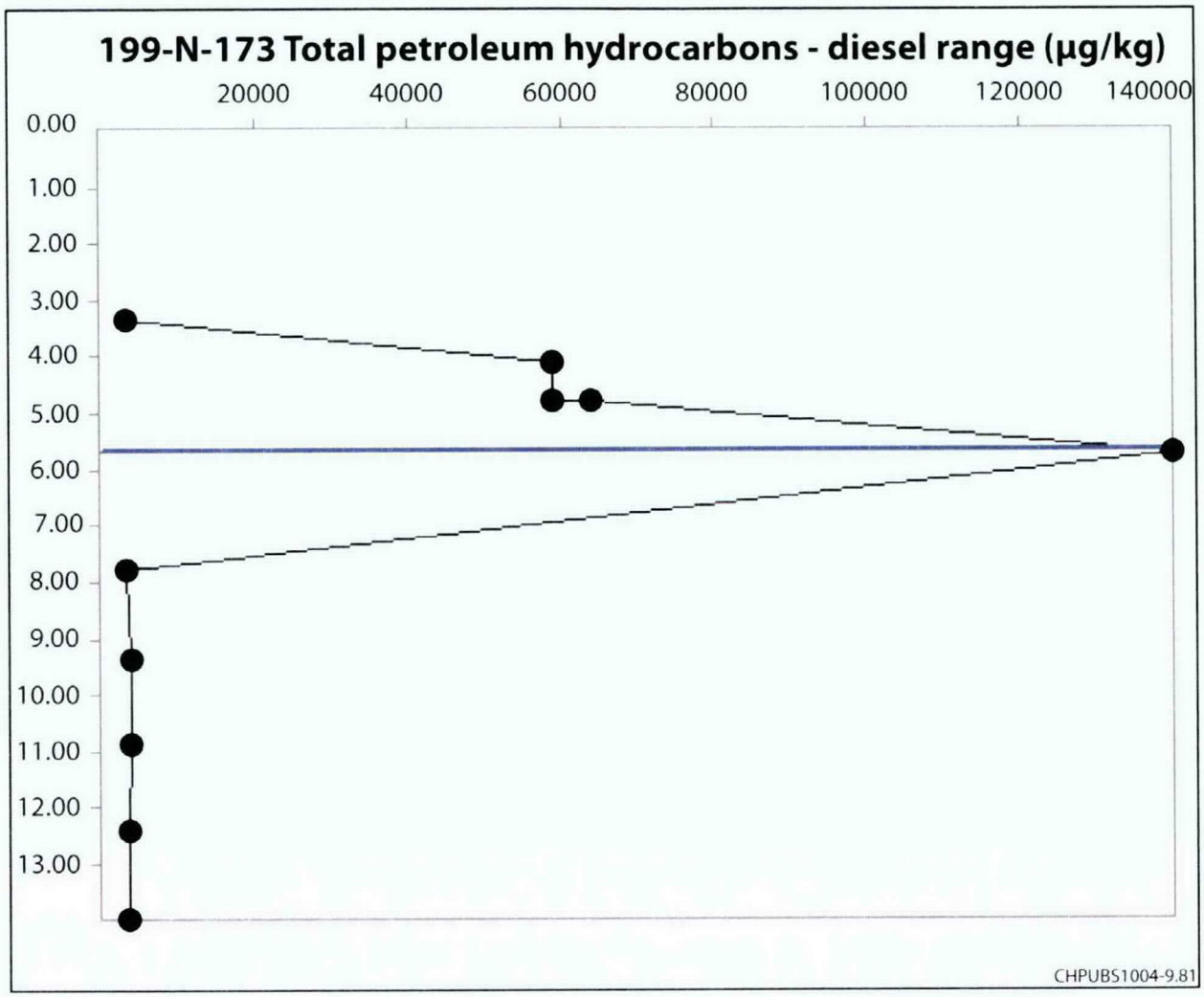


Figure 2-45. Well 199-N-173 TPH-DR Concentration with Depth

Lower levels of TPH-DR have been detected in two wells and aquifer tubes downgradient of the former tank farm. Table 2-8 shows values from these wells and aquifer tubes.

Table 2-8. Other Well and Aquifer Tube Groundwater Sample Results (2009 to 2010)

Well Name	2-3-2009	8-19-2009	9-16-2009
199-N-173	4,300 µg/L	1,900 µg/L	2,100 µg/L
---------	3-25-2009	6-18-2009	9-15-2009
199-N-96A	70 µg/L (nondetect)	70 µg/L (nondetect)	260 µg/L
---------	4-1-2009	9-17-2009 to 12-17-2009	3-8-2010
116mArray-0A	70 µg/L (nondetect)	810 to 840 µg/L	440 µg/L
---------	4-8-2009	12-17-2009	3-8-2010
C6135	70 µg/L (nondetect)	770 µg/L	240 µg/L

All other wells sampled in the area surrounding the former diesel spill were nondetect for TPH-DR in 2009 (199-N-3, -19, -21, -56, -57, and -64).

Data are also available for work performed during the installation of the WCH bioventing wells (WCH-370). Specifically, a vadose zone of TPH-DR and gasoline range was identified starting about 16.76 m (55 ft) bgs and extending to the groundwater table (top of unconfined aquifer).

2.3.3.4 Tritium

In FY 2008, only one well, 199-N-32, had an average tritium concentration exceeding the DWS (20,000 pCi/L). Both the high and low river stage measurements at this well, located near the 116-N-3 Facility, were 20,000 pCi/L. Historically, the highest tritium concentration detected in 100-N wells was 400,000 pCi/L from Well 199-N-3 in 1972. Other wells had exceeded the DWS in the past, including several no longer monitored for a variety of reasons (the well is dry, the well is not part of the monitoring network as the information it would provide is redundant with other monitoring wells in the area, the well has been decommissioned). Overall, the current tritium plume map shows tritium levels decreasing throughout the area. There is evidence to support the hypothesis that a single well in a general area that previously exhibited tritium levels above the DWS would not continue to exceed it, based on other wells in the general area, which are currently below the DWS. For example, Well 199-N-4 was last sampled in February 1990 (and has been decommissioned), with a tritium level of 43,100 pCi/L. The highest level measured at this well was 130,000 pCi/L in November 1987. From 1987 to the last sample taken in 1990, tritium levels in this well decreased at a consistent and steady rate. Current groundwater tritium levels in the vicinity and downgradient of this well are below the DWS. This same situation is true for other wells previously above the DWS, which are no longer sampled. When nearby monitoring wells are in the same general area or downgradient from these wells are sampled, they exhibit activity concentration levels below the DWS. Tritium concentrations in the groundwater beneath 100-N have decreased a great deal since effluent discharges to the 116-N-3 Facility ceased in 1991. Figure 2-46 shows two wells near the 116-N-3 facility that illustrate this effect. Tritium concentrations in most of the wells in 100-N have decreased by 100 to 500 percent and several others have decreased by over 500 percent.

Tritium is generally evenly distributed throughout the unconfined aquifer. Concentrations in Wells 199-N-69 and 199-N-70, completed at the base of the unconfined aquifer, are approximately equal to those detected in nearby shallow wells. Tritium concentration in Well 199-N-80, which monitors a sandy interval in the RUM, was 15,000 pCi/L in FY 2008, and has not been above the MCL since 2005.

2.3.3.5 Total and Hexavalent Chromium

Hexavalent chromium is present within 100-N. Groundwater monitoring for Cr(VI) is inconsistent and discontinuous in frequency and well location. Therefore, only one Cr(VI) plume is mappable using available data. This plume is located in the western portion where a contaminant plume has migrated northeastward from 100-K (Figure 2-47). Because this plume originates in 100-K, it will not be addressed by 100-N remedial actions.

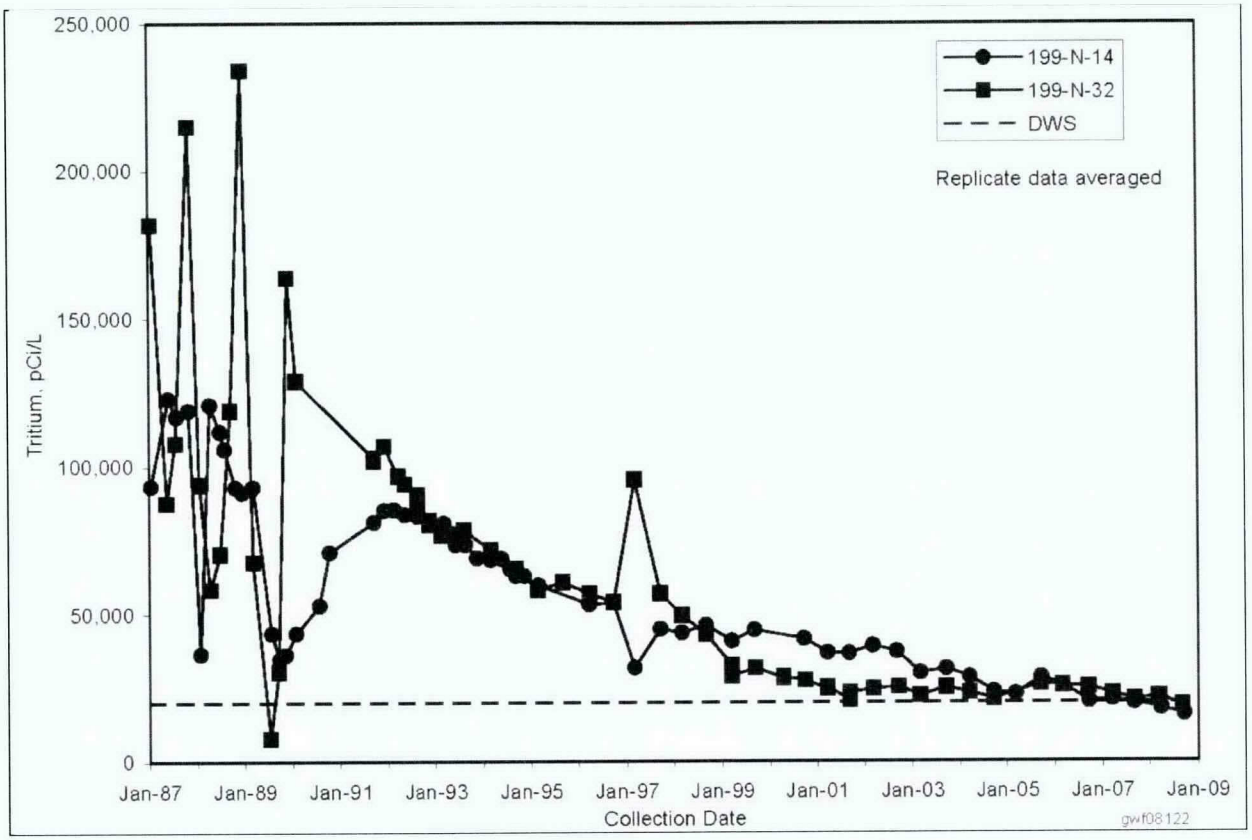


Figure 2-46. Tritium Concentrations in Groundwater near the 116-N-1 and 116-N-3 Waste Sites

Near the N Reactor, Cr(VI) has been analyzed from 23 groundwater samples—11 monitoring wells in the unconfined aquifer and 22 samples from 12 aquifer tubes. The analytical results from these nonfiltered samples revealed maximum Cr(VI) concentrations up to 300 µg/L in monitoring wells (199-N-3 in 1969) and 24 µg/L in aquifer tubes (C6318 in 2008). The last Cr(VI) detection above 20 µg/L (the concentration protective of aquatic receptors) was 60.3 µg/L from Well 199-N-64 in 2005, which was the only Cr(VI) sample collected from this well. Cr(VI) is not a typical analyte in 100-N wells. DWSs for total chromium were exceeded in samples from six wells during FY 2008; four are part of the apatite barrier and considered artifacts related to the barrier performance. In addition, total chromium exceeded the DWSs in several wells in the early 1990s, but has not been an analyte since that time.

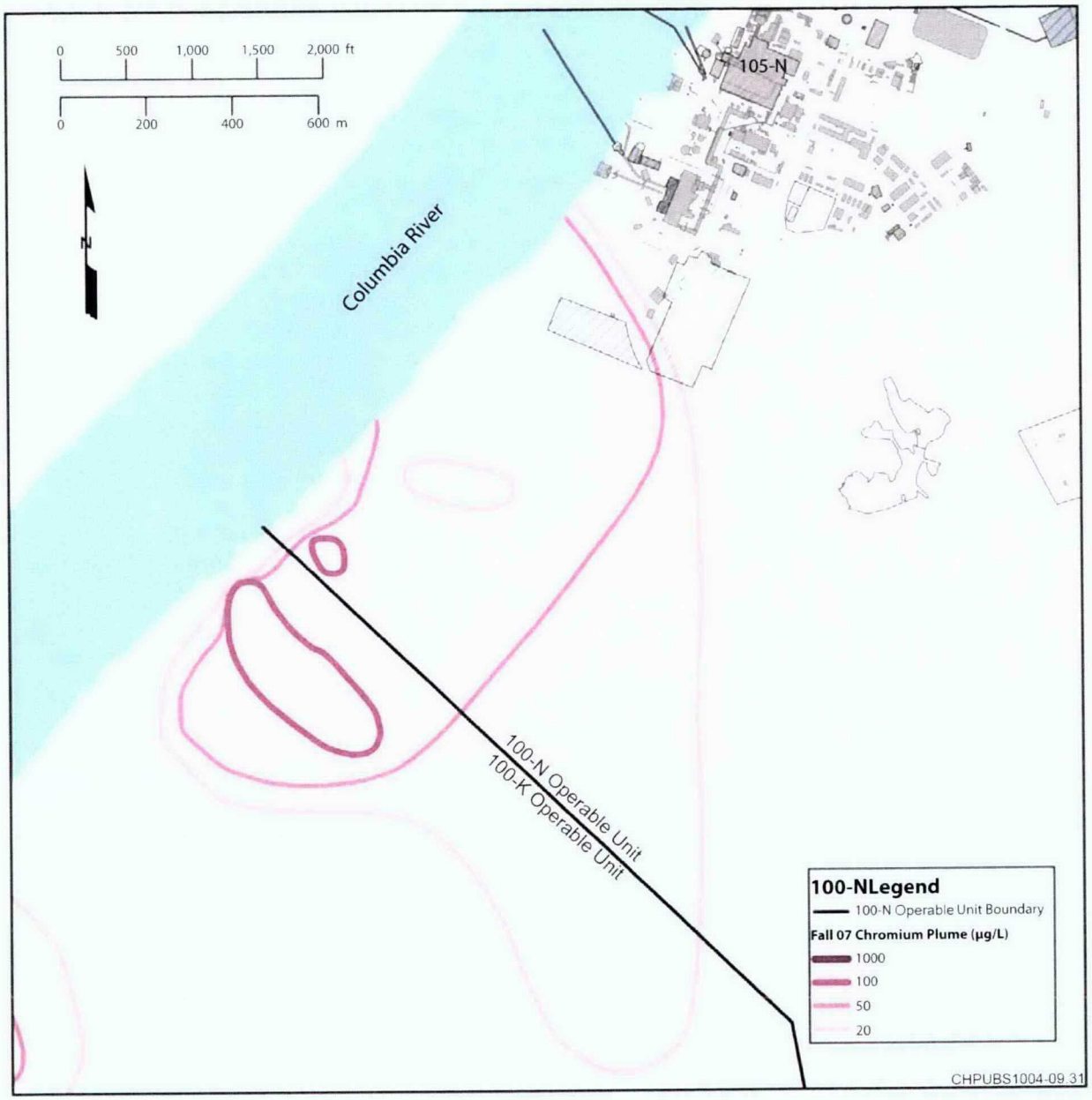


Figure 2-47. Hexavalent Chromium on the Western Portion of 100-N, Unconfined Aquifer

Insufficient Cr(VI) samples were collected during any sampling event to provide the basis for a plume map. Current (2009 to 2010) filtered chromium results, which are analogous to Cr(VI) results, indicate very little Cr(VI) present in groundwater at 100-N, so it is unlikely a plume map could be created, but as discussed in Chapter 4, additional sampling of existing monitoring wells for Cr(VI) is proposed to answer this question.

Total chromium samples have been collected from wells in the unconfined aquifer in the 100-N since 1985. The state and federal DWSs (100 µg/L) were exceeded in several wells. Some wells that revealed exceedances in the mid-1990s have not been resampled since that time (e.g., Well 199-N-17, which is decommissioned). In 2008, total chromium in filtered samples (assumed representative of Cr(VI)) exceeded the 20 µg/L in seven wells. Ecology and EPA have expressed the concern that filtered groundwater samples may cause an underestimation of the amount of contamination that is naturally

mobile in the groundwater (Ecology and EPA letter, August 7, 2007). Samples taken for the RI-FS will be unfiltered per the SAP (DOE-RL-2009-42, Rev. 0). Six wells are part of the apatite barrier, and the elevated concentrations observed were an artifact of apatite injections performed in this area. The chemicals used to foster the creation of the apatite matrix temporarily change the geochemical environment and allow previously sorbed species to move through groundwater. This effect is short lived and lasts from only two to four weeks; the liberated species are resorbed as the apatite barrier traps Sr-90 (DOE-RL-2010-29, Rev. 0). Monitoring specifically for this phenomenon will occur during apatite construction. Appendix E contains the groundwater data evaluated for this document. Several samples analyzed have the word "NULL" in the results column. In almost all the samples where this occurs, there is also a "U" in the Lab Qualifier Column. This "U" means the analyte in question was not detected above the limiting criteria. For a short time, predominately the 1990s, laboratories were allowed to put "NULL" in a spreadsheet if the value were essentially zero or if the cell would have been blank. For a few samples, the word "NULL" appears in the results column and in the Lab Qualifier column. In these cases, there is an "R" in the Review Qualifier column. An "R" means the data should not be used, because further review of that data indicated the result was not valid. Documentation for the "HEIS Results Table" provides for further explanations of Lab, Review, and Validation Qualifiers.

In one well completed beneath the unconfined aquifer (Well 199-N-80, completed in an approximately 1.5 m [5 ft] thick sandy interval within the RUM), the federal DWS has been exceeded for total chromium since 1992, with concentrations ranging from 130 to 234 µg/L. Both the filtered and unfiltered values for total chromium are essentially the same, indicating the chromium is in the form of Cr(VI). It is important to note that this well has documented well screen corrosion, which is causing the elevated chromium levels, and the reason why the chromium is present as Cr(VI). As a further indicator of corrosion as the cause of the elevated chromium levels, sulfate is also elevated and trends like the chromium values. This is a strong indicator of the breakdown of stainless steel due to corrosion, as pits in the sulfide impurities found in all steels are where the corrosion starts ("Why Stainless Steel Corrodes" [Ryan et al., 2002]). Therefore, if corrosion is occurring, both sulfate and chromium should be present in solution, and mirroring each other in trend plots. Figure 2-48 shows the trend plot for Well 199-N-80 for chromium and sulfate.

2.3.3.6 Other Contaminants

Additional contaminants were detected in groundwater in the unconfined aquifer above the DWS within 100-N, generally within the area of the Sr-90 plume. Contaminants such as iron, manganese, and sulfate exceed the secondary DWS. Groundwater monitoring for these cations/anions is inconsistent, discontinuous, infrequent, and sporadic by well location. EPA established the secondary DWSs as guidelines to assist in managing drinking water for aesthetic considerations, such as taste, color, and odor. These contaminants do not present a risk to human health.

These other contaminants did not necessarily originate from the same primary sources as the Sr-90. Radiological contaminants (other than Sr-90) have been detected in groundwater near former reactor buildings and associated structures, but at concentrations less than DWSs (except tritium, as discussed in Section 2.3.1).

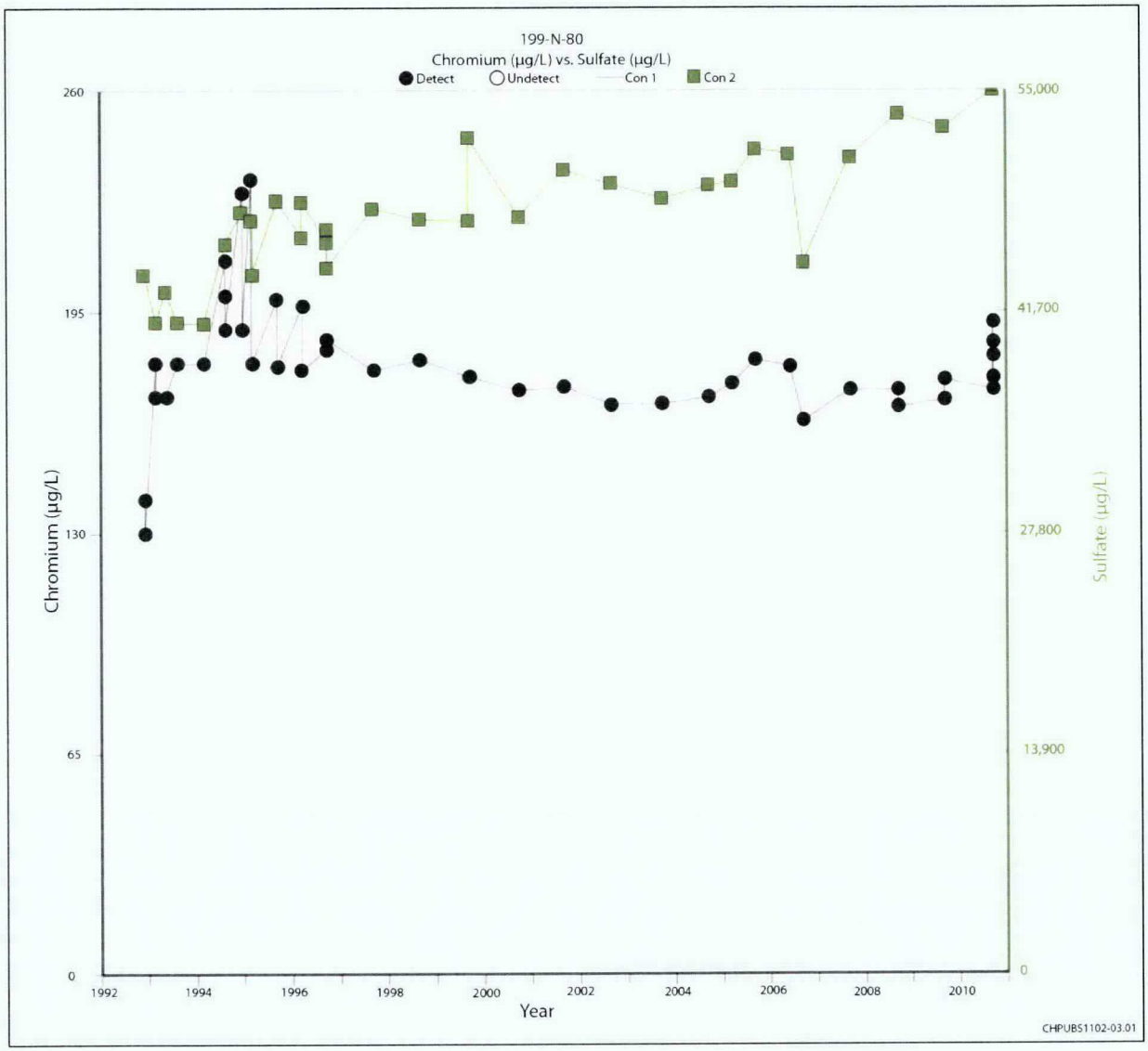


Figure 2-48. Trend Plot for Chromium and Sulfate in Well 199-N-80

Other radiological contaminants found in groundwater include cobalt (Co-60), cesium (Cs-137), and technetium (Tc-99) during well sampling efforts, with respective DWSs of 100, 200, and 900 pCi/L.

Cobalt detected in Well 199-N-45 during a 1988 sampling round yielded an analytical result of 91.8 pCi/L, which is below the DWS. The half-life is 5.27 years, so the mass was reduced by three half-lives, or 75 percent (1993 at 45.9; 1998 at 22.95; 2003 at 11.5 pCi/L) in 2003, or about 10 percent of the DWS. Cobalt analyses were discontinued due to the reduced total mass and associated risk from the specie.

Cesium 137 has been recorded as a nondetect in Well 199-N-70, a status held since year 2000. The analytical database provides few numeric values, and they are all followed with nondetect. As such, there is no reason to continue sampling and analyzing for Cs-137 in groundwater.

The DWS for Tc-99 is 900pCi/L, and there are no well sampling results approaching the DWS. The nature of Tc-99 is similar to tritium, in that it will move as water. The Tc-99 reacts with nitrates in groundwater to form pertechnetate ion (TcO4), which is extremely water soluble, resulting in Tc-99 not

adsorbing to sediments, but staying in water. Because Tc-99 has a biological half-life of three days, it is a minimal radioactive hazard. Since there is, or was no indication that Tc-99 was near the DWS, its analyses were discontinued during the sampling events.

Part of the sampling task(s) is to reduce the sample volume by removing nondetected analytes from the list.

Manganese concentrations continued to exceed the secondary DWS (50 μg/L) in filtered samples from two wells affected by petroleum contamination: 199-N-16 (371 μg/L) and 199-N-18 (4,570 μg/L). Iron concentrations also exceeded the secondary DWS (300 μg/L) in Well 199-N-18 (20,500 μg/L).

The former 120-N-1 Percolation Pond introduced sulfate and sodium into 100-N groundwater. The sulfate plume in 100-N is depicted in Figure 2-49. The second highest sulfate concentration in 2009 was 208 mg/L in Well 199-N-165, which is a monitoring well for the facility. Wells located downgradient of the Percolation Pond (199-N-56, 199-N-57, and 199-N-64) also had elevated sulfate levels. The highest sulfate concentration in 2009 was 503 mg/L in Well 199-N-67, which is near the head end of the former 116-N-1 LWDF. This is the only measured sulfate value that exceeded the secondary DWS (250 mg/L). Elevated sulfate concentrations were detected near both the 116-N-1 and 116-N-3 LWDFs. The contamination beneath these facilities is residual from previous flow conditions that carried sulfate from the 120-N-1 Percolation Pond inland. Current groundwater flow conditions are carrying this plume to the north and northwest (DOE-RL-2008-66).

Well 199-N-18 also exhibits anomalously low sulfate TPH contamination (0.66 mg/L), which is believed related to hydrocarbon biodegradation and chemical reduction occurring in and near this well.

2.3.4 Near-Shore Metals Sampling Summary

Near-shore metals characterization was conducted at 100-N collaboratively by PNNL and the Washington State Department of Health in 1997 (*Hanford Site Environmental Report for Calendar Year 1997* [PNNL-11795] and *Survey of Radiological Contaminants in the Near-shore Environment at the Hanford Site 100-N Reactor Area* [PNNL-11933]). Five stations were investigated: Sites 1 and 2 (199-N-99A well area, downstream); Site 3 (199-N-46 well area); and Sites 4 and 5 (199-N-96A well area, upstream). Table 2-9 presents the metals concentrations found. Locations of some sites are shown in Figure 1-17 and can be found in the *Aquatic and Riparian Receptor Impact Information for the 100-NR-2 Groundwater Operable Unit* report (DOE-RL-2006-26). The sediment data indicate elevated chromium in the seep at Site 3 and in the downstream sector of 100-N.

The maximum arsenic value (12μg/g) at Station 1 represents the only arsenic value that exceeded the 90th percentile value (6.47μg /g) accepted as Hanford Site arsenic background concentration (DOE-RL-92-24, Rev. 0). However, it should be noted that the median arsenic concentration for the sediment samples from this area is 6.9 μg/g; the same as the median value reported for the upstream Priest Rapids sampling results (6.9μg/g; see Table 2-9).

This EMA designation was based on the appearance of elevated metal concentrations in environmental media, primarily based on chromium results.

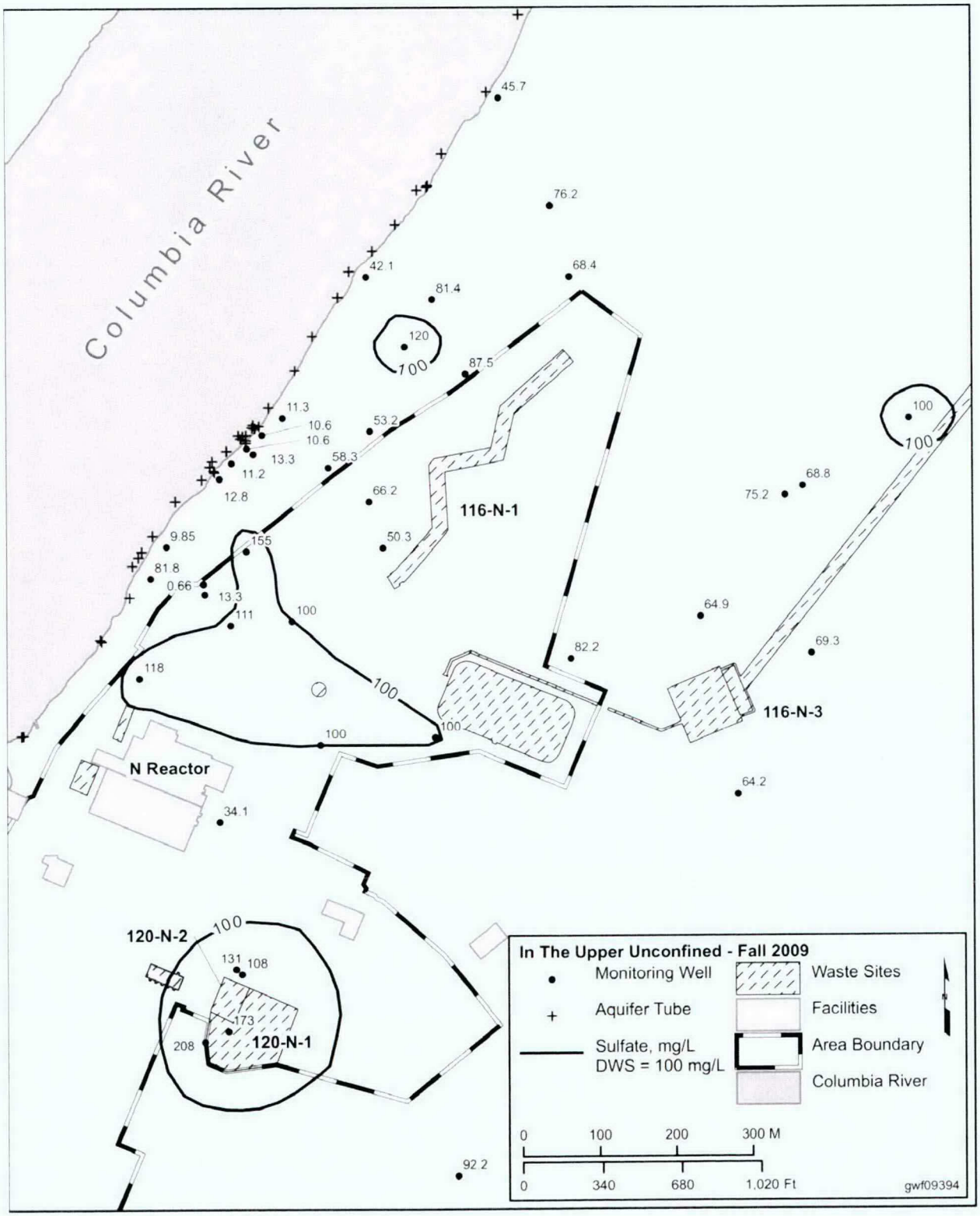


Figure 2-49. Sulfate Plume

Table 2-9. 1997 Metals Concentrations in Sediment (µg/g dry wt) at 100-N

Site	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Selenium	Silver	Thallium	Zinc
100-N Station 1	0.96	12	1.4	2.2	69	40	0.08	34	60	1.8U	0.36	1.3	330
100-N Station 3 A	0.45	3.5	1.4	0.5	33	21	0.02	19	17	1.8U	0.2	0.51	130
100-N Station 3 B Riverbank Seep	1.1	4.2	1.4	3.3	100	43	0.2	39	52	1.8U	0.56	1.2	370
100-N Station 5	0.16	1.8	0.34	0.33	14	7.2	0.06	7.3	7.1	1.8U	0.07	0.18	50
Priest Rapids (median conc.)	0.8	6.9	1.1	4.3	68	39	--*	36	36	0.12	0.34	1.5	450

Source: DOE-RL-92-24, Rev. 4, Volume 1 (http:--www2.hanford.gov-arpir-?content=findpage&AKey=0096062), lists arsenic with an overall maximum concentration of 27.7 mg/kg (from Summary Table 1); therefore, the Station 1 value is within the range of Hanford Site arsenic values used to develop the 6.47 µg/g background value, though it exceeds the 90th percentile value of 6.47 µg/g.

* = not analyzed

µg/g dry wt = microgram per gram dry weight

U = undetected

3 Identification of Investigation Requirements

This chapter is included for completeness to satisfy CERCLA requirements for this RI/FS work plan addendum. The following sections of the work plan (DOE/RL-2008-46) are included by reference.

- Assessment of Baseline and Residual Risks in the 100 Area (Section 3.6) summarizes the past and ongoing risk assessment activities within the 100 Area.
- Preliminary Remedial Action Objectives (Section 4.1) presents a preliminary list for groundwater, surface water, and soil.
- Preliminary Remediation Goals (Section 4.2) provides target cleanup levels for use in evaluating how objectives will be achieved.
- Potential Applicable or Relevant and Appropriate Requirements (Section 4.3) provides the laws and regulations pertaining to response actions.
- Preliminary Remedial Actions (Section 4.5) provides a compilation of potential remedial actions.

For this work plan addendum, there are no exceptions to the sections of the work plan.

4 Conceptual Site Model

This chapter describes the CSM for 100-N OU. The CSM expresses the current understanding of site conditions and makes possible the identification of data gaps and data needs in conjunction with the planning process described in Section 4.4 of this work plan. The CSM identifies waste site key features, distills the known information, and captures decisions to be made. It describes sources, receptors, and their linking interactions; identifies uncertainties; and provides a framework for data and information needed to resolve each uncertainty. The CSM will evolve as new data and information are developed. The goal of the CSM is the synthesis of knowledge in a manner that supports project needs and addresses decision making requirements (including the design of remedial actions). The CSM is presented here as a discussion of known and potential contaminant sources (including release mechanisms), contaminant migration and distribution in the vadose zone and groundwater, and exposure pathways and receptors.

This discussion focuses primarily on Sr-90, the contaminant for which the bulk of remediation efforts at 100-N have been directed. Specific discussions are provided for petroleum species, tritium, and nitrate, which have been observed in the unconfined aquifer. In addition, a discussion is provided for sodium dichromate, which was used for a few years at 100-N and is a prominent contaminant of concern at 100 Area reactor sites (particularly 100-D and 100-K). Numerous other contaminants were released in liquid discharges at 100-N. The operational and environmental conditions described through the discussion of the highlighted contaminants as primary factors controlling their migration are considered applicable to these contaminants. The dominant factors are recharge history (and associated water fluxes through the vadose zone and unconfined aquifer) and chemical reactivity with crib, trench, and vadose zone soils. The commonly shared factor for all contaminants is the wastewater and natural water recharge history while the chemical reactivity factor varies among contaminants. In a summary discussion (Section 4.3.6), general expectations for the additional contaminants nature and extent in the subsurface are provided and based on the CSM. As final information is collected supporting site closure decisions, revisions of the CSM will specifically address these contaminants.

4.1 Contaminant Inventory and Release Characteristics

At 100-N, the N Reactor (105-N) operated for the better part of 23 years from late 1963 through late 1986. In support of its operation to produce special nuclear materials through irradiation of uranium-enriched fuels and to generate commercial power, large quantities of contaminated fluids and solids were routinely generated and discharged to the surrounding environment.

4.1.1 Waste Sites

Characterization of 100-N waste sites began under the authority provided by DOE/RL-90-22 and continued under *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measures Study/Closure Plan* (DOE/RL-96-39), both of which focused on the liquid waste disposal facilities and a select few waste sites. Later investigations of the 100-N waste sites included DOE/RL-93-80, DOE/RL-93-81, and DOE/RL-95-111. The highest Co-60, Cs-137, and Pu-239/240 concentrations detected in 100 Area soil were from 100-N. The highest Co-60 concentration (18 +/- 1.80 pCi/g) was detected west of the head end of the 116-N-1 Crib (1301-N). Additionally, soil at the head end but southwest of the 116-N-1 Crib and Trench contained the highest Cs-137 concentration (2.2 +/- 0.223 pCi/g). The highest Pu-239/240 concentration (0.06 +/-0.008 pCi/g) detected was at the same location as the highest Co-60 concentration (WHC-SD-ER-TI-251).

Remediation of general 100-N waste sites commenced under authority of the Interim Action ROD (EPA/ROD/R10-99/112) in 1999. Remediation of the RCRA liquid waste disposal facilities commenced under the authority of the Interim Action ROD (EPA/ROD/R10-00-120), also known as the treatment,

storage, and disposal (TSD) ROD, in 2000. The standard remedy selected for source waste sites in the 100 Area is RTD. Remedial actions are designed to achieve RAO and goals specified in interim action RODs for direct exposure from 0 to 4.6 m (0 to 15 ft) bgs and protection of groundwater and the Columbia River. In practice, this has involved excavating wastes and soil exceeding cleanup criteria, and disposing waste to the ERDF. Residual contamination (after the selected remedy) is sampled and modeled to assess impacts to groundwater and the Columbia River. Where RAOs are achieved, the waste site is considered interim closed. Remedial actions for contaminated sites in the 100-NR-1 OU are organized into several categories.

One category is waste sites covered by the 2000 TSD ROD, which includes the large 100-N RCRA TSD units (116-N-1 [1301-N] and 116-N-3 [1325-N] LWDF) and the associated site UPR-100-N-31. Verification of interim remedial actions for the RCRA TSD sites was addressed under DOE/RL-2000-07.

The remedial action remedy for the remaining CERCLA waste sites is under the authority of the Interim Action ROD (EPA/ROD/R10-99/112) and the ESD (EPA/ESD/R10-03/605). The waste sites that are covered by the 1999 ROD were split into several waste site groups based on their suspected primary contaminants and characteristics: radioactive, near-surface petroleum contamination, deep petroleum contamination, inorganic, burn pit, surface solid, and the river shoreline site, which is closely tied to the remediation of the 100-NR-2 Groundwater OU and N-Springs.

The remedial design and implementation of the remedial action process for the CERCLA waste sites in the 1999 ROD is described in the remedial design/remedial action work plan (*Remedial Design Report/Remedial Action Work Plan for the 100-N Area* [DOE/RL-2005-93]). The selected remedy for the CERCLA waste sites is RTD for the majority of the sites (radioactive, inorganic, burn pit, and surface solid), performing in situ and ex situ bioremediation of the petroleum contaminated waste sites, and application of institutional controls at the shoreline site (as defined in the Interim Action ROD [EPA/ROD/R10-99/112]).

Determining RCRA closed and/or CERCLA interim closed waste sites is based on data assembled in the CVPs and summarized in Appendix B. These data are intended to support the premise that the residual contamination at interim closed waste sites is less than the regulatory action level, and meets or exceeds the remedial action goal. A list of sites remediated in 100-N (as of October 31, 2009) in accordance with the Interim Action RODs (EPA/ROD/R10-99/112 or EPA/ROD/R10-00/120) is provided in Table 4-1. Approximately 129 waste sites remain to be remediated (Table 2-3).

Data Gap No. 1: Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath unremediated waste sites.

Data Gap No. 2: Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath remediated waste sites.

Data Gap No. 3: Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath and around reactor structures.

Table 4-1. Closed Out and Interim Closed Out Waste Sites in 100-N

Site Code	Site Type	Record of Decision	Site Names	Reclassification Status	Closure Document
100-N-1	Pond	EPA/ROD/R10-99/112	100-N-1, HGP SWMU No. 6, Settling Pond	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10; WSRF 2004-060
100-N-3	French Drain	EPA/ROD/R10-99/112	100-N-3, Maintenance Garage French Drain, HGP-SWMU No. 9, Maintenance Garage Waste Water Treatment Unit	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-4	Drain/Tile Field	EPA/ROD/R10-99/112	100-N-4, HGP SWMU No. 5 Tile Field	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-41	Septic Tank	EPA/ROD/R10-99/112	100-N-41, 1701-NE Gate House Septic Tank, HGP-SWMU No. 9	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-45	Septic Tank	EPA/ROD/R10-99/112	100-N-45, 1703-N Septic Tank, HGP-SWMU No. 9	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-46	Underground Storage Tank	None	100-N-46, HGP Diesel Oil Storage Tank	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-5	Storage	EPA/ROD/R10-99/112	100-N-5, HGP Disposal and Storage Area, HGP Bone Yard, HGP-SWMU No. 10	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10

Table 4-1. Closed Out and Interim Closed Out Waste Sites in 100-N

Site Code	Site Type	Record of Decision	Site Names	Reclassification Status	Closure Document
100-N-50	Single-Shell Tank	EPA/ROD/ R10-99/112	100-N-50, HGP SWMU 4, Turbine Oil Filter Unit, Turbine Oil Cleaning System	Interim Closed Out	HGP-CVP-SWMUs 1, 2, 3, & 4, *Cleanup Verification Package for the Hanford Generating Plant UPR-100-N-37 Transformer Yard (SWMU #1), 100-N-51 Oil Storage Area (SWMU #2), 185-N Building Drains and Sumps (SWMU #3), and 100-N-50 Turbine Oil Filter Unit (SWMU #4)*
100-N-51	Storage	EPA/ROD/R10-99/112	100-N-51, HGP Building Oil Storage Area, 100-N-51A, HGP SWMU No. 2	Interim Closed Out	HGP-CVP-SWMUs 1, 2, 3, & 4
100-N-51B	Sump	EPA/ROD/R10-99/112	100-N-51B, HGP Building Floor Drains and Sumps, HGP SWMU No. 3	Interim Closed Out	HGP-CVP-SWMUs 1, 2, 3, & 4
100-N-52	Storage Tank	None	100-N-52, HGP Gasoline Storage Tank	Interim Closed Out	HGP-CVP-SWMUs 5, 6, 7, 8, 9, & 10
100-N-58	Pond	None	100-N-58, South Pond, 120-N South Settling Pond, 1324-N South Settling Pond	Closed Out	CVP-2001-00021, *Cleanup Verification Package/Clean Closure Report for the Soil Column of the 120-N-1 and 120-N-2 Dangerous Waste Treatment and Disposal Sites and the 100-N-58 Site*

Table 4-1. Closed Out and Interim Closed Out Waste Sites in 100-N

Site Code	Site Type	Record of Decision	Site Names	Reclassification Status	Closure Document
100-N-63:1	Radioactive Process Sewer	EPA/ROD/ R10-00/120	100-N-63:1, Pipeline Section from 116-N-1 to 116-N-3 Crib Including Concrete Encased Pipe Bypass Structure	Interim Closed Out	CVP-2002-00002
100-N-78	Maintenance Shop	EPA/ROD/ R10-99/112	100-N-78, 1716-NE Maintenance Garage, HGP SWMU No. 8	Interim Closed Out	HGP-CVP- SWMUs 5, 6, 7, 8, 9, & 10
116-N-1	Crib	EPA/ROD/ R10-00/120	116-N-1, 1301-N Liquid Waste Disposal Facility, 1301-N Crib and Trench	Interim Closed Out	CVP-2006-00004
116-N-3	Crib	EPA/ROD/ R10-00/120-	116-N-3, 1325-N Liquid Waste Disposal Facility, 1325-N Crib and Trench	Interim Closed Out	CVP-2002-00002
120-N-1	Pond	None	120-N-1; 1324-NA Percolation Pond	Closed	CVP-2001-00021
120-N-2	Surface Impoundment	None	120-N-; 1324-N Surface Impoundment	Closed	CVP-2001-00021
1908-NE	Outfall	EPA/ROD/ R10-99/112	1908-NE, HGP Outfall, 1908-NE Building, HGP-SWMU No. 7	Interim Closed Out	HGP-CVP- SWMUs 5, 6, 7, 8, 9, & 10
UPR-100-N-37	Unplanned Release	EPA/ROD/ R10-99/112	UPR-100-N-37, HGP Transformer Yard Oil Stained Gravel (SWMU No. 1)	Interim Closed Out	HGP-CVP- SWMUs 1, 2, 3, & 4

CVP = cleanup verification package
HGP = Hanford Generating Plant
SWMU = solid waste management unit
UPR = Unplanned Release

4.1.2 Liquid Waste Sites

The majority of contaminant mass released to the environment was dissolved or suspended as particulates in various fluids discharged to LWDFs near the reactor, primarily 116-N-1 (1301-N) LWDF and 116-N-3 (1325-N) LWDF. Throughout the reactor operations period and for some time afterward, these facilities received liquid waste. The majority of the discharge volume went to 116-N-1 (1301-N) LWDF from 1964 to late 1985 and the remainder went to 116-N-3 (1301-N) LWDF from 1983 into 1993. The major types of fluids included the following:

- Reactor coolant and periphery cooling systems bleed off
- Reactor primary coolant loop decontamination rinse solution
- Spent fuel storage basin cooling water overflow
- Building drains where radioactive solutions were generated and disposed

With the exception of the primary coolant loop decontamination rinse solution, which was generated every 2 to 4 years (*Groundwater Impact Assessment Report for the 1325-N Liquid Waste Disposal Facility* [WHC-EP-0675]), all solutions were generated and discharged continuously. The coolant fluids and basin fluids were the primary sources of LWDF discharge (see Figure 4-1, adapted from WCH-0675). These fluids became contaminated by contact with ruptured fuel elements and subsequent dissolution of readily dissolvable isotopes. The fluids were piped from the N Reactor or the fuel storage basin to the 1322-N Facility, then to the 1310-N Storage Facility or the cribs, depending on the contamination levels. Fluids with unacceptably high contamination levels went to 1310-N and were transported by rail to the 200 Area for disposal. Supporting documentation describing criteria to transport waste to the 200 Area were not recovered.

4.1.3 Strontium-90 Releases

Readily available documentation provides summary level quantitative information about Sr-90 and other radioactive contaminants and their concentration levels in the various discharged fluids. An explicit discussion of early contamination levels was provided in *Radioisotopes Released in DUN Liquid Effluents* (DUN-7372-RD), where measured concentrations in reactor effluents were reported for about 25 radionuclides. The fluids collected in the winter of 1969 to 1970. Concentrations of notable contaminants measured subsequently in soils underneath the cribs and in groundwater are listed in Table 4-2. Measurements were provided in DUN-7372-RD for a suite of radionuclides with half-lives less than 1 year. The estimated annual discharge volume for this inventory was 4.2E+09 L (1.11E+09 gal), of which 3.8E+09 L (1.003E+09 gal) came from the reactor coolant systems and 4.0E+08 L (1.06E+08 gal) from the basins overflow. These data show the basin waters provided the majority of contaminant mass to the 116-N-1 (1301-N) Crib in about 10 percent of the total discharge volume. The basin fluids higher concentrations are apparently the result of prolonged exposure to ruptured fuel rods in the storage basin compared to that in the reactor cooling systems, and the discharge of particulates in fluids accompanying fuel transfer to the storage basin (WHC-SD-EN-TI-251).

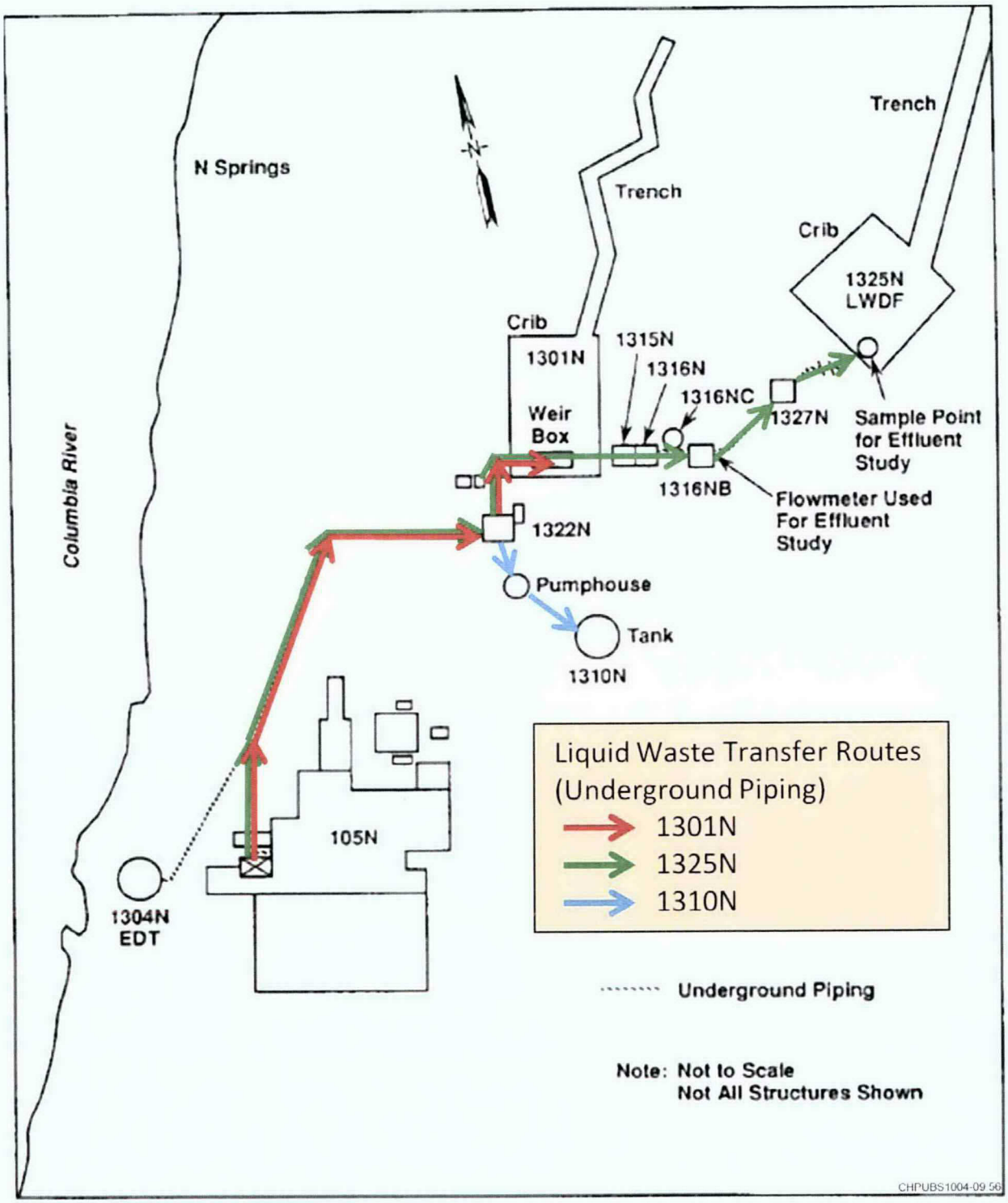


Figure 4-1. Primary Reactor Fluid Discharge Pathways in 100-N

Table 4-2. Radionuclide Concentrations and Estimated Annual Discharges in 1969 to 1970 from N Reactor Effluents

	Reactor Coolant Fluids						Annual Total
	Primary Loop		Rod Coolant		Basin Fluids		
Isotope	pCi/L	Ci/Yr	pCi/L	Ci/Yr	pCi/L	Ci/Yr	Ci
Co-60	6.4E+04	1.0E+02	1.5E+02	3.3E-01	1.0E+05	4.0E+01	1.4E+02
Sr-90	2.0E+01	3.2E-02	1.8E+02	3.9E-01	1.7E+04	6.8E+00	7.2E+00
Cs-137	1.2E+03	1.9E+00	1.3E+02	2.8E-01	6.6E+04	2.6E+01	2.8E+01
H-3					3.0E+05	1.20E+02	1.2E+02

Source: DUN-7372-RD

Ci = Curies

Ci/Yr = Curies per year

pCi/L = picoCuries per liter

Historical radioactive contaminant discharge records indicate annual volumes and average radioactive contaminant concentrations were generally similar to those measured in 1969 and 1970. Annual reports of crib discharges were prepared for most of the operations periods beginning in 1973. These reports provided measured total volume releases to the cribs and contaminant contents (both average concentrations and total quantities). Table 4-3 provides a partial summary of these data.

Table 4-3 data show annual fluid discharges were relatively constant during the reactor operations period, but the annual contaminant releases were not. As an example, a comparison of annual discharge volumes versus Sr-90 discharges is shown in Figure 4-2, where there is a general but inconsistent correlation between the two data sets. During reactor operations between 1964 and 1987, annual discharges fluctuated over a relatively small range between 3 and 5.5 E+9 L. During that time, a substantial drop in the annual Sr-90 release occurred in 1969 versus 1968 (7.4 and 270 Ci, respectively). Then for the remainder of the reactor operations period, annual Sr-90 releases increased. This particular divergence in behavior has not been explained in the historical documentation but is attributed to changes in basin overflow contamination levels, which responded to differences in ruptured fuel storage practices and existing administrative controls placed on acceptable Sr-90 limits. It is significant that almost one-third of the total Sr-90 releases (about 1,125 Ci) are estimated as discharged by 1969.

This inventory is considered the primary Sr-90 source that first reached N-Springs in the mid-1980s (Figure 4-16). Strontium-90 release and transport simulations (*Simulations of Strontium-90 Transport from the 100-N Area to the Columbia River Using VAM2DH* [WHC-EP-0369] and *Numerical Simulation of Strontium-90 Transport from the 100-N Area Liquid Waste Disposal Facilities* [WHC-SD-ER-TA-001]) have successfully replicated the N-Springs contamination history (Figure 4-16), considering the operations discharge history (Figure 4-2).

Table 4-3. Annual Volume and Radioactive Contaminant Releases to 116-N-1 (1301-N) and 116-N-3 (1301-N) Liquid Waste Disposal Facilities

			Annual Crib Discharges (L)			Discharged Inventory (Ci)						Average Concentrations (pCi/L)		
						Sr-90		Cs-137		Co-60				
Source Document	Date of Discharge	Years Since Discharge	116-N-1 (1301-N)	1325-N	Total	At Discharge	2010	At Discharge	2010	At Discharge	2010	Sr-90	Cs-137	Co-60
UNI-3533 and DOE/RL-96-11	1964[a]	46	3.45E+09		3.45E+09	195	64.5	60	20.9	180	0.4	5.65E+04	1.74E+04	5.21E+04
	1965[a]	45	3.45E+09		3.45E+09	195	66.0	60	21.4	180	0.5	5.65E+04	1.74E+04	5.21E+04
	1966[a]	44	3.45E+09		3.45E+09	195	67.6	60	21.9	180	0.6	5.65E+04	1.74E+04	5.21E+04
	1967[a]	43	3.45E+09		3.45E+09	270	95.9	88	32.8	200	0.7	7.82E+04	2.55E+04	5.79E+04
	1968[a]	42	3.45E+09		3.45E+09	270	98.3	41	15.6	82	0.3	7.82E+04	1.19E+04	2.37E+04
DUN-7372-RD and UNI-3533	1969	41	4.18E+09		4.18E+09	7.4	2.8	28	10.9	84	0.4	1.77E+03	6.70E+03	2.01E+04
	1970	40	4.18E+09		4.18E+09	7.3	2.8	51	20.4	230	1.2	1.75E+03	1.22E+04	5.50E+04
UNI-3533	1971[a]	39	3.45E+09		3.45E+09	17	6.7	92	37.6	330	2.0	4.92E+03	2.66E+04	9.55E+04
UNI-3533 and DOE/RL-96-11	1972[a]	38	3.45E+09		3.45E+09	21	8.4	18	7.5	220	1.5	6.08E+03	5.21E+03	6.37E+04
DOE/RL-96-11	1973	37	3.18E+09		3.18E+09	16	6.6	48	20.5	320	2.5	5.04E+03	1.51E+04	1.01E+05
DOE/RL-96-11	1974	36	3.47E+09		3.47E+09	63	26.5	170	74.4	320	2.8	1.82E+04	4.90E+04	9.23E+04
DOE/RL-96-11	1975	35	3.47E+09		3.47E+09	93	40.1	240	107.5	370	3.7	2.68E+04	6.92E+04	1.07E+05
DOE/RL-96-11	1976	34	3.61E+09		3.61E+09	110	48.5	320	146.6	640	7.3	3.04E+04	8.86E+04	1.77E+05
DOE/RL-96-11	1977	33	5.29E+09		5.29E+09	120	54.2	380	178.1	870	11.3	2.27E+04	7.18E+04	1.64E+05
DOE/RL-96-11	1978	32	4.56E+09		4.56E+09	120	55.6	340	163.1	940	14.0	2.63E+04	7.45E+04	2.06E+05
DOE/RL-96-11	1979	31	4.93E+09		4.93E+09	130	61.7	290	142.3	770	13.1	2.64E+04	5.89E+04	1.56E+05
DOE/RL-96-11	1980	30	4.56E+09		4.56E+09	160	77.7	36	18.1	1,200	23.2	3.51E+04	7.89E+03	2.63E+05
DOE/RL-96-11	1981	29	3.83E+09		3.83E+09	84	41.8	240	123.3	370	8.2	2.19E+04	6.26E+04	9.65E+04
DOE/RL-96-11	1982	28	3.83E+09		3.83E+09	140	71.4	270	142.0	500	12.6	3.65E+04	7.05E+04	1.30E+05
DOE/RL-96-11	1983[b]	27	2.53E+09	7.15E+08	3.25E+09	110	57.4	200	107.6	770	22.1	3.39E+04	6.16E+04	2.37E+05
DOE/RL-96-11	1984[b]	26	2.96E+09	6.94E+08	3.65E+09	310	165.8	210	115.6	1,500	49.1	8.49E+04	5.75E+04	4.11E+05
UNI-3533 and DOE/RL-96-11	1985[b]	25	2.63E+09	1.02E+09	3.65E+09	240	131.5	88	49.6	590	22.0	6.58E+04	2.41E+04	1.62E+05
UNI-4370	1986	24		2.65E+09	2.65E+09	36.0	20.2	210	121.0	390	16.6	1.36E+04	7.94E+04	1.47E+05
DOE/RL-96-11	1987	23		7.67E+08	7.67E+08	15.0	8.6	48	28.3	200	9.7	1.96E+04	6.26E+04	2.61E+05
DOE/RL-96-11	1988	22		6.06E+08	6.06E+08	15.0	8.8	8	4.8	11	0.6	2.47E+04	1.32E+04	1.82E+04
DOE/RL-96-11	1989	21		6.06E+08	6.06E+08	28	16.9	23	14.2	33	2.1	4.62E+04	3.80E+04	5.45E+04
BHI-00368	1990	20		2.00E+08	2.00E+08	14	8.7	7.1	4.5	7.8	0.6	7.00E+04	3.55E+04	3.90E+04
BHI-00368	1991	19		NA	NA	0.85	0.5	0.13	0.1	0.0048	3.9E-04			

Table 4-3. Annual Volume and Radioactive Contaminant Releases to 116-N-1 (1301-N) and 116-N-3 (1301-N) Liquid Waste Disposal Facilities

			Annual Crib Discharges (L)			Discharged Inventory (Ci)						Average Concentrations (pCi/L)		
						Sr-90		Cs-137		Co-60				
Source Document	**Date of Discharge**	**Years Since Discharge**	**116-N-1 (1301-N)**	**1325-N**	**Total**	**At Discharge**	**2010**	**At Discharge**	**2010**	**At Discharge**	**2010**	**Sr-90**	**Cs-137**	**Co-60**
BHI-00368	1992	18		NA	NA	14	9.1	7.1	4.7	7.8	0.7			
BHI-00368	1993	17		NA	NA	0.85	0.6	0.13	0.1	0.0048	5.1E-04			
Totals			**8.14E+10**	**7.26E+09**	**8.86E+10**	**2,997**	**1,325**	**3,633**	**1,755**	**11,496**	**230**			

Source: UNI-3533, DOE/RL-96-11, DUN-7372-RD, *UNC Nuclear Industries Reactor and Fuels Production Facilities 1986 Effluent Release Report* (UNI-4370), BHI-00368.

a. Because annual discharge volumes were unreported in these years, the values shown were extrapolated from early 1970s reported volumes. From 1964 to 1966, contaminant releases were not reported and values shown are similarly extrapolated.

b. Fluids were discharged to both facilities in 1983, 1984, and 1985. The annual contaminant releases to each crib are assumed proportional to the discharge volume ratios. For example, in 1983, estimated annual Sr-90 releases to 116-N-1 (1301-N) and 116-N-3 (1301-N) are 24 and 85 Ci; in 1984, 59 and 251 Ci; and in 1985, 97 and 173 Ci, respectively.

Ci = Curies

pCi/L = picoCuries per liter

NA = not available

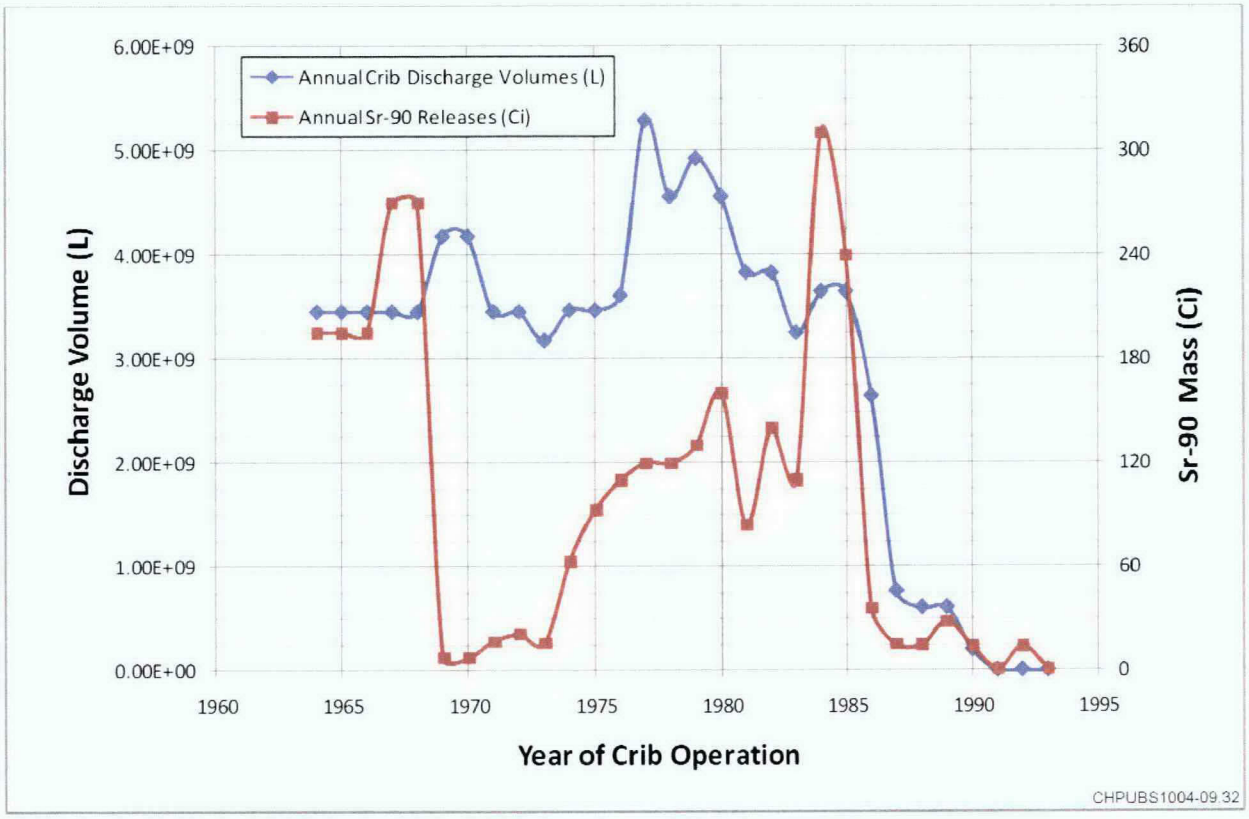


Figure 4-2. Comparison of Annual Fluid Discharges vs. Annual Strontium-90 Releases into 116-N-1 (1301-N) and 116-N-3 (1301-N)

The end of reactor operations, which started between 1985 and 1986, is clearly indicated by the rapid drop in both curves. Reactor operations began slowing in 1985 and placed into cold standby in early 1987, at which point the primary fluid discharges became draining facility fluids as part of the shutdown. Also, beginning in late 1984, fuel storage basin water was diverted to the 107-N recirculation facility, filtered through ion exchange resins, and routed to the 1314-N LWLS (DOE/RL-90-22). This operational change caused the large decrease in Sr-90 receipt at 116-N-1 (1301-N) and 116-N-3 (1301-N) in 1985 and 1986.

In addition to intentional releases of Sr-90-bearing liquid wastes, several unplanned releases (UPRs) from cracked pipelines discharged Sr-90 and other radioactive contaminants to the subsurface. Of these, the two most notable events were leaks at the 111-N spacer silos (UPR-100-N-3/118N and UPR-100-N-12/118-N-1, see Table 4-3), which released an estimated 80 and 120 μCi respectively. Clearly, these releases are relatively insignificant compared to the intentional discharges to 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs.

4.1.3.1 100-N Skyshine Dose Evaluation

The 100-N facilities and waste sites with inventories of gamma-emitting radionuclides can create a phenomenon known as "skyshine," which is produced by the interaction of gamma rays with the atmosphere and the subsequent downward scatter of the gamma rays. Skyshine was first observed in 1980 by 100-N operators who were able to correlate elevated radiation readings with the amount of shielding (i.e., depth of water) over the 116-N-1 and 116-N-3 Cribs. Skyshine increases radiation exposure to users of the Columbia River and its shoreline adjacent to 100-N. Decommissioning, deactivation, and interim remedial action (e.g., removal of shielding and excavation) temporarily contribute to skyshine.

The *N Area Skyshine Dose Evaluation (*BHI-01204) showed that skyshine results in an increase in ambient radiation over background conditions in 100-N. As a result of cleanup efforts at 105-N Basin, the report indicates the average dose rate calculated for 13 skyshine exposure points is 1.2 mrem over an 888-hour period. Although the average dose rate was twice the original value calculated prior to cleanup, it remained less than 2 mrem over an 888-hour period (BHI-01204). Ecology and DOE have established a deactivation average dose cleanup criteria along the shoreline as no more than 2 mrem increase over 888 hours (Logan, 1998). The maximum dose rate for the 13 skyshine exposure points after cleanup of 100-N deactivation buildings was 11.2 mrem over 888 hours. The minimum skyshine dose rate was 5.5 mrem over 888 hours. The total skyshine dose rate from 100-N buildings deactivation was well below the total 100-N Reactor allowable contribution of 25 mrem over an 888-hour period (BHI-01204).

Since 1980, measures were taken to minimize impact from skyshine, including placing concrete panels over the 116-N-1 and 116-N-3 Cribs and cleanup of waste sites and facilities. Skyshine has been minimized or eliminated after cleanup (i.e., interim remedial actions) as contaminants are effectively removed and waste sites are backfilled. At the 116-N-1 and 116-N-3 Cribs, known historical contributors of skyshine, contaminated soils were removed to a maximum depth of 6.5 m (21.3 ft). The skyshine effect was further minimized or eliminated by placing backfill over remaining residual contamination.

4.1.4 Petroleum Releases

Petroleum product releases occurred at fuel storage facilities (notably the 166-N Tank Farm and the 184-N Day Tanks) and connecting underground transfer lines on several occasions (see Appendix A). The 166-N Tank Farm (Figure 4-3) consisted of one large fuel oil storage tank (5,204,941 L [1,375,000 gal]) and four smaller diesel oil storage tanks (397,468 L [105,000 gal]). From the 166-N Tank Farm, underground pipelines transferred fuel to the 184-N Day Tanks, which then supplied fuel to the N Reactor (105-N).

Beginning in 1966, a number of mechanical and operational failures (pipe system failures of transport diesel and fuel oils, storage facilities overfilling, and spills during fuel transfers [WCH-323]) at these facilities resulted in the release of petroleum hydrocarbon contamination into the subsurface. The first and largest known leak occurred in August 1966 when a 10.16 cm (4 in.) diameter diesel fuel line leaked, due to corrosion, releasing an estimated 301,832 L (80,000 gal) of fuel. The leak (UPR-100-N-17) was detected through an observed discrepancy in the fuel inventory. The line was excavated and repaired.

Subsequently, numerous smaller leaks and some tank overflows released estimated fuel volumes of more than 16,600 L (4,400 gal). Generally, these lines were repaired.

The 184-N Day Tank consists of two 130,000 L (35,000 gal) Number 6 fuel only tanks and one 30,000 L (8,000 gal) diesel oil tank. These tanks had several spills over the life of the facility. On April 25, 1986, 3,000 L (800 gal) of diesel oil spilled (UPR-100-N-21), and 7,600 L (2,000 gal) of fuel oil spilled in April 1987 (UPR-100-N-19). Well 199-N-16, located adjacent to the 184-N Day Tanks, has nondetect values for TPH-DR and gasoline range in 2007 and 2009.

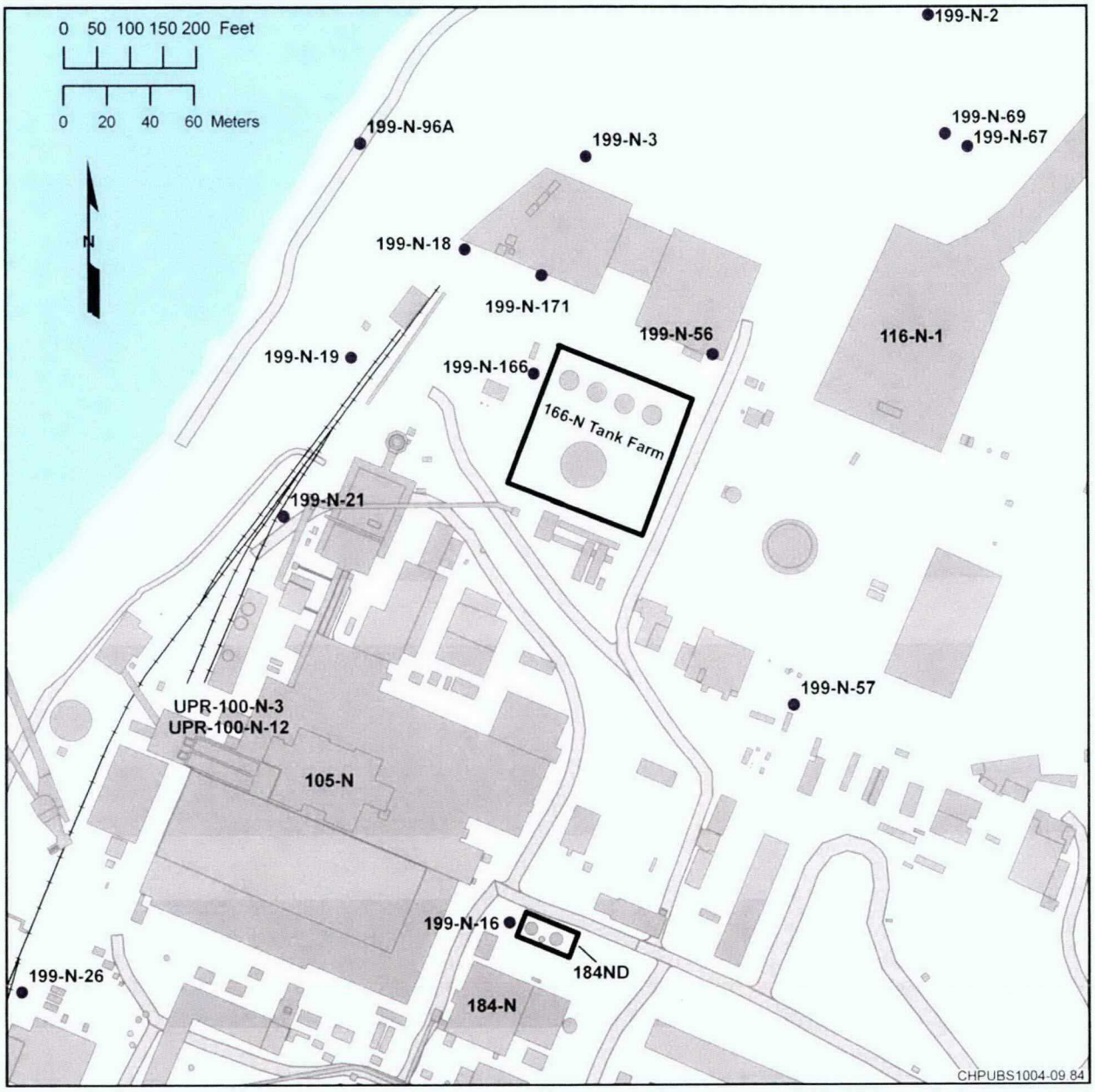


Figure 4-3. Location of the 166N Tank Farm and 184-N Day Tank Facility

4.1.5 Sodium Dichromate Releases

The primary function of sodium dichromate used in the N Reactor was providing corrosion protection for aluminum parts. This included ancillary equipment supporting the primary loop cooling system (HW-69000), rod cooling system, and aluminum-bearing fuel used for tritium production runs between 1965 and 1967 (WHC-MR-0521). The reactor design required less sodium dichromate (approximately 100 times less) for corrosion control compared to that required at eight constructed and operated single pass reactors in the 100 Area. Generally, using a recirculating cooling water system reduced water usage at 105-N, and using more corrosion resistant metals in the fuel and facility (e.g., Zircaloy) reduced the need for sodium dichromate as a corrosion inhibitor. Other chemicals, primarily hydrazine for oxygen control and morpholine for pH control, were used throughout reactor operations to minimize corrosion rates. Consequently, less sodium dichromate was used annually. Anecdotal historical information

(BHI-00368) suggests sodium dichromate use at 105-N ended in the early 1970s, with the last use reported in 1973 (*UNC Nuclear Industries Reactor and Fuel Production Facilities 1973 Environmental Release Report* [UNI-158]). The relatively small amount suggests that the practice was essentially abandoned in 1972. Given this chronology, all sodium dichromate used during operations was discharged to 116-N-1 (1301-N) LWDF from the N Reactor (105-N) (Figure 4-1).

Sodium dichromate was stored in solid form at 105-N and mixed into cooling water as needed. Documented sodium dichromate quantities are available for four years: 1965 and 1968 through 1970 (Table 4-4). For purposes of this discussion, an average mass of 6,804 kg (15,000 lb) of sodium dichromate is assumed in the years for which no documentation is readily available. Given the total discharges, average concentrations in the discharge wastewater are estimated between 0.5 and 0.9 mg/L. These concentrations are consistent with those reported at the single pass reactors.

Table 4-4. Annual Wastewater Volume and Sodium Dichromate Releases to 116-N-1 (1301-N) and 116-N-3 (1301-N) Liquid Waste Disposal Facilities

Document Source	Year	116-N-1 (1301-N) Discharges (L/yr)	Sodium Dichromate Used (lb)	Cr Fraction (kg)	Average Concentration (mg/L)
RL-NRD-828*	1964	3.45E+09	15,000	2,727	7.90E-01
	1965	3.45E+09	11,280	2,051	5.94E-01
	1966	3.45E+09	15,000	2,727	7.90E-01
	1967	3.45E+09	15,000	2,727	7.90E-01
DUN-4668	1968	3.45E+09	15,700	2,855	8.26E-01
DUN-6205	1969	4.18E+09	18,400	3,345	8.00E-01
DUN-7162	1970	4.18E+09	15,300	2,782	6.66E-01
	1971	3.45E+09	15,000	2,727	7.90E-01
	1972	3.45E+09	15,000	2,727	7.90E-01
UNI-158	1973	3.18+09	200	36	1.1E-02
Totals		**3.25E+10**	**135,680**	**24,704**	

Source: *Chemical Disposal to the Columbia River by 100-N Area* (RL-NRD-828), DUN-4668, DUN-6205, DUN-7162, UNI-158.

* An additional 9,600 lb of sodium dichromate was reported to be in storage as of January 1966.

4.1.6 Tritium and Nitrate Release

Tritium, like Sr-90, Cs-137, and Co-60, was a primary radioactive contaminant in the wastewater discharged to 116-N-1 (1301-N) and 116-N-3 (1301-N). Typical concentrations were 1E+05 pCi/L and approximately 6,500 Ci were released through 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs. This total is the sum of annual estimates documented in annual liquid effluent reports (1973 through 1989). For other years, the discharge inventory was estimated by taking the product of the approximate average concentration (1E+05 pCi/L) and the annual volume discharge estimates (Table 4-3). Given the short half-life of tritium (12.5 years), approximately 75 percent of this inventory has decayed.

The nitrate source has never been clearly determined. The common source of nitrate in wastewater is nitric acid, which was used in many facilities. At 116-N-1 (1301-N) and 116-N-3 (1301-N), minor nitrate concentrations have been measured in wastewater (e.g., average nitrate values of about 400 µg/L were measured in 1989 to 1990 in 116-N-3 (1301-N) liquids (WHC-EP-0342, ADD 3). The shape of the current and previous plume interpretations in the late 1990s (*Hanford Site Groundwater Monitoring for Fiscal Year 1998* [PNNL-12086]) implies separate plume centers proximal and downgradient from these facilities (e.g., see the nitrate plume map in the 1998 groundwater monitoring report PNNL-12086). In particular, a persistent nitrate hot spot is present at Well 199-N-67 immediately downgradient of 116-N-1 (1301-N) (see also the 1995 nitrate plume map in IROD 100-NR-1/2). Thus, these facilities have been at least partial sources. Another wastewater nitrogen source is ammonia, which can react to form nitrate. The ammonia source was ammonium hydroxide added to cooling water systems during operations to moderate pH levels (*UNC Nuclear Industries Reactor and Fuels Production Facilities 1985 Effluent Release Report* [UNI-3880]) and some was released in liquid discharges to 116-N-1 (1301-N) and 116-N-3 (1301-N) through bleed valves. Ammonium hydroxide usage was reported as 110,000 to 190,000 L (30,000 to 50,000 gal) in annual effluent release reports (e.g., UNI-158, *United Nuclear Industries Inc., Reactor and Fuel Production Facilities 1975 Environmental Release Report* [UNI-544], and *United Nuclear Industries, Inc., Reactor and Fuel Production Facilities 1974 Environmental Release Report* [UNI-349]). Average ammonium levels in 116-N-3 (1301-N) liquids of about 180 µg/L were measured in 1989 and 1990 (WHC-EP-0342, ADD 3). Given the lack of historical records about such losses, no inventory estimate can be determined. Table 4-5 presents the potential nitrate source facilities at 100-N.

Table 4-5. 100-N Potential Nitrate Source Facilities

Waste Site	Site Type
100-N-22	Septic Tank
100-N-4	Drain/Tile Field
124-N-1	Septic Tank
124-N-10	Sewage Lagoon
124-N-2	Septic Tank
124-N-3	Septic Tank
124-N-4	Septic Tank
124-N-5	Septic Tank
124-N-6	Septic Tank
124-N-7	Septic Tank
124-N-8	Septic Tank
124-N-9	Septic Tank
2607-FSM	Septic Tank
100-N-1	Pond
116-N-1	Crib
NA	Storage Tank

4.2 Contaminant Migration and Distribution in the Vadose Zone

Following contaminant discharge into the subsurface (as described in this chapter), migration through the vadose zone began. The rate of migration and subsequent distribution within the vadose zone was dependent on several dominant factors including the recharge history, contaminant-specific reactivity with vadose zone soils, and the physical properties of the discharge facility floor and vadose zone stratigraphy (e.g., thickness and permeability). At 100-N, critical characteristics included the following:

- The creation of high recharge rate zones under 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs during reactor operations
- A vadose zone stratigraphy consisting primarily of highly permeable Hanford formation sands and gravels of moderate thickness
- Contaminant reactivity ranging from essentially inert to highly reactive

In the following sections, groundwater and vadose zone characterization data are discussed and interpreted in the context of the conceptual site model, which incorporates these dominant environmental characteristics.

4.2.1 Strontium-90 Migration and Distribution in the Vadose Zone

Migration of Sr-90 through and its current distribution within the vadose zone has been strongly influenced by the recharge history through 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs and its reactivity with crib, trench floor, and vadose zone sediments. The existing data set indicating the nature of Sr-90 migration in the vadose zone is the soil characterization data suite collected prior to and during remediation. Given the operations history, soil-sampling locations (shown in Figure 4-4) have been concentrated near 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs, along the river shore downgradient of LWDFs, and in the intermediate zone between 116-N-1 (1301-N) and the shore.

At 116-N-1 (1301-N), boreholes were drilled through and near the crib and samples collected as a function of depth from the near surface into the unconfined aquifer. In addition, during the later stages of operations (1981 to 1985), sediments were collected along the trench floor (TS-1 through TS-9). Sampling was not as extensive at 116-N-3 (1301-N) LWDF and consisted of two boreholes in the crib area, and operational period crib bottom samples (C-1 through C-12) taken in the latter stages of facility operation (1985 to 1987). Finally, as both facilities were excavated during remediation (concrete materials and underlying soils), cleanup verification soils were collected to about 6.1 m (20 ft) bgs throughout the length of the facility.

As noted in Chapter 2, several Sr-90 distribution patterns were apparent from the soil sample data. With respect to the CSM, the notable characteristics are maximum concentrations underneath the crib and trench footprints, decreasing concentrations away from the116-N-1 (1301-N) and 116-N-3 (1301-N) structures, and concentration spikes at numerous wells in the deep vadose zone and upper unconfined aquifer relative to contamination levels in the shallow vadose zone.

These key observations suggest the following conceptual model for Sr-90 migration through the vadose zone, a model essentially the same as described in previous documents (BHI-00368 and DOE/RL-96-11). Liquid waste discharged into 116-N-1 (1301-N) and 116-N-3 (1301-N) largely dictated the initial points of entry into the subsurface. Once discharged at the pipe outlets into the cribs, Sr-90-bearing fluids migrated down the trenches and entered the subsurface along the way, thereby creating long narrow flux planes that functioned almost continuously throughout the operational history. Subsequent migration through the vadose zone occurred through a 9.1 to 12.2 m (30 to 40 ft) interval during operations. After operations ceased, the water table dropped and the vadose zone interval increased by 3 to 6 m (10 to 20 ft), depending on river stage effects.

Two distinct zones of retarded Sr-90 flux relative to water flux are indicated by data and migration analyses. Migration was retarded most strongly at the crib and trench floors (an area similar to Zone A in the CSM described in DOE/RL-96-11) to the extent that a significant portion of released Sr-90 did not migrate farther than a few feet below this depth. In a previous calculation for 116-N-1 (1301-N) crib and trench sediments (BHI-00368), an estimated Sr-90 inventory was 500 Ci, assuming an average Sr-90 concentration from soil analyses distributed through a 1 m (3.3 ft) thick crib-trench/vadose zone interface. This inventory represents about 25 percent of the estimated total mass discharged into 116-N-1 (1301-N) and could be low, providing the bulk density and average Sr-90 concentration estimates were unrealistically low. This inventory is no longer a potential source term because a portion of the contaminated soil was excavated and sent to the ERDF.

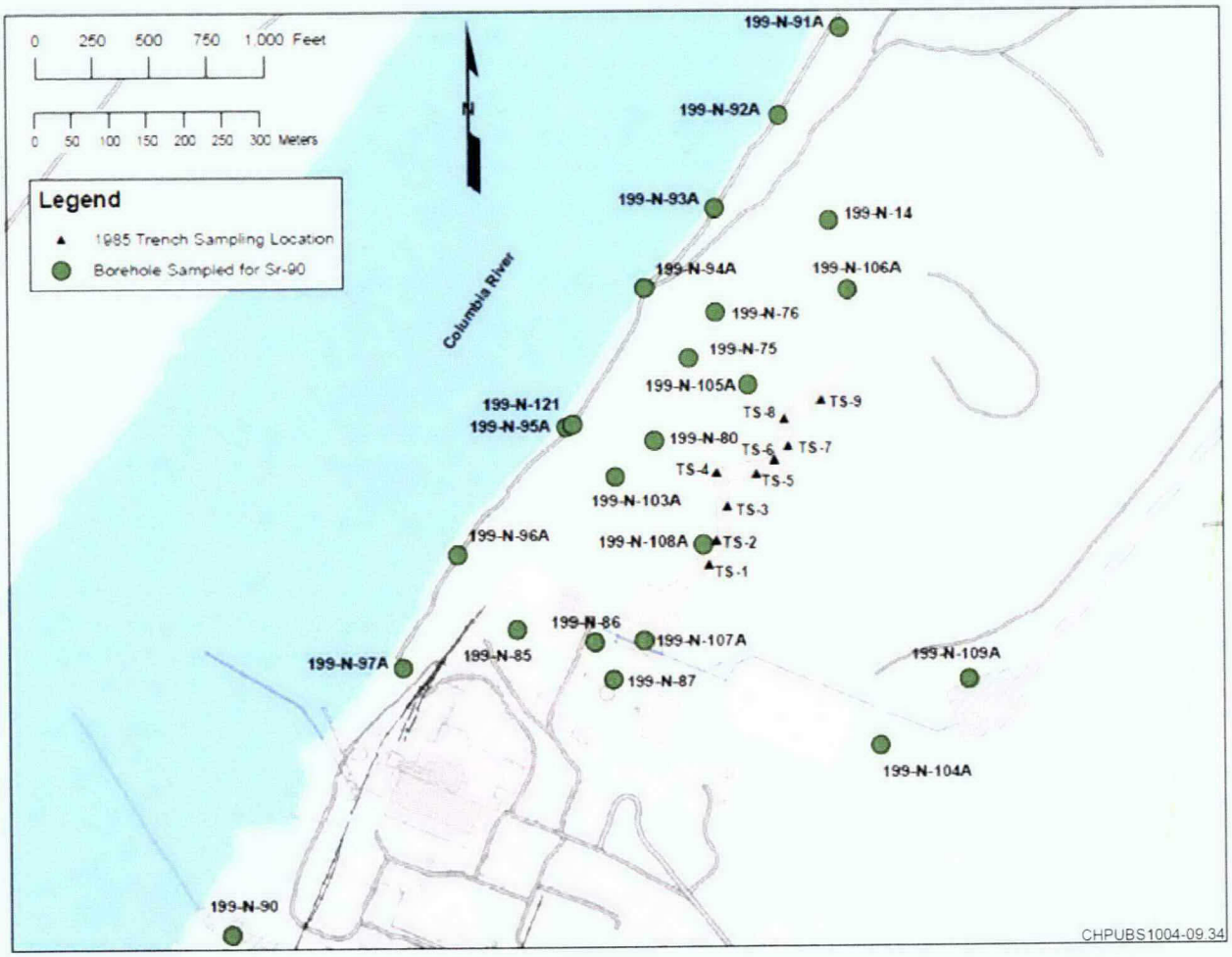


Figure 4-4. Subsurface Sampling Locations for Sediments Contaminated with Sr-90 at 100-N

A combination of chemical and physical processes resulted in the high level Sr-90 capture near the crib and trench floors. Sr-90 is moderately sorptive (e.g., a K_d of about 15 mL/g, see PNL-10899) and sorption reactions no doubt occurred. However, given the extremely high wastewater discharge rates during the reactor operations period, a modest sorption reaction is insufficient to retain such a large fraction of the initial Sr-90 inventory near the crib and trench floor. In two early modeling studies whose purpose was to simulate the Sr-90 migration to N-Springs seepage water (WHC-EP-0369 and WHC-SD-ER-TA-001), the authors found it necessary to assign K_d values greater than 1,500 mL/g in the crib/trench floor layer to get relevant retardation estimates and good correlation with N-Springs Sr-90 concentration time profiles. The authors concluded these high K_d values were not representative chemical behaviors but evidence of some type of physical capture in addition to sorption. The most obvious mechanism is Sr-90-bearing particulates filtration. The K_d application was therefore a crude and nonrealistic, but successful approach for simulating the observed migration rate. In these analyses, inventory estimates very similar to that provided in Table 4-3 were assumed.

Once Sr-90 passed through the interface zone, physical retardation was no longer a significant factor, leaving only chemical sorption as a retarding mechanism. Historical sorption experiments on Hanford Site soils (e.g., EPA 402-R-99-004B and PNL-10899 report K_d values between 10 and 20 mL/g for normal vadose zone conditions [moderate pH values, about 8, and moderate dissolved species levels] with naturally present calcium being the primary competitor for sorption sites). Sorption value variabilities are introduced through several environmental factors including changes in soil mineralogy, particle size

distribution (theoretically, a smaller size grain distribution should have a higher sorptive capacity), solution pH, concentrations of other aqueous species competing for sorption sites, and sorption/desorption kinetics. Typically, these mechanisms are addressed empirically by conducting batch sorption experiments simulating the site-specific environment. Previous sorption studies (PNL-10899) suggest Sr-90 sorbs by simple ion exchange, competitors for sorption sites include calcium and magnesium, and sorption/desorption kinetics are rapid.

Significant perturbation of natural vadose zone groundwater chemical conditions from interactions with wastewater seems unlikely at these sites, given the lack of high salt concentrations and extreme pH characteristics in the discharged wastewater. The early modeling transport studies (WHC-EP-0369 and WHC-SD-ER-TA-001) suggest a moderate K_d value is correct. In these analyses, Sr-90 inventory derived from historical records (2,998 Ci) and K_d values of 10 and 15 mL/g resulted in a good match between measured and modeled concentration versus time profiles at N-Springs. Thus, retardation effects decreased by about a factor of 100 in the vadose zone (similar to Zone B in the CSM described in DOE/RL-96-11) versus the crib/trench floor zone.

In addition to substantially reduced retardation, the 20-year high liquid discharge rates through 116-N-1 (1301-N) and 116-N-3 (1301-N) accelerated and leached a substantial fraction of Sr-90 from the crib and trench bottom and passed entirely through the vadose zone into the unconfined aquifer. To grasp the magnitude of the water flux history, it is useful to consider historical fluxes in wastewater pore volumes terms that passed through the vadose zone into the unconfined aquifer underlying 116-N-1 (1301-N) and 116-N-3 (1301-N). Maximum discharges occurred directly under the crib and trench footprints and lesser but still substantial discharges occurred through the region between and around the cribs and trenches.

To calculate an upper bound number of pore volumes transmitted directly underneath the cribs and trenches, the ratio of the total facility discharge to the vadose zone pore space volume is determined as follows. The 116-N-1 (1301-N) and 116-N-3 (1301-N) footprint areas that received wastewater were approximately 10,700 and 9,400 m^2 (115,000 and 101,000 ft^2), respectively (DOE/RL-96-11). The vadose zone thicknesses were approximately 9 m (30 ft) during operations at all locations except under the 116-N-1 (1301-N) crib where a depth of 12 m (40 ft) was estimated (Figures 3-1 and 3-2, DOE/RL-96-11). If an average depth of 10 m (~30 ft) is assumed, vadose zone volumes of 107,000 and 94,000 m^3 (3.5E5 and 3.1E5 ft^3) are calculated. Assuming an average 30 percent porosity, the available vadose zone volume for wastewater filling was about 32,100 and 28,700 m^3 (1.1E5 and 9.3E4 ft^3). Given the pore volume estimate and the total volume discharge estimates of 8.14E10 and 7.26E9 L at 116-N-1 (1301-N) and 116-N-3 (1301-N) (Table 4-3) respectively, approximately 2,500 and 250 calculated pore volumes passed through these facilities underlying sediments.

To estimate average pore volumes transmitted in the region affected by discharge, pore volumes in the vadose zone including and between the two trenches (approximately 300 × 300 × 10 m [1,000 × 1,000 × 30 ft]) and the combined discharge volume through both facilities are used. These assumptions result in an estimated 100 pore volumes transmitted during operations.

Despite this large wastewater flux and lower Sr-90 retardation, vadose zone sampling data before and after remediation activities show a fraction of the initial Sr-90 inventory remains distributed through the vadose zone, presumably in finer-grained sediments that hold sorbing Sr-90 more efficiently than surrounding gravels. Since Sr-90 persisted in the discharge fluid during most facility operations, complete transport through the vadose zone did not occur. These data suggest the Sr-90 migration was dominantly vertical even though some lateral wastewater flow is indicated by chromium data (next section). That is, the available data (described in Chapter 2, Section 2.3.1) suggest high concentration zones directly underneath 116-N-1 (1301-N) and 116-N-3 (1301-N) contain the residual inventory in the vadose zone.

For example, Sr-90 concentrations in the upper vadose zone (Hanford formation) at Well 199-N-107A near the 116-N-1 (1301-N) pipe outlet are 1,000 to 2,000 pCi/g versus Sr-90 concentrations less than 5 pCi/g in Well 199-N-105A (Figure 4-5) and other wells further downstream (Figure 4-6). Restriction on Sr-90 lateral movement is attributed to predominantly vertical wastewater flow induced by high permeability vadose zone sediments and sorption. Strontium-90 flux rates are estimated at more than 50 times slower than water flux rates, assuming the standard retardation calculation (e.g., retardation equals one plus K_d [10+] times the ratio of bulk density [1.7] to porosity [0.3]). Applying this concept to vadose zone flow indicates the great majority of Sr-90 mass remained directly underneath the LWDFs.

With the end of high flux liquid discharge through 116-N-1 (1301-N) and 116-N-3 (1301-N) in the late 1980s, Sr-90 migration rates decreased correspondingly to much lower levels proportionate with the overall change from operations dominated discharge (about 73,000 and 16,000 cm/yr for 116-N-1 [1301-N] and 116-N-3 [1301-N], respectively, per DOE/RL-96-11) versus natural recharge (about 2 to 10 cm/yr). Some variability in natural recharge rates is expected because occasional high precipitation or snowmelt events may temporarily increase recharge and contaminant migration rates. However, such increases are minute and momentary compared to operational discharges. Evidence supporting enhanced Sr-90 migration cannot be identified due to river stage effects that dominate Sr-90 contamination level fluctuations (next section). Consequently, the water table (groundwater mound) dropped approximately 3 to 6 m (10 to 20 ft) (see Figure 4-5), causing the operations-wetted sediments in the upper aquifer to revert to vadose zone conditions (referred to as Zone C in the CSM described in DOE/RL-96-11). Note that within the lower vadose zone sediments, Sr-90 concentrations are greater than those in soils directly above. For example, at Well 199-N-108A (Figure 4-5), soil concentrations are 58 and 4 pCi/g at 13.1 and 14.3 m (43 and 47 ft) bgs. At a depth around 18 m (60 ft) bgs, concentrations are 144 and 239 pCi/g. These sediments were the unconfined aquifer during operations. Therefore, these higher concentrations are interpreted as residual Sr-90 inventory having entered the unconfined aquifer and migrating through the upper aquifer until 116-N-1 (1301-N) ceased. The working hypothesis for the 100-N CSM supports the concept that elevated Sr-90 concentrations at the vadose-aquifer interface were derived through precipitation and/or sequestering on soils from the remaining groundwater mound during late stage discharges to 116-N-1 (1301-N) and 116-N-3 (1301-N). Should data derived during RI/FS work indicate an alternate CSM, it will be addressed in the RI report.

Given these observations, the reduced recharge conditions will limit the amount of Sr-90 remaining in the vadose zone entering the aquifer from slow migration rates and attenuation from natural radioactive decay. For example, travel time calculations (DOE/RL-96-11) estimate that Sr-90 present 0.6 m (2 ft) above the water table requires about 200 years to enter the aquifer at an average recharge rate of 10 cm/yr. Given the water table fluctuations from river stage effects, the accessible zone for Sr-90 migration into the aquifer is below 15.2 to 16.8 m (50 to 55 ft) bgs, as long as recharge rates imposed by natural infiltration rates remain in effect. This conclusion has been drawn previously (PNL-10899).

4.2.2 Petroleum Product Migration and Distribution in the Vadose Zone

Migration of petroleum products through the vadose zone is inferred from data collected at Well 199-N-85, drilled to evaluate the subsurface contamination caused from the1966 diesel fuel line leak 302,833 L (80,000 gal) on the west side of the 166-N Tank Farm. Characterization Well 199-N-85 is located proximal to the leak location. Ten samples were collected through the vadose zone between 4.6 and 22.5 m (15 and 74 ft) bgs. VOCs and SVOCs considered species present in diesel fuel or degradation products (e.g., xylene, anthracene, 2 methylnaphthalene) were found between 18 and 22.5 m (59 and 74 ft) bgs (DOE/RL-93-80).

Despite the limited nature of this dataset, several observations suggest minimal petroleum product remains in the vadose zone. First, while these early 1990s samples were in the vadose zone, they would

have been at the top of the unconfined aquifer at an elevation of the groundwater mounds established by wastewater discharges from 116-N-1 (1301-N) LWDF. Extrapolated water table elevation contours (see Section 4.3.1) suggest an elevation of 16.8 to 17 m (55 to 56 ft) bgs in the mid-1960s. Second, the well's proximity to the leak location would make it the most likely to show vadose zone contamination if present. Third, petroleum products likely migrated through the vadose zone as a nonaqueous phase liquid (NAPL) that did not react chemically with vadose zone sediments, as indicated by current groundwater sample data showing minor petroleum product is still a NAPL (see Section 4.3.3). The highly permeable (primarily sandy gravel) and thin vadose zone would have facilitated rapid migration and minimal dissolution.

More recent work near the original diesel spill has been and continues to be performed by Washington Closure Hanford, LLC (WCH). Seven wells were installed around Well 199-N-18 to test a bioventing technology for petroleum hydrocarbons (WCH-370). Further discussion of this work and sampling results can be found in Chapter 2, Section 2.3.2, Petroleum.

4.2.3 Chromium Migration and Distribution in the Vadose Zone

Migration of chromium through, and its current distribution within, the vadose zone has been strongly influenced by the recharge history through 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs, and slightly influenced by its interaction with vadose zone sediments (see discussion below on leaching studies, which provide an indication of rapid migration for the larger portion of the chromium and fixation/slower migration for the smaller portion of the inventory). The existing data set, which indicates the nature of chromium migration in the vadose zone, is the suite of soil characterization data collected prior to and during remediation. As with Sr-90, soil-sampling locations (Figure 4-7) have been concentrated near 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs, along the river shore downgradient of the LWDFs, and in the intermediate zone between 116-N-1 (1301-N) LWDF and the shore.

From these data, two key characteristics are notable and illustrated in Figures 4-8 and 4-9. These figures are similar to Figures 4-5 and 4-6, showing chromium contamination at depth at various well locations. As before, sampling locations are shown in the context of subsurface stratigraphy and water table history. First, the highest chromium concentrations (46 and 58 mg/kg) occur at Well 199-N-107A at the interface between the 116-N-1 (1301-N) Crib floor and the vadose zone. This is the sample taken nearest to the pipe outlet. Sediment total chromium concentrations decrease away from this location and the reductions at distant locations are generally within factors of two to ten. However, concentration reductions show no consistent decrease with distance either vertically or horizontally. Second, the collected data do not indicate a well defined volume of vadose zone chromium contamination. Chromium is not present at elevated levels at all available sample locations but, rather, appears to be distributed randomly over the large vadose zone volume contacted by the discharged fluids.

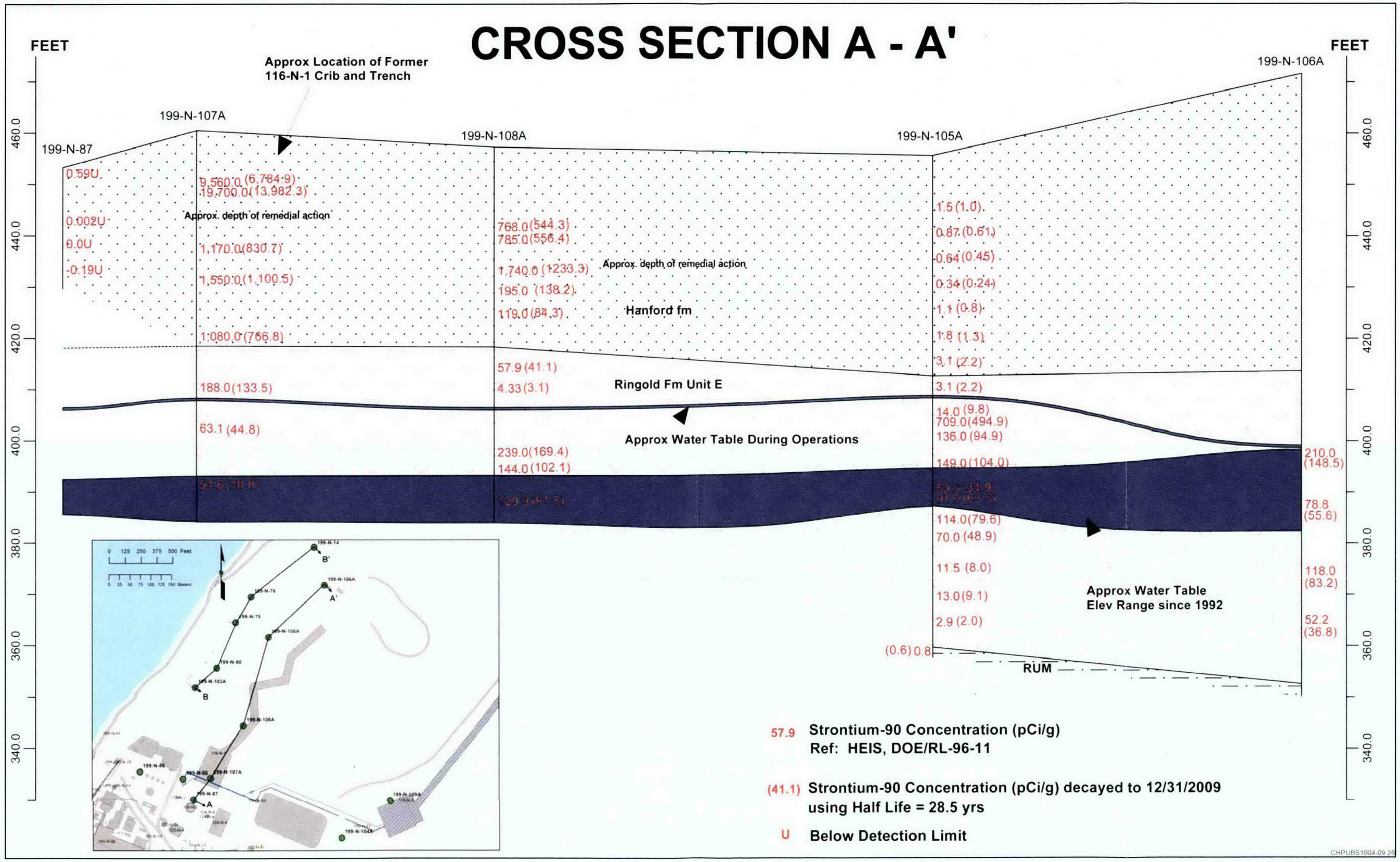


Figure 4-5. Sr-90 Concentrations with Depth at Five Boreholes along the Long Axis of 116-N-1 (1301-N)

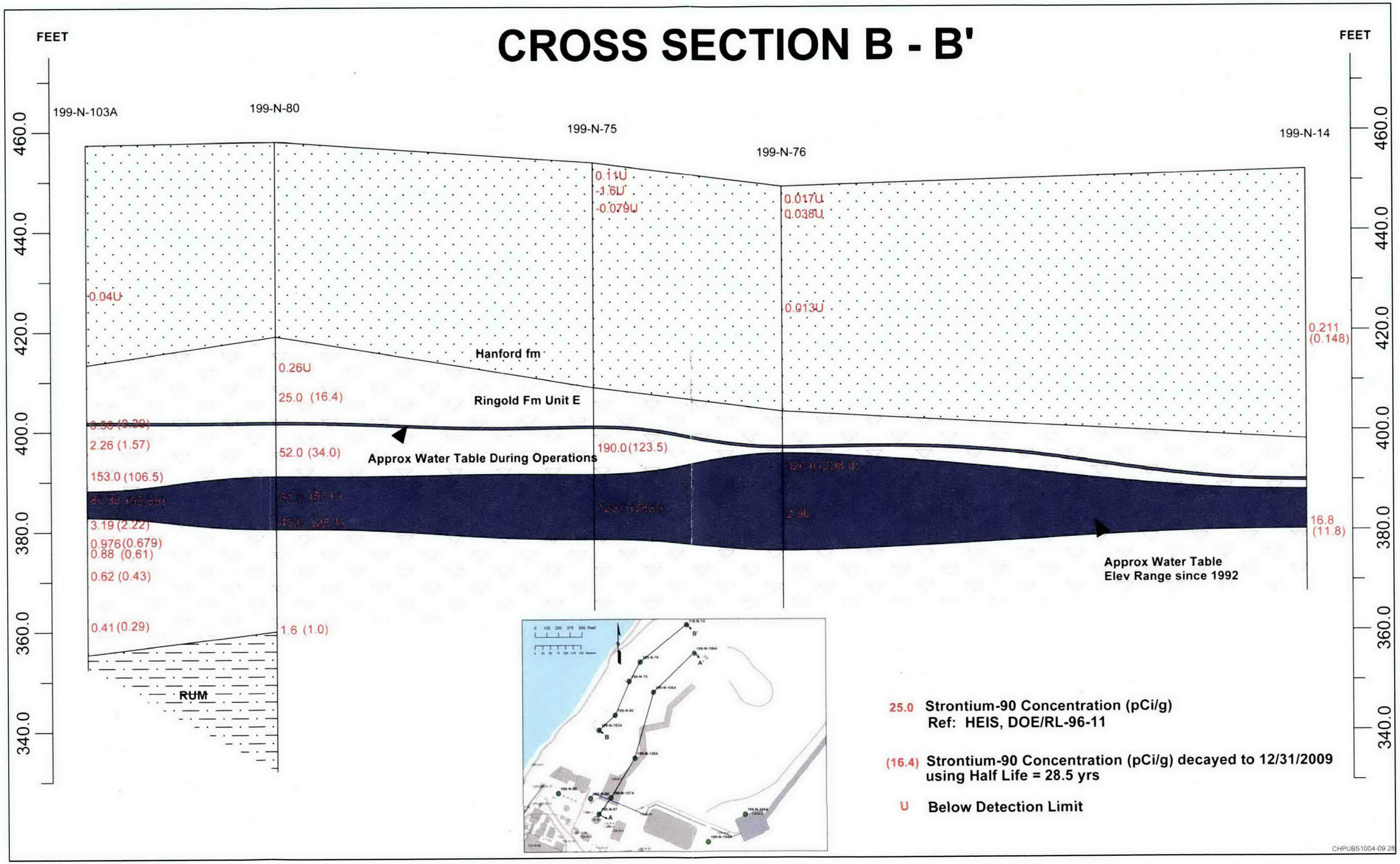


Figure 4-6. Sr-90 Concentrations with Depth at Five Boreholes Downgradient of 116-N-1 (1301-N) Liquid Waste Disposal Facility

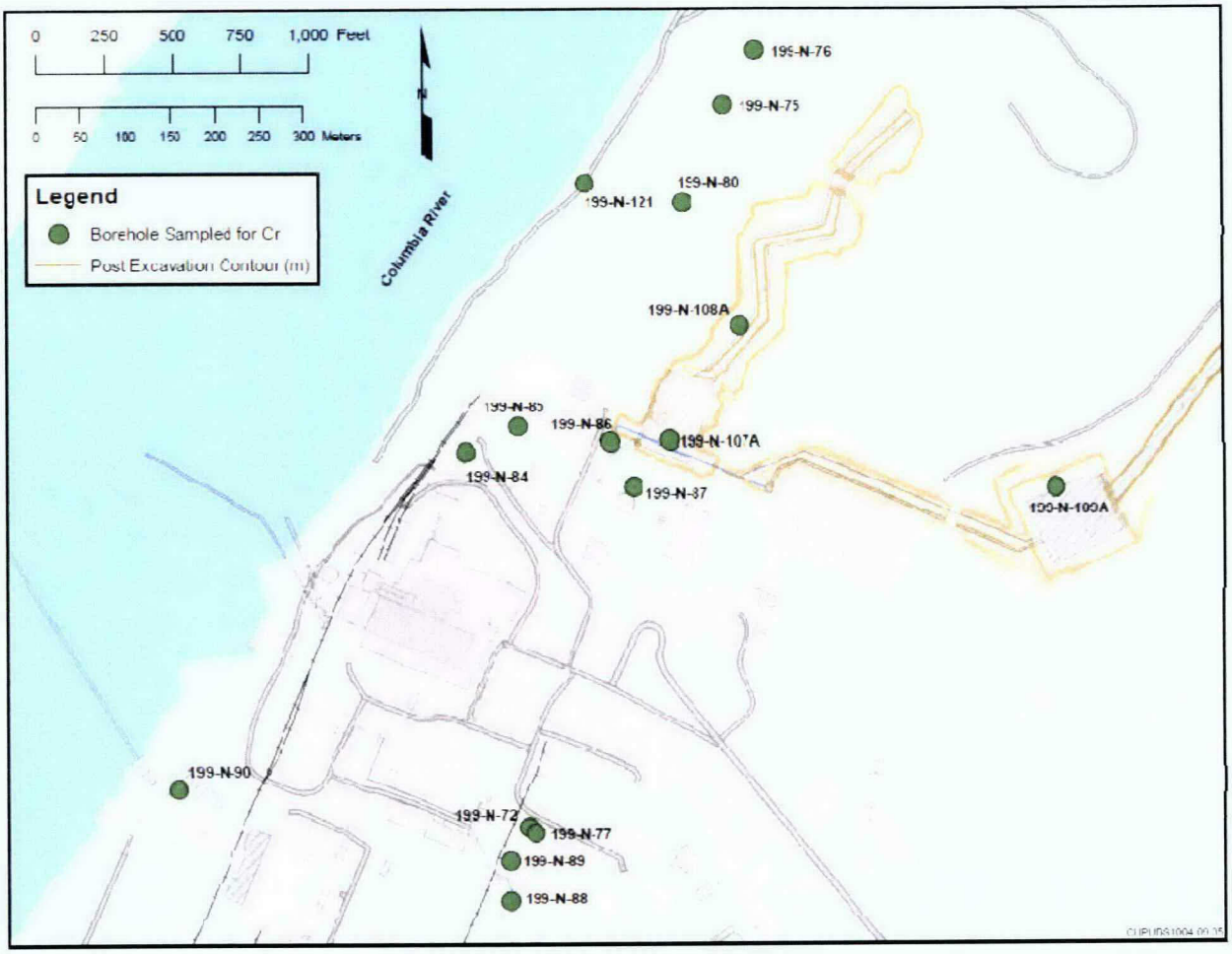


Figure 4-7. Subsurface Sampling Locations for Sediments Contaminated with Chromium at 100-N

Higher chromium levels were also measured in vadose sediments collected underneath and around the 1324-NA Percolation Pond and 1324-N Surface Impoundment at Wells 199-N-72, 199-N-77, 199-N-88, and 199-N-89 (Figure 4-7). Elevated chromium concentrations ranged between 10 and 15 mg/kg and higher concentrations were found near the surface and near the bottom of the vadose zone in some of the boreholes. The occurrence of these higher concentrations appears related to facility use, primarily neutralization of acidic and caustic fluids from the 163-N Demineralization Plant. Given that the 1324-NA Percolation Pond was unlined, some of the relatively extreme pH solutions could have entered the vadose zone before complete neutralization, and dissolved natural chromium. If so, transport deeper into the vadose zone and entry into the unconfined aquifer is plausible. Another possibility is that chromium contamination was present in the effluents as trace contamination. Given the high discharge rates of about 605,600 L/day (160,000 gal/day) (DOE/RL-93-80) at the 1324-N/1324-NA area, total inventory loss could have been environmentally significant, although unlikely to approach the sodium dichromate inventory used deliberately for corrosion control.

The key observations summarized previously suggest the following conceptual model for chromium migration through the vadose zone. Historical records indicate chromium was discharged to the 116-N-1 (1301-N) LWDF, but not 116-N-3 (1301-N) LWDF. Once discharged into the 116-N-1 (1301-N) Crib and 116-N-1 (1301-N) Trench, chromium migration was slightly retarded at the crib and trench floors. Consequently, a small fraction of the total chromium mass received by 116-N-1 (1301-N) was retained at the near surface. A rough calculation of the chromium content at the 116-N-1 (1301-N) Crib, assuming

the 199-N-107A concentrations of about 50 mg/kg distributed over a 1 m (3.3 ft) thick layer underneath the 116-N-1 (1301-N) Crib, produces a total chromium mass of no more than a few thousand kilograms of chromium. This mass represents a few percent of the estimated total mass discharge of over 25,000 kg (55,000 lb) (Table 4-4).

The presumed lack of chromium retardation is consistent with observations of rapid chromium migration rates at other 100 Area locations where widespread chromium contamination in the unconfined aquifer is present, particularly in 100-D and 100-K. The extensive chromium aquifer contamination at 100-D and 100-K is attributed to large-scale wastewater discharges similar to those at 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs (e.g., the 116-K-2 Trench received approximately 300 billion L [79.25 billion gal]) of wastewater containing chromium over a 16-year period). In the unconfined aquifer, the current chromium concentrations under 100-N versus its higher concentration levels (above MCLs) and more widespread presence under 100-D and 100-K is attributed to lower discharged inventories (e.g., for comparison, an estimated 6.3E6 and 7.9E5 kg of chromium at 100-K and 100-D, respectively; see DOE/RL-2008-46 ADD1 and *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 OUs* [DOE/RL-2008-46-ADD2]) and more efficient flushing into the river, not differences in chemical behavior.

The small fraction of initial chromium inventory near the 116-N-1 (1301-N) floor/vadose zone interface has probably remained because of a combination of physical entrapment processes (e.g., particulate filtration) and various chemical reactions. With regard to chemical reactions, leaching studies have been conducted on chromium contaminated soils collected during remediation at 100-N (*Cleanup Verification Package/Clean Closure Report for the Soil Column of the 116-N-1 Crib and Trench* [CVP-2006-00004]), 100-D (*Cleanup Verification Package for the 116-D-7 Retention Basin* [CVP-99-00007]), and 100-H (CVP-99-2000-00027). The soils were collected from high discharge zones including the crib floor at the 116-N-1 (1301-N) and 100-N and beneath the 116-D-7 and 116-H-7 retention basins and had been leached extensively before they were collected. In all cases, only a small fraction of the existing contamination was leachable. In the 100-N sample containing a soil concentration of 2.96 mg/kg, chromium was undetectable in the leachate solution (< 0.005 mg/L). In the 100-D and 100-H samples, laboratory leaching studies were able to remove less than 1 percent of the remaining chromium. These observations support the conceptual site model that the remaining chromium in the soil is leach resistant because of chemically binding reactions.

A more detailed leaching and characterization study was completed using near surface soils (less than 3 m [10 ft] bgs) collected near sodium dichromate storage tanks and railroad tracks in 100-BC (*Geochemical Characterization of Chromate Contamination in the 100 Area Vadose Zone at the Hanford Site* [PNNL-17674]). Unlike the leaching sediments described previously, these soils were only leached by natural infiltration. In this study, two types of leaching behavior were observed. First, large fractions of the Cr(VI) in the contaminated soil were eluted in the first pore volume (about 65 percent) and about 4 percent of the initial mass was released in the next five pore volumes. After five pore volumes, the leachate concentration had decreased about three orders of magnitude. For example, in one soil sediment initially containing chromium concentrations of about 550 mg/kg, the first pore volume concentration was greater than 8,000 mg/L. After five pore volumes, the concentration was approximately 2 mg/L. The remaining Cr(VI) leached much more slowly, and at the end of the experiment (after exposure to 25 pore volumes), between 10 and 30 percent of the Cr(VI) remained in the soils and leachate concentrations were about 0.1 mg/L. Micro-scale sediment characterizations suggested leach resistant Cr(VI) might be precipitated in a barium chromate phase and/or incorporated in alumino-silicates and/or iron-rich alumino-silicates. Association of chromium with iron bearing minerals suggests localized reduction of Cr(VI) to Cr(III) by Fe(II).

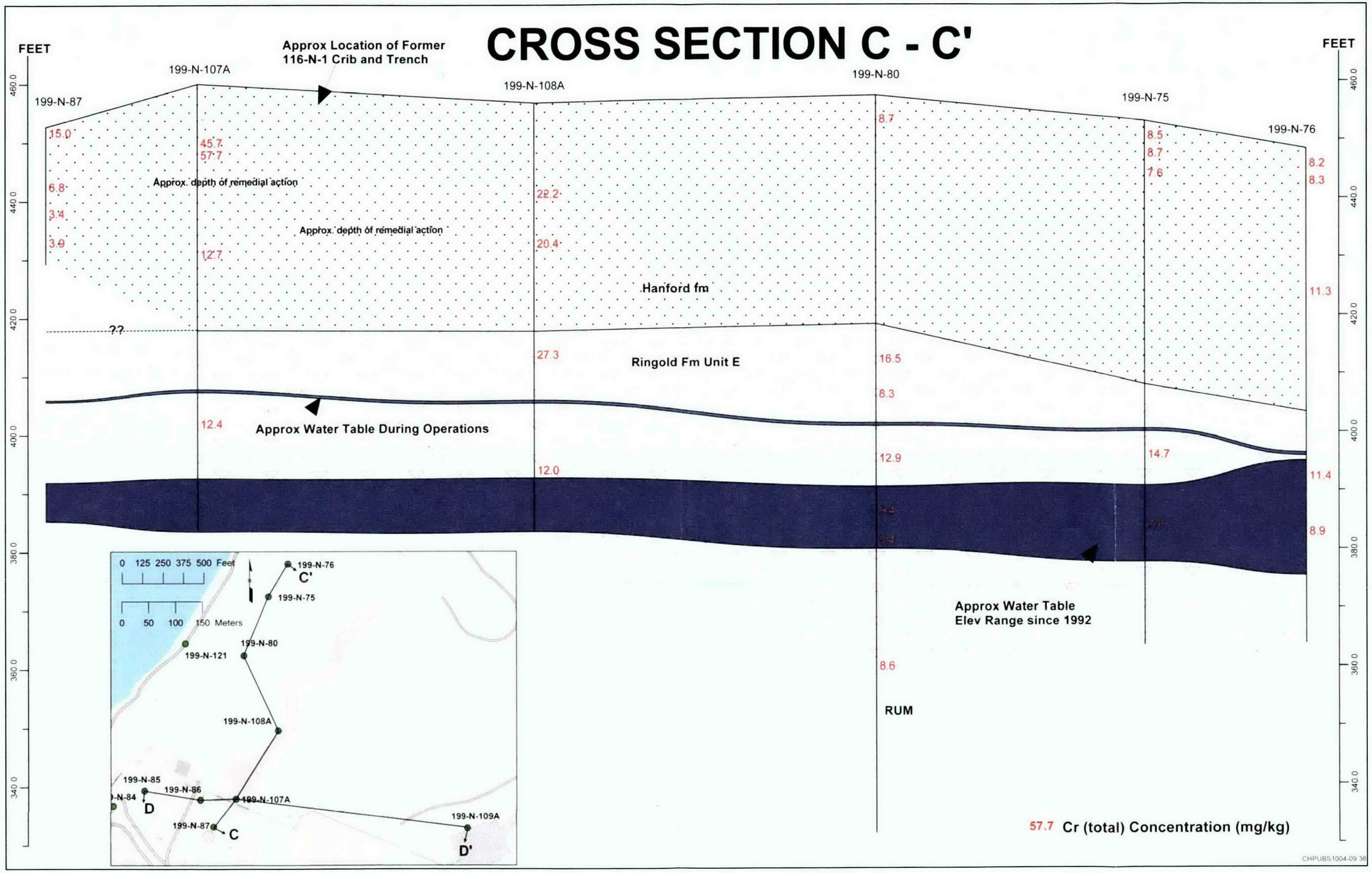


Figure 4-8. Total Chromium Concentrations with Depth at Five Boreholes along the Long Axis of 116-N-1 (1301-N) Liquid Waste Disposal Facility

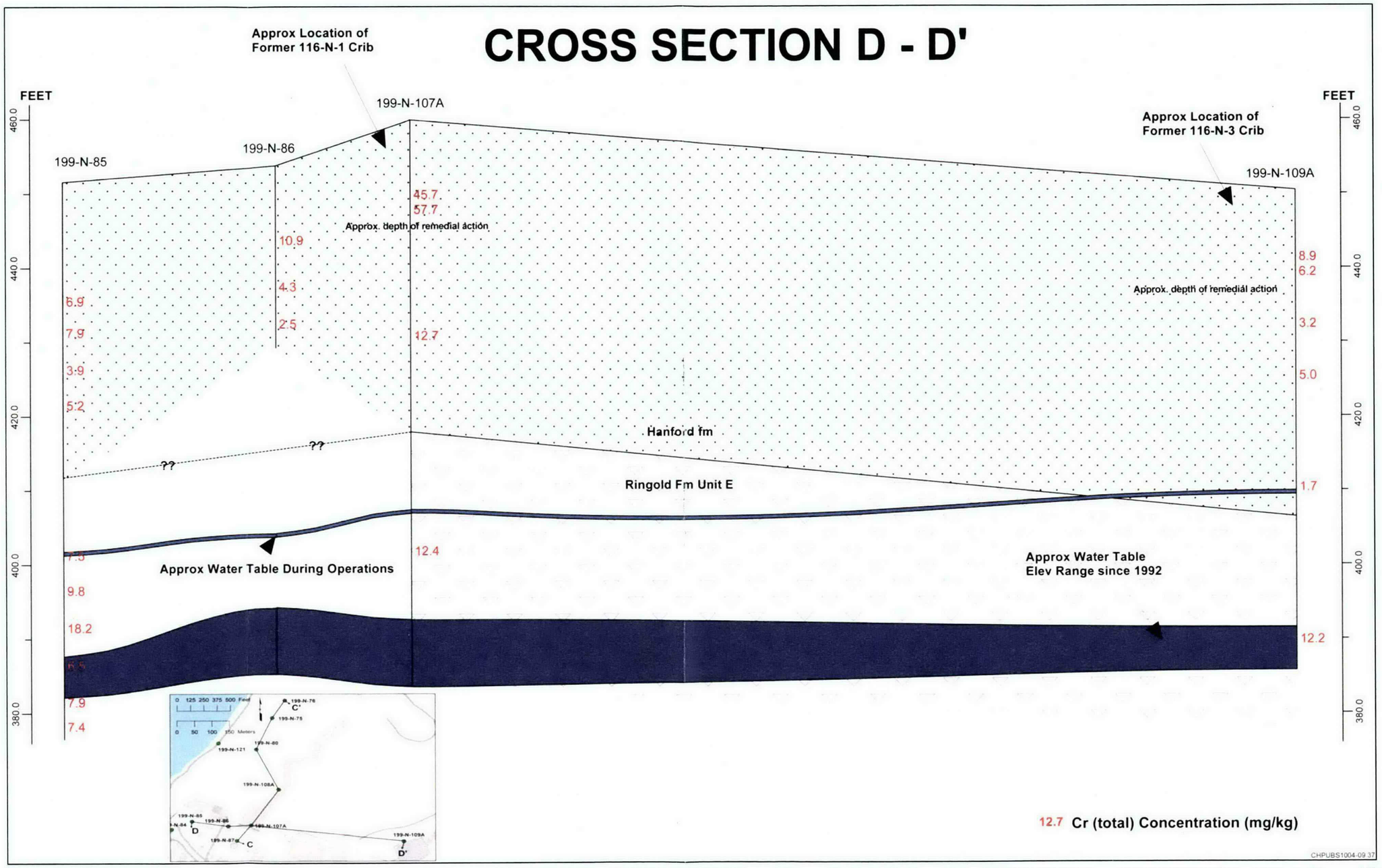


Figure 4-9. Total Chromium Concentrations with Depth at Three Boreholes through the 116-N-1 (1301-N) and 116-N-3 (1301-N) Cribs and Perpendicular to the Long Axis of 116-N-1 (1301-N) and 116-N-3 (1301-N) Liquid Waste Disposal Facilities

Unlike the testing on surface samples described previously, the 116-N-1 (1301-N) and 116-N-3 (1301-N) batch leach testing will be on sediment samples collected at depth, during drilling. Results from these tests will in part confirm the CSM.

Considered collectively, these experimental results suggest that after Cr(VI) is discharged to the soil column through high discharge rate liquid disposal facilities, two primary phases of chromium reactivity occur that influence its transport characteristics. First, the majority of Cr(VI) remains mobile and transports readily through the vadose zone. Second, given the experimental data collected, the remaining Cr(VI) appears to have been retarded by a variety of mechanisms.

It is likely that after sodium dichromate use was discontinued at the 105-N Reactor in the early 1970s, the discharge of more than 10 years of chromium free wastewater decreased the Cr(VI) concentration in the soil column. In the 116-N-1 (1301-N) Crib soil and the 100-D and 100-H retention basin soils, it appears the initial highly mobile component of discharged Cr(VI) had already been flushed from the sampled soils (particularly at 116-N-1 [1301-N]) because of repeated leaching from chronic leakage, leaving only the second phase of leaching to occur. It is likely that after sodium dichromate use was discontinued at the 105-N Reactor in the early 1970s, subsequent discharge through the vadose zone did not add more chromium to the soil column but continued removing leachable chromium.

As chromium penetrated deeper into the vadose zone, physical entrapment processes would have been insignificant, but the chemical reactions continued, allowing the majority of chromium to move with wastewater and a small fraction sequestered by the chemical reactions discussed previously. Given the high solubility of most chromium and its limited entry point into the vadose zone under the 116-N-1 (1301-N) LWDF footprint, its apparent widespread but sporadic presence in the vadose zone (Figures 4-8 and 4-9) suggests some lateral migration of wastewater in the vadose zone. This lateral spreading is attributed to the inability of the soil column to process the high volume discharges efficiently. The surface overflow potential was a concern during the operations period, requiring construction and use of expanded capacity discharge facilities, beginning in 1964 with the construction and use of the 116-N-1 (1301-N) Crib followed by the 116-N-1 (1301-N) Trench in 1965, the 116-N-3 (1301-N) Crib in 1983, and the 116-N-3 (1301-N) Trench in1985. The discharge water lateral movement apparently began near the crib/trench floor depth, given the chromium contamination depths of about 3 m (10 ft) bgs at various well locations (e.g., at Well 199-N-109A beside the 116-N-3 [1301-N] Crib). Assuming this chromium emanated from 116-N-1 (1301-N), lateral migration extended at least 500 m (1,640 ft) inland. Despite the lateral spreading of wastewater in the vadose zone, the sheer volume of discharge water enabled significant exposure of chromium contaminated soils to wastewater in the contiguous regions around 116-N-1 (1301-N) and 116-N-3 (1301-N). As noted in Section 4.2.1, more than 100 pore volumes of water likely contacted chromium contaminated soils. Experimental work on chromium leaching (PNNL-17674) indicates this amount of leaching is likely sufficient to remove the great majority of leachable chromium from the vadose zone and minimize release rates for the remainder. Nevertheless, the existence of some highly leachable chromium away from 116-N-1 (1301-N) and 116-N-3 (1301-N) still remaining in the vadose zone cannot be discounted.

Currently, low concentration total chromium appears widespread in the vadose zone. Near surface chromium (e.g., underneath 116-N-1[1301-N] and 116-N-3 [1301-N] LWDFs) was removed while deeper contamination remains. Because of the extensive wastewater discharge history, the conceptual site model predicts that ample soil washing occurred, leaving behind only the chromium strongly bound to the soil by various reactions. The CSM predicts that this characteristic, along with reduced recharge rates, would limit the chromium migration within the vadose zone. Characterization of chromium concentrations (hexavalent, total, and leachable) will be performed during the RI to determine if the remaining chromium

provides a source term to the unconfined aquifer insufficient to generate or sustain chromium concentrations above acceptable levels.

4.2.4 Tritium and Nitrate Migration and Distribution in the Vadose Zone

Both tritium and nitrate are essentially nonreactive with subsurface sediments. Therefore, the tritium in the 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs wastewater migrated quickly through the vadose zone, leaving limited residuals in the vadose zone. Because of the limited source term of nitrate in the LWDFs, its migration rate and remaining vadose zone contamination cannot be determined. Additionally, the high recharge rates through 116-N-1 (1301-N) and 116-N-3 (1301-N) and a highly permeable and relatively thin vadose zone suggest that nitrate has been essentially flushed from the vadose zone. Data provide nitrate concentrations at low levels or below detection in numerous CVP and LFI soil samples. The following data are from DOE/RL-96-17, Rev. 6, *Remedial Design Report/Remedial Action Work Plan for the 100 Area.*

Per the nitrate data for 116-N-1 and 116-N-3 shallow and deep zone soils:

- For the 116-N-1 Crib and Trench, there were 20 deep zone soil samples, 20 shallow zone soil samples, 10 overburden samples, and 10 land bridge shallow zone samples. Of these samples, **none** were above direct exposure, groundwater protection, or river protection criteria.
- For the 116-N-3 Crib and Trench, there were 20 shallow zone soil samples, 20 deep zone soil samples, and 10 overburden soil samples. Of these samples, **none** were above direct exposure, groundwater protection, or river protection criteria.
- There was also one sample from borehole 199-N-80 with a nitrate concentration of 54.6 mg/kg at 13.7 m (45 ft).

Direct exposure criteria: 128,000 mg/kg
Groundwater protection criteria: 1,000 mg/kg
River protection criteria: 2,000 mg/kg

These data indicate no significant nitrate source at the base of the excavated waste sites 116-N-1 or 116-N-3. There is likely no correlation between the groundwater plume and a 100-N residual nitrate source (Table 4-6 presents the potential nitrate sources list for 100-N). Additional boreholes, completed as wells, are being drilled and will provide data regarding any remaining nitrate sources in the vadose zone. Current work scope at the 116-N-1 (1301-N) and 116-N-3 (1301-N) Trenches will confirm the CSM.

Table 4-6. Potential Nitrate Sources at 100-N

Waste Site	Site Type	Waste Site	Site Type
100-N-22	Septic Tank	124-N-6	Septic Tank
100-N-4	Drain/Tile Field	124-N-7	Septic Tank
124-N-1	Septic Tank	124-N-8	Septic Tank
124-N-10	Sewage Lagoon	124-N-9	Septic Tank
124-N-2	Septic Tank	2607-FSM	Septic Tank
124-N-3	Septic Tank	100-N-1	Pond
124-N-4	Septic Tank	116-N-1	Crib
124-N-5	Septic Tank	NA	Storage Tank

In the existing database, occasional tritium soil concentrations (16,000 to 127,000 pCi/g) were reported at Wells 199-N-103A and 199-N-105A between 15.2 and 21.3 m (50 and 70 ft) bgs, the portion of the deep vadose zone that comprised the upper unconfined aquifer during operations (DOE/RL-96-11).

4.3 Contaminant Migration and Distribution in the Unconfined Aquifer

Contaminants migrated through the vadose zone and discharged into the unconfined aquifer. The rate of migration and subsequent distribution within the unconfined aquifer was dependent on several dominant factors including the recharge history, contaminant-specific reactivity with unconfined aquifer soils, and physical properties of unconfined aquifer stratigraphy (e.g., thickness and permeability). At 100-N, critical characteristics were the perturbations to the natural hydrologic system imposed by the long term, high volume discharges through the 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs, an unconfined aquifer stratigraphy composed largely of the Ringold E Formation and bounded by the RUM unit, and contaminant reactivity ranging from essentially inert to highly reactive.

Given the importance of the evolution of groundwater flow in the unconfined aquifer at 100-N for all contaminants, this section addresses this topic. In subsequent sections, the unconfined aquifer data for Sr-90, sodium dichromate, and petroleum are described and interpreted in the context of the dominant environmental characteristics described previously.

4.3.1 Summary of Groundwater Flow History

Prior to the startup of 100-N operations, the unconfined aquifer properties were presumed to have been essentially the same as pre-Hanford Site conditions. Although very little data are available to quantify those conditions, a well accepted hypothesis is that pre-Hanford Site conditions are generally similar to those observed currently, and that groundwater flow is generally north-northwest under a low hydraulic gradient, primarily in the Ringold E Formation. In addition, daily, weekly, and seasonal changes in river elevations caused water table fluctuations throughout 100-N. At peak river stage levels in midsummer, hydraulic gradients were reversed and river water flowed inland.

The reactor operations startup and simultaneous initiation of high volume discharges to the 116-N-1 (1301-N) Crib in 1963 quickly created a groundwater mound underneath the crib. In Well 699-86-60, located approximately 200 m (656 ft) southeast of the 116-N-1 (1301-N) Crib, the water table rose about 4 m (13 ft) between early 1964 and late 1966 (Figure 4-10). The majority of the water table rise occurred in the first six months of operation and reflects the rapid vertical migration rates imposed by high volume discharges. In addition, the rapidity of mound formation was facilitated by highly permeable vadose zone sediments (primarily sandy gravels) and a moderate vadose zone thickness of about 21.3 m (70 ft). Figure 4-11 is a map view of the groundwater mound beneath 116-N-1 (1301-N) as it existed in 1965, and water flowed radially from the mound center. No additional groundwater mound depictions during operations are available. This groundwater mound was maintained into the mid-1980s when wastewater discharges transitioned from the 116-N-1 (1301-N) LWDF to the 116-N-3 (1301-N) LWDF between 1983 and 1985. Over this period, the groundwater mound under the 116-N-1 (1301-N) LWDF dissipated and the water table began to rise under the 116-N-3 (1301-N) LWDF. The extent of the groundwater mound that formed under 116-N-3 (1301-N) is not well bounded, but the available data suggest it was most pronounced in 1985 and lasted into 1989. The mounding effects are inferred from the comparison of head data at Well 199-N-32 west of 116-N-3 (1301-N) versus Well 199-N-52 east of 116-N-3 (1301-N) LWDF (Figure 4-12). During the period of high volume discharges, water table elevations were higher at Well 199-N-32 because it was nearer to the discharge point. About 1990, when high volume discharges ceased, relative water table elevations reversed and were higher at Well 199-N-52 because it is upgradient of Well 199-N-32 in the natural unperturbed flow regime.

Despite the continued discharges into the 116-N-3 (1301-N) LWDF, a general decline in water table elevation began at the end of 1985 and continued thereafter with the exception of a response to an undocumented discharge event in 1989, causing the spike shown in Figures 4-10 and 4-12. This gradual decline was due to a combination of two factors—discharge at a greater distance from the river and decreasing annual discharge volumes after 1985. By the early 1990s, drainage was essentially complete and the natural flow condition was essentially restored. The completion of drainage is demonstrated by subsequent moisture content measurements in vadose zone soils taken during the 116-N-1 (1301-N) and 116-N-3 (1301-N) LFI (DOE/RL-96-11). Measured moisture contents in sediments retrieved from Wells 199-N-108A and 199-N-109A ranged between 1 and 6 wt percent, which was estimated to be consistent for sands and gravels subjected to naturally occurring steady recharge rates of 2 to 10 cm/yr. Moisture content measurements were also done for sand and gravel vadose zone soils taken from Wells 199-N-103A, 199-N-104A, and 199-N-105A (PNL-10899). For samples containing less than 55 percent silty particles (<2 mm), moisture content generally ranged between 1 and 9 wt percent. Of the 23 soil samples in this class, 2 contained more moisture, about 18 and 19 wt percent. Overall, both sets of results are consistent for data regarding sand and gravel sediments; however, silt was only studied by Serne. The identified work scope will likely confirm the CSM.

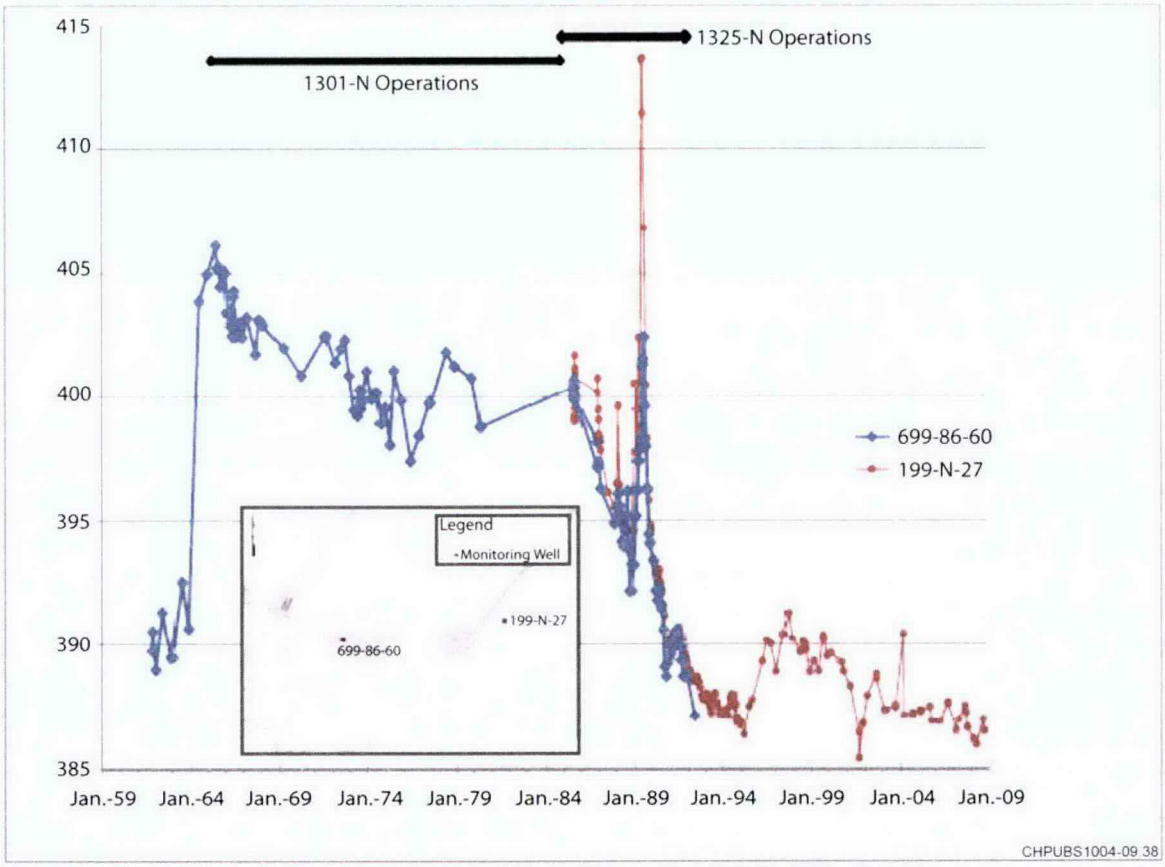
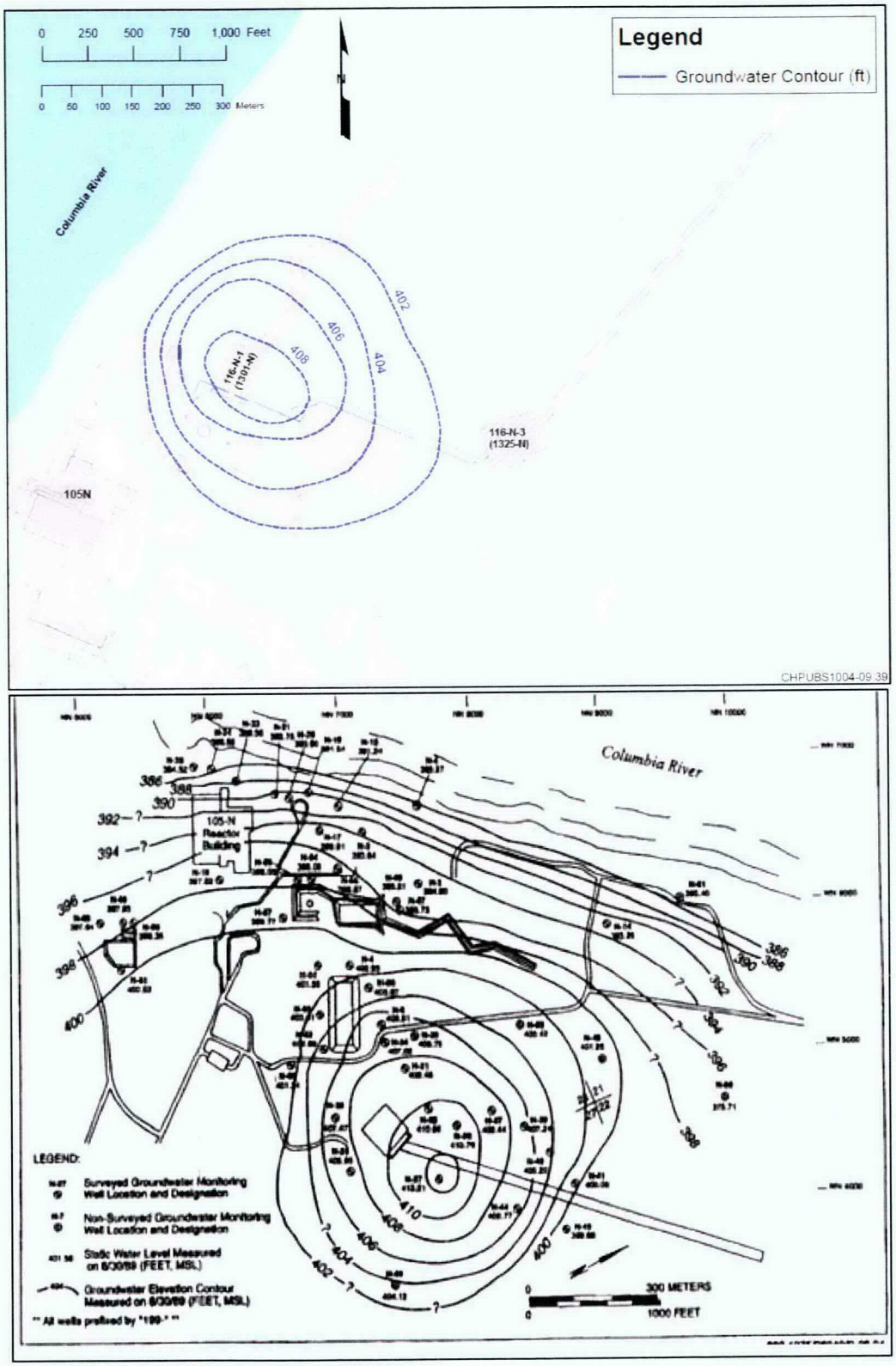


Figure 4-10. Water Table Elevations at Wells near 116-N-1 (1301-N) and 116-N-3 (1301-N) Liquid Waste Disposal Facilities



Source: DOE/RL-90-22

Figure 4-11. Water Table Mounds Associated with 116-N-1 (1301-N) Crib and Trench—July 1965 and 116-N-3 (1301-N) Crib—June 1989

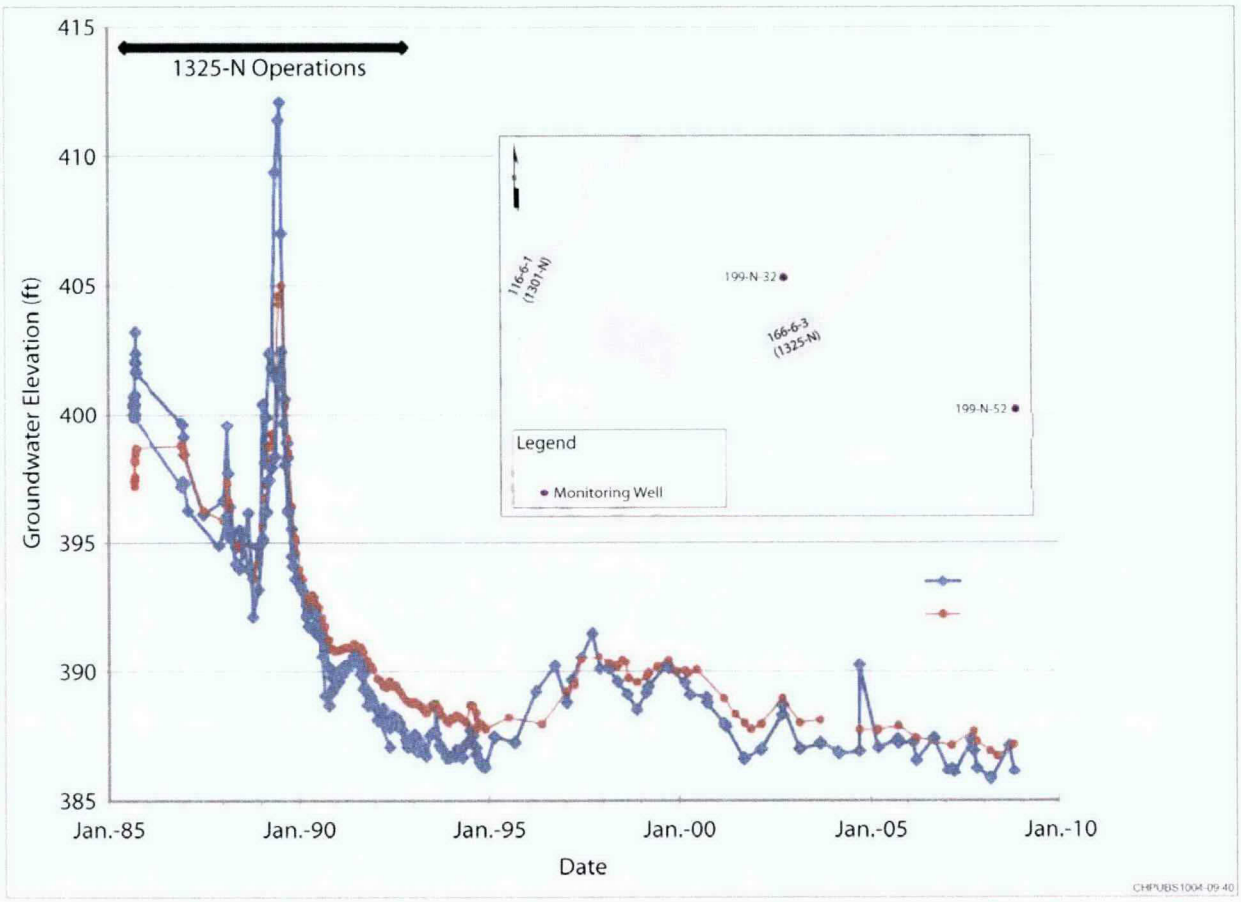


Figure 4-12. Comparison of Water Table Elevations over Time at Groundwater Monitoring Wells near 116-N-3 (1301-N) Liquid Waste Disposal Facility (Wells 199-N-32 and 199-N-52)

In the post-operation period, aquifer conditions reverted to natural processes and seasonal runoff river stage fluctuations created sympathetic fluctuations in nearby groundwater heads. The jagged profiles in water table elevations shown in 100-N monitoring wells (Figures 4-10 and 4-12) after cessation of operations illustrate this phenomenon. Figure 4-13 provides a direct comparison of river stage and 199-N-32 wellhead fluctuations. Maximum water elevations, which occur in the July - August period, are shown for each year. The higher river gauge elevations show that river water is pushing inland. The overall good correlation between the patterns of water elevation fluctuations shows the influence of river stage processes on wellheads. Relative changes at the well are not as dramatic because of its inland location.

Water table changes on a larger scale are shown in Figures 4-14 and 4-15, where water table conditions are shown at high and low river stage in 1995. These changes occur because the weight of the water column in the river provides an opposing hydraulic pressure to that provided by recharge into the unconfined aquifer. While aquifer recharge provides relatively constant hydraulic pressure, river stage changes apply variable degrees of opposing pressure, thereby changing the net flux almost continuously.

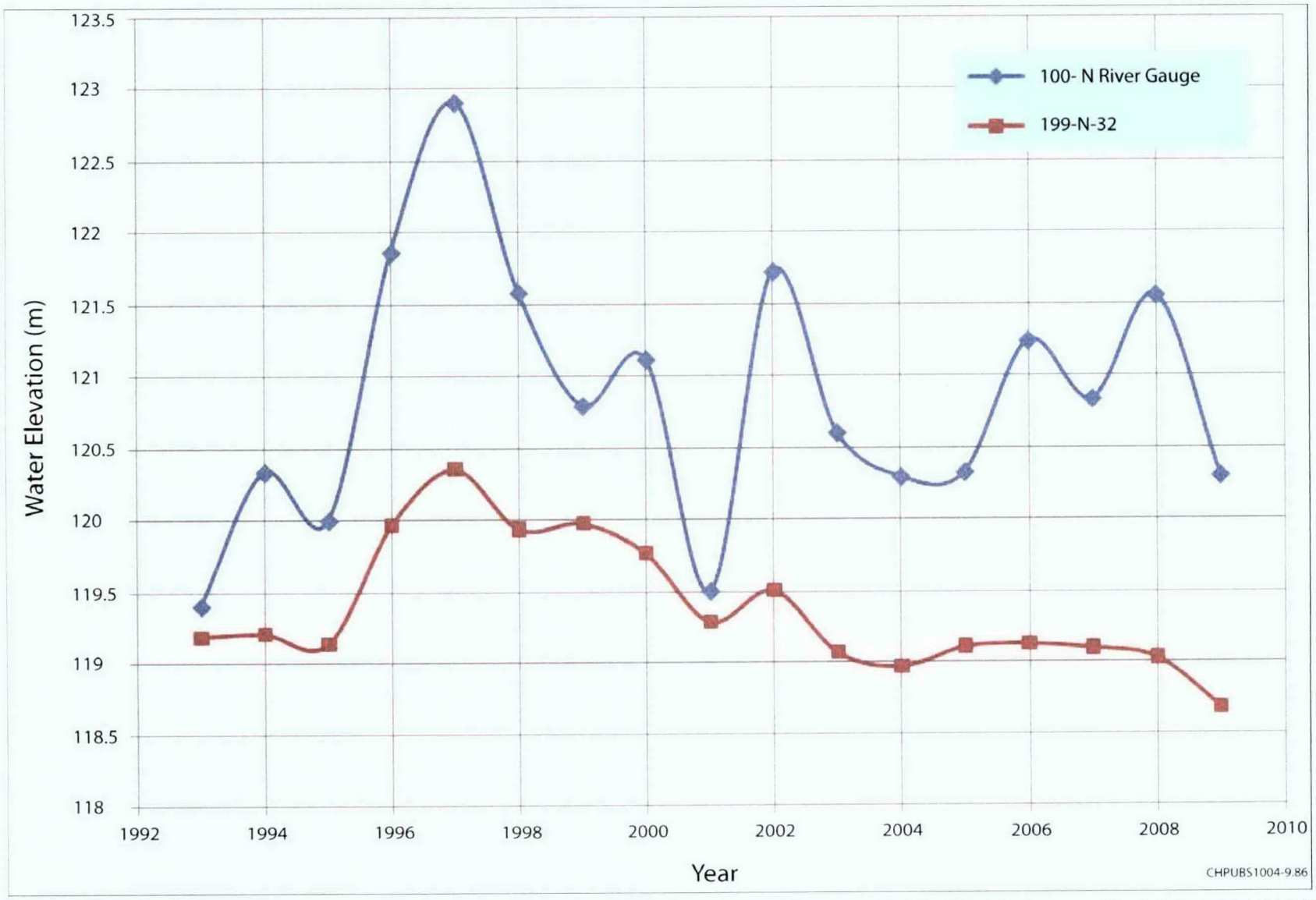


Figure 4-13. Comparison of Yearly Maximum Water Elevations at the 100-N River Gauge Station and Well 199-N-32 Downgradient of 116-N-3 (1301-N)

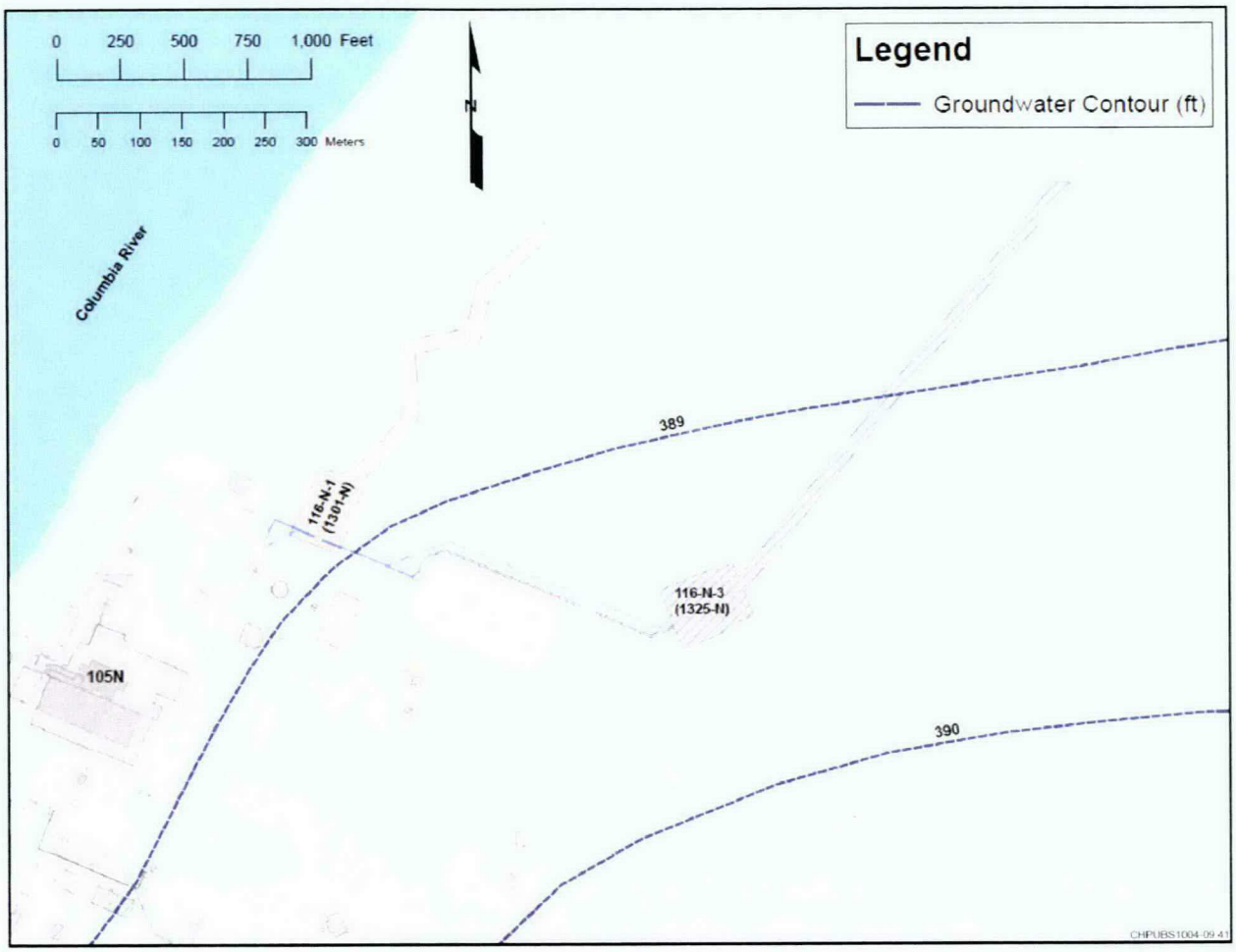
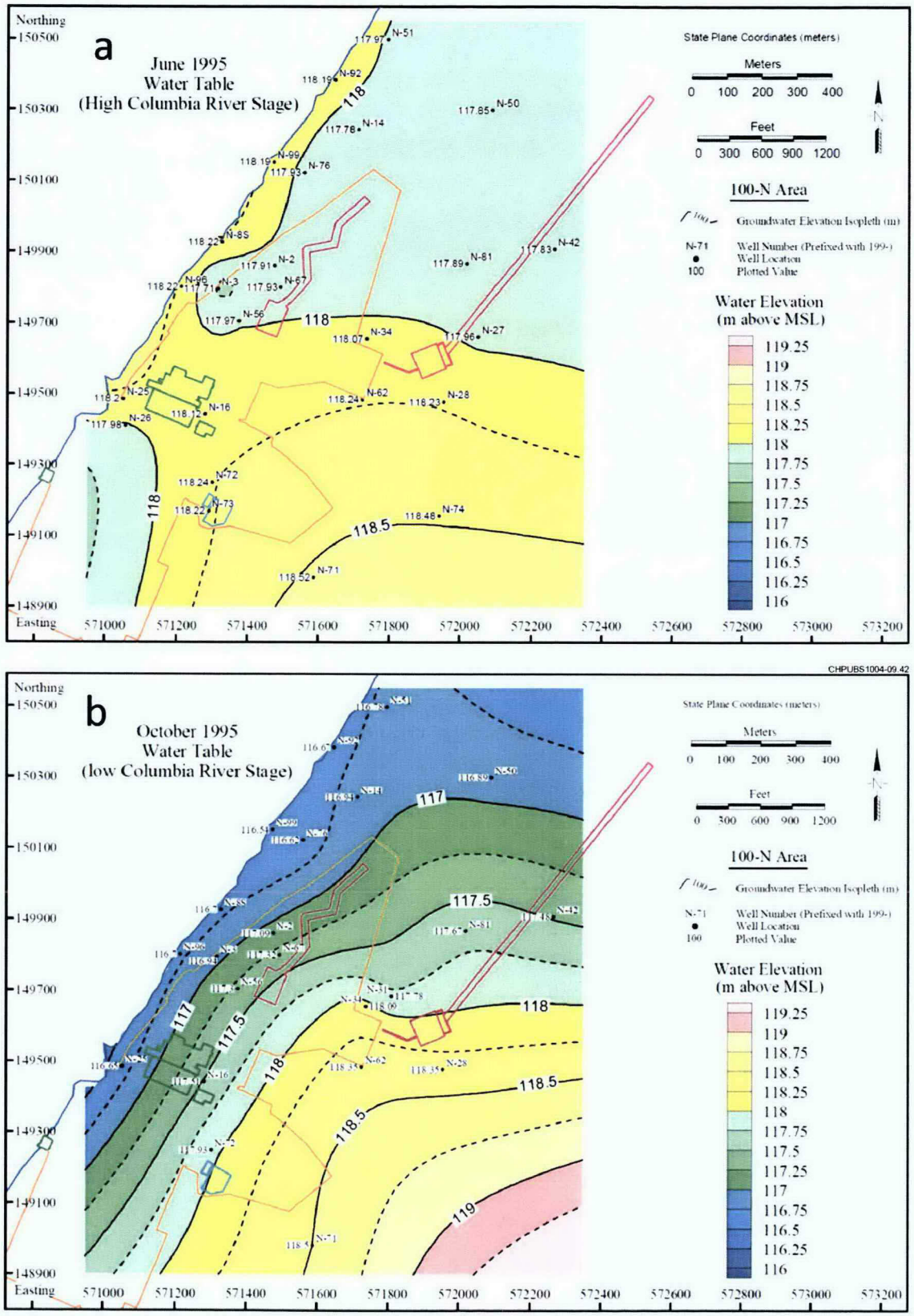


Figure 4-14. Current Water Table Elevations—100-N, 2009

At maximum river stage in midsummer, the water table elevates over the entire 100-N area and net water flux is inland (Figure 4-15a). Conversely, at minimum river stage, the water table drops and net flux is into the Columbia River (Figure 4-15b). A comparison of water table contours in Figure 4-13 shows inland flow is not uniform because of variable permeability in the rewetted vadose zone, which is composed of different lenses with variable particle size distribution. Examination of these differing water table contours reveals an oscillating primary groundwater flow direction occurring annually because of seasonal changes in river elevations. The 116-N-1 (1301-N) downgradient flow direction ranges from northwesterly to almost northerly.

Regional changes in water table elevations occurred seasonally during the reactor operations period as indicated by measured water table fluctuations. However, well data are too sparse to indicate the specific changes in these contours for comparison with the post-operations characteristics shown in Figure 4-15. However, the additional hydraulic head (energy) imposed by the 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs discharges greatly increased the aquifer gradient and caused increased flux into the river. It is reasonable to assume the general direction of preferential flow during inland flux was maintained to some degree. In June 2006, the Confederated Tribes of the Umatilla Indian Reservation conducted a geophysical investigation (*Investigation of Preferential Groundwater Flow Pathways in the 100-NR-2 Area Hanford Site* [Repasky, 2006]) for DOE whose results compare favorably with the June water table map (Figure 4-15a).



Source: HydroGeoLogic, 1999

Figure 4-15. 100-N Water Table Map for June and October 1995

4.3.2 Strontium-90 Migration and Distribution in the Unconfined Aquifer

The majority of Sr-90 that entered the unconfined aquifer originated in the 116-N-1 (1301-N) LWDF and probably from the early releases, particularly prior to 1970 when approximately one-third of the total inventory (about 1,100 Ci) was discharged. This hypothesis is supported by the combination of discharge rate history and Sr-90 concentration levels measurements over time in monitoring wells.

The time at which initial fluxes of Sr-90 from the 116-N-1 (1301-N) LWDF into the unconfined aquifer began is not known because of insufficient monitoring data. A rough approximation can be derived from monitoring data around the 116-N-3 (1301-N) LWDF where more data were collected and discharge rates were similar, although smaller and shorter in duration. At the 116-N-3 (1301-N) LWDF, about two-thirds of the Sr-90 in wastewater was discharged between 1983 and 1985 (Table 4-3). Sr-90 measurements at Monitoring Well 199-N-36, at the edge of the 116-N-3 (1301-N) Crib, show a rise in Sr-90 concentrations beginning in early 1987 and peaking in late 1988 and perhaps beyond. These data suggest a travel time of about five years in the vadose zone for the majority of mobile Sr-90. The comparison with 116-N-1 (1301-N) LWDF migration characteristics is only approximate because the retarding processes at the crib/vadose zone interface were not necessarily the same and lower discharge rates occurred at the 116-N-3 (1301-N) LWDF. Nevertheless, an estimate of a few years for significant entry into the unconfined aquifer is reasonable.

Assuming the beginning of major releases into the unconfined aquifer around 1970, transport through the unconfined aquifer was largely controlled by the groundwater mound under the 116-N-1 (1301-N) LWDF that was fully established. This condition accelerated migration rates compared to unperturbed conditions, and spread contamination in all directions, although preferential distribution is clearly indicated by soil and groundwater sampling data.

Because of these discharges, Sr-90 appeared at the N-Springs (seepage locations that developed along the riverbank because of crib discharges) and routine monitoring practices tracked changes in concentration levels, which were documented in annual effluent release reports. The first reported Sr-90 contamination measurements were reported in 1973 (UNI-158) as an annual average value of periodic measurements taken at several shoreline locations. The average concentration rose through 1988 (Figure 4-16) and are interpreted as indicators of the leading edge of the Sr-90 plume migrating through the unconfined aquifer during the operations period. The annual inventory flux into the Columbia River during this time was estimated simply as the product of half the annual discharge volume to the cribs and the average concentration. Using these assumptions, a cumulative loss of 45 Ci was estimated for 1973 to 1990. This estimate may be substantially in error because it did not take into account the influence of river stage fluctuations on contaminant migration and the Sr-90 releases further inland beginning in 1983.

When high volume discharges to the 116-N-3 (1301-N) LWDF were terminated in 1990, Sr-90 migration through the unconfined aquifer slowed substantially. The groundwater mound dissipated, the hydraulic gradient decreased, and natural flow directions became dominant. For example, Figure 4-16 shows a nearly five-fold decrease in the average Sr-90 concentration at the river shore between 1990 and 1991, illustrating transport rates from upgradient sources were no longer sufficient to increase or maintain shoreline concentration levels. This hypothesis is supported by groundwater data collected since then in 100- N. Generally, the 116-N-1 (1301-N) LWDF downgradient data show very little change in plume concentration contours, suggesting minimal Sr-90 migration since the early 1990s.

Figure 4-17 shows Sr-90 concentrations and head data at two wells that bound the extent of high Sr-90 distribution in the unconfined aquifer where sampled (i.e., Well 199-N-67 30 m [100 ft] north of 116-N-1 [1301-N] Crib and Well 199-N-14 north of 116-N-1 [1301-N] Trench [Figure 4-1]). In both wells, Sr-90 concentrations vary over a small range, particularly after 1992, and the average value changes very little.

This behavior can be explained by two offsetting processes, migration toward the Columbia River at a rate controlled by hydraulic properties (hydraulic gradient, sediment hydraulic conductivity and porosity) and sorption versus radioactive decay. Thus, although the Sr-90 migration process is dynamic, net Sr-90 migration is generally static. Figure 4-18 shows the current regional Sr-90 distribution in the unconfined aquifer.

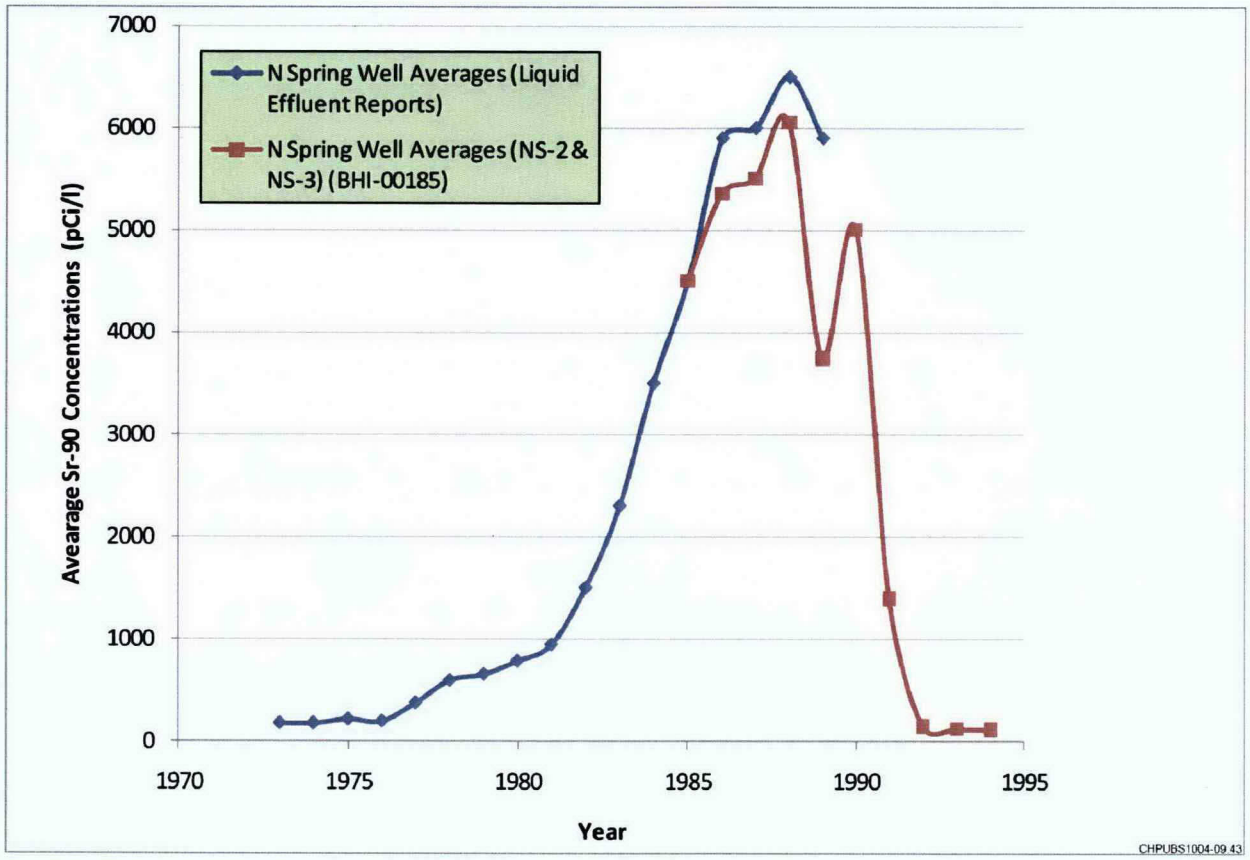


Figure 4-16. Measured Annual Average Sr-90 Concentrations at N-Springs (pCi/L) and Estimate Inventory Flux into the Columbia River

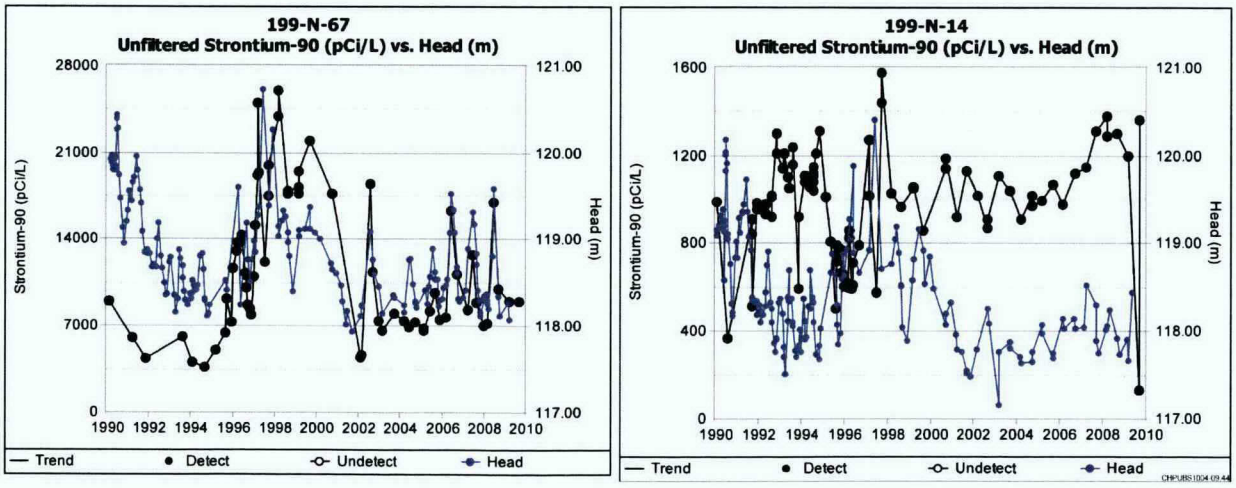


Figure 4-17. Unfiltered Strontium-90 Concentrations vs. Head Levels at Wells 199-N-67 and 199-N-14

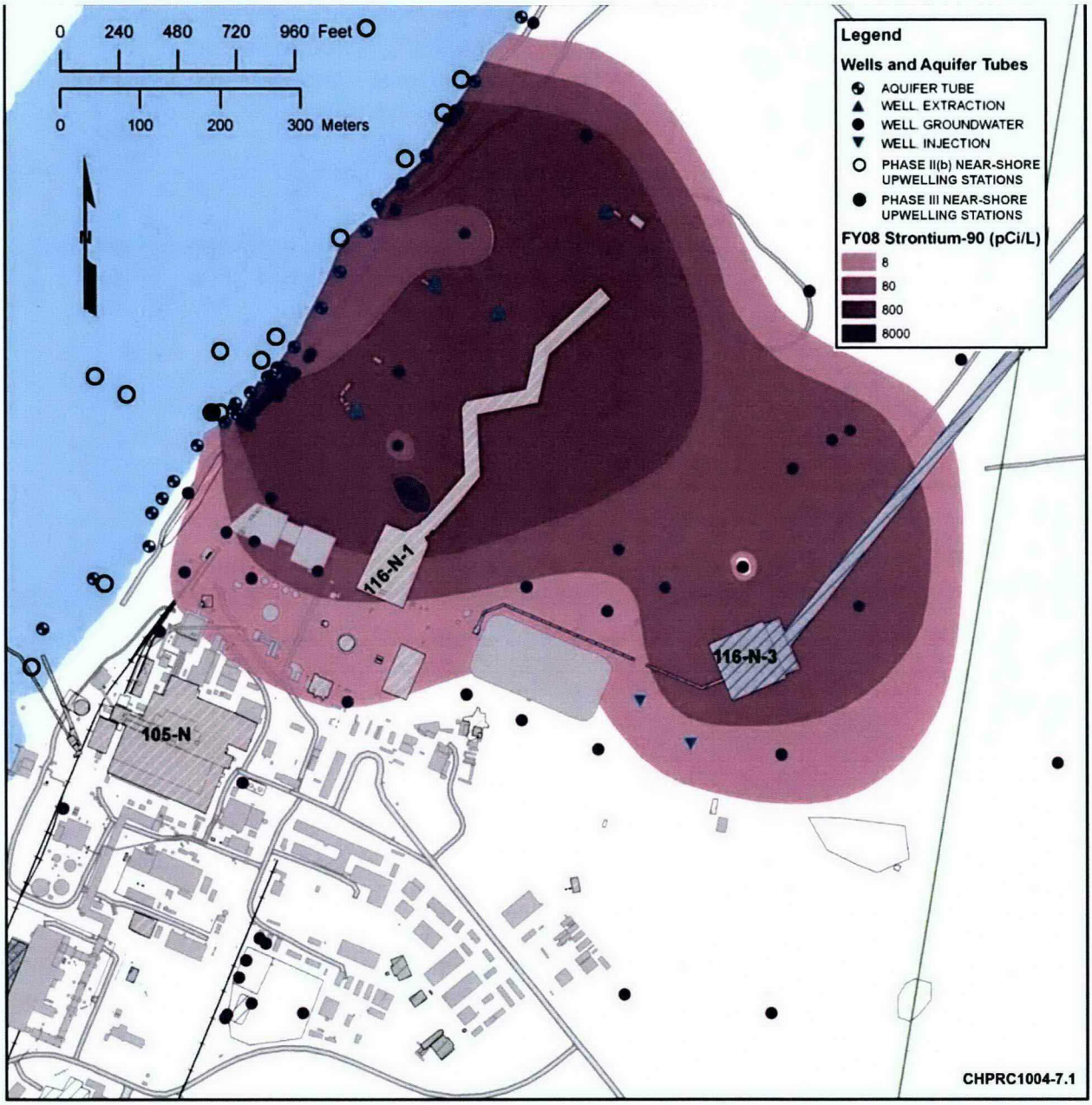


Figure 4-18. Current Sr-90 Distribution in the Unconfined Aquifer under 100-N

Given the relative spatial stability of fluid Sr-90 concentration contours in the unconfined aquifer, the sorbed portion of Sr-90 in the aquifer has been essentially fixed since the early 1990s. The subsurface soils characterization and aquifer data collected show the following notable characteristics:

- Sr-90 is generally distributed in a layer around the current water table, mostly in the upper part of Ringold unit E (see Figures 2-10 and 2-11). This layer is thickest around the LWDFs (up to 12.2 m [40 ft]) and thins toward the Columbia River 1.5 to 6.1 m (5 to 20 ft). Less than 100 Ci of Sr-90 have been estimated as present in this layer with about 99 percent sorbed and 1 percent in solution (PNL-10899). This vertical distribution of Sr-90 in the unconfined aquifer is further demonstrated from groundwater samples collected from Wells 199-N-119, 199-N-120, and 199-N-121 as shown in Figure 4-19.

- Sr-90 mass inventory for a given soil volume within the contamination levels tends to diminish gradually and, for the most part, evenly away from the 116-N-1 (1301-N) LWDF with soil sample measurements frequently above 100 pCi/g within 150 m (492.1 ft) of 116-N-1 (1301-N) LWDF (Figures 4-5 and 4-6), and dropping below 100 pCi/g near the shoreline.
- Some spatial anomalies in contamination levels are apparent. First, a groundwater hot spot persists next to the crib at Well 199-N-67 (about 15,000 pCi/L), indicating a residual maximum concentration zone. Second, a less contaminated zone appears downgradient of the middle of the trench around Well 199-N-80, where the maximum soil concentration was 52 pCi/g (about three times less than soil measured at adjacent wells). This contrast extends to Well 199-N-121 straight downgradient of Well 199-N-80 and within 15 m (50 ft) of the Columbia River. Third, soil and groundwater contamination hot spots exist. A more contaminated zone is present at the northern end of the trench (near Wells 199-N-105A, 199-N-106A, and 199-N-14). Another hot zone exists at the shoreline around Wells 199-N-46 and 199-N-122, in the middle of the apatite barrier. This hot spot extends underneath the river to a cluster of aquifer tubes, including NVP1-5, NVP2, and NS-3A.

These observations suggest a logical and relatively uncomplicated evolution of Sr-90 spatial distribution in the unconfined aquifer developed during the reactor operations period. Sr-90 discharged into the unconfined aquifer as a line source underneath the 116-N-1 (1301-N) LWDF footprint. At the 116-N-1 (1301-N) LWDF, a somewhat larger release of Sr-90 occurred at the crib because it was the initial point of entry into the subsurface. Thus, the apparent residual hot spot nearby is reasonable.

The dominant flow directions ranged from north-northwesterly to northerly and are common as imposed by both the groundwater mound and the regional gradient. This commonality may explain why there appears less migration to the west, south, and east. Sr-90 did not migrate deeply into the unconfined aquifer because of its chemical reactivity and lateral transport in the more permeable Hanford formation. Finally, within the downgradient subsurface soils, there may be preferential flow paths, particularly one leading from the 116-N-1 (1301-N) Crib toward Wells 199-N-46 and 199-N-122 at the river shore and the nearby aquifer tubes. N-Springs monitoring activities (*Analysis of Travel Time of I-131 From the 1301-N Crib to the Columbia River During July 1969* [BNWL-CC-2326]) have described this particular flow path since 1969.

A recent study performed at 100-N using the AquaTrack™ method (a proprietary electromagnetic technology), which identifies subsurface saturated zones and preferential groundwater flow pathways, has shown potential routes where 100-N effluent disposed to the 116-N-1 (1301-N) Crib/Trench went directly to the river near Well 199-N-46 (Repasky, 2006). This study also shows another potential preferential pathway down the length of 116-N-1 (1301-N) to the northeast. The results from this study will be reviewed along with new information generated by RI/FS activities to better define the CSM and contaminant travel routes.

An elevated zone is present under the 116-N-3 (1301-N) LWDF, but soil and groundwater data indicate a smaller Sr-90 mass that is less widely distributed. For example, Sr-90 soil concentrations in Well 199-N-109A (near the crib wastewater entry point) are about 15 pCi/g in the deep vadose zone, approximately 10 times less than 116-N-1 (1301-N) soil concentrations. Groundwater concentrations around 116-N-3 (1301-N) have generally been less than a few hundred pCi/L with occasional spikes approaching 2,000 pCi/L. Overall, these concentrations are several times lower than those measured in wells downgradient of the 116-N-1 (1301-N) LWDF. These measurements are consistent with the historical evidence that notably less wastewater and Sr-90 was discharged at the 116-N-3 (1301-N) LWDF.

™ AquaTrack is a trademark of WillowStick Technologies, LLC, Draper, Utah.

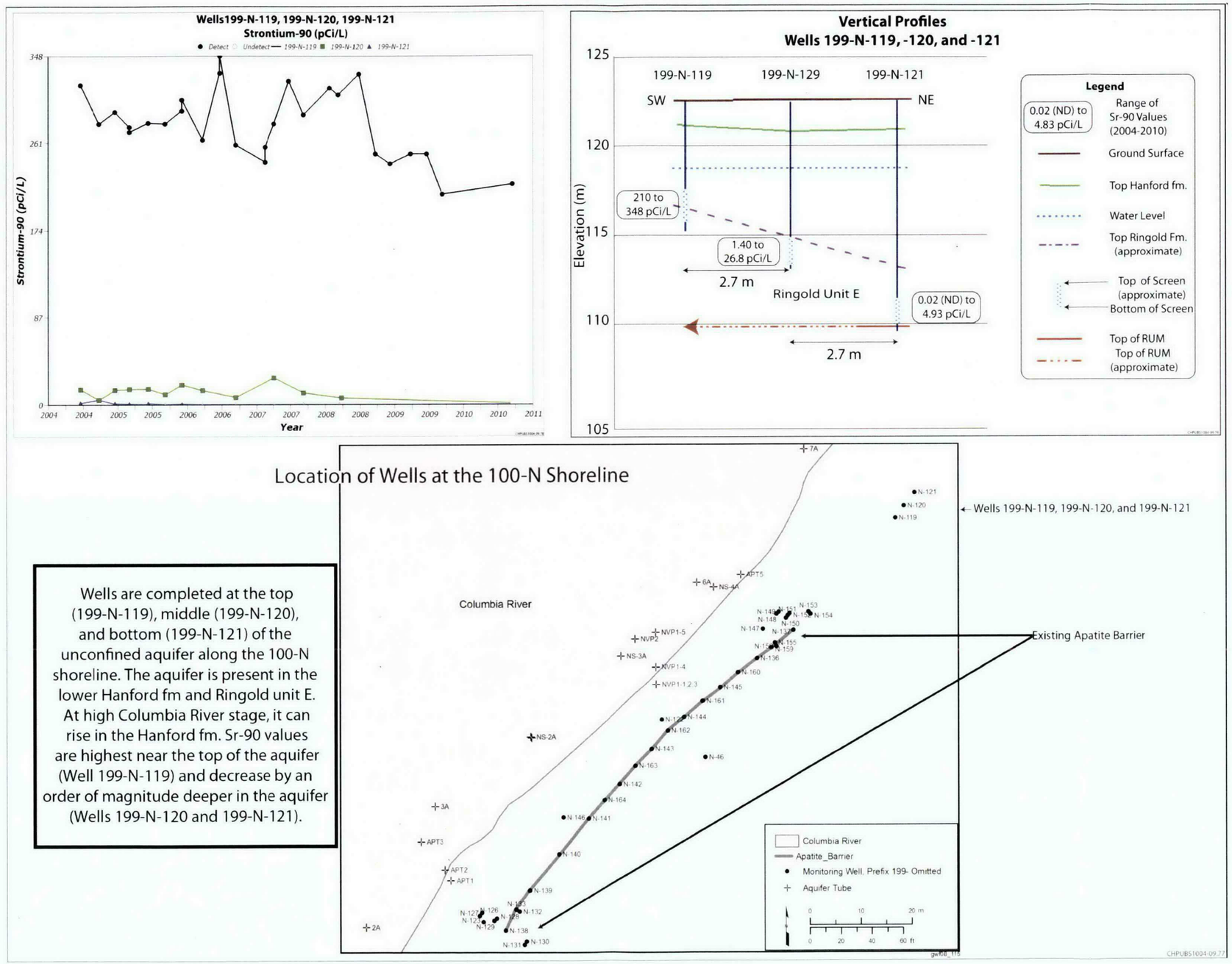
While regional Sr-90 immobility in 100-N subsurface soil has been demonstrated over the last 20 years, local periodic oscillations in Sr-90 groundwater concentrations are ubiquitous at inland monitoring wells. These oscillations correlate with seasonal river stage changes (Figure 4-17). From this correlation, a cause and effect hypothesis is indicated. During high river stage, uncontaminated river water moves inland and raises the water table, thereby periodically rewetting the lower few feet of the vadose zone. This water then desorbs contamination in the rewetted zone and, because the sorbed contamination tends to be more concentrated in the rewetted zone, the dissolved concentrations are higher. Conversely, when the river stage is low, the water table drops and aquifer water equilibrates with less contaminated sediments causing dissolved Sr-90 concentrations to decrease as excess Sr-90 resorbs. The fraction of the Sr-90 that is not resorbed adds to the dissolved mass but the additional flux created by these additions has not changed the plume configuration. This observation suggests that radioactive decay may be sufficient to counteract added flux. An analysis of the correlation of river stage/groundwater level, Sr-90 concentration in groundwater, and significant precipitation will be provided in the RI report.

In contrast to monitoring well groundwater data inland, fluctuations in Sr-90 concentrations in concert with river stages are not clearly indicated in samples taken from aquifer tubes located in the Columbia River since 2005. These tubes allow collection of groundwater below the riverbed at various depths. A comparison of gross beta measurements (a proxy for Sr-90) with river stage elevations is shown in Figure 4-20 for some of the aquifer tube locations. Therefore, it is assumed these fluctuations are not caused by river stage cycles.

A reasonable correlation between these fluctuations in Sr-90 concentrations in the aquifer tubes can be made with local changes in groundwater chemistry caused by tests conducted to develop the nearby apatite barrier. The barrier is designed to immobilize Sr-90 near the Columbia River. On several occasions (2006, 2007, and 2008), solutions were injected into the subsurface through a row of injection wells about 15.24 m (50 ft) inland from, and parallel to the river shore (PNNL-17429, DOE/RL-2008-66).

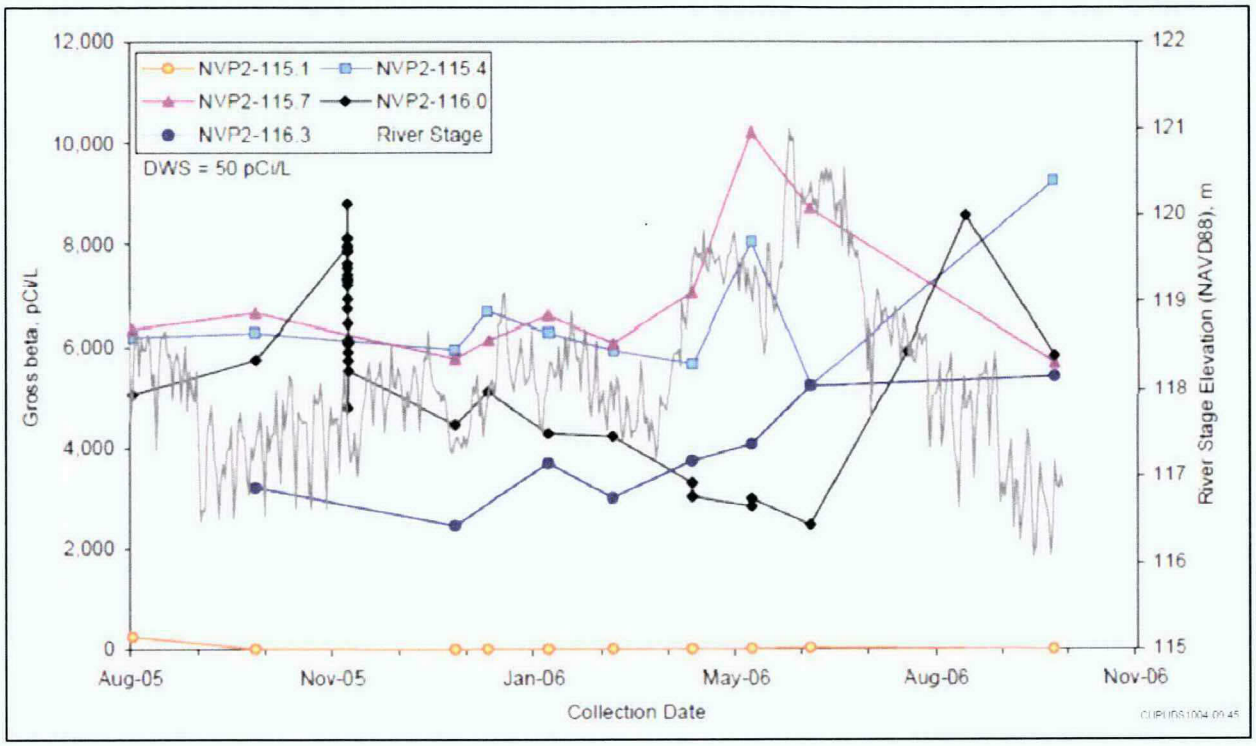
The hot spot Wells 199-N-122 and 199-N-46 are located in the middle of this row. Both calcium-rich and phosphate-rich solutions were injected to precipitate in situ apatite, which both sorbs and incorporates Sr-90 into its mineral structure. The apatite formation process has not been entirely efficient, leaving excess calcium and phosphate in solution, which has migrated toward the Columbia River under the influence of the injected solution volumes. During these transient events, the added calcium replaced pre-existing Sr-90 sorbed onto sediments, thereby liberating a fraction of the Sr-90 along the flow path. The mobilized Sr-90 and calcium traveled as far as some of the aquifer tubes in the riverbed and caused observable concentration spikes in groundwater sampled just below the riverbed. This supports the reasonable supposition that Sr-90 discharge to the Columbia River occurs through groundwater upwelling in the riverbed.

Given the discussion presented earlier, current and future discharges into the Columbia River are and will be strongly influenced by Sr-90 mobility. Most importantly, Sr-90 immobility implies that the source of Sr-90 currently discharging into the Columbia River must be limited in extent and most likely close to the shoreline, underneath the riverbed, and a short distance inland. By extension, the inland mass and larger fraction of Sr-90 in the subsurface cannot reach the region near the Columbia River and will not be a source of future Sr-90 discharge into the river. Critical factors preventing significant migration are chemical retardation, low hydraulic gradient, and radioactive decay. The slow movement of Sr-90 toward the river allows radioactive decay of the contaminant to occur before it is discharged into the river in all but the narrow area near and under the river. These factors will be dominant as long as recharge rates are not significantly increased.



Wells are completed at the top (199-N-119), middle (199-N-120), and bottom (199-N-121) of the unconfined aquifer along the 100-N shoreline. The aquifer is present in the lower Hanford fm and Ringold unit E. At high Columbia River stage, it can rise in the Hanford fm. Sr-90 values are highest near the top of the aquifer (Well 199-N-119) and decrease by an order of magnitude deeper in the aquifer (Wells 199-N-120 and 199-N-121).

Figure 4-19. Sr-90 Groundwater Distribution in Wells 199-N-119, 199-N-120, and 119-N-121



Source: PNNL-16346

Figure 4-20. Comparison of Aquifer Tube Gross Beta Measurements with River Stage Elevations (*Hanford Site Groundwater Monitoring for Fiscal Year 2006*)

To better understand the dynamics of Sr-90 plume behavior and improve confidence in this hypothesis, a complex modeling analysis was completed in 2004 (HydroGeoLogic, Inc., 2004). In this analysis, a two half-life projection was completed from 1995 forward on regional Sr-90 contamination levels along a cross section perpendicular to the Columbia River and parallel to the general direction of hydrologic flow. The model considered hydraulic processes including river stage effects, the existing Sr-90 distribution in the subsurface, chemical retardation effects, radioactive decay, and recharge conditions similar to current levels.

The analysis provided several informative results. First, no significant movement of the center of mass of the Sr-90 plume toward the Columbia River occurred during the 57-year simulation. This result, entirely consistent with the past decade of observations, was expected because none of the major plume controlling factors was modeled differently from existing conditions. The implication is that the available source term for Columbia River discharge is unlikely to increase significantly and must not extend very far inland from the river shore. A quantitative determination of the size of the source term area has not been estimated. Second, despite the large fluxes of water across the river shore boundary, the net annual flux into the river is quite small, about 0.35 m^3 per meter (12.36 ft^3 per foot) of flux plane width parallel to the river shore and should be relatively constant as long as current recharge conditions remain within natural variation of precipitation over months/years/decades. Third, the flux into the Columbia River occurs primarily through the lower part of the unconfined aquifer, and Sr-90 concentrations in these fluids are largely unaffected by river stage effects such as those noted at inland wells. Results imply that Sr-90 concentrations should be constant over the short term as suggested by the aquifer tube data. However, Sr-90 concentrations and fluxes will decrease over time because of decay. Consequently, the estimated cumulative release over the 57-year projection (0.0123 Ci across 1 m of the flux plane and 5.5 Ci across the total flux plane of 450 m) makes up about 90 percent of all future releases. Extrapolating this estimate across a flux plane 450 m long along the river shore yields a cumulative future 6 Ci inventory release into the Columbia River.

In summary, Figure 4-21 illustrates the estimated evolution of Sr-90 subsurface distribution near 100-N, which has been derived from characterization data plus the flow and transport modeling described previously. The activity estimates have not been set to one period because processes occurring over several half-lives are represented in the figure. The initial inventory is based on historical records, the subsurface soils inventory account for decay through the mid-1990s, and the river source term is inventory to be released until decay eliminates additional fluxes into the river.

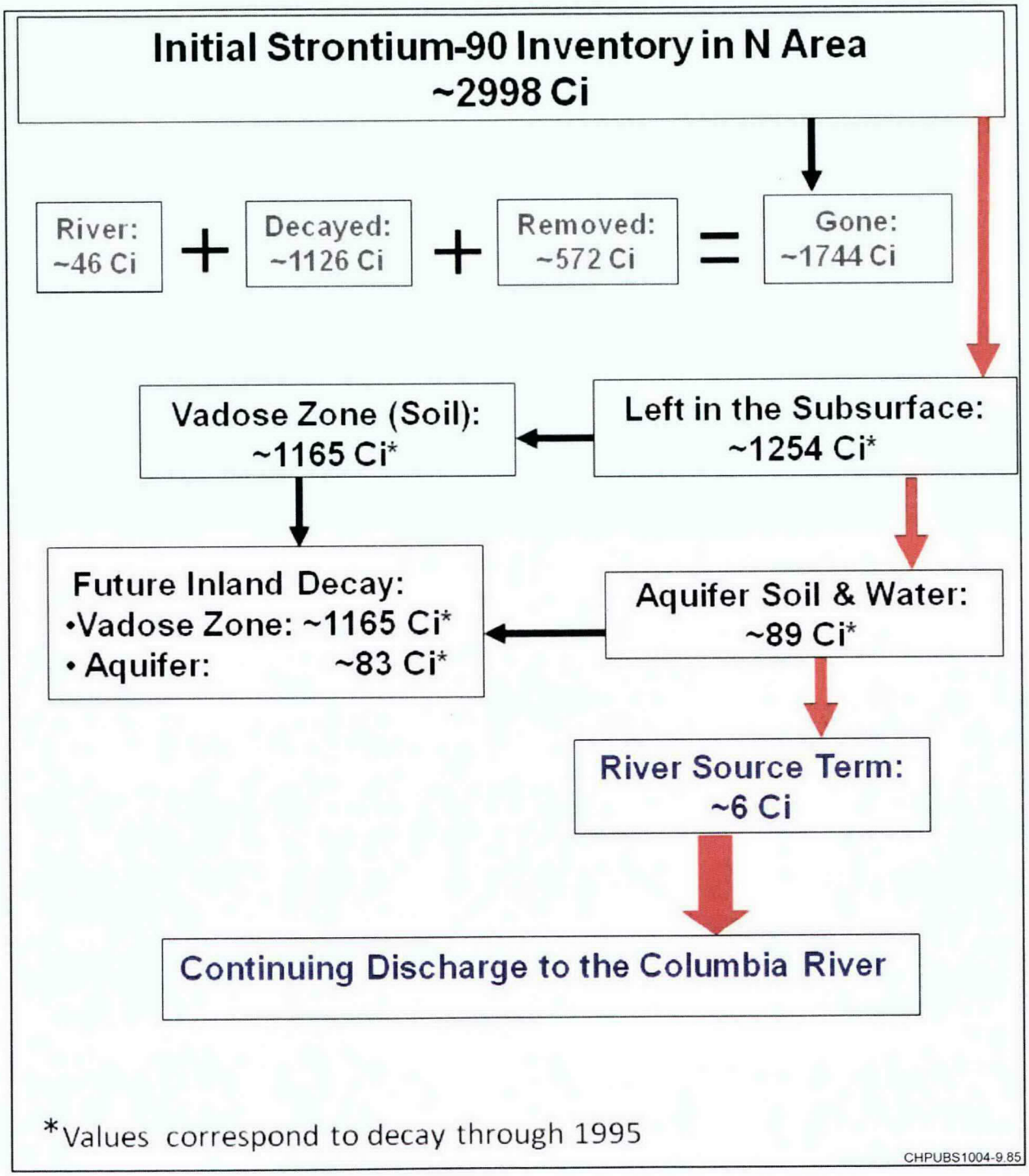


Figure 4-21. Mass Balance Estimate of Sr-90 Distribution in the Subsurface Over Time

Efforts to hasten the reduction of the Sr-90 source term with the development of the apatite barrier and potential use of phytoremediation treatments are ongoing for purposes of accelerating the removal of the Sr-90 source. If successful, Sr-90 flux into the Columbia River could be reduced more quickly.

In addition to the high volume discharges from 116-N-1 (1301-N) and 116-N-3 (1301-N) Trenches, a second source type for Sr-90 migration into the unconfined aquifer is from low volume spills/leaks. Historically, elevated Sr-90 was present in groundwater downgradient of the reactor building (see discussion in Section 2.3.3). A number of low volume spills and leaks (UPRs 100-N-3, -7, -10, -12, -30, -35, and -39) occurred near the Fuel Storage Basin, Emergency Discharge Basin, and Emergency Discharge Trench. A significant feature of this area is the 100-N outfall and spillway, because these constructions required an excavation below the river (Figure 2-4) from the reactor, and the resulting trench created and/or provided a preferential pathway for contaminant movement.

The gravel-filled trench likely retains a small Sr-90 inventory as indicated from the upwelling sampling results. Preliminary results from 2009 to 2010 pore water samples taken from the 100-N locations (Figure 4-18) indicate detectable amounts of Sr-90. However, results from most of the 100-N locations were below detection. Five detections were reported and Sr-90 values ranged from 11 to 72 pCi/L, with measurements of 11 and 17 pCi/L at two locations downriver from the 100-N outfall and spillway, and outside the known Sr-90 plume contours.

Data Gap No. 5: The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in select areas.

Data Gap No. 6: The level of groundwater contamination entering the Columbia River (in particular, the hyporheic zone) is not well known.

Data Gap No. 9: The rate of chemical and hydraulic exchange between the aquifer and the river in the near shore is unknown.

Data Gap No. 13: Data are needed to better define the spatial and temporal distribution of groundwater contamination.

4.3.3 Petroleum Product Migration and Distribution in the Unconfined Aquifer

The diesel fuel leak into the unconfined aquifer occurred over a small area underneath the 166-N Tank Farm. Assuming little interaction with vadose zone soils and migration as a NAPL, complete discharge into the unconfined aquifer occurred well before the end of the reactor operations period. Given the generally low solubility of petroleum products and their tendency to persist as an immiscible fluid, migration rates and dispersion through the unconfined aquifer are difficult to understand and predict. Petroleum products were found as fluids floating at the water table in Well 199-N-18 in the 1980s, then disappeared until 2003 (*Hanford Site Groundwater Monitoring for Fiscal Year 2003* [PNNL-14548]). Since 2003, petroleum is being passively removed from the well using absorbent sponges (Chapters 1 and 2 provide further discussion of the petroleum removal). An existing trench along the Columbia River was used to burn petroleum products as they migrated toward the Columbia River from the 1966 spill, and burning continued until about 1969. The trench was backfilled in 1994.

Currently, some portion of the discharged inventory remains in the subsurface by the Columbia River. Recent monitoring and characterization efforts indicate a relatively narrow area downgradient of the leak location that is currently contaminated with petroleum products (Figures 4-22 and 4-23). The largest concentrations of total TPH-DR are found in Well 199-N-18 where concentrations in excess of 1E+05 μg/L have been measured (Figure 4-24). Other characterization data suggest the heart of the plume trends along a northwest line from Well 199-N-18, between Wells 199-N-173 and 199-N-96A, and

intersects the Columbia River between aquifer tubes N116mArray-0A and C6135 (Figure 4-23). This trend is consistent with the regional groundwater gradient. In this zone, source term inventory is clearly still present. Recent soil characterization data collected at Well 199-N-173 and near the shoreline (Figure 4-22) show TPH-DR concentrations ranging from 30 to 1,200 mg/kg (*Summary of TPH Monitoring Conducted at 100-NR-2 During CY 2008 and 2009* [PNNL-18645]). Contamination at these sites is present throughout the lower vadose zone sediments periodically wetted at high river stage and concentration levels increase with depth.

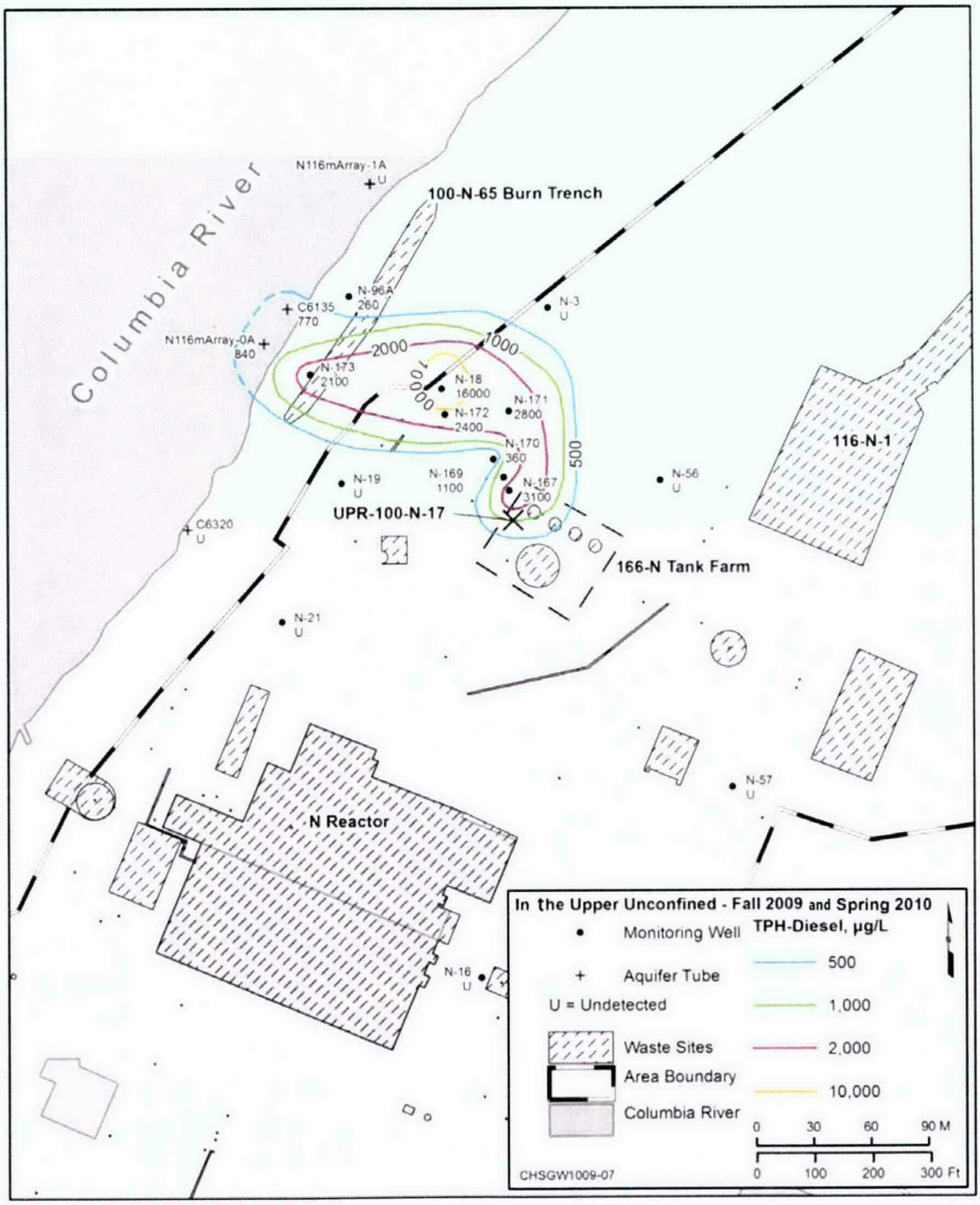


Figure 4-22. Petroleum Plume Extent in 100-N

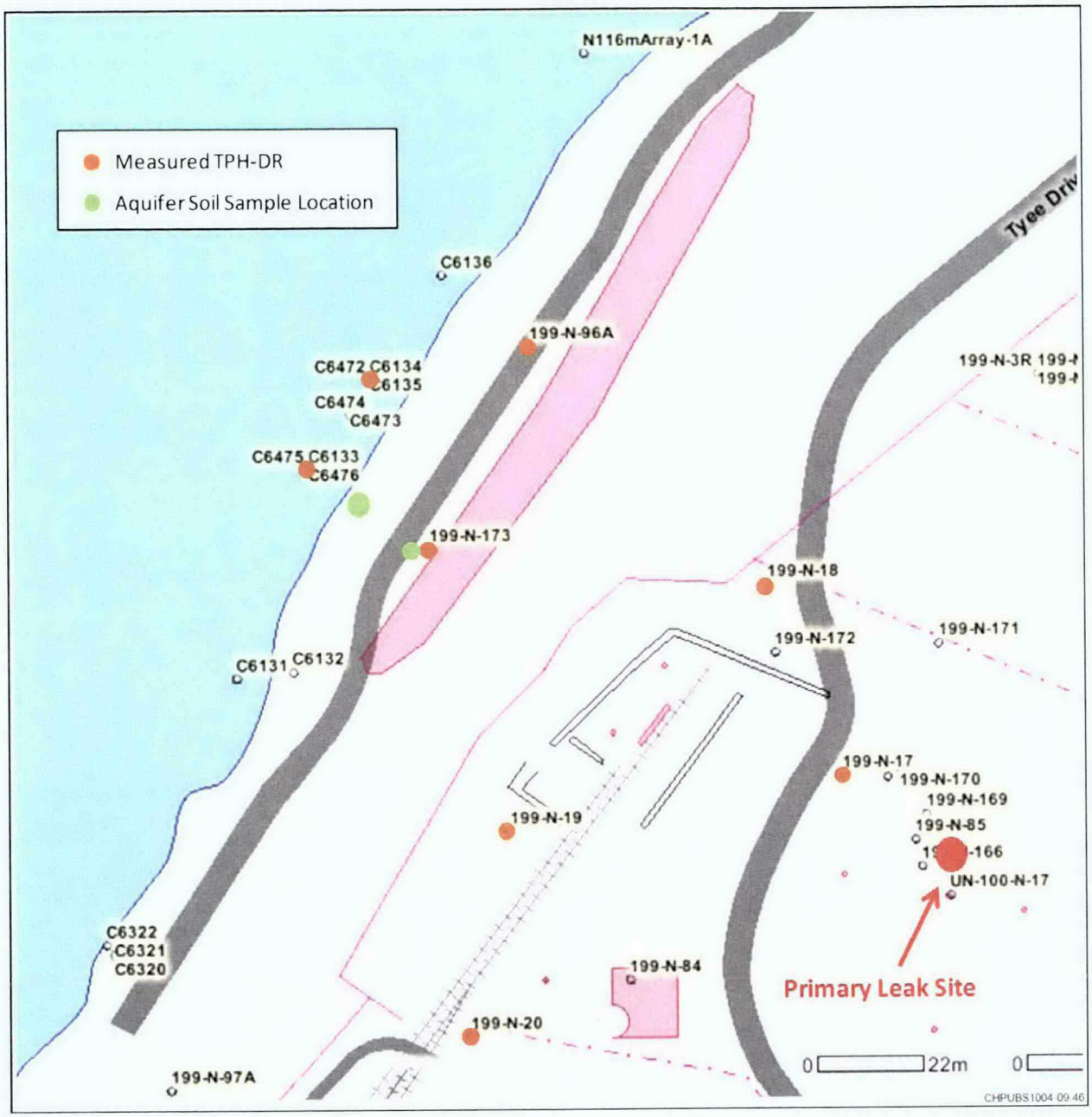


Figure 4-23. Sediment and Groundwater Sampling Locations for Total Petroleum Hydrocarbons-Diesel Range

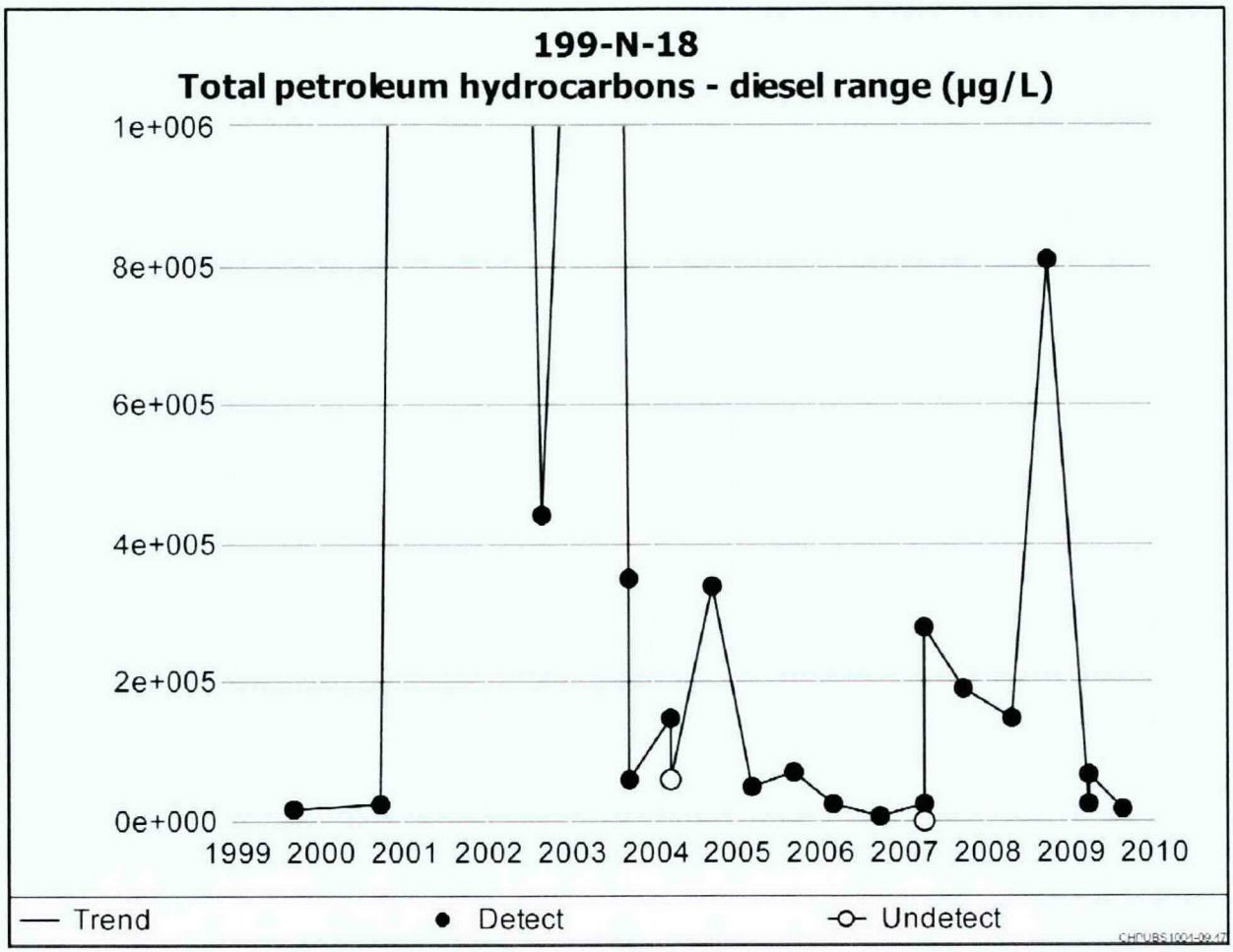


Figure 4-24. Total Petroleum Hydrocarbons—Diesel Range Measurements at Well 199-N-18

The groundwater beneath the 184-N Day Tank has been monitored by Well 199-N-16. Low levels of hydrocarbon contamination have previously been observed; however, 2009 data from this well did not have detectable levels (DOE/RL-2010-11, Rev. 1).

Data Gap No. 9: The rate of chemical and hydraulic exchange between the aquifer and the river in the near shore is unknown.

These data suggest a reasonable and expected migration direction for this plume in the future, but migration rates and the length of time for plume dissipation are uncertain because of poorly quantified residual inventory and the uncertain nature of immiscible fluid migration characteristics.

Data Gap No. 5: The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in select areas.

Data Gap No. 6: The level of groundwater contamination entering the Columbia River (in particular, the hyporheic zone) is not well known.

Data Gap No. 10: The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain.

Data Gap No. 13: Data are needed to better define the spatial and temporal distribution of groundwater contamination.

4.3.4 Chromium Migration and Distribution in the Unconfined Aquifer

The majority of chromium that entered the unconfined aquifer originated from discharges through the 116-N-1 (1301-N) LWDF. Given its high solubility and lack of sorption to subsurface sediments, chromium is assumed to have entered the unconfined aquifer over a fairly large flux plane, and very shortly after discharges began at the 116-N-1 (1301-N) LWDF. The size of the flux plane was determined by the amount of lateral migration of 116-N-1 (1301-N) discharge volumes in the vadose zone before vertical movement became the dominant flow direction. As discussed in Section 4.3.3, the measurement of slightly elevated chromium near the bottom of the 116-N-3 (1301-N) Trench is attributed to lateral spreading of 116-N-1 (1301-N) wastewater containing dissolved chromium. This observation corresponds to a lateral spreading distance of about 500 m (approximately 1,640 ft). If so, lateral spreading in the vadose zone could have reached the river shore. Similar types of releases may have occurred under 116-N-3 (1301-N) and 1324-NA, which operated from 1977 until the end of reactor operations. The facility received an average of 605,600 L/day (160,000 gal/day) (DOE/RL-93-80), enough discharge volume to drive some lateral spreading.

During the reactor operations period, the large hydraulic gradients imposed and maintained by crib discharges forced very rapid migration of nonsorbing contaminants to the river shore. In 1969, I-131 migration was tracked from the 116-N-1 (1301-N) LWDF to the N-Springs by noting the timing between the discharge of more concentrated solutions into the 116-N-1 (1301-N) LWDF, and then the occurrence of an I-131 concentration peak at N-Springs sampling locations. This study showed that transport to N-Springs took about two weeks. Given the high continuous discharge rates while chromium was delivered to 116-N-1 (1301-N) and then continued for another 10 years after sodium dichromate ceased, the mobile portion of discharged chromium was thoroughly flushed into the Columbia River by the end of the reactor operations period.

Since the early 1990s, total chromium has been measured, for the most part, at low levels (less than 20 μg/L) in numerous groundwater monitoring wells. The well data do not indicate a plume, but rather somewhat random occurrences in the unconfined aquifer under 100-N. The continuing presence of chromium in the unconfined aquifer is attributed to leaching the sorbed or precipitated chromium in soils in the lower vadose zone, which are more resistant to leaching.

One exception to these observations was the occurrence of higher concentration levels in the early 1990s at numerous wells. These data show a repeated pattern with respect to water table elevations. Following the water table spike in 1989 that occurred in wells around the 116-N-1 (1301-N) and 116-N-3 (1301-N) LWDFs, a spike in chromium concentration appeared about three years later in those wells. An example of this pattern is shown in Figure 4-25 at Well 199-N-67 near the 116-N-1 (1301-N) Crib. This relationship suggests that the rising water table caused a temporary resumption of chromium contaminated sediment leaching in the rewetted zone that had stopped with the cessation of crib discharges several years previously. Because chromium was present in a more leach resistant condition, leach rates were slow and vertical migration rates of the leached chromium were retarded relative to the subsequent drop in the water table elevation. Therefore, appearance of the spike occurred afterwards. The higher chromium concentrations are attributed to leaching of more contaminated sediments in the rewetted zone where less leaching had occurred since cessation of high volume crib discharge.

If this hypothesis is correct, future spikes in contamination levels may occur if significant water table elevations occur again. Given that reactor operations will not resume, this event seems unlikely. Otherwise, no plausible mechanism would permit future increases in chromium contamination in the unconfined

aquifer. Currently, only Well 199-N-80, downgradient of the 116-N-1 (1301-N) LWDF, shows elevated chromium concentrations above the DWS (about 175 µg/l). This anomalous behavior, which is thought to be the result of chromium stainless steel well screen corrosion, will continue to be monitored.

The CSM discussed above leads to the expectation that chromium contamination levels in the unconfined aquifer will remain constant long-term. Given the limitations of the database upon which this CSM is based, future soil characterization and groundwater monitoring data are needed to provide additional information against which to compare the reliability of the CSM.

Data Gap No. 5: The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in select areas.

Data Gap No. 7: The nature and extent of contaminants beneath the unconfined aquifer has not been evaluated.

Data Gap No.8: It is unknown if contamination within the RUM unit will adversely impact aquatic receptors in the Columbia River.

Data Gap No. 10: The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain.

Data Gap No. 13: Data are needed to better define the spatial and temporal distribution of groundwater contamination.

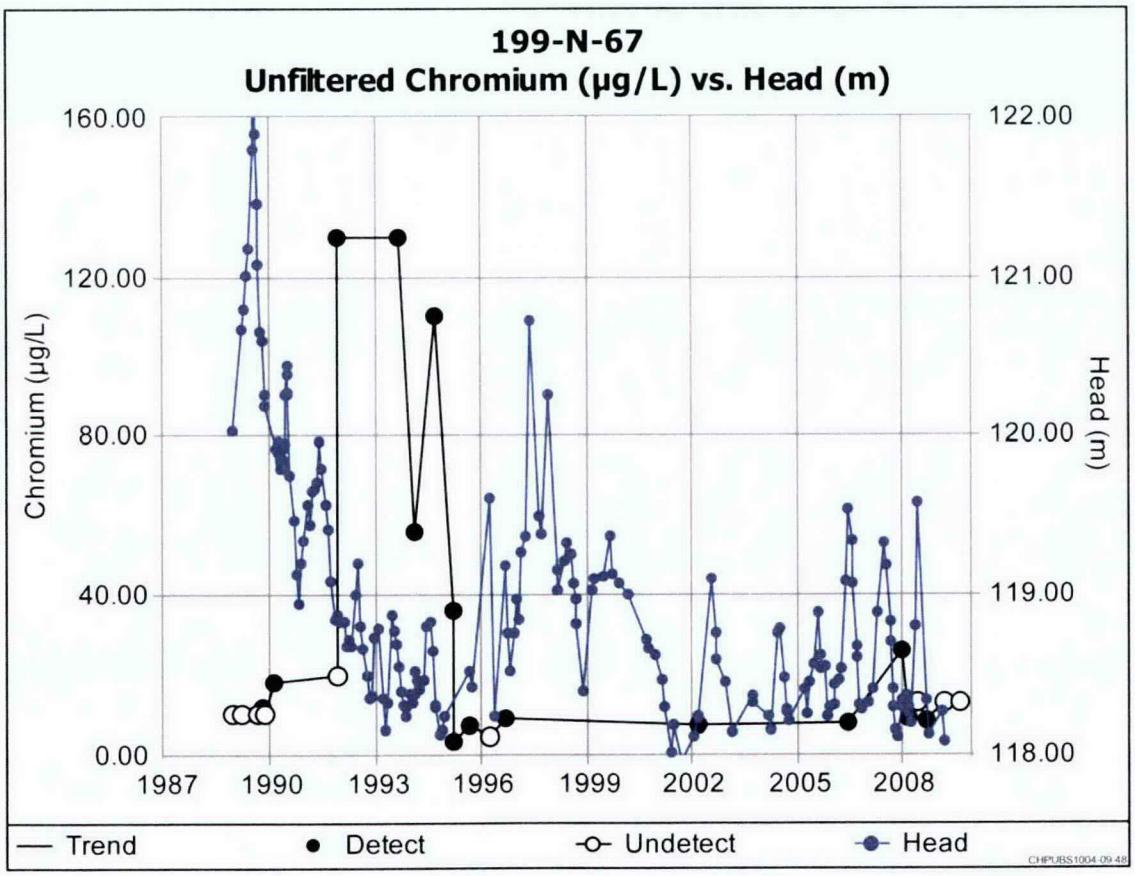


Figure 4-25. Comparison of Water Table Elevations and Chromium Concentrations over Time at Well 199-N-67

4.3.5 Tritium and Nitrate Migration and Distribution in the Unconfined Aquifer

Essentially, complete tritium and nitrate solubility causes these contaminants to move as water in the subsurface. Given the strong influence of crib discharges on groundwater movement during reactor operations and a good understanding of the tritium source term, the major characteristics of tritium migration and contaminant level changes over time at 100-N are easily explained. Unfortunately, uncertainty about nitrate source terms makes interpretation of its migration patterns in the unconfined aquifer equally ambiguous. Each is described in the following text.

At groundwater monitoring wells near 116-N-1 (1301-N) and 116-N-3 (1301-N), two periods of peak activity were observed. The first occurred in the early 1970s and the second in the late 1980s. Tritium contamination level peaks are shown in Figure 4-26 for groundwater monitoring Well 199-N-4, located between 116-N-1 (1301-N) and 116-N-3 (1301-N). The early peak occurs in the early 1970s and is attributed to tritium contaminated discharge through 116-N-1 (1301-N), a period when a substantial inventory (approximately 1,200 Ci) was reported in the wastewater. The second peak occurred in the late 1980s when 116-N-3 (1301-N) was the only operating crib. The end of this peak period coincides with the cessation of high volume discharges in 1991. Annual effluent release reports documented tritium concentrations at N-Springs between 1973 and 1989. The annual average concentrations (Figure 4-27) show essentially the same tritium level occurring in essentially the same time interval, again showing how rapidly discharged wastewater moved downgradient during reactor operations and how little dispersion occurred prior to arrival at the river shore.

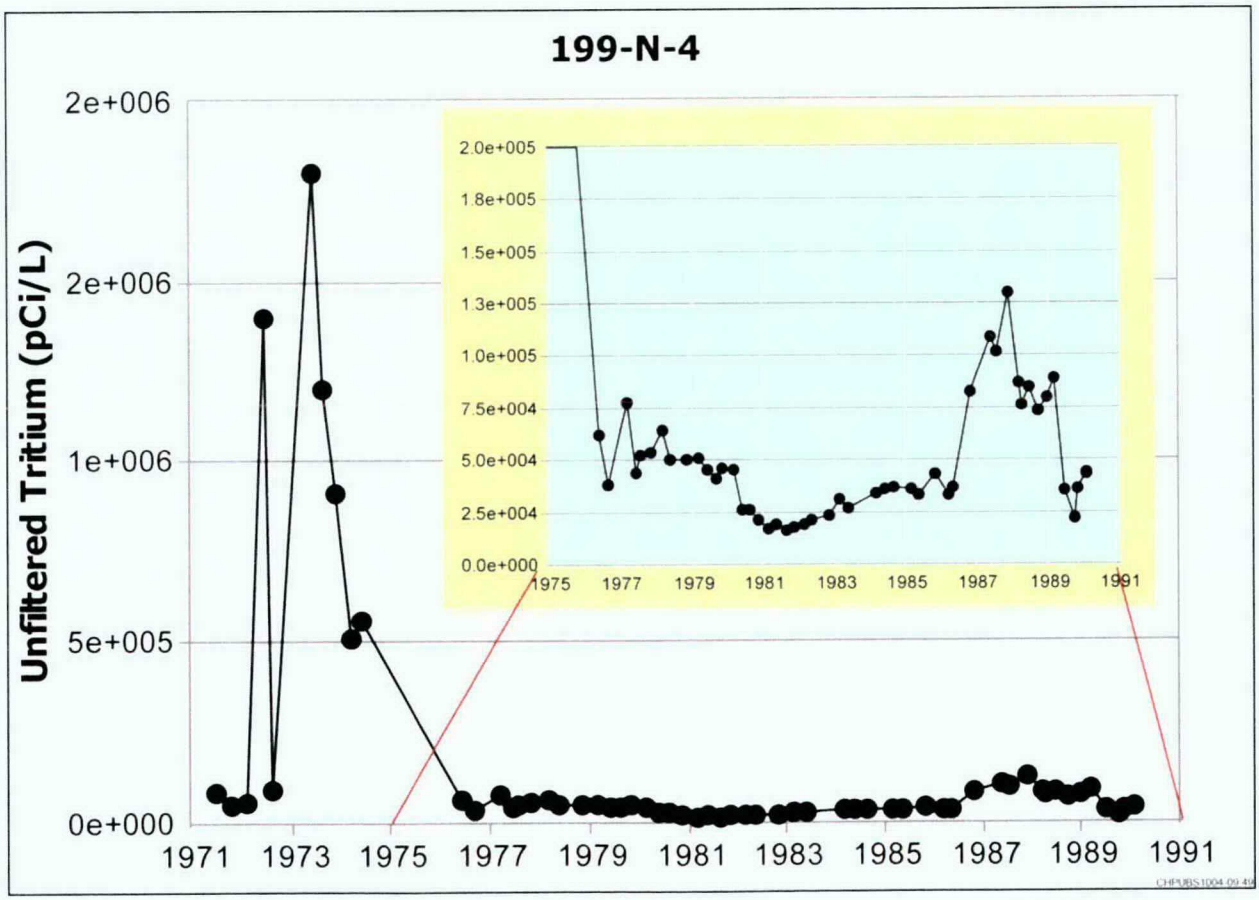


Figure 4-26. Tritium Contamination Levels (pCi/L) at Groundwater Monitoring Well 199-N-4

Following the cessation of reactor discharges, most tritium was present in the unconfined aquifer. Tritium migration rates slowed with the reduction in hydraulic gradient and contamination levels have been diminishing since then in most monitoring wells. Consistent monitoring data over the last two decades are available for a limited number of wells (e.g., 199-N-2, 199-N-3, 199-N-14, 199-N-27, 199-N-32, 199-N-75, 199-N-76, 199-N-80, 199-N-81) and all showed decreasing concentrations by factors between 2 and 10. Other wells, not analyzed for tritium after the mid-1990s (e.g., 199-N-4, 199-N-29, 199-N-31, 199-N-33, 199-N-36, 199-N-39, 199-N-43, 199-N-62, 199-N-66), showed concentrations above the 20,000 pCi/L DWS maximum activity concentration limit in their final analytical result. Longer term data suggest decreases in these wells are also occurring. The observations suggest that ongoing discharges from vadose zone sources, if any, are not significant and the observed decreases are primarily caused by natural radioactive decay. Average tritium measurements in all wells currently being used to collect tritium data are below 20,000 pCi/L and are expected to continue to decrease naturally.

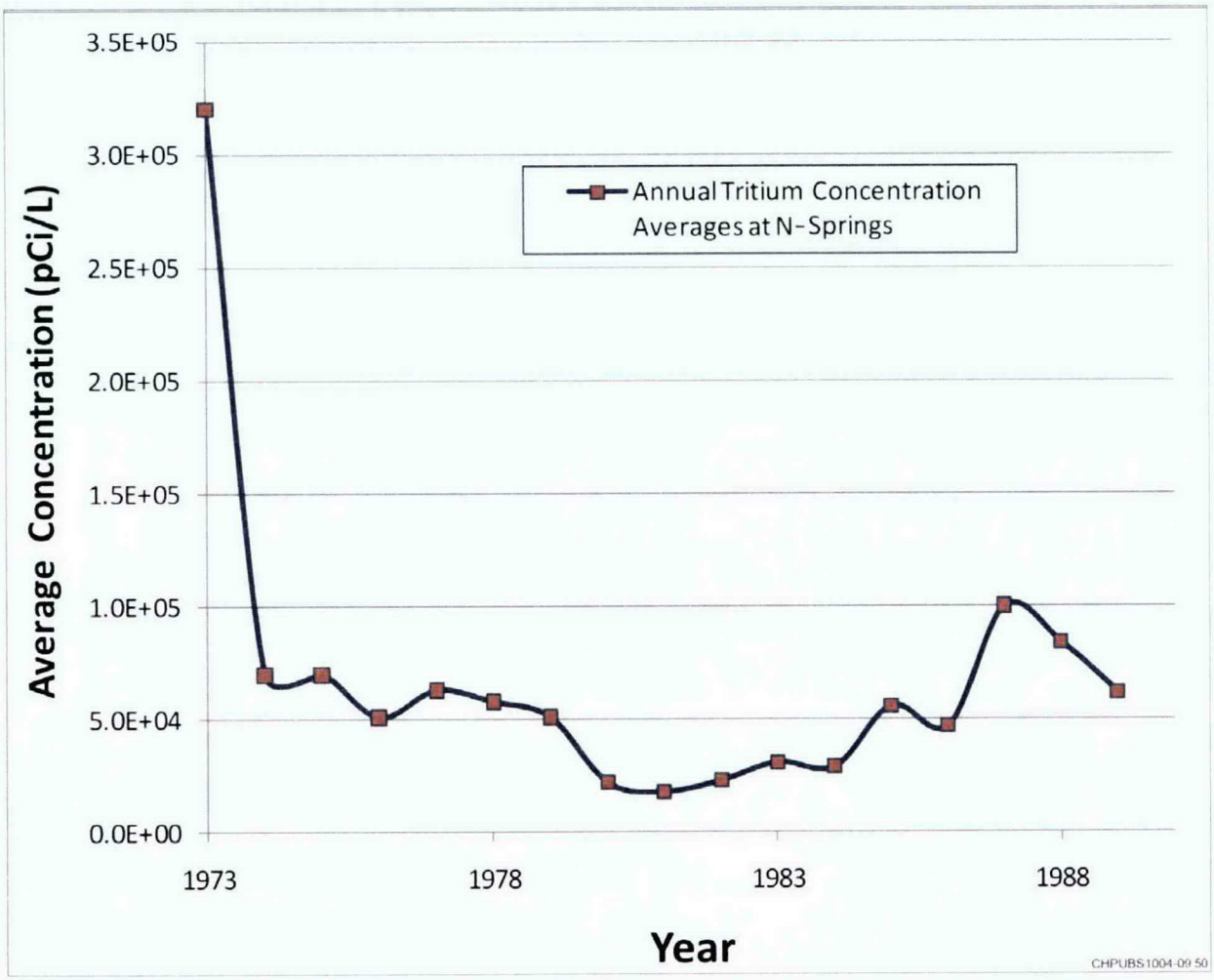


Figure 4-27. Annual Average Tritium Concentrations (pCi/L) at N-Springs (100 Area Liquid Effluent Reports)

The nitrate migration patterns indicated by groundwater monitoring data available since the early 1970s are difficult to interpret because of uncertainty about the source term or source terms, and incomplete chronological and spatial coverage for nitrate contamination levels. Only three monitoring wells around 116-N-1 (1301-N) were used to measure nitrate concentrations in the 1970s and few wells cover the

period from 1965 to present. One of the more complete records is available at Well 199-N-3, downgradient of 116-N-1 (1301-N) (Figure 4-28). Several characteristics are notable:

- In the mid-1970s, concentrations ranged from 5,000 to 10,000 µg/L. Similar nitrate contamination levels were measured in this period at Wells 199-N-4 and 199-N-5 near the 116-N-1 (1301-N) Crib and Well 199-N-14 north of the 116-N-1 (1301-N) Trench.
- By the early 1980s, nitrate concentrations began to rise, and in late 1985, a sharp nitrate peak occurred, followed by a rapid drop in concentration until about 1990. During the same time, this peak was measured at wells to the west, around 105-N and slightly earlier at some wells to the east around 116-N-3 (1301-N) in May 1985. High concentrations were generally between 100,000 and 150,000 µg/L around 116-N-1 (1301-N) and between 105-N and the river shore.
- Since about 1990, a general nitrate concentration increase began and has continued in contrast to water table elevations, which have decreased. This pattern occurs in numerous wells throughout the area. Highest concentrations are again generally between 100,000 and 200,000 µg/L around 116-N-1 (1301-N) and between 105-N and the river shore. One exception is a hot spot at 199-N-67, adjacent to 116-N-1 (1301-N), where concentrations have frequently exceeded 3,000,000 µg/L. Concentrations in other parts of the 100 Area are lower. Farther north along the river shore, concentrations are generally less than 50,000 µg/L. In the Columbia River substrate, off shore, aquifer tube data show concentration levels less than 10,000 µg/L.

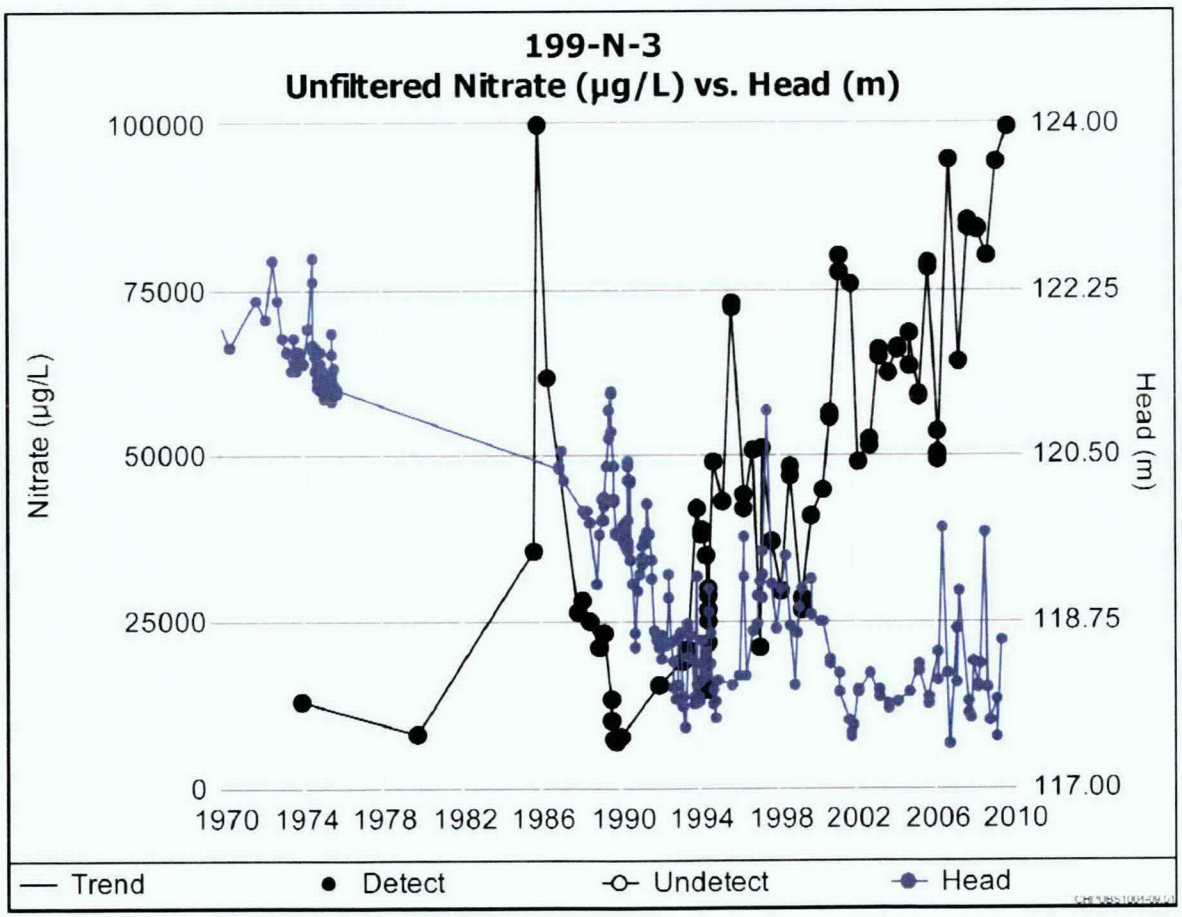


Figure 4-28. Nitrate and Head Measurements at Groundwater Monitoring Well 199-N-3 between 1970 and the Present

These data strongly indicate the primary sources of nitrate have been, and continue to be, upgradient of 100-N. If the primary sources of nitrate were in 100-N, then nitrate migration patterns should have mimicked the tritium pattern (Figure 4-29).

If so, nitrate should have been effectively flushed into the Columbia River during the operations period, leaving behind a dwindling plume. Instead, nitrate contamination levels began to increase after the high discharge period ended. Given that nitrate is highly mobile, its migration trend in the 1990s has reflected the prevailing hydraulic gradient imposed by regional hydrologic flow to the northwest and north.

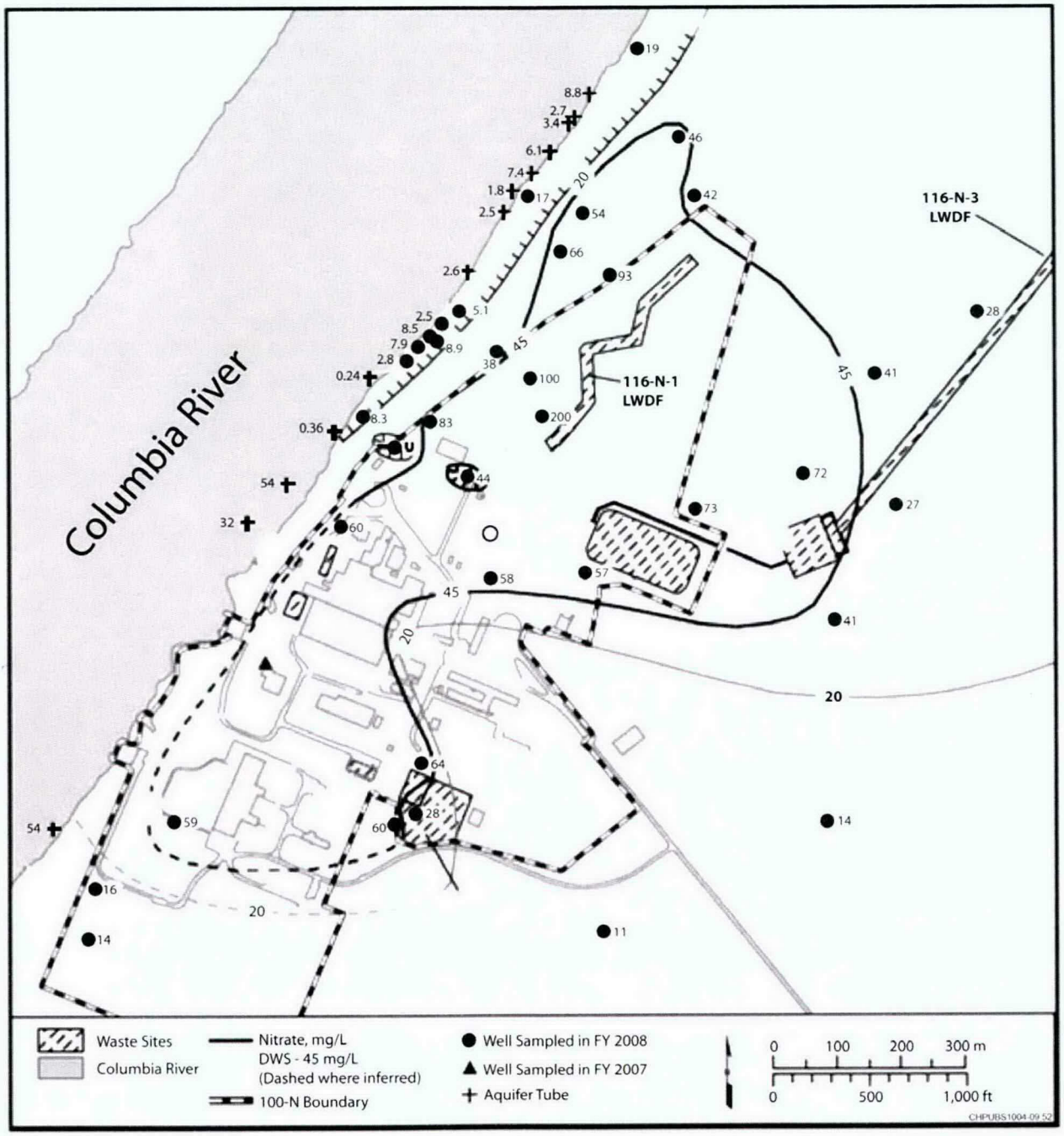


Figure 4-29. Current Regional Distribution of Nitrate in 100-N

The fact that the pattern shown in Figure 4-29 is repeated almost simultaneously in multiple areas suggests a broad contaminant plume over much of 100-N at the same time. If so, perhaps two plumes have entered the area, one in the early 1980s, and another in the early 1990s, which is still present. Finally, some additive and continuing contributions for 116-N-1 (1301-N) and 116-N-3 (1301-N) sources cannot be completely ruled out, given the apparent hot spot persisting just downgradient of 116-N-1 (1301-N).

The reason for the dip in the contour curve between 116-N-1 (1301-N) and 105-N (Figure 4-29) is not clearly understood. It is interesting to note that this area readily increases in water table elevation during high river stages (see Figure 4-15a). This commonality may indicate a zone where river stage effects are more efficient in removing nitrate.

Data Gap No. 5: The nature and extent of contaminants in the unconfined aquifer above cleanup standards has not been defined in select areas.

Data Gap No. 7: The nature and extent of contaminants beneath the unconfined aquifer has not been evaluated.

Data Gap No. 10: The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain.

Data Gap No. 13: Data are needed to better define the spatial and temporal distribution of groundwater contamination.

4.3.6 Application of the CSM to the Fate and Transport of Other Contaminants Discharged in the 100-N Area

In the previous sections, a CSM has been developed by considering the nature and extent of specific contaminants discharged in relatively large quantities into the environment at 100-N, primarily through 116-N-1 (1301-N) and 116-N-3 (1301-N) Trenches. The CSM can be applied to other wastewater contaminants present (e.g., radionuclides, heavy metals, and organic species). To apply the CSM for this purpose, key aspects recognizing differences in contaminant specific behavior influencing subsurface transport patterns must be considered.

Available subsurface soil characterization indicates substantial differences exist in the nature and extent of one contaminant versus another, despite the fact that contaminants discharged through the LWDFs were subjected to the same recharge history (very high recharge during operations and substantially lower recharge following reactor shutdown). These differences are largely attributed to variances in contaminant specific chemical reactivity. Three broad reactivity categories, and associated fate and transport, can be distinguished:

- First, nonreactive (e.g., tritium) and slightly reactive contaminants migrated rapidly through the vadose zone, into the unconfined aquifer, then the Columbia River with the recharge water. The CSM proposes a majority of the initial inventory entered the river during operations. However, a remnant inventory resides in the unconfined aquifer due to the abrupt, large decrease in recharge rates at the end of operations in the early 1990s. Discharge cessation slowed transport through the unconfined aquifer proportionately. These contaminants will continue to migrate at a much slower rate and will be the first to discharge completely into the river. The CSM proposes no significant nonreactive inventory remains in the vadose zone.

- Second, moderately reactive contaminants (e.g., strontium-90) transported at a slower rate during operations and, consequently, a smaller initial inventory fraction entered the Columbia River during

the operations period. Therefore, remnant inventory resides in both the aquifer and vadose zone (water and sediments). The remnant inventory is roughly proportional to the initial inventory. In the vadose zone, contaminants are found primarily in the upper vadose zone underneath the LWDF structures and in the portion of the lower vadose zone, which comprised the upper unconfined aquifer during operations. The CSM proposes contaminants in the upper vadose zone are not plausible sources of future contamination unless recharge conditions are greatly accelerated in the future. Contaminants in the lower vadose zone can enter the aquifer as the water table rises seasonally during high river stage but then resorb and migrate slowly thereafter.

- Third, the highly reactive contaminants (either sorption or precipitation) migrated the least distance from the facility/vadose zone interface and may not have been discharged into the unconfined aquifer despite the high recharge history. The CSM proposes that the great majority, if not all the initial inventory, remains in the upper vadose zone. The CSM presumes that this inventory is not considered a plausible source of unacceptable aquifer contamination in the future.

As noted in previous sections of this chapters, tritium, nitrate, and most chromium fall into the first category. Among the other radionuclides not discussed previously and potentially present in the subsurface, carbon-14, iodine-129, technetium-99, and the uranium inventory fraction that does not precipitate are also assigned to this category. Inorganic chemicals in this category include anionic species, such as chloride, sulfate, and fluoride, derived from rapid soluble compounds dissolution (acids and salts). Moderately reactive radionuclides include europium isotopes and neptunium-237. Ammonia and hydrazine may be partly mobile and partly reactive. A review of available technical publications suggests these species will sorb on clays and metal oxides, and ammonia can be broken down by soil bacteria. Because these conditions are not prevalent in vadose zone soil at 100-N, it is plausible that much of the inventory was highly mobile and has discharged into the Columbia River. Any ammonia or hydrazine still present in the vadose zone is well sorbed. Highly reactive radionuclides include cesium-137, cobalt-60, plutonium, curium, and americium isotopes. Highly reactive inorganic species include the heavy metals (e.g., cadmium, lead, mercury, nickel) and arsenic.

Determining the organic species mobility can be more difficult for several reasons. Depending on the species, there is a potential for loss of inventory through volatilization during the discharge process and degradation into reaction product species that are more or less mobile than the original species. Also, data describing mobility of a particular species, either generally or for site-specific conditions, are frequently unavailable. Examples of mobile organic species include naphthalenes, chloroform, and morpholine (*Compilation of Data to Estimate Groundwater Migration Potential for Constituents in Active Liquid Discharges at the Hanford Site* [PNL-7660]). Examples of reactive species include phthalates and Aroclor.

None of the contaminants discussed in this section are currently found in the unconfined aquifer at significant concentrations. While exclusion of these and other contaminants as potential aquifer contaminants cannot be demonstrated absolutely, no likely candidate is currently apparent. The great majority of mobile contaminant inventories should have passed through the vadose zone and unconfined aquifer during operations. For contaminants remaining in the vadose zone, factors restricting transport include retardation by chemical reactivity, insufficient recharge rates, and radioactive decay. Additionally, many contaminants are likely not present in large enough quantities to contaminate the aquifer above acceptable levels, regardless of other factors. Any groundwater results that exceed water standards (aquatic, MCLs) will be evaluated and discussed in the RI Report.

Data Gap No. 10: The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain.

Data Gap No. 12: Insufficient data are available to support fate and transport modeling.

4.4 Potential Contamination below the Unconfined Aquifer

As described in Chapter 2, the RUM unit is considered an aquitard and separates the unconfined aquifer from the deeper confined aquifer. The hydraulic conductivity of the RUM unit within 100-N is not well known. Channels were eroded into the top of the RUM unit, which established an undulating surface throughout the 100 Area. Figure 2-16 shows RUM unit elevations within 100-N. The Ringold unit E overlies the RUM unit and is typically fluvial gravels with lesser amounts of sand, silt, and clay, with variable and locally discontinuous cementation. Most of the monitoring wells in 100-N are screened in the top 6 m (20 ft) and monitor contaminants in the unconfined aquifer. Two wells (199-N-80 and 199-N-8P) are screened within sandy layers encountered within the RUM unit. Confirmation of the hydraulic properties of the RUM unit and the potential presence of contamination are needed to support the CSM with respect to the effects of the RUM unit on water movement and contaminant transport and any impacts to potential aquatic receptors in the Columbia River.

Data Gap No. 7: The nature and extent of contaminants beneath the unconfined aquifer has not been evaluated.

Data Gap No. 8: It is unknown if contamination within the RUM unit will adversely impact aquatic receptors in the Columbia River.

Data Gap No. 10: The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain.

Data Gap No. 12: Insufficient data are available to support fate and transport modeling.

4.5 Human Receptors and Exposure Pathways

A number of evaluations of exposure of human receptor pathways to contaminants in the 100 Area have been conducted in support of remediation. Activities performed include the LFIs and qualitative risk assessments (QRAs) to support interim action ROD remedy selection. In addition, the cleanup verification process following remedial actions under interim action RODs includes an evaluation of human exposure and assessment of risk for each waste site. Ongoing exposure evaluation and risk assessment activities include the Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment (DOE/RL-2007-21), which further evaluates the protection of human health using exposure scenarios reflecting future potential land uses not defined during past risk assessment activities. Additional ongoing human health exposure evaluation and risk assessment activities pertaining to 100 Area Hanford Site contaminants include the remedial investigation for Hanford Site releases to the Columbia River. These evaluations are discussed in detail in Chapter 4 of the integrated work plan. In addition, Chapter 4 of the integrated work plan discusses uncertainties associated with the risk assessment results and the additional information needed to reduce these uncertainties. An evaluation of the results from current monitoring programs indicates selected groundwater monitoring is considered necessary to characterize the spatial, temporal, and chemical extent of groundwater contamination. For source units in 100-N, DOE plans to evaluate all waste sites that currently have an "interim closed" or "no action" reclassification status in the RI report. Where available, the verification data from these waste sites will be compared to Preliminary Remediation Goals (PRGs) to determine which sites will require further evaluation in the FS. PRGs will be developed to address multiple exposure pathways for human health and ecological protection, protection of groundwater, and consideration of applicable or relevant and appropriate requirement (EPA).

Data Gap 13: Data are needed to better define the spatial and temporal distribution of groundwater contamination.

4.6 Ecological Receptors and Exposure Pathways

Exposure of ecological receptors to 100 Area contaminants has been characterized in support of remedial action decisions. Initially, to support remedial decisions of interim action RODs, a streamlined evaluation of exposure and risk to ecological receptors was conducted in the QRAs (*Qualitative Risk Assessment for the NR-1 Source OU* [BHI-00054, Rev. 01] and *Qualitative Risk Assessment for the NR-2 Source OU* [BHI-00055, Rev. 01]). Subsequently, an analysis of the receptors in 100-N was provided in DOE/RL-2006-26. Additional receptor information will be provided in the River Corridor baseline ecological risk assessment (DOE/RL-2007-21). A detailed exposure pathways description and the ecological receptors evaluated are provided in DOE/RL-2007-21.

4.7 Identification and Resolution of Data Needs

During the 100-N planning workshops, before and after issuing Draft A and B of this addendum, discussions were held to identify the extent of new information needed to support reducing existing uncertainties to refine the CSM and decision making in a final ROD. The data gaps and needs discussed herein resulted from the planning process, and were further refined during preparation of this addendum and in response to comments on the Draft A and Draft B version.

The evaluation of site-specific conditions at 100-N indicates that not all data gaps are applicable but all have been kept in the discussion to maintain consistency with the other addenda and to indicate a level of comprehensiveness not achievable if some were eliminated. The justification used to indicate a data gap was "not applicable" is provided and considered an important part of the overall planning process.

Table 4-7 lists the data gaps and associated data needs, and summarizes the required scope of work planned to address each. Data gaps are general statements indicating insufficient information is available to support decision making. Data needs are analytical (laboratory sample results), quantitative (sample geographical coordinates), and process-related (fate and transport calculations) would fill the data gap. Some work scope will address multiple data gaps. Data gaps are presented in the Executive Summary, and data needs are discussed below.

Implementation details are found in the SAP (DOE/RL-2009-42). Tables 4-8 and 4-9 summarize the field program necessary to fill the data gaps.

4.7.1 100-N Data Needs—Source Areas

Data needs specific to sources (soils) are identified and described in this section.

Data Need No. 1: Characterize unremediated waste sites to assess nature and extent of contamination in the vadose zone.

Data Need Description: Continue interim remedial actions. Obtain data documenting the remaining residual contamination following completion of the interim remedial action. Remediation in 100-N began in 1999 under remedial authority of an interim action ROD and continues to the present. Ongoing soil remedial action efforts include remedial action planning, implementation, site verification and interim closeout, backfill, and revegetation. Remedial action schedules are driven by enforceable milestones established as part of the Tri-Party Agreement (Ecology et al., 1989a) and a CERCLA statutory requirement(s).

The unremediated waste sites associated with this data need remain, and will be addressed according to the Interim Action ROD (EPA/ROD/R10-99/112) or a future ROD. Data needs associated with soil remedial actions in 100-N will be met by planning and scheduling the remedial actions, collecting data to

verify waste sites cleanup, and obtaining regulatory concurrence on the achievement of remedial action goals for direct exposure, and protection of groundwater and surface waters.

The implementation of interim remedial actions for the 108 unremediated sites is described and directed by *Remedial Design Report/Remedial Action Work Plan for the 100-NR-1 Treatment, Storage, and Disposal Units* (DOE/RL-2000-16) and *Remedial Design Report/Remedial Action Work Plan for the 100-N Area* (DOE/RL-2005-93). This addendum recognizes these data are an important source of information for assessing contaminant distribution, direct exposure, and protecting groundwater and the Columbia River. After the unremediated sites are addressed according to the Interim Action ROD (EPA/ROD/R10-99/112), additional characterization (borehole/test pits) at selected sites will be evaluated with the agencies.

Accepted and discovery waste sites within this data need are identified in Section 2.1.3 of this addendum. Appendix B provides the description and history for each waste site. Locations of the 100-N waste sites are shown in Appendix C.

Data Need No. 2: Characterize beneath and adjacent to remediated waste sites to assess the nature and extent of contamination in the vadose zone.

Data Need Description: Fifty-eight waste sites, of which 17 are interim closed and 3 are closed (Appendix C Maps), have been remediated or dispositioned in accordance with an interim action ROD or other regulatory mechanism (Table 4-1). The data and information available for interim closed and closed sites were reviewed for contaminant fate and transport, site remediation, risk assessment, and environmental modeling and evaluated by subject matter experts. Descriptive information on these sites and a summary of characterization conducted is provided in Table 4-10. The following criteria were considered in deciding which waste sites would be characterized further: site type, remediation depth in relation to the engineered structure, characterization greater than the remediation depth, completeness of CVP analytes, and Model Toxics Control Act—Cleanup Levels (WAC 173-340).

Waste site 100-N-63:1, the radioactive process sewer, had contaminants reported in other sources and omitted from the CVP. However, soil concentrations for most radioactive contaminants analyzed were below interim remedial action cleanup goals (Table 4-10). Four contaminants (Co-60, Cs-137, Ni-63, and Sr-90) exceed 1,000 pCi/g at depth greater than 4.6 m (15 ft) bgs (Table 4-10).

Waste sites 116-N-1 and 116-N-3 have contamination below their maximum remediated depths (4.6 to 6.5 m [15.1 to 21.3 ft] bgs), contaminants reported in other sources were omitted from the CVP, and for 116-N-1, contamination increases with depth (see Table 4-10). Pre-remediation data for 116-N-1 indicated Sr-90, uranium-234/235, potassium-40, tritium, and nitrate were present beneath and adjacent to this waste site. RESRAD modeling (using 2002- and 2006-accepted input parameters and assumptions DOE/RL-2005-93, Rev. 0) and protectiveness comparisons for 116-N-1 predict that residual tritium, Cr(VI), and nitrate concentrations are protective of groundwater and the river (CVP-2006-00004). The 95 percent UCL activities for Co-60 and Cs-137 at 116-N-3 (exceed 3,000 pCi/g at depths greater than 4.6 m (15 ft) bgs (Table C-1). Based on this information for 116-N-1 and 116-N-3, three new characterization boreholes (two at 116-N-1 and one at 116-N-3) will be constructed to address uncertainties regarding the groundwater and Columbia River protectiveness afforded by interim remedial actions at these sites and to support final decision making.

Based on this evaluation, two interim closed and no closed sites were identified for further soil characterization to address CSM uncertainties regarding contaminant distribution in the vadose zone and groundwater protection. Excavation and removal of waste site contamination, cleanup verification

sampling and analyses, and previous borehole characterization data eliminate the need for additional drilling at these 15 interim closed and 3 closed sites.

Data Need No. 3: Characterize beneath and around the reactor structures to assess nature and extent of contamination in the vadose zone.

Data Need Description: Data are needed to determine the nature and vertical extent of contamination in the vadose zone around reactor structures (105-N Reactor and fuel storage basin).

There is a concern at 100-N that there may be chemicals and/or radionuclides beneath and/or around the reactor structures that are adversely affecting groundwater quality.

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath unremediated waste sites.	1	Characterize below unremediated waste sites to assess nature and extent of contamination in the vadose zone.	Continue interim remedial actions as they have been demonstrated to be efficient in obtaining the necessary data during remediation using the observational approach. Obtain data documenting the remaining residual contamination following completion of the interim remedial action.	Yes	Complete interim remedial action and sampling as applicable following the 100-N Remedial Action Work Plan (DOE/RL-2005-93) at waste sites in the 100-NR-1 OU. The location of unremediated waste sites is shown in Appendix C. This work will be completed during field remediation and the results for remediation of approximately 15 to 20 waste sites are expected to be available for use in the RI/FS Report.	The remedial action directed by the interim RODs is needed to protect human health and the environment. Data collected at the completion of remediation will be used to assess risk for direct exposure, protection of groundwater, and protection of the Columbia River.
Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath remediated waste sites.	2	Characterize beneath and adjacent to remediated waste sites to assess the nature and extent of contamination in the vadose zone.	Drill 3 boreholes (complete as wells under work scope).	Yes	Drill 2 boreholes (complete as monitoring wells) through/in the 116-N-1 (1301-N) LWDF. Drill 1 borehole (complete as a monitoring well) through/in the 116-N-3 (1301-N) LWDF.	Characterization will verify the effectiveness of interim remedial action, address uncertainty regarding nature and extent of remaining contamination in soils (including target analytes from Table 1-2 and COPCs from Table 1-3 of the SAP), verify the conceptual site model, and support decision making for the final ROD for 100-N. These data will confirm modeling input parameters, assumptions, and predictions regarding contaminant migration. CVP and other data will be used to assess risk for direct exposure, protection of groundwater, and protection of the Columbia River.
Vadose zone contaminant nature and extent needed to assess protection of groundwater beneath and around reactor structures.	3	Characterize beneath and around the reactor structures to assess nature and extent of contamination in the vadose zone.	Data are needed to determine the nature and extent of contamination beneath and around reactor structures (105-N and 109-N Reactor/Heat Exchange Building). One borehole will be drilled near the reactor buildings in the area likely to contain soil contamination (currently proposed location is beneath the fuel storage basin). Samples will be collected and analyzed to assess vertical extent of contamination in the vadose zone. The borehole will be completed as a groundwater monitoring well.	Yes	Continue contaminated soil and structure removal and sampling of waste sites around and associated with the 105-N/109-N sites. Follow Removal and Remedial Action Work Plans (*Removal Action Work Plan for 100-N Area Ancillary Facilities*, [DOE/RL-2002-70], *Removal Action Work Plan for 105-N Buildings Interim Safe Storage and Related Facilities* [DOE/RL-2005-43], and DOE/RL-2005-93). Drill one borehole (complete as a groundwater monitoring well under work scope) in the boundary of the 118-N Reactor Fuel Storage Basin. Future documentation will cover this work scope.	The reactor fuel storage basin was selected for characterization due to documented releases (UPR-100-N-35) and contaminated groundwater upwelling in the river that occurs upriver to the LWDFs. The ongoing facility removal and remediation programs provide an efficient mechanism to identify reactor building waste sites. This program provides data after remediation to assess the potential for residual contamination at the remediated depth to have a negative impact in the area of the reactor buildings. However, characterization beneath and around the reactor structure(s) in an area most likely to contain soil contamination (i.e., associated with liquid waste management) is needed to assess nature and extent of contamination in the deep vadose zone. Due to the 118-N Reactor Fuel Storage Basin remediation schedule, it is not anticipated vadose zone characterization information will be available to support final ROD remediation decisions. However, it is anticipated that the 118-N Reactor Fuel Storage Basin vadose zone characterization information will be available to support the 4th CERCLA ROD five-year review (~2016). Therefore, this characterization activity is not included in the RI/FS SAP (DOE/RL-2009-42, Rev. 0).
Unidentified waste sites (orphan/ discovery sites) may exist in 100-N.	4	Identify new waste sites and potential sources of contamination.	Complete orphan site evaluation process in 100-N. Continue to use the waste site discovery process as needed.	Yes	*The 100-N Area Orphan Sites Evaluation Report* (OSR-2009-0001, Rev. 0) has been issued (12/17/09). The waste site discovery process will continue to be used through the end of the 100-N remediation project.	The orphan site evaluation and waste site discovery process identifies new waste sites and sources that are not in CERCLA decision documents.

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
The nature and extent of contamination in the unconfined aquifer above cleanup standards has not been defined in select areas.	5	Define additional groundwater needs to support groundwater remediation decisions.	Evaluate the potential for known Sr-90 "hot spot" to impact remedial actions and define the scope of the petroleum contamination. Evaluate groundwater quality at locations of high-volume waste disposal, known releases, where information indicates potential groundwater contamination, or where CSM verification is needed.	Yes	Well No. 1 is planned to define the extent of the Sr-90 "hot spot" adjacent to and downgradient of 116-N-1 (1301-N) and serve as an indicator of movement. Well No. 1 will also help define the contamination relating to diesel fuel spills. Well No. 2 is planned to define the nature and extent of contamination relating to diesel fuel spills in the vicinity of Well 199-N-18. Wells 3 and 4 are planned to characterize beneath the interim remediated waste site 116-N-1 (1301-N) to assess the nature and extent of contamination in the vadose zone beneath the extent of the interim remediation and groundwater. Well No. 5 is planned to characterize beneath the interim remediated waste site 116-N-3 (1301-N) to assess the nature and extent of contamination in the vadose zone beneath the extent of the interim remediation and groundwater. Well No. 6 is proposed to define the known extent of hexavalent chromium in groundwater associated with 100-K. Additionally, samples from the existing groundwater monitoring wells will be analyzed for hexavalent chromium to help delineate the 100-K plume, as it exists near 100-N. These results will be shared with the 100-KR-4 Groundwater Project. Sampling these 6 new wells, 7 existing site-specific groundwater monitoring wells, and 2 existing and 2 new aquifer tube arrays will be in accordance with the SAP (DOE/RL-2009-42, Rev. 0). Collect additional data (including from upgradient wells) and evaluate 100-N groundwater monitoring data as necessary to better understand nitrate contamination.	A new well is planned to better define the extent of Sr-90 "hot-spot" and address the impact of any potential movement on proposed remedies. A second new well is planned near the petroleum spill to support remedy selection and potentially to support remediation. New wells (2) are planned at the 116-N-1 (1301-N) LWDF and 1 at the 116-N-3 (1301-N) LWDF to evaluate the adequacy of remediation to date, groundwater quality post-interim remediation, and determine if additional Sr-90 "hot spots" exist that may impact remedial actions. The wells will verify the CSM for Sr-90 transport to groundwater through contaminated vadose zone and verify the CSM for chromium. Sampling results will determine groundwater quality for RCRA permitted waste constituents, and determine groundwater quality for COPCs, including trends. A new well is planned at the 118-N Reactor Fuel Storage Basin to evaluate the adequacy of remediation, groundwater contamination post-interim remediation, determine if additional Sr-90 "hot spots" exist, and determine groundwater quality for COPCs. Existing site specific groundwater monitoring wells (7) will be sampled per the SAP (Well 199-N-72 will be sampled based on its proximity to the 1324-N/NA Surface Impoundment, Well 199-N-41 based on its proximity to the 116-N-3 [1301-N] LWDF, and for additional COPCs; Well 199-N-18 will be sampled based on past contaminant observations, and its location; Well 199-N-96A will be sampled based on its location; Well 199-N-67 will be sampled due to its "hot spot" location and previous contaminant observations; Wells 199-N-99A and 199-N-147 will be sampled due to their proximity to the shoreline and their downgradient location to the Sr-90 groundwater contamination sources). Existing aquifer tubes (C6321, C6322, C6320, C6263, C6264, and C6265) will be sampled due to their proximity to the 118-N Reactor Fuel Storage Basin, lack of groundwater monitoring wells downgradient to the fuel storage basin, river groundwater upwelling characterization information, proximity to HGP settling pond and transformer yard, and lack of groundwater monitoring wells downgradient to the settling pond and transformer yard. New aquifer tubes (C7934, C7935, C7936, C7937, C7938, and C7939) were added and sampled in the area of the 100-N-79 Emergency Spillway. Chromium contamination is migrating from 100-K. Extent of contamination is not adequately understood. Encroachment of the 100-K chromium plume may impact the remediation associated with 100-KR-4 and/or 100-NR-1 and 100-NR-2 OUs. Nitrate concentrations have increased in certain 100-N wells, indicating the need to refine the CSM.

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
The level of groundwater contamination entering the Columbia River (in particular, the hyporheic zone) is not well known.	6	Evaluate the utility and/or adequacy of aquifer tubes in understanding groundwater contamination entering the Columbia River. Collect groundwater upwelling data and information.	Groundwater contamination at N-Springs and 100-N has been studied and modeled (HydroGeoLogic, Inc., 2004) since shortly after the start of N Reactor Operations. More recently, aquifer tubes have been added to support estimates of groundwater discharge to the Columbia River. Recent data indicate upwelling of Sr-90 into the river is occurring near the N Reactor outfall and spillway. Investigating this issue requires installing two aquifer tube arrays to address the extent of the plume associated with Sr-90 upwelling in the river. Groundwater discharge to the river at concentrations above water quality standards has been documented at 100-N (river groundwater upwelling and/or aquifer tubes). Groundwater upwelling sampling and analysis in the Columbia River channel took place in 2010 (DOE/RL-2008-11 and DOE/RL-2010-69). It is expected data will provide further insight regarding contaminant levels entering the river through the hyporheic zone and groundwater/river mixing ratios within the biotic zone. (upper 30 cm [~12 in.] of substrate).	Yes	Review groundwater upwelling samples from the Columbia River. Sample two new aquifer tube arrays to evaluate the presence and location of Sr-90 in the unconfined aquifer upgradient from the contaminated pore water detected near the outfall and spillway. Continue collecting aquifer tube data and information per the existing program and SAP (DOE/RL-2009-42, Rev. 0). Collect groundwater upwelling samples in the Columbia River (*Sampling and Analysis Plan for the 100-NR-2 OU River Pore Water Investigation* [DOE/RL-2010-69]). In addition, a task is included in the Integrated 100 Area RI/FS Work Plan (DOE/RL-2008-46) for evaluating and developing an approach for obtaining data demonstrating compliance with ambient water quality criteria in the river, for final ROD decisions. For this task, data may be needed to show representativeness of contaminant concentrations for compliance.	Data will support the evaluation of what and how much contamination reaches the river. Expert panel report (*Technical Evaluation of the Interaction of Groundwater with the Columbia River at the Department of Energy Hanford Site, 100-D Area* [SGW-39305]) suggests re-evaluation of the current mixing/dilution conceptual model.

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
The nature and extent of contaminants beneath the unconfined aquifer has not been evaluated.	7	Collect and analyze samples to characterize the soil and groundwater quality in the RUM.	Sr-90 has been detected at the Ringold "E" and Ringold upper mud contact (Well 199-N-122). Chromium and tritium have been detected in Well 199-N-80 (completed beneath the unconfined aquifer) above the ambient water quality criteria (AWQC) and DWS. The presence of other indicator contaminants has also been detected in Well 199-N-80. Limited data indicate there is contamination in the upper few feet of the RUM unit over DWS (total chromium in Well 199-N-80). The nearly 21.6 m (70 ft) silt unit is generally considered to possess low transmissivity. However, sandy pockets are known to exist that can be highly transmissive. Very limited information on the lithology, soil properties, and the depth to which contamination may exist is available.	Yes	Drill and sample soil and groundwater from two new wells drilled approximately 15.24 m (50 ft) into the RUM unit. The locations are shown as boreholes R1 and R2 (DOE/RL-2009-42, Rev. 0).	Only two wells (199-N-80 and 199-N-8P) have been installed in the RUM unit in 100-N. Total chromium has been detected in one of the wells above water quality standards. Groundwater contaminant concentrations in 100-N remain above the aquatic (AWQC) and DWS in wells completed beneath the unconfined aquifer. Two wells completed in the RUM unit will assess potential sand lenses and confirm its aquitard nature.
It is unknown if contamination within the RUM unit will adversely impact aquatic receptors in the Columbia River.	8	Update bathymetric data for the river within 100-N to support calculations of contaminant transport to the river and ecological receptors.	Ecological receptors (e.g., salmon redds) have been identified within the river. In order to evaluate flow paths of contaminants to receptors (particularly from beneath the unconfined aquifer), updated and accurate bathymetric data for the river are needed. Groundwater upwelling sampling and analysis in the Columbia River channel was conducted and it is expected to provide information regarding the effect of the RUM on groundwater upwelling into the Columbia River.	No	The digital bathymetric data will be evaluated to better understand the relationship between the riverbed and the 100-N geology to determine if the RUM intersects the river.	Confirmation is needed that the confining unit (RUM) does not intersect the Columbia River at 100-N.

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
The rate of chemical and hydraulic exchange between the aquifer and the river in the near shore is unknown.	9	Collect geochemical and hydrogeologic data to evaluate near-shore area groundwater contaminant fate and transport.	The near-shore area is directly affected by river stage. The study of N-Springs historical information, past modeling, and the recent addition of the apatite barrier under treatability tests have provided reasonable estimates of groundwater/river interactions. Although limited data are available to entirely understand groundwater flow paths, contaminant migration, and mixing in the near-shore area, additional remediation technology optimization studies are underway for a near-shore permeable barrier from which additional data will be obtained while evaluating the implementation of the remediation technology. The IROD identifies this as a remedial action goal. Tri-Party Agreement milestones state compliance with cleanup standards in this area is a target.	Yes	Although no specific data collection activities are proposed in this RI, data from historical work and other ongoing efforts (Design Optimization Studies) will be used in the RI/FS when available in time to support the schedule for completion of the RI/FS.	This information will be used during preparation of the 100-N feasibility study and ultimately to support the final ROD. Due to the schedule of ongoing testing, it is not anticipated all of the data will be available and/or evaluated to support final ROD remediation decisions. However, it is anticipated information will be available to support the 4th CERCLA ROD five-year review (~2016).
The mass distribution in the subsurface within the vadose zone, periodically rewetted zone, aquifer, and aquitard for select contaminants is uncertain	10	Vadose and groundwater information is needed to better evaluate the extent of contamination remaining from: past high-volume liquid waste disposal, past petroleum leaks, and past fuel storage basin releases and other interim remediated sites.	Soil and water analyses are needed to determine the potential for waste sites and "hot spots" to contain sufficient contamination to be a continuing source of groundwater contamination.	Yes	Through this RI, drill and sample soil and groundwater from a total of 3 new boreholes completed as wells in interim remediated waste sites—2 in. 116-N-1 (1301-N) LWDF (Wells 3 and 4) and 1 in. 116-N-3 (1301-N) LWDF (Well 5). Drill and sample soil and groundwater from 1 new borehole in the 118-N Fuel Storage Basin; future documentation will be provided to cover this scope of work. Drill and sample soil and groundwater from 2 new boreholes drilled 15.24 m (~50 ft) into the RUM (Wells R1 and R2). Drill and sample soil and groundwater from 1 new borehole (completed as a well) drilled 1.5 m (~5 ft) into the RUM (Well 1). Drill and sample soil and groundwater from 1 new borehole (completed as a well) in the petroleum plume. Data from historical work and other ongoing efforts (Phase I and II Deep Zone In Situ Bioremediation/Bioventing Project) will be used in the RI/FS when available in time to support the schedule for completion of the RI/FS. Drill and sample soil and groundwater from 1 new borehole (completed as a well) to determine potential influence of 100-K hexavalent chromium plume on 100-N groundwater quality (Well 6). Sample 7 site-specific groundwater monitoring wells.	These data are primarily needed to evaluate the adequacy of remedial actions taken to date. In addition, these data are needed to evaluate alternative CSM components and to define the nature and extent of remaining (post-remediation) deep vadose zone, groundwater, and RUM contamination. This information will support better understanding of contaminant transport TPH contaminant characterization to date does not fully define the lateral and upgradient boundaries of the TPH diesel contamination zone (WCH-370, Rev. 0). An understanding of contaminant distribution is needed to design a bioremediation well field (*Bioventing Pilot Study Summary Report Deep Zone Petroleum Contamination*, Draft [AMEC, 2010]).

Table 4-7. Identified Data Gaps and Needs for 100-N (2/08/2011)

Data Gap	Data Need Number	Data Need	Description	Additional Data Collection Recommended?	Scope of Work	Justification
Potential alternative remedial technologies for groundwater have not been sufficiently tested.	11	Test potential remedial technologies to determine if remedial action goals can be met. Currently, petroleum bioremediation and Sr-90 permeable reactive barrier testing, and phytoextraction testing is underway.	Groundwater contamination above groundwater quality standards has been detected at 100-N. Interim remedial action groundwater pump-and-treat for Sr-90 was terminated. Permeable reactive barrier testing and phytoextraction for Sr-90 treatment is being conducted. In addition, bioremediation testing for petroleum contamination is underway. Data collected under the permeable reactive barrier treatability and the bioremediation treatability test plans will be used in the RI/FS.	Yes	Although no specific data collection activities are proposed in this RI, data from historical work and other ongoing efforts (permeable reactive barrier testing, phytoextraction for Sr-90, and bioremediation) will be used in the RI/FS when available in time to support the schedule for completion of the RI/FS.	This information will be used during preparation of 100-N feasibility study and, ultimately, to support the final ROD. Due to the schedule of ongoing testing, it is not anticipated that all of the data will be available and/or evaluated to support final ROD remediation decisions. However, it is anticipated that information will be available to support the 4th CERCLA ROD five-year review (~2016).
Insufficient data are available to support fate and transport modeling.	12	Collect additional data to support future fate and transport modeling. Assess the physical and hydraulic properties of soil and confirm contaminant distribution coefficients to support modeling.	Measure groundwater levels beneath the high volume liquid waste disposal sites. Measure sediment moisture content in boreholes associated with the high volume liquid waste disposal sites. On selected soil samples, estimate soil properties, hydraulic properties, determine contaminant levels, and perform batch leach testing.	Yes	Through this RI, collect and analyze soil samples from (1) each of the two deep boreholes proposed (see R1 and R2 [DOE/RL-2009-42, Rev. 0]), (2) three boreholes (completed as wells) drilled through remediated waste sites Wells 3, 4, and 5 (DOE/RL-2009-42, Rev. 0), (3) one borehole (completed as well) in petroleum plume, (4) one borehole (complete as a well) in Sr-90 "hot spot" (Well 1), and (5) one borehole (completed as a well) in area near 100-K hexavalent chromium plume (Well 6). Perform batch leach test. Measure groundwater levels and sediment moisture content (DOE/RL-2009-42, Rev. 0).	These data will be used in fate and transport modeling as part of interim ROD remedial activities (e.g., RESRAD for radiological contaminants) and later to support final remediation decisions (e.g., STOMP, ModFlow, etc., for nonradiological contaminants). Groundwater elevations will be used to satisfy groundwater elevation measurement requirements.
Data are needed to better define the spatial and temporal distribution of groundwater contamination.	13	Collect and analyze groundwater samples from select groundwater monitoring wells.	Additional groundwater data are needed that are spatially representative of the area, reflect river stage influence, and include groundwater COPCs.	Yes	Collect groundwater data that chemically, spatially, and temporally represents the groundwater beneath 100-N. Eighteen existing wells (DOE/RL-2009-42, Rev. 0) will be sampled and analyzed for this purpose.	This spatial/temporal groundwater data is needed to address uncertainties associated with the initial groundwater risk results.

Table 4-8. Proposed 100-N Characterization

Type	100-N
New boreholes/test pits (vadose zone)	0
New wells (unconfined aquifer)	6
Aquifer tube arrays (2 new and 2 existing arrays)	4
New wells into RUM	2
Sampling of monitoring wells (to support groundwater spatial/temporal uncertainty)	18
Sampling of monitoring wells (site-specific)	7
Note: For a complete description of work scope see Table 4-7 and SAP (Rev. 0 and/or Rev. 1).	

Table 4-9. Number of Field Samples and Analytes Proposed for 100-N

Source	Soil Samples*	Groundwater Samples	Analytes
New boreholes/test pits (vadose zone)	0	0	0
New wells (unconfined aquifer)	131	32	8,747
Aquifer tube arrays (2 new and 2 existing arrays)	0	27	765
New wells into Ringold unit B	17	10	1,687
Sampling of monitoring wells (to support groundwater spatial/temporal uncertainty)	0	54	5,841
Sampling of monitoring wells (site-specific)	0	21	2,334

Notes: Table does not include field quality control or archive samples.

* Includes both chemical and physical property analyses.

The 105-N Reactor fuel storage basin (FSB) has been selected for additional soil and groundwater characterization due to documented releases (UPR-100-N-35) and contaminated groundwater upwelling in the Columbia River that occurs upriver from the 116-N-1 (1301-N) and 116-N-3 (1301-N) Cribs/Trenches.

A borehole will be drilled near the reactor in an area most likely to contain soil contamination (i.e., beneath the FSB). Samples will be collected and analyzed to assess vertical extent of contamination in the vadose zone. The borehole will be completed as a groundwater monitoring well.

Ongoing facility removal and remediation programs (per the Removal and Remedial Action Work Plans [*Removal Action Work Plan for 100-N Area Ancillary Facilities* (DOE/RL-2002-70), DOE/RL-2005-43, DOE/RL-2005-93]) provide an efficient mechanism to identify and remediate reactor building waste sites. Therefore, WCH will continue contaminated soil and structure removal, 105-N Reactor ISS, and waste site sampling around and associated with the FSB. As outlined in the Integrated Work Plan (DOE/RL-2008-46, Rev. 0), contingent on physical accessibility, this remedy can include additional field instrument surveys

(radiological and/or chemical), borehole drilling, and/or test pitting to better define the nature and extent of contamination and identify sources potentially affecting groundwater quality in the vadose zone. Due to the schedule for FSB (and immediately surrounding area) remediation completion in 2012, it is anticipated that the FSB characterization information will not be available to support the 100-N RI/FS Report effort, but will be available to support the 4th CERCLA ROD five-year review in 2016.

Data Need No. 4: Identify new waste sites and potential sources of contamination.

Data Need Description: Complete orphan site evaluation process.

The orphan site evaluation process identifies new waste sites (i.e., discovery sites) and sources not in CERCLA decision documents. The orphan site process has been performed for the 100-NR-1 OU and the report (*The 100-N Area Orphan Sites Evaluation Report* [OSR-2009-0001, Rev. 0]) has been issued.

4.7.2 100-N Data Needs—Groundwater

Data needs specific to groundwater are identified and described in this section.

Data Need No. 5: Define additional groundwater needs to support groundwater remediation decisions.

Data Need Description: Drill and sample two new groundwater monitoring wells to determine the nature and extent of contamination and rate of movement at the Sr-90 hot spot and characterize petroleum contamination near the 166-N Facility.

Groundwater Monitoring Well 1 (Figure 4-28) will be installed and used to define the extent of the Sr-90 "hot spot" (concentration of Sr-90 in groundwater greater than 1,000 times the MCL) adjacent to and downgradient of 116-N-1. This well would provide information on the rate of movement of this hot spot that may provide information important to potential remediation decisions. This well will help define the extent of contamination relating to diesel fuel spills.

Groundwater Monitoring Well 2 (Figure 4-30) is planned to define the nature and extent of contamination relating to diesel fuel spills.

Justification: Well 1 is needed to define the extent of Sr-90 hot spot in the direction of the groundwater flow and verify the assumption the plume is not moving. Its planned location is adjacent to and downgradient of the existing116-N-1 Wells (199-N-67 and 199-N-69). These existing wells currently exhibit elevated Sr-90 concentrations (greater than 8,000 pCi/L or more than 1,000 times the MCL).

Well 2 will be downgradient of the petroleum leak site (166-N Tank Farm) and will define the scope and support potential remediation for the petroleum plume.

Data Need No. 6: Evaluate the utility and/or adequacy of aquifer tubes in understanding groundwater contamination entering the Columbia River. Collect groundwater upwelling data and information.

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-1 (SWMU #6)	HGP-CVP SWMU_5_6_7_8_9_10	Pond/dumping area (HGP Settling Pond)	No (0.9 m; 3 ft)	Analytical data not collected during LFIs (1992 and 1995).	No	No	No. Borehole 199-N-90 data indicates contamination does not increase with depth.	Data collected before remediation showed no elevated contamination below the first 0.9 m (3 ft) of the pond; however, elevated levels of Co-60, chromium, lead, nickel, copper, and zinc were present near the surface of the pond. Post-remediation data (95% UCL) shows contamination below interim remedial action cleanup goals. Contaminants of concern were Co-60, Cs-137, Sr-90, metals, leachable metals, and petroleum hydrocarbons. The 95% UCL for lead (15.6 mg/kg) exceeded groundwater and river protection criteria (10.2 mg/kg). 95% UCLs for the other COCs were below cleanup standards. The SAP called for 14 sample points collected at the settling pond surface and at 0.3, 0.9, 1.5, and 3.0 m (1, 3, 5, and 10 ft) depths, resulting in 70 samples. Actual results from depths below remediation were 1 to 2.1 m (5 to 7 ft), 3 to 3.6 m (10 to 12 ft), and 4.6 to 5.3 m (15 to 17.5 ft) bgs. Petroleum hydrocarbons (heavy oil and diesel range) were analyzed by GC-MS following EPA 8015B. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). Samples were analyzed for total metals and leachable metals. Maximum concentrations of total metals were as follows: arsenic (2.5 mg/kg), barium (96 mg/kg), cadmium (0.22 mg/kg), chromium (16 mg/kg), lead (33 mg/kg), selenium (3.8 mg/kg), silver (3 mg/kg), and mercury (1.4 mg/kg). Vanadium concentrations detected in 199-N-90 increase with depth but are at the lower end of commonly encountered background concentrations, and do not appear to warrant additional consideration.
100-N-3 (SWMU #9)	HGP-CVP SWMU_5_6_7_8_9_10	French drain (HGP Maintenance Garage French Drain, Maintenance Garage Waste)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	No. Diesel and heavy oil were <2,000 mg/kg (direct exposure and groundwater protection criteria).	NA (no excavation)	Samples collected indicate petroleum hydrocarbons are not present in soil samples. Petroleum hydrocarbons were analyzed by GC-MS following EPA 8015B. Diesel range petroleum hydrocarbons were below detection at 20 mg/kg; heavy oil range petroleum hydrocarbons were below detection at 50 mg/kg. The below-grade structure of the drain was demolished in place and backfilled with soil in 2004. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-4 (SWMU #5)	HGP-CVP SWMU_5_6_7_8_9_10	Sanitary and laboratory drain/ tile field (HGP, Tile Field)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	Yes	Yes	No. Samples collected to a depth of 1.5 m (5 ft) below excavation do not indicate an increase in contamination with depth.	In 2001, soil samples were collected from the surface to a maximum depth of 1.5 m (5 ft). Soil samples were again taken in 2003 at the surface. Samples were analyzed for Co-60, Sr-90, Cs-137, total metals, leachable metals, and petroleum hydrocarbons. The maximum concentrations of both sampling events combined were as follows: cadmium (1 mg/kg), chromium (30 mg/kg), lead (48 mg/kg), mercury (7.3 mg/kg), and Co-60 (2.99 pCi/g). Only data from 2003 was used for the 95% UCL value. The 95% UCL for lead (10.7 mg/kg) exceeded groundwater and river protection criteria (10.2 mg/kg). 95% UCLs for the other COCs were below cleanup standards. Testing for corrosion inhibitors hydrazine and morpholine were performed in the lab, so it is likely that reagents used for these tests were discharged to the unit.
100-N-41 (SWMU #9)	HGP-CVP SWMU_5_6_7_8_9_10	Septic tank (HGP 1701-NE Gate House Septic Tank)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	No. Diesel and heavy oil were <2,000 mg/kg (direct exposure and groundwater protection criteria).	Samples were only taken directly below depth of remediation.	The site received sanitary waste from the former 1701-NE Gate House Building. Soil below the tank was analyzed for diesel range petroleum hydrocarbon (reported below detection at 20 mg/kg) and heavy oil range petroleum hydrocarbon (reported below detection at 50 mg/kg). The septic tank was an open bottom cesspool constructed of concrete brick. The below-grade structures were demolished in place and backfilled with soil in 2004. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, other compounds (i.e., PCBs, halogenated VOCs), and metals were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).
100-N-45 (SWMU #9)	HGP-CVP SWMU_5_6_7_8_9_10	Septic tank (HGP 1703-N Office Building Septic Tank)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	No. Diesel and heavy oil were <2,000 mg/kg (direct exposure and groundwater protection criteria).	Samples were only taken directly below depth of remediation.	The site received sanitary waste from the former 1703-N Office Building. Soil below the tank was analyzed for diesel range petroleum hydrocarbon (below detection at 20 mg/kg) and heavy oil range petroleum hydrocarbon (below detection at 50 mg/kg). The septic tank was an open bottom cesspool constructed of concrete brick. The below-grade structures were demolished in place and backfilled with soil in 2004. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, other compounds (i.e., PCBs, halogenated VOCs), and metals were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-46	HGP-CVP SWMU_5_6_7_8_9_10	Diesel oil storage tank underground) (HGP Diesel Oil Storage Tank)	No (6.7 m; 22 ft)	Analytical data not collected during LFIs (1992 and 1995).	No	No. Diesel range was below detection (400 mg/kg), and below protection criteria (2,000 mg/kg).	Samples were only taken directly below depth of remediation.	The 20,000 gal underground diesel storage tank was removed in 2001. Contaminated soils below and adjacent to the tank were removed. Diesel was not detected in soil samples after removal. The site was not identified in the ROD; however, it was included in the CVP to document the UST had been removed and surrounding soil remediated. The only COC was Petroleum hydrocarbons (diesel range hydrocarbons), and was below detection (400 mg/kg) in verification samples. Petroleum hydrocarbons were analyzed by GC-MS following EPA 8015B. Carcinogenic PAHs and naphthalenes were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-5 (SWMU #10)	HGP-CVP SWMU_5_6_7_8_9_10	Outdoor storage area (HGP Disposal and Storage Area, HGP Bone Yard)	NA (no structure)	Analytical data not collected during LFIs (1992 and 1995).	No	No (HGP-CVP SWMU 5_6_7_8_9_10 (2 of 2) Table 2 Summary of Post Excavation Soil Analytical Results).	Samples were only taken directly below depth of remediation.	Oil stained soil, garnet sandblasting grit/material, and ion exchange resin was removed from the waste site that did not meet applicable cleanup levels. The Site Summary Report also states other material removed included scrap metal, pipes, electrical gear, and cables. Characterization soil samples were collected from various areas where sand blast media, ion exchange resin media, soil staining, and distressed vegetation were identified in 2001, October 2003 and February 2004. Thirteen samples collected from five locations indicated COCs were below detection (Hg and TPH-DR) or interim remedial action cleanup goals for direct exposure, protection of groundwater, and protection of the river. Maximum concentrations for cadmium* (1.46 mg/kg) and total chromium* (32.8 mg/kg) exceeded groundwater and river protection standards (cadmium cleanup standard is 0.81 mg/kg and total chromium cleanup standard is 18.5 mg/kg). Maximum concentrations for other COCs were below cleanup standards. Pre-remediation, two samples were found by mass spectrometry to contain a variety of PAHs, most likely the result of combustion of material in situ or disposal of combusted material at those locations. Contaminant concentrations measured in resin samples indicated lead* (1,200 mg/kg) exceeded Hanford Site background and 2007 MTCA direct exposure and river protection standards. Silver exceeded Hanford Site background and 2007 MTCA river protection standards. "Since discolored soil was selectively sampled, collection was biased towards finding such sites and these results should not be considered an indication of overall bone yard contamination. The resin samples were lower on average in arsenic, barium, cadmium, and silver than was the soil, while the resin was higher in chromium and lead. The variability in the results indicates these differences are not statistically significant. TCLP metal concentrations for both lead and chromium were higher in the soil, a reversal of the results from total metal analyses (HGP-CVP SWMU 5_6_7_8_9_10). Diesel range petroleum hydrocarbons were analyzed for by GC-MS following EPA Method 8015B for cleanup verification. Fuel additives and blending compounds, and naphthalenes were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). PAHs were not analyzed post-remediation.

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-50 (SWMU #4)	HGP-CVP SWMU_1_2_3_4	Single-shell tank (turbine oil filter unit) (HGP Turbine Oil Filter Unit, Turbine Oil Cleaning System)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	N/A (no analytical CVP laboratory data collected).	NA (no excavation)	The unit was located in the basement of the 185-N Building on a concrete floor with a concrete curb surrounding it. The basement was about 15.2 m (50 ft) bgs Contamination (e.g., stained concrete) was removed from this site prior to the removal action by chipping and scabbling. As a part of the removal action, building debris, cement grout, and clean soil were used to backfill the waste site. Closeout documentation demonstrated that the removal action achieved the RAOs and corresponding cleanup standards established in the action memorandum and removal action work plan. Verification of cleanup is based on photographic documentation and a qualitative and conservative bounding assessment rather than analytical laboratory data. RAOs are documented in the 100-N Ancillary Facilities Action Memorandum (1999) and in the Removal Action Work Plan for the Hanford Generating Plant Ancillary Facilities (1999). Photographic documentation is provided in the CVP. 95% UCL concentrations for cesium-137 (16.9 pCi/g) and cobalt-60 (60.8 pCi/g) exceeded direct exposure standards (cesium-137 direct exposure standard is 6.2 pCi/g and cobalt-60 direct exposure standard is 1.4 pCi/g). Cesium-137 and cobalt-60 were the only COCs for 100-N-51B, but all three sites (100-N-50, 100-N-51, and 100-N-51B) were included together in the CVP. 95% UCL concentrations for the other COCs were below cleanup standards. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). Samples were analyzed for cadmium, chromium, lead, and mercury using TCLP analysis. Maximum concentrations were as follows: cadmium* (1.9 mg/L), chromium* (48 mg/L), lead* (14 mg/L), and mercury* (0.14 mg/L).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-51 (SWMU #2)	HGP-CVP SWMU_1_2_3_4	Oil storage area (HGP Building Oil Storage Area, 100-N-51A)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	N/A (no analytical CVP laboratory data collected).	NA (no excavation)	The unit was a cinder block room with a steel grate floor, wall shelves, and a sub-floor sump. The unit was located in the basement of the 185-N Building on a concrete floor about 15.2 m (50 ft) bgs. The grate and sump floor were stained. Material and equipment were removed while sump stains were removed by washing and scabbling the concrete. As a part of the removal action, building debris, cement grout, and clean soil were used to backfill the waste site. Closeout documentation demonstrated the removal action achieved the RAOs and corresponding cleanup standards established in the action memorandum and removal action work plan. Verification of cleanup is based on photographic documentation and a qualitative and conservative bounding assessment rather than analytical laboratory data. RAOs are documented in the 100-N Ancillary Facilities Action Memorandum (1999) and in the Removal Action Work Plan for the Hanford Generating Plant Ancillary Facilities (1999). Photographic documentation is provided in the CVP. 95% UCL concentrations for cesium-137 (16.9 pCi/g) and cobalt-60 (60.8 pCi/g) exceeded direct exposure standards (cesium-137 direct exposure standard is 6.2 pCi/g and cobalt-60 direct exposure standard is 1.4 pCi/g). Cesium-137 and cobalt-60 were the only COCs for 100-N-51B, but all three sites (100-N-50, 100-N-51, and 100-N-51B), were included together in the CVP. 95% UCL concentrations for the other COCs were below cleanup standards. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). Samples were analyzed for cadmium, chromium, lead, and mercury using TCLP analysis. Maximum concentrations were as follows: cadmium* (0.059 mg/L), chromium* (14 mg/L), lead* (2.9 mg/L), and mercury* (0.19 mg/L).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-51B (SWMU #3)	HGP-CVP SWMU_1_2_3_4	Sump (HGP Building floor drain, and sumps, and all piping to the settling pond and outfall)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	95% UCL for Cs-137 and Co-60 exceed direct exposure criteria but are far below groundwater and river protection criteria.	No known vertical data below depth of remediation.	This site is also located in the basement of the 185-N Building. Cleanup consisted of equipment/material removal and concrete floor scabbling. Verification of cleanup is based on photographic documentation and a qualitative and conservative bounding assessment rather than analytical laboratory data. Pipelines below grade are still intact. Any piping leaving the building below grade has been identified as a CERCLA (WIDS) waste site. These pipes fall into mainly the 100-N-84. RAOs are documented in the 100-N Ancillary Facilities Action Memorandum (1999) and in the Removal Action Work Plan for the Hanford Generating Plant Ancillary Facilities (1999). Photographic documentation is provided in the CVP. 95% UCL concentrations for cesium-137 (16.9 pCi/g) and cobalt-60 (60.8 pCi/g) exceeded direct exposure standards (cesium-137 direct exposure standard is 6.2 pCi/g and cobalt-60 direct exposure standard is 1.4 pCi/g). 95% UCL concentrations for the other COCs were below cleanup standards. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). Samples were analyzed for cadmium, chromium, lead, and mercury using TCLP analysis. Maximum concentrations were as follows: cadmium* (0.53 mg/L), chromium* (1.1 mg/L), lead* (18 mg/L), and mercury* (8.06 ug/L).
100-N-52	HGP-CVP SWMU_5_6_7_8_9_10	HGP gasoline storage tank (underground; 1,000 gal)	No	Analytical data not collected during LFIs (1992 and 1995).	No	No	Samples were only taken directly below depth of remediation.	The UST and contaminated soil below/around tank were removed. Soils remaining onsite were analyzed for Washington total petroleum hydrocarbon – hydrocarbon identification. Hydrocarbons were not detected. The site was not identified in the ROD; however, it was included in the CVP to document the UST had been removed and surrounding soil remediated. The only COC was petroleum hydrocarbons (diesel range hydrocarbons), and was not detected in verification samples. Petroleum hydrocarbons were analyzed by GC-MS following EPA 8015B. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, and other compounds (i.e., PCBs, halogenated VOCs) were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900). A site investigation, per applicable procedures specified in the UST site check/site assessment guidance issued and certified by Ecology in 1992, certification is included in the CVP. All results were nondetectable for WTPH-HCID analyses.

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-58 120-N-1 (1324-NA) 120-N-2 (1324-N)	CVP-2001-00021	Settling Pond (unlined), South Pond, South Settling Pond) Percolation Pond Surface Impoundment)	100-N-58 (0.15 m; 0.5 ft) 120-N-1 (no excavation) 120-N-2 (no excavation)	No	No	No	No	Ponds (100-N-58, 120-N-1, 120-N-2) received 163-N (Demineralization Plant) anion/cation regeneration effluent and 183-N (Filtered Water Plant; raw water treated with liquid alum, settled, then filtered) filter backwash effluent. Two boreholes and one test pit were excavated and sampled, the boreholes were sampled to the water table. Closeout documentation in the CVP indicates contaminant concentrations are below interim remedial action cleanup goals for direct exposure, groundwater, and river protectiveness. The waste site reclassification form for 100-N-58 was approved by Ecology in 2002. 120-N-1 and 120-N-2 were included in the 100-NR-1 Corrective Measures Study and Proposed Plan; however, because these documents indicated no soil contamination was present, EPA did not include them in the 100-N CERCLA ROD. Closure activities for 120-N-1 and 120-N-2 have been completed and approved as provided in 03-RCA-0236 (Ecology letter dated February 7, 2003). Post-closure groundwater monitoring is performed for sulfates. Samples were collected from site soil and from pipeline scale. For the pipeline scale samples, the maximum concentrations were as follows: barium (211 mg/kg), total chromium (31.3 mg/kg), copper (30.9 mg/kg), lead (20.8 mg/kg), mercury (0.83 mg/kg), nickel (20.3 mg/kg), zinc (608 mg/kg), and sulfate (460 mg/kg). However, these samples were collected from inside the pipeline are not representative of soil concentrations. None of the 95% UCL soil concentrations for COCs exceeded Hanford Site or Washington State soil background concentrations. RESRAD modeling was performed because pipeline scale data did not meet one or more MTCA 3-part test criteria for barium, total chromium, copper, lead, mercury, and zinc. The SIS report for 120-N-2 indicates that the site had two configurations. The original unlined pond was in use from 1977 to 1982. In 1986, a lined surface impoundment was constructed in the same location, which may be seen in photographs.
100-N-63:1	CVP-2002-00002	RAD Process Sewer (Pipeline Section) (100-N-63, 100-N Reactor, 1314-N, 116-N-1 and 116-N-3, TSD Underground Pipelines)	No (>4.6 m: > 15 ft)	No	Yes. 199-N-109A is nearest.	Shallow zone contaminants are below cleanup goals. Some deep zone contaminants are above cleanup goals.	No	This pipeline was remediated >15 ft below ground surface. The pipeline did not have a deep zone decision unit because contaminant concentrations for the entire pipeline excavation met the more stringent shallow zone criteria. 95% UCL concentrations in the shallow zone were below cleanup standards for COCs.

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
100-N-78 (SWMU #8)	HGP-CVP SWMU_5_6_7_8_9_10	Maintenance Shop (1716-NE Maintenance Garage)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	No	No visual indication of contamination below remediation.	The building and foundation were removed and the underlying soils were visually inspected for staining. Because no soil stains/soil discolorations were observed, sampling was not required. From Appendix A of the CVP it is stated: "The purpose of the DQO was to provide criteria for sampling and analysis to support the D&D of the steam system and initial assessment of contamination of the SWMUs. The levels for verification of the remediation of the concrete and other structures were not finalized as the DQO decision makers focused on the liability issues." Historical and known contaminant information listed in the CVP for this site included pesticides, anti-freeze, paint, chemical solvents, and petroleum products, although the source of historical data is not identified. These supplies were stored in a separate storage room of the northeast corner of the maintenance garage within no floor drain. Carcinogenic PAHs, naphthalenes, volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), and fuel additives and blending compounds were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).
116-N-1	CVP-2006-00004 Rev. 1	Crib (1301-N Liquid Waste Disposal Facility, 116-N-1 (1301-N) Crib and Trench)	No (6.5 m; 21.3 ft)	Yes	Yes	No	Yes	Characterization of 116-N-1 has been extensive for a subset of identified target analytes and COPCs. Boreholes and groundwater wells have been drilled in and adjacent to the trench to characterize the vertical and lateral extent of contamination. Contamination is present to groundwater and extends laterally towards the river. Pre-remediation data indicates strontium-90, uranium-233/234, potassium-40, tritium, and nitrate are present beneath, and/or adjacent to the trench. Closeout verification data also indicate tritium and Cr(VI) exceed soil concentrations protective of groundwater, the river, or both. RESRAD modeling and protectiveness comparisons predict tritium, Cr(VI), and nitrate concentrations are protective of groundwater and the river. The remedial action remedy for the CERCLA waste sites is under the authority of the Interim Action ROD (EPA/ROD/R10-99/112) and the ESD (EPA/ESD/R10-03/605). Only the soils of the overburden, shallow zone, and the deep zone layer immediately in contact with the shallow zone have been sampled, analyzed, and modeled for groundwater protection for the CVP. Wells 199-N-107A and 199-N-108A indicate the highest radiological contamination at 15 ft in depth and the highest chromium concentration 3.3 to 3.9 m (11 to 13 ft) in depth.

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization
116-N-3	CVP-2002-00002	Crib (116-N-3, 1325-N Liquid Waste Disposal Facility, 1325-N Crib and Trench)	No (>4.6 m; >15 ft)	Yes	Yes	Shallow zone contaminants are below cleanup goals. Some deep zone contaminants are above cleanup goals.	No	116-N-3, which is located adjacent to 116-N-1, received the same waste stream. The two sites are analogous. 95% UCL concentrations in the shallow zone were below cleanup standards for COCs. 95% UCL concentrations in the deep zone exceeded direct exposure standards for: Am-241 (154 pCi/g), Cs-137 (4,900 pCi/g), Co-60 (5,580 pCi/g), Eu-154 (8.7 pCi/g), Pu-239/240 (258 pCi/g), and Sr-90 (1,460 pCi/g). Groundwater protection standards were exceeded for Cs-137, Ni-63, and Sr-90. Surface water protection standards were not exceeded. The highest level of contamination was found in the zone 2 m below the excavation floor, and decreased with depth.
1908-NE (SWMU #7)	HGP-CVP SWMU_5_6_7_8_9_10(1of2)	Outfall (HGP Outfall, 1908-NE Building)	NA (no excavation)	Analytical data not collected during LFIs (1992 and 1995).	No	No	No known vertical data below depth of remediation.	This outfall received single-pass raw river water that passed through the Hanford Generating Plant condensers. It also received waste water from the 100-N-1 Settling Basin. The preferred action for the 1908-NE Outfall site is continued institutional control; therefore, no removal action has been performed for this site. Two seal well sludge sediment samples were collected, it was noted "UNABLE TO SAMPLE" for the remaining location(s). The remaining locations did not have sludge present and attempts to retrieve sludge from alternate locations also revealed no sludge present. Sludge samples were not analyzed for total metals; however, TCLP cadmium, chromium, and mercury were below detection, though lead by TCLP was in both leachates, at 0.05 mg/L. Diesel and lube oil range organics were not detected in the 2 samples. Gamma spectroscopy results were below detection for Co-60 for both samples. One seal well water sample associated with the outfall detected Co-60 at -0.98 pCi/g and Cs-137 at -4.56 pCi/g. For the two seal well sludge samples, petroleum hydrocarbons were analyzed by GC-MS following EPA 8015B. Volatile petroleum compounds (i.e., benzene, toluene, ethyl benzene, xylenes, and n-hexane), fuel additives and blending compounds, carcinogenic PAHs, and naphthalenes were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).
UPR-100-N-37 (SWMU #1)	HGP-CVP SWMU_1_2_3_4	Unplanned release (transformer yard) (HGP Transformer Yard Oil Stained Gravel)	NA (no structure)	Analytical data not collected during LFIs (1992 and 1995).	No	No	No	Oil-stained gravel was removed from the yard. Soils below excavated areas were analyzed for PCBs and total petroleum hydrocarbons as mineral oil. Contaminant concentrations were below interim remedial action cleanup goals for direct exposure, protection of groundwater, and protection of the river. Because Aroclor 1262 cleanup verification data (including method PQLs) for two samples were not below IROD RAGs for protection, RESRAD modeling was performed to assess protectiveness. Volatile petroleum compounds (i.e. benzene, toluene, ethyl benzene, xylenes, and n-hexane) and naphthalenes were not analyzed (see Tables 740-1 and 830-1, WAC 173-340-900).

Table 4-10. Summary of Characterization at Interim Closed/Closed Waste Sites

Waste Site ID	Reference	Site Type	RTD Depth <Engineered Structure (RTD Depth)	Contamination Reported in Other Sources > RTD Depth	Contaminants Reported in Other Sources Omitted in Verification Sampling	Concentrations in CVP >MTCA 2007 Cleanup Goals	Contamination Increases with Depth Below RTD Depth	Summary of Characterization

Notes: Direct exposure, groundwater protection, and river protection standards are MTCA 2007 values.

* = sample concentration was preremediation

Am-241 = americium-241
Cd = cadmium
Co-60 = cobalt-60
COC = contaminant of concern
COPC = contaminants of potential ecological conern
Cr = chromium
Cs-137 = cesium-137
CVP = Closeout Verification Package
D&D = demolition and decommissioning
DQO = data quality objective
ESD = explanation of significant differences
Eu-154 = europium-154
Eu-155 = europium-155
GC-MS = gas chromatography-mass spectrometry
Hg = mercury
HGP = Hanford Generating Project
ID = identification
IROD = interim record of decision
LFI = limited field investigation
MTCA = Model Toxic Control Act
NA = not applicable
Ni-63 = nickel-63
PAH = polynuclear aromatic hydrocarbons
Pb = lead
pCi/g = picoCuries per gram
PCB = polychlorinated biphenyl
PQL = practical quantitation limit
Pu = plutonium
RAG = remedial action goal
RESRAD = residual radioactivity
RTD = remove, treat, and dispose
SIS = Stewardship Information System
Sr-90 = strontium-90
SWMU = solid waste management unit
TCLP = toxicity characteristic leaching procedure
TPH = total petroleum hydrocarbon
UCL = upper confidence limit
UST = underground storage tank
WTPH-HCID = waste total petroleum hydrocarbons-hydrocarbon identification

Data Need Description: Groundwater contamination at N-Springs and 100-N has been studied and modeled (HydroGeoLogic, Inc., 2004) since the beginning of N Reactor operations. More recently, aquifer tubes have been added to support estimates of the level of groundwater contamination entering the river. Sampling should be continued and performed over a period of months to address changes over time and the effect of changes in river stage. Direct measurement of groundwater upwelling is recommended and is planned under programs outside this addendum. Upwelling studies were completed in FY 2010 (DOE/RL-2010-69, Rev. 0, *Sampling and Analysis Plan for the 100-NR-2 OU River Pore Water Investigation*). This activity scope is documented in the upwelling study report (*Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River* [DOE/RL-2008-11]).

Groundwater discharge to the river at concentrations above aquatic cleanup levels (e.g., Sr-90 and Cr(VI)) has been documented in the 100-N OU. Aquifer tubes have been installed to analyze groundwater contaminants discharging to the river. Groundwater upwelling sampling and analysis in the Columbia River channel are complete (as part of the Columbia River remedial investigation). It is anticipated these data will provide further insight regarding contaminant levels entering the river through the hyporheic zone and groundwater/river mixing ratios within the biotic zone (upper ~0.3 m [~12 in.] of substrate), which is in concert with the expert panel's suggestion that these be better understood. Data generated will support the task included in the Integrated 100 Area RI/FS Work Plan (DOE/RL-2008-46) for evaluating and developing an approach to obtain data to demonstrate compliance with ambient water quality criteria in the river, for target Milestone M-016-11-T03 and final ROD decisions.

Recent information from the program to measure pore water that represents groundwater "upwelling" into the Columbia River indicated a potential source of Sr-90 may be entering the river near the N Reactor outfall and spillway. The investigation of this potential Sr-90 source will be conducted by installing two aquifer tube arrays (Figure 4-31) to help define the nature and extent of Sr-90.

Data Need No. 7: Collect and analyze samples to characterize the soil and groundwater quality in the RUM.

Data Need Description: Data from one existing well indicates there is contamination in a sand layer of the RUM unit above DWS (total chromium in Well 199-N-80). Further discussion of the occurrence of chromium in this well is found in Section 2.3.1.The nearly 21.34 m (70 ft) thick silt unit is generally considered to possess low transmissivity. However, sand lenses/pockets are known to exist and can be highly transmissive. Limited information is available to assess the lithology, soil properties, and vertical contamination distribution and extent in this unit.

The RUM unit is considered an aquitard where the integrity and potential transport mechanisms have not been evaluated in 100-N. The RUM unit groundwater may potentially discharge to aquatic receptors, or portions may be technically considered an aquifer capable of a drinking water resource. Data collection is planned to further define the extent of potential contamination in the RUM unit, better define its lithology, and support fate and transport evaluations.

Two wells are proposed (R1 and R2, see Figure 4-30) and will be drilled approximately 15.24 m (50 ft) into the RUM unit, then completed as groundwater monitoring wells. The monitoring wells will be completed in the first water producing unit within the RUM. Water samples will be collected from within RUM water producing units. Soil collection (split spoons) will begin at the base of the unconfined aquifer, immediately on drilling into the RUM unit, and at two additional locations within the RUM unit outside any producing zone. Details of the data collection and sampling can be found in the SAP (DOE/RL-2009-42).

Figure 4-30. 100-N Planned and Existing Well Sampling Locations

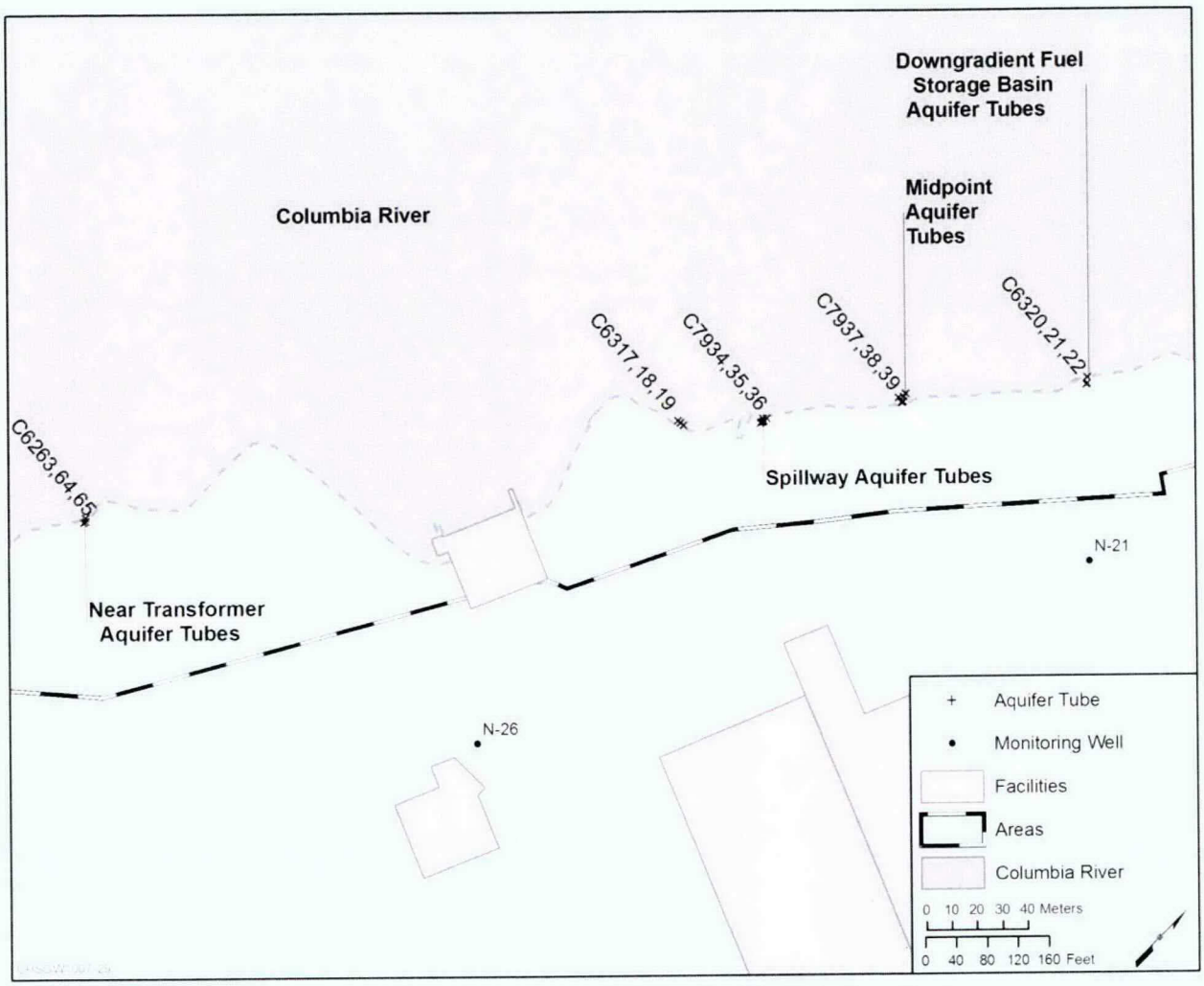


Figure 4-31. 100-N Planned and Existing Aquifer Tube Locations

Water samples will be analyzed for all groundwater COPCs. Soil samples will be analyzed as follows:

- Soil property information (e.g., density, porosity, sieve fraction, and permeability) will be collected.
- Analytes, including Cr(VI), total chromium, metals, and radionuclides, will be collected from a distilled water leach and from the soil fraction.
- One split-spoon sample will be collected from each of the monitoring wells proposed in Data Need No. 4, from the upper 1.5 m (5 ft) of the RUM unit, to address spatial variability of hydraulic properties of the RUM unit, and as defined by the SAP, or determined by the field geologist.

Data Need No. 8: Update bathymetric data for the river within 100-N to support calculations of contaminant transport to the river and ecological receptors. The digital bathymetric data will be evaluated to better understand the relationship between the riverbed and the 100-N geology to determine if the RUM intersects the river.

Data Need No. 9: Collect geochemical and hydrogeologic data to evaluate near-shore area groundwater contaminant fate and transport. Although no specific data collection activities are proposed in this RI, data from historical work and other ongoing efforts (Design Optimization Studies) will be used in the RI/FS when available in time to support the schedule for completion of the RI/FS.

Data Need No. 10: Vadose and groundwater information is needed to better evaluate the extent of contamination remaining from: past high-volume liquid waste disposal, past petroleum leaks, and past fuel storage basin releases and other interim remediated sites.

Data Need Description: Soil and water analyses are needed to determine the potential for waste sites and "hot spots" to contain sufficient contamination to be a continuing source of groundwater contamination. Details of the data collection and sampling are presented in the SAP (DOE/RL-2009-42).

Data Need No. 11: Test potential remedial technologies to determine if remedial action goals can be met. Currently, petroleum bioremediation and Sr-90 permeable reactive barrier testing, and phytoextraction testing is underway.

Data Need No. 12: Collect additional data to support future fate and transport modeling. Assess the physical and hydraulic properties of soil and confirm contaminant distribution coefficients to support modeling.

Data Need No. 13: Collect and analyze groundwater samples from 18 existing groundwater monitoring wells.

Data Need Description: Additional groundwater data are needed as spatially representative of 100-N, reflects river stage influence, and includes groundwater COPCs.

Collect and analyze groundwater samples from 18 monitoring wells to characterize the spatial, temporal, and chemical extent of groundwater contamination. Wells are shown in Figure 4-32. Sampling details are found in the SAP (DOE/RL-2009-42).

Three rounds of groundwater samples will be collected for analysis to support the remedial investigation for each contaminant. A sampling round, or event, will be conducted for each seasonal high, low, and transition river stages, for a total of three samples per well. Each round of monitoring in the network of wells should be completed within 30 consecutive calendar days to minimize statistical variability in water levels. Additional wells were added to networks to define potential exposures associated with known contaminant plumes. Current monitoring wells were chosen to provide data on maximum contaminant levels and to define plume extents. For areas with active remedial activities, extraction/injection and chemical treatment wells were not included in any of the well networks (Table 4-11). The pump-and-treat wells are not configured for routine sampling and the chemical treatment wells are not representative of ambient groundwater conditions.

Table 4-11. Spatial and Temporal Uncertainty Groundwater Monitoring Well Network

Well Numbers				
199-K-37	199-N-14	199-N-69	199-N-74	699-73-61
199-K-151	199-N-16	199-N-50	199-N-81	699-77-54
199-K-152	199-N-19	199-N-51	199-N-165	699-87-55
199-K-182	199-N-32	199-N-71		

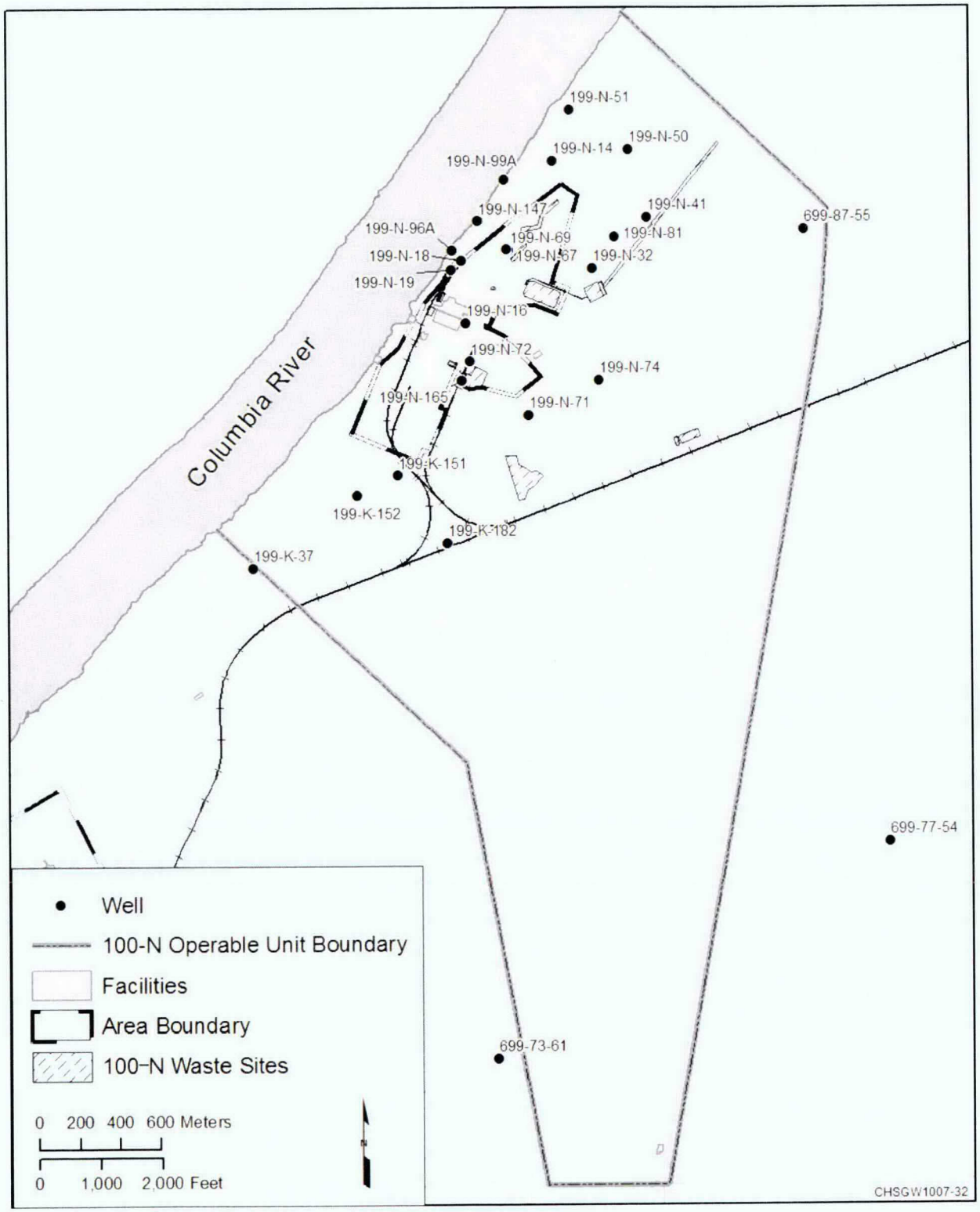


Figure 4-32. 100-N Groundwater RI/FS Sampling Locations

5 Project Schedule

The project schedule for activities discussed in this addendum is shown in Figure 5-1. This schedule will serve as the baseline for the work planning process and used to measure the implementation progress. Milestones associated with the activities described in this addendum are provided in the work plan (DOE/RL-2008-46, Appendix C). Updates to the project schedule will be reflected in the annual work planning process and are not anticipated to require a revision to this addendum.

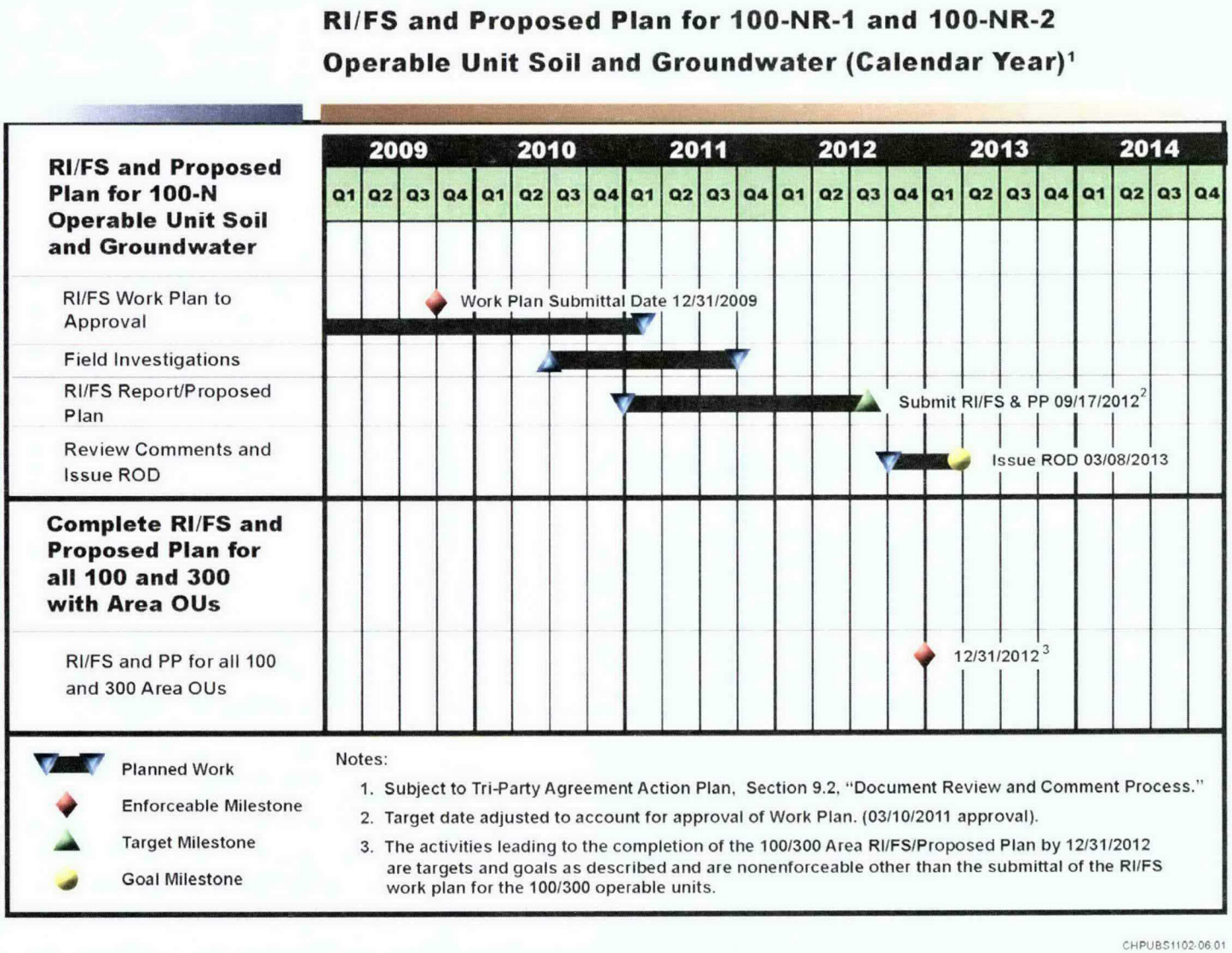


Figure 5-1. 100-N Operable Unit Schedule

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Appendix A

100-N Waste Site Facilities

A1 Introduction

Table D-1 provides a summary of the buildings/facilities that have existed in 100-N of the Hanford Site. Many of these buildings/facilities have been demolished or are no longer used. Table D-1 also provides physical dimensions and a brief history for each building/facility.

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