**Department of Energy**
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

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Mr. D. A. Faulk, Program Manager
Office of Environmental Cleanup
Hanford Project Office
U.S. Environmental Protection Agency
309 Bradley Boulevard, Suite 115
Richland, Washington 99352

Ms. J. A. Hedges, Program Manager
Nuclear Waste Program
State of Washington
Department of Ecology
3100 Port of Benton
Richland, Washington 99354

Addressees:

CALENDAR YEAR 2011 ANNUAL SUMMARY REPORT FOR THE 100-HR-3 AND 100-KR-4 PUMP-AND-TREAT OPERATIONS, AND 100-NR-2 GROUNDWATER REMEDIATION, D0E/RL-2012-02, REVISION 0

This letter transmits the Calendar Year 2011 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation, DOE/RL-2012-02, Revision 0.

This report presents the annual evaluation of the performance of the pump-and-treat systems for the 100-HR-3 and 100-KR-4 Operable Units and the 100-NR-2 Groundwater Remediation at the Hanford Site. Results are provided for Calendar Year 2011, which covers the period from January 1, 2011, through December 31, 2011.

If you have any questions, please contact me, or your staff may contact, Briant Charboneau, of my staff, on (509) 373-6137.

Sincerely,

Jonathan Dowell

Jonathan A. Dowell, Assistant Manager
for the River and Plateau

AMRP:NMB

Attachment

cc: See Page 2

cc w/attach:
G. Bohnee, NPT
L. Buck, Wanapum
C. J. Guzzetti, EPA
S. Harris, CTUIR
R. Jim, YN
S. L. Leckband, HAB
N. M. Menard, Ecology
K. Niles, ODOE
D. Rowland, YN
Administrative Record
Environmental Portal

cc w/o attach:
L. M. Dittmer, CHPRC
D. E. Dooley, CHPRC
R. A. Kaldor, MSA
T. W. Noland, MSA
R. E. Piippo, MSA

DOE/RL-2012-02
Revision 0

# Calendar Year 2011 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation

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

U.S. DEPARTMENT OF ENERGY | Richland Operations Office
**P.O. Box 550**
**Richland, Washington 99352**

**Approved for Public Release;**
**Further Dissemination Unlimited**

DOE/RL-2012-02
Revision 0

# Calendar Year 2011 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation

Date Published
June 2012

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

U.S. DEPARTMENT OF ENERGY | Richland Operations Office
**P.O. Box 550**
**Richland, Washington 99352**

***APPROVED***
***By G. E. Bratton at 9:41 am, Aug 22, 2012***

Release Approval Date

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# Executive Summary

Interim remedies are operating in the 100-HR-3, 100-KR-4, and 100-NR-2 Groundwater Operable Units (OUs). Hexavalent chromium is the primary contaminant of concern (COC) in the 100-HR-3 and 100-KR-4 OUs. The hexavalent chromium is being treated by pump-and-treat (P&T) systems at these two OUs. The P&T systems extract groundwater and remove the hexavalent chromium with ion-exchange resin in treatment plants before injecting the treated water back into the aquifer. At the 100-HR-3 OU, a permeable reactive barrier (PRB) is also used for in-situ treatment of hexavalent chromium. This passive system reduces hexavalent chromium to the immobile, nontoxic trivalent form as it flows through a zone in the aquifer that is treated with sodium dithionite. A notice of non-significant change to the ROD was issued in 2010[1], which indicated that the barrier would no longer be actively maintained and P&T system expansion (i.e. pumping wells downgradient of the barrier) will be used to address breakthrough and provide a protective interim remedy. In the 100-NR-2 OU, the COC is strontium-90. A P&T system developed for strontium-90 proved to be ineffective; subsequently, a PRB was installed to treat the aquifer with the mineral apatite, where strontium-90 adsorbs to the apatite to immobilize it within the aquifer.

This annual summary report describes operations and results of these remedies during 2011. The goals of the remedies are to protect the Columbia River, protect human health and aquatic life, and provide information that will enhance remediation. Target Tri-Party Agreement (Ecology et al., 1989[2]) milestones have been established to ensure that the impact of hexavalent chromium and other contaminants to the Columbia River and groundwater are remediated in a timely manner. The following four milestones are directly applicable to the 100 Area OUs:

[1] Holten, Richard A., 2010, "Non-Significant Change for the 100-HR-3 and 100-KR-4 Operable Units Interim Action Record of Decision, Hanford Site, Washington, July 2010, Memo to File Regarding: Supplemental Actions for the In-Situ Reduction/Oxidation Manipulation Barrier Performance for the 100-HR-3 Groundwater Operable Unit Interim Remedy," CCN 0092078, letter to J.A. Hedges (Washington State Department of Ecology) and D.A. Faulk (U.S. Environmental Protection Agency), U.S. Department of Energy, Richland Operations Office, Richland, Washington, October 26. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1011290677.

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

- ***Milestone M-016-110-TO1 (December 31, 2012)*:** DOE shall take actions necessary to contain or remediate hexavalent chromium groundwater plumes in each of the 100 Area NPL [National Priority List] Operable Units to ensure ambient water quality standards for hexavalent chromium are achieved in the hyporheic zone and river column water.

- ***Milestone M-016-110-TO2 (December 31, 2020)*:** DOE shall take actions necessary to remediate hexavalent chromium groundwater plumes to ensure hexavalent chromium will meet drinking water standards in each of the 100 Area NPL Operable Units.

- ***Milestone M-016-110-TO3 (December 31, 2016)*:** DOE shall take actions to contain the strontium-90 plume at 100-NR-2 Operable Unit to ensure the default ambient water quality standard (8 pCi/L) is achieved in the hyporheic zone and river water column.

- ***Milestone M-016-110-TO4 (December 31, 2016)*:** DOE shall implement remedial actions selected in all 100 Area Records of Decision for Groundwater OUs to ensure no contamination above drinking water standards enters the Columbia River unless otherwise specified in a CERCLA decision

This report describes, in detail, the volumes of water treated, amount of mass removed from the P&T systems, efficiency of the P&T systems, the effectiveness of the PRBs, and resulting impact on groundwater concentrations. These interim remedies were initially implemented in the mid-1990s based on the understanding of the nature and extent of contamination at that time. Since then, through implementation of the interim remedies, the understanding of the nature and extent of groundwater contamination has improved significantly. In 2006, based on *The Second CERCLA Five-Year Review Report for the Hanford Site* (DOE/RL-2006-20)[3], planning was initiated to expand the treatment systems to provide comprehensive treatment of the plumes in the aquifer. Expanded capacity has been installed, or is currently being installed, at all three OUs.

A significant amount of water was treated, and mass was removed from the aquifer during CY 2011, as follows:

[3] DOE/RL-2006-20, 2006, *The Second CERCLA Five-Year Review Report for the Hanford Site*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=DA04570094.

- At the 100-HR-3 OU, treatment capacity was expanded to 5,300 L/min (1,400 gallons per minute [gpm]) with the addition of the DX and HX P&T systems. The enhanced systems allowed the DR-5 and HR-3 P&Ts to be placed in cold standby in 2011 after the new P&T systems began operations. Approximately 1,365 million L (360 million gal) of groundwater were treated, removing 471 kg of hexavalent chromium, primarily using the new systems. This represents an increase in over 370 percent in the volume of groundwater treated and mass of hexavalent chromium removed as compared to 2010 where 268 million L (97 million gal) of groundwater was treated and 124 kg of hexavalent chromium was removed.
- The PRB at the 100-D Area continued to operate; much of the barrier works well but a portion of the barrier is not presently effective. Data from recent years indicates that hexavalent chromium is breaking through the northeast portion of the barrier, and DX extraction wells were added to supplement these portions of the barrier. At the end of 2011, concentrations in barrier wells ranged from below detection limits to723 µg/L, which is consistent with previous years. Groundwater in well 199-D4-39, also near the northeastern end of the barrier, had hexavalent chromium levels ranging from 33 to 516 µg/L in 2011. These levels show less fluctuation than observed in 2010, which had a range in concentrations of 798 to 2,960 µg/L.
- Treatment capacity is 4,164 L/min (1,100 gpm) at the 100-KR-4 OU. During CY 2011, 1,543 million L (408 million gal) of groundwater were treated, removing 61.4 kg of hexavalent chromium.
- The PRB at the 100-NR-2 continued to remove strontium-90 out of solution within the treated area, and groundwater concentrations have been reduced by 90 percent from pretreatment conditions along the barrier.
- Apatite barrier extensions were installed in fall 2011 at the 100-NR-2 PRB, which included injecting 24 wells along an additional 100 m (300 ft) at each end of the original barrier. The total length of the apatite barrier is 290 m (950 ft).

Continued work is required to monitor the interim remedies and continue optimization of the treatment system as new information becomes available. The P&T facilities and well network have been expanded in recent years to increase treatment capacity, including the new treatment facilities at the 100-D and 100-H Area in 2010 and 2011, respectively, the KW P&T system expansion from 100 gpm to 200 gpm in 2009, and new KX P&T

system addition in the 100-K Area in 2009, and lengthening of the PRB at the 100-N Area. Operational effectiveness continues to be assessed to adjust extraction and injection well flow rates and identify locations for new wells or supplemental technologies as trouble spots arise.

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# Terms

| | |
|---|---|
| AWLN | Automated Water Level Network |
| bgs | below ground surface |
| CERCLA | *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* |
| CEM | capture efficiency model |
| CFM | capture frequency model |
| CHPRC | CH2M HILL Plateau Remediation Company |
| COC | contaminant of concern |
| CSM | conceptual site model |
| CY | calendar year |
| DO | dissolved oxygen |
| DOE | U.S. Department of Energy |
| DWS | drinking water standard |
| ESD | explanation of significant differences |
| FS | feasibility study |
| FSB | fuel storage basin |
| FY | fiscal year |
| gpm | gallons per minute |
| IC | institutional control |
| ISRM | In Situ Redox Manipulation |
| IX | ion-exchange |
| MCL | maximum contaminant level |
| MDA | minimum detectable activity |
| MDL | minimum detection limit |
| NA | not applicable |
| NTU | nephelometric turbidity unit |
| O&M | operations and maintenance |
| ORP | oxidation-reduction potential |
| OU | operable unit |

| | |
|---|---|
| P&T | pump-and-treat |
| ppm | parts per million |
| PRB | permeable reactive barrier |
| RAO | remedial action objective |
| RCRA | *Resource Conservation and Recovery Act of 1976* |
| RI | remedial investigation |
| ROD | record of decision |
| RPD | relative percent difference |
| RPO | remedial process optimization |
| RUM | Ringold upper mud |
| TBD | to be determined |
| TKN | Total Kjeldahl Nitrogen |
| TPA | Tri-Party Agreement |
| TPH | total petroleum hydrocarbon |
| Tri-Party Agreement | *Hanford Federal Facility Agreement and Consent Order* |
| UPR | unplanned release |
| WCH | Washington Closure Hanford |
| WIDS | Waste Information Data System |
| WSCF | Waste Sampling and Characterization Facility |

# 1 Introduction

The U.S. Department of Energy (DOE) operates and maintains seven ion-exchange (IX) pump-and-treat (P&T) systems and two permeable reactive barriers (PRBs) as part of ongoing efforts to remediate contaminated groundwater in the Hanford Site's 100-K, 100-N, 100-D, and 100-H Areas (Figure 1-1). The primary contaminant of concern (COC) in 100-K, 100-D, and 100-H is hexavalent chromium. At 100-N, the primary COC is strontium-90.

Four of the seven P&T systems operating during 2011 remediate hexavalent chromium in the 100-HR-3 Groundwater Operable Unit (OU), located within the combined 100-D and 100-H Areas. In addition, an In Situ Redox Manipulation (ISRM) PRB, located in the southwestern portion of the 100-D Area, continues to remove hexavalent chromium contamination from groundwater. The remaining three ion exchange (IX) P&T systems operate within the 100-KR-4 OU to remediate hexavalent chromium groundwater contamination.

The interim actions conducted at the 100-HR-3 and 100-KR-4 OUs are part of the effort to achieve the following interim remedial action objectives (RAOs) described in the record of decision (ROD) (EPA/ROD/R10-96/134, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington*):

- **RAO 1:** Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River.
- **RAO 2:** Protect human health by preventing exposure to contaminants in the groundwater.
- **RAO 3:** Provide information that will lead to a final remedy.

For the 100-NR-2 OU, the primary COC in groundwater is strontium-90. The interim remedial action initially chosen for the 100-NR-2 OU was P&T using an IX medium to remove strontium-90. The RAOs were reviewed in 2005, and the P&T system was deemed ineffective in reducing the flux of strontium-90 to the Columbia River. In accordance with the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989), also known as the Tri-Party Agreement (TPA), the 100-NR-2 P&T system was placed in cold standby status on March 9, 2006, in accordance with TPA (Ecology et al., 1989) Milestone M-16-06-01 ("Complete a Permeable Reactive Barrier [PRB] at 100-N"). The U.S. Department of Energy (DOE) began emplacement of a PRB along the 100-N Area shoreline in 2007 with the goal of sequestering strontium-90 in the aquifer (DOE/RL-2005-96, *Strontium-90 Treatability Test Plan for 100-NR-2 Groundwater Operable Unit*). The progress on the barrier and other strontium-90 treatment technology tests is reported in this document.

The four RAOs for 100-NR-2 OU from the current interim ROD (EPA et al., 2010, *Amended Record of Decision, Decision Summary and Responsiveness Summary, U.S. Department of Energy 100-NR-1 and NR-2 Operable Units, Hanford Site – 100 Area, Benton County, Washington*) are listed below. The remedial technology implemented uses apatite as a reactive material to sequester strontium-90 from the groundwater.

- **RAO 1:** Protect the Columbia River from adverse impacts from the 100-NR-2 groundwater so that designated beneficial uses of the Columbia River are maintained.
- **RAO 2:** Protect the unconfined aquifer by implementing remedial actions that reduce concentrations of radioactive and nonradioactive contaminants present in the unconfined aquifer.

- **RAO 3:** Obtain information to evaluate technologies for strontium-90 removal and evaluate ecological receptor impacts from contaminated groundwater.
- **RAO 4:** Prevent destruction of sensitive wildlife habitat. Minimize disruption of cultural resources and wildlife habitat, and prevent adverse impacts to cultural resources and threatened or endangered species.

Target TPA (Ecology et al., 1989) milestones have been established to ensure that the impact of hexavalent chromium and other contaminants to the Columbia River and groundwater are remediated in a timely manner. The following four milestones are directly applicable to the 100 Area OUs:

- ***Milestone M-016-110-T01 (December 31, 2012):*** *DOE shall take actions necessary to contain or remediate hexavalent chromium groundwater plumes in each of the 100 Area NPL [National Priority List] Operable Units such that ambient water quality standards for hexavalent chromium are achieved in the hyporheic zone and river column water.*
- ***Milestone M-016-110-T02 (December 31, 2020):*** *DOE shall take actions necessary to remediate hexavalent chromium groundwater plumes such that hexavalent chromium will meet drinking water standards in each of the 100 Area NPL Operable Units.*
- ***Milestone M-016-110-T03 (December 31, 2016):*** *DOE shall take actions to contain the strontium-90 plume at 100-NR-2 Operable Unit such that the default ambient water quality standard (8 pCi/L) is achieved in the hyporheic zone and river water column.*
- ***Milestone M-016-110-T04 (December 31, 2016):*** *DOE shall implement remedial actions selected in all 100 Area Records of Decision for Groundwater Operable Units so that no contamination above drinking water standards enters the Columbia River unless otherwise specified in a CERCLA decision.*

This annual summary report discusses the groundwater remedial actions conducted in 2011 at the 100-HR-3, 100-KR-4, and 100-NR-2 OUs. Chapter 2 discusses the 100-HR-3 OU, Chapter 3 discusses the 100-KR-4 OU, and Chapter 4 discusses the 100-NR-2 OU. An evaluation of costs is presented in Chapter 5, and the references cited in this report are included in Chapter 6. Additional supporting information is included in the following appendices:

- Appendix A, Site History
- Appendix B, Methods and Results of Capture Zone Modeling

## 1.1 Summary of Operable Unit Activities

Active interim action remediation continued during 2011 in the OUs, as well as initiation of remedial investigations (RIs) and feasibility studies (FSs) to reach RODs for future implementation of final remedies. An overview of these activities is provided in this chapter, and detailed discussions for each OU are provided in Chapters 2 through 4.

## 1.2 100-HR-3 Operable Unit Activities

The following subsections provide a brief summary of the activities at the 100-HR-3 OU for the reporting period.

### 1.2.1 100-HR-3 Operable Unit P&T Systems

Five *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remedial actions were operating in the 100-HR-3 OU at various times of the year to remediate the principal COC (hexavalent chromium) in the groundwater. These included the original 100-HR-3 P&T system (100-H Area), DR-5 P&T system (100-D Area), DX P&T system (100-D Area), HX P&T system (100-H Area), and ISRM barrier (100-D Area).

During 2011, an expansion of the P&T systems in the 100-D and 100-H Areas was completed to enhance remediation efforts by expanding the pumping capacity and capture zone. The DX and HX P&T systems were brought online and replaced the existing HR-3 and DR-5 P&T systems that were previously operating. The new P&T systems are designed to reduce the amount of hexavalent chromium entering the Columbia River in the 100-D and 100-H Areas.

The DX facility with a treatment capacity of 2,300 L/min (600 gallons per minute [gpm]) became operational in December 2010. As a result, the DR-5 P&T system went offline in March 2011. Extraction and injection wells formerly connected to the DR-5 P&T were disconnected and transferred to the new DX P&T system, with the exception of injection well 199-D5-41 which was not needed for injection in the DX P&T well configuration. In May, the HR-3 P&T system went offline to support realignment of its wells to the new DX and HX well networks. Consolidation was done on the extraction and injection wells within the two areas to reduce water transfer across the Horn Area. Disconnection of the HR-3 P&T wells was completed in May 2011, and the HR-3 system was placed in cold standby. Extraction and injection wells formerly connected to the HR-3 P&T were connected to the new DX and HX P&T systems. Four extraction wells (199-D8-53, 199-D8-54A, 199-D8-68, and 199-D8-72) that were part of the D Area transfer line to the HR-3 P&T will be connected to the DX P&T in a future well realignment. Injection well 199-H4-7 was not connected to the HX P&T since this will is not needed for injection in the HX P&T well configuration. Construction of the HX P&T system, with a treatment capacity of 3,000 L/min (800 gpm), was completed in July 2011. Acceptance test activities took place in August through September, and the system became fully operational on October 1, 2011.

Figures 1-2 and 1-3 show annual and cumulative trends for volume treated and mass removed, respectively, from the 100-HR-3 OU P&T systems. The four P&T systems removed 471 kg of hexavalent chromium from the aquifer and treated approximately 1,364.6 million L (360.5 million gal) of groundwater. This change is a 279 percent increase in mass removal from 2010 in which the DR-5 and HR-3 P&T systems removed 124.16 kg of hexavalent chromium and treated approximately 367.9 million L (97.2 million gal) of groundwater. In 2011, hexavalent chromium concentrations in the 100-D and 100-H Areas decreased compared to 2010 but remained above the 20 µg/L remedial action goal with a high concentration of 28,100 µg/L in one well in the south 100-D Area plume.

The size of the 100-H Area hexavalent chromium plume has been significantly reduced since startup of P&T operations in 1997. Contamination extends across the Horn from the 100-D Area and has subsequently migrated toward the 100-H Area. For the first time, groundwater is captured from the central Horn Area with extraction wells installed for the HX P&T system. A relatively smaller and lower concentration hexavalent chromium plume remains adjacent to the Columbia River, to the north of the remediated zone. Concentrations in groundwater have decreased with startup of the DX and HX P&T system.

### 1.2.2 In Situ Redox Manipulation

In 2000, additional cleanup action was taken using an in situ chemical treatment technology (i.e., ISRM). Use of this new technology was approved by the 1999 interim ROD amendment (EPA/AMD/R10-00/122, *Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site,*

*Benton County, Washington*). Rather than pumping contaminated groundwater to the surface for treatment, this technology treats the groundwater in the aquifer by reducing the hexavalent chromium to trivalent chromium, which is a much less toxic and less mobile form.

The ISRM barrier continued to convert hexavalent chromium to a nontoxic, immobile form (trivalent chromium) within a portion of the aquifer. Concentrations in some downgradient wells remained above the interim remedial action goal of 20 µg/L due to the northeast segment of the barrier not working effectively; therefore, new DX extraction wells were installed downgradient of the barrier to treat this area. The ISRM treatment technology and its effectiveness are discussed in more detail in Section 2.3.5.

### 1.2.3 Remedial Investigation/Feasibility Study Activities

An RI/FS is being conducted for the 100-D and 100-H Areas. Characterization activities began in 2009, as described in *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units* (DOE/RL-2008-46-ADD1) and implemented through *Sampling and Analysis Plan for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units Remedial Investigation/Feasibility Study* (DOE/RL-2009-40). The RI/FS addresses contaminant sources (e.g., site history), contaminant flow and transport, and exposure assessment. It also supports risk characterization, remedial action selection, performance monitoring, and site closure. The RI/FS activities for 2011 are discussed in more detail in Section 2.4.1.

## 1.3 100-KR-4 Operable Unit Activities

The following subsections provide a brief summary of activities at the 100-KR-4 OU for the reporting period.

### 1.3.1 100-KR-4 Operable Unit P&T Systems

Three active systems continued to operate at the 100-KR-4 OU during 2011. The KR4 system treats groundwater downgradient of the 116-K-2 Trench and has a treatment capacity of 1,136 L/min (300 gpm). The KX system treats groundwater between the 116-K-2 Trench and the N Reactor area, as well as a plume downgradient of the KE Reactor. The KX system has a treatment capacity of 2,300 L/min (600 gpm). The KW P&T system extracts groundwater from around the KW Reactor facility and has a treatment capacity of 757 L/min (200 gpm). The combined systems treated 1,542 million L (407.5 million gal) and removed 61.3 kg of hexavalent chromium during 2011. Figures 1-4 and 1-5 show annual and cumulative trends for volume treated and mass removed, respectively, from the 100-KR-4 OU P&T systems.

Upgrades to the KR-4 P&T process logic control (PLC) system and well head modifications were completed in January 2012 and the KR4 P&T system was restarted on January 14, 2012. The KR4 system was shutdown during the last quarter of 2010 for the upgrades to replace outdated process control systems and equipment that are no longer supported by vendors and bring control systems for the over 15 year old facility comparable to current technologies at the 100-KW and 100-KX P&T systems. The upgrades also included facility modifications for future addition of two new extraction wells that will be added to the KR-4 P&T system as part of planned RPO realignments.

Well realignments at the 100-KX P&T system in 2011 included converting two extraction wells (199-K-149 and 199-K-150) to monitoring wells. The groundwater hexavalent concentration at the two wells have been less than the 10 µg/L aquatic water quality standard since October 2009 at 199-K-150 and June 2010 at 199-K-49. Continued extraction from the two wells was discontinued to make available treatment capacity for locations with higher hexavalent chromium contamination.

Monitoring wells 199-K-152 and 199-K-182 were converted to extraction wells. Well 199-K-152 was connected to the KX P&T in April 2011. All construction activities to convert well 199-K-182 to an extraction well is complete except for final piping and cable connections which have not been completed.

### 1.3.2 Remedial Investigation/Feasibility Study Activities

Characterization activities began in 2009, as described in *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units* (DOE/RL-2008-46-ADD2) and implemented through *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study* (DOE/RL-2009-41). The RI/FS report was issued in 2011 for Regulatory review, with the final report scheduled for completion in 2012.

### 1.3.3 Remedial Process Optimization Activities

The RPO studies to improve the effectiveness of remediation and meet target milestones were initiated in 2009 and carried over into 2010. Extensive groundwater modeling (through repeated updates as soil and aquifer data became available) has been used to design the treatment systems, relying on P&T and combined bioremediation/P&T approaches. Modeling has guided Phases 1 and 2 and the well realignments between treatment systems, and it is supporting well drilling for Phases 3 and 4. Phase 3 drilling, which was implemented in 2011, consists of four new wells drilled in key areas within the KR4 and KW plume area. Phase 4 drilling will be consistent with the final remedy selected in the RI/FS currently in process for the 100-K Area OUs, with ROD issuance anticipated in 2012.

A comprehensive resin strategy was conducted as part of the RPO and culminated in *100 Area Groundwater Chromium Resin Management Strategy for Ion Exchange Systems* (SGW-46621), which recommends implementation of single-use resin (i.e., ResinTech SIR-700) for treatment of hexavalent chromium at the River Corridor P&T systems. The SIR-700 resin is implemented at both the DX and HX P&T systems in 100-HR-3. The strategy report (SGW-46621) recommended that the remaining 100 Area P&T facilities be converted to single-use resin in order to reduce operating costs and eliminate offsite transportation. The 100-KW P&T facility was selected to test the implementation of SIR-700 resin at a mildly acidic pH (5.5 ± 0.5), to determine if the pH would cause any system lining degradation and aquifer effect, and whether there would be any negative effects to the aquifer as a result of injecting lower pH water.

The process test was conducted at the 100-KW P&T facility in 2011 to operate the P&T system using ResinTech SIR-700 as the ion exchange media for removal of hexavalent chromium. The test objectives, as described in the test plan (SGW-48686, *Test Plan to Implement ResinTech SIR-700 in the 100-KW Pump and Treat*,), included installation of SIR-700 in the KW P&T facility and initial operation to generate data to determine the effective operating range for pH control in the 100-KR-4 OU P&T systems, verification of process equipment compatibility and capability to control the influent to a lower pH (5.5 ± 0.5), and to confirm compatibility of reduced pH effluent with the aquifer. The test period began on August 31, 2011 when the SIR-700 resin was placed in service in the first of two treatment trains (Train A). The second treatment train (Train B) was loaded with SIR-700 and placed in service on September 12, 2011. The system operated normally throughout the test with both trains running at capacity (757 L/m [200 gpm]) with the exception of 1 week where the system was shut down to repair a failed fitting in the acid addition system early in the test.

The process test continued into February 2012, and the results are documented in *100-KW Pump and Treat ResinTech SIR-700 Test Results and Recommendations for Use Across 100-KR-4 Operable Unit* (SGW-51721). The test objectives were met and the 100-KW P&T system continues to operate with SIR-700 resin. Further discussion of the process test is provided in Section 3.3.2.1.

## 1.4 100-NR-2 Operable Unit Activities

The following subsections provide a brief summary of activities at the 100-NR-2 OU for the reporting period.

### 1.4.1 100-NR-2 Operable Unit P&T System

The 100-N Area P&T system was placed in cold standby status in March 2006. Contaminant concentrations have been tracked to quantify the effect on groundwater and recovery of the water table to pre-pumping conditions.

### 1.4.2 100-NR-2 Operable Unit Permeable Reactive Barrier

Under the existing interim action ROD (EPA/ROD/R10-99/112, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*) and TPA (Ecology et al., 1989) Change Control Form M-16-06-01, DOE agreed to construct and evaluate the effectiveness of a PRB for strontium-90 using apatite sequestration technology as part of the CERCLA RI/FS process. From 2006 through 2008, the first apatite PRB was installed along 91.5 m (300 ft) of the most contaminated section of 100-N Area shoreline. Since 2008, this section has been in performance monitoring to track the formation of apatite within the vadose zone and groundwater and to determine the effectiveness of the PRB in attenuating strontium-90 and preventing its release to the Columbia River. To date, the PRB has shown a 90 percent reduction of strontium-90 concentrations at the river's edge (PNNL-19572, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization, Final Report*). In response to the success of the existing PRB, 146 new injection wells and 25 new monitoring wells were drilled and installed along the remainder of the 100-N Area shoreline in late 2009 to early 2010, both upriver and downriver of the existing PRB.

In September of 2011, two sections of apatite PRB were installed expanding the original barrier upstream and downstream, increasing the current treated portion of 100-N shoreline to 290 m (950 ft) in length. The injections were performed using a two-step process, where the deeper Ringold Formation wells were injected first and then the overlying Hanford formation wells were injected second. These staggered injections overlay each other and maximize the coverage in the upper unconfined aquifer and lower vadose zones. The formulation for these injections was the high-concentration calcium-citrate-phosphate solution amendment that was tested in 2008 (PNNL-19572, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization, Final Report*). Performance monitoring is ongoing along the entire treated portion of the barrier, with samples collected twice yearly at high and low-river stages. Future PRB expansion will increase the barrier along the entire length of the contaminated portion of the 100-N Area shoreline (approximately 762 m [2,500 ft]). In fall 2011, PRB extensions were installed and included injecting wells along an additional 91.5 m (200 ft) on each end of the original barrier.

## 1.5 Quality Assurance/Quality Control

Quality assurance (QA) and quality control (QC) issues associated with sampling and analysis of all applicable wells are discussed in Appendix D of *Hanford Site Groundwater Monitoring for 2011* (DOE/RL-2011-118, in publication). Appendix D of that document includes an overall view of the QA/QC issues that may affect interpretation of the groundwater data for the P&T OUs.

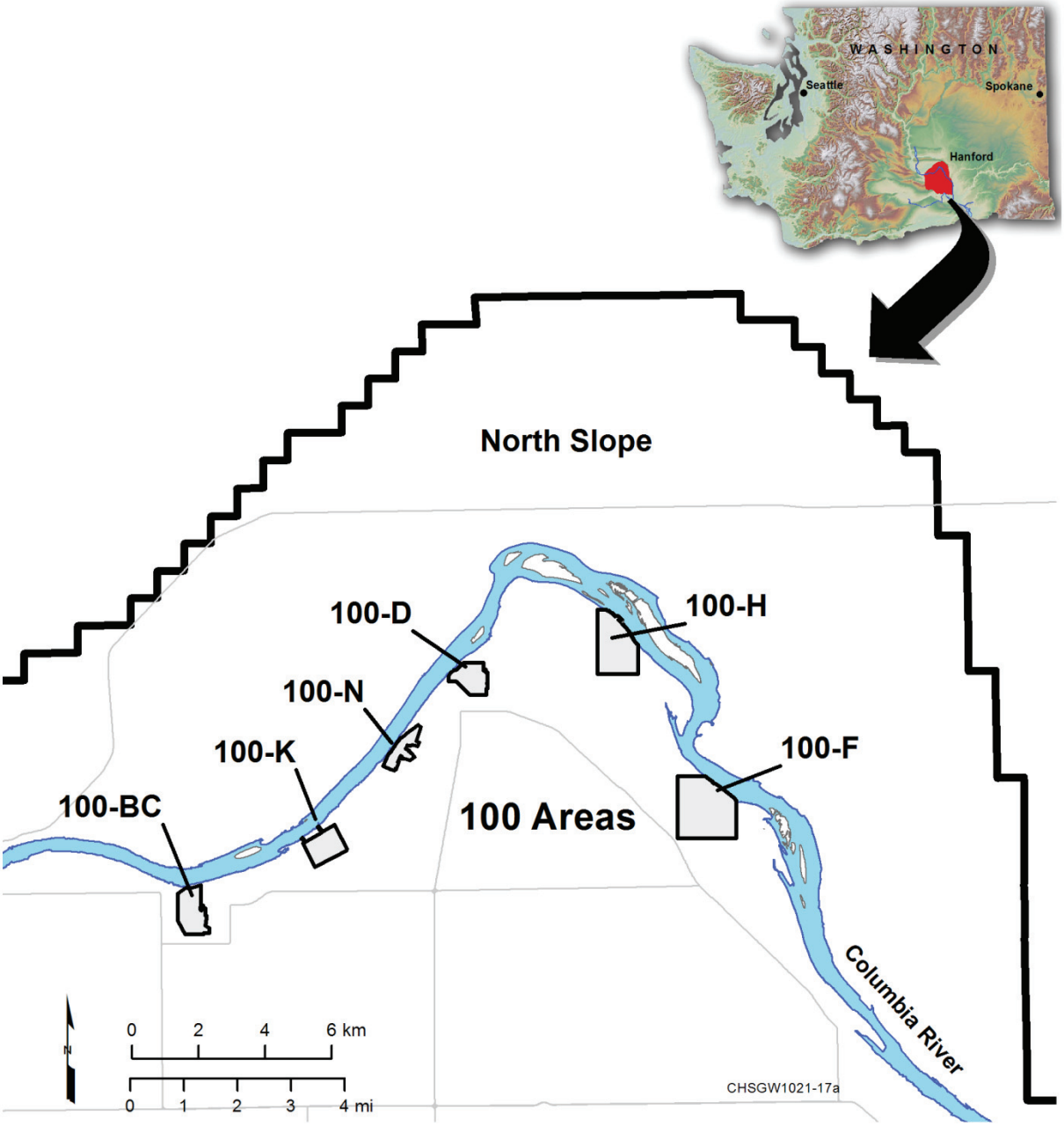


**Figure 1-1. OU Locations Along the Columbia River**

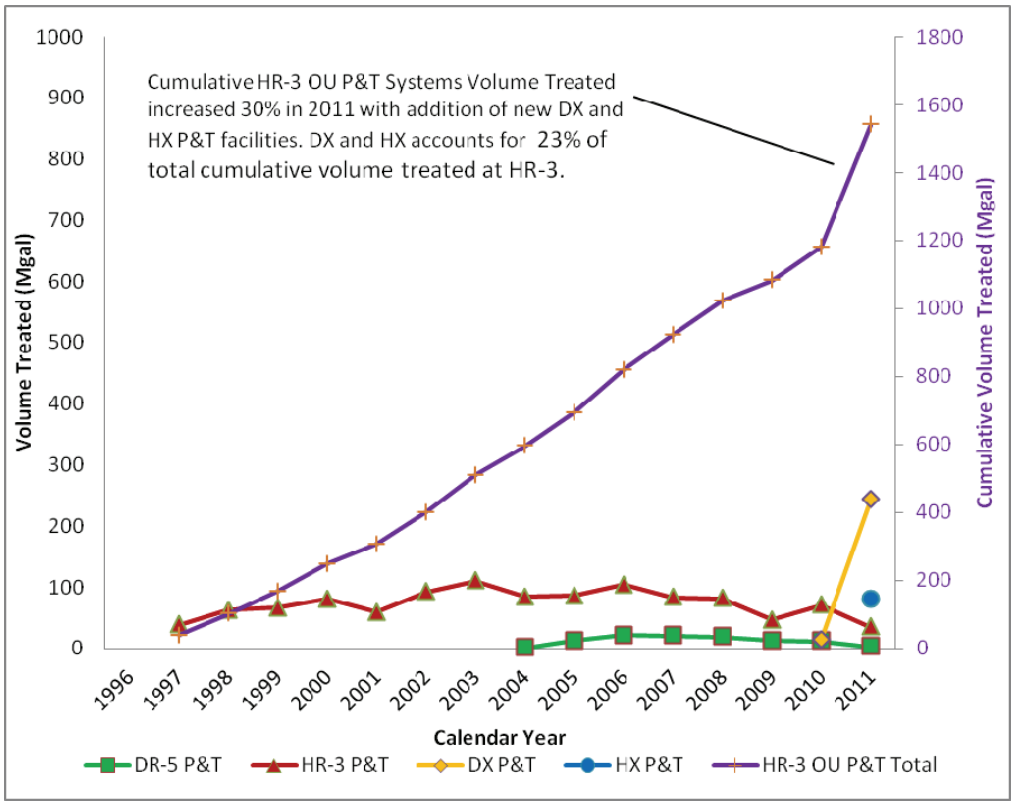


**Figure 1-2. Volume Treated at 100-HR-3 OU P&T Systems**

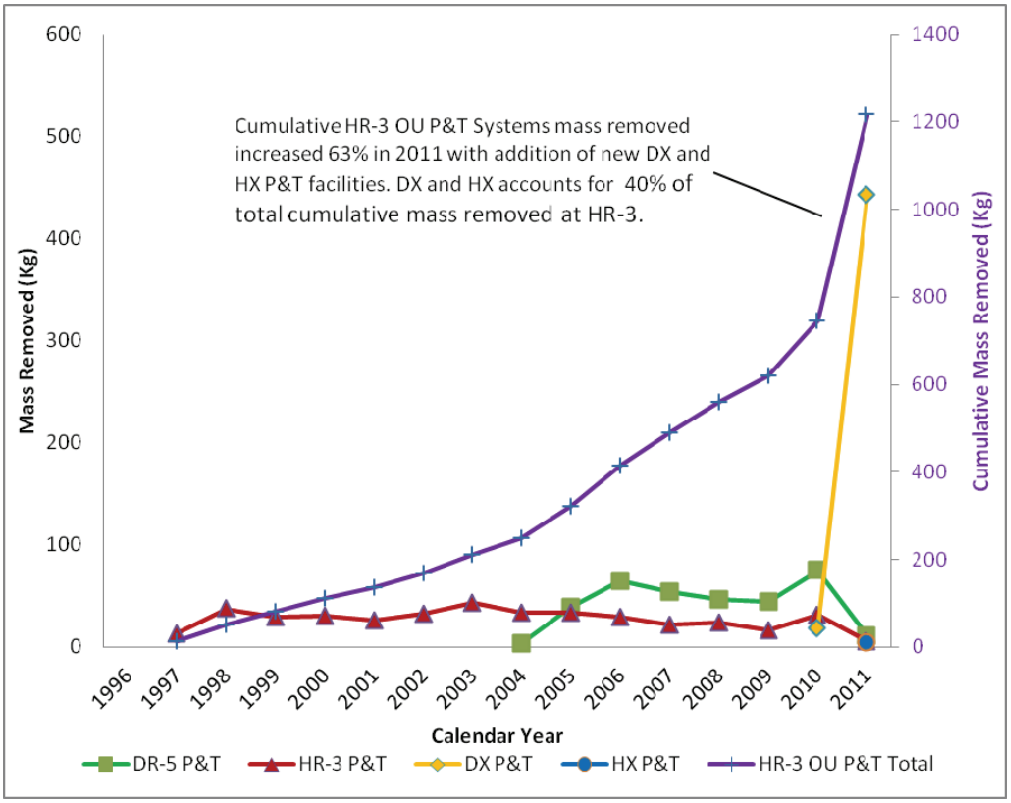


**Figure 1-3. Hexavalent Chromium Mass Removed by 100-HR-3 OU P&T Systems**

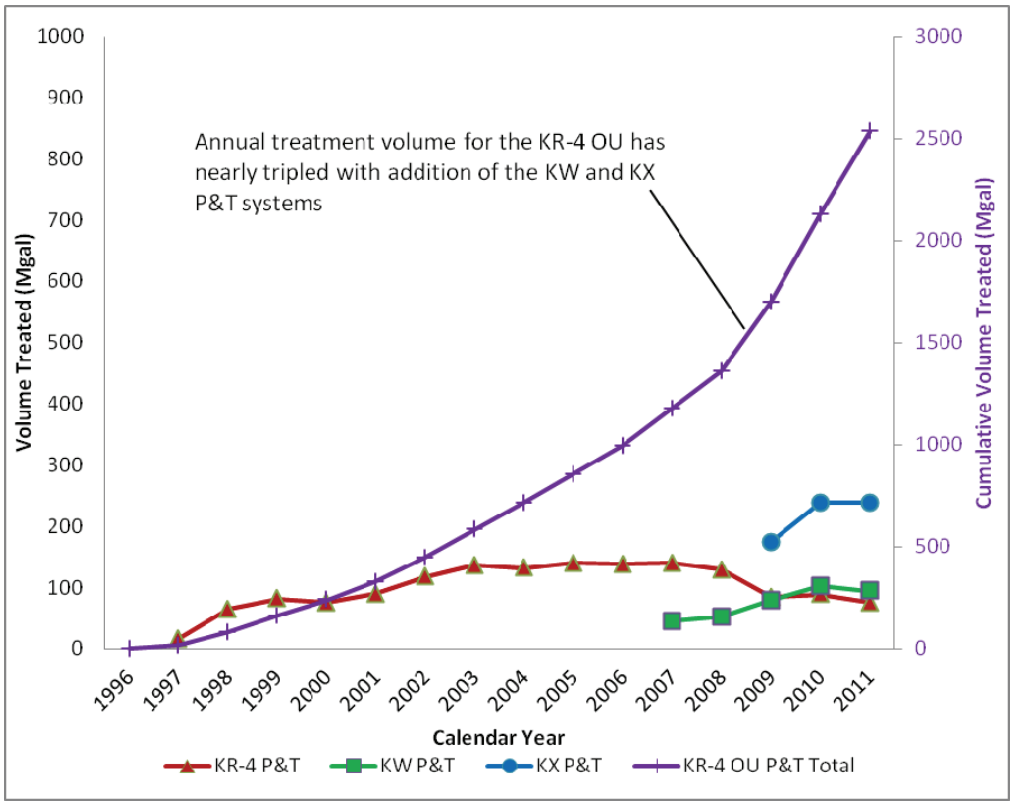


**Figure 1-4. Volume Treated at 100-KR-4 OU P&T Systems**

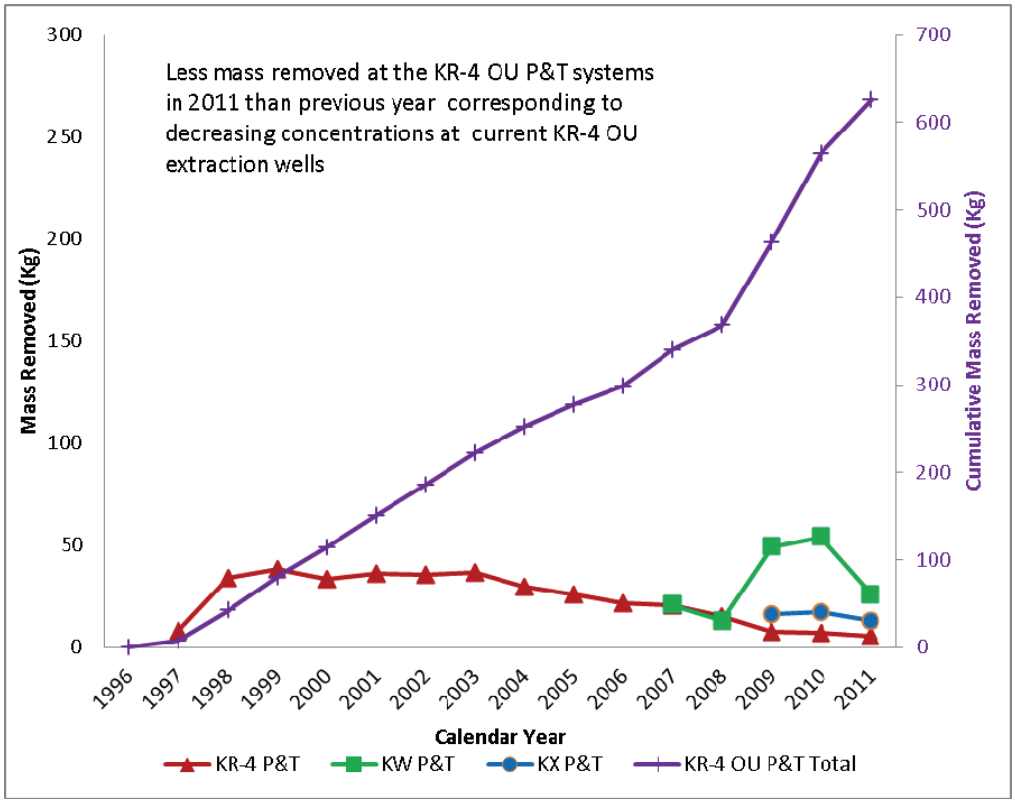


**Figure 1-5. Hexavalent Chromium Mass Removed by 100-KR-4 OU P&T Systems**

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# 2 100-HR-3 Operable Unit Remediation

The 100-HR-3 Groundwater OU consists of groundwater underlying the 100-D Area, the 100-H Area, and the region between known as the Horn Area (Figure 2-1). During 2011, five different interim action remedies operated in the 100-HR-3 OU at various times of the year. The following five systems were included:

- HR-3 P&T in the 100-H Area
- DR-5 P&T in the 100-D Area
- DX P&T in the 100-D Area
- HX P&T in the 100-H Area
- ISRM barrier in the 100-D Area

These systems are interim remedial actions intended to meet the RAOs described in Chapter 1.

The HR-3 P&T system was specified as the first interim action for the 100-HR-3 OU to protect the Columbia River and groundwater (EPA/ROD/R10-96/134). The groundwater extraction system was installed at the D and H Reactor areas in June 1997, with a common treatment facility located in a surplus building near the H Reactor (HR-3 system). An additional system was installed in 2004 at the 100-D Area (DR-5 P&T system) to extract and treat high hexavalent chromium concentrations in the central portion of the 100-D Area. Monitoring of these systems over time provided significant additional characterization information about the nature and extent of contamination and revealed that the hexavalent chromium footprint in groundwater was much larger than initially anticipated.

Based on new characterization information on that expanded the extent of contamination, it was determined that additional treatment capacity was needed. Consequently, to meet RAOs, the DX (100-D Area) and HX (100-H Area) systems were developed with treatment capacities of 600 gpm and 800 gpm respectively.

The new P&T system at 100-D (DX) and 100-H (HX) became fully operational in December 2010 and October 2011, respectively. The DR-5 and HR-3 P&T systems were removed from service in 2011 after the expanded systems began operations. The enhanced P&T systems expand the capture zone in the 100-D and 100-H Areas. In addition, for the first time, groundwater is also captured from the central Horn Area. The new systems also improve operating efficiency in capturing and treating additional contaminated groundwater. The 2011 extraction, injection, and monitoring well locations for the 100-D and 100-H Areas are shown in Figures 2-2 and 2-3, respectively. Figure 2-4 shows well locations in the Horn Area.

## 2.1 Summary of Operable Unit Activities

The new P&T systems are designed to reduce the amount of hexavalent chromium entering the Columbia River in the 100-D and 100-H Areas. The DX facility, with a treatment capacity of 2,300 L/min (600 gpm), became operational in December 2010 and operated full time throughout 2011. The DR-5 P&T went offline in April 2011, and its wells were transferred to the DX P&T system.

In May 2011, the HR-3 P&T system was taken offline. The wells from the system were added to the new HX well network. Disconnection was completed on May 16, 2011, and the HR-3 system was placed in cold standby. Construction of the HX P&T system with a treatment capacity of 3,000 L/min (800 gpm) was completed in July 2011. Acceptance test activities continued until September 28, 2011, and the system became operational on October 1, 2011.

During 2011, the four P&T (HR-3, DR-5, DX, and HX) extraction systems removed 471 kg of hexavalent chromium from the aquifer, treating approximately 1,365 million L (361 million gal) of groundwater. This is a significant increase from 2010, in which the DR-5 and HR-3 P&T systems removed a combined 106 kg of hexavalent chromium from the aquifer and treated approximately 313 million L (83 million gal) of groundwater. In 2011, hexavalent chromium concentrations in the 100-D and 100-H Areas have decreased compared to 2010 but remained above the 20 µg/L interim remedial action goal in the compliance wells for the P&T system.

The southern 100-D Area hexavalent chromium plume is also being remediated along the ISRM barrier. Data from recent years indicates that hexavalent chromium is breaking through the northeast portion of the barrier, and DX extraction wells were added to supplement these portions of the barrier. At the end of 2011, concentrations in barrier wells ranged from below detection limits to 723 µg/L, which is consistent with previous years. Most of the elevated concentrations are in the northeastern half of the barrier. Downgradient of the barrier, the 20 µg/L interim remedial action goal was met at three of the seven compliance wells.

An RI/FS is being conducted to support a ROD for the 100-D and 100-H Areas. Characterization activities began in 2009, as described in the RI/FS work plan addendum (DOE/RL-2008-46-ADD1) and implemented through the sampling and analysis plan (SAP) (DOE/RL-2009-40). The RI/FS addresses contaminant sources (e.g., site history), contaminant flow and transport, and exposure assessment, and it supports risk characterization, remedial action selection, performance monitoring, and site closure. Data gaps were identified and addressed through additional data collection and other investigations that will support final remediation decisions. Subsurface characterization activities included 12 monitoring wells completed in the unconfined aquifer, 5 monitoring wells completed in the Ringold upper mud (RUM), 10 vadose zone boreholes of which 5 boreholes were converted to temporary wells, and 5 test pits. The RI field work was completed in November 2011, with the RI/FS report scheduled for issuance later in 2012.

The following subsections discuss the major components of the 100-HR-3 OU interim remedies for groundwater:

- Section 2.2 summarizes the conceptual site model (CSM) for groundwater flow and describes the contaminant plumes and concentrations.
- The activities at the OU for the reporting period, including interim action groundwater remediation, are discussed in Section 2.3. Section 2.3.5 discusses ISRM operations.
- Additional OU investigations are summarized in Section 2.4.
- The conclusions and recommendations for the 100-HR-3 OU are presented in Sections 2.5 and 2.6, respectively.

## 2.2 Conceptual Site Model

Data from wells drilled in 2011 were evaluated and combined with historic information and data from wells drilled since the 1996 ROD (EPA/ROD/R10-96/134) to support the interim actions. The new data has improved the understanding of the nature and extent of contamination.

Several borehole summary reports were published in 2011. A series of 70 wells were drilled and constructed in the 100-HR-3 OU to support enhanced P&T operations at the new DX and HX systems. These wells were drilled according to the RPO SAP (DOE/RL-2009-09, *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells*). Details on well construction, sampling, and geology are described in *Borehole Summary Report for the Installation*

*of 70 Remedial Process Optimization, Pump-and-Treat Expansion Wells, for the 100-HR-3 Operable Unit* (SGW-48612). In addition, a characterization campaign was conducted to support an RI/FS at 100-D/H. This characterization included 10 vadose zone characterization boreholes (SGW-50131, *Borehole Summary of Ten Characterization Boreholes in the 100-DR-1, 100-DR-2 and 100-HR-1, 100-HR-2 Source Operable Units in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit*) and 17 groundwater characterization wells (SGW-49912, *Borehole Summary Report for the Installation of 16 Resource Protection Wells in the 100-HR-3 Groundwater Operable Unit in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit*; SGW-51502, *Borehole Summary Report for the Installation of Well C8668 at 100-D-12 in FY2012*).

The information has been integrated to form an updated interpretation of 100-D/H geology. The following subsection provides a brief summary of the geologic and hydrogeologic setting and the groundwater contaminants that are the basis for the CSM. Additional details are provided in DOE/RL-2008-46-ADD1.

### 2.2.1 Geologic/Hydrogeologic Setting

The 100-D/H Area is located in the north central portion of the Hanford Site within the 100-HR-3 Groundwater OU (Figure 2-1). 100-D/H is the operational name for the area that contained the D, DR, and H Reactor buildings and associated support facilities. It is bordered by the Columbia River and is located approximately 45 km (28 mi) north-northwest of Richland, Washington. The 100-D and 100-H Areas are geographically connected by the intervening Horn Area. On the northern border of the Horn Area, the Columbia River turns from the northeastern path and flows to the southeast.

#### *2.2.1.1 Geology*

The surficial deposits at the 100-D/H Area consist of recent backfill sand and gravel overlying Holocene aeolian deposits (Figure 2-5). Construction backfill varies in depth depending on the excavated depth of waste sites and building foundations, and backfill material may cover larger graded areas to a depth up to 4.6 m (15 ft) below ground surface (bgs). Where not disrupted by construction activities, Holocene surficial deposits form a thin (0.3 m [1 ft]) veneer and consist of fine-grained aeolian deposits (loess) and Columbia River deposits of silt, sand, and gravel (WHC-SD-EN-TI-155, *Geology of the 100-K Area, Hanford Site, South-Central Washington*).

These surface deposits are underlain, in descending order, by the Hanford formation, the Ringold Formation, and bedrock consisting of the Columbia River Basalt Group. The Hanford formation and the Ringold Formation are described in the following paragraphs. Figure 2-5 illustrates the hydrostratigraphic units located in the 100-HR-3 OU.

Geologic data from the new RI wells and the new RPO wells improved the knowledge of 100-D/H stratigraphic relationships. Prior to installation of the new wells, the trace line of where the unconfined aquifer matrix transitions from the Ringold Formation unit E to the Hanford formation was not well defined. The location of this trace line (East of 100-D) is important because the Hanford formation is more transmissive than the Ringold Formation unit E, which can affect groundwater flow (Section 2.2.1.2). Data from the new wells also provided better delineation of the Ringold Formation upper mud (RUM) surface.

***Hanford formation.*** The informally named Hanford formation consists of boulders, gravel, sand, and silt deposited by the cataclysmic floodwaters released from glacial Lake Missoula during the Pleistocene Epoch (DOE/RW-0017, *Draft Environmental Assessment for Reference Repository Location, Hanford Site, Washington*). The Hanford formation is the dominant material in the 100 Area vadose zone, ranging in thickness from 2 to 30 m (6.6 to 98 ft) beneath the 100-D/H Area. The Hanford formation can be loosely divided into three facies: gravel-dominated, sand-dominated, and slackwater

(WHC-SD-EN-TI-011, *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*). The gravel-dominated matrix of the Hanford formation generally contains greater than 40 percent basalt (sand-size fraction) displaying a salt-and-pepper or gray coloring (WHC-SD-EN-TI-132, *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*). The Hanford formation is unconsolidated and has low cementation allowing for faster infiltration through the vadose zone. Discrete sand lenses are present in the 100-D/H Area, which may form preferential flow paths or collection zones for vadose zone contaminants.

***Ringold Formation.*** Disconformably underlying the Hanford formation, the Ringold Formation unit E is composed of fluvial matrix-supported gravels and sands with intercalated fine to coarse sand and silt lenses. The contact between the Hanford formation and the Ringold Formation unit E can be difficult to distinguish. Unit E lithology is between 35 percent and 90 percent felsic, consisting of mainly metamorphic, intermediate volcanic, and felsic volcanic clasts (WHC-SD-EN-TI-011). In general, Ringold unit E gravels are more rounded and more cemented, and they show a distinct oxidized reddish-brown color as compared to the Hanford formation. Silica and carbonate cementation are highly variable depending on depth and location (WHC-SD-EN-TI-132). Hydraulic conductivities vary locally, but the Ringold Formation unit E is generally regarded as a low-conductivity unit.

Ringold Formation unit E had been considered absent east of the 100-D Area. Data from new wells indicate that several pockets are present as isolated erosional remnants of varying size located throughout the Horn Area. Where Ringold unit E is not present, the Hanford formation sediments directly overlay the RUM.

The RUM is primarily composed of variably cemented overbank flood deposits and paleosols. Primarily composed of silt and clay, the RUM is typically described as various shades of brown to olive-brown. Within the RUM, thin sand-to-gravel lenses form discontinuous confined to semi-confined aquifers. At some locations in the 100-HR-3 OU, the lower Hanford formation contains isolated but numerous rip-up clasts of the RUM (WHC-SD-EN-TI-132). The RUM marks the base of the unconfined aquifer.

#### *2.2.1.2 Hydrogeology*

Groundwater generally enters the 100-HR-3 OU from the south, with most of the flow moving toward the lower elevations of the 100-H Area. A much smaller portion of the regional flow moves directly toward the 100-D Area. Underlying the 100-D Area, groundwater generally flows toward the Columbia River. Northeast of the 100-D Area, groundwater flow is parallel to the river, thereby flowing east-northeast across the Horn Area and toward the 100-H Area. Groundwater below the 100-H Area discharges northeast and east to the Columbia River. Figure 2-6 presents a groundwater contour map of the area, which was developed using 2011 data.

Groundwater flow in the 100-HR-3 OU is significantly influenced by the Columbia River stage. The river stage fluctuates regularly in seasonal and shorter cycles (e.g., daily river stage change) due to a combination of natural (e.g., spring snowmelt and runoff) and anthropogenic influences (e.g., dam releases). During periods of the year when the river stage is relatively low, typically during the fall, natural groundwater flow is toward the river; when river stage is relatively high, typically in the late spring/early summer (Figure 2-6), groundwater can flow away from the river and/or parallel to the river. Depending on operations at the upstream Priest Rapids Dam, river stage can fluctuate by greater than 3 m (9.8 ft) annually with changes of 1 m (3 ft) or more over short time periods (i.e., hours to days).

Other influences on groundwater flow are leakage from the 182-D reservoir and drawdown or mounding from the groundwater extraction and injection well network. The zone of uncontaminated groundwater near the 182-D facility suggests long-term contaminant mixing and diversion of contaminated

groundwater from the mounding caused by the leaks. In response to the reservoir leakage, a specific issue was included in *The Second CERCLA Five-Year Review Report for the Hanford Site* (DOE/RL-2006-20) for DOE to provide direction to its operating contractor to conduct changes to the operation of the reservoir to minimize leakage. These actions were completed and documented in the closeout of the 5-year review issue. These leaks and resulting impacts to groundwater flow have significantly diminished since the reservoir water level was reduced in 2004, to the point that influences on groundwater flow from reservoir leakage are much less noticeable.

### 2.2.2 Origin of Contaminants in the 100-HR-3 Operable Unit

The 100-D Area reactors operated between 1944 and 1967, and the 100-H Area reactor operated between 1949 and 1965. Each reactor required at least 95,000 L/min (25,000 gpm) of water for cooling in the process tubes. The primary sources of groundwater contamination in the 100-HR-3 OU are associated with reactor operations. Most of the groundwater contamination is associated with various activities involved in the cooling water cycle for the reactors. One of the most important factors in reactor operations was the control of corrosion in the process tubes inside the reactor at high temperatures. Sodium dichromate dihydrite was added to cooling water as a corrosion inhibitor prior to passing through the reactors. Sodium dichromate dihydrite was used, first in a dry granular form delivered in bags and later delivered as a concentrated liquid solution via railcar. Sodium dichromate dihydrite was initially utilized at 2 parts per million (ppm) in the cooling water but was later reduced to 1 ppm. The primary mechanism for hexavalent chromium contamination to groundwater is leaching through the soil of unplanned releases of concentrated solutions of sodium dichromate dihydrite to the ground and, and discharges of reactor cooling water to retention basins and trenches. Other significant sources are the water-filled fuel storage basins (FSBs) on the back side of the reactor where the fuel slugs were allowed to cool before being transported to the 200 Area for processing. Both the cooling water and the FSB water could become contaminated with radionuclides as a result of fuel cladding failures and be diverted to trenches and cribs to protect the river from radionuclides.

### 2.2.3 100-HR-3 Operable Unit Groundwater Contaminants

Hexavalent chromium has been identified as the principal COC in the 100-HR-3 OU under the interim action. The interim remedial action goal for the P&T system is to reduce the hexavalent chromium concentration to less than 10 µg/L in groundwater discharging to the Columbia River as measured at an adjacent monitoring well at 20 µg/L and applying a 1:1 dilution factor. Strontium-90, tritium, technetium-99, and nitrate are co-contaminants that are actively monitored as prescribed in the interim action ROD (EPA/ROD/R10-96/134). In addition, sulfate is a contaminant of interest because the secondary drinking water standard (DWS) has been exceeded in the past in a limited number of wells, primarily as a result of previous sodium dithionite solution injections for the ISRM barrier installation. Institutional controls (ICs) are implemented to satisfy RAO 2, which limits human exposure to hexavalent chromium and co-contaminants.

The groundwater contamination in the 100-HR-3 OU is primarily the result of operations at the three water-cooled nuclear reactors (D, DR, and H Reactors), the associated support structures (e.g., FSBs), and waste disposal processes. These operations generated large quantities of liquid and solid waste contaminated with radionuclides and/or hazardous chemicals. Most contaminant sources can be characterized as high-volume, low-concentration wastes emplaced under high hydraulic head or as low-volume, high-concentration wastes emplaced under low hydraulic head. Waste released to the environment created potential secondary sources of contamination beneath ponds, ditches, cribs, burial grounds, and unplanned release sites. Contaminants from these sites can be retained in the vadose zone and released to the aquifer over extended periods of time.

The ongoing characterization and remediation of waste sites in the 100-D and 100-H Areas began in 1996 under the authority provided by the interim action RODs and the *Resource Conservation and Recovery Act of 1976* (RCRA) closure and monitoring plans. Remediation primarily consists of removing and disposing soil, debris, and waste material, and then backfilling the remediated waste site. A portion of the 100-D and 100-H Area waste sites (i.e., trenches, pits, and burial grounds) have already been remediated and dispositioned. The remediation status of each waste site is described in detail in DOE/RL-2008-46-ADD1.

The RI/FS field effort, implemented in 2010, targeted several waste sites located in the 100-D and 100-H Areas for additional characterization. The objectives were to define the nature and extent of contaminants more accurately and to identify any remaining potential sources of contamination. The following 17 waste sites were investigated:

- 100-D-12 French Drain associated with the sodium dichromate/acid railcar and truck unloading station (where highly concentrated sodium dichromate solutions may have been drained during railcar unloading operations)
- 100-D-4 Sludge Pit
- 100-D-56 Pipelines
- 116-D-1A Trench
- 116-D-1B Trench
- 116-D-4 Crib
- 116-D-7 Retention Basin
- 116-DR-1&2 Trenches
- 116-DR-9 Retention Basin
- 118-D-6 FSB
- 116-H-1 Trench
- 116-H-2 Trench
- 116-H-4 Crib
- 116-H-6 (183-H) Solar Evaporation Basins
- 116-H-7 Retention Basin
- 118-H-6 FSB
- 1607-H4 Septic System

*Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90) and "Sampling Changes to the 100-HR-3 and 100-KR-4 Operable Units" (Wanek, 1998) define the sampling analytes and frequencies based on the general principles defined in the 1996 ROD (EPA/ROD/R10-96/134). A revised integrated SAP is being developed to update the documentation for sampling in the 100-HR-3 OU. The contaminant monitoring results are presented in the following subsections. Summaries of the maximum 2010 and 2011 contaminant and co-contaminant concentrations

detected in the 100-D and 100-H Area wells and aquifer tubes are provided in Tables 2-1 and 2-2, respectively.

This report focuses on evaluating analytical results for hexavalent chromium being remediated through the interim action P&T systems. Further summary and analysis of the other COCs and contaminants of interest is presented in DOE/RL-2011-118.

For the first time in this report, contaminant plume maps were constructed by computer programs using a method called quantile kriging to produce a continuous spatial illustration of the contaminant distribution. The measured concentrations in wells are interpolated to a grid using a quantile kriging technique based on that described by *GSLIB: Geostatistical Software Library and User's Guide* (Deutsch and Journel, 1992), "Rank Order Geostatistics: A Proposal for a Unique Coding and Common Processing of Diverse Data" (Journel and Deutsch, 1997), and "Spatial Interpolation Methods for Nonstationary Plume Data" (Reed et. al., 2004), among others. The quantile kriging approach is based upon two-dimensional ordinary kriging of a non-parametric (uniform-score) transform of the concentration, and a subsequent back-transform of the interpolated scores into the original units of measured concentration. Quantile kriging was accomplished using an open-source program based upon the United States Geological Survey kriging routines from *Semi-Variogram Estimation and Universal Kriging Program* (Skrivan and Karlinger, 1980) that incorporates routines to conduct the uniform-score transform/back-transform.

The computer factored in variables such as groundwater flow direction to create more realistic plumes. Limitations of the technique arise because the computer does not account for factors such as the locations of the known sources of contaminants, historical trends in concentrations, or relative mobility of contaminants. To minimize the adverse effects of these limitations, control data points were inserted where necessary, based on historical information and expert knowledge.

The following conventions were applied to create data sets for plume maps.

- Selected wells screened in the upper portion of the unconfined aquifer. In most areas there are not sufficient numbers of deeper wells to create contour maps.
- Selected and averaged data (if more than one sample) from the period of interest (all of 2011 for most maps; high or low water-level conditions for some plumes near the Columbia River).
- Aquifer tubes are typically installed in clusters with screens at different depths in the unconfined aquifer. The mapped data sets include only the highest concentration in each cluster.
- If no data were available from a well during the desired time period, included data from outside the time period.
- Excluded data that appear to be nonrepresentative. Quality control staff and the project scientist in charge of the operable unit or monitored unit determine data representativeness. The evaluation employs a documented procedure and uses various methods and best professional judgment (DOE/RL-2011-118, Appendix D).
- "U" flagged data (less than detection limits) were counted as zero in averaging. Although this skews the averages low, the effect is insignificant at the current contouring levels.

Contour levels for the maps in this report were chosen as follows:

- Aquatic water quality criteria and drinking water standards (e.g., 10 µg/L AWQC, 48 µg/L "Model Toxics Control Act—Cleanup " [WAC 173-340] and 100 µg/L federal drinking water standard for hexavalent chromium)
- Cleanup levels or interim remedial action goals, where applicable (for example, 20 µg/L for hexavalent chromium)
- Intermediate levels to help define plume shape (for example, 500 µg/L for hexavalent chromium).

#### 2.2.3.1 Hexavalent Chromium

The remedial action goal for hexavalent chromium for 100-HR-3 OU groundwater interim actions is 20 µg/L in a near-shore compliance well for both the P&T systems and the ISRM barrier system. These systems are given an allowance for a 1:1 attenuation factor to meet the 10 µg/L ambient water quality standard in the hyporheic zone, as determined by the following:

- *Declaration of the Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units, Benton County, Richland, Washington* (EPA/AMD/R10-00/122).
- *Interim Action Record of Decision for the 100-BC-1, 100-BC-2, 100-DR-1, 100-DR-2, 100-FR-1, 100-FR-2, 100-HR-1, 100-HR-2, 100-KR-1, 100-KR-2, 100-IU-2, 100-IU-6, and 200-CW-3 Operable Units, Hanford Site, Benton County, Washington (100 Area Remaining Sites)* (EPA/ROD/R10-99/039).
- *Explanation of Significant Differences for the 100-HR-3 and 100-KR-4 Operable Units Interim Action Record of Decision: Hanford Site, Benton County, Washington* (EPA et al., 2009).

Hexavalent chromium concentrations are monitored in extraction wells, compliance wells, monitoring wells, and aquifer tubes in the 100-D and 100-H Area P&T operational areas (Figures 2-2 and 2-3). Figure 2-7 shows the distribution of hexavalent chromium in 100-HR-3 OU groundwater during the fall of 2011. Maximum hexavalent chromium levels generally coincide with low river conditions and occur in the late fall to early spring. In areas where data are sparse, historical iso-concentration contours were used to aid in completing the map. Tables 2-3 and 2-4 compare the fall 2011 hexavalent chromium concentrations from wells and aquifer tubes to the fall 2010 and 2009 concentrations for both the 100-D and 100-H Areas, respectively. The tables also include 2009 to 2011 and 2010 to 2011 changes in concentration.

***Southern 100-D Area Plume.*** Underlying the 100-D Area, hexavalent chromium in the unconfined aquifer occurs in two distinct plumes often referred to as the southern and northern plumes. Historical handling activities of 70 percent sodium dichromate solution at the 100-D Area (100-D-12 and former railcar unloading station) are the likely sources of the southern plume. The southern plume lies south and west of the 183-DR filter plant. A chromium source investigation was completed in 2010 (DOE/RL-2009-92, *Report on Investigation of Hexavalent Chromium in the Southwest 100-D Area*). This study significantly improved the characterization of the hot spot in the 100-D South plume and the adjacent areas in the aquifer. However, it did not identify any particular source area within the vadose zone. Subsequent excavations in the vicinity have revealed significant hexavalent chromium at the 100-D-100 waste site just south of the study area.

In 2011, the areal plume configuration did not change, compared to 2010, but concentrations of hexavalent chromium decreased. The maximum concentration in 2011 was 28,100 µg/L, which is much lower than previous years that had maximum concentrations of 69,700 µg/L (2010) and 59,600 µg/L (2009).

Among the wells in the 100-D Area southern hexavalent chromium plume, the highest hexavalent chromium concentrations in groundwater samples in 2011 were found in well extraction well 199-D5-104 (10,304 µg/L) and monitoring well 199-D5-122 (28,100 µg/L). For well 199-D5-104, hexavalent chromium concentrations are higher than measured in 2010 (8,910 µg/L). Concentrations in groundwater samples from well 199-D5-122 have considerably decreased from 2010 (69,700 µg/L). Operation of the DX system has reduced concentrations but has also resulted in the separation of the area of highest concentrations into two areas. The 100-D Area hexavalent chromium plume for fall 2011 is shown in Figure 2-8. The figure also shows hexavalent chromium trend plots for selected wells within the plume.

Wells that monitor the aquifer in the central 100-D Area (199-D5-33 and 199-D5-36) continue to have low hexavalent chromium concentrations. These wells are located between the southern and northern hexavalent chromium plumes (Figure 2-7). Historically, hexavalent chromium has not been detected in groundwater samples from these wells, which may have be the result of infiltration of clean water from the 182-D reservoir, leaking raw water pipes, or injection of treated water into wells 199-D5-41 and 199-D5-42. Repairs and operational changes have reduced the amount of infiltration from the 182-D reservoir, but hexavalent chromium concentrations have not fully rebounded in this area. Well 199-D5-36 samples were all below detection limits. Hexavalent chromium was detected in only one sample in well 199-D5-33 at a concentration of 4.6 µg/L.

In 100-D Area aquifer tubes, hexavalent chromium concentrations in 2011 were at the lower end of the historical range (Figure 2-9). The highest hexavalent chromium concentration detected in aquifer tubes in the 100-D Area was in Redox-1-6.0 (96.7 µg/L), downgradient of the ISRM barrier. Hexavalent chromium detected downgradient of the ISRM barrier has decreased since the late 1990s but continued to remain above the cleanup standard in 2011. Aquifer tubes located downgradient of the ISRM barrier had hexavalent chromium concentrations ranging from nondetect to 15.4 µg/L. The aquifer tubes located the furthest upstream (C7645, C7646, C7647, and C7648) in the area had a maximum concentration of 2.3 µg/L.

***Northern 100-D Area Plume.*** The northern hexavalent chromium plume extends north from the D Reactor to the Columbia River. Operationally, the northern plume is located downgradient of the former sodium dichromate distribution system, which contained less concentrated solutions than the initial 70 percent solution brought in by railcar at 100-D-12. In 2011, the northern hexavalent chromium plume size had not changed significantly compared to 2010, but concentrations had decreased slightly. Among the wells in the 100-D Area northern plume, the highest hexavalent chromium concentrations in groundwater were found in wells 199-D5-125 and 199-D5-126, as high as 1,570 µg/L and 1,980 µg/L, respectively. This data shows a decrease from the 2010 concentrations of 2,310 µg/L (199-D5-125) and 2,150 µg/L (199-D5-126). Figure 2-10 shows hexavalent chromium concentrations within the north plume, as well as the hexavalent chromium concentration trend plots for selected wells within the plume.

Well 199-D5-15 monitors groundwater near a potential source of the northern hexavalent chromium contamination. Hexavalent chromium concentrations were low from 1999 through 2003 due to mixing with nearby leaking water lines, which were repaired in 2004 (PNNL-15070, *Hanford Site Groundwater Monitoring for Fiscal Year 2004*). In 2004, concentrations began to increase, reaching a maximum of 2,450 µg/L in May 2007. Hexavalent chromium in this well has been subsequently declining and had a maximum concentration of 699 µg/L during 2011. Hexavalent chromium in wells 199-D5-14 and 199-D5-16 (downgradient of well 199-D5-15) also increased in 2008 but has been steadily decreasing. Vadose zone soil sampling conducted during the 100-D Area chromium source investigations in the northern 100-D Area (DOE/RL-2010-40, *Report on Investigation of Hexavalent Chromium Source in the Northern 100-D Area*) discovered small amounts of hexavalent chromium in the vadose zone in a few

locations but did not identify a large source capable of producing the high concentrations in some groundwater monitoring wells.

Hexavalent chromium concentrations in aquifer tubes downgradient of the northern plume have declined since the late 1990s. Only two aquifer tubes had a groundwater sample above the remedial action goal at tube 36-D (24.8 µg/L) and DD-17-3 (21.6 µg/L).

***Horn Area Plume.*** The hexavalent chromium plume underlying the Horn Area is believed to have originated in the 100-D Area and has subsequently migrated toward the 100-H Area. A significant portion of the mass in the Horn Area may have resulted from routing of cooling water to the 116-DR-1&2 Trench during the final months of operation at the D reactor.

During 2011, groundwater sampling results still showed the presence of hexavalent chromium in groundwater beneath the Horn Area and no significant change in the plume compared to 2010. Higher hexavalent chromium concentrations are still restricted to the area immediately adjacent to the 100-D Area. Injection wells in the 100-H Area create a hydrologic barrier on the northeastern side of the plume, preventing the plume from extending eastward into the northern portion of 100-H Area (Figure 2-7).

The central core of the Horn Area plume had concentrations between 50 and 90 µg/L in wells 699-98-46, 699-97-45, 699-97-43B, and 699-95-45. Hexavalent chromium concentrations in these wells were largely unchanged from 2010 to 2011.

Three wells in the Horn Area monitor the RUM: 699-97-43C, 699-97-45B, and 699-97-48C. Well 699-97-48C reported a low hexavalent chromium concentration of 27.0 µg/L in August 2011 and a high hexavalent chromium concentration of 52.9 µg/L in December 2011, which is slightly higher than the previous year's high concentration of 42.3 µg/L. Well 699-97-43C and 699-97-45B reported undetected hexavalent chromium for all samples in 2011.

Concentrations greater than 20 µg/L were also observed along the Horn Area, reflecting the plume as it intercepts the Columbia River. The highest concentration upstream of the Horn Area plume was 40.9 µg/L in aquifer tube C5641. This remains unchanged from the 2010 maximum concentration of 42.2 µg/L in the same tube. This area of contamination is captured in the HX extraction well network and concentrations are expected to decrease.

***100-H Area Plume.*** The size of the hexavalent chromium plume in the unconfined aquifer underlying the 100-H Area has been significantly reduced since startup of P&T operations in 1997. However, in 2011, the plume did not change significantly compared to 2010. A small and low concentration hexavalent chromium plume remains adjacent to the Columbia River. During 2011, groundwater in the 100-H Area had concentrations at less than 20 µg/L of hexavalent chromium, though several wells upgradient of the 100-H Area continued to have hexavalent chromium above the interim remedial action goal.

The highest 100-H Area plume hexavalent chromium concentration for 2011 was in new RI/FS well 199-H3-9. Samples were collected from this well at discrete depths during drilling. A concentration of 287 µg/L was detected in the first water bearing unit of the RUM. Hexavalent chromium had not been detected above 10 µg/L in the unconfined aquifer at this location. A sample collected from well 199-H3-9 after completion and development had a concentration of 115 µg/L.

Well 699-97-43B, which is located upgradient of the 100-H Area, has had the highest hexavalent chromium concentration since 2007. In 2011, well 699-97-43B had a maximum 87.3 µg/L of hexavalent chromium, which has not changed from the previous reporting period. Hexavalent chromium in groundwater underlying the 100-H Area and selected trend plots are shown in Figure 2-11.

In 2010, an increase in hexavalent chromium concentration was noted in the southern portion of the 100-H Area near well 199-H3-5, which is one of the original injection wells at the HR-3 system. Since shutdown of this well, some encroachment of the Horn Area plume has occurred in the vicinity. A future realignment is recommended to add this well to the HX extraction well network.

Extraction wells 199-H3-2C and 199-H4-12C and piezometer 199-H4-15CS are screened within the first water-bearing layer of the RUM. Groundwater samples collected from these wells and piezometer continued to show elevated hexavalent chromium concentrations. In 2009, these wells and piezometer were used for a series of aquifer tests to gather data on the presence of deep chromium in the RUM (SGW-47776, *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation*). The results from these tests showed high hexavalent chromium concentration in the RUM.

The following observations were noted for 2011:

- Well 199-H3-2C (screened in the first water-bearing layer in the RUM) is located on the western side of the 100-H Area, upgradient of the 100-H Area waste sites. Hexavalent chromium concentrations in groundwater samples from this well increased in 2009, but have slowly declined. During the 2009 aquifer test, the highest hexavalent chromium value observed was 112 µg/L. In 2011, the concentration was 80 µg/L. Adjacent well 199-H3-2A, completed in the unconfined aquifer, had much lower hexavalent chromium concentrations (less than 12.1 µg/L).
- Well 199-H4-12C (screened in the first water-bearing layer in the RUM) is located near the Columbia River, downgradient of the 183-H solar evaporation basins and adjacent to extraction well 199-H4-12A (screened in the unconfined aquifer). Throughout most of 2009, well 199-H4-12C hexavalent chromium concentrations were between 80 and 100 µg/L. In early November 2009 concentrations increased to a maximum value of 121 µg/L, in response to the aquifer testing. The highest hexavalent chromium concentration detected in 2011 was 147 µg/L, which is similar to the maximum in 2010 of 140 µg/L.
- Piezometer 199-H4-15CS is adjacent to an extraction well. Hexavalent chromium concentrations in this piezometer were steady at levels near 100 µg/L until November 2009, when it increased to 115 µg/L as a result of the aquifer testing. In 2011, the highest concentration detected was 153 µg/L; however, in shallower wells 199-H4-15A and 199-H4-15B, hexavalent chromium levels were much lower at 27 and 17 µg/L, respectively.

Hexavalent chromium concentrations in aquifer tubes in the main 100-H Area were below 20 µg/L, with the exception of tube C7650. Aquifer tube C7650 was installed as part of the RI activities, downgradient of the 116-H-7 waste site in April 2010, to define the extent of hexavalent chromium and strontium-90 contamination. Groundwater samples collected from this aquifer tube during 2011 had a maximum hexavalent chromium concentration of 26.6 µg/L, with the duplicate sample at 21.5 µg/L.

#### 2.2.3.2 Sulfate

The source of sulfate includes sulfuric acid that was used in a variety of cleaning and decontamination activities in the reactor areas, as well as the use of sodium dithionite in the treatment of the ISRM barrier in the 100-D Area.

***100-D Area.*** Excluding wells influenced by the ISRM barrier, sulfate concentrations in 2011 were below the secondary DWS (250 mg/L), with a maximum concentration of 187 mg/L in well 699-98-51. Sulfate concentrations in samples from 100-D Area aquifer tubes are generally low, with the exception of those downgradient of the ISRM barrier.

Previous sodium dithionite solution injections at the barrier increased sulfate concentrations to levels above the secondary DWS in the ISRM barrier and in some downgradient wells and aquifer tubes. Elevated sulfate might have been expected sooner in aquifer tubes in this area; water level increases in the aquifer due to rises in river stage may sufficiently reduce or reverse the local gradient and result in extended travel times. Sulfate concentrations in groundwater underlying much of the southern 100-D Area remained greater than 100 mg/L. The highest concentration in 2011 was 466 mg/L in aquifer tube DD-42-4, which is the only aquifer tube that had results above the secondary DWS, and the concentration is a decrease from the 2010 maximum concentration of 776 mg/L in tube DD-43-3.

***100-H Area.*** Only two wells underlying the 100-H Area detected sulfate concentrations above the secondary DWS (250 mg/L) in groundwater. Wells 199-H1-27 and 199-H4-75 had concentrations of 410 and 359 mg/L, respectively. Concentrations in 2011 show an increase from 2010, which had a maximum of 83.6 mg/L. These two wells were recently drilled in the last half of 2010, but only well 199-H1-27 was sampled for sulfate at that time and had a concentration of 40 mg/L.

## 2.3 CERCLA Operable Unit Interim Action Activities

This section summarizes the non-RI/FS CERCLA activities for the100-HR-3 OU during the reporting period, including groundwater remedial actions.

An interim remedial action ROD for the 100-HR-3 Groundwater OU was issued in April 1996 (EPA/ROD/R10-96/134) pursuant to the Hanford Site's 1989 listing on the "National Oil and Hazardous Substances Pollution Contingency Plan," Appendix B, "National Priorities List" (40 CFR 300) for CERCLA. The goal of the resulting interim remedial action is to prevent discharge of hexavalent chromium to the Columbia River. *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) implemented the P&T interim remedial actions in accordance with the interim ROD.

The interim action goal was changed from 22 µg/L to 20 µg/L in August 2009 by the explanation of significant differences (ESD) for the 100-HR-3 and 100-KR-4 OUs (EPA et al., 2009). The ESD sets a 20 µg/L threshold at onshore, near-river monitoring locations. As indicated in the interim action ROD, an attenuation factor of 1:1 is expected before the groundwater would reach the aquatic receptor point of concern within the river substrate, ensuring that the ambient water quality criterion of 10 µg/L in the river substrate will be met.

The second CERCLA 5-year review (DOE/RL-2006-20) was published in November 2006. The review identified four actions pertaining to the 100-HR-3 OU interim action groundwater remediation:

- **Action 9-2 COMPLETE:** *Incorporate the Horn Area into the 100-HR-3 OU interim ROD (EPA/ROD/R10-99/039); Action 9-1 indicates that the Horn Area contains a plume requiring immediate remediation (September 2009).*

  DOE has completed the RPO evaluation of the P&T systems and is currently implementing the results (SGW-40044, *100-HR-3 Remedial Process Optimization Modeling Technical Memorandum*). DOE installed additional extraction and injection wells throughout the Horn Area in fiscal year (FY) 2009 and FY 2010 as part of the RPO and connected them to the P&T systems in CY 2011, which resulted in the 2,300 L/min (600 gpm) DX system and the 3,000 L/min (800 gpm) HX system.

- **Action 11-1 COMPLETE:** *Initiate limited iron amendments to evaluate whether this enhances ISRM barrier performance (September 2007).*

This action was completed in 2009. Results of the iron amendment tests are documented in *Treatability Test Report on Mending the In Situ Redox Manipulation Barrier Using Nano-Size Zero Valent Iron* (DOE/RL-2009-35).

- **Action 11-2 COMPLETE:** *Expand groundwater P&T extraction within the 100-D Area by 378.5 L/min (100 gpm) to enhance remediation of the hexavalent chromium plume (no due date).*

  DOE installed additional extraction and injection wells in FY 2009 as part of the RPO (SGW-38338, *Remedial Process Optimization for the 100-D Area Technical Memorandum Document*; SGW-40044). The wells were added to the new DX P&T system, which became operational in January 2011.

- **Action 12-1 COMPLETE:** *Perform additional characterization of the 100-H Area aquifer below the initial aquitard (September 2009).*

  DOE installed three wells in the Horn Area screened in the RUM (DOE/RL-2008-42, *Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit*) and continues to monitor three wells in the 100-H Area.

  In 2009, aquifer tests were performed to gather data to provide additional information on the deep hexavalent chromium contamination in the 100-H Area. The findings are presented in SGW-47776).

  Five wells (three in the 100-H Area and two in the 100-D Area) were installed as part of the RI/FS work plan. The wells were drilled through the RUM and screened within the first water-bearing layer encountered (DOE/RL-2008-46-ADD1).

DOE issued Revision 1 of the third 5-year review (DOE/RL-2011-56, *Hanford Site Third CERCLA Five-Year Review Report*) in March 2012. DOE issued an errata sheet in June 2012 (12-EMD-0070, "Hanford Site Third Comprehensive Environmental Response, Compensation, and Liability Act Five-Year Review Report, April 2012"). The review identified one action item pertaining to the 100-HR-3 OU interim action groundwater remediation (**Action 2-1:** *Complete the engineering export water scoping study to evaluate whether the 182-D Reservoir and export water system is necessary to support the Hanford Cleanup Mission*).
Approximately 80 percent of the pressurized water lines in the 100-D Area have been cut and capped, greatly reducing potential water line leakage as a contaminant driving force; however, the potential for leakage still exists. In February 2010, a major water leak near the 182-D Reservoir discharged at least 37,850 L (10,000 gal) of raw water to the ground and adjacent water sites; consequently, additional work to identify and remove potential water sources, including the 182-D reservoir, is necessary to complete this action.

### 2.3.1 HR-3 P&T System

The HR-3 P&T system extracted groundwater through wells in the northern plume (100-D Area) and in the 100-H Area plume from 1997 until it was placed in cold standby in May 2011. The extracted groundwater was transferred through an above-ground pipeline to a treatment building in the 100-H Area. Hexavalent chromium was removed from the extracted groundwater using IX resins. Treated water was then discharged to injection wells, which are screened in the unconfined aquifer underlying the 100-H Area. The treatment capacity for the HR-3 P&T system was 1,100 L/min (300 gpm). The system used up to 12 extraction wells (10 wells screened in the unconfined aquifer and 2 wells screened in the RUM). The system also included three injection wells in the 100-H Area. Table 2-5 identifies the extraction, compliance, and injection wells for the HR-3 P&T system used in 2011. The majority of these wells were added to the new HX P&T system.

#### 2.3.1.1 Changes in 2011

The size of the hexavalent chromium plume in the unconfined aquifer underlying the 100-H Area has been significantly reduced since startup of P&T operations in 1997. However, in 2011, this plume did not change significantly compared to 2010. A relatively small hexavalent chromium plume with low concentrations remains adjacent to the Columbia River. Pumpage from the uppermost water-bearing unit in the RUM continued in 2011 from wells 199-H3-2C and 199-H4-12C. Concentrations at well 199-H3-2C remained relatively constant during the year in a range between 57 – 71 µg/L; concentrations at well 199-H4-12C also remained relatively constant in a range between 135 – 148 µg/L.

In May 2011, the HR-3 P&T system went offline as an outcome of the RPO. The wells from the system were disconnected and then added to the new HX well network. Consolidation was done on the extraction and injection wells within the two areas to reduce water movement across the Horn Area. Groundwater wells that extracted from the northern portion of the 100-D Area and piped to the 100-H Area for treatment were disconnected from the HR-3 P&T system and will be added to the DX P&T system in a future well realignment. These wells include four extraction wells (199-D8-53, 199-D8-54A, 199-D8-68, and 199-D8-72). These wells have not been hooked up yet to the DX P&T system due to funding and injection capacity constraints.

The remaining HR-3 P&T wells were disconnected and then added to the new HX P&T well network; wells 199-H4-3 and 199-H4-12A were disconnected and not added to the network. Disconnection of the wells was completed on May 16, 2011, and then the HR-3 system was placed in cold standby. Rebound in hexavalent chromium concentrations was observed in several wells north of the 105H reactor during the transition from the HR-3 system to the HX system while the pumps were shut down. These included extraction well 199-H4-4 and monitoring wells 199-H4-15A and 199-H4-48. These wells are located in the vicinity of the 100-H-28 waste site remediation.

#### 2.3.1.2 Treatment System Performance

During 2011, the HR-3 P&T system extracted 134 million L (35 million gal) of groundwater from the 100-HR-3 OU. The system removed 5.6 kg of hexavalent chromium during 2011, bringing the total amount removed to 406 kg since 1997, in addition to the 30 kg removed by a pilot-scale system in the early 1990s. A summary of operational parameters and total system performance for the HR-3 P&T system (100-D and 100-H Areas) in 2011 is provided in Table 2-6.

The average influent hexavalent chromium concentration for the duration of operation in 2011 was 43.5 µg/L. The average effluent concentration for the reporting period was 3 µg/L, which makes an average removal efficiency of 93.1 percent for the HR-3 P&T system.

#### 2.3.1.3 Compliance Monitoring

The monitoring requirements for the HR-3 P&T system are specified in the interim monitoring plan (DOE/RL-96-90). Long-term monitoring requirements are derived from TPA (Ecology et al., 1989) Change Control Form 107.

Wells 199-D8-54A and 199-D8-71 are the two specified compliance points for the HR-3 P&T system in the 100-D Area. Hexavalent chromium concentrations in these compliance wells exceeded the 20 µg/L interim remedial action goal during 2011, which is unchanged from the previous reporting period. Well 199-D8-54A was sampled monthly until the HR-3 P&T system was shutdown. The well had concentrations ranging from 4 to 91 µg/L. Well 199-D8-71 was sampled quarterly and hexavalent chromium as high as 131 µg/L, which was similar to the maximum of 130 µg/L in 2010.

In the northeastern boundary of the 100-D Area, hexavalent chromium concentrations have decreased in compliance wells 199-D8-69 and 199-D8-70. The compliance wells continued to show variable hexavalent chromium concentrations, with the lowest concentrations in the early summer when the river stage was high (Figure 2-6). Concentrations in these compliance wells exceeded the 20 µg/L interim remedial action goal during the winter, but concentrations were below 20 µg/L during part of the year for the first time, with an undetected value in May at 199-D8-69 and 8.8 µg/L in August at 199-D8-70. The highest detected concentrations were 39 and 36.6 µg/L in wells 199-D8-69 and 199-D8-70, respectively.

In the 100-H Area, one compliance well (199-H4-5) was sampled 6 times during the year at both low and high water. None of the samples exceeded the 20 µg/L remedial action goal, and the maximum hexavalent chromium concentration detection was 3 µg/L. Concentrations have been below 20 µg/L in this well since 2005.

Four additional wells in the 100-H Area are designated as dual purpose wells. Well 199-H4-3 is designated as an extraction/performance well, and wells 199-H4-4, 199-H4-63, and 199-H4-64 are designated as extraction/compliance wells. Only one well had a hexavalent chromium concentration above the interim remedial action goal of 20 µg/L during 2011. Well 199-H4-63 had the highest concentration of hexavalent chromium at 22 µg/L, which is a decrease from 26 µg/L in 2010.

### 2.3.2 DR-5 P&T System

A second P&T system, DR-5, began operating at the end of July 2004 to treat significant concentrations of hexavalent chromium characterized in 100-D Area wells southwest of the original HR-3 P&T system D-transfer wells. The DR-5 P&T system extracted, treated, and injected groundwater in the 100-D Area until it was shut down in April 2011. Groundwater was treated at the DR-5 treatment facility using a metal anion-exchange system with onsite regeneration. Treated groundwater was then injected back into wells in the 100-D Area. The treatment capacity for the DR-5 P&T system was 190 L/min (50 gpm). The system consisted of four extraction wells: two wells (199-D5-20 and 199-D5-92) are located in the northern hexavalent chromium plume (100-D Area), and two wells (199-D5-39 and 199-D5-104) are located in the southern hexavalent chromium plume (100-D Area). In 2011, well 199-D5-104 was offline. The DR-5 P&T system also included two injection wells (199-D5-41 and 199-D5-42) in the 100-D Area. Table 2-7 identifies the extraction and injection wells used during the P&T operation.

#### *2.3.2.1 Changes in 2011*

On March 2, wells 199-D5-20 and 199-D5-39 were shut off, leaving only well 199-D5-92 operating. In mid-April, the entire DR-5 P&T system was shut down, the wells were disconnected, and then they were added to the new DX well network with the exception of well 199-D5-41. The DR-5 system was then placed in cold standby.

#### *2.3.2.2 Treatment System Performance*

For the four months of operation in 2011, the DR-5 P&T system extracted 9.1 million L (2.4 million gal) of groundwater from the 100-D Area. The system removed 11.3 kg of hexavalent chromium during the reporting period, for a total of 384 kg removed since 2004. A summary of operational parameters and total system performance for the DR-5 P&T system is presented in Table 2-8.

The average influent hexavalent chromium concentration in 2011 was 1,285.8 µg/L. The average effluent concentration for the reporting period was 1.5 µg/L. Total system pumping rates remained relatively constant until shutdown. The average removal efficiency for 2011 was 99.9 percent, which is essentially the same as the 99.8 percent reported in 2010.

#### 2.3.2.3 Compliance Monitoring

The DR-5 P&T system currently does not have any compliance wells; however, the system is monitored on a regular basis.

#### 2.3.2.4 DX P&T System

The DX facility (Figure 2-12) entered acceptance testing in the fourth quarter of 2010 and became operational in December 2010. The new DX facility, with a treatment capacity of 2,300 L/min (600 gpm), facilitates remediation by expanding the capture zone, thereby drawing a larger volume of contaminated groundwater for treatment. The design of the DX P&T system is described in *Functional Design Criteria for the 100-DX Pump and Treat System* (SGW-40243). The design and operational philosophy optimizes containment along the river, and containing and removing the mass in the hot spots. In 2011, the 11,400 $ft^2$ (1,059 $m^2$) DX process plant uses 37 extraction wells and over 40 mi (64 km) of piping to bring groundwater to the facility that is treating up to 75 million L (20 million gal) per month (Figure 2-13). The treated water is returned to the aquifer through a series of 14 injection wells. Table 2-9 identifies the extraction and injection wells. The extraction and injection wells were operating at the same time; therefore, the total extraction and injection rates may vary.

The treatment trains are utilizing ResinTech® SIR-700 resin to treat hexavalent chromium as it flows through tanks in the treatment facility. The resin binds hexavalent chromium as the contaminated groundwater passes through it. The technology is very efficient, leaving little or no measurable chromium in the water afterwards. The clean water is reinjected into the aquifer. This is the same technology used at the HX plant. The new resin does not need to be replaced as often, saving time and money. No resin changes occurred during 2011 and none are anticipated in 2012. The treated water is then returned to the aquifer through a series of injection wells. The DX P&T system significantly upgrades capacity to treat groundwater along the river and is a key component of DOE's strategy for stopping chromium from entering the Columbia River in 2012.

For 2011, the areal extent of the southern hexavalent chromium plume in the 100-D Area did not change significantly compared to 2010. However, a significant amount of the mass removed from the DX systems has come from wells 199-D-104 and 100-D-39. The DX system significantly upgrades capacity to treat groundwater along the river and is a key component of DOE's strategy for stopping hexavalent chromium from entering the Columbia River in 2012.

#### 2.3.2.5 Changes in 2011

For 2011, there were no configuration changes to the DX P&T system. The DX P&T systems will evolve while groundwater remediation activities continue toward meeting TPA (Ecology et al., 1989) remediation goals. To manage and refine the DX systems, the RPO process will use available source area data; groundwater monitoring data, including compliance wells; updated contaminant fate and transport modeling results; and extraction/injection well performance data. Action items may include installing additional extraction/injection wells, converting injection wells to extraction wells (or vice versa), changing extraction/injection rates, and addressing source areas to remove contaminant contributions to groundwater.

#### 2.3.2.6 Treatment System Performance

During 2011, the DX P&T system extracted 919 million L (243 million gal) of groundwater from the 100-D Area, which is a significant increase compared to the 44.6 million L (11.8 million gal) processed by the DR-5 P&T system in 2010. The system removed 443 kg of hexavalent chromium during the

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reporting period, in addition to the 18.4 kg removed by the pilot-scale system in December 2010. The amount of hexavalent chromium removed by the DX P&T system in 2011 was an increase of 491 percent in mass removed when compared to 74.9 kg processed by the DR-5 system in 2010.

The average influent hexavalent chromium concentration in 2011 was 429.3 µg/L. The average effluent concentration for the reporting period was 0.6 µg/L. Figure 2-14 shows the influent and effluent concentrations for the treatment systems. The average removal efficiency for 2011 was 99.8 percent. A summary of operational parameters and total system performance for the DX P&T system is presented in Table 2-10. The system operated at a relatively constant rate of about 1,893 L/min (500 gpm) throughout CY 2011, with a period of reduced pumping rates (around 1,514 L/min [400 gpm]) from April to June 2011. Figure 2-15 shows the system availability for the reporting period.

The resin tests performed for selecting ResinTech® SIR-700 resin for the DX P&T (SGW-41642, *Resin Evaluation and Test Report to Support DX Treatment System*) estimated that the resin change out rate would be two vessels per train each year after processing 40,000 bed volumes (one bed volume is the volume of resin in the treatment system) of contaminated groundwater through each treatment train. The resin has outperformed the design basis and no resin change out has been required since the DX P&T startup in December 2010. The resin has processed over 74,000 bed volumes in each treatment train; over 86 percent more volume than planned.

For 2011, the areal extent of the hexavalent chromium plumes in the 100-D Area did not change compared to 2010. However, average concentrations beneath the 100-D Area have significantly decreased.

#### *2.3.2.7 Compliance Monitoring*

The DX P&T system currently does not have any compliance wells; however, the system is monitored on a regular basis. A SAP is being developed that will address groundwater monitoring requirements and system compliance. The SAP incorporates several monitoring requirements, including interim action monitoring for compliance, performance, and operations required to assess the P&T and ISRM barrier remedial actions currently deployed in the 100-HR-3 OU.

### 2.3.3 HX P&T System

The HX P&T facility (Figure 2-16) entered acceptance testing in September 2011 and became operational on October 1, 2011. The new system has a treatment capacity of 3,000 L/min (800 gpm) compared to the 300 gpm capacity of the old HR-3 system. The design of the HX P&T system is described in *Functional Design Criteria for the 100-HX Pump and Treat System* (SGW-43616). The design and operational philosophy optimizes containment along the river, and containing and removing the mass in higher contaminated areas. The 1,625 $m^2$ (17,500 $ft^2$) HX process plant uses 31 extraction wells, 15 injections wells, and over 98 km (61 mi) of piping to bring groundwater to the facility. It will be able to treat up to 132 million L (35 million gal) per month (Figure 2-17). Table 2-11 identifies the extraction and injection wells.

ResinTech® SIR-700 treats hexavalent chromium as it flows through tanks in the treatment facility. This is the same technology used at the DX plant. The new resin does not need to be replaced as often, saving time and money. The treated water is then returned to the aquifer through a series of injection wells. The HX P&T system significantly upgrades capacity to treat groundwater along the river and is a key component of DOE's strategy for stopping chromium from entering the Columbia River in 2012.

#### 2.3.3.1 Changes in 2011

For 2011, there were no configuration changes to the HX P&T system. The HX P&T system alignment will evolve while groundwater remediation activities continue toward meeting TPA (Ecology et al., 1989) remediation goals. To manage and refine the HX systems, the RPO process will use available source area data; groundwater monitoring data, including compliance wells; updated contaminant fate and transport modeling results; and extraction/injection well performance data. Action items may include installing additional extraction/injection wells, converting injection wells to extraction wells (or vice versa), changing extraction/injection rates, and addressing source areas to remove contaminant contributions to groundwater.

#### 2.3.3.2 Treatment System Performance

In 2011, the HX P&T system extracted 303 million L (80 million gal) of groundwater from the 100-H Area since startup, which includes 15 million L (4 million gal) of groundwater extracted during acceptance testing in September 2011. The new system removed 11 kg of hexavalent chromium during the reporting period.

The average influent hexavalent chromium concentration in 2011 was 35.6 µg/L. The average effluent concentration for the reporting period was 1.6 µg/L. Figure 2-18 shows the influent and effluent concentrations for the treatment systems. The average removal efficiency for 2011 was 95.5 percent. A summary of operational parameters and total system performance for the HX P&T system is presented in Table 2-12. The system operated at a relatively constant rate of about 2,081 to 2,271 L/min (550 to 600 gpm). Figure 2-19 shows the system availability for the reporting period.

For 2011, the areal extent and concentration of the hexavalent chromium plume in the 100-H Area did not change significantly compared to 2010.

#### 2.3.3.3 Compliance Monitoring

The HX P&T system currently does not have any compliance wells; however, the system is monitored on a regular basis at performance monitoring wells across the OU and at all extraction wells.

### 2.3.4 Hydraulic Capture

Plume capture effectiveness in the 100-HR-3 OU was evaluated for the combined capture zones of the DR-5, DX, HR-3, and HX P&T systems (Figure 2-20). An overview of the extent and effectiveness of the combined (OU-wide) capture zone is discussed in the following paragraphs. A capture frequency model (CFM) depicting the extent of hydraulic capture developed by the 100-HX and 100-DX systems was calculated based on weekly maps from October to November, representing the period during which both systems were operational and transducer data was available. A separate evaluation using a capture efficiency model (CEM) is calculated using the 100 Area groundwater model (SGW-46279, *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model*), which represents the three months from October to December. More detailed descriptions of the methods used and results of the capture zone evaluation are presented in Appendix B.

Figure 2-20 depicts CEM and CFM calculated representations of the combined site-wide capture zone for the 100-HR-3 OU. The results shown in Figure 2-20(a) were based primarily on groundwater modeling analysis, while the results shown in Figure 2-20(b) are based on a deterministic approach that incorporates high-frequency mapping of nearly continuously data logged water level measurements of the aquifer during several months of system operation (see Appendix B for details of both methods of capture zone analysis).

Figures 2-27(a) and 2-27(b) suggests that the approximate extents of capture calculated using the mapping method and the groundwater model for the 100-HR-3 system are similar in appearance, although there are some areas that differ. The overlays of the CEM and CFM maps with the contoured extents of hexavalent chromium presented in Figures 2-27(a) and 2-27(b), respectively, identify areas where capture appears conclusive and satisfactory, and where capture appears inconclusive and/or unsatisfactory. Throughout the majority of the 100-HR-3 groundwater operable unit that is contaminated by chromium, the CEM and CFM provide a fairly consistent interpretation of the extent of capture developed by the 100-HX and 100-DX remedies from October to December 2011. Both methods consistently suggest that the capture is inconclusive or unsatisfactory in the southeastern portion of the 100-H area (e.g., upgradient of wells 199-H4-64, 199-H4-12C, 199-H4-4, and 199-H4-63), and in portions of the Horn area between the 100-D and 100-H areas.

The differences in capture depicted by the CEM and CFM approaches arise from a combination of (a) the variable distribution of water level monitoring, (b) the different periods used in preparing the CEM and CFM maps, as described above, and (c) differences in the methods used. With regard to the distribution of water level monitoring locations, Figure 2-20(b) includes dashed grey lines, which delineate the areas located about 500 meters or more from the nearest monitoring well used in the groundwater elevation mapping. In these areas, the relative sparsity of water level monitoring data results in increased uncertainty in the estimated extent of capture. Differences between the modeled CEM and mapped CFM are expected to be greatest in these areas. Differences that result from the contrasting methods and the averaging periods used are expected to diminish over time when the monitoring network is optimized and comparable summary periods are used in the analyses.

### 2.3.5 In Situ Redox Manipulation System

A PRB for in situ chemical treatment of the hexavalent chromium in the southern plume (100-D Area) was emplaced as an interim remedial action in accordance with the interim ROD amendment (EPA/AMD/R10-00/122) beginning in 2000 (Figure 2-21). The reduction-oxidation treatment zone is approximately 680 m (2,230 ft) long (aligned parallel to the Columbia River) and approximately 100 to 200 m (330 to 660 ft) inland. The barrier consists of 65 wells spaced across almost the entire width of the southern hexavalent chromium plume. The treatment zone was designed to reduce the concentration of hexavalent chromium in groundwater to no more than 20 µg/L at seven compliance wells located between the treatment zone and the Columbia River.

The PRB uses ISRM technology to create a treatment zone in which ferric iron is reduced to ferrous iron within the aquifer matrix. This is accomplished by injecting sodium dithionite into the aquifer through wells, then withdrawing the unreacted reagent and reaction products (predominately sulfate) through the same wells and pumping to the ISRM evaporation pond. The sodium dithionite serves as a reducing agent for iron, producing a reducing-type environment in the aquifer. As the groundwater migrates through the treatment zone, the mobile hexavalent chromium is reduced to the less toxic, immobile trivalent chromium, which precipitates from solution. Dissolved Oxygen (DO) and some nitrate are also removed from the groundwater as it passes through the PRB.

The barrier is discussed in this report in order to provide a consolidated discussion of all interim remedies that are being used in the River Corridor. A notice of non-significant change to the ROD was issued in 2010, which indicated that the barrier would no longer be actively maintained (Holten, 2010, "Non-Significant Change for the 100-HR-3 and 100-KR-4 Operable Units Interim Action Record of Decision, Hanford Site, Washington, July 2010, Memo to File Regarding: Supplemental Actions for the In-Situ Reduction/Oxidation Manipulation Barrier Performance for the 100-HR-3 Groundwater Operable Unit Interim Remedy").

#### 2.3.5.1 Hydraulic Monitoring

Groundwater elevations in the unconfined aquifer were measured in monitoring wells at and surrounding the ISRM site in 2011. The water levels were measured using an automated recording system (AWLN) and were supplemented by quarterly manual measurements using an electric tape, and then comparing the measurements to known survey elevations. The height of the Columbia River is also monitored electronically at the 100-D Area river gauge, located directly north of the ISRM barrier. The AWLN recorded data from pressure transducers at 17 locations on an hourly basis.

Groundwater velocity in the 100-D Area is lower compared to the 100-H Area (DOE/RL-2009-92). Water levels in the 100-D Area are similar to water levels in the regional flow field to the south. Regional flow entering the southern portion of the 100-HR-3 OU tends to flow toward the 100-H Area leaving the 100-D Area, to the edge of regional groundwater flow streamlines. River elevation can vary as much as 3.2 m (10.5 ft) throughout the year. During low river stage (September through December), groundwater flow is generally toward the river. During the spring (April through June), high levels in the Columbia River create flow from the river inland, with a steeper gradient near the river and flattening somewhat further inland. This mechanism may have allowed chromium to build up for years in the aquifer based on the current observed hot spot upgradient of the ISRM barrier.

Groundwater flow is also affected by the P&T system. Small groundwater mounds are due to injection of treated groundwater from the DR-5 and DX P&T systems. A small number of groundwater depressions were observed around the DR-5 and DX systems extraction wells.

#### 2.3.5.2 Compliance Monitoring

Groundwater at the ISRM site is sampled as part of CERCLA interim action monitoring, and hexavalent chromium is the COC. As required by the sampling documents, DO is also monitored. The barrier treatment process reduces oxygen content in the aquifer. Groundwater with depleted DO levels could harm aquatic receptors. Other groundwater constituents and properties are also monitored to provide better understanding of the chemical characteristics of the plume.

The ISRM barrier (Figure 2-22) intersects the southern hexavalent chromium plume and has largely cut off the highest concentration portion of the plume and prevented it from extending to the Columbia River. Figure 2-23 shows hexavalent chromium concentration plots for the ISRM compliance wells. The 2011 hexavalent chromium concentration of 5.5 µg/L was below the 20 µg/L remedial action goal in the southernmost compliance well 199-D4-86.

Historically, the compliance monitoring wells in the northeastern portion of the ISRM barrier generally had higher hexavalent chromium concentrations in the northeast portion of the barrier. In 2011, the most northeastern well, 199-D4-83, had a maximum hexavalent chromium concentration of 11 µg/L, which is a decrease from the 2010 maximum concentration of 109 µg/L. Groundwater in well 199-D4-39, also near the northeastern end of the barrier, had hexavalent chromium levels ranging from 33 to 516 µg/L in 2011. These levels show less fluctuation than observed in 2010, which had a range in concentrations of 798 to 2,960 µg/L. Concentrations remained above the remedial action goal in wells 199-D4-38 and 199-D4-84 (downgradient from the central portion of the ISRM barrier) with maximum concentrations of 64 and 43 µg/L, respectively. Remedial action monitoring is described in *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation* (DOE/RL-99-51).

Figure 2-24 shows hexavalent chromium concentrations in the ISRM barrier for the four quarters of 2011. The histograms in the figure show that hexavalent chromium concentrations are lowest in the summer. In the first quarter, fewer barrier wells were below the RAO of 20 µg/L. Since groundwater flow is predominately toward the river and the hydraulic gradient was the highest during this period, there is less time for groundwater to react with reduced sediments in the ISRM barrier. Conversely, when the river stage is high and groundwater gradients are reversed (i.e., groundwater flow is inland from the river), water has a longer residence time in the barrier and/or previously treated water flows back to the barrier. As a result, more hexavalent chromium is reduced to trivalent chromium, and concentrations of hexavalent chromium decrease. The northeastern half of the barrier continues to have the greatest number of wells with concentrations greater than 20 µg/L. Overall, concentrations in the barrier decreased in 2011, most likely due to the startup of the new DX P&T system.

Dissolved Oxygen concentrations are monitored as required by the ROD amendment (EPA/AMD/R10-00/122) and the remedial design report/remedial action work plan (DOE/RL-99-51). The sodium-dithionite injection process reduced DO in the groundwater at the barrier to low levels. Low levels of DO are monitored to assess changes in concentration as groundwater approaches the Columbia River. The DO profile near the ISRM treatment zone is generally characterized by relatively high DO concentrations upgradient of the treatment zone, decreasing significantly through the treatment zone, and recovering to higher DO concentrations as groundwater flow approaches the river (Figure 2-25). A comparison was made between several wells in a line located upgradient of the ISRM (199-D4-15 and 199-D4-20), wells within the ISRM (199-D4-7 and 199-D4-19), and wells downgradient of the ISRM (199-D4-23 and 199-D4-84).

Dissolved Oxygen sampling results from April through July were compared. The east line of wells moving from upgradient to downgradient (199-D4-15 [4,960 µg/L], 199-D4-7 [3,770 µg/L], and 199-D4-23 [9,400 µg/L]) shows a slight reduction in oxygen of approximately 24 percent then an increase moving downgradient toward the Columbia River. The west line of wells moving from upgradient to downgradient (199-D4-20 [2,570 µg/L], 199-D4-19 [1,730 µg/L], and 199-D4-86 [10,550 µg/L]) shows a reduction in oxygen in the groundwater moving through the barrier with an increase moving downgradient beyond the barrier. Based on these results, it is evident that the ISRM barrier continues to create favorable conditions for reducing hexavalent chromium even though the oxygen reduction is lower than in previous years. This system, together with the downgradient DX system extraction wells, will aid in meeting remedial action goals. It is also important to note that the reduction in DO can result in negative impact to aquatic organism; there is a requirement to address this via air sparging or other means if significant low values persist.

Sulfate is a byproduct of the sodium-dithionite reaction used to establish the ISRM treatment zone. It is also listed as a groundwater contaminant with a national secondary DWS of 250 mg/L (40 CFR 143, "National Secondary Drinking Water Regulations"). Sulfate concentrations exceeded the secondary DWS in two areas located at the southwestern portion of the ISRM barrier and downgradient from the barrier. The following sulfate results are for wells influenced by the ISRM barrier during 2011:

- Sulfate concentrations in groundwater underlying much of the 100-D Area remained above 100 mg/L.
- Overall, the sulfate concentrations in 2011 were comparable to 2010, with most wells showing stable or slightly decreasing concentrations.
- Sulfate concentrations in wells ranged from 11 to 358 mg/L.

- Two wells and one aquifer tube had sulfate concentrations exceeding the secondary MCL of 250 mg/L:
  - Downgradient well 199-D4-99
  - One treatment zone injection/monitoring well (199-D4-4)
  - Aquifer tubes DD-42-4 (466 mg/L), which have historically had the highest detected sulfate concentrations

All of the 100-D Area wells are sampled quarterly for pH, which generally ranges from 7.5 to 8.5, although some values greater than 9 are reported. Monitoring pH is an important component in ISRM barrier performance; trivalent and hexavalent chromium speciation in the aquifer depends on both pH and oxidation-reduction potential (ORP). While the scoping studies for the barrier stressed the importance of maintaining basic pH levels greater than 7 for optimum barrier performance, it is possible that excessively high pH may be counterproductive, given that hexavalent chromium is the predominant species for pH greater than approximately 8.5 and for ORP greater than 0.3 volts. Three of the wells with pH greater than 9 (199-D4-7, 199-D4-14, and 199-D4-48) are monitoring wells located in the original ISRM treatability test area.

## 2.4 Additional Investigations

Field work as part of the River Corridor RI/FS characterization was completed in 2011. The work included installing ten boreholes, seventeen groundwater monitoring wells, five test pits, and six aquifer tubes. Spatial and temporal analysis of groundwater conditions was also conducted. Draft A of the RI/FS Report (DOE/RL-2010-95, *Remedial Investigation/Feasibility Study for 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*) is scheduled for release in 2012.

## 2.5 Conclusions

The conclusion for the 100-HR-3 OU and conclusions with respect to each RAO are as follows:

- The RAOs will be met with the implementation of the DX and HX P&T systems that are now operational. These additional remedies will reduce hexavalent chromium concentrations in groundwater before they can reach the Columbia River. In 2011, the DX and HX P&T systems have removed a significant amount of hexavalent chromium from the aquifer.
- **RAO 1—**Protect aquatic receptors in the river bottom substrate from contaminants in the groundwater entering the Columbia River.
  - 100-D Area:
    - The DR-5 P&T system extracted an additional 9.1 million L (2.4 million gal) of groundwater and removed 11.3 kg of hexavalent chromium from the 100-D Area for the four months it operated in 2011. In April, the DR-5 P&T system was shut down, and the wells were disconnected and added to the new DX well network. The DR-5 system was placed in cold standby.
    - During 2011, the DX P&T system extracted 919 million L (243 million gal) of groundwater from the 100-D Area, which is a considerable increase compared to the 44.6 million L (11.8 million gal) the DR-5 P&T system processed in 2010. The system removed 443 kg of hexavalent chromium during the reporting period, in addition to the 18.4 kg removed by the pilot-scale system in December 2010. The amount of hexavalent chromium removed by

the DX P&T system in 2011 was an increase of 491 percent in mass removed when compared to the 74.9 kg processed by the DR-5 system in 2010.

- Hexavalent chromium concentrations in the 100-D Area have been decreasing. In 2011, the plume configuration did not change compared to 2010; however, concentrations have decreased significantly. Maximum concentration of hexavalent chromium were at 28,100 µg/L in 2011, compared with the maximum concentrations of 2010 and 2009 at 69,700 µg/L and 59,600 µg/L, respectively.
- In 2011, hexavalent chromium concentrations were above the 20 µg/L interim remedial action goal in both compliance wells (199-D8-69 and 199-D8-70). Well 199-D8-69 has since been converted into an extraction well for the DX P&T system, which should reduce hexavalent chromium concentrations within this portion of the unconfined aquifer.
- Overall, the ISRM barrier continues to help reduce hexavalent chromium in the aquifer. However, during periods of low flow, hexavalent chromium values above the RAO were observed in some downgradient wells, which increased in concentration since 2009. However, downgradient DX extraction wells now exist to compensate for ISRM breakthrough, which will reduce hexavalent chromium concentrations in groundwater before reaching the Columbia River.
- Operational monitoring of treatment zone (barrier) wells indicates that low chromate concentrations and generally reducing conditions persist in the majority of the ISRM barrier, particularly in the southwestern portion of the barrier. The northeastern half of the barrier continues to have the greatest number of wells with concentrations greater than 20 µg/L. Overall, the barrier's performance in 2011 was slightly less effective than observed in 2010.
- The effect of high river stage during the early summer months provides a natural hydraulic barrier for movement of the hexavalent chromium plume to the Columbia River.

– 100-H Area:

- During 2011, the HR-3 P&T system extracted 134 million L (35 million gal) of groundwater from the 100-HR-3 OU. The system removed 5.6 kg of hexavalent chromium during the reported year. In May, the HR-3 P&T system was shut down, the wells were disconnected, and the system was placed in cold standby.
- In 2011, the HX P&T system extracted 303 million L (80 million gal) of groundwater from the 100-H Area, which includes the 15 million L (4 million gal) of groundwater extracted during acceptance testing in September 2011. The new system removed 11 kg of hexavalent chromium during the reporting period.
- During 2011, hexavalent chromium concentrations were less than the 20 µg/L remedial action goal in three of the four original compliance wells (199-H4-4, 199-H4-5, and 199-H4-64). Well 199-H4-63 had a hexavalent chromium concentration of 22 µg/L from a September 2011 sample date.
- Contaminant concentrations in aquifer tubes have been reduced.

– Horn Area:

- The new RPO wells installed in the Horn Area during 2010 to remediate groundwater underlying this area were added to the new DX/HX P&T system.

- **RAO 2:** Protect human health by preventing exposure to contaminants in the groundwater.
  - The interim remedial ROD (EPA/ROD/R10-96/134) establishes a variety of ICs that must be implemented and maintained throughout the interim action period. These provisions include the following:
    - Access control and visitor escorting requirements
    - Signage providing visual identification and warning of hazardous or sensitive areas
    - Excavation permit process to control all intrusive work (e.g., well drilling and soil excavation)
    - Regulatory agency notification of any trespassing incidents
  - The effectiveness of ICs was presented in *2004 Site Wide Institutional Controls Annual Assessment Report for Hanford CERCLA Response Actions* (DOE/RL-2004-56). The findings of this report indicate that ICs were maintained to prevent public access, as required.
- **RAO 3:** Provide information that will lead to a final remedy.
  - An RI/FS was completed in 2011. Field work included the installation of 10 boreholes, 17 groundwater monitoring wells, 8 test pits, and 6 aquifer tubes. Spatial and temporal analysis of groundwater conditions was also conducted. Draft A of the RI/FS Report (DOE/RL-2010-95) is scheduled for release in 2012.
  - Since 1997, a significant mass of hexavalent chromium (1,365 kg) has been removed from groundwater underlying the 100-HR-3 OU. The overall areal extent of the 100-D Area hexavalent chromium plume, however, has not been affected significantly by P&T operations. The new DX and HX P&T systems will continue to improve remediation by expanding the capture zone. Hexavalent chromium concentrations still exceed RAOs in compliance wells downgradient after ISRM has operated for multiple years. However, downgradient extraction wells for the DX P&T system were added to reduce hexavalent chromium concentrations before they can reach the Columbia River downgradient of the ISRM barrier. Concentrations will be reduced to a level that is manageable by the ISRM barrier.

## 2.6 Recommendations

The 100 and 300 Area River Corridor units are undergoing the CERCLA process for completing remediation of waste sites and groundwater. Draft A of the 100-D and 100-H Operable Units RI/FS Report (DOE/RL-2010-95) is scheduled for release in 2012. The following recommendations are made regarding future groundwater monitoring and remedial action evaluations. As with any such recommendation, these warrant further review and their implementation depends on technical priorities and available funding. Recommendations for the 100-HR-3 OU are as follows:

- Evaluate the effectiveness of the new DX and HX P&T systems in 2013 using groundwater concentration data, hydraulic head data, capture zone analyses, and further modeling to optimize the operation of the systems. Include a comparison of DX and HX to the HR-3 and DR-5 systems and prepare a written report.
- Conduct a Data Quality Objective analysis for 100-HR-3 data needs for the new DX and HX systems to support RAOs in 2013 and prepare a written report.
- Continue with RPO to evaluate the realignment and/or addition of specific wells to the DX and HX P&T system well network in 2013, targeting locations of higher concentration contaminated wells to increase mass removal, and prepare a written report.

- Evaluate the deployment of pressure transducers and data loggers in selected wells within the AWLN and formalize the AWLN into the performance monitoring plan via a SAP in 2013.
- Revise the remedial design/remedial action work plan in 2013 to reflect upgrades to the 100-HR-3 systems.
- Plan a compliance well network of up to 15 HR-3 wells for both river protection monitoring and groundwater cleanup monitoring and prepare a written report in 2013.
- Continue to integrate with the source area remediation team to determine impacts to the groundwater and Columbia River from vadose zone soil contamination being removed, treated, and disposed and utilizing the P&T systems to mitigate those impacts.
- Determine additional extraction and monitoring well placements down gradient from selected active vadose zone remediation sites (100-D-100, 100-D-30, and 100-D-104) to prevent contamination from reaching the Columbia River.
- Evaluate the response of the 100-D Area hotspot to the extraction of the larger volumes of groundwater by the DX P&T system and prepare a written report in 2013.
- Continue to P&T and monitor the contaminated zone in the RUM in the 100-H Area. The preliminary results of the remedial investigation characterization suggest that the RUM dips to the south-southwest in the upgradient direction towards the Horn and that current pumping is sufficient to the north. An additional pumping well could enhance remediation to the south which will be evaluated in a written report in 2013.
- Conduct additional monitoring of hexavalent chromium contamination within the RUM at 100-H.
- Consider the collection of groundwater from the base of deep excavations in 2013 using sandpoints, shallow bore temporary wells, or aquifer tubes and prepare a written report on the impacts.
- Continue to review and modify the groundwater cleanup strategy for interim actions and provide information that will lead to the final remedy.
- Add well 199-H3-5 to the HX P&T extraction well network to target hexavalent chromium migration from the Horn Area into the southern portion of 100-H Area. Add injection well capacity to the DX P&T system to allow for additional extraction to protect the river and utilize available capacity at the DX P&T.
- Complete the transfer of the HR-3 D-transfer wells to DX (199-D8-53, 199-D8-54A, 199-D8-68, and 199-D8-72).
- Evaluate historic plume depiction using current plume mapping technology to evaluate cleanup effectiveness of the P&T systems.

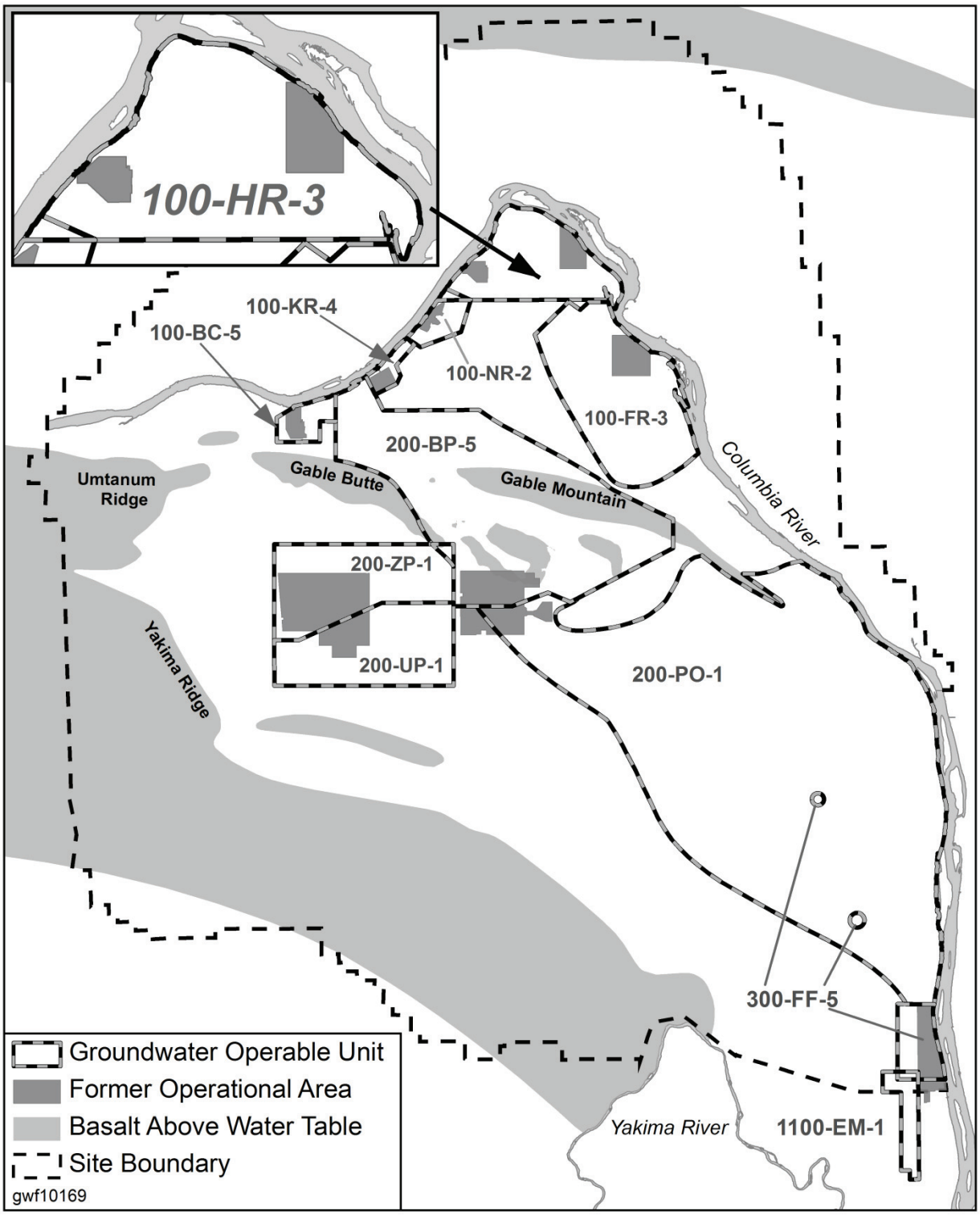



**Figure 2-1. Location Map of the 100-HR-3 OU**

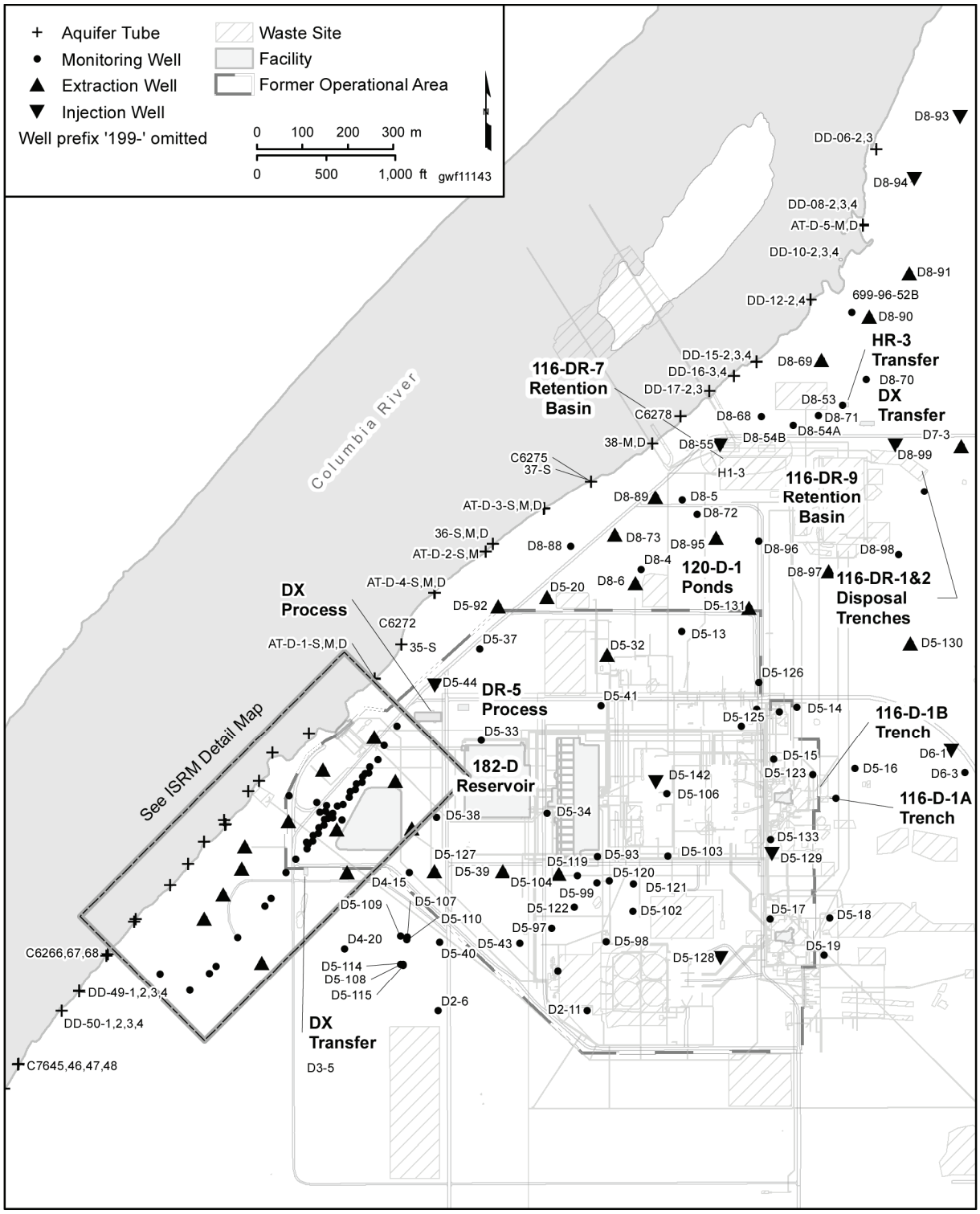



**Figure 2-2. 100-D Area Wells and Aquifer Tubes**

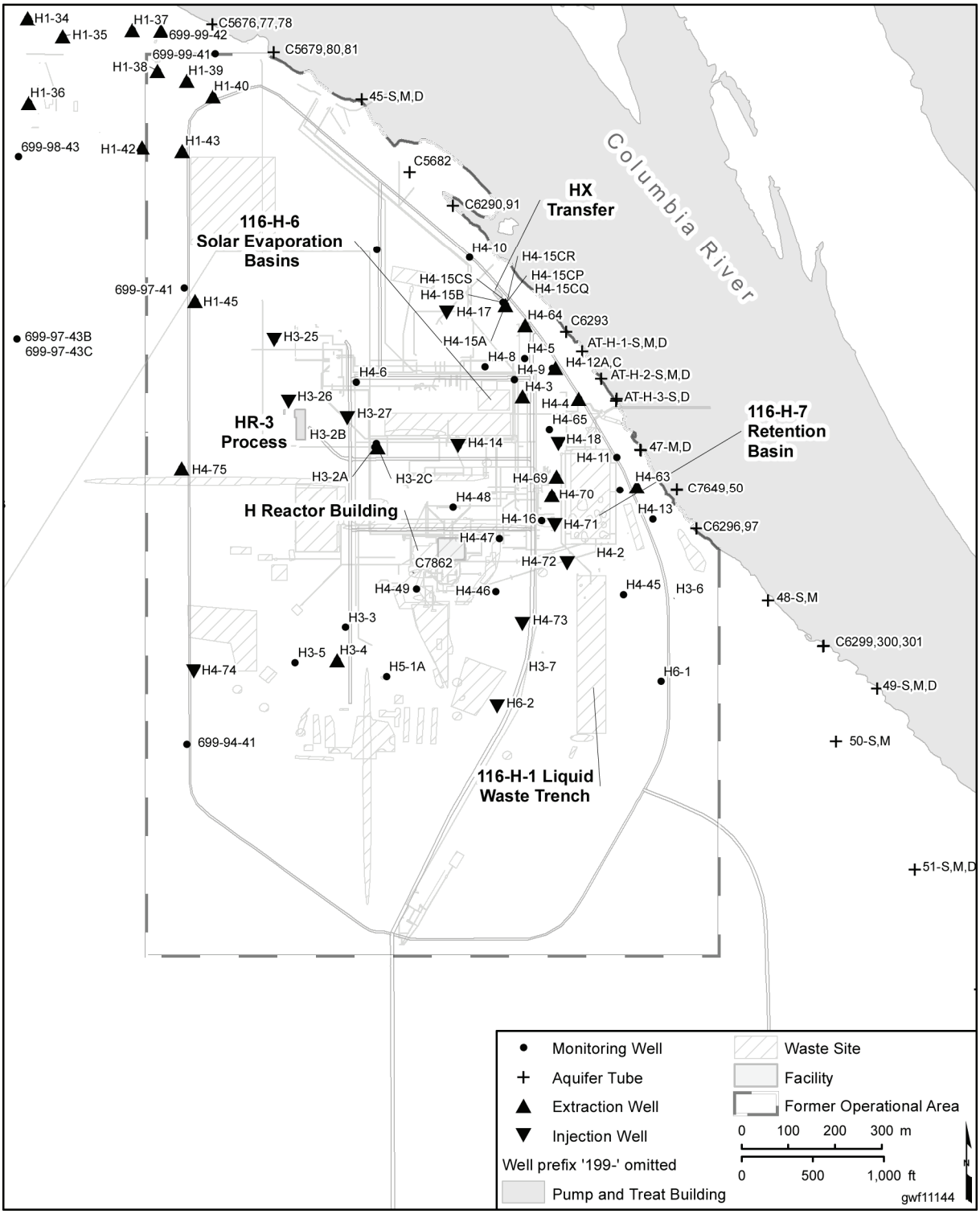



**Figure 2-3. 100-H Area Wells and Aquifer Tubes**

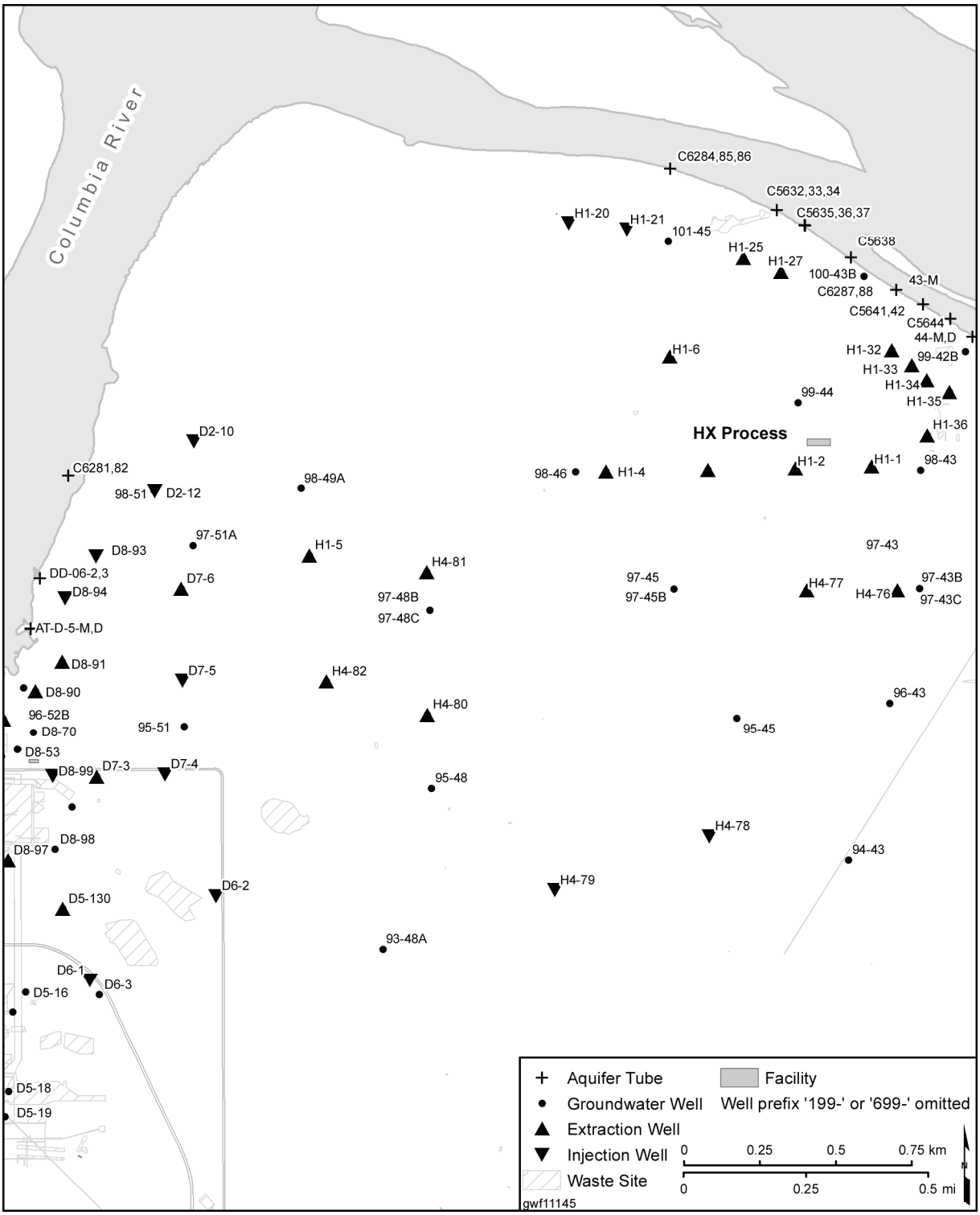
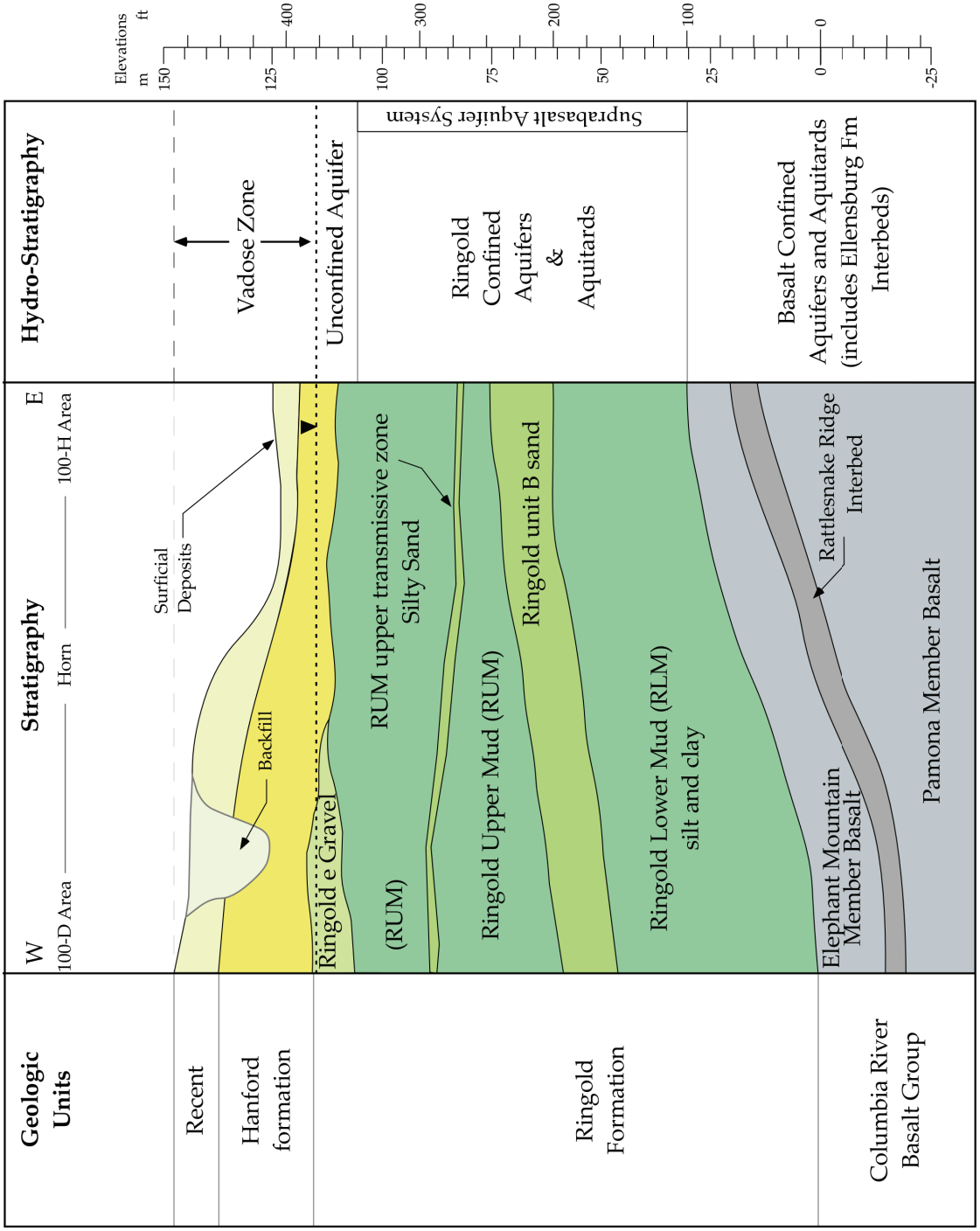



**Figure 2-4. Monitoring Well Locations within the Horn Area of the 100-HR-3 OU**




FESI_2011_0063 (after DOE/RL-2008-42, Figure 2-1)

**Figure 2-5. Conceptual Cross Section of the 100-D and 100-H Areas**

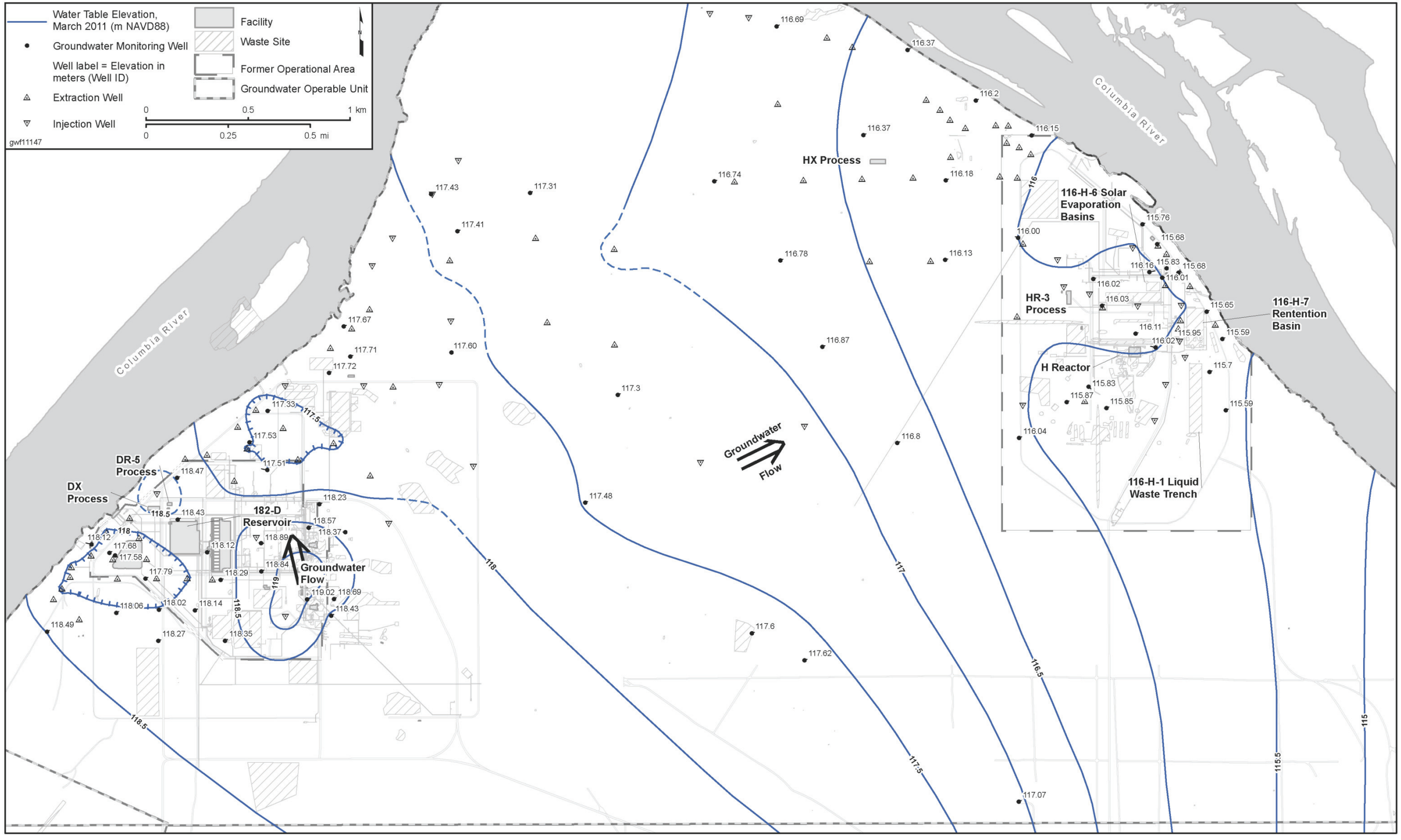



Figure 2-6. 100-HR-3 OU Water Table Elevation Map, March 2011

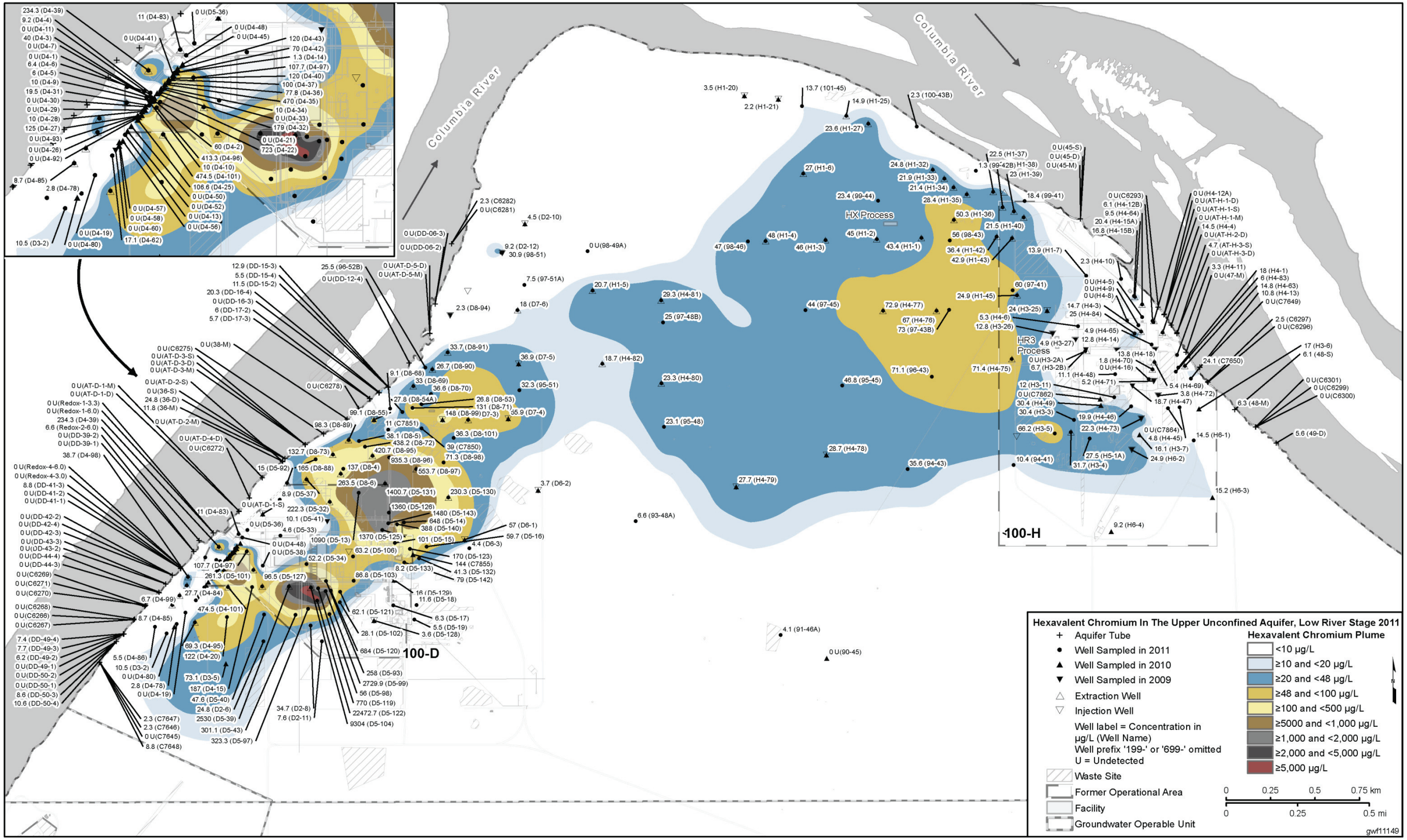



**Figure 2-7. 100-HR-3 OU Hexavalent Chromium Map, Fall 2011**

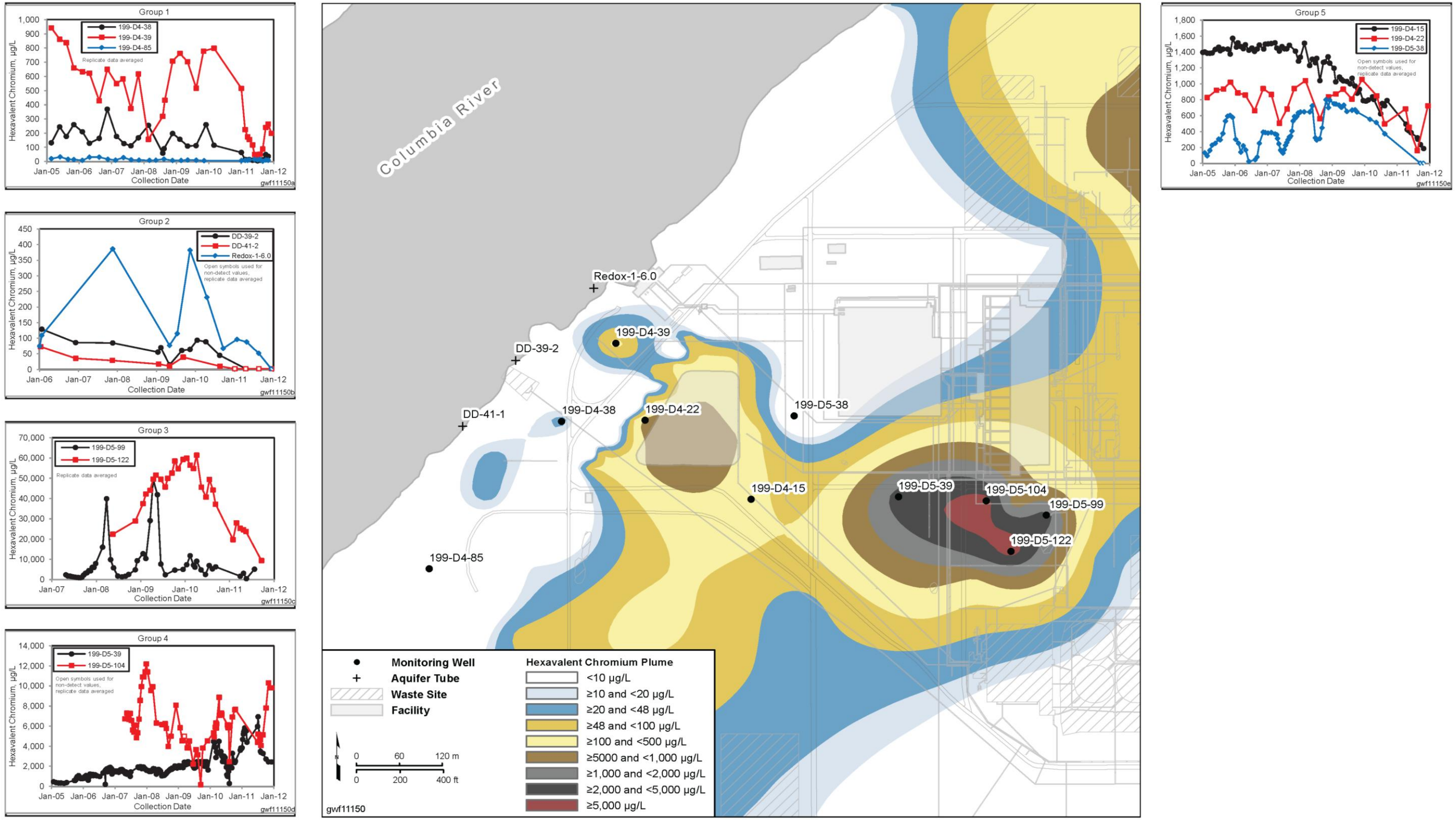



**Figure 2-8. 100-D Area Hexavalent Chromium Fall 2011 Plume with Trend Plots (South Plume)**

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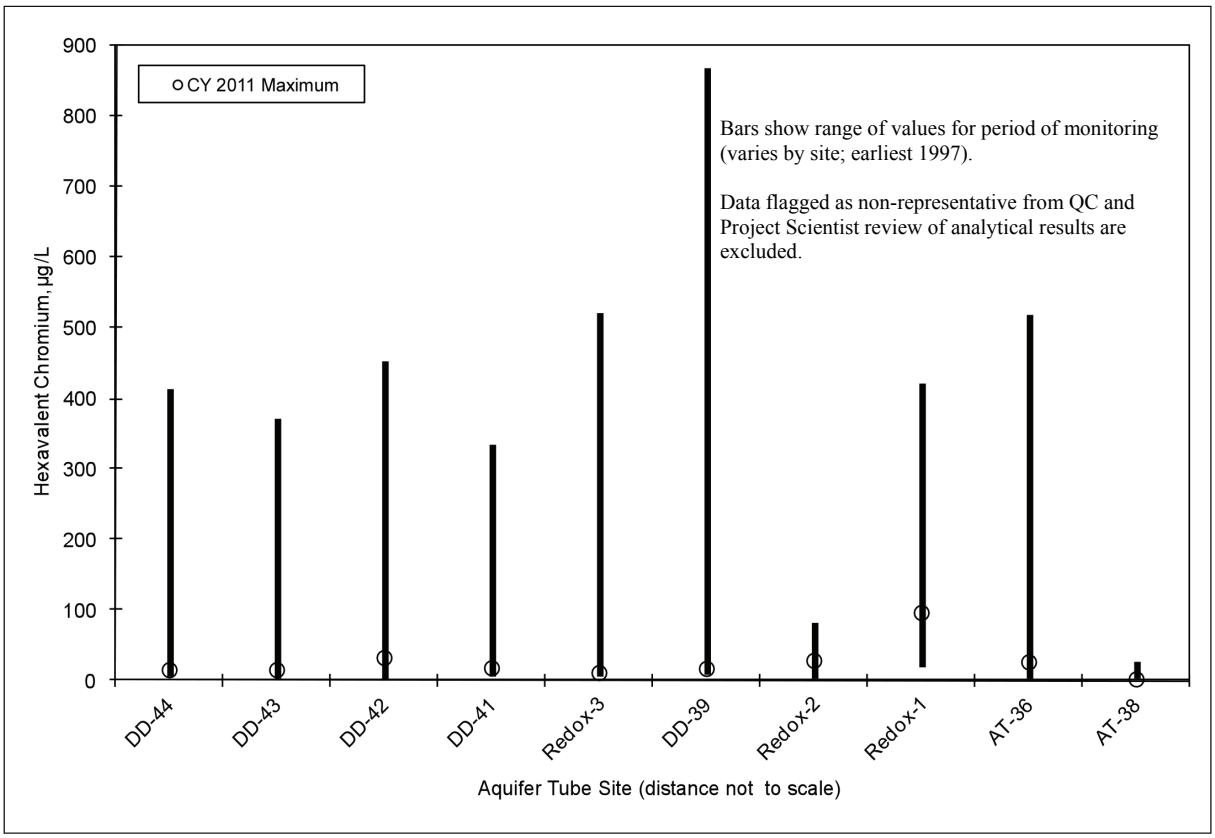


**Figure 2-9. 100-D Area Aquifer Tubes**

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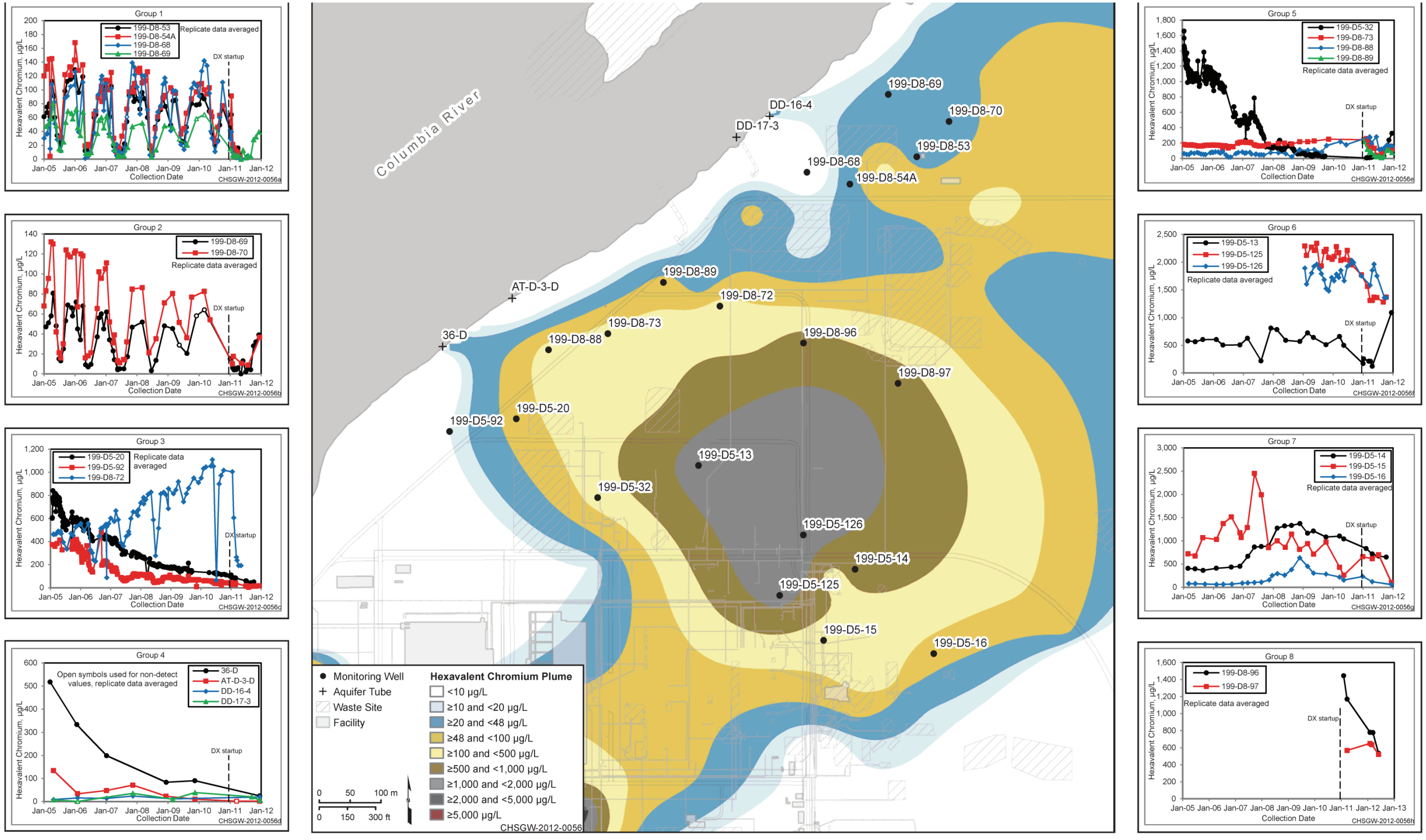


**Figure 2-10. 100-D Area Hexavalent Chromium Fall 2011 Plume with Trend Plots (North Plume)**

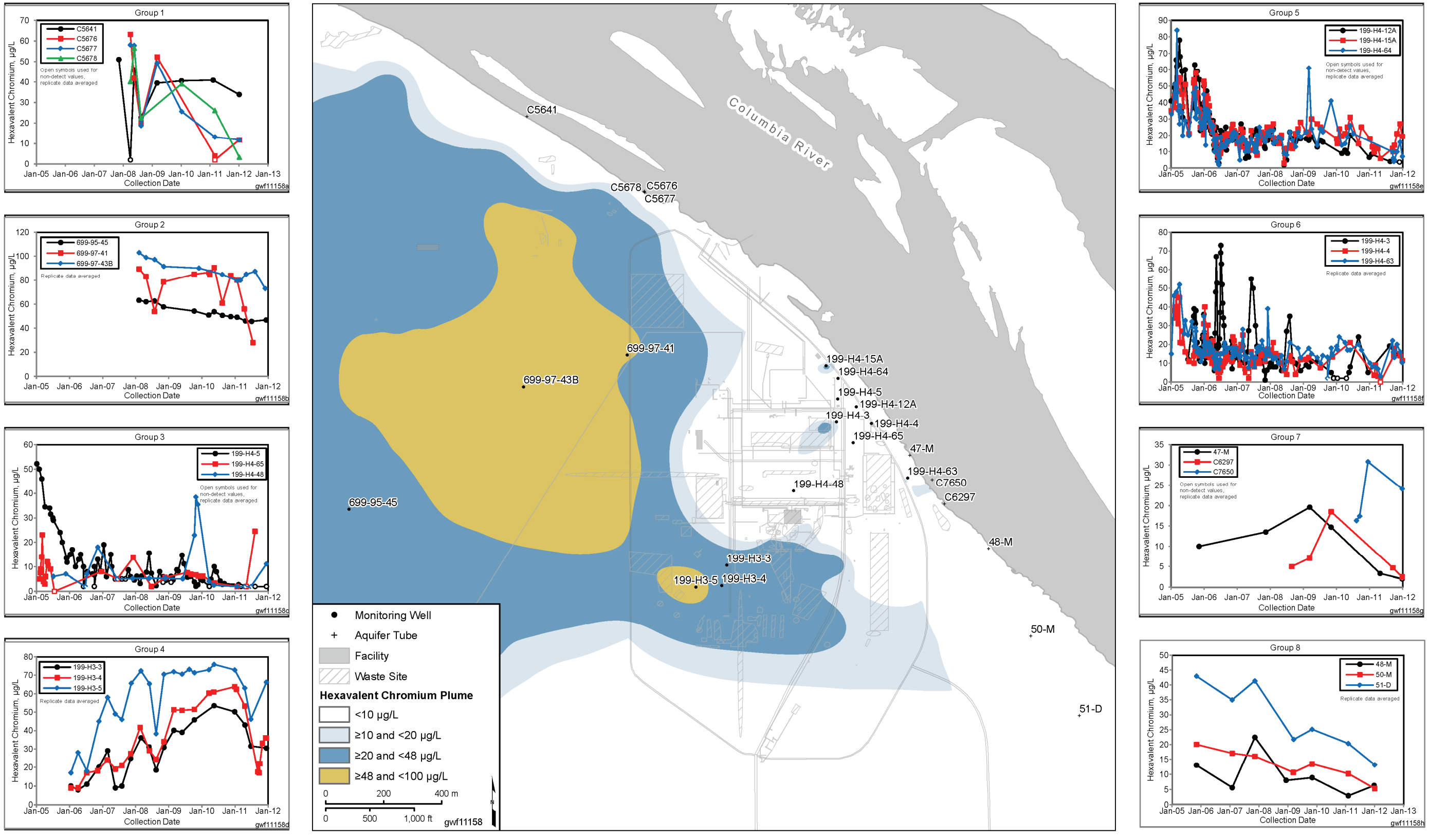


**Figure 2-11. 100-H Area Hexavalent Chromium Fall 2011 Plume Trend Plots**

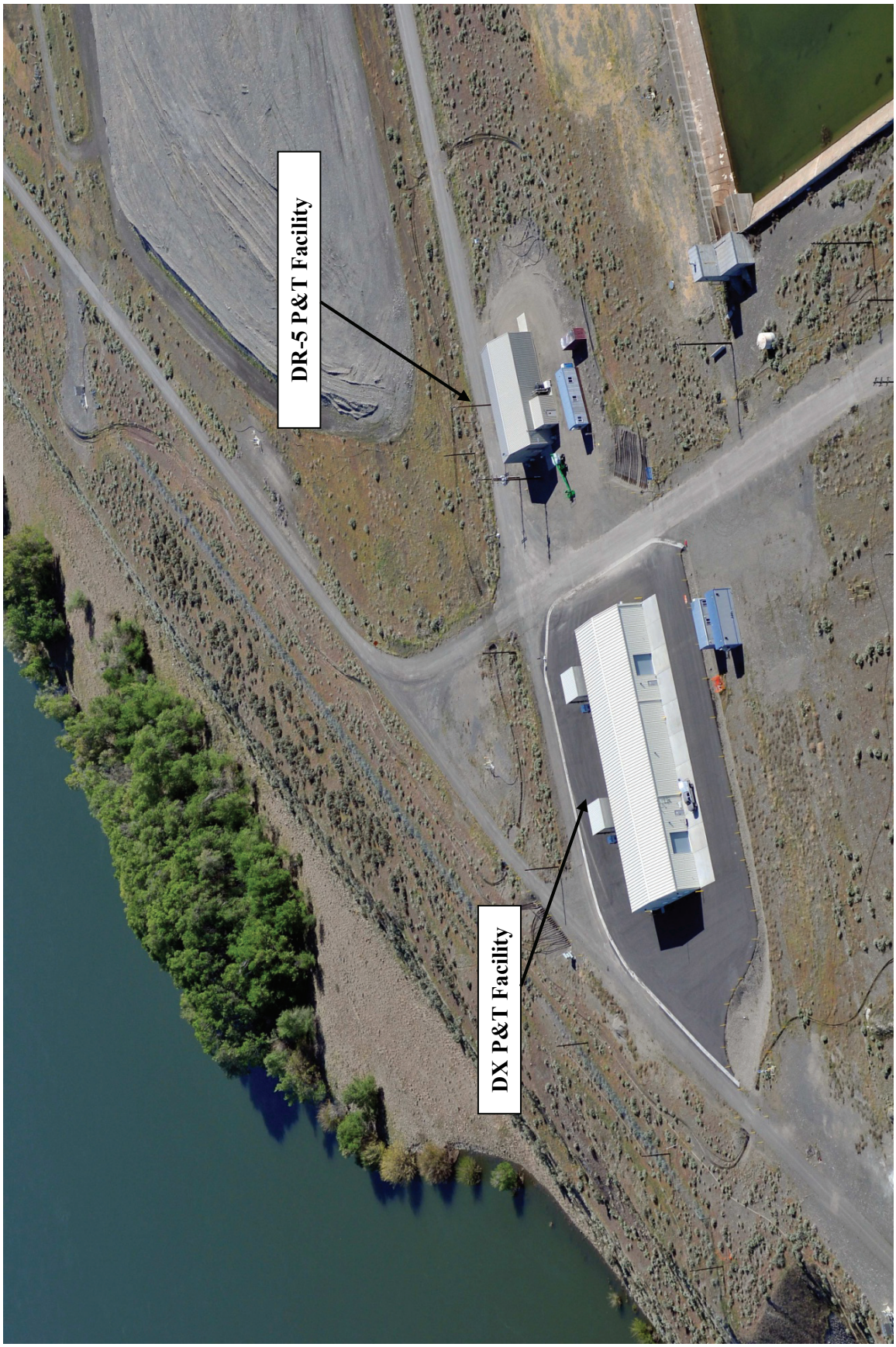


Figure 2-12. Aerial View of DX P&T System

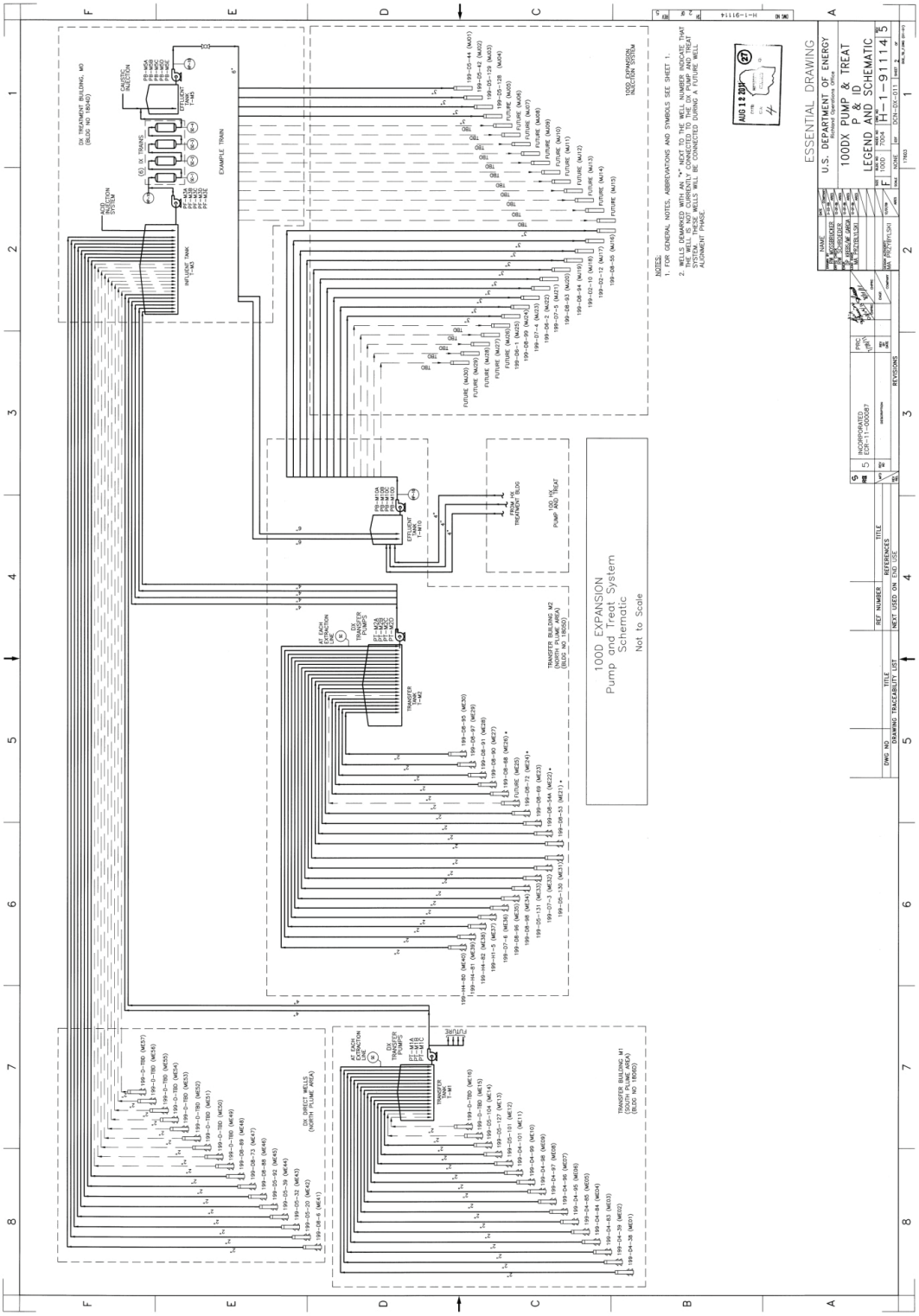


**Figure 2-13. DX P&T System Schematics**

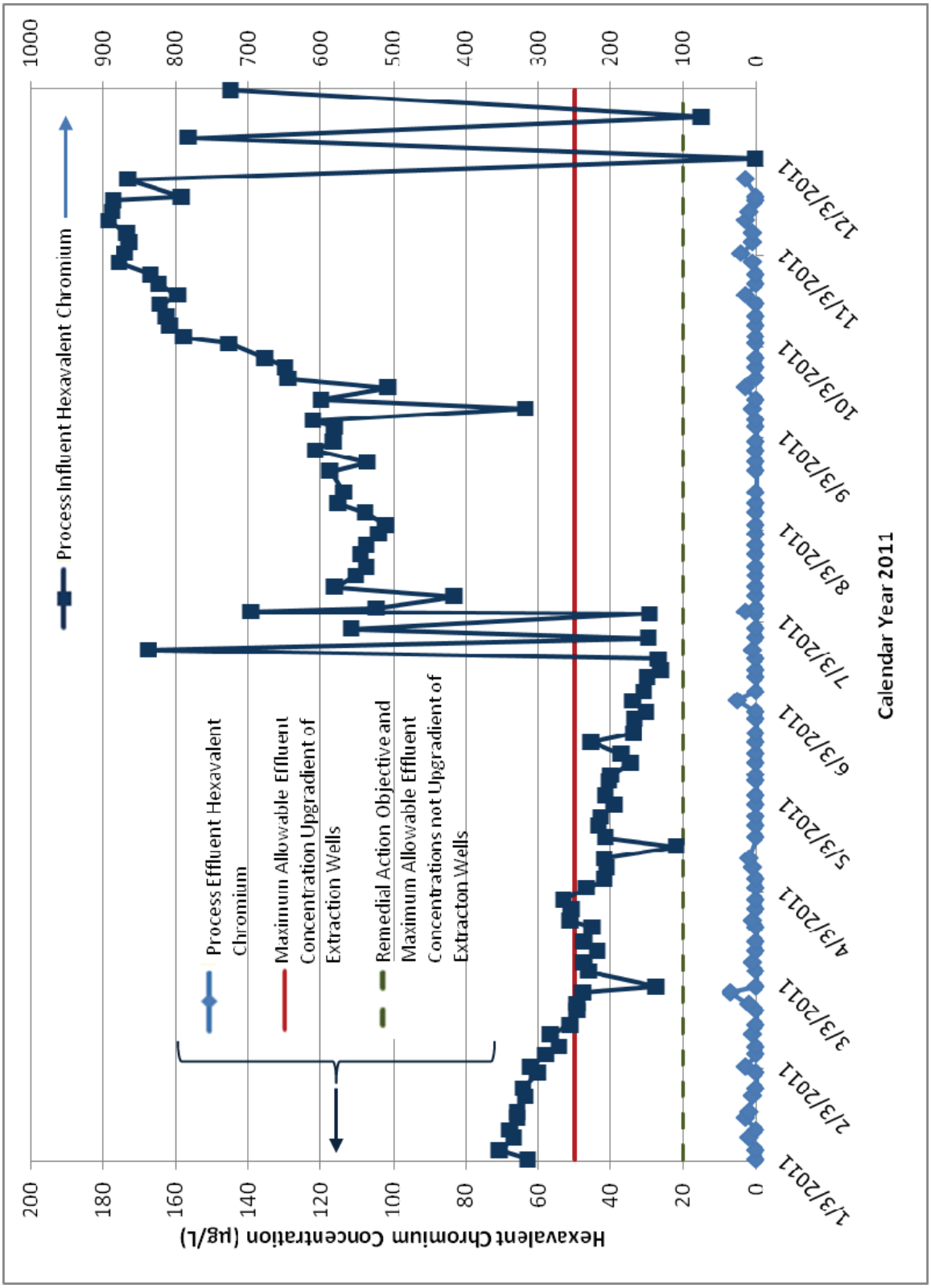


**Figure 2-14. Influent/Effluent Concentrations for DX P&T System**

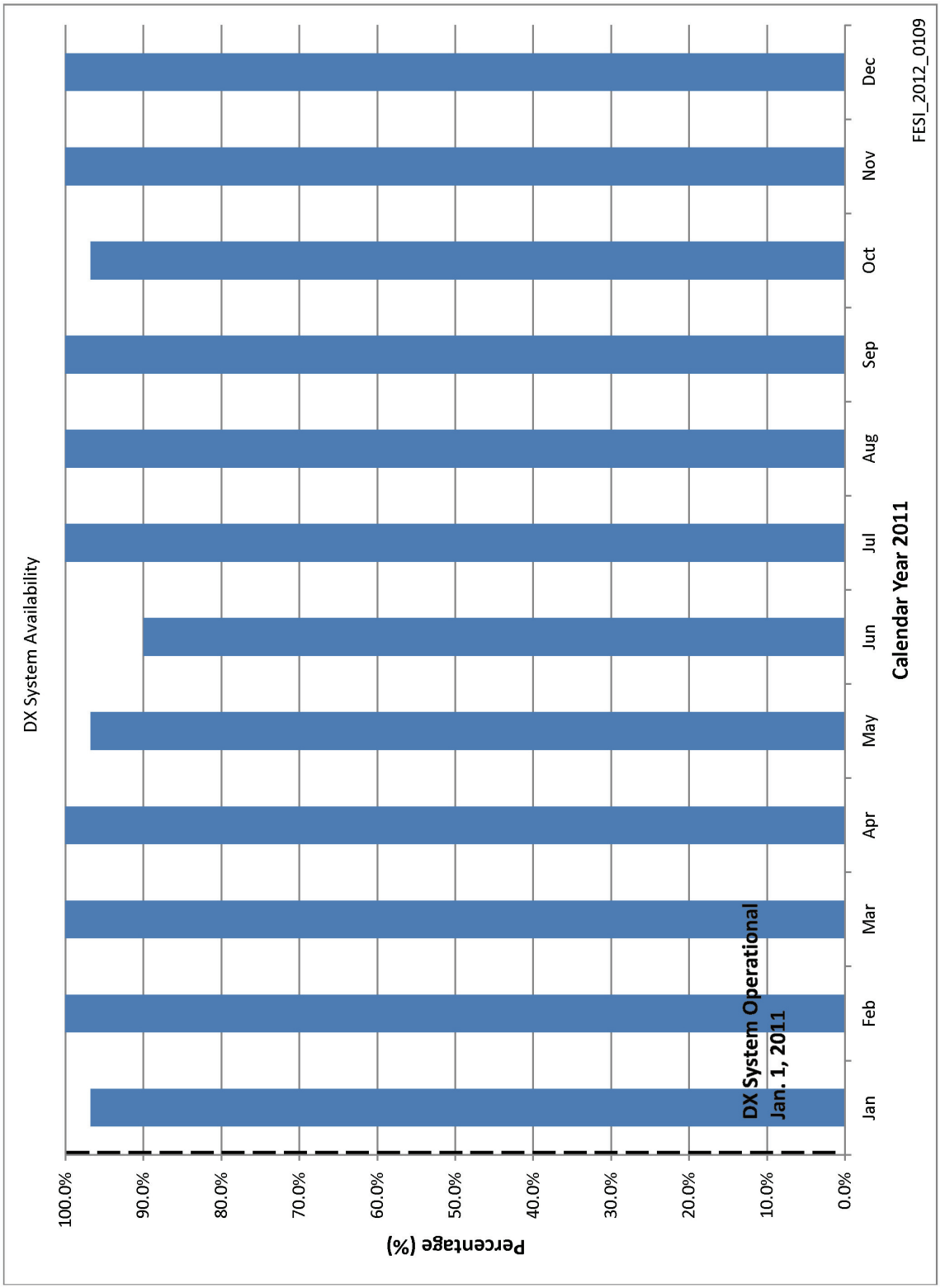


**Figure 2-15. System Availability for DX P&T System**

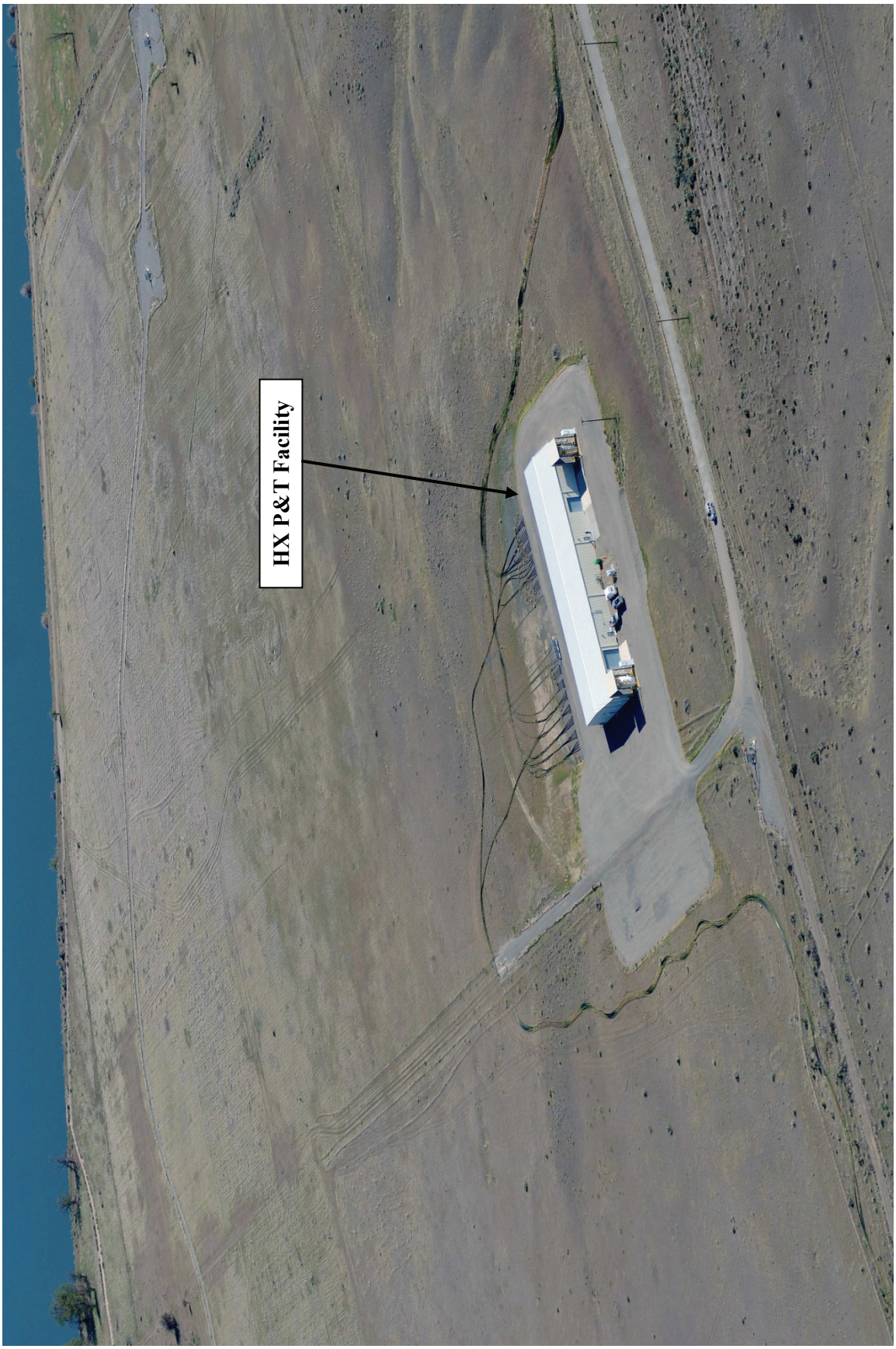


Figure 2-16. Aerial View of HX P&T System

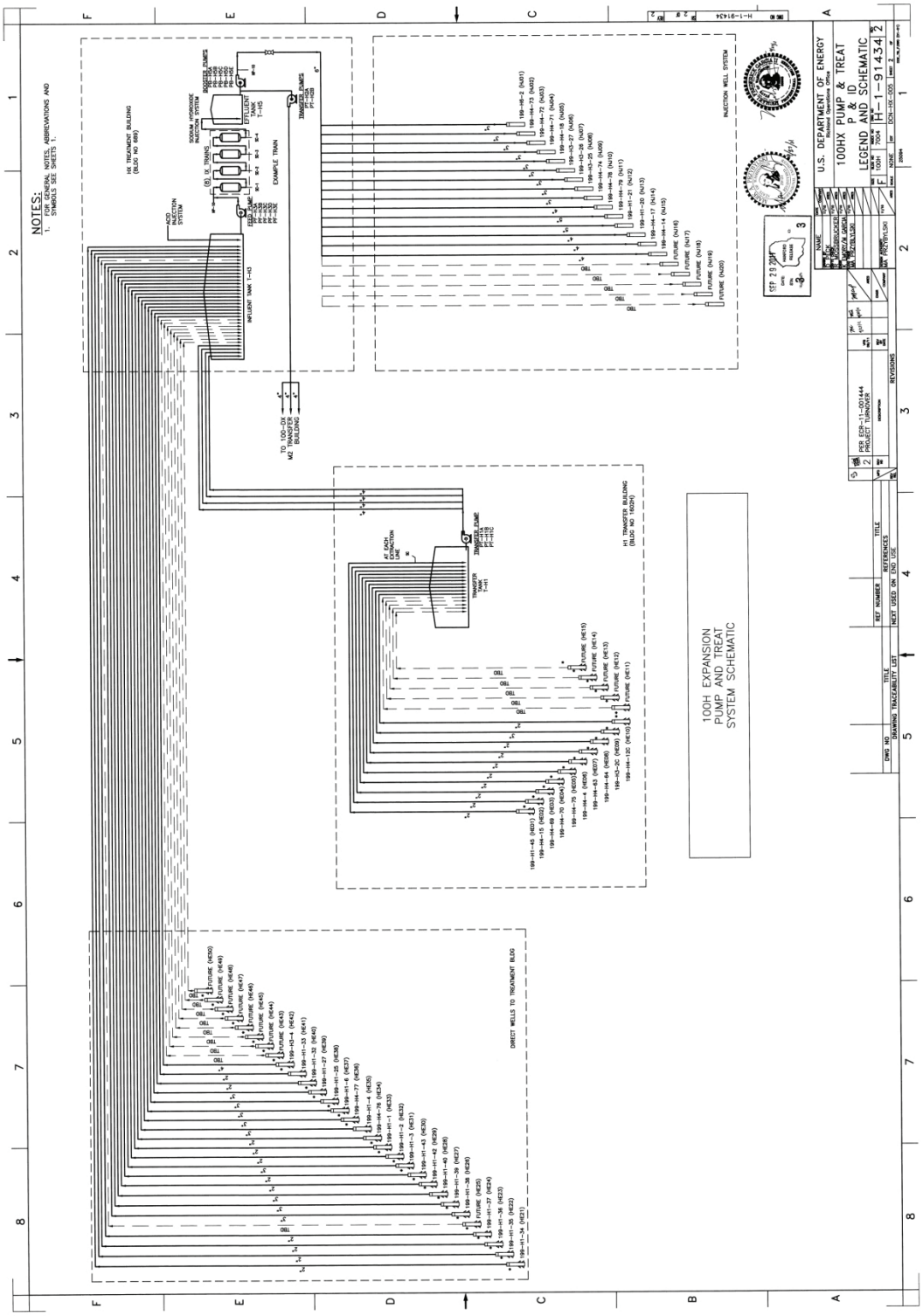


**Figure 2-17. HX P&T System Schematics**

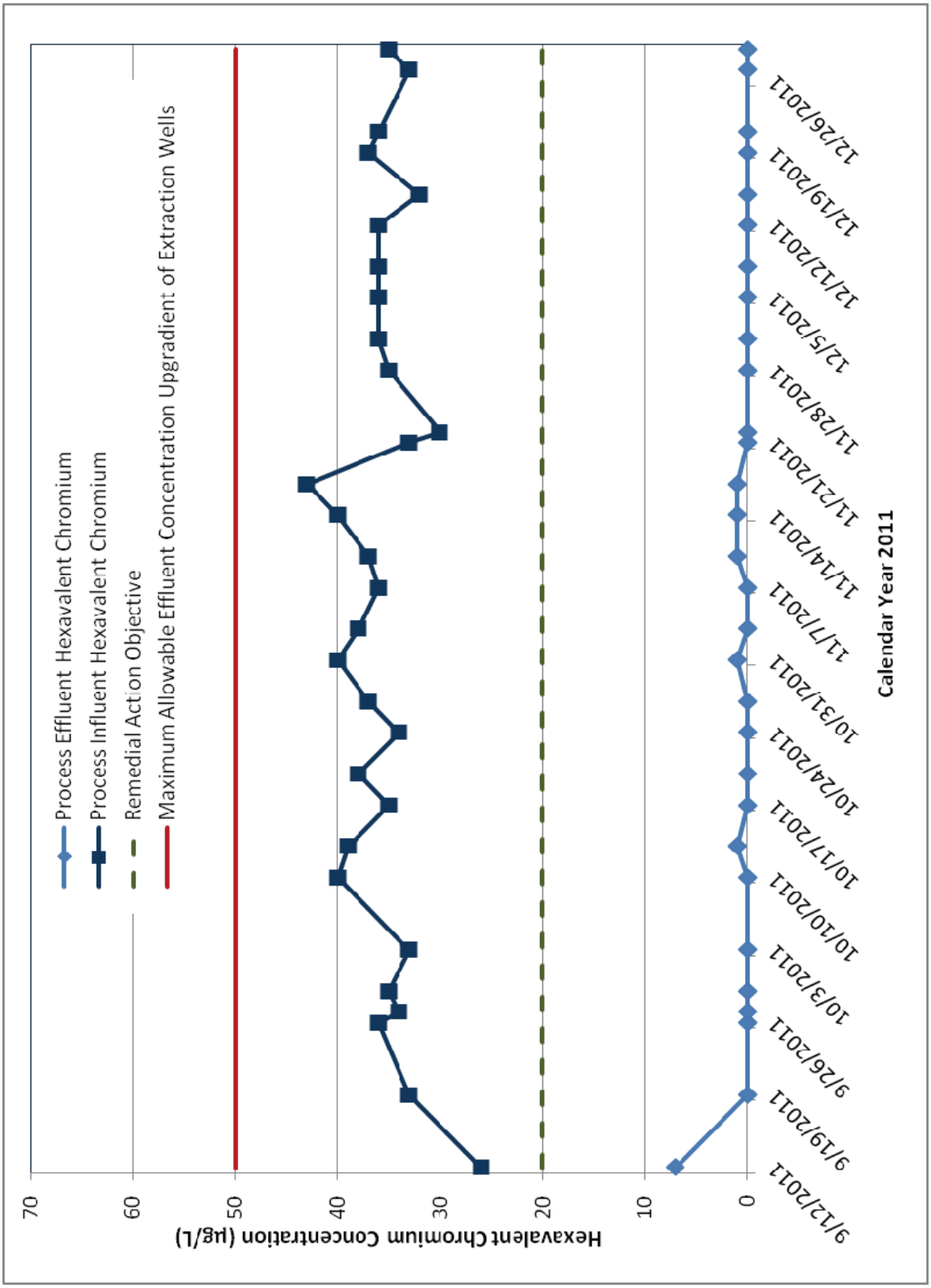


**Figure 2-18. Influent/Effluent Concentrations for HX P&T System**

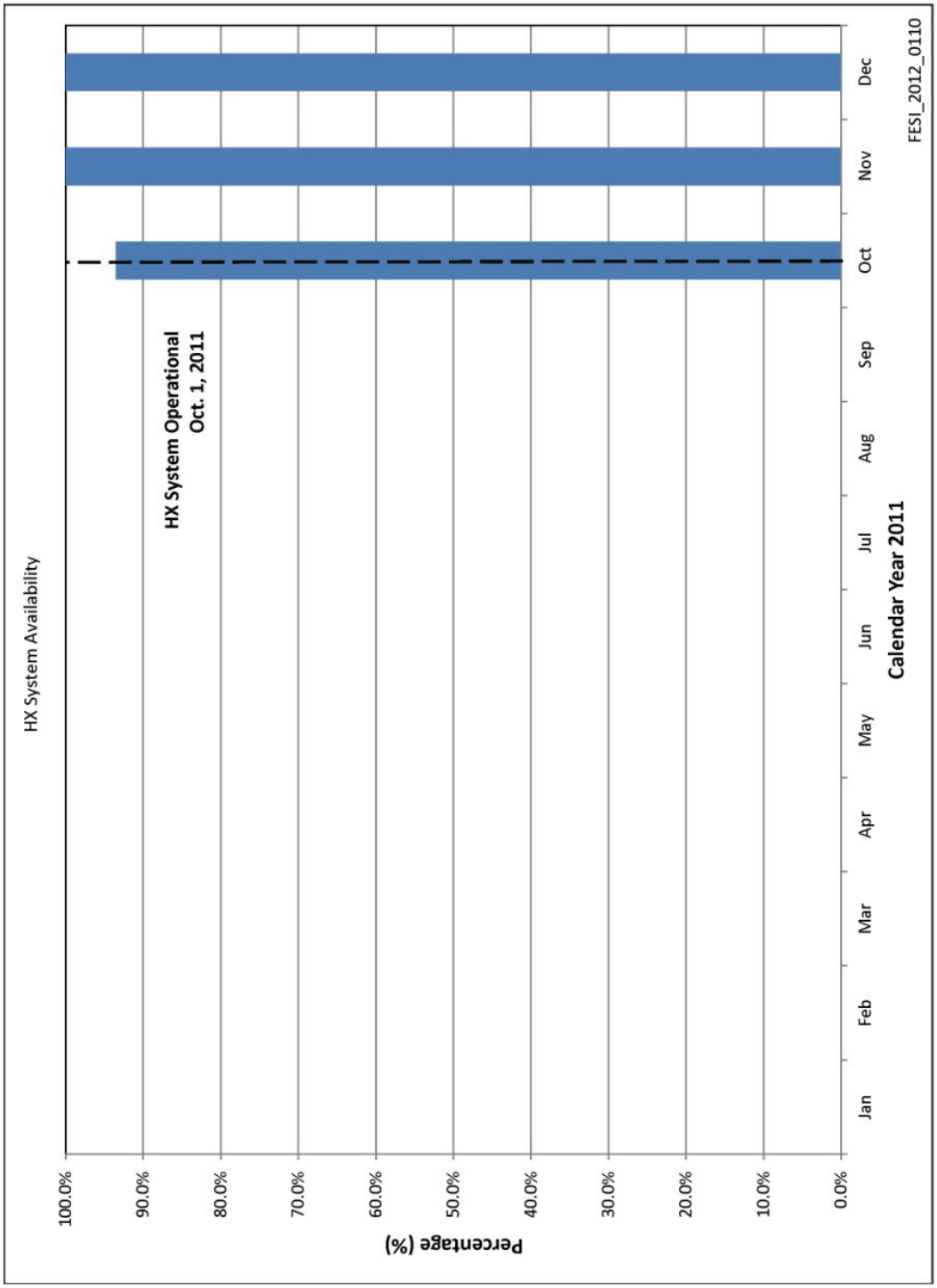


**Figure 2-19. System Availability for HX P&T System**

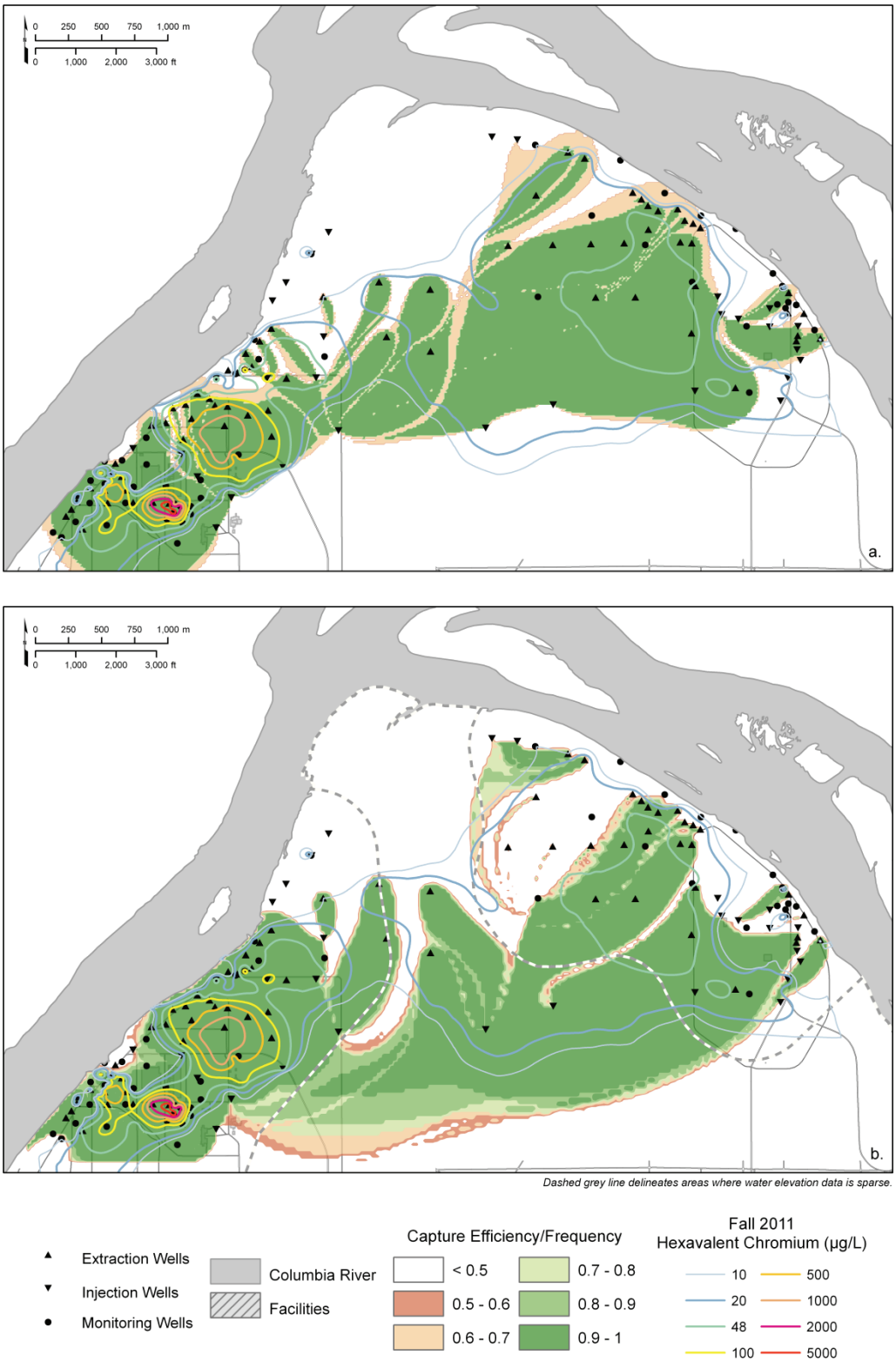


**Figure 2-20. Approximate Extent of Capture Throughout the 100-D and 100-H Area for October to December 2011, Calculated Using (a) Modeling Method and (b) Mapping Method (Overlaid with Spring 2011 Contoured Extent of Hexavalent Chromium)**

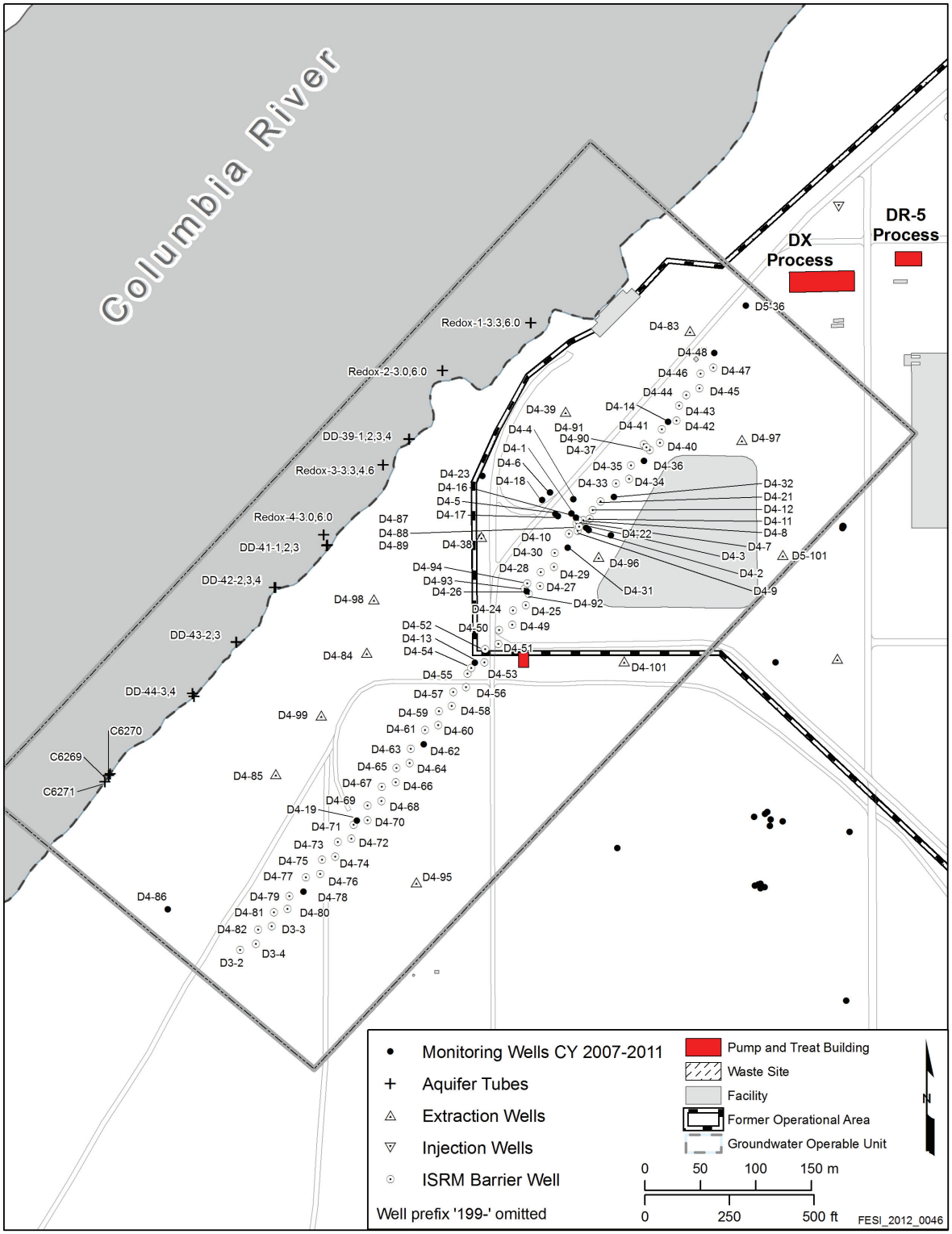


**Figure 2-21. In Situ Redox Manipulation Detail Map**

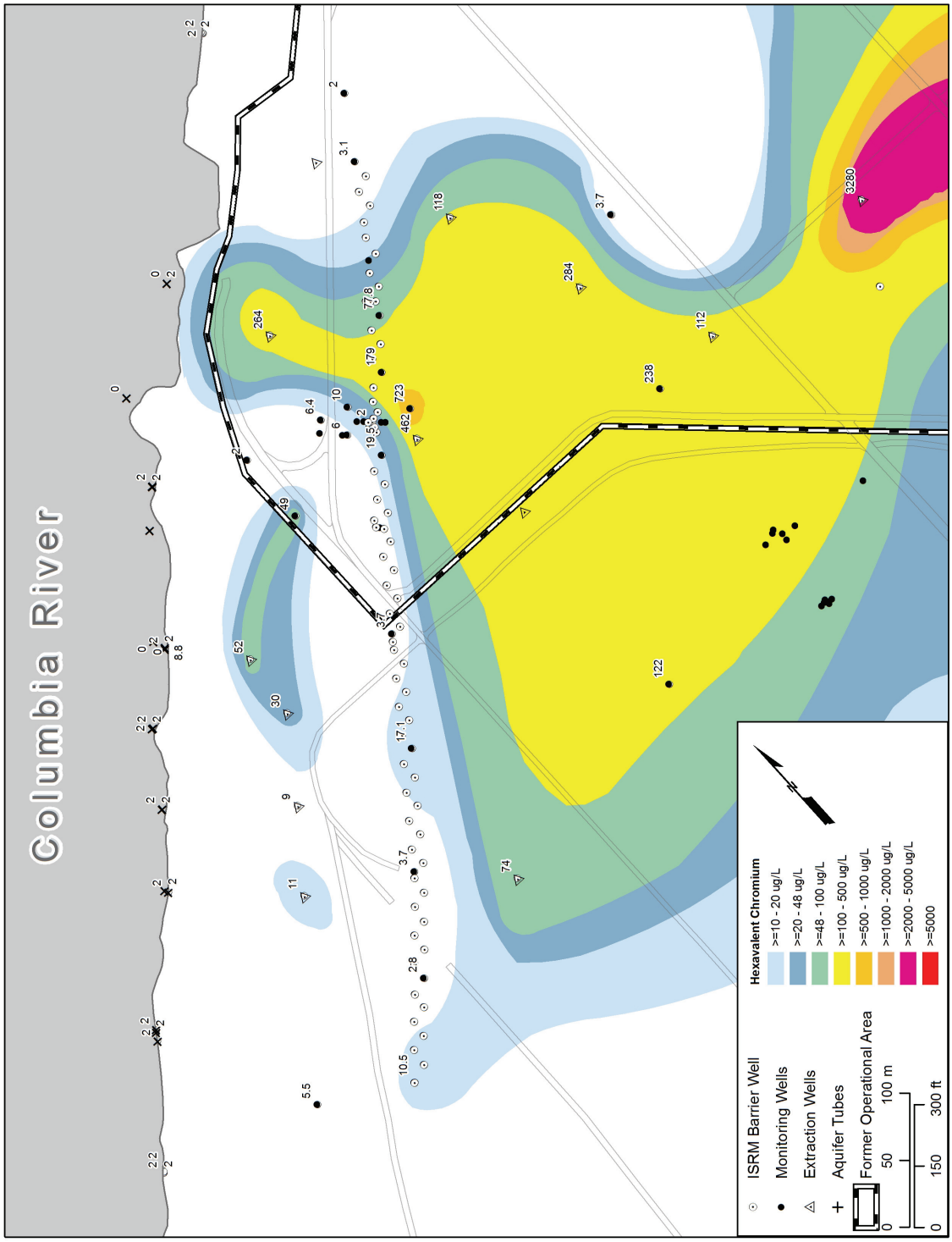


**Figure 2-22. In Situ Redox Manipulation Hexavalent Chromium Map**

(krm 8/22/12 per telcon)

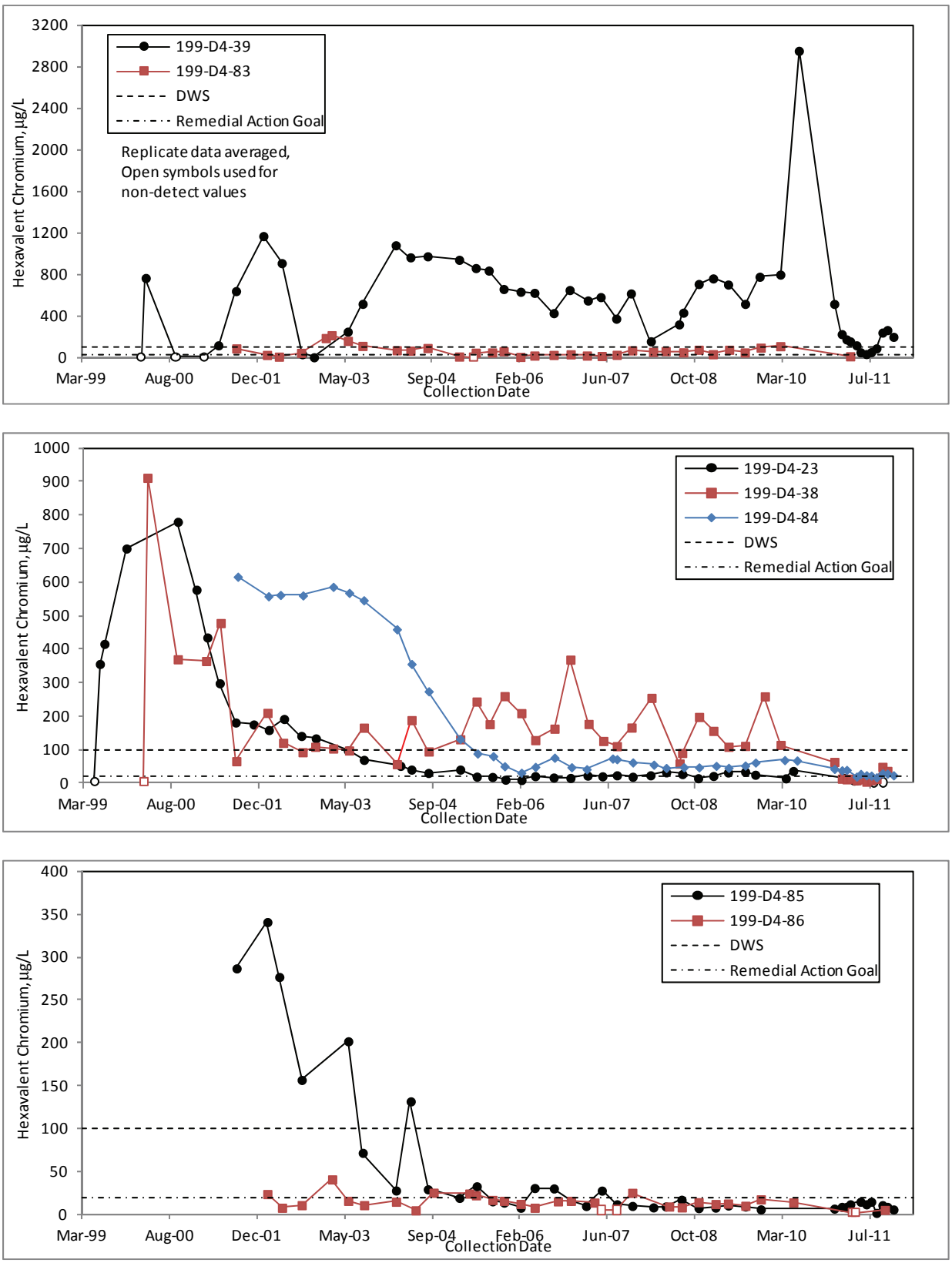


**Figure 2-23. In Situ Redox Manipulation Hexavalent Chromium Trend Plots for Compliance Wells**

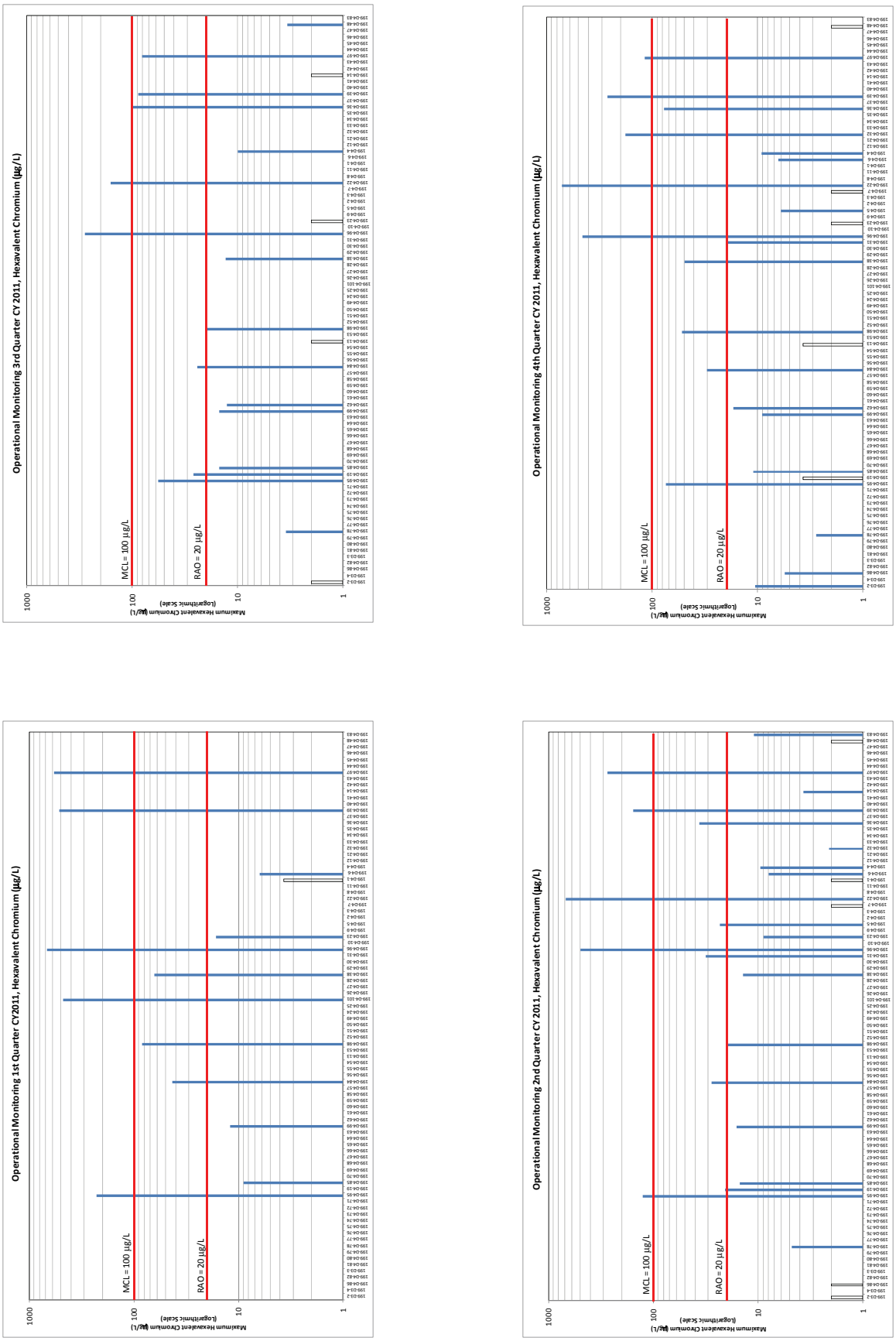


**Figure 2-24. In Situ Redox Manipulation Operational Monitoring, Hexavalent Chromium**

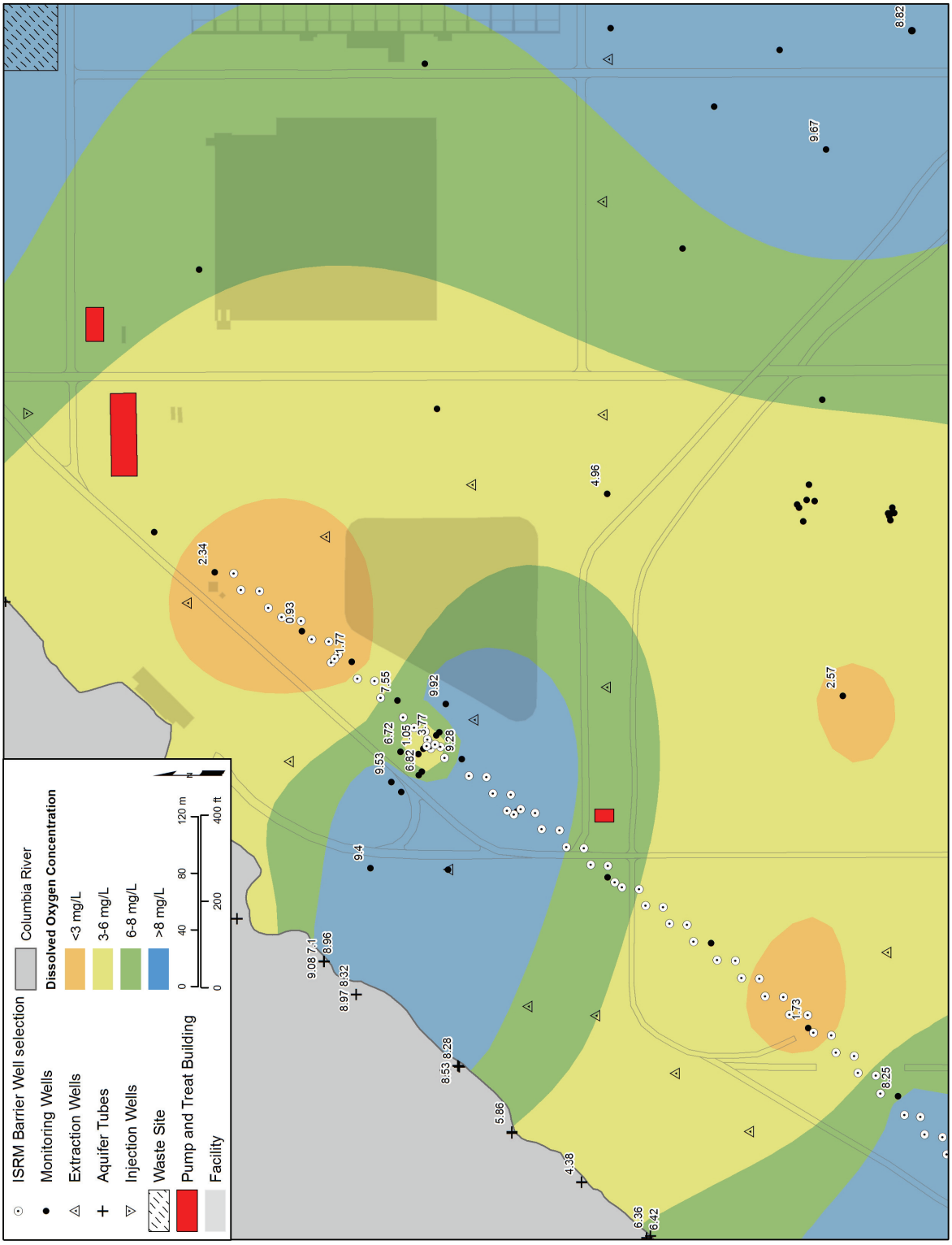


**Figure 2-25. In Situ Redox Manipulation Dissolved Oxygen Concentrations, April to July 2011**

**Table 2-1. Maximum Contaminant and Co-Contaminant Concentrations for 100-D Area, 2010 and 2011**

| Constituent | Maximum Value Detected (µg/L or pCi/L) | Filtered (F) or Unfiltered (UF) | Date Sampled | Well/Aquifer Tube Name |
|---|---|---|---|---|
| **2011** | | | | |
| Hexavalent chromium | 28,100 | F | 02/27/11 | 199-D5-122 |
| Hexavalent chromium | 27,900 | UF | 02/27/11 | 199-D5-122 |
| Total chromium | 6,290 | UF | 03/02/11 | 199-D5-141 |
| Nitrate | 98,300 | UF | 01/30/11 | 199-D8-4 |
| Strontium-90 | 45 | UF | 01/13/11 | 199-D5-132 |
| Tritium | 24,000 | UF | 02/17/11 | 199-D8-89 |
| Technetium-99 | 5.7 | UF | 03/22/11 | 199-D8-97 |
| Sulfate | 466,000 | UF | 01/06/11 | DD-42-4 |
| Uranium | 6.1 | UF | 10/27/11 | 199-D4-15 |
| Gross beta | 186 | UF | 02/23/11 | 199-D4-1 |
| Gross alpha | 4.28 | UF | 10/12/11 | 199-D5-93 |
| **2010** | | | | |
| Hexavalent chromium | 69,700 | F | 08/18/10 | 199-D5-122 |
| Hexavalent chromium | 69,100 | UF | 08/18/10 | 199-D5-122 |
| Total Chromium | 61,100 | UF | 02/11/10 | 199-D5-122 |
| Nitrate | 99,200 | UF | 03/22/10 | 199-D5-15 |
| Strontium-90 | 8.5 | UF | 11/19/10 | 199-D3-5 |
| Tritium | 20,000 | UF | 12/02/10 | 199-D6-3 |
| Technetium-99 | 2,100 | UF | 05/12/10 | 199-D5-18 |
| Sulfate | 776,000 | UF | 04/15/10 | DD-43-3 |
| Uranium | 5.82 | UF | 12/02/10 | 199-D6-3 |
| Gross beta | 27 | UF | 12/13/10 | 199-D5-40 |
| Gross alpha | 9.8 | UF | 11/30/10 | 199-D5-133 |

**Table 2-2. Maximum Contaminant and Co-Contaminant Concentrations for 100-H Area, 2010 and 2011**

| Constituent | Maximum Value Detected (µg/L or pCi/L) | Filtered (F) or Unfiltered (UF) | Date Sampled | Well/Aquifer Tube Name |
|---|---|---|---|---|
| **2011** | | | | |
| Hexavalent chromium | 133 | F | 01/24/11 | 199-H4-15CS |
| Hexavalent chromium | 287 | UF | 01/24/11 | 199-H3-9 |
| Total chromium | 319 | UF | 01/24/11 | 199-H3-9 |
| Total chromium | 142 | F | 12/14/11 | 199-H4-12C |
| Nitrate | 167,000 | UF | 12/29/11 | 199-H4-75 |
| Strontium-90 | 33 | UF | 12/15/11 | 199-H4-13 |
| Tritium | 4,330 | UF | 12/02/11 | 699-97-43B |
| Technetium-99 | 157 | UF | 10/12/11 | 199-H4-3 |
| Sulfate | 410,000 | UF | 12/29/11 | 199-H1-27 |
| Uranium | 289 | UF | 10/12/11 | 199-H4-3 |
| Gross beta | 68 | UF | 12/29/11 | 199-H4-14 |
| Gross alpha | 14 | UF | 03/22/11 | 199-H3-10 |
| **2010** | | | | |
| Hexavalent chromium | 140 | F | 12/16/10 | 199-H4-12C |
| Hexavalent chromium | 139 | UF | 12/16/10 | 199-H4-12C |
| Total chromium | 133 | UF | 12/16/10 | 199-H4-12C |
| Total chromium | 128 | F | 12/16/10 | 199-H4-12C |
| Nitrate | 44,300 | UF | 11/05/10 | 199-H6-3 |
| Strontium-90 | 160 | UF | 06/02/10 | 199-H1-20 |
| Tritium | 5,300 | UF | 05/16/10 | 199-H3-3 |
| Technetium-99 | 94 | UF | 12/29/10 | 199-H4-12A |
| Sulfate | 83,600 | UF | 05/13/10 | 199-H4-46 |
| Uranium | 12.2 | UF | 01/11/10 | 199-H4-3 |
| Gross beta | 69 | UF | 12/13/10 | 199-H4-13 |
| Gross alpha | 12 | UF | 11/8/10 | 199-H6-3 |

**Table 2-3. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D), DR-5, and DX P&T Systems**

| System | Well or Aquifer Tube Name | Well Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| DX | 199-D4-38 | E | 12/01/09 | 265 | -- | -- | 10/05/11 | 49 | 81.51 | -- |
| DX | 199-D4-39 | E | 11/03/09 | 779 | -- | -- | 11/02/11 | 264 | 66.11 | -- |
| DX | 199-D4-83 | E | 11/09/09 | 95.8 | -- | -- | -- | -- | -- | -- |
| DX | 199-D4-84 | E | 10/08/09 | 62 | -- | -- | 10/05/11 | 30 | 51.61 | -- |
| DX | 199-D4-85 | E | 11/09/09 | 6.1 | -- | -- | 10/05/11 | 11 | -80.33 | -- |
| DX | 199-D4-95 | E | 11/20/09 | 367 | -- | -- | 10/05/11 | 74 | 79.84 | -- |
| DX | 199-D4-96 | E | 10/28/09 | 970 | -- | -- | 10/04/11 | 462 | 52.37 | -- |
| DX | 199-D4-97 | E | 11/03/09 | 411 | -- | -- | 10/05/11 | 118 | 71.29 | -- |
| DX | 199-D4-98 | E | 12/04/09 | 26.5 | -- | -- | 10/05/11 | 52 | -96.23 | -- |
| DX | 199-D4-99 | E | 11/24/09 | 2 U | -- | -- | 10/05/11 | 9 | -350.00 | -- |
| DX | 199-D4-101 | E | -- | -- | -- | -- | -- | -- | -- | -- |
| | 199-D5-13 | M | 10/08/09 | 510 | -- | -- | 12/15/11 | 1090 | -113.73 | -- |
| | 199-D5-14 | M | 10/07/09 | 1,080 | -- | -- | 10/13/11 | 648 | 40.00 | -- |
| | 199-D5-15 | M | 10/07/09 | 944 | 12/30/10 | 654 | 12/15/11 | 101 | 89.30 | 84.56 |
| | 199-D5-16 | M | 10/07/09 | 272 | 12/30/10 | 231 | 12/15/11 | 59.7 | 78.05 | 74.16 |
| | 199-D5-17 | M | 10/07/09 | 10.9 | 12/30/10 | 10.7 | 10/13/11 | 6.3 | 42.20 | 41.12 |
| | 199-D5-18 | M | 10/21/09 | 10.8 | 12/30/10 | 7.8 | 12/15/11 | 11.6 | -7.41 | -48.72 |
| | 199-D5-19 | M | 10/08/09 | 7.9 | 12/30/10 | 6.1 | 10/13/11 | 5.5 | 30.38 | 9.84 |
| DR-5/DX | 199-D5-20 | E/E | 09/14/09 | 140 | 10/11/10 | 115 | 10/05/11 | 49 | 65.00 | 57.39 |
| DR-5/DX | 199-D5-32 | E/E | 09/21/09 | 31 | -- | -- | 12/07/11 | 326 | -951.61 | -- |

**Table 2-3. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D), DR-5, and DX P&T Systems**

| System | Well or Aquifer Tube Name | Well Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | 199-D5-33 | M | 11/09/09 | 2 | -- | -- | 12/15/11 | 4.6 | -130.00 | -- |
| | 199-D5-36 | M | 11/09/09 | 2.3 | -- | -- | 09/22/11 | 2 U | 13.04 | -- |
| | 199-D5-37 | M | 10/07/09 | 52.2 | -- | -- | 10/13/11 | 8.9 | 82.95 | -- |
| DR-5/DX | 199-D5-39 | E/E | 12/07/09 | 1,627 | 12/21/10 | 3,825 | 09/01/11 | 3,280 | -101.60 | 14.25 |
| DR-5/DX | 199-D5-92 | E/E | 12/07/09 | 68 | 09/13/10 | 46 | 12/07/11 | 16 | 76.47 | 65.22 |
| | 199-D5-97 | M | 11/04/09 | 458 | -- | -- | -- | -- | -- | -- |
| | 199-D5-98 | M | 11/04/09 | 80.8 | -- | -- | -- | -- | -- | -- |
| | 199-D5-99 | M | 12/15/09 | 5,040 | 09/09/10 | 6,060 | -- | -- | -- | -- |
| DX | 199-D5-101 | E | -- | -- | -- | -- | 11/02/11 | 284 | -- | -- |
| | 199-D5-102 | M | 12/15/09 | 444 | 09/09/10 | 285 | 10/11/11 | 28.1 | 93.67 | 90.14 |
| | 199-D5-103 | M | 12/15/09 | 165 | 09/09/10 | 122 | | | 100.00 | 100.00 |
| DR-5/DX | 199-D5-104 | E/E | 12/01/09 | 4,550 | 10/18/10 | 7,680 | 11/02/11 | 10,304 | -126.46 | -34.17 |
| | 199-D5-115 | M | -- | -- | -- | -- | -- | -- | -- | -- |
| DX | 199-D5-127 | E | -- | -- | -- | -- | 11/02/11 | 95 | -- | -- |
| DX | 199-D5-130 | E | -- | -- | -- | -- | 10/05/11 | 239 | -- | -- |
| DX | 199-D5-131 | E | -- | -- | -- | -- | 10/05/11 | 1,474 | -- | -- |
| DX | 199-D7-3 | E | -- | -- | -- | -- | 11/02/11 | 77 | -- | -- |
| DX | 199-D7-6 | E | -- | -- | -- | -- | 09/01/11 | 29 | -- | -- |
| | 199-D8-3 | M | -- | -- | -- | -- | | | -- | -- |
| | 199-D8-4 | M | 11/09/09 | 204 | -- | -- | 10/11/11 | 137 | 32.84 | -- |

**Table 2-3. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D), DR-5, and DX P&T Systems**

| System | Well or Aquifer Tube Name | Well Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | 199-D8-5 | M | 10/08/09 | 645 | 12/30/10 | 379 | 10/11/11 | 38.1 | 94.09 | 89.95 |
| DX | 199-D8-6 | E | 11/09/09 | 137 | -- | -- | -- | -- | -- | -- |
| HR-3/DX | 199-D8-53 | E/E | 12/02/09 | 78 | 10/04/10 | 75 | -- | -- | -- | -- |
| HR-3/DX | 199-D8-54A | E&C/E | 12/02/09 | 97 | 10/04/10 | 77 | -- | -- | -- | -- |
| | 199-D8-54B | M | 11/04/09 | 2.7 | -- | -- | -- | -- | -- | -- |
| HR-3/DX | 199-D8-68 | E/E | 12/02/09 | 106 | 10/04/10 | 111 | -- | -- | -- | -- |
| HR-3/DX | 199-D8-69 | C/E | 12/01/09 | 58.2 | -- | -- | 12/07/11 | 39 | 32.99 | -- |
| HR-3 | 199-D8-70 | C | 10/07/09 | 77 | -- | -- | 12/16/11 | 36.6 | 52.47 | -- |
| HR-3 | 199-D8-71 | C | 10/07/09 | 134 | -- | -- | 12/16/11 | 131 | 2.24 | -- |
| HR-3/DX | 199-D8-72 | E/E | 12/02/09 | 911 | 10/04/10 | 1,017 | -- | -- | -- | -- |
| DX | 199-D8-73 | E | 11/04/09 | 250 | -- | -- | 11/02/11 | 159 | 36.40 | -- |
| DX | 199-D8-88 | E | 10/08/09 | 167 | -- | -- | 10/05/11 | 170 | -1.80 | -- |
| DX | 199-D8-89 | E | 11/03/09 | 380 | -- | -- | 10/05/11 | 112 | 70.53 | -- |
| DX | 199-D8-90 | E | -- | -- | -- | -- | 12/07/11 | 33 | -- | -- |
| DX | 199-D8-91 | E | -- | -- | -- | -- | 10/05/11 | 35 | -- | -- |
| DX | 199-D8-95 | E | -- | -- | -- | -- | 12/07/11 | 645 | -- | -- |
| DX | 199-D8-96 | E | -- | -- | -- | -- | 10/05/11 | 1,023 | -- | -- |
| DX | 199-D8-97 | E | -- | -- | -- | -- | 11/02/11 | 655 | -- | -- |
| DX | 199-D8-98 | E | -- | -- | -- | -- | 11/02/11 | 78 | -- | -- |
| DX | 199-H1-5 | E | -- | -- | -- | -- | 11/02/11 | 22 | -- | -- |

**Table 2-3. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D), DR-5, and DX P&T Systems**

| System | Well or Aquifer Tube Name | Well Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| DX | 199-H4-80 | E | -- | -- | -- | -- | 10/05/11 | 24 | -- | -- |
| DX | 199-H4-81 | E | -- | -- | -- | -- | 10/05/11 | 32 | -- | -- |
| DX | 199-H4-82 | E | -- | -- | -- | -- | 11/02/11 | 20 | -- | -- |
| **Aquifer Sampling Tubes** | | | | | | | | | | |
| | 36-S | AT | 11/13/09 | 12.8 | 11/10/2010 | 4.2 | 12/15/2011 | 2 U | 84.38 | 52.38 |
| | 38-M | AT | 11/14/09 | 4.6 | 11/10/2010 | 2U | 12/13/2011 | 2 U | 56.52 | NC |
| | AT-D-1-M | AT | -- | -- | -- | -- | 12/13/2011 | 2 U | -- | -- |
| | AT-D-2-M | AT | 11/13/09 | 3.6 | -- | -- | 12/14/2011 | 2 U | 44.44 | -- |
| | AT-D-3-D | AT | 11/14/09 | 11 | -- | -- | 12/14/2011 | 2 U | 81.82 | -- |
| | AT-D-4-D | AT | 11/13/09 | 8.9 | -- | -- | 12/14/2011 | 2 U | 77.53 | -- |
| | DD-12-2 | AT | -- | -- | -- | -- | -- | -- | -- | -- |
| | DD-15-3 | AT | 11/14/09 | 11 | -- | -- | 12/21/2011 | 12.9 | -17.27 | -- |
| | DD-16-3 | AT | 02/24/09 | 2.3 | -- | -- | 12/16/2011 | 2 U | 13.04 | -- |
| | DD-17-2 | AT | 11/14/09 | 26.5 | -- | -- | 9/13/2011 | 18.6 | 24.53 | -- |
| | DD-17-3 | AT | 11/14/09 | 40.8 | -- | -- | 9/13/2011 | 21.6 | 47.06 | -- |

Note: The change in hexavalent chromium was calculated using only equivalent analytes.
Well-use abbreviations: M =monitoring well, E = extraction well, I=Injection, C = compliance well, AT = aquifer tube.
Laboratory qualifier: U = undetected (shown with detection limit in parentheses).
Blank cells indicate that the sample was not collected, the analysis was not performed, or the change in concentration was not calculated.
If more than one sample was collected on the same date, the maximum result was used.
The change in concentration was not calculated if both results included an undetect (U) laboratory qualifier.

**Table 2-4. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H), HR-3, and HX P&T Systems**

| P&T System | Well or Aquifer Tube Name | Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Unfiltered (µg/L) | Date Collected | Concentration (µg/L) | 2009 to 2011 | 2010 to 2011 |
| HX | 199-H1-1 | E | -- | -- | -- | -- | 12/29/11 | 48.7 | -- | -- |
| HX | 199-H1-2 | E | -- | -- | -- | -- | 09/12/11 | 51 | -- | -- |
| HX | 199-H1-25 | E | -- | -- | -- | -- | 09/26/11 | 26 | -- | -- |
| HX | 199-H1-27 | E | -- | -- | -- | -- | 10/04/11 | 32 | -- | -- |
| HX | 199-H1-3 | E | -- | -- | -- | -- | 10/04/11 | 46 | -- | -- |
| HX | 199-H1-32 | E | -- | -- | -- | -- | 09/12/11 | 28 | -- | -- |
| HX | 199-H1-33 | E | -- | -- | -- | -- | 12/05/11 | 25 | -- | -- |
| HX | 199-H1-34 | E | -- | -- | -- | -- | 09/12/11 | 32 | -- | -- |
| HX | 199-H1-35 | E | -- | -- | -- | -- | 09/19/11 | 38 | -- | -- |
| HX | 199-H1-36 | E | -- | -- | -- | -- | 09/12/11 | 65 | -- | -- |
| HX | 199-H1-37 | E | -- | -- | -- | -- | 11/01/11 | 29 | -- | -- |
| HX | 199-H1-38 | E | -- | -- | -- | -- | 11/01/11 | 26 | -- | -- |
| HX | 199-H1-39 | E | -- | -- | -- | -- | 11/01/11 | 25 | -- | -- |
| HX | 199-H1-4 | E | -- | -- | -- | -- | 10/04/11 | 49 | -- | -- |
| HX | 199-H1-40 | E | -- | -- | -- | -- | 10/04/11 | 24 | -- | -- |
| HX | 199-H1-42 | E | 10/02/09 | 85.5 | -- | -- | 09/12/11 | 42 | 97.7 | -- |
| HX | 199-H1-43 | E | 10/02/09 | 81.5 | -- | -- | 12/29/11 | 49.7 | 97.5 | -- |
| HX | 199-H1-45 | E | 09/28/09 | 75.2 | -- | -- | 09/12/11 | 31 | 97.3 | -- |
| HX | 199-H1-6 | E | -- | -- | -- | -- | 11/01/11 | 27 | -- | -- |
| | 199-H3-2A | M | 10/27/09 | 10.5 | 12/30/10 | 2.3 | 12/15/11 | 2 (U) | 81.0 | 13.0 |
| | 199-H3-2B | M | 10/27/09 | 7.4 | -- | -- | -- | -- | -- | -- |
| HR-3/HX | 199-H3-2C | E/E | 10/23/09 | 112 | 10/04/10 | 41 | 09/12/11 | 80 | 28.6 | -95.1 |

**Table 2-4. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H), HR-3, and HX P&T Systems**

| P&T System | Well or Aquifer Tube Name | Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Unfiltered (µg/L) | Date Collected | Concentration (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | 199-H3-3 | M | 10/11/09 | 45.1 | 12/30/10 | 51 | 12/15/11 | 30.4 | 32.6 | 40.4 |
| HX | 199-H3-4 | E | 10/11/09 | 52 | 12/30/10 | 62.7 | 12/05/11 | 36 | 30.8 | 42.6 |
| | 199-H3-5 | M | 10/11/09 | 71.4 | 12/30/10 | 73.2 | 12/15/11 | 66.2 | 7.3 | 9.6 |
| HR-3 | 199-H4-3 | EP | 12/01/09 | 2 (U) | 12/16/10 | 5.2 | 10/12/11 | 14.7 | -635.0 | -182.7 |
| HR-3/HX | 199-H4-4 | EC/E | 11/19/09 | 13.3 | -- | -- | 10/03/11 | 18 | -35.3 | -- |
| HR-3 | 199-H4-5 | C | 12/21/09 | 3.1 | 09/07/10 | 3 | 12/15/11 | 2 (U) | 35.5 | 33.3 |
| | 199-H4-6 | M | 10/11/09 | 8.4 | 12/30/10 | 5.2 | 10/12/11 | 5.3 | 36.9 | -1.9 |
| | 199-H4-8 | M | 09/02/09 | 5.3 | 12/16/10 | 2 (U) | 11/29/11 | 3.7 (U) | 30.2 | NC |
| | 199-H4-9 | M | 11/18/09 | 2.7 | -- | -- | 11/29/11 | 3.7 (U) | -37.0 | -- |
| | 199-H4-10 | M | 11/18/09 | 20.4 | 12/30/10 | 21 | 12/15/11 | 2.3 | 88.7 | 89.0 |
| | 199-H4-11 | M | 10/21/09 | 12.1 | 12/13/10 | 4.7 | -- | -- | -- | -- |
| HR-3 | 199-H4-12A | E | 08/04/09 | 16 | 12/29/10 | 6.80 | 11/29/11 | 3.70 | 76.9 | 45.6 |
| | 199-H4-12B | M | 11/19/09 | 11.3 | -- | -- | -- | -- | -- | -- |
| HR-3/HX | 199-H4-12C (deep well) | E/E | 11/19/09 | 121 | 12/16/10 | 139 | 09/12/11 | 147 | -21.5 | -5.8 |
| | 199-H4-13 | M | 11/23/09 | 13.7 | 12/13/10 | 9.7 | 12/15/11 | 10.8 | 21.2 | -11.3 |
| HR-3/HX | 199-H4-15A | E/E | 07/08/09 | 25 | 10/04/10 | 25 | 12/05/11 | 27 | -8.0 | -8.0 |
| | 199-H4-15B | M | 11/19/09 | 7.1 | -- | -- | -- | -- | -- | -- |
| | 199-H4-15CP (deep well) | M | 11/09/09 | 7.4 | -- | -- | 10/18/11 | 2 (U) | 73.0 | -- |
| | 199-H4-15CQ (deep well) | M | 11/09/09 | 2 (U) | -- | -- | 10/18/11 | 2 (U) | NC | -- |
| | 199-H4-15CR (deep well) | M | 11/09/09 | 2 (U) | -- | -- | 10/18/11 | 3.9 | -95.0 | -- |

**Table 2-4. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H), HR-3, and HX P&T Systems**

| P&T System | Well or Aquifer Tube Name | Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Unfiltered (µg/L) | Date Collected | Concentration (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | 199-H4-15CS (deep well) | M | 11/09/09 | 115 | -- | -- | 10/18/11 | 153 | -33.0 | -- |
| | 199-H4-16 | M | 11/18/09 | 4.9 | 12/30/10 | 2 (U) | 12/15/11 | 2 (U) | 59.2 | NC |
| | 199-H4-45 | M | -- | -- | 12/30/10 | 12.3 | 12/15/11 | 4.8 | -- | 61.0 |
| | 199-H4-46 | M | 10/11/09 | 17.6 | -- | -- | -- | -- | -- | -- |
| | 199-H4-47 | M | -- | -- | -- | -- | -- | -- | -- | -- |
| | 199-H4-48 | M | 11/18/09 | 35.4 | -- | -- | 12/15/11 | 11.1 | 68.6 | -- |
| | 199-H4-49 | M | 11/23/09 | 28.8 | -- | -- | -- | -- | -- | -- |
| HR-3/HX | 199-H4-63 | EC/E | 11/19/09 | 14.4 | 09/02/10 | 20 | 09/12/11 | 22 | -52.8 | -10.0 |
| HR-3/HX | 199-H4-64 | EC/E | 11/02/09 | 41 | -- | -- | 12/15/11 | 16 | 61.0 | -- |
| | 199-H4-65 | M | 11/23/09 | 6.3 | -- | -- | -- | -- | -- | -- |
| HX | 199-H4-69 | E | 09/21/09 | 6.7 | -- | -- | 09/12/11 | 11 | -64.2 | -- |
| HX | 199-H4-70 | E | 09/21/09 | 6.2 | -- | -- | 09/12/11 | 10 | -61.3 | -- |
| HX | 199-H4-75 | E | -- | -- | -- | -- | 09/12/11 | 76 | -- | -- |
| HX | 199-H4-76 | E | -- | -- | -- | -- | 09/12/11 | 90 | -- | -- |
| HX | 199-H4-77 | E | -- | -- | -- | -- | 12/29/11 | 77.8 | -- | -- |
| | 199-H5-1A | M | 10/11/09 | 17.6 | 12/30/10 | 30.7 | 12/15/11 | 27.5 | -56.3 | 10.4 |
| | 199-H6-1 | M | 10/11/09 | 9.7 | -- | -- | 12/15/11 | 14.5 | -49.5 | -- |
| | 699-90-45 | M | -- | -- | 11/18/10 | 2 | 11/28/11 | 3.7 (U) | -- | NC |
| | 699-91-46A | M | -- | -- | -- | -- | 11/28/11 | 3.7 (U) | -- | -- |
| | 699-94-41 | M | -- | -- | 11/18/10 | 10.5 | 12/13/11 | 10.4 | -- | 1.0 |
| | 699-94-43 | M | -- | -- | 11/18/10 | 36.3 | 12/13/11 | 35.6 | -- | 1.9 |
| | 699-95-45 | M | -- | -- | 11/16/10 | 49.3 | 12/13/11 | 46.8 | -- | 5.1 |
| | 699-97-41 | M | -- | -- | 11/16/10 | 83.6 | -- | -- | -- | -- |

**Table 2-4. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H), HR-3, and HX P&T Systems**

| P&T System | Well or Aquifer Tube Name | Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Unfiltered (µg/L) | Date Collected | Concentration (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | 699-97-43B | M | -- | -- | -- | -- | 12/02/11 | 73 | -- | -- |
| | 699-97-43C | M | -- | -- | -- | -- | 12/28/11 | 2 U | -- | -- |
| | 699-97-45 | M | -- | -- | 11/16/10 | 58.6 | 12/19/11 | 44 | -- | 24.9 |
| | 699-97-45B | M | -- | -- | -- | -- | 12/28/11 | 2 (U) | -- | -- |
| | 699-98-43 | M | -- | -- | 11/18/10 | 65.9 | 12/19/11 | 56 | -- | 15.0 |
| | 699-98-46 | M | -- | -- | -- | -- | 12/28/11 | 47 | -- | -- |
| | 699-99-41 | M | -- | -- | -- | -- | 12/21/11 | 18.4 | -- | -- |
| | 699-99-44 | M | -- | -- | -- | -- | 12/21/11 | 23.4 | -- | -- |
| | 699-100-43B | M | -- | -- | -- | -- | 12/19/11 | 2.3 | -- | -- |
| | 699-101-45 | M | -- | -- | -- | -- | 12/19/11 | 13.7 | -- | -- |
| **Aquifer Tubes** | | | | | | | | | | |
| | 44-M | AT | -- | -- | 11/10/10 | 16.9 | -- | -- | -- | -- |
| | 45-S | AT | -- | -- | 11/10/10 | 2 (U) | 12/29/11 | 2 (U) | -- | NC |
| | 45-M | AT | -- | -- | 11/10/10 | 2 (U) | -- | -- | -- | -- |
| | 45-D | AT | -- | -- | 11/10/10 | 2 (U) | -- | -- | -- | -- |
| | 47-M | AT | 11/03/09 | 14.5 | -- | -- | 12/27/11 | 2 (U) | 86.2 | -- |
| | 48-S | AT | 11/04/09 | 8.3 | -- | -- | 12/27/11 | 6.1 | 26.5 | -- |
| | 48-M | AT | -- | -- | -- | -- | 12/27/11 | 6.3 | -- | -- |
| | 49-D | AT | 11/04/09 | 7 | -- | -- | 12/27/11 | 5.6 | 20.0 | -- |
| | AT-H-1-D | AT | 11/03/09 | 12.1 | -- | -- | 12/29/11 | 2 (U) | 83.5 | -- |
| | AT-H-1-M | AT | -- | -- | -- | -- | 12/29/11 | 2 (U) | -- | -- |
| | AT-H-1-S | AT | -- | -- | -- | -- | 12/29/11 | 2 (U) | -- | -- |
| | AT-H-2-D | AT | 11/03/09 | 13.7 | -- | -- | 12/29/11 | 2.3 | 83.2 | -- |
| | AT-H-3-D | AT | 11/03/09 | 8.2 | -- | -- | 09/16/11 | 2.8 | 65.9 | -- |

**Table 2-4. Hexavalent Chromium Concentrations in Calendar Years 2009 to 2012 for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H), HR-3, and HX P&T Systems**

| P&T System | Well or Aquifer Tube Name | Use | Fall 2009 Unfiltered Cr(VI) | | Fall 2010 Unfiltered Cr(VI) | | Fall 2011 Unfiltered Cr(VI) | | Percent Change in Concentration (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Date Collected | Conc. (µg/L) | Date Collected | Unfiltered (µg/L) | Date Collected | Concentration (µg/L) | 2009 to 2011 | 2010 to 2011 |
| | C6286 | AT | -- | -- | -- | -- | 09/15/11 | 2.3 | -- | -- |
| | C6288 | AT | -- | -- | -- | -- | 09/15/11 | 13 | -- | -- |
| | C6290 | AT | -- | -- | -- | -- | 09/16/11 | 2 (U) | -- | -- |
| | C6291 | AT | -- | -- | -- | -- | 09/16/11 | 2.1 | -- | -- |
| | C6293 | AT | -- | -- | -- | -- | 09/22/11 | 7.4 | -- | -- |
| | C6299 | AT | -- | -- | -- | -- | 09/14/11 | 2 (U) | -- | -- |
| | C6300 | AT | -- | -- | -- | -- | 09/14/11 | 2 (U) | -- | -- |
| | C6301 | AT | -- | -- | -- | -- | 09/14/11 | 2 (U) | -- | -- |
| | C7649 | AT | -- | -- | 12/16/10 | 2 (U) | 12/28/11 | 2 (U) | -- | NC |
| | C7650 | AT | -- | -- | 12/16/10 | 20 | 12/28/11 | 26.6 | -- | -33.0 |

Note: The change in hexavalent chromium was calculated using only equivalent analytes.

Well use abbreviations: M =monitoring well, E = extraction well, I=Injection, C = compliance well, AT = aquifer tube.

Laboratory qualifier: U = undetected (shown with detection limit in parentheses).

Blank cells indicate that the sample was not collected, the analysis was not performed, or the change in concentration was not calculated.

If more than one sample was collected on the same date, the maximum result was used.

The change in concentration was not calculated if both results included an undetect (U) laboratory qualifier.

**Table 2-5. HR-3 P&T System Wells**

| Well Name | Use in 2011 |
|---|---|
| 199-D8-53 | Extraction |
| 199-D8-54A | Extraction |
| 199-D8-68 | Extraction |
| 199-D8-69 | Compliance |
| 199-D8-70 | Compliance |
| 199-D8-72 | Extraction |
| 199-H3-2C[a] | Extraction |
| 199-H4-12A[b,c] | Extraction |
| 199-H4-12C[a] | Extraction |
| 199-H4-14 | Injection |
| 199-H4-15A | Extraction |
| 199-H4-17 | Injection |
| 199-H4-18 | Injection |
| 199-H4-3[b] | Extraction |
| 199-H4-4 | Extraction |
| 199-H4-5 | Compliance |
| 199-H4-63 | Extraction |
| 199-H4-64[c] | Extraction |

a. RUM well added in 2010.
b. Wells that will not be transferred to HX P&T system.
c. Well not operating during 2011.

**Table 2-6. 100-HR-3 OU Operating Parameters and System Performance for 2011**

| Total 100-HR-3 Processed Groundwater | 2010 | 2011* |
|---|---|---|
| Total amount of groundwater treated (since 1997) (million L) | 4,037 | 4,171 |
| Total amount of groundwater treated during CY (million L) | 268 | 134 |
| **Mass of Hexavalent Chromium Removed** | **2010** | **2011*** |
| Total amount of hexavalent chromium removed (since 1997 startup) (kg) | 400 | 406 |
| Total amount of hexavalent chromium removed in CY (kg) | 31 | 5.6 |
| **Summary of Operational and System Availability** | **2010** | **2011*** |
| Removal efficiency (% by mass) | 96.0% | 93.1% |
| Total possible run-time (hours) | 8,760 | 3,240 |
| Scheduled downtime (hours) | 201.2 | 0 |
| Planned operations (hours) | 8,558.8 | 3,240 |
| Unscheduled downtime (hours) | 690.8 | 0 |
| Total time online (hours) | 7,868 | 3,240 |
| Total availability (%) | 97.7% | 100% |
| Scheduled system availability (%) | 89.8% | 100% |

Note: Scheduled system availability [(total possible run-time - scheduled downtime) ÷ total possible run-time].
Total availability [(total possible run-time - scheduled and unscheduled downtime) ÷ total possible run-time].
* Values are calculated during the system operation, from January 1, 2011 until the system shut down in May 16, 2011.

**Table 2-7. DR-5 P&T System Wells**

| Well Name | Use in 2011 |
|---|---|
| 199-D5-20 | Extraction |
| 199-D5-39 | Extraction |
| 199-D5-42 | Injection |
| 199-D5-92 | Extraction |
| 199-D5-104[a] | Extraction |
| 199-D5-41[b] | Injection |

a. Well not operating during 2011.
b. Well not transferred to the DX P&T system.

**Table 2-8. DR-5 P&T System Operating Parameters and System Performance for 2011**

| Total DR-5 Processed Groundwater | 2010 | 2011* |
|---|---|---|
| Total amount of groundwater treated (since December 2004) (million L) | 375 | 384 |
| Total amount of groundwater treated during CY (million L) | 44.6 | 9.1 |
| **Mass of Hexavalent Chromium Removed** | **2010** | **2011*** |
| Total amount of hexavalent chromium removed (since August 2004 startup) (kg) | 326.7 | 338 |
| Total amount of hexavalent chromium removed in CY (kg) | 74.9 | 11.3 |
| **Summary of Operational and System Availability** | **2010** | **2011*** |
| Removal efficiency (% by mass) | 99.8% | 99.9% |
| Total possible run-time (hours) | 8,760 | 1,440 |
| Scheduled downtime (hours) | 165.6 | 0 |
| Planned operations (hours) | 8,594.4 | 1,440 |
| Unscheduled downtime (hours) | 2,211.1 | 0 |
| Total time online (hours) | 6,383.3 | 1,440 |
| Total availability (%) | 98.1% | 100% |
| Scheduled system availability (%) | 72.9% | 100% |

Note: Scheduled system availability: [(total possible run-time - scheduled downtime) ÷ total possible run-time].
Total availability: [(total possible run-time - scheduled and unscheduled downtime) ÷ total possible run-time].
* Values are calculated during the system operation, from January 1, 2011 to March 2, 2011.

**Table 2-9. 100-DX Wells for the 100-D/H Area**

| 100-DX Extraction Wells | | | | 100-DX Injection Wells | |
|---|---|---|---|---|---|
| **Well ID** | **Well Name** | **Well ID** | **Well Name** | **Well ID** | **Well Name** |
| B8989 | 199-D4-38 | C7611 | 199-D7-6 | C7089 | 199-D2-10 |
| B8990 | 199-D4-39 | A4585 | 199-D8-6 | C7090 | 199-D2-12 |
| C3315 | 199-D4-83 | A4581 | 199-D8-53 | B8752 | 199-D5-42 |
| C3316 | 199-D4-84 | A4582 | 199-D8-54A | B8754 | 199-D5-44 |
| C3317 | 199-D4-85 | B2772 | 199-D8-68 | C7612 | 199-D5-128 |
| C7083 | 199-D4-95 | B2773 | 199-D8-69 | C7600 | 199-D5-129 |
| C7084 | 199-D4-96 | C3829 | 199-D8-72 | C7592 | 199-D6-1 |
| C7085 | 199-D4-97 | C4474 | 199-D8-73 | C7607 | 199-D6-2 |
| C7086 | 199-D4-98 | C4536 | 199-D8-88 | C7594 | 199-D7-4 |

**Table 2-9. 100-DX Wells for the 100-D/H Area**

| 100-DX Extraction Wells | | | | 100-DX Injection Wells | |
|---|---|---|---|---|---|
| **Well ID** | **Well Name** | **Well ID** | **Well Name** | **Well ID** | **Well Name** |
| C7087 | 199-D4-99 | C7091 | 199-D8-89 | C7608 | 199-D7-5 |
| C7580 | 199-D4-101 | C7092 | 199-D8-90 | A4584 | 199-D8-55 |
| A4577 | 199-D5-20 | C7093 | 199-D8-91 | C7095 | 199-D8-93 |
| C4185 | 199-D5-32 | C7589 | 199-D8-95 | C7096 | 199-D8-94 |
| B8748 | 199-D5-39 | C7603 | 199-D8-96 | C7593 | 199-D8-99 |
| C4583 | 199-D5-92 | C7582 | 199-D8-97 | | |
| C7583 | 199-D5-101 | C7602 | 199-D8-98 | | |
| C5400 | 199-D5-104 | C7610 | 199-H1-5 | | |
| C7591 | 199-D5-127 | C7595 | 199-H4-80 | | |
| C7590 | 199-D5-130 | C7596 | 199-H4-81 | | |
| C7601 | 199-D5-131 | C7609 | 199-H4-82 | | |
| C7599 | 199-D7-3 | | | | |

**Table 2-10. DX P&T System Operating Parameters and System Performance for 2011**

| **Total DX Processed Groundwater** | **2010** | **2011** |
|---|---|---|
| Total amount of groundwater treated (since December 2010) (million L) | 55.4 | 974 |
| Total amount of groundwater treated during CY (million L) | 55.4 | 919 |
| **Mass of Hexavalent Chromium Removed** | **2010** | **2011** |
| Total amount of hexavalent chromium removed (since December 2010 startup) (kg) | 18.4 | 461 |
| Total amount of hexavalent chromium removed in CY (kg) | 18.4 | 443 |
| **Summary of Operational and System Availability** | **2010*** | **2011** |
| Removal efficiency (% by mass) | -- | 99.8% |
| Total possible run-time (hours) | -- | 8,760 |
| Total time online (hours) | -- | 8,458 |
| Total availability (%) | -- | 96.6% |

* Values not calculated; system only operational for the month of December.

**Table 2-11. 100-HX Wells for the 100-D/H Area**

| 100-HX Extraction Wells | | | | 100-HX Injection Wells | |
|---|---|---|---|---|---|
| **Well ID** | **Well Name** | **Well ID** | **Well Name** | **Well ID** | **Well Name** |
| C7585 | 199-H1-1 | B2779 | 199-H3-4 | C7113 | 199-H1-20 |
| C7584 | 199-H1-2 | A4618 | 199-H4-12C | C7111 | 199-H1-21 |
| C7478 | 199-H1-25 | A4621 | 199-H4-15 | C7110 | 199-H3-25 |
| C7480 | 199-H1-27 | A4630 | 199-H4-4 | C7115 | 199-H3-26 |
| C7581 | 199-H1-3 | B2776 | 199-H4-63 | C7114 | 199-H3-27 |
| C7100 | 199-H1-32 | B2777 | 199-H4-64 | A4620 | 199-H4-14 |
| C7105 | 199-H1-33 | C7485 | 199-H4-69 | A4627 | 199-H4-17 |
| C7108 | 199-H1-34 | C7483 | 199-H4-70 | A4628 | 199-H4-18 |
| C7106 | 199-H1-35 | C7597 | 199-H4-75 | C7487 | 199-H4-71 |
| C7102 | 199-H1-36 | C7587 | 199-H4-76 | C7488 | 199-H4-72 |
| C7099 | 199-H1-37 | C7605 | 199-H4-77 | C7484 | 199-H4-73 |
| C7098 | 199-H1-38 | | | C7598 | 199-H4-74 |
| C7109 | 199-H1-39 | | | C7588 | 199-H4-78 |
| C7604 | 199-H1-4 | | | C7586 | 199-H4-79 |
| C7104 | 199-H1-40 | | | C7489 | 199-H6-2 |
| C7107 | 199-H1-42 | | | | |
| C7492 | 199-H1-43 | | | | |
| C7477 | 199-H1-45 | | | | |
| C7606 | 199-H1-6 | | | | |
| A4613 | 199-H3-2C | | | | |

**Table 2-12. HX P&T System Operating Parameters and System Performance for 2011**

| **Total HX Processed Groundwater** | **2011** |
|---|---|
| Total amount of groundwater treated (since September 2011 startup) (million L) | 303 |
| **Mass of Hexavalent Chromium Removed** | **2011** |
| Total amount of hexavalent chromium removed (since September 2011 startup) (kg) | 11 |
| **Summary of Operational and System Availability** | **2011** |
| Removal efficiency (% by mass) | 98.7% |
| Total possible run-time (hours) | 2,208 |
| Total time online (hours) | 2,150 |
| Total availability (%) | 97.4% |

# 3 100-KR-4 Operable Unit Remediation

This chapter describes the status of interim remedies for the 100-KR-4 OU, as well as the status of other CERCLA activities for the OU. The following discussion includes the performance of the interim remedy P&T systems, RPO, and a brief summary of the RI/FS activities that occurred during 2011.

## 3.1 Summary of Operable Unit Activities

The 100-KR-4 Groundwater OU lies within the 100-K Area (Figure 3-1) and includes the groundwater underlying the 100-KR-1 and 100-KR-2 source OUs (DOE/RL-2008-46-ADD2). The 100-KR-4 OU comprises groundwater contaminated by releases from facilities and waste sites associated with past operation of the KE and KW Reactors (Figure 3-2). Hexavalent chromium released from these facilities and waste sites poses a risk to human health and/or the environment and was identified in the interim action ROD (EPA/ROD/R10-96/134) as the primary COC for groundwater in the 100-KR-4 OU. Interim action co-contaminants for the 100-KR-4 OU include tritium and strontium-90. Carbon-14, nitrate, trichloroethene, chloroform, and technetium-99 are considered target analytes or constituents of interest that may be addressed as part of a final remedy for this OU. However, no exceedances or near exceedances of chloroform or technetium-99 were detected in the 100-KR-4 OU during 2011; therefore, these constituents are not addressed further in this chapter.

The interim action ROD for the 100-KR-4 OU (EPA/ROD/R10-96/134) defined the cleanup goal for hexavalent chromium in groundwater discharging to the Columbia River. Based in part on the allowance that contaminated groundwater (prior to discharging to the river) is mixed on a 1:1 basis with relatively uncontaminated water within a near-shore mixing zone along the river, the attainment of less than 22 µg/L of hexavalent chromium in the compliance monitoring well network of the 100-KR-4 OU was deemed to be consistent with achievement of this RAO. The ESD for the 100-HR-3 and 100-KR-4 OUs (EPA et al., 2009) reduced the remediation target for surface water to 20 µg/L. Consequently, a compliance criterion of 20 µg/L for hexavalent chromium in groundwater is currently applied to near-shore and compliance wells along the river. The current ambient water quality criterion is 10 µg/L. The DWS for total chromium at the 100-K Area inland wells remains at 100 µg/L.

To control and mitigate the risks associated with hexavalent chromium contamination in groundwater, three CERCLA interim action IX P&T systems have been installed in the 100-KR-4 OU. All three systems were operational for most of 2011. The KR4 system was the first system installed and began operation in 1997. This system was designed to remediate groundwater around the 116-K-2 Trench (Figure 3-2). The KW system was the second system installed, and it started remediating hexavalent chromium in the KW Reactor area in January 2007. The third and newest system, KX, began operations in February 2009. The KX system is used primarily to treat hexavalent chromium in groundwater that has migrated from the 116-K-2 Trench area toward N Reactor. Figure 3-2 shows the extraction and injection wells that comprise the well fields for these systems, as well as the associated monitoring wells and other monitoring locations.

Monitoring, data evaluation, and site characterization activities are conducted each year as part of the ongoing effort to determine or identify; 1) if the 100-KR-4 OU P&T systems are performing as designed, 2) if modifications to the system design or operating parameters will further optimize system performance, and 3) the extent of progress toward achieving plume cleanup and river protection RAOs. This chapter discusses the results of the 2011 100-KR-4 OU P&T evaluation, including the following:

- Section 3.2 presents an overview of the CSM and any changes in the nature and extent of groundwater contamination.

- Section 3.3 discusses system operations, performance monitoring results, and capture zone analysis of extraction wells.
- Section 3.4 provides a summary of the RI/FS activities for this OU.
- Sections 3.5 and 3.6 present the conclusions and recommendations, respectively, for the 100-KR-4 OU.

### 3.1.1 100-KR-4 Operable Unit P&T Systems

This subsection describes the general operating status of the three interim action P&T systems and the notable modifications made to these systems during 2011.

The KR4 system was shutdown during the last quarter of 2010 for upgrades to the process logic control system. The upgrades were complete in January 2012 and the KR4 system was restarted on January 14, 2012. In June, the P&T system was shutdown for planned 3 day 100-Area wide electrical outage. Total pumping rates from the KR4 system remained relatively constant from January to May 2011. From May until December 2011, the total pumping rate was reduced, and several wells were shut down because groundwater sampling showed hexavalent chromium concentrations at less than 10 µg/L. These wells were operated once per week for sampling; if hexavalent concentrations exceeded 10 µg/L, then the well was restarted.

For the KX P&T system, total pumping rates were relatively constant throughout 2011, with two short periods of reduced pumping rates during March and early June for planned system outages. The KX Transfer Building #2 was shut down during the last two weeks in March to relocate P&T lines and cables in support of waste site remediation activities at 100-N. The work was complete and flow through the transfer building resumed in April 2011. In June, the P&T system was shutdown for planned 3 day 100-Area wide electrical outage. Two extraction wells, 199-K-149 and 199-K-150, were converted to monitoring wells since hexavalent chromium concentrations at the wells have been less than 10 µg/L since June 2010 and October 2009, respectively. Monitoring well 199-K-152, where hexavalent chromium concentration is above 60 µg/L, was converted to an extraction well and connected to the KX P&T system and started extracting groundwater for treatment in April 2011.

Total pumping rates also remained relatively constant in the KW P&T system for most of the year. Rates were reduced for a brief period in June (for 100-Area wide electrical outage), and again in late August and September, when overall systems rates were decreased the treatment trains were taken offline one at a time for facility modifications to conduct the process test for using ResinTech SIR-700 as the ion exchange media for the 100-KR-4 OU P&T systems. The KW P&T system flow returned to normal rates after the resin in both treatment trains was changed out to SIR-700 at the end of September. Monitoring well 199-K-196 was drilled as part of the Phase 3 RPO and will serve as an extraction well for the KW P&T system. The well is necessary to determine hexavalent chromium stratification or deep occurrence near the river and provide improved capture of contaminants deeper in the aquifer.

### 3.1.2 Remedial Investigation/Feasibility Study Activities

An RI/FS was conducted to support the final ROD for the 100-K Area in 2010 and 2011. Characterization activities began in 2009, as described in DOE/RL-2008-46-ADD2, and were implemented through the SAP (DOE/RL-2009-41). A drilling program of 13 wells and 2 boreholes, initiated in May 2010, was completed in the first quarter of 2011. Groundwater and vadose zone sampling at 1.5 m (5 ft) intervals was specified for many of the borings. Screen placement in the final well design was based on the vertical profile for hexavalent chromium in groundwater wells. The 100-K RI/FS Report (DOE/RL-2010-97,

*Remedial Investigation/Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*) is scheduled to be issued as Rev. 0 in 2012.

### 3.1.3 Remedial Process Optimization Activities

RPO studies to improve the effectiveness of remediation and meet target milestones were initiated in 2009. Extensive groundwater modeling with repeated updates has been used to design treatment systems relying on P&T technology and on combined bioremediation/P&T approaches. Modeling has guided two phases of well realignments between treatment systems and supported an additional phase of well drilling in 2011.

Four wells were drilled in 2011 as part of Phase 3 of the RPO activities. Three of the four wells (199-K-196 at the KW system, and 199-K-198 and 199-K-199 at the KR4 system) will be connected to the respective treatment systems, while the fourth well (199-K-197) will monitor groundwater conditions near the southwest end of the 116-K-2 Trench. These wells were drilled through the entire unconfined aquifer thickness to the top of the RUM to characterize vertical contaminant distribution. All wells were designed so the well screens intersect the zones of greatest hexavalent chromium concentrations. Well 199-K-196 was screened across the entire thickness of the unconfined aquifer to provide coverage in an area otherwise populated with shallow extraction wells. In addition to the wells noted above, well 199-N-189 was constructed near the area border between 100-K and 100-N Areas. This well was drilled to contact with the RUM and was constructed with a fully-penetrating screen across the thickness of the shallow unconfined aquifer. Detection of hexavalent chromium in this well is consistent with concentrations in the nearby 199-K-182.

The resin management strategy (SGW-46621) conducted as part of the RPO recommended that the remaining 100 Area P&T facilities be converted to single-use resin in order to reduce operating costs and eliminate offsite transportation. The 100-KW P&T facility was selected to test the implementation of SIR-700 at the 100-KR-4 OU P&T systems. The process test was conducted at the 100-KW P&T facility in 2011. Further discussion of the process test is provided in Section 3.3.2.1.

## 3.2 Conceptual Site Model

Data from wells drilled in 2011 were evaluated and combined with historic information and data from older wells and boreholes. The new data has improved the understanding of the nature and extent of contamination, as wells as the geology, hydrology and major ion geochemistry that forms the basis of the CSM, described in detail in the 100-K RI/FS (DOE/RL-2010-97).

Borehole summary reports published in 2011 present the details of the wells and boreholes (SGW-49459, *Borehole Summary Report for the Drilling and Installation of RI/FS Wells in the 100-KR-4 Operable Unit*).

### 3.2.1 Geologic/Hydrogeologic Setting

100-K is the operational name for the area that contained the K-East and K-West Reactor buildings and associated support facilities located in the north central portion of the Hanford Site (Figure 3-1). It is bordered by the Columbia River to the north and is located approximately 45 km (28 mi) north-northwest of Richland, Washington. The two 100-K Area reactors, KE and KW, operated in tandem from 1955 to 1971. In addition to its operational history, the reactor FSBs were used to store spent fuel from N Reactor from 1975 until 2007. The primary sources of groundwater contamination in the 100-KR-4 OU are associated with reactor operations.

#### 3.2.1.1 Geology

The surficial deposits at the 100-K Area consist of recent backfill sand and gravel overlying Holocene aeolian deposits (Figure 3-3). Construction backfill varies in depth depending on the excavated depth of waste sites and building foundations, and backfill material may cover larger graded areas to a depth of up to 4.6 m (15 ft). Where not disturbed by construction activities, Holocene surficial deposits form a thin (0.3 m [1 ft]) veneer and consist of fine-grained aeolian deposits (loess) and Columbia River deposits of silt, sand, and gravel (WHC-SD-EN-TI-155).

These surface deposits are underlain, in descending order, by the Hanford formation, the Ringold Formation, and bedrock consisting of Columbia River Basalt Group. The Hanford formation and the Ringold Formation are described in the following paragraphs. Figure 3-3 presents a generalized cross section of the geology beneath the 100-K Area.

***Hanford Formation.*** The informally named Hanford formation overlies the late Miocene to middle Pliocene Ringold Formation in the 100-K Area. The formation consists of boulders, gravel, sand, and silt deposited by cataclysmic glacial Lake Missoula Ice Age floods that occurred during the Pleistocene Epoch (DOE/RW-0017). The Hanford formation is comprised of gravel-dominated, sand-dominated, and silt-dominated sequences of which only the upward-fining, gravel-dominated unit occurs along the Columbia River (DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*). The Hanford formation is the dominant material in the 100 Area vadose zone, ranging in thickness from less than 1 m (3.3 ft) near the river shoreline to 20 m (65 ft) along the southern edge of the K Reactor area, approximately 30 m (100 ft) near the southeastern boundary of the 100-K Area (WHC-SD-EN-TI-011). The unit thins near the shoreline of the Columbia River and becomes mixed with terrace gravel deposits laid down by the ancestral Columbia River. The Hanford formation underlying the 100-K Area essentially comprises a sand and gravel wedge that generally coarsens eastward (DOE/RL-2002-39). The Hanford formation has been eroded in locations to where the underlying Ringold Formation is exposed along the riverbank and up to 366 m (1,200 ft) inland (EPA/ROD/R10-96/134).

***Ringold Formation.*** The Miocene-Pliocene Ringold Formation disconformably underlies the Hanford formation and overlies the Columbia River Basalt Group (Figure 3-3). It has a maximum thickness of approximately 185 m (600 ft) in the Pasco Basin and a maximum thickness of 161 m (527 ft) in the 100-K Area. During the Pleistocene flood events that produced the Hanford formation in the 100-K Area, the Ringold Formation experienced widespread erosion that resulted in an irregular contact between the two units. This contact presents a contrast between the loose, permeable, coarse Hanford deposits and the denser, less-permeable, locally cemented Ringold Formation unit E gravels.

The Ringold Formation in the 100-K Area consists of four water-bearing, stratigraphic intervals dominated by fluvial gravels and sand. These lower Ringold units are designated, in descending stratigraphic order, as units E, C, B, and A; unit D is missing locally. These units are separated by, and interbedded with, two widespread mud and silt deposits of overbank and lacustrine origin (BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*).

Ringold Formation unit E is the uppermost coarse-grained unit of the Ringold Formation present in the 100-K Area, and it comprises the majority of the shallow unconfined aquifer. This unit is composed of loose to semi-indurated clay, silt, fine- to coarse-grained sand, gravel, and cobbles. Hydraulic conductivities vary locally, but the Ringold Formation unit E is generally regarded as a low-conductivity unit.

The Ringold Formation unit E is underlain by the low-permeability, silt-rich and clay-rich RUM. The RUM is up to 60 m (200 ft) thick in the 100-K Area and marks the base of the shallow unconfined aquifer. In general, the RUM has an undulating surface and dips toward the Columbia River. The RUM/ Ringold Formation unit E contact is also disconformable with evidence of erosion by the ancestral Columbia River system that deposited the Ringold Formation unit E.

#### *3.2.1.2 Hydrogeology*

Long-term groundwater flow in the vicinity of the 100-K Area is toward the Columbia River and occurs primarily in the low to moderately permeable sands and gravels of the Ringold Formation unit E. The saturated thickness of the Ringold Formation unit E ranges from 5.2 m (17 ft) at well 199-K-161 to more than 32 m (105 ft) in the 100-K Area. The mean transmissivity value obtained from constant discharge tests in 100-KR-4 injection wells was approximately 90 $m^2$/day (969 $ft^2$/day). The underlying silt-rich and clay-rich RUM is considered an aquitard rather than an aquiclude. Measurements of hydraulic conductivity of the Ringold Formation unit E ranged from approximately 0.98 to 44.2 m/day (3 to 145 ft/day) in monitoring wells 199-K-108A and 199-K-37, respectively. Along the 116-K-2 Trench, hydraulic conductivities ranged between 0.9 and 34 m/day (3 and 111 ft/day), with the greatest conductivity value near the center of the trench.

Columbia River water stage is controlled at Priest Rapids Dam and is strongly influenced by fluctuations in flow rates due to both natural and anthropogenic effects (e.g., spring snowmelt and runoff). These fluctuations in river stage similarly affect the water table elevation and groundwater flow direction within the aquifer proximal to the river. Even short-term fluctuations in the discharge rates from Priest Rapids Dam are known to cause river elevations to change by as much as 2.7 m (9 ft) in a single day (PNL-9437, *Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River*). Longer term seasonal changes in the river stage produce longer term increases in the water table elevation that gradually extend further inland over time (up to several thousand meters) from the river, while the magnitude of the increase progressively decreases with distance from the river.

In response to the seasonal changes in river stage, the groundwater flow gradients in the 100-KR-4 OU steepen toward the Columbia River during seasonal periods of low river flow (i.e., in the fall and winter) (Figure 3-4). Conversely, the groundwater gradient flattens as river water pushes into the aquifer during the spring when the river stage is high (Figure 3-4).

The hydraulic effects of the P&T systems at the 100-KR-4 OU are superimposed onto these broad seasonal fluctuations, and the efficiencies of the treatment systems (i.e., mass of hexavalent chromium captured per unit volume of water extracted) typically decrease during high river stage. The effects of seasonal changes in river stage (and water table elevation) on contaminant concentrations in the aquifer and treatment system performance are discussed in Section 3.3.

#### *3.2.1.3 Major Ion Groundwater Chemistry*

An evaluation of the major ion chemical characteristics of the groundwater associated with the different hexavalent chromium plumes (i.e., K West, K East, and the 116-K-2 Trench plume [KR4 and K North plumes]) within the 100-KR-4 OU is summarized in this section.

The groundwater of the unconfined aquifer has a pH generally ranging between 7.5 and 8.5, with a DO concentration averaging approximately 8 mg/L. All of the samples evaluated can be classified as predominantly calcium bicarbonate water that also contain notable but variable sulfate and nitrate concentrations. Mineral saturation/solubility calculations indicate that the groundwater of the unconfined aquifer is saturated, or nearly saturated, with respect to calcium carbonate.

Elevated levels of chloride, relative to the typical groundwater sampled in the 100-KR-4 OU, were noted in groundwater from monitoring well 199-K-110A, located near the KE Reactor and KE FSB (Figure 3-2). The DO concentration of this chloride-rich water was approximately 6.6 mg/L, near the lower end of the range of DO values observed for the 100-KR-4 OU. The origin of the high chloride component and the relatively low DO concentrations of the water in this area is uncertain but may be reflective of disposal activities at the KE Reactor and KE FSB.

The major ion chemistry of groundwater sampled from monitoring well 199-K-135 and other wells located at the calcium polysulfide (and vegetable oil injection) test site (Figure 3-2) is substantially different than groundwater from elsewhere in the OU. Calcium and alkalinity values are three-fold to four-fold higher than typically found elsewhere in the OU. The DO (at 2.8 mg/L), sulfate, and nitrate concentrations are all notably lower in this area, consistent with ongoing biogeochemical reduction of oxidation-reduction sensitive groundwater and aquifer matrix constituents in the test area. Depending on the extent of groundwater with these geochemical characteristics in the former treatment area and the longevity of continuing biogeochemical reduction, nearby downgradient extraction wells may be subject to increased rates of mineral and/or biological fouling and associated loss of extraction capacity. This situation will continue to be monitored when sampling at these wells is resumed. Additional discussion on the geochemistry at 100-K is included in the RI/FS Report (DOE/RL-2010-97), scheduled to be issued in 2012.

### 3.2.2 Origin of Contaminants in the 100-KR-4 OU

The groundwater contamination in 100-KR-4 OU is primarily the result of the operation of two now inactive, water-cooled nuclear reactors (KE and KW Reactors), associated structures (e.g., FSBs), and waste disposal processes associated with reactor operations. During operation of these reactors, large quantities of liquid and solid wastes (e.g., contaminated reactor cooling water, FSB water, and decontamination solutions) were generated and released to the environment, resulting in contamination of 100-K Area groundwater by a range of constituents.

### 3.2.3 100-KR-4 OU Groundwater Contaminants

Hexavalent chromium has been identified as the primary COC for groundwater in the 100-KR-4 OU. Strontium-90 and tritium are listed in the interim action ROD for the OU (EPA/ROD/R10-96/134) as co-contaminants and are monitored as secondary COCs. Target analytes include carbon-14, nitrate, and trichloroethene, which are contaminants of interest because they have exceeded their maximum contaminant levels (MCLs) in some wells or because these analytes were identified as constituents of interest in a qualitative risk assessment documented in *100-KR-4 Operable Unit Focused Feasibility Study* (DOE/RL-94-48).

Contaminant concentration data are collected each year from the 100-KR-4 OU compliance wells, other monitoring and extraction wells, and aquifer tubes within the OU. The data are used to update the status of the plumes and evaluate the effectiveness of ongoing remedial activities. Particular emphasis is given to data collected during the fall of each year when river levels are low and contaminant flux towards the river is the highest. Tables 3-1 through 3-3 display the highest 2011 hexavalent chromium, tritium, strontium-90, carbon-14, nitrate, and trichloroethene concentrations for the 116-K-2 Trench Area, KW Reactor Area, and KE Reactor Area, respectively. This report focuses on evaluating analytical results for hexavalent chromium being remediated through the interim action P&T systems. Further summary and analysis of the other COCs and contaminants of interest is presented in *Hanford Site Groundwater Monitoring for 2011* (DOE/RL-2011-118).

Available fall monitoring results for hexavalent chromium, tritium, strontium-90, carbon-14, nitrate, and trichloroethene at the 100-KR-4 OU plume areas are presented in Tables 3-4 through 3-6. Where fall 2009 and 2010 data for any of these constituents were previously collected at the locations monitored during fall 2011, the older data were also included in these tables. In wells where sufficient data were available, the concentration trends of these constituents between the fall of 2009 and 2011 were evaluated. The percent increases or percent decreases in the concentrations of the contaminants of interest between 2009 and 2011, and between 2010 and 2011, are also presented in the data summary tables. Longer term changes in hexavalent chromium concentrations at selected monitoring and extraction wells in the 100-KR-4 OU are addressed as part of the CERCLA system performance assessment (Section 3.3).

Spring and fall plume maps for hexavalent chromium for the 100-KR-4 OU are presented in Figure 3-5. Unless specified otherwise, contaminant plume maps in this report are based on average results for samples collected during 2011 for each well shown. The plume maps, data summary tables, and a summary of notable data observations are presented in the following subsections. Contaminant plume maps were constructed by computer programs using a method called quantile kriging to produce a continuous spatial illustration of the contaminant distribution as described in Section 2.2.3 (Chapter 2).

#### *3.2.3.1 Hexavalent Chromium*

Hexavalent chromium plume maps for spring and fall 2011 are presented in Figure 3-5. At periods of high river stage, each of the hexavalent chromium plumes is pushed inland. The plumes at the 116-K-2 Trench and the KE Reactor are most affected by the change in river stage, where the K East plume and the southwestern portion of the 116-K-2 Trench plume become connected at high river stage. As a result of the influx of river water into the aquifer during the spring, the mapped extent and absolute hexavalent chromium concentrations in the aquifer (and of the subsequent co-contaminants discussed in this section) are generally higher during the fall. However, seasonal changes in hexavalent chromium concentrations are most evident in wells within 200 m (650 ft) of the shoreline.

The hexavalent chromium distribution within the 100-KR-4 OU may be depicted as three separate plumes, differentiated by geographic location and/or source area. Primary release sites for hexavalent chromium include the 116-K-2 Trench and the 183.1-KE and 183.1-KW Headhouses. Secondary sites include leaks at the former 107-KE and 107-KW Retention Basins, post-reactor cooling water pipelines, and the 116-K-1 Crib. The post-reactor cooling water was characterized by hexavalent chromium concentrations of approximately 700 to 170 µg/L in groundwater, values which declined with operational refinements to corrosion protection. Prior to 2006, the mapped distribution of hexavalent chromium in the 100-KR-4 OU consisted of two relatively small plumes currently present in the KW and KE Reactor areas and a much larger plume associated with the 116-K-2 Trench (Appendix A).

Leaks and spills have yielded hexavalent chromium concentrations in groundwater greater than 700 µg/L, to as high as 4,900 µg/L, at the 183.1-KE and 183.1-KW Headhouses. A plume associated with the KW Reactor is identified as far upgradient as the headhouse structure, and it extends close to the Columbia River. Concentrations have reached as high as 3,340 µg/L in well 199-K-195, upgradient of the KW Reactor. Well 199-K-195 was installed as part of the RI/FS field effort. The highest concentration collected during drilling of this well was 4,890 µg/L at a depth of 30.4 m (100 ft). This maximum value is higher than the previously observed maximum of 771 µg/L detected in well 199-K-35 in 2010. Well 199-K-195 and adjacent well 199-K-35 were decommissioned to permit continued waste site remediation efforts around the former 183.1-KW Headhouse.

The K East plume extends from the 183.1-KE Headhouse (in the vicinity of wells 199-K-36 and 199-K-188) toward the river (in the vicinity of extraction wells 199-K-141 and 199-K-178). Previous interpretations of the plume showed a smaller, less continuous area. With the installation of additional

wells and more data, the extent of the plume has been reevaluated. During the low river stage, the plume is less continuous and much smaller. The shape of the plume during this time period is consistent with previous interpretations of the plume shape. During periods of high river state, the plume extends south of the headhouse to the new well (199-K-187) and connects to the southernmost portion of the 116-K-2 Trench plume.

The 116-K-2 Trench plume originally extended the length of the trench. This is consistent with the very large volumes (37,850 to 75,700 L/min [10,000 to 20,000 gpm]) of spent reactor coolant water that was discharged to the 116-K-2 Trench between 1955 and 1971. The P&T activities that began near the 116-K-2 Trench in 1997 gradually have reduced the hexavalent chromium concentrations in the central section of the 116-K-2 Trench plume (between the trench and the river) to near or below 20 µg/L. Due in part to higher local hydraulic conductivities near the middle of the trench, these remedial actions divided the original plume into a southwestern segment and a northeastern segment at opposite ends of the 116-K-2 Trench (Appendix A), also referred to (from northeast to southwest) as the K North plume and the KR4 plume.

The KR4 plume represents either the residual 116-K-2 Trench plume caught within low-conductivity Ringold Formation unit E sediments or a combination of 116-K-2 Trench plume combined with diluted 183.1-KE Headhouse losses. Some activation of this plume may be the result of remediation activities at the 118-K-1 Burial Ground.

***116-K-2 Trench Area (K North and KR4).*** The northeastern portion of the 116-K-2 Trench plume extends northeast into 100-NR-2 (Figure 3-5). Groundwater sampling and analysis during drilling at well 199-N-189 detected hexavalent chromium over the full thickness of the shallow unconfined aquifer at concentrations ranging from 29 to 39 µg/L. Well 199-N-74, 2 km (1.2 miles) from the end of the trench and farther north than 199-N-189, has hexavalent chromium concentrations near 30 µg/L. The contamination in both locations likely resulted from migration of the plume at 116-K-2 Trench during the historical discharge period when radial flow away from the large discharge mound at the trench would have moved contaminated water toward 100-N in addition to the rest of the surrounding area. The measurement of hexavalent chromium in wells 199-N-189 and 199-N-74 is consistent with the conceptual historical movement of chromium-contaminated groundwater away from the recharge mound at 116-K-2 Trench. These measurements are also consistent with the historical measurement of total chromium in filtered samples (a confident indication of hexavalent chromium) in wells in that area over the past twenty years (Figure 3-5). Modest amounts of sodium dichromate were used during the years immediately following startup of N Reactor (estimated at about 6,300 to 8,200 kg). Management and ultimate disposal of sodium dichromate solutions at 100-N may have contributed to some of the hexavalent chromium observed at 100-N. The hexavalent chromium plume observed northeast of 100-K and inland of 100-N most likely resulted from migration of reactor cooling water away from 116-K-2 Trench during the period of operation of 105-KE and 105-KW Reactors.

The K North plume can be further subdivided into a southwestern lobe and a northeastern lobe where concentrations have exceeded 50 µg/L. Each of these plume lobes is centered on separate small zones of hexavalent chromium with concentrations that currently exceed 48 µg/L and are at, or just below, the 100 µg/L DWS. These separate small zones of elevated concentrations are enveloped by a larger area of hexavalent chromium concentrations (i.e., greater than or equal to 20 µg/L and less than or equal to 48 µg/L), which defines the bulk of the K North plume (Figure 3-5).

Upgradient extents of these plumes suggest that considerable mass may remain to be treated. In the northeastern lobe, the plume is not bounded beyond well 199-K-182. The overall pumping strategy employed in this area should be evaluated to determine if the center of mass for each of these higher

concentration plume zones should be more directly targeted for remediation. Both the K North and the KR4 hexavalent chromium plumes are larger than the KE or KW Reactor plumes and are being actively remediated by the KR4 and KX P&T systems.

The KR4 plume comprises the southern remnant in the vicinity of the 116-K-2 Trench and is substantially smaller than the K North plume area. The KR4 plume overlaps the southern end of the 116-K-2 Trench and contains a small core zone with a concentration of hexavalent chromium that exceeded 100 µg/L (Figure 3-5). Concentrations at this zone declined below 100 µg/L in 2011 for the first time since 2002.

Table 3-1 presents the highest hexavalent chromium concentrations from wells and aquifer tubes associated with the 116-K-2 Trench (KR4 and K North) plumes and from the intervening central area of the 116-K-2 Trench in 2011. Table 3-4 includes the available 2009 and 2010 data collected at these locations. The following notable observations concerning the nature and extent of hexavalent chromium concentrations in the 116-K-2 Trench area data are presented in Tables 3-1 and 3-4:

- The hexavalent chromium concentrations between the river and the central section of the 116-K-2 Trench (i.e., between the KR4 and K North plumes) have been reduced to less than 20 µg/L. Monitoring wells 199-K-21 and 199-K-117A, and extraction wells 199-K-119A and 199-K-127, have been characterized by hexavalent chromium concentrations of less than 20 µg/L since 2008. Additionally, hexavalent chromium concentrations were less than 20 µg/L in monitoring well 199-K-19 and extraction well 199-K-120A in the fall of 2011.

- Fall 2011 hexavalent chromium concentrations were less than 20 µg/L in 22 of 37 wells sampled, and 16 wells were less than 10 µg/L.

- Hexavalent chromium concentrations decreased or were stable (results compared included "U" [nondetect] qualifiers) in 20 of 28 wells from 2010 to 2011 and in 20 of 20 wells from 2009 to 2011.

- The fall 2011 hexavalent chromium concentration in well 199-K-18 fell 54 percent to 64 µg/L, continuing a steady decrease since the fall 2009 concentration. Hexavalent chromium concentrations had been increasing in this well since the start of KR4 P&T system operations in 1997. Recent data suggest that the nearby KR4 system extraction wells 199-K-145 and 199-K-162 are beginning to notably reduce the mass remaining in this portion of the plume.

- Well 199-K-111A, located upgradient of the head end of the 116-K-2 Trench, is the only well in the 116-K-2 Trench area in which hexavalent chromium increased significantly from 2009 to 2011 (30 µg/L to 78 µg/L). This could be the result of treated injected water pushing contaminated groundwater towards this well.

- Well 199-K-22, located within the area of the former 116-K-2 Trench, displayed 120 µg/L hexavalent chromium concentrations in 2009 and also consistently during the period of P&T operations. Concentrations at well 199-K-22 decreased 56.7 percent to 52 µg/L in 2011.

- Hexavalent chromium concentrations in 7 of 12 aquifer tubes were less than 10 µg/L, and 9 of 12 tubes had hexavalent chromium concentrations less than 20 µg/L. The maximum hexavalent chromium concentration in an aquifer tube was 67.4 µg/L in AT-K-3-D located downgradient of extraction well 199-K-162; this is an increase of 18.4 percent since 2010.

- The extent of the contamination that has historically been associated with the 116-K-2 Trench continued to decrease during 2011. Reductions in the extent of contamination are particularly notable in the central area of the 116-K-2 Trench (e.g., wells 199-K-115A and 199-K-116A) and in the K North plume area (e.g., wells 199-K-148).

- Treated water injections at wells 199-K-159, 199-K-160, and 199-K-164 are regarded as contributing to reductions in the extent of the K North plume area.
- The K North plume is unbounded around well 199-K-182 (Figure 3-5).

***KW Reactor Area.*** The KW Reactor area hexavalent chromium plume is located near the KW Reactor, supporting water treatment facilities, and associated waste sites (Figure 3-5). The KW Reactor area plume has been monitored since the early 1990s when many of the CERCLA monitoring wells were initially installed. The KW P&T system, consisting of four extraction wells and two injection wells, became operational in January 2007 to remediate this plume after elevated hexavalent chromium concentrations were detected in aquifer tube AT-K-1. Four wells drilled in 2008 detected high chromium concentrations, and three of the wells were later converted to extraction wells. The capacity of the KW P&T system was subsequently expanded from 380 to 760 L/min (100 to 200 gpm), with seven extraction wells and three injection wells comprising the well field. The expanded KW P&T system began operation in April 2009. The upgradient edge of the plume is controlled by the presence of injection wells 199-K-175, 199-K-174, and 199-K-158. The plume does not extend inland past well 199-K-175, which had concentrations below 10 µg/L when the well was sampled before conversion to an injection well.

The hexavalent chromium concentrations obtained from wells and aquifer tubes for the KW Reactor area plume during 2011 are presented in Tables 3-2 and 3-5. Table 3-5 provides data from 2009 and 2010 for comparison. The findings and observations based on the results presented in Tables 3-2 and 3-5 are summarized as follows:

- Vertical profiling conducted during RI/FS drilling of well 199-K-195 detected a peak hexavalent chromium concentration of 4,890 µg/L. This well was drilled adjacent to the former 183.1-KW Headhouse. The elevated hexavalent chromium concentration suggests that the core of the KW Reactor area plume may have originated from one or more vadose zone or groundwater sources located in this area. These results are available in the 100-K RI/FS Report (DOE/RL-2010-97).
- The highest concentrations in the plume are located in the upgradient section of the plume that generally extends from the reactor area to the former 183.1-KW Headhouse (Figure 3-5). In fall 2008, samples collected from monitoring well 199-K-137 (located just upgradient of the KW Reactor) and monitoring well 199-K-165 (located between approximately 31 and 61 m [100 and 200 ft] further upgradient) yielded hexavalent chromium concentrations of 1,390 and 2,530 µg/L, respectively (Table 3-5), which are well above typical coolant water concentrations (approximately 700 to 170 µg/L).
- Well 199-K-165 was converted to an extraction well for the KW P&T system in early 2009 and, by fall 2011, the concentrations observed in extraction wells 199-K-137 and 199-K-165 had declined to 54 µg/L and 150 µg/L, respectively (Table 3-5).
- Hexavalent chromium concentrations increased in well 199-K-173 from 104 µg/L in 2009 to 968 µg/L in 2010 and decreased to 527 µg/L in 2011. This well is located upgradient of extraction well 199-K-165 and northeast of injection well 199-K-158. The cause of this increase is likely associated with the upgradient remediation efforts.

Additional observations based on the results presented in Tables 3-2 and 3-5 are as follows:

- The maximum 2011 hexavalent chromium concentration from a KW P&T well was 659 µg/L in monitoring well 199-K-173.

- Fall 2011 hexavalent chromium concentrations were less than 20 µg/L in 8 of 15 wells sampled, and 6 of 15 wells had hexavalent chromium concentrations less than 10 µg/L.
- Hexavalent chromium concentrations decreased from 2009 to 2011 in 11 of 12 wells and decreased or were unchanged from 2010 to 2011 in 7 of 11 wells monitored.
- Hexavalent chromium concentrations stabilized at 20 µg/L in downgradient extraction well 199-K-132 and decreased to 18 µg/L in extraction well 199-K-138. Hexavalent chromium was below the detection limit of 2 µg/L in aquifer tube AT-K-1.

***KE Reactor Area.*** The KE Reactor plume is currently being remediated by the KX P&T system. This plume has been intensively monitored since the early 1990s when several CERCLA monitoring wells were installed to characterize potential groundwater contamination in the area. It is the smallest hexavalent chromium plume in the 100-KR-4 OU. Areas of higher concentrations are located near extraction wells 199-K-141 and 199-K-178, downgradient of the KE Reactor, and near wells 199-K-36 and 199-K-188 near the headhouse (Figure 3-5). The plume area with concentrations between 10 and 20 µg/L merge with the southern portion of the KR4 plume.

The source of this plume is believed to be a combination of localized spills or leaks of highly concentrated sodium dichromate associated with the KE Reactor water treatment facilities and the large plume created by mounding around the 116-K-2 Trench. None of the KE Reactor area wells have displayed very high hexavalent chromium concentrations that could be attributed to spilled concentrated sodium dichromate. Table 3-3 displays the highest 2011 hexavalent chromium and co-contaminant concentrations, and Table 3-6 compares 2011 hexavalent chromium concentrations from wells and aquifer tubes to the 2009 and 2010 concentrations. The table also includes 2009 to 2011 and 2010 to 2011 changes in concentration. The following details are from Tables 3-3 and 3-6:

- Fall 2011 hexavalent chromium concentrations were less than 20 µg/L in 7 of 10 wells sampled.
- The maximum 2011 hexavalent chromium concentration was 97.4 µg/L in well 199-K-23 location east (along gradient) from the former KE Reactor building.
- Hexavalent chromium concentrations were decreased or remain unchanged from 2009 to 2011 in 4 of 6 wells but increased in 4 of 5 wells from 2010 to 2011.
- The maximum decrease in fall hexavalent chromium concentration from 2009 to 2011 was 73.6 percent in extraction well 199-K-141 (from 91 to 24 µg/L). The maximum increase in hexavalent chromium from 2009 to 2011 was 4.4 percent in well 199-K-181; however, the concentration during 2011 was 9 µg/L.
- Hexavalent chromium concentrations have decreased in the core of the plume downgradient of the KE Reactor. However, the upgradient plume around well 199-K-23 is likely connected to the main KE Reactor plume.
- A concentrated area is also centered around well 199-K-36, located between the 183.1-KE Headhouse and the KE sedimentation basin, was identified in 2010. Concentrations in this well increased from 37.5 µg/L in December 2010 to more than 119 µg/L in June 2011.

These observations suggest minimal contribution from any continuing sources in the vadose zone. The new RI/FS wells help delineate horizontal and vertical stratification of hexavalent chromium and other contaminants in the confined aquifer.

## 3.3 CERCLA OU Activities

This section summarizes activities related to operation and performance monitoring of the KR4, KW, and the KX P&T systems during 2011. Specific activities and operational performance details for these systems include changes to system configuration, system availability, mass of contaminants removed during operation, contaminant removal efficiencies, quantity and quality of extracted and disposed groundwater, and waste generation.

The remedial performance of the KW, KR4, and KX P&T systems (i.e., extent and effectiveness of plume capture) was evaluated by reviewing the changes in hexavalent chromium concentrations over time in selected monitoring and extraction wells associated with the KR4, KW, and KX well fields and by using two different methods of capture zone analysis to estimate the extent of plume capture by the three P&T systems under 2011 operating conditions.

Plume capture effectiveness in the 100-KR-4 OU was evaluated for the combined capture zones of the KR4, KW, and KX P&T systems (Figure 3-6). An overview of the extent and effectiveness of the combined (OU-wide) capture zone is discussed in the following paragraphs. Overviews of the capture zone distribution and the efficiency of each treatment system (KR4, KW, and KX) are presented in Sections 3.3.1.3, 3.3.2.3, and 3.3.3.3, respectively. More detailed descriptions of the methods used and results of the capture zone evaluation are presented in Appendix B.

Figure 3-6 depicts independently calculated representations of the combined site-wide capture zone for the 100-KR-4 OU. The results shown in Figure 3-6(a) were based primarily on groundwater modeling analysis, while the results shown in Figure 3-6(b) are based on a deterministic approach that incorporates high-frequency mapping of nearly continuously data logged water level measurements of the aquifer during several months of system operation (see Appendix B for details of both methods of capture zone analysis).

The data inputs and assumptions underlying these different methods of capture zone analysis are not the same, and the depictions of the extent and aggregate performance of the capture zones generated by these two methods are not identical. For example, the groundwater modeling approach (Figure 3-6[a]) depicts areas where current and future capture zone frequency/efficiency of the 100-KR-4 OU systems are based on the actual operating conditions of the systems during 2011, including periods when the systems were not operating (e.g., planned or unplanned system shutdown). This approach is useful for evaluating how periods of reduced extraction during the year would, if not remediated, reduce the long-term capture efficiency of the affected system. Conversely, Figure 3-6(b) presents those areas where current and future site-wide capture zone frequency/efficiency is based (with the exception of small duration stoppages) only on the hydraulic conditions of the aquifer while the system was operating during 2011. This approach does not include the effects of long-term, nonroutine shutdown events that occurred during 2011 as a continuing aspect of future capture zone performance. Consequently, the capture zone performance illustrated in Figure 3-6(b) is a better representation of long-term capture zones effectiveness/efficiency of the treatments systems if it assumed that the currently proposed operating conditions will continue in the future.

A comparison of Figure 3-6(a) and (b) demonstrates many similarities and also some key differences in capture zone effectiveness that are obtained using these two different methods for the 100-KR-4 OU. Both approaches indicate that the northern and southern areas of the capture zone distributions have a capture efficiency of upgradient groundwater of between 80 and 100 percent.

### 3.3.1 KR4 P&T System

The KR4 P&T system was designed to capture and treat the hexavalent chromium plume associated with the 116-K-2 Trench (Figure 3-2). Since startup in 1997, this system has treated over 5.72 billion L (1.51 billion gal) of water and has removed 354.9 kg of hexavalent chromium. Over time, the KR4 system has remediated much of the plume originally present along the central portion of the 116-K-2 Trench to less than 20 µg/L (Figure 3-5 and Appendix A). However, substantial areas of contamination remain in the groundwater at either end of the trench (i.e., KR4 and K North plumes). This may be attributed to the lower hydraulic conductivity values affecting movement in the aquifer at either end of the 116-K-2 Trench, the impact of increased hydraulic gradient from groundwater mounding at the injection wells acting cross-gradient on the plume, or a combined effect. The substantial reduction in the mass of contamination near the central section of the 116-K-2 Trench area since system startup is reflected in the decline in the overall influent concentration to the treatment system (Figure 3-7). The decreasing influent concentrations also reflect a decrease to removal efficiency since there is less hexavalent chromium mass to be removed.

#### *3.3.1.1 KR4 P&T System Configuration and Changes*

The KR4 P&T system (Figure 3-8) was designed to receive and process up to 1,135.6 L/min (300 gpm). The current system design includes 10 extraction wells (199-K-113A, 199-K-114A, 199-K-115A, 116-K-116, 199-K-116A, 199-K-120A, 199-K-127, 199-K-144, 199-K-145, and 199-K-162), and five injection wells (199-K-121A, 199-K-122A, 199-K-123A, 199-K-128, and 199-K-179) (Figure 3-2). Three of the extraction wells (199-K-144, 199-K-145, and 199-K-162) were originally connected to the KX P&T system; these three wells were realigned and connected to the KR4 system in 2009 and were put into service as KR4 system extraction wells in February 2010. Realignment of these wells as KR4 extraction wells was implemented to limit the extent of a tritium plume migrating toward these extraction wells from the vicinity of the 118-K-1 Burial Grounds. Although neither the KR4 nor the KW IX treatment system will remove tritium from the extracted water, the reinjection well system for the KR4 system restricts the injection of tritium-contaminated, treated effluent to a relatively small area. The injected water is partially extracted and recirculated back to the KR4 system, thereby reducing further spread of tritium. Tritium trends at monitoring well 199-K-119A, downgradient of the central half of the 116-K-2 Trench, decreased to 4,300 pCi/L in 2011 from 6,700 pCi/L in 2010. Tritium increased to 10,400 pCi/L in extraction well 199-K-127. Well 199-K-127 was not sampled in the fall of 2010, but the year-long tritium trend for the well is upward.

Upgrades to the KR-4 P&T process logic control (PLC) system and well head modifications were completed in January 2012 and the KR4 P&T system was restarted on January 14, 2012. The KR4 system was shutdown during the last quarter of 2010 for the upgrades to replace outdated process control systems and equipment that are no longer supported by vendors and bring control systems for the over 15 year old facility comparable to current technologies at the 100-KW and 100-KX P&T systems. This included replacement of power and control cables to the extraction and injection wells, motor controllers, and instruments at the well heads. The upgrades were performed to maintain system reliability and extend the system operational period as groundwater remediation activities continue.

The upgrades also included facility modifications for future addition of two new extraction wells that will be added to the KR-4 P&T system as part of planned RPO realignments to improve hydraulic containment down gradient of the southwest end of the 116-K-2 Trench. The two new wells, 199-K-198 and 199-K-199, were drilled in 2011 as part of the Phase 3 RPO and are located closer to the river than existing wells. These wells will serve as future extraction wells for the KR4 P&T system to capture hexavalent chromium within the near river mixing zone. In addition, new monitoring well 199-K-197 was completed in 2011 to monitor contamination levels and drawdown induced by adjacent extraction wells.

This will provide hydrologic information to the hydrologic model and will contribute to knowledge of the effectiveness of the extraction wells in capturing contamination.

#### *3.3.1.2 KR4 P&T System Performance*

Table 3-7 presents an overview of the operational parameters and total system performance for the KR4 P&T system during 2011. Overall, groundwater was processed at an average pumping rate of approximately 592 L/min (156 gpm). The maximum hexavalent chromium concentrations in the influent of the KR4 system was 46 µg/L in June, averaging 22.8 µg/L (Figure 3-9) compared to 23 µg/L in CY 2010.

The maximum hexavalent chromium concentration observed in the effluent of the KR4 system during 2011 was 12 µg/L, and the average concentration was 3.8 µg/L. Additional operational and system characteristics of the KR4 P&T system for 2011 are summarized as follows:

- In total, 284.9 million L (75.3 million gal) of groundwater were treated, and approximately 5.4 kg of hexavalent chromium were removed.
- The mass removal efficiency for 2011 was 83.36 percent, which is somewhat lower than the 90.6 percent reported in 2010 and is a direct result of the KR-4 P&T system having an affect in reducing the influent concentration to the treatment system (Figure 3-7 and Table 3-7).
- Total system availability for 2011 was 91.6 percent, substantially higher than the 74.9 percent total availability reported in 2010. The KR4 P&T system was upgraded in 2010 and was restarted on January 14, 2011.
- The scheduled system availability for 2011 was 98.1 percent (Figure 3-10).

Table 3-8 presents the pumping flow rates and total run-time (total flow hours divided by total possible run-time) for each extraction well currently at use in the KR4 P&T system. Except where noted, the recommended flow rates are based on updated numerical modeling results that were prepared to support the CERCLA 5-year review design modification. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping.

A comparison of the recommended and actual extraction rates indicates that wells 199-K-114A, 199-K-116A, 199-K-120A, and 199-K-127 were pumped at lower flow rates during the year than recommended. These lower flow rates were implemented primarily to prevent additional dilution of the already low hexavalent chromium concentrations being captured by these wells. Other extraction wells at the KR4 P&T system were operated at extraction rates that were very close to the recommended flow rates.

During 2011, all wells were subject to downtime due to equipment failures and/or maintenance. The downtime is reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction well.

After 13 years of successful treatment, influent concentrations at the KR4 system continue to decline. Average annual influent concentrations are noted as decreasing over time since 1997 (Figure 3-7). When hexavalent chromium concentrations in the groundwater influent are low, the hexavalent chromium already on the resins may be eluted off because of the higher affinity to higher phosphate and sulfate concentrations present in the groundwater, thus reducing or negating the gains of chromium captured by the resins. This “tailing effect” is unavoidable in a mature system unless new sources of contaminants are identified. Within the bounds of the KR4 plume, only a few of the original extraction wells are capable of producing hexavalent chromium concentrations above the 20 µg/L cleanup standard. Given the

decreasing size of the residual KR4 plumes and the current extraction well coverage in those areas, prospects for increasing the influent concentration at the KR4 system include hooking up new and/or active KX system wells to the KR4 system well field.

#### 3.3.1.3 Capture Zone Analysis

Figure 3-6 illustrates the composite capture zone produced by the KR4 P&T system well field. The extent and projected capture efficiency of the KR4 composite capture zone were developed based on high-frequency mapping of the water table levels at the site during operation of the system during 2011 (see Appendix B for details on methods). The predicted capture efficiency for groundwater contaminants within and upgradient of the KR4 extraction well field ranges between 90 and 100 percent. The extent and the high predicted capture efficiencies of the KR4 system capture zone are consistent with the observed remediation of the hexavalent chromium plume in the central area of the 116-K-2 Trench.

#### 3.3.1.4 KR4 P&T System Compliance Monitoring

The remedial performance of the KR4 P&T systems (i.e., extent and effectiveness of plume capture) has been evaluated using hexavalent chromium data from selected monitoring locations including, but not limited to, compliance monitoring wells 199-K-20 and 199-K-117A and active extraction/compliance wells 199-K-114A and 199-K-129 (DOE/RL-2006-75, *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System*). Well 199-K-18 has been dropped as a compliance well because extraction and Phase 3 RPO wells are now located downgradient. The general effectiveness of the KR4 system in the central section of the 116-K-2 Trench area is evident by the long-term decreasing concentration trends of hexavalent chromium in compliance monitoring wells 199-K-117A, 199-K-21, and 199-K-20. The hexavalent chromium concentrations at monitoring wells 199-K-117A and 199-K-21 have averaged below 10 µg/L since 2008 (Figure 3-11), while concentrations at 199-K-20 fluctuate above and below 10 µg/L with seasonal water level variations. In addition, the concentrations in wells 199-K-125A and 199-K-119A have steadily decreased, from about 40 µg/L in 2004 to below the detection limit (less than 2 µg/L) by January 2010 (Figure 3-11 and Table 3-4).

The KR4 extraction/compliance well 199-K-114A and nearby extraction well 199-K-113A are located downgradient of the northeast section of the 116-K-2 Trench and near the river in the K North plume (Figure 3-11). The pronounced sawtooth pattern is evident in the long-term hexavalent chromium concentration trends in these extraction wells and indicates that hexavalent chromium concentrations in groundwater near the shoreline are attenuated by mixing with river water during the spring when river stage is high (Figure 3-11). Both wells appeared to show a subtle decrease in hexavalent chromium concentrations in groundwater samples collected during the summer to early fall 2011 (when the river stage was lower) relative to previous years. Concentrations in well 199-K-113A remained below 10 µg/L during low river stage when hexavalent chromium concentrations in near-shore plume wells are generally highest and 199-K-114A concentrations were between 10 µg/L and 15 µg/L during low river stage.

The KR4 extraction/compliance well 199-K-129 is also located near the river in the central area of the K North plume but is somewhat further to the north than wells 199-K-114A and 199-K-113A (Figure 3-11). The long-term concentration trend in extraction well 199-K-129 shows a more subdued seasonal sawtooth pattern, and hexavalent chromium concentrations have gradually decreased from a high of about 60 µg/L in early 2004 to a low of 5 µg/L in January 2011 (Figure 3-11). Well 199-K-129 was not sampled after January 2011 due to failure of the adjustable frequency drive for the extraction well pump. Decreasing concentration trends, observed throughout 2011 for KR4 extraction wells 199-K-114A and

199-K-113A, that continue throughout 2012 may signify achievement of the interim action objective of protecting the river along this section of the K North plume (Figures 3-5 and 3-11).

Compliance well 199-K-18 is located in the KR4 plume, in the vicinity of the southern end of the 116-K-2 Trench (Figures 3-5 and 3-11). The hexavalent chromium concentrations in this well steadily increased from approximately 140 µg/L in 2004 to approximately 200 µg/L by April 2010 (Figure 3-11). However, the concentrations in this well declined steadily during the remainder of 2010 and 2011, reaching a concentration of 139 µg/L by December 2010 (Table 3-4 and Figure 3-11). Concentrations decreased to 64 µg/L in October 2011. The reversal in the long-term increasing concentration trend for hexavalent chromium in this well likely reflects the February 2010 startup of three nearby KR4 extraction wells (199-K-162, 199-K-145, and 199-K-120A). Of these three new extraction wells, the hexavalent chromium concentrations in water sampled at well 199-K-145 averaged approximately 60 µg/L during 2010 decreasing to approximately 25 µg/L in 2011, which is higher than concentrations extracted at wells 199-K-162 and 199-K-120A. In these latter two wells, concentrations have averaged less than 10 µg/L since 2010 (Figure 3-11). Injection of treated effluent at KX system well 199-K-156 (active since February 2009) may also be a factor affecting the decreasing concentrations at these two wells.

Although aquifer tubes are not official compliance points for treatment system performance, samples collected from these tubes are helpful for locating areas where hexavalent chromium may be discharging to the Columbia River at concentrations greater than 20 µg/L. Aquifer tube AT-K-3-D is located downgradient of monitoring well 199-K-18 and new extraction wells 199-K-162, 199-K-145, and 199-K-120A. This aquifer tube has had concentrations ranging from approximately 32 to 85 µg/L since it was first sampled in 2004 (Figure 3-11); the September 2011 results were 67.4 µg/L, near the middle of that range. Given the recent startup of upgradient extraction wells 199-K-162, 199-K-145, and 199-K-120A, as well as the abrupt decrease in concentration in monitoring well 199-K-18 during 2010 and 2011, the hexavalent chromium concentrations reaching this aquifer tube and, therefore, the Columbia River are expected to decrease substantially in this section of the KR4 plume within the next few years.

### 3.3.2 KW P&T System

The KW P&T system became operational on January 29, 2007 and has treated over 1.4 billion L (372.4 million gal) of groundwater and removed 163.1 kg of hexavalent chromium. This P&T system was installed to address additional hexavalent chromium contamination discovered near the KW Reactor (Figure 3-5).

#### *3.3.2.1 KW P&T System Configuration and Changes*

The KW P&T system (Figure 3-12) was originally designed to receive and process up to 378.5 L/min (100 gpm). System upgrades in CY 2009 expanded the treatment capacity to 757 L/min (200 gpm). The system is currently processing at the treatment capacity of 757 L/min (200 gpm).

The KW system currently consists of seven extraction wells (199-K-132, 199-K-137, 199-K-138, 199-K-139, 199-K-165, 199-K-166, and 199-K-168), three injection wells (199-K-158, 199-K-174, and 199-K-175), and an IX treatment system similar in design to that used in the 100-KR-4 and 100-HR-3 OUs.

In 2011, a performance test of ResinTech® SIR-700 Ion-Exchange Resin at the 100-KW groundwater treatment system was initiated and continued into 2012. This test demonstrates the successful conversion of an existing treatment system from the previously specified DOWEX™ 21K resin to the higher-performing SIR-700 resin to remove hexavalent chromium from contaminated groundwater. The test report (SGW-51721) documents the successful conversion and operation of the 100-KW system.

The SIR-700 met target installation and performance objectives relative to DOWEX™ 21K. The test results indicate that the SIR-700 was able to replace the DOWEX™ 21K effectively in the treatment trains at 100-KW. Measurements of hexavalent chromium concentrations in the effluent were less than 3 µg/L throughout the test (Figure 3-17) and mass removal efficiency averaged 97.6 percent. No resin replacement has been required since resin replacement in September 2011, and the initial installment of SIR-700 continues to operate after treating over 100,000 bed volumes of contaminated groundwater. By comparison, the capacity of the DOWEX™ 21K resin between resin change out for regeneration averages 4,800 bed volumes of treated contaminated groundwater. Operation of the treatment system with SIR-700 resin will result in less system down time for resin change out and significant cost reduction by eliminating need for resin regeneration.

The pH adjustment system was found to be implementable and adequate to provide mildly acidic water (pH 5.5 ± 0.5) into the treatment train to allow the SIR-700 resin to operate under design conditions. The field pH readings of the influent and effluent tanks are shown in Figure 3-13 No degradation due to lower operating influent pH was observed. Each of the four resin vessels in each treatment train was measured at 10 locations for a total of 80 measurements on July 6, 2011, and again on January 25, 2012, using the ultrasonic measurement technique. No significant changes in vessel wall thickness were measured.

The injection well flow rates are shown in Figure 3-14 and the injection well water levels are shown in Figure 3-15. The flow rates and head levels within the injection wells have remained constant over the duration of the test. This is a favorable condition because it indicates that flow from the injection well into the aquifer is not being negatively affected by well or aquifer fouling that would reduce the porosity of the aquifer matrix and cause reduced pumping rates and/or increased water levels (hydraulic head). These flow rate and water level data indicate that addition of the pH 6.0-6.5 water into the approximately 8.0 pH groundwater has not negatively affected either injection well flow rates or water levels. This indicates that no observable effect to the hydraulic conductivity of the aquifer or efficiency of the wells has occurred as a result of the test.

#### *3.3.2.2 KW P&T System Performance*

Table 3-9 presents an overview of the operational parameters and total system performance for the KW P&T system during 2011. During 2011, the KW system processed groundwater at an average annual pumping rate of approximately 717 L/min (189 gpm) and operated at or near 100 percent of the scheduled availability during each month of the year (Figure 3-16). The average influent hexavalent chromium concentration for 2011 was 73.1 µg/L, which is approximately half the average concentration of 145.5 µg/L reported for 2010.

Clear trends are evident in the influent concentrations during 2011. The hexavalent chromium concentrations in the influent of the KW system gradually decreased from about 100 µg/L in January to 75 µg/L by the end of April; it declined further to about 55 to 60 µg/L and stabilized during the summer months. Influent concentrations gradually increased from about 55 µg/L in July to about 100 µg/L by middle to late September, generally coincident with declining river levels. From late September to the end of December, the influent concentrations averaged about 73 µg/L.

Concentrations in KW P&T system effluent remained consistently below 10 µg/L for all but 4 of the 89 samples collected during the year. The maximum hexavalent chromium concentration in KW effluent was 15 µg/L (Figure 3-17). The average hexavalent concentration in the effluent during 2011 was 3 µg/L, which is significantly lower than the average effluent concentration of 4.6 µg/L reported for 2010. Selected operational and system characteristics of the KW P&T system for 2011 are summarized as follows:

- The scheduled system availability for 2011 was 97.1 percent, slightly lower than the 99.7 percent reported in 2010. The total availability was 94.7 percent, which was lower than the online availability of 99.6 percent reported in 2010. The monthly online percentages and the method used to calculate availability and online percentage for the reporting period are shown in Figure 3-16.
- In total, 357 million L (94.3 million gal) of groundwater were treated, and approximately 25.9 kg of hexavalent chromium were removed.
- The mass removal efficiency for 2011 was 95.8 percent, slightly lower than 2010 (96.9 percent) and 2007 and 2008 efficiencies (Figure 3-18). The declining efficiencies may be a result of decreasing influent concentrations.

Table 3-10 presents the pumping flow rates and total run-time for the extraction and injection wells currently active in the KW P&T system. Except where noted, the recommended flow rates are based on updated numerical modeling results that were prepared to support the CERCLA 5-year review design modification. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. All of the wells were subject to downtime because of equipment failures, and/or maintenance. This downtime is reflected in the yearly average flow rate calculations and the total run-time percentages for the individual extraction wells.

#### *3.3.2.3 KW P&T System Capture Zone Analysis*

Figure 3-6 illustrates the composite capture zone produced by the KW P&T system well field. The extent and projected capture efficiency of the composite KW system capture zone was developed using high-frequency mapping of the water table during actual 2011 operating conditions. For 2011, the KW hexavalent chromium plume was located entirely within the part of the KW system that is predicted to have capture efficiencies between 90 and 100 percent. The extent and capture efficiency of the KW system composite capture zone is consistent with effective remediation of the KW Reactor area plume (as currently defined) and achievement of interim groundwater RAOs.

#### *3.3.2.4 KW P&T System Compliance Monitoring*

The remedial performance of the KW P&T system has been evaluated using the 2009 to 2011 hexavalent chromium data presented in Table 3-5 and the long-term concentration trends for selected KW system monitoring locations (Figure 3-19).

Extraction wells 199-K-132 and 199-K-138 are located downgradient of the KW Reactor, near the leading edge of the KW Reactor area plume (Figure 3-5). Hexavalent chromium concentrations at wells 199-K-132 and 199-K-138 were approximately 120 and 75 µg/L, respectively, in January 2007 (Figure 3-19). Since startup of the KW P&T system, concentrations in these wells have steadily declined. The measured concentrations in these wells during November 2011 were 20 and 18 µg/L, respectively (Table 3-5). The 2010 hexavalent chromium concentrations in wells 199-K-132 and 199-K-138 were 16.8 µg/L and 20.6 µg/L, respectively, indicating that the concentrations are stabilizing near the P&T action level of 20 µg/L.

The 2011 hexavalent chromium concentration in aquifer tube AT-K-1 was below the detection limit. This value is consistent with the hexavalent chromium concentration trend for KW aquifer tubes since 2006, which is consistently below 10 µg/L (Figure 3-19). The concentrations in upgradient extraction wells 199-K-168, 199-K-139, 199-K-137, and 199-K-166 have all generally declined substantially over time (Figure 3-19). From 2010 to 2011, hexavalent chromium decreased from a maximum of 83.3 percent in well 199-K-139 (to 19 µg/L) to a minimum of 26.9 percent in well 199-K-166 (to 41 µg/L) (Table 3-5).

### 3.3.3 KX P&T System

The KX P&T system (Figure 3-20) was designed to receive and process groundwater at a rate of up to 2,300 L/min (600 gpm). This system was primarily designed to treat the K North hexavalent chromium plume located between the northern end of the 116-K-2 Trench and the N Reactor fence line. A small plume downgradient of the KE Reactor is also being treated by the KX system. The KX system began partial operation in November 2008 and became fully operational in early February 2009. The system is currently processing at an average annual pumping rate of approximately 1,720 L/min (455 gpm). Since startup, the system has treated more than 2.59 billion L (685.2 million gal) of water and removed approximately 114 kg of hexavalent chromium.

#### *3.3.3.1 KX P&T System Configuration and Changes*

The KX P&T system currently includes 13 extraction wells (199-K-130, 199-K-131, 199-K-141, 199-K-146, 199-K-147, 199-K-148, 199-K-152, 199-K-153, 199-K-154, 199-K-161, 199-K-163, 199-K-171, and 199-K-178) and 9 injection wells (199-K-143, 199-K-156, 199-K-159, 199-K-160, 199-K-164, 199-K-169, 199-K-170, 199-K-172, and 199-K-180) (Figure 3-2). One of these extraction wells (199-K-152) was converted from a monitoring well in 2011. Well 199-K-152 was connected to the KX P&T in April 2011. Activities to convert monitoring well and 199-K-182 to an extraction well was also initiated in 2011. All construction activities to convert well 199-K-182 to an extraction well is complete except for final piping and cable connections which have not been completed.

In 2011, two extraction wells (199-K-149 and 199-K-150) were converted to monitoring wells. The groundwater hexavalent concentration at the two wells have been less than the 10 µg/L aquatic water quality standard since October 2009 at 199-K-150 and June 2010 at 199-K-49 as reflected in the well trend plots in Figure 3-24. Continued extraction from the two wells was discontinued to make available treatment capacity for locations with higher hexavalent chromium contamination.

#### *3.3.3.2 KX P&T System Performance*

Table 3-11 presents an overview of the operational parameters and total system performance for the KX P&T system during 2011. Over the year, the KX system processed groundwater at an average pumping rate of approximately 1,744 L/min (461 gpm). The system operated nearly 100 percent of the time (Figure 3-21).

The average influent hexavalent chromium concentration for 2011 was 37 µg/L compared to 47.6 µg/L for 2010, a decrease of about 21 percent. Influent concentrations from late May to the end of September were about 10 µg/L lower than spring and fall concentrations (Figure 3-22).

The maximum reported concentration of hexavalent chromium in the effluent during 2011 was 10 µg/L. The average effluent concentration for the year was 3.4 µg/L, which is higher than the average effluent concentration of 2.8 µg/L reported for 2010. The following additional operational and system parameters for the KX P&T system are for 2011:

- In total, 900.6 million L (240 million gal) of groundwater were treated, and approximately 30.1 kg of hexavalent chromium were removed.
- The mass removal efficiency was 91 percent, which is slightly lower than the 94 percent mass removal efficiency reported for 2010 and is a direct result of the KX P&T system having an effect in reducing the influent concentration to the treatment system (Figure 3-23).

- The scheduled system availability was 98.8 percent, which is slightly lower than the system availability of 99.2 percent reported in 2010. The total availability was 98.3 percent, which is slightly higher than the online availability of 96.8 percent reported in 2010.

Table 3-12 presents the pumping flow rates and total run-time for the extraction and injection wells currently active in the KX P&T system. Except where noted, the recommended flow rates are based on updated numerical modeling results that were prepared to support the second CERCLA 5-year review design modification. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. All of the wells were subject to downtime because of equipment failures, and/or maintenance. This downtime is reflected in the yearly average flow rate calculations and the total run-time percentages for the individual extraction wells.

#### *3.3.3.3 KX P&T System Capture Zone Analysis*

Figure 3-6 illustrates the composite capture zone produced by the KX P&T system well field. The extent and projected capture efficiency of the composite KX system capture zone were developed using high-frequency mapping of the water table during the 2011 operating conditions. The KX hexavalent chromium plume for 2011 was located entirely within that part of the KX system capture predicted to have capture efficiencies between 80 and 100 percent. The extent and capture efficiency of the KX system composite capture zone under currently proposed operating conditions is consistent with effective remediation of the K North plume (as currently defined) and achievement of interim groundwater RAOs. A slight reduction in capture zone efficiency to 80 to 90 percent is noted for the small KE plume.

#### *3.3.3.4 KX P&T System Compliance Monitoring*

The remedial performance of the KX P&T system has been evaluated using the 2009 through 2011 hexavalent chromium data presented in Table 3-4 and long-term concentration trend plots (Figure 3-24) for the 13 extraction wells for the KX P&T system and associated monitoring wells, including compliance monitoring/extraction wells 199-K-130, 199-K-131, 199-K-146, 199-K-147, 199-K-148, and 199-K-161 (Figure 3-24).

Most of the KX system extraction wells are currently used to capture and remediate the plume area between the northern end of the 116-K-2 Trench and the N Reactor fence line (i.e., K North plume). Former extraction wells 199-K-149 and 199-K-150 were most northeastern extraction wells in the KX system well field (Figures 3-5 and 3-24). Hexavalent chromium concentrations in these wells have decreased from approximately 80 µg/L in late 2008 to below detection limits in fall 2011. The decrease in concentrations observed in both wells likely reflects upgradient aquifer cleanup, as well as partial capture and recirculation of treated effluent from injection wells 199-K-159 and 199-K-160 (located 150 to 200 m [492 to 656 ft] cross-gradient to the northeast) and possibly from injection well 199-K-164 (located 430 m [1,411 ft] upgradient) (Figure 3-5). The hexavalent chromium concentrations obtained for fall 2010 in wells 199-K-149 and 199-K-150 bound the northern boundary of the northeastern lobe of the K North plume.

Extraction wells 199-K-131, 199-K-148, 199-K-130, and 199-K-147 are located progressively further to the southwest. These well locations extend across the northeastern plume lobe of the K North plume, approximately 152 to 183 m (500 to 600 ft) upgradient from, and roughly parallel to, the Columbia River shoreline (Figure 3-24). The concentrations in these wells have steadily decreased since system startup but still retain concentrations above 30 µg/L. Upgradient monitoring wells 199-K-152 (converted to an extraction well in 2011) and 199-K-151 have demonstrated very different concentration trends since startup of the KX P&T system. Well 199-K-152 is located in the core of the northeastern plume lobe. The concentrations in this well have steadily declined from approximately 80 µg/L in mid-2008 to

approximately 70 µg/L in late 2011 (Table 3-4 and Figure 3-24). Monitoring well 199-K-151 is located 230 m (755 ft) northeast/cross-gradient of monitoring well 199-K-152. In September 2008, prior to system startup, the concentration of hexavalent chromium in this well was 75.5 µg/L. After start up, the concentrations in monitoring well 199-K-151 rapidly declined, reaching approximately 20 µg/L by early 2009. Concentrations continued to decline and by fall 2011, the hexavalent chromium concentration in this well was below the detection limit. Monitoring well 199-K-151 currently defines the northern upgradient extent of the K North plume.

Chromium concentrations at well 199-K-182, the farthest upgradient of wells in this plume segment, ranged between 74 and 81 µg/L in 2010 (samples were not collected in fall 2011). The plume is unbounded upgradient of this well. New RI well 199-N-189 was installed in 2011 north of well 199-K-182. Sampling during drilling detected hexavalent chromium concentrations of 35 µg/L at the water table. This data point is not directly comparable to the other sample points, however, because the sample was collected during drilling and prior to well development. Additional monitoring of this well will be needed to substantiate the value. Well 199-N-74, 2 km (1.2 miles) from the end of the trench and farther north than 199-N-189, has hexavalent chromium concentrations near 30 µg/L. The contamination in both locations may result from the 100-KR-3 plume at the 116-K-2 Trench migrating northward. The detection of hexavalent chromium in wells 199-N-189 and 199-N-74 indicates that the plume extends farther to the northeast than previously thought.

The concentration trends described for extraction wells 199-K-131, 199-K-148, 199-K-130, and 199-K-147 and the monitoring wells suggest that injection of large volumes of treated effluent in injection wells 199-K-159, 199-K-160, and 199-K-164 (Figure 3-5) has shifted the northeastern lobe of the K North plume further to the southwest. The potential to optimize remediation of the northeastern plume lobe by modifying the amount of groundwater injected (either more or less) into wells 199-K-159, 199-K-160, and 199-K-164 should be evaluated. For example, injection of less water into wells 199-K-159, 199-K-160, and 199-K-164 may optimize this process.

Other KX system extraction wells 199-K-146, 199-K-161, 199-K-153, 199-K-154, and 199-K-163 are located in the southwestern plume lobe of the K North plume (Figure 3-24). Extraction wells 199-K-146 and 199-K-161 are closer to the river than wells 199-K-153, 199-K-154, and 199-K-163. Between the fall of 2009 and 2011, the hexavalent chromium concentrations in these two wells decreased from 44.8 to 9 µg/L and from 85.9 to 6 µg/L, respectively. In conjunction with nearby KR4 system extraction wells 199-K-114A and 199-K-113A, these two downgradient KX system extraction wells appear to have reduced hexavalent chromium concentrations near the river in this area to below 10 µg/L (Figure 3-5). The concentrations in extraction wells 199-K-154 and 199-K-163 were above 100 µg/L in late 2008. Since system startup, however, concentrations in wells 199-K-154 and 199-K-163 had declined to 27 and 35 µg/L, respectively, by fall 2011. The considerable decline of the concentrations in these extraction wells suggests that a considerable mass of hexavalent chromium has been removed upgradient of these wells.

Monitoring wells 199-K-22 and 199-K-37 are located between upgradient extraction wells 199-K-154 and 199-K-163 and downgradient extraction wells 199-K-146 and 199-K-161. The hexavalent chromium concentrations in well 199-K-22 have decreased to 52 µg/L in 2011, from 120 µg/L in 2009. It appears that the contaminant levels in this well are being reduced by the upgradient extraction wells. At monitoring well 199-K-37, cross-gradient of the high-concentration area defined by monitoring well 199-K-22, concentrations were approximately 80 µg/L in 2004 and declined very little until mid-2009. Perhaps as a result of the startup of the KX extraction system, concentrations decreased relatively quickly beginning in mid-2009, reaching 16.2 µg/L in late 2011. If this trend is maintained in

2012, the remediated area located downgradient may soon extend upgradient to the vicinity of monitoring well 199-K-37.

Two KX system extraction wells, 199-K-178 and 199-K-141, are operating in the area of the KE Reactor area plume. Extraction well 199-K-178 was installed relatively recently, and all available data were collected after 2008. The concentrations in this well decreased from 117 µg/L in 2009 to 24 µg/L in fall 2011 (Table 3-6). Data for well 199-K-141 (as a monitoring well) are available as far back as 2007, and a high value of approximately 450 µg/L was noted in January 2009 (Figure 3-24). After KX P&T system startup, the hexavalent chromium concentrations in this new extraction well decreased rapidly to 24 µg/L by fall 2011.

## 3.4 Summary of RI/FS Results

The highlights of the RI/FS characterization activity conducted at the 100-KR-4 OU are as follows:

- The highest hexavalent chromium concentrations were found at well 199-K-195 during discrete depth sampling, where a 3 m (10 ft) thickness of aquifer detected hexavalent chromium concentrations at 1,900 to 4,900 µg/L in the upper aquifer. A concentration of 753 µg/L was also identified at one zone deep in the unconfined aquifer, with intermediate zones where hexavalent chromium was not detected.
- Hexavalent chromium concentrations above the WAC 173-340 standard (48 µg/L) were detected at wells 199-K-184 and 199-K-192. Concentrations in temporary well 199-K-201 were as high as 125 µg/L in 2011.
- One of four wells drilled 15.2 m (50 ft) into the RUM encountered a water-bearing zone, with mostly nondetects for contaminants of interest.
- Tritium was encountered at concentrations of 36,000 to 1.4 million pCi/L in the upper 12.2 m (40 ft) of the aquifer at well 199-K-192. At well 199-K-189, tritium concentrations of 86,000 to 140,000 pCi/L were found within the upper 7.6 m (25 ft) of the aquifer. All other wells were below the 20,000 pCi/L DWS.
- Carbon-14 was found at well 199-K-185 at concentrations of 1,600 to 2,390 pCi/L in the upper 6.1 m (20 ft) of the aquifer. Where carbon-14 was present at concentrations approaching 50 percent of the 2,000 pCi/L DWS, as in wells 199-K-184, 199-K-189, and 199-K-195, it was found in the upper half of the aquifer.
- Strontium-90 was found in the aquifer above the 8 pCi/L DWS in temporary well 199-K-200 at concentrations up to 251 pCi/L. Concentrations of strontium-90 were also detected above the DWS in well 199-K-192 (19 pCi/L) and temporary well 199-K-201 (18 pCi/L).
- Nitrate above the 45,000 µg/L DWS was found at wells 199-K-185 (116,000 µg/L maximum), 199-K-190 (54,000 µg/L), 199-K-191 (76,600 µg/L), and 199-K-192 (56,200 µg/L). Concentrations were the highest across the upper aquifer in all wells and diminished with depth at many wells.
- Trichloroethene is found primarily at wells associated with the KW Reactor area. Wells 199-K-184 (8.1 µg/L) and 199-K-185 (6.5 µg/L) exceeded the 5 µg/L DWS, and trichloroethene was detected in most sample intervals at these two wells. Trichloroethene is present at concentrations below the DWS in wells 199-K-183, 199-K-186 (at the bottom of the aquifer), 199-K-188 (one detection at 1.5 µg/L), 199-K-190 (up to 1.6 µg/L), and 199-K-195 (several detections, up to 3.7 µg/L).

## 3.5 Conclusions

The current status of the 100-KR-4 OU illustrates that remedial progress has been achieved for the plume areas associated with each of the three P&T systems currently active within this OU. The following conclusions for the OU are based on each of the RAOs:

- **RAO 1:** Protect aquatic receptors in the river bottom substrate from contaminants in the groundwater entering the Columbia River.

  **Results:**

  - Capture zone analysis suggests that operation of the three P&T systems, under the recommended 2011 operating conditions, results in capture efficiency between 90 and 100 percent for most of the hexavalent chromium plumes in the 100-KR-4 OU.
  - Based on the aquifer tube data for 2011, the extent of hexavalent chromium discharged to the Columbia River within the 100-KR-4 OU appears to have decreased in response to P&T activities except downgradient of the head end on the 116-K-2 Trench, the KR4 plume.
  - The P&T systems at the 100-KR-4 OU have removed significant amounts of hexavalent chromium from the unconfined aquifer. In total, the systems have removed an estimated 632 kg of hexavalent chromium from the shallow, unconfined aquifer.
  - The KR4 P&T system has removed a substantial mass of hexavalent chromium from the plume zones located along the 116-K-2 Trench. Between September 1997 and December 31, 2011, the KR4 system extracted and treated approximately 5.72 billion L (1.51 billion gal) of groundwater, resulting in removal of 354.9 kg of hexavalent chromium from the aquifer. As a result of remediation activities, the hexavalent chromium concentrations in 22 of 29 monitoring and extraction wells sampled near the 116-K-2 Trench area declined or remained below detection limits between fall 2010 and fall 2011. Wells displaying increases were characterized by concentrations less than 10 µg/L.
  - The KR4 P&T system has largely attained the RAO for river protection along the central portion of the 116-K-2 Trench area. Fall 2011 hexavalent chromium concentrations were less than 10 µg/L in monitoring wells and extraction wells. Elevated hexavalent chromium concentrations remain in plume areas located at either end of the 116-K-2 Trench (i.e., KR4 plume and the southern portion of the K North plume).
  - Hexavalent chromium concentrations remained elevated at former compliance monitoring well 199-K-18, (located in the KR4 plume) for the first half of 2011 before declining to 64 µg/L. This decrease may have resulted from changes in groundwater flow dynamics due to nearby downgradient KR4 system extraction wells (e.g., 199-K-145 and 199-K-162) that are accelerating the downgradient transport of more highly contaminated groundwater originally located further upgradient in this plume.
  - The KW system started up in January 2007. As of December 31, 2011, the system extracted approximately 1.4 billion L (372.4 million gal) of groundwater and removed an estimated 163.1 kg of hexavalent chromium. Long-term trends for hexavalent chromium in the monitoring network for the KW plume suggest that this system is rapidly reducing the remaining mass of this plume.

- The KX P&T system was designed to treat the K North hexavalent chromium plume, located between the northern end of the 116-K-2 Trench and the N Reactor fence line. Two KX extraction wells were added to remediate the small KE plume. The KX system began partial operation in November 2008 and became fully operational in early February 2009. Since system startup, more than 2.59 billion L (685.2 million gal) of water have been treated, and approximately 114 kg of hexavalent chromium have been removed. Although the system has been operating a relatively short time, the data collected during 2011 and the capture zone analysis suggest that this system should intercept the majority of the K North plume before it can discharge to the Columbia River. Hexavalent chromium concentrations decreased from 2009 to 2011 in 11 of 12 monitoring and extraction wells.

- RPO extraction wells (199-K-196, 199-K-198, and199-K-199) were drilled in 2011. Well 199-K-198 and 199-K-199 will be added to the KR4 P&T system to capture hexavalent chromium closer to the river in the river mixing zone. Well 199-K-196 will serve as an extraction well for the KW P&T system. The well is necessary to determine hexavalent chromium stratification or deep occurrence near the river and to provide improved capture deeper in the aquifer.

- One monitoring well, 199-K-197, was drilled in 2011 to monitor contamination levels and the amount of drawdown induced by adjacent extraction wells. This will provide hydrologic information to the hydrologic model and will contribute to knowledge of the effectiveness of the extraction well in capturing contamination.

- The ratio of hexavalent chromium mass to the unit volume of groundwater treated at the 14-year-old KR4 system is diminishing as the hexavalent chromium plume associated with the 116-K-2 Trench is cleaned up. A “tailing effect” such as this is typical for P&T systems as they mature. This conclusion is based on observed trend of declining in hexavalent chromium concentrations in the treatment system influent and at extraction wells to below aquatic standards (in some instances). Both the KW and KX systems generally retain higher ratios of hexavalent chromium per unit volume of groundwater treated, but decreasing concentrations are observed seasonally, and some extraction wells have been taken offline as concentrations temporarily or permanently drop below 10 µg/L. Current extraction well layouts in the vicinity of the two KR4 plumes are successfully reducing concentrations at known hot spots at the ends of the 116-K-2 Trench. The operation of extraction wells in the center of the former plume, where hexavalent chromium concentrations are now below 10 µg/L, reduces the influent concentrations and efficiency of chromium removal by the IX resins.

For other key plumes in the 100-KR-4 OU during 2011, the results are as follows:

- Tritium activities below the 20,000 pCi/L DWS are widespread across the 100-KR-4 OU. Activities above the DWS are confined to plumes that appear to be derived from the 118-K-1 Burial Ground and the 116-KE-1 gas condensate crib.

- Strontium-90 near the 116-K-2 Trench has generally been attributed to discharges of cooling water associated with failed fuel rods. The maximum activity of strontium-90 near the 116-K-2 Trench during 2011 was 251 pCi/L in new RI well 199-K-200. This hot spot located on the head end of the 116-K-2 trench confirms that strontium-90 in this area is derived from the 116-K-2 Trench.

- Carbon-14 in groundwater is closely associated with the 116-KE-1 and 116-KW-1 gas condensate cribs and is present above the 2,000 pCi/L DWS at wells downgradient of the two cribs. The maximum fall 2011carbon-14 concentration in an aquifer tube was 314 pCi/L in C6247 located along the shoreline downgradient of the KE reactor.

- **RAO 2:** Protect human health by preventing exposure to contaminants in groundwater.

  The interim remedial action ROD (EPA/ROD/R10-96/134) establishes a variety of ICs that must be implemented and maintained throughout the interim action period. These provisions include the following:

  - Access control and visitor escorting requirements
  - Signage providing visual identification and warning of hazardous or sensitive areas
  - Excavation permit process to control all intrusive work (e.g., well drilling and soil excavation)
  - Regulatory agency notification of any trespassing incidents

  The effectiveness of ICs is presented in DOE/RL-2004-56. The findings of this annual report indicate that ICs were maintained to prevent public access, as required.

- **RAO 3:** Provide information that will lead to a final remedy.

  **Results:**

  - An RI/FS is being conducted to support the final ROD for the 100-K Area. Characterization activities began in 2009, as described in the RI/FS work plan addendum (DOE/RL-2008-46-ADD1) and implemented through the SAP (DOE/RL-2009-40). Fifteen new RI/FS wells and four RPO wells will provide geologic and hydrologic data to improve the CSM for the 100-KR-4 OU. The data will also improve numerical modeling predictions of contaminant fate and transport simulations and also capture zone analysis. The complete data set from these investigations will be fully evaluated and reported in the 100-K RI/FS report (DOE/RL-2010-97), scheduled for submittal later in 2012, which will lead to the selection of alternatives for final cleanup action.

  - Preliminary RI results indicate that the CSM for the 100-KR-4 OU remains the same. Most of the hexavalent chromium is already contained in the groundwater. Therefore, the interim remedy P&T systems will capture and treat residual hexavalent chromium.

## 3.6 Recommendations

Recommendations for the 100-KR-4 OU are as follows:

- Four Phase 3 RPO wells were drilled in 2011. Complete the realignment of wells 199-K-196, 199-K-198, and 199-K-199 with the existing P&T systems to increase capture efficiency.

- Evaluate improvements to the monitoring program, including placement of additional wells, to provide indication for future well realignments for containment of hexavalent chromium and co-contaminant from reaching the Columbia River.

- Monitoring wells 199-K-29 and 199-K-30 (downgradient of the 116-KE-1 gas condensate crib) and well 199-K-109A (downgradient of the KE Basin) were decommissioned in December 2010 following sampling and borehole logging. The wells were used to monitor carbon-14 and tritium concentration trends in these areas. The installation of replacement wells should be considered for

wells 199-K-109A, 199-K-29, and 199-K-30 to provide sufficient monitoring coverage of these mobile radionuclides.

- Complete connection of converted extraction well 199-K-182 to the KX P&T system to treat this area where hexavalent chromium concentrations at the well is above 50 µg/L.
- One to two additional monitoring wells will be needed inland to the southeast and southwest of well 199-K-182 to bound the hexavalent chromium plume near the 100-NR-2 OU.
- The hexavalent chromium observed in groundwater in the inland portion of 100-N Area should be evaluated to assess the need for remedial action in that area and to determine the most appropriate response in the event that a response is needed.
- New wells are needed to replace those removed due to building/facility demolition and waste site remediation. Wells lost or expected to be lost to surface remediation include former injection well 199-K-35 and RI well 199-K-195 at the 183.1-KW Headhouse, as well as monitoring well 199-K-36 and RI well 199-K-188, following remediation at the 183.1-KE Headhouse and 183.2 sedimentation basin. Implement recommendations from the 100-KW P&T SIR-700 process test report (SGW-51721) to use SIR-700 at the 100-KR-4 OU P&T systems.
- Evaluate the effectiveness of the 100-K Area P&T systems with respect to the 2012 TPA (Ecology et al., 1989) Milestone M-016-110-TO1 target criteria. Groundwater concentration trends and hydraulic head data should be used with capture zone analysis and additional modeling to maximize the treatment capacity of existing P&T systems.

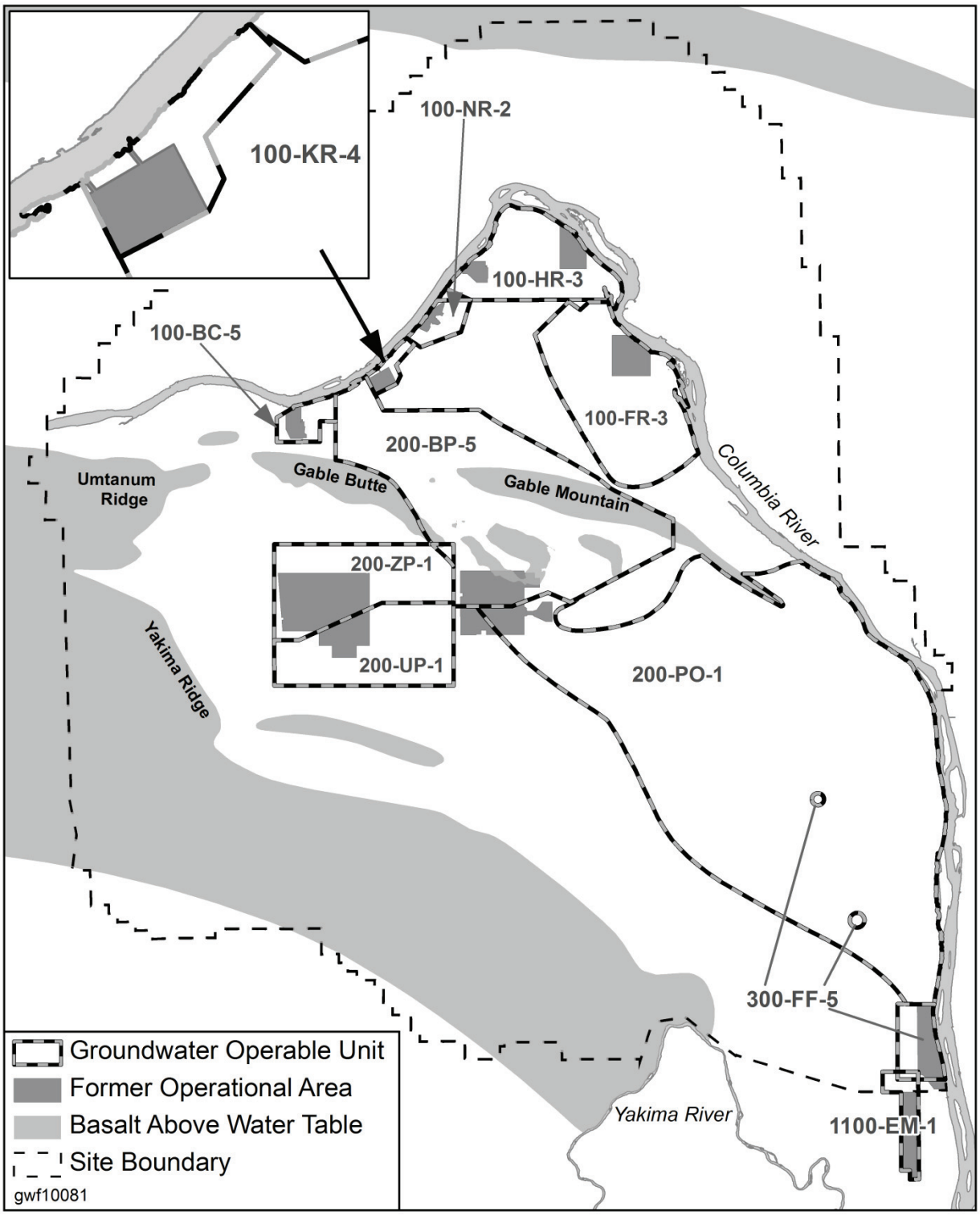


**Figure 3-1. Location of the Hanford Site and the 100-KR-4 OU**

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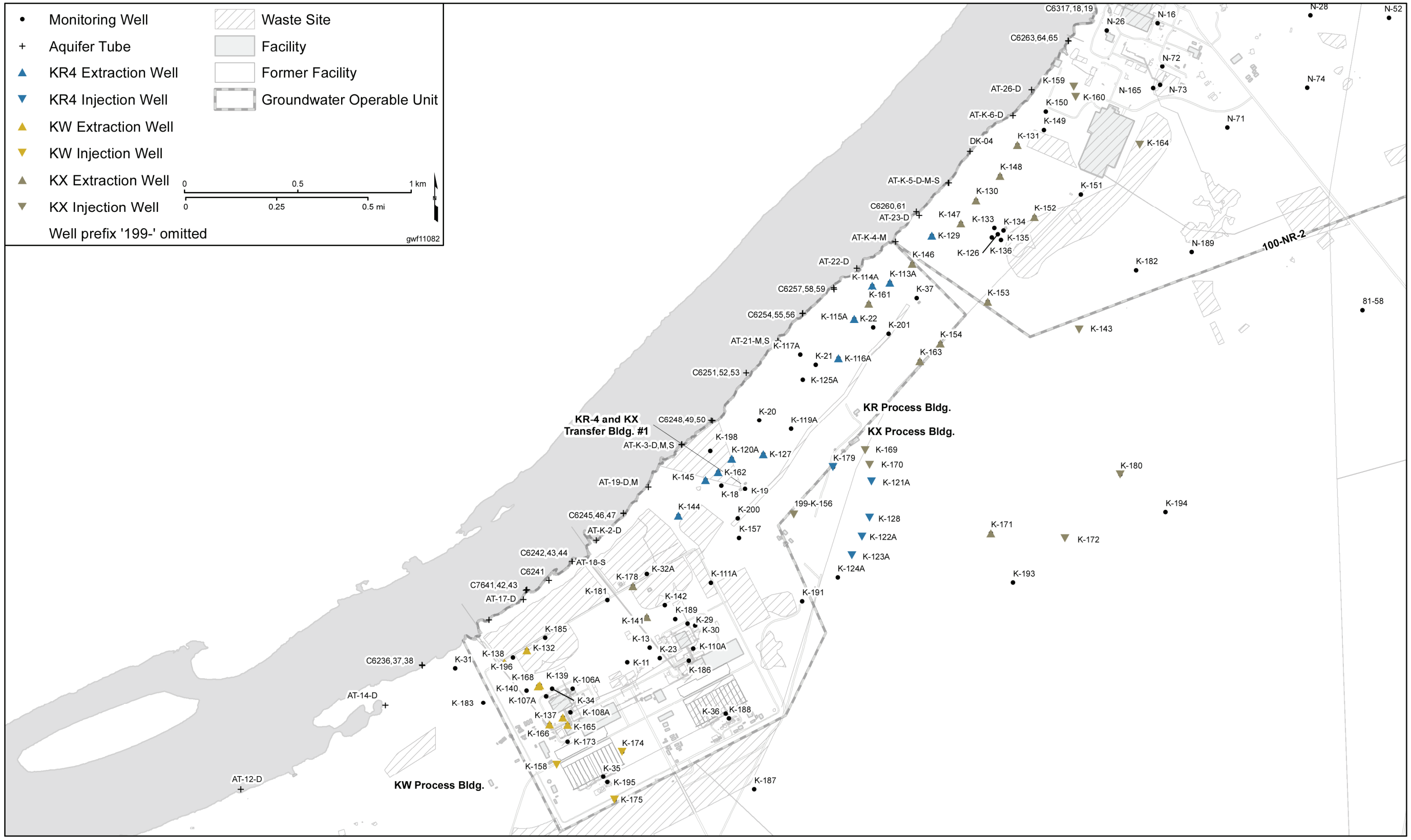


**Figure 3-2. 100-KR-4 OU Wells and Aquifer Sampling Tubes**

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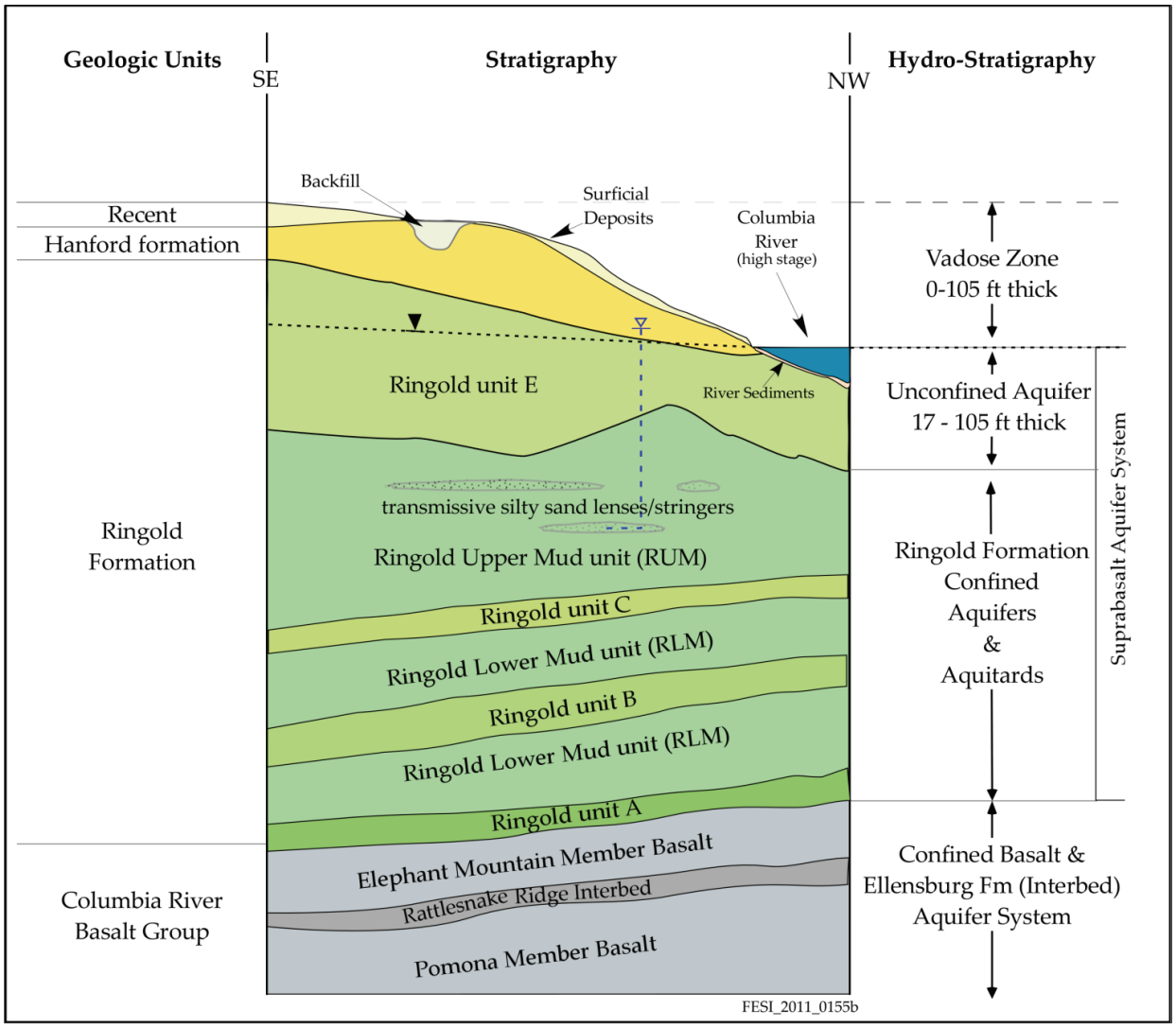
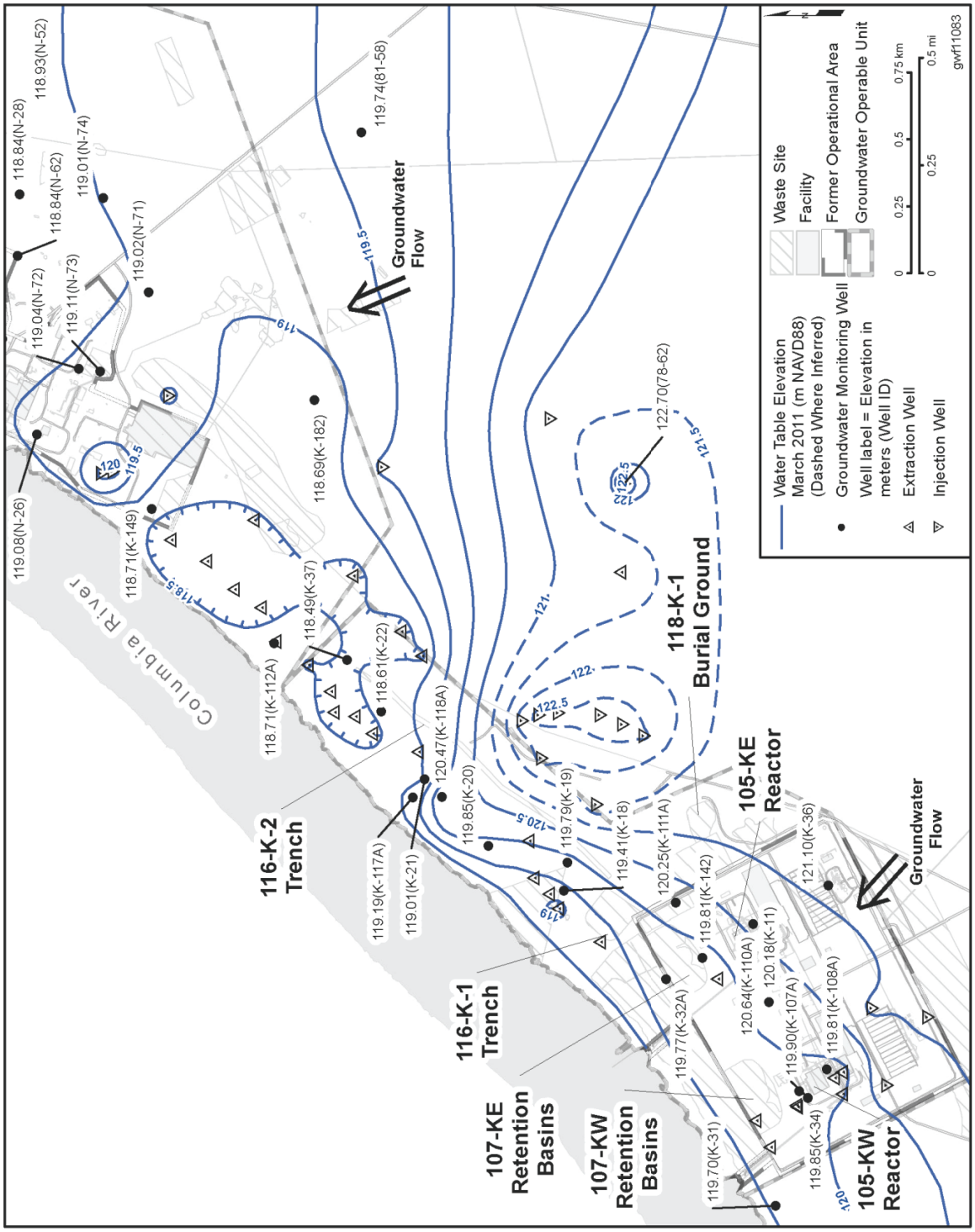



**Figure 3-3. Generalized Stratigraphic Column at 100-KR-4 OU**




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

**Figure 3-4. Water Table Map, March 2011**

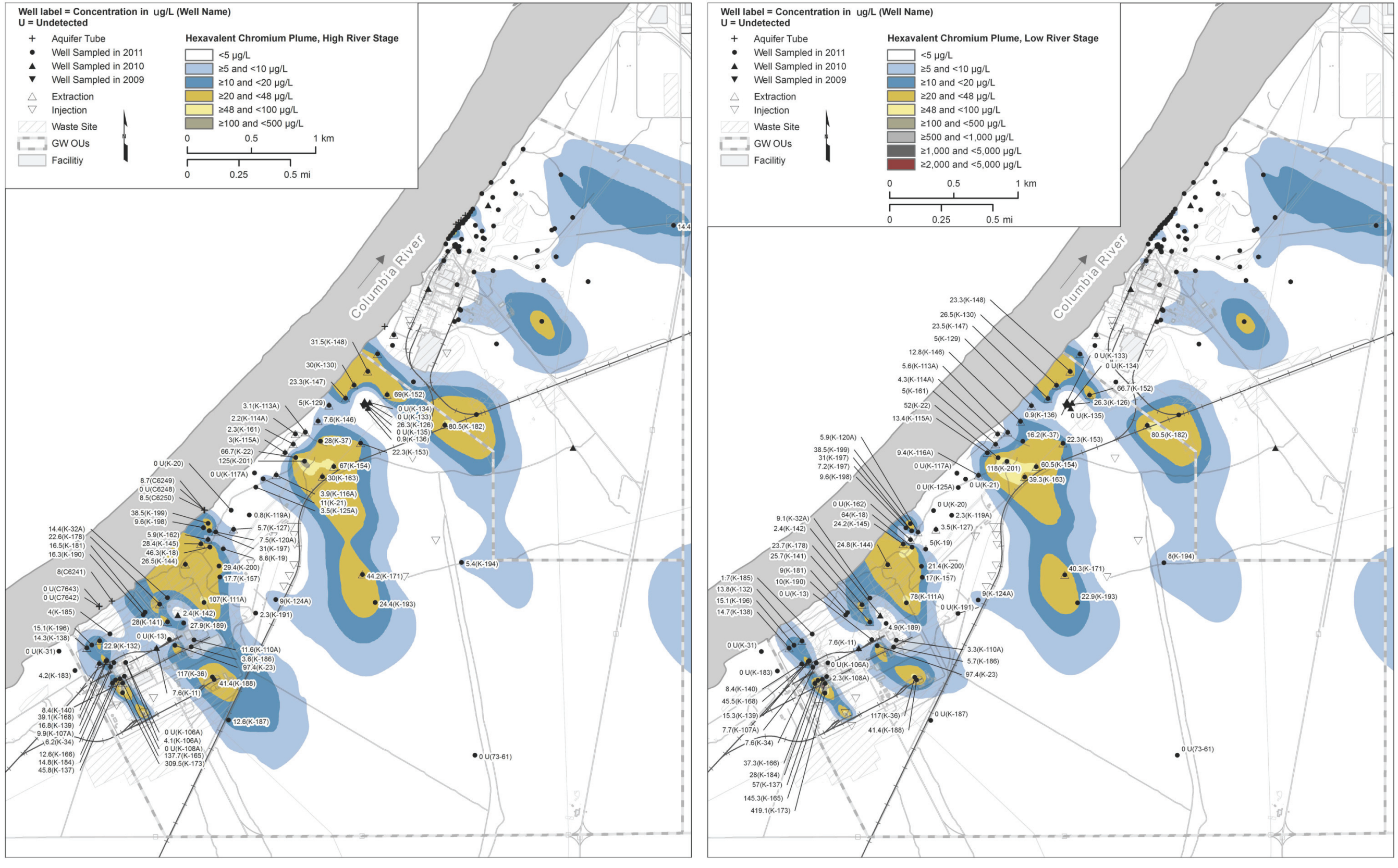



**Figure 3-5. CY 2011 Spring and Fall Hexavalent Chromium Plume Maps**

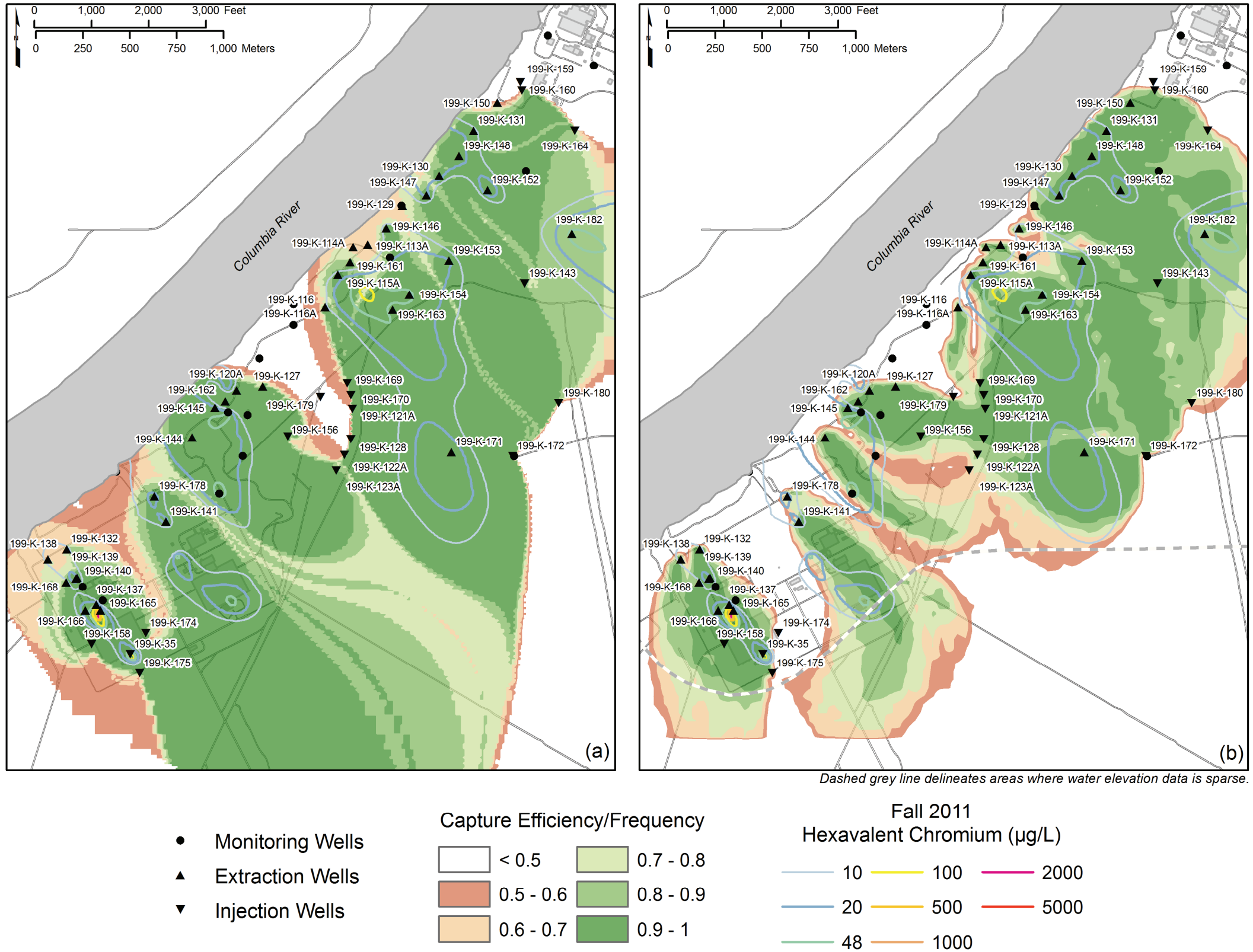
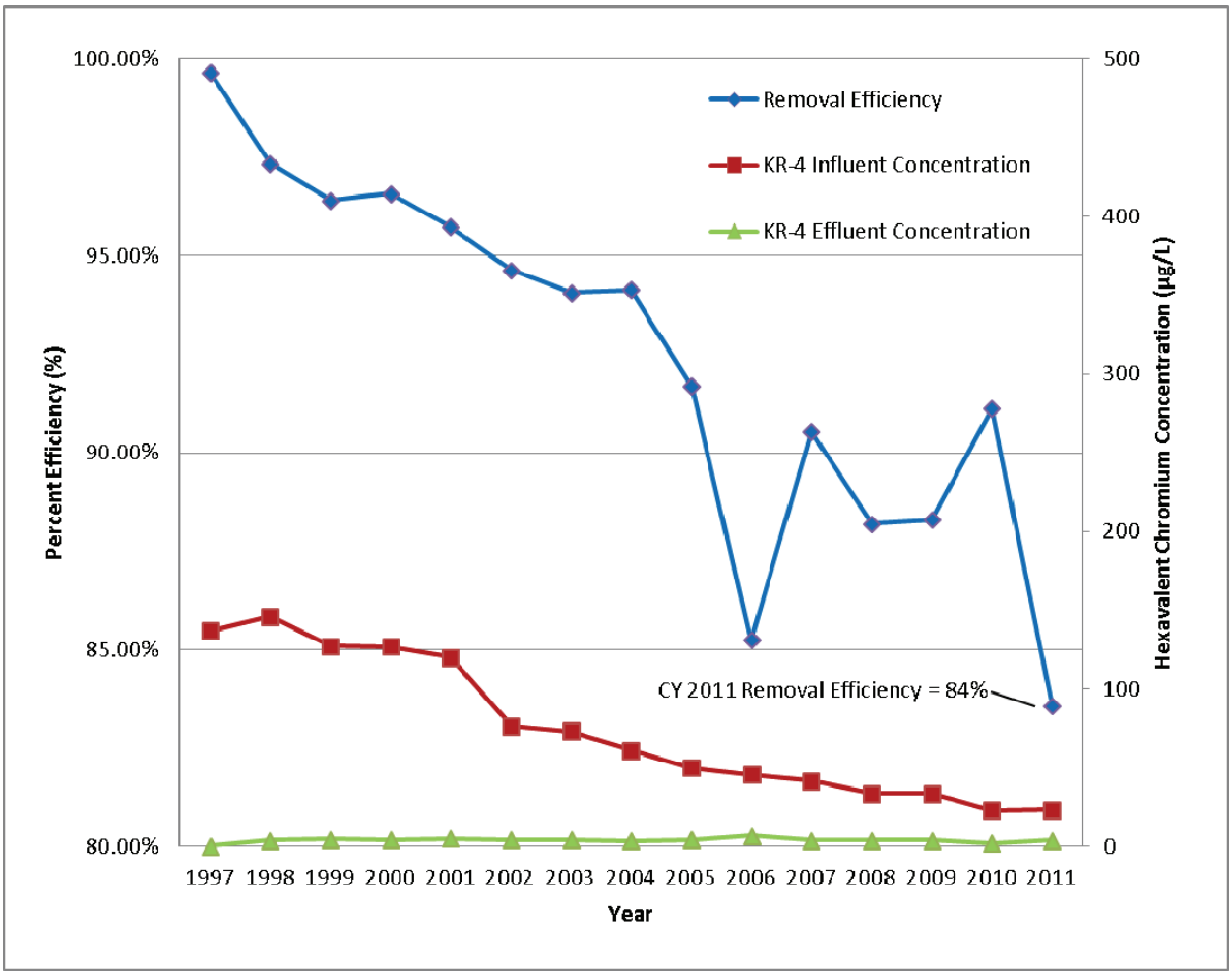



**Figure 3-6. Composite Capture Zone Efficiency/Frequency Maps for the 100-KR-4 OU**




Note: Average removal efficiency (% by mass) = [(influent – effluent) ÷ influent].

**Figure 3-7. KR4 P&T System Average Removal Efficiencies**

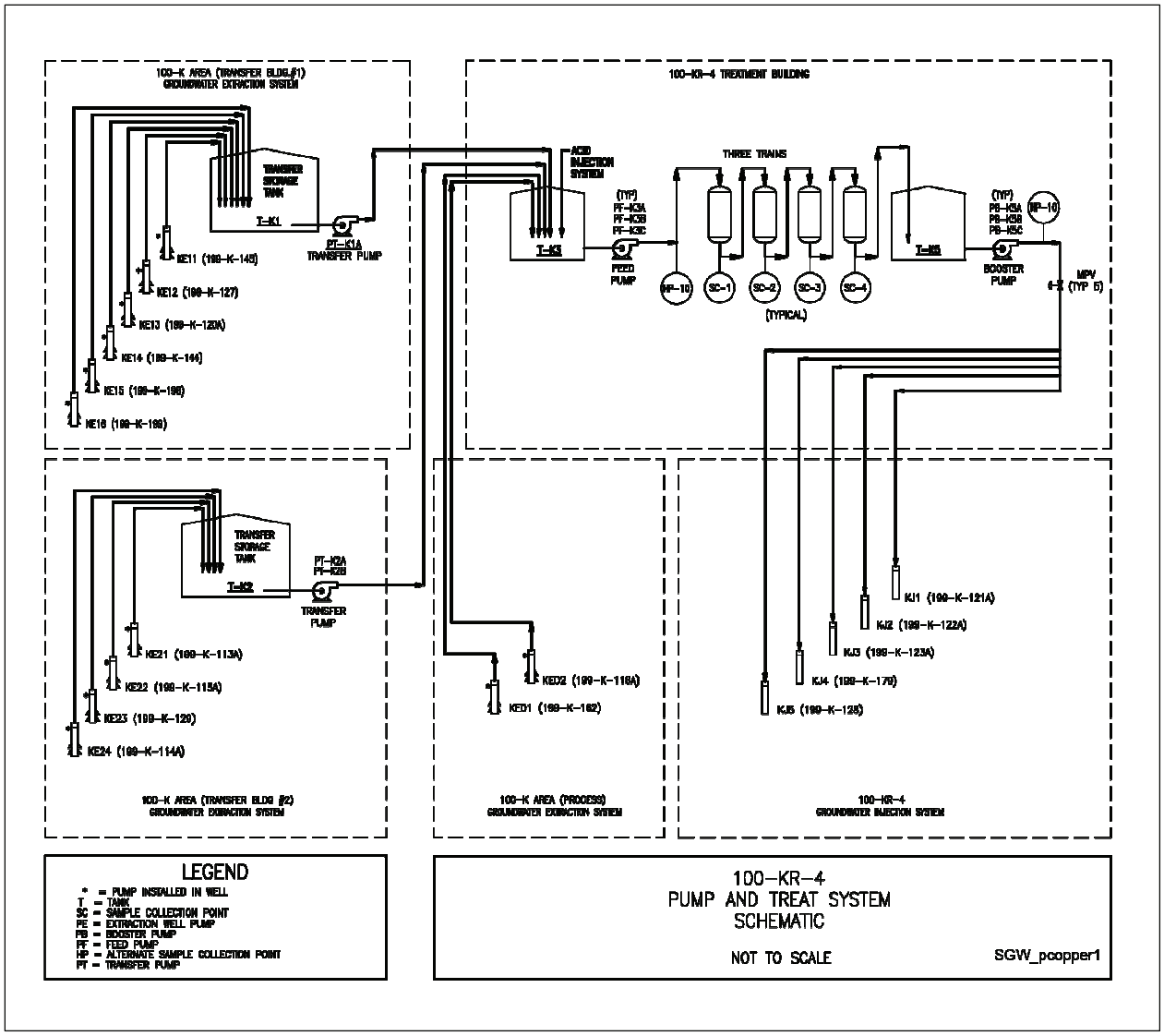



**Figure 3-8. KR4 P&T System Schematic**

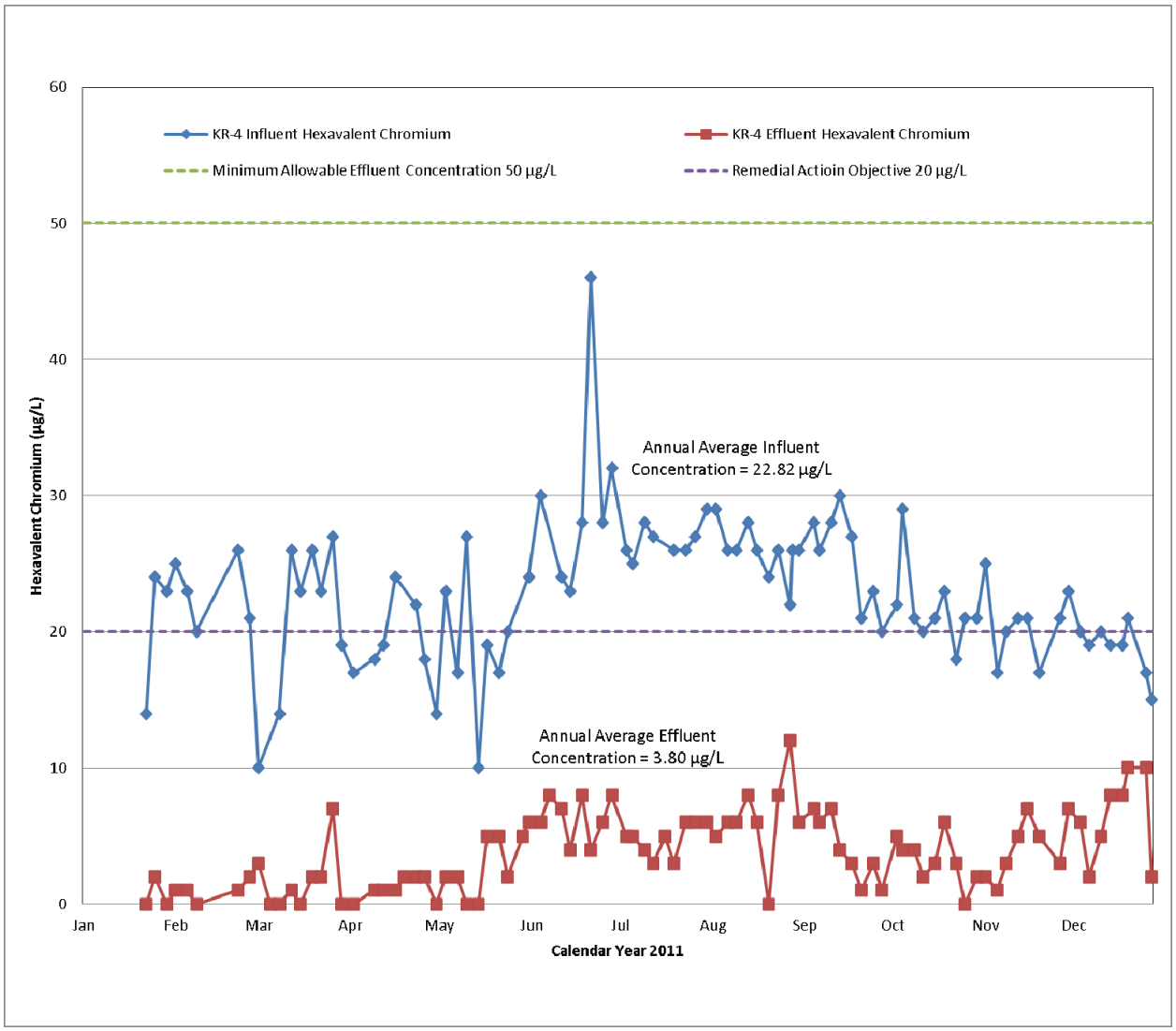



**Figure 3-9. KR4 P&T System Trends of Influent and Effluent Hexavalent Chromium Concentrations, CY 2011**

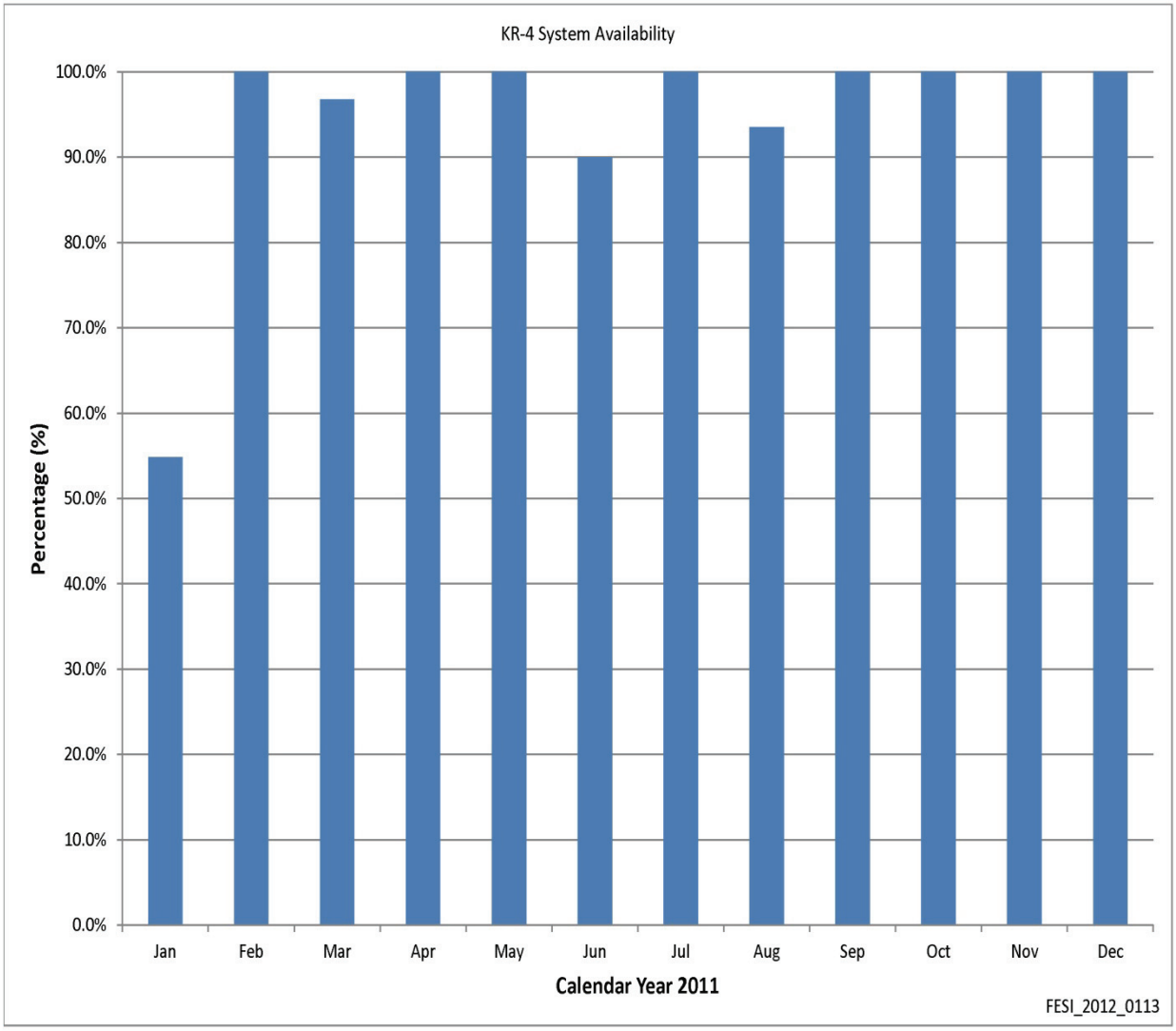



**Figure 3-10. Monthly Online Availability for KR4 P&T System, CY 2011**

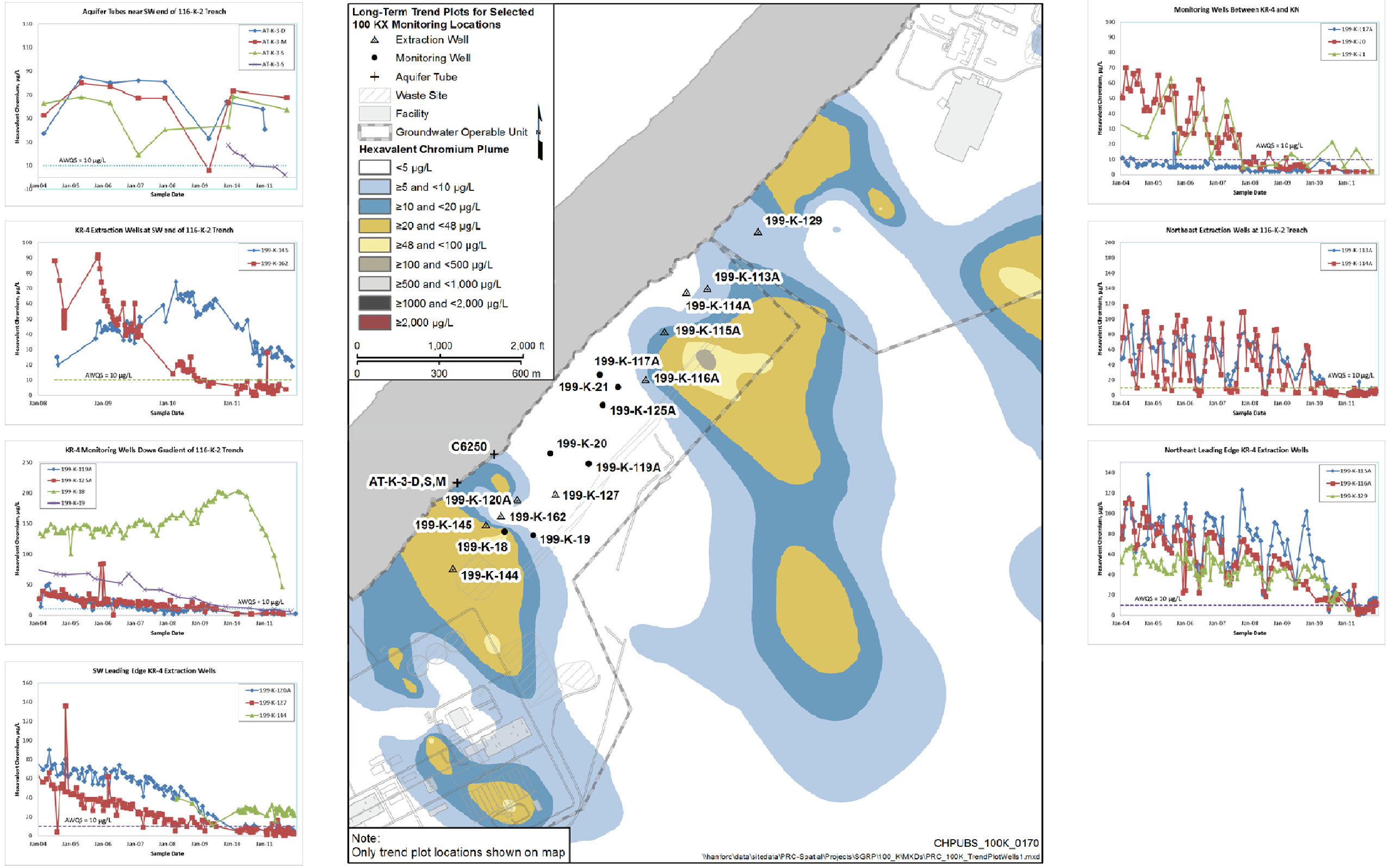



**Figure 3-11. 2011 Hexavalent Chromium Concentration Trend Plots for Selected 100-KR-4 OU Monitoring Locations**

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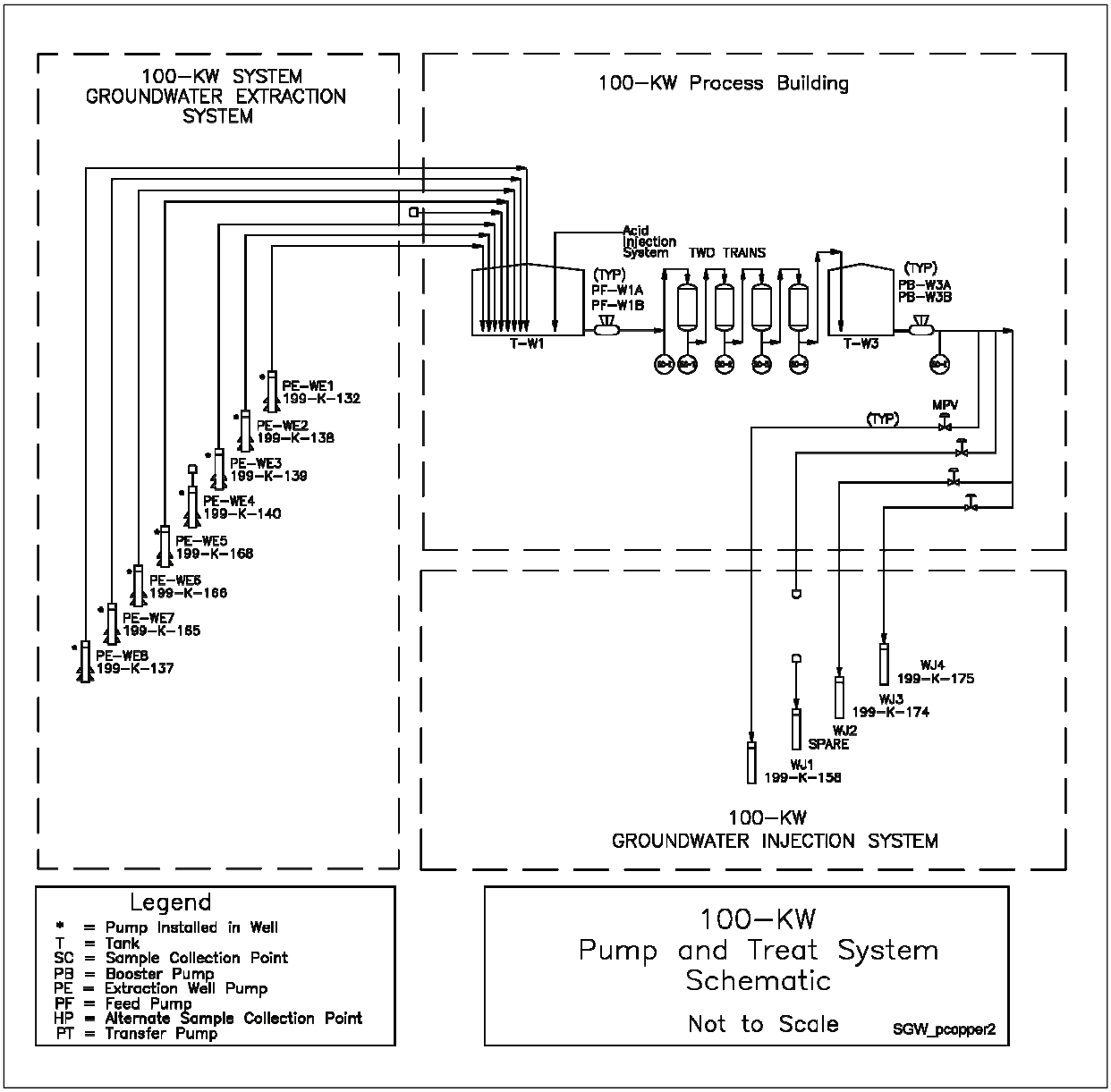



**Figure 3-12. KW Reactor Area P&T System Schematic**

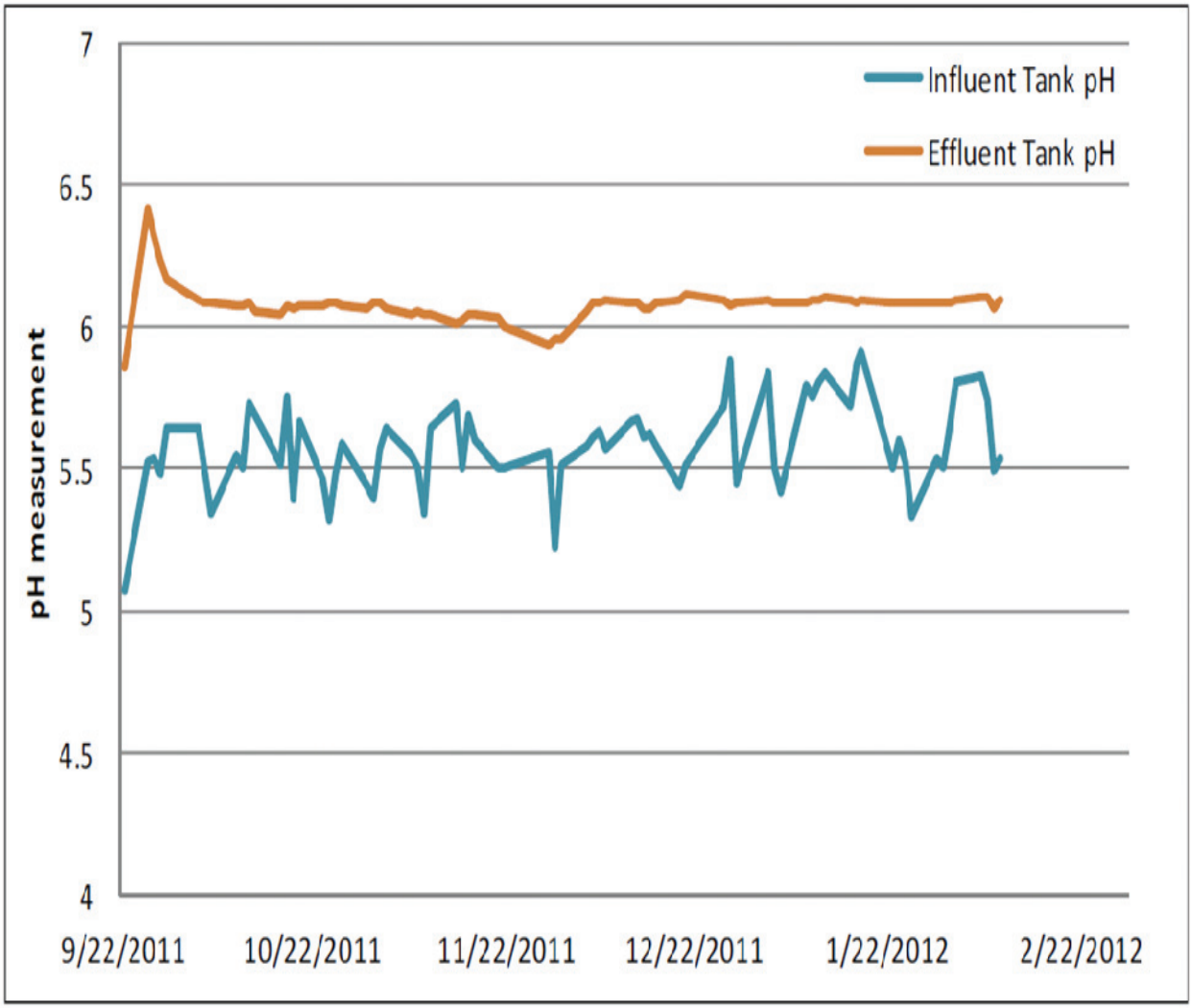



**Figure 3-13. KW Influent and Effluent Tank pH Trends through SIR-700 Process Test**

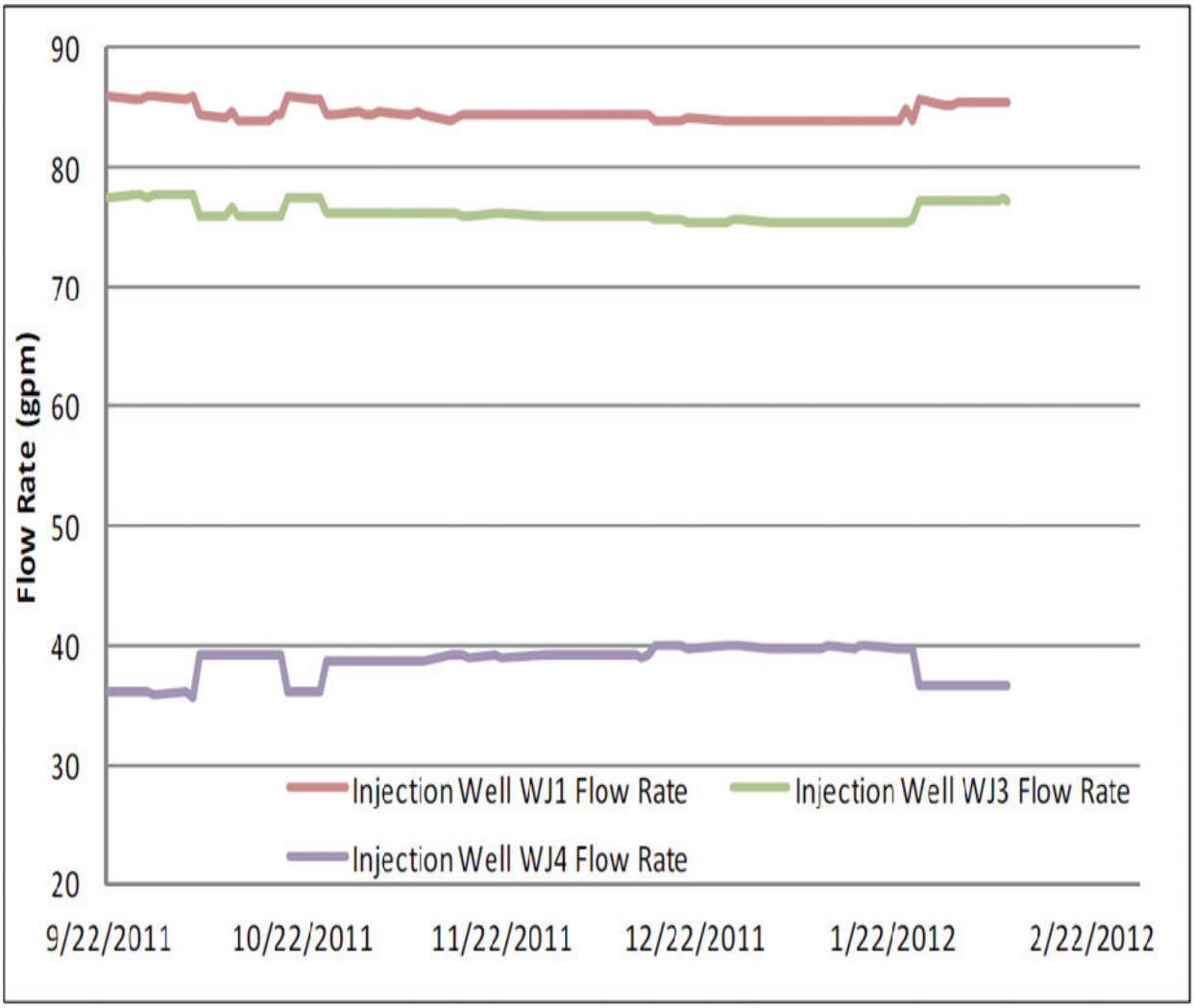



**Figure 3-14. KW Injection Well Flow Rates through SIR-700 Process Test**

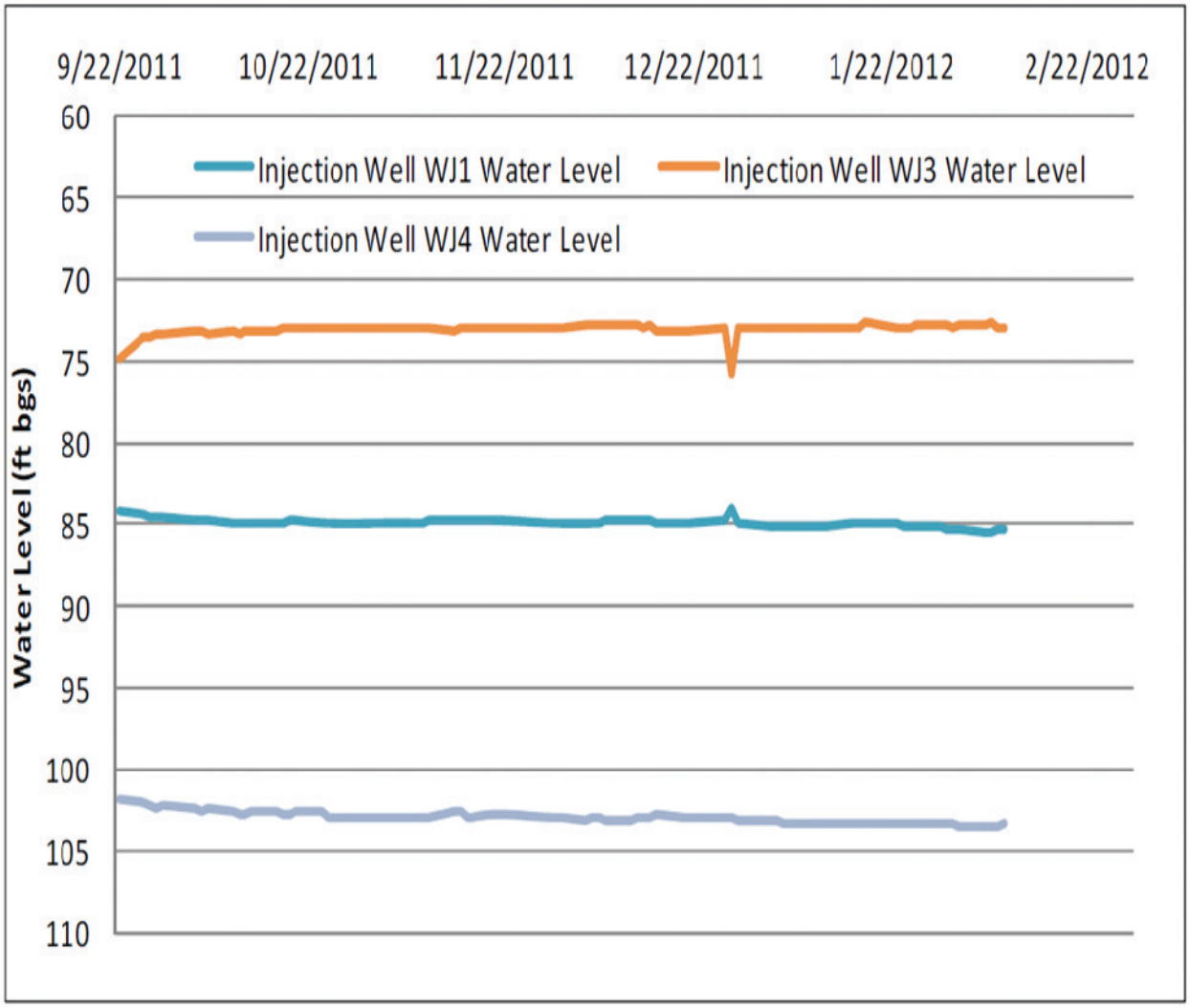



**Figure 3-15. KW Injection Well Water Levels (ft bgs) through SIR-700 Process Test**

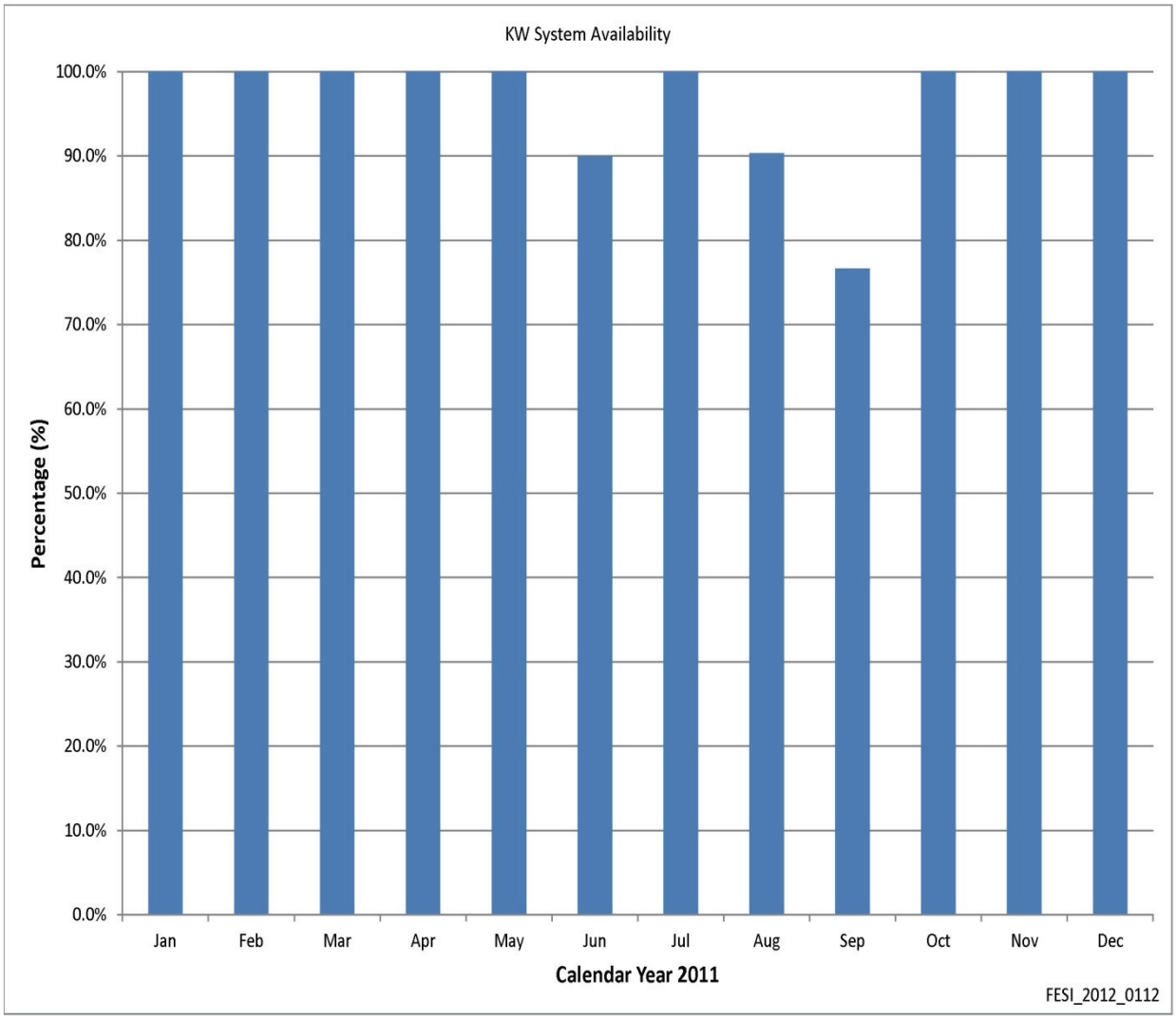



**Figure 3-16. Monthly Online Availability for KW P&T System, CY 2011**

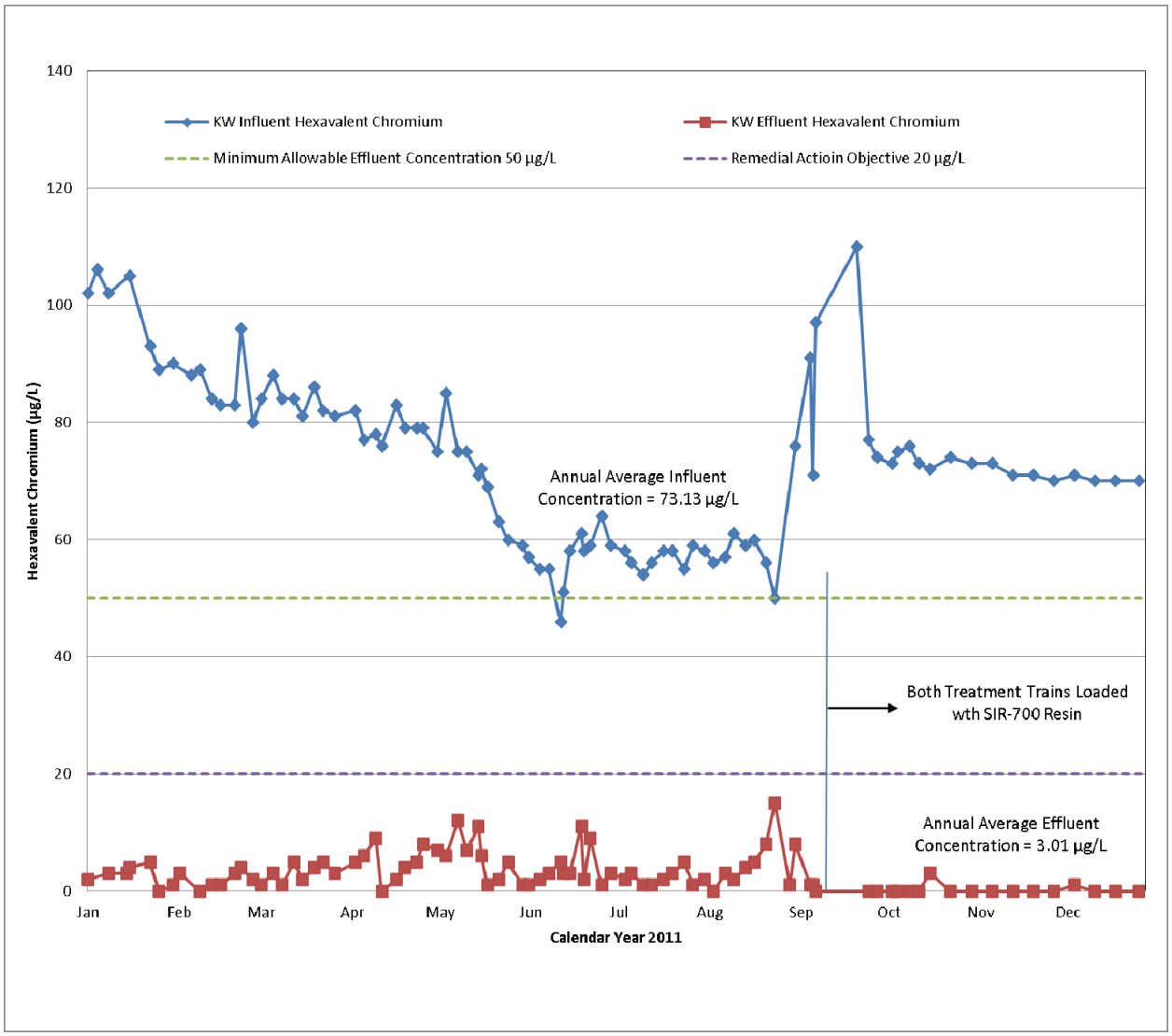
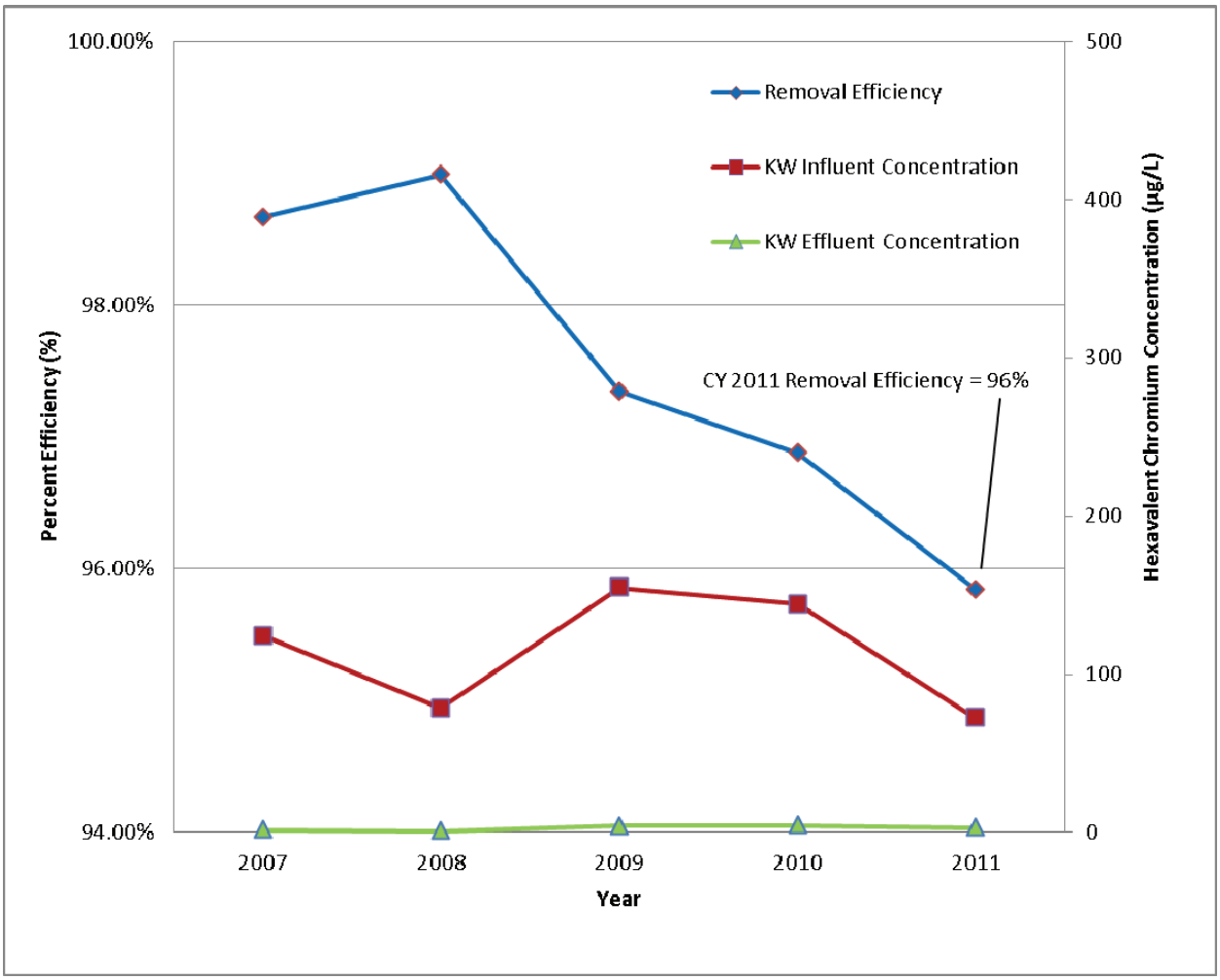



**Figure 3-17. KW P&T Trends of Influent and Effluent Hexavalent Chromium Concentrations, CY 2011**




Note: Average removal efficiency (% by mass) = [(influent – effluent) ÷ influent].

**Figure 3-18. KW P&T System Average Removal Efficiencies**

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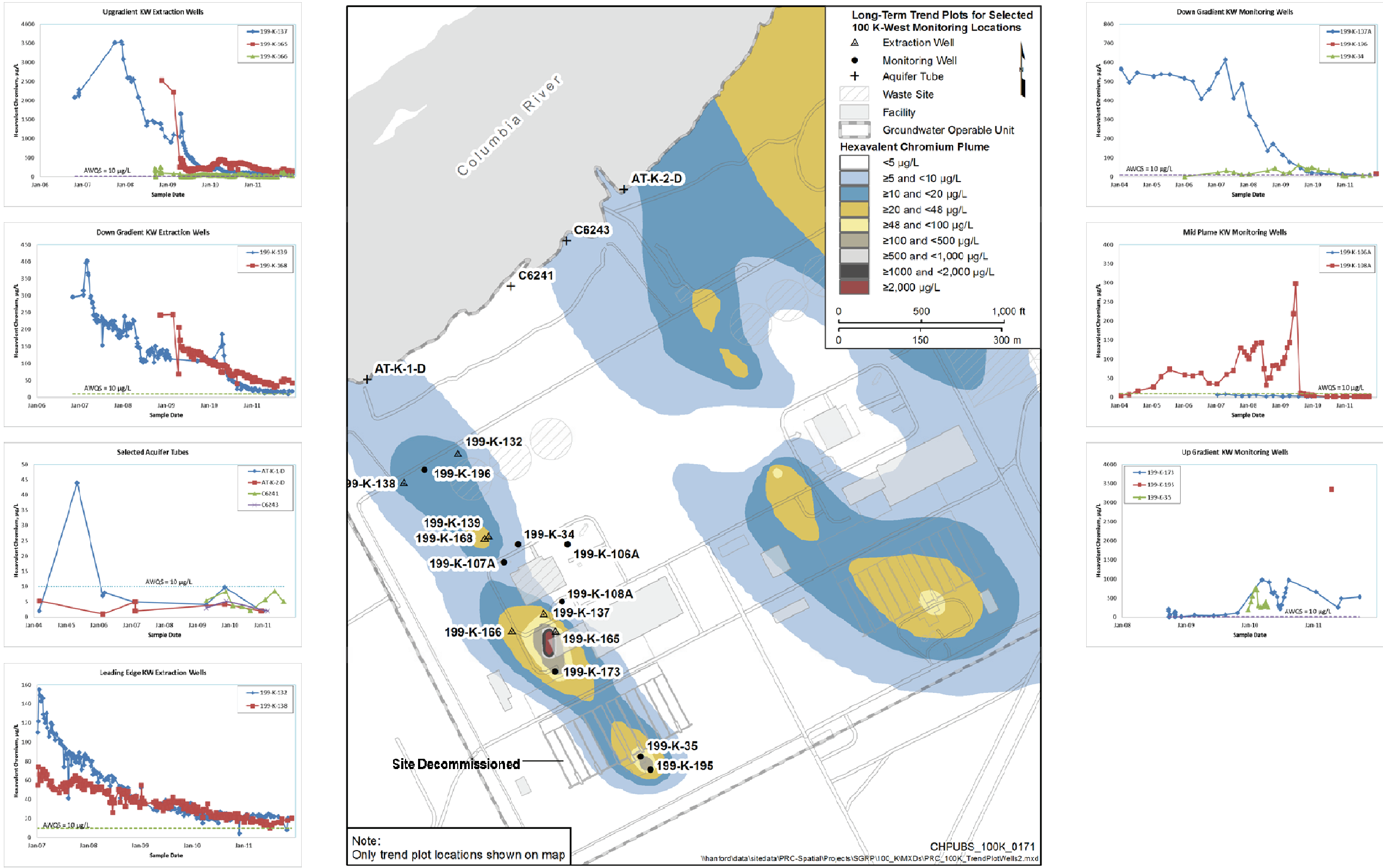


**Figure 3-19. 2011 Hexavalent Chromium Concentration Trend Plots for Selected KW Reactor Area Monitoring Locations**

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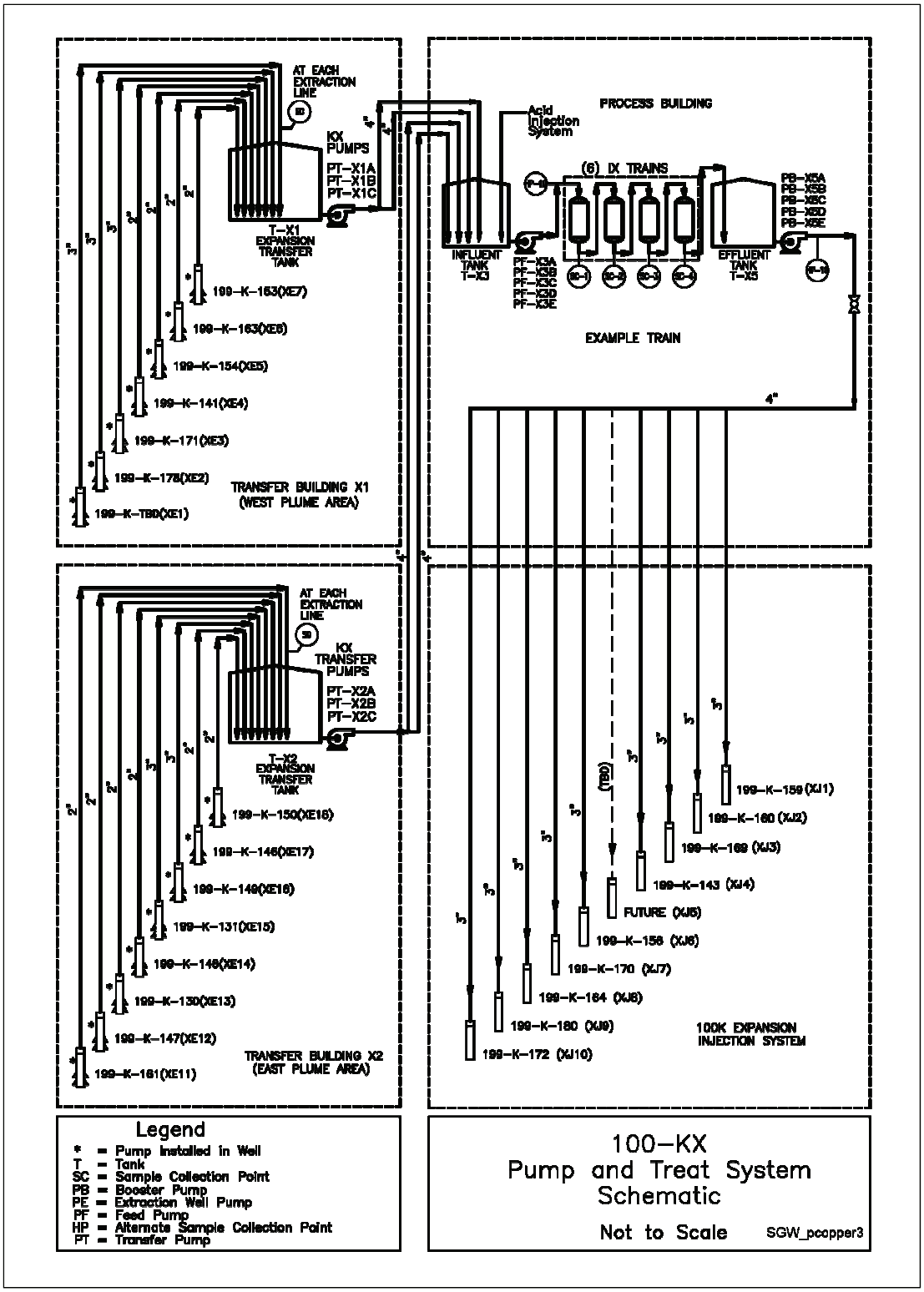



**Figure 3-20. KX P&T System Schematic**

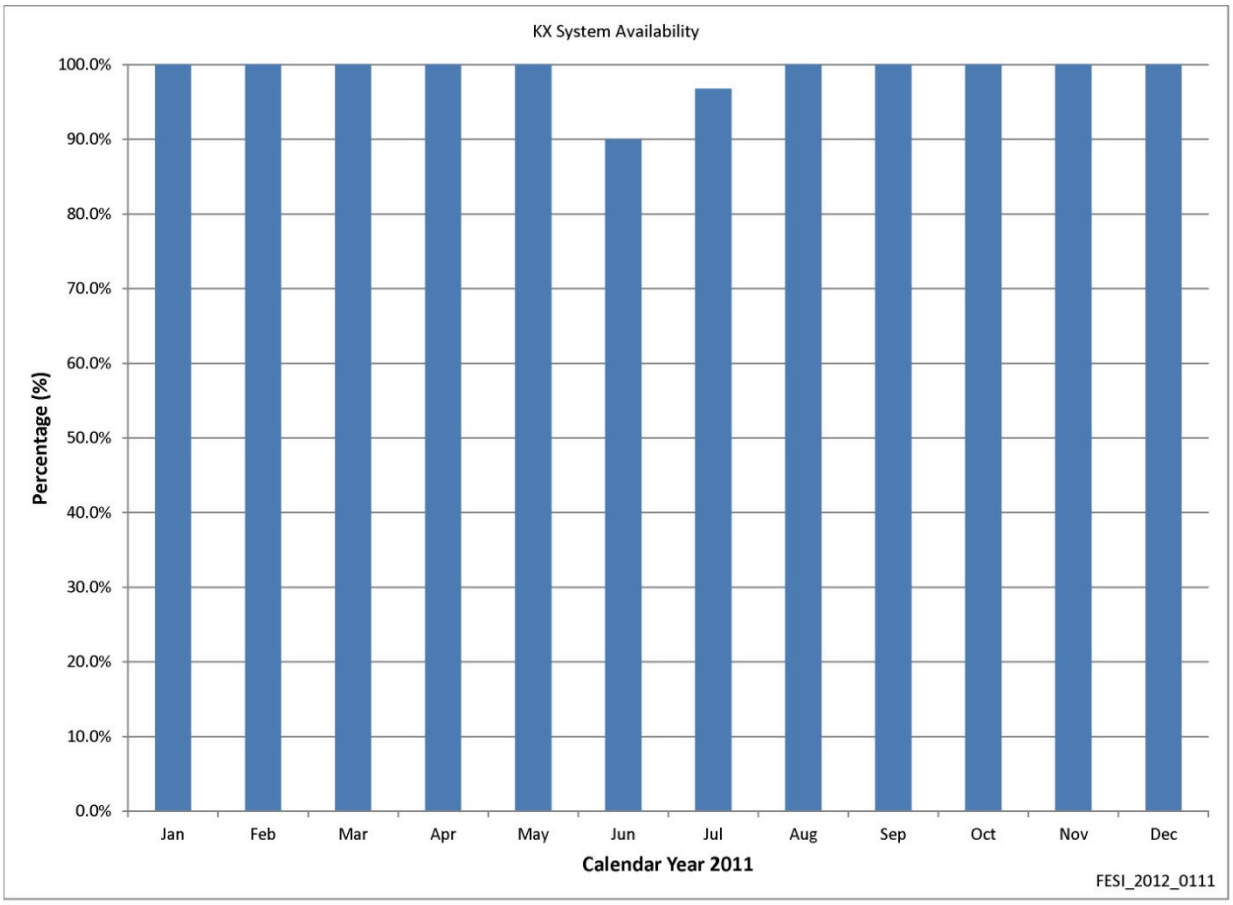



**Figure 3-21. Monthly KX P&T System Availability, CY 2011**

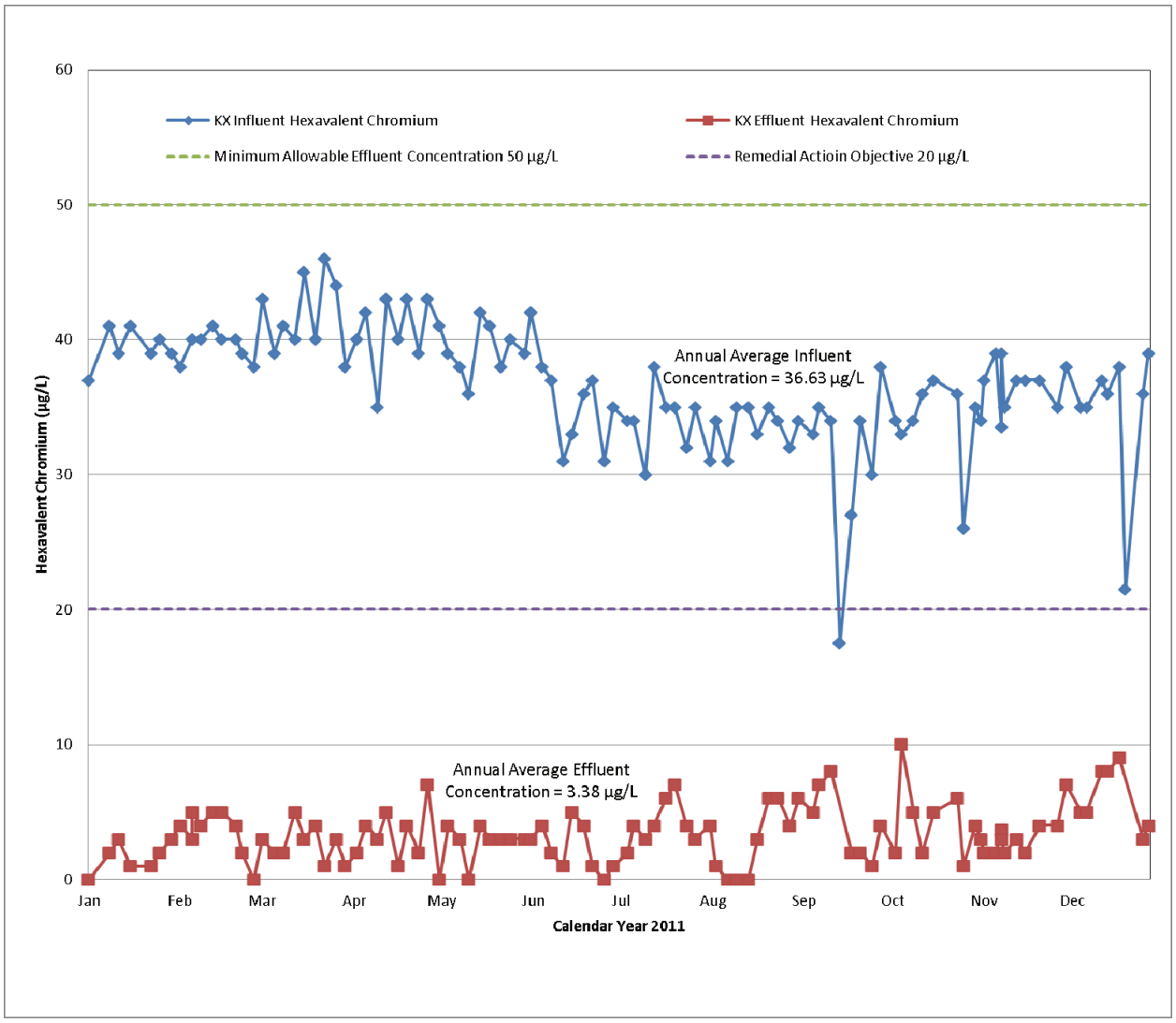
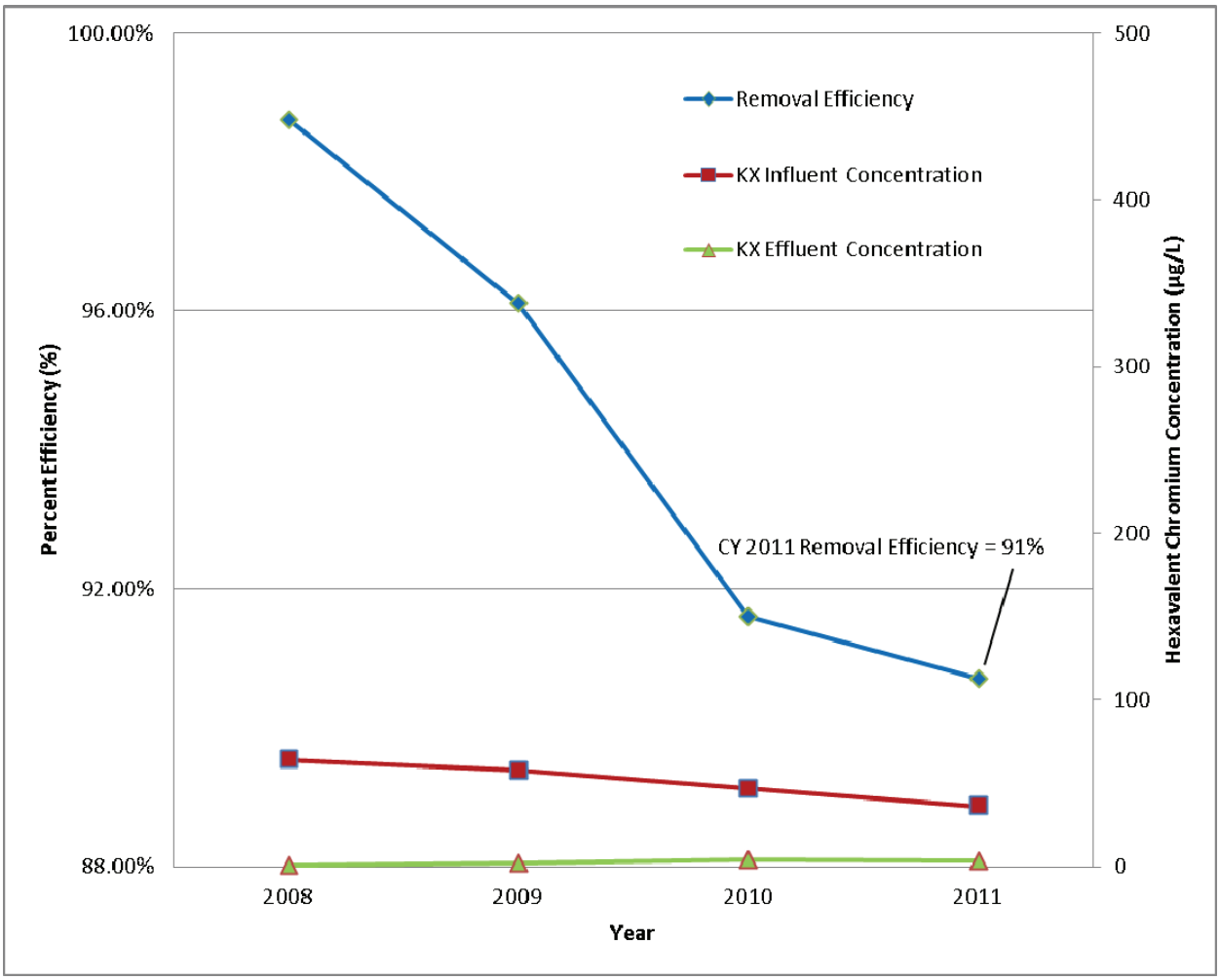



**Figure 3-22. KX P&T System Trends of Influent and Effluent Hexavalent Chromium Concentrations, CY 2011**




Note: Average removal efficiency (% by mass) = [(influent – effluent)/influent].

**Figure 3-23. KX P&T System Average Removal Efficiencies**

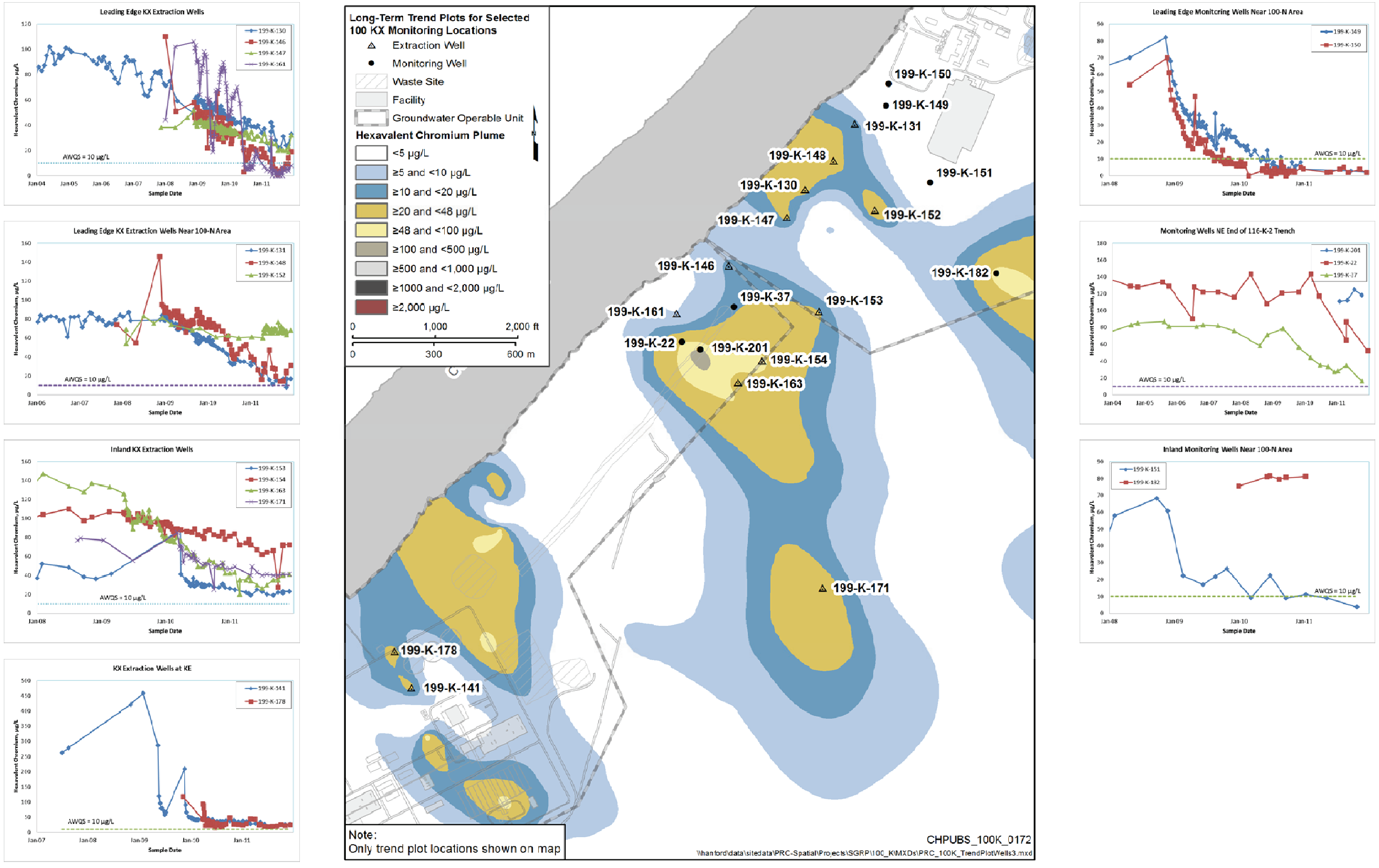



**Figure 3-24. 2010 Hexavalent Chromium Concentration Trend Plots for Selected KX P&T System Monitoring Locations**

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**Table 3-1. Maximum Contaminant and Co-Contaminant Concentrations for 116-K-2 Trench Area (KR4 and K North Plumes) 2010 and 2011**

| Constituent | Maximum Value Detected (µg/L) or (pCi/L) | Filtered (F) or Unfiltered (UF) | Date Sampled | Well Name |
|---|---|---|---|---|
| **2010** | | | | |
| Hexavalent Chromium | 203 | F | 3/5/10 | 199-K-18 |
| Hexavalent Chromium | 201 | UF | 3/5/10 | 199-K-18 |
| Strontium-90 | 17 | UF | 12/3/10 | 199-K-21 |
| Tritium | 230,000 | UF | 12/8/10 | 199-K-18 |
| Carbon-14 | 23.4 | UF | 3/5/10 | 199-K-18 |
| Nitrate | 76,600 | UF | 3/5/10 | 199-K-18 |
| Trichloroethene | 0.18 (U) | UF | 6/11/10 | 199-K-18 |
| **2011** | | | | |
| Hexavalent Chromium | 131 | F | 1/20/11 | 199-K-18 |
| Hexavalent Chromium | 128 | UF | 1/20/11 | 199-K-18 |
| Strontium-90 | 251 | UF | 10/11/11 | 199-K-200 |
| Tritium | 290,000 | UF | 11/9/11 | 199-K-18 |
| Carbon-14 | 40.4 | UF | 10/24/11 | 199-K-150 |
| Nitrate | 43,400 | UF | 10/24/11 | 199-K-18 |
| Trichloroethene | Trichloroethene analyses not performed | | | |

**Table 3-2. Maximum Contaminant and Co-Contaminant Concentrations for 100-KW Area 2010 and 2011**

| Constituent | Maximum Value Detected (µg/L) or (pCi/L) | Filtered (F) or Unfiltered (UF) | Date Sampled | Well Name |
|---|---|---|---|---|
| **2010** | | | | |
| Hexavalent Chromium | 968 | UF | 8/12/10 | 199-K-173 |
| Hexavalent Chromium | 966 | F | 8/12/10 | 199-K-173 |
| Strontium-90 | 45 | UF | 12/7/10 | 199-K-34 |
| Tritium | 7,500 | UF | 11/22/10 | 199-K-132 |
| Carbon-14 | 3,880 | UF | 6/30/10 | 199-K-34 |
| Nitrate | 84,600 | UF | 6/13/10 | 199-K-106A |
| Trichloroethene | 7.4 | UF | 6/13/10 | 199-K-106A |
| **2011** | | | | |
| Hexavalent Chromium | 659 | UF | 1/13/11 | 199-K-173 |
| Hexavalent Chromium | 649 | F | 1/13/11 | 199-K-173 |
| Strontium-90 | 50 | UF | 1/5/11 | 199-K-34 |
| Tritium | 3,700 | UF | 10/31/11 | 199-K-132 |
| Carbon-14 | 11,500 | UF | 10/10/11 | 199-K-106A |
| Nitrate | 97,400 | UF | 5/31/11 | 199-K-106A |
| Trichloroethene | 8.1 | UF | 1/6/11 | 199-K-184 |

**Table 3-3. Maximum Contaminant and Co-Contaminant Concentrations for 100-KE Area 2010 and 2011**

| Constituent | Maximum Value Detected (µg/L) or (pCi/L) | Filtered (F) or Unfiltered (UF) | Date Sampled | Well Name |
|---|---|---|---|---|
| **2010** | | | | |
| Hexavalent Chromium | 93 | UF | 3/29/10 | 199-K-178 |
| Hexavalent Chromium | 89.1 | F | 4/1/10 | 199-K-178 |
| Strontium-90 | 4.4 | UF | 12/3/10 | 199-K-32A |
| Tritium | 280,000 | UF | 1/14/10 | 199-K-30 |
| Carbon-14 | 6,900 | UF | 4/6/10 | 199-K-30 |
| Nitrate | 60,600 | UF | 1/14/10 | 199-K-30 |
| Trichloroethene | 1.6 | UF | 8/16/10 | 199-K-190 |
| **2011** | | | | |
| Hexavalent Chromium | 97.4 | UF | 10/10/11 | 199-K-23 |
| Hexavalent Chromium | 34 | F | 2/17/11 | 199-K-141 |
| Strontium-90 | 17.8 | UF | 9/27/11 | 199-K-141 |
| Tritium | 8,400 | UF | 1/5/11 | 199-K-141 |
| Carbon-14 | 743 | UF | 9/12/11 | 199-K-189 |
| Nitrate | 46,500 | UF | 10/10/11 | 199-K-23 |
| Trichloroethene | 4.3 | UF | 7/20/11 | 199-K-190 |

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-18 | C | 10/22/09 | 192 | 12/8/10 | 139 | 10/24/11 | 64 | 66.6 | 54.0 |
| 199-K-19 | P | 10/18/09 | 13.7 | 12/3/10 | 7.3 | 10/27/11 | 5 | 63.5 | 31.5 |
| 199-K-20 | C | 10/28/09 | 2.3 (B) | -- | -- | 10/10/11 | 2 (U) | dec | -- |
| 199-K-21 | P | 10/18/09 | 6 (N) | 12/3/10 | 5.5 | 10/11/11 | 2 (U) | dec | dec |
| 199-K-22 | P | 10/22/09 | 120 | -- | -- | 12/19/11 | 52 | 56.7 | -- |
| 199-K-37 | P | 10/22/09 | 56.7 | 12/3/10 | 27.1 | 10/11/11 | 16.2 | 71.4 | 40.2 |
| 199-K-111A | P | 10/21/09 | 30.0 | 12/7/10 | 46.4 | 10/6/11 | 78 | -160 | -68.1 |
| 199-K-113A | E/C-KR4 | 10/21/09 | 58 | 9/8/10 | 3 | 10/10/11 | 9 | 84.5 | -200 |
| 199-K-114A | E/C-KR4 | 10/21/09 | 62.9 | 9/8/10 | 3 | 10/10/11 | 6 | 90.4 | -100 |
| 199-K-115A | E/C-KR4 | 10/21/09 | 84.4 | 9/8/10 | 17 | 10/10/11 | 12 | 85.8 | 29.4 |
| 199-K-116A | E/C-KR4 | 10/21/09 | 25.3 | 9/8/10 | 15 | 10/10/11 | 11 | 56.5 | 26.7 |
| 199-K-117A | C | 10/22/09 | 2 (U) | 12/3/10 | 2 (U) | 9/28/11 | 2 (U) | NC | NC |
| 199-K-119A | P-KR4 | -- | -- | 12/8/10 | 2 (U) | 12/20/11 | 2.3 (B) | -- | inc |
| 199-K-120A | E/C-KR4 | -- | -- | 10/4/10 | 9 | 10/10/11 | 9 | -- | NC |
| 199-K-125A | C | -- | -- | -- | -- | 11/11/11 | 3.7 (U) | -- | -- |
| 199-K-126 | M | 10/21/09 | 36.6 | 9/22/10 | 27.2 | -- | -- | -- | -- |
| 199-K-127 | E/C-KR4 | -- | -- | 10/4/10 | 7 | 10/10/11 | 8 | -- | -12.5 |
| 199-K-129/K-112A | E/C-KR4 | 10/21/09 | 45.2 | 9/8/10 | 22 | -- | -- | -- | -- |
| 199-K-130 | E/C-KX | 10/20/09 | 49.7 | 11/22/10 | 37.5 | 12/7/11 | 33 | 33.6 | 12.0 |

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-131 | E/C-KX | 10/20/09 | 58 | 9/7/10 | 37 | -- | -- | -- | -- |
| 699-78-62 | M | -- | -- | -- | -- | -- | -- | -- | -- |
| 199-K-121A | I-KR4 | -- | -- | -- | -- | 2011 Avg | 3.85 | -- | -- |
| 199-K-122A | I-KR4 | -- | -- | -- | -- | 2011 Avg | 3.85 | -- | -- |
| 199-K-123A | I-KR4 | -- | -- | -- | -- | 2011 Avg | 3.85 | -- | -- |
| 199-K-124A | M | -- | -- | 12/7/10 | 6.1 | 10/25/11 | 9 | -- | -47.5 |
| 199-K-128 | I-KR4 | -- | -- | -- | -- | 2011 Avg | 3.85 | -- | -- |
| 199-K-143 | I-KR4 | -- | -- | -- | -- | 2011 Avg | 3.85 | -- | -- |
| 199-K-144 | E/C-KR4 | -- | -- | 10/4/10 | 25 | 10/10/11 | 27 | -- | -7.4 |
| 199-K-145 | E/C-KR4 | 12/7/09 | 59 | 10/4/10 | 62 | 10/10/11 | 28 | 52.5 | 54.8 |
| 199-K-146 | E/C-KX | 10/20/09 | 44.8 | 10/4/10 | 21 | 10/4/11 | 9 | 80 | 57.1 |
| 199-K-147 | E/C-KX | 10/20/09 | 37.9 | 11/22/10 | 31.5 | 10/4/11 | 20 | 47.2 | 36.5 |
| 199-K-148 | E/C-KX | 10/20/09 | 85.3 | 11/22/10 | 52.6 | 10/4/11 | 14 | 83.6 | 73.3 |
| 199-K-149 | E/C-KX | 10/20/09 | 27.2 | 10/25/10 | 8 | 12/19/11 | 2 (U) | dec | dec |
| 199-K-150 | E/C-KX | 10/20/09 | 8.8 | 10/11/10 | 2 | 11/9/11 | 3.7 (U) | dec | dec |
| 199-K-151 | P | 10/22/09 | 26.4 | 9/20/10 | 7.9 | 10/26/11 | 3.7 (U) | dec | dec |
| 199-K-152 | P/E/C-KX | 10/22/09 | 69.9 | 9/21/10 | 59.4 | 10/4/11 | 70 | -0.1 | -17.8 |
| 199-K-153 | M | -- | -- | 11/22/10 | 30.2 | 12/7/11 | 23 | -- | 23.8 |
| 199-K-154 | E/C-KX | 10/12/09 | 94 | 11/22/10 | 85.2 | 10/4/11 | 27 | 71.3 | 68.3 |

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-156 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-157 | P | 10/29/09 | 51.5 | 12/7/10 | 30.2 | 11/11/11 | 17 | 67 | 43.7 |
| 199-K-159 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-160 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-161 | E/C-KX | 10/21/09 | 85.9 | 11/22/10 | 14.1 | 10/4/11 | 6 | 93.0 | 57.4 |
| 199-K-162 | E/C-KR4 | -- | -- | 9/14/10 | 8 | 11/1/11 | 3.7 (U) | -- | dec |
| 199-K-163 | E/C-KX | 10/12/09 | 96 | 11/22/10 | 52.2 | 10/4/11 | 35 | 63.5 | 33 |
| 199-K-164 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-169 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-170 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-171 | E-KX | -- | -- | 11/22/10 | 53 | 10/4/11 | 40 | -- | 24.5 |
| 199-K-172 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-179 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-180 | I-KX | -- | -- | -- | -- | 2011 Avg | 3.38 | -- | -- |
| 199-K-182 | P | -- | -- | 9/20/10 | 80.5 | -- | -- | -- | -- |
| 199-K-191 | RI/FS | -- | -- | -- | -- | 11/9/11 | 3.7 (U) | -- | -- |
| 199-K-192 | RI/FS | -- | -- | -- | -- | 10/26/11 | 3.7 | -- | -- |
| 199-K-193 | RI/FS | -- | -- | -- | -- | 9/28/11 | 15.5 | -- | -- |
| 199-K-200 | RI/FS | -- | -- | -- | -- | 10/12/11 | 21.4 | -- | -- |

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-201 | RI/FS | -- | -- | -- | -- | 10/10/11 | 118 | -- | -- |
| 199-N-16 | P | -- | -- | -- | -- | 10/12/11 | 2 (U) | -- | -- |
| 199-N-71 | P | -- | -- | -- | -- | -- | -- | -- | -- |
| 199-N-72 | P | -- | -- | -- | -- | -- | -- | -- | -- |
| Effluent Annual Avg (KR4) | | -- | -- | -- | -- | 2011 Avg | 3.81 | -- | -- |
| Effluent Annual Avg (KX) | | | | | | 2011 Avg | 3.38 | -- | -- |
| 19-D | AT | 11/17/09 | 2 (U) | -- | -- | 9/12/11 | 2 (U) | NC | -- |
| 21-M | AT | 11/18/09 | 2 (U) | -- | -- | 9/26/11 | 2 (U) | NC | -- |
| 22-M/D | AT | 11/21/09 | 7 | -- | -- | -- | -- | -- | -- |
| 23-D | AT | 11/23/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| 26-D | AT | -- | -- | -- | -- | -- | -- | -- | -- |
| C6246 | AT | 11/16/09 | 16 | -- | -- | 9/12/11 | 12.2 | 23.7 | -- |
| C6249 | AT | 11/17/09 | 20 | -- | -- | -- | -- | -- | -- |
| C6250 | AT | 11/17/09 | 24.5 | -- | -- | -- | -- | -- | -- |
| C6251 | AT | 11/21/09 | 3.5 (B) | -- | -- | 9/26/11 | 8.9 | inc | -- |
| C6252 | AT | 11/21/09 | 2.3 (B) | -- | -- | 9/26/11 | 23 | inc | -- |
| C6253 | AT | 11/21/09 | 49.4 | -- | -- | 9/26/11 | 29 | 41.2 | -- |
| C6254 | AT | 11/21/09 | 2 (U) | -- | -- | 9/26/11 | 2 (U) | NC | -- |

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |
| C6255 | AT | 11/21/09 | 5.4 | -- | -- | 9/26/11 | 3.3 (B) | dec | -- |
| C6256 | AT | 11/21/09 | 30.1 | -- | -- | 9/26/11 | 13 | 56.8 | -- |
| C6257 | AT | 11/21/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| C6258 | AT | 11/21/09 | 2 (U) | -- | -- | 9/9/11 | 2 (U) | NC | -- |
| C6259 | AT | 11/21/09 | 2 (U) | -- | -- | 9/9/11 | 2 (U) | NC | -- |
| C6260 | AT | 11/23/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| C6263 | AT | 11/21/09 | 2 (U) | 12/28/10 | 2 (U) | -- | -- | -- | -- |
| C6264 | AT | 11/21/09 | 2 (U) | 12/28/10 | 2 (U) | -- | -- | -- | -- |
| C6265 | AT | 11/21/09 | 2 (U) | 12/28/10 | 2 (U) | -- | -- | -- | -- |
| DK-04-2 | AT | 11/21/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| AT-K-3-D/M | AT | 11/01/09 | 62.8 | 12/17/10 | 56.9 | 9/12/11 | 67.4 | -7.3 | -18.4 |
| AT-K-4-M | AT | 11/23/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| AT-K-5-D | AT | 11/23/09 | 45.6 | -- | -- | -- | -- | -- | -- |
| AT-K-6-M | AT | -- | -- | -- | -- | -- | -- | -- | -- |

Note:

1. Well use: C = compliance, E = extraction, I = injection, M = monitoring, P = performance, AT = aquifer tube, E/C-KR4 = expansion well (use to be determined), E/C-KX = expansion well (use to be determined), RI/FS = remedial investigation feasibility study.

2. Abbreviations: NC = change in concentration not calculated because results are both nondetect, Unfilt=Unfiltered sample.

3. Aquifer tube nomenclature regarding relative depth: D = deepest and M = middle.

4. The 2011 average (Avg) results for injection wells are hexavalent chromium concentrations from treated effluent.

5. Laboratory qualifiers: U = nondetect (shown with detection limit), B = detected above instrument or method detection limit but below contract-required detection limit. N = spiked sample recovery not within control limits.

**Table 3-4. Hexavalent Chromium Concentrations in 116-K-2 Trench Area (KR4 and K North Plumes), CY 2009 to 2011**

| Well or Aquifer Tube Name | Current Well Use and P&T System | Fall 2009 Sample, Unfiltered Cr+6 | | Fall 2010 Sample, Unfiltered Cr+6 | | Fall 2011 Sample, Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | Date Collected | Unfilt. Cr+6 (µg/L) | 2009 to 2011 | 2010 to 2011 |

6. Blank cells (marked with"--") indicate that the sample was not collected or the analysis was not performed.

7. Where contaminant concentration comparisons involve one nonqualified result and one qualified result, the percent change was not calculated but rather and increase (inc.) or decrease (dec.) in concentration between years was noted.

**Table 3-5. Hexavalent Chromium Concentrations, KW Plume CY 2009 to 2011**

| Well Name | Use | Fall 2009 Unfiltered Cr+6 | | Fall 2010 Unfiltered Cr+6 | | Fall 2011 Sample Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-34 | M | 10/22/09 | 36.8 | 12/7/10 | 5.1 | 10/11/2011 | 7.6 | 79.3 | -49 |
| 199-K-35 | M | 12/22/09 | 188 | Decommissioned | -- | -- | -- | -- | -- |
| 199-K-106A | M | 10/22/09 | 2.1 (B) | -- | -- | 10/10/11 | 3.7 (U) | dec | -- |
| 199-K-107A | M | 10/22/09 | 29.3 | 12/3/10 | 14.4 | 10/6/11 | 7.7 | 73.3 | 46.5 |
| 199-K-108A | M | 10/22/09 | 5.2 | 12/8/10 | 2 (U) | 10/6/11 | 2.3 (B) | dec | inc |
| 199-K-31 | M | 10/22/09 | 5.6 | 12/8/10 | 5.6 | -- | -- | -- | -- |
| 199-K-132 | E | 10/20/09 | 20 | 11/22/10 | 16.8 | 11/7/11 | 20 | NC | -19 |
| 199-K-137 | M/E | 10/26/09 | 211 | 11/1/10 | 109 | 11/7/11 | 54 | 74.4 | 50.5 |
| 199-K-138 | E | 10/12/09 | 38 | 11/22/10 | 20.6 | 11/7/11 | 18 | 52.6 | 12.6 |
| 199-K-139 | E | 11/10/09 | 117 | 11/15/10 | 25 | 11/7/11 | 19 | 83.3 | 24 |
| 199-K-140 | E | 10/20/09 | 13 | -- | -- | -- | -- | -- | -- |
| 199-K-158 | I | -- | -- | -- | -- | 2011 Avg | 3.01 | -- | -- |
| 199-K-165 | E | 10/20/09 | 232 | 11/15/10 | 321 | 11/7/11 | 150 | 35.3 | 53.2 |
| 199-K-166 | E | 10/20/09 | 56.1 | 11/22/10 | 30.5 | 11/7/11 | 41 | 26.9 | -34.4 |
| 199-K-168 | E | 10/20/09 | 130 | 11/15/10 | 57 | 11/7/11 | 50 | 61.5 | 12.2 |
| 199-K-173 | M | 10/21/09 | 104 | 8/12/10 | 968 | 9/20/11 | 527 | -407 | 45.6 |
| 199-K-174 | I | -- | -- | -- | -- | 2011 Avg | 3.01 | -- | -- |
| 199-K-175 | I | -- | -- | -- | -- | 2011 Avg | 3.01 | -- | -- |
| 199-K-183 | RI/FS | -- | -- | -- | -- | 10/24/11 | 3.7 (U) | -- | -- |

**Table 3-5. Hexavalent Chromium Concentrations, KW Plume CY 2009 to 2011**

| Well Name | Use | Fall 2009 Unfiltered Cr+6 | | Fall 2010 Unfiltered Cr+6 | | Fall 2011 Sample Unfiltered Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-184 | RI/FS | -- | -- | -- | -- | 11/11/11 | 28 | -- | -- |
| 199-K-185 | RI/FS | -- | -- | -- | -- | 12/20/11 | 3.3 (B) | -- | -- |
| Effluent Annual Avg (KW) | | -- | -- | -- | -- | 2011 Avg | 3.01 | -- | -- |
| AT-K-1 | AT | 11/1/09 | 7.5 | -- | -- | 12/17/10 | 2 (U) | 74 | -- |
| C7641 | AT | -- | -- | 11/22/10 | 2 (U) | -- | -- | -- | -- |
| C7642 | AT | -- | -- | 11/22/10 | 2 (U) | 9/6/11 | 2 (U) | NC | NC |
| C7643 | AT | -- | -- | 11/22/10 | 2 (U) | 9/6/43 | 2 (U) | NC | NC |

Note:

1. Well use: E = extraction, I = injection, M = monitoring, AT = aquifer tube, RI/FS = remedial investigation feasibility study.
2. Abbreviations: NC = change in concentration not calculated because results are both nondetect, Unfilt=Unfiltered sample.
3. The 2011 average (Avg) results for injection wells are hexavalent chromium concentrations from treated effluent.
4. Laboratory qualifiers: U = nondetect (shown with detection limit), B = detected above instrument or method detection limit but below contract-required detection limit.
5. Blank cells (marked with"--") indicate that the sample was not collected or the analysis was not performed.
6. Where contaminant concentration comparisons involve one nonqualified result and one qualified result, the percent change was not calculated but rather and increase (inc.) or decrease (dec.) in concentration between years was noted.

**Table 3-6. Hexavalent Chromium Concentrations, KE Reactor Area Plume, CY 2009 to 2011**

| Well Name | Use | Fall 2009 Unfilt. Cr+6 | | Fall 2010 Unfilt. Cr+6 | | Fall 2011 Sample Unfilt. Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| 199-K-32A | P | 10/22/09 | 11.8 | 12/3/10 | 8.3 | 10/11/11 | 9.1 | 28.9 | -9.6 |
| 199-K-32B | M | 10/18/09 | 5.1 | 12/8/10 | 2.9 (B) | 10/11/11 | 3.9 (B) | dec | inc |
| 199-K-30 | M | 10/18/09 | 2.1 (B) | 12/2/10 | 7.5 | -- | -- | -- | -- |
| 199-K-29 | M | -- | -- | 12/2/10 | 2 (U) | -- | -- | -- | -- |
| 199-K-23 | M | -- | -- | -- | -- | 10/10/11 | 97.4 | -- | -- |
| 199-K-11 | M | 10/28/09 | 2 (U) | 12/3/10 | 5.3 | -- | -- | -- | -- |
| 199-K-110A | M | 10/18/09 | 2 (U) | 12/8/10 | 2 (U) | 10/6/11 | 3.3 (B) | inc | inc |
| 199-K-36 | M | 10/22/09 | 20.0 | 12/3/10 | 34.2 | -- | -- | -- | -- |
| 199-K-141 | E-KX | 11/23/09 | 91 | 10/4/10 | 38 | 10/4/11 | 24 | 73.6 | 58.3 |
| 199-K-142 | M | 10/22/09 | 3.3 (B) | 12/8/10 | 4 | -- | -- | -- | -- |
| 199-K-178 | E-KX | 11/5/09 | 117 | 11/17/10 | 23.8 | 10/4/11 | 25 | 78.6 | -4.8 |
| 199-K-181 | C | 11/5/09 | 8.6 | -- | -- | 11/9/11 | 9 | -4.4 | -- |
| 199-K-186 | RI/FS | -- | -- | -- | -- | 10/10/11 | 5.7 | -- | -- |
| 199-K-187 | RI/FS | -- | -- | -- | -- | 10/25/11 | 3.7 (U) | -- | -- |
| 199-K-190 | RI/FS | -- | -- | -- | -- | 10/24/11 | 10 | -- | -- |
| C6242 | AT | 11/18/09 | 2 (U) | -- | -- | -- | -- | -- | -- |
| C6243 | AT | 11/18/09 | 4.8 (B) | -- | -- | -- | -- | -- | -- |
| C6244 | AT | 11/18/09 | 5.2 | -- | -- | -- | -- | -- | -- |
| C6245 | AT | 11/16/09 | 14.8 | -- | -- | 9/12/11 | 11.3 | 23.6 | -- |

**Table 3-6. Hexavalent Chromium Concentrations, KE Reactor Area Plume, CY 2009 to 2011**

| Well Name | Use | Fall 2009 Unfilt. Cr+6 | | Fall 2010 Unfilt. Cr+6 | | Fall 2011 Sample Unfilt. Cr+6 | | % Change in Cr+6 Conc. (Negative = Increase) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | Date Collected | Conc. (µg/L) | 2009 to 2011 | 2010 to 2011 |
| C6246 | AT | 11/16/09 | 16 | -- | -- | 9/12/11 | 12.2 | 23.8 | -- |
| C6247 | AT | 11/16/09 | 15.7 | -- | -- | 9/12/11 | 15.4 | 1.9 | -- |
| 19-D | AT | 11/17/09 | 2 (U) | -- | -- | 9/12/11 | 2 (U) | NC | -- |
| AT-K-2-D | AT | 11/1/09 | 3.4 (B) | 12/17/10 | 2 (U) | -- | -- | -- | -- |

Note:

1. Well use: C = compliance, E = extraction, M = monitoring, P = performance, AT = aquifer tube, KX = expansion well, RI/FS = remedial investigation feasibility study.

2. Abbreviations: NC = change in concentration not calculated because results are both nondetect, Unfilt=Unfiltered sample.

3. Aquifer tube nomenclature regarding relative depth: D = deep.

4. Laboratory qualifiers: U = nondetect (shown with detection limit), B = detected above instrument or method detection limit but below contract-required detection limit. N = spiked sample recovery not within control limits.

5. Blank cells (marked with"--") indicate that the sample was not collected or the analysis was not performed.

6. Where contaminant concentration comparisons involve one nonqualified result and one qualified result, the percent change was not calculated but rather and increase (inc.) or decrease (dec.) in concentration between years was noted.

**Table 3-7. Operational Parameters and System Performance of KR4 P&T System**

| **Total Processed Groundwater** | **CY 2010** | **CY 2011** |
|---|---|---|
| Total amount of groundwater treated (since September 1997 startup) (billion L) | 5.44 | 5.72 |
| Total amount of groundwater treated during CY (million L) | 336.8 | 284.9 |
| **Mass of Hexavalent Chromium Removed** | | |
| Total amount of hexavalent chromium removed since September 1997 startup (kg) | 349.5 | 354.9 |
| Total amount of hexavalent chromium removed in CY (kg) | 7.21 | 5.42 |
| **Summary of Operational Parameters** | | |
| Removal efficiency (% by mass) | 90.6 | 83.6 |
| Waste generation ($m^3$) | 0 | 0.63 |
| Regenerated resin installed ($m^3$) | 45 | 9 |
| New resin installed ($m^3$) | 0 | 0 |
| Number of resin vessel changeouts | 20 | 4 |
| **Summary of System Availability** | | |
| Total possible run-time (hours) | 8,760 | 8,760 |
| Scheduled downtime (hours) | 2,170 | 166.6 |
| Planned operations (hours) | 6,590 | 8,593.4 |
| Unscheduled downtime (hours) | 22.1 | 568.8 |
| Total time online (hours) | 6,567.9 | 8,024.6 |
| Total availability (%)[a] | 74.9[c] | 91.6 |
| Scheduled system availability (%)[b] | 75.2[c] | 98.1 |

a. Total availability [(total possible run-time – scheduled and unscheduled downtime) ÷ total possible run-time)].

b. Scheduled system availability [(total possible run-time – scheduled downtime) ÷ total possible run-time].

c. The relatively low system availability in CY 2010 is due to a system shutdown for upgrades and maintenance during the last 3 months of the year.

**Table 3-8. Flow Rates and Total Run-Times for KR4 P&T System Extraction and Injection Wells, CY 2011**

| Well | Recommended[a] Flow Rate, L/min (gpm) | Yearly Average Flow Rate, L/min (gpm) | Total Flow Hours in Calendar Year 2011 | Total Run-Time[b] (Percent) | Purpose |
|---|---|---|---|---|---|
| 199-K-129 | 94.6 (25.0) | 0 | 0 | 0 | Extraction |
| 199-K-113A | 56.8 (15.0) | 40.1 (10.6) | 3,312 | 40.0 | Extraction |
| 199-K-114A | 94.6 (25.0) | 35.6 (9.4) | 3,048 | 36.8 | Extraction |
| 199-K-115A | 94.6 (25.0) | 90.8 (24.0) | 5,496 | 66.4 | Extraction |
| 199-K-116A | 151.4 (40.0) | 79.1 (20.9) | 3,744 | 45.2 | Extraction |
| 199-K-120A | 113.6 (30.0) | 42.8 (11.3) | 3,096 | 37.4 | Extraction |
| 199-K-127 | 151.4 (40.0) | 40.9 (10.8) | 3,072 | 37.1 | Extraction |
| 199-K-144 | TBD | 177.2 (46.8) | 8,064 | 97.4 | Extraction |
| 199-K-145 | TBD | 212.4 (56.1) | 8,064 | 97.4 | Extraction |
| 199-K-162 | TBD | 56.8 (15) | 3,120 | 37.7 | Extraction |
| 199-K-198[c] | TBD | N/A | N/A | N/A | Extraction |
| 199-K-199[c] | TBD | N/A | N/A | N/A | Extraction |
| 199-K-121A | NA | 107.5 (28.4) | 8,040 | 97.1 | Injection |
| 199-K-122A | NA | 166.2 (43.9) | 8,232 | 99.4 | Injection |
| 199-K-123A | NA | 78 (20.6) | 7,800 | 94.2 | Injection |
| 199-K-128 | NA | 126.1 (33.3) | 8,208 | 99.1 | Injection |
| 199-K-179 | NA | 106 (28.0) | 8,232 | 99.4 | Injection |

a. Recommended flow rate is based upon drawdown analysis.

b. Percentage total run-time is calculated by (total flow hours ÷ total possible run-time).

c. New extraction wells not yet connected to the KR-4 P&T system

**Table 3-9. Operational Parameters and System Performance for KW P&T System**

| **Total Processed Groundwater** | **CY 2010** | **CY 2011** |
|---|---|---|
| Total amount of groundwater treated since January 2007 startup (million L) | 1,052.76 | 1,409.73 |
| Total amount of groundwater treated in CY (million L) | 387.15 | 357.0 |
| **Mass of Hexavalent Chromium Removed** | | |
| Total amount of hexavalent chromium removed since January 2007 startup (kg) | 137.2 | 163.1 |
| Total amount of hexavalent chromium removed in CY (kg) | 54.12 | 25.9 |
| **Summary of Operational Parameters** | | |
| Removal efficiency (% by mass) | 96.9 | 95.8 |
| Waste generation ($m^3$) | 0 | 44.82 |
| Regenerated resin installed ($m^3$) | 93 | 36 |
| New resin installed ($m^3$) | 27 | 12 |
| Number of resin vessel changeouts | 41 | 16 |
| **Summary of System Availability** | | |
| Total possible run-time (hours) | 8,760 | 8,760 |
| Scheduled downtime (hours)[a] | 29.3 | 257.3 |
| Planned operations (hours) | 8,730.7 | 8,502.7 |
| Unscheduled downtime (hours) | 6.2 | 209.5 |
| Total time online (hours) | 8,724.5 | 8,293.2 |
| Total availability (%)[a] | 99.6 | 94.7 |
| Scheduled system availability (%)[b] | 99.7 | 97.1 |

a. Total availability [(total possible run-time – scheduled and unscheduled downtime) ÷ total possible run-time)].

b. Scheduled system availability [(total possible run-time – scheduled downtime) ÷ total possible run-time].

**Table 3-10. Flow Rates and Total Run-Times for KW P&T System Extraction and Injection Wells, CY 2011**

| Well | Recommended[a] Flow Rate, L/min (gpm) | Yearly Average Flow Rate, L/min (gpm) | Total Flow Hours in Calendar Year 2011 | Total Run-Time[b] (Percent) | Purpose |
|---|---|---|---|---|---|
| 199-K-132 | 96 (25) | 49.6 (13.1) | 8,184 | 96.9 | Extraction |
| 199-K-137 | 170 (45) | 101.4 (26.8) | 8,424 | 99.7 | Extraction |
| 199-K-138 | 114 (30) | 50 (13.2) | 8,160 | 96.6 | Extraction |
| 199-K-139 | 38 (10) | 75.7 (20.0) | 8,064 | 95.5 | Extraction |
| 199-K-165 | 189 (50) | 213.5 (56.4) | 8,400 | 99.4 | Extraction |
| 199-K-166 | 38 (10) | 102.6 (27.1) | 8,400 | 99.4 | Extraction |
| 199-K-168 | 151 (40) | 127.2 (33.6) | 8,400 | 99.4 | Extraction |
| 199-K-173[c] | TBD | N/A | N/A | N/A | Extraction |
| 199-K-196[d] | TBD | N/A | N/A | N/A | Extraction |
| 199-K-158 | NA | 316.1 (83.5) | 8,400 | 99.4 | Injection |
| 199-K-174 | NA | 261.6 (69.1) | 8,400 | 99.4 | Injection |
| 199-K-175 | NA | 135.1 (35.7) | 8,376 | 99.1 | Injection |

a. Recommended flow rate is based upon drawdown analysis.
b. Percentage total run-time is calculated by (total flow hours ÷ total possible run-time).
c. This monitoring well was converted into an extraction well in 2011.
d. New extraction wells not yet connected to KW P&T system

**Table 3-11. Operational Parameters and System Performance for KX P&T System**

| **Total Processed Groundwater** | **CY 2010** | **CY 2011** |
|---|---|---|
| Total amount of groundwater treated since November 2008 startup (million L) | 1,693.1 | 2,593.7 |
| Total amount of groundwater treated in CY (million L) | 904.5 | 900.6 |
| **Mass of Hexavalent Chromium Removed** | | |
| Total amount of hexavalent chromium removed since November 2008 startup (kg) | 83.9 | 114.0 |
| Total amount of hexavalent chromium removed in CY (kg) | 40.1 | 30.1 |
| **Summary of Operational Parameters** | | |
| Removal efficiency (% by mass) | 94.0 | 90.7 |
| Waste generation ($m^3$) | 0 | 3.62 |
| Regenerated resin installed ($m^3$) | 147 | 111 |
| New resin installed ($m^3$) | 52 | 0 |
| Number of resin vessel changeouts | 65 | 49 |
| **Summary of System Availability** | | |
| Total possible run-time (hours) | 8,760 | 8,760 |
| Scheduled downtime (hours) | 68.6 | 104.1 |
| Planned operations (hours) | 8,691.4 | 8,655.9 |
| Unscheduled downtime (hours) | 214.7 | 49.1 |
| Total time online (hours) | 8,476.7 | 8,606.8 |
| Total availability (%)[a] | 96.8 | 98.3 |
| Scheduled system availability (%)[b] | 99.2 | 98.8 |

a. Total availability [(total possible run-time – scheduled and unscheduled downtime) ÷ total possible run-time)].

b. Scheduled system availability [(total possible run-time – scheduled downtime) ÷ total possible run-time].

**Table 3-12. Flow Rates and Total Run-Times for KX P&T System Extraction and Injection Wells, CY 2011**

| Well | Recommended[a] Flow Rate, L/min (gpm) | Yearly Average Flow Rate, L/min (gpm) | Total Flow Hours in Calendar Year 2011 | Total Run-Time (Percent)[b] | Purpose |
|---|---|---|---|---|---|
| 199-K-130 | 227 (60) | 92.4 (24.4) | 8,328 | 96.1 | Extraction |
| 199-K-131 | 227 (60) | 187.4 (49.5) | 8,328 | 96.1 | Extraction |
| 199-K-141 | TBD | 130.2 (34.4) | 8,664 | 100 | Extraction |
| 199-K-146 | 38 (10) | 36.7 (9.7) | 8,328 | 96.1 | Extraction |
| 199-K-147 | 76 (20) | 73.8 (19.5) | 8,304 | 95.8 | Extraction |
| 199-K-148 | 189 (50) | 163.9 (43.3) | 8,232 | 95.0 | Extraction |
| 199-K-152[c] | TBD | 183.6 (48.5) | 6,264 | 72.3 | Extraction |
| 199-K-153 | TBD | 157.1 (41.5) | 8,664 | 100 | Extraction |
| 199-K-154 | TBD | 219.9 (58.1) | 8,664 | 100 | Extraction |
| 199-K-161 | 114 (30) | 45.8 (12.1) | 2,328 | 26.9 | Extraction |
| 199-K-163 | TBD | 208.6 (55.1) | 8,664 | 100 | Extraction |
| 199-K-171 | TBD | 216.5 (57.2) | 8,592 | 99.2 | Extraction |
| 199-K-178 | TBD | 158.2 (41.8) | 7,224 | 83.4 | Extraction |
| 199-K-182[c] | TBD | 0 | 0 | 0 | Extraction |
| 199-K-143 | NA | 110.5 (29.2) | 7,680 | 88.6 | Injection |
| 199-K-156 | NA | 242.3 (64.0) | 8,760 | 101.1 | Injection |
| 199-K-159 | NA | 221.1 (58.4) | 8,088 | 93.4 | Injection |
| 199-K-160 | NA | 221.8 (58.6) | 8,088 | 58.6 | Injection |
| 199-K-164 | NA | 182.2 (48.4) | 7,512 | 86.7 | Injection |
| 199-K-169 | NA | 202.5 (53.5) | 8,664 | 100 | Injection |
| 199-K-170 | NA | 187.8 (49.6) | 5,256 | 60.7 | Injection |
| 199-K-172 | NA | 241.1 (63.7) | 8,664 | 100 | Injection |
| 199-K-180 | NA | 187.8 (49.6) | 8,664 | 100 | Injection |

a. Recommended flow rate based upon drawdown analysis.

b. Percentage total run-time calculated by (total flow hours ÷ total possible run-time).

c. Converted from monitoring to extraction wells in calendar year 2011.

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# 4 100-NR-2 Operable Unit Interim Action Status

The 100-NR-2 Groundwater OU is along the Columbia River between the 100-KR-4 and the 100-HR-3OU (Figure 4-1). The 100-NR-2 OU consists of the groundwater underlying and near the 100-NR-1 Source OU within the 100-N Area. The 100-NR-2 P&T system was placed in cold-standby status in March 2006 to facilitate a treatability test for installation of an apatite permeable reactive barrier constructed along the 100-N Area shoreline. Figure 4-2 shows the location of the former 100-NR-2 P&T extraction and injection wells and the associated monitoring wells in relation to the primary facilities. Figure 4-2 also shows the area of the apatite permeable reactive barrier in relation to these wells (inset). Figures 4-3, 4-4, and 4-5 show enlargements of the inset permeable reactive barrier areas.
The authorization for the P&T status change in the 100-NR-2 interim action is documented in Tri-Party Agreement Change Request M-16-06-01, dated February 15, 2006.

This chapter provides the annual performance report for the 100-NR-2 groundwater remediation, as required by the interim remedial action ROD (EPA/541/R-99/112). The purpose of this chapter is to describe the observed effects of the P&T system's cold-standby status and subsequent installation of the apatite permeable reactive barrier on the aquifer. A general overview of the effects of the apatite permeable reactive barrier is provided, as well as an update on progress for other remediation activities currently taking place in 100-NR-2. Groundwater monitoring data collected in 2011 pertinent to the interim remedial action is included in this chapter.

Section 4.1 provides a brief overview of activities pertaining to the 100-NR-1 source area remedial actions and 100-NR-2 groundwater remediation activities that occurred within the 100-N Area during 2011. Section 4.2 describes environmental conditions and groundwater contaminants as they relate to remedial activities. Section 4.3 discusses the strontium-90 treatment technologies currently being tested and planned for future testing in the 100-N Area. Section 4.4 discusses activities related to the total petroleum hydrocarbon-diesel range plume contamination occurring in the 100-N Area. The conclusions and recommendations are presented in Section 4.5.

## 4.1 Summary of Operable Unit Activities

The selected interim action remedy in the 100-NR-2 (EPA et al., 2010) to address strontium-90 contamination in groundwater consists of the following:

1. Extend the apatite permeable reactive barrier from 90 m to approximately 760 m.
2. Apply one round of additional apatite injections within 5 years of all first-round apatite injections.
3. Decommission the existing 100-NR-2 P&T building and components.
4. Use monitored natural attenuation.
5. Maintain existing Institutional Controls.
6. Perform periodic groundwater monitoring.

Because the P&T system has been in cold-standby since March 2006, the total volume of water processed and activity of strontium-90 removed were unchanged from those reported in 2008:

- Total processed groundwater since September 1995 startup: 1,155.3 million L (more than 305 million gal)
- Total mass of strontium removed since September 1995 startup: 1.83 Ci

## 4.2 Conceptual Site Model

This section describes the conceptual site model, including the general hydrogeologic conditions in the 100-N Area and changes in contaminant concentrations in monitoring wells.

### 4.2.1 Geologic/Hydrologic Setting

#### *4.2.1.1 Geology*

The 100-N Area is underlain by the Hanford formation, the Ringold unit E, and the Ringold upper mud, in descending order. The uppermost unit, the Hanford formation, is 6 to 23 m (19.7 to 75.5 ft) thick and underlies most of the area. In a few places along the shoreline lower road, the Hanford formation is absent because of excavation and fill that were placed to build the roadway. The Ringold Formation underlies the entire area and is 5 to 20 m (16.4 to 65.6 ft) thick. Based on borehole information, the Ringold upper mud underlies the entire decision unit and is 17 to 29 m (55.8 to 95.1 ft) thick; it is a relatively low-permeability unit and forms the base of the unconfined aquifer.

Most of the monitoring wells in the 100-N Area are completed in the upper portion of the unconfined aquifer, which is predominantly in the Ringold unit E. At high Columbia River levels, the aquifer can rise into the Hanford formation in wells along the shoreline and nearby inland wells. Five wells monitor the base of the unconfined aquifer in the lower Ringold unit E. One well is completed in a fine-grained, sandy unit in the Ringold upper mud, approximately 12 m (39 ft) below the water table. The properties of these formations influence the distribution and behavior of contamination in the subsurface. Within the 100-N Area, the vadose zone is composed mainly of the Hanford formation with portions of the Ringold unit E in some areas. Figure 4-6 provides a generalized geologic cross section of the 100-N Area.

The surface of the Hanford formation/Ringold unit E contact has a topographic high near the 116-N-1 facility (Figure 4-7), and the Ringold unit E/Ringold upper mud contact has a topographic low beneath and to the southwest of the Hanford formation/Ringold unit E high spot (Figure 4-8). This depression or trough (2 to 2.5 m [6.6 to 8.2 ft] lower than surrounding area) in the Ringold upper mud runs from adjacent to the head end of the 116-N-1 facility to the river shoreline; it has created a preferential pathway at the base of the aquifer that closely mirrors where higher concentrations of contaminants from the disposal units have been found on the shoreline. Liquid wastes disposed of to the ground in the 100-N Area quickly migrated downward through the gravels of the Hanford formation, with very little lateral spreading until reaching groundwater. During operations, the water table was much higher and was located in the Hanford formation, forming mounds under the disposal facilities. Once in groundwater and the Ringold Formation, the wastes moved radially outward from the disposal sites and eventually followed groundwater flow and geologic structure to the Columbia River. The surface of the Hanford-Ringold contact and the Ringold upper mud contributed to a preferential pathway to the Columbia River shoreline. The first seeps along the shoreline were discovered in 1983 in this location on the shoreline between current Wells 199-N-123 and 199-N-119 (PNL-5289, *Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River*). When discharges ceased, the groundwater mounds dissipated and left residual contamination in the vadose zone above groundwater. Chapters 2 and 4 in *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units* (DOE/RL-2008-46-ADD5) provide further details on the hydrogeologic conditions and the manner in which contaminants migrated through the vadose zone and groundwater.

#### *4.2.1.2 Hydrology*

During the spring months, the Columbia River elevation generally increases because of additional flow from snow melt runoff. Flow is regulated at the Priest Rapids Dam to provide irrigation water and to aid in fish migration. Figure 4-9 shows the monthly average river stage at the 100-N Area gauging station from 2006 through May 2011. The average river stage during the first part of 2011 was 118.59 m (389.07 ft). Table 4-1 compares the yearly average river stages over the last 7 years. The values in the table indicate that minor changes have occurred from year to year and the percent difference is usually less than 1 percent. Prolonged high river levels well into June contributed to a higher river level average for the first third of 2011. Incomplete 100-N Area river gauge data did not allow the difference to be calculated, but levels were higher than the previous year for a longer time. The partial yearly average for 2011 was slightly higher than all six of the previous years. During 2011, the river stage was highest between mid-June to early July and lowest between mid-September to early November (based on data from wells along the 100-N Area shoreline). Figure 4-10 provides hydrographs for 2011 for the three wells listed in Table 4-2. The well closest to the river, 199-N-99A, has the most erratic water-level graph because it is highly influenced by river-level changes. Wells 199-N-14 and 199-N-50 have much smoother graphs; river-level changes are more gradual in these wells and take longer to occur. Water levels in wells respond to changes in river stage. Wells on the river shore respond very quickly to changes in river levels; the response is delayed in wells further inland from the river. It can take several days before a change in river level has an effect on wells further inland, and unless the river level stays high or low for several days in a row, the effect may not be noticeable. Table 4-2 shows river-to-inland response for one set of water-level network wells in the 100-N Area during two low periods and one high period in river stages. Well 199-N-146 is on the 100-N Area shoreline, about 2 m (6.5 ft) from the river and about 2 m (6.5 ft) above the river. Wells 199-N-3 and 199-N-71 are further inland, approximately 107 and 762 m (351 and 2,500 ft), respectively, from the river. Both wells are considerably higher in surface elevation (at least 20 to 22 m [66 to 72 ft] above river level). The effects of high and low river stages are also visible at these inland wells.

Groundwater generally flows northwest toward the Columbia River beneath the 100-N Area. As the effects of extraction and injection dissipated after March 2006, the hydraulic gradient began to flatten. This effect was first discussed in the 2008 P&T report for 100-N (DOE/RL-2009-15, *Calendar Year 2008 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operation*). It is further illustrated when comparing the March 2009 and 2010 water tables (Figure 4-11) to the ones from 2007/2008 (DOE/RL-2009-15). Groundwater flow in 2011 was influenced by groundwater extraction and injection for the KX P&T remediation system in 100-KR-4 (Section 3), in the southern portion of 100-N. Figure 4-12 provides the March 2011 water table map for 100-NR-2. A groundwater mound at least 1 meter high creates the potential for radial flow in the southernmost part of 100-NR-2. The water table beneath the rest of the area was nearly flat in March 2011, when the river stage was higher than normal for that time of year. The river stage can change daily (plus or minus 1.5 m [5 ft]) and seasonally (plus or minus 2.4 m [7.8 ft]) for sustained periods, which affects the saturated zone thickness and causes flow reversals (Section 1.1 of PNNL-16891, *Hanford 100-N Area Apatite Emplacement: Laboratory Results of Ca-Citrate-PO4 Solution Injection and Sr-90 Immobilization in 100-N Sediments*). In 2011, the river stage peaked in late May and early June, and remained high into early July. Water levels in Well 199-N-2, 170 meters from the river, rose more than 1.5 m (5 ft) with a lag time of a few days. Water levels in 199-N-34, 500 m from the river, rose more than 0.5 m (1.6 ft) with a lag time of approximately 2 months. The changes affected groundwater flow directions.

Vertical hydraulic gradients are difficult to measure in the unconfined aquifer at 100-NR-2. The difference in water levels in well pairs 199-N-81/199-N-70 and 199-N-119/199-N-121 was only

a few hundredths of a meter during 2011, which is within the instrument measurement error. The screen depths differ by approximately 5 to 6 m (16.4 to 19.7 ft).

### 4.2.2 100-N Area Groundwater Contaminants

The following discussion summarizes the results of 2011 interim action groundwater monitoring in the 100-N Area. Wells and constituents monitored are defined in the following documents: (1) *Remedial Design Report/Remedial Action Work Plan for the 100-NR-2 Operable Unit* (DOE/RL-2001-27) and modifications in TPA-CN-256, *Change Notice for Modifying Approved Documents/Workplans in Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: DOE/RL-2001-27, Rev 0, Remedial Design Report/Remedial Action Work Plan for the 100-NR-2 Operable Unit and the Interim Action Waste Management Plan for the 100-NR-2 Operable Unit, DOE/RL-2000-41, Rev. 1*, (2) *100-N Area Integrated Groundwater Sampling and Analysis Plan* (DOE/RL-2009-58), and (3) strontium-90 treatability teat plans (DOE/RL-2005-96 with modifications in TPA-CN-271, *Change Notice for Modifying Approved Documents/Workplans in Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: Treatability Test Plan Addendum for the 100-NR-2 Groundwater Operable Unit, DOE/RL-2005-96 Addendum*; DOE/RL-2010-29, *Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit*). The CERCLA sampling is conducted mainly in September, with selected wells also monitored in March. The RCRA sampling is conducted twice a year. Analytical results from these other monitoring programs are also presented in this discussion where the data are useful for assessing rebound or defining plumes. This report focuses on evaluating analytical results for strontium-90 and total petroleum hydrocarbons being remediated through the interim actions. Further summary and analysis of the other COCs and contaminants of interest is presented in DOE/RL-2011-118.

#### *4.2.2.1 Strontium-90*

The size and shape of the strontium-90 plume changes very little from year to year, except in the vicinity of the apatite permeable reactive barrier treatment site. The plume extends from beneath the 116-N-1 and 116-N-3 facilities to the Columbia River at levels above the Drinking Water Standard (8 pCi/L) (Figure 4-13). The majority of the strontium-90 remaining in the unsaturated and saturated zones in the 100-N Area is in the vadose zone above the aquifer. Far more strontium-90 is contained within the unsaturated zone than in the groundwater. Strontium-90 has a much greater affinity for sediment than for water (i.e., a high distribution coefficient), so its rate of transport in groundwater to the Columbia River is considerably slower than the actual groundwater flow rate. The relative velocity of strontium-90 to groundwater is approximately 1:100. Strontium-90 is in the upper portion of the unconfined aquifer, and concentrations decrease with depth; deeper wells are essentially free of strontium-90 contamination.

Strontium-90 trends in monitoring wells near the 116-N-1 facility show no obvious long-term decline in concentrations but do show significant variability related to water levels. Figure 4-14 shows strontium-90 concentrations and water levels in well 199-N-67, which has the highest level of contamination. Figure 4-15 shows strontium-90 concentrations and water levels in well 199-N-105A. When the water table rises, strontium-90 from the vadose zone is mobilized and concentrations in groundwater increase. Concentrations increased in the mid-1990s, which correlated with several years of high river stage. Concentration peaks in 2006, 2007, 2008, 2009, 2010, and 2011 were also correlated with periods when the water table was high.

After the extraction wells were shut off in March 2006, strontium-90 concentrations increased in the former cone of depression. Concentrations had been lower during P&T system operation because groundwater extraction lowered the water table into a less contaminated portion of the aquifer (the contamination is concentrated in the upper portion of the aquifer). As shown in Table 4-3,

Wells 199-N-14, 199-N-27, 199-N-34, 299-N-56, 199-N-57, 199-N-67, 199-N-76, 199-N-96A, 199-N-103A, and 199-N-105A showed increases in strontium-90 concentrations between 2005 and 2011. Well 199-N-75 showed increases between 2005 and 2010 but was not able to be sampled in 2011. Several of these wells are completed in the higher concentration portions of the strontium-90 plume and are downgradient from the 116-N-1 Liquid Waste Disposal Facility. Wells 199-N-75, 199-N-103A, 199-N-105A, and 199-N-106A are former P&T extraction wells.

Rebound of strontium-90 concentrations is observed at some locations. Figure 4-16 provides trend plots for the former extraction wells versus river level. The increases are partially attributable to a rebound effect after P&T operations ceased, but the higher river stages over the last few years have also had an effect. Some of the wells exhibited higher concentrations in 2011 than in 1994, before the P&T system was started (Table 4-3), and concentrations increased four-fold in Well 199-N-105A in 2011. The increase in Well 199-N-105A may have been caused by the high water table in June 2011, which mobilized strontium-90 from contaminated sediments in the lower vadose zone. Another explanation is that the increases reflect a change in groundwater flow directions resulting from the groundwater mound in the southern part of 100-NR-2. Future groundwater monitoring will determine whether the changes persist and whether they are linked to changes in the river stage.

The highest strontium-90 concentrations in soil and groundwater along the Columbia River are found near the original apatite permeable reactive barrier and immediately downriver to the northeast. This area is the focus of increased monitoring and remediation activities. Figure 4-17 depicts the strontium-90 concentrations at the 100-NR-2 shoreline in the area affected by the original apatite barrier. Following initial injections in 2006, the barrier helped to reduce strontium-90 concentrations in its immediate vicinity, including the wells within the barrier itself, on both sides of the injection wells on each end of the barrier, and the monitoring wells downgradient from the barrier. Figure 4-18 also includes one well upgradient from the barrier; Well 199-N-46 showed a decrease in strontium-90 concentrations for 2 years (2008 and 2009) following injections, but strontium-90 is once again on an upward trend in this well. While most locations remain at 90 percent reduction in strontium-90 since injections began in 2006, some areas appear to be candidates for additional apatite treatment (Section 4.3.1). Concentrations in all but two monitoring points are below 1,000 pCi/L. Well 199-N-123 exhibited an increase to 1,770 pCi/L in September 2011, and aquifer tube NVP2-116.0m showed an increase to 1,100 pCi/L in August 2011. Concentrations subsequently decreased at both sites. The increase at Well 199-N-123 was caused by the upstream barrier extension injections in September 2011. Variability in concentration is affected by the depth of well completion and local geology, but overall, the values are well below pre-treatment levels.

Strontium-90 concentrations in aquifer tubes are consistent with those seen in monitoring wells. Levels greater than the Drinking Water Standard are present only above approximately 115 m (377 ft) in elevation (that is, the top 2 to 3 m [6.5 to 9.8 ft] of the aquifer), so this location is where most of the aquifer tubes are screened. The majority of the aquifer tubes completed below this elevation are in the area where strontium-90 concentrations along the river are known to be highest. Figure 4-19 shows the strontium-90 trend plots for aquifer tubes N116Array-3A, N116Array-4A, and N116Array-6A. Figure 4-20 shows the strontium-90 trend plot for aquifer tube NVP2-116m. The plots clearly show an increase when the P&T system was shut down, increases after apatite injections, and decreases following injections. Overall, a significant decrease in strontium-90/gross beta contamination has occurred along the shoreline since installation of the apatite permeable reactive barrier.

The only strontium-90 detections in aquifer tubes outside the area where the strontium-90 plume intersects the Columbia River (Figure 4-13) are at aquifer tube cluster C7934/35/36. These tubes are in the engineered fill around the 1908-N Outfall, which indicates that outfall construction created a preferential pathway in the fill for contamination migration. Some potential sources of strontium-90

contamination at this location are from the 105-N Reactor Building/Fuel Storage Basin, the 1909-N Waste Disposal Valve Pit, the 107-N Basin Recirculating Cooling Facility, the 1304-N Emergency Dump Tank, the 1300-N Emergency Dump Basin, and other associated structures (Section 4.2 of SGW-49370, *Columbia River Pore Water Sampling in 100-N Area, December 2010*).

#### *4.2.2.2 Total Petroleum Hydrocarbons*

Petroleum hydrocarbons from a 1960s diesel fuel tank spill (site code: unplanned release [UPR]-100-N-17) continue to be detected in 100-NR-2 groundwater. The occurrence of diesel in the vadose zone and groundwater will be discussed in more detail in Section 4.4. The petroleum hydrocarbon plume in groundwater (Figure 4-21) is confined to a relatively small region and is centered on Well 199-N-18, with a concentration of 7,700 µg/L total petroleum hydrocarbon-diesel range in 2011. This is a substantial decrease from the 2010 value of 420,000 µg/L. The current plume is mapping as two separate sections, but the plume is most likely connected between the two locations. Fewer wells detected petroleum hydrocarbons in 2011 than in 2010. This reduction may be partly attributable to the high-volume bioventing test on the vadose zone performed in 2010 and 2011 (WCH-490, *UPR-100-N-17; Bioventing Pilot Plant Performance Report*). Introduction of large amounts of air may have temporarily displaced the diesel in the vicinity of the well screens or contributed to an increased rate of diesel degradation. Only continued monitoring will indicate whether the trend continues and confirms a long-term decrease has occurred. Other wells with total petroleum hydrocarbon-diesel range detections were as follows: 199-N-19 (670 µg/L) and 199-N-169 (760 µg/L).

Evidence of low levels of petroleum hydrocarbon contamination has been observed in Well 199-N-3 in the past (PNNL-14187, *Hanford Site Groundwater Monitoring for Fiscal Year 2002*), but not during 2011. Well 199-N-3 is near Well 199-N-18 and has been influenced by contamination from the same source in the past. Near the N Reactor building, Well 199-N-16 has also had evidence of petroleum contamination, which is believed to be from a separate past source (184-N day tank spills). Well 199-N-16's concentration was just above the detection limit in 2010, but it was nondetect for total petroleum hydrocarbon-diesel range in 2011.

In 2011, DOE continued passive remedial actions to remove free product from well 199-N-18 in accordance with the interim action ROD (EPA/541/R-99/112). Passive remediation involves the use of a polymer "smart sponge" that selectively absorbs petroleum products from the surface of the water within the well. Every two months, two of the smart sponges are lowered onto the surface of the aquifer in Well 199-N-18 and left in place to soak up the diesel fuel. The smart sponges are weighed prior to placement in the well and again after removal. The weight difference between the two measurements is the amount of product, or diesel fuel contamination, removed from the well. Table 4-4 shows the results of this remediation activity since it began in 2003 through the end of 2011.

As part of the RI/FS process, Well 199-N-183 was drilled to replace 199-N-18 as a monitoring well (Section 4.7 of DOE/RL-2008-46-ADD5). This decision was made for two reasons: (1) the low water level in Well 199-N-18 makes sampling difficult and requires the use of a bailer, and (2) the inability to completely remove material from a broken smart sponge from the well will cause long-term potential for interference with sampling and the quality of samples that can be collected (Section 6.1.4 of DOE/RL-2011-01). Well 199-N-18 was kept for continued product removal because that particular process is not affected by the residual smart sponge material on the well casing.

Aquifer tubes near Wells 199-N-173 and 199-N-96A along the 100-NR-2 shoreline are sampled for petroleum hydrocarbons. In 2011, two aquifer tubes also had detections for total petroleum hydrocarbon-diesel range: N116mArray-0A (360 µg/L) and C6135 (160 µg/L) (Figure 4-21). These samples were collected in mid-September 2011 when the river level was low. Diesel contamination is

more likely to be upwelling into the river under these conditions because groundwater flows into the river.

## 4.3 Strontium-90 Treatment Technologies

Different treatment technologies have been tested at the 100-N Area:

- Apatite and apatite-forming injections by two methods (groundwater/vadose zone well injections and jet injection of the vadose zone)
- Apatite-forming infiltration galleries
- Phytoextraction

The current active method is discussed in the first two sections, and reports on the performance of the other three methods are discussed in the third section.

### 4.3.1 Performance Monitoring of Original Apatite Permeable Reactive Barrier

DOE agreed to construct and evaluate the effectiveness of a permeable reactive barrier for strontium-90 using apatite sequestration technology as part of the CERCLA RI/FS process, which is consistent with the interim remedial action ROD for the 100-NR-1 and 100-NR-2 OUs (EPA/541/R-99/112) and the Tri-Party Agreement (Ecology et al., 1989) Change Control Form M-16-06-01. Strontium-90 sequestration using this technology occurs by injecting a calcium-citrate-phosphate solution into the aquifer. After the solution is injected, biodegradation of the citrate results in apatite (a calcium phosphate mineral [$Ca_5(PO_4)^3(F, Cl, OH)$]) precipitation. Strontium-90 (and strontium) ions in groundwater substitute for calcium ions via cation exchange and eventually become trapped as part of the mineral matrix during apatite crystallization (Section 1.3 of PNNL-16891).

The original apatite treatability test site covers approximately 90 meters along the Columbia River shoreline (Figure 4-3). In total, 45 monitoring points are associated with this site, including injection/barrier wells, monitoring wells, and aquifer tubes. A total of 16 wells comprises the actual permeable reactive barrier. Four monitoring wells are parallel to the barrier between the river and the injection/barrier wells. Two pilot test sites (PT#1 and PT#2) are at each end of the barrier (around the two end injection/barrier wells) and contain smaller diameter monitoring wells surrounding the individual end injection/barrier wells.

Strontium-90 contamination in the 100-N Area is primarily absorbed to sediments by ion exchange in the lower vadose zone and upper portion of the unconfined aquifer. Approximately 99 percent of the strontium-90 is absorbed and 1 percent remains in solution in the groundwater. Although primarily absorbed, some strontium-90 is mobilized by seasonal water level increases that remove strontium-90 from sediments not previously in contact with groundwater (PNNL-16891). DOE injected apatite-forming solutions into the Hanford and Ringold Formations over a period of 3 years (from 2006 through 2008). Performance monitoring at the existing apatite barrier was performed twice in 2011, with high river stage sampling in May and June, and low river stage sampling in November. Since injections ceased in July 2008, strontium-90 and gross beta concentrations have declined steadily in the sampled wells, with very few exceptions. As of November 2011, the strontium-90 and gross beta values were considerably less in all wells and aquifer tubes monitored along the barrier than before the injections started. All of the wells have shown an approximately 90 percent decline in gross beta from the measured pre-injection values.

Figure 4-17 provides the strontium-90 contours for the original apatite permeable reactive barrier. Figure 4-18) shows the gross beta[1] concentrations in the most contaminated portion of the 100-N Area shoreline. The scale on Figure 4-18 is logarithmic to make it easier to see the 90 percent decrease that has occurred in the treated wells and Monitoring Well 199-N-122. This set of four wells consists of a monitoring well (199-N-122) and two injection wells (Well 199-N-162 screened only in the Ringold Formation, Well 199-N-144 screened across the Hanford formation and Ringold Formation), and one monitoring well behind the barrier (199-N-46 screened in the top of the unconfined aquifer). All four wells showed high strontium-90 concentrations following the injections in 2008. The high-concentration apatite injection solution had a higher ionic strength than groundwater. When the fluid was initially injected, it temporarily mobilized cations and anions, causing their concentrations in groundwater to increase. Over time, the concentration of gross beta began to decline, which is most evident in injection well 199-N-162. The injection wells show more fluctuation in gross beta values, but all four wells show much lower concentrations of gross beta than concentrations prior to injections in 2008. Well 199-N-46, which historically has had high levels of gross beta, is starting to slowly trend downward since treatments began.

Concentrations of strontium-90 and gross beta began to increase slightly in 2010 (Figure 4-18). This trend was occurring in more locations in 2011. At some point, additional injections will need to occur in the existing permeable reactive barrier, based on data presented in the two reports on the initial low-concentration and high-concentration injections (PNNL-17429, *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injections for In Situ Strontium-90 Immobilization*; PNNL-19572) and the follow-up report on barrier performance progress (PNNL-20252, *100-NR-2 Apatite Treatability Test: An Update on Barrier Performance*).

Injections for the existing barrier will occur as budget and schedule allow within the next few years. Semiannual performance monitoring (high and low river stages) will continue for the existing barrier until those injections occur, at which time a revised performance monitoring schedule will be initiated. Table 4-5 shows the monitoring points for the apatite barrier and indicates which locations are currently being used to cover the treated portions of the barrier.

### 4.3.2 Expansion of the Apatite Permeable Reactive Barrier

Apatite barrier extensions were installed in fall 2011 and included injection wells along an additional 100 m (328 ft) on each end of the original barrier. DOE performed the work under a design optimization study (DOE/RL-2010-29) and the 100-NR-2 remedial design/remedial action work plan (DOE/RL-2001-27, Rev. 1, when issued). Table 4-6 lists all the apatite permeable reactive barrier injection wells and shows which sections have been treated as of 2011.

The injections were performed using a two-step process, where the deeper Ringold Formation wells are injected first and then the overlying Hanford formation wells are injected second. These staggered injections overlay each other and maximize the coverage in the upper unconfined aquifer and lower vadose zones. The formulation for these injections was the high-concentration calcium-citrate-phosphate solution amendment that was tested in 2008.

The goals of the study were as follows (DOE/RL-2010-29):

1. Refine the application of high-concentration calcium-citrate-phosphate solution over a large scale.

[1] Strontium-90 is a beta-emitter. Gross beta concentrations are approximately two times the strontium-90 concentrations.

2. Test the effectiveness of high-concentration calcium-citrate-phosphate injection in previously untested sediment to compare with areas that received sequential injections of low- and then high-concentration injections.
3. Test the new well design installed under *100-NR-2 Groundwater Operable Unit Sr-90 Plume Rivershore Sampling and Analysis Plan* (DOE/RL-2009-32) to evaluate the adequacy of injection solution delivery to the target zone.
4. Test and optimize operation of the new injection system to verify that the system can deliver the designed injection solution flow volume at multiple well locations.
5. Determine whether the new well design and injection system can complete chemical injections at various river stages, thereby eliminating the need for injections during specific river levels.
6. Further evaluate the high-concentration calcium-citrate-phosphate solution impact on the release of strontium-90 and other metals from previously untreated sediments to groundwater.
7. Evaluate the permeable reactive barrier to assess whether it can achieve up to a 90 percent reduction in strontium-90 flux to the Columbia River.

The first five objectives were adequately tested, and to date, they have been met (DOE/RL-2012-02). The sixth objective is being tested in 2012 as samples are collected to determine how long the release of strontium-90 and other metals takes after injections. Initial samples were collected for 1 month after injections, with the first set collected immediately after injections ceased. The second set was collected after 2 weeks, and the third set was collected after 1 month. At the end of a month, the strontium-90 and metal levels were almost back to pre-injection levels. The spring 2012 sampling event is scheduled for more than six months after the end of 2011 injections. The last objective will require the collection of data over the next few years to determine whether a 90 percent reduction of strontium-90 has occurred in the permeable reactive barrier monitoring wells. Semiannual performance monitoring (high and low river stages) will begin for the barrier extensions in 2012. Table 4-5 shows the monitoring points for the apatite barrier and indicates which locations are currently being used to cover the treated portions of the barrier.

Overall, the upriver and downriver barrier expansions worked very well, and it appears from the initial data that good coverage of the groundwater and lower vadose zone were achieved. In addition, the high-concentration injection formulation performed well according to initial sample results.

### 4.3.3 Other Strontium-90 Treatment Technologies

Several different types of strontium-90 treatment technologies are being evaluated at 100-NR-2 in addition to the current permeable reactive barrier. Several types of treatment are needed to address the entire zone of contamination effectively. The existing barrier has treated groundwater and the lower vadose zone, but it has not treated the upper vadose zone and near-shore riparian zone. No additional work on these technologies occurred in 2011. The following reports provide additional information on these technologies from previous investigations:

- **Jet Injection** – SGW-47062, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*
- **Infiltration Gallery** – PNNL-20322, *100-NR-2 Apatite Treatability Test: Fall 2010 Tracer Infiltration Test*
- **Phytoextraction** – PNNL-19120, *100-N Area Strontium-90 Treatability Demonstration Project: Phytoextraction Along the 100-N Columbia River Riparian Zone – Field Treatability Study*

Of the other technologies tested, two of the three show potential for further application in treatment of the strontium-90 contamination along the shoreline. Passive infiltration did not prove to be a viable method for emplacement of apatite-forming chemicals along the 100-N Area shoreline, but it may be applicable in other locations. Jet injection tests performed in December 2009 showed that the technology can effectively place apatite or apatite-forming chemicals into the upper vadose zone, with good coverage. Jet injection technology is a good follow-up treatment to the groundwater and lower vadose zone injections. It can treat the entire vadose zone and reach the currently untreated upper vadose zone. Phytoextraction has been demonstrated to remove strontium in the riparian zone in the tests done at 100-K.

## 4.4 Characterization of Petroleum Contamination

### 4.4.1 Vadose Zone

Throughout its operational history, the 100-N Reactor and support facilities had UPRs, spills, and discharges of petroleum products. These were documented in unplanned release reports. Several of the releases at the 100-N Area resulted in petroleum hydrocarbons being introduced into the soil column/vadose zone, groundwater, and the Columbia River. The types of releases included the following: 1) corrosion failure of diesel and fuel oil piping systems, 2) overfilling of storage facilities, and 3) spills during fuel transfers. Two of the releases were substantial and extended through the vadose zone and into groundwater. Estimates made in reports at the time of operation indicate that up to 39,000 $m^3$ (1,377,272 $ft^3$) of soil was contaminated with petroleum hydrocarbons (Section 1.1 of WCH-323, *Sampling and Analysis Instruction for Installation of UPR-100-N-17 Bioremediation Wells and Performance of Bioventing Pilot Tests*). The releases occurred in two general areas and in a few other isolated places, so the releases were divided in three groups based on where they occurred. Group 1 includes releases near the 1715-N Storage Tanks and 166-N Transfer Areas (166-N Tank Farm). Figure 4-22 shows this location and the nearby Monitoring Well 199-N-18. Group 2 includes releases around the 184-N Day Tank Storage Facility. Monitoring Well 199-N-16 monitors this location. Group 3 includes miscellaneous other sites. Table 4-7 shows these three groups and the releases associated with them.

In 2007, Washington Closure Hanford issued an engineering study for evaluating the use of bioremediation on the petroleum hydrocarbon contaminated soil (WCH-158, *100-N Area Bioremediation Engineering Study*). A sampling and analysis plan was issued in 2008 (WCH-323). As part of this effort, Washington Closure Hanford installed seven bioremediation wells to perform bioremediation/bioventing pilot tests in early 2009. The seven wells were completed as two vadose zone wells and five groundwater wells that were completed with the screen at the top of the unconfined aquifer. The wells installed for this study are listed in Table 4-8. During the installation of these wells, samples were taken to characterize the area to be treated in the bioremediation tests. Washington Closure Hanford used the information gathered during the well drilling and installation process to create a site conceptual model and cross section for the study area (Figure 4-23). This figure is included as information for this section and to show the general nature of the sediments in the area of the diesel plume. A summary of the relevant lithologic properties for the test site (UPR-100-N-17) follows:

1. The Hanford formation is approximately 13.7 m (45 ft) thick throughout the drilling area, and the contact with the Ringold Formation is unconformable as expected.
2. Minor stringers of clay and silt were noted in the drill cuttings from both formations.
3. A 0.3 m (1 ft) lens of silt was noted from 16.2 to 16.5 m (53 to 54 ft) below ground surface (Ringold Formation) in the borehole for Well 199-N-171.

4. A 0.15 m (0.5 ft) thin bed of silt was noted at 15.5 m (51 ft) below ground surface (Ringold Formation) in the borehole for Well 199-N-172. Another thin bed of silt was encountered at 18.0 m (59 ft) below ground surface.

5. Intermittent zones of caliche and carbonate deposits were noted in the drilling cuttings from both formations.

6. Zones of cementation were noted in the Ringold Formation; the depths were random and noted between 13.7 to 23.8 m (45 to 78 ft) below ground surface.

7. A 1.5 to 2.1 m (5 to 7 ft) thick bed of fine- to coarse-grained sand (Ringold Formation) was contiguous in the study area and ranged in depth from approximately 19.2 to 21.5 m (63 to 70.5 ft) below ground surface.

The overall lithology of the study area was dominated by silty-sandy gravels in the upper vadose zone and sandy gravels, silty-sandy gravels, and sand in the lower portion of the vadose zone. Most lithologies correlated well between the boreholes, but there were intermittent lenses of discontinuous materials (WCH-370, *Bioremediation Well Borehole Soil Sampling and Data Analysis Summary Report for the 100-N Area Bioremediation Project (UPR-100-N-17)*).

Sample results from the well installation are summarized below:

1. **Microbes** – Soil microbes capable of digesting and breaking down petroleum hydrocarbons were detected at all locations. The estimate of the size of the soil community is between 100 and 1,000 colony-forming units per gram (CFU/g) of soil.

2. **Total Petroleum Hydrocarbons, Oil and Grease** – All boreholes were sampled for total petroleum hydrocarbon-diesel range, total petroleum hydrocarbon-gasoline range, and oil and grease. All three analyses were positive in all boreholes and at levels above the cleanup level of 200 mg/kg.

3. **Moisture Content** – Some correlation of moisture zones was found between boreholes and was related to lithology (silty soil versus sandy soil). Moisture content increased with depth as the water table was approached and as higher levels of total petroleum hydrocarbons were encountered. The minimum result was 0.2 percent moisture by weight, and the maximum result was 10 percent moisture by weight. The average values fell within the range for bioremediation to occur.

4. **Organics** – All samples were below the current 100-N Area cleanup levels for direct exposure, protection of groundwater, and protection of the Columbia River. This indicates most of the volatile and semivolatile compounds have volatilized or degraded over time in the vadose zone at this location.

5. **Nitrogen** – Total Kjeldahl Nitrogen (TKN) method was used to determine total nitrogen available. The average TKN concentration was 28 mg/kg. This value is lower, but it has been reported as adequate to support bioremediation by EPA.

6. **Phosphorus** – Phosphorus was detected in all boreholes with an average of 543 mg/kg.

7. **pH** – Soil pH ranged from 6.6 to 9.2 with an average of 8.6. The average is near the upper end of the range that supports bioremediation, but the average will be sufficient. These values are in line with other 100-N Area studies and show that 100-N Area soil tends to be slightly alkaline.

8. **Metals** – All boreholes were sampled for RCRA metals. Metal toxicity to microorganisms and bacteriological processes can occur, but generally the effects are minimal as colonies adapt to their environment.

9. **Radionuclides** – All boreholes were sampled for radionuclides to see if levels were elevated for either man-made or naturally occurring background in soil. Radionuclide levels were determined to ensure worker safety and soil microbial activity. Several radionuclides were detected but at relatively low levels. Strontium-90 was present in all boreholes but at concentrations below the cleanup level of 4.5 pCi/g. The borehole for Well 199-N-171 had the highest concentration at 1.8 pCi/g.

All results can be found in WCH-370.

Bioremediation involves the use of microorganisms to degrade contaminants, with the goal of obtaining nonhazardous final products. The microorganisms produce natural catalysts (enzymes) that degrade organic compounds forming carbon dioxide, methane, water, and mineral salts. Enhanced bioremediation involves the introduction of nutrients (typically nitrogen and phosphate) and electron donors or acceptors (oxygen) to enhance the biodegradation provided by the naturally occurring microbes indigenous to the site. Water is also frequently introduced to the subsurface to bring soil moisture content into the optimum range for bioremediation. Upon the introduction of air, nutrients, and, if necessary, water into the subsurface, the population of indigenous microbes thrives and uses the total petroleum hydrocarbons as its food source.[2] The result is that the hydrocarbons are degraded aerobically, or oxidized, to carbon dioxide and water (WCH-323).

Installation of the seven wells listed in Table 4-8 identified zones of petroleum hydrocarbon contamination based on the sample results. All wells had high concentrations of petroleum hydrocarbons in a zone that started about 17 m (55 ft) below ground surface and extended to the groundwater table in the unconfined aquifer. The distance from Well 199-N-166 to the bioremediation well closest to the river (199-N-172) is approximately 61 m (200 ft). Well 199-N-172 is on the approximate azimuth as the currently accepted direction of the hydraulic gradient for groundwater in the unconfined aquifer. Because the petroleum hydrocarbon concentration did not noticeably decrease from Wells 199-N-166 to 199-N-172, it may be assumed the zone of petroleum hydrocarbon contamination extends beyond 61 m (200 ft) and may extend to the Columbia River. The full nature and extent of subsurface hydrocarbon impacts in the UPR-100-N-17 waste site have not been determined and are beyond the scope of the pilot tests performed at the 100-N Area (WCH-490).

Bioventing pilot tests were conducted from February 2010 through May 2011, to evaluate contaminant removal rates and the distribution of air flow within the contaminated zone. The tests consisted of the following: (1) collection of baseline measurements at the seven bioremediation wells, (2) a respirometry test, (3) an air injection/radius of influence test, and (4) a 6-month operational test period. The final report from these tests have been issued (WCH-490). The results of the Bioremediation Pilot Test at UPR-100-N-17 are as follows:

1. Overall microbial degradation of hydrocarbons is significantly enhanced through bioventing in the vadose zone, although oxygen utilization rates varied between monitoring wells.

2. The radius of influence for deep Injection Well DIW-1 (199-N-167) is at least 61 m (200 ft) under the testing conditions. Similar radius of influence values are expected for the other deep bioremediation wells at this site when air is injected at approximately 250 cubic feet per minute or higher.

3. Microbial degradation in the shallow Wells SIW-1 (199-N-166) and SMP-1 (199-N-168) was not measureable using protocols established for the testing. Baseline soil vapor levels for oxygen and

[2] The addition of water to the vadose zone is currently not anticipated for the application of this technology at the UPR-100-N-17 waste site.

carbon dioxide were at atmospheric concentrations. Therefore, it was not possible to determine an oxygen utilization rate (and oxygen is not a rate limiting factor).

4. Bioventing appears to be an effective and efficient method of promoting in-situ bioremediation in the deep vadose zone soil at the site. Depressed baseline oxygen levels are clearly a key rate-limiting factor. Even at moderate air flow rates, bioventing has been shown to affect a large area around injection wells, suggesting the soils are relatively permeable to air flow.

Based on the results of the pilot study, bioventing may provide a method for enhancing in-situ bioremediation of deep soil contaminated with hydrocarbons at the UPR-100-N-17 waste site. The data from this test will support the design of the Phase II testing for this waste site (WCH-490).

### 4.4.2 Groundwater

If present in large enough quantities, the diesel in groundwater is found in the very top of the aquifer or floating on top of the water table (Section 4.4 of DOE/RL-2011-25, *Calendar Year 2010 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and 100-NR-2 Groundwater Remediation*). During the drilling of Well 199-N-173, which sits on the shoreline below Well 199-N-18, vertical profile samples were collected from the vadose zone and groundwater (Figure 4-2). These samples confirmed the location of the diesel contamination in the lower vadose zone above the water table and in the top few feet of the unconfined aquifer. Figure 4-21 shows the petroleum hydrocarbon-diesel range plume as it currently exists in the 100-N Area. It is clear from the shape and direction of the plume that the main source of contamination is the 166-N Tank Farm. The plume is moving toward the Columbia River and intersects the river by aquifer tubes N116mArray-0A and C6135. Several wells and aquifer tubes in the 100-N Area have had detections of petroleum hydrocarbons in the past. Appendix D of *Investigation of the Strontium-90 Contaminant Plume along the Shoreline of the Columbia River at the 100-N Area of the Hanford Site* (PNNL-16894) discusses evidence for this contamination. Low levels (less than 1 mg/L) of total petroleum hydrocarbon-diesel range were reported in several aquifer tubes around N116m-Array 0A. Workers observed small amounts of oil sheen during installation of these tubes in January 2007. During drilling of monitoring wells for the apatite permeable reactive barrier in 2005, diesel product was recovered from Wells 199-N-122 and 199-N-123 (WMP-27771, *Borehole Summary Report for Wells 199-N-122 (C4954) and 199-N-123 (C4955); 100-NR-2 Operable Unit*).

The seven wells for the Bioremediation Pilot Study were drilled in early 2009. Groundwater samples were collected from the five wells completed in the top of the unconfined aquifer. Table 4-9 gives the total petroleum hydrocarbon-diesel range results from these wells for samples taken from 2009 through 2011. Well 199-N-173 was also drilled in early 2009 for characterization of the near-shore petroleum hydrocarbon plume and for testing petroleum hydrocarbon remediation technologies. The well is approximately 120 m (394 ft) southwest (upriver) of the original apatite permeable reactive barrier and on the shoreline immediately below Well 199-N-18. Well 199-N-173 also serves as the last upriver monitoring well for the apatite barrier upriver extension. Samples were collected from this well when it was drilled in February 2009 and four times since. Total petroleum hydrocarbon-diesel range organics were detected in Well 199-N-173 from 2009 through 2010. The 2011 sample result was below detection for total petroleum hydrocarbon-diesel range. Several wells drilled for the apatite barrier upriver extension also had detections of total petroleum hydrocarbon-diesel range. Table 4-10 gives the total petroleum hydrocarbon-diesel range results in the known area of the diesel plume for selected other sampled wells and aquifer tubes. Table 4-11 provides the total petroleum hydrocarbon-diesel range results for the upriver apatite barrier extension injections and monitoring wells that were collected after well acceptance in 2010.

Total petroleum hydrocarbon-diesel range concentrations in wells in the plume were altered very dramatically between 2010 and 2011 by the Bioremediation Pilot Study. Concentrations of total petroleum hydrocarbon-diesel range organics dropped to below detection limits in several of the groundwater monitoring wells in the plume. The large amount of air introduced into the deep vadose zone caused an area of decreased or absent petroleum hydrocarbons in groundwater near the well screens. Of the 13 wells near the test area, 9 had dramatic changes in measured total petroleum hydrocarbon-diesel range concentrations. Eight of the nine had decreases, with all but two dropping to below the detection limits. One well on the outer fringe of the test area increased from nondetect to detect. It appears that the increased air flow and oxygen levels displaced or decreased the hydrocarbons near the well screens. It is uncertain whether the decreases in concentration will be long-term. No samples are planned to be collected from the bioremediation wells (199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172) in the near future, so total petroleum hydrocarbon concentrations in groundwater will only be available from the 100-N Area CERCLA monitoring wells. Only continued monitoring will determine whether these decreased levels are an indicator of actual groundwater cleanup or just an artifact of the testing.

## 4.5 Conclusions

Conclusions for the 100-NR-2 OU are as follows:

- **Remedial Action Objective (RAO) #1:** Protect the Columbia River from adverse impacts from the 100-NR-2 OU groundwater so that designated beneficial uses of the Columbia River are maintained.

  **Result:** The permeable reactive barrier has been increased from 90 m (300 ft) to approximately 292 m (950 ft) long; the remainder of the extensions are future work.

- **RAO #2:** Protect the unconfined aquifer by implementing remedial actions that reduce concentrations of radioactive and nonradioactive contaminants in the unconfined aquifer.

  The P&T system was not effective at reducing strontium-90 flux to the Columbia River; therefore, the P&T system was placed in cold-standby status on March 9, 2006, when the pumps were shut off. The effects of the pump shutdown are summarized below.

  **Results:**

  – Strontium-90 concentrations increased in the capture zone of some former P&T extraction wells after the pumps were shut off. The reason for this increase may be related to increasing aquifer elevations after the pumps were stopped. As the effects of the cone of depression decreased, samples were collected from a shallower, more contaminated interval within the aquifer, causing strontium-90 concentrations to increase sharply. Concentrations in three of the four former extraction wells are still trending upward; the rate is slower in two of the three wells than immediately after P&T operations ceased in 2006. The third well has seen a much larger increase. Concentrations in the fourth well are trending downward.

  – Strontium-90 concentrations in some aquifer tubes and wells temporarily increased near the apatite permeable reactive barrier in 2007 and 2008 in response to the apatite barrier emplacement injections. The concentrations in these aquifer tubes and wells are now lower than pre-injection levels by at least 90 percent. However, strontium-90 levels are currently above 8 pCi/L in these aquifer tubes.

  – The TPH concentrations decreased in 2011 with reinstallation of the smart sponges in Well 199-N-18 to remove 650 g (1.4 lb) of total petroleum hydrocarbons.

- **RAO #3:** Obtain information to evaluate technologies for strontium-90 removal and evaluate ecological receptor impacts from contaminated groundwater.

  **Results:**

  - DOE installed a 91.4 m (300 ft) apatite permeable reactive barrier near the Columbia River shoreline in 2006, 2007, and 2008. A jet injection test was performed along the shoreline with favorable results. The permeable reactive barrier has been increased from 90 m (300 ft) to approximately 292 m (950 ft); the remainder of the planned permeable reactive barrier extension to approximately 760 m (2,500 ft) will be performed as future work. Additionally, re-injections at the current 91.5 m (300 ft) permeable reactive barrier are needed and are planned following completion of the initial expansion efforts.

  - Several types of strontium-90 treatment technologies are being evaluated at 100-NR-2 in addition to the current permeable reactive barrier. Several types of treatment are needed to treat effectively the entire zone of contamination. The existing barrier has treated groundwater and the lower vadose zone, but it has not treated the upper vadose zone and near-shore riparian zone. No additional work on these technologies occurred in 2011.

- **RAO #4:** Prevent destruction of sensitive wildlife habitat. Minimize disruption of cultural resources and wildlife habitat, in general, and prevent adverse impacts to cultural resources and threatened or endangered species.

  **Results:**

  The interim remedial action ROD (EPA/ROD/R10-99/112) establishes a variety of institutional controls that must be implemented and maintained throughout the interim action period. These provisions include the following:

  - Access control and visitor escorting requirements

  - Signage providing visual identification and warning of hazardous or sensitive areas (new signs were placed along the river and at major road entrances at each reactor area)

  - Excavation permit process to control all intrusive work (e.g., well drilling and soil excavation)

  - Regulatory agency notification of any trespassing incidents

The primary goal is protection of the Columbia River with a remedial action goal of 8 pCi/L for surface water and groundwater. Successful implementation will support the goal of achieving a strontium-90 concentration of 8 pCi/L in the hyporheic zone and Columbia River water column by 2016.

## 4.6 Recommendations

The recommendations for the 100-NR-2 OU are as follows:

- Continue to monitor strontium-90 plumes, focusing on the portion of the plume near the Columbia River.

- Continue to evaluate the extent of possible shoreline water quality impacts related to the diesel spill that occurred in about 1966. Aquifer tubes at the upstream end of the array will continue to be sampled for total petroleum hydrocarbons and related contaminants. Work continues on characterizing and testing remediation technologies for the petroleum contamination plume.

Washington Closure Hanford is designing bioventing technology for UPR-100-N-17, based on tests performed in seven wells in 2010 and 2011.

- Continue apatite barrier expansion along the currently untreated portions of the shoreline by injecting high-concentration calcium-citrate-phosphate solution into the groundwater and the lower vadose zone in the manner described in the design optimization study (DOE/RL-2010-29).
- Continue using jet injection technology to treat the vadose zone above previously treated portions of the apatite barrier using the jet injection design optimization study proposed in *Jet Injection Treatability Test Plan for 100-NR-2 Groundwater Operable Unit* (DOE/RL-2010-68).
- Conduct phytoextraction contaminated zone test on the 100-N Area shoreline as proposed in PNNL-19120.

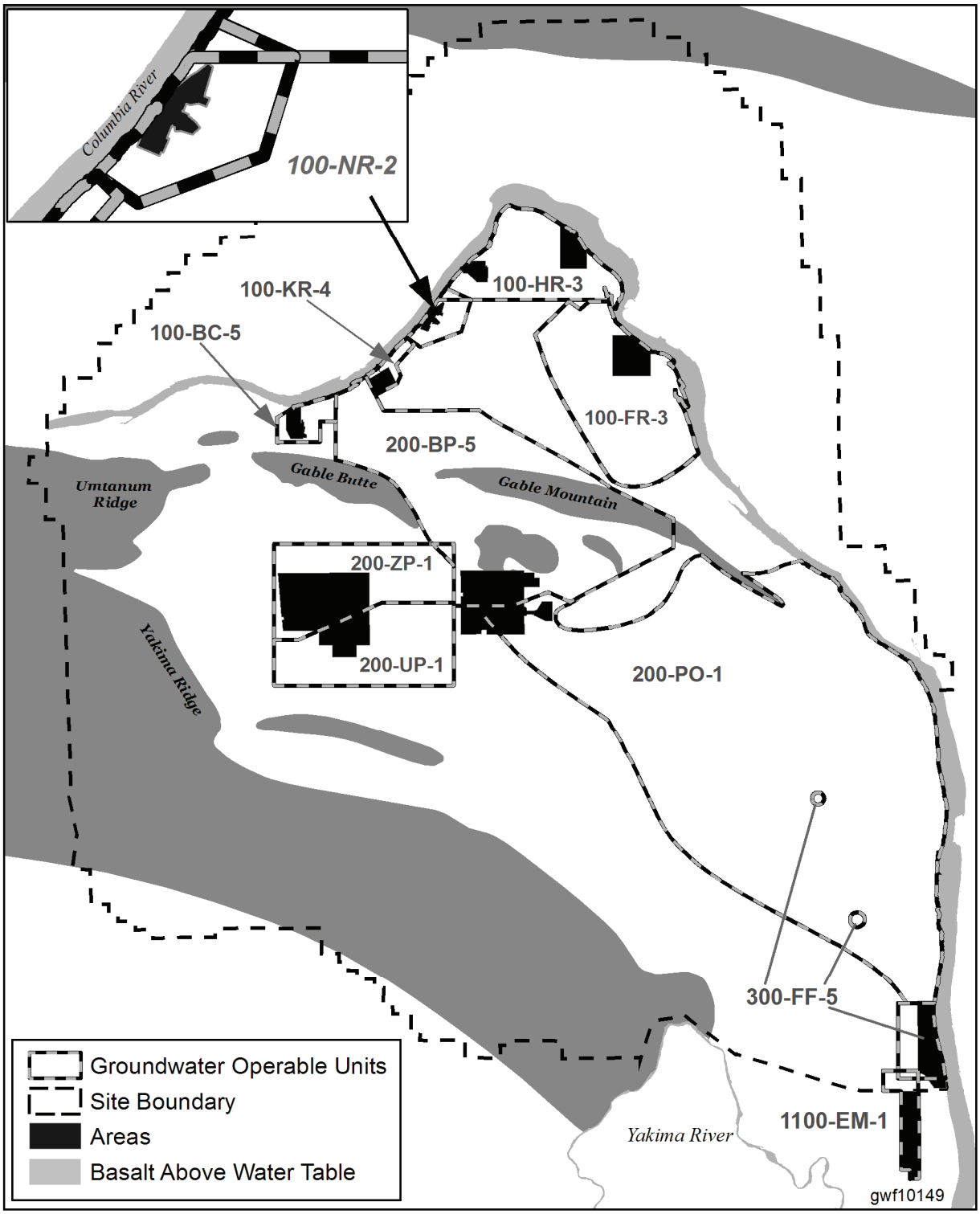



**Figure 4-1. 100-N OU Location**

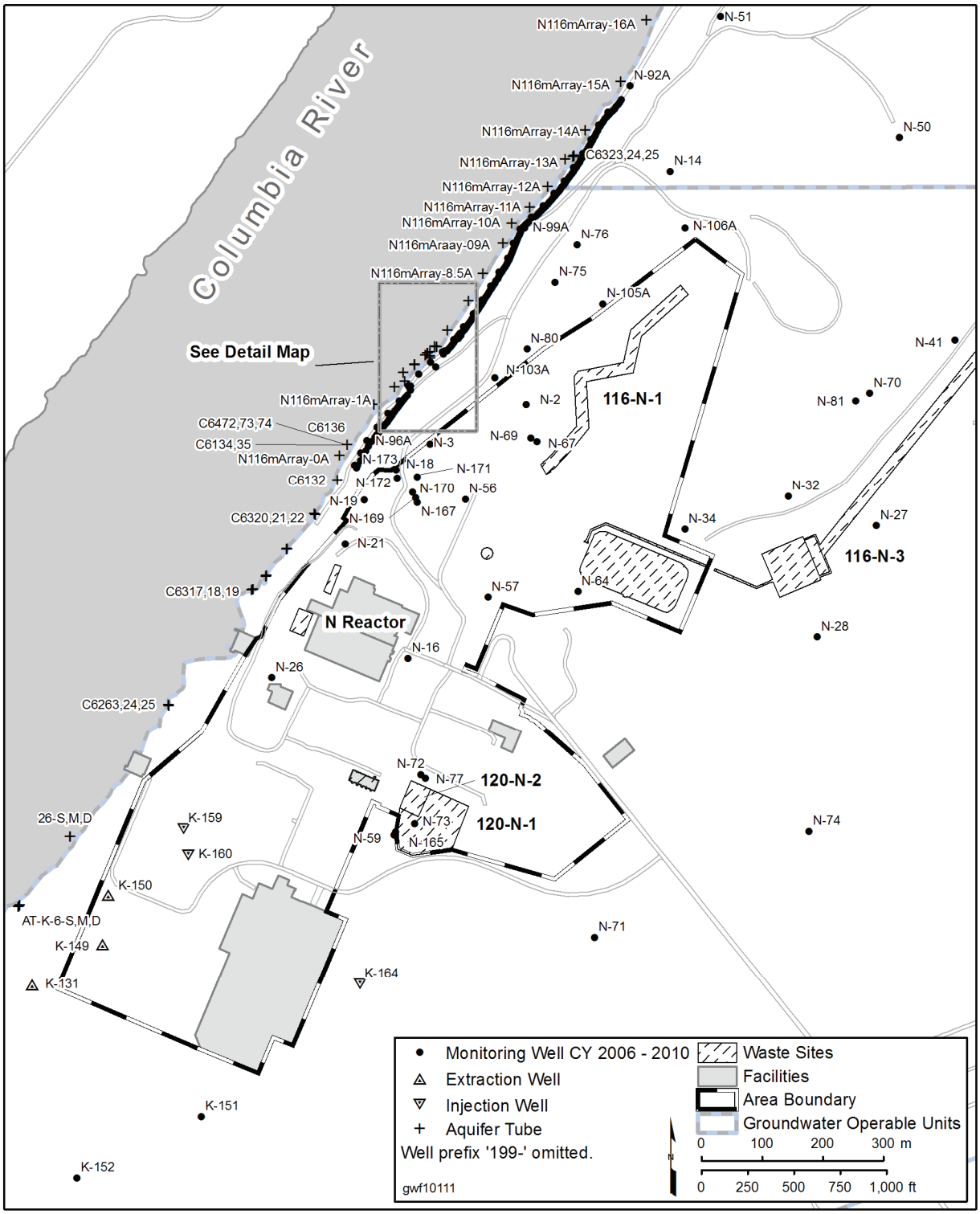



**Figure 4-2. 100-N OU Wells**

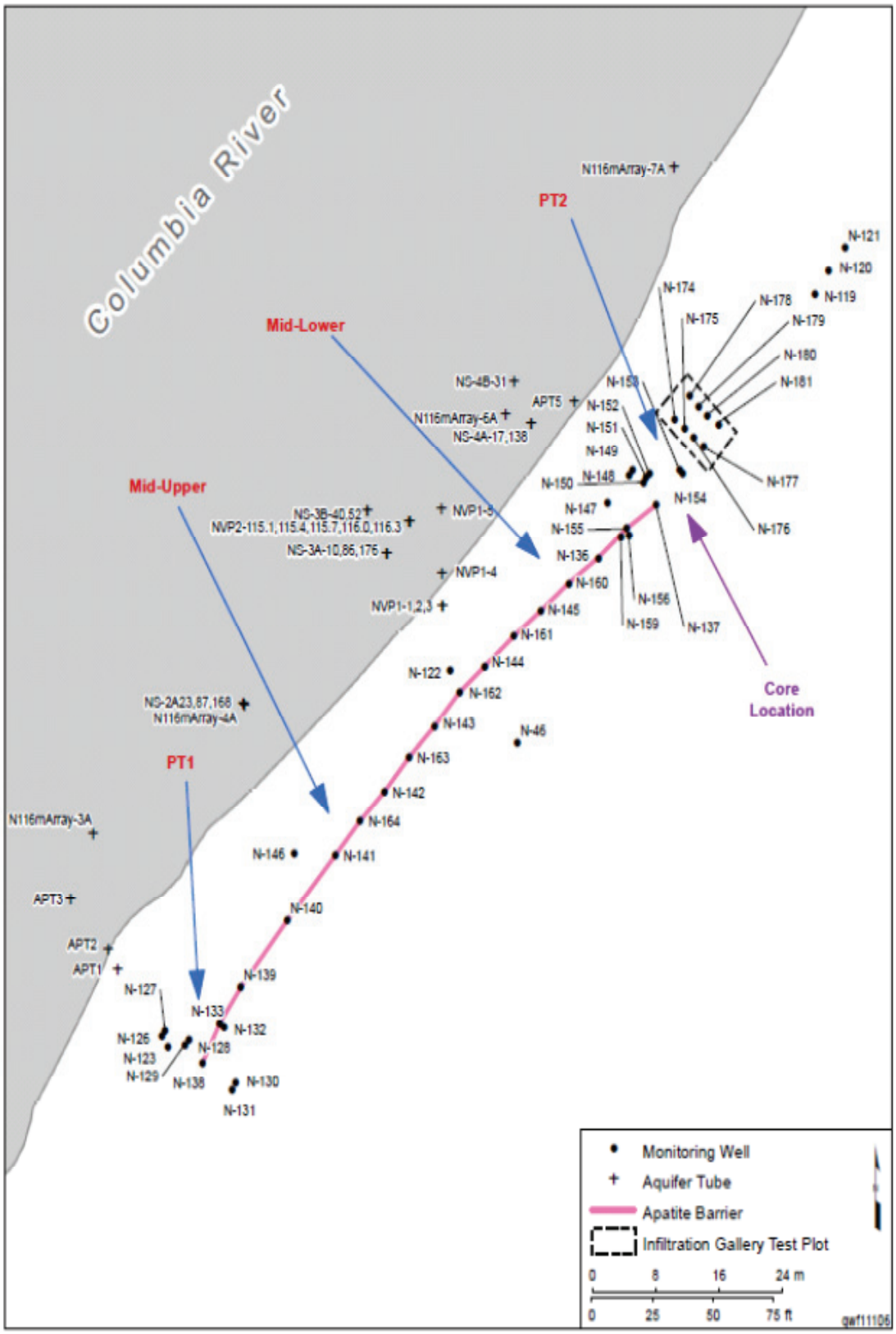



**Figure 4-3. Original Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline**

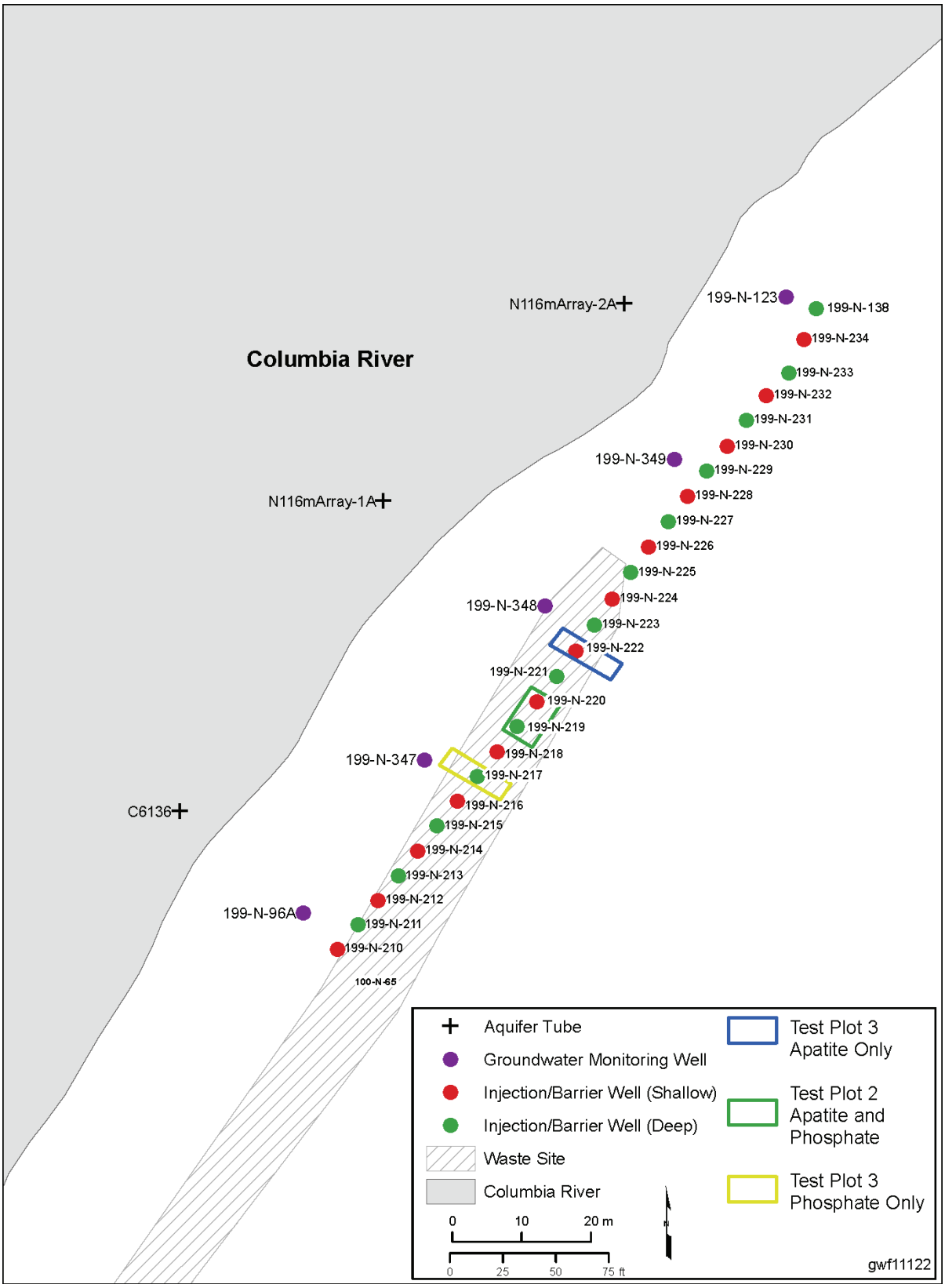



**Figure 4-4. Upriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline**

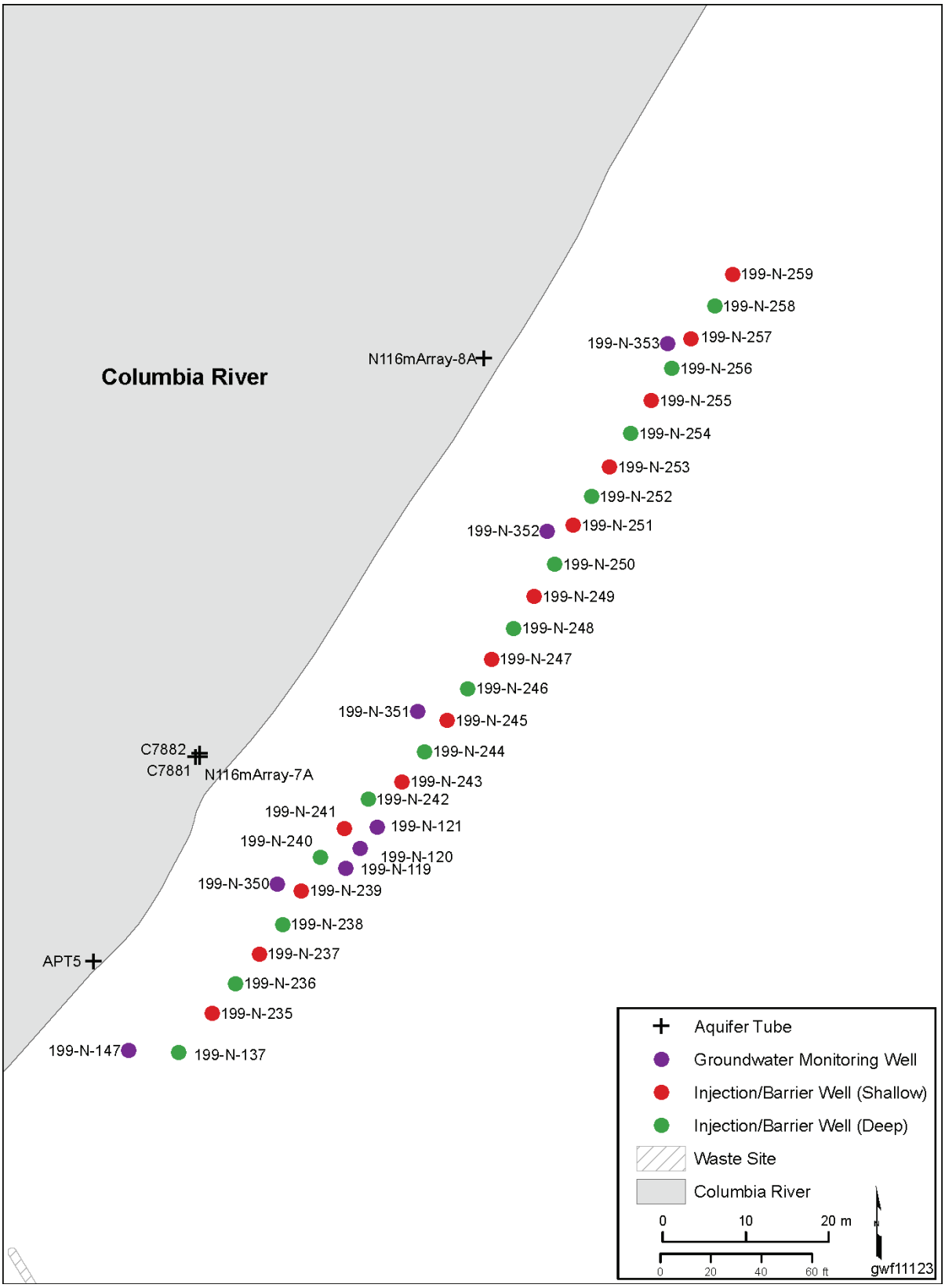



**Figure 4-5. Downriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline**

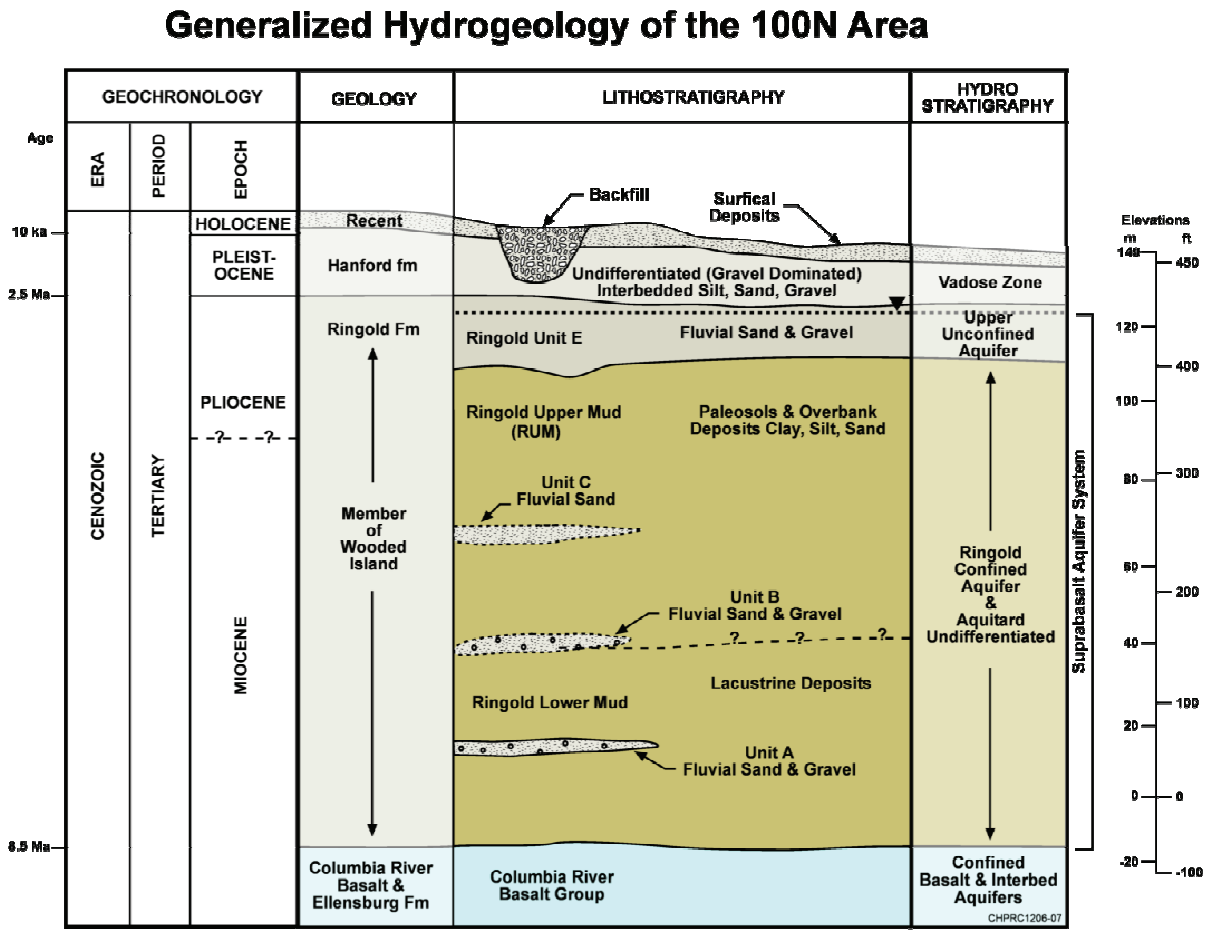



**Figure 4-6. Generalized Geologic Cross Section of 100-N OU**

# Ringold Formation Unit E Stucture Map

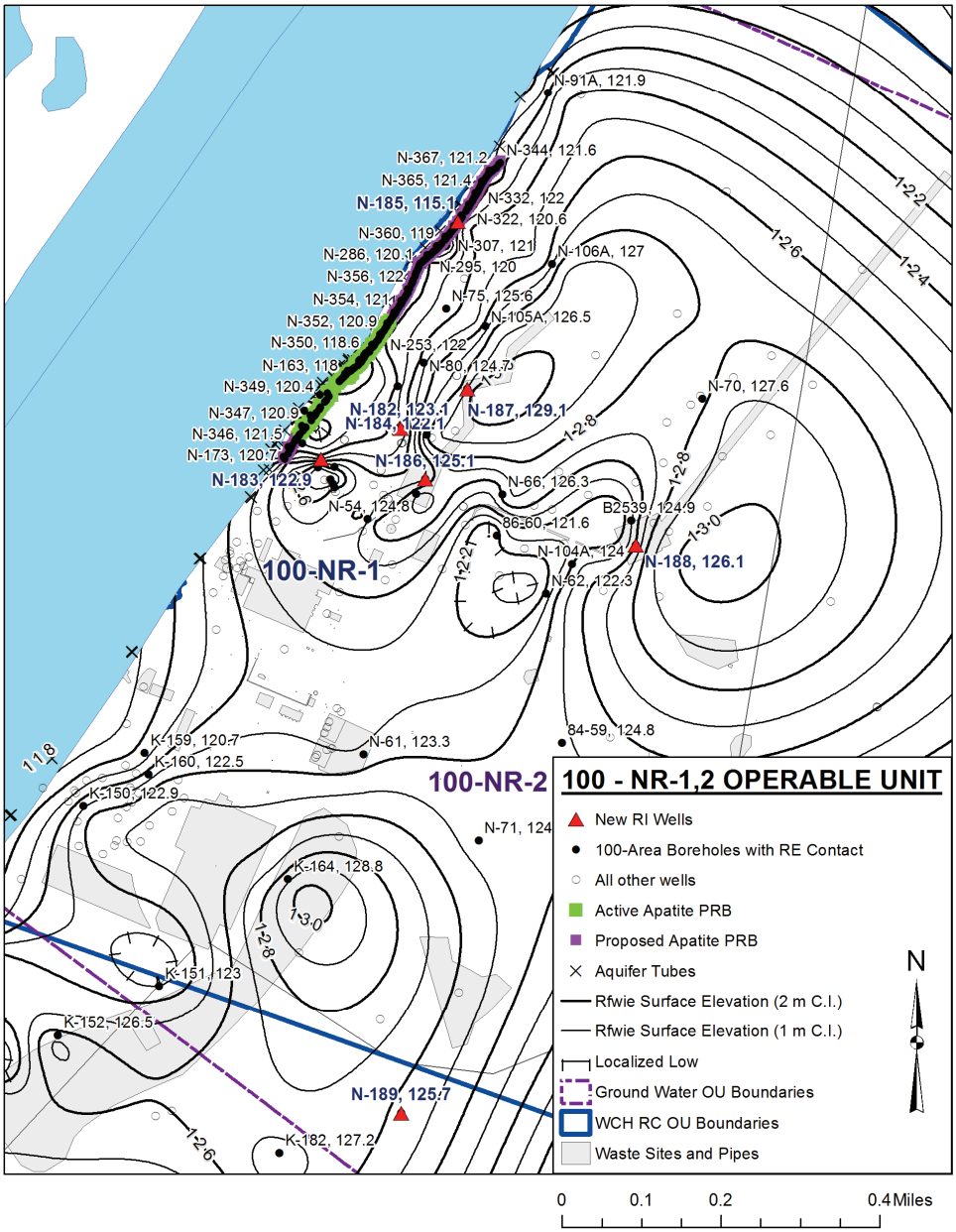



**Figure 4-7. Surface of the Hanford Formation / Ringold Unit E Contact**

# Ringold Formation Upper Mud (RUM) Stucture Map

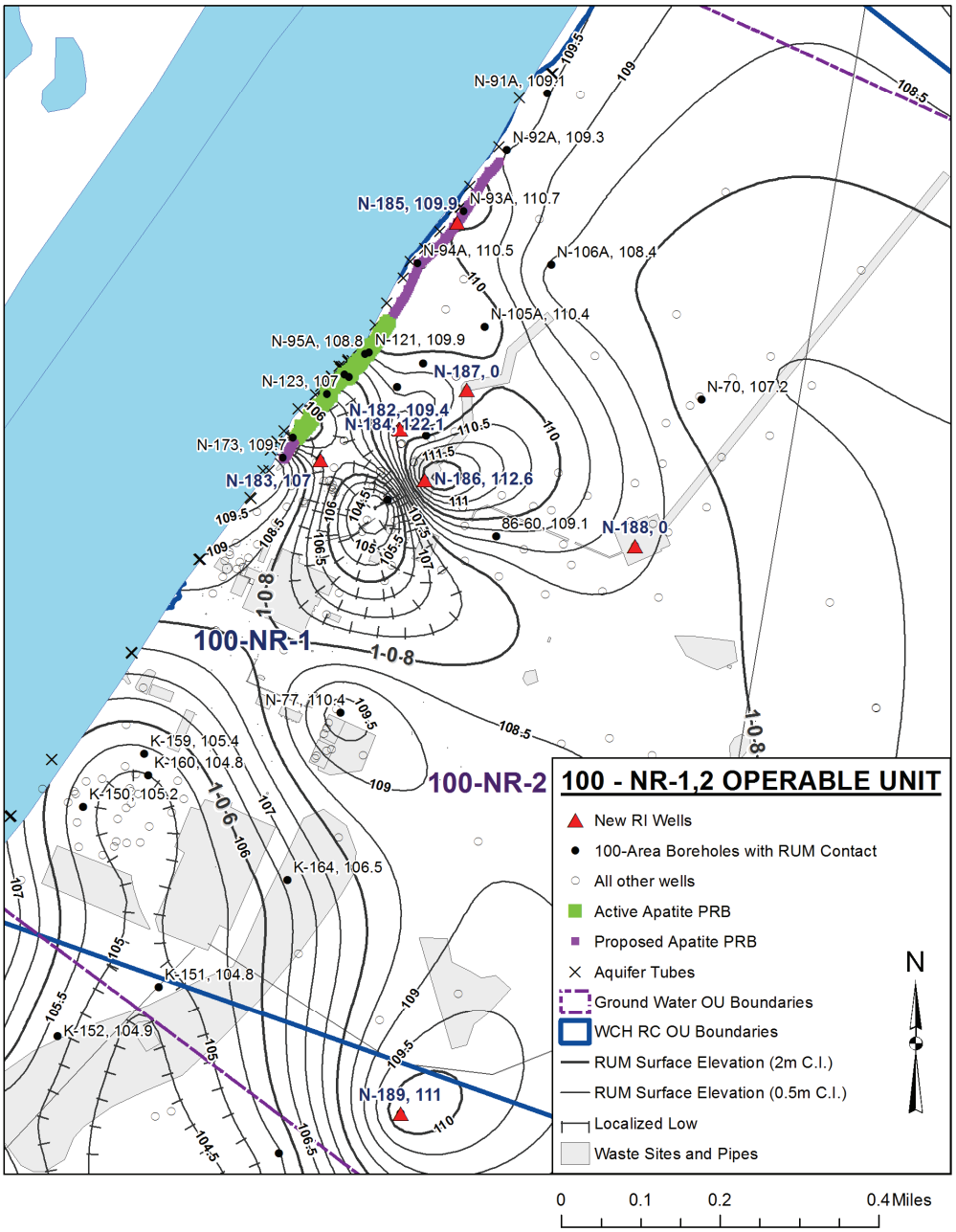



**Figure 4-8. Surface of the Ringold Unit E / Ringold Upper Mud Contact**

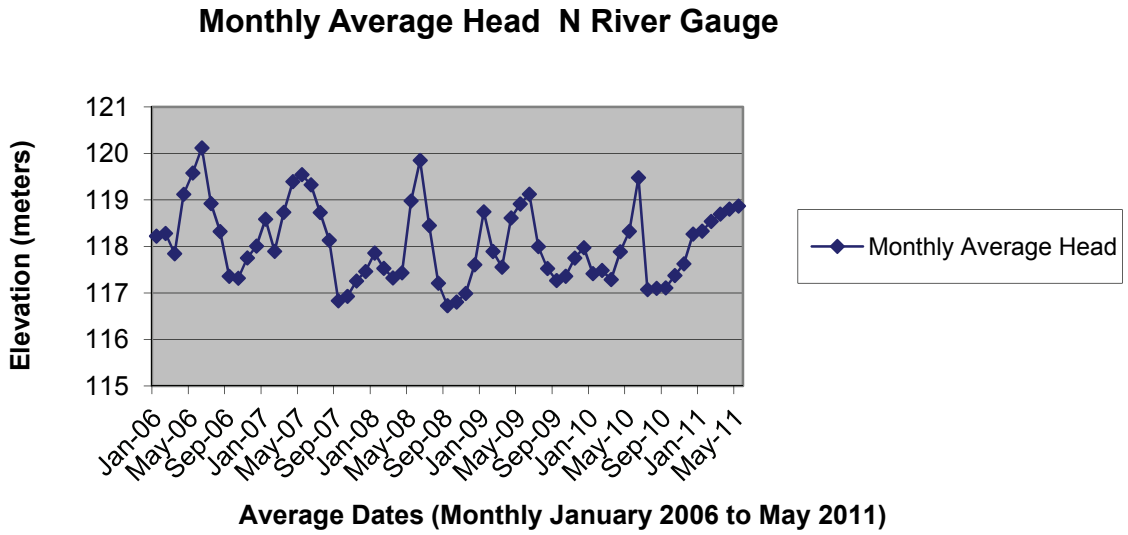



**Figure 4-9. Elevation of Columbia River at 100-N Area, 2006 to 2011**

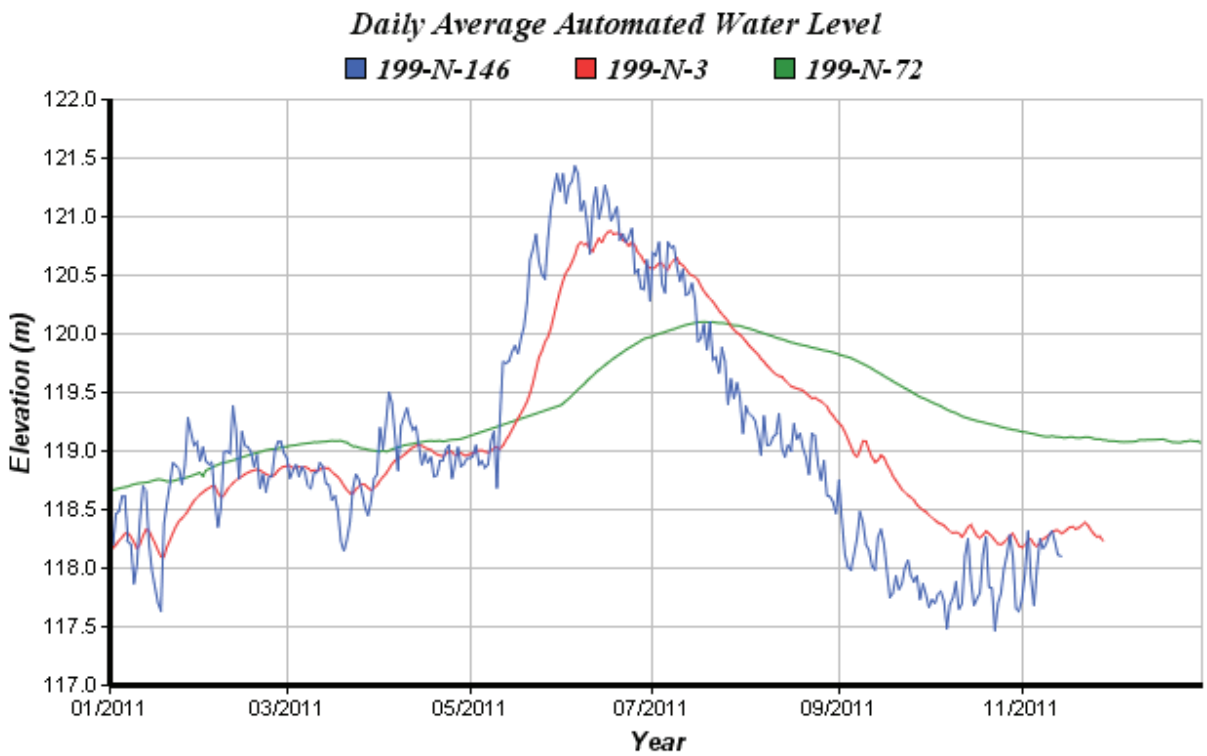
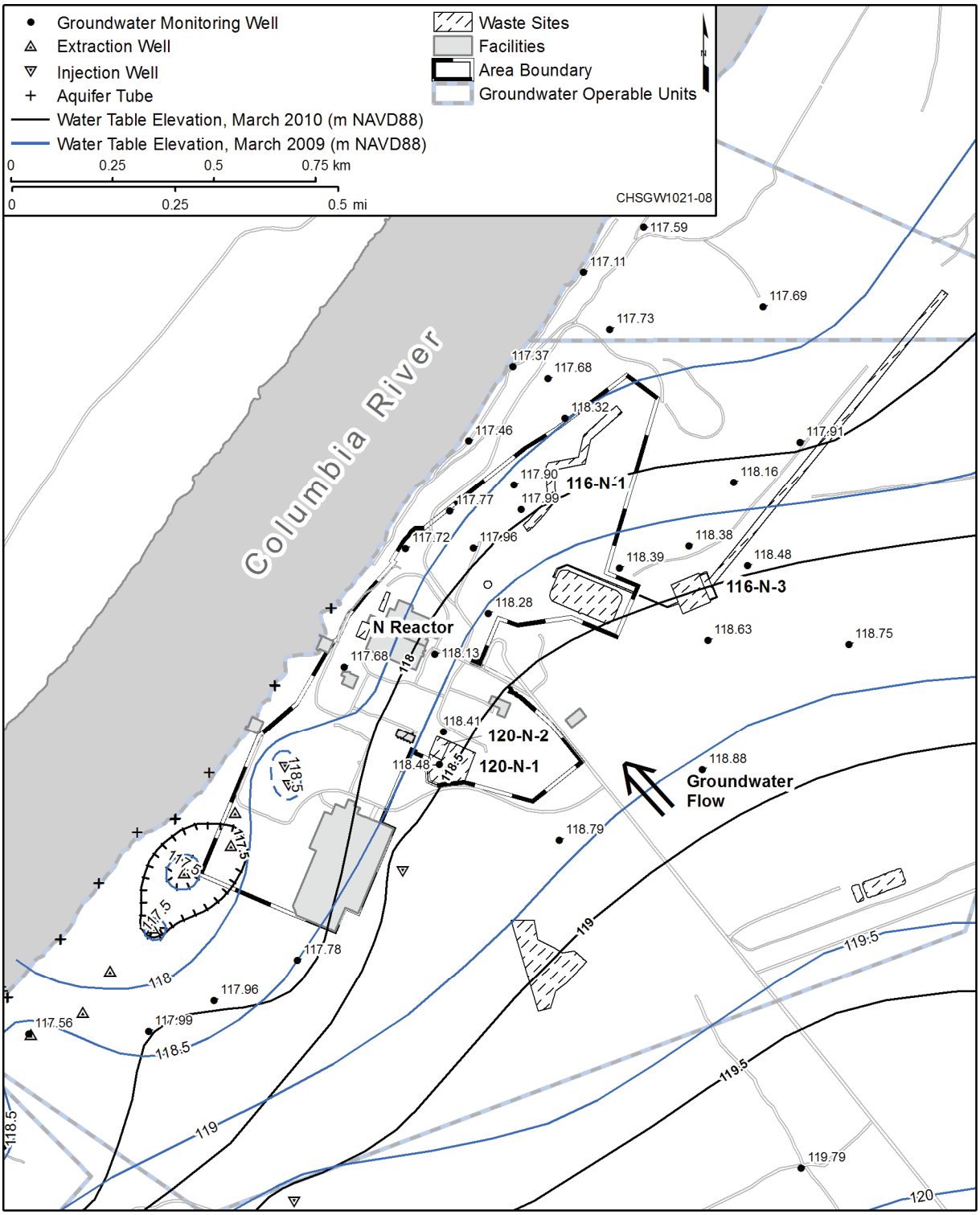
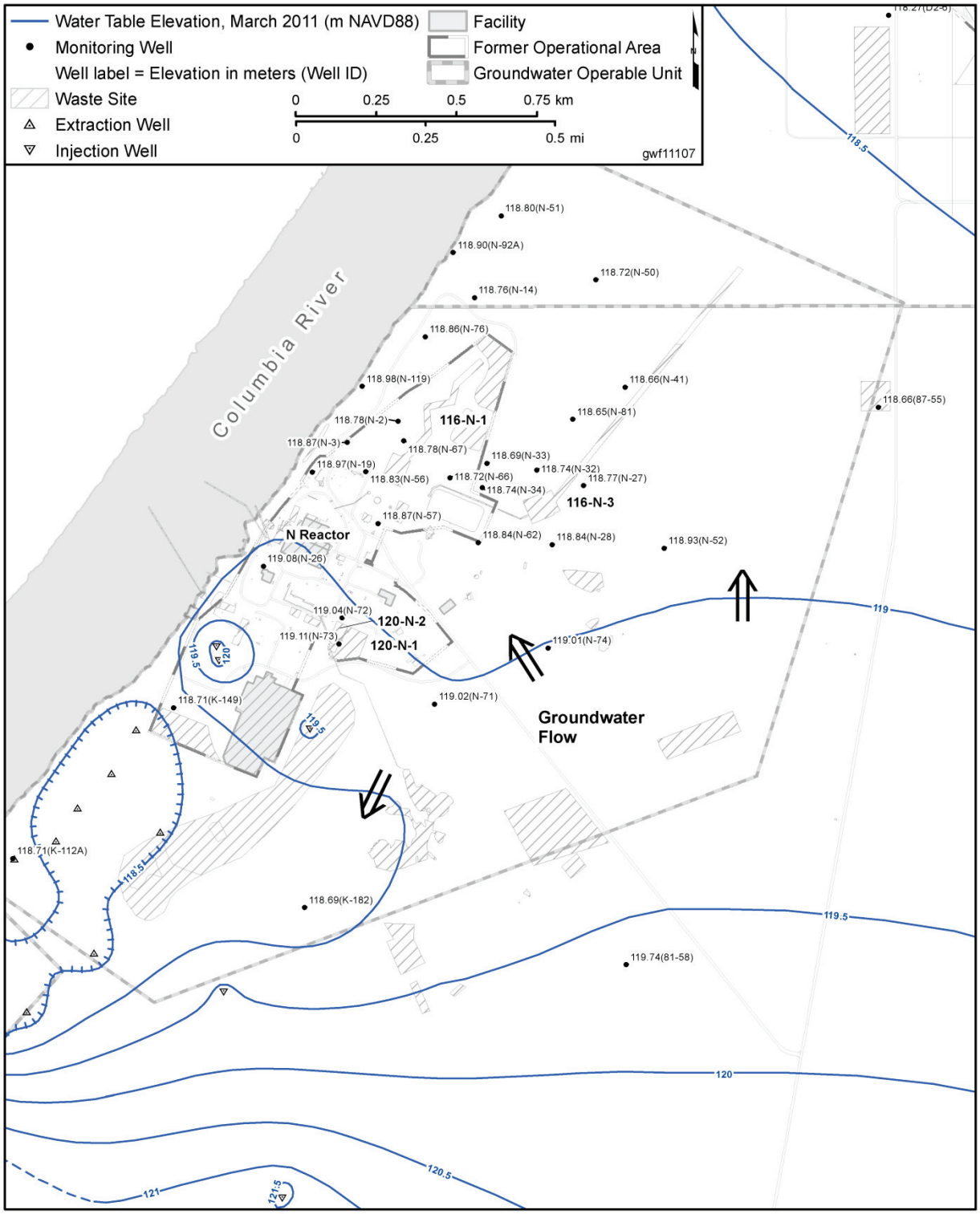



**Figure 4-10. 2011 Daily Average Water Level in Wells 199-N-99A, 199-N-14, and 199-N-50**




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

**Figure 4-11. 100-N Area Water Table Map, March 2009 and March 2010**




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

**Figure 4-12. 100-N Area Water Table Map, March 2011**

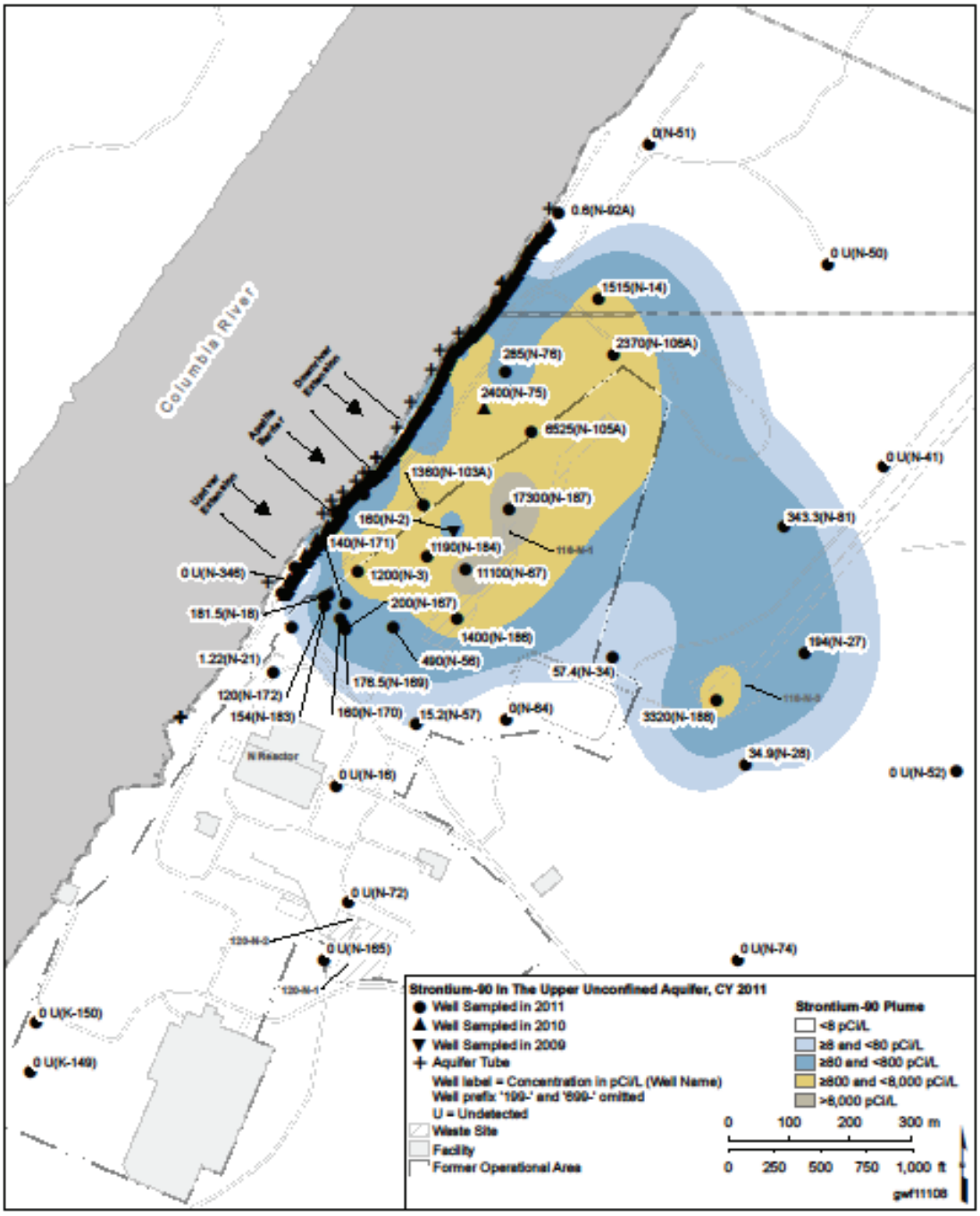



**Figure 4-13. Strontium-90 Plume Map for the 100-N Area**

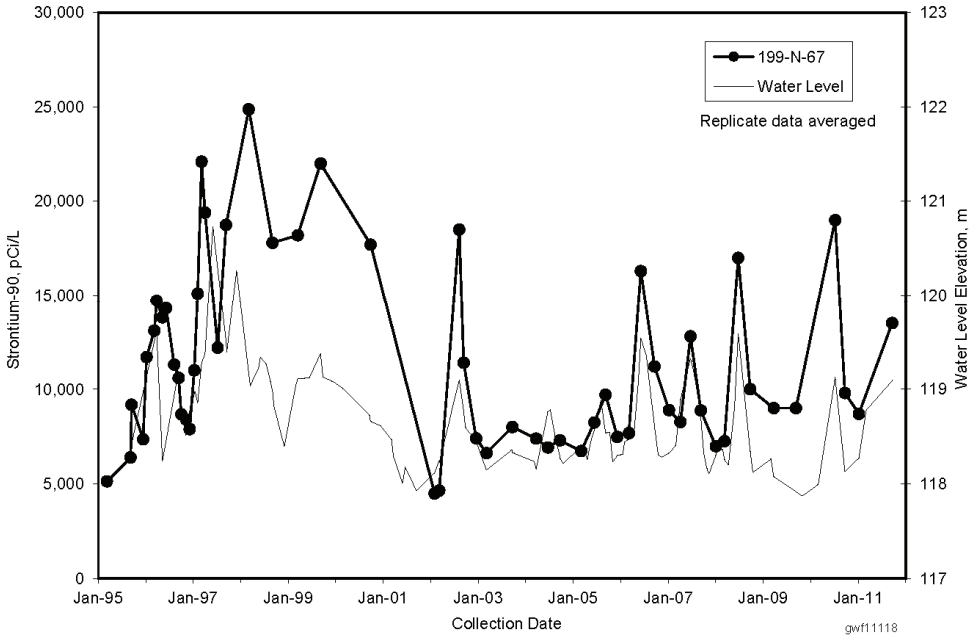



**Figure 4-14. Strontium-90 Trend Plot and Water Levels for Well 199-N-67**

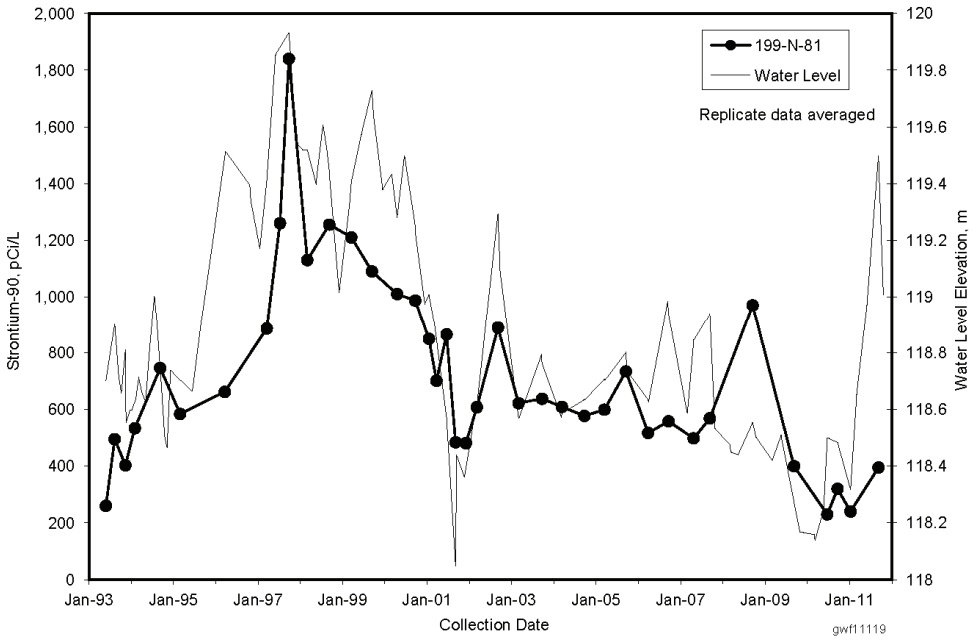



**Figure 4-15. Strontium-90 Trend Plot and Water Levels for Well 199-N-105A**

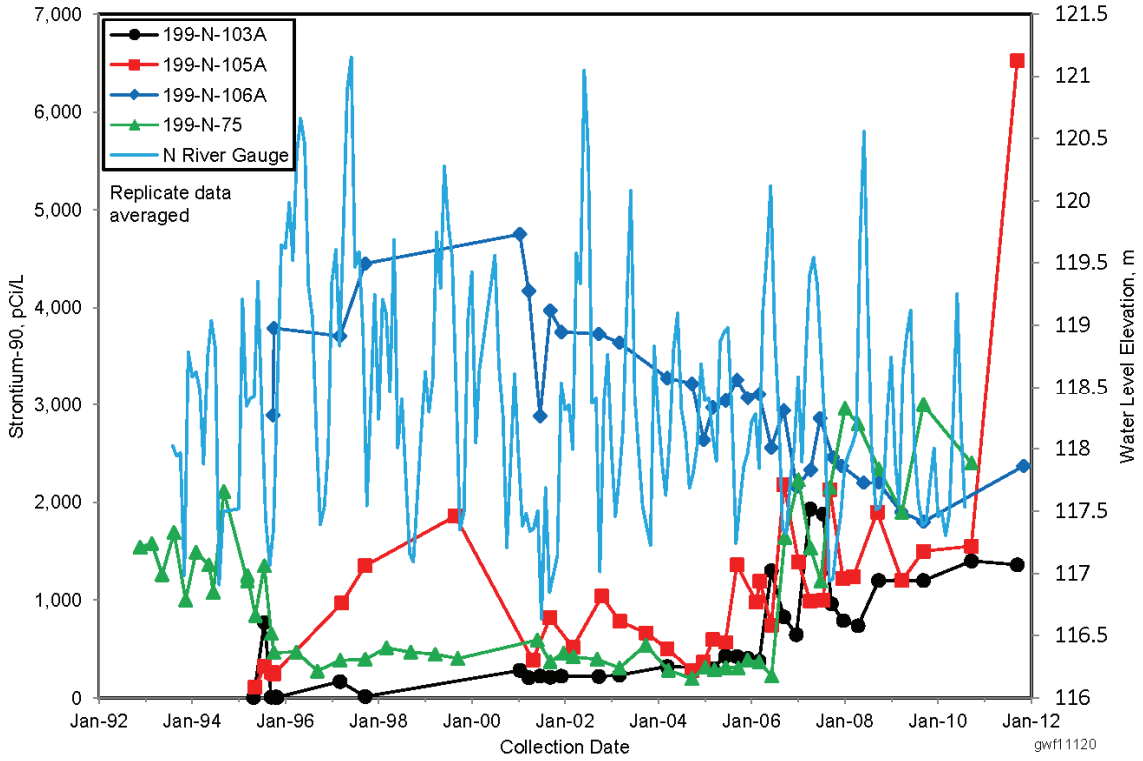



**Figure 4-16. Strontium-90 Trend Plots for the Four Former P&T Extraction Wells (Well 199-N-75 was not Sampled in 2011)**

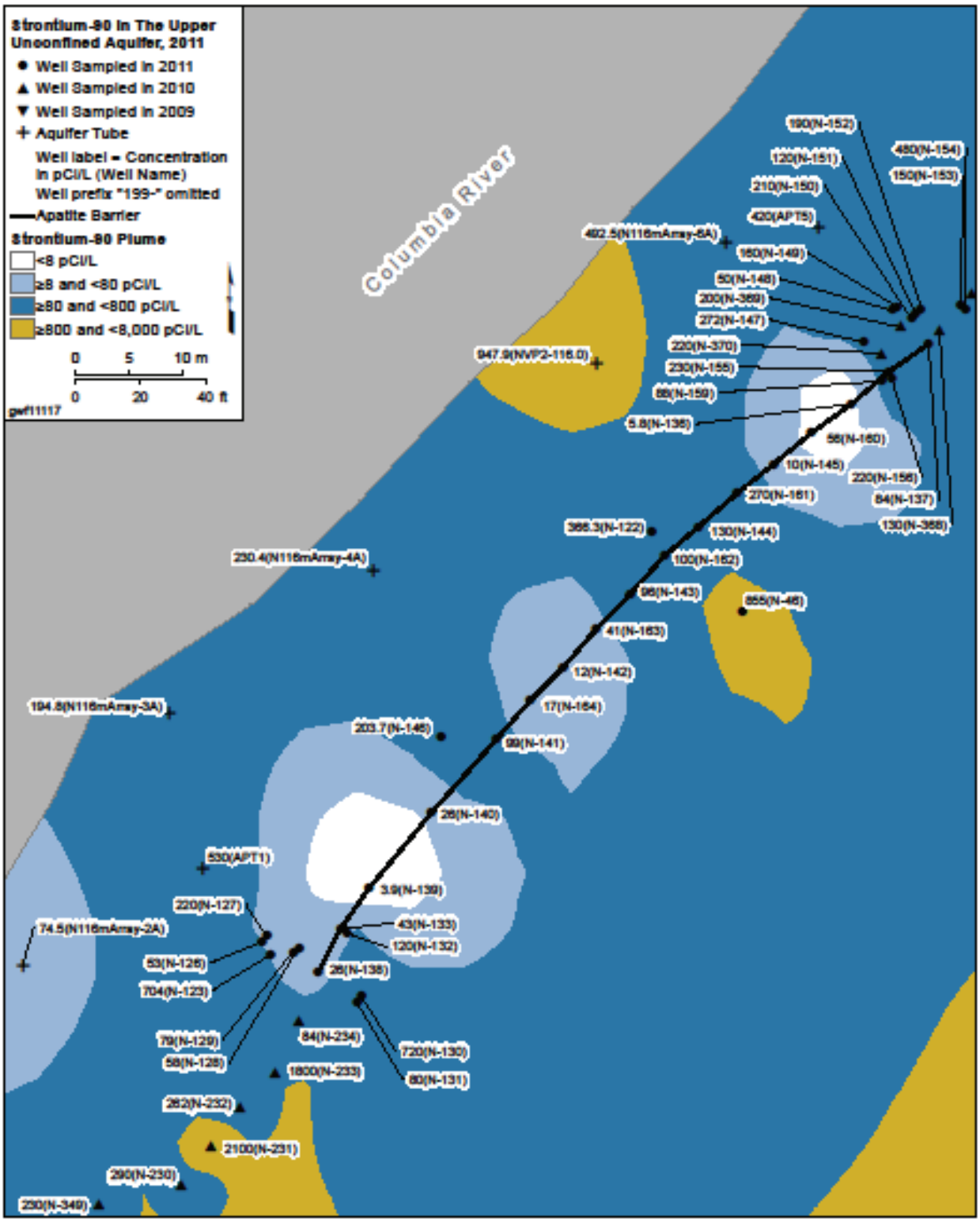



**Figure 4-17. Strontium-90 Plume Map for the 100-N Area**

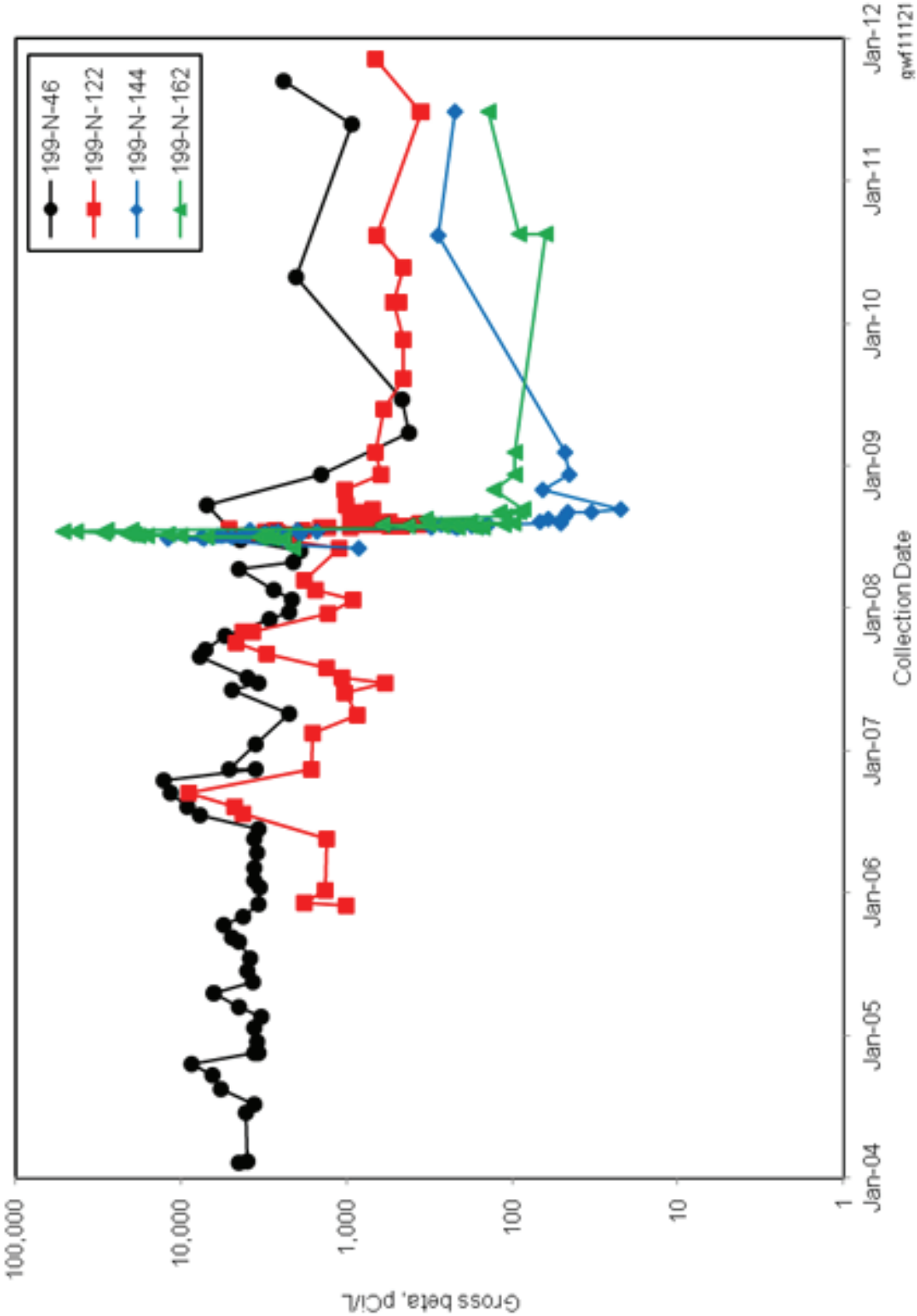



**Figure 4-18. Gross Beta Values in the Highest Concentration Portion of the Original Apatite Barrier**

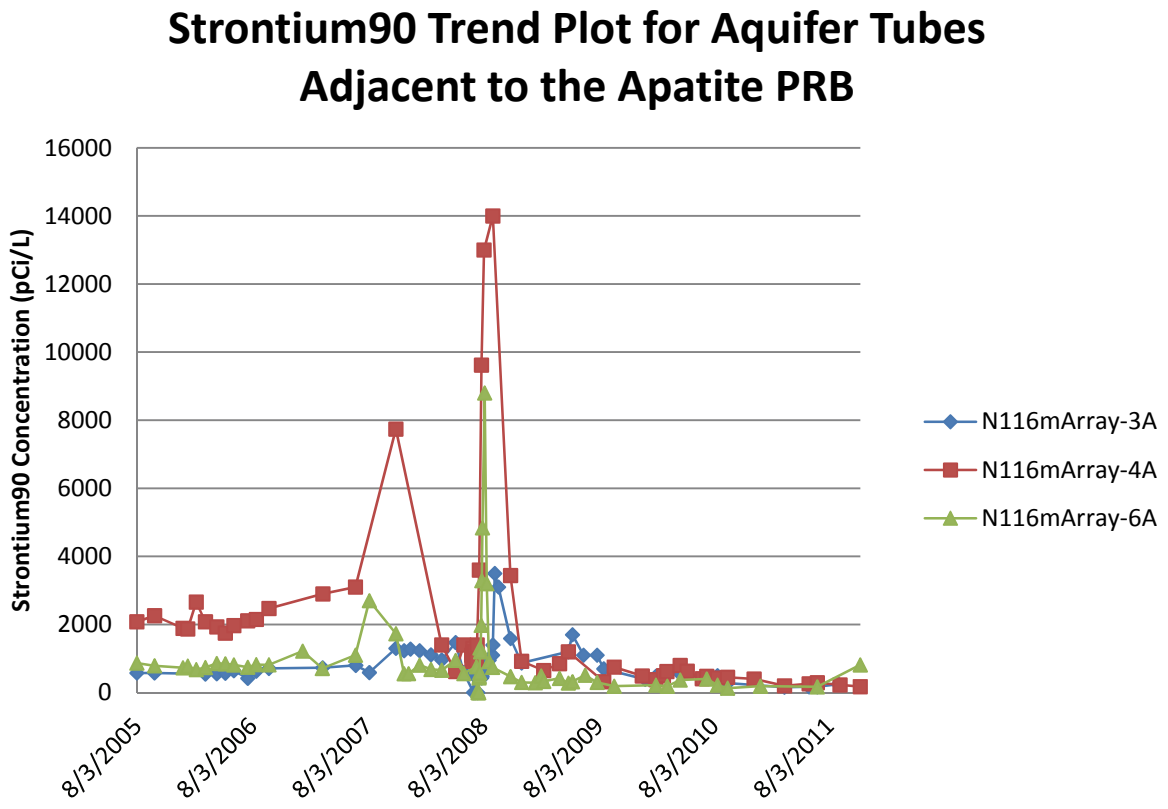



**Figure 4-19. Strontium-90 Trend Plots for Aquifer Tubes Adjacent to the Apatite Permeable Reactive Barrier**

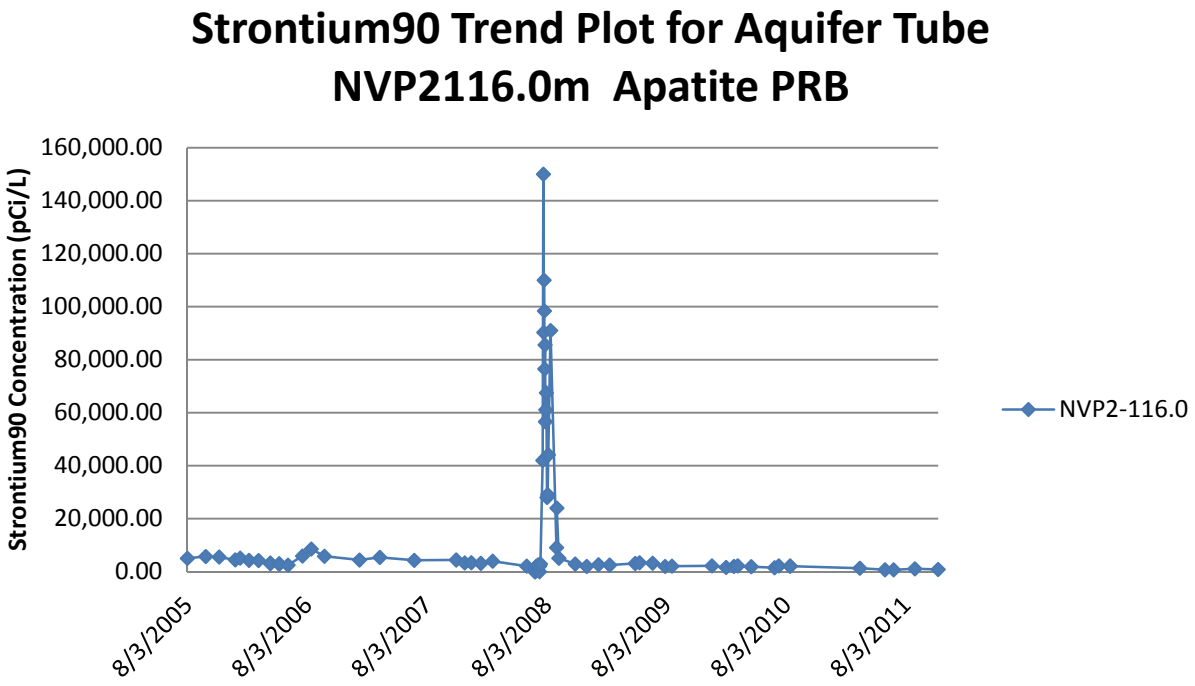



**Figure 4-20. Strontium-90 Trend Plot for Aquifer Tube NVP2-116.0m, Apatite Permeable Reactive Barrier**

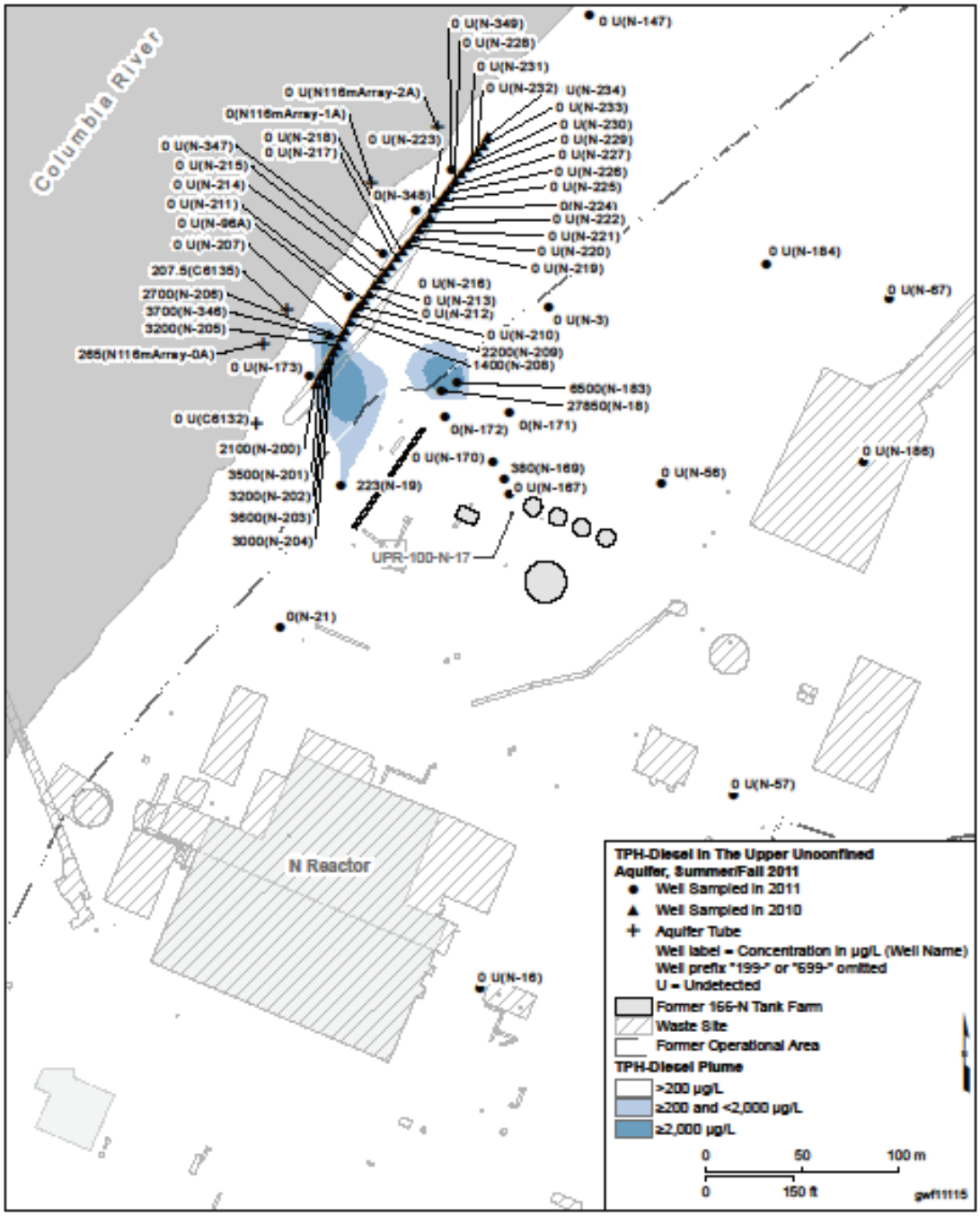



**Figure 4-21. Petroleum Hydrocarbons-Diesel Plume Map for the 100-N Area**

**Figure 4-22. Photograph of 166-N Tank Farm Facility and Location of Well 199-N-18**

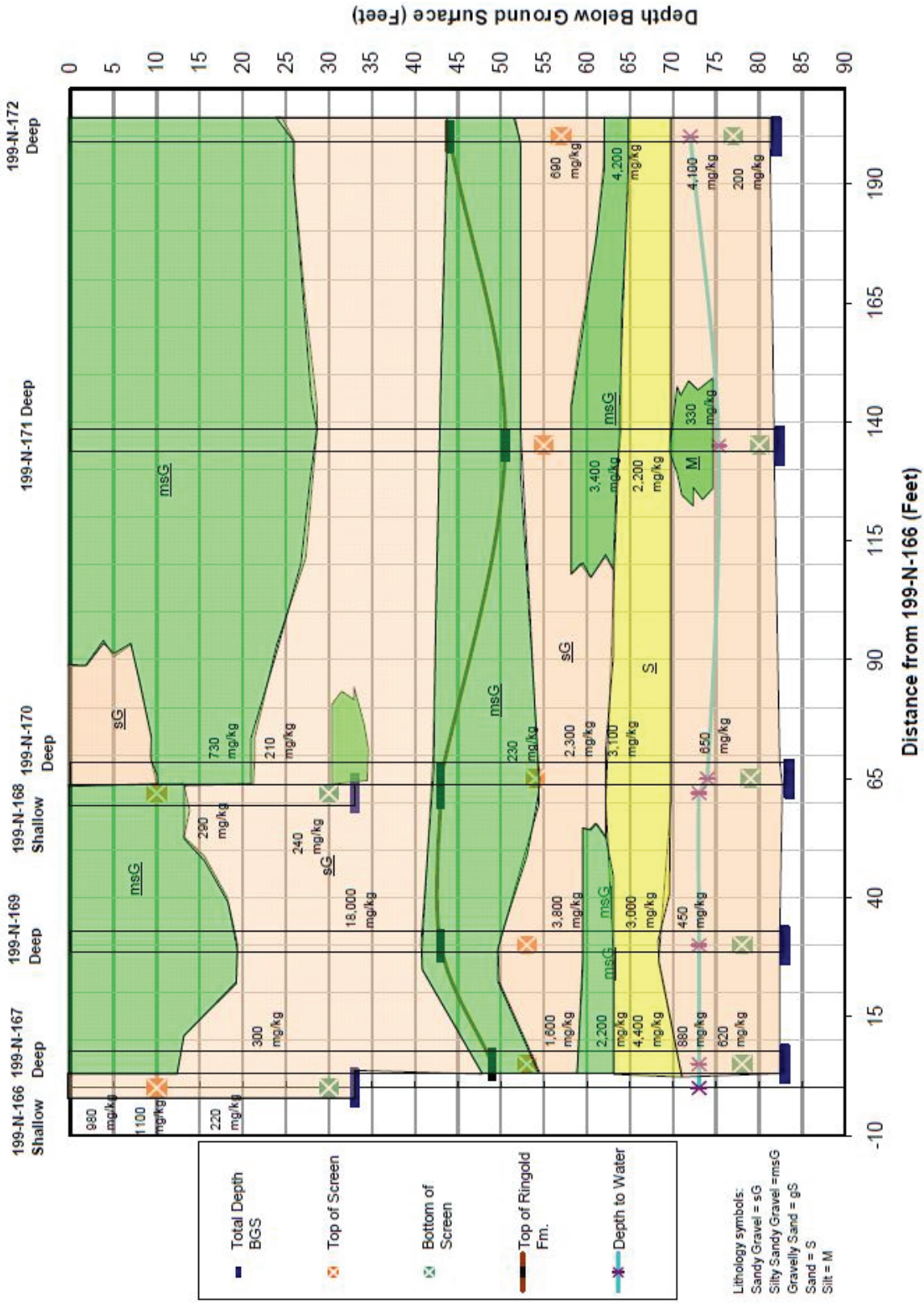



**Figure 4-23. Geologic Cross Section of Washington Closure Hanford Bioremediation Test Site with Total Petroleum Hydrocarbons and Oil, and Grease Results**

**Table 4-1. Yearly Peak Averages, 100-N Area River Gauge Station**

| Year | Average River Elevation | Percent Difference from Previous Year |
|---|---|---|
| 2011 (1-1-11 to 5-1-11) | 118.59 m (389.07 ft) | Not calculated because it is a partial year |
| 2010 | 117.76 m (386.35 ft) | 0.28% |
| 2009 | 118.09 m (387.43 ft) | 0.09% |
| 2008 | 118.20 m (387.47 ft) | 0.03% |
| 2007 | 118.24 m (387.93 ft) | 0.14% |
| 2006 | 118.41 m (387.47 ft) | 0.17% |
| 2005 | 118.21 m (387.83 ft) | --- |

**Table 4-2. Well Water-level Response to Changes in River Stage**

| 199-N-146 | | 199-N-3 | | 199-N-72 | |
|---|---|---|---|---|---|
| Date | Elevation* (m) | Date | Elevation* (m) | Date | Elevation* (m) |
| **Late Winter Low** | | | | | |
| 1/18/11 | 117.637 | 1/19/11 | 118.096 | 1/21/11 | 118.741 |
| **Early Summer High** | | | | | |
| 6/5/11 | 121.47 | 6/17/11 | 120.876 | 7/18/11 | 120.102 |
| **Late Fall/Early Winter Low** | | | | | |
| 10/23/11 | 117.475 | 11/1/11 | 118.179 | 11/15/11 | 119.113 |

* Average Daily Head Elevation

**Table 4-3. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes**

| Well/Tube Name | Before P&T, Fall 1994 (pCi/L) | During P&T, Fall 2005 (pCi/L) | P&T in Cold-standby Status, 2008 (pCi/L) | P&T in Cold-standby Status, 2009 (pCi/L) | P&T in Cold-standby Status, 2010 (pCi/L) | P&T in Cold-standby Status, 2011 (pCi/L) | % Change 1994 to 2011 | % Change 2005 to 2011 |
|---|---|---|---|---|---|---|---|---|
| 199-N-2 | 121 | 80.7 | 1,100 | 160 | -- | -- | -- | -- |
| 199-N-3 | 927 | 1.330 | 1,200 | 1,060 | 870 | 1,200 | 29% | -10% |
| 199-N-14 | 1,210 | 1.070 | 1,300 | 1,360 | 1,400 | 1,730 | 43% | 62% |
| 199-N-16 | 0.34 | -0.08 (U) | 0.06 (U) | -0.04 (U) | -2.70 (U) | -0.12 (U) | NC | NC |
| 199-N-18 | 392 | -- | 290 | -12 (U) | 260 | 203 | -48% | -30% |
| 199-N-19 | 43.6 | 28.2 | -- | -- | 23 | 26.4 | -39% | -6% |
| 199-N-21 | 1.50 | -- | -- | -2.60 (U) | -7.6 (U) | 1.22 | NC | NC |
| 199-N-27 | 171 | 167 | 160 | 130 | 125 | 194 | 13% | 16% |
| 199-N-28 | 120 | 25.1 | 21 | 25 | 20 | 34.9 | -71% | 39% |
| 199-N-32 | 1.27 | 0.358 (U) | -1.40 (U) | -1.60 (U) | -4.8 (U) | 0.15 (U) | NC | NC |
| 199-N-34 | 69.3 | 53.5 | 67 | 44 | 37 | 57.4 | -17% | 7% |
| 199-N-41 | 0.004 (U) | -0.10 (U) | -0.41 (U) | -1.20 (U) | -1.80 (U) | 0.50 (U) | NC | NC |
| 199-N-46 | 5,850 | 2.690 | 630 | 580 | 530 | 1,220 | -79% | -55% |
| 199-N-50 | -0.02 (U) | -- | -- | -- | -0.20 (U) | -0.13 (U) | NC | NC |
| 199-N-51 | 0.254 (U) | 0.05 (U) | -- | -- | -5.30 (U) | 0.52 (U) | NC | NC |
| 199-N-56 | 164[a] | 317 | 170 | 140 | -7.5 (U) | 490 | 199% | 55% |
| 199-N-57 | 26 | 9.71 | 8.51 | 2.90 | 5.80 | 15.2 | -42% | 57% |
| 199-N-64 | 0.185 (U) | 0.785 (U) | 0.256 (U) | -5.30 (U) | -4.60 (U) | 0.48 (U) | NC | NC |
| 199-N-67 | 3,680 | 9.710 | 10,000 | 9,000 | 9,800 | 13,500 | 267% | 39% |
| 199-N-69[b] | -0.09 (U) | 0.21 (U) | -- | -- | -3.20 (U) | 2.96 | NC | NC |

**Table 4-3. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes**

| Well/Tube Name | Before P&T, Fall 1994 (pCi/L) | During P&T, Fall 2005 (pCi/L) | P&T in Cold-standby Status, 2008 (pCi/L) | P&T in Cold-standby Status, 2009 (pCi/L) | P&T in Cold-standby Status, 2010 (pCi/L) | P&T in Cold-standby Status, 2011 (pCi/L) | % Change 1994 to 2011 | % Change 2005 to 2011 |
|---|---|---|---|---|---|---|---|---|
| 199-N-70[b] | 0.321 (U) | 0.156 (U) | -2.60 (U) | -2.40 (U) | -3.80 (U) | 0.79 | NC | NC |
| 100-N-71 | 0.55 | -- | 0.38 (U) | -0.05 (U) | -2.80 (U) | -3.90 (U) | NC | NC |
| 199-N-72 | 2.59[c] | -- | -1.00 (U) | -- | -1.70 (U) | -2.60 (U) | NC | NC |
| 199-N-73 | 0.53 | 0.0 (U) | -- | -- | -- | -- | NC | NC |
| 199-N-74 | 0.415 | -0.08 (U) | 2.3[c] | 405[c] | -2.0 (U) | -3.60 (U) | NC | NC |
| 199-N-75[d] | 2,110 | 307 | 2,500 | 3,000 | 2,400 | NS | NC | NC |
| 199-N-76 | 84.9 | 216 | 180 | 180 | 120 | 387 | 356% | 79% |
| 199-N-77 | 0.45 | 0.01 | -- | -- | -- | -- | NC | NC |
| 199-N-80[b] | 0.734 (Q) | -0.154 (U) | 0.82 (U) | -0.07 (U) | -5.9 (U) | 0.22 (U) | NC | NC |
| 199-N-81 | 746 | 734 | 970 | 400 | 320 | 395 | -47% | -46% |
| 199-N-92A | 0.59 (U) | 0.92 | 1.22 | 3.50 | -9 (U) | 0.60 | NC | NC |
| 199-N-96A | 4.90[e] | 5.74 | 1.65 | -1.30 (U) | 3.94 | 9.90 | 102% | 72% |
| 199-N-99A | 2,860[e] | 1,270 | 1,200 | 1,400 | 1,500 | 1,020 | -64% | -20% |
| 199-N-103A[d] | 4.08[e] | 422 | 1,200 | 1,200 | 1,400 | 1,360 | 33,233% | 222% |
| 199-N-105A[d] | 112[e] | 1,360 | 1,900 | 1,500 | 1,600 | 6,580 | 5775% | 384% |
| 199-N-106A[d] | 2,890[e] | 3,260 | 2,200 | 1,800 | NS | 2,370 | -18%[a] | -27%[c] |
| 199-N-119 | -- | 280 | 250 | 210 | 220 | 274 | -- | -2% |
| 199-N-120[b] | -- | 10.1 | 6.55 | -- | 1.40 (U) | 6.93 | -- | -31% |
| 199-N-121[b] | -- | 0.272 (U) | 0.0169 (U) | -- | -2.00 (U) | -0.02 (U) | -- | NC |
| 199-N-122 | -- | 730 | 1,160 | 260 | 800 | 740 | -- | 1% |

**Table 4-3. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes**

| Well/Tube Name | Before P&T, Fall 1994 (pCi/L) | During P&T, Fall 2005 (pCi/L) | P&T in Cold-standby Status, 2008 (pCi/L) | P&T in Cold-standby Status, 2009 (pCi/L) | P&T in Cold-standby Status, 2010 (pCi/L) | P&T in Cold-standby Status, 2011 (pCi/L) | % Change 1994 to 2011 | % Change 2005 to 2011 |
|---|---|---|---|---|---|---|---|---|
| 199-N-123 | -- | 871 | 255 | -1.60 (U) | 280 | 1,770 | -- | 103% |
| 199-N-146 | -- | 318[f] | 412 | 260 | 300 | 328 | -- | 3% |
| 199-N-147 | -- | 522[f] | 791 | 250 | 250 | 478 | -- | -8% |
| 199-N-165 | -- | -- | -- | -1.90 (U) | -6.60 (U) | 0.14 (U) | -- | -- |
| 199-N-173 | -- | -- | -- | 16 | 23 | 19 | -- | -- |
| 116m Array 3A | -- | 379 | 1,750[c] | 500 | 110 | 248 | -- | -35% |
| 116m Array 4A | -- | 1,260 | 7,000[c] | 340 | 270 | 226 | -- | -82% |
| NVP2-116.0 | -- | 3,200 | 2,550[c] | 1,100 | 1,200 | 1,100 | -- | -66% |
| 116m Array 6A | -- | 477 | 370[c] | 95[c] | 110 | 170 | -- | -64% |

Notes:

Data from the fall of the year, unless otherwise noted.

Pink shaded cells indicate increases in concentration since before P&T operations started or after P&T operations ceased.

Yellow shaded cells show wells with concentrations above the drinking water standard (8 pCi/L).

a. Not sampled in 1994; value from 1993 used for table.

b. Screened at depth in Ringold Formation.

c. Value calculated from gross beta data (no Strontium-90 data available) – value listed is ½ gross beta value measured.

d. Former P&T extraction well.

e. Not sampled in 1994; value from 1995 used for table.

f. Not sampled in 2005; value from 2006 used for table.

NC = not calculated because concentrations are too low or both numbers are nondetect

NS = not sampled

Q = associated with out-of-limits quality control samples

U = nondetect

**Table 4-4. Petroleum Hydrocarbon Removal from Well 199-N-18**

| 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 2 months. |
| 2006 | 1,370 | Changed every 2 months. |
| 2007 | 1,294 | Changed every 2 month. |
| 2008 | 920 | Changed every 2 months. |
| 2009 | 1,380 | Changed approximately every 2 months. |
| 2010 | 225.5 | Changed only twice prior to June 2010; smart sponge broke in well. No removal for second half of 2010. |
| 2011 | 650 | Changed approximately every 2 months |
| | **Total** | **11,564.5 g (~11.56 kg) total removed through end of 2011** |

Notes:

* *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. *Calendar Year 2004 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operations* (DOE/RL-2005-18) states that the average mass removal for fiscal year 2004 (October 2003 through October 2004) was approximately 0.4 kg/month, so an estimate is provided for the 3 months missing in calendar year 2003.

**Table 4-5. Apatite Permeable Reactive Barrier Monitoring Points**

| Well Name/ID | Well Type | Well Name/ID | Well Type | Well Name/ID | Well Type |
|---|---|---|---|---|---|
| C6132 | AT | NVP2-116.0m/C5251 | AT | N116mArray-10A/C5264 | AT |
| 199-N-173/C7038 | MW | N116mArray-6A/C5259 | AT | 199-N-359/C7452 | MW |
| N116mArray-0A/C5514 | AT | 199-N-147/C5116 | MW | N116mArray-11A/C5265 | AT |
| 199-N-346/C7442 | MW | APT-5/C5386 | AT | 199-N-360/C7453 | MW |
| C6135 | AT | 199-N-350/C7443 | MW | N116mArray-12A/C5266 | AT |
| 199-N-96A/A9882 | MW | N116mArray-7A/C5260 * | AT | 199-N-361/C7454 | MW |
| C6136 | AT | C7881* | AT | 199-N-362/C7455 | MW |
| 199-N-347/C7441 | MW | 199-N-351/C7444 | MW | 199-N-363/C7456 | MW |
| N116mArray-1A/C5255 | AT | 199-N-352/C7445 | MW | N116mArray-13A/C5267 | AT |
| 199-N-348/C7440 | MW | 199-N-353/C7446 | MW | 199-N-364/C7457 | MW |
| N116mArray-2A/C5256 | AT | N116mArray-8A/C5261 | AT | 199-N-365/C7458 | MW |
| 199-N-349/C7439 | MW | 199-N-354/C7447 | MW | N116mArray-14A/C5268 | AT |
| 199-N-123/C4955 | MW | N116mArray-8.5A/C5262 | AT | 199-N-366/C7459 | MW |
| APT-1/C5269 | AT | 199-N-355/C7448 | MW | 199-N-367/C7463 | MW |
| N116mArray-3A/C5257 | AT | 199-N-356/C7449 | MW | 199-N-92A/A8878 | MW |
| 199-N-146/C5052 | MW | 199-N-357/C7450 | MW | N116mArray-15A/C5512 | AT |
| N116mArray-4A/C5258 | AT | N116mArray-9A/C5263 | AT | | |
| 199-N-122/C4954 | MW | 199-N-358/C7451 | MW | | |

Notes:

* N116mArray-7A was monitored for the apatite permeable reactive barrier from June 2006 through September 2009. It became unusable in 2009 and was replaced with C7881at the same location.

Blue shading indicates locations currently being monitored for treated portion of current barrier.

AT = aquifer tube

MW = 6-in monitoring well

**Table 4-6. Apatite Permeable Reactive Barrier Injection Wells**

| Well Name/ID | Purpose | Well Name/ID | Purpose | Well ID | Purpose | Well Name/ID | Purpose |
|---|---|---|---|---|---|---|---|
| 199-N-200/C7327 | IW H | 199-N-222/C7305 | IW H-Core | 199-N-144/C5050 | IW HR | 199-N-250/C7343 | IW R |
| 199-N-201/C7326 | IW R | 199-N-223/C7304 | IW R | 199-N-161/C6179 | IW R | 199-N-251/C7344 | IW H |
| 199-N-202/C7325 | IW H | 199-N-224/C7303 | IW H | 199-N-145/C5051 | IW HR | 199-N-252/C7345 | IW R |
| 199-N-203/C7324 | IW R | 199-N-225/C7302 | IW R | 199-N-160/C6178 | IW R | 199-N-253/C7346 | IW H |
| 199-N-204/C7323 | IW H | 199-N-226/C7301 | IW H | 199-N-136/C5042 | IW HR | 199-N-254/C7347 | IW R |
| 199-N-205/C7322 | IW R | 199-N-227/C7300 | IW R | 199-N-159/C6177 | IW R | 199-N-255/C7348 | IW H |
| 199-N-206/C7321 | IW H | 199-N-228/C7299 | IW H | 199-N-137/C5043 | IW HR | 199-N-256/C7349 | IW R |
| 199-N-207/C7320 | IW R | 199-N-229/C7298 | IW R | 199-N-235/C7328 | IW H | 199-N-257/C7350 | IW H |
| 199-N-208/C7319 | IW H | 199-N-230/C7297 | IW H | 199-N-236/C7329 | IW R | 199-N-258/C7351 | IW R |
| 199-N-209/C7318 | IW R | 199-N-231/C7296 | IW R | 199-N-237/C7330 | IW H | 199-N-259/C7352 | IW H |
| 199-N-210/C7317 | IW H | 199-N-232/C7295 | IW H | 199-N-238/C7331 | IW R | 199-N-260/C7353 | IW R |
| 199-N-211/C7316 | IW R | 199-N-233/C7294 | IW R | 199-N-239/C7332 | IW H | 199-N-261/C7354 | IW H |
| 199-N-212/C7315 | IW H | 199-N-234/C7293 | IW H | 199-N-240/C7333 | IW R | 199-N-262/C7355 | IW R |
| 199-N-213/C7314 | IW R | 199-N-138/C5044 | IW HR | 199-N-241/C7334 | IW H | 199-N-263/C7356 | IW H |
| 199-N-214/C7313 | IW H | 199-N-139/C5045 | IW HR | 199-N-242/C7335 | IW R | 199-N-264/C7357 | IW R |
| 199-N-215/C7312 | IW R | 199-N-140/C5046 | IW HR | 199-N-243/C7336 | IW H | 199-N-265/C7358 | IW H |
| 199-N-216/C7311 | IW H | 199-N-141/C5047 | IW HR | 199-N-244/C7337 | IW R | 199-N-266/C7359 | IW R |
| 199-N-217/C7310 | IW R-Core | 199-N-164/C182 | IW R | 199-N-245/C7338 | IW H | 199-N-267/C7360 | IW H |
| 199-N-218/C7309 | IW H | 199-N-142/C5048 | IW HR | 199-N-246/C7339 | IW R | 199-N-268/C7361 | IW R |
| 199-N-219/C7308 | IW R-Core | 199-N-163/C6181 | IW R | 199-N-247/C7340 | IW H | 199-N-269/C7362 | IW H |

**Table 4-6. Apatite Permeable Reactive Barrier Injection Wells**

| Well Name/ID | Purpose | Well Name/ID | Purpose | Well ID | Purpose | Well Name/ID | Purpose |
|---|---|---|---|---|---|---|---|
| 199-N-220/C7307 | IW H-Core | 199-N-143/C5049 | IW HR | 199-N-248/C7341 | IW R | 199-N-270/C7363 | IW R |
| 199-N-221/C7306 | IW R | 199-N-162/C6180 | IW R | 199-N-249/C7342 | IW H | 199-N-271/C7364 | IW H |
| 199-N-272/C7365 | IW R | 199-N-291/C7384 | IW H | 199-N-310/C7403 | IW R | 199-N-329/C7422 | IW H |
| 199-N-273/C7366 | IW H | 199-N-292/C7385 | IW R | 199-N-311/C7404 | IW H | 199-N-330/C7423 | IW R |
| 199-N-274/C7367 | IW R | 199-N-293/C7386 | IW H | 199-N-312/C7405 | IW R | 199-N-331/C7424 | IW H |
| 199-N-275/C7368 | IW H | 199-N-294/C7387 | IW R | 199-N-313/C7406 | IW H | 199-N-332/C7425 | IW R |
| 199-N-276/C7369 | IW R | 199-N-295/C7388 | IW H | 199-N-314/C7407 | IW R | 199-N-333/C7426 | IW H |
| 199-N-277/C7370 | IW H | 199-N-296/C7389 | IW R | 199-N-315/C7408 | IW H | 199-N-334/C7427 | IW R |
| 199-N-278/C7371 | IW R | 199-N-297/C7390 | IW H | 199-N-316/C7409 | IW R | 199-N-335/C7428 | IW H |
| 199-N-279/C7372 | IW H | 199-N-298/C7391 | IW R | 199-N-317/C7410 | IW H | 199-N-336/C7429 | IW R |
| 199-N-280/C7373 | IW R | 199-N-299/C7392 | IW H | 199-N-318/C7411 | IW R | 199-N-337/C7430 | IW H |
| 199-N-281/C7374 | IW H | 199-N-300/C7393 | IW R | 199-N-319/C7412 | IW H | 199-N-338/C7431 | IW R |
| 199-N-282/C7375 | IW R | 199-N-301/C7394 | IW H | 199-N-320/C7413 | IW R | 199-N-339/C7432 | IW H |
| 199-N-283/C7376 | IW H | 199-N-302/C7395 | IW R | 199-N-321/C7414 | IW H | 199-N-340/C7433 | IW R |
| 199-N-284/C7377 | IW R | 199-N-303/C7396 | IW H | 199-N-322/C7415 | IW R | 199-N-341/C7434 | IW H |
| 199-N-285/C7378 | IW H | 199-N-304/C7397 | IW R | 199-N-323/C7416 | IW H | 199-N-342/C7435 | IW R |
| 199-N-286/C7379 | IW R | 199-N-305/C7398 | IW H | 199-N-324/C7417 | IW R | 199-N-343/C7436 | IW H |
| 199-N-287/C7380 | IW H | 199-N-306/C7399 | IW R | 199-N-325/C7418 | IW H | 199-N-344/C7437 | IW R |
| 199-N-288/C7381 | IW R | 199-N-307/C7400 | IW H | 199-N-326/C7419 | IW R | 199-N-345/C7438 | IW H |
| 199-N-289/C7382 | IW H | 199-N-308/C7401 | IW R | 199-N-327/C7420 | IW H | | |
| 199-N-290/C7383 | IW R | 199-N-309/C7402 | IW H | 199-N-328/C7421 | IW R | | |

**Table 4-6. Apatite Permeable Reactive Barrier Injection Wells**

| Well Name/ID | Purpose | Well Name/ID | Purpose | Well ID | Purpose | Well Name/ID | Purpose |
|---|---|---|---|---|---|---|---|

Notes:

Core means that a core was taken at this well for jet injection study (2010).

Blue shading indicates down river barrier extension wells treated in 9-2011.

Green shading indicates original barrier wells treated in 2006 through 2008.

Pink shading indicates upriver barrier extension wells treated in 9-2011.

No shading indicates wells are not treated yet.

H = screened in Hanford fm.

IW = injection well

R = screened in Ringold Fm.

**Table 4-7. Petroleum Hydrocarbon Releases at 100-N**

| Group | WIDS Number | Location | Description |
|---|---|---|---|
| Group 1 – 166-N & 1715-N | UPR-100-N-17 | 166-N Diesel Oil Supply Line Leak | In August 1966, an estimated 302,832 L (80,000 gal) of diesel leaked from a failed transfer system near the 166-N facility. In August 1967, J. M. Shelby documented the possible impacts on the Columbia River. Diesel was slipping from the bluff below the 166-N Tank Farm and into the river. A trench was excavated below the bluff to collect the diesel to be burned off; WIDS site 100-N-65 Diesel Burn Trench (BNWL-CC-1296; UNI-228). |
| | UPR-100-N-18 | 166-N Diesel Oil Supply Line Leak | In August 1973, an estimated 757 L (200 gal) of diesel oil leaked from a transfer line between 166-N and 184-N facilities (PNL-6456; UNI-228). |
| | UPR-100-N-20 | 166-N Diesel Oil Supply Line Leak | In June 1985, an estimated 757 L (200 gal) of diesel oil leaked from a transfer line near Tank 1 in the 166-N facility (UNI-228). |
| | UPR-100-N-24 | 166-N Diesel Oil Supply Line Leak | On February 1, 1987, a line leak was reported. Petroleum product type and quantity were not reported. No further information is available (WHC-SD-EN-TI-251). |
| Group 2 – 184-N | UPR-100-N-42 | 184-N Day Tank Area Liquid Unplanned Release | On October 9, 1987, an unspecified quantity of petroleum material with an unspecified description was documented around the 184-N facility day tanks (WIDS). |
| | UPR-100-N-19 | 184-N Day Tank Fuel Oil Line Leak | In April 1984, an estimated 28,391 L (7,500 gal) of No. 6 fuel oil leaked at the 184-N Day Tank facility. It was reported that all the fuel oil stayed within the tank confinement basin and did not penetrate the hard-packed sand bottom. Waste oil was removed and disposed of (UNI-228). |

**Table 4-7. Petroleum Hydrocarbon Releases at 100-N**

| Group | WIDS Number | Location | Description |
|---|---|---|---|
| | UPR-100-N-21 | 184-N Diesel Oil Day Tank Overflow | On April 25, 1986, an estimated 3,028 L (800 gal) of diesel oil spilled into the area surrounding a day tank at 184-N. Approximately 2,461 L (650 gal) were reported as pumped/cleaned up. Nearby Monitoring Well 199-N-16 reported no detections (WIDS). |
| | UPR-100-N-22 | Diesel Oil Supply Line Leak No. 1 | On June 23, 1986, an estimated 3,785 L (1,000 gal) of diesel oil leaked from a transfer line. This release was detected in nearby Well 199-N-16 (WIDS). An unspecified quantity of petroleum material was pumped from the well (WHC-SD-EN-TI-251). |
| | UPR-100-N-23 | Diesel Oil Supply Line Leak No. 2 | On January 10, 1987, an estimated 757 L (200 gal) of diesel oil leaked from a transfer line. This release was detected in nearby Well 199-N-16. An unspecified quantity of petroleum material was pumped from the well (WHC-SD-EN-TI-251). |
| | 100-N-12 | 184-N Pipeline Spill | A spill inside the 184-N pipeline that leaked to the outside occurred on October 14, 1987. An unknown amount of fuel oil leaked from a loose pipe fitting at the 184-N Annex. Spill was contained in a drain trench and cleaned up (WIDS). |
| **Group 2 – Other Miscellaneous Sites** | UPR-100-N-43 | 166-N to 184-N Transfer Line Multiple Leak | Diesel oil leaks occurred at three locations along a pipeline from 166-N to 184-N at three different flange points. The exact locations of the flange points were not provided. The release was reported on April 26, 1989. In total, 46 drums and 8 dump trucks of contaminated soil were removed. Sampling was conducted in nearby Wells 199-N-16 and 199-N-17 and oil was detected. Reported as cleaned up by April 26, 1989 (DOE/RL-90-22; WHC-C-89-047-100N-20) |
| | UPR-100-N-36 | 184-N Annex Diesel Generator Area Release | During excavation between 184-N and 153-N (area of approximately 40 by 18 m (130 by 60 ft), a strong smell of petroleum was noted. Neither date nor quantity of material is reported (WIDS). |
| | 100-N-36 | Oil-Stained Pad (near 107-N building) | This site was once used to support an air compressor. Neither date nor amount of petroleum material leaked is available; however, available documentation suggests that the quantity was minimal and limited to the soil immediately beneath the pad. The small amount of petroleum released may have leaked to the ground through a crack between the concrete pads and asphalt (WIDS). |
| | 100-N-35 | Hanford Generating Plant/BPA Switchyard | This portion of the 100-N Area is still in use by the Bonneville Power Administration and is reported to contain spills of oil materials that could contain polychlorinated biphenyls. |
| | 100-N-65 | Diesel Burn Pit Adjacent to River | This site was a trench/pit excavated adjacent to the river to intercept and burn diesel oil before it could significantly affect the Columbia River (refer to UPR-100-N-17). In 1994, the trench was backfilled with material to the top of the adjacent berm (WIDS). |

**Table 4-7. Petroleum Hydrocarbon Releases at 100-N**

| Group | WIDS Number | Location | Description |
|---|---|---|---|
| | 124-N-2 | 182-N Septic System | This site was a septic system east of 182-N that was reported to have had petroleum introduced into it. This site includes a septic tank and seepage pit and was reported pumped and isolated after the 124-N-10 Septic Treatment Facility was placed in service in February 1987 (WIDS). |

Sources: BNWL-CC-1296, *Environmental Significance of Diesel Fuel Entering Columbia River at 100-N*.

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

PNL-6456, *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford: Volume 1 – Evaluation Methods and Results*.

UNI-228, *Oil Spill Prevention, Control, and Countermeasures Plan*.

WHC-C-89-047-100N-20, *Critique Report, 184-N Powerhouse Diesel Oil Leak (Apr#26, 1989)*.

WHC-SD-EN-TI-251, *100-N Area Technical Baseline Report*.

**Table 4-8. Washington Closure Hanford Bioventing Study Wells**

| Well Name | Well ID | Well Completion – Screen, m (ft) |
|---|---|---|
| 199-N-166 | C7031 | SV: 2.90 – 9.00 m (9.53 – 29.54 ft) |
| 199-N-167 | C7032 | DV-GW: 16.13 – 23.73 m (52.91 – 77.86 ft) |
| 199-N-168 | C7033 | SV: 2.97 – 9.07 m (9.75 – 29.75 ft) |
| 199-N-169 | C7034 | DV-GW: 16.30 – 23.90 m (53.47 – 78.4 ft) |
| 199-N-170 | C7035 | DV-GW: 16.72 - 24.34 m (54.87 – 79.84 ft) |
| 199-N-171 | C7036 | DV-GW: 16.70 – 24.29 m (54.79 – 79.68 ft) |
| 199-N-172 | C7037 | DV-GW: 17.43 – 23.51 m (57.17 – 77.14 ft) |

DV-GW = R vadose-groundwater completion
SV = H vadose completion

**Table 4-9. Total Petroleum Hydrocarbon-Diesel Range Results from Washington Closure Hanford Wells***

| Date | 199-N-167 | 199-N-169 | 199-N-170 | 199-N-171 | 199-N-172 |
|---|---|---|---|---|---|
| 8/20/09 | 3,100 | --- | --- | --- | 2,400 |
| 9/16/09 | 1,900 | --- | --- | --- | 2,200 (D) |
| 4/23/10 | 4,600 (N) | 1,100 (N) | 360 (N) | 2,800 (N) | 25,000 (D,N) |
| 5/20/11 | --- | 760 | 70 (U,N,X) | --- | --- |
| 5/25/11 | 70 (U,N) | --- | --- | --- | 70 (U,N) |
| 6/8/11 | --- | --- | --- | 70 (U,N) | --- |

Note:
*Highest detected sample reported for each event; if not detected, then lowest nondetect value is reported.
D = analyte reported at a secondary dilution factor
N = spike or spike duplicate is outside control limits
U =
X =

**Table 4-10. Total Petroleum Hydrocarbon-Diesel Range Results* for Selected Wells and Aquifer Tubes**

| Date | N-3 | N-16 | N-18 | N-19 | N-21 | N-56 | N-57 | N-96A | N-173 | Array0A | C6135 | Array1A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1992** | NR | 200 (U) | NR | 200 (U) | 200 (U) | 1,000 (U) | NR | NR | NR | NR | NR | NR |
| **1993** | 1,000 (U) | 67 J | NR | 100 (U) | 100 (U) | NR | 100 (U) | NR | NR | NR | NR | NR |
| **1994** | 1000 | 4000 | NR | 500 (U) | 1000 | NR | NR | NR | NR | NR | NR | NR |
| **1995 - 1998** | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| **1999** | NR | NR | 16,000 (D) | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| **2000** | 92 (U) | NR | 23,000 (D,N) | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| **2001** | 92 (U) | NR | 6,800,000 (D,N) | NR | NR | NR | NR | 50 (U) | NR | NR | NR | NR |
| **2002** | 50 (U) | NR | 440,000 (D,N) | 50 (U) | NR | NR | NR | 1,500 | NR | NR | NR | NR |
| **2003** | 50 (U) | 6,500 (N) | 630,000,000 (D,Z) | 50 (U) | NR | NR | NR | 900 | NR | NR | NR | NR |
| **2004** | 50 (U) | 6,100 (N) | 340,000 (D,N) | 50 (U) | 60 (U,H) | 60 (U) | NR | 750 (N) | NR | NR | NR | NR |
| **2005** | 50 (U) | 11,000 (N) | 69,000 (D,N) | 580 (N,Q) | 50 (U) | 50 (U) | NR | 610 | NR | NR | NR | NR |
| **2006** | 50 (U) | 50 (U) | 23,000 (D) | 50 (U) | 50 (U) | 50 (U) | NR | 50 (U) | NR | NR | NR | 50 (UD) |
| **2007** | 50 (U) | 33 (U,D,N) | 190,000 | 50 (U) | 71 (U) | 50 (U) | NR | 50 (U) | NR | 970 | 290 | 15 (U) |
| **2008** | 33 (U) | NR | 809,000 (D) | 72 (U) | NR | NR | NR | 71 (U) | NR | 94 (U) | 320 | 72 (U) |
| **2009** | 17 (U) | 70 (U) | 67,000 (D) | 17 (U) | 70 (U) | 70 (U) | 70 (U) | 260 | 2,100 | 840 | 770 | 70 (U) |
| **2010** | 70 (U) | 79 (J) | 420,000 (D) | 70 (U) | 70 (U) | 70 (U) | 70 (U) | 200 (X) | 2,100 | 570 | 910 | 200 |
| **2011** | 70 (U) | 70 (U) | 48,000 (H) | 670 | 70 (U) | 70 (U) | 70 (U) | 70 (U) | 70 (U) | 360 | 670 | 80 (U) |

**Table 4-10. Total Petroleum Hydrocarbon-Diesel Range Results* for Selected Wells and Aquifer Tubes**

| Date | N-3 | N-16 | N-18 | N-19 | N-21 | N-56 | N-57 | N-96A | N-173 | Array0A | C6135 | Array1A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

Note:

*Highest detected result or lowest nondetectable result for a calendar year reported in table.

Data Flags:

D = sample was diluted for analysis
H = Laboratory holding time exceeded before sample was analyzed
J = Concentration is estimated
N = spike sample outside limits
NR = Not reported
Q = associated with out-of-limit quality control data
U = undetected
X = See hard copy data report for further explanation
Z = Miscellaneous circumstances exist, see project file

**Table 4-11. Total Petroleum Hydrocarbon-Diesel Range Results* for Apatite Barrier Injection and Monitoring Wells**

| Date | N-200 | N-201 | N-202 | N-203 | N-204 | N-205 | N-206 | N-207 | N-208 | N-209 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4-1-2010 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 17 (U) | ----- | ----- |
| 4-6-2010 | ----- | 3,500 | ----- | 3,600 | ----- | 3,200 | ----- | ----- | ----- | 2,200 |
| 6-24-2010 | 2,100 (X) | ----- | 3,200 (X) | ----- | 3,000 (X) | ----- | 2,700 (X) | ----- | 1,400 (X) | ----- |
| **Date** | **N-210** | **N-211** | **N-212** | **N-213** | **N-214** | **N-215** | **N-216** | **N-217** | **N-218** | **N-219** |
| **4-1-2010** | ----- | 17 (U) | ----- | 17 (U) | ----- | 17 (U) | ----- | 17 (U) | ----- | 17 (U) |
| **4-6-2010** | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| **6-24-2010** | 70 (U) | ----- | 70 (U) | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| **6-25-2010** | ----- | ----- | ----- | ----- | 70 (U) | ----- | 70 (U) | ----- | 70 (U) | ----- |

**Table 4-11. Total Petroleum Hydrocarbon-Diesel Range Results* for Apatite Barrier Injection and Monitoring Wells**

| Date | N-220 | N-221 | N-222 | N-223 | N-224 | N-225 | N-226 | N-227 | N-228 | N-229 |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-31-2010 | ----- | ----- | ----- | | ----- | 70 (U) | ----- | 70 (U) | ----- | 70 (U) |
| 4-1-2010 | ----- | 17 (U) | ----- | 17 (U) | ----- | ----- | ----- | ----- | ----- | ----- |
| 6-25-2010 | 90 (U) | ----- | 100 (U) | ----- | 70 (U) | ----- | 70 (U) | ----- | 70 (U) | ----- |
| **Date** | **N-230** | **N-231** | **N-232** | **N-233** | **N-234** | **N-346** | **N-347** | **N-348** | **N-349** | |
| 3-31-2010 | ----- | 70 (U) | ----- | 70 (U) | ----- | ----- | ----- | ----- | ----- | |
| 4-6-2010 | ----- | ----- | ----- | ----- | ----- | 3,700 | 17 (U) | 3,800 | 17 (U) | |
| 6-25-2010 | 70 (U) | ----- | 70 (U) | ----- | 70 (U) | ----- | ----- | ----- | ----- | |
| 2011 | ----- | ----- | ----- | ----- | ----- | ----- | 80 (U) | 80 (U) | 70 (U) | |

Note:

*Highest detected result or lowest nondetectable result for a calendar year reported in table

Orange shading indicates barrier injection well–deep

Pink shading indicates barrier monitoring well–deep

Yellow shading indicates barrier injection well–shallow

U = undetected

X = see hard copy data report for further explanation

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# 5 P&T System Cost Data

The actual costs for the 100-HR-3 and 100-KR-4 OU P&T systems for 2011 are presented in Sections 5.1 and 5.2, respectively. Section 5.3 addresses the 100-NR-2 OU and the cost breakdown for apatite PRB and related technology tests. The primary categories of expenditures are described as follows:

- **Capital design—**Includes design activities to construct the P&T systems and designs for major system upgrades and modifications.
- **Capital construction—**Includes oversight labor, material, and subcontractor fees for capital equipment, initial construction, construction of new wells, redevelopment of existing wells, and modifications to the P&T system.
- **Project support—**Includes project coordination-related activities and technical consultation, as required, during the course of the facility design, construction, acceptance testing, and operation.
- **Operations and maintenance (O&M)—**Represents facility supplies, labor, and craft supervision costs associated with operating the facility. It also includes the costs associated with routine field screening and engineering support as required during the course of P&T operation and periodic maintenance.
- **Performance monitoring—**Includes system and groundwater sampling and sample analysis, as required in accordance with the 100-HR-3 and 100-KR-4 OU interim action work plan (DOE/RL-96-84).
- **Waste management**—Includes the cost for the management of spent resin at the 100-HR-3 and 100-KR-4 OUs in accordance with applicable laws for suspect hazardous, toxic, and regulated wastes. Cost includes waste designation sampling and analysis, resin regeneration, and new resin purchase.

Costs are burdened and based on actual operating costs incurred during CY 2010. Summaries of the costs for each P&T system are presented in the following sections.

## 5.1 100-HR-3 Operable Unit P&T Systems Costs

The 100-HR-3 OU costs for CY 2011 are associated with four P&T systems (e.g., HR-3, DR-5, DX, and HX). The cost breakdowns for the 100-HR-3 OU P&T systems are shown in Tables 5-1 through 5-4. The HR-3 and DR-5 P&T systems operated primarily during the first half of 2011.

### 5.1.1 HR-3 P&T System

In May, the HR-3 P&T system was shut down to disconnect and transfer the wells to the HX well network. The disconnection was completed on May 16, 2011, and the HR-3 P&T system was then placed in cold standby. The total cost for the HR-3 system during 2011 was approximately $0.8 million, which consists of the sum of the categories shown in Table 5-1. The largest single component of the total cost was the $0.79 million spent during the year for O&M. Project support followed at approximately $11,700. No other costs were accrued. The percentage cost breakdown for the HR-3 P&T system for 2011 indicates that the majority of the costs, in decreasing order, were charged to O&M (99 percent) and project support (1 percent).

### 5.1.2 DR-5 P&T System

The DR-5 P&T went offline in March to disconnect and transfer the wells to the DX P&T system. The total cost for the DR-5 system during 2011 was approximately $0.19 million, which consists of the sum of the categories shown in Table 5-2. The largest single component of the total cost was the

$185,400 spent during the year for O&M. Project support followed at approximately $2,700. No other costs were accrued. After the DR-5 P&T was shut down, the system was put into cold standby.
The percentage cost breakdown for the DR-5 P&T system for 2011 indicates that the costs, in decreasing order, were charged to O&M (99 percent) and project support (1 percent).

### 5.1.3 DX P&T System

Construction of the DX facility was completed at the end of 2010. Acceptance testing of the facility began in December 2010, and the system became operational in January 2011. The total cost for the DX P&T system during 2011 was approximately $3.1 million, which consists of the sum of the categories shown in Table 5-3. The largest single component of the total cost was the $2.98 million spent during the year for O&M. The cost breakdown percentage for the DX system, shown in Figure 5-1, indicates that the majority of the costs, in decreasing order, were charged to O&M (95.3 percent), design (3.2 percent), project support (1.5 percent), and performance monitoring (0.1 percent).

Based on the total 2011 cost of $3,128,000, the yearly production rate of 919.1 million L (242.8 million gal), and 442.9 kg of hexavalent chromium removed, the annual treatment costs equate to $0.0034/L, or $7/g of hexavalent chromium removed.

### 5.1.4 HX P&T System

Construction of the HX P&T system was completed in July 2011. Acceptance testing activities commenced on August 1, 2011 and were completed on September 28, 2011. The system became operational on October 1, 2011. The total cost for the HX system during 2011 was approximately $14.7 million, which consists of the sum of the categories shown in Table 5-4. The largest single component of the total cost was the $11.3 million spent during the year for capital construction. The cost breakdown for the HX system for 2011, shown in Figure 5-2, indicates that the majority of the costs, in decreasing order, were charged to treatment system capital construction (76.9 percent), project support (13.5 percent), design (7.3 percent), O&M (2.2 percent), and performance monitoring (0.1 percent).

## 5.2 100-KR-4 Operable Unit P&T Systems Costs

The 100-KR-4 OU costs for CY 2011 are associated with three P&T systems (KR4, KX, and KW). Total cost breakdown includes non-recurring costs related to the installation of four new groundwater wells and the conversion of five additional wells to either monitoring or extraction wells. The yearly cost breakdowns for each of the three 100-KR-4 OU P&T systems are shown in Tables 5-5 through 5-7.

### 5.2.1 100-KR-4 P&T System

The total cost for the 100-KR-4 system during 2011 was $3.93 million, which consists of the sum of the categories shown in Table 5-5. The cost of drilling one new monitoring well (199-K-197) and two new extraction wells (199-K-198 and 199-K-199) is included in the capitol construction expense. Despite the cost of the new wells, the 2011 capital construction expense is $1.7 million less than the 2010 capitol construction expense. The percentage that each category comprises of the total cost for the 100-KR-4 system, illustrated in Figure 5-3, is as follows in decreasing order: treatment system capital construction (47.3 percent), O&M (23.2 percent), performance monitoring (22.8 percent), waste management (2.8 percent), project support (2.4 percent), design (1.3 percent), and field studies (0.05 percent).

Based on the total 2011 cost of $3,931,000, the yearly production rate of 285 million L (75.3 million gal), and 5.4 kg of hexavalent chromium removed, the annual treatment costs equate to $0.0138/L, or $728/g of hexavalent chromium removed.

### 5.2.2 KX P&T System

The total cost for the KX P&T system for CY 2011 was $2.66 million (Table 5-6). Extraction Wells 199-K-149 and 199-K-150 were converted to monitoring wells, and monitoring Wells 199-K-152 and 199-K-182 were converted to extraction wells. The cost to perform this work would have been reflected in the treatment system capitol construction expense, but expense corrections resulted in a surplus of $1,700. The percentage that each category comprises of the total cost for the KX system, illustrated in Figure 5-4, is as follows in decreasing order: O&M (62 percent), performance monitoring (25.4 percent), waste management (8.2 percent), project support (3.5 percent), and design (0.8 percent).

Based on the total 2011 cost of $2,656,000, the yearly production rate of 900.5 million L (237.9 million gal) and 30.1 kg of hexavalent chromium removed, the annual treatment costs equate to $0.0029/L, or $88/g of hexavalent chromium removed.

### 5.2.3 KW P&T System

The total cost for the KW system during 2011 was $2.71 million, which consists of the sum of the categories shown in Table 5-7. One new extraction well (199-K-196) was added to the KW system, and the resulting cost is reflected in the treatment system capital construction total. Additional capital construction cost was accrued from converting monitoring Well 199-K-173 to an extraction well. The percentage that each category comprises of the total cost for the KW system, illustrated in Figure 5-5, is as follows in decreasing order: O&M (38.4 percent), treatment system capital construction (29.3 percent), performance monitoring (24.9 percent), project support (3.5 percent), waste management (3.1 percent), and design (0.7 percent).

Based on the total 2011 cost of $2,709,000, the yearly production rate of 357.0 million L (94.3 million gal), and 25.9 kg of hexavalent chromium removed, the annual treatment costs equate to $0.0076/L, or $104.6/g of hexavalent chromium removed.

## 5.3 100-NR-2 Apatite PRB System Costs

The cost breakdown for CY 2011 for the apatite PRB and related technology tests (replacement for P&T at the 100-N Area) is presented in Table 5-8 and Figure 5-6. The total CY 2011 construction and operation costs were $3,212,000. The cost breakdown indicates that the majority of the cost was for barrier maintenance (57.4 percent), followed, in decreasing order, by performance monitoring (33.3 percent), project support (5.6 percent), field studies (3.7 percent), O&M (0.9 percent), waste management (0.1 percent), and , design and treatment system capital construction (both less than 0 percent).

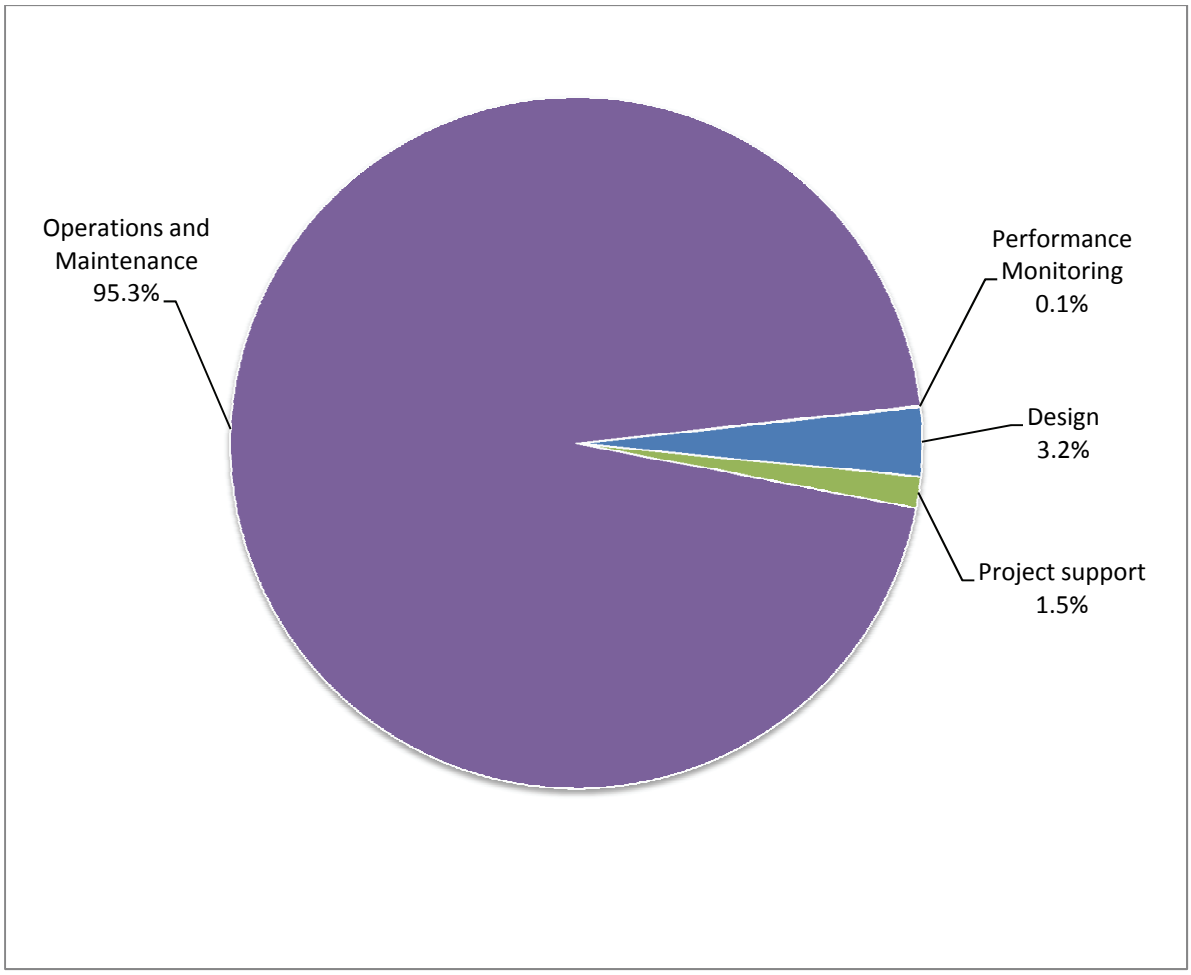


**Figure 5-1. DX P&T System, 2011 Cost ($3.1 M) Breakdown (by Percentage)**

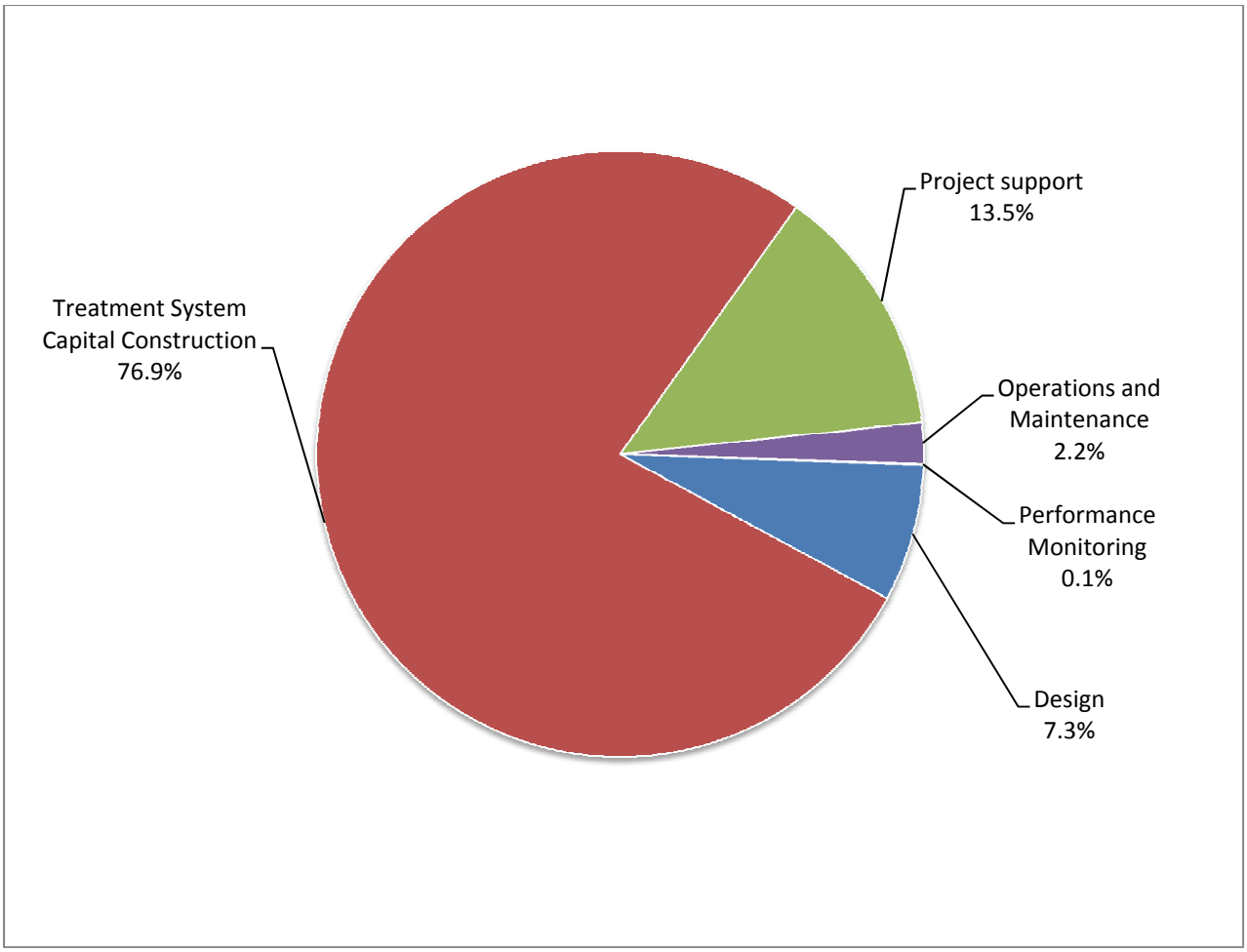


**Figure 5-2. HX P&T System, 2011 Cost ($14.7 M) Breakdown (by Percentage)**

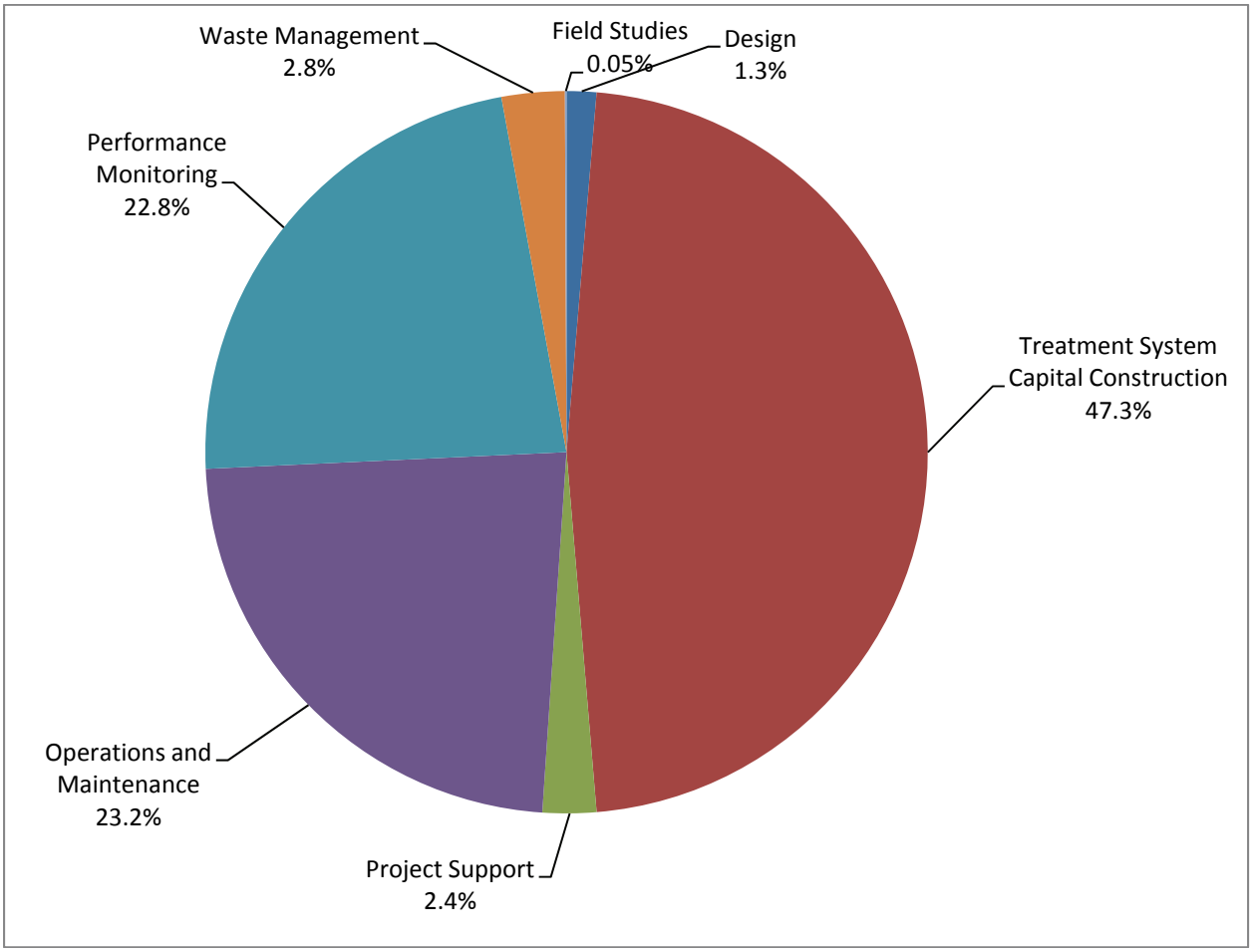


**Figure 5-3. 100-KR-4 P&T System, CY 2011 Cost Breakdown (by Percentage)**

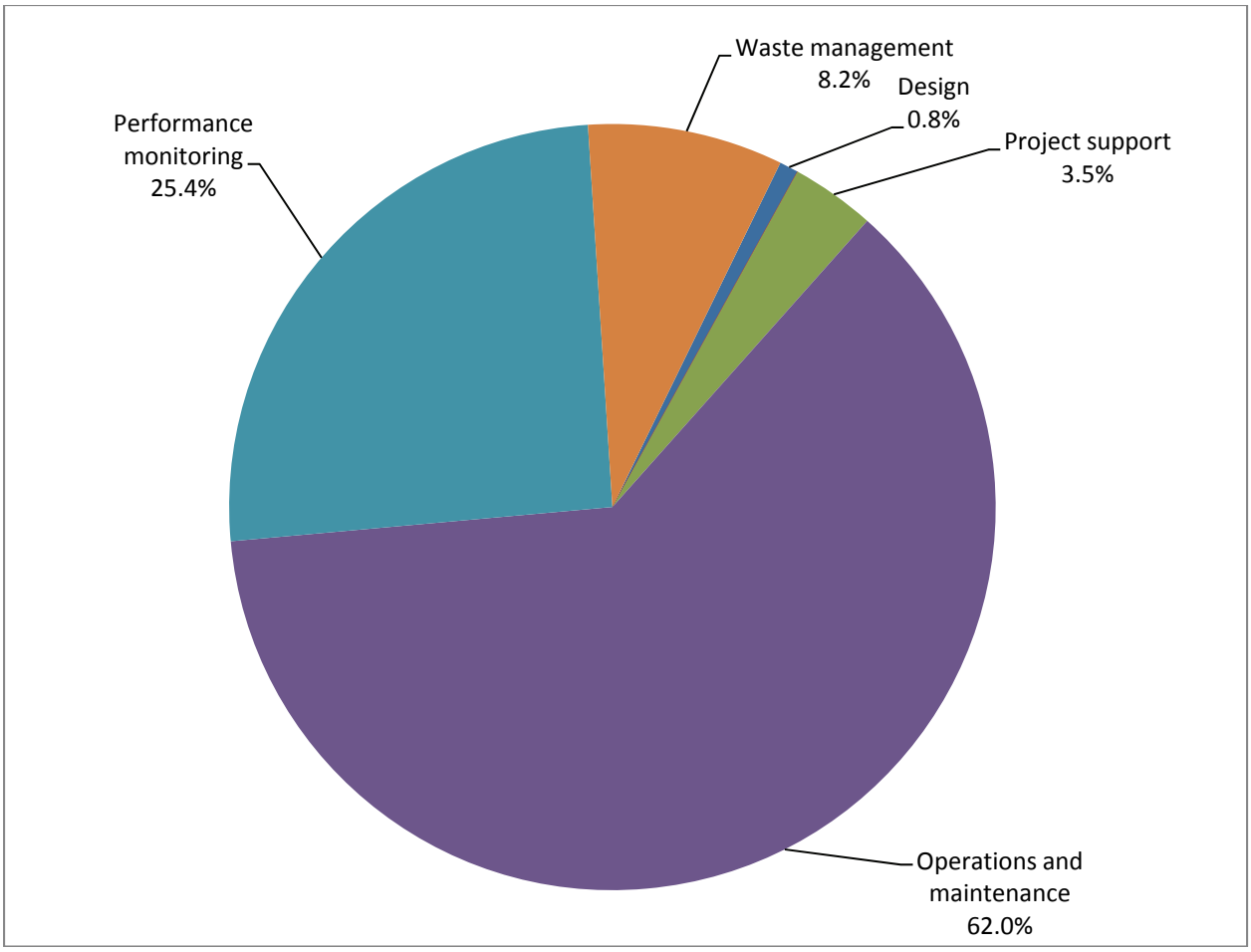


**Figure 5-4. KX P&T System, CY 2011 Cost Breakdown (by Percentage)**

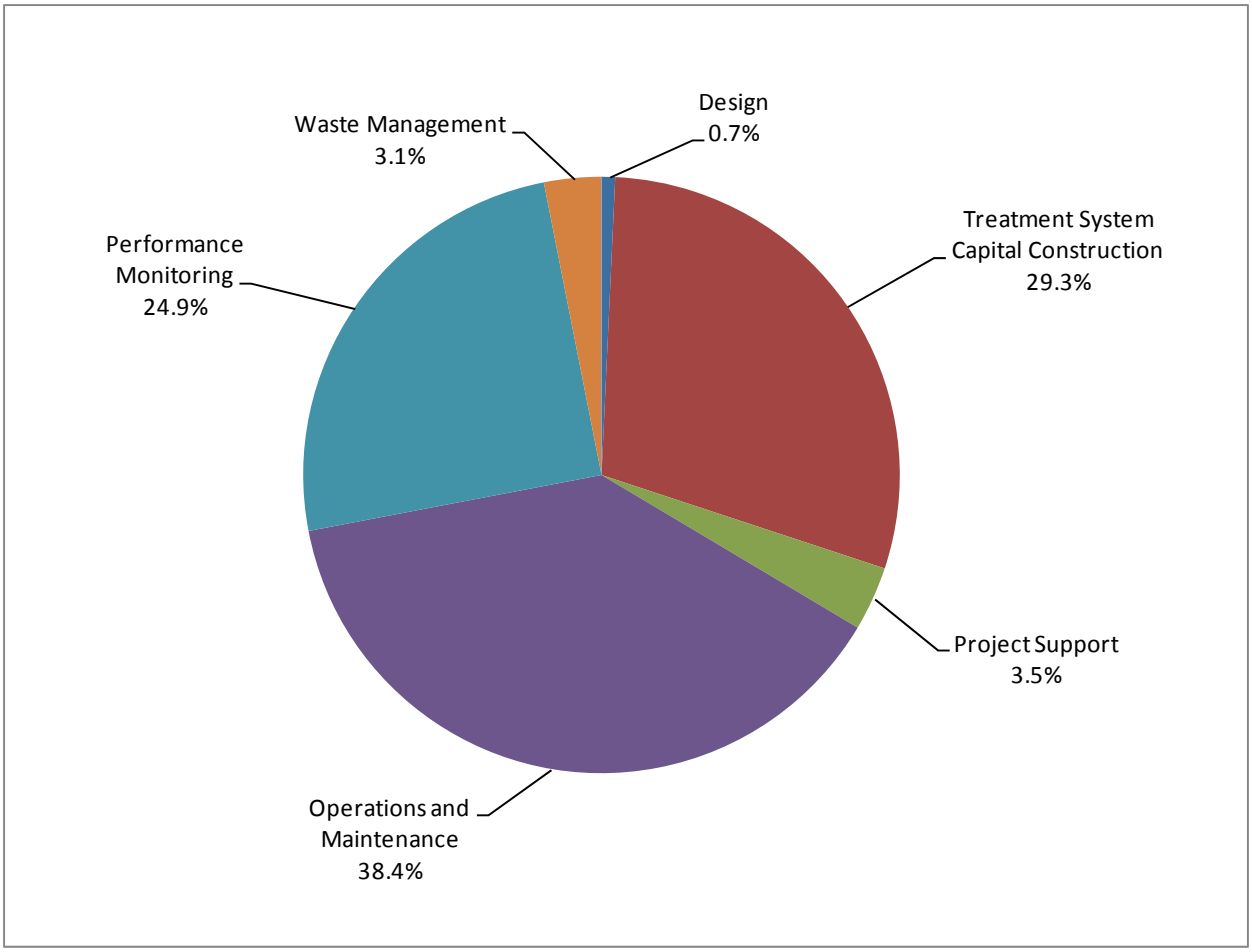


**Figure 5-5. KW P&T System, CY 2011 Cost Breakdown (by Percentage)**

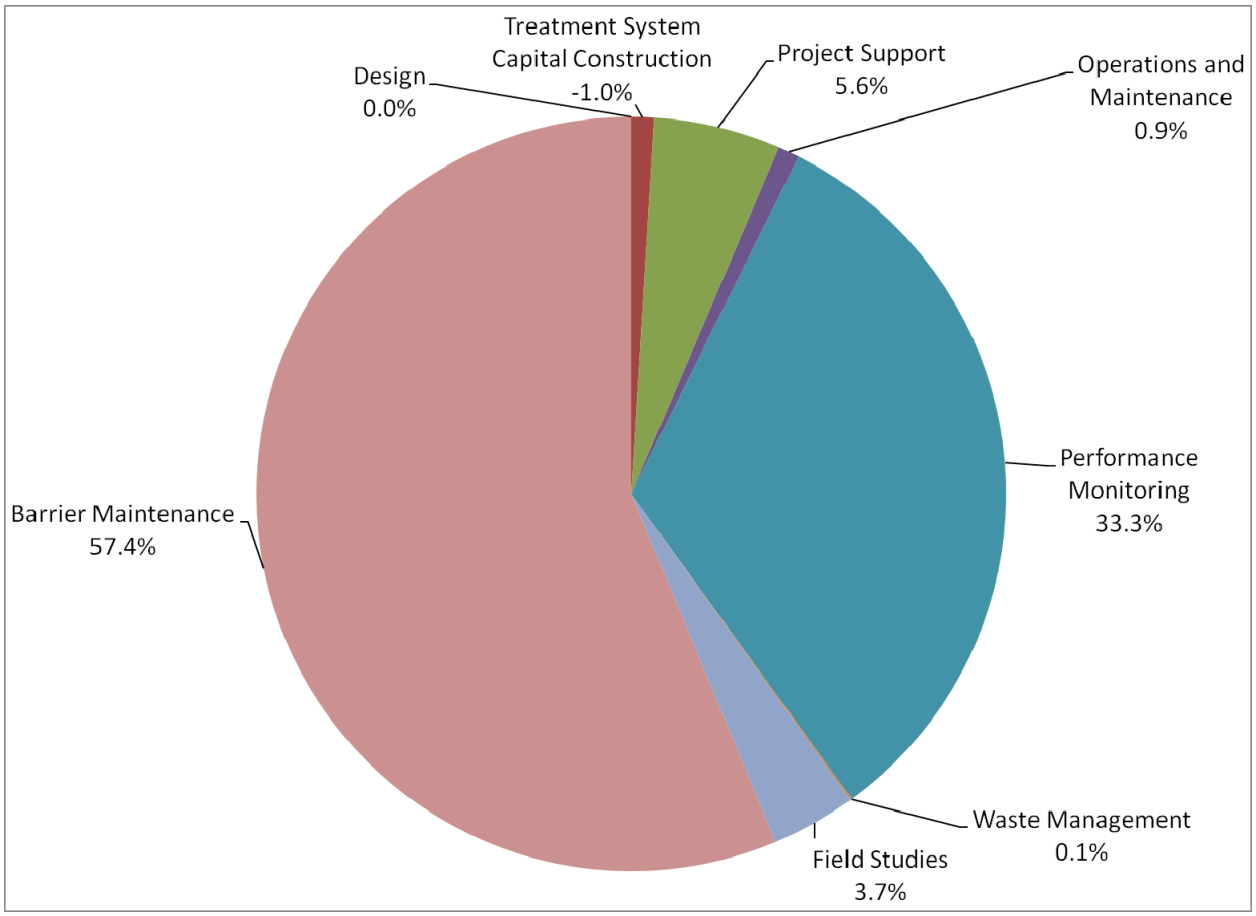


**Figure 5-6. 100-NR-2 Apatite Barrier, CY 2010 Cost Breakdown (by Percentage)**

**Table 5-1. Breakdown of HR-3 P&T System Construction and Operation Costs**

| Description | Actual Costs (Dollars × 1,000) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1999** | **2000** | **2001[a]** | **2002[b]** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009[c]** | **2010** | **2011[d]** |
| Design | -- | -- | 97.7 | 15.4 | 8.1 | 196.1 | 196.0 | 55.0 | 92.0 | -- | 0.0 | 26.5 | -- |
| Treatment system capital construction | -- | 57.7 | (36.1) | 750.3 | -- | 496.6 | 10.0 | -- | -- | -- | -- | -- | -- |
| Project support | 265.3 | 276.7 | 225.8 | 309.3 | 229.8 | 211.8 | 722.6 | 697.6 | 171.9 | 169.5 | 204.7 | 139.6 | 11.7 |
| Operations and maintenance | 1,650.8 | 799.1 | 739.2 | 816.6 | 733.7 | 1,049.5 | 618.5 | 891.2 | 679.6 | 1,084.8 | 1,091.8 | 1,411.5 | 788.9 |
| Performance monitoring | -- | 173.7 | 219.9 | 120.0 | 163.2 | 120.3 | 353.0 | 489.6 | 219.5 | 508.5 | 237.7 | 240.0 | -- |
| Waste management | -- | 895.3 | 424.9 | 720.1 | 877.2 | 501.7 | 202.2 | 217.6 | 434.7[e] | 192.2 | 16.6 | 75.0 | -- |
| **Totals** | **$1,916** | **$2,203** | **$1,671** | **$2,732** | **$2,012** | **$2,576** | **$2,102** | **$2,351** | **$1,598** | **$1,955** | **$1,551** | **$1,893** | **$801** |

a. 2001 costs were corrected for project support and waste management. Initial expense calculations for 2001 were not properly categorized.

b. 2002 accrual costs were corrected for appropriate split between Bechtel Hanford, Inc. and Fluor Hanford, Inc.

c. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period. The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.

d. The 100-HR-3 P&T system went into cold standby in May 2011.

e. Additional costs were associated with drilling wastes and resin cleared for shipment and handling.

-- = not available

**Table 5-2. Breakdown of DR-5 P&T System Construction and Operation Costs**

| Description | Actual Costs (Dollars × 1,000) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2008 | 2009[a] | 2010 | 2011[b] |
| Design | 246.9 | 196.8 | 100.4 | -- | 3.2 | 3.4 | -- |
| Treatment system capital construction | -- | 22.2 | -- | -- | -- | -- | -- |
| Project support | 586.4 | 370.6 | 240.3 | 233.6 | 204.7 | 139.6 | 2.7 |
| Operations and maintenance | 459.6 | 605.7 | 541.3 | 884.7 | 1,091.7 | 919.9 | 185.4 |
| Performance monitoring | 106.2 | 1.6 | 11.3 | 127.1 | 237.7 | 240.0 | -- |
| Waste management | 28.3 | 154.7 | 45.4 | 23.8 | 1.7 | 29.0 | -- |
| **Totals** | **$1,427** | **$1,352** | **$939** | **$1,269** | **$1,539** | **$1,332** | **$188** |

a. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period. The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.

b. The DR-5 P&T system went into cold standby in March 2011.

-- = not available

**Table 5-3. Breakdown of DX P&T System Construction and Operation Costs**

| Description | Actual Costs (Dollars × 1,000) | | |
|---|---|---|---|
| | 2009[a] | 2010 | 2011[b] |
| Design | 2,115.2 | 1,287.8 | 100.7 |
| Treatment system capital construction | 5,759.8 | 16,266.3 | -- |
| Project support | 495.1 | 1,236.9 | 45.7 |
| Operations and maintenance | -- | -- | 2,979.3 |
| Performance monitoring | -- | -- | 1.8 |
| Waste management | 7.4 | 9.2 | -- |
| **Totals** | **$8,377** | **$18,800** | **$3,128** |

a. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period. The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.

b. DX P&T construction was completed in December 2010, entered acceptance test procedures, and became fully operational in January 2011.

-- = not available

**Table 5-4. Breakdown of HX P&T System Construction Costs**

| Description | Actual Costs (Dollars × 1,000) | | |
|---|---|---|---|
| | 2009[a] | 2010 | 2011[b] |
| Design | 896.4 | 1,047.5 | 1,079.8 |
| Treatment system capital construction | 214.1 | 9,354.2 | 11,316.2 |
| Project support | -- | 400.2 | 1,981.4 |
| Operations and maintenance | -- | -- | 321.2 |
| Performance monitoring | -- | -- | 8.0 |
| Waste management | -- | 0.1 | -- |
| **Totals** | **$1,111** | **$10,802** | **$14,707** |

a. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period. The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.

b. HX P&T construction was completed in September 2011, entered acceptance test procedures, and became fully operational in October 2011.

-- = not available

**Table 5-5. Breakdown of 100-KR-4 P&T System Construction and Operation Costs**

| Description | Actual Costs (Dollars × 1,000) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1999 | 2000 | 2001[a] | 2002[b] | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009[f,g] | 2010[h] | 2011 |
| Design | 0.2 | -- | 96.5 | 55.2 | 70.8 | 163.9 | 190.8 | 97.8 | 187[c] | 63.1 | 157.7 | 25.4 | 52.2 |
| Treatment system capital construction | -- | 109.1 | (0.1) | 860.1 | 379.9 | 94.2 | 273.8 | 1,505.8 | 2,114.1[d] | 8,368.5 | 6,651.0[d] | 3,556.2 | 1,860.8 |
| Project support | 157.2 | 143.0 | 188.2 | 257.8 | 171.0 | 211.8 | 851.9 | 530.5 | 489.8 | 963.0 | 174.1 | 77.6 | 94.3 |
| Operations and maintenance | 717.4 | 538.0 | 578.6 | 771.9 | 789.7 | 1,118.2 | 878.6 | 1,350.8 | 804.3 | 916.0 | 1,619.3 | 1,418.1 | 911.8 |
| Performance monitoring | -- | 111.2 | 122.6 | 124.6 | 119.7 | 83.3 | 446.3 | 548.8 | 395.7 | 634.9 | 569.1 | 928.1 | 897.9 |
| Waste management | -- | 481.8 | 367.5 | 343.3 | 684.7 | 475.8 | 198.3 | 230.2 | 458.9[e] | 438.2 | 599.8 | 266.7 | 110.6 |
| Field studies | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 25.0 | 653.1 | 3.0 |
| **Totals** | **$875** | **$1,383** | **$1,353** | **$2,413** | **$2,216** | **$2,147** | **$2,840** | **$4,264** | **$4,450** | **$11,384** | **$9,796** | **$6,925** | **$3,931** |

a. 2001 costs were corrected for project support and waste management. Initial expense calculations for 2001 were not properly categorized.
b. 2002 accrual costs were corrected for appropriate split between Bechtel Hanford, Inc. and Fluor Hanford, Inc.
c. Additional design costs were associated with P&T expansion.
d. Additional treatment system capital construction costs were associated with new wells and buildings to support P&T expansion.
e. Additional costs were associated with drilling wastes and resin cleared for shipment and handling.
f. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period.
The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.
g. KX system costs prior to startup are included in with 2009.
h. 2010 accrual costs were corrected. KR4 and KX expense calculations were incorrectly grouped together.
-- = not available

**Table 5-6. Breakdown of KX P&T System Costs**

| Description | Actual Costs (Dollars × 1,000) | |
|---|---|---|
| | 2010 | 2011 |
| Design | 31.4 | 21.4 |
| Treatment system capital construction | 22.9 | (1.7) |
| Project support | 77.6 | 94.3 |
| Operations and maintenance | 1,224.4 | 1,647.8 |
| Performance monitoring | 528.9 | 674.9 |
| Waste management | 579.6 | 219.1 |
| Field studies | -- | -- |
| **Totals** | **$2,465** | **$2,656** |

-- = not available

**Table 5-7. Breakdown of KW P&T System Costs**

| Description | Actual Costs (Dollars × 1,000) | | | | |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009[a] | 2010 | 2011 |
| Design | 13.0 | 27.7 | 78.1 | 11.6 | 20.0 |
| Treatment system capital construction | 2,187.8 | 1,088.3 | 2,301.8 | 324.3 | 794.8 |
| Project support | 118.9 | 155.3 | 174.1 | 77.6[b] | 94.3 |
| Operations and maintenance | 402.4 | 599.6 | 758.6 | 1,149.6[b] | 1,041.3 |
| Performance monitoring | 9.7 | 126.6 | 215.9 | 528.9[b] | 674.9 |
| Waste management | 405.4 | 164.3 | 95.4 | 207.5[b] | 84.0 |
| Field studies | -- | -- | -- | -- | -- |
| **Totals** | **$3,137** | **$2,162** | **$3,624** | **$2,300** | **$2,709** |

a. Annual report has been transitioned from a fiscal year reporting period to a calendar year reporting period. The cost breakdown for 2009 is for the 15 month period from October 2008 through December 2009.

b. Values were incorrectly calculated and later corrected.

-- = not available

**Table 5-8. Breakdown of 100-NR-2 P&T System Construction and Operation Costs**

| Description | Actual Costs (Dollars x 1000) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1999** | **2000** | **2001[a]** | **2002[b]** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| Design | 0.2 | -- | -- | -- | -- | -- | 447.9 | -- | -- | -- | 20.5 | 31.0 | -- |
| Treatment system capital construction | -- | -- | -- | -- | -- | -- | 161.9 | 922.6 | -- | -- | 316.2 | (0.1) | (32.1) |
| Project support | 113.1 | 96.3 | 183.5 | 219.4 | 133.0 | 329.7 | 416.5 | 284.4 | 79.8 | 10.7 | 278.5 | 276.5 | 178.9 |
| Operations and maintenance | 657.4 | 462.2 | 631.5 | 631.8 | 604.3 | 553.0 | 650.6 | 592.6 | 199.9 | 107.4 | 50.2 | 23.6 | 30.4 |
| Performance monitoring | -- | 82.6 | 83.1 | 72.4 | 51.6 | 79.6 | 408.7 | 182.2 | 62.7 | 36.2 | 466.2 | 956.3 | 1,069.0 |
| Waste management | -- | 131.6 | 112.5 | 100.0 | 45.4 | 27.4 | 7.6 | 13.0 | 43.4 | 8.9 | 3.6 | 0.5 | 2.3 |
| Field studies | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 874.1 | 1,228.3 | 119.5 |
| Barrier maintenance | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 634.3 | 1,468.0 | 1,844.4 |
| **Totals** | **$771** | **$773** | **$1,011** | **$1,024** | **$834** | **$990** | **$2.093** | **$1,995** | **$386** | **$163** | **$2,644** | **$3,984** | **$3,212** |

a. 2001 costs corrected for project support and waste management. Initial expense calculations for 2001 were not properly categorized.

b. 2002 accrual costs corrected for appropriate split between Bechtel Hanford, Inc. and Fluor Hanford, Inc.

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# Appendix A

# Site History

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# A1 Site History

Information on the site history for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Units (OUs) is provided in this appendix.

# A2 100-HR-3 Operable Unit History

In September 1994, *Limited Field Investigation Report for the 100-HR-3 Operable Unit* (DOE/RL-93-43), including a qualitative risk assessment, was completed. Hexavalent chromium was identified as a contaminant of concern for ecological receptors in the Columbia River. In August 1995, *100-HR-3 Operable Unit Focused Feasibility Study* (DOE/RL-94-67) and *Proposed Plan for Interim Remedial Measure at the 100-HR-3 Operable Unit* (DOE/RL-94-102) were finalized. The proposed plan (DOE/RL-94-102) recommended the use of a pump-and-treat (P&T) system to mitigate chromium migration to the Columbia River. In 1994, a pilot-scale P&T system was deployed, and *Pilot-Scale Treatability Test Summary Report for the 100-HR-3 Operable Unit* (DOE/RL-95-83) was issued in December 1995. The report indicated that removing hexavalent chromium from extracted groundwater in the 100-HR-3 OU using a resin treatment (ion-exchange) system was viable.

In April 1996, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington* (EPA/ROD/R10-96/134) was issued for the 100-HR-3 OU P&T system. The interim record of decision (ROD) specified installation of a P&T system in the 100-HR-3 and 100-KR-4 OUs to intercept portions of the hexavalent chromium plumes that affect the Columbia River. Full-time operation of the 100-HR-3 treatment system began on July 1, 1997 with a treatment capacity of 1,136 L/min (300 gallons per minute [gpm]). On August 5, 1998, the P&T system was modified to permit groundwater from the 100-D Area to be treated separately from 100-H Area groundwater.

In October 1999, *Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington* (EPA/AMD/R10-00/122) was approved, which modified the selected remedial action by deploying an innovative treatment technology, In Situ Redox Manipulation (ISRM), to address the groundwater chromium plume located southwest of the D/DR Reactors. This plume is not within the established treatment zone for the P&T system for the interim action. The initial phase of the ISRM remedial action was implemented in 2000.

An additional P&T system was installed in 2004 at the 100-D Area (DR-5 P&T system with a 189 L/min (50 gpm) treatment capacity) to extract and treat high hexavalent chromium concentrations in the central portion of the 100-D Area. The two P&T systems operated to remediate hexavalent chromium in the 100-HR-3 OU groundwater. The HR-3 system extracted contaminated groundwater from the 100-D and 100-H Areas; the groundwater was then treated and injected in the 100-H Area. The DR-5 system extracted, treated, and injected groundwater in the 100-D Area.

Monitoring of these systems over time provided significant additional information on the nature and extent of contamination and revealed that the hexavalent chromium footprint in groundwater was much larger than anticipated. A remedial process optimization study began in 2008 to determine how to optimize the remediation of hexavalent chromium in groundwater at the 100-HR-3 OU by 2012. The study included cleanup of groundwater within the Horn Area based on field investigations conducted in 2007 and 2008 that further delineated the extent of hexavalent chromium in the area (DOE/RL-2008-42, *Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit*). Two new, expanded P&T systems, the DX (100-D Area) and HX (100-H Area) P&T systems, have been constructed and increase the treatment capacity for groundwater cleanup by 2,273 L/min (600 gpm) and 3,030 L/min (800 gpm), respectively, in the

100-HR-3 OU. Table A-1 provides a summary of treatment capacities for the 100-HR-3 OU P&T systems. The DR-5 and HR-3 P&T systems were phased out in calendar year (CY) 2011 by the expanded systems.

The DX P&T system, which came online in December 2010, will focus on hexavalent chromium contamination in groundwater underlying the 100-D Area and the northwestern portion of the Horn Area. The HX P&T system came online in September 2011 and will focus on hexavalent chromium contamination in groundwater underlying 100-H Area and the southeastern portion of the Horn Area.

Additional detailed site characterization and background information on the 100-HR-3 OU and the P&T activity are provided in *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units* (DOE/RL-2008-46-ADD1). Further information on the P&T system design and operation is provided in *Remedial Design/Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit Interim Actions* (DOE/RL-2009-56). The groundwater monitoring requirements are described in *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90).

## A3 100-KR-4 Operable Unit History

In July 1994, *Limited Field Investigation Report for the 100-KR-4 Operable Unit* (DOE/RL-93-79), including a qualitative risk assessment, was completed. The report concluded that an interim remedial measure was not warranted based on human health risk, but an interim remedial measure could be justified for ecological concerns related to hexavalent chromium. In October 1995, *100-KR-4 Operable Unit Focused Feasibility Study* (DOE/RL-94-48) and *Proposed Plan for Interim Remedial Measure at the 100-KR-4 Operable Unit* (DOE/RL-94-113) were completed. The proposed plan (DOE/RL-94-113) recommended using a P&T interim remedial measure to mitigate hexavalent chromium migration into the Columbia River.

In April 1996, an interim remedial action ROD (EPA/ROD/R10-96/134) was issued for the 100-KR-4 P&T system. The ROD specified installation of a P&T system in the 100-HR-3 and 100-KR-4 OUs to intercept portions of the hexavalent chromium plumes that affect the Columbia River. Full-time operation of the treatment system began on October 1, 1997.

Detailed site characterization and background information for the 100-KR-4 OU and P&T activities are provided in the focused feasibility study (DOE/RL-94-48) and the proposed plan (DOE/RL-94-113). Further information on P&T system design and operation is provided in *Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action* (DOE/RL-96-84) and *100-HR-3 and 100-KR-4 Operable Units Interim Action Performance Evaluation Report* (DOE/RL-97-96). Groundwater monitoring requirements are described in *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units* (DOE/RL-96-90). Additional current background information is available in *Hanford Site Groundwater Monitoring for 2011* (DOE/RL-2011-118).

The KR4 P&T system treats groundwater downgradient of the 116-K-2 Trench (also referred to as the Mile-Long Trench) and has a treatment capacity of 1,136 L/min (300 gpm). The KX P&T system came online in CY 2009 and added 2,271 L/min (600 gpm) treatment capacity. For the hexavalent chromium plumes associated with the 116-K-2 Trench, *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System* (DOE/RL-2006-75) describes the changes made with the addition of the KX system.

The KW P&T system came online in CY 2007 with a 387 L/min (100 gpm) treatment capacity and was expanded to a 757 L/min (200 gpm) capacity in 2009. The system continued operation in 2011 near the groundwater treatment capacity of 757 L/min (200 gpm). For the hexavalent chromium plume associated with the KW Reactor, *The KW Pump-and-Treat System Remedial Design and Remedial Action Work Plan, Supplement to the 100-KR-4 Groundwater Operable Unit Interim Action* (DOE/RL-2006-52) describes the changes made with the addition of the P&T system. The combined groundwater treatment capacity of the three P&T systems (i.e., KR4, KX, and KW) for the 100-KR-4 OU is 4,167 L/min (1,100 gpm). Table A-2 provides a summary of treatment capacities for the 100-KR-3 OU P&T systems.

## A4 100-NR-2 Operable Unit History

On September 23, 1994, the Washington State Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) issued "Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Richland, Washington" (Ecology and EPA, 1994) to the U.S. Department of Energy, Richland Operations Office (DOE-RL) to initiate groundwater remedial actions immediately in the 100-N Area. The requested remedial actions included the design, construction, and operation of a groundwater P&T system and the construction of a sheet-pile barrier wall at N-Springs. However, in a letter dated March 1995 (CCN 012354, "RE: U.S. Department of Energy Request to Change N-Springs Action Memorandum"), Ecology and EPA concurred with DOE-RL that installation of the sheet-pile wall could not be achieved in the manner specified. This conclusion was based on a construction test conducted in December 1994.

Ecology and EPA subsequently directed DOE-RL to proceed with installing a P&T system as an expedited response action. The N-Springs P&T system was completed by August 1995 and began full operation by September 1995, meeting *Hanford Federal Facility Agreement and Consent Order*, also known as Tri-Party Agreement (TPA) (Ecology et al., 1989) Milestone M-16-12D.

From system startup in September 1995 through November 8, 1996, the N-Springs P&T system operated at a nominal rate of 189 L/min (49.9 gpm). During this period, the system consisted of four extraction wells (199-N-75, 199-N-103A, 199-N-106A, and 199-N-105A, with three wells operating and one well as a backup) and two injection wells (199-N-29 and 199-N-104A).

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 shut down and upgraded to operate at 227 L/min (60 gpm) between November 8 and December 17, 1996. The P&T system was brought back online on December 17, 1996, and continued to operate until it was shut down and placed in cold standby status in March 2006 (interim action status change are documented in TPA Change Request M-16-06-01, dated February 15, 2006). The historical configuration of the P&T network consisted of three extraction wells (199-N-75, 199-N-103A, and 199-N-106A) and two injection wells (199-N-29 and 199-N-104A), with well 199-N-105A serving as a backup extraction well.

Additional information regarding progress of the 100-NR-2 P&T operations is provided in previous fiscal year summary reports (e.g., DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 and 2*). Additional current background information is available in *Hanford Site Groundwater Monitoring Report for 2010* (DOE/RL-2011-01).

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 installed as a primary treatment technology and phytoextraction is being studied as a secondary treatment or "polishing" step.

## A5 Historical Plume Maps

Figures A-1 through A-5 show the historical shape and extent of hexavalent chromium plumes in the 100-D, 100-H, and 100-K Areas.

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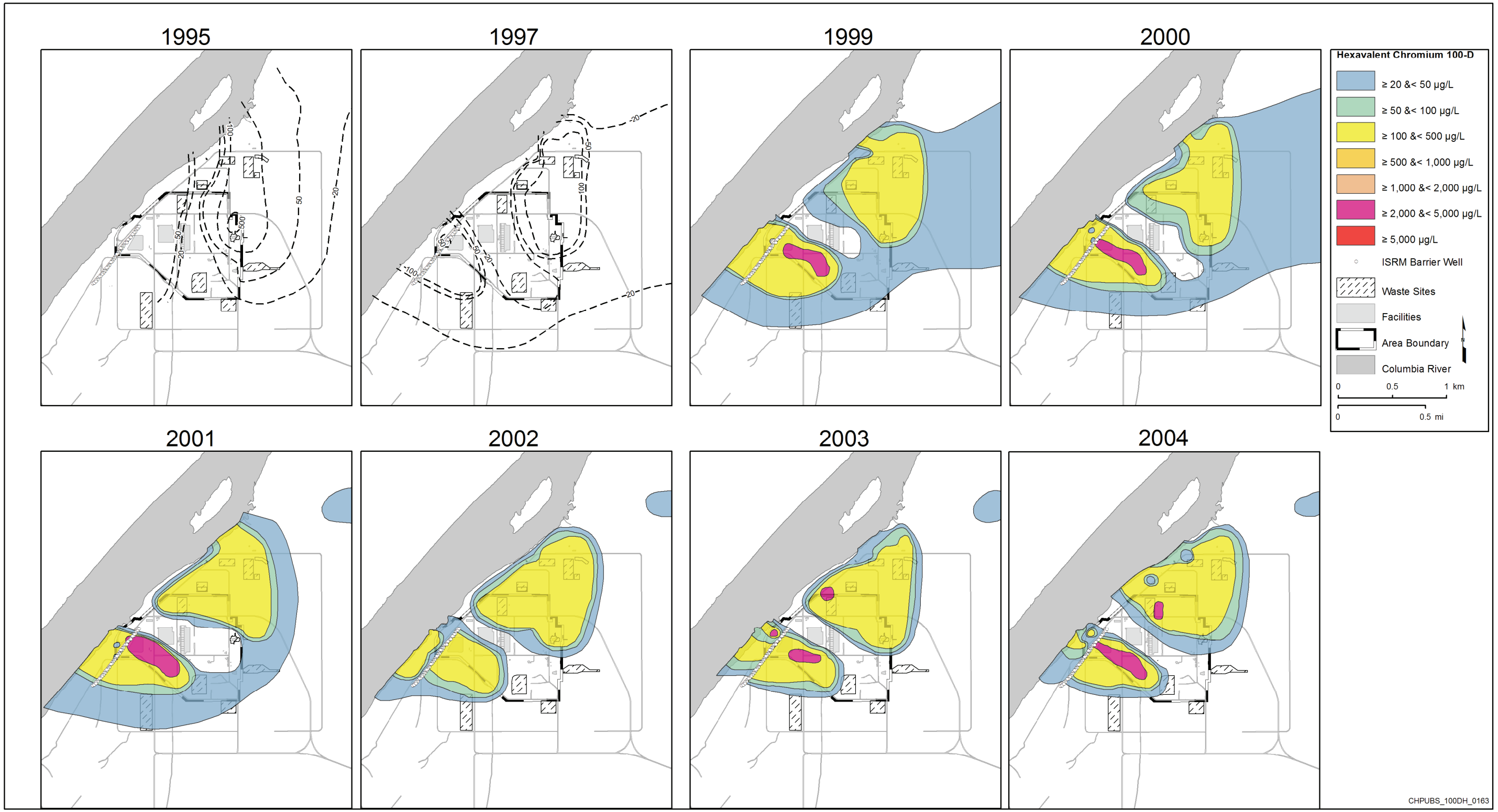


**Figure A-1. 100-D Area Chromium Plumes, 1995 to 2004**

**Figure A-2. 100-D Area Chromium Plumes, 2005 to 2011**

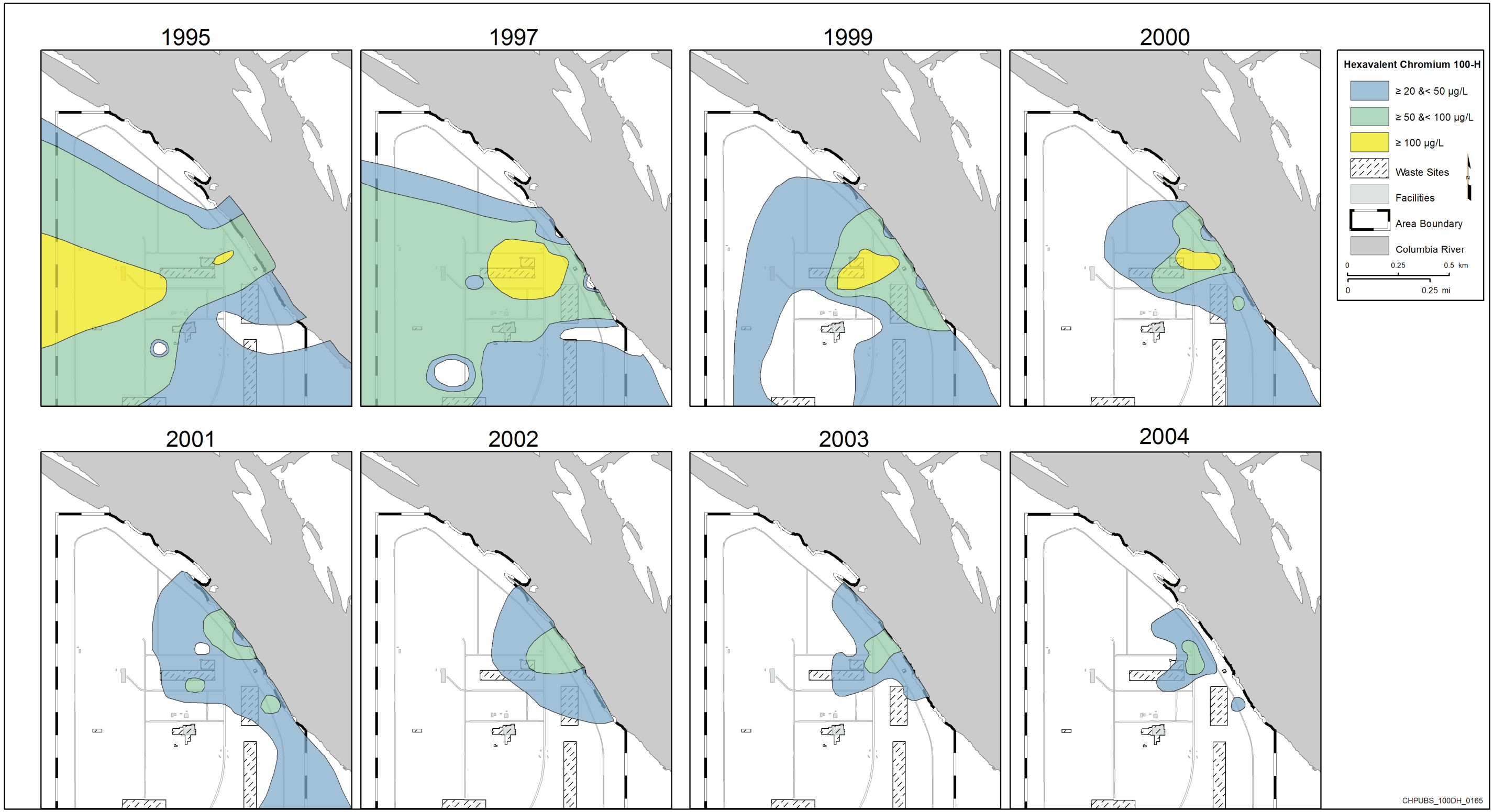


**Figure A-3. 100-H Area Chromium Plume, 1995 to 2004**

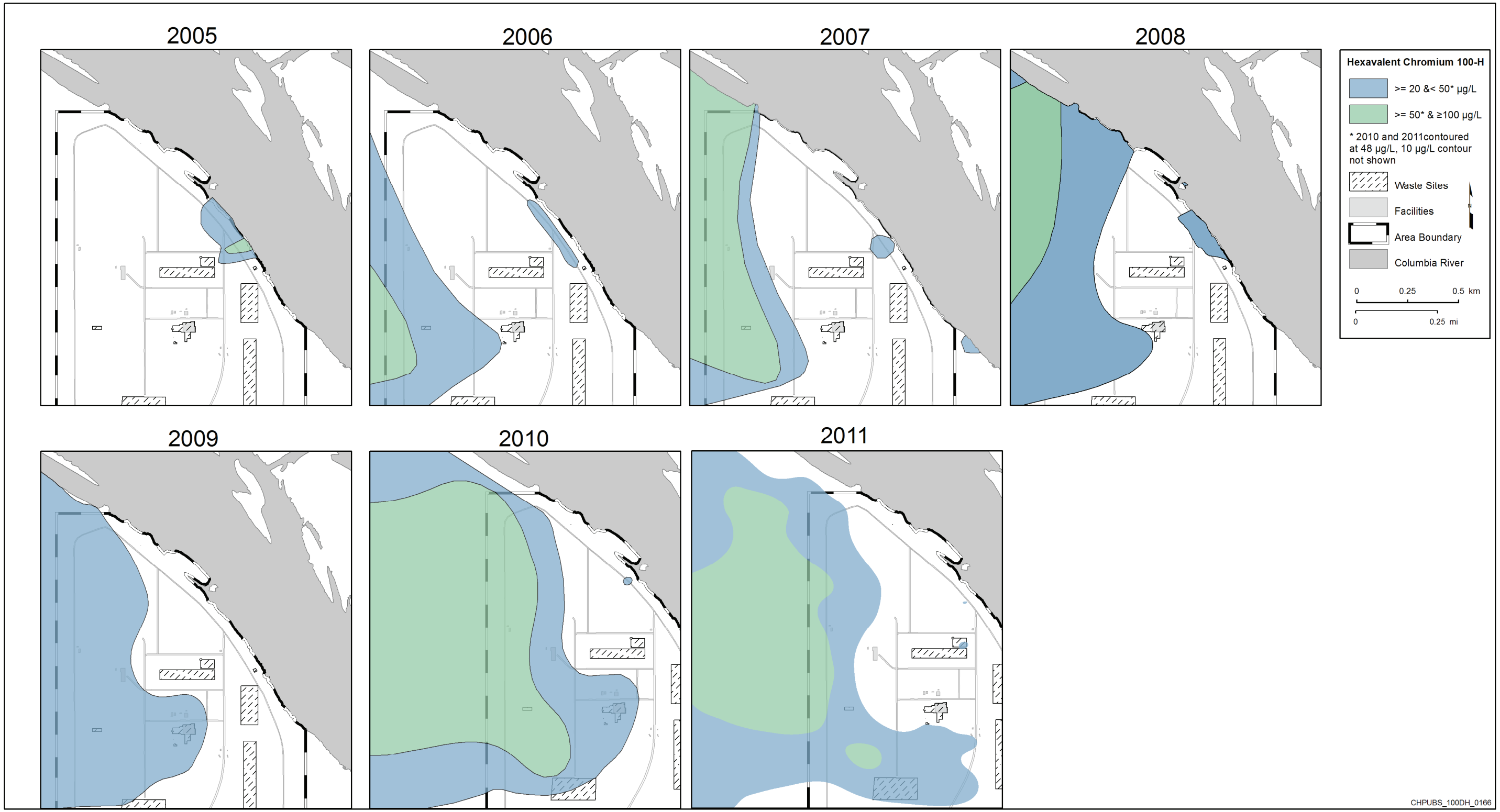


**Figure A-4. 100-H Area Chromium Plume, 2005 to 2011**

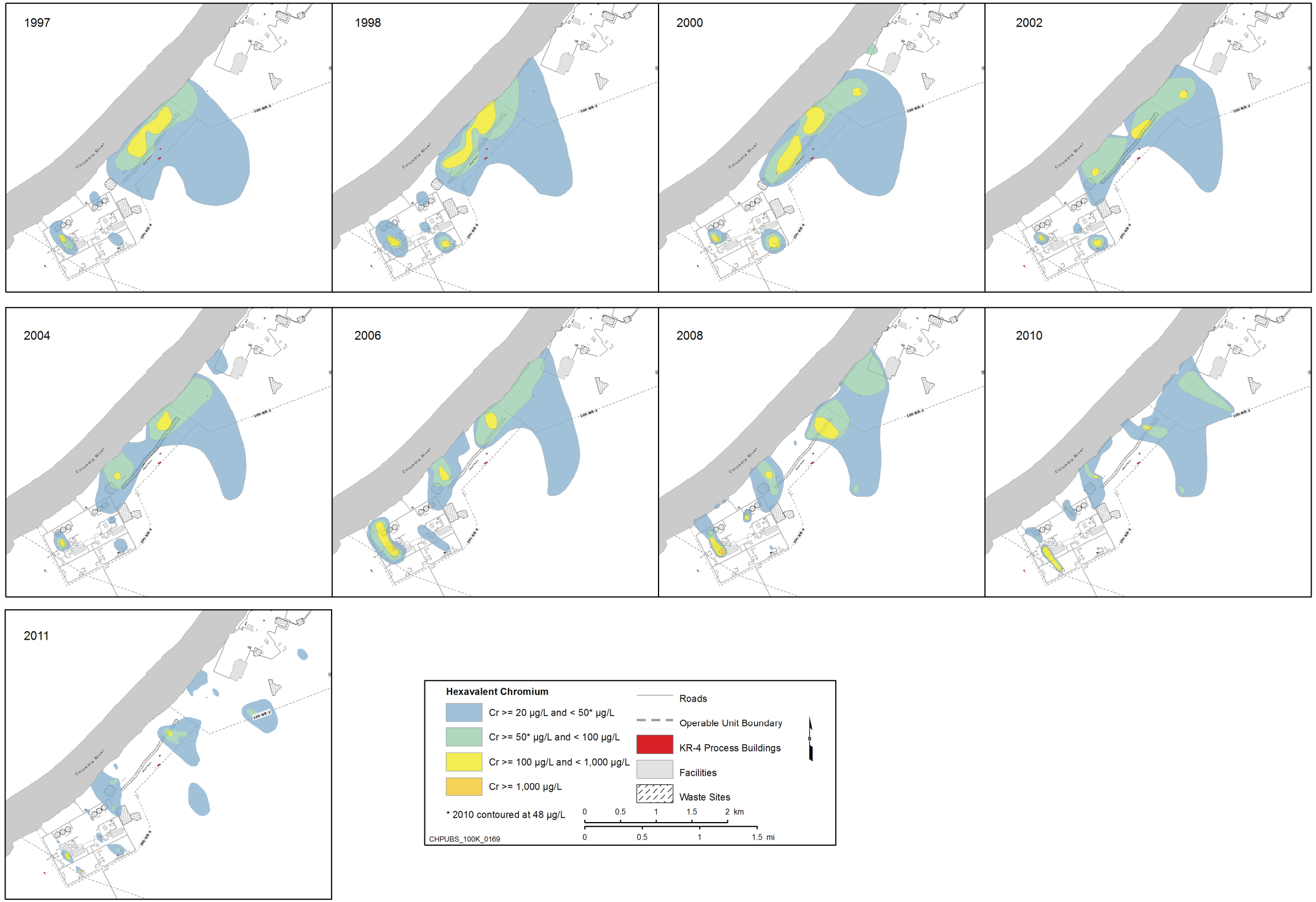


**Figure A-5. 100-K Area Chromium Plume, 1997 to 2011**

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**Table A-1. Treatment Capacity Summary of P&T Systems in the 100-HR-3 Operable Unit**

| P&T | Actual/Scheduled Operation | Design Capacity (L/min [gpm]) | Number of Extraction Wells in the Current Network | Number of Injection Wells in the Current Network |
|---|---|---|---|---|
| HR-3 | June 1997 to May 2011 | 1,136 (300) | 10 | 4 |
| DR-5 | July 2004 to March 2011 | 189 (50) | 5 | 2 |
| DX | December 2010 to present | 2,273 (600) | 37 | 14 |
| HX | September 2011 to present | 3,030 (800) | 31 | 15 |

gpm = gallons per minute

**Table A-2. Treatment Capacity Summary of P&T Systems in the 100-KR-4 Operable Unit**

| P&T | Actual/Scheduled Operation | Design Capacity (L/min [gpm]) | Number of Extraction Wells in the Current Network | Number of Injection Wells in the Current Network |
|---|---|---|---|---|
| KR-4 | September 1997 to present | 1,136 (300) | 10 | 5 |
| KX | February 2009 to present | 2,273 (600) | 14 | 9 |
| KW | January 2009 to present | 757 (200) | 7 | 15 |

gpm = gallons per minute

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# Appendix B

# Methods and Results Capture Zone Modeling

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# B1 Site History

This appendix describes groundwater flow and the extent of capture estimated for the 100-HR-3 and 100-KR-4 Operable Units (OUs) during calendar year (CY) 2011. The terms "hydraulic capture", "capture", "hydraulic containment" and "containment" are used interchangeably within this appendix. Groundwater levels are measured throughout the 100 Area continuously at some wells using pressure transducers with data loggers, and on a regular basis at other wells using manual (depth-to-water) measurements. Groundwater elevations indicate that flow is generally toward the Columbia River, but the rates and directions of flow are affected by pumping associated with the pump-and-treat (P&T) at the remedies. Consistent with the recommendations in *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems Final Project Report* (EPA 600/R-08/003), multiple lines of evidence are used to estimate capture. The two complementary methods used and discussed in this appendix are water-level mapping and groundwater modeling.

# B2 Water-Level Mapping and Capture Zone Estimation Method

The water-level mapping and capture zone estimation method is an alternative to the use of a numerical model for interpreting capture. The technique is detailed in *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance* (SGW-42305). Capture estimation using water-level maps follows a three-step procedure. Derivations for equations in this section are presented in SGW-42305.

First, two-dimensional (2D) water-level maps are prepared using universal kriging (*Geostatistics: Modeling Spatial Uncertainty* [Chiles and Delfiner, 1999]; "On the Use of a Main Trend for the Kriging Technique in Hydrology" [Volpi and Gambolati, 1978]), which enables a deterministic trend to be included in the map. When mapping water levels in the vicinity of River Corridor extraction and injection wells, the deterministic trend form comprises the summation of a plane together with terms describing the effects of pumping and the effect of the Columbia River. Using superposition to sum the effects of multiple pumped wells, pumping effects can be combined with the planar trend to give the following estimate of the water level, $H$, at any location $(x,y)$ (Equation B-1):

$$H(x,y) = A + Bx + Cy + D\sum_{1}^{n} Q_i + E\sum_{1}^{m} L_j + \varepsilon(x,y) \qquad \textbf{(Equation B-1)}$$

where:

$A$, $B$, $C$, $D$, and $E$ = regression coefficients
$n$ = number of pumped wells
$m$ = number of river segments
$Q_i$ = describes the effect on heads of pumping at well $i$
$L_j$ = describes the effect on heads of reach $j$ of the Columbia River
$\varepsilon(x,y)$ = residual from the trend

Second, particle tracking is used to estimate the extent of capture. Particles are released throughout the area of interest, and tracked forward until their fate (e.g., captured at a well) is determined. Particle tracking on a single water-level map provides an "instantaneous" depiction of capture corresponding to the water levels and pumping rates used to prepare that map. Since data loggers provide essentially continuous water-level data and corresponding pumping rates are available, maps depicting water levels

and capture can be produced on any frequency. However, discerning a best estimate of capture on the basis of numerous maps can be difficult. This is accomplished in the third step of the analysis.

In the third step, a capture frequency map (CFM) is used to depict the capture estimated on the basis of numerous water-level maps. A CFM depicts the frequency with which each particle terminates at an extraction well, calculated over all water-level maps. A frequency of 1.0 indicates that the particle is captured on every map, a frequency of zero indicates that a particle is not captured on any map, and intermediate frequencies indicate that the particle is captured using some maps and not on others. A CFM is most appropriately interpreted as an ensemble estimate for the monitoring period. Causes for frequencies below 1.0 include changing pumping rates. Only frequencies of 0.5 and higher are depicted in figures because low capture frequencies can be misleading.

When interpreting the results of this analysis, in this section should be noted:

- A CFM typically provides a reasonable estimate of remedy-wide capture within the footprint of the measured data, but distinguishing the capture zones of individual wells within a multi-well remedy can be difficult.
- Results presented on the basis of water-level mapping assume that vertical flow is negligible compared to horizontal flow, which is usually a reasonable assumption at some distance from pumping wells.

## B3 Groundwater Flow Modeling and Capture Zone Estimation Method

The 100 Area groundwater model encompasses the OUs in the 100-BC, 100-D, 100-F, 100-H, 100-K, and 100-N Areas. The model simulates three-dimensional groundwater flow using MODFLOW-2000 (*MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process* [Harbaugh et al., 2000]) and simulates the advective transport of contaminants using the particle-tracking program MODPATH program (*User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model* [Pollock, 1994]). The model simulates monthly stress periods, with monthly average river stage and pumping rates for each stress period.

Although a single depiction of capture can be calculated using particle tracking when a model simulates quasi-steady-state conditions, the approximate extent of hydraulic capture presented here is calculated with the transient 100 Area model using the following three-step procedure similar to the description for calculating a CFM ("Sources of Water to Wells for Transient Cyclic Systems" [Reilly, 1996]; "The Capture Efficiency Map: The Capture Zone Under Time-Varying Flow" [Festger, 2002]), which focuses on the evaluation of the temporal variation in capture due to changing flow patterns and hydraulic gradients:

1. The groundwater model is used to simulate conditions for 2011 using monthly stress periods, during which monthly averaged extraction and injection rates are used to represent pumping at the various remedies.
2. Particles are released at the commencement of each of the 12 monthly stress periods, and their migration and fate are simulated using a very low effective porosity to ensure that particle travel times are essentially instantaneous. The instantaneous fate of each particle during each stress period is recorded.

3. A capture efficiency map (CEM) is used to depict the capture estimated on the basis of the 12 instantaneous capture maps in a manner analogous to that used for a CFM. An efficiency of 1.0 indicates that each released particle is captured during every stress period; an efficiency of zero indicates that the particle is not captured during any stress period; and intermediate efficiencies indicate that the particle is captured during some stress periods and not others.

As for the CFM prepared using the mapping technique, a CEM is most appropriately interpreted as an ensemble estimate for the monitoring period, and inferences should focus on the relative extents and distribution of the low and high efficiencies. Causes for efficiencies below 1.0 include changing pumping rates and other boundary conditions. Only efficiencies of 0.5 and higher are depicted in figures because low efficiencies can be misleading.

A high capture frequency (for the CFM resulting from water-level mapping) or capture efficiency (for the CEM resulting from groundwater modeling) does not necessarily indicate that the particle was actually *captured* (i.e., recovered at a pumped well) during the time period. Whether or not a particle was captured depends upon the actual migration velocity and travel time. Rather, a high capture frequency and/or efficiency indicate that the particle was hydraulically contained by the remedy and that if conditions persisted, would ultimately be captured at some time.

# B4 100-HR-3 OU Capture Zone Modeling

Capture zone modeling for 100-HR-3 is described in the following subsections.

## B4.1 Configuration of 100-HR-3 OU Groundwater Pump-and-Treat Remedies

Figure B-1 summarizes extraction and injection rates in the 100-HR-3 groundwater P&T remedy. The system operated at a relatively constant rate of about 200 gallons per minute (GPM) from January to early May 2011, at which time the system was taken offline. Extraction wells 199-H3-2C, 199-H4-12C, 199-H4-15, 199-H4-4, and 199-H4-63 and injection wells 199-H4-14, 199-H4-18, and 199-H4-17 were later incorporated into the 100-HX groundwater P&T remedy.

Figure B-2 summarizes extraction and injection rates in the 100-HX groundwater P&T remedy. The system started up in late September 2011. From October to December, the system operated at a relatively constant rate of about 550 – 600 GPM. The HX system consists of 31 extraction wells and 15 injection wells. Pumping rates in most wells averaged 50 GPM or less, with a few exceptions. Average extraction rate in well 199-H3-4 was 80-125 GPM, and average injection rates in wells 199-H1-20 and 199-H1-21 were about 75 GPM and 95 GPM, respectively. All wells operated at typical rates from October to December, with no significant shutdown periods.

Figure B-3 summarizes extraction and injection rates in the 100-DR-5 groundwater P&T remedy. The system operated at about 30 GPM from January to the end of February, at which time wells 199-D5-20 and wells 199-D5-39 were shut down. The entire system was offline in March with only limited pumping from extraction well 199-D5-92 in April for resin regeneration purposes. Extraction wells 199-D5-20, 199-D5-39, and 199-D5-92, and injection well 199-D5-42 were incorporated into the 100-DX groundwater P&T remedy

Figure B-4 summarizes extraction and injection rates in the 100-DX groundwater P&T remedy. The DX system consists of 37 extraction wells and 14 injection wells. The system operated at a relatively constant rate of about 500 GPM throughout CY 2011, with a period of reduced pumping rates (around 400 GPM) from April to June 2011. Injection and extraction rate data were not available for the month of September,

but the system was operating at typical rates. During CY 2011, there were no significant shutdown periods for the 100-DX system.

## B4.2 100-HR-3 OU Groundwater Approximate Flow Patterns and Extents of Capture

Figures B-5(a) and B-5(b) show example water level contours for the 100-HR-3 area for high and low river stage conditions (May and October, 2011, respectively). Multiple maps analogous to those presented in B-5 were constructed using weekly-averaged water levels obtained from January to November 2011 with transducers, and corresponding weekly pumping rates. Figures B-5(a) and B-5(b) illustrate the changes in flow direction and hydraulic gradients in response to changes in river stage. For most of the year, gradients are relatively steep and flow is toward the Columbia River as illustrated in Figure B-5(b). During high river stage (May to July), gradients become less steep – and may reverse near the shoreline- as shown in Figure B-5(a). Typical groundwater flow direction towards the river that is more consistent with lower river stage resumed in late July.

A CFM depicting the extent of hydraulic capture developed by the 100-HX and 100-DX remedies was calculated based on weekly maps from October to November, representing the period during which both systems were operational and transducer data was available. The CFM is supplemented by a CEM calculated using the 100 Area groundwater model which represents the three months from October to December.

Figure B-6(a) depicts the CEM for the 100-HX and 100-DX remedies for the period from October to December 2011, determined using the groundwater model. Figure B-6(a) represents the combination of 3 instantaneous monthly capture zone estimates. Figure B-6(b) depicts the CFM for the 100-HX and 100-DX remedies from October to November 2011, determined using the groundwater level mapping approach. Figure B-6(b) represents the combination of 8 weekly-average water level and pumping rate datasets. Figures B-7(a) and B-7(b) show the same estimated extents of hydraulic capture developed by the 100-H system as Figures B-6(a) and B-6(b), overlaid with contours that illustrate the extent of hexavalent chromium in groundwater during Fall 2011.

### B4.2.1 Conclusions

Review of Figures B-6(a) and B-6(b) suggests that the approximate extents of capture calculated using the mapping method and the groundwater model for the 100-HR-3 system are similar in appearance, although there are some areas that differ. The overlays of the CEM and CFM maps with the contoured extents of hexavalent chromium presented in Figures B-7(a) and B-7(b), respectively, identify areas where capture appears conclusive and satisfactory, and where capture appears inconclusive and/or unsatisfactory. It is evident that:

- Throughout the majority of the 100-HR-3 groundwater OU that is contaminated by chromium, the CEM and CFM provide a fairly consistent interpretation of the extent of capture developed by the 100-HX and 100-DX remedies from October to December 2011.
- Both methods consistently suggest that the capture is inconclusive or unsatisfactory in the following areas:
  - In the southeastern portion of the 100-H area – e.g., upgradient of wells 199-H4-64, 199-H4-12C, 199-H4-4, and 199-H4-63.
  - In portions of the area between the 100-D and 100-H OUs, referred to as the Horn.

- The two methods show some inconsistent results in one area: the CFM suggests that capture is inconclusive or unsatisfactory in a fairly broad area northwest of the H area, while the CEM suggests that capture is only inconclusive or unsatisfactory in a more limited area northwest of the H area.

The differences in capture depicted by the CEM and CFM approaches arise from a combination of (a) the variable distribution of water level monitoring, (b) the different periods used in preparing the CEM and CFM maps, as described above, and (c) differences in the methods used. With regard to the distribution of water level monitoring locations: Figures B-6(b) and B-7(b) include dashed grey lines, which delineate the areas located about 500 meters or more from the nearest monitoring well used in the groundwater elevation mapping (and also used in the groundwater model calibration). In these areas, the relative sparsity of water level monitoring data results in increased uncertainty in the estimated extent of capture. Differences between the modeled CEM and mapped CFM are expected to be greatest in these areas: and this is reflected in the calculated CEM and CFM presented. Differences that result from the contrasting methods and the averaging periods used are expected to diminish over time when the monitoring network is optimized and comparable summary periods are used in the analyses.

# B5 100-KR-4 OU Capture Zone Modeling

Capture zone modeling for 100-KR-4 is described in the following subsections.

## B5.1 100-KR-4 OU Groundwater Approximate Flow Patterns and Extents of Capture

Figures B-8, B-9, and B-10 summarize pumping rates for the three 100-K groundwater P&T systems: KR-4, KX, and KW, respectively. All systems remained operational throughout CY 2011, although several adjustments to pumping rates were made over the year.

For the KR-4 system, total pumping rates remained relatively constant from January to May 2011, with a short period of lower rates during late February/early March. From May until December, total pumping rate for the KR-4 system was reduced. During this time, several wells were shut down because groundwater sampling showed hexavalent chromium concentrations less than 10 parts per billion (ppb). These wells were started up once per week for sampling; if hexavalent concentrations exceeded 10 ppb, the well was re-started (Figure B-8). For the KX system, total pumping rates were relatively constant throughout CY 2011, with two short periods of reduced pumping rates during March and early June (Figure B-9). For the KW system, total pumping rates remained relatively constant for most of CY 2011. Rates were reduced for a brief period in June, and in late August and September, overall systems rates were decreased as wells were taken offline one at a time for facility modifications. The KW system returned to normal rates by October (Figure B-10).

Figure B-11 shows example water level contours for the entire 100-K area that represent (a) high and (b) low river stage conditions (the weeks of June 12, 2011 and September 25, 2011, respectively). Multiple maps analogous to those presented in Figure B-11 were constructed as described in the previous section, using weekly-averaged water levels and corresponding weekly-averaged pumping rates. Water level maps were generated for each of the 48 weeks between January and November 2011. Water level measurements were not available for the month of December. Thirty-six of the weekly-average water level maps were used to calculate a CFM depicting the extent of hydraulic capture developed by the 100-K systems from January to November 2011; the periods of high river stage (the weeks of May 8 to July 17) were excluded. This CFM is supplemented by a CEM calculated using the 100 Area groundwater model.

Figure B-12(a) depicts the CEM for the combined 100-K systems determined using the 100 Area groundwater model. Figure B-12(a) represents the combination of 12 instantaneous monthly capture zone estimates. Figure B-12(b) depicts the CFM for the combined 100 K Area systems determined using the

mapping approach. Figure B-12(b) represents the combination of 36 weekly average water-level and pumping rate and river stage data sets. The CFM presented in Figure B-12(b) excludes high-river stage conditions (the weeks from May 8 to July 17), and periods during which transducer data was unavailable (the weeks of November 30 to December 25). Figure B-13(a and b) show the same estimated extents of capture as do Figure B-12(a and b), overlain with contours that illustrate the extent of hexavalent chromium in groundwater during Fall CY 2011.

### B5.1.1 Conclusions

Within the contoured extent of hexavalent chromium, the CFM and CEM depict relatively consistent effectiveness of capture. While the estimated capture extent is broadly similar when calculated using and CEM and CFM approaches, the two methods show different capture effectiveness in some areas such as along the shoreline downgradient of the K West area. In particular, Figures B-12 (a and b) and B-13 (a and b) indicate that:

- High capture efficiencies and high capture frequencies encompass the majority of the area showing hexavalent chromium concentrations above 10 ppb; both methods therefore indicate that the combined 100-K systems provide hydraulic containment over most of the plume.
- The CFM indicates that hydraulic capture may be insufficient in a small area near wells 199-K-178 and 199-K-141, where high capture frequencies do not fully encompass the 10 ppb hexavalent chromium contour. However, the same area lies within high capture efficiencies on the CEM, which suggests that the hydraulic capture is sufficient. This uncertainty will likely be addressed by the installation of a new transducer/datalogger at the K-River Gage.
- On the CFM, a band of lower capture frequency exists within the 10 ppb hexavalent chromium contour between wells 199-K-144 and 199-K-145; i.e., some of the weekly capture zone maps show a gap in hydraulic capture between these two wells. On the CEM, this area is fully encompassed by high capture efficiencies. Therefore, the effectiveness of hydraulic containment in this area is somewhat uncertain although it is likely containment is achieved for most of the year.

These differences likely result from a combination of (1) the variable distribution of water-level monitoring locations used to calibrate the 100 Area model and to map the water levels, (2) the different averaging periods used in preparing the CEM and CFM maps, and (3) differences in the methods used. With regard to the distribution of water level monitoring locations: Figures B-12 (b) and B-13 (b) include a dashed grey line which delineates the area located about 500 meters or more from the nearest monitoring well used in the groundwater elevation mapping (also used in the groundwater model calibration). In this area, the relative sparse water level monitoring data results in increased uncertainty in the estimated extent of capture. Differences between the modeled CEM and mapped CFM are expected to be greatest in these areas, and this is reflected in the calculated CEM and CFM. Differences resulting from the difference between the methods are expected to diminish over time when the monitoring network is optimized and comparable summary periods are used in the analyses.

## B6 References

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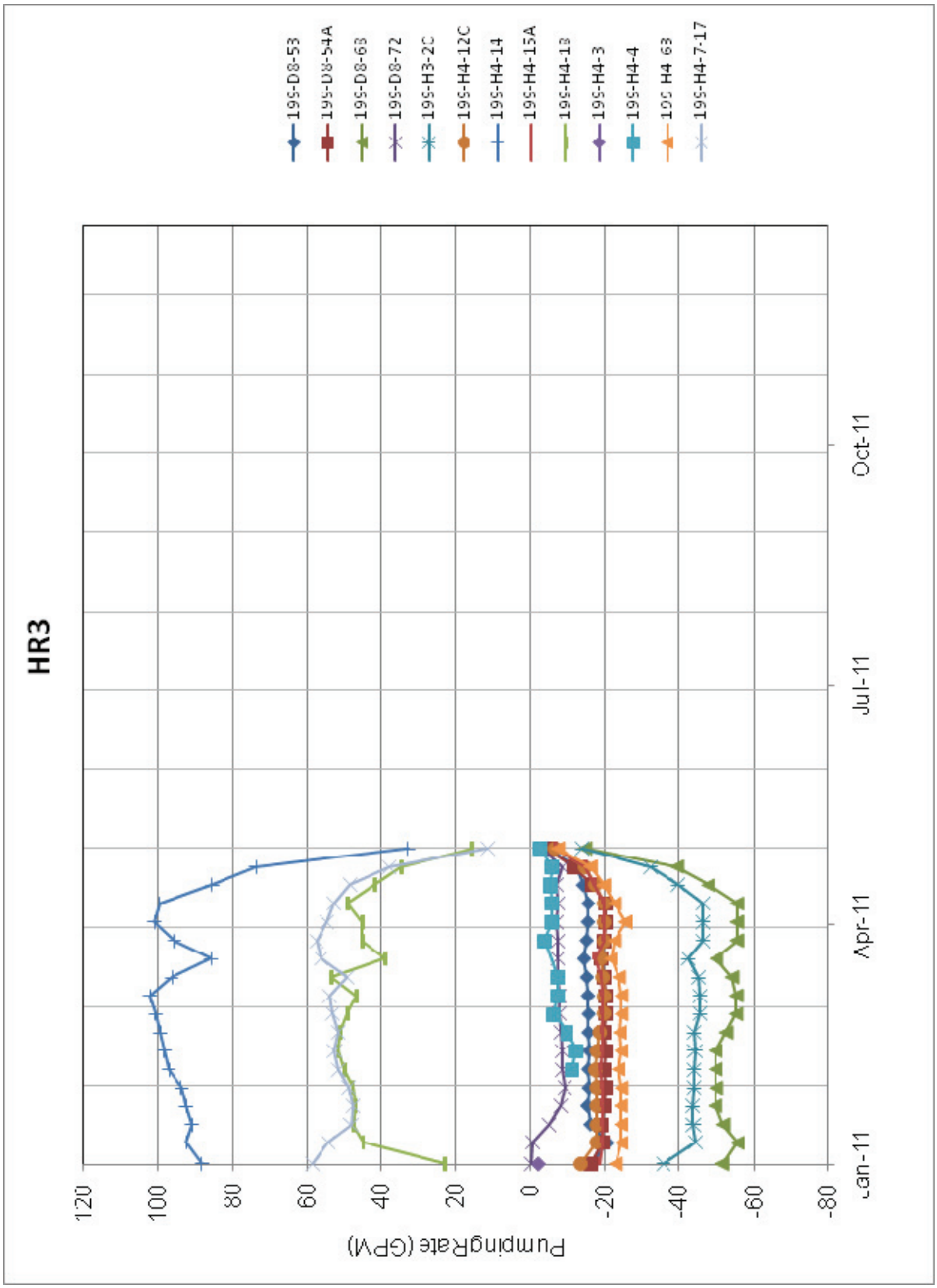



**Figure B-1. CY 2011 Pumping Rates for the HR-3 P&T System**

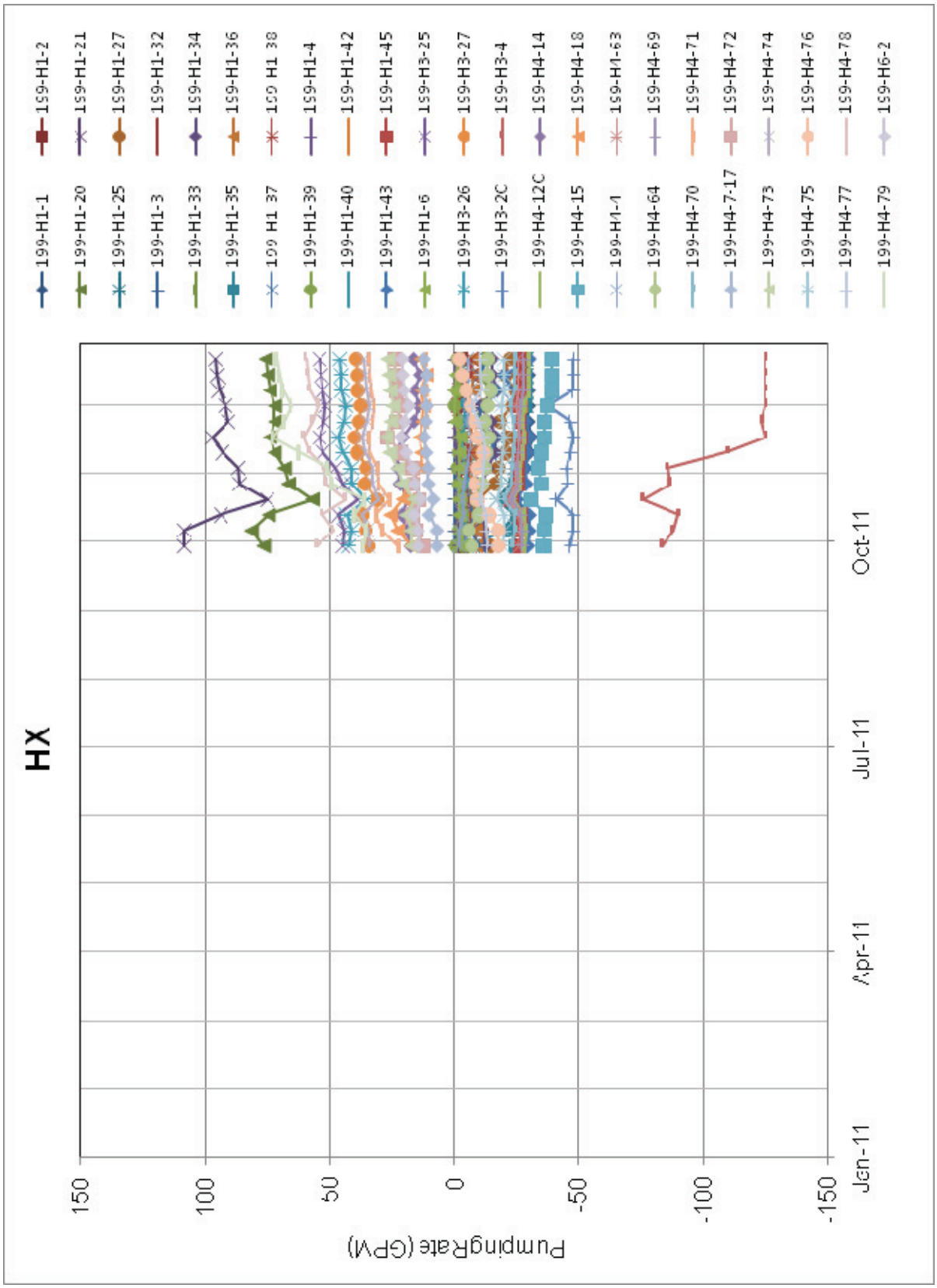



**Figure B-2. CY 2011 Pumping Rates for the HX P&T System**

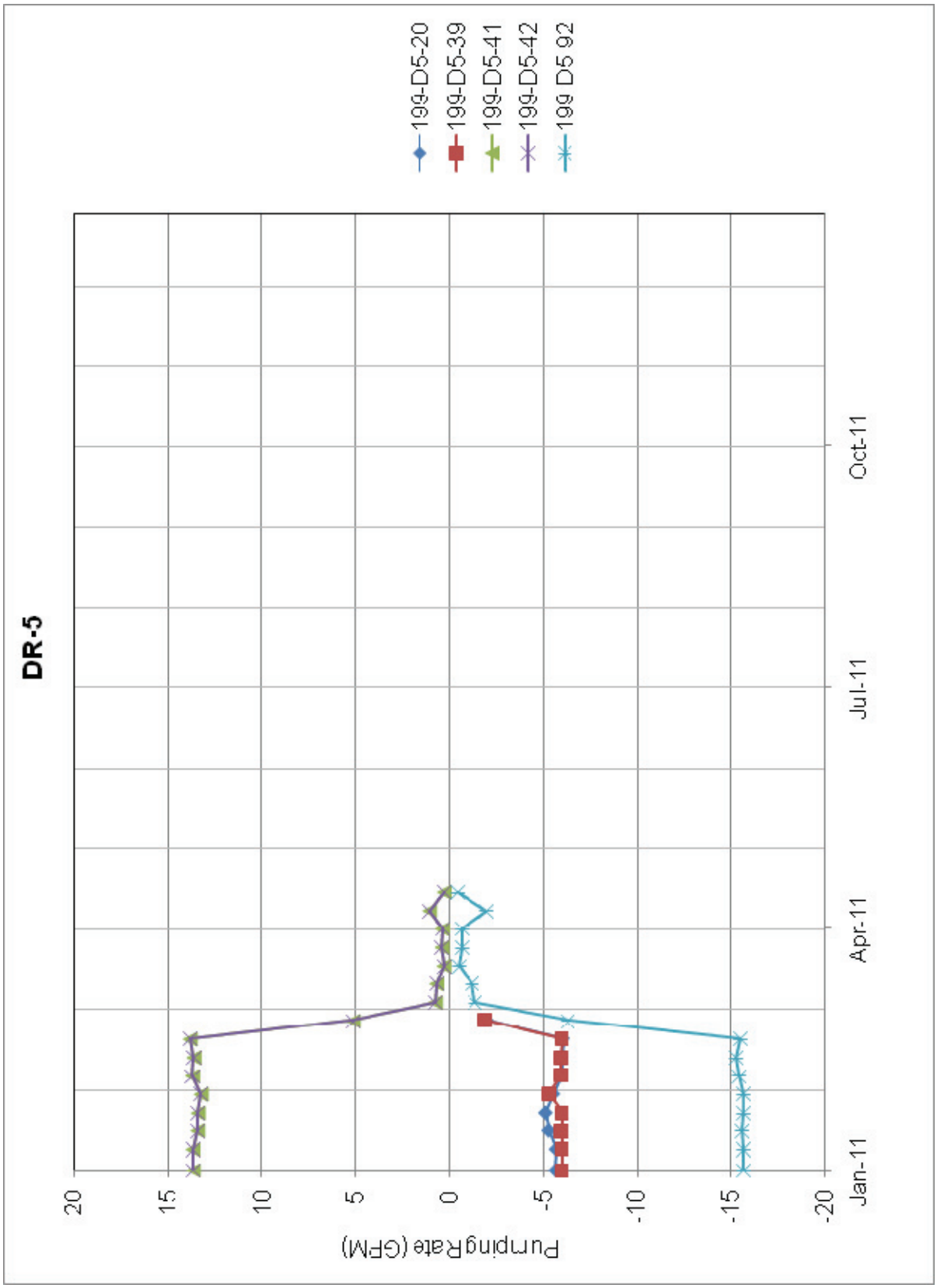



**Figure B-3. CY 2011 Pumping Rates for the DR-5 P&T System**

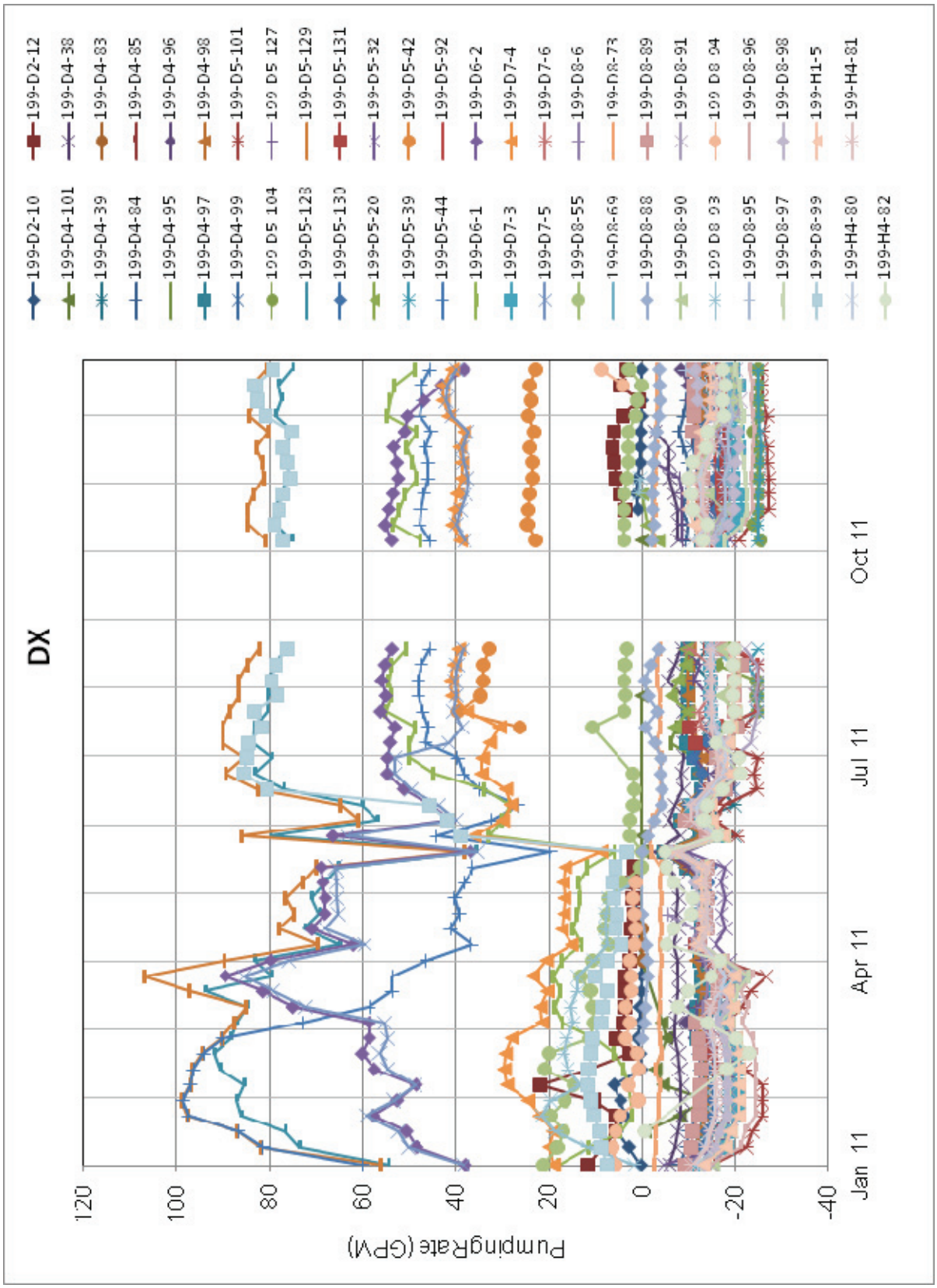



**Figure B-4. CY 2011 Pumping Rates for the DX P&T System**

(krm 8/22/12 per telcon)

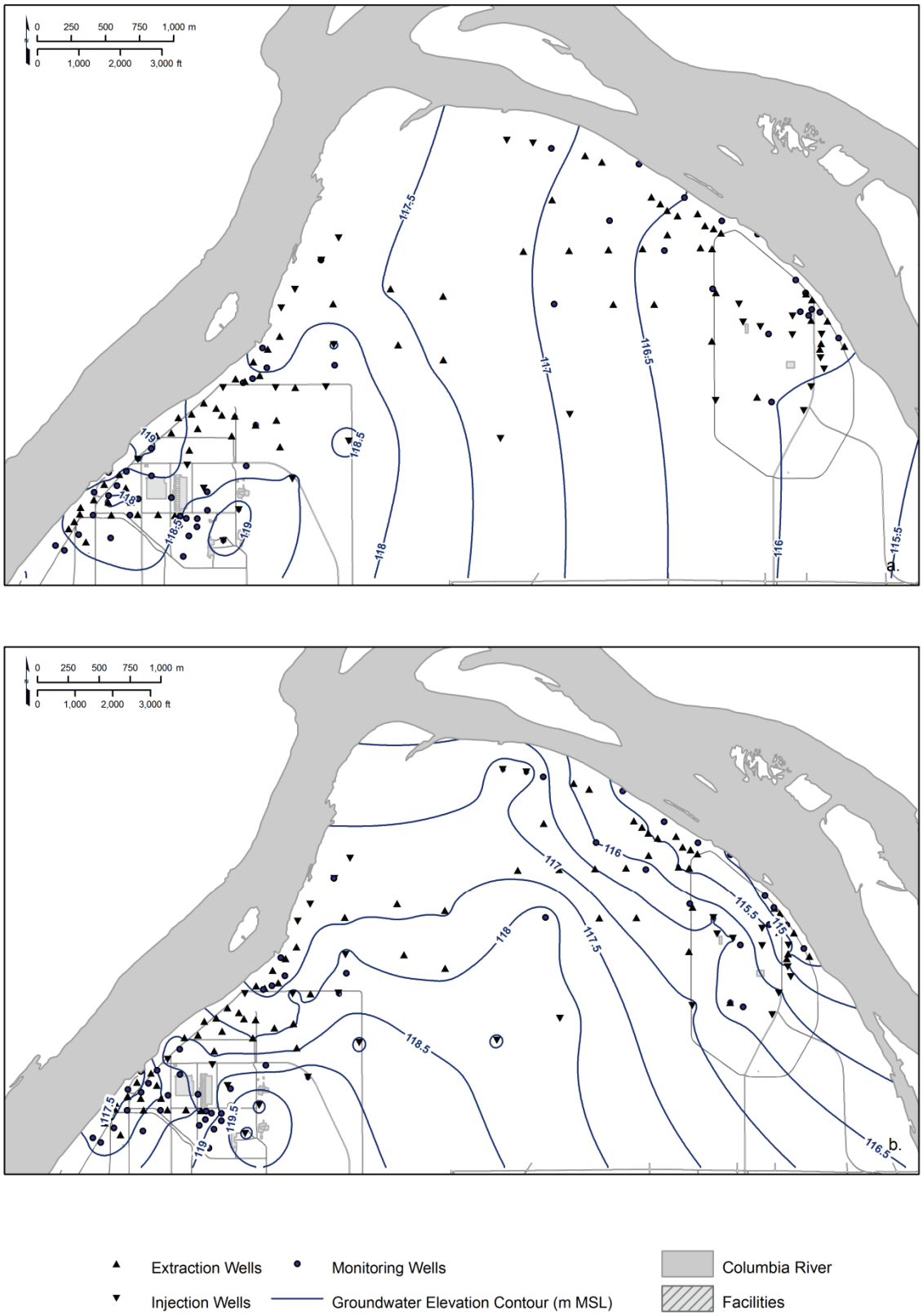



**Figure B-5. Groundwater Elevation Contours Throughout the 100-HR-3 OU for (a) High River-Stage Conditions (May 2011) and (b) Low River-Stage Conditions (October 2011)**



B-12

(krm 8/22/12 per telcon)

**Figure B-6. Approximate Extent of Capture Throughout the 100-HR-3 OU for October – December 2011, Calculated Using (a) Modeling Method and (b) Mapping Method**

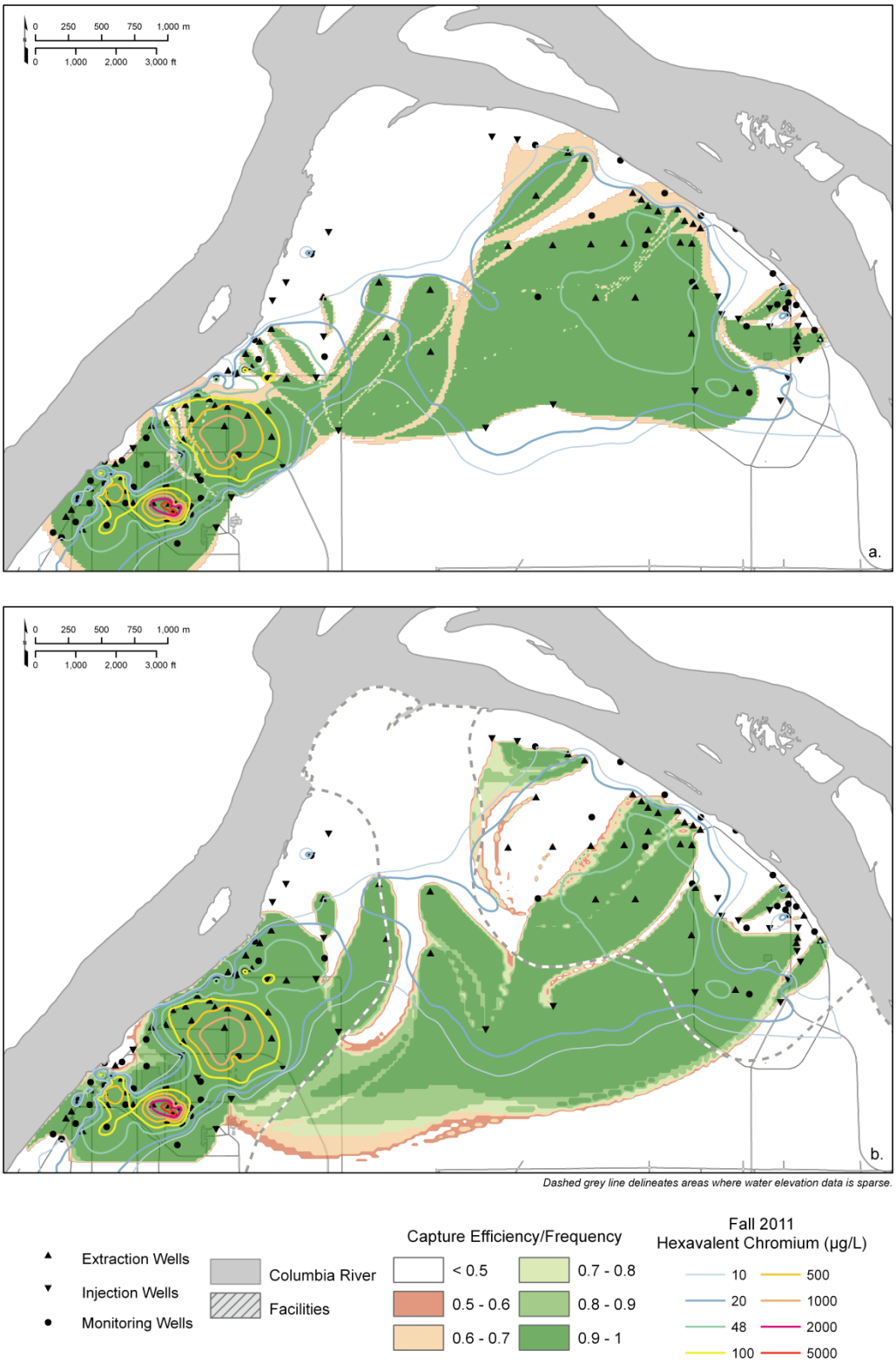



**Figure B-7. Approximate Extent of Capture Throughout the 100-HR-3 OU for October – December 2011, Calculated Using (a) Modeling Method and (b) Mapping Method (Overlaid with Fall 2011 Contoured Extent of Hexavalent Chromium)**

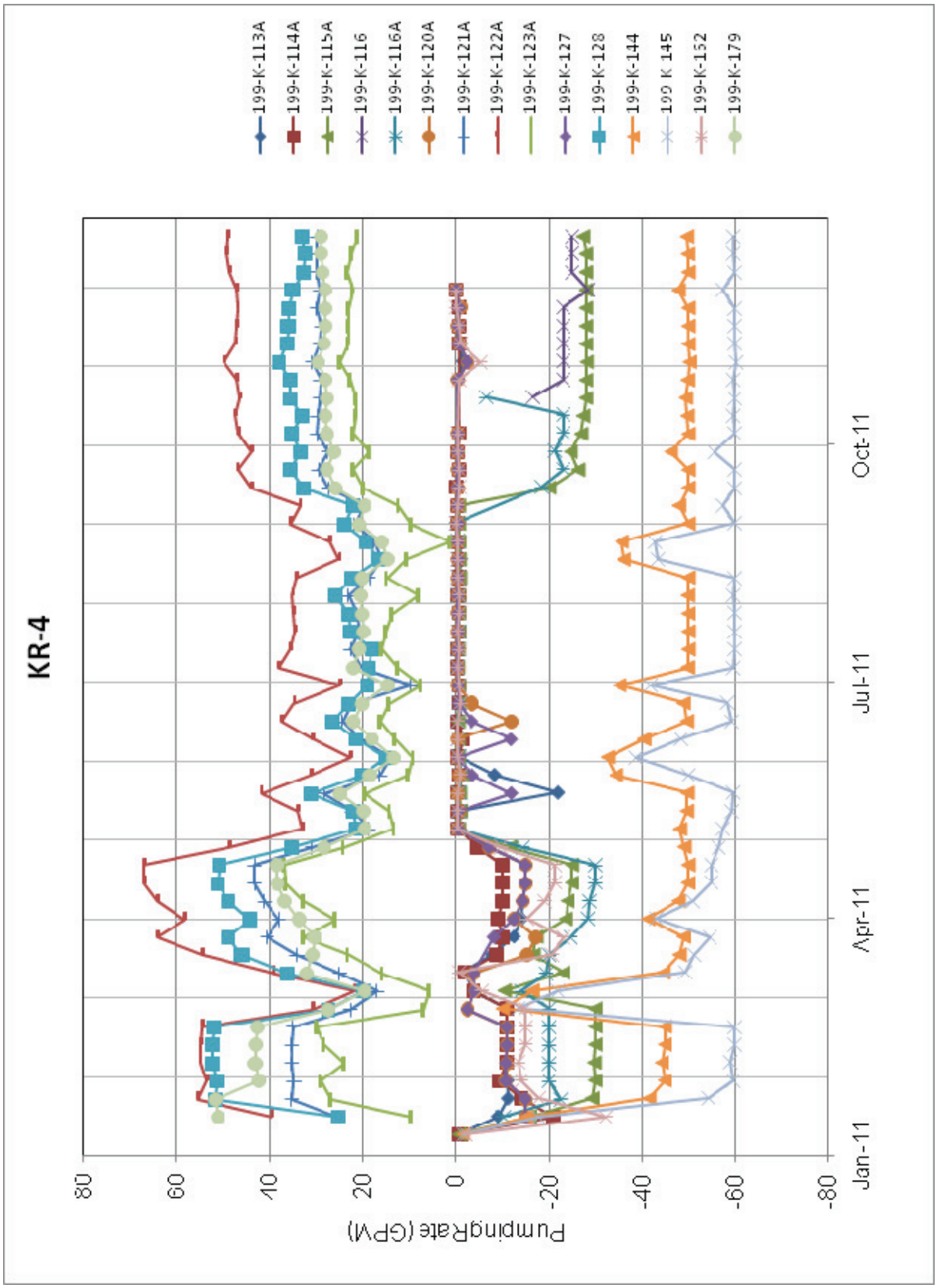



**Figure B-8. CY 2011 Pumping Rates for the KR4 P&T System**

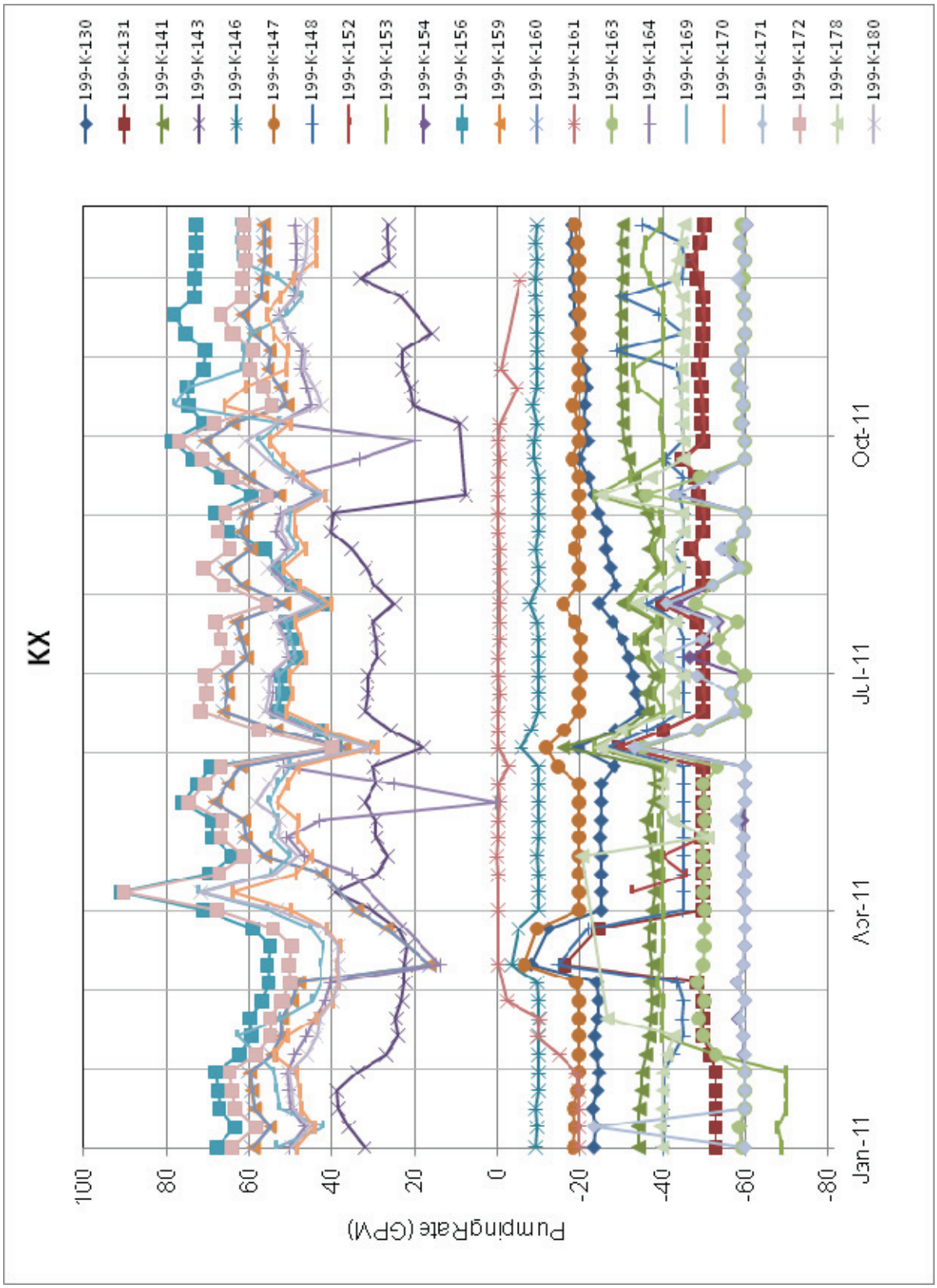



**Figure B-9. CY 2011 Pumping Rates for the KX P&T System**

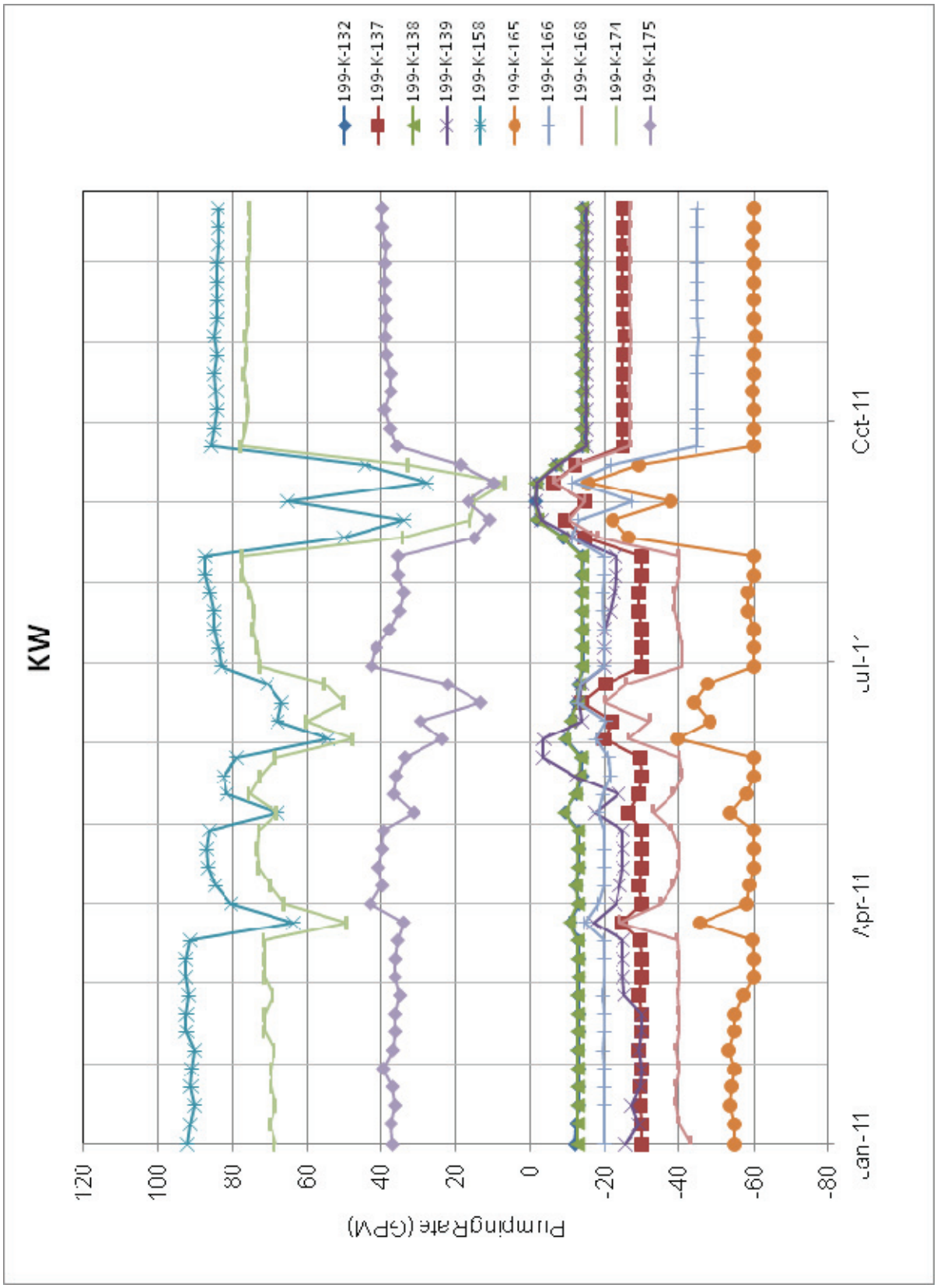
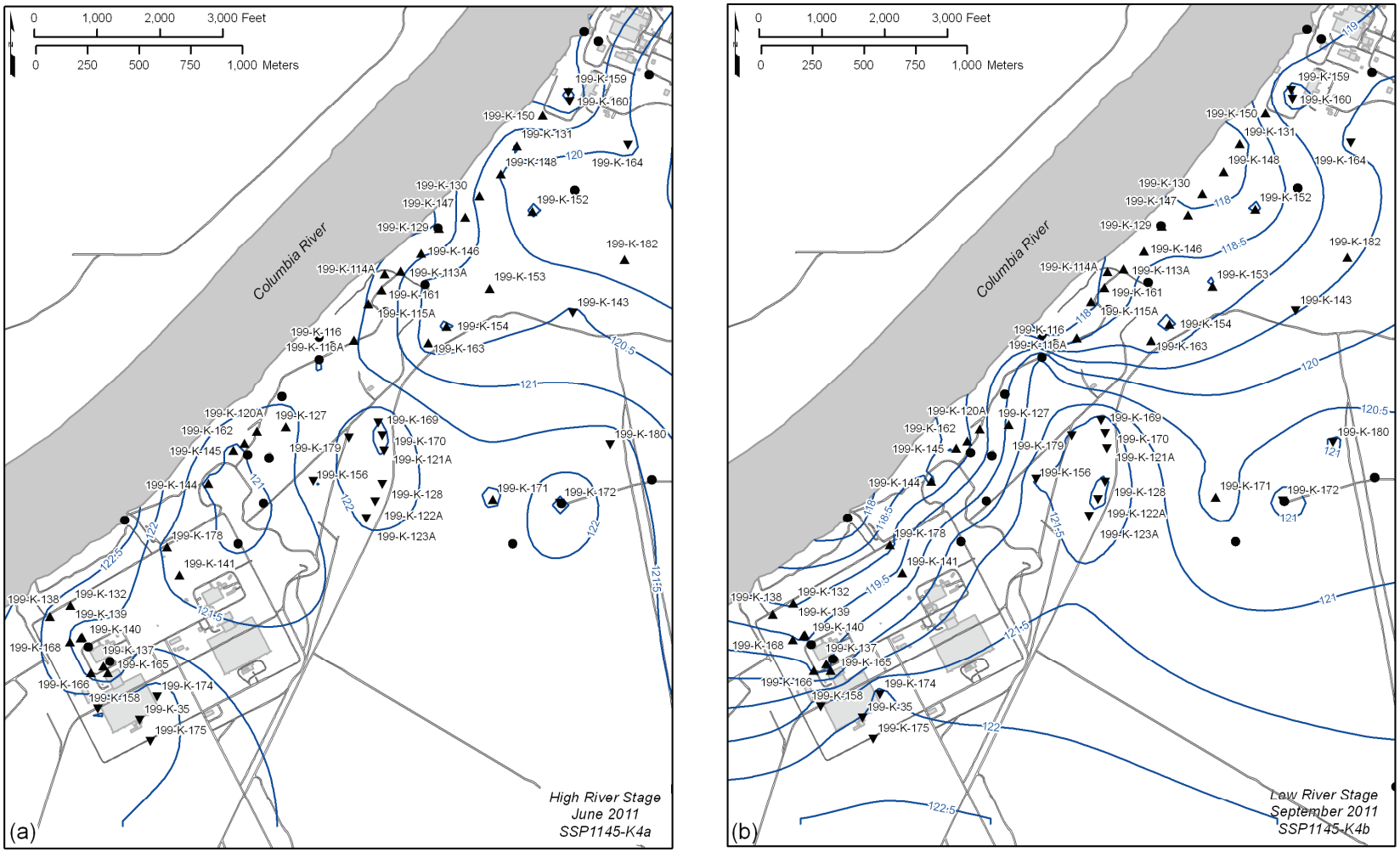



**Figure B-10. CY 2011 Pumping Rates for the KW P&T System**




● Monitoring Wells ▲ Extraction Wells ▼ Injection Wells —— Water Elevation Contour (m NAVD88)

**Figure B-11. CY 2011 Groundwater Elevation Contours Throughout the 100-KR-4 OU for (a) High River-Stage and (b) Low River-Stage Conditions**

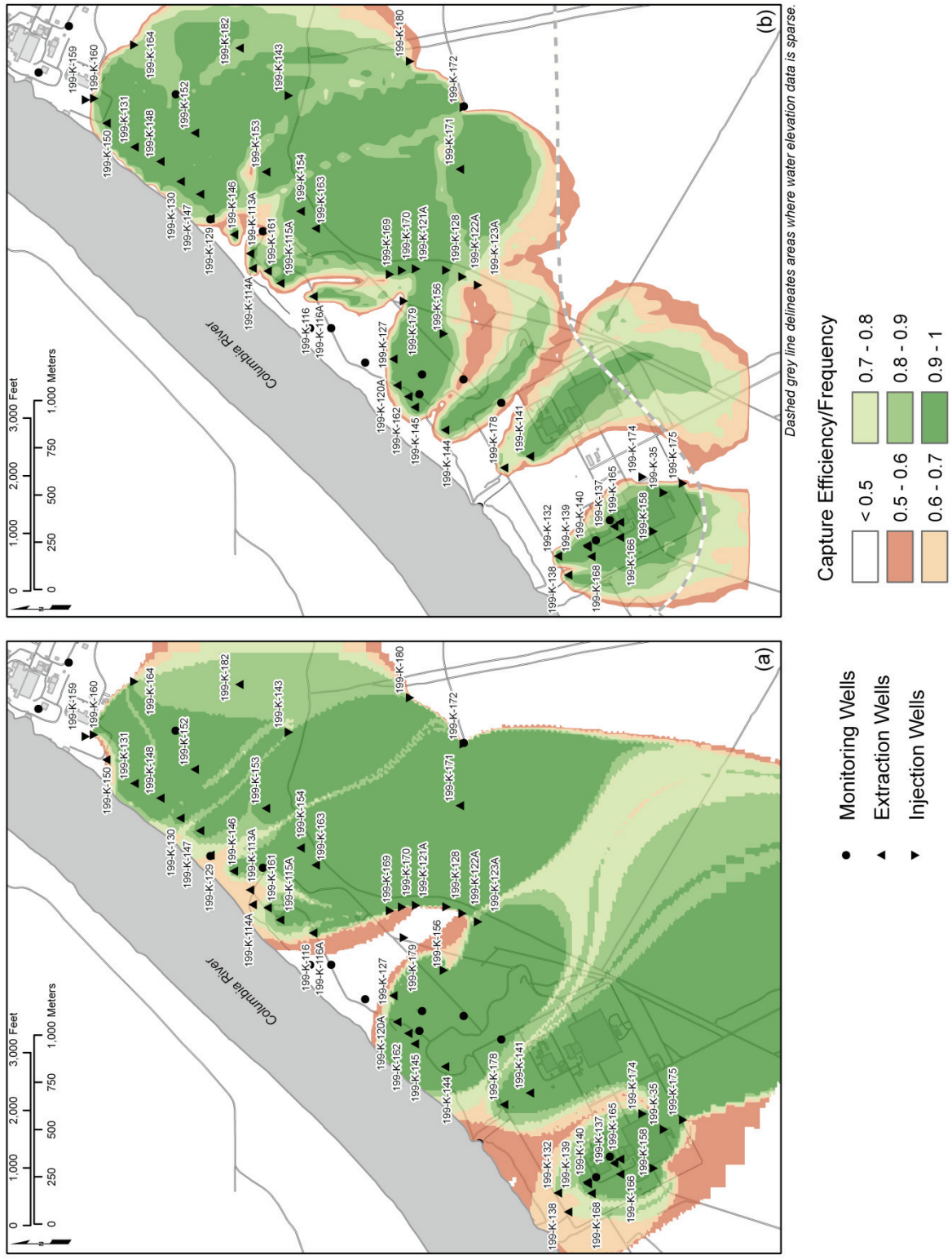



**Figure B-12. Approximate Extent of Capture Throughout the 100-KR-4 OU for CY 2011, Calculated Using (a) Modeling Method and (b) Mapping Method**

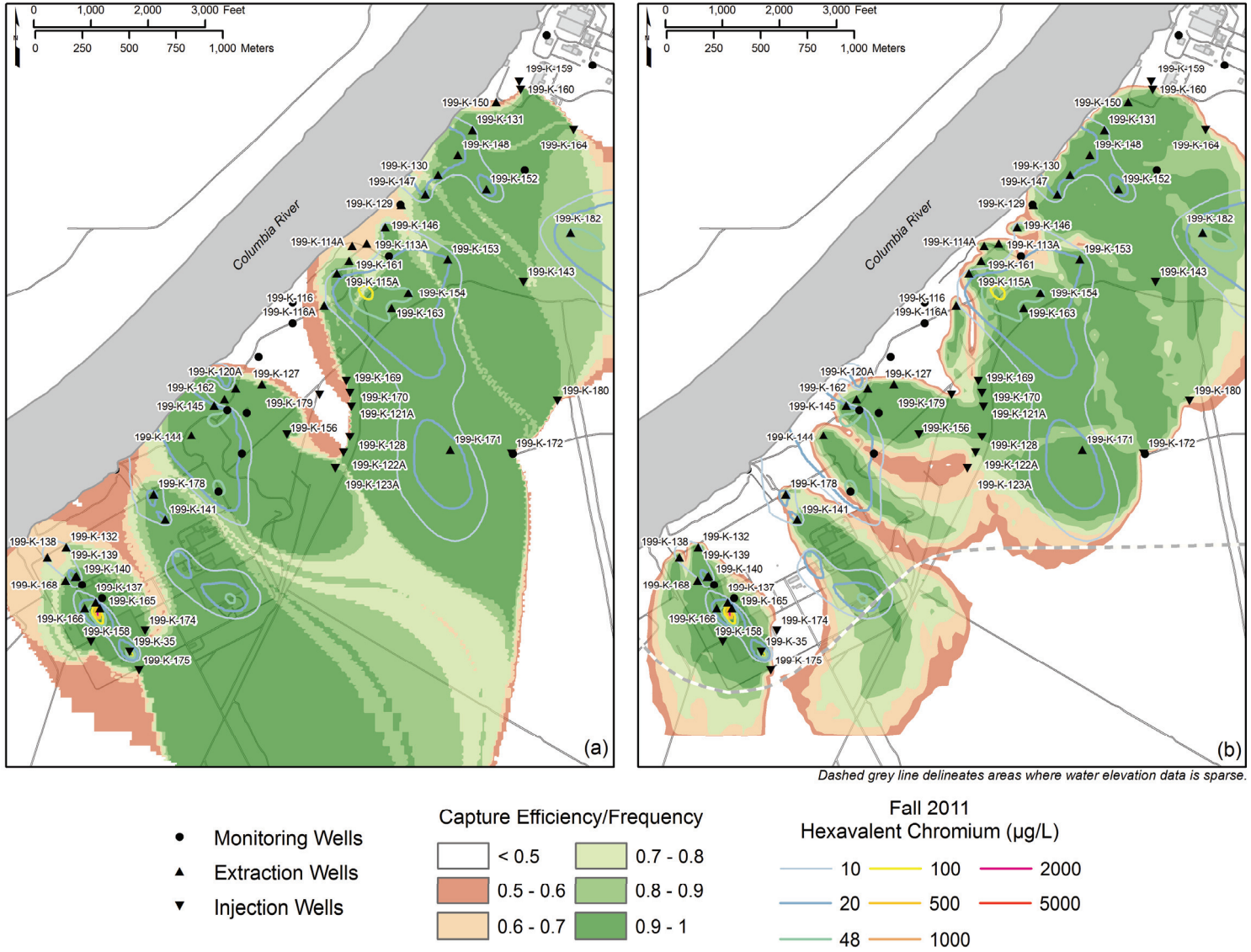



**Figure B-13. Approximate Extent of Capture Throughout the 100-KR-4 OU for CY 2011, Calculated Using (a) Modeling Method and (b) Mapping Method (Overlaid with Contoured Extent of Hexavalent Chromium)**