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Calendar Year 2016 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

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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P.O. Box 1600
Richland, Washington 99352

100-HR-3
100-KR-4
100-NR-2

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Executive Summary

Interim groundwater treatment remedies are operating in the 100-HR-3, 100-KR-4, and 100-NR-2 Groundwater Operable Units (OUs). Hexavalent chromium (Cr(VI)), the primary contaminant of concern (COC) in the 100-HR-3 and 100-KR-4 OUs, is being addressed by pump and treat (P&T) systems under a Record of Decision (ROD) for interim remedial action.[1] Two P&T systems (DX and HX) are operating in the 100-HR-3 OU and three P&T systems (KR4, KW, and KX) are operating in the 100-KR-4 OU. The objectives of the 100-HR-3 and 100-KR-4 ROD for interim action are:

- Protection of aquatic receptors
- Protection of human health from exposure to groundwater
- Provide information that will lead to a final remedy

The P&T systems in the 100-HR-3 and 100-KR-4 OUs extract groundwater and remove the Cr(VI) using an ion-exchange resin in treatment plants before reinjecting the treated water into the aquifer. A total of 5,061 million L (1,336 million gal) of groundwater was extracted and treated by the P&T systems in the 100-HR-3 and 100-KR-4 OUs during 2016. These actions removed 115.8 kg (255 lb) of hexavalent chromium from the aquifer, described as follows:

- At the 100-HR-3 OU, the combined DX and HX P&T systems processed 2,603 million L (687 million gal) of groundwater and removed 84.8 kg (186 lb) of Cr(VI) in 2016. Since startup, the 100-HR-3 OU P&T systems have treated 18,145 million L (4,790 million gal) of groundwater and removed 2,434 kg (5,354 lb) of Cr(VI).

- Concentrations of Cr(VI) in 100-D Area groundwater have been decreasing since 2010 due to DX P&T system operations and source area removal of waste sites such as 100-D-100, and the combined 100-D-30/100-D-104 waste sites. In 2016, the maximum Cr(VI) concentration detected in groundwater was 640 µg/L, compared to 69,700 µg/L in 2010. The areal extent of the plume at the remedial action target

[1] EPA/ROD/R10-96/134, 1996, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0078950H.

concentration of 20 µg/L declined between 2015 and 2016. The extent of the high-concentration portions of the plume were also reduced.

- During calendar year 2016, 2,458 million L (649 million gal) of groundwater were treated and 31 kg (68 lb) of Cr(VI) were removed from groundwater by the 100-KR-4 OU P&T systems. Since startup, the 100-KR-4 OU P&T systems have treated 21,297 million L (5,622 million gal) of groundwater and removed 867 kg (1,908 lb) of Cr(VI). Increased extraction rates resulting from the installation of new wells and realignment of existing wells over the last 3 years is providing enhanced plume control in near-river regions of the 100-KR-4 OU.
- In May 2016, the KW P&T system was shut down to initiate a rebound study to evaluate whether contaminant concentrations would remain below cleanup levels and determine if continuing secondary source material exists in the deep vadose zone. Groundwater in the area affected by the KW pump and treat system have exhibited Cr(VI) concentrations below the interim remedial action target concentration of 20 **µg/L at all monitoring locations** at the beginning of 2016. This area has been selected for performing a rebound study to assess the completion of the interim remedial action. The KW P&T system was shut down in May 2016 to initiate the rebound study.

Cr(VI) is also being addressed in the 100-HR-3 OU through continued monitoring of a permeable reactive barrier (PRB) that was implemented as a ROD Amendment for the interim remedial action.[2] In situ redox manipulation (ISRM) is used to produce a PRB for treatment of Cr(VI). This passive system reduces Cr(VI) to the immobile trivalent form as it flows through an aquifer zone treated with sodium dithionite. A notice of non-significant change to the Record of Decision was issued in 2010, which indicated that the barrier would no longer be actively maintained and P&T system expansion (i.e., extraction wells downgradient of the PRB) would be used to address breakthrough and provide a protective interim remedy.[3] The ISRM PRB at the 100-D Area continues to chemically reduce

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[2] EPA/AMD/R10-00/122, 2000, *Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Region 10, Washington State Department of Ecology, and U.S. Department of Energy, Seattle, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D199159580.

[3] 11-AMCP-0002, 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

Cr(VI), supplemented by P&T system extraction wells. At the end of 2016, Cr(VI) concentrations at barrier wells ranged from below detection to 84 µg/L, with an overall decrease in concentrations compared to 2015. The observed changes in Cr(VI) concentration are attributed to a combination of residual chemical reduction by the ISRM PRB and extraction and treatment of contaminated groundwater in areas where the PRB is no longer effective.

Protection of the Columbia River against discharge of chromium-contaminated groundwater continues to improve. River protection is assessed against conditions that may cause the river interface area to exceed the 10 µg/L ambient water quality criterion. During 2016, only 200 m (655 ft) of the 2,800 m (9,185 ft) of shoreline impacted by the Cr(VI) plume in the 100-D Area was identified as not adequately protected. This reflected an improvement in river protection along the northern portion of the 100-D Area compared to 2015. Of the 4,400 m (14,430 ft) of shoreline impacted by the Cr(VI) plume in the 100-H Area, 400 m (1,310 ft) was identified as not adequately protected in 2016. Improved capture in areas previously identified where action may be required resulted in an additional 600 m (1,965 ft) of shoreline length identified as protected in 2016 compared to 2015.

In the 100-K Area, all 4,000 m (13,120 ft) of affected shoreline were identified as either protected or protected, but additional action may be required in 2016. This is an improvement compared to the 100 m (330 ft) identified as not adequately protected in 2015. In both the 100-HR-3 and 100-KR-4 OUs, the improvements in river protection status are the direct result of ongoing improvements in the capture and treatment of contaminated groundwater by the P&T systems. Improvements in 2016 included increased extraction rates and placement of new extraction wells at locations selected to intercept targeted plume segments.

Remedy" (letter to J.A. Hedges, Washington State Department of Ecology, and D.A. Faulk, U.S. Environmental Protection Agency, from R.A. Holten), U.S. Department of Energy, Richland Operations Office, Richland, Washington, October 26. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1011290677.

In the 100-NR-2 OU, interim remedial actions are implemented for strontium-90 and total petroleum hydrocarbon (TPH) groundwater COCs as described in a ROD for interim action.[4] The objectives of the interim action ROD are:

- Protect the Columbia River from adverse impacts from 100-NR-2 groundwater
- Protect the unconfined aquifer by reducing contaminants present in groundwater
- Obtain information to evaluate strontium-90 removal technologies and evaluate ecological receptor impacts from contaminated groundwater
- Prevent destruction of sensitive wildlife habitat

A P&T system developed in the 1990s for the removal and treatment of strontium-90-contaminated groundwater proved ineffective, and subsequently, a PRB was installed along the shoreline to intercept and treat the migrating groundwater contaminated with strontium-90 with the mineral apatite as described in a ROD Amendment.[5] An initial 91 m (300 ft) length of the barrier was installed from 2006 to 2008, and later expanded to 311 m (1,020 ft) in 2011, to target the shoreline downgradient of the highest strontium-90 concentration areas. As groundwater flows through the barrier, strontium-90 contamination adsorbs to the apatite and is immobilized within the barrier, thereby reducing the amount of contamination migrating to the Columbia River. Groundwater samples at the PRB monitoring points show that the concentrations in the majority of the monitoring wells in 2016 continue to be lower than pre-barrier levels by nearly 90 percent. However, in 2015 concentrations of strontium-90 increased in some of the monitoring wells, and remained elevated in 2016.

Removal of TPH free product (primarily in the diesel range) from well 199-N-18 continued in 2016. The diesel is removed using a polymer "smart sponge" that selectively absorbs petroleum products from the groundwater within the well. In 2016, 950 g of diesel was removed from well 199-N-18.

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[4] EPA/ROD/R10-99/112, 1999, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Region 10, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Seattle, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0078951H.

[5] EPA, 2010, *U.S. Department of Energy 100-NR-1 and NR-2 Operable Units Hanford Site – 100 Area Benton County, Washington Amended Record of Decision, Decision Summary and Responsiveness Summary*, U.S. Environmental Protection Agency, Seattle, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0084198.

This annual summary report describes the operations and results of these groundwater treatment remedies during 2016 including details on the volume of water treated, contaminant mass removed, efficiency, the effectiveness of the interim remedial actions, and the resulting effect on groundwater concentrations. Since the interim remedies were implemented in the 1990s, additional characterization activities (i.e., the remedial investigations), along with information gained from continued operation of the remedial systems and expansion of well networks, have improved the understanding of the nature and extent of contaminants of interest in groundwater. Data evaluation and presentation has been improved through implementation of enhanced contaminant plume interpolation processes and development of a method to evaluate the degree of river protection afforded by the remedial systems in place.

Although the interim remedial actions are effective and have demonstrated improvement in both protecting the Columbia River and reducing groundwater contaminant concentrations, remedies are not yet complete. Interim remedial action operations will continue, along with monitoring activities and remedial process optimization. Routine monitoring and optimization activities include the following:

- Evaluating results from analytical samples collected from wells, aquifer tubes, and treatment process locations
- Evaluating individual extraction and injection well performance
- Evaluating estimated hydraulic capture by remedial systems
- Evaluating treatment process performance
- Adjusting P&T system operations to optimize system performance in response to observed conditions. System adjustments have included modifying the treatment plants in the 100-K Area to expand treatment capacity by reducing the number of resin vessels in each treatment train to use the ion-exchange resin more effectively
- Evaluating 100-N apatite PRB performance for additional apatite chemical injections

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Terms

AT	aquifer tube
AWLN	automated water-level network
BAT	best available technology
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFM	capture frequency map
COC	contaminant of concern
COPC	contaminants of potential concern
Cr(VI)	hexavalent chromium
CSM	conceptual site model
CY	calendar year
D&D	deactivation and decommissioning
DCS	Derived Concentration Standards
DOE	U.S. Department of Energy
DWS	drinking water standard
Ecology	Washington State Department of Ecology
ESD	explanation of significant differences
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FSB	fuel storage basin
IC	institutional control
ICFM	interpolated capture frequency map
ID	identification
ISRM	in situ redox manipulation
IX	ion exchange
LNAPL	light nonaqueous-phase liquid
MCL	maximum contaminant level
MDA	minimum detectable activity
MTCA	"Model Toxics Control Act—Cleanup" (WAC 173-340)
MW	monitoring well

N/A	not applicable
NC	not calculated
NR	not reported
NS	not sampled
NSD	not sufficient data
O&M	operations and maintenance
OU	operable unit
P&T	pump and treat
PLC	programmable logic controller
PRB	permeable reactive barrier
PRD	Priest Rapids Dam
PRZ	periodically rewetted zone
QA	quality assurance
QC	quality control
RAO	remedial action objective
RCRA	*Resource Conservation and Recovery Act of 1976*
RD/RAWP	remedial design report/remedial action work plan
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RPO	remedial process optimization
RUM	Ringold Formation upper mud unit
SAP	sampling and analysis plan
SCFM	simulated capture frequency map
TCE	trichloroethene
TCP	Traditional Cultural Property
TED	total effective dose
TPH	total petroleum hydrocarbon
TPH-D	TPH-diesel
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989)
UPR	unplanned release
WIDS	Waste Information Data System

1 Introduction

Along the Columbia River Corridor of the Hanford Site, the U.S. Department of Energy (DOE) currently operates and maintains five pump and treat (P&T) systems, maintains one permeable reactive barrier (PRB), and monitors a second PRB. These systems are part of ongoing efforts to remediate contaminated groundwater in the Hanford Site's 100-KR-4, 100-HR-3, and 100-NR-2 Groundwater Operable Units (OUs) (Figure 1-1). The primary contaminant of concern (COC) in the 100-KR-4 and 100-HR-3 OUs is hexavalent chromium (Cr(VI)). The primary COC in the 100-NR-2 OU is strontium-90.

Two P&T systems (DX and HX) operated throughout 2016 to remediate Cr(VI) in the 100-HR-3 OU, which includes the combined 100-D and 100-H Areas, and the Horn. These larger P&T systems replaced the DR-5 and HR-3 P&T systems, which were shut down in 2011. In addition, an in situ redox manipulation (ISRM) PRB was installed in the southwestern portion of the 100-D Area starting in 2000. This barrier continues to reduce Cr(VI) in groundwater, but is no longer maintained as an active remediation treatment. The remaining three P&T systems (KR4, KX, and KW) remediate Cr(VI) contamination associated with the 100-KR-4 OU. Table 1-1 summarizes 2016 information about the five P&T systems.

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), as described in 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.

The interim remedial action initially chosen for the 100-NR-2 OU was P&T using an ion exchange (IX) medium to remove strontium-90. The RAOs were reviewed in 2005, and the P&T system was deemed ineffective in reducing the strontium-90 flux to the Columbia River. In accordance with the Ecology et al., 1989, *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Change Number M-16-06-01 (*Establish Interim Milestone M-016-14, Complete Construction of a Permeable Reactive Barrier at 100-N*), the 100-NR-2 P&T system was placed in cold-standby status on March 9, 2006. DOE began installing 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 remedial technology implemented uses apatite as a reactive material to sequester strontium-90 from the groundwater.

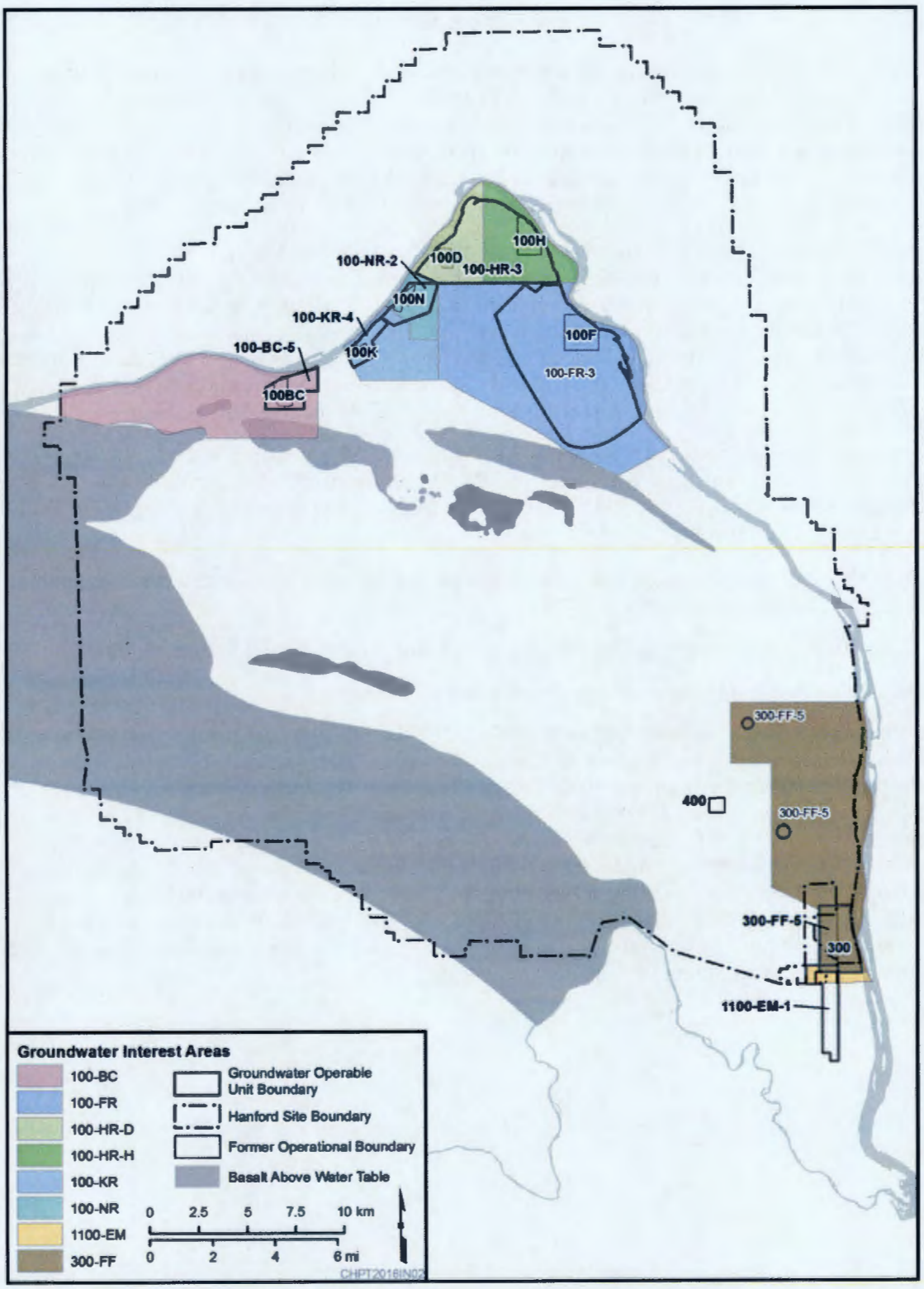

Figure 1-1. Locations of Groundwater OUs and Interest Areas Along the Columbia River

Table 1-1. 2016 P&T Performance Summary

Groundwater Operable Unit: Pump and Treat system	100-HR-3		100-KR-4		
	DX	HX	KW[a]	KR4	KX
Design capacity (L/min [gal/min])	2,936 (775)	3,407 (900)	1,249 (330)	1,249 (330)	3,407 (900)
Extraction wells (post-realignment)[b]	48	38	11[c]	11	21
Injection wells (post-realignment)[b]	15	17	4[c]	5	10
Average flow rate (L/min [gal/min])	2,760 (729)	2,178 (575)	1,229[d] (325)	1,116 (295)	3,121 (825)
Volume treated (million L [million gal])	1,454 (384)	1,149 (303)	242 (64)	580 (153)	1,636 (432)
Cr(VI) mass removed (kg)	59.0	25.7	2.9	2.5	25.6
Average Cr(VI) influent concentration (µg/L)	36.8	22.7	12.4	4.8	16.9
Average Cr(VI) effluent concentration (µg/L)	<2	<2	<2	<2	<2

a. The KW P&T was placed on standby in May 2016 for a rebound test.

b. The number of extraction and injection wells does not include those that are not operational.

c. KW extraction and injection wells were disconnected from the KW P&T in May 2016 for a rebound test.

d. Average flow rate while KW P&T was operating prior to standby.

Cr(VI) = hexavalent chromium

The following four RAOs for the 100-NR-2 OU are described in the current interim Record of Decision (ROD) (EPA, 2010, *U.S. Department of Energy 100-NR-1 and NR-2 Operable Units Hanford Site - 100 Area Benton County, Washington Amended Record of Decision, Decision Summary and Responsiveness Summary*):

- **RAO #1**: Protect the Columbia River from adverse impacts from the 100-NR-2 groundwater so 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 in general and prevent adverse impacts to cultural resources and threatened or endangered species.

Tri-Party Agreement target date milestones have been established for remedial actions to protect the Columbia River and groundwater from further impact due to Cr(VI) and other contaminants resulting from Hanford Site operations. The following target date milestones are directly applicable to the 100-HR-3, 100-KR-4, and 100-NR-2 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 National Priorities List (NPL) Operable Units such that ambient water quality standards for hexavalent chromium are achieved in the hyporheic zone and river column water.*

  Remedial actions toward achieving Tri-Party Agreement Milestone M-016-110-T01 have been implemented in the 100-HR-3 and 100-KR-4 OUs (12-AMRP-0172, "Completion of Hanford Facility Agreement and Consent Order (Tri-Party Agreement) Target Milestone M-016-110-T01 ("DOE Shall Take Actions Necessary to Contain or Remediate Hexavalent Chromium Groundwater Plumes in Each of the 100 Area National Priority List Operable Units Such that Ambient Water Quality Standards for Hexavalent Chromium are Achieved in the Hyporheic Zone and River Water Column").

- ***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.*

  DOE's operation and enhancement of Cr(VI) groundwater remedies in the 100-HR-3 and 100-KR-4 OUs continued to reduce overall groundwater chromium concentrations. Plume areas exceeding drinking water standards continue to decrease in the 100-HR-3 and 100-KR-4 OUs.

DOE continues to optimize groundwater remedies in the 100-HR-3, 100-KR-4, and 100-NR-2 OUs. Groundwater P&T systems in the 100-HR-3 and 100-KR-4 OUs show continuing improvement in river protection. In 2016, the 100-D Area exhibited a 30 percent reduction in unprotected shoreline length as compared to 2015. The 100-H Area exhibited a 20 percent increase in protected shoreline length and a 20 percent reduction in unprotected shoreline length as compared to 2015. In the 100-K Area, the 4,000 m (13,120 ft) of affected shoreline was identified as either protected or protected-action may be required in 2016. These remedial actions are not yet complete, but current estimates indicate that the P&T approach is capable of remediating the Cr(VI) contamination in the affected aquifer. Annual assessments of river protection status, which are presented in Chapter 2 for the 100-HR-3 OU and in Chapter 3 for the 100-KR-4 OU, indicate continuing improvement in river protection for these two OUs. DOE reviews remedial action progress regularly and annually evaluates recommendations for changes to the remedial action systems to improve system performance and shorten the time to remedy completion.

Appendix A of DOE/RL-2014-25, *Calendar Year 2013 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation* provides additional information on site history for the 100-HR-3, 100-KR-4, and 100-NR-2 OUs. The appendix presents a chronology of the investigations and decisions for the interim remedial actions, and it summarizes the conceptual site models (CSMs) associated with groundwater contamination at the OUs.

This annual summary report discusses the groundwater remedial actions conducted during 2016 at the 100-HR-3 OU (Chapter 2), the 100-KR-4 OU (Chapter 3), and the 100-NR-2 OU (Chapter 4). A cost evaluation for each OU is presented in the respective chapters. Chapter 5 provides the references cited in this report.

1.1 100-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.

1.1.1 100-HR-3 Operable Unit Pump and Treat systems

The DX and HX P&T systems operated throughout 2016, with several wells realigned to improve capture and remove contaminant mass from the aquifer. As presented in DOE/RL-2014-25, areas along the Columbia River were classified as "protected," "not protected," or "action may be required." Those areas considered at risk for impacts from contamination were evaluated, and actions were initiated to improve river protection in those areas.

The 2016 system modifications to the DX P&T system included, converting monitoring well 699-97-61 in the first water-bearing unit of the Ringold Formation upper mud unit (RUM) to an extraction well, converting well 199-D8-99 from injection to extraction, converting monitoring wells 199-D-108 and 19-D-111 to injection wells, and connecting new well 699-90-47B as an injection well. The system changes are to improve contaminant mass removal and increase groundwater movement toward targeted downgradient extraction locations. Wells 199-D5-42 and 199-D5-44 were disconnected as injection wells to reduce the potential for diluting contaminant concentrations between the southern and northern 100-D plumes system well network. As a result of extraction operations at the new extraction wells, the concentrations in downgradient wells have declined and capture has improved (see Section 2.2.6).

Three new wells that were installed in 2015 (199-H1-46, 199-H4-92, and 199-H5-16) were connected as extraction wells to the HX P&T system in 2016 to increase groundwater extraction and improve contaminant mass reduction. Well 699-90-45B was installed and connected to the HX P&T system in 2016 as an injection well to increase the operational capacity of the HX system. Figure 1-2 shows the current 100-HR-3 P&T system layout, and Figure 1-3 highlights the well changes to the P&T system configuration for 2014, 2015, and 2016. Section 2.2 discusses the changes to the DX and HX P&T systems in detail.

Figures 1-4 and 1-5 show the annual and cumulative trends for groundwater volume treated and Cr(VI) mass removed by the 100-HR-3 P&T systems. In 2016, the systems treated 2,603 million L (687 million gal) of groundwater and removed 84.8 kg (186 lb) of Cr(VI). This was 23 percent less mass than the 109.6 kg (241 lb) removed in 2015, due to the decrease in Cr(VI) concentrations in the 100-D Area southern plume near the 100-D-100 waste site. Cr(VI) concentrations declined as a result of ongoing extraction by the DX P&T system and source area remediation.

1.1.2 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 Cr(VI) to trivalent chromium, which is a much less toxic and less mobile form. Due to breakthrough of contaminants at the ISRM barrier, a notice of non-significant change to the ROD was issued in 2010, which indicated that the barrier would no longer be actively maintained (11-AMCP-0002, "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"). The notice of non-significance shifted the groundwater remedy at the ISRM barrier to the P&T system.

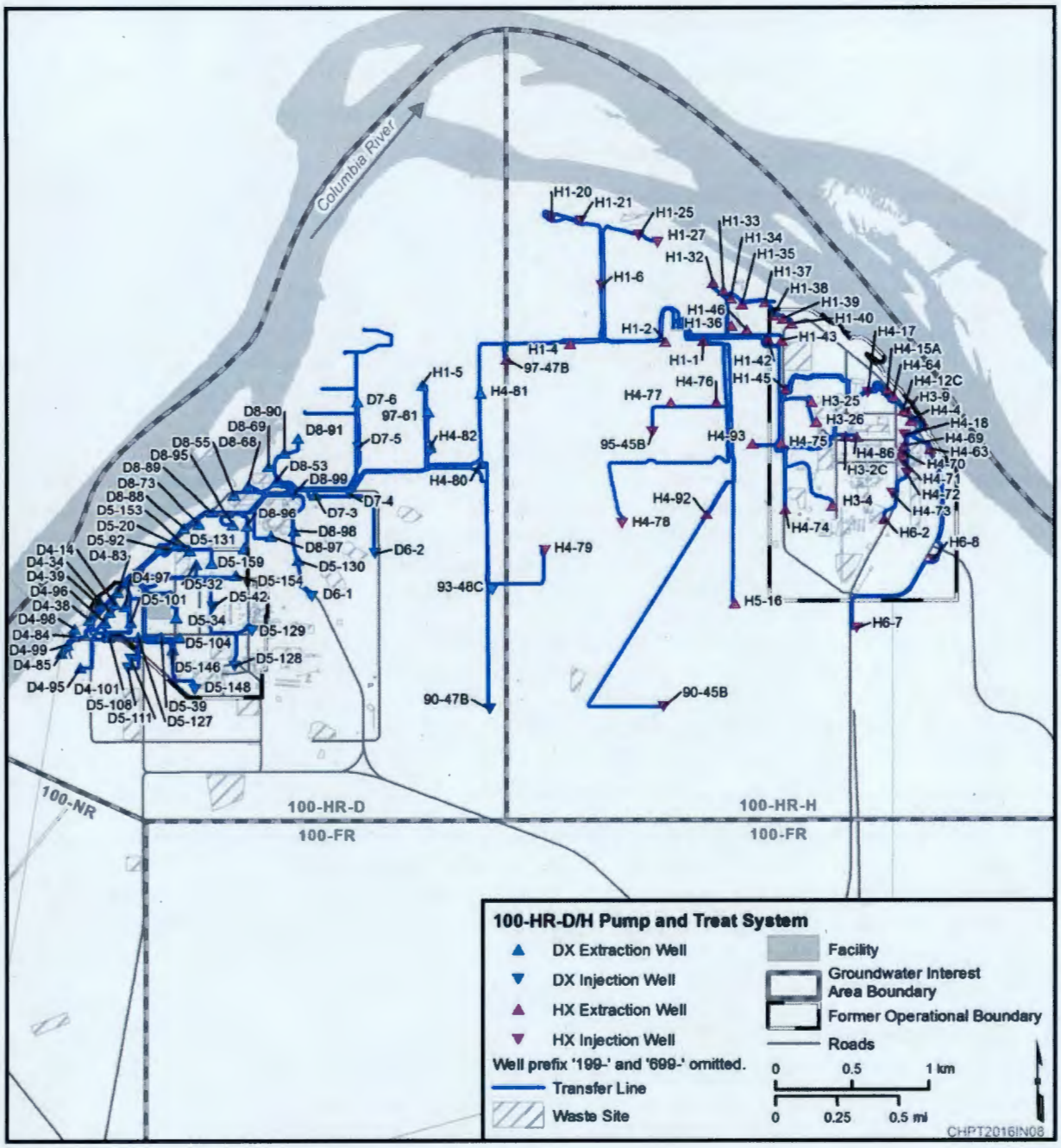

Figure 1-2. Layout of the 100-HR-3 OU P&T Systems (as of December 31, 2016)

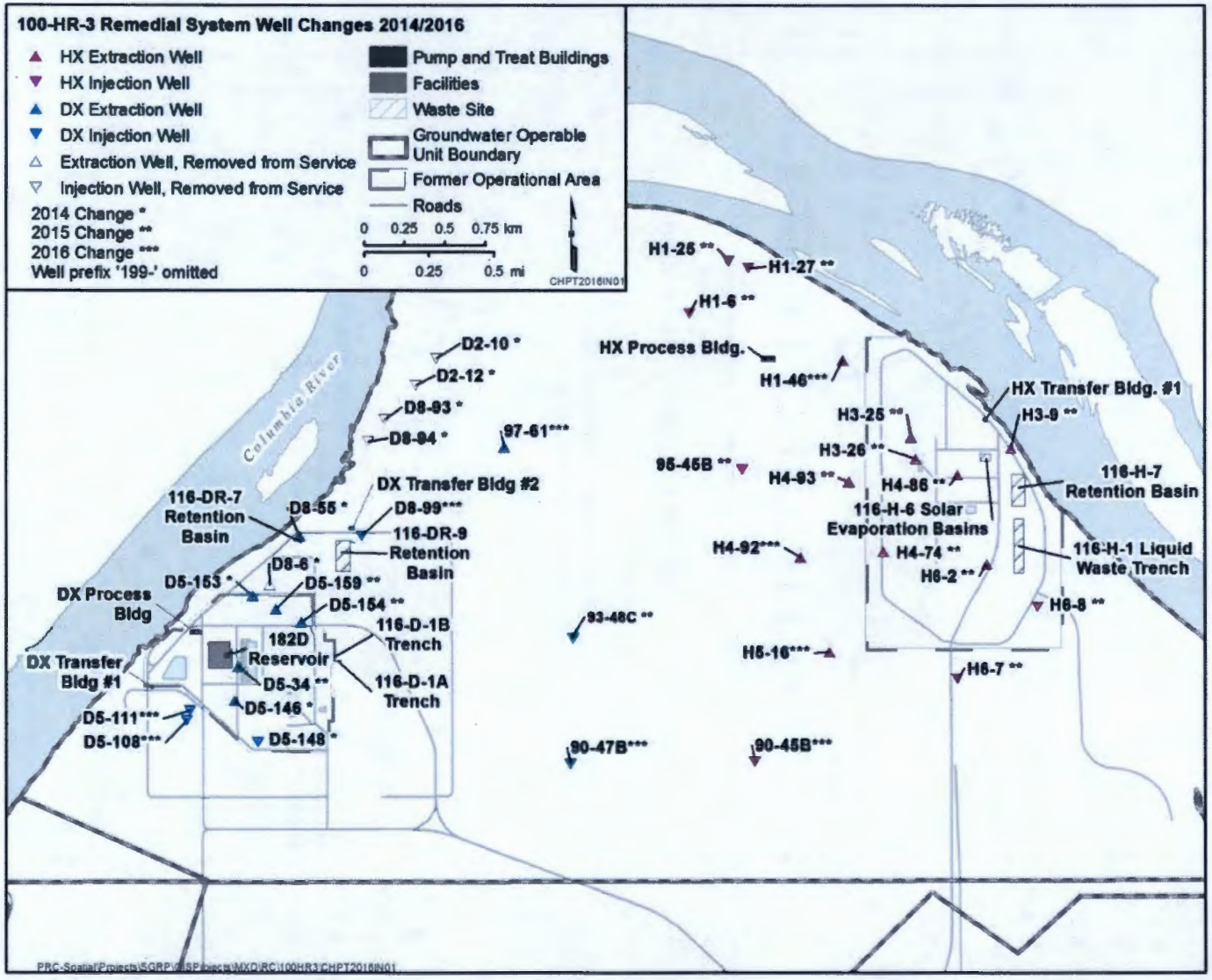

Figure 1-3. Well Changes to the 100-HR-3 OU P&T Systems in 2016

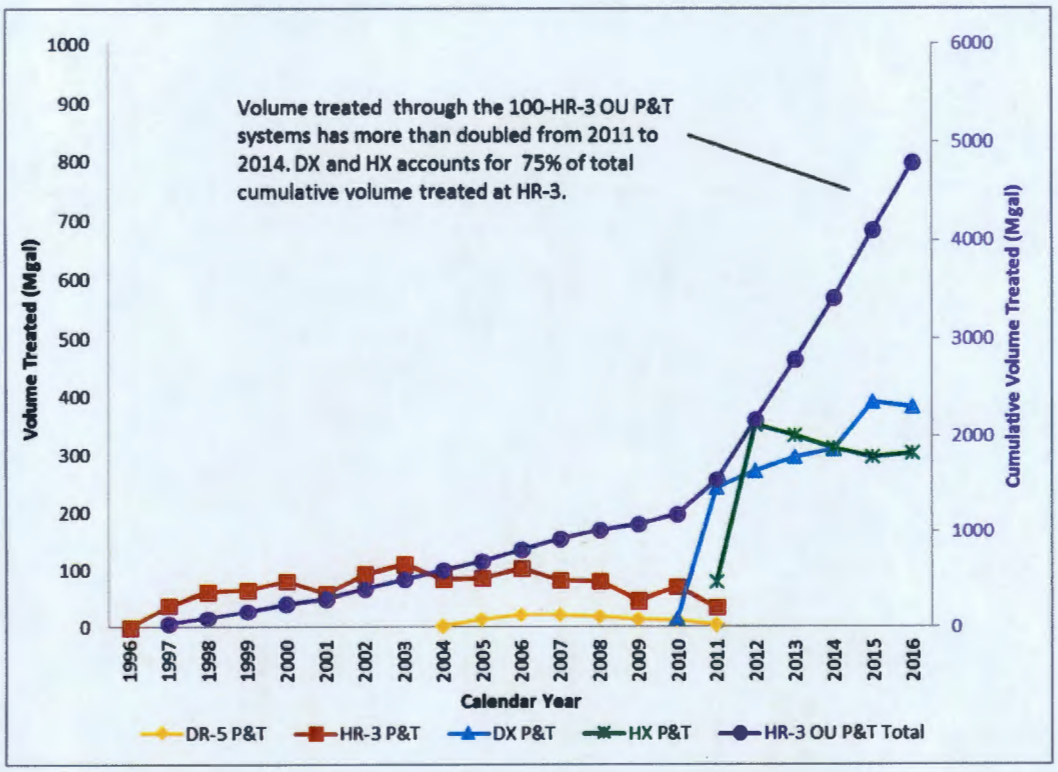

Figure 1-4. Volume Treated at the 100-HR-3 OU P&T Systems

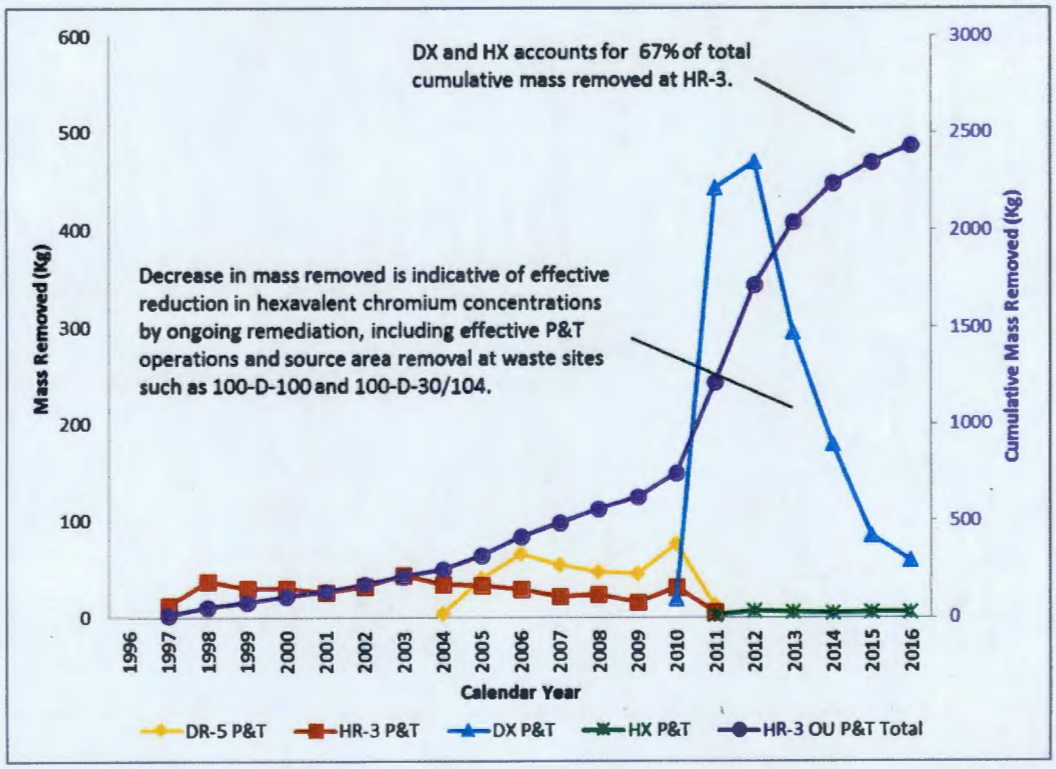

Figure 1-5. Cr(VI) Mass Removed by the 100-HR-3 OU P&T Systems

The ISRM barrier is still monitored for effectiveness. It continued to convert Cr(VI) to trivalent chromium within a portion of the aquifer in 2016. Cr(VI) concentrations in some downgradient wells remained above the ambient water quality criteria and interim remedial action target of 10 µg/L and 20 µg/L, respectively, because the northeast segment of the barrier does not work effectively. Groundwater in this area is captured by extraction wells installed for the DX P&T system. Sections 2.1.2 and 2.2.8 discuss the ISRM treatment technology and its effectiveness in detail.

1.1.3 Remedial Investigation/Feasibility Study Activities

A remedial investigation/feasibility study (RI/FS) was completed for the 100-D and 100-H Areas and the Horn. Characterization activities began in 2009, as described in DOE/RL-2008-46-ADD1, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*; and implemented through DOE/RL-2009-40, *Sampling and Analysis Plan for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units Remedial Investigation/Feasibility Study*. DOE published a Rev. 0 RI/FS report (DOE/RL-2010-95, *Remedial Investigation/Feasibility Study for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*) in October 2014. The RI/FS results support selection of final remedies under *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), using an approach that integrates source and groundwater remedial actions, which is documented in the DOE/RL-2011-111, *Proposed Plan for Remediation of the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*. Public comment was completed on the Proposed Plan in 2016. Public comments have been addressed and a ROD is anticipated in 2017 that will identify the final remedial alternative.

In the 100-KR-4 OU, active groundwater interim action remediation continued during 2016, in conjunction with preparing RI/FS reports that will support RODs for future implementation of final remedies.

1.2 100-KR-4 Operable Unit Activities

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

1.2.1 100-KR-4 Operable Unit Pump and Treat systems

Three active P&T systems continued operating in the 100-KR-4 OU during 2016. The KR4 P&T system treats groundwater downgradient from the 116-K-2 Trench, with a treatment capacity of 1,249 L/min (330 gal/min). The KX P&T 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 P&T system has a 3,407 L/min (900 gal/min) design treatment capacity. The KW P&T system extracts groundwater around the KW Reactor facility and has a treatment capacity of 1,249 L/min (330 gal/min). Figure 1-6 shows the layout of the 100-KR-4 OU P&T systems.

Figure 1-7 highlights the changes to the 100-KR-4 OU P&T system configuration implemented from 2013 through 2016. Well configuration changes to the 100-KR-4 OU P&T systems in 2016 included realigning extraction well 199-K-144 and injection well 199-K-179 from the KR4 P&T system to the KX P&T system. Well 199-K-144 was the only extraction well connected to the KR4 P&T system with concentrations over the interim remedial action cleanup target of 20 µg/L. Realigning this well to the KX P&T system enables the KR4 system to operate for hydraulic containment only. Injection well 199-K-179 was realigned to the KX system to increase injection capacity for the KX system. This also provided an available injection line for injection well 199-K-124A that previously shared the injection line with 199-K-123A. New well 199-K-225 was connected to the KX system in 2016. This well shares the same extraction well line as 199-K-220 so only one well operates at a time.

Figure 1-6. Layout of the 100-KR-4 OU P&T Systems

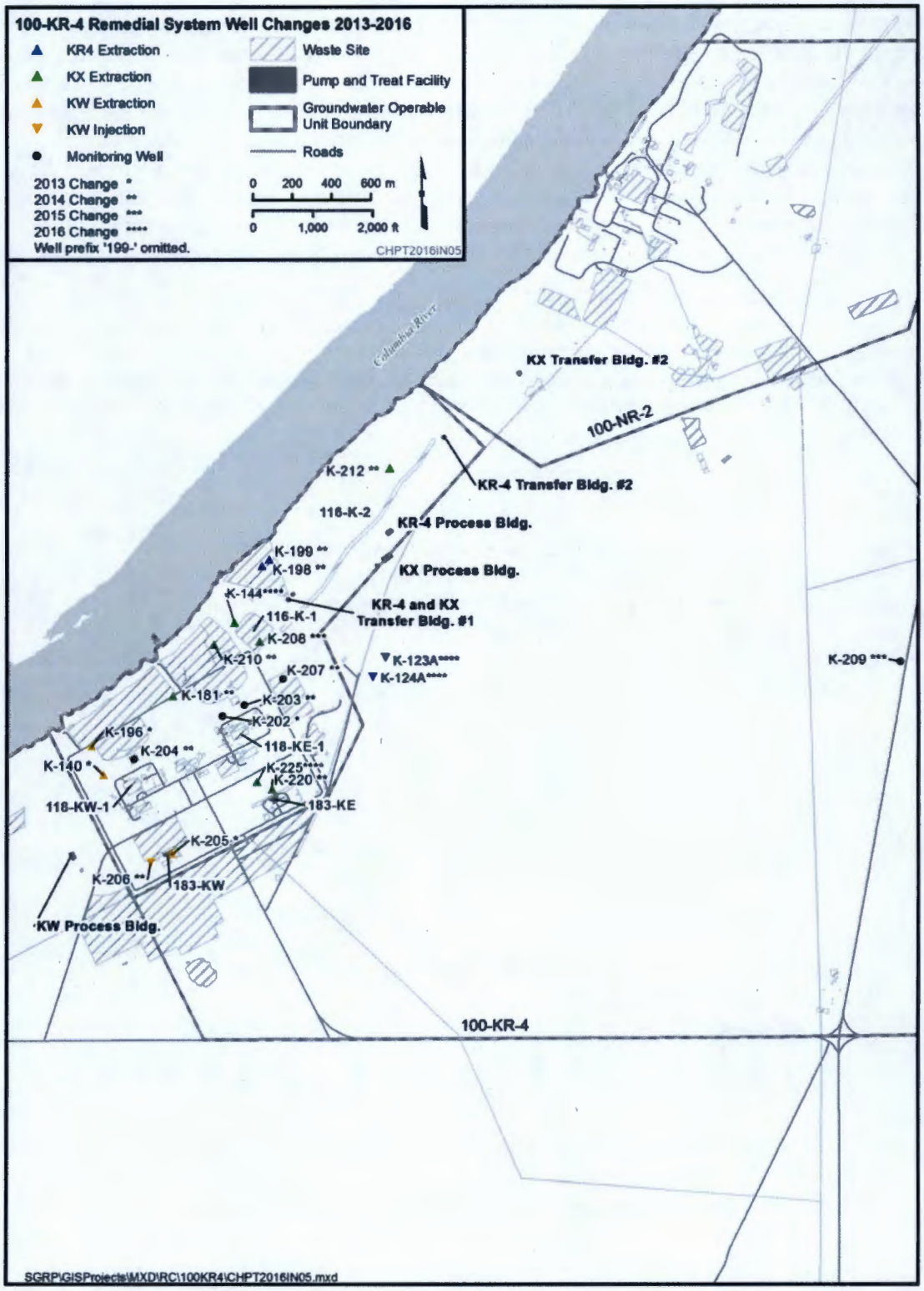

Figure 1-7. Extraction, Injection, and Monitoring Wells Added to the 100-KR-4 OU Well Network in 2016

In 2016, the KW P&T system was shut down to initiate a rebound study to evaluate whether contaminant concentrations would remain below cleanup levels and evaluate if continuing secondary vadose zone source Cr(VI) impacts groundwater above groundwater cleanup levels. Groundwater in the area affected by the KW P&T system has exhibited hexavalent chromium concentration below the interim remedial action target concentration of 20 µg/L at all monitoring locations in January 2016. This area was selected for performing a rebound study to assess the completion of the interim remedial action.
The KW P&T system was shutdown in May 2016 to initiate the rebound study. From January 1 through May 16, the KW P&T system continued to operate under the 2015 focused pumping strategy of using six extraction wells at higher pumping rates to remove groundwater along the axis of the Cr(VI) plume generally perpendicular to the river.

During 2016, the combined 100-KR-4 OU P&T systems treated 2,458 million L (648 million gal) of groundwater and removed 31 kg (68 lb) of Cr(VI). Figures 1-8 and 1-9 show the annual and cumulative volume treated and mass removed. With the use of high-efficiency, high-capacity SIR-700 IX resin, the systems function effectively using a two-vessel treatment train. This allows the remaining two vessels of the original four-vessel train to be used for additional plant treatment capacity, increasing the treatment capacity of each system.

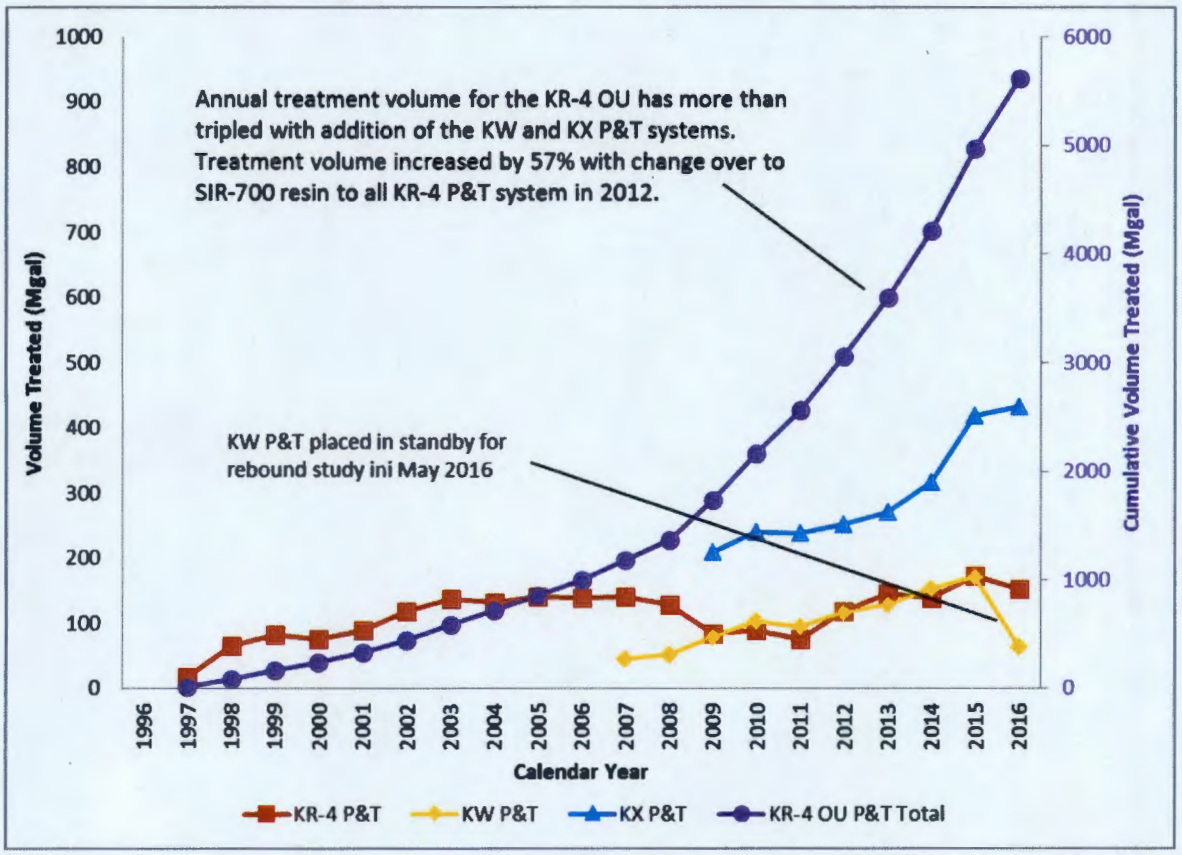

Figure 1-8. Volume Treated at the 100-KR-4 OU P&T Systems

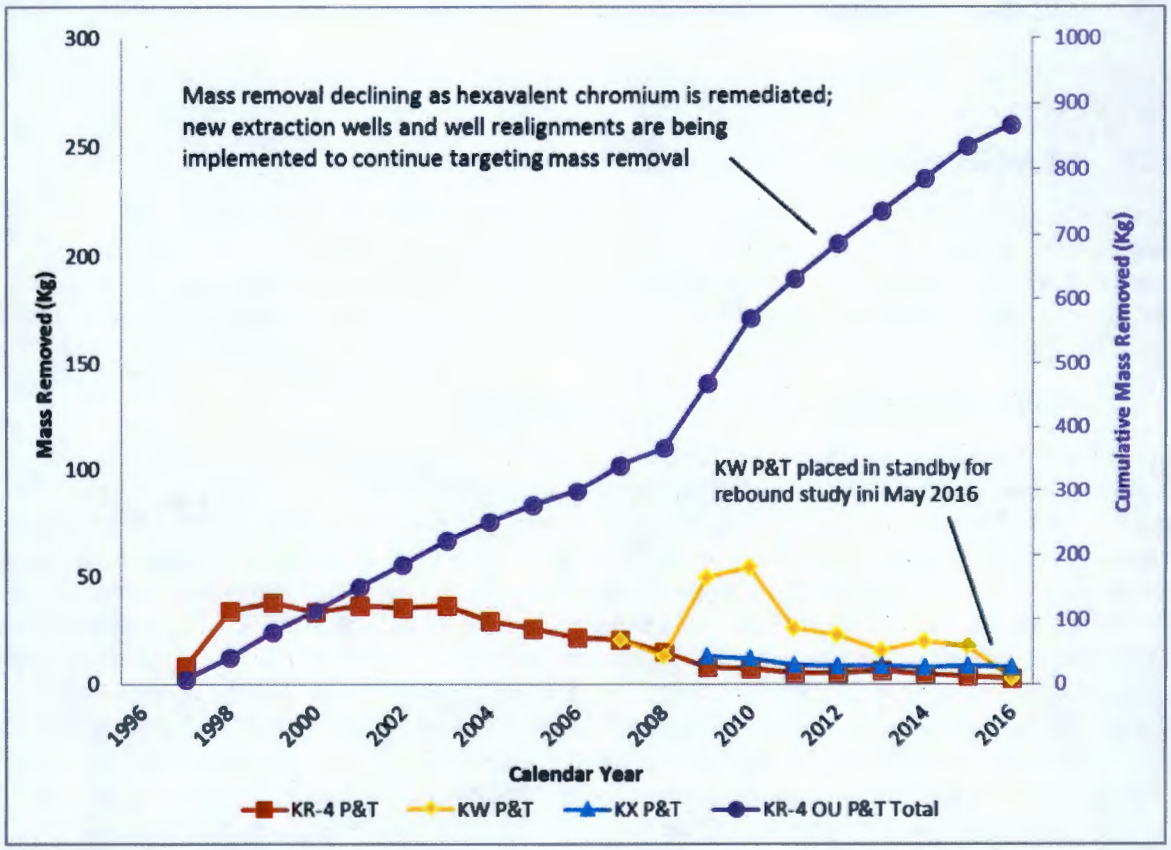

Figure 1-9. Cr(VI) Mass Removed by the 100-KR-4 OU P&T Systems

1.2.2 Remedial Process Optimization Activities

Remedial process optimization (RPO) activities for 2016 at the 100-KR-4 OU remedial systems focused on the following:

- **Assessing extraction and injection well performance**: This includes evaluating individual well performance and the identifying wells that need maintenance. This also includes evaluating individual pumping rates for extraction wells located within specific portions of contaminant plumes (e.g., at or near source areas, along the leading edge of plumes).

- **Evaluating well network performance**: This includes evaluating the placement and pumping rates of wells with respect to contaminant plume distribution. Modeling tools were used to evaluate anticipated well field performance under selected pumping scenarios. Based on these assessments, additional extraction capability was added to the 100-K remedial systems by realigning selected existing wells as extraction wells and by drilling and constructing new wells, focusing on enhancing contaminant capture and mass removal in source areas (e.g., the 183-KE and 183-KW Head House areas) and protecting the river by enhancing capture along the leading edges of plumes that approach or intersect the river.

- **Assessing treatment process effectiveness**: This evaluation led to the changeover in 2011 to the current SIR-700 IX resin. In 2016, this resin continued to provide highly efficient removal of Cr(VI) from extracted groundwater. No resin changes have been required at any of the three 100-K Area treatment systems since the use of SIR-700 resin was initiated.

1.3 100-NR-2 Operable Unit Activities

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

1.3.1 100-NR-2 Operable Unit Pump and Treat system

The 100-NR-2 P&T system was placed in cold-standby status in March 2006. This system was demolished, excavated, and removed during August through November 2016. Surface and subsurface features associated with the system—including permanent and temporary structures, concrete slab, vaults and culverts beneath roads and three 100-NR-2 P&T signs—were removed from the site and disposed of at the Environmental Restoration Disposal Facility (ERDF).

1.3.2 100-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 (Tri-Party Agreement) Change Control Form M-16-06-01 dated February 15, 2006, 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. Change Number M-16-06-01 established two new milestones [M-016-14(a) and M-016-14(b)] for the construction and evaluation of a 91.4 m (300-ft) permeable reactive barrier utilizing apatite sequestration at 100-N. Milestones M-016-14(a) and M-016-14(b) were completed in 2007 (as documented by 07-AMCP-0266, "Completion of Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) Milestone M-16-14A, "Complete Construction of a Permeable Reactive Barrier at 100-N" and Completion of Calendar Year 2007 Construction Activities at the 100-N Sequestration Barrier" and 2009 (as documented by 10-AMCP-0032, "Proposed Plan for Amendment of 100-NR-1/NR-2 Interim Action Record of Decision, DOE/RL-2009-54, Draft B", respectively.

Performance monitoring is ongoing along the entire treated portion of the barrier and is discussed further in Chapter 4. Figure 1-10 shows the location of the original PRB and the upstream and downstream extensions. No additional injections were conducted in 2016. Wells and aquifer tubes downgradient of the treated segments of the PRB continued to be monitored. Groundwater monitoring of the upriver and downriver PRB extension indicate the concentrations in the majority of the monitoring wells in 2016 were lower than pre-injection levels. However, in 2015 concentrations of strontium-90 increased in some of the monitoring wells, and remained elevated concentrations in 2016. Chapter 4 presents a further discussion on PRB performance.

1.3.3 Total Petroleum Hydrocarbon Removal

Removal of total petroleum hydrocarbon free floating product from well 199-N-18 continued in 2016 using a polymer "smart sponge" that selectively absorbs petroleum products from the groundwater within the well. Chapter 4 provides a further discussion on total petroleum hydrocarbon remediation.

1.4 Quality Assurance/Quality Control

Appendix E of DOE/RL-2016-67, *Hanford Site Groundwater Monitoring Report for 2016* provides discussions on quality assurance (QA) and quality control (QC) encompassing sampling and analysis of the wells. It includes an overall view of the QA/QC issues that may affect interpretation of the groundwater data.

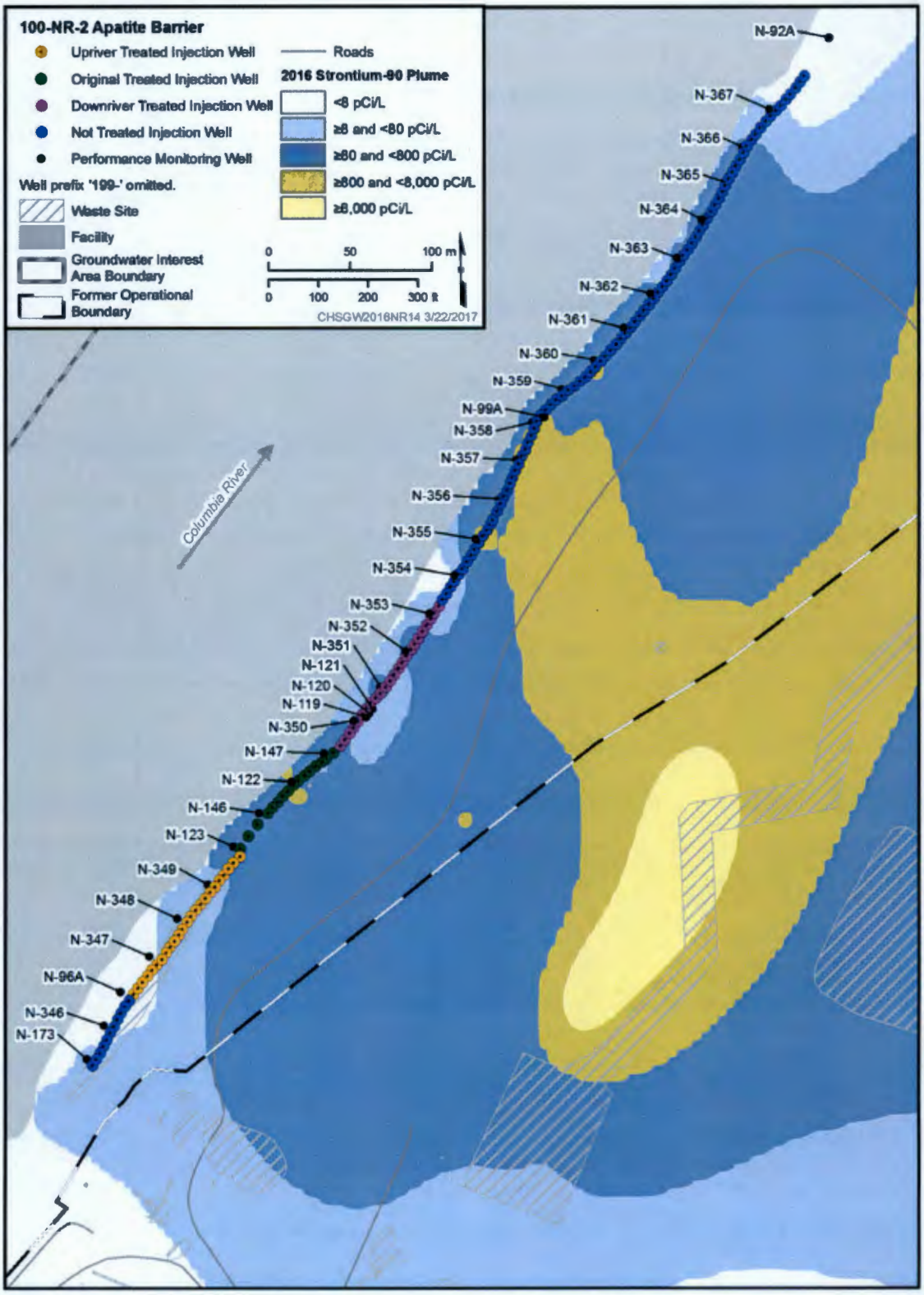

Figure 1-10. Treated Segments of the 100-NR-2 OU Apatite PRB

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2 100-HR-3 Operable Unit Remediation

This chapter describes the status of the interim remedies and other CERCLA activities for the 100-HR-3 Groundwater OU. The following discussion includes the interim remedy P&T system performance and ISRM barrier monitoring.

2.1 Overview of Operable Unit Activities

The 100-HR-3 OU consists of the groundwater contaminated by releases from facilities and waste sites associated with past operation of the D, DR, and H Reactors that underlie the 100-D Area, the 100-H Area, and the region between known as the Horn (Figure 2-1). The Cr(VI) released from facilities and waste sites poses a risk to human health and/or the environment and is the primary COC identified in the interim action ROD (EPA/ROD/R10-96/134) for groundwater in the 100-HR-3 OU. Groundwater co-contaminants identified in this interim remedial action scope are nitrate, strontium-90, tritium, uranium, and technetium-99.

The interim remedial action ROD (EPA/ROD/R10-96/134) for the 100-HR-3 OU defined the cleanup goal for Cr(VI) in groundwater discharging to the Columbia River as the ambient water quality criterion at that time of 11 µg/L. Based in part on the assumption 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, attaining less than 22 µg/L of Cr(VI) in the compliance monitoring well network is consistent with achieving this RAO. The explanation of significant differences (ESD) for the 100-HR-3 and 100-KR-4 OUs (EPA et al., 2009, *Explanation of Significant Differences for the 100-HR-3 and 100-KR-4 Operable Units Interim Action Record of Decision: Hanford Site, Benton County, Washington*) reduced the groundwater remediation target to 20 µg/L to meet the revised surface water quality criterion of 10 µg/L. Consequently, a compliance criterion of 20 µg/L for Cr(VI) in groundwater is currently applied to near-shore and compliance wells along the river. The drinking water standard (DWS) for total chromium remains at 100 µg/L. Washington State Department of Ecology (Ecology) has established a Method B groundwater cleanup level of 48 µg/L for Cr(VI) under WAC 173-340, "Model Toxics Control Act—Cleanup" (MTCA).

To mitigate the risks associated with Cr(VI) contamination in groundwater discharging to the river, DOE initially installed a CERCLA interim action P&T system in the 100-HR-3 OU in 1997. The P&T interim remedial actions were implemented under DOE/RL-96-84, *Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*, in accordance with the interim ROD (EPA/ROD/R10-96/134). A second P&T system, DR-5, was installed in 2004. In 2010, the two original systems were replaced with the larger DX and HX P&T systems, which continue to operate. In addition, an ISRM barrier was installed in the southern portion of the 100-D Area in 2000. Due to early breakthrough of contaminants at the ISRM barrier, a notice of non-significant change to the ROD was issued in 2010, which indicated that the barrier would no longer be actively maintained (11-AMCP-0002). The notice of non-significance change shifted the groundwater remedy in the ISRM barrier area to P&T but maintained monitoring of the ISRM. The current interim action remedy in the 100-HR-3 OU is P&T and consists of the DX and HX P&T systems. A new remedial design/remedial action work plan (RD/RAWP) (DOE/RL-2013-31, *100-HR-3 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*) was issued in May 2016 to supersede DOE/RL-96-84 and DOE/RL-99-51, *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit In Situ Redox Manipulation*. DOE/RL-2013-31 includes design and completion of the DX and HX P&T systems and operation of these systems to meet the RAOs described in Chapter 1. A sampling and analysis plan (DOE/RL-2013-30, *Sampling and Analysis Plan for 100-HR-3 Groundwater Operable Unit Monitoring*) was also issued in May 2016 establishing groundwater monitoring to track changing conditions, performance of the remedy, and effectiveness of interim remedial actions in meeting performance criteria required by the interim action ROD.

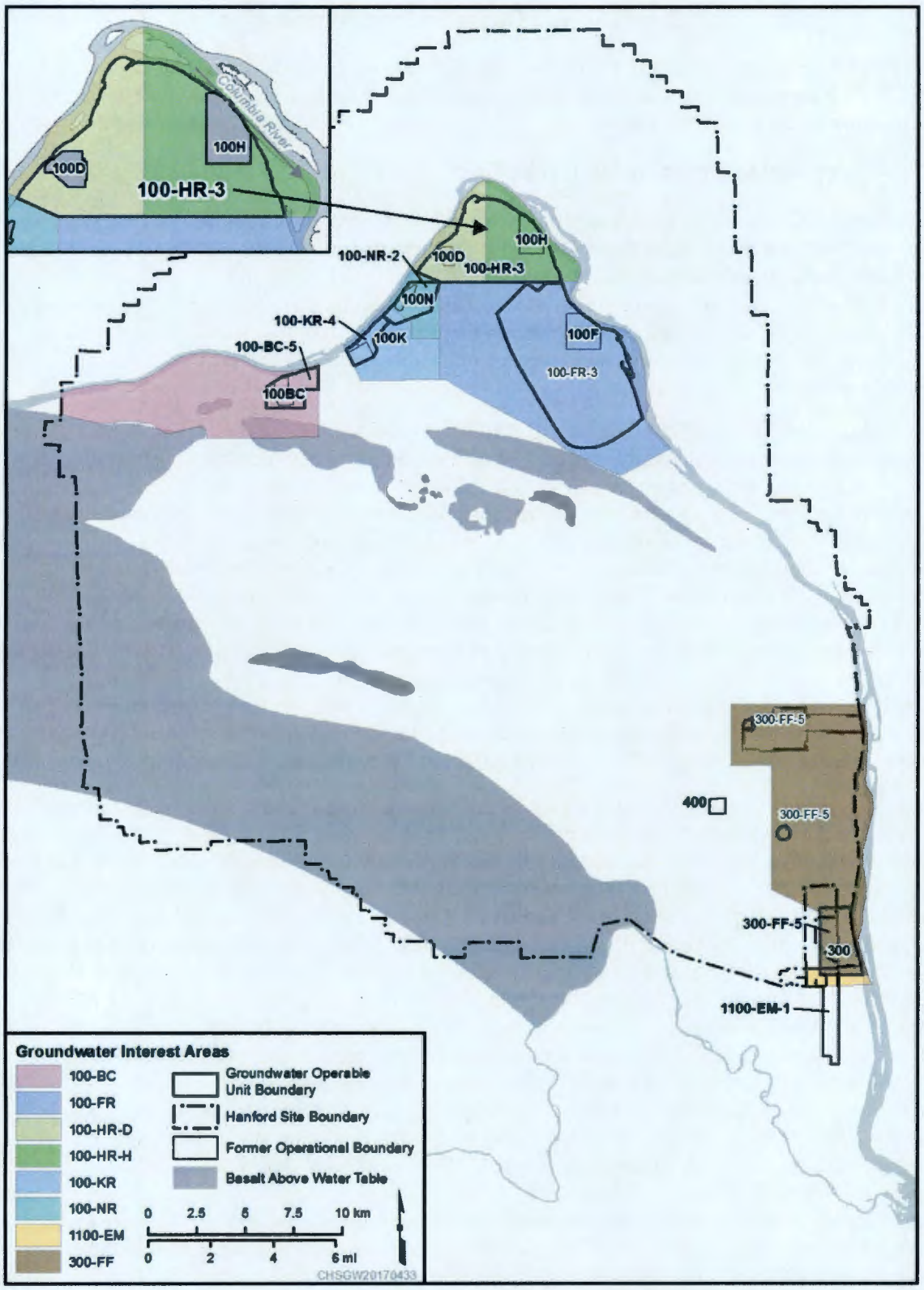

Figure 2-1. Location of the 100-HR-3 OU and Groundwater Interest Areas

Monitoring, data evaluation, and site characterization activities are conducted to evaluate the 100-HR-3 OU P&T systems' performance compared to design criteria, whether system design modifications or operating parameters will further optimize performance, and the measurable progress toward achieving plume cleanup and river protection RAOs. This chapter discusses the results of the 2016 100-HR-3 OU P&T evaluation and includes the following:

- Section 2.2 discusses the interim action groundwater-remediation activities, including the condition of ISRM barrier.
- Section 2.3 discusses the radiological dose analysis of the effluent from the 100-HR-3 OU P&T systems.
- Section 2.4 provides the remedial action cost summary.
- Section 2.5 presents the conclusions on 2016 remedy performance for the 100-HR-3 OU.

2.1.1 100-HR-3 Operable Unit Pump and Treat Systems

Changes to remedial systems during 2016 consisted of:

- Constructing additional wells for extraction and injection
- Realigning existing monitoring wells for extraction or injection
- Disconnecting extraction and injection wells to use as monitoring wells
- Converting extraction wells to injection use
- Adjusting the flow rates in select wells

These actions were intended to enhance hydraulic plume capture, reduce Cr(VI) plume concentrations, and remove mass from groundwater near source areas. Eight new wells were drilled in 2016, two of which were connected to the P&T systems at 100-HR-3. In addition, there were 14 well realignments in the OU. Changes to the remedial systems are shown in Table 2-1 and discussed in detail in Sections 2.2.1.1 and 2.2.2.1 for the DX and HX P&T systems, respectively. Chapter 1, Figure 1-3 shows the locations of the new and realigned wells in 2016.

Figures 2-2, 2-3, and 2-4 present the 2016 extraction, injection, and monitoring well locations for the 100-D Area, the ISRM portion of 100-D, and the 100-H Area, respectively. Figure 2-5 shows the well and aquifer tube locations in the Horn. Figure 2-6 shows the layouts of the P&T systems.

2.1.2 In Situ Redox Manipulation Barrier

Prior to installation of the DX P&T system, additional cleanup action was deemed necessary in the southern portion of the 100-D Area. As approved by the 1999 interim ROD amendment (EPA/AMD/R10-00/122), an in situ chemical treatment technology was implemented in 2000. The ISRM barrier (Figure 2-3) was installed to treat groundwater in the aquifer by reducing Cr(VI) to trivalent chromium, which is a less toxic and less mobile form. Groundwater at the ISRM site is still monitored for Cr(VI) and dissolved oxygen as part of CERCLA interim action monitoring, with Cr(VI) as the target contaminant. The dissolved oxygen levels are monitored along the barrier since the treatment process reduces oxygen content in the aquifer.

Table 2-1. 100-HR-3 Groundwater OU Remedial System Well Changes Completed in 2016

System	Well	Action	Purpose	Status as of December 31, 2016
DX	199-D4-102	Drill as potential extraction well	River protection/hydraulic control	Not connected to P&T due to insufficient well yield (<10 gal/min). Will be used as a monitoring well.
	199-D4-103	Drill as potential extraction well	River protection/hydraulic control	Not connected to P&T due to insufficient well yield (<10 gal/min). Will be used as a monitoring well.
	199-D8-99	Realign from injection to extraction	River protection/hydraulic control	In service as extraction well
	699-97-61	Connect as extraction well	Mass removal	In service as extraction well
	199-D5-44	Disconnect Injection Well	Operational/plume control	Removed from DX P&T
	199-D5-42	Disconnect Injection Well	Operational/plume control	Removed from DX P&T
	199-D5-111	Connect as injection well	Operational/plume control	In service as injection well
	199-D5-108	Connect as injection well	Operational/plume control	In service as injection well
	199-D8-102	Drill as potential extraction well	Mass removal	Not connected to P&T since Cr(VI) concentrations <40 µg/L Will be used as a monitoring well.
	699-90-47B	New Well Constructed as Injection Well	Operational/plume control	In service as injection well
HX	199-H4-92	Drill as extraction well	Mass removal	In service as extraction well
	199-H5-16	Drill as extraction well	Mass removal	In service as extraction well
	199-H1-46	Drill as extraction well	River protection/hydraulic control	In service as extraction well
	699-90-45B	Drill and connect as injection well	Operational/plume control	In service as injection well

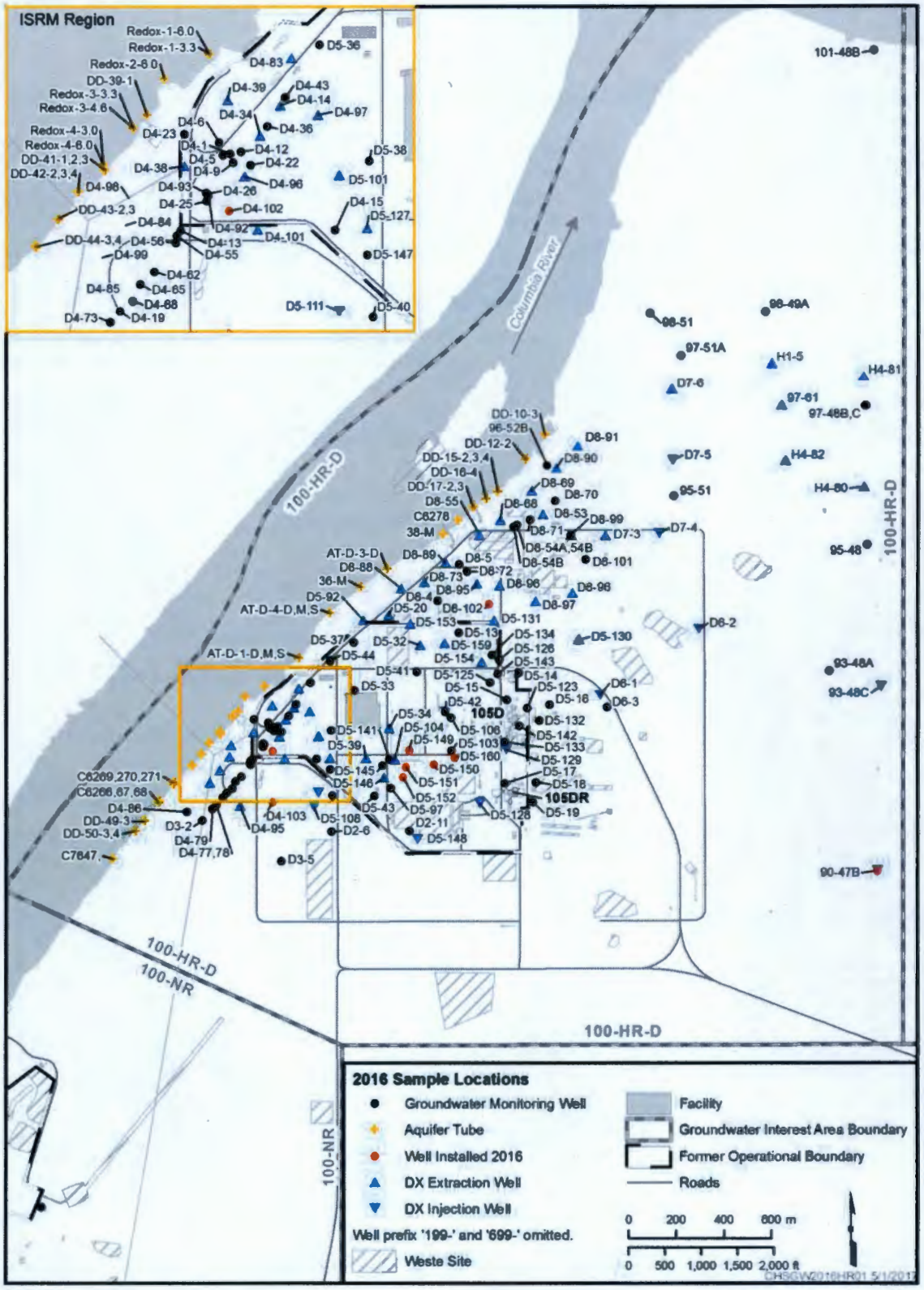

Figure 2-2. 100-D Area Wells and Aquifer Tubes

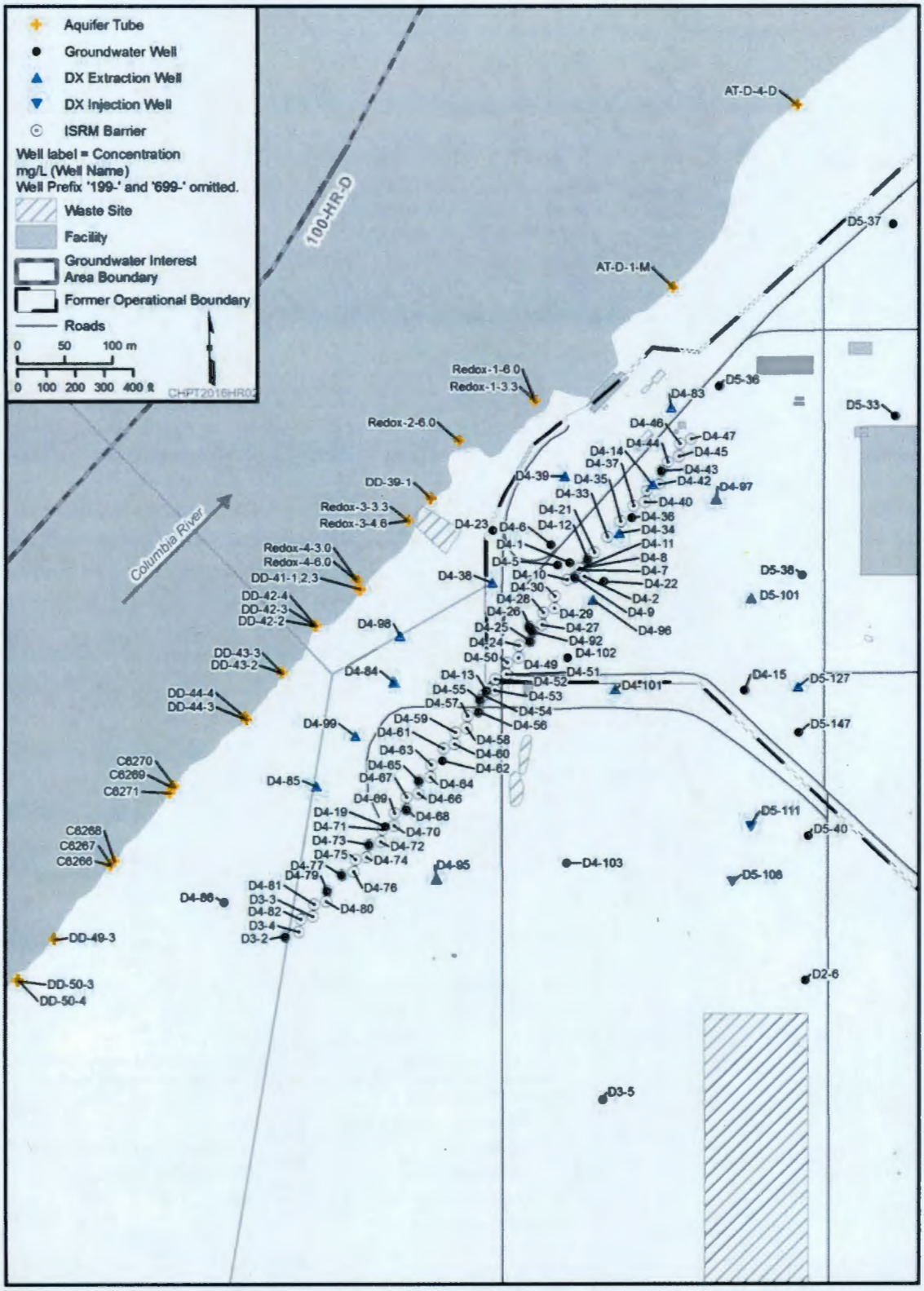

Figure 2-3. ISRM Detail Map

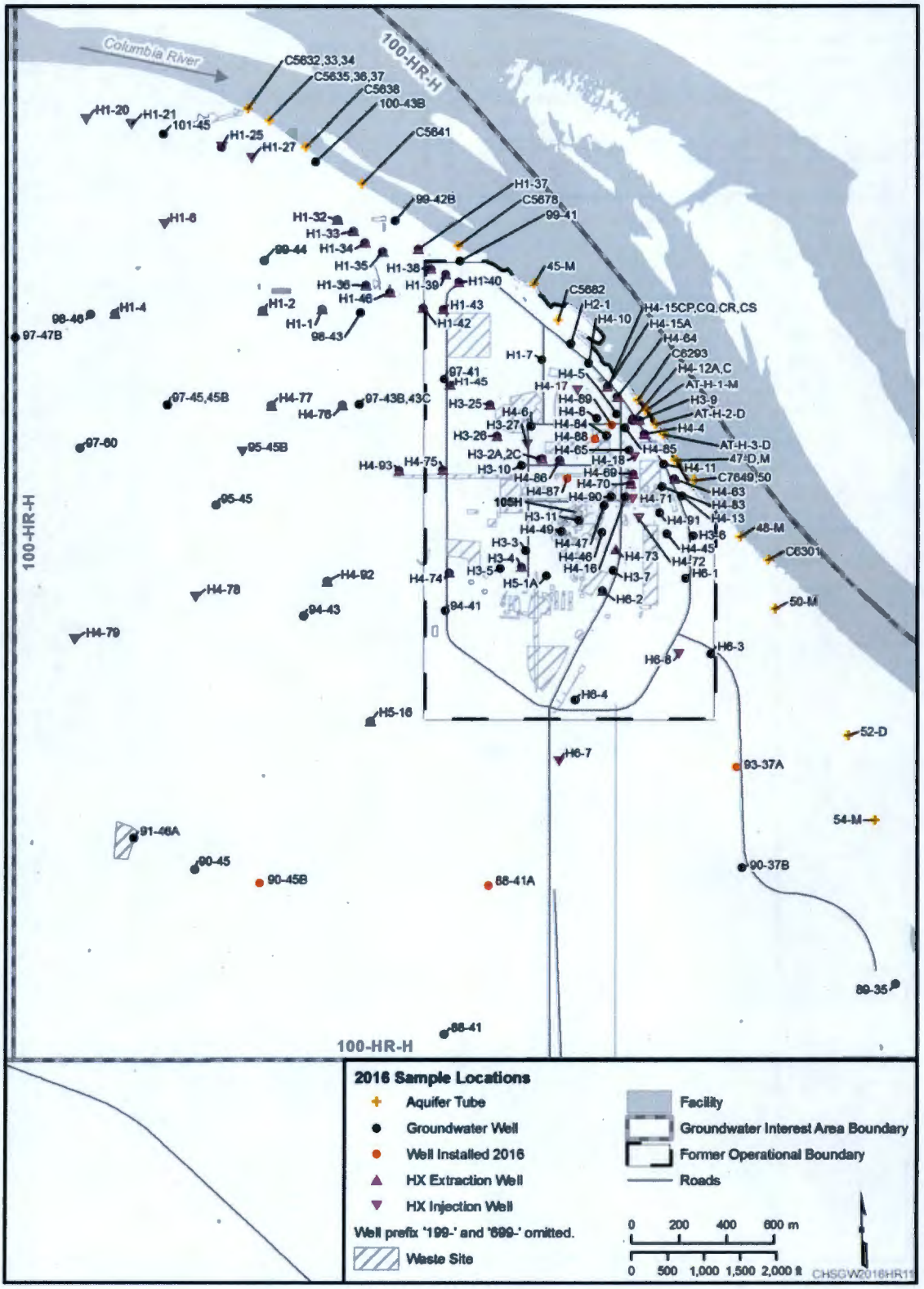

Figure 2-4. 100-H Area Wells and Aquifer Tubes

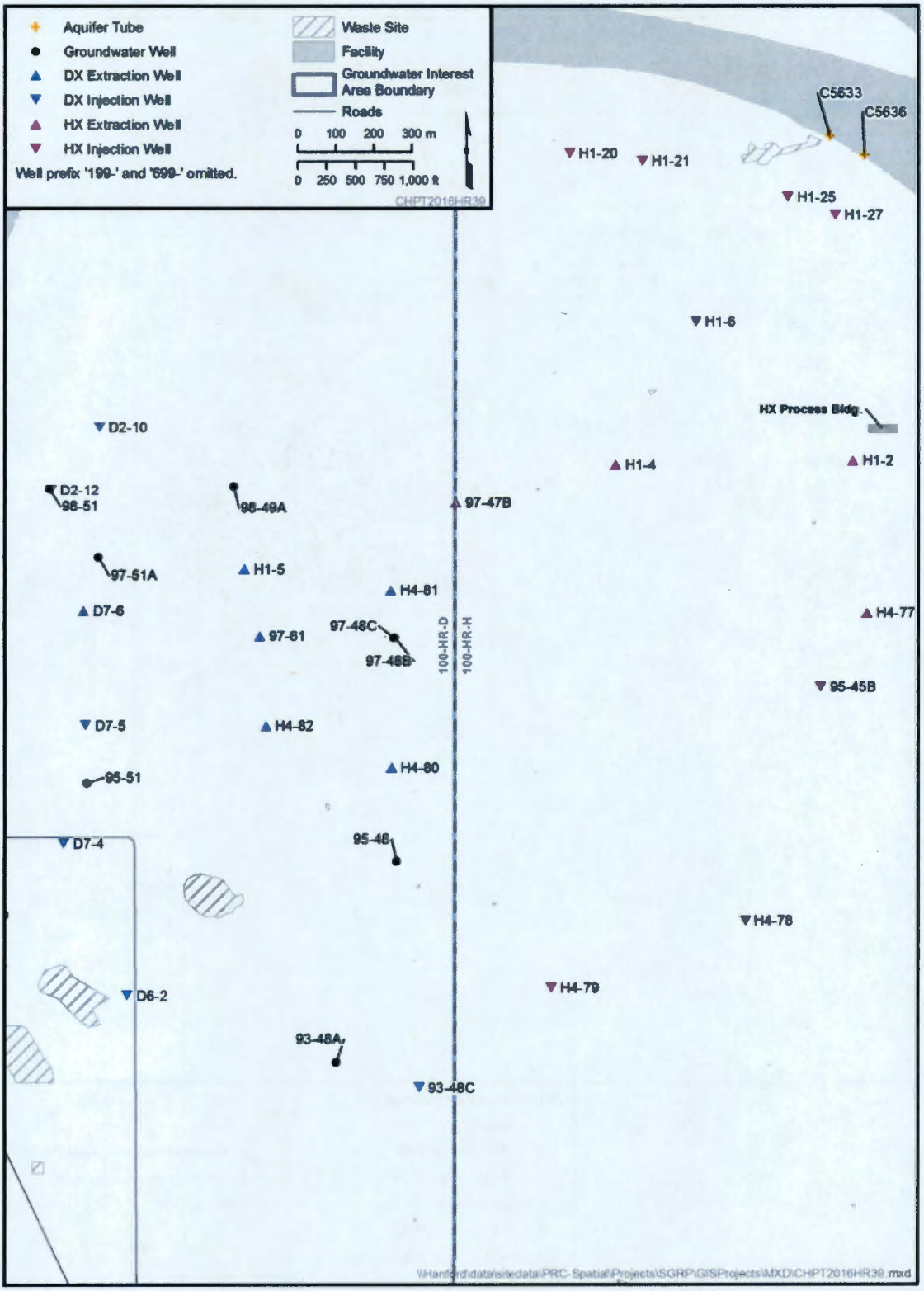

Figure 2-5. Horn Wells and Aquifer Tubes

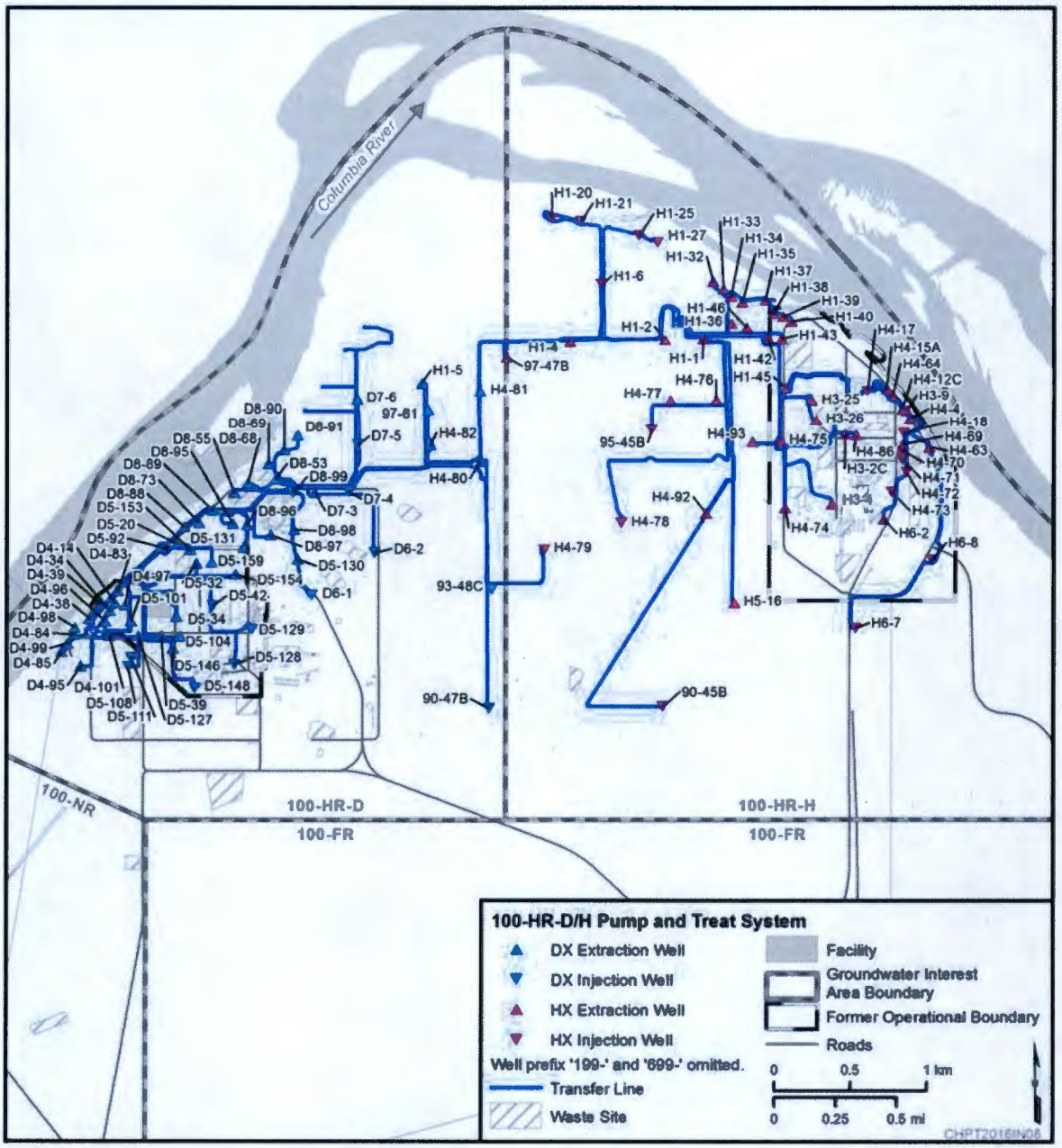

Figure 2-6. Layout of the 100-HR-3 OU P&T Systems (as of December 31, 2016)

Dissolved oxygen levels along most of the ISRM barrier have returned to normal or nearly normal levels, greater than 6 mg/L in most wells. An area of lower dissolved oxygen is present between wells 199-D4-19 and 199-D4-13, and at small area around well 199-D4-26 (Figure 2-7). The area within the barrier where levels remain low coincides with where groundwater velocity is slower and the aquifer is thinner due to a high in the RUM surface (the base of the unconfined aquifer). The oxygen levels on the downgradient side of the barrier are normal. A second area of lower dissolved oxygen is associated with the former treatability tests (wells 199-D5-107 and 199-D5-108) (PNNL-18784, *Hanford 100-D Area Biostimulation Treatability Test Results*). Overall, the area of low dissolved oxygen is smaller than in previous years, indicating reduced barrier performance, as expected.

Figure 2-7. ISRM Area Dissolved Oxygen Concentrations, 2016

The Cr(VI) concentrations in barrier wells in 2016 ranged from below detection limits to a maximum of 84 µg/L at well 199-D4-96. Although the overall maximum Cr(VI) concentration observed in barrier wells in 2016 was lower than the previous year (101 µg/L at well 199-D4-22 in 2015), there were multiple locations where concentrations increased during 2016. For example, Cr(VI) increased in wells 199-D4-1, 199-D4-5, 199-D4-6, 199-D4-62, and 199-D4-96 in 2016. These increases indicate continued reduced barrier performance and generally correlate with increasing dissolved oxygen levels. The overall declining Cr(VI) concentrations in and near the ISRM barrier are attributed to the ongoing P&T system operations and the upgradient removal of source material, especially at waste site 100-D-100 where large volumes of highly contaminated soil were removed from both the vadose zone and the upper aquifer. The Cr(VI) concentrations at well 199-D4-22, which had the highest concentration observed in the barrier in 2015, have been decreasing and the highest concentrations measured at this well in 2016 was 33 µg/L.

2.2 100-HR-3 Operable Unit Interim Action Activities

This section discusses the CERCLA activities for the 100-HR-3 OU during the reporting period, including activities related to operation and performance monitoring of the DX and HX P&T systems during 2016. Specific activities and operational performance details for these systems include system configuration changes and availability, contaminant mass removed during operation, contaminant removal efficiencies, quantity and quality of extracted and reinjected groundwater, and waste generation.

2.2.1 DX Pump and Treat System

The DX P&T system (Figure 2-8) was designed to capture and treat the Cr(VI) plume located in the 100-D Area. Releases of highly concentrated stock solution of sodium dichromate to the environment through spills, washout of vehicles and containers, and leaks in the conveyance system resulted in high concentrations of Cr(VI) in the groundwater in the 100-D southern plume. Disposal of large volumes of reactor cooling water to cribs and trenches and smaller releases of sodium dichromate solution resulted in Cr(VI) contamination of the groundwater in the northern plume area of the 100-D Area.

The DX P&T system was originally designed to receive and process up to 2,273 L/min (600 gal/min). Over the past several years, optimization activities have increase the operational capacity of the system to 2,936 L/min (775 gal/min). From startup of the DX P&T system in 2010 through the end of 2016, the system has treated over 7,234 million L (1,910 million gal) of groundwater and has removed 1,547 kg (3,403 lb) of Cr(VI). During 2016, the DX system included 48 operating extraction wells and 13 operating injection wells (Figure 2-9). Treated water is returned to the aquifer through the injection wells.

The DX P&T system utilizes ResinTech® SIR-700 resin to bind Cr(VI) as influent groundwater flows through tanks in the treatment facility. The SIR-700 resin is a single-pass resin that does not require regeneration, saving time and money. Resin change for DX vessels have only had to be performed once so far since the DX P&T started operations. The resin change-out to replace the resin in the first vessel of each of the six DX P&T IX trains started in August 2014 and completed in April 2015. The DX P&T system improved the groundwater treatment capacity along the river and is a key component in DOE's strategy for keeping Cr(VI) from entering the Columbia River. Changes in concentrations and overall trends are discussed in Section 2.2.3.

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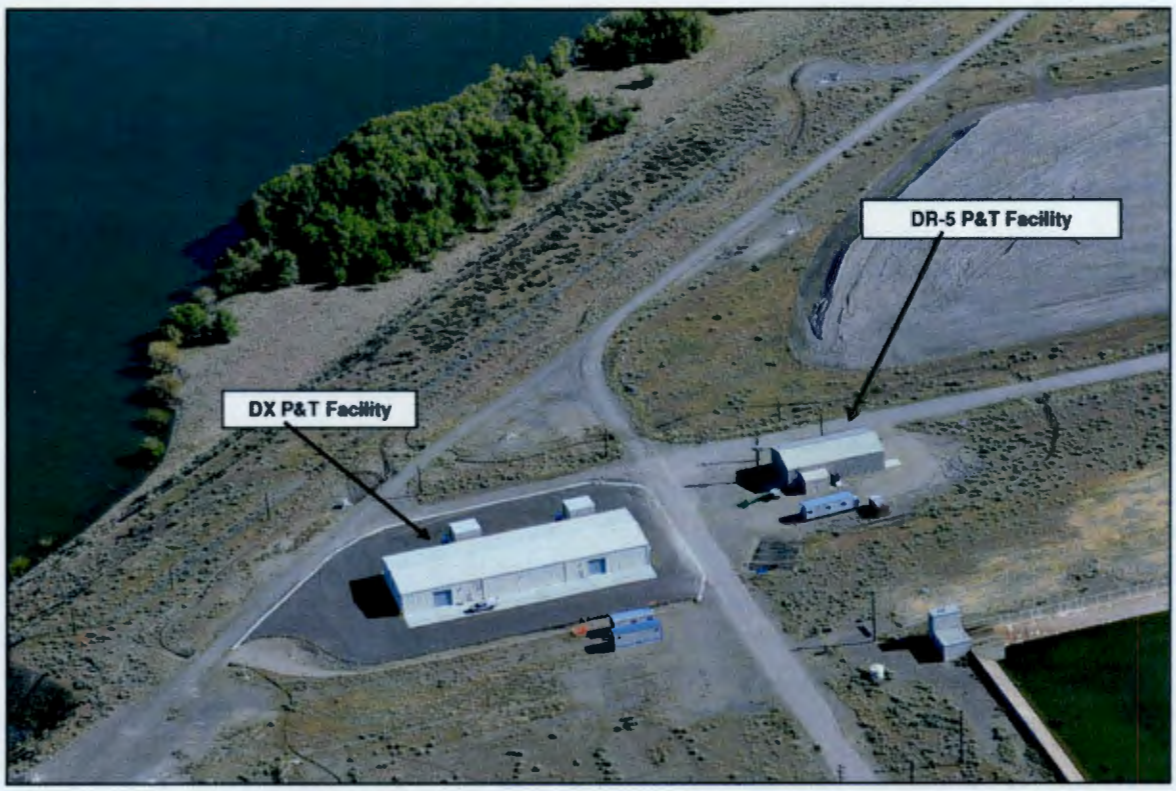

Figure 2-8. Aerial View of the DX P&T System

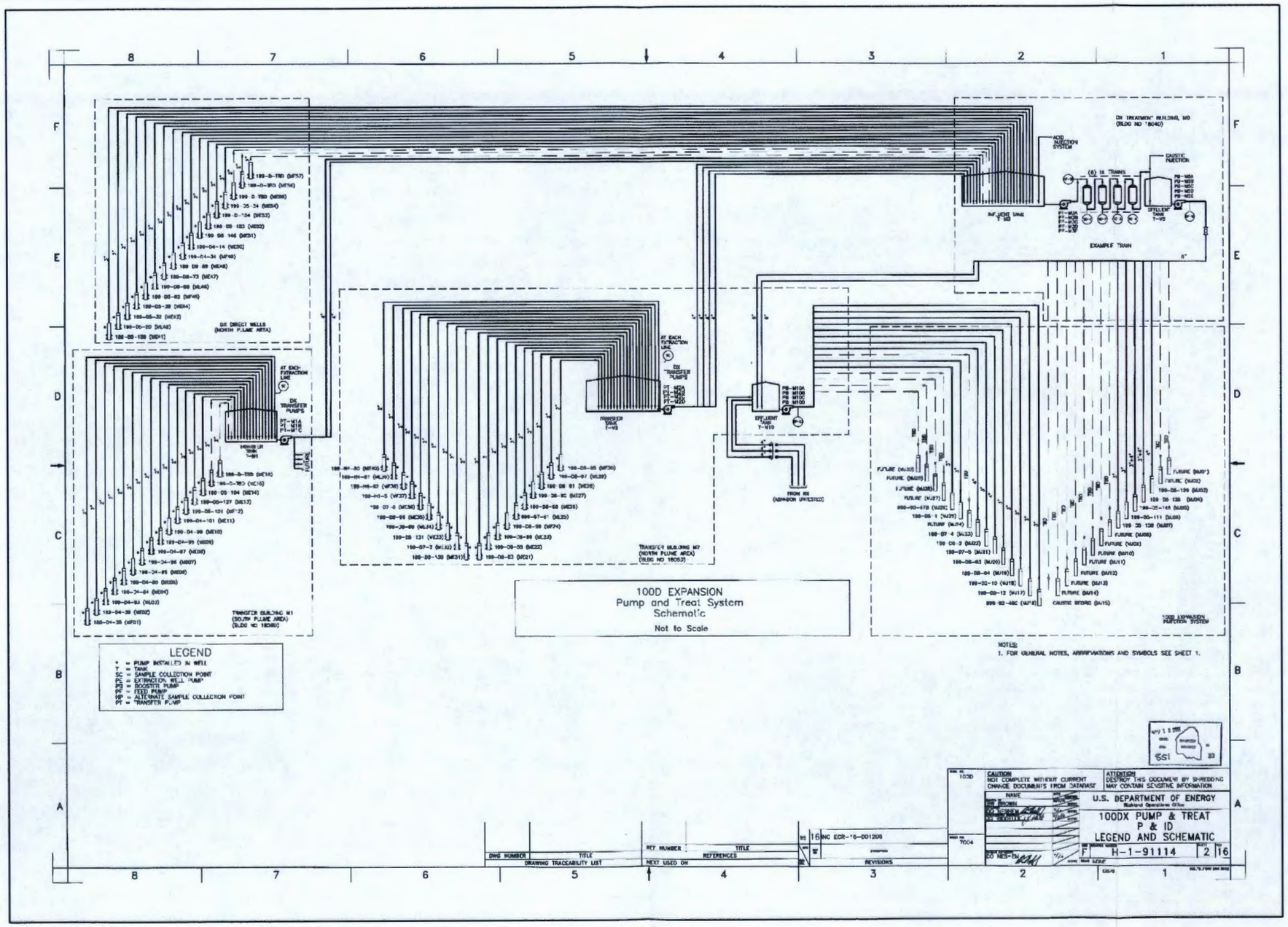

Figure 2-9. DX P&T System Schematic

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2.2.1.1 DX Pump and Treat System Configuration and Changes

The annual evaluation of the plume capture from 2015 (DOE/RL-2016-19, *Calendar Year 2015 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater Remediation*) was used to identify areas along the Columbia River where additional plume capture was needed. In addition, the evaluation identified areas where Cr(VI) concentrations were declining slower than in other areas. The DX P&T system changes completed in 2016 (Figure 1-3 in Chapter 1) include the following:

- Monitoring well 699-97-61, completed in the first water-bearing unit of the RUM, was connected to the DX system as an extraction well in August 2016 to address high Cr(VI) concentrations in RUM in the western area of the Horn. The well operates at an average of 49 L/min (13 gal/min). Concentrations generally declined from 184 µg/L in August to 123 µg/L in December 2016, however, an annual maximum of 196 µg/L was observed in late September.

- Well 199-D8-99 was connected to the DX system as an extraction well in August 2016. This well was one of the original DX system wells and operated as an injection well from December 2010 until August 2015. It was converted from an injection to an extraction well in order to address the potential continuing source in that area and eliminate the potential for diluting higher Cr(VI) concentrations on the northeastern edge of northern 100-D plume. The well operates at an average of 72 L/min (19 gal/min). Cr(VI) concentrations have fluctuated since connection as an extraction well. They initially declined from 49 µg/L in August to 6 µg/L in October, and then increased to 34 µg/L in December 2016.

- Monitoring well 199-D5-108 was connected to the DX system as an injection well in July 2016. The well operates at an average of 55 L/min (15 gal/min) and is intended to increase groundwater movement toward targeted downgradient extraction locations.

- Monitoring well 199-D5-111 was connected to the DX system as an injection well in July 2016. The well operates at an average of 80 L/min (21 gal/min) and is intended to increase groundwater movement toward targeted downgradient extraction locations.

- Injection well 199-D5-42 was disconnected from the DX system and converted to a monitoring well at the end of May 2016. This was done to eliminate potential for diluting Cr(VI) concentrations between the southern and northern 100-D plumes. A Cr(VI) sample taken from well 199-D5-42 in December 2016 (six months after injection stopped) was below the detection limit of 1.5 µg/L.

- Injection well 199-D5-44 was disconnected from the DX system and converted to a monitoring well at the end of May 2016. This was done to reduce the potential for diluting Cr(VI) concentrations between the southern and northern 100-D plumes. A Cr(VI) sample taken from well 199-D5-44 in December 2016 (six months after injection stopped) was below the detection limit of 1.5 µg/L.

- New well 699-90-47B was drilled and connected to the DX system as an injection well in 2016. This well was installed primarily to increase discharge capacity for treated extraction water. The well went into service in July and operates at an average rate of 128 L/min (34 gal/min).

- New well 199-D8-102 was drilled for potential connection to the DX system as an extraction well in 2016. This well was installed in the northern 100-D plume in a location where high Cr(VI) concentrations were expected based on concentrations in neighboring wells (e.g. 199-D8-95 and 199-D8-96). However, Cr(VI) concentrations from samples collected during drilling and after the well was completed ranged from below detection to less than 40 µg/L. Accordingly, well 199-D8-102 was not connected as an extraction well and will be used for monitoring.

The DX P&T system will continue to be optimized using available source area data, groundwater monitoring data, updated contaminant fate and transport modeling results, and extraction/injection well performance data.

2.2.1.2 Treatment System Performance

The DX P&T system operated near full time throughout 2016 (except for short down-times for corrective maintenance). Table 2-2 presents the summary of groundwater extracted, mass removed, and system performance for the DX P&T system. The DX P&T system extracted 1,454 million L (384 million gal) of water in 2016, similar to the volume extracted the previous year. The system removed 59 kg (130 lb) of Cr(VI) during the reporting period, compared to 85 kg (187 lb) the previous year. The mass of Cr(VI) removed each year continues to decrease primarily a result of rapidly declining Cr(VI) concentrations in the high-concentration areas, such as the middle of the 100-D southern plume from removal of source material.

Table 2-2. DX P&T System Operational Parameters and System Performance

Total DX P&T System Processed Groundwater	2015	2016
Cumulative amount of groundwater treated (since December 2010 startup) (million L)	5,780	7,234
Total amount of groundwater treated during CY (million L)	1,482	1,454
Mass of Hexavalent Chromium Removed	**2015**	**2016**
Cumulative amount of Cr(VI) removed (since December 2010 startup) (kg)	1,488	1,547
Total amount of hexavalent chromium removed in CY (kg)	85	59
Summary of Operational Parameters	**2015**	**2016**
Average pumping rate (L/min)	2,818	2,760
Average Cr(VI) influent concentration (μg/L)	53.3	36.8
Average Cr(VI) effluent concentration (μg/L)	<2	<2
Removal efficiency (% by mass)	96.4	95.6
Waste generation (m^3)	3.6	7.5
Regenerated resin Spent resin disposed (m^3)	21.7[a]	0
New resin installed (m^3)	8.8[b]	0
Number of resin vessel change-outs	3	0
Summary of Other COCs Detected in Effluent		
Average tritium concentration (pCi/L)	2,193	1,830
Average nitrate concentration (μg/L)	16,841	23,900
Average strontium-90 concentration (pCi/L)	0.8	1.0
Average total chromium concentration (μg/L)	4.0	6.2

Table 2-2. DX P&T System Operational Parameters and System Performance

Summary of Operational and System Availability	2015	2016
Total possible run-time (hours)	8,760	8,784
Total time online (hours)	8,686	8,678
Total availability (%)[c]	99.2	98.8

a. Volume represents the total waste container volumes disposed containing resin. Actual resin volume disposed was 13.2 m^3.

b. New resin was installed in the first vessel of four IX trains, completing the change out started in 2014.

c. Total availability [(total time online) ÷ (total possible run-time)].

Cr(VI) = hexavalent chromium

CY = calendar year

The influent and effluent concentrations for the treatment systems are shown in Figure 2-10. The average influent Cr(VI) concentration in 2016 was 36.8 µg/L, a decline from the previous year's average of 53.3 µg/L. The effluent concentration was usually below the laboratory detection limit for 2016, with a maximum reported value of 6 µg/L. The average reported effluent concentration was less than 2 µg/L. The average removal efficiency for 2016 was 96 percent, and the system operated at an average rate of 2,760 L/min (729 gal/min). The influent concentration predominantly reflects the concentrations from extraction wells 199-D5-34 and 199-D5-104, which extract from the southern 100-D plume hot spot. Well 199-D8-95 is located in the high-concentration area of the northern 100-D plume and also contributes a substantial amount to the DX influent concentrations. The overall declining influent concentration trend in both the southern and northing 100-D plumes is a result of significant mass removal from source sites in that area as discussed further in Section 2.2.3.2.

Figure 2-11 shows the system availability for the reporting period. The system operated 99 percent of the time in 2016, with short downtimes for corrective maintenance. As reflected in Figure 2-11, the total flow rate through the DX P&T system (in terms of percentage of system capacity) is reduced slightly during periods of system and well maintenance and reconfiguration of piping.

Table 2-3 presents the pumping flow rates and total run-time for the extraction and injection wells currently active in the DX P&T system. The flow rate was calculated by dividing the total volume extracted for the period by the hours of pumping. Figure 2-12 shows the hydrograph for the Columbia River at the 100-D and 100-H Areas. Operational downtime of extraction and injection wells due to downtime (e.g., low water in wells during low river stage, repair, and/or maintenance) is reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction well.

Several wells had low operational run-time percentages during 2016. Wells 199-D4-39, 199-D4-83, 199-D4-96, 199-D5-20, and 199-D8-73 had low run times (less than 70 percent) due primarily to low water levels within the wells. These wells are located near the shoreline and are responsive to changes in river stage. The run time for wells added to the system in 2016 was also low, since these wells were not operational for the entire year. A list of the new wells is provided in Section 2.2.1.1. Injection wells 199-D2-12, 199-D2-10, 199-D8-94, and 199-D-93, which have limited injection capacity at high river stage, are out of service.

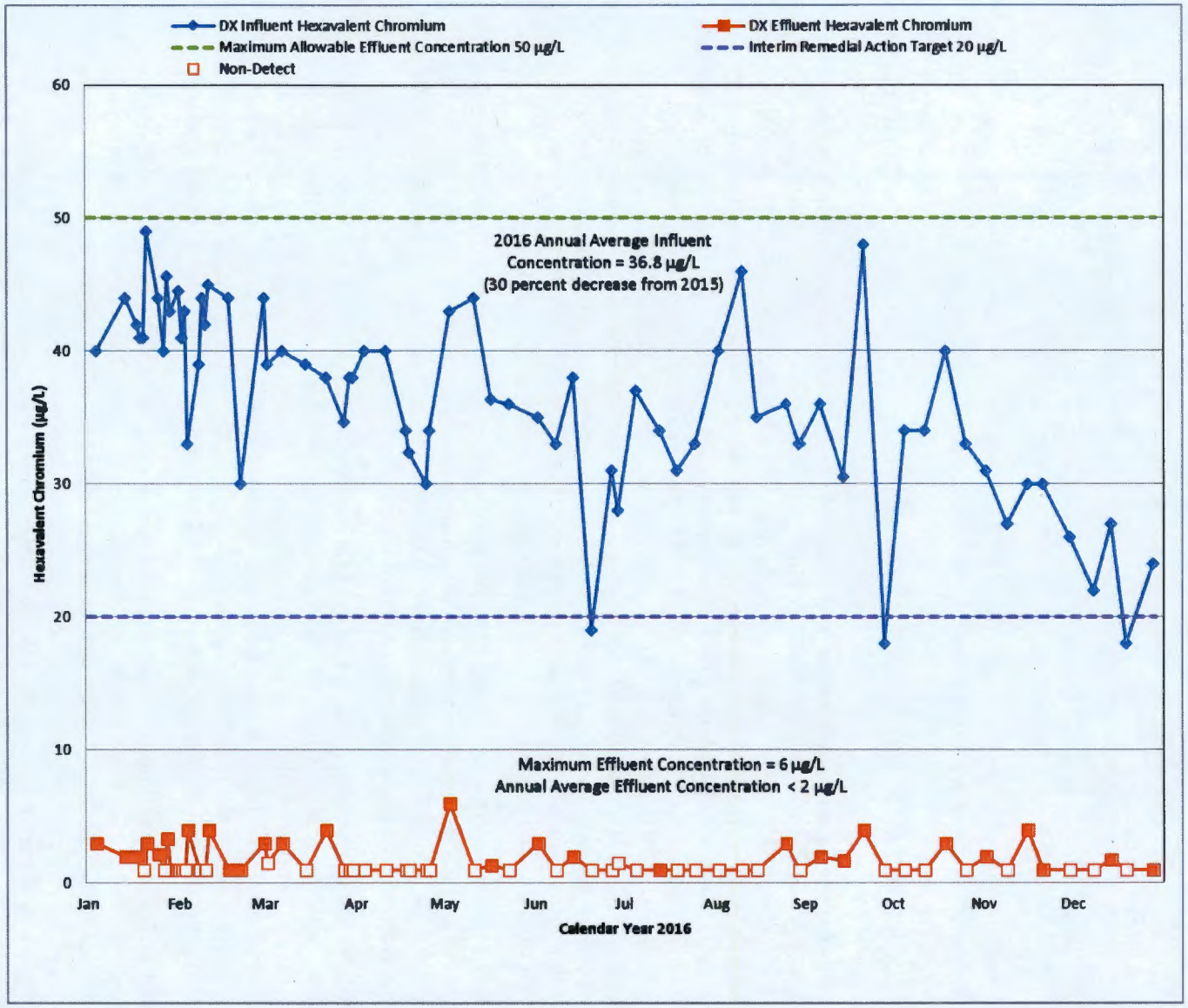

Figure 2-10. Influent/Effluent Concentrations for the DX P&T System

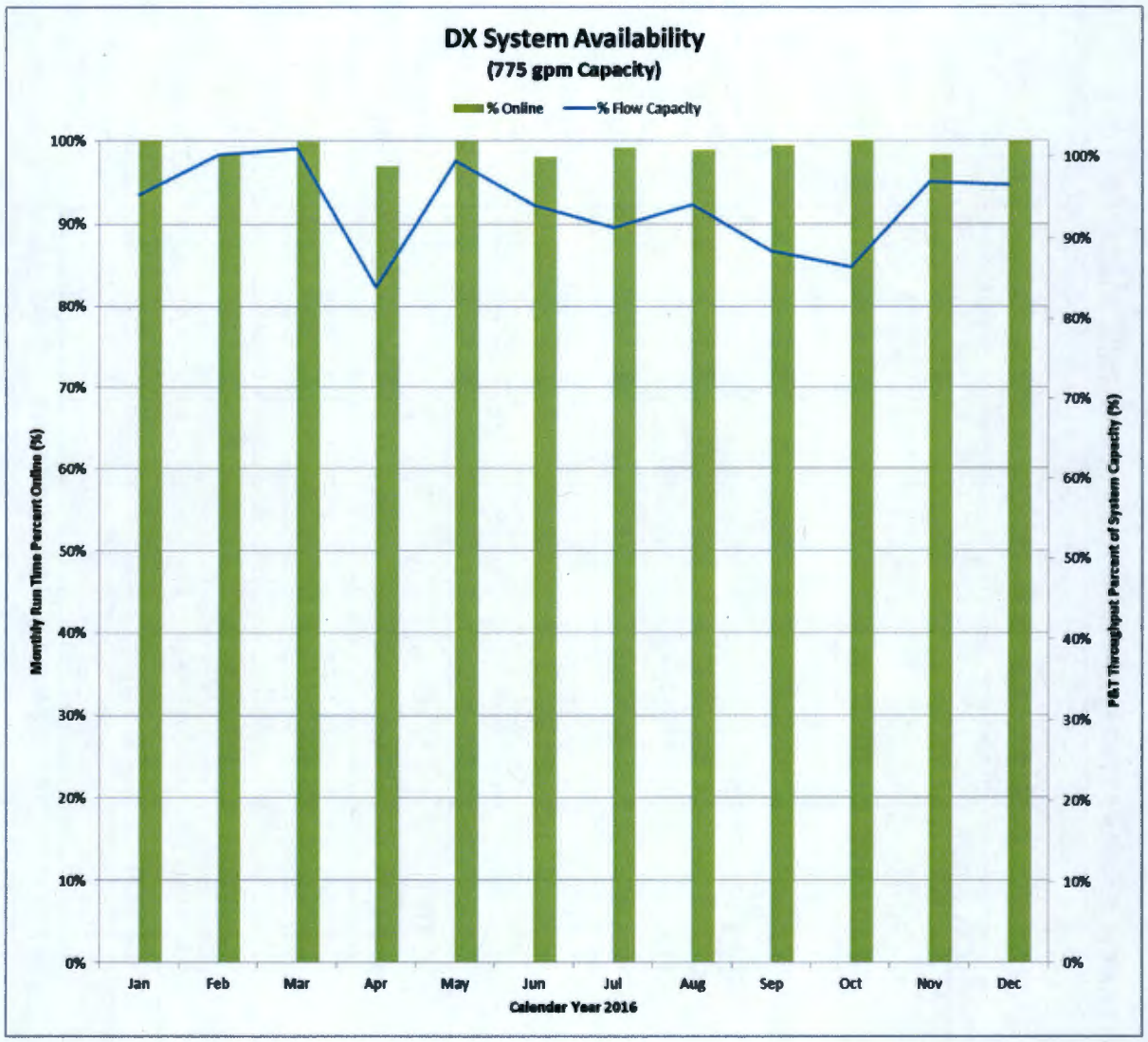

Figure 2-11. System Availability for the DX P&T System

Table 2-3. Flow Rates and Total Run-Times for DX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2016	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
B8989	199-D4-38	ME01	29 (7.7)	29.6 (7.8)	6,480	74	Extraction
B8990	199-D4-39	ME02	39.2 (10.4)	35.7 (9.4)	5,472	62	Extraction
C3315	199-D4-83	ME03	43.3 (11.4)	37.5 (9.9)	5,808	66	Extraction
C3316	199-D4-84	ME04	26.5 (7)	31.9 (8.4)	6,840	78	Extraction
C3317	199-D4-85	ME05	55.6 (14.7)	55.8 (14.7)	7,632	87	Extraction
C7083	199-D4-95	ME06	86.8 (22.9)	80.9 (21.4)	8,280	94	Extraction
C7084	199-D4-96	ME07	37.8 (10)	41.7 (11)	5,016	57	Extraction
C7085	199-D4-97	ME08	45.3 (12)	44.4 (11.7)	8,784	100	Extraction
C7086	199-D4-98	ME09	39.8 (10.5)	50.8 (13.4)	6,864	78	Extraction
C7087	199-D4-99	ME10	36.6 (9.7)	41.3 (10.9)	7,224	82	Extraction
C7580	199-D4-101	ME11	32.3 (8.5)	41.4 (10.9)	8,784	100	Extraction
C7583	199-D5-101	ME12	59.5 (15.7)	67.6 (17.8)	7,968	91	Extraction
C7591	199-D5-127	ME13	63.9 (16.9)	54.5 (14.4)	7,440	85	Extraction
C5400	199-D5-104	ME14	91.5 (24.2)	91.5 (24.2)	8,736	99	Extraction
A4581	199-D8-53	ME21	69.9 (18.5)	75.8 (20)	8,256	94	Extraction
A4584	199-D8-55	ME22	12.4 (3.3)	20.6 (5.4)	6,192	70	Extraction
B2773	199-D8-69	ME23	71.4 (18.8)	59.9 (15.8)	8,352	95	Extraction
C7593[b]	199-D8-99	ME24	70.5 (18.6)	8.5 (2.2)	3,696	42	Extraction
C8794[c]	699-97-61	ME25	51.2 (13.5)	2.8 (0.7)	3,696	42	Extraction

Table 2-3. Flow Rates and Total Run-Times for DX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2016	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
B2772	199-D8-68	ME26	161 (42.5)	184.1 (48.6)	8,784	100	Extraction
C7092	199-D8-90	ME27	64.5 (17)	45.5 (12)	8,352	95	Extraction
C7093	199-D8-91	ME28	88.2 (23.3)	77.2 (20.4)	8736	99	Extraction
C7582	199-D8-97	ME29	89.6 (23.7)	92.3 (24.4)	8,784	100	Extraction
C7589	199-D8-95	ME30	26.4 (7)	28.8 (7.6)	8,784	100	Extraction
C7590	199-D5-130	ME31	27.4 (7.2)	33.2 (8.8)	6,960	79	Extraction
C7599	199-D7-3	ME32	66.8 (17.6)	39.5 (10.4)	7,896	90	Extraction
C7601	199-D5-131	ME33	71.1 (18.8)	69.5 (18.4)	7,872	90	Extraction
C7602	199-D8-98	ME34	71.5 (18.9)	70.3 (18.6)	8,784	100	Extraction
C7603	199-D8-96	ME35	91.7 (24.2)	79.8 (21.1)	8,184	93	Extraction
C7611	199-D7-6	ME36	63.8 (16.8)	40.4 (10.7)	8,352	95	Extraction
C7610	199-H1-5	ME37	77 (20.3)	74 (19.5)	8,784	100	Extraction
C7609	199-H4-82	ME38	90.4 (23.9)	85.1 (22.5)	8,784	100	Extraction
C7596	199-H4-81	ME39	60.9 (16.1)	55.4 (14.6)	8,784	100	Extraction
C7595	199-H4-80	ME40	63.8 (16.9)	62.9 (16.6)	8,784	100	Extraction
C9377	199-D5-159	ME41	61.4 (16.2)	143.5 (37.9)	8,664	99	Extraction
A4577	199-D5-20	ME42	6 (1.6)	19.1 (5)	3,240	37	Extraction
C4185	199-D5-32	ME43	60.2 (15.9)	66 (17.4)	8,784	100	Extraction
B8748	199-D5-39	ME44	94 (24.8)	89.6 (23.7)	8,784	100	Extraction

Table 2-3. Flow Rates and Total Run-Times for DX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2016	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C4583	199-D5-92	ME45	42.8 (11.3)	38.9 (10.3)	6,816	78	Extraction
C4536	199-D8-88	ME46	14.6 (3.9)	13.9 (3.7)	8,352	95	Extraction
C4474	199-D8-73	ME47	8.3 (2.2)	14.8 (3.9)	2,928	33	Extraction
C7091	199-D8-89	ME48	40 (10.6)	65.1 (17.2)	8,712	99	Extraction
B8985	199-D4-34	ME49	36.8 (9.7)	36.5 (9.6)	8,736	99	Extraction
B8072	199-D4-14	ME50	40.2 (10.6)	40.2 (10.6)	8,688	99	Extraction
C8726	199-D5-146	ME51	98.7 (26.1)	95.3 (25.2)	8,784	100	Extraction
C8789	199-D5-153	ME52	97.7 (25.8)	89 (23.5)	8,784	100	Extraction
C8790	199-D5-154	ME53	148.6 (39.2)	151.5 (40)	8,784	100	Extraction
C4187	199-D5-34	ME54	116.3 (30.7)	134.3 (35.5)	8,160	93	Extraction
B8754[d]	199-D5-44	MJ01	0 (0)	58.3 (15.4)	3,528	40	Injection
B8752[d]	199-D5-42	MJ02	0 (0)	50.7 (13.4)	3,528	40	Injection
C7600	199-D5-129	MJ03	487 (128.6)	555.9 (146.8)	8,784	100	Injection
C7612	199-D5-128	MJ04	269.7 (71.2)	254 (67.1)	8,784	100	Injection
C8728	199-D5-148	MJ05	509 (134.4)	557.7 (147.2)	8,784	100	Injection
C5581[e]	199-D5-111	MJ06	84.3 (22.3)	62.5 (16.5)	4,104	47	Injection
C5578[e]	199-D5-108	MJ07	54.7 (14.5)	81.2 (21.4)	4,104	47	Injection
C8929	699-93-48C	MJ16	187.2 (49.4)	256.9 (67.8)	8,784	100	Injection
C7090[f]	199-D2-12	MJ17	0 (0)	0 (0)	0	0	Injection

Table 2-3. Flow Rates and Total Run-Times for DX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2016	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C7089[f]	199-D2-10	MJ18	0 (0)	0 (0)	0	0	Injection
C7096[f]	199-D8-94	MJ19	0 (0)	0 (0)	0	0	Injection
C7095[f]	199-D8-93	MJ20	0 (0)	0 (0)	0	0	Injection
C7608	199-D7-5	MJ21	200.4 (52.9)	306.8 (81)	8,784	100	Injection
C7607	199-D6-2	MJ22	148.1 (39.1)	91.2 (24.1)	8,568	98	Injection
C7594	199-D7-4	MJ23	528.6 (139.6)	524.6 (138.5)	8,712	99	Injection
C7592	199-D6-1	MJ25	110.5 (29.2)	89.4 (23.6)	8,784	100	Injection
C9584[g]	699-90-47B	MJ26	151.6 (40)	134.6 (35.5)	3,744	43	Injection

Note: For purposes of deriving average flow rates for low river and high river stage, flow rates from mid-August through early-December were averaged for low river, and flow rates from April through July were averaged for high river.

a. Percentage total run-time is calculated by [(days well in operation) ÷ (number of days in the CY)].

b. Converted from injection well to extraction well in August 2016.

c. Converted RUM monitoring well to extraction well in August 2016.

d. Disconnected as injection well in June 2016.

e. Converted to injection well in August 2016.

f. Flows at well are minimal and not used for injection in 2016.

g. Added as new injection well in August 2016.

ID = identification

PLC = programmable logic controller

RUM = Ringold Formation upper mud unit

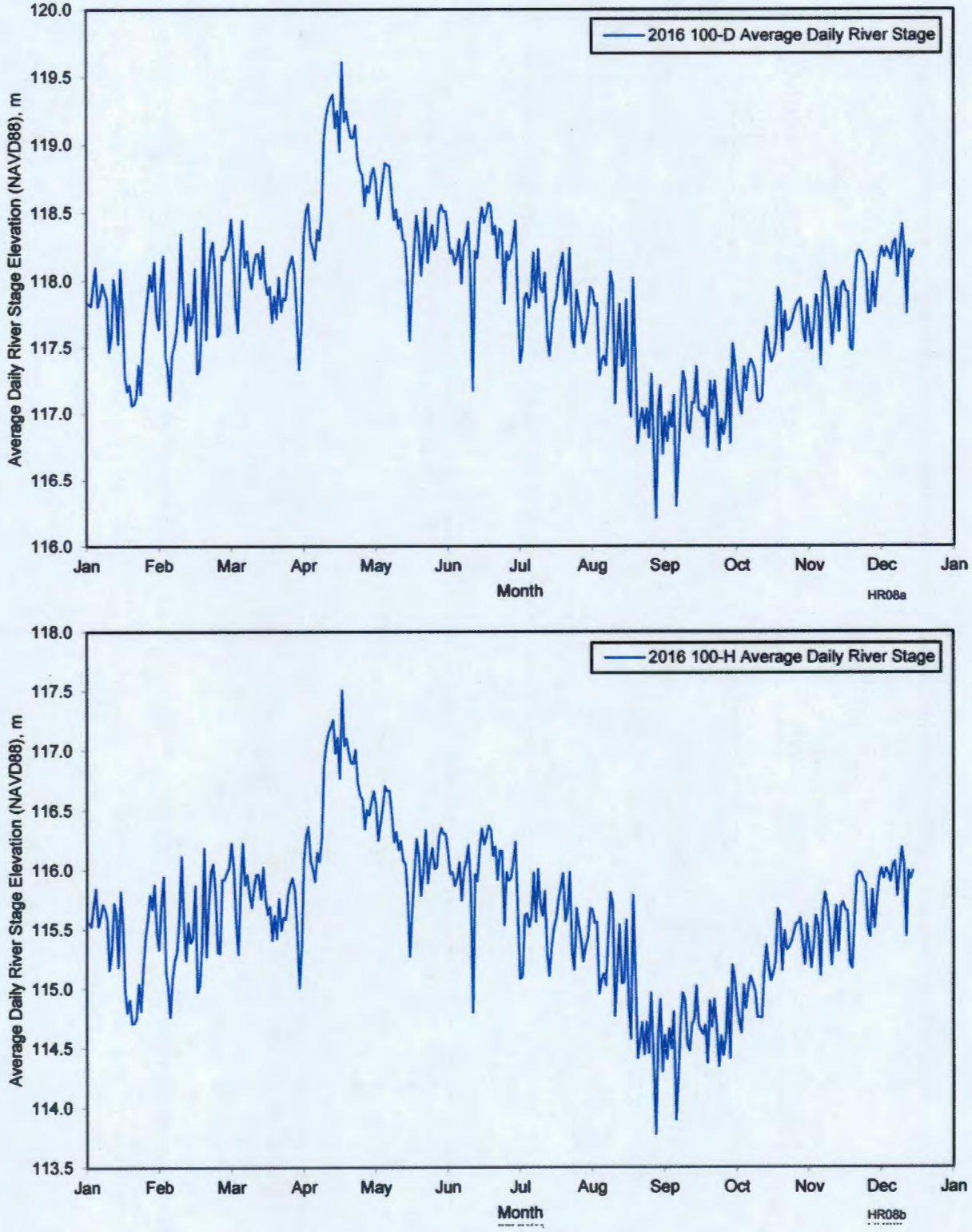

Figure 2-12. River Stage Hydrograph at 100-D and 100-H

2.2.2 HX Pump and Treat System

The HX P&T system (Figure 2-13) became fully operational in 2011. The design of the HX P&T system is described in SGW-43616, *Functional Design Criteria for the 100-HX Pump and Treat System*. During 2014 and 2015, the system capacity was upgraded from the original design of 3,000 L/min (800 gal/min) to 3,407 L/min (900 gal/min). Overall, however, the water available in the aquifer limits the throughput volume. The design and operational philosophy optimizes containment along the river, and containment and removal of contaminant mass in areas with higher contamination. Since startup of the HX P&T system in 2011 to the end of 2016, the system has treated over 6,300 million L (1,678 million gal) of groundwater and has removed 144 kg (318 lb) of Cr(VI). The HX P&T system included 38 extraction wells and 17 injection wells (Figure 2-14) in 2016.

Similar to the 100-DX P&T, ResinTech SIR-700 is used to treat the Cr(VI) as it flows through tanks in the HX treatment facility. The resin capacity at HX has not been exceeded and replacement of resin in the IX vessels has not been necessary since startup of the HX P&T.

Figure 2-13. Aerial View of the HX P&T System

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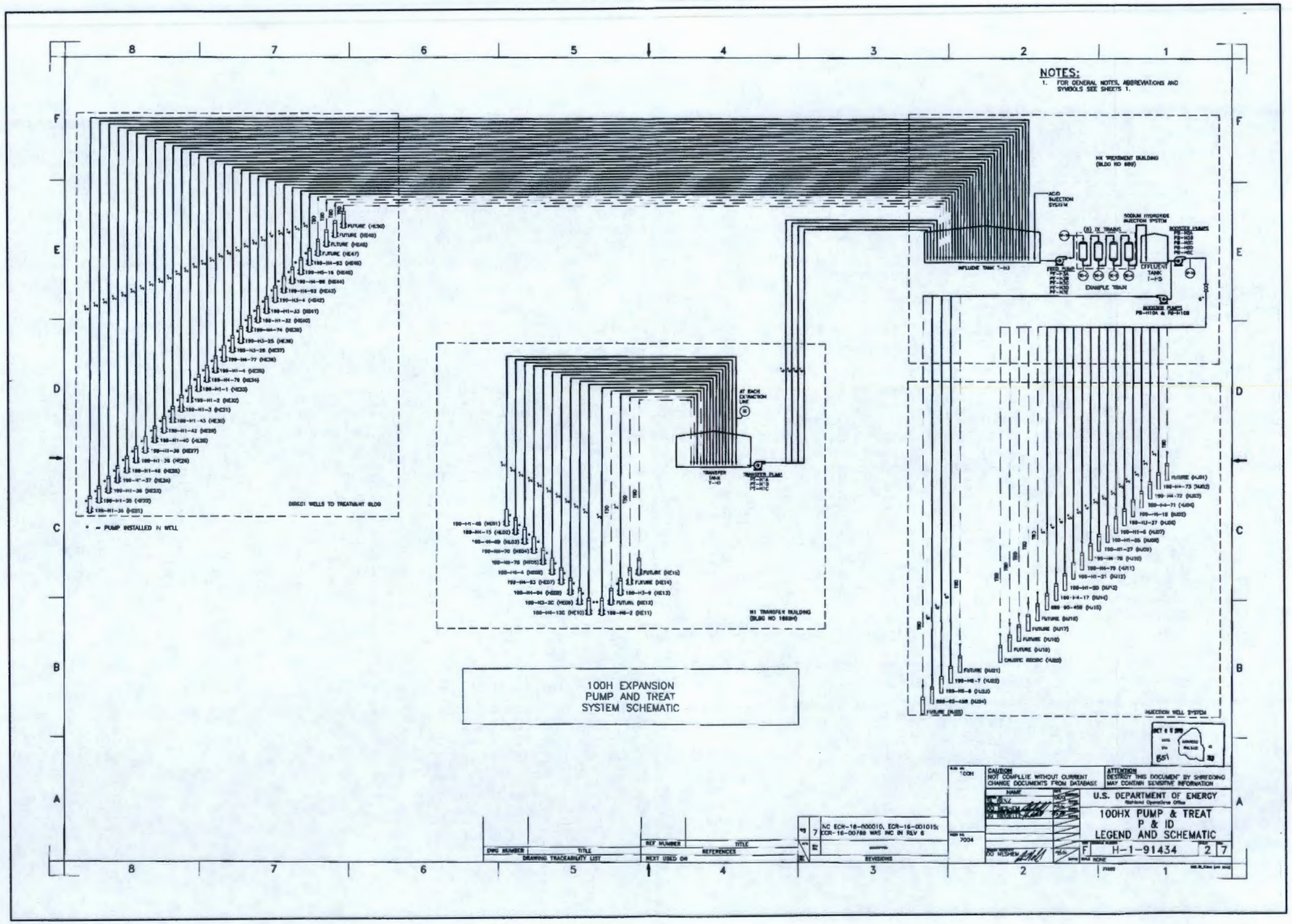

Figure 2-14. HX P&T System Schematic

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2.2.2.1 HX Pump and Treat System Configuration and Changes

As with DX, the 2015 capture analysis was evaluated to determine system modifications needed during 2016. A summary of the 2016 system modifications and the effect of those changes to the plume are discussed below. Multiple well realignments and system additions were made during 2016.
Well realignments are focused on the following goals:

- Decreasing the extent of the Cr(VI) plume area
- Increasing extraction in areas with higher Cr(VI) concentrations
- Allowing rebound in the reactor area in order to determine if residual sources are present

Realignments included leaving several extraction and injection wells out of service within the reactor area (similar to 2015) and connecting additional extraction and injection wells. The HX P&T system changes in 2016 (Figure 1-3 in Chapter 1) included the following:

- Well 199-H1-46, installed in 2015, was connected as an extraction well in 2016 to increase groundwater extraction in the northeastern Horn area where the aquifer is thin and higher Cr(VI) is migrating toward river. This well went into service in June 2016 and has operated at an average extraction rate of 22 L/min (5.8 gal/min). Cr(VI) concentrations fluctuated seasonally from 48 µg/L in June to 59 µg/L in November, and then decreasing in December to 39 µg/L.

- Well 199-H4-92, installed in 2015, was connected as an extraction well in June 2016 to increase groundwater extraction in the southern Horn area and contract the area of the Cr(VI) plume. The average extraction rate following connection in June has been 90 L/min (24 gal/min). Cr(VI) concentrations averaged 12 µg/L during 2016.

- Well 199-H5-16, installed in 2015, was connected in June 2016 as an extraction well to increase extraction along southern end of 100-H for plume control. This well has a high yield, and extraction rates averaged 190 L/min (50 gal/min) since connection. Concentrations of Cr(VI) fluctuated between 7 and 19 µg/L during 2016.

- New well 699-90-45B was installed and connected to the HX P&T system in 2016 as an injection well. The well is located in the far southern 100-H area and will increase the operational capacity of the HX system. Flow rates in this well since injection started in September 2016 averaged 83 L/min (22 gal/min).

- A larger pump (and motor) was installed in well 199-H1-45 to allow for an increased extraction rate. Cr(VI) concentrations in well 199-H1-45 during 2016 ranged from 35 to 59 µg/L. The new pump was installed in June 2016 and flows increased from 102 L/min (27 gal/min) to 136 L/min (36 gal/min). The size of the conveyance line will be increased in 2017 from 5.1 cm (2 in.) to 7.6 cm (3 in.) diameter to accommodate additional extraction rate increases.

2.2.2.2 Treatment System Performance

The HX P&T system extracted 1,149 million L (303 million gal) of groundwater from the 100-H Area in 2016, similar to annual water volumes treated since 2012. The system removed 25.7 kg (57 lb) of Cr(VI) during the reporting period, compared to 25 kg (55 lb) in 2015. The mass removed during 2016 was essentially the same as the amount removed in 2015. A summary of operational parameters and total system performance for the HX P&T system is presented in Table 2-4.

Table 2-4. HX P&T System Operational Parameters and System Performance for 2016

Total HX P&T System Processed Groundwater	2015	2016
Cumulative amount of groundwater treated (since September 2011 startup) (million L)	5,204	6,353
Total amount of groundwater treated in CY (million L)	1,123	1,149
Mass of Hexavalent Chromium Removed	**2015**	**2016**
Cumulative amount of Cr(VI) removed (since September 2011 startup) (kg)	118.0	143.8
Total amount of Cr(VI) removed in CY (kg)	24.9	25.7
Summary of Operational Parameters	**2015**	**2016**
Average pumping rate (L/min)	2,138	2,178
Average Cr(VI) influent concentration (μg/L)	23.3	22.7
Average Cr(VI) effluent concentration (μg/L)	<2	<2
Removal efficiency (% by mass)	95.0	95.1
Waste generation (m^3)	3.6	3.6
Spent resin disposed (m^3)	0	0
New resin installed (m^3)	0	0
Number of resin vessel changeouts	0	0
Summary of Other COCs Detected in Effluent		
Average tritium concentration (pCi/L)	1,050	1,110
Average nitrate concentration (μg/L)	14,400	14,500
Average strontium-90 concentration (pCi/L)	1.0	1.2
Average total chromium concentration (μg/L)	1.6	3.7
Summary of Operational and System Availability	**2015**	**2016**
Total possible run-time (hours)	8,760	8,784
Total time online (hours)	8,633	8,739
Total availability (%)*	98.6%	99.5%

*Total availability [(total time online) ÷ (total possible run-time)].

Cr(VI) = hexavalent chromium

CY = calendar year

The average influent Cr(VI) concentration in 2016 was 22.7 µg/L. The average effluent concentration for the reporting period was less than 2 µg/L. The influent and effluent concentrations for the treatment systems are shown in Figure 2-15. The average removal efficiency for 2016 was 95.1 percent, essentially the same as in 2015. The HX system operated at an average rate of 2,178 L/min (575 gal/min) during 2016, similar to 2015. Slightly higher influent concentrations were observed during the winter and fall; this seasonal fluctuation is reflective of the decreased pumping rates at extraction wells closer to the river shoreline as water levels in the wells decline. In comparison, pumping rates from extraction wells 199-H3-2C and 199-H4-12C, which extract groundwater from the first water-bearing unit in the RUM, have relatively constant pumping rates and high Cr(VI) concentrations.

A series of aquifer tests were performed in 2016 in five RUM wells in the 100-H Area (199-H3-10, 199-H3-2C, 199-H4-90, 199-H3-9, and 199-H4-12C). Results from these tests and analyses are being evaluated to help determine the hydraulic connectivity between RUM wells and connections between the RUM aquifer and the overlying unconfined aquifer and Columbia River. Additionally, this study is expected to provide quantitative aquifer hydraulic properties (e.g., transmissivity and storativity) for the first water-bearing unit of the RUM. Results will be evaluated and published in 2017.

Figure 2-16 shows the system availability for the reporting period. The system operated at 99.5 percent of the time in 2016, with short downtimes for corrective maintenance. As reflected in Figure 2-16, the total flow rate through the HX P&T system (in terms of percentage of system capacity) was reduced during system outages, as well as during periods of low river stage, because pumping rates are reduced at extraction wells closer to the river shoreline as water levels in the wells decline with river stage.

Along the northern and eastern portions of the Horn, as well as in the 100-H Area, the aquifer thickness ranges from about 0 to 6 m (0 to 20 ft), depending on the river stage. There is often less than 3 m (10 ft) of available water in the extraction wells during much of the year. As a result, pumping cannot be sustained from these wells during low river stage since an insufficient amount of water is present over the top of the submersible pump to allow for pump operation. Modifications to the system such as alternative well construction (e.g., using horizontal wells or larger diameter wells) and manipulation of the groundwater flow regime by using injection water to push contaminants toward extraction wells are being evaluated as an overall strategy to address low water periods.

Table 2-5 presents the pumping flow rates and total run-time for the extraction and injection wells currently active in the HX P&T system. The flow rate was calculated by dividing the total volume pumped by the hours of pumping. Operational downtime of extraction and injection wells (e.g., low water in wells during low river stage, repair, and/or maintenance) is reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction well.

The following extraction wells had low (less than 70 percent) operational run-time percentages in 2016: 199-H1-32, 199-H1-33, 199-H1-37, 199-H1-38, 199-H1-39, 199-H1-4, 199-H1-40, and 199-H3-26. These wells are located in areas that have a thin aquifer, low flows, and periods of nonoperation during low river stage. The low run times are typical in these wells. Other wells along the river also experienced periods of low flow rates, but the pumps were operating more than 75 percent of the time.

Well 199-H1-3 (removed from service during 2014 due to low production rates) remained off in 2016. Well 199-H4-76, located in the Horn in an area with a thicker aquifer, also experienced reduced operational frequency during the year, primarily related to river stage. The operational run-times for injection wells 199-H4-71, 199-H4-72, and 199-H4-73, located in the H Reactor area, were reduced or remained off, along with other extraction wells in that area (e.g., 199-H4-18 and 199-H6-2), to allow for potential rebound in the localized area and determine if residual sources are present.

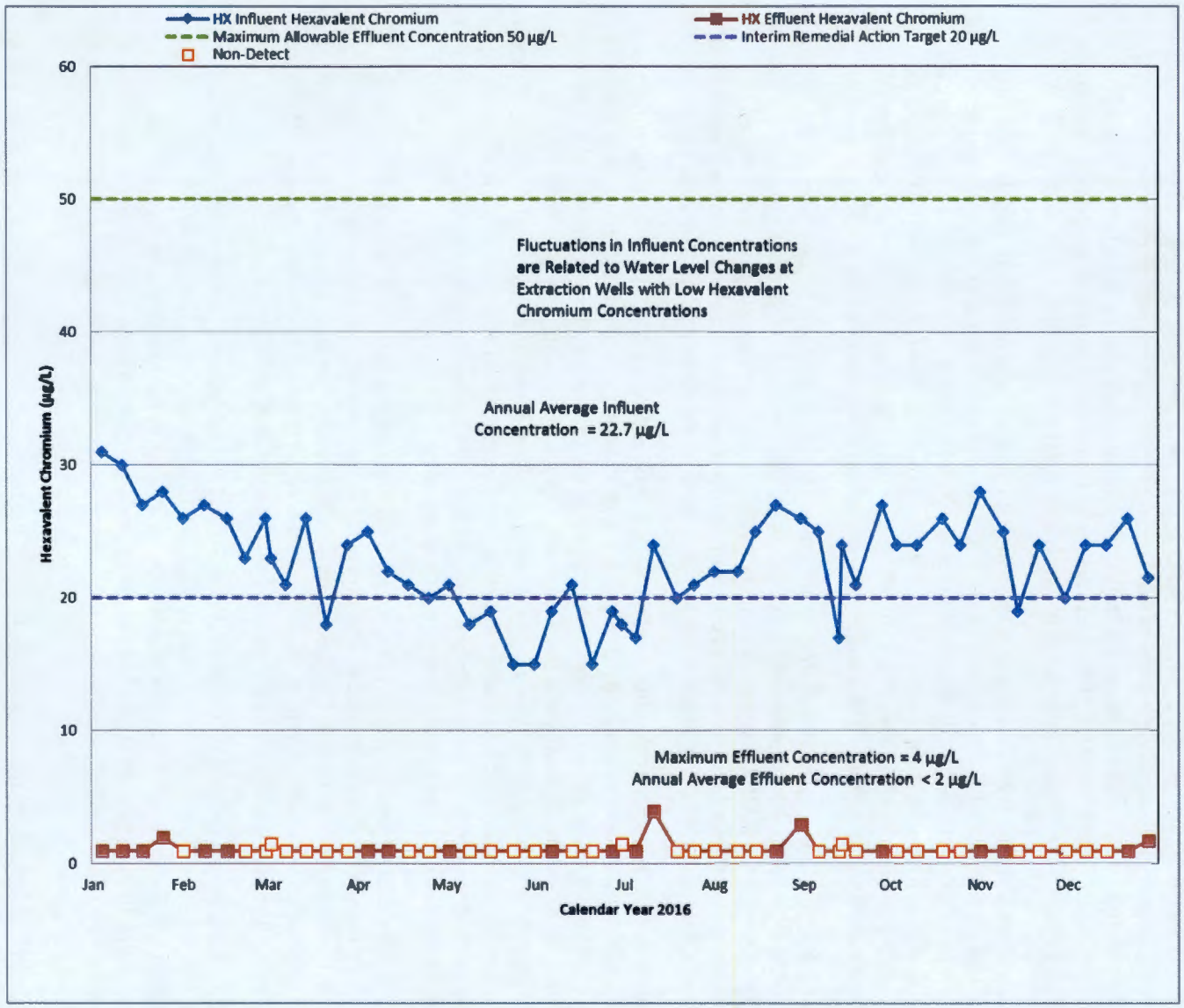

Figure 2-15. Influent/Effluent Concentrations for the HX P&T System

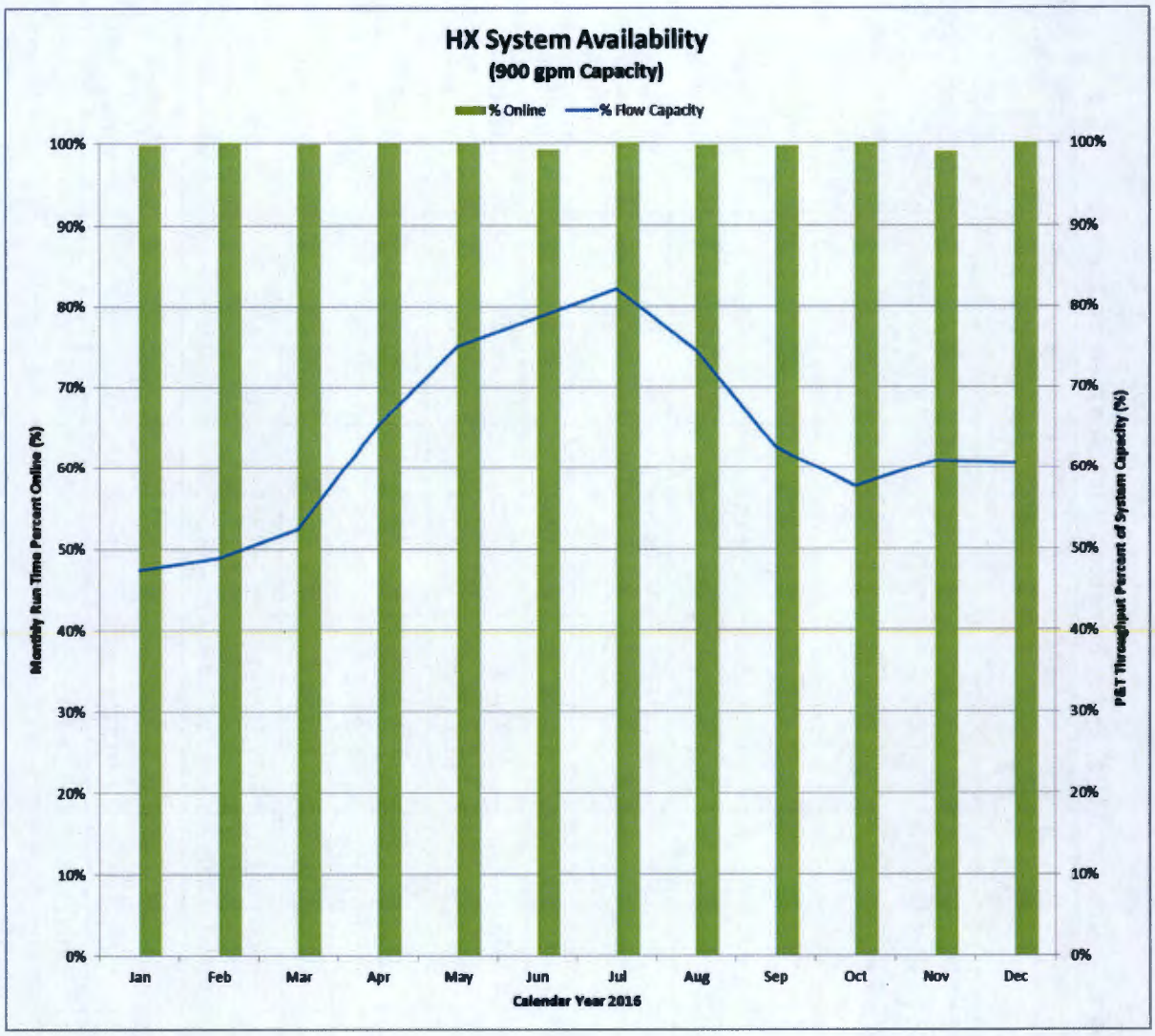

Figure 2-16. System Availability for the HX P&T System

Table 2-5. Flow Rates and Total Run-Times for HX P&T System Extraction and Injection Wells for 2016

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2015	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C7477	199-H1-45	HE01	132 (34.9)	105 (27.7)	8,568	98	Extraction
A4621	199-H4-15A	HE02	61.6 (16.3)	100.2 (26.4)	8,664	99	Extraction
C7485	199-H4-69	HE03	45.8 (12.1)	61 (16.1)	8,664	99	Extraction
C7483	199-H4-70	HE04	20 (5.3)	40.2 (10.6)	8,664	99	Extraction
C7597	199-H4-75	HE05	42.4 (11.2)	53.9 (14.2)	8,784	100	Extraction
A4630	199-H4-4	HE06	17 (4.5)	30.9 (8.2)	6,864	78	Extraction
B2776	199-H4-63	HE07	100.6 (26.6)	91.8 (24.2)	8,664	99	Extraction
B2777	199-H4-64	HE08	33 (8.7)	60.9 (16.1)	7,728	88	Extraction
A4613	199-H3-2C	HE09	99.4 (26.2)	109.6 (28.9)	8,208	93	Extraction
A4618	199-H4-12C	HE10	112.1 (29.6)	90 (23.8)	8,088	92	Extraction
C7489	199-H6-2[e]	HE11	0 (0)	3.8 (1)	360	4	Extraction
C7639	199-H3-9	HE13	45.1 (11.9)	41.7 (11)	8,040	92	Extraction
C7108	199-H1-34	HE21	36.5 (9.6)	77.3 (20.4)	8,784	100	Extraction
C7106	199-H1-35	HE22	60.1 (15.9)	100.6 (26.5)	8,784	100	Extraction
C7102	199-H1-36	HE23	13.6 (3.6)	28.7 (7.6)	8,712	99	Extraction
C7099	199-H1-37	HE24	15.1 (4)	90.5 (23.9)	5,088	58	Extraction
C9486[b]	199-H1-46	HE25	21.8 (5.8)	31.4 (8.3)	4,512	51	Extraction

Table 2-5. Flow Rates and Total Run-Times for HX P&T System Extraction and Injection Wells for 2016

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2015	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C7098	199-H1-38	HE26	8.7 (2.3)	30.8 (8.1)	3,936	45	Extraction
C7109	199-H1-39	HE27	0 (0)	64.5 (17)	1,728	20	Extraction
C7104	199-H1-40	HE28	0 (0)	18.7 (4.9)	3,384	39	Extraction
C7107	199-H1-42	HE29	26.3 (7)	44.2 (11.7)	6,456	74	Extraction
C7492	199-H1-43	HE30	67 (17.7)	113.1 (29.8)	8,784	100	Extraction
C7581	199-H1-3[c]	HE31	0 (0)	0 (0)	0	0	Extraction
C7584	199-H1-2	HE32	8.8 (2.3)	12.5 (3.3)	8,640	98	Extraction
C7585	199-H1-1	HE33	100.3 (26.5)	102.8 (27.1)	8,784	100	Extraction
C7587	199-H4-76	HE34	24.7 (6.5)	31.7 (8.4)	5,112	58	Extraction
C7604	199-H1-4	HE35	0 (0)	8.5 (2.2)	4,224	48	Extraction
C7605	199-H4-77	HE36	29 (7.7)	36.1 (9.5)	8,448	96	Extraction
C7115	199-H3-26	HE37	27.2 (7.2)	202.3 (53.4)	2,328	27	Extraction
C7110	199-H3-25	HE38	309.2 (81.6)	304.6 (80.4)	8,784	100	Extraction
C7598	199-H4-74	HE39	16 (4.2)	16.7 (4.4)	2,040	23	Extraction
C7100	199-H1-32	HE40	6.5 (1.7)	22.7 (6)	4,440	51	Extraction
C7105	199-H1-33	HE41	21.2 (5.6)	86.6 (22.9)	5,112	58	Extraction
B2779	199-H3-4	HE42	368.1 (97.2)	355 (93.7)	8,760	100	Extraction

Table 2-5. Flow Rates and Total Run-Times for HX P&T System Extraction and Injection Wells for 2016

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2015	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C8792[b]	199-H4-92	HE43	93.7 (24.7)	96.1 (25.4)	4,824	55	Extraction
C8724	199-H4-86	HE44	63.6 (16.8)	130.5 (34.4)	8,568	98	Extraction
C8948[b]	199-H5-16	HE45	203.3 (53.7)	189.8 (50.1)	4,872	55	Extraction
C8949	199-H4-93	HE46	29.1 (7.7)	30.7 (8.1)	8,016	91	Extraction
C7484	199-H4-73	HJ02	104.7 (27.6)	98.9 (26.1)	3,216	37	Injection
C7488	199-H4-72	HJ03	113.1 (29.9)	101.7 (26.9)	5,640	64	Injection
C7483[c]	199-H4-71[f]	HJ04	0 (0)	0 (0)	24	0	Injection
A4628	199-H4-18	HJ05	56 (14.8)	49.2 (13)	3,216	37	Injection
C7114	199-H3-27	HJ06	67.4 (17.8)	112.4 (29.7)	8,304	95	Injection
C7606	199-H1-6	HJ07	218.6 (57.7)	188.5 (49.8)	8,784	100	Injection
C7478	199-H1-25	HJ08	98.8 (26.1)	162 (42.8)	8,736	99	Injection
C7480	199-H1-27	HJ09	179 (47.3)	137 (36.2)	8,784	100	Injection
C7588	199-H4-78	HJ10	143.8 (38)	274.7 (72.5)	8,784	100	Injection
C7586	199-H4-79	HJ11	39.9 (10.5)	279.3 (73.7)	4,272	49	Injection
C7111	199-H1-21	HJ12	99.5 (26.3)	102.4 (27)	8,736	99	Injection
C7113	199-H1-20	HJ13	105 (27.7)	81.5 (21.5)	8,784	100	Injection
A4627	199-H4-17	HJ14	32.4 (8.5)	31.6 (8.3)	5,784	66	Injection

Table 2-5. Flow Rates and Total Run-Times for HX P&T System Extraction and Injection Wells for 2016

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2015	Total Run-Time[a] (%)	Purpose
			Low River Stage Average	High River Stage Average			
C9585	699-90-45B[g]	HJ15	93.7 (24.7)	0 (0)	2,736	31	Injection
C8947	199-H6-7	HJ22	467.1 (123.3)	409.1 (108)	8,784	100	Injection
C8951	199-H6-8	HJ23	470.4 (124.2)	431.1 (113.8)	8,784	100	Injection
C8950[d]	699-95-45B	HJ24	348.1 (91.9)	420.4 (111)	6,480	74	Injection

Note: For purposes of deriving average flow rates for low river and high river stage, flow rates from mid-August through early-December were averaged for low river, and flow rates from April through July were averaged for high river.

a. Percentage total run-time is calculated by [(days well in operation) ÷ (number of days in the CY)].

b. New well connection in 2015, connected as extraction well in July 2016.

c. Flows at the well are minimal. Well is being re-evaluated for removal from the system. Well 199-H1-3 is not operating.

d. New well connection in 2015, connected as injection well in September 2016.

e. Well 199-H6-2 only ran very briefly in April and May; otherwise, it was not running in 2016.

f. Flows to injection well 199-H4-71 have been turned off to allow for rebound in the reactor area to determine if residual sources are present.

g. New injection well connected in September 2016.

ID = identification

PLC = programmable logic controller

2.2.3 Performance Monitoring

Control of Cr(VI) in groundwater remains the principal objective of the active groundwater interim remedial action at the 100-HR-3 OU. Nitrate, strontium-90, tritium, uranium, and technetium-99 are listed in the interim action ROD for the OU (EPA/ROD/R10-96/134) as contaminants of potential concern and are monitored as part of the remedial action. The ROD acknowledges that other (non-chromium) groundwater contaminants are not treated by the interim action remedy. Sulfate is a contaminant of interest because the secondary DWS (250 mg/L) has previously been exceeded in a limited number of wells, primarily due to sodium dithionite solution injections during the ISRM barrier installation. Sulfate has also been detected at increasing levels in monitoring wells located near the DX P&T injection wells, as discussed in Section 2.2.3.3. The increases in sulfate concentrations have not occurred in the 100-H Area, primarily because HX has required less sulfuric acid for pH adjustment as a result of lower Cr(VI) influent concentrations.

Contaminant concentration data are collected each year from 100-HR-3 OU compliance wells, monitoring and extraction wells, and aquifer tubes within the OU. The sampling data are used to update the status of the plumes and to 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 natural groundwater flow is directed toward the river. Tables 2-6 through 2-8 depict the highest 2016 concentrations for Cr(VI), total chromium, nitrate, strontium-90, tritium, technetium-99, sulfate, uranium, gross alpha, and gross beta emitters detected in the 100-D Area (Table 2-6), 100-H Area, and Horn area (Table 2-7) wells, aquifer tubes, and wells completed in the first water-bearing unit of the RUM (Table 2-8). This report focuses on evaluating the analytical results for Cr(VI) being remediated through the interim action P&T systems. Further summary and analysis of the other COCs and contaminants of interest are presented in the annual groundwater monitoring report (Chapter 4 of DOE/RL-2016-67).

Tables 2-9 through 2-11 present the high and low river stage 2016 monitoring results for Cr(VI). P&T system performance assessment addresses longer term changes in Cr(VI) concentrations at selected monitoring and extraction wells in the 100-HR-3 OU. Figures 2-17 and 2-18 illustrate the Cr(VI) plumes during periods of low river-stage and high river-stage in 2016 for the 100-D and 100-H Areas, respectively. The contaminant plume maps presented in this report are based on average results for samples collected either during the low river or high river stage during 2016 for each well shown. During high river-stage periods, many of the aquifer tubes become submerged and unable to sample or samples would be mostly diluted with river water, so most aquifer tubes in the 100-HR-3 OU are usually only sampled during low river stage. During 2016, however, a small subset of aquifer tubes was sampled during high river-stage conditions in late May. The selected aquifer tubes were those with historically higher concentrations and those with a high probability of being accessible during a higher river stage.

In locations where aquifer tubes were sampled during the high river-stage period, those Cr(VI) values were used for plume map development. In locations where aquifer tubes were sampled only during low river stage, the Cr(VI) values were used for both high and low river-stage plume map development (Figures 2-17 and 2-18). Methods for generating contaminant plume representation are described in ECF-Hanford-16-0061, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2015 Hanford Site Groundwater Monitoring Report.*

The following subsections present the contaminant monitoring results. Further summary and analysis of contaminants and co-contaminants are presented in the annual groundwater monitoring report (Chapter 4 of DOE/RL-2016-67).

Table 2-6. 2016 Maximum Contaminant and Co-Contaminant Concentrations for 100-D Area

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well/Aquifer Tube Name
Hexavalent chromium	640	F	11/14/2016	199-D5-103
Hexavalent chromium	630	UF	11/14/2016	199-D5-103
Total chromium	185	F	10/26/2016	199-D8-95
Total chromium	190	UF	2/29/2016	199-D5-34
Nitrate	44,300	UF	10/25/2016	199-D4-96
Strontium-90	30.1	UF	2/10/2016	199-D5-132
Tritium	11,300	UF	8/16/2016	199-D4-103
Technetium-99*				—
Sulfate	240,000	UF	2/10/2016	199-D5-133
Uranium	6.7	F	4/28/2016	699-97-61
Uranium	82	UF	6/24/2016	199-D5-125
Gross beta	74.4	UF	11/11/2016	199-D4-19
Gross alpha	7.8	UF	10/11/2016	199-D8-102

Note: This table considers those wells included in the 100-D groundwater area of interest, with the exception of those wells screened in the Ringold Formation upper mud unit (199-D5-134, 199-D5-141, 199-D8-54B, 699-97-61, and 699-97-48C).

*Analytical results for all collected samples analyzed for technetium-99 in 2016 were non-detect.

Table 2-7. 2016 Maximum Contaminant and Co-Contaminant Concentrations for 100-H and Horn Area

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well/Aquifer Tube Name
Hexavalent chromium	222	F	6/7/2016	699-90-45B
Hexavalent chromium	100	UF	2/8/2016	199-H1-7
Total chromium	75	F	8/5/2016	199-H4-84
Total chromium	178	UF	10/11/2016	199-H4-84
Nitrate	66,400	UF	5/10/2016	199-H4-84
Strontium-90	19.7	UF	11/18/2016	199-H4-83
Tritium	1,410	UF	6/29/2016	199-H1-46
Technetium-99	84.3	UF	8/5/2016	199-H4-84
Sulfate	140,000	UF	5/11/2016	199-H3-11
Uranium	50	F	8/5/2016	199-H4-84
Uranium	50	UF	8/5/2016	199-H4-84
Gross beta	67.4	UF	10/11/2016	199-H4-84
Gross alpha	12.5	UF	2/10/2016	199-H4-85

Note: This table considers wells included in the 100-H groundwater area of interest, with the exception of those wells screened in the Ringold Formation upper mud unit (199-H2-1, 199-H3-2C, 199-H3-9, 199-H3-10, 199-H4-12C, 199-H4-15CS, 199-H4-90, 199-H4-91, 699-97-43C, 699-97-45B, and 699-97-60) or other deeper aquifer wells (199-H4-15CQ and 199-H4-15CR).

Table 2-8. 2016 Maximum Contaminant and Co-Contaminant Concentrations for 100-H Area and 100-D Area RUM Wells

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well Name
Hexavalent chromium	160	F	8/18/2016	699-97-61
Hexavalent chromium	196	UF	9/21/2016	699-97-61
Total chromium	180	F	8/18/2016	699-97-61
Total chromium	183	UF	8/18/2016	699-97-61
Nitrate	18,600	UF	11/22/2016	199-H4-90
Strontium-90	Not detected	UF	N/A	N/A
Tritium	1,250	UF	7/22/2016	699-97-60
Technetium-99	33.7	UF	7/25/2016	199-H4-12C
Sulfate	68,000	UF	7/22/2016	699-97-60
Uranium	6.72	F	4/28/2016	699-97-61
Uranium	6.72	UF	4/28/2016	699-97-61
Gross beta	16.8	UF	11/16/2016	199-H4-12C
Gross alpha	1.47	UF	11/8/2016	699-97-48C

Note: This table considers wells included in the 100-D and 100-H groundwater areas of interest that are screened in the Ringold Formation upper mud unit (100-D: 199-D5-134, 199-D5-141, 199-D8-54B, 699-97-61, and 699-97-48C; and 100-H: 199-H2-1, 199-H3-2C, 199-H3-9, 199-H3-10, 199-H4-12C, 199-H4-15CS, 199-H4-90, 199-H4-91, 699-97-60, 699-97-43C, and 699-97-45B).

N/A = not applicable

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-D2-11	M	5/22/2016	1.8	11/8/2016	1.5(U)	2/16/2016	3.4
	199-D2-6	M	5/22/2016	2.9	11/8/2016	3.3	11/8/2016	3.3
ISRM	199-D3-2	M	6/17/2016	11	11/8/2016	9.2	5/15/2016	11
	199-D3-5	M	5/22/2016	6.1	11/8/2016	8.7	2/16/2016	9
ISRM	199-D4-1	M	—	—	11/13/2016	24	11/13/2016	24
DX	199-D4-101	E	6/13/2016	26	9/21/2016	24	6/13/2016	26
	199-D4-102	M	7/27/2016	21	11/14/2016	23	8/10/2016	29
	199-D4-103	M	7/12/2016	5	11/14/2016	4.3	8/16/2016	20
DX	199-D4-14	E	4/4/2016	13	11/2/2016	20	11/2/2016	20
	199-D4-15	M	—	—	11/13/2016	5.8	11/13/2016	5.8
ISRM	199-D4-19	M	4/21/2016	4.5	11/11/2016	2.2	4/21/2016	4.5
ISRM	199-D4-22	M	6/19/2016	31	—	—	3/15/2016	33
ISRM	199-D4-23	M	6/17/2016	1.5(U)	11/11/2016	2.8	11/11/2016	2.8
ISRM	199-D4-25	M	6/10/2016	13	11/11/2016	64	11/11/2016	64
ISRM	199-D4-26	M	6/10/2016	1.5(U)	—	—	4/27/2016	1.5(U)
DX	199-D4-34	E	4/4/2016	15	10/12/2016	22	10/12/2016	22
ISRM	199-D4-36	T	—	—	12/9/2016	47	12/9/2016	47
DX	199-D4-38	E	6/13/2016	3	11/10/2016	10	8/17/2016	16

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
DX	199-D4-39	E	6/13/2016	5	10/5/2016	19	10/5/2016	19
ISRM	199-D4-43	M	—	—	—	—	12/30/2016	15
ISRM	199-D4-5	M	—	—	10/24/2016	25	10/24/2016	25
ISRM	199-D4-55	M	7/19/2016	62	—	—	1/14/2016	77
ISRM	199-D4-56	M	—	—	—	—	12/30/2016	69
ISRM	199-D4-6	M	—	—	10/24/2016	20	10/24/2016	20
ISRM	199-D4-62	T	6/10/2016	1.5(U)	12/9/2016	20	12/9/2016	20
ISRM	199-D4-65	M	6/1/2016	1.5(U)	—	—	4/17/2016	1.5(U)
ISRM	199-D4-68	M	—	—	—	—	12/30/2016	5.2
ISRM	199-D4-73	M	—	—	—	—	12/30/2016	12
ISRM	199-D4-77	M	7/20/2016	6.4	—	—	7/20/2016	6.4
ISRM	199-D4-79	M	—	—	—	—	12/30/2016	12
DX	199-D4-83	M	4/18/2016	2	11/29/2016	6.7	3/7/2016	13
DX	199-D4-84	M	7/5/2016	7	11/10/2016	8.3	3/7/2016	10
DX	199-D4-85	M	6/13/2016	12	11/10/2016	9.1	3/7/2016	20
ISRM	199-D4-86	M	5/31/2016	11	10/24/2016	10	5/31/2016	11
	199-D4-92	M	6/10/2016	1.5(U)	—	—	4/27/2016	1.5(U)
	199-D4-93	M	6/10/2016	1.5(U)	—	—	4/27/2016	1.5(U)

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
DX	199-D4-95	E	4/9/2016	15	9/21/2016	20	9/21/2016	20
DX	199-D4-96	E	4/4/2016	46	10/25/2016	84	10/25/2016	84
DX	199-D4-97	E	6/13/2016	22	10/5/2016	31	6/21/2016	31
DX	199-D4-98	E	7/26/2016	5.6	10/25/2016	13	10/25/2016	13
DX	199-D4-99	E	7/26/2016	5.6	10/25/2016	2.7	2/3/2016	6
DX	199-D5-101	E	4/14/2016	27	9/21/2016	27	3/7/2016	37
	199-D5-103	M	6/17/2016	65	11/14/2016	640	11/14/2016	640
DX	199-D5-104	E	4/4/2016	123	9/21/2016	101	1/18/2016	161
	199-D5-106	M	5/25/2016	9.5	—	—	2/16/2016	12
	199-D5-123	M	6/19/2016	9.3	12/8/2016	7.5	3/15/2016	13
	199-D5-125	M	6/24/2016	30	12/8/2016	21	6/24/2016	30
	199-D5-126	M	6/19/2016	15	—	—	3/15/2016	17
DX	199-D5-127	E	4/4/2016	20	9/21/2016	25	9/21/2016	25
	199-D5-13	M	4/11/2016	69	10/24/2016	34	1/14/2016	98
DX	199-D5-130	E	5/13/2016	24	9/21/2016	33	9/21/2016	33
DX	199-D5-131	E	6/13/2016	52	9/21/2016	52	2/3/2016	61
	199-D5-132	M	5/23/2016	8.9	11/14/2016	7.3	2/10/2016	12
	199-D5-133	M	5/23/2016	3.3	11/17/2016	2.6	2/10/2016	7.4

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-D5-14	M	4/11/2016	12	11/13/2016	12	1/14/2016	15
	199-D5-142	M	5/26/2016	5.6	11/14/2016	4.3	5/26/2016	5.6
	199-D5-143	M	5/23/2016	30	11/29/2016	28	2/10/2016	45
	199-D5-145	M	4/11/2016	32	11/17/2016	17	2/3/2016	49
DX	199-D5-146	E	6/4/2016	8	11/2/2016	14	1/4/2016	18
	199-D5-147	M	5/25/2016	4.3	—	—	2/10/2016	20
	199-D5-149	M	5/25/2016	22	11/18/2016	20	5/25/2016	22
	199-D5-15	M	6/17/2016	6.6	—	—	6/17/2016	6.6
	199-D5-150	M	5/23/2016	20	9/7/2016	16	2/8/2016	196
	199-D5-151	M	7/21/2016	100	11/3/2016	190	11/3/2016	190
	199-D5-152	M	5/24/2016	10	11/20/2016	12	11/20/2016	12
DX	199-D5-153	E	4/4/2016	38	9/21/2016	48	9/21/2016	48
DX	199-D5-154	E	7/5/2016	35	10/12/2016	38	1/7/2016	40
DX	199-D5-159	E	7/5/2016	73	12/14/2016	85	12/14/2016	85
	199-D5-16	M	6/19/2016	19	12/8/2016	15	3/15/2016	21
	199-D5-160	M	7/19/2016	53	10/26/2016	91	10/26/2016	91
	199-D5-17	M	—	—	10/24/2016	6.8	10/24/2016	6.8
	199-D5-18	M	5/25/2016	6.4	—	—	5/25/2016	6.4

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-D5-19	M	—	—	10/25/2016	11	10/25/2016	11
DX	199-D5-20	E	4/14/2016	14	—	—	3/7/2016	17
DX	199-D5-32	E	6/14/2016	58	9/21/2016	54	6/14/2016	58
	199-D5-33	M	5/31/2016	1.5(U)	—	—	4/17/2016	1.5(U)
DX	199-D5-34	E	4/4/2016	169	9/21/2016	128	1/18/2016	235
	199-D5-36	M	4/13/2016	5.4	10/25/2016	5.5	1/29/2016	5.7
	199-D5-37	M	4/18/2016	5.6	—	—	1/19/2016	7.7
	199-D5-38	M	6/19/2016	10	12/8/2016	9.6	6/19/2016	10
DX	199-D5-39	E	4/4/2016	82	9/21/2016	51	2/3/2016	102
	199-D5-40	M	5/22/2016	5.6	11/13/2016	3	5/22/2016	5.6
	199-D5-41	M	5/22/2016	2.9	11/13/2016	2.1	5/22/2016	2.9
	199-D5-42	M	—	—	12/12/2016	1.5(U)	12/12/2016	1.5(U)
	199-D5-43	M	6/19/2016	4.4	12/8/2016	3.8	3/15/2016	5.4
	199-D5-44	M	—	—	12/11/2016	1.5(U)	12/11/2016	1.5(U)
DX	199-D5-92	E	4/4/2016	4	11/2/2016	23	11/2/2016	23
	199-D5-97	M	5/22/2016	5.1	11/17/2016	3.4	5/22/2016	5.1
	199-D6-3	M	5/27/2016	4.8	11/17/2016	3.2	5/27/2016	4.8
DX	199-D7-3	E	6/13/2016	7	9/21/2016	7	8/2/2016	7

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
DX	199-D7-6	E	6/9/2016	6	9/21/2016	12	9/21/2016	12
	199-D8-101	M	4/20/2016	7.8	10/26/2016	7.4	1/19/2016	8.3
	199-D8-102	M	7/8/2016	3.8	10/11/2016	35	10/11/2016	35
	199-D8-4	M	4/18/2016	52	11/20/2016	17	1/18/2016	140
	199-D8-5	M	6/20/2016	2.6	12/8/2016	3	12/8/2016	3
DX	199-D8-53	E	6/13/2016	10	9/21/2016	15	12/28/2016	16
	199-D8-54A	M	6/20/2016	13	12/8/2016	15	12/8/2016	15
DX	199-D8-55	E	4/4/2016	15	11/16/2016	14	2/3/2016	21
DX	199-D8-68	E	4/4/2016	11	9/21/2016	22	9/21/2016	22
DX	199-D8-69	E	6/30/2016	7.4	9/21/2016	17	12/28/2016	26
	199-D8-70	M	6/20/2016	5.5	12/8/2016	4.4	6/20/2016	5.5
	199-D8-71	M	5/26/2016	15	11/17/2016	1.5(U)	2/16/2016	17
	199-D8-72	M	6/20/2016	2.4	12/7/2016	2.6	7/27/2016	2.6
DX	199-D8-73	E	7/5/2016	8	12/14/2016	5	7/5/2016	8
DX	199-D8-88	E	6/30/2016	3.6	9/21/2016	14	9/21/2016	14
DX	199-D8-89	E	4/4/2016	19	9/21/2016	24	5/28/2016	24
DX	199-D8-90	E	6/13/2016	11	11/16/2016	13	12/28/2016	17
DX	199-D8-91	E	7/26/2016	11	11/16/2016	16	12/28/2016	18

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
DX	199-D8-95	E	4/4/2016	186	9/14/2016	227	2/3/2016	261
DX	199-D8-96	E	7/4/2016	79	9/21/2016	120	9/21/2016	120
DX	199-D8-97	E	4/14/2016	55	9/21/2016	50	2/3/2016	69
DX	199-D8-98	E	4/14/2016	25	9/21/2016	34	9/21/2016	34
DX	199-D8-99	E	—	—	11/16/2016	26	8/1/2016	49
DX	199-H1-5	E	4/4/2016	19	9/21/2016	28	9/21/2016	28
DX	199-H4-80	E	6/13/2016	20	9/21/2016	36	9/21/2016	36
DX	199-H4-81	E	6/13/2016	25	9/21/2016	42	9/21/2016	42
DX	199-H4-82	E	6/13/2016	17	9/21/2016	37	9/21/2016	37
	699-101-48B	M	—	—	10/30/2016	1.5(U)	10/30/2016	1.5(U)
DX	699-90-47B	I	5/9/2016	33	—	—	5/9/2016	33
	699-93-48A	M	5/27/2016	7.2	10/28/2016	11	10/28/2016	11
	699-95-48	M	5/24/2016	16	10/30/2016	17	10/30/2016	17
	699-95-51	M	5/27/2016	4.4	10/30/2016	4.4	8/13/2016	4.4
	699-96-52B	M	5/27/2016	7.5	11/3/2016	7.4	2/11/2016	8.1
	699-97-48B	M	—	—	10/28/2016	21	10/28/2016	21
	699-97-51A	M	6/1/2016	9.6	10/28/2016	5.8	2/16/2016	9.8
	699-98-49A	M	6/1/2016	1.6	11/7/2016	1.5(U)	6/1/2016	1.6

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	699-98-51	M	5/31/2016	4.5	—	—	2/16/2016	8.4
Aquifer Sampling Tubes								
	36-M	AT	—	—	10/6/2016	1.5(U)	10/6/2016	1.5(U)
	38-M	AT	—	—	10/10/2016	3.6	10/10/2016	3.6
	AT-D-1-M	AT	—	—	10/6/2016	1.5(U)	10/6/2016	1.5(U)
	AT-D-3-D	AT	—	—	10/6/2016	3.4	10/6/2016	3.4
	AT-D-4-D	AT	—	—	10/6/2016	1.5(U)	10/6/2016	1.5(U)
	C6266	AT	5/23/2016	1.6	—	—	5/23/2016	1.6
	C6267	AT	5/23/2016	4.2	—	—	5/23/2016	4.2
	C6268	AT	5/23/2016	6.8	—	—	5/23/2016	6.8
	C6269	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	C6270	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	C6271	AT	5/23/2016	8.2	—	—	5/23/2016	8.2
	C6278	AT	—	—	10/10/2016	2.1	10/10/2016	2.1
	C7647	AT	—	—	10/6/2016	7.4	10/6/2016	7.4
	DD-10-3	AT	—	—	10/10/2016	1.5(U)	10/10/2016	1.5(U)
	DD-12-2	AT	—	—	10/10/2016	1.8	10/10/2016	1.8
	DD-15-3	AT	—	—	10/10/2016	5.9	10/10/2016	5.9

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	DD-16-4	AT	—	—	10/10/2016	10	10/10/2016	10
	DD-17-2	AT	—	—	10/10/2016	7.4	10/10/2016	7.4
	DD-39-1	AT	5/27/2016	1.5(U)	—	—	5/27/2016	1.5(U)
	DD-41-1	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-41-2	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-41-3	AT	5/23/2016	1.5(U)	10/6/2016	1.5(U)	7/30/2016	1.5(U)
	DD-42-2	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-42-3	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-42-4	AT	5/23/2016	3.3	—	—	5/23/2016	3.3
	DD-43-2	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-43-3	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-44-3	AT	5/23/2016	1.5(U)	—	—	5/23/2016	1.5(U)
	DD-44-4	AT	5/23/2016	1.5(U)	10/6/2016	8.9	10/6/2016	8.9
	DD-49-3	AT	—	—	10/6/2016	14	10/6/2016	14
	DD-50-3	AT	—	—	10/6/2016	13	10/6/2016	13
	DD-50-4	AT	—	—	10/6/2016	22	10/6/2016	22
	Redox-1-3.3	AT	5/27/2016	1.5(U)	—	—	5/27/2016	1.5(U)
	Redox-1-6.0	AT	5/27/2016	1.5(U)	10/6/2016	1.5(U)	8/1/2016	1.5(U)

Table 2-9. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (D) and DX P&T Systems

System	Well or AT Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	Redox-2-6.0	AT	5/27/2016	9	—	—	5/27/2016	9
	Redox-3-3.3	AT	5/27/2016	1.5(U)	10/6/2016	22	10/6/2016	22
	Redox-3-4.6	AT	5/27/2016	1.5(U)	—	—	5/27/2016	1.5(U)
	Redox-4-3.0	AT	5/27/2016	1.5(U)	—	—	5/27/2016	1.5(U)
	Redox-4-6.0	AT	5/27/2016	1.5(U)	—	—	5/27/2016	1.5(U)

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

Blank cells indicate well/aquifer tube is not tied directly to a P&T system.

*High river stage represents the period from April through July. Low river stage represents the period from mid-August to early December.

— = indicates that the sample was not collected or analysis was not performed
AT = aquifer tube
Cr(VI) = hexavalent chromium
E = extraction well
I = injection well
ISRM = in situ redox manipulation
M = monitoring well
P&T = pump and treat
T = in situ redox manipulation aquifer treatment well
U = undetected (detection limit is listed with qualifier in parentheses)

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
HX	199-H1-1	E	4/5/2016	42	9/7/2016	44	9/7/2016	44
HX	199-H1-2	E	5/20/2016	49	9/7/2016	50	9/7/2016	50
HX	199-H1-25	I/M	—	—	—	—	3/22/2016	12
HX	199-H1-32	E	4/5/2016	23	—	—	3/1/2016	28
HX	199-H1-33	E	4/5/2016	28	—	—	4/5/2016	28
HX	199-H1-34	E	4/5/2016	14	9/24/2016	21	9/24/2016	21
HX	199-H1-35	E	7/5/2016	6	11/1/2016	10	11/1/2016	10
HX	199-H1-36	E	4/5/2016	39	11/1/2016	53	11/1/2016	53
HX	199-H1-37	E	7/5/2016	6	—	—	7/5/2016	6
HX	199-H1-38	E	7/5/2016	7	11/1/2016	5	7/5/2016	7
HX	199-H1-39	E	5/2/2016	4	—	—	5/2/2016	4
HX	199-H1-4	E	7/5/2016	41	—	—	7/5/2016	41
HX	199-H1-40	E	7/5/2016	9	—	—	7/5/2016	9
HX	199-H1-42	E	4/5/2016	56	11/1/2016	82	11/1/2016	82
HX	199-H1-43	E	4/5/2016	26	10/17/2016	28	1/18/2016	32
HX	199-H1-45	E	4/5/2016	59	9/6/2016	40	4/5/2016	59
HX	199-H1-46	E	7/5/2016	53	11/1/2016	59	11/1/2016	59
	199-H1-7	M	5/11/2016	17	11/16/2016	9	2/8/2016	100
	199-H3-11	M	5/11/2016	5.6	11/18/2016	4.6	5/11/2016	5.6

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
HX	199-H3-25	E	7/5/2016	22	9/7/2016	18	7/5/2016	22
HX	199-H3-26	E	7/5/2016	9	9/7/2016	17	9/7/2016	17
	199-H3-2A	M	6/15/2016	1.5(U)	11/16/2016	5.7	11/16/2016	5.7
	199-H3-3	M	5/11/2016	6.8	11/16/2016	8.3	11/16/2016	8.3
HX	199-H3-4	E	4/5/2016	20	9/7/2016	13	4/5/2016	20
	199-H3-5	M	5/10/2016	25	—	—	5/10/2016	25
	199-H3-6	M	5/11/2016	3.4	11/16/2016	1.8	5/11/2016	3.4
	199-H3-7	M	5/11/2016	1.5(U)	11/15/2016	2	6/28/2016	2
	199-H4-10	M	6/13/2016	1.5(U)	12/7/2016	1.5(U)	7/12/2016	1.5(U)
	199-H4-11	M	5/20/2016	3.2	11/18/2016	4.5	2/10/2016	4.6
	199-H4-12A	M	5/10/2016	2.2	11/15/2016	2.3	11/15/2016	2.3
	199-H4-13	M	6/13/2016	5.6	11/18/2016	9.4	11/18/2016	9.4
HX	199-H4-15A	E	4/5/2016	11	10/4/2016	5	4/5/2016	11
	199-H4-15CP	M	—	—	11/18/2016	1.5(U)	11/18/2016	1.5(U)
	199-H4-15CQ	M	—	—	11/18/2016	1.5(U)	11/18/2016	1.5(U)
	199-H4-15CR	M	—	—	11/18/2016	5.3	11/18/2016	5.3
	199-H4-16	M	5/20/2016	1.5(U)	—	—	2/11/2016	1.9
HX	199-H4-4	E	4/5/2016	8	11/1/2016	10	11/1/2016	10
	199-H4-45	M	6/13/2016	3	12/7/2016	3.1	12/7/2016	3.1

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-H4-46	M	5/20/2016	1.5(U)	11/18/2016	1.5(U)	6/17/2016	1.5(U)
	199-H4-47	M	5/20/2016	1.5(U)	11/18/2016	1.5(U)	6/16/2016	1.5(U)
	199-H4-49	M	5/20/2016	9.3	11/18/2016	9.7	2/10/2016	11
	199-H4-5	M	6/15/2016	3.4	12/7/2016	3.9	12/7/2016	3.9
	199-H4-6	M	4/25/2016	1.5(U)	—	—	3/6/2016	1.5(U)
HX	199-H4-63	E	4/5/2016	11	11/1/2016	12	11/1/2016	12
HX	199-H4-64	E	4/5/2016	10	11/1/2016	8	4/5/2016	10
	199-H4-65	M	5/20/2016	5	11/20/2016	6.6	2/10/2016	9.4
HX	199-H4-69	E	4/5/2016	13	11/19/2016	9	4/5/2016	13
HX	199-H4-70	E	4/5/2016	10	11/1/2016	7	4/5/2016	10
HX	199-H4-74	E	7/5/2016	38	9/7/2016	41	9/7/2016	41
HX	199-H4-75	E	4/5/2016	61	11/1/2016	52	4/5/2016	61
HX	199-H4-76	E	4/27/2016	22	9/7/2016	13	4/27/2016	22
HX	199-H4-77	E	7/5/2016	8	9/7/2016	9	1/4/2016	15
	199-H4-8	M	—	—	11/15/2016	6	11/15/2016	6
	199-H4-83	M	—	—	11/18/2016	42	11/18/2016	42
	199-H4-84	M	5/10/2016	37	11/15/2016	43	8/5/2016	83
	199-H4-85	M	5/22/2016	5.9	10/7/2016	9.1	2/10/2016	15
HX	199-H4-86	E	7/5/2016	16	9/7/2016	15	7/5/2016	16

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-H4-87	M	6/1/2016	3	11/22/2016	2.2	6/1/2016	3
	199-H4-88	M	7/24/2016	11	11/29/2016	9.3	7/24/2016	11
	199-H4-89	M	—	—	11/22/2016	1.5(U)	7/26/2016	1.5(U)
HX	199-H4-92	E	7/5/2016	17	9/7/2016	18	9/7/2016	18
HX	199-H4-93	E	4/5/2016	69	9/7/2016	56	4/5/2016	69
HX	199-H5-16	E	7/5/2016	17	9/7/2016	19	9/7/2016	19
	199-H5-1A	M	5/22/2016	5.9	11/20/2016	2.8	2/10/2016	8.1
	199-H6-1	M	5/22/2016	3.6	11/20/2016	4.7	11/20/2016	4.7
HX	199-H6-2	E	5/2/2016	2	—	—	5/2/2016	2
	199-H6-3	M	5/22/2016	1.8	11/20/2016	1.5(U)	5/22/2016	1.8
	199-H6-4	M	5/22/2016	1.5(U)	—	—	5/22/2016	1.5(U)
	699-100-43B	M	7/28/2016	1.6	11/7/2016	1.5	7/28/2016	1.6
	699-101-45	M	7/28/2016	19	—	—	7/28/2016	19
	699-88-41	M	4/25/2016	12	11/1/2016	12	5/29/2016	12
	699-88-41A	M	7/6/2016	5.5	11/3/2016	5.7	11/3/2016	5.7
	699-89-35	M	7/24/2016	12	—	—	5/23/2016	12
	699-90-37B	M	4/18/2016	3.4	11/1/2016	6.5	11/1/2016	6.5
	699-90-45	M	—	—	11/1/2016	6.5	11/1/2016	6.5
HX	699-90-45B	I/M	6/7/2016	222	—	—	11/7/2016	222

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	699-91-46A	M	—	—	10/28/2016	6.4(U)	10/28/2016	6.4(U)
	699-93-37A	M	5/18/2016	19	11/1/2016	8.8	5/18/2016	19
	699-94-41	M	5/22/2016	14	11/2/2016	18	11/2/2016	18
	699-94-43	M	5/22/2016	16	10/28/2016	10	2/9/2016	17
	699-95-45	M	5/27/2016	2	10/30/2016	1.6(U)	5/27/2016	2
	699-97-41	M	5/27/2016	18	11/2/2016	42	11/2/2016	42
	699-97-43B	M	—	—	11/7/2016	5.8	11/7/2016	5.8
	699-97-45	M	—	—	11/2/2016	34(U)	11/2/2016	34(U)
	699-97-47B	M	4/27/2016	28	11/2/2016	25(U)	4/27/2016	28(U)
	699-98-43	M	—	—	10/28/2016	27	10/28/2016	27
	699-98-46	M	5/27/2016	31	11/9/2016	35	11/9/2016	35
	699-99-41	M	5/31/2016	1.5	10/30/2016	1.5	2/18/2016	56
	699-99-42B	M	—	—	11/9/2016	1.5(U)	11/9/2016	1.5(U)
	699-99-44	M	4/29/2016	24	10/30/2016	33	8/7/2016	33
Aquifer Tubes								
	45-M	AT	—	—	10/11/2016	1.5(U)	10/11/2016	1.5
	47-D	AT	—	—	10/17/2016	6.9	10/17/2016	6.9
	47-M	AT	—	—	10/17/2016	12	10/17/2016	12
	48-M	AT	—	—	10/17/2016	5.1	10/17/2016	5.1

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	50-M	AT	—	—	10/17/2016	4.1	10/17/2016	4.1
	52-D	AT	—	—	10/12/2016	1.5	10/12/2016	1.5
	54-M	AT	—	—	10/12/2016	4.1	10/12/2016	4.1
	AT-H-1-M	AT	—	—	10/17/2016	2.1	10/17/2016	2.1
	AT-H-2-D	AT	—	—	10/17/2016	2.8	10/17/2016	2.8
	AT-H-3-D	AT	—	—	10/17/2016	5.9	10/17/2016	5.9
	C5633	AT	—	—	10/11/2016	6.1	10/11/2016	6.1
	C5636	AT	—	—	10/11/2016	5.4	10/11/2016	5.4
	C5638	AT	—	—	10/11/2016	12	10/11/2016	12
	C5641	AT	—	—	10/11/2016	13	10/11/2016	13
	C5678	AT	—	—	10/11/2016	1.5(U)	10/11/2016	1.5(U)
	C5682	AT	—	—	10/11/2016	1.5(U)	10/11/2016	1.5(U)
	C6293	AT	—	—	10/11/2016	1.5(U)	10/11/2016	1.5(U)
	C6301	AT	—	—	10/17/2016	2.9	10/17/2016	2.9
	C7649	AT	—	—	10/17/2016	2.4	10/17/2016	2.4

Table 2-10. 2016 Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-HR-3 (H) and HX P&T Systems

System	Well or Aquifer Tube Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	C7650	AT	—	—	10/17/2016	27	10/17/2016	27

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

Blank cells indicate well/aquifer tube is not tied directly to a P&T system.

*High river stage represents the period from April through July. Low river stage represents the period from mid-August to early December.

— = indicates that the sample was not collected or analysis was not performed
AT = aquifer tube
Cr(VI) = hexavalent chromium
E = extraction well
I = injection well
M = monitoring well
P&T = pump and treat
U = undetected (detection limit is listed with qualifier in parentheses)

Table 2-11. 2016 Maximum Cr(VI) Concentrations for 100-H Area and 100-D Area RUM Wells

System	Well Name	Well Use	High River Stage* Maximum Cr(VI)		Low River Stage* Maximum Cr(VI)		Annual Maximum Cr(VI)	
			Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
	199-D5-134	M	—	—	11/20/2016	1.5(U)	11/20/2016	1.5(U)
	199-D5-141	M	—	—	10/25/2016	1.5(U)	10/25/2016	1.5(U)
	199-D8-54B	M	6/20/2016	6.2	12/8/2016	7.7	12/8/2016	7.7
DX	699-97-61	E	4/28/2016	110	9/21/2016	196	9/21/2016	196
	199-H2-1	M	5/11/2016	20	11/16/2016	17	3/25/2016	20
	199-H3-10	M	5/10/2016	3.5	11/15/2016	3.8	5/12/2016	3.8
HX	199-H3-2C	E	4/5/2016	67	9/3/2016	61	4/5/2016	67
HX	199-H3-9	E	4/5/2016	100	10/4/2016	69	4/5/2016	100
HX	199-H4-12C	E	5/9/2016	136	9/3/2016	123	5/9/2016	136
	199-H4-15CS	M	—	—	11/18/2016	38	11/18/2016	38
	199-H4-90	M	6/13/2016	14	11/22/2016	12	6/13/2016	14
	199-H4-91	M	6/15/2016	29	11/20/2016	41	11/20/2016	41
	699-97-43C	M	4/18/2016	1.5(U)	11/9/2016	1.5(U)	7/29/2016	1.5
	699-97-45B	M	4/18/2016	3.9	11/8/2016	3.8	4/18/2016	3.9
	699-97-60	M	4/27/2016	11	11/9/2016	1.5	4/27/2016	11
	699-97-48C	M	4/28/2016	120	11/8/2016	130	11/8/2016	130

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

Blank cells indicate well/aquifer tube is not tied directly to a P&T system.

*High river stage represents the period from April through July. Low river stage represents the period from mid-August to early December.

— = indicates that the sample was not collected or analysis was not performed

Cr(VI) = hexavalent chromium

E = extraction well

M = monitoring well

P&T = pump and treat

U = undetected (detection limit is listed with qualifier in parentheses)

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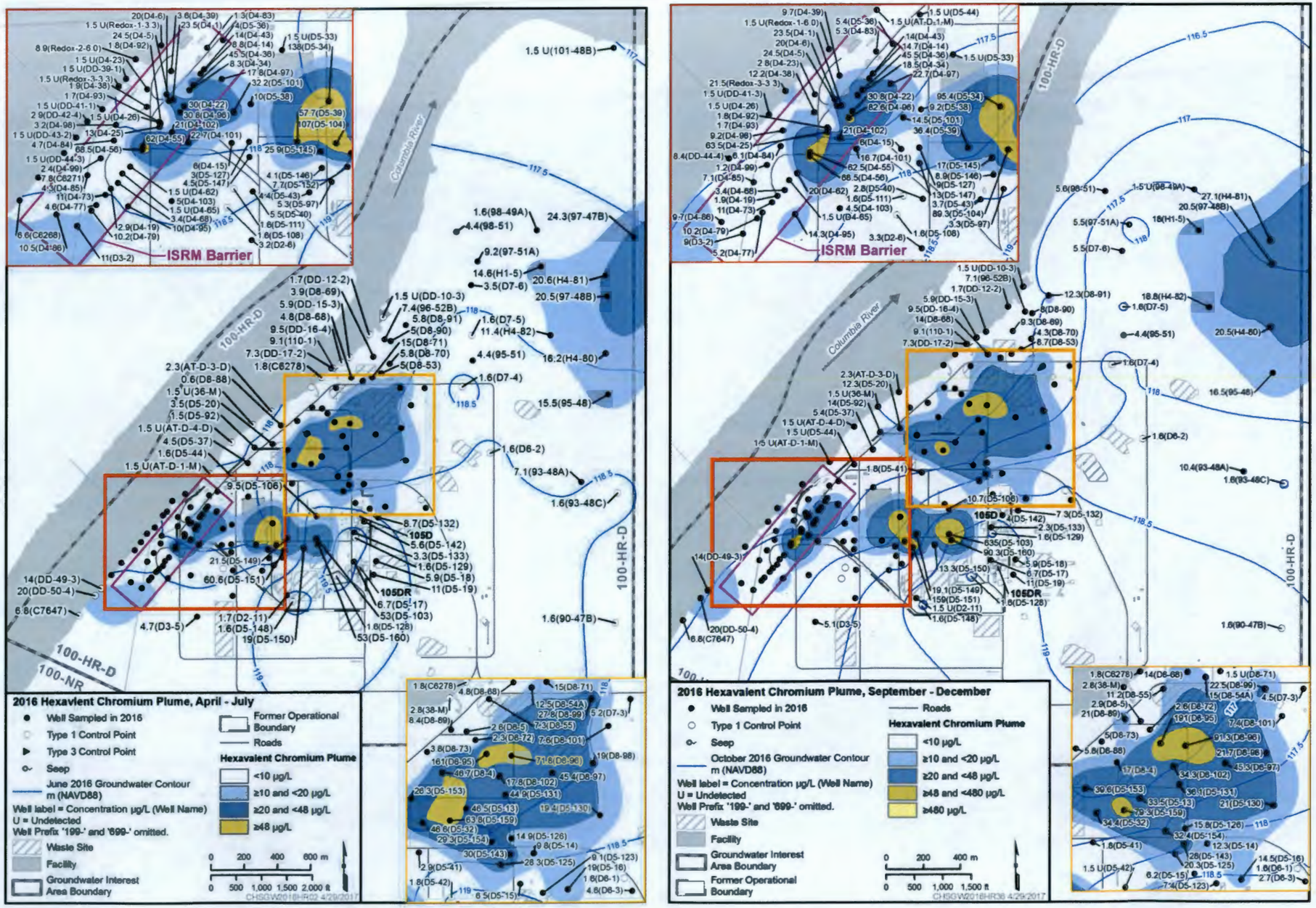

Figure 2-17. 100-HR-3 OU (100-D Area) Cr(VI) High River Stage to Low River Stage Comparison, 2016

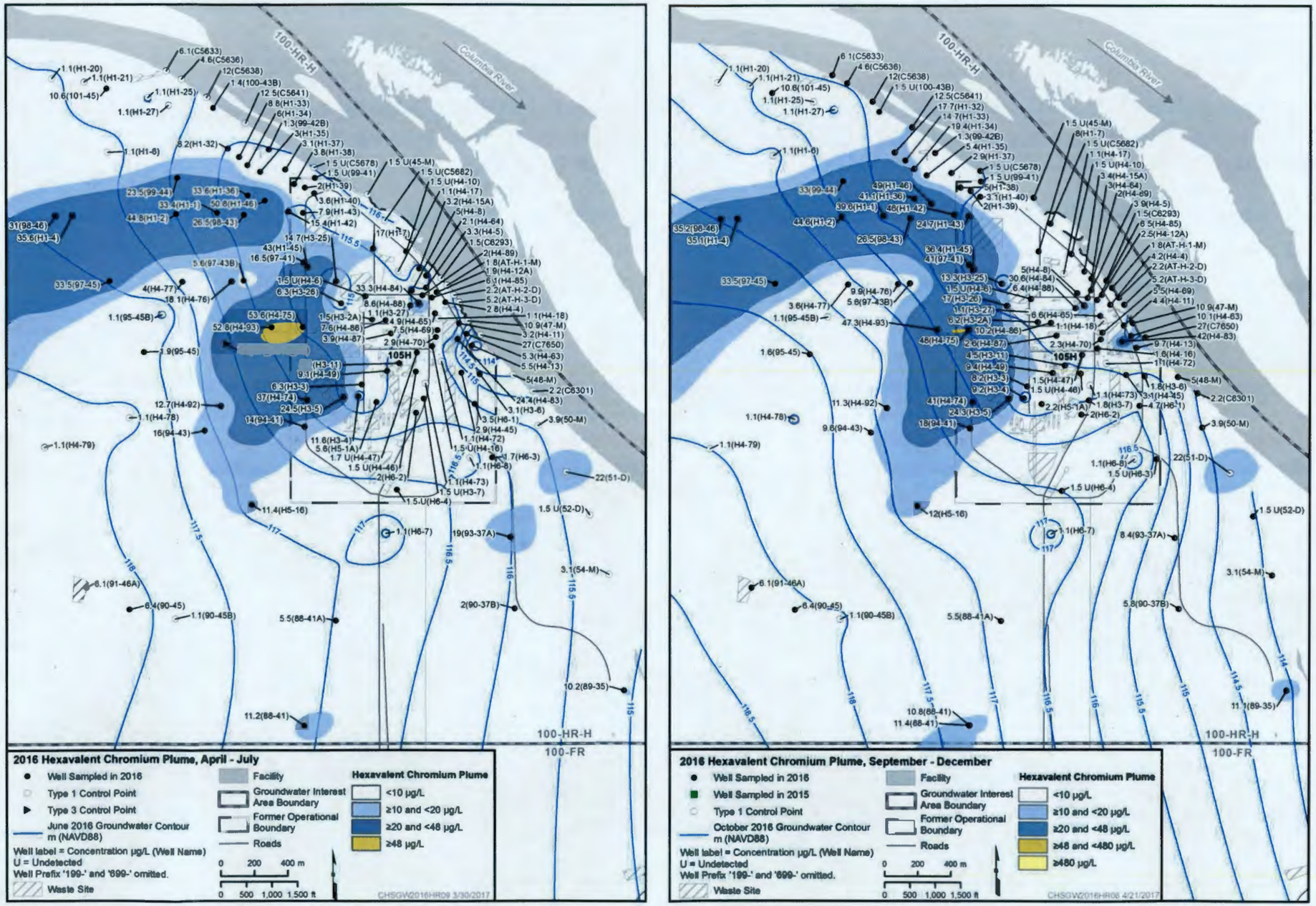

Figure 2-18. 100-HR-3 OU (100-H Area) Cr(VI) High River Stage to Low River Stage Comparison, 2016

2.2.3.1 River Stage Effects

The rise and fall of the Columbia River creates a zone of interaction of surface water and groundwater. River stage varies over short (e.g., hourly) and long (e.g., seasonal) intervals in response to natural influences and the operation of dams on the Columbia River system. In 2016, the river stage was highest in April through early July and lowest in September and October (Figure 2-12). Groundwater levels and contaminant concentrations in groundwater in many locations vary as groundwater elevation changes in response to Columbia River stage. These relationships are most evident in wells located closest to the Columbia River, although apparent relationships are also evident in water levels and sample data obtained from wells hundreds of meters inland of the shoreline.

Groundwater-specific conductance was mapped to evaluate the potential for migration of river water into the aquifer due to capture by pumping (Figure 2-19). A specific conductance level of less than 200 µS/cm is indicative of river water (i.e., the Columbia River exhibits a relative low dissolved solids load and, thus, a low specific conductance). Specific conductance of 300 µS/cm (or greater) is typical of groundwater in the former industrial operating area of the 100-HR-3 OU. Specific conductance of 200 to 300 µS/cm indicates a likely mixing of groundwater with river water.

Well locations along the ISRM barrier exhibited specific conductance greater than 300 µS/cm in most locations (Figure 2-19). The shoreline along the northern 100-D plume had specific conductance values that represented both river water and areas of mixing. At 100-H, the specific conductance was less than 200 µS/cm along the majority of shoreline. The specific conductance values are consistent with the inferred water table maps and the areas of groundwater capture (as indicated by a definable groundwater depression) as discussed in Section 2.2.4.

2.2.3.2 Hexavalent Chromium

As described in Section 2.1, the cleanup goal for Cr(VI) in groundwater discharging to the Columbia River is the current ambient water quality criterion of 10 µg/L. Consequently, a target compliance criterion of 20 µg/L for Cr(VI) in groundwater is currently applied to near-shore and compliance wells along the river is based in part on the expectation 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 (EPA et al., 2009).

The Cr(VI) concentrations are monitored in wells and aquifer tubes in the 100-HR-3 OU. Figures 2-17 and 2-18 show spring and fall 2016 comparison of the distribution of Cr(VI) in the unconfined aquifer in the 100-D and 100-H Areas, respectively. In wells near the Columbia River, maximum Cr(VI) levels generally coincide with low river conditions and occur in late fall to early spring. The exception is where monitoring wells are located within a source area; in this case, the contaminant concentrations increase at high river stage. Tables 2-9, 2-10, and 2-11 present the fall 2016 Cr(VI) concentrations from extraction wells, compliance wells, monitoring wells, and aquifer tubes, along with concentrations in the first water-bearing unit of the RUM.

Hexavalent Chromium in the 100-D Area. Cr(VI) concentrations in groundwater within the southern area of 100-D remained above the 48 µg/L MTCA standard during 2016 but continued to decline. Areas with high Cr(VI) concentrations decreased in size (Figure 2-17). The removal of high concentrations of Cr(VI) from the vadose zone and aquifer have resulted in overall reductions in Cr(VI) in groundwater.

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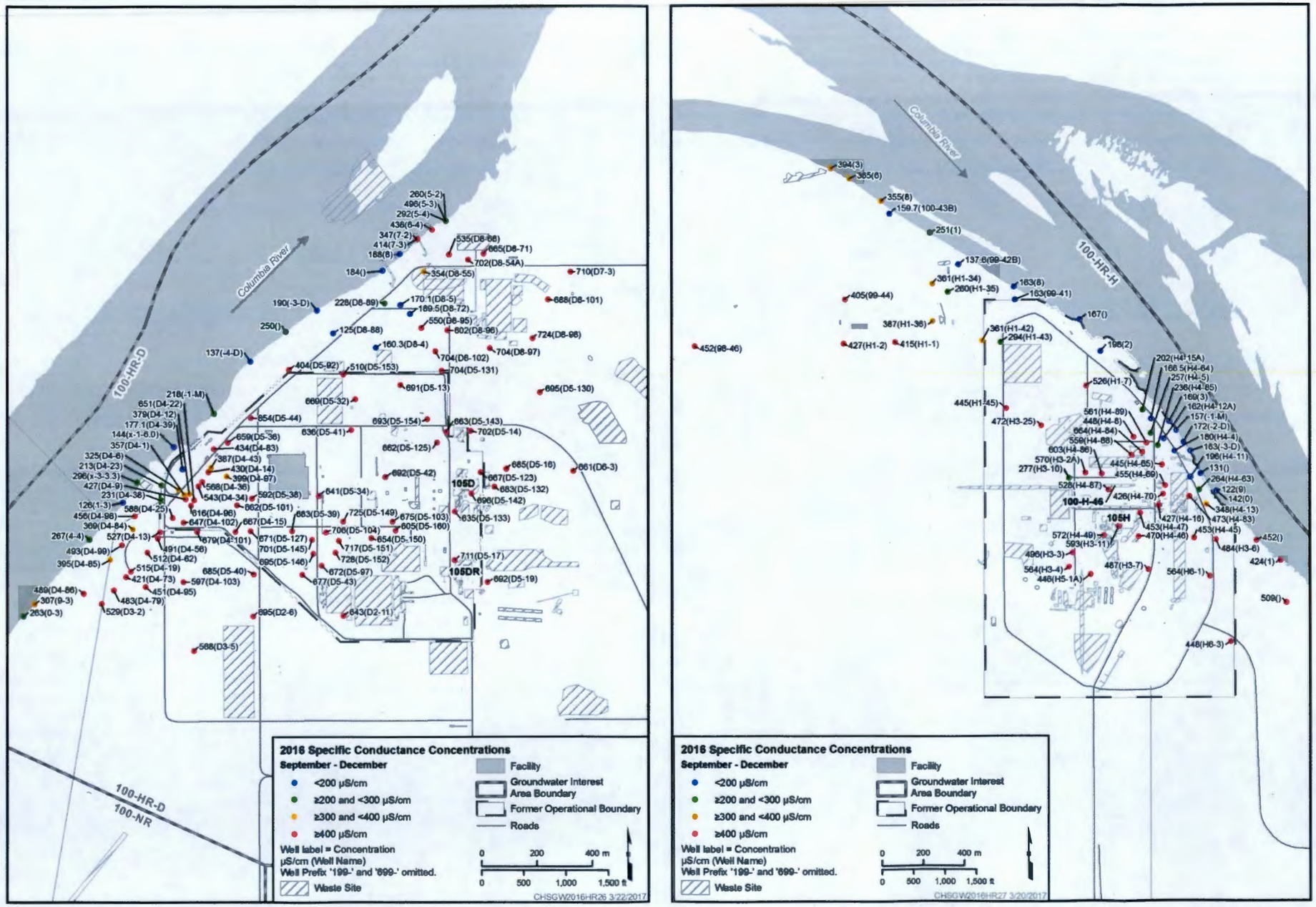

Figure 2-19. Specific Conductance at 100-HR-3 (Fall 2016)

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The primary contributor to high Cr(VI) concentrations at the 100-D southern plume was the 100-D-100 waste site. The vadose zone and upper 3 m (10 ft) of the aquifer at the 100-D-100 waste site were excavated in 2014 and the beginning of 2015, removing a large portion of the contaminant source. The excavation included removing chromium-substitute calcite precipitate, which provides a slow-leaching source of Cr(VI) to the aquifer, resulting in a long-term secondary source (SGW-58416, *Persistent Source Investigation at 100-D Area*). The discovery of this slow-leaching material led DOE to remove this source precipitate from below the water table at 100-D-100. Removal of this type of secondary source material, where present, has the potential to greatly decrease the duration and cost of groundwater remediation. The impact of source removal is evident in Cr(VI) concentrations at extraction well 199-D5-104, which is directly downgradient of the 100-D-100 waste site. Cr(VI) concentrations in well 199-D5-104 declined from 5,392 µg/L in April 2013 to 81 µg/L by December 2016. The downward trend at this well, however, is showing signs of a tailing effect, likely due to the remaining source material that was identified below the excavation at the base of unconfined aquifer where removal was not practical.

The areas of higher concentrations (greater than 48 µg/L) in the 100-D northern plume are primarily located near the 120-D-1 (100-D Pond) waste site, the 126-D-1 coal ash waste site, and southwest of the 116-DR-1&2 Trenches. Elevated Cr(VI) remains present in wells 199-D8-95, 199-D8-96, and 199-D5-159 (Figure 2-20). The highest concentrations in the northern 100-D plume are in extraction well 199-D8-95 (164 µg/L on December 28, 2016). A new extraction well (199-D8-102) was installed in this area in 2016 (Table 2-1), just upgradient from well 199-D8-95, in hopes of addressing the remaining elevated concentrations. However, Cr(VI) concentrations detected in well 199-D8-102 are lower than in nearby extraction wells 199-D8-95 and 199-D8-96, and, therefore, it was not connected as an extraction well. The Cr(VI) concentration in a filtered sample from well 199-D8-102 on October 11, 2016 was 35 µg/L. Well 199-D8-102 will continue to be monitored, and, if concentrations increase sufficiently, it will be re-evaluated for use as an extraction well.

Moderate levels of contamination remain in wells located between the 116-DR-1&2 Trenches and the Columbia River, despite years of remediation. A concentration of 148 µg/L of Cr(VI) was detected in well 199-D8-99, located near the 116-DR-1&2 Trenches, when it was initially installed in 2010. It was used as an injection well from December 2010 to July 2015. Concentrations downgradient of this area would be expected to fall below detection after 5 years of upgradient injection of P&T effluent. The continued presence of moderate to low-level concentrations may be related to a residual source area near well 199-D8-99. In order to evaluate the potential for a continual source in this area, well 199-D8-99 was converted to an extraction well in July 2016. Since conversion, Cr(VI) concentrations in extraction well 199-D8-99 have varied from as high as 49 µg/L on August 1, 2016 shortly after extraction began to as low as 6 µg/L on October 12, 2016, and then increasing again to 34 µg/L by December 28, 2016. Sampling results in early 2017 indicate concentrations are remaining below 20 µg/L. It is still unclear if there is a continual source in the area and extraction in 199-D8-99 and monitoring will continue.

Hexavalent Chromium in the Horn and 100-H Area. Discharge to the 116-DR-1&2 Trenches during 1967 resulted in the unconfined aquifer Cr(VI) plume that extends across the Horn from 100-D to 100-H (Figures 2-17 and 2-18). This plume encompasses the largest area of 100-HR, but concentrations in the unconfined aquifer remain consistently less than 100 µg/L, and less than the MTCA (WAC 173-340) standard of 48 µg/L in most of the area.

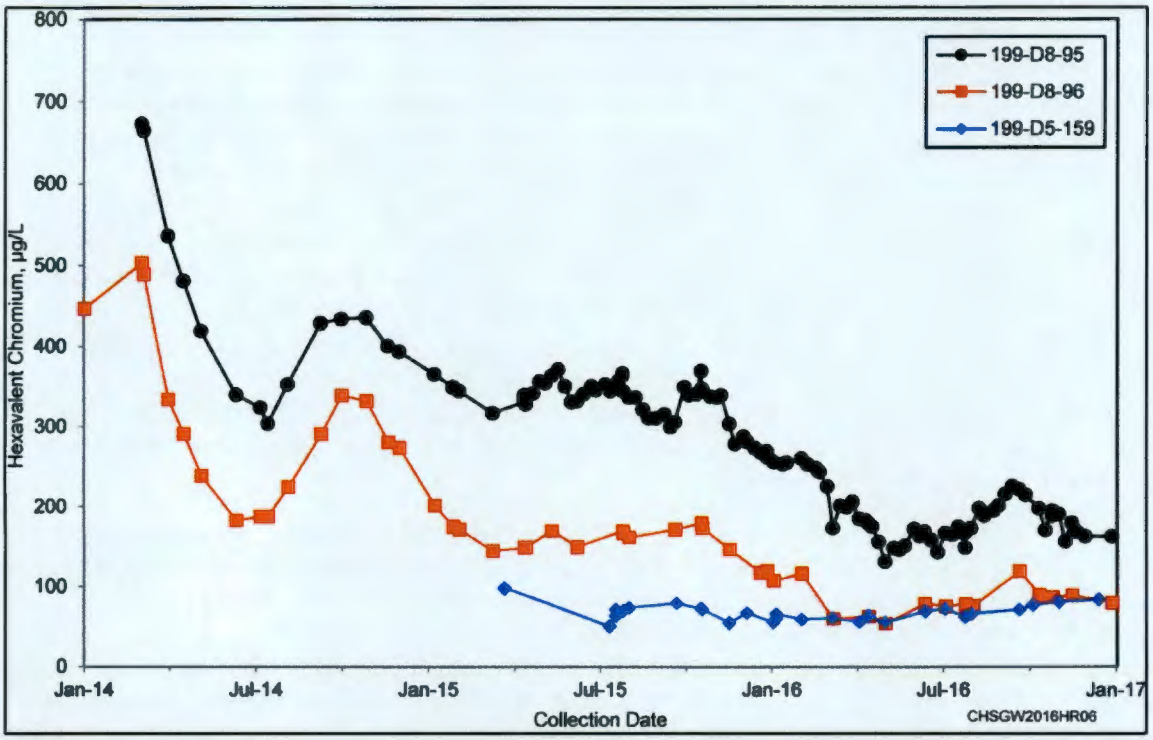

Figure 2-20. 100-HR Hexavalent Chromium Data for Wells 199-D8-95, 199-D8-96, and 199-D5-159

Remediation activities continue to reduce contaminant levels slowly, but removal effectiveness is complicated by the hydrogeology of the area. To operate, extraction pumps require a minimum of 0.6 m (2 ft) of water above the pump intake. Across the Horn and in the northern portion of 100-H, the aquifer is less than 1 m (3.3 ft) thick in some locations during low river stage, with the thinnest locations along the northern portion of the Horn. During low river-stage periods, the amount of water available in the aquifer is minimal, and even when pumps are set low into well sumps, there may be insufficient water for them to operate. This results in low pumping rates during the low river-stage periods (typically winter) and minimized contaminant removal and hydraulic containment.

Wells 199-H4-93 and 199-H4-75, located together in the Horn area west of the H Reactor, had the highest average (Figure 2-18) and point-in-time Cr(VI) concentrations during 2016 within the unconfined aquifer at 100-H Area. A moderate amount of Cr(VI) has persisted in both of these wells. The aquifer is less than 3 m (10 ft) thick in this area, limiting groundwater extraction. The total combined extraction rate of these two wells averaged 68 L/min (18 gal/min) in 2016, and was as low as 40 L/min (11 gal/min) during December. Cr(VI) results in December in wells 199-H4-93 and 199-H4-75 were both 47 µg/L.

Cr(VI) concentrations in several wells northwest of the H Reactor in the Horn area had a seasonal variation in concentrations in 2016, fluctuating near an average concentration of about 48 µg/L. The lower concentrations generally occurred during high-river periods, when groundwater flow was directed inland in near river areas (e.g., well 199-H1-42; Figure 2-21). Well 199-H1-46 had average Cr(VI) concentrations of 50 and 49 µg/L during the high and low-river periods, respectively (Figure 2-18). Unlike the previous year, the average Cr(VI) values in wells 199-H1-42 and 199-H1-45 were slightly below 48 µg/L during 2016 (Figures 2-18 and 2-21).

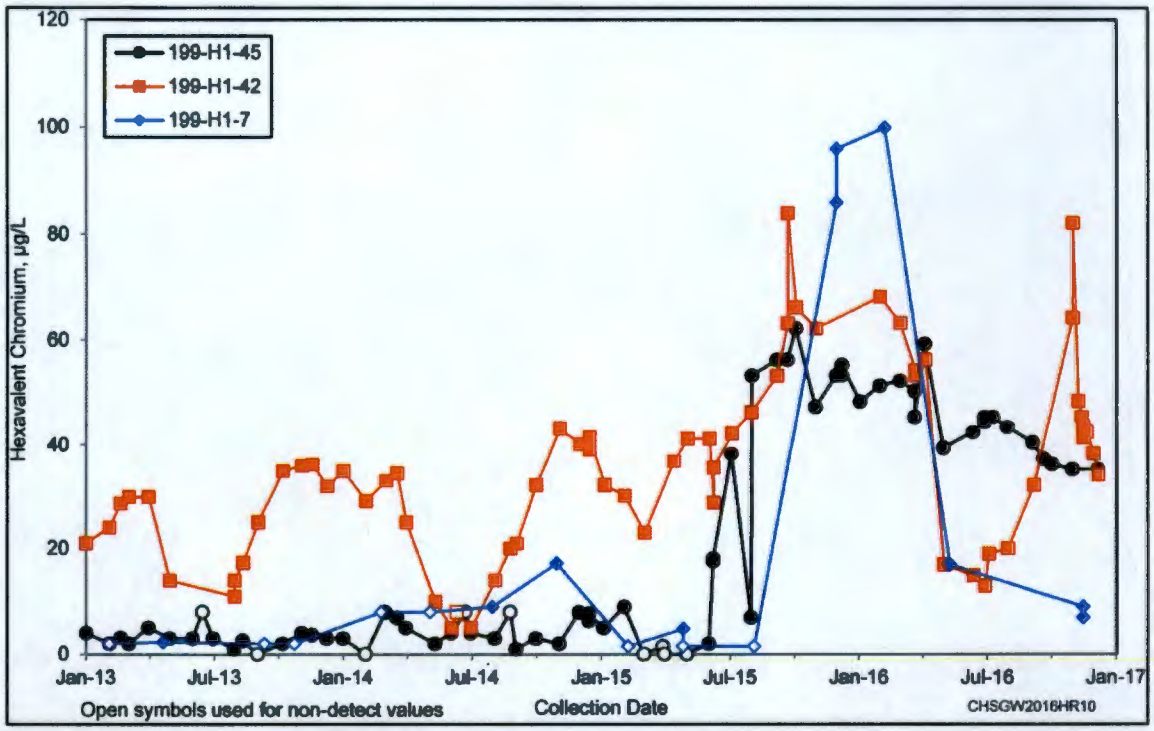

Figure 2-21. 100-HR Hexavalent Chromium Data for Wells 199-H1-45, 199-H1-42, and 199-H1-7

Cr(VI) concentrations dramatically increased in well 199-H1-45 in mid-2015 as the plume migrated north and northeast, most likely in response to injecting water at well 699-95-45B (Figure 2-21). Concentrations began to decrease in well 199-H1-45 in 2016, reaching 35 µg/L by December. Cr(VI) concentrations in 199-H1-7, located downgradient of extraction well 199-H1-45, rose sharply in December 2015 and declined in 2016. Cr(VI) concentrations decreased from 100 µg/L in February to 9 µg/L in November (Figure 2-21).

Cr(VI) concentrations in the 100-H Area unconfined aquifer are typically less than 10 µg/L. However, higher concentrations were detected in several 100-H Area monitoring wells during 2016 (Figure 2-18). Well 199-H4-83, located just east (downgradient) of the 107-H Retention Basin, had a Cr(VI) concentration of 42 µg/L in November, which was the highest observed value since monitoring began in 2011. Wells and aquifer tubes downgradient of 199-H4-83 also had concentrations above 10 µg/L (Figure 2-18), which suggests that this high value is not related to sampling or analytical error. The increase in concentrations may be in response to reduced injection during 2016 in injection wells in the vicinity combined with a possible residual contaminant source at the 107-H retention basin.

Hexavalent Chromium in the Ringold Formation Upper Mud Unit. Cr(VI) contamination is present in the first water-bearing unit of the RUM in both 100-H and the Horn. Contamination has not been identified in the RUM within 100-D. Concentrations of Cr(VI) in 100-H range from 1.5 µg/L or less in well 699-97-43C to 197 µg/L in well 699-97-61 during 2016. The two RUM wells with the highest concentrations (699-97-61 and 199-H4-12C) are connected to the HX P&T system. Figure 2-22 shows the maximum Cr(VI) concentrations in the RUM wells at the 100-HR-3 OU. It should be noted that a seasonal trend has not yet been identified.

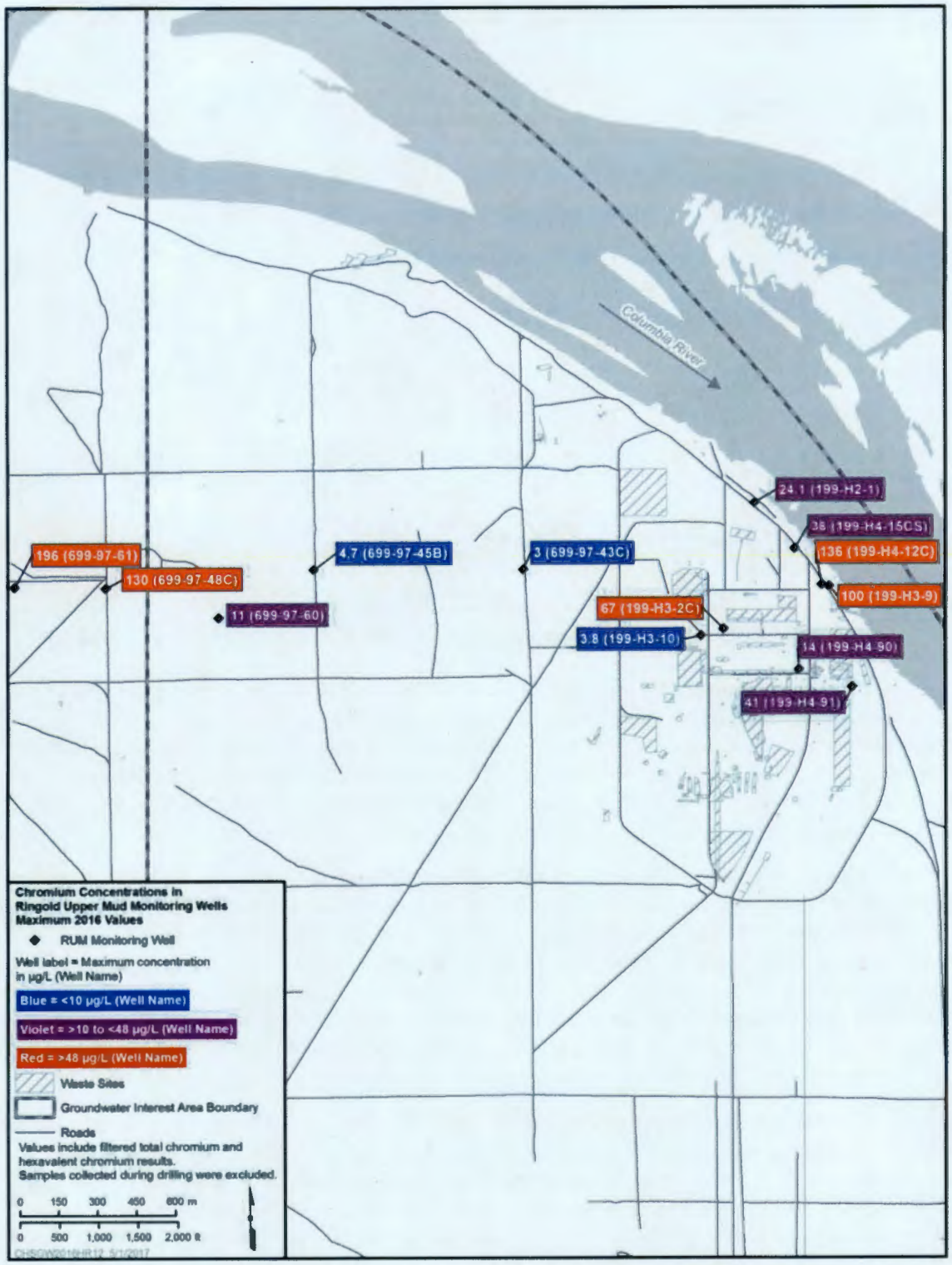

Figure 2-22. 100-H Area and Horn: Cr(VI) in the First Water-Bearing Unit of the RUM, 2016

Well 699-97-61 is located on the western area of the Horn (Figure 2-22) and was connected in 2016. From August to December 2016, extraction flow rates fluctuating between 45 and 53 L/min (12 and 14 gal/min) at well 699-97-61. Concentrations varied from 99 to 196 µg/L during 2016. Well 699-97-61 was installed in 2015 and put into service as an extraction well in 2016 due to the high concentrations seen here and the neighboring RUM well 699-97-48C (Figure 2-22). The Cr(VI) concentration in well 699-97-48C on November 8, 2016 was 130 µg/L.

At well 199-H4-12C, located closer to the river, Cr(VI) concentrations reached as high as 136 µg/L in 2016 (Figure 2-23). This well showed relatively consistent Cr(VI) concentrations during 2016, unlike the previous year where atypically low deviations in concentrations were observed and interpreted to be related to extraction rates and intercommunication between the unconfined and RUM aquifers (Figure 2-23). In order to evaluate this interpretation and stabilize Cr(VI) concentrations, the extraction rates in well 199-H4-12C were decreased from about 110 L/min (29 gal/min) to about 34 L/min (9 gal/min) between November 2015 and March 2016, and then gradually increased back to previous flow rates in July 2016. Cr(VI) concentrations in this well remained consistently on trend and did not significantly fluctuate during this period of variable extraction rate (Figure 2-23). Flow rates and Cr(VI) concentrations in 199-H4-12C will continue to be evaluated and extraction rates will be adjusted if necessary to minimize the potential for aquifer intercommunication.

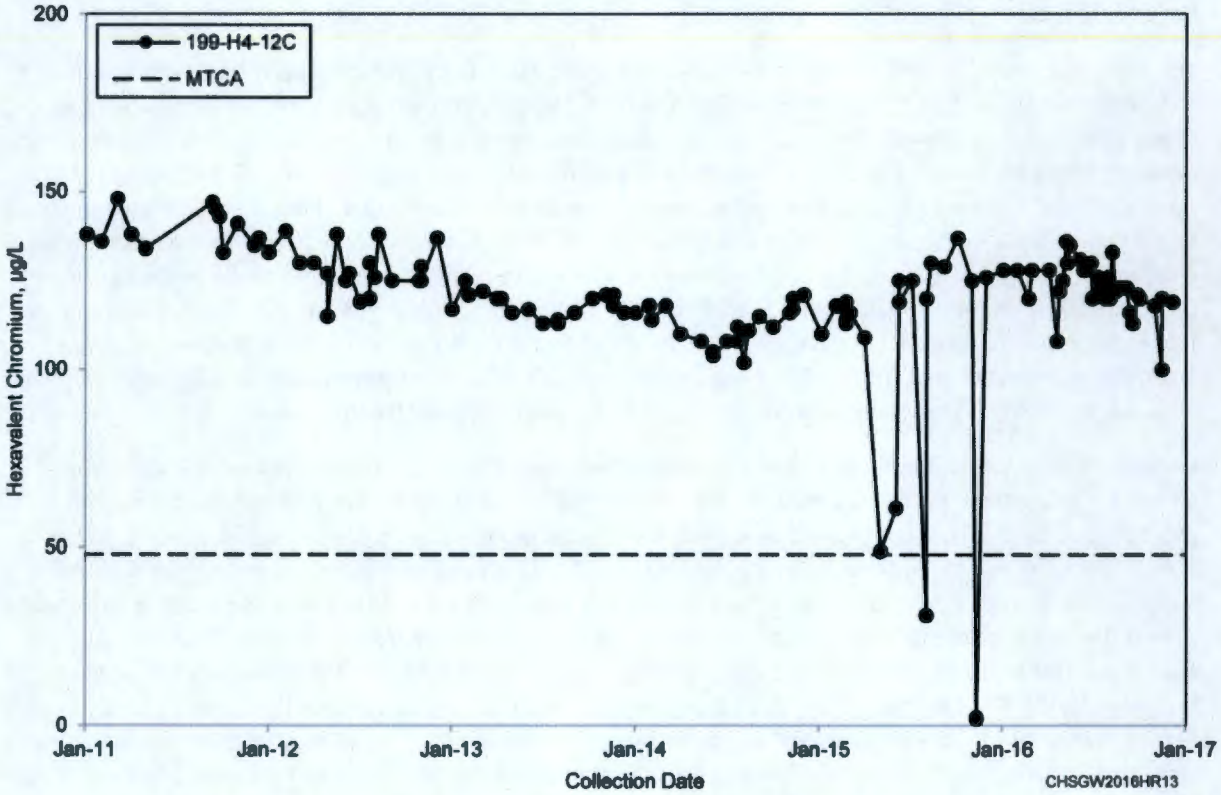

Figure 2-23. Trend Plot for RUM Extraction Well 199-H4-12C

2.2.3.3 *Sulfate*

Sulfate has been detected at increasing levels in monitoring wells located near injection wells. Groundwater that has been treated by the DX P&T system is affected by the addition of sulfuric acid, which changes the sulfate concentrations. The acid is used to lower the pH in the influent groundwater because the SIR-700 IX resin used to remediate Cr(VI) is more efficient at a lower pH. Sodium hydroxide is added to the treated groundwater prior to reinjection into the aquifer to neutralize the acid and return the pH to near neutral. However, sulfate concentrations in the effluent are near the secondary DWS, altering the sulfate concentration of the aquifer near the injection wells. The aquifer sulfate concentrations now appear to be stabilizing in areas near the injection wells at levels above 200 mg/L but below the secondary DWS of 250 mg/L. During 2016, the highest concentrations of sulfate were in wells 199-D5-133, 199-D5-146, and 199-D5-43 (peak concentrations near 220 mg/L), with concentrations stabilizing.

2.2.4 Hydraulic Monitoring

Hydraulic monitoring (i.e., water-level monitoring) is performed to evaluate the effect of the P&T systems on the water table and to evaluate groundwater flow direction and gradient. The hydraulic effects of the P&T systems are superimposed on seasonal fluctuations in the river levels and inland groundwater elevation to evaluate the effectiveness of providing hydraulic containment and capture of Cr(VI) plumes.

Groundwater elevations are measured during regularly scheduled groundwater sampling events, during focused events to collect elevation measurements from many wells over a short period of time, and in selected wells by automated data-logging pressure transducers placed in the wells (automated water-level network [AWLN]). A total of 57 AWLN stations are currently operating at 100-HR-3, including both the 100-D and 100-H river gauges recording water level measurements on an hourly basis. System improvements are discussed in SGW-53543, *Automated Water Level Network Functional Requirements Document*. The number and location of monitoring wells with AWLN data improve the certainty for the hydraulic monitoring system and, therefore, the ability to determine hydraulic capture. Additional localized, dynamic water-level data are collected at each of the P&T extraction and injection wells. Reported water-level data from AWLN wells and manual depth-to-water measurements are reviewed and reduced, and a final dataset is compiled to assemble the groundwater elevation maps.

Groundwater in the southern portion of 100-D generally flows to the northwest, toward the Columbia River. In the northern portion of the 100-D Area, the gradient changes to a northward direction, with groundwater flow inland being more eastward, moving across the Horn toward the 100-H Area. In the 100-H Area, the natural groundwater gradient is toward the east and southeast and toward the Columbia River on the eastern side of the Horn. The groundwater velocity in the 100-D Area is generally lower than that of the 100-H Area (DOE/RL-2009-92, *Report on Investigation of Hexavalent Chromium in the Southwest 100-D Area*). Groundwater flow entering the southern portion of the 100-HR-3 OU tends to flow toward the 100-H Area. Figure 2-24 presents the March 2016 groundwater flow map, which demonstrates a mid-period river stage when the flow direction is changing toward high river-stage conditions. Hydraulic effects of the P&T systems in the 100-HR-3 OU (i.e., the formation of depressions at extraction wells and mounds at injection locations) are superimposed onto these broad seasonal fluctuations. Groundwater mounds are due to the injection of treated groundwater from the P&T systems.

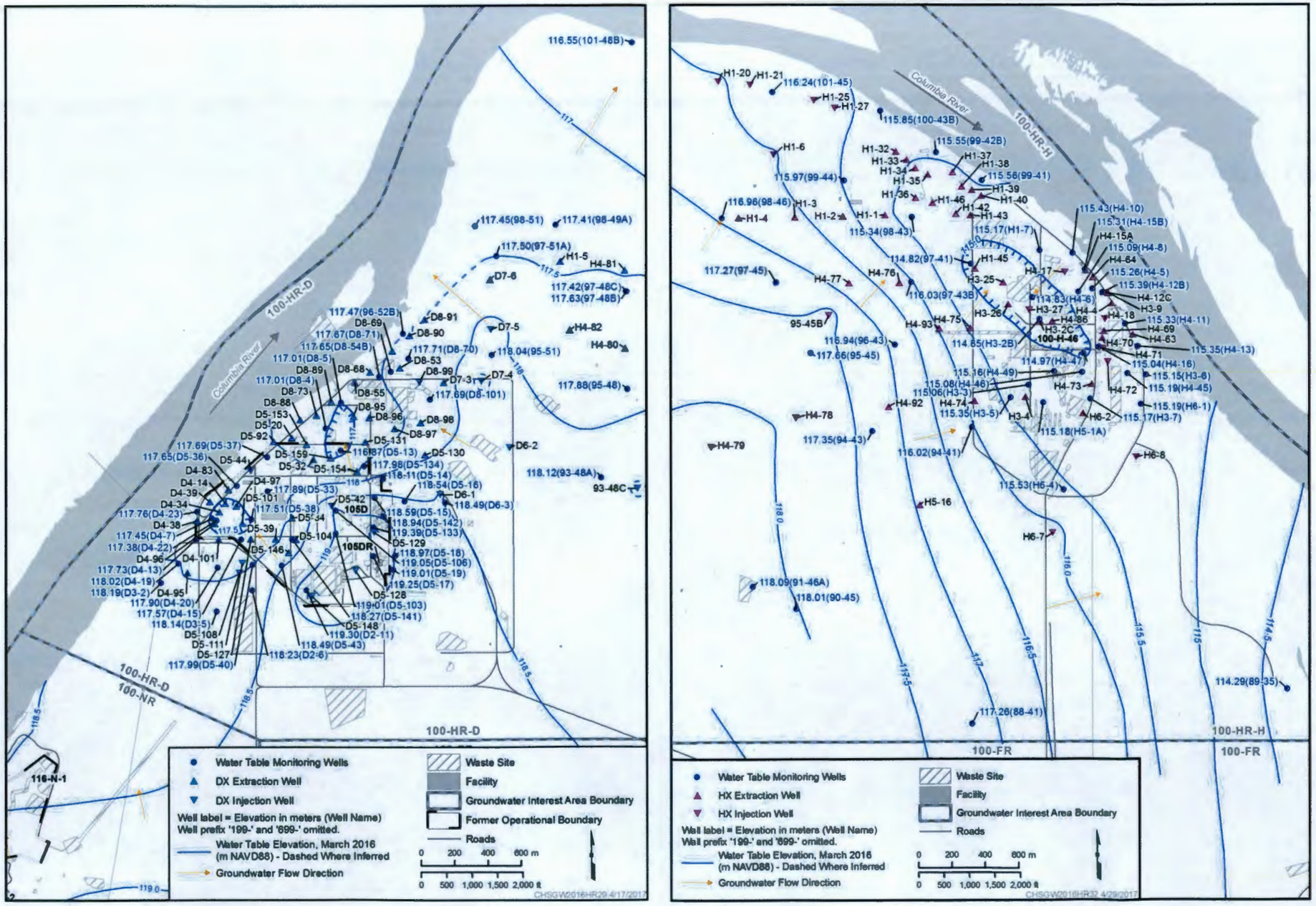

Figure 2-24. 100-HR-3 OU Water Table Elevation Map, March 2016

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Figures 2-17 and 2-18 present the water table maps for June and October 2016, along with the low and high river-stage Cr(VI) plumes. The effect of the P&T systems is most apparent during 2016 in areas where closely-spaced extraction wells create a zone of depression mainly along the shoreline, and where injection wells have created a groundwater mound, especially at DX where large volumes of water are injected into wells that are more closely spaced.

Section 2.2.5 provides a discussion of the effects of seasonal changes in river stage (and water table elevation) on contaminant concentrations in the aquifer and treatment system performance. The highest river stage in 2016 was observed in April (Figure 2-12). The low river-stage period for 2016 was from late August through December, with the lowest river stage in September (Figure 2-12).

2.2.5 Hydraulic Containment

This section compares the estimated extent of hydraulic containment for the 100-HR-3 OU P&T systems with the estimated extent of chromium contamination in groundwater. The assessment is based upon a joint evaluation of groundwater levels, pumping rates (extraction and injection), and water quality data. The extent of hydraulic containment is estimated using two methods:

- Water-level mapping using an extension of the hybrid universal kriging/analytic element method technique detailed in SGW-42305, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance.*
- Groundwater modeling using the 100 Area groundwater model, which is documented in SGW-46279, *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model.*

In each case, the estimated extent of hydraulic containment is depicted using a capture frequency map (CFM). The CFM constructed using the water-level mapping technique is referred to as an interpolated capture frequency map (ICFM) whereas the CFM constructed using the 100 Area groundwater model is referred to as a simulated capture frequency map (SCFM). In each case, the CFM depicts the frequency with which particles representing mobile groundwater and contaminants are captured at extraction wells, calculated over a series of mapped or simulated groundwater levels that represent conditions throughout the year. A frequency of 1.0 indicates that groundwater in the area is hydraulically contained under all conditions encountered during the period (i.e., groundwater is always moving toward extraction wells). A frequency of zero indicates that groundwater in the area was not hydraulically contained under any conditions encountered during the period (i.e., at no time during the period was groundwater moving toward extraction wells). Intermediate frequencies indicate that the groundwater was contained under some conditions, but not all.

Water-level mapping using the ICFM approach was completed using monthly averaged groundwater elevations, pumping rates, and stage of the Columbia River, which resulted in 12 water-level maps encompassing the entire River Corridor, and correspondingly 12 individual depictions of the extent of hydraulic containment for use in constructing an ICFM. Groundwater modeling using the 100 Area groundwater model was completed using monthly average pumping rates, stage of the Columbia River, and other time-varying boundary conditions. This resulted in 12 simulated groundwater level and flow fields, and correspondingly, 12 individual depictions of the extent of hydraulic containment for use in constructing an SCFM.

The ICFM and SCFM are collective estimates for the monitoring period. Emphasis is placed on regions of high frequency and on comparing areas where the ICFM and SCFM are similar or where they differ. Where the ICFM and SCFM are similar, confidence is relatively high that containment is being achieved (where both maps suggest that containment is achieved); or that it is either weak or it is not being achieved (where both maps suggest that containment is not achieved or, in most cases, where capture frequencies are very low). Where the ICFM and SCFM differ substantially, confidence is lower in the assessment of containment because one method suggests that containment is being achieved whereas the other method suggests either that containment is not achieved or that it is weak.

The extent of chromium contamination in groundwater during high and low river stage conditions is estimated using a systematic approach to develop contaminant plume maps using an integrated numerical interpolation methodology, as detailed in ECF-HANFORD-16-0138, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2016 Hanford Site Groundwater Monitoring Report.*

Figures 2-25 through 2-30 compare the estimated extent of hydraulic containment and the estimated extent of chromium contamination in groundwater for both high and low river-stage conditions for the 100-D Area as follows:

- Figure 2-25 and Figure 2-26 depict chromium contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-27 and Figure 2-28 depict chromium contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-29 depicts the groundwater flow lines from particle tracking to estimate the aquifer capture zone of the DX P&T system over a 10-year period with the 2016 flow field repeated annually, and Figure 2-30 overlays the capture zone flow lines on the chromium plume contours under low river-stage conditions.

Figures 2-31 through 2-36 compare the estimated extent of hydraulic containment and the estimated extent of chromium contamination in groundwater for both high and low river-stage conditions for the 100-H Area as follows:

- Figure 2-31 and Figure 2-32 depict chromium contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-33 and Figure 2-34 depict chromium contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-35 depicts the groundwater flow lines from particle tracking to estimate the aquifer capture zone of the HX P&T system over a 10-year period with the 2016 flow field repeated annually, and Figure 2-36 overlays the capture zone flow lines on the chromium plume contours under low river-stage conditions.

The capture flow lines in some areas may undergo a more indirect path to an extraction well, as observed especially in Figure 2-35 and Figure 2-36, which reflects the effects of river stage fluctuations and aquifer hydraulic conditions on a particle flow path. When comparing those tortuous flow paths to capture frequency maps, it is shown that even in areas of relatively low capture frequency, flow lines calculated under transient conditions will, in most cases, result in migration pathways that ultimately lead to capture at an extraction well. In such cases, low capture frequency is not evidence of failure to protect the river from contaminant discharges; instead, it suggests that hydraulic containment is relatively weak, and that capture may take longer to occur.

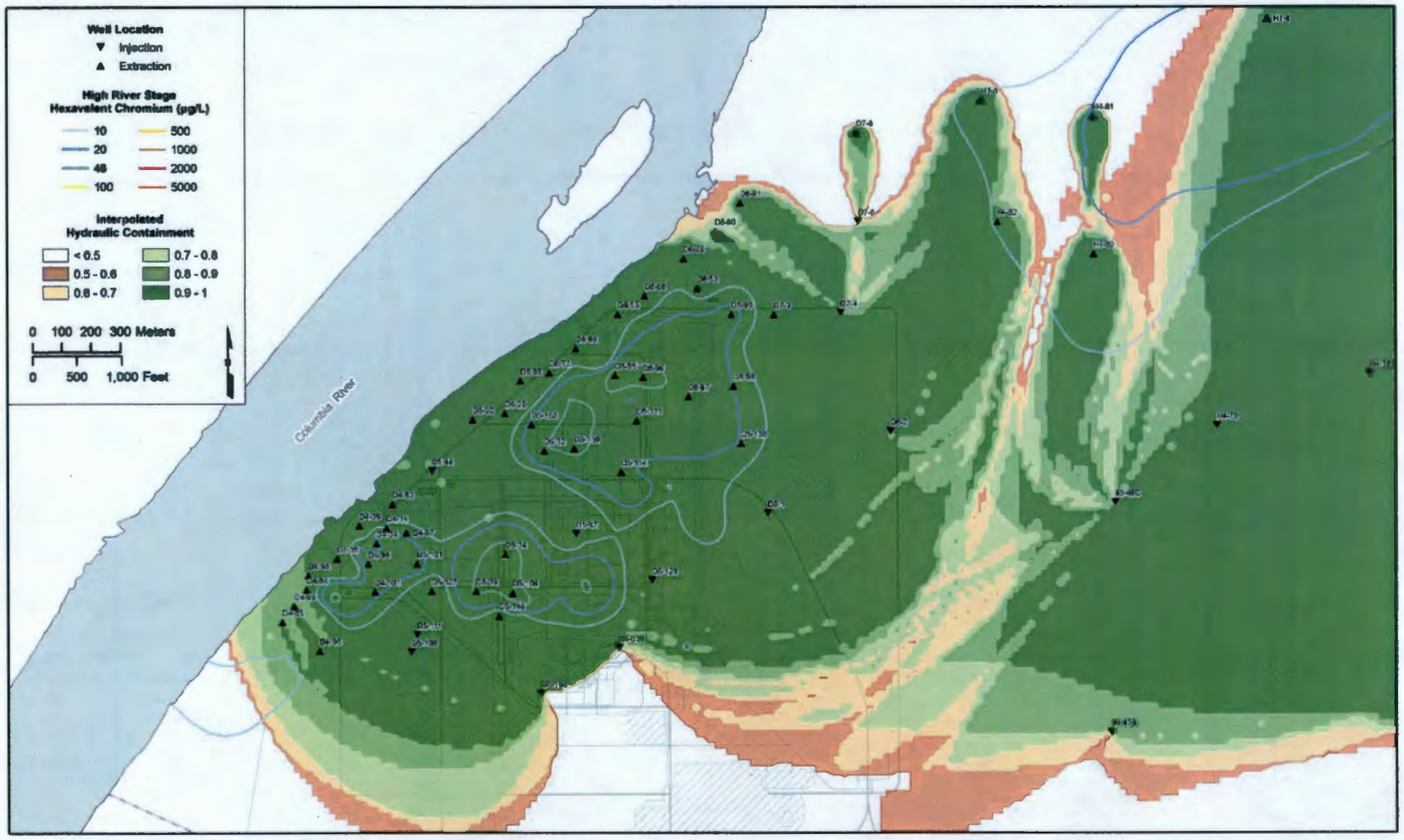

Figure 2-25. 100-D Area Interpolated CFM and High River Stage Chromium Contamination

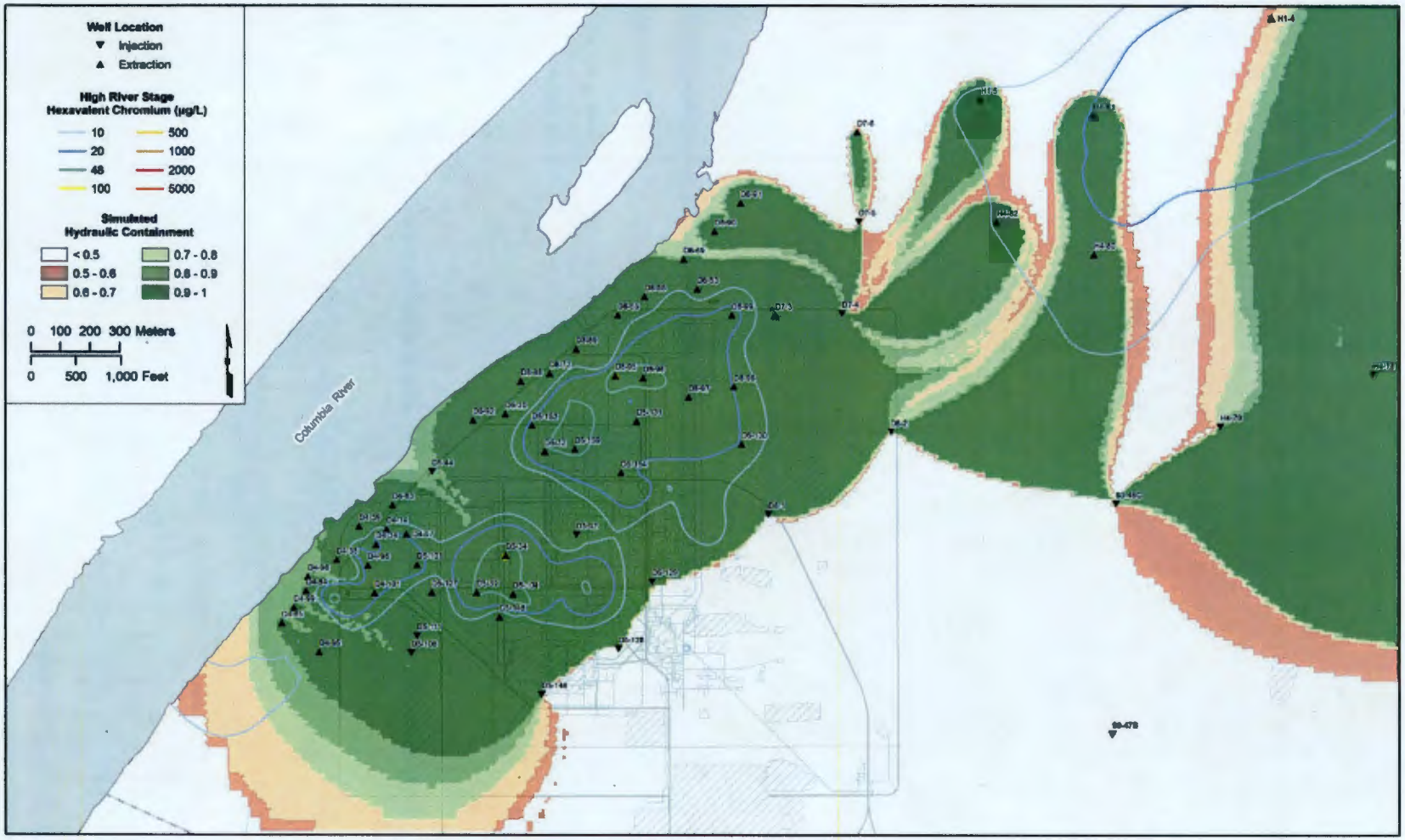

Figure 2-26. 100-D Area Simulated CFM and High River Stage Chromium Contamination

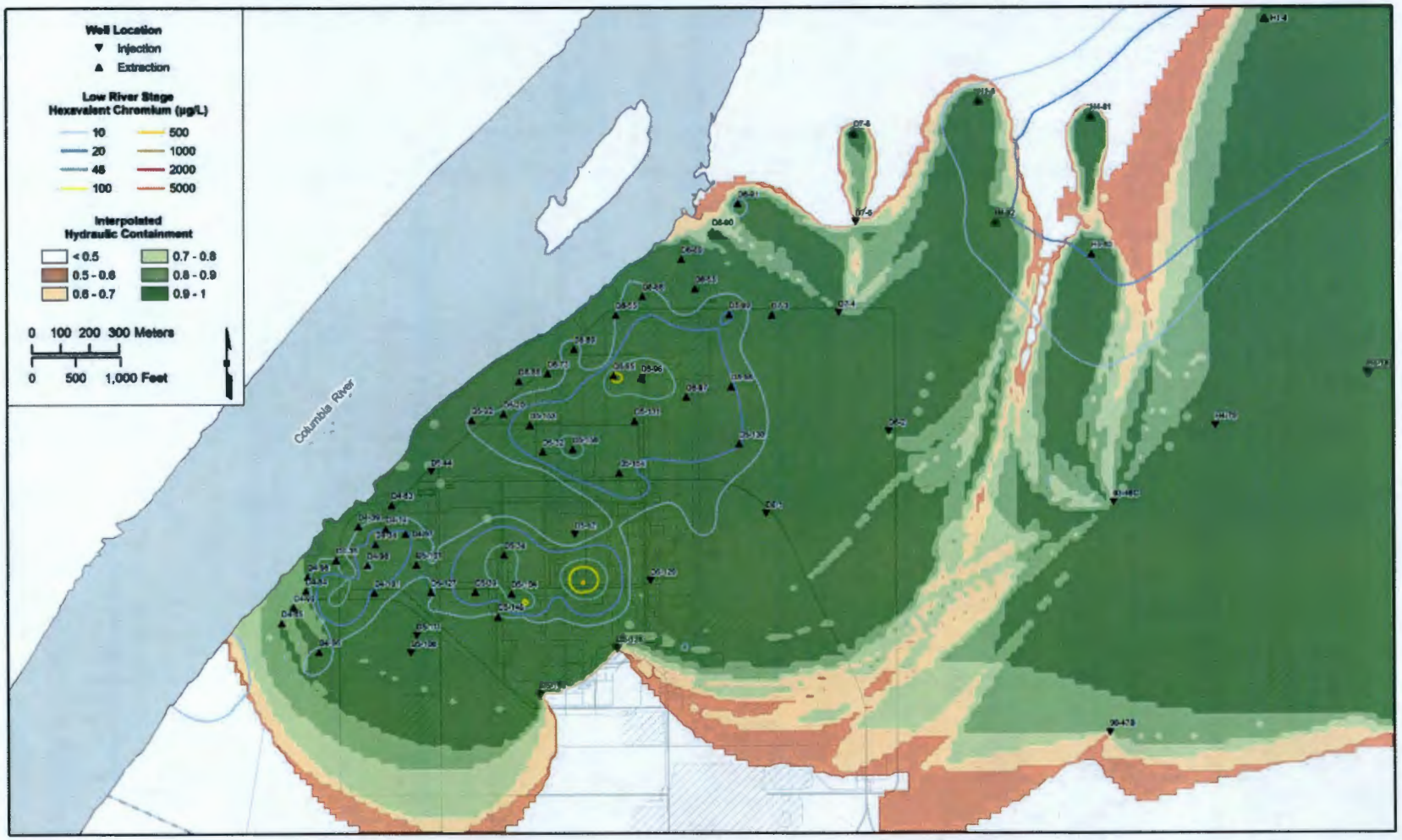

Figure 2-27. 100-D Area Interpolated CFM and Low River Stage Chromium Contamination

Figure 2-28. 100-D Area Simulated CFM and Low River Stage Chromium Contamination

Figure 2-29. 100-D Area Groundwater Flow Lines of Capture Zone for 2016 Flow Field

Figure 2-30. 100-D Area Groundwater Flow Lines of Capture Zone Overlay with Low River Stage Chromium Plume Contours

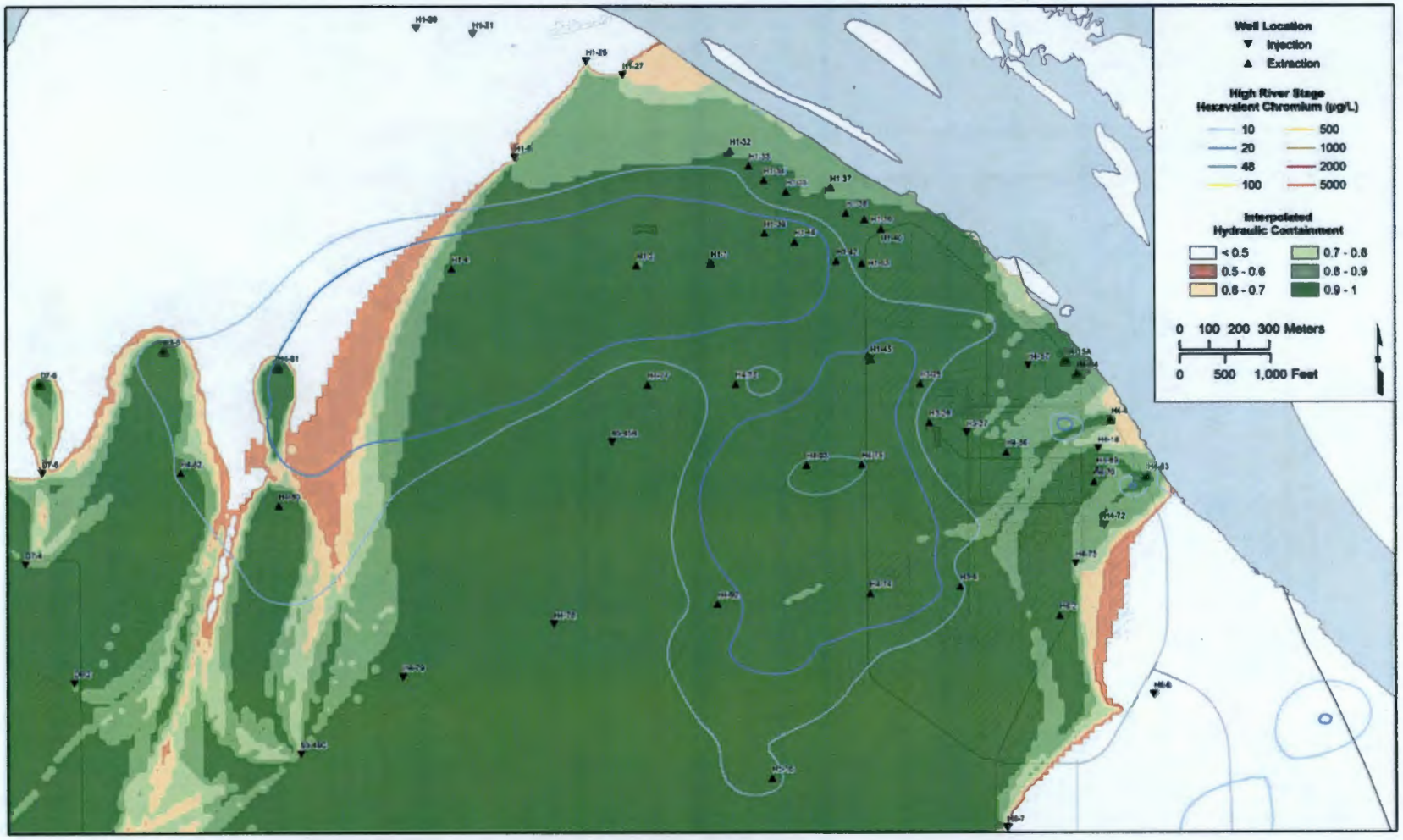

Figure 2-31. 100-H Area Interpolated CFM and High River Stage Chromium Contamination

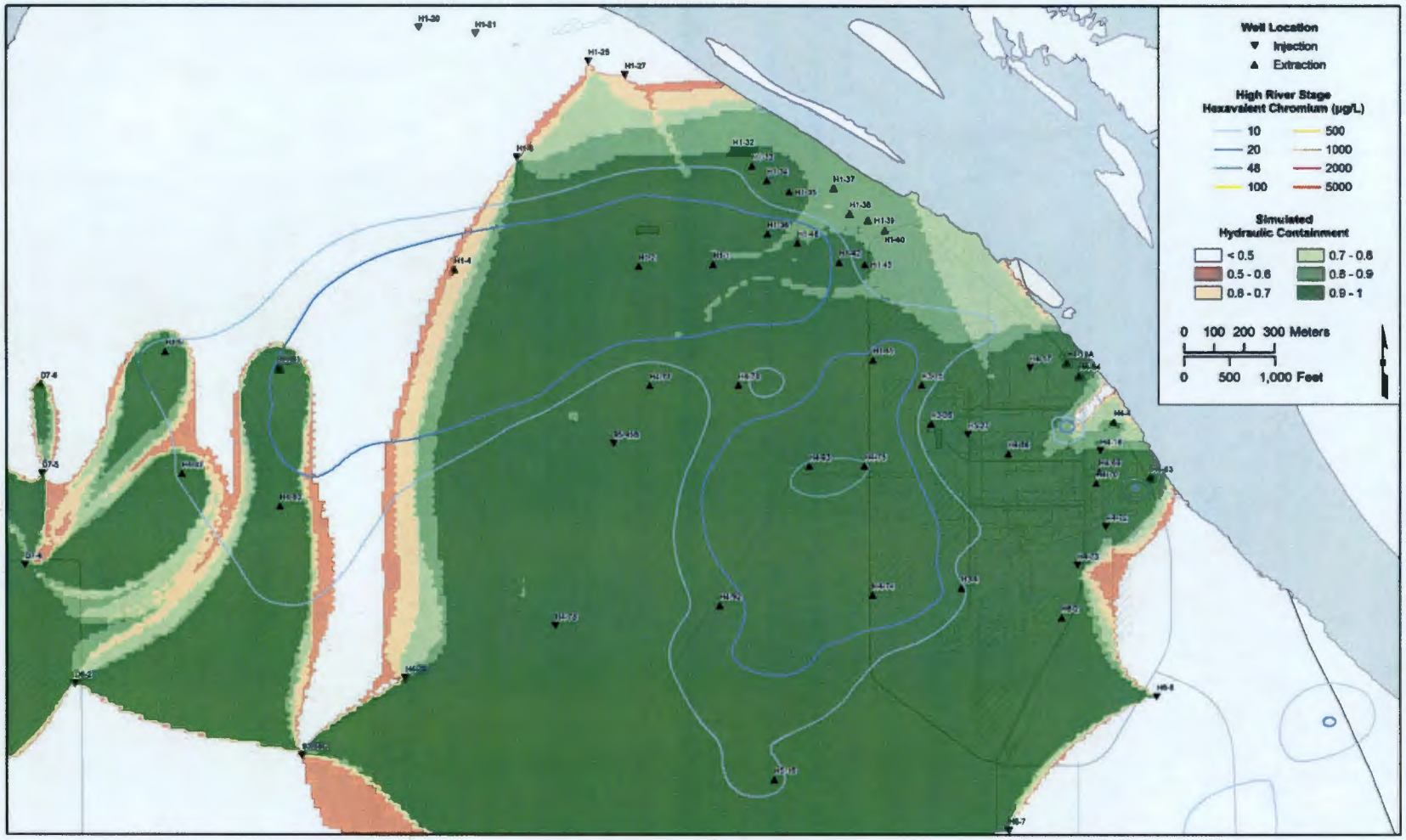

Figure 2-32. 100-H Area Simulated CFM and High River Stage Chromium Contamination

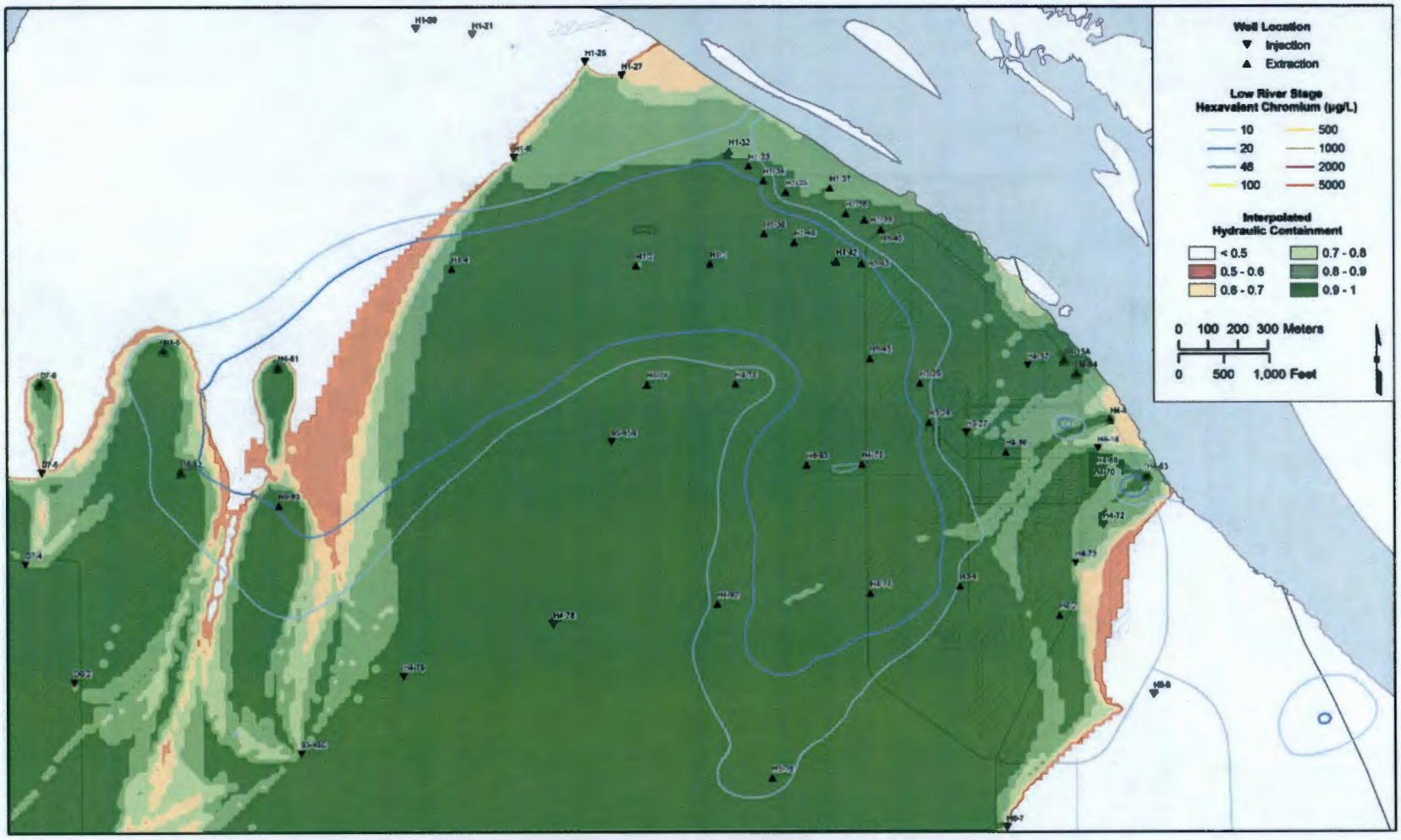

Figure 2-33. 100-H Area Interpolated CFM and Low River Stage Chromium Contamination

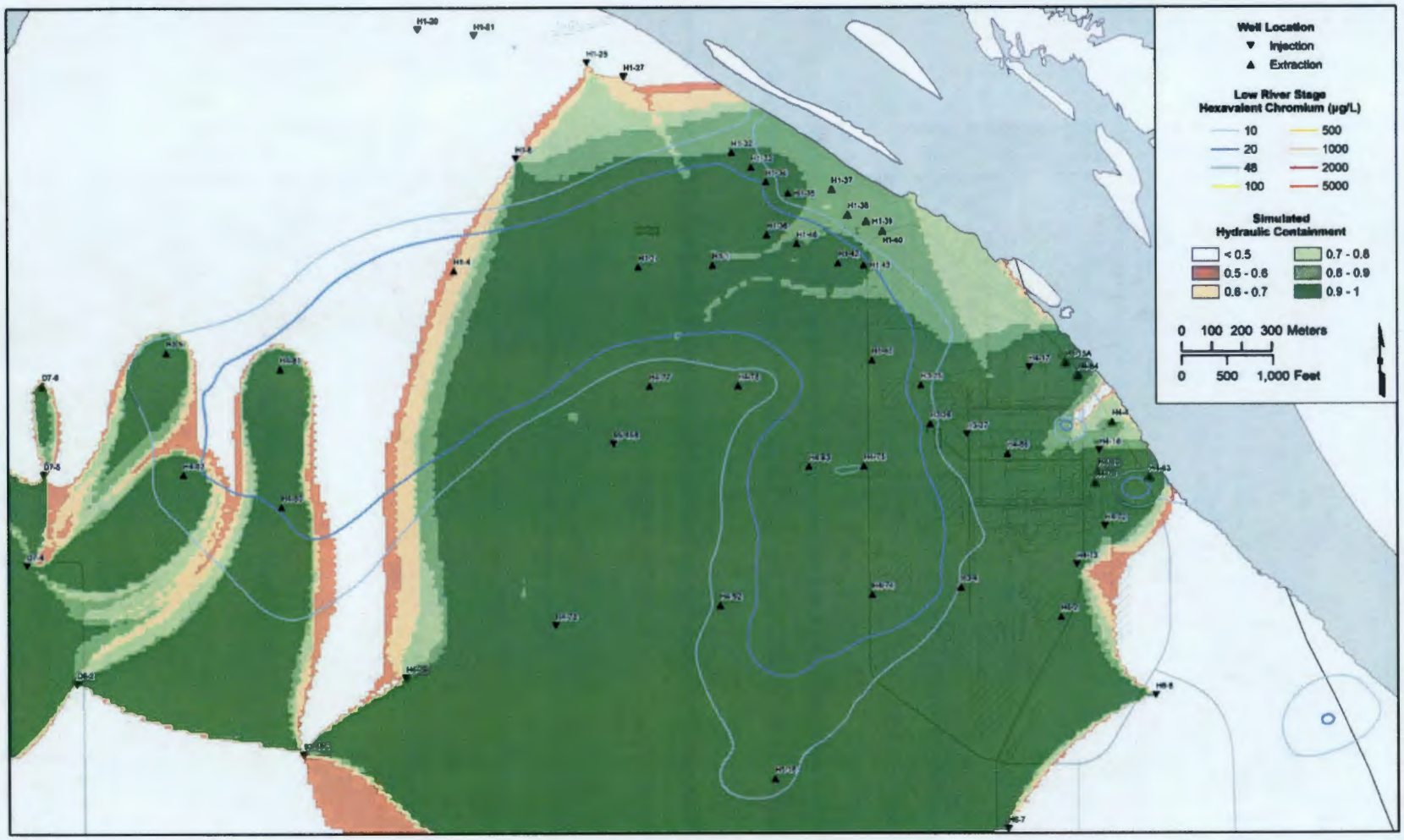

Figure 2-34. 100-H Area Simulated CFM and Low River Stage Chromium Contamination

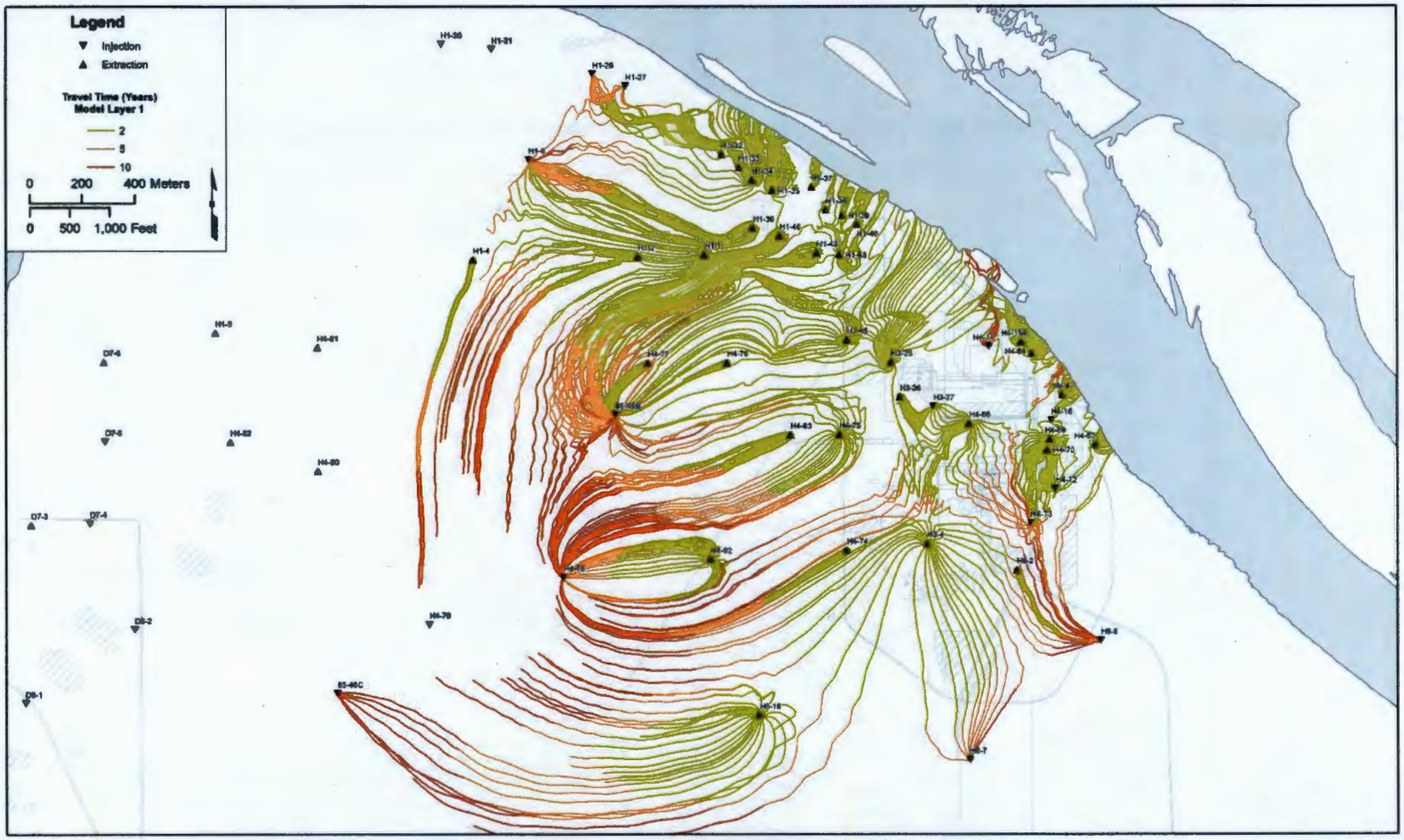

Figure 2-35. 100-H Area Groundwater Flow Lines of Capture Zone Flow Field, 2016

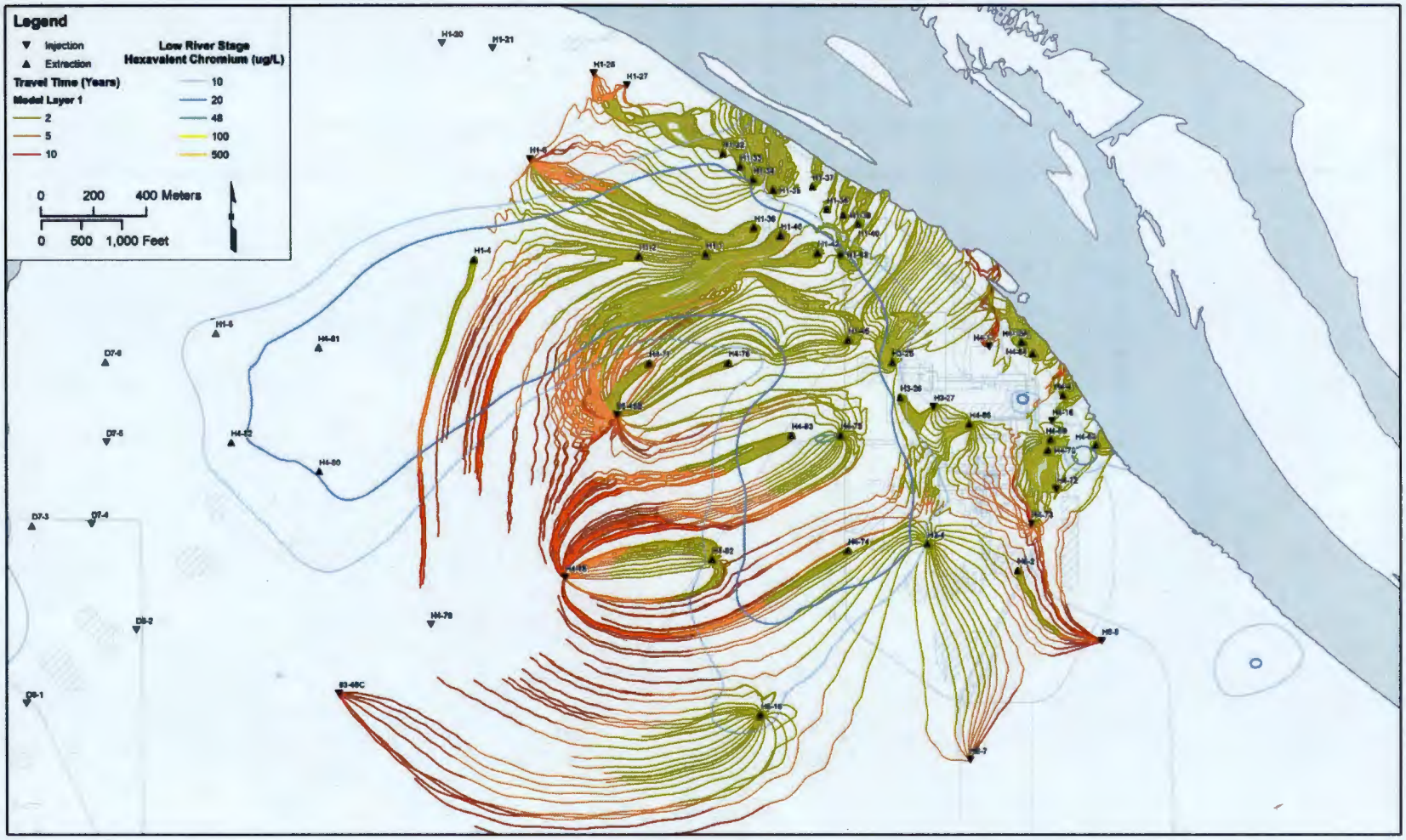

Figure 2-36. 100-H Area Groundwater Flow Lines of Capture Zone Overlay with Low River Stage Chromium Plume Contours

ECF-HANFORD-17-0028, *Description of Groundwater Calculations and Assessments for the Calendar Year 2016 (CY2016) 100 Areas Pump-and-Treat Report*, presents details on the specific calculations used to produce these figures depicting capture, including updates to and implementation of the 100 Area groundwater model; the methodology for water-level mapping; and the development of the ICFM and SCFM. Finally, although advanced interpolation techniques are used in developing water-level maps, confidence in these maps is heavily dependent on the density of the monitoring well network and the quality of the available data. During 2016, the extent and quality of the available AWLN data continued improving compared to previous years, due to station technology improvements and additional AWLN stations. However, although the interpolated water-level maps are consistent with observations and qualitative interpretations of aquifer conditions and resulting flow fields during the year, improvements to the monitoring network by increasing the AWLN stations and reducing reliance on synoptic water-level measurements, are required to increase confidence in these interpretations. Maintenance and data checks are being conducted on a regular basis to improve the system reliability and data quality.

2.2.6 River Protection Evaluation

The river protection status of conditions at the 100-HR-3 OU is based on an assessment of the hydraulic effects of operation of the remedial action systems, along with an evaluation of changes in the discharge boundary head conditions associated with the Columbia River and the inferred distribution of Cr(VI) in groundwater. Both a quantitative and a qualitative approach are used for this assessment. The assessment indicates that the river protection status improved in 2016 over the assessment for 2015.

This subsection describes the river protection evaluation process and presents the results of the 2016 analysis. SGW-54209, *Systematic Method for Evaluating the Length of the Hanford Reach of the Columbia River Shoreline that is Protected from Further Discharges of Chromium from the 100 Area Operable Units (OUs)*, describes a method for evaluating progress toward attaining RAO #1, referred to as the "river protection objective." Since RAO #1 emphasizes protection of aquatic receptors, the river protection objective focuses on the performance of P&T (and other remedies) in protecting the Columbia River from further discharges of dissolved chromium from inland at concentrations above 10 µg/L. Use of this standard is consistent with Tri-Party Agreement, Milestone M-016-110-T01. ECF-HANFORD-12-0078, *Assessment of the River Protection Objective: Calculation for Calendar Year 2011 (CY2011)*, and demonstrates the methods described in SGW-54209 for evaluating the progress toward attaining the river protection objective using data obtained during (or prior to) 2011.

An assessment of the progress toward attaining the river protection objective for 2016 is presented in Figures 2-37 and 2-38 and Figures 2-39 and 2-40. SGW-54209 details the technical methods and process that are used to complete the calculations necessary to prepare these figures. ECF-HANFORD-17-0028 presents details for the specific calculations used to produce these figures for 2016. Figures 2-37 through 2-40 present the results of contaminant standard and trend tests described in SGW-54209 to identify low-, moderate-, and high-concern wells, using the symbols in Table 2-12.

Table 2-12. Standard and Trend Test Symbology for Wells

Low Concern Wells			High Concern Wells			Moderate Concern Wells		
Symbol	Standard	Trend	Symbol	Standard	Trend	Symbol	Standard	Trend
▼	Less than	Down	▲	Exceed	Up	△	Less than	Up
■	Less than	None	■	Exceed	None	▽	Exceed	Down
●	Less than	NSD	●	Exceed	NSD			

NSD = not sufficient data to calculate trend

Shoreline lengths are calculated and reported in increments of 100 m (328 ft); the results of the assessment are presented in these figures as color-filled circles of diameter equal to 100 m (328 ft). The color fill of each circle indicates the relative river protection objective status (i.e., green = protected; yellow = protected, but action may be required to ensure long-term protectiveness; and red = not protected) for the unconfined aquifer only. Table 2-13 presents the symbols depicting the results of the river protection evaluation.

Table 2-13. Symbology for Status of River Protection Objective

Symbol	Explanation
●	Protected
●	Protected (Action May Be Required)
●	Not Protected

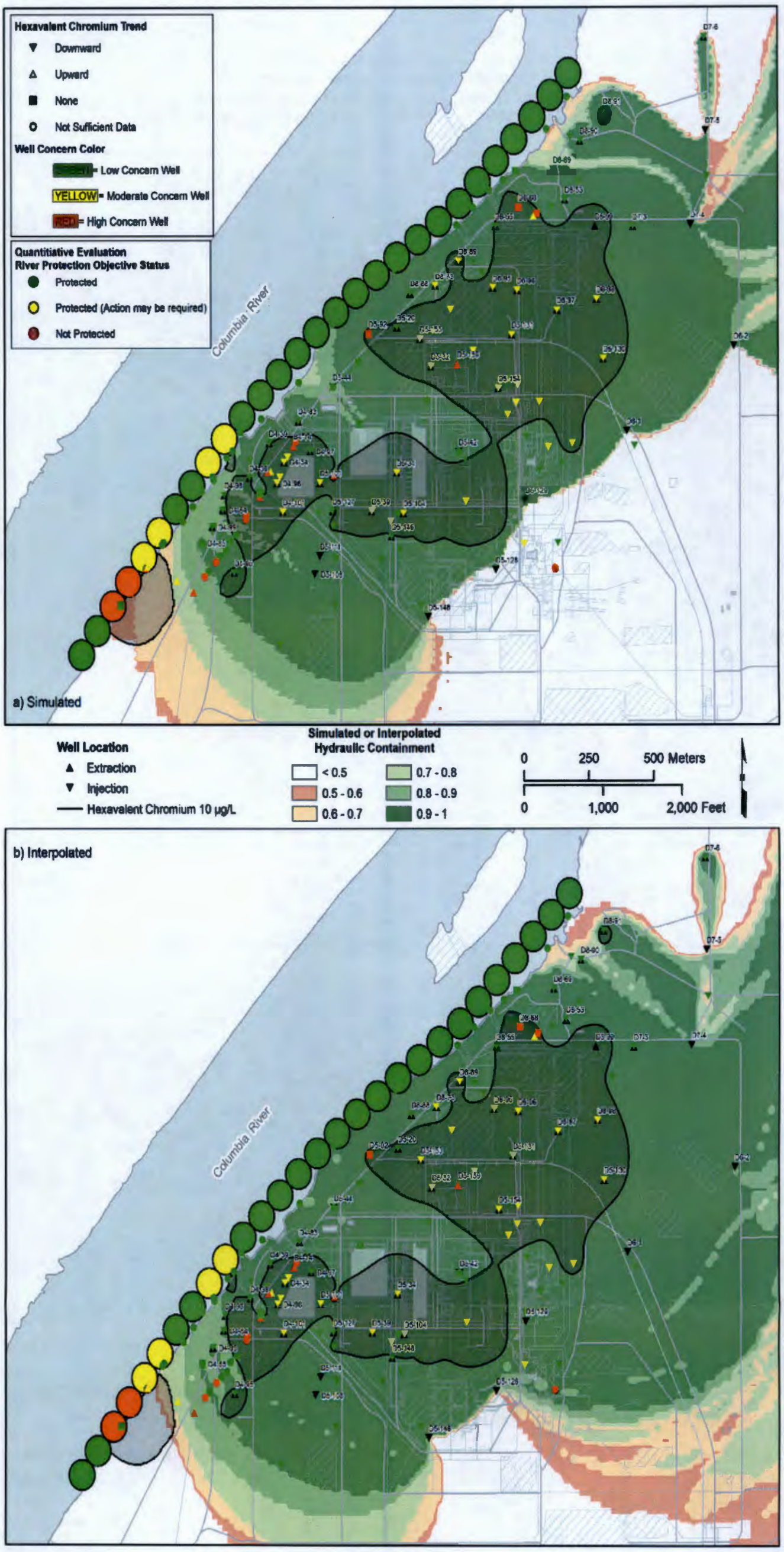

Figure 2-37. 100-D Area Quantitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River Stage Chromium Contamination above 10 µg/L and Results of Standard Test and Trend Test

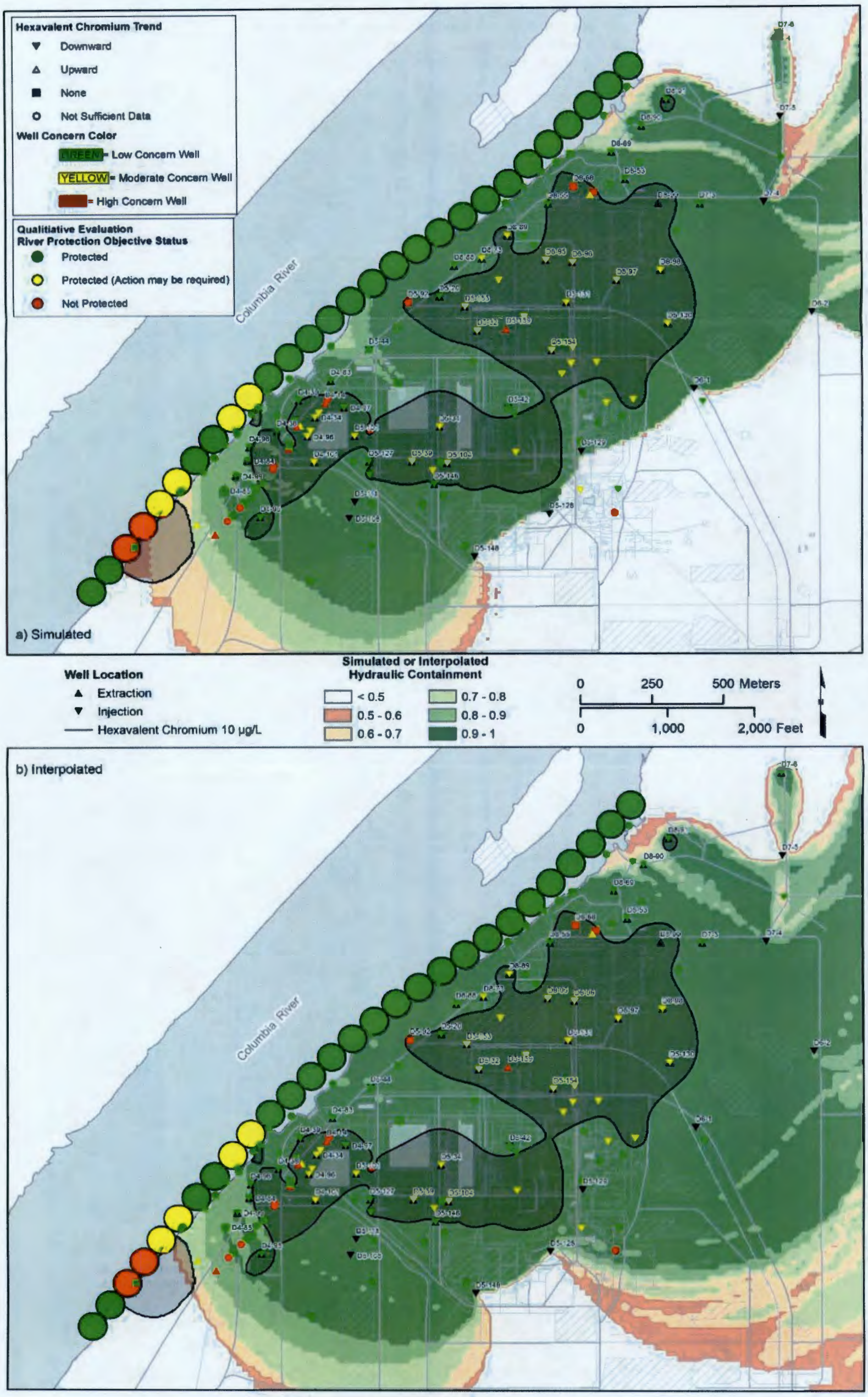

Figure 2-38. 100-D Area Qualitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River Stage Chromium Contamination above 10 µg/L and Results of Standard Test and Trend Test

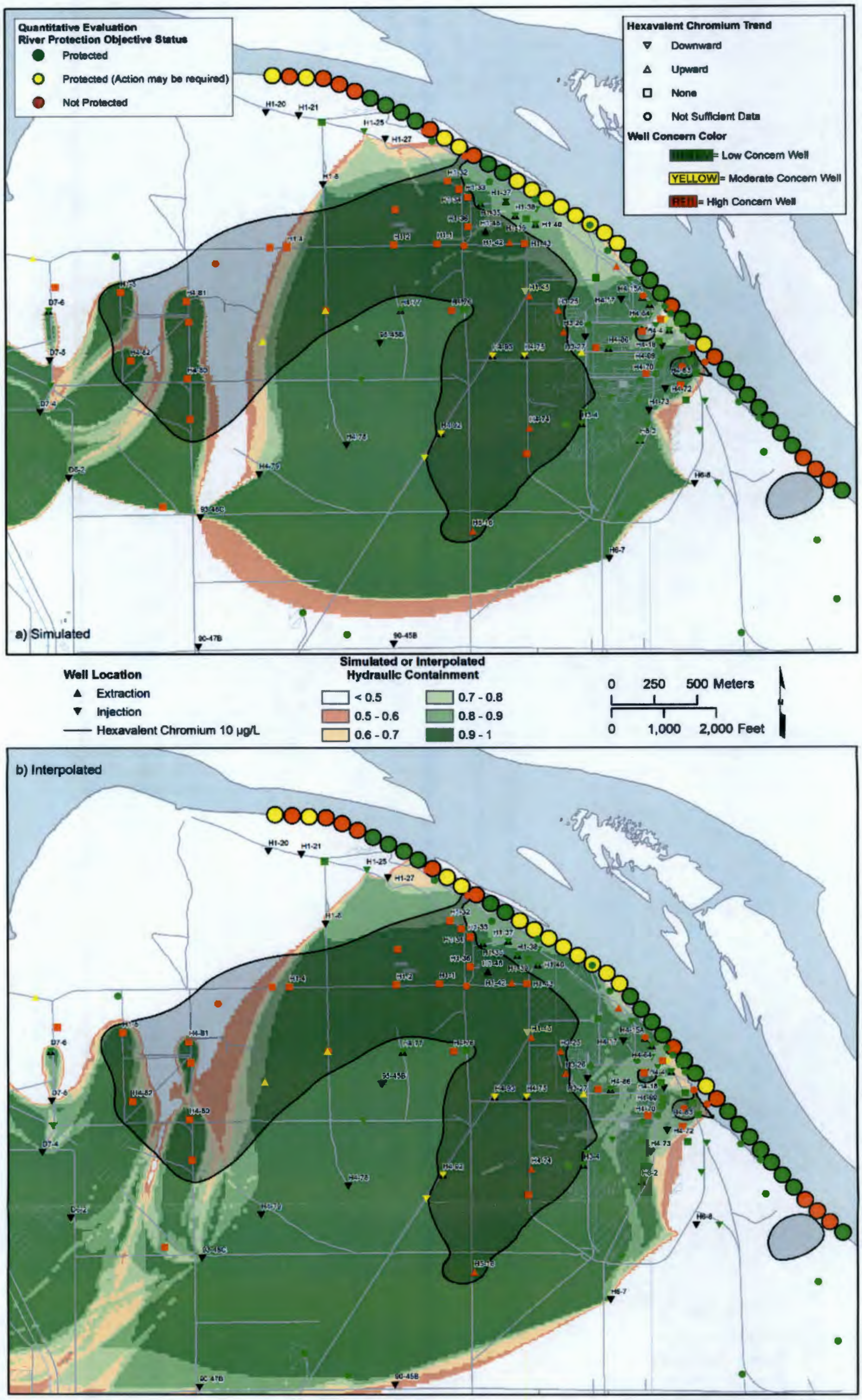

Figure 2-39. 100-H Area Quantitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River Stage Chromium Contamination above 10 µg/L and Results of Standard Test and Trend Test

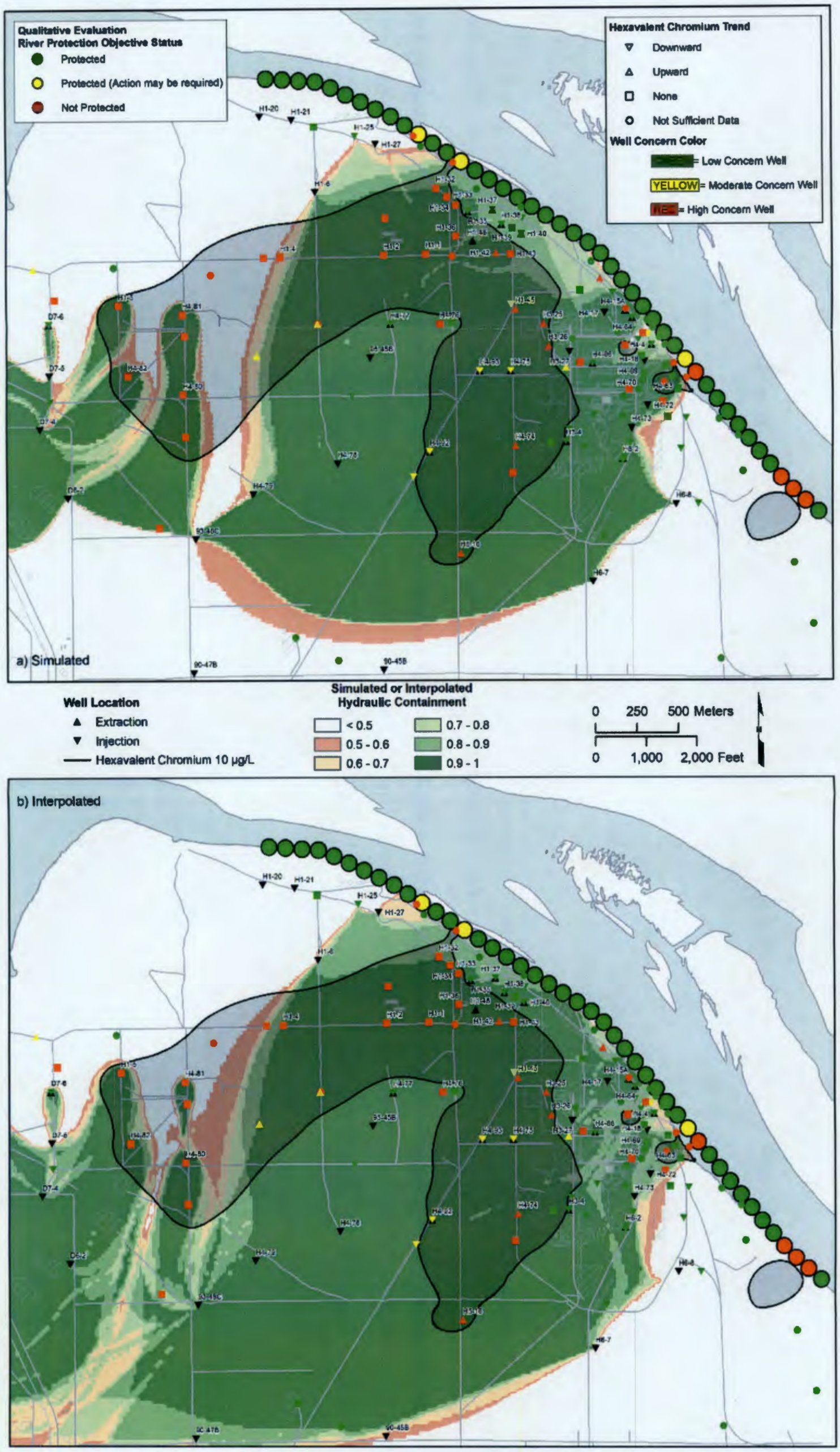

Figure 2-40. 100-H Area Qualitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River Stage Chromium Contamination above 10 µg/L and Results of Standard Test and Trend Test

Figures 2-37 and 2-38 depict the assessment of progress toward attaining the river protection objective for chromium in the 100-D Area. Figure 2-37 shows the results of the quantitative evaluation of the objective, which is determined based upon overlay and quantitative comparison of the extent of chromium contamination with the extent of hydraulic containment. Figure 2-38 depicts the results of the qualitative evaluation of the objective, which is based upon the quantitative evaluation but also incorporates qualitative considerations (e.g., the duration and magnitude of hydraulic gradients along the shoreline, the locations of pumping wells, and trends in concentrations). It should be noted that, similarly to calendar year (CY) 2015, for CY 2016 the quantitative and qualitative evaluations were identical, as it was concluded that the quantitative evaluation reflected rather accurately the conditions in the aquifer in 100-D Area (that is, effects of pumping and river stage on hydraulic gradients, plume migration and concentration trends); therefore, adjustments were not required. Based on these qualitative calculations, the river protection evaluation for the 100-D Area is as follows (note that all lengths are rounded to the nearest 5 m [or 5 ft]):

- Total length of shoreline adjacent to the 100-D Area: 2,800 m (9,185 ft)
- Length identified as protected: 2,200 m (7,215 ft)
- Length identified as protected (action may be required): 400 m (1,315 ft)
- Length identified as not protected: 200 m (655 ft)

Figures 2-39 and 2-40 depict the assessment of progress toward attaining the river protection objective for chromium in the 100-HR-3 OU/100-H Area. Figure 2-39 depicts the results of the quantitative evaluation of the objective, which are determined based upon overlay and quantitative comparison of the extent of chromium contamination with the extent of hydraulic containment. Figure 2-40 shows the results of the qualitative evaluation of the objective. Based on these qualitative calculations, the river protection evaluation for the 100-H Area is as follows:

- Total length of shoreline adjacent to the 100-H Area: 4,400 m (14,430 ft)
- Length identified as protected: 3,700 m (12,135 ft)
- Length identified as protected (action may be required): 300 m (985 ft)
- Length identified as not protected: 400 m (1,310 ft)

Table 2-14 compares the results of the qualitative evaluations for the 100-D Area and the 100-H Area for 2016 and 2015. The effect of river-stage fluctuations on groundwater flow, combined with the aquifer response to pumping, resulted in qualitative evaluations of the river protection objective for 2016 that indicate consistently efficient performance of the DX and HX P&T systems.

Quantitative evaluations of the river protection objective provide a conservative assessment of shoreline protection; qualitative evaluations incorporate the transient effects of hydraulic capture. The CFMs describe the aggregate fate of particles, under an ensemble of steady-state conditions, each reflecting a snapshot of hydraulic gradient magnitude and direction due to pumping and fluctuations of river stage. As a result, CFMs only indicate the relative strength of hydraulic containment and not a depiction of actual transient hydraulic capture patterns. CFMs provide an effective metric to evaluate the relative strength of the capture zone, but they should not be considered an absolute indicator of hydraulic containment success or failure. Even during months of steeper hydraulic gradients near the shoreline, groundwater flow velocities result in actual plume migration expected to occur over very short distances. Relative dissipation of hydraulic gradient magnitude in subsequent months results in even slower plume migration and transient hydraulic containment. Capture can, and does, occur in areas where CFMs indicate relatively low-capture frequency.

Table 2-14. Comparison of River Protection Assessment Results

Assessed Shoreline Lengths 100-HR-3/100-D	2015	2016	Change from 2015 to 2016*
Total length of shoreline adjacent to 100-D Area	2,800 m (9,185 ft)		
Length identified as "protected" Percent of shoreline "protected"	2,400 m (7,870 ft) 86% of shoreline	2,200 m (7,215 ft) 79% of shoreline	300 m (985 ft) of shoreline identified as "protected" now identified as "protected (action may be required)" 100 m (330 ft) of shoreline identified as "protected (action may be required)" now identified as "protected"
Length identified as "protected (action may be required)" Percent of shoreline "protected (action may be required)"	100 m (330 ft) 3% of shoreline	400 m (1,315 ft) 14% of shoreline	300 m (985 ft) of shoreline identified as "protected" now identified as "protected (action may be required)" 100 m (330 ft) of shoreline identified as "protected (action may be required)" now identified as "protected" 100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)"
Length identified as "not protected" Percent of shoreline "not protected"	300 m (985 ft) 11% of shoreline	200 m (655 ft) 7% of shoreline	100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)"
Assessed Shoreline Lengths 100-HR-3/100-H	**2015**	**2016**	**Change from 2015 to 2016**
Total length of shoreline adjacent to 100-H Area	4,400 m (14,430 ft)		
Length identified as "protected" Percent of shoreline "protected"	3,100 m (10,175 ft) 71% of shoreline	3,700 m (12,135 ft) 84% of shoreline	800 m (2,625 ft) of shoreline previously identified as "protected (action may be required)" now identified as "protected" 200 m (660 ft) of shoreline previously identified as "protected" now identified as "protected (action may be required)"

Table 2-14. Comparison of River Protection Assessment Results

Assessed Shoreline Lengths 100-HR-3/100-H	2015	2016	Change from 2015 to 2016
Length identified as "protected (action may be required)" Percent of shoreline "protected (action may be required)"	800 m (2,625 ft) 18% of shoreline	300 m (985 ft) 7% of shoreline	800 m (2,625 ft) of shoreline previously identified as "protected (action may be required)" now identified as "protected" 200 m (660 ft) of shoreline previously identified as "protected" now identified as "protected (action may be required)" 100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)"
Length identified as "not protected" Percent of shoreline "not protected"	500 m (1,640 ft) 11% of shoreline	400 m (1,310 ft) 9% of shoreline	100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)"

*Details on year-to-year changes are provided in ECF-HANFORD-17-0028, *Description of Groundwater Calculations and Assessments for the Calendar Year 2016 (CY2016) 100 Areas Pump-and-Treat Report.*

The chromium plume depiction for 2016 illustrates that implementation of well realignments, combined with moderate river stage fluctuation and short-duration high river-stage conditions, has translated into increased hydraulic containment. Comparison of the chromium plume depictions for 2015 and 2016 indicates a consistent number of shoreline segments where chromium concentrations are below the aquatic standard, including in areas of lower-capture frequency. Acknowledgement of these processes is reflected in the qualitative evaluation results.

2.2.7 Comparison of Simulated to Measured Contaminant Mass Recovery

Comparison of the ICFM and SCFM provides comparative depiction of the hydraulic simulation capabilities of the flow component of the 100 Area groundwater model. A similar qualitative comparison can be made for the transport component of the 100 Area groundwater model by comparing simulated and measured rates of contaminant mass recovery.

Figure 2-41 presents a comparison of the monthly and cumulative mass of chromium that was recovered throughout 100-HR-3 OU at the DX and HX P&T systems for 2016, as determined using actual influent concentrations and flow rates versus the mass recovery simulated using the 100 Area groundwater model. For the DX and HX P&T systems, mass recovery is presented showing the results with extraction from the RUM wells included in the plot and with the mass from the RUM wells excluded from the measured recovery plot, since the groundwater model addresses the presence of chromium in the unconfined aquifer only. As indicated in Figure 2-41, more than half the mass recovered at the HX P&T system originates in the RUM aquifer. For this simulation, the initial distribution of chromium in groundwater was assumed to

be the low river-stage depiction of chromium for 2015, reflecting data collected during the period from September 1, 2015, to January 15, 2016, as presented in ECF-HANFORD-16-0061.

The model typically under-predicts the mass of chromium that was recovered by each system. ECF-HANFORD-17-0028 presents graphs comparing the simulated and measured mass recovery at each individual extraction well for the HX and DX P&T systems, which generally compare well to the simulated results presented in Figure 2-41. In each case, however, there are system-specific and systematic conditions that might lead to differences between the simulated and measured values, most notably the groundwater model assumption that no continuing sources are present.

At the DX P&T system, chromium mass immediately downgradient of the 100-D-100 waste site may be under-represented in the initial conditions of the numerical model. Mass recovery at wells 199-D5-104 and 199-D5-34 suggests that higher chromium concentrations are present in the aquifer near those wells, compared to the initial plume for the simulation. The investigation at the 100-D-100 waste site (SGW-58416) indicated that chromate-substituted calcite remaining in the periodically rewetted zone soil and aquifer sediment provides a potential source of ongoing release of Cr(VI) into groundwater. Since the simulated mass recovery reflects only the dissolved chromium distribution as delineated for low river-stage conditions in 2015, and does not include any contribution from continuing sources, the mass recovery may not correlate well in locations where a source remains. This condition may also affect the long-term model predictions of cleanup time since unaccounted mass may remain in the soil and/or the aquifer in isolated locations.

Recovery data from extraction wells near the northwestern end of the ISRM (e.g., 199-D4-96, 199-D4-97) indicate a number of minor concentration differences that are not reflected in the simulation results, and that contribute to the small mass-recovery difference between the measured and calculated values. This could be due to higher concentration levels in the aquifer in the area upgradient of those wells, which is not reflected in the initial conditions used in the simulation. However, the results of the river-protection evaluation suggest strong hydraulic containment in that area.

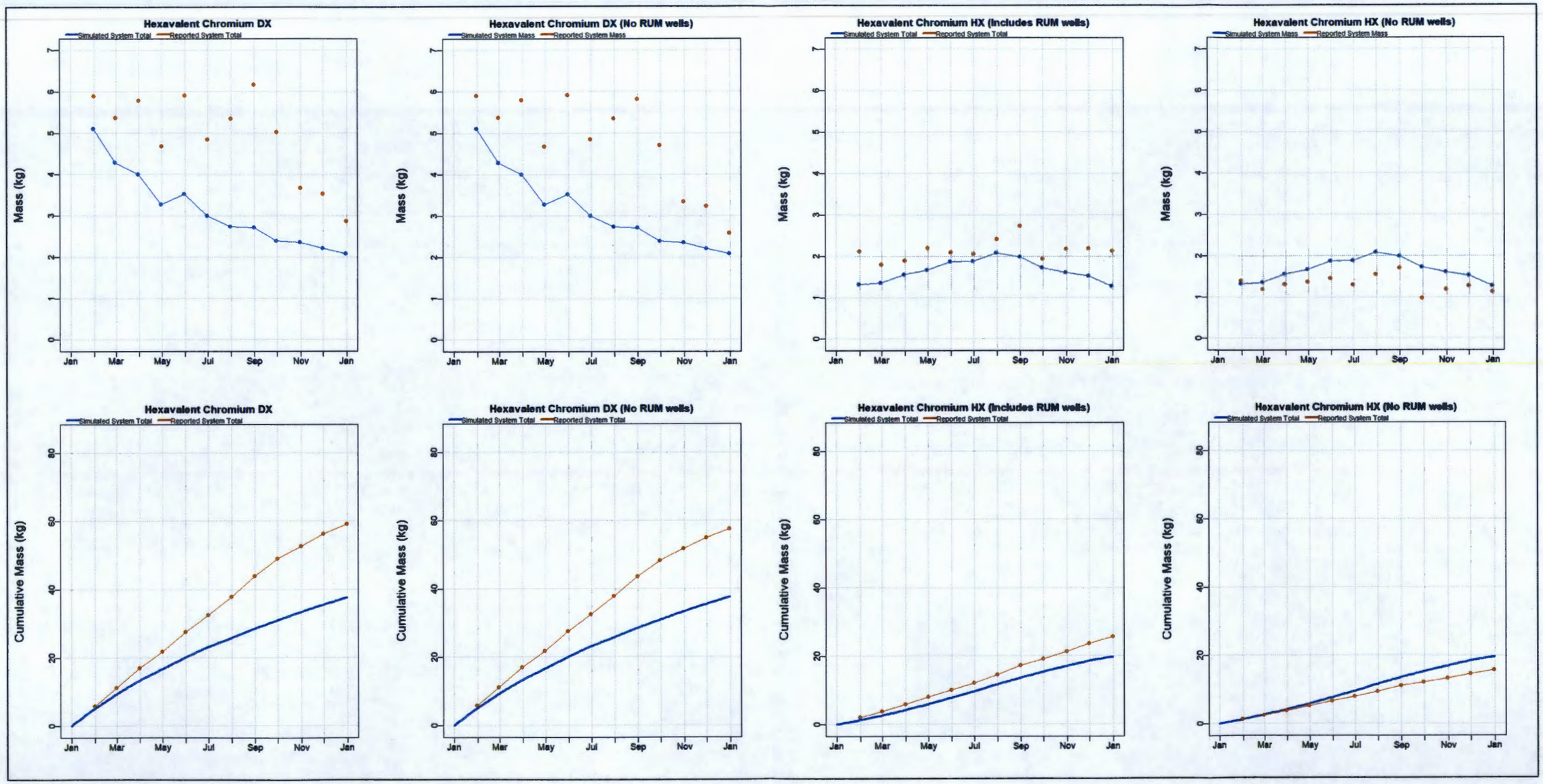

Figure 2-41. Comparison of Observed to Calculated Cr(VI) Mass Removal (Top Row = Monthly Mass Removal; Bottom Row = Cumulative Mass Removal)

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Finally, comparison of the simulated and measured mass recovery for wells located near the high-concentration zone in 100-D north area, indicates that higher concentrations are likely present closer to the downgradient wells (e.g., 199-D8-95, 199-D8-96, 199-D5-32) rather than near the inland wells (e.g., 199-D5-131). Development of the interpolated chromium distribution in that area was primarily based on data from extraction wells and some monitoring wells that essentially define the perimeter of that high-concentration zone, with uncertainty associated with the distribution and magnitude of the highest concentrations within that zone. In addition, potential presence of continuing sources in that area could also result in mass recovery differences between the simulated and measured values.

The HX P&T system removed 25.7 kg (56.6 lb) of Cr(VI) during 2016 (Figure 2-41). Approximately 9.9 kg (21.9 lb) of the mass recovered by the HX P&T system was extracted from wells completed within the RUM (i.e., wells 199-H3-2C, 199-H4-12C, 199-H3-9, 199-H3-10 and 199-H4-90), which are not simulated by the 100 Area groundwater model. The remaining mass of approximately 15.8 kg (33.7 lb) that was recorded as recovered by the HX P&T system originates from the unconfined aquifer that is simulated by the 100 Area groundwater model. In comparing the observed mass removed from the unconfined aquifer (15.8 kg [34.7 lb]) to the mass recovery simulated by the 100 Area groundwater model (19.8 kg [43.6 lb]), the simulated value is an overestimation (Figure 2-41). Comparison between simulated and measured concentrations at the extraction wells for the HX P&T system is presented in detail in ECF-HANFORD-16-0060, *Description of Groundwater Calculations and Assessments for the Calendar Year 2015 (CY2015) 100 Areas Pump-and-Treat Report*. In general, the comparison between simulated and measured concentrations indicates patterns similar to those observed in the DX P&T system. Measured concentrations in the HX P&T system are much lower than those measured in the DX P&T system and, in most cases, about or below 48 µg/L. The difference between measured and simulated mass recovery are likely attributed to the extent and distribution of concentrations above 48 µg/L in the initial conditions, upgradient of wells 199-H1-42 and 199-H1-45. The separation distance between monitoring wells and the absence of monitoring wells in the center of that area resulted in an interpolated distribution that underestimates the highest concentrations in that area, as well as the extent of the zone of concentrations above 48 µg/L. Also, some uncertainties in the geologic setting in that area and the corresponding hydraulic conductivity distribution may have also impacted the model-simulated aquifer response and concentration variation at some wells (e.g. 199-H1-42, 199-H1-45, or 199-H3-25), resulting in slightly overestimating the wellhead concentrations at those wells and, in turn, the corresponding simulated mass recovery. These discrepancies are rather localized but, given the narrow range and relatively low levels of measured concentrations, result in overestimation of mass recovery in HX.

From a systematic perspective, differences between the simulated and measured mass recovery could result from using contaminant transport parameters in the transport model that do not exactly reflect conditions encountered in the subsurface. Simulated mass recovery estimates, however, present a useful tool for estimating the system performance over time and developing estimates of time to complete remediation, but these estimates will tend to under-estimate remediation timeframes where a continuing source is present.

2.2.8 In Situ Redox Manipulation Barrier Compliance Monitoring

The reduction-oxidation treatment zone (Figure 2-3) is approximately 680 m (2,230 ft) long, aligned parallel to the Columbia River, and is approximately 100 to 200 m (330 to 660 ft) inland from the river. The barrier includes 65 wells spaced across almost the entire width of the southern Cr(VI) plume. The treatment zone was designed to reduce the Cr(VI) concentration in groundwater to below 20 µg/L at the compliance wells located between the treatment zone and the Columbia River. Figure 2-42 shows the Cr(VI) concentrations along the barrier for 2016.

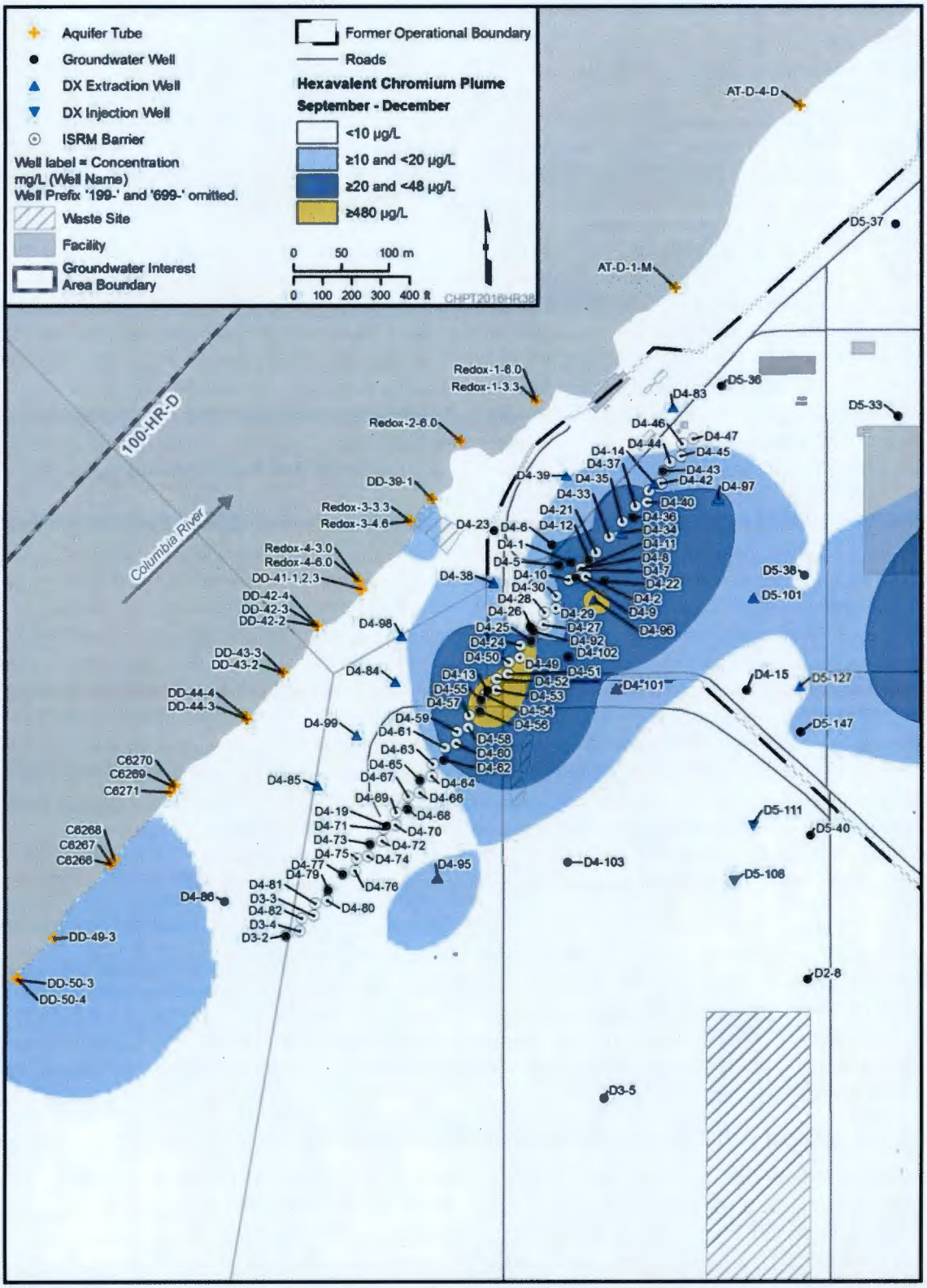


Figure 2-42. ISRM Cr(VI) Map, 2016

As discussed in Section 2.1.2, a notice of non-significance shifted the groundwater remedy at the ISRM barrier to the P&T system. Groundwater at the ISRM site continues to be monitored for Cr(VI) as part of CERCLA interim action. ISRM monitoring is discussed in this report in order to provide a consolidated discussion of all interim remedies being used in the River Corridor. Dissolved oxygen is monitored since the treatment process reduces oxygen content in the aquifer, and groundwater with depleted oxygen levels could harm aquatic receptors. Other groundwater constituents and properties are monitored to provide a better understanding of the chemical characteristics of the plume.

2.2.8.1 Hexavalent Chromium

The ISRM barrier initially included seven compliance wells. Of these, monitoring wells 199-D4-86 and 199-D4-23 are the only remaining wells that have not been converted to extraction wells. Figure 2-43 provides Cr(VI) concentration plots for the seven compliance wells: 199-D4-23, 199-D4-38, 199-D4-39, 199-D4-83, 199-D4-84, 199-D4-85, and 199-D4-86. The 20 µg/L interim remedial action target was met in all but one of the seven ISRM compliance wells during 2016 (well 199-D4-85 had a Cr(VI) concentration of 20 µg/L in sample collected in March).

The ten highest concentrations observed in ISRM wells during 2016 were at wells 199-D4-96, 199-D4-55, 199-D4-56, and 199-D4-25. The highest concentration was in well 199-D4-96 at 84 µg/L on October 25, 2016. The Cr(VI) concentration in groundwater flowing across the ISRM barrier continued to decrease from 2015 to the end of 2016 or remained similar (with some seasonal fluctuation) in most locations. In well 199-D4-96, however, concentrations increased from 30 µg/L in September to 84 µg/L in October 2015. Wells 199-D4-1 and 199-D4-5, 199-D4-6, 199-D4-39, 199-D4-96, and 199-D4-97 also demonstrated general increasing trends in concentrations during the last 2 years. These increases may indicate areas of reduced barrier performance. The declining or stabilizing of the overall concentrations in the barrier vicinity are attributed to the effects of the P&T system. Remedial action monitoring is described in DOE/RL-2013-31.

Figures 2-44 through 2-47 show the Cr(VI) concentrations in the ISRM barrier for the four quarters of 2016. Cr(VI) concentrations during 2016 were the lowest in the late spring and early summer (second and third quarters). The greatest number of wells had concentrations over the remedial action target of 20 µg/L in the fourth quarter (Figure 2-47), which was consistent with previous years. Since groundwater flow is predominantly toward the river during low-river stage and the hydraulic gradient were 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 Cr(VI) is reduced to trivalent chromium, and the concentrations of Cr(VI) decrease. The northeastern portion of the barrier continues to have a large number of wells with concentrations greater than 20 µg/L. Two new extraction wells upgradient of the southern end of the barrier are planned to improve both capture of the plume and river protection in this area.

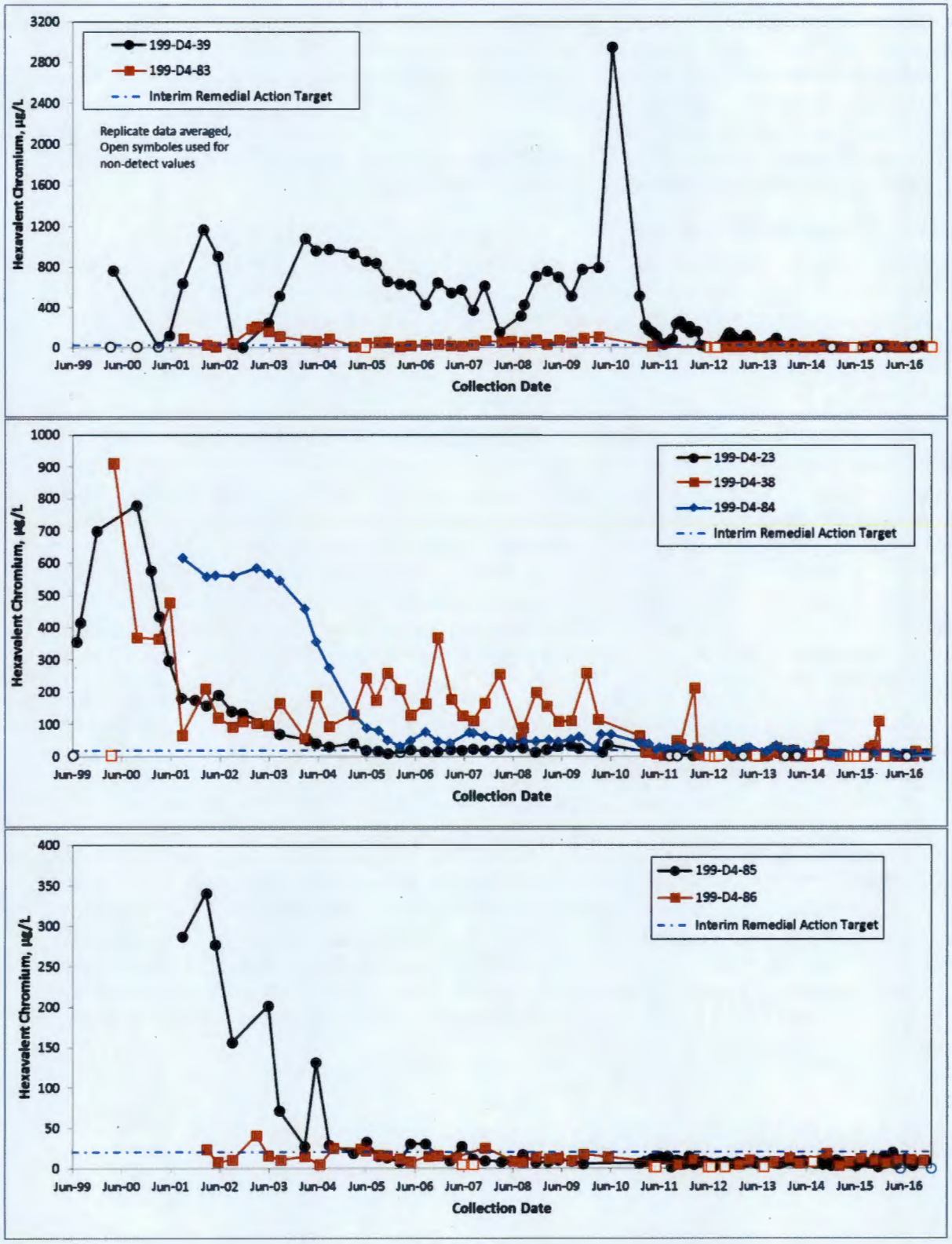
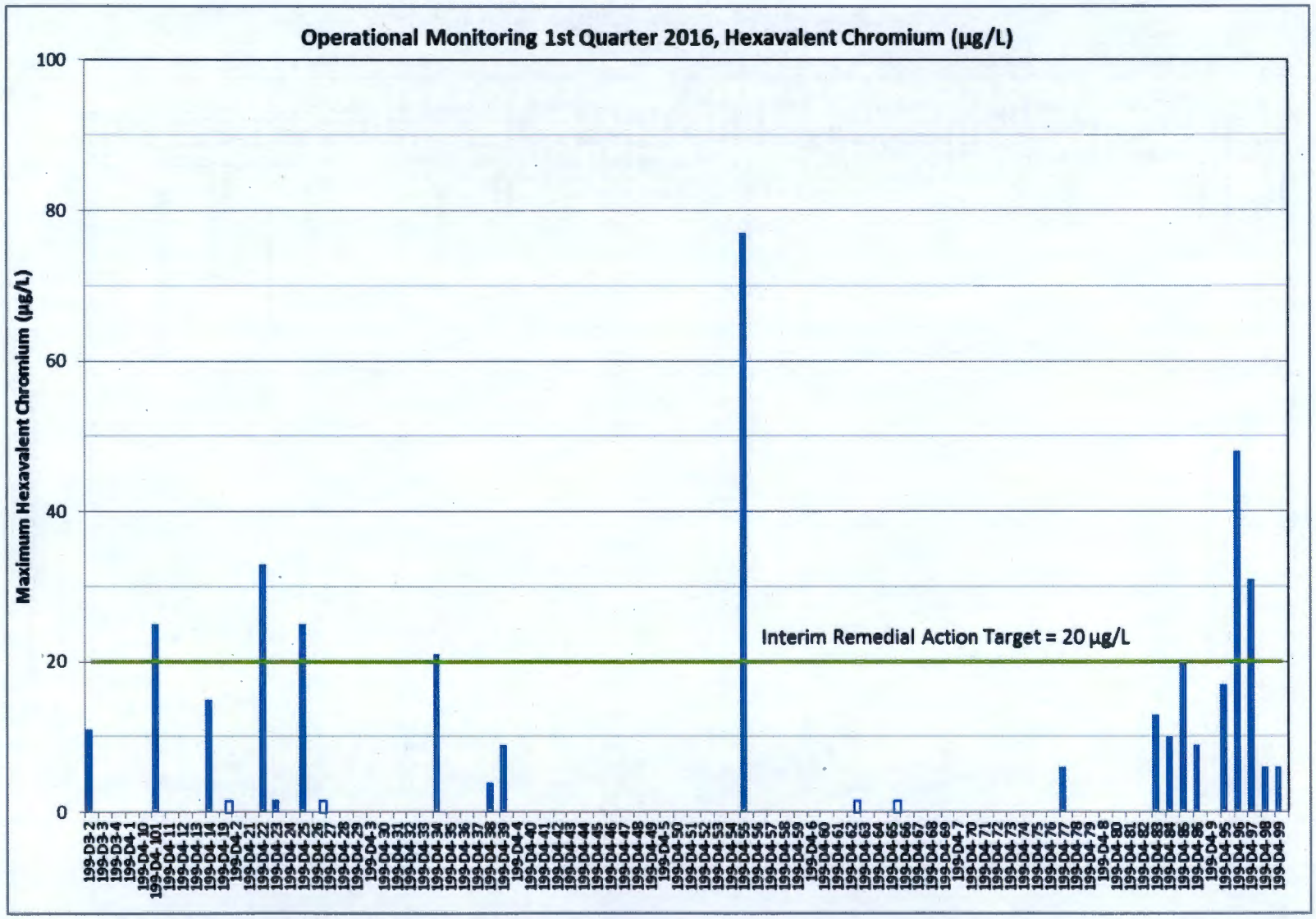
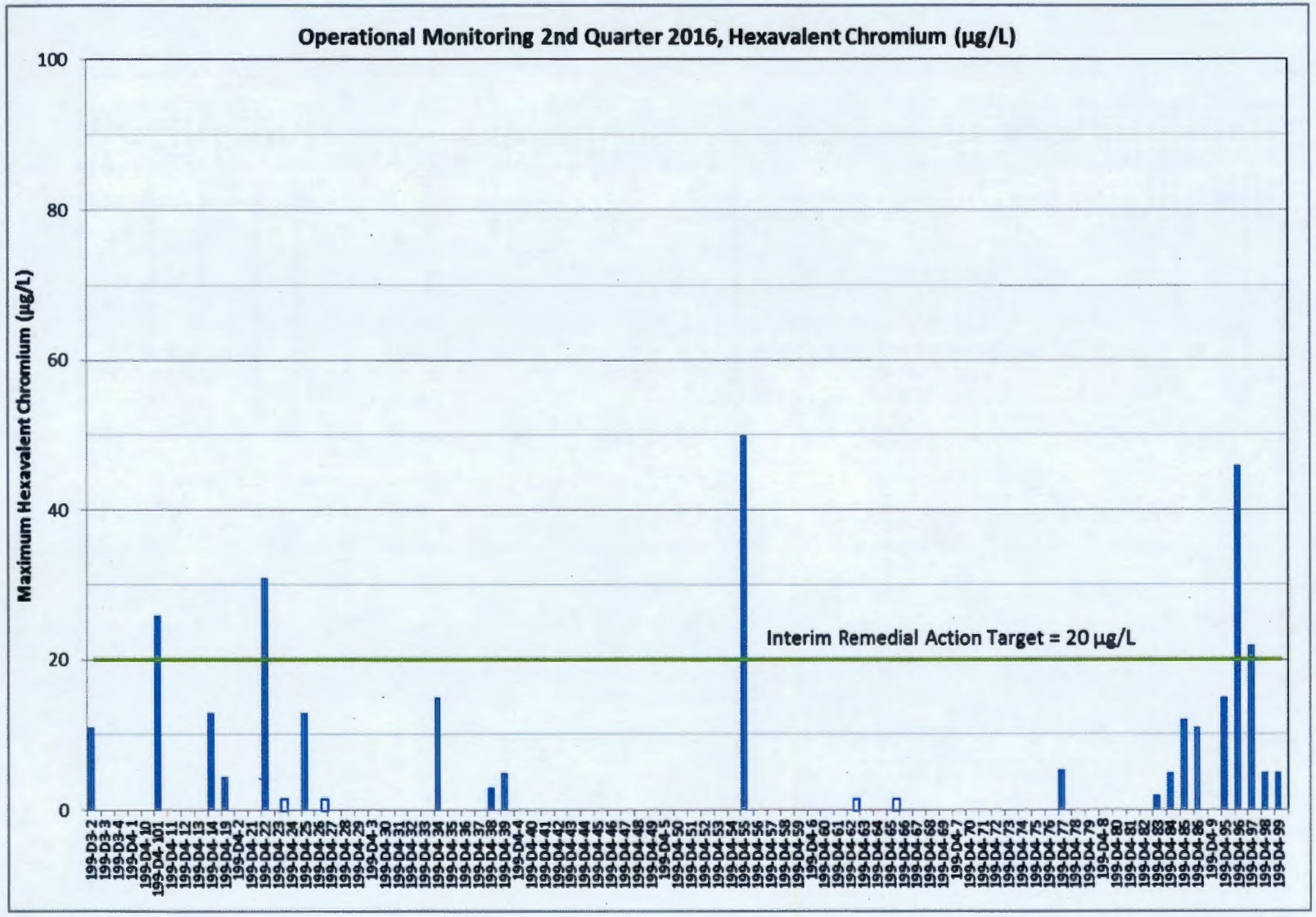


Figure 2-43. ISRM Cr(VI) Trend Plots for Compliance Wells



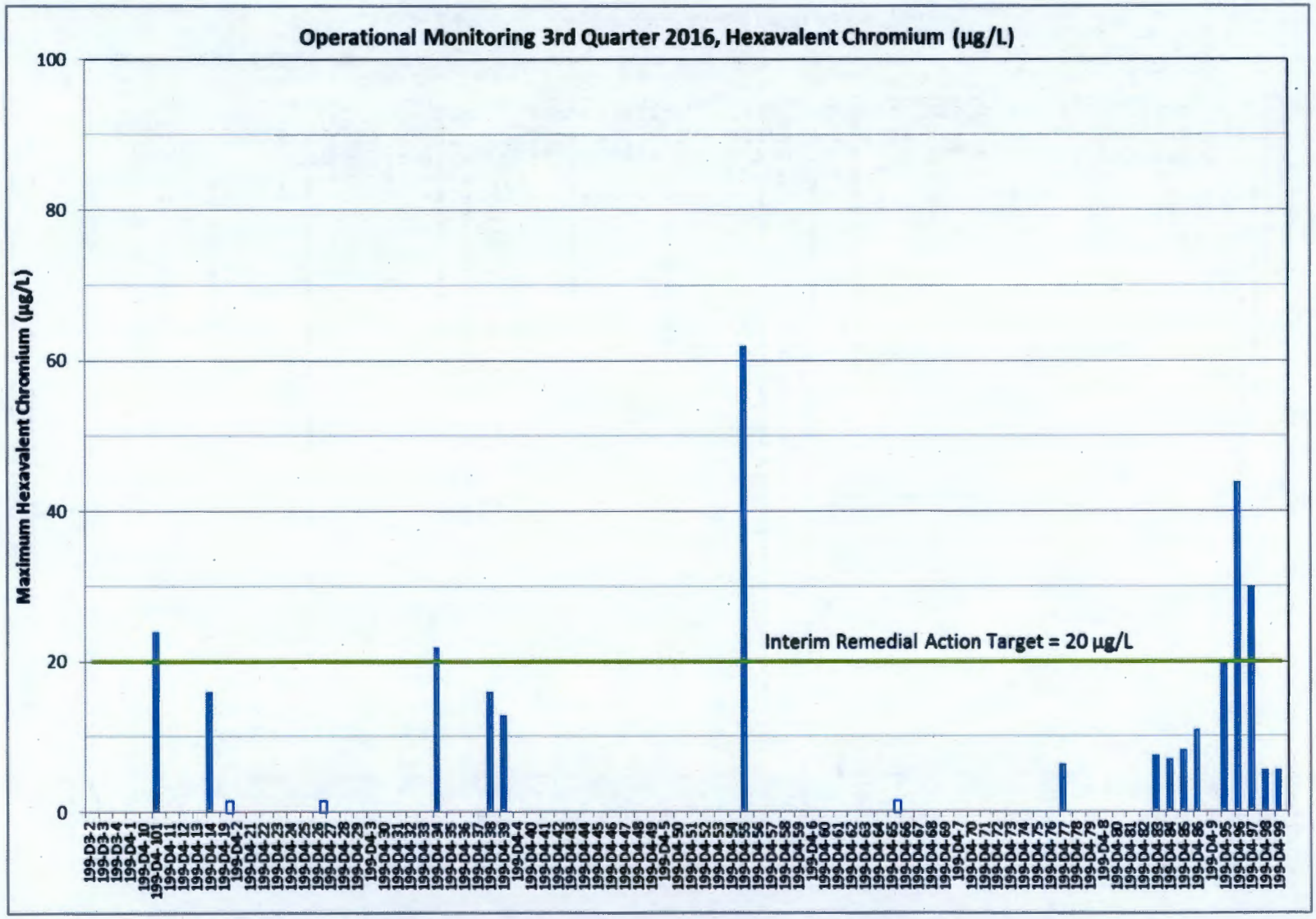
Note: Unshaded bars indicate values below detection limit.

Figure 2-44. ISRM Operational Monitoring, Cr(VI), First Quarter



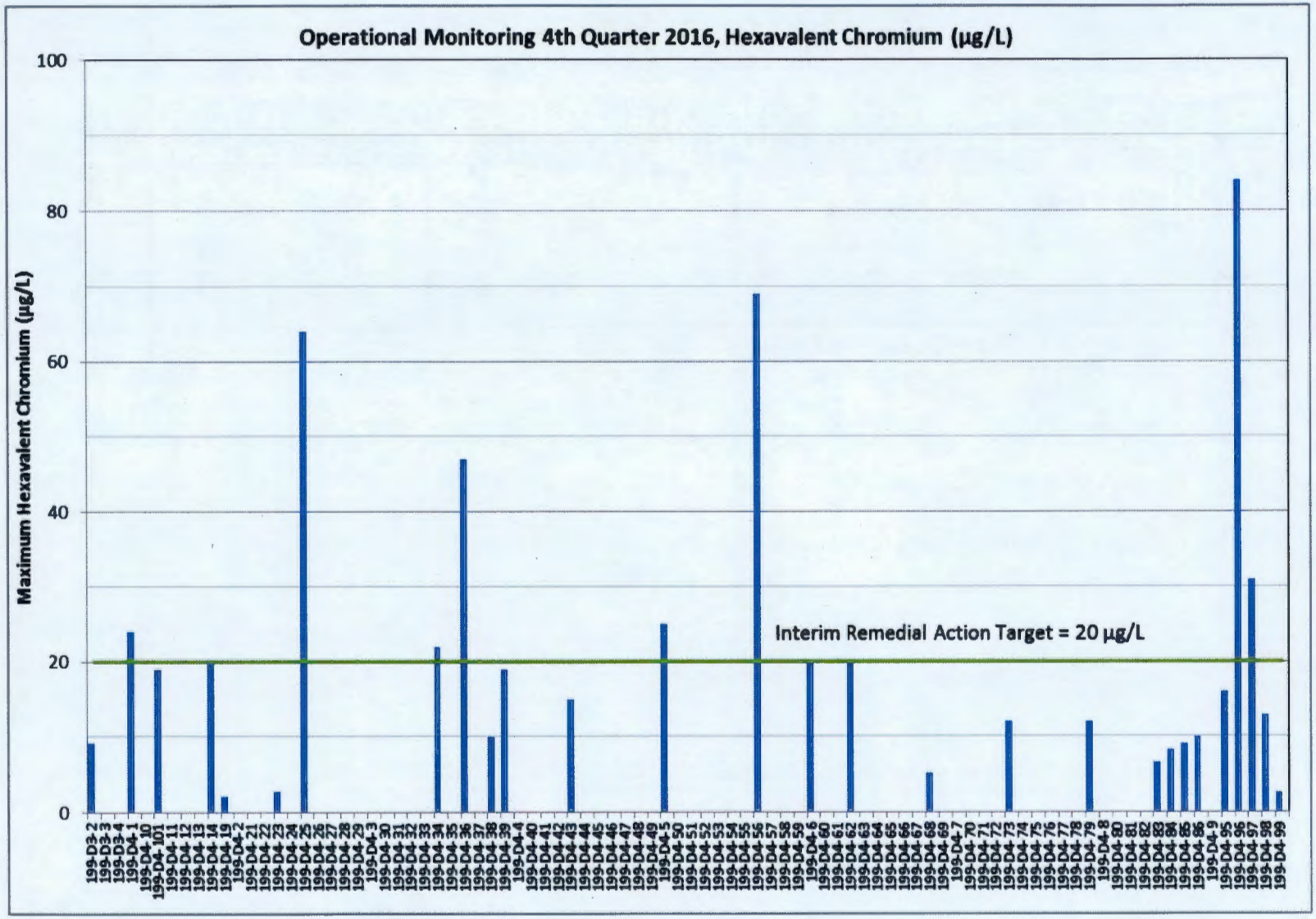
Note: Unshaded bars indicate values below detection limit.

Figure 2-45. ISRM Operational Monitoring, Cr(VI), Second Quarter



Note: Unshaded bars indicate values below detection limit.

Figure 2-46. ISRM Operational Monitoring, Cr(VI), Third Quarter



Note: Unshaded bars indicate values below detection limit.

Figure 2-47. ISRM Operational Monitoring, Cr(VI), Fourth Quarter

2.2.8.2 Dissolved Oxygen

Dissolved oxygen concentrations are monitored as required by the ROD amendment (EPA/AMD/R10-00/122) and the 100-HR-3 OU RDR/RAWP (DOE/RL-2013-31). The sodium dithionite injection process reduced oxygen in the groundwater at the barrier to low levels. Dissolved oxygen is monitored to assess changes as groundwater approaches the Columbia River. Low levels of oxygen in the river may pose a risk to aquatic organisms. Monitoring dissolved oxygen will assist in developing actions to increase the oxygen in groundwater via air sparging, or other means, if significant low values persist. The ISRM treatment zone is generally characterized by relatively high oxygen concentrations upgradient of the treatment zone (except in the area of the former treatability test wells [199-D5-107 and 199-D5-108]), decreasing significantly through the treatment zone, and recovering to higher concentrations as groundwater flow approaches the river (Figure 2-7). The barrier is becoming less effective, as indicated by only a small area of dissolved oxygen levels below 3 mg/L near wells 199-D4-19 and 199-D4-62. Dissolved oxygen levels in the majority of the barrier are currently between 3 and 6 mg/L.

2.2.8.3 Sulfate

Sulfate is listed as a groundwater contaminant with a national secondary DWS of 250 mg/L (40 CFR 143, "National Secondary Drinking Water Regulations"). Sulfate is a byproduct of the sodium dithionite reaction used to establish the ISRM treatment zone. Sulfate previously exceeded the 250 mg/L secondary DWS in wells within and downgradient of the ISRM barrier as a result of the sodium dithionite solution injections. No exceedances of the sulfate DWS occurred at the ISRM barrier or elsewhere in the 100-HR-3 OU during 2016. The highest sulfate concentrations within the ISRM barrier were 130 mg/L at well 199-D4-22.

2.2.9 Remedial Process Optimization Activities

Contractors have developed a pumping optimization model and interface, based on the 100 Area Groundwater Model that will be used by OU scientists to evaluate the relative performance of alternative well configurations. The OU scientists will evaluate pumping configurations throughout the year and provide recommended adjustments to flow rates and recommendations for well realignment and/or the installation of new wells. Specific remedial process activities performed at the 100-HR-3 OU during 2016 included the following:

- Identifying and installing new extraction, injection, and monitoring wells based on previous years' evaluation of plume capture and river protection analyses
- Designing and constructing new injection wells as high-performance wells (i.e., using high-capacity well screens and matching filter pack to screen and formation)
- Placing new and realigned extraction and injection wells in service to enhance plume capture and increase operational capacity
- Maintaining the AWLN system to ensure enhance hydraulic monitoring capacity
- Identifying low-performing extraction and injection wells for maintenance or removal from operations
- Identifying system infrastructure components to be changed to enhance groundwater extraction and injection performance
- Initially using the pumping optimization model to evaluate expected extraction/injection well effects on plume capture

2.3 Radiological Dose and Drinking Water Standard Analysis of 100-DX and 100-HX Pump and Treat Effluent

Effluent water from the two P&T systems located in 100-HR-3 Operable Unit (i.e., 100-DX and 100-HX) was evaluated for compliance with the requirements for radiological protection of human health and the environment. This evaluation includes calculation of the total effective dose (TED) produced by radioisotopes present in the effluent water following treatment of extracted groundwater to remove identified contaminants. The resultant dose was compared to the target cumulative dose limit of 100 mrem/yr to the public established by DOE O 458.1, *Radiation Protection of the Public and the Environment*. The cumulative TED is based on use of the Derived Concentration Standards (DCS) defined in DOE-STD-1196-2011, *Derived Concentration Technical Standard*.

Additional guidance for screening of radiological dose related to discharge of liquid effluents at DOE facilities is provided in DOE-HDBK-1216-2015, *Environmental Radiological Effluent Monitoring and Environmental Surveillance*. The Handbook provides recommended criteria for radiological effluent monitoring based on the DCS to ensure effective effluent monitoring that identifies problematic effluent conditions before they exceed target metrics.

This evaluation further compares the radioisotopes present in effluent water to the following radiological drinking water standards: the 4 mrem/yr maximum contaminant level (MCL) dose for beta/photon emitters and the 30 µg/L uranium mass concentration MCL.

The recommended criteria described in the Handbook are summarized in Table 2-15.

Table 2-15. Recommended Criteria for Liquid Radiological Effluent Monitoring (from Table 3-1 of DOE-HDBK-1216-2015)

Criterion Number	DCS Sum-of-fractions	And	Potential Annual Dose from Exposure to a Likely Receptor (mrem)	Minimum Criteria for Liquid Radiological Effluent Monitoring
1	>/= 1		--	Apply BAT to reduce effluent releases (except H-3). Use continuous monitoring/sampling, but where effluent streams are low flow and potential public dose is very low, (<<1mrem in a year) alternative sampling approaches may be appropriate.
2	>/= 0.01 to 1		>1	Continuously monitor or sample. Identify radionuclides contributing >/= 10% of the dose. Determine accuracy of results (+/- accuracy and percent confidence level).

Table 2-15. Recommended Criteria for Liquid Radiological Effluent Monitoring (from Table 3-1 of DOE-HDBK-1216-2015)

Criterion Number	DCS Sum-of-fractions	And	Potential Annual Dose from Exposure to a Likely Receptor (mrem)	Minimum Criteria for Liquid Radiological Effluent Monitoring
3	>/= 0.001 to 0.01		<1	Monitor using a graded approach to select the appropriate method and duration. Identify radionuclides contributing >/= 10% or more of the dose. Assess annually the facility inventory and potential for radiological effluent release.
4	<0.001		--	No monitoring required. Evaluate annually the potential for liquid radiological effluent release.

-- = not applicable

BAT = best available technology

2.3.1 Evaluation of Effluent Water Total Effective Dose for 100-DX and 100-HX Pump and Treat for CY 2016

Effluent monitoring at the 100-DX and 100-HX P&T systems was performed using sampling and analysis of the stream exiting the plant prior to pumping effluent to the injection well fields. Sampling and analysis was performed periodically for target radionuclides identified as contaminants of interest for the groundwater remedial actions supported by the treatment system. The radionuclides of interest for the 100-DX and 100-HX P&T systems are:

- Tritium (100-DX and 100-HX)
- Strontium-90 (100-DX and 100-HX)
- Uranium (100-DX and 100-HX)

The results of periodic sampling and analysis of effluent from 100-DX and 100-HX P&T systems are summarized in Table 2-16. Where multiple measurements were determined for an analyte during a single sampling and analysis event, the maximum value was selected for use in this evaluation.

Individual radioisotope activity concentrations were subsequently converted to estimated effective dose using the DCS values in Table 2-17.

Table 2-16. Summary of Effluent Radioisotope Sampling and Analysis Results for CY 2016 at 100-DX and 100-HX Pump and Treat

Sample Location	Sample Date	Tritium (pCi/L)	Sr-90 (pCi/L)	Uranium (µg/L)
100-DX Pump and Treat				
Effluent Tank –M5	3/2/2016	-NM-	-NM-	0.12
Effluent Tank –M5	6/29/2016	-NM-	-NM-	(0.23)
Effluent Tank –M5	9/14/2016	-NM-	-NM-	(0.23)
Effluent Tank –M5	12/14/2016	1830	1.01	(0.4)
100-HX Pump and Treat				
Effluent Tank – H5	3/2/2016	-NM-	-NM-	(0.027)
Effluent Tank – H5	6/30/2016	-NM-	-NM-	(0.23)
Effluent Tank – H5	9/14/2016	-NM-	-NM-	(0.23)
Effluent Tank – H5	12/28/2016	1,110	(1.31)	(0.4)

Note: Values in parentheses were reported as not detected; the value is the reported minimum detectable activity or minimum detectable concentration.

-NM- = Isotope not measured in this sample event.

Table 2-17. Derived Concentration Standards for Radioisotopes Evaluated in 100-DX and 100-Hx Pump and Treat Effluent

DCS	Tritium	Sr-90
DCS (µCi/ml)[a]	1.90E-03	3.30E-07
DCS (pCi/L)[b]	1.90E+06	3.30E+02

a. DCS from Table 5 of DOE-STD-1196-2011, *Derived Concentration Technical Standard.*

b. DCS converted to pCi/L for direct comparison to measurement results.

DCS = Derived Concentration Standard

The individual radioisotope dose contributions for each effluent sampling event at 100-DX and 100-HX P&T and the cumulative TED estimates for calendar year 2016 are shown in Table 2-18. The TED was calculated using two approaches. The first a conservative approach incorporating the minimum detectable activity (MDA) for non-detect measurements as a value; the second includes no value for non-detect measurements. The resultant TED and DCS fractions were then compared to the criteria presented in Table 2-15.

The cumulative TED and DCS fraction values shown in Table 2-18 indicated that results of effluent sampling events during CY 2016 at 100-DX and 100-HX P&T systems met monitoring Criterion #3, with the exception of a single sample from 100-HX analyzed on 12/28/2016, which exhibited no detectable strontium-90.

Table 2-18. Calculated Individual Radioisotope Dose Contributions and TED for 100-DX and 100-HX Pump and Treat Effluent in CY 2016

Sample Location	Sample Date	Individual Isotope Effective Dose Contribution		TED Cumulative (mrem/yr[a])	DCS Fraction Cumulative (Fraction[a])	TED Detects Only (mrem/yr[a])	DCS Fraction Detects Only (Fraction[a])
		Tritium (mrem/yr)	Sr-90 (mrem/yr)				
100-DX Pump and Treat							
Effluent Tank – M5	3/2/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – M5	6/29/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – M5	9/14/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – M5	12/14/2016	1830	1.01	0.402	0.004	0.402	0.004
100-HX Pump and Treat							
Effluent Tank – H5	3/2/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – H5	6/30/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – H5	9/14/2016	-NM-	-NM-	-NC-	-NC-	-NC-	-NC-
Effluent Tank – H5	12/28/2016	1110	(1.31)[b]	0.455	0.0046	0.058	0.0006

a. Shaded cells: Cumulative TED and DCS Fraction values meet Criterion #3 in Table 2-15.

b. Values in parentheses were reported as not-detected. Value presented is dose contribution based on minimum detectable activity concentration for samples reported as analyzed but not detected.

-NC- = Parameter not calculated for this sampling event.

-NM- = Analyte not measured in this sampling event.

2.3.2 Comparison of 100-DX and 100-HX Pump and Treat Effluent Water Radiological Constituents to Drinking Water Standards for Beta/Photon Emitters and Uranium for CY 2016

The radioisotopes measured in P&T effluent from 100-DX and 100-HX systems were also evaluated against the 4 mrem/yr drinking water maximum contaminant level for beta and photon emitters. Individual and average values for beta/photon emitters measured in the effluent at these two systems do not exceed the Dose MCL. Total uranium mass concentration for both systems does not exceed the 30 μg/L MCL. The summary of this evaluation is shown in Table 2-19.

Table 2-19. Summary of Drinking Water Beta/Photon Emitter MCL Comparison for 100-DX and 100-HX Pump and Treat Effluent for CY 2016

Location	Sample Date	Contributing Radioisotopes		Sum of Fractions[a]	Drinking Water β/ϒ Dose (mrem/yr)[a]	Sum of Fractions Detects Only[b]	Drinking Water β/ϒ Dose from Detects Only (mrem/yr)[b]
		Tritium	Sr-90				
		Derived Concentrations (pCi/L)					
		20,000	8				
		Beta/Photon MCL Fraction					
100-DX Pump and Treat							
Effluent Tank – T-M5	12/14/2016	0.09	0.12	0.218	0.9	0.2	0.9
100-HX Pump and Treat							
Effluent Tank – T-H5	12/14/2016	0.06	(0.16)[c]	0.22	0.9	0.06	0.2

a. Sum of MCL fractional derived concentration values and calculated MCL dose, including non-detect values using the MDA as a value.

b. Sum of MCL fractional derived concentration values and calculated MCL dose, excluding non-detect measurements.

c. Values in parentheses were reported as non-detects; the value is the reported value of the MDA.

MDA = minimum detectable activity

MCL = maximum contaminant level

2.3.3 Conclusions of Evaluation of Radiological Constituents in 100-DX and 100-HX Pump and Treat Effluent Water for CY 2016

Evaluation of radiological dose of the 100-DX and 100-HX P&T effluent water during CY 2016 indicates that the effluent met the following standards and criteria:

- The calculated DCS-based TED of the effluent for both 100-DX and 100-HX was less than 1 mrem/yr, substantially below the 100 mrem/yr public dose limit.
- The calculated DCS-based sum-of-fractions and resultant TED of the effluent for both 100-DX and 100-HX P&T systems were consistent with recommended monitoring using a graded approach and annual review.
- The calculated MCL-based beta/photon emitter drinking water dose was below the 4 mrem/yr MCL dose for both 100-DX and 100-HX P&T systems.
- Total uranium mass concentration in effluent for both systems was below the 30 µg/L MCL. Uranium was only detected above the detection limit in one sample at 100-DX effluent; uranium was not detected in any sample at 100-HX.

2.4 100-HR-3 Operable Unit Pump and Treat Systems Costs

This section summarizes the actual costs for the 100-HR-3 OU P&T systems for 2016. The primary categories of expenditures are described as follows:

- **Capital design**: Includes design activities to construct the P&T systems, including wells, 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 systems.
- **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 operations and periodic maintenance.
- **Performance monitoring**: Includes system and groundwater sampling and sample analysis, as required in accordance with the 100-HR-3 OU RD/RAWP (DOE/RL-2013-31) and 100-HR-3 OU SAP (DOE/RL-2013-30).
- **Waste management**: Includes the cost for managing spent resin at the 100-HR-3 OU 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.
- **Field Studies**: Includes costs for conducting field tests (e.g., step tests, pumping tests, tracer studies) to support evaluation of hydraulic properties and remedy optimization.
- **Well Realignments**: Includes costs for well conversions to add/remove wells as extraction or injection wells to the P&T facilities. Costs include fabrication and installation/modification of equipment and systems for well conversions and installation of piping runs and electrical cables from the P&T facilities to wells.

The costs include all activities associated with the interim remedial actions, including construction of new wells and interim action performance monitoring. The 100-HR-3 OU costs for 2016 are associated with four P&T systems: HR3, DR5, DX, and HX. The cost breakdown for each of these P&T systems are shown in Tables 2-20 through 2-23, respectively. The HR3 and DR5 P&T systems were shut down in 2011; however, historical costs for these systems are included as part of the overall cost of the interim action remedy (Tables 2-20 and 2-21). Costs for the HR3 and DR5 P&T systems after system shutdown in 2011 are associated with surveillance and maintenance, and decommissioning of the facilities. Costs are burdened and are based on actual operating costs incurred during 2016. Summaries of the costs for the DX and HX P&T systems are presented in the following subsections.

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Table 2-20. 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]	2012[e]	2013[f]	2014[e]	2015[g]	2016[g]
Design	—	—	97.7	15.4	8.1	196.1	196.0	55.0	92.0	—	0.0	26.5	—	0.7	—	—	0.0	—
Treatment system capital construction	—	57.7	(36.1)	750.3	—	496.6	10.0	—	—	—	—	—	—	—	—	—	1,053.2	—
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	—	0.7	—	0.1	—
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	42.5	201.6	2.2	29.4	104.4
Performance monitoring	—	173.7	219.9	120.0	163.2	120.3	353.0	489.6	219.5	508.5	237.7	240.0	—	—	—	—	0.1	—
Waste management	—	895.3	424.9	720.1	877.2	501.7	202.2	217.6	434.7[h]	192.2	16.6	75.0	—	3.0	—	—	5.1	—
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**	**$46**	**$202**	**$2**	**$1,088**	**$104**

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 HR-3 P&T system went into cold-standby status in May 2011.

e. Costs after system shutdown in 2011 are associated with surveillance and maintenance pending decommissioning of the HR-3 P&T facility.

f. Costs for 2013 were associated with disposal of Dowex® 21K resin.

g. Costs for 2015 and 2016 are associated with surveillance and maintenance and decommissioning of the HR-3 P&T facility.

h. Additional waste management costs in 2007 were associated with drilling wastes and resin cleared for shipment and handling.

— = not available

P&T = pump and treat

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Table 2-21. 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]	2012[c]	2014[c]	2015[d]	2016[c]
Design	246.9	196.8	100.4	—	3.2	3.4	—	(0.1)	—	0.0	—
Treatment system capital construction	—	22.2	—	—	—	—	—	—	—	1,053.2	—
Project support	586.4	370.6	240.3	233.6	204.7	139.6	2.7	—	—	0.1	—
Operations and maintenance	459.6	605.7	541.3	884.7	1,091.7	919.9	185.4	21.6	9.5	25.6	7.5
Performance monitoring	106.2	1.6	11.3	127.1	237.7	240.0	—	—	10.7	0.0	—
Waste management	28.3	154.7	45.4	23.8	1.7	29.0	—	—	—	5.2	—
Totals	**$1,427**	**$1,352**	**$939**	**$1,269**	**$1,539**	**$1,332**	**$188**	**$21**	**$20**	**$1,084**	**$8**

a. Annual reporting 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.

c. Costs after system shutdown in 2011 are associated with ongoing surveillance and maintenance while the facility is in standby. In 2014, the facility was transitioned for use as a well maintenance facility.

d. Costs for 2015 are associated with surveillance and maintenance end decommissioning of the DR-5 P&T facility.

— = not available

P&T = pump and treat

Table 2-22. Breakdown of DX P&T System Construction and Operation Costs

Description	Actual Costs (Dollars × 1,000)							
	2009[a]	2010	2011[b]	2012	2013	2014	2015	2016
Design	2,115.2	1,287.8	100.7	34.3	28.9	5.7	44.4	11.0
Treatment system capital construction	5,759.8	16,266.3	—	(3.1)	244.2	565.7	851.4	714.1
Project support	495.1	1,236.9	45.7	71.3	186.0	132.4	14.3	118.7
Operations and maintenance	—	—	2,979.3	1,566.3	2,186.4	1,857.9[c]	1,618.4[c]	1,931.5
Performance monitoring	—	—	1.8	294.9	125.4	226.6	167.4	271.4
Waste management	7.4	9.2	—	0.8	0.0	0.6	114.7	44.1
Field studies	—	—	—	—	—	0.4	—	—

Table 2-22. Breakdown of DX P&T System Construction and Operation Costs

Description	Actual Costs (Dollars × 1,000)							
	2009[a]	2010	2011[b]	2012	2013	2014	2015	2016
Well Realignments[c]	—	—	—	—	—	171.9	2,750.4	2,224.8
Totals	**$8,377**	**$18,800**	**$3,128**	**$1,965**	**$2,771**	**$2,961**	**$5,675**	**$5,316**

a. Annual reporting 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.

c. Cost for well realignments were previously included as part of the O&M costs, but are now reported as a separate cost category. The 2014 and 2015 O&M costs reported in previous reports have been adjusted in this report to separate out the well realignment costs.

— = not available

O&M = operations and maintenance

P&T = pump and treat

Table 2-23. Breakdown of HX P&T System Construction Costs

Description	Actual Costs (Dollars × 1,000)							
	2009[a]	2010	2011[b]	2012	2013	2014	2015	2016
Design	896.4	1,047.5	1,079.8	35.9	3.6	6.0	37.8	9.4
Treatment system capital construction	214.1	9,354.2	11,316.2	(2.3)	220.0	566.9	725.8	608.7
Project support	—	400.2	1,981.4	53.2	179.4	128.7	10.9	101.2
Operations and maintenance	—	—	321.2	1,187.4	1,727.6	1,792.7[c]	1,586.4[c]	1,905.0
Performance monitoring	—	—	8.0	189.7	122.7	189.7	153.1	225.4
Waste management	—	0.1	—	1.0	—	—	103.3	31.3
Field studies	—	—	—	—	—	0.4	—	446.4
Well Realignments[c]	—	—	—	—	—	171.9	2,344.6	1,896.5
Totals	**$1,111**	**$10,802**	**$14,707**	**$1,465**	**$2,253**	**$2,856**	**$5,033**	**$5,224**

a. Annual reporting 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.

c. Costs for well realignments were previously included as part of the O&M costs, but are now reported as a separate cost category. The 2014 and 2015 O&M costs reported in previous reports have been adjusted in this report to separate out the well realignment costs.

— = not available

O&M = operations and maintenance

P&T = pump and treat

2.4.1 DX Pump and Treat System

The total cost for the DX P&T system during 2016 was approximately $5.32 million, which consists of the sum of the categories shown in Table 2-22. Well realignment and O&M costs made up 78 percent of the total 2016 cost year. The cost breakdown percentage for the DX P&T system (Figure 2-48) is as follows, in decreasing order:

- Well realignments: 41.9 percent ($2,224,800)
- O&M; 36.3 percent ($1,931,500)
- Treatment system capital construction: 13.4 percent ($714,100)
- Performance monitoring: 5.1 percent ($271,400)
- Project support: 2.2 percent ($118,700)
- Waste management: 0.8 percent ($44,100)
- Design and field studies costs were negligible in 2016

The cost increase compared to 2014 for the DX P&T system is associated capital construction for well installation and realignments conducted in 2015 and 2016. The DX P&T system changes and well realignment activities for 2016 are described in Section 2.2.1.

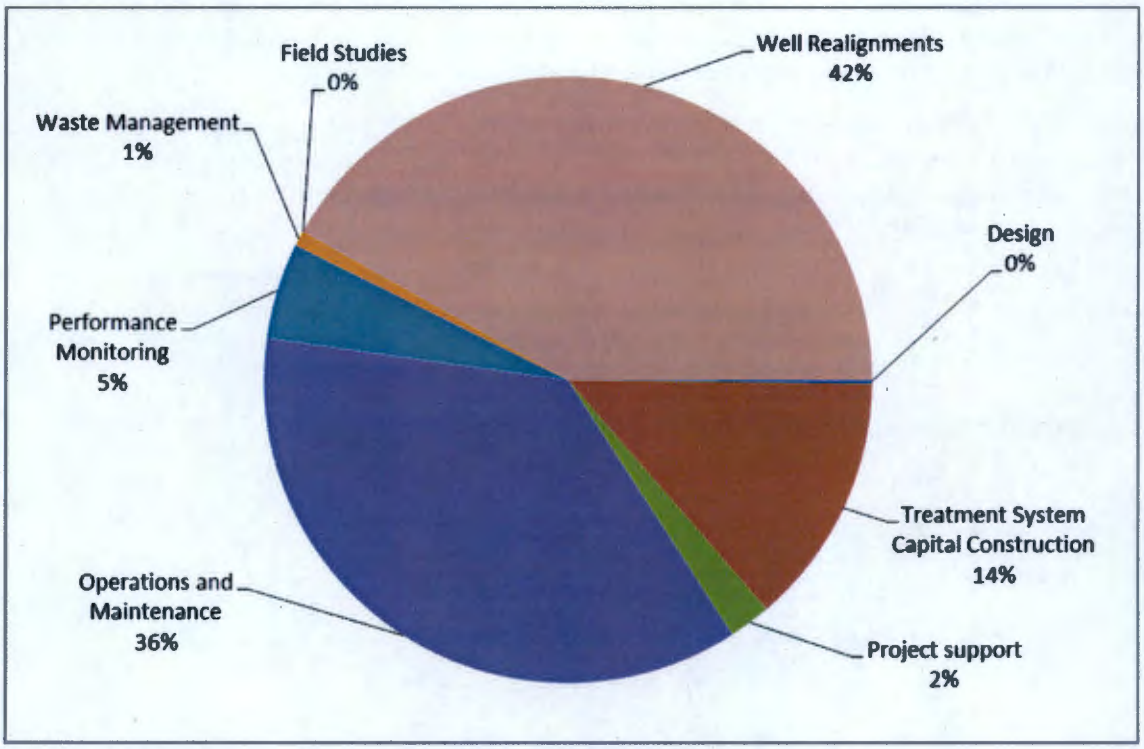


Figure 2-48. DX P&T System, 2016 Cost ($5.32 million) Breakdown (by Percentage)

Based on the total 2016 cost of $5,316,000, the yearly production rate of 1,454 million L (384 million gal), and 59.0 kg (130 lb) of Cr(VI) removed, the annual treatment costs equate to $0.0037/L, or $90.04/g of Cr(VI) removed.

2.4.2 HX Pump and Treat System

The total cost for the HX P&T system during 2016 was approximately $5.22 million, which consists of the sum of the categories shown in Table 2-23. Well realignment and O&M costs made up 73 percent of the total cost during the year. The cost breakdown for the HX P&T system for 2016 (Figure 2-49) is as follows, in decreasing order:

- O&M: 36.5 percent ($1,905,000)
- Well realignments: 36.3 percent ($1,896,500)
- Treatment system capital construction: 11.7 percent ($608,700)
- Field studies: 8.5 percent ($446,400)
- Performance monitoring: 4.3 percent ($225,400)
- Project support: 1.9 percent ($101,200)
- Waste management: 0.6 percent ($31,300)
- Design costs were negligible in 2016

The cost increase compared to 2014 for the HX P&T system is associated capital construction for well installation and realignments conducted in 2015 and 2016. The HX P&T system changes and well realignment activities for 2016 are described in Section 2.2.2. Field studies consisted of aquifer tests performed to help determine the hydraulic connectivity between RUM wells and connections between the RUM aquifer and the overlying unconfined aquifer and Columbia River.

Based on the total 2016 cost of $5,224,000, the yearly production rate of 1,149 million L (303 million gal), and 25.7 kg (57 lb) of Cr(VI) removed, the annual treatment costs equate to $0.0045/L, or $203.15/g of Cr(VI) removed.

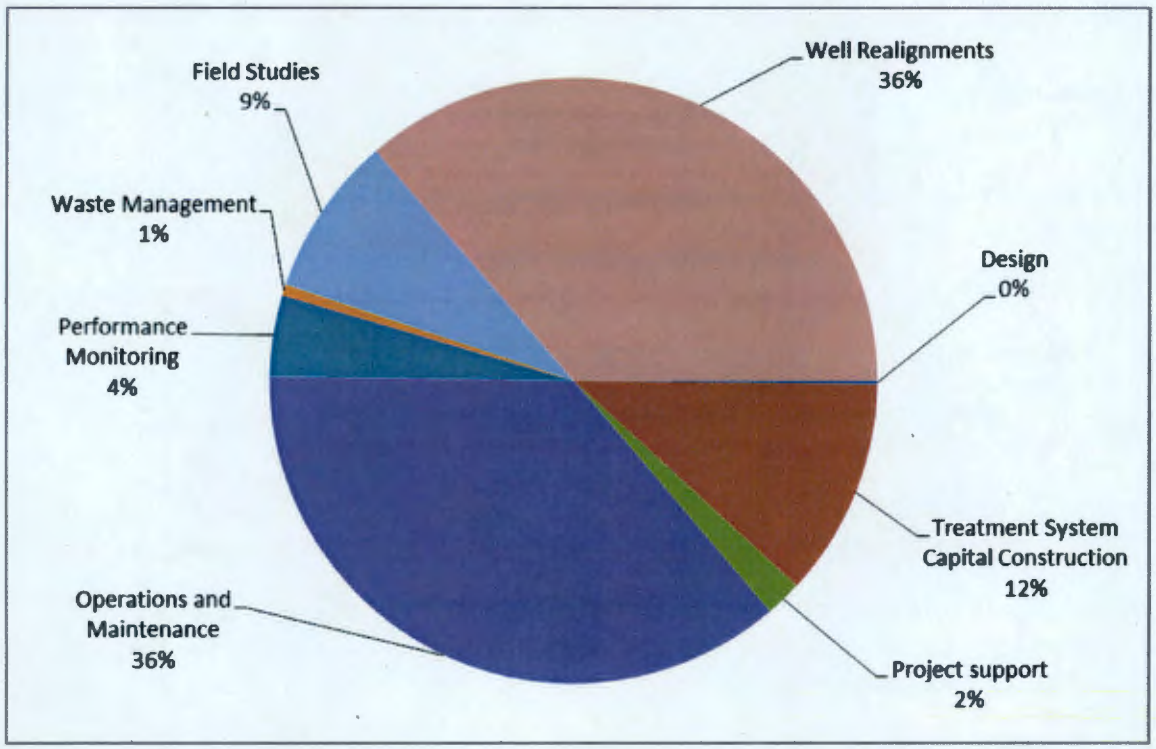


Figure 2-49. HX P&T System, 2016 Cost ($5.22 million) Breakdown (by Percentage)

2.5 Conclusions

The status of the 100-HR-3 OU illustrates that remediation has progressed for the Cr(VI) groundwater contamination associated with each of the P&T systems that operated in 2016 within the 100-HR-3 OU.

The DX and HX P&T systems removed a significant amount of Cr(VI) mass from the aquifer in 2016. The amount of mass removed each year continues to decrease as the areas of high Cr(VI) concentrations are remediated. RPO will continue, and system modifications will be conducted to target the remaining mass and increase river protection.

The combined hydraulic and water quality data evaluation suggests that the extent of hydraulic containment developed by the DX and HX P&T systems during 2016 is consistent with the design of the systems and is within expectations. Calculations suggest that the river protection objective is being achieved along the majority of the 100-HR-3 OU shoreline.

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 P&T systems is resulting in a capture frequency of 70 to 90 percent over most of the 100-HR-3 OU Cr(VI) plume at concentrations above 10 µg/L.

  The combined hydraulic and water quality data evaluation indicates that the extent of hydraulic containment developed by the DX and HX P&T systems improved in 2016 versus 2015. This improvement is consistent with expectations from 2016 extraction and injection well locations and planned extraction rates. Calculations indicate that the river protection objective is being achieved along most of the 100-HR-3 OU shoreline. The performance of remedial action systems confirms that DOE has taken the necessary measures to control the discharge of Cr(VI) into the Columbia River (Tri-Party Agreement Milestone M-016-110-T01). The increase in protection in both 100-D and 100-H Areas is related to the addition of new wells to the P&T system, and remediation of high concentration sources.

  Based on the aquifer tube data for 2016, the concentrations of Cr(VI) discharged to the Columbia River within the 100-HR-3 OU continue to decline. This appears directly related to improved overall capture from system alignments. The locations where Cr(VI) discharged to the river remained generally the same as observed in previous years, although the length of shoreline where the discharges occurred decreased. The area to the north of 100-H exhibited increased capture and river protection. To the south of 100-H, river protection continues to improve. Localized areas where contaminants may still discharge to the river include a small area downgradient of the 100-D southern plume, a small area along the northern portion of the Horn, and in the H Reactor area.

  The DX P&T system has largely attained the RAO for river protection downgradient of the 100-D northern plume. The improvements in these areas are directly related to well field modifications. South and downgradient of the ISRM barrier, the RAO is not currently attained; however, additional extraction is planned for that area with two new wells planned for installation.

  The HX P&T system has largely attained the RAO for river protection at the 100-H Area, and the Horn. The reactor area continues to be addressed by ongoing extraction. The area to the north of the 100-H Area where the RAO is not fully attained decreased in area during 2016, and additional realignments are planned.

The 100-HR-3 OU P&T systems have removed substantial amounts of Cr(VI) from the groundwater. Since startup of the DX and HX P&T systems, an estimated total of 1,691 kg (3,728 lb) of Cr(VI) has been removed from the shallow unconfined aquifer and RUM, with the DX P&T system alone removing 1,547 kg (3,411 lb) of that total.

The observed concentrations of Cr(VI) in groundwater at both the DX and HX P&T systems are declining as remediation progresses.

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

  Results: The interim remedial ROD (EPA/ROD/R10-96/134) establishes a variety of institutional controls (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 DOE/RL-2004-56, *2004 Site Wide Institutional Controls Annual Assessment Report for Hanford CERCLA Response Actions*. 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.

  Results: Rev. 0 of the RI/FS report (DOE/RL-2010-95) was completed in October 2014. The Proposed Plan (DOE/RL-2011-111), which will lead to issuance of a ROD for cleanup of contaminated soil and groundwater at the 100-D and 100-H Areas, was completed in July 2016 and issued for public comment. The final ROD is currently under review.

  Additional information on the groundwater contamination at the 100-HR-3 OU continues to be gathered. Ongoing groundwater monitoring activities provide information on the changes in contaminant concentrations, as well as the spatial distribution of the groundwater plumes. Information collected during source remediation actions is assessed to provide details regarding the sources of groundwater contamination, including the persistence of source material within the aquifer and the potential for continuing contributions from secondary sources within the vadose zone for Cr(VI).

  Evaluation of information from multiple activities indicates that while the interim groundwater remedial actions at the 100-HR-3 OU have been successful at reducing Cr(VI) concentrations and reducing plume sizes across the OU, residual secondary sources likely remain. A final remedy will need to address ongoing contributions from vadose zone sources, as well as high contaminant concentrations in groundwater at or near source release areas.

3 100-KR-4 2016 Operable Unit Remediation

This chapter describes the status of interim groundwater remedies and other CERCLA activities for the 100-KR-4 Groundwater OU. The following discussion includes the interim remedy P&T system performance for 2016 and a summary of progress made towards remediating the aquifer since the start of P&T operations.

3.1 Overview of Operable Unit Activities

The 100-KR-4 OU incorporates groundwater contaminated by releases from facilities and waste sites associated with past operation of the 105-KE and 105-KW Reactors (Figure 3-1). The Cr(VI) 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 groundwater COC in this OU. Groundwater co-contaminants identified in this interim remedial action scope are nitrate, tritium, strontium-90, carbon-14, and trichloroethene (TCE).

The interim remedial action ROD (EPA/ROD/R10-96/134) for the 100-KR-4 OU defined the cleanup goal for Cr(VI) in groundwater discharging to the Columbia River as the ambient water quality criterion at the time of 11 µg/L. Based in part on the assumption 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, attaining less than 22 µg/L of Cr(VI) in the compliance monitoring well network is consistent with achieving this RAO. The ESD for the 100-HR-3 and 100-KR-4 OUs (EPA et al., 2009) reduced the groundwater remediation target to 20 µg/L to meet a revised surface water quality criterion of 10 µg/L. Consequently, a compliance criterion of 20 µg/L for Cr(VI) in groundwater is currently applied to near-shore and compliance wells along the river. The DWS for total chromium remains at 100 µg/L. Ecology has established a Method B groundwater cleanup level of 48 µg/L for Cr(VI) in accordance with WAC 173-340.

To mitigate risks associated with Cr(VI) contamination in groundwater discharging to the river, three CERCLA interim action IX P&T systems have been installed in the 100-KR-4 OU. All three P&T systems (KR4, KW, and KX) operated throughout 2016. The KR4 P&T system was the first system installed and began operation in 1997; it was designed to remediate groundwater around the 116-K-2 Trench (Figure 3-1). The KW P&T system was the second system installed and began remediating Cr(VI) in the KW Reactor area in February 2007. In May 2016, the KW P&T system was shut down to initiate a rebound study to evaluate the potential for contaminant concentrations to remain below cleanup levels and determine if continuing secondary source material exists in the deep vadose zone. The third and newest P&T system, KX, began operating in November 2009. The KX P&T system is used primarily to treat Cr(VI) in groundwater that migrated from the 116-K-2 Trench area toward N Reactor and near the proximal end of the trench near the KE Reactor area. Figure 3-2 shows the extraction and injection wells comprising the well fields for these systems, as well as associated monitoring wells and other monitoring locations. The inferred distribution of Cr(VI) in groundwater in the 100-KR-4 OU vicinity, as well as the inferred groundwater elevation contours for the low and high river-stage periods during 2016, are shown in Figures 3-3 and 3-4, respectively.

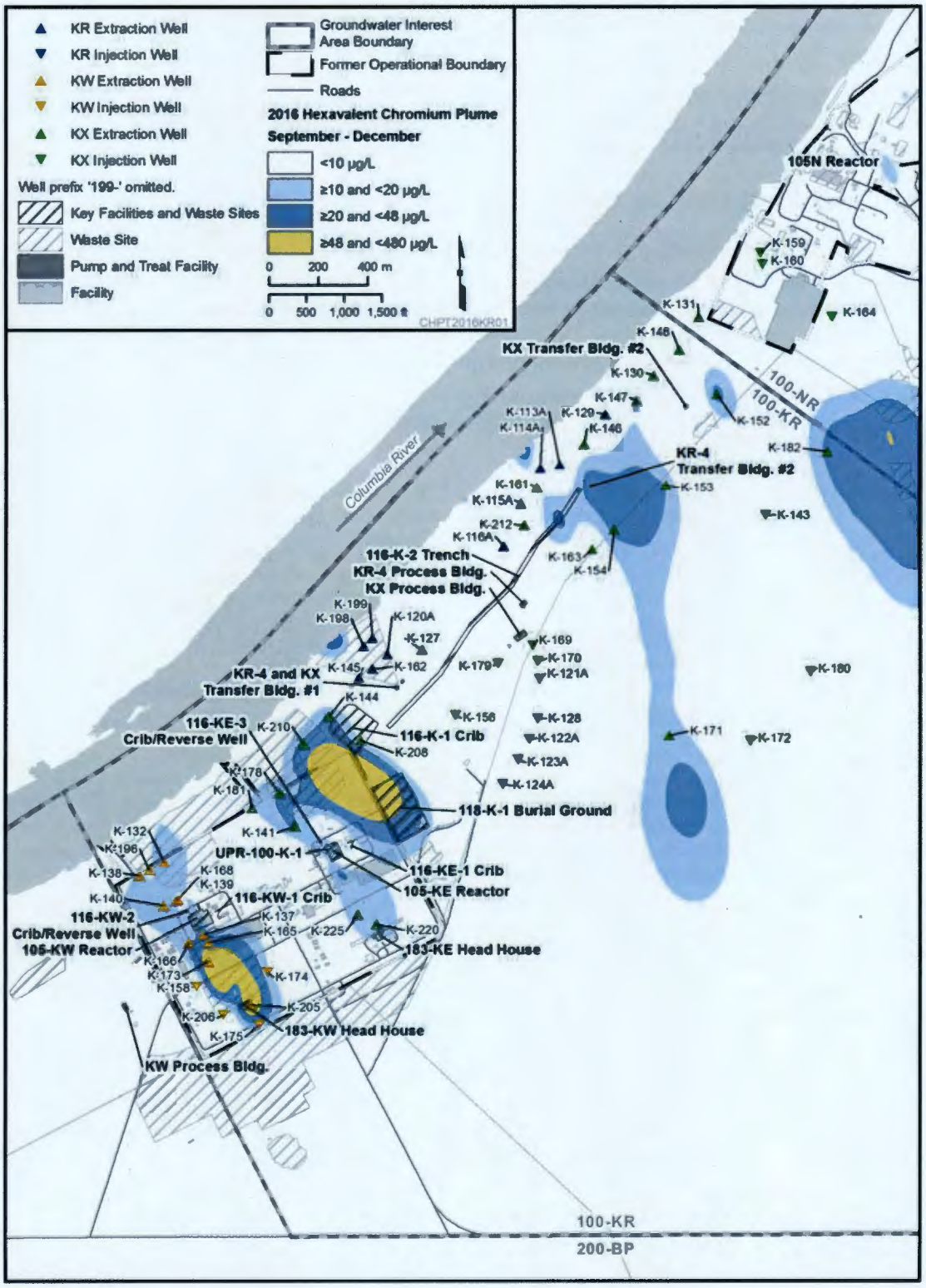


Figure 3-1. Layout of the 100-KR-4 OU P&T Systems (as of December 31, 2016) and Key Waste Sites and Facilities

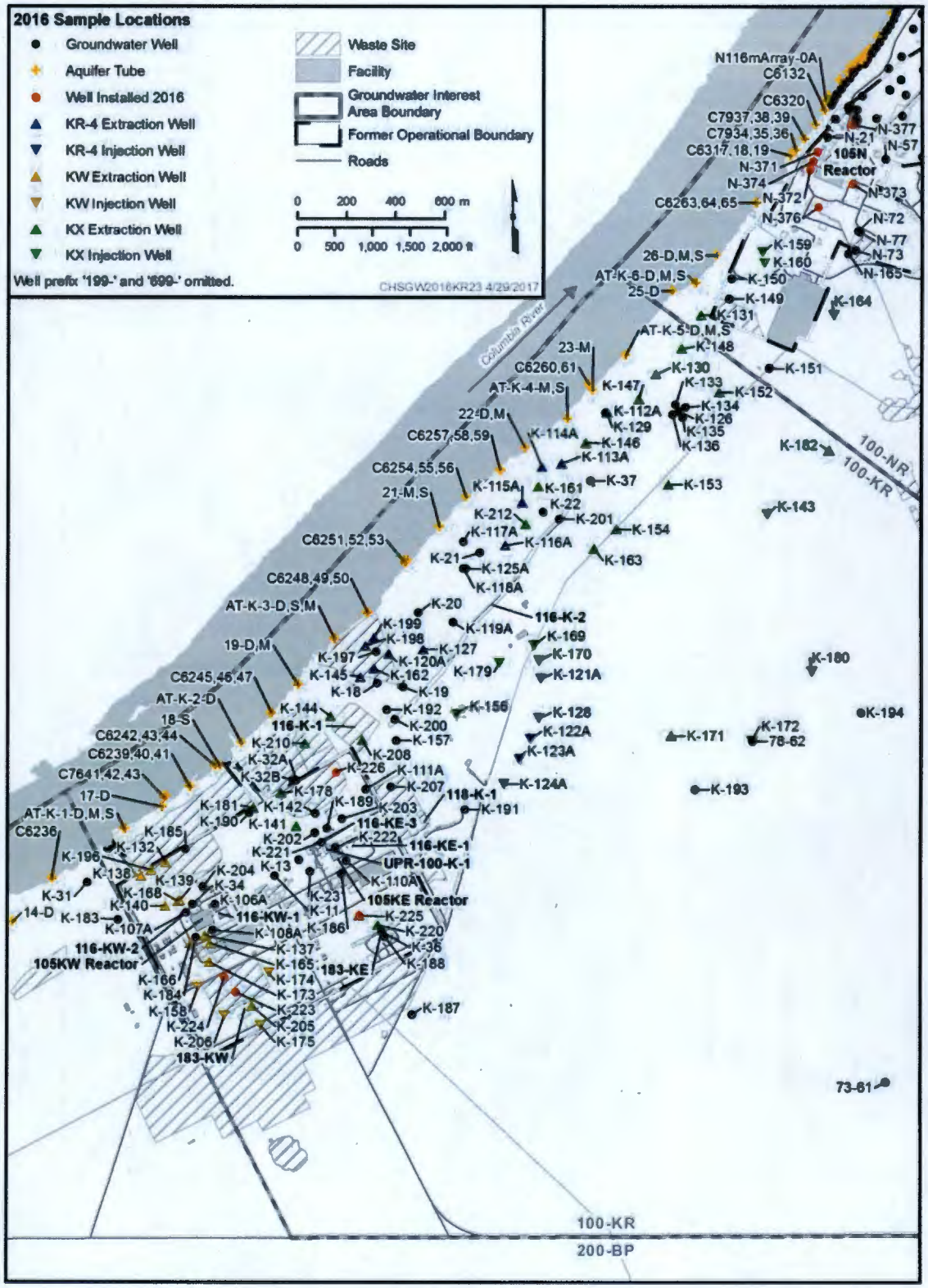


Figure 3-2. 100-KR-4 OU 2016 Remedial System Wells, Monitoring Wells, and Aquifer Sampling Tubes

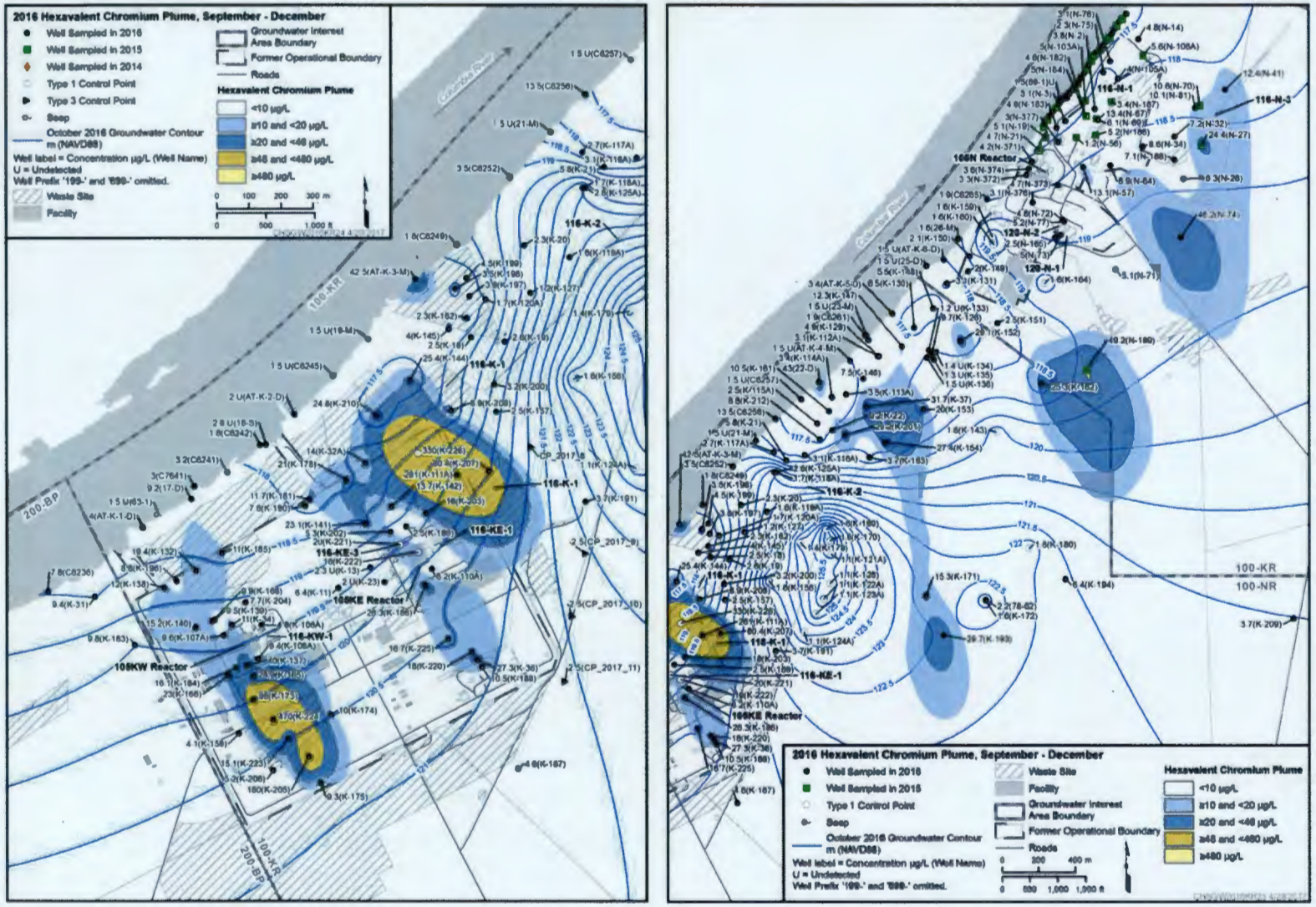


Figure 3-3. Cr(VI) Plume Distribution in Groundwater at the 100-KR-4 OU (Low River Stage, 2016)

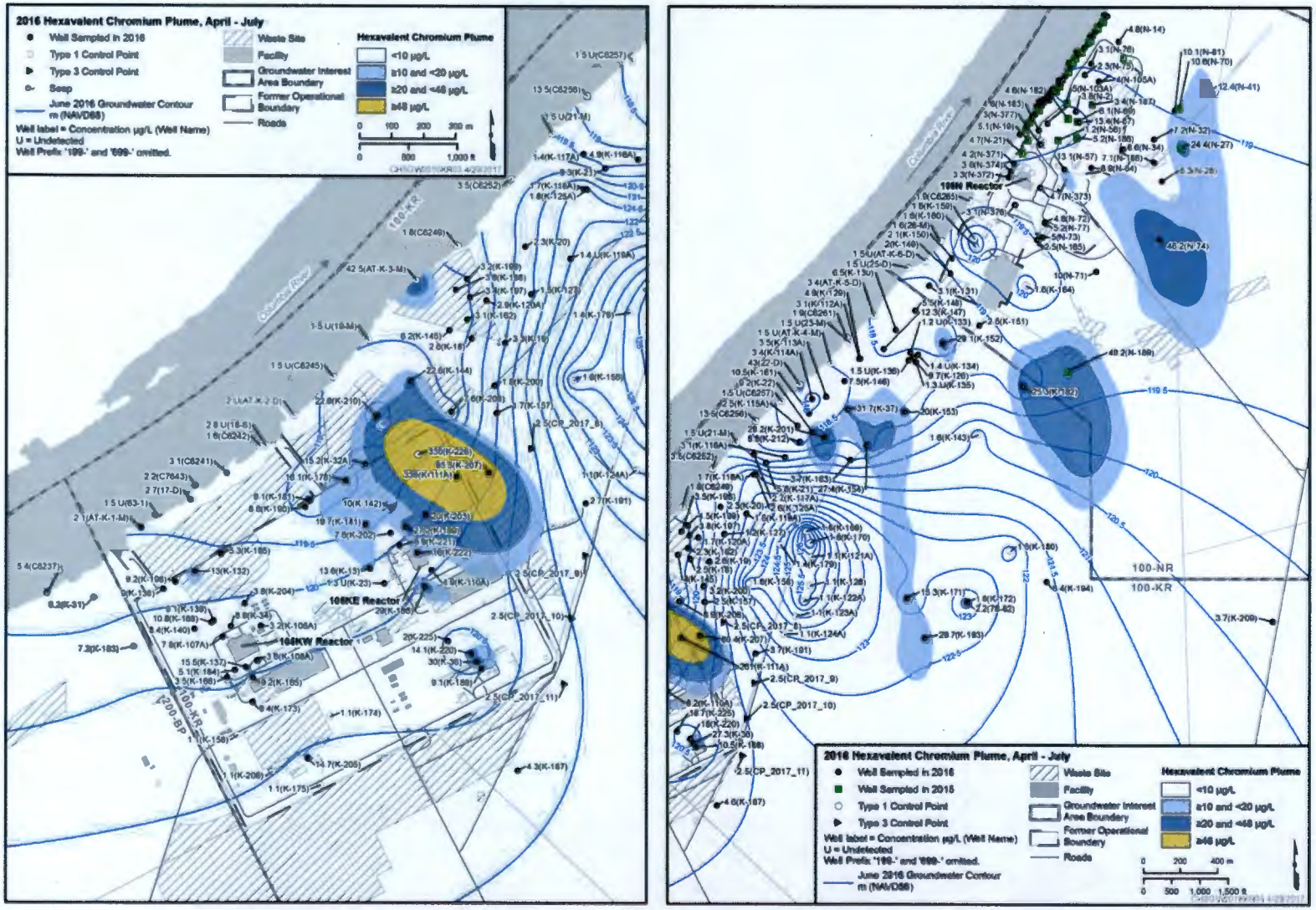


Figure 3-4. Cr(VI) Plume Distribution in Groundwater at the 100-KR-4 OU (High River Stage, 2016)

Monitoring, data evaluation, and site characterization activities are conducted each year in an ongoing effort to determine the 100-KR-4 OU P&T systems' performance compared to design criteria, whether system design modifications or operating parameters will further optimize performance, and the measurable progress toward achieving plume cleanup and river protection RAOs. This chapter discusses the results of the 2016 100-KR-4 OU P&T evaluation and includes the following:

- Section 3.2 discusses the interim action groundwater remediation activities.
- Section 3.3 discusses the radiological dose analysis of the effluent from the 100 KR-4 OU P&T systems.
- Section 3.4 provides the remedial action cost summary.
- Conclusions on 2016 remedy performance for the 100-KR-4 OU are presented in Section 3.5.

3.1.1 100-KR-4 Operable Unit Pump and Treat Systems

Changes to the 100-KR-4 OU interim action P&T systems during 2016 (Table 3-1) consisted primarily of installing additional wells for monitoring, extraction, and injection, as well as realigning selected existing wells for use as extraction wells, and shutting down the KW P&T for a rebound study. Well installation and realignment were intended to enhance hydraulic plume capture, reduce Cr(VI) plume concentrations, and remove mass from source areas. Chapter 1, Figure 1-7 shows the locations of the new and realigned wells for 2016.

Table 3-1. 100-KR-4 Groundwater OU Remedial System Well Changes Initiated in 2016

System	Well	Action	Purpose	Status as of December 31, 2016
100-KR4	199-K-144	Realign extraction well from the KR-4 to the KX P&T system	Reduce the average influent Cr(VI) concentration to allow system to operate for hydraulic containment.	Completed in August 2016
	199-K-179	Realign injection well from the KR-4 to the KX P&T system	Increase injection capacity at KX	Completed in July 2016
	199-K-124A	Realign injection well to decouple from 199-K-123A	Increase injection capacity	Completed in July 2016
100-KW	All Wells	Disconnect from KW P&T System	Perform KW rebound study	Rebound study initiated in May 2016
100-KX	199-K-144	Realign extraction well from the KR-4 to the KX P&T system	Reduce the average influent Cr(VI) concentration to allow system to operate for hydraulic containment.	Completed in August 2016
	199-K-179	Realign injection well from the KR-4 to the KX P&T system	Increase injection capacity	Completed in July 2016

Table 3-1. 100-KR-4 Groundwater OU Remedial System Well Changes Initiated in 2016

System	Well	Action	Purpose	Status as of December 31, 2016
100-KX (con't)	199-K-182	Install large capacity pump to increase flow	Increase mass removal	Completed in February 2016
	199-K-225	Install and connect new extraction well to KX P&T	Target mass removal	Completed in October 2016 - uses same line as 199-K-220 (only one operational at a time)

Cr(VI) = hexavalent chromium
OU = operable unit
P&T = pump and treat

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, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan Addendum 2: 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*) and were implemented through the sampling and analysis plan (SAP) DOE/RL-2009-41, *Sampling and Analysis Plan for the 100-K Decision Unit Remedial Investigation/Feasibility Study*. The 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*), was submitted as Draft A for regulatory review in September 2011. The U.S. Environmental Protection Agency (EPA) and DOE identified a need for additional characterization beneath the KE Reactor fuel storage basin (FSB) and the 116-KE-3 FSB crib/reverse well to fill a data gap regarding nature and extent of vadose zone contamination around the reactor structures before issuing Rev. 0 of the RI/FS report. These characterization activities, including drilling two exploratory boreholes, 199-K-221 and 199-K-222, collecting and analyzing subsurface soil and groundwater samples, and completing the two boreholes as monitoring wells, were performed during 2015. Contaminated soil and groundwater were observed beneath the two waste sites. A characterization report for this activity is currently being prepared and should be available during CY 2017.

3.1.3 Other CERCLA Document and Plans

In December 2016, DOE finalized updates to the supporting interim remedial action documents. These included an operations and maintenance plan, RD/RAWP, and SAP. The RD/RAWP describes how the interim remedies are designed, installed, and operated to meet the ROA's identified in the in interim action ROD (EPA/ROD/R10-96/134). The groundwater monitoring described in DOE/RL-2013-29, *Sampling and Analysis Plan for the 100-KR-4 Groundwater Operable Unit Monitoring*, puts forth the sampling requirements for monitoring groundwater contaminant concentrations, the performance of the remedy, and the effectiveness of the interim remedial action in meeting performance criteria required by EPA/ROD/R10-96/134. DOE/RL-2013-29 also supersedes all previous sampling documents for the 100-KR-4 OU. The operation and maintenance plan (DOE/RL-2013-48, *Operation and Maintenance Plan for the 100-KR-4 Pump and Treat Systems*), describes the remedial system operation to meet remedy performance goals.

In May 2016, DOE finalized and issued the KW Rebound Study SAP (DOE/RL-2016-42, *Sampling and Analysis Plan for KW Pump and Treat System Rebound Study*). The purpose of this SAP was to define the sampling requirements for wells in the area affected by the KW P&T to assess the completion of the

interim action. The original sampling performance period was May 30, 2016 through September 30, 2016. However, TPA-CN-0752, *Change Notice for DOE/RL-2016-42 Sampling and Analysis Plan for KW Pump and Treat System Rebound Study Rev. 0,* was signed on September 29, 2016, to modify the sample requirements for some locations and extend the period of performance through the end of March 2017. The results of the rebound study through the end of calendar year 2016 are discussed in DOE/RL-2016-67, Sections 5.2 through 5.8.

3.2 100-KR-4 Operable Unit Interim Action Activities

This section summarizes the non-RI/FS CERCLA activities for the 100-KR-4 OU during the reporting period, including activities related to operation and performance monitoring of the KR4, KW, and KX P&T systems during 2016. Specific activities and operational performance details for these systems include system configuration changes and availability, contaminant mass removed during operation, contaminant removal efficiencies, quantity and quality of extracted and disposed groundwater, and waste generation.

3.2.1 KR4 Pump and Treat System

The KR4 P&T system was designed to capture and treat the Cr(VI) plume associated with the 116-K-2 Trench (Figure 3-2). A large volume of reactor cooling water was discharged to the 116-K-1 Crib and subsequently to the 116-K-2 Trench during reactor operations. This water contained Cr(VI) at varying concentrations, up to 600 µg/L. The releases created a large, widespread Cr(VI) plume centered on the trench that extends to the Columbia River and several kilometers inland in all directions. Since startup in 1997, the KR4 P&T system has treated more than 8,484 million L (2,241 million gal) of groundwater and has removed 378 kg (833 lb) of Cr(VI). The KR4 P&T system has remediated much of the original plume along the central 116-K-2 Trench to Cr(VI) concentrations less than 20 µg/L, but contamination above 20 µg/L remains in the groundwater at both ends of the trench and inland areas. This plume dissection was caused by extracting high-concentration groundwater along the trench and injecting treated water into wells near the middle of the trench. The contaminant mass reduction near the central 116-K-2 Trench is reflected in the overall influent concentration decline observed at the treatment system (Figure 3-5). All of the current KR4 extraction wells exhibited Cr(VI) concentration below 10 µg/L during 2016. Continued operation of the KR4 P&T system provides hydraulic containment of groundwater near the Columbia River at the proximal and distal regions of the trench.

3.2.1.1 KR4 Pump and Treat System Configuration and Changes

The KR4 P&T system was originally designed to receive and process up to 1,137 L/min (300 gal/min). Over the past several years, optimization activities have increase the operational capacity of the system to 1,249 L/min (330 gal/min). The current system design includes 11 extraction wells and 5 injection wells (Figure 3-6). The following highlights the modifications to the KR4 P&T systems during 2016:

- KR4 injection well 199-K-179 was realigned to the KX P&T system to increase injection capacity at the KX P&T system.
- Existing KR4 injection well 199-K-124A, which shared flows with 199-K-123A, was reconfigured as a separate injection well.

  KR4 extraction well 199-K-144 was realigned to the KX P&T system. This change reduced the average influent Cr(VI) concentration from 5.7 to 3.8 µg/L allowing the KR4 system to operate for hydraulic containment only.

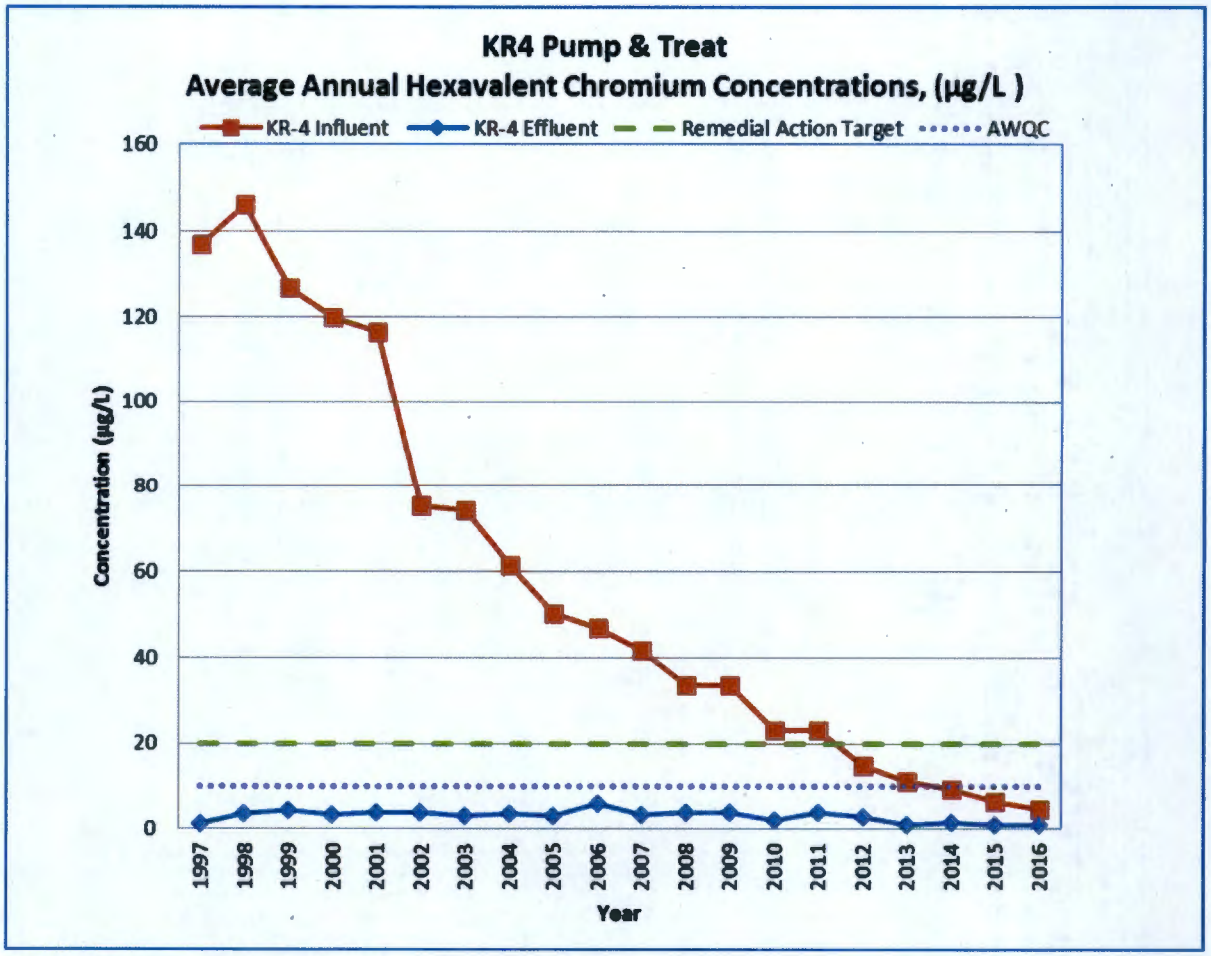


Figure 3-5. KR4 P&T System Annual Average Influent and Effluent Concentrations

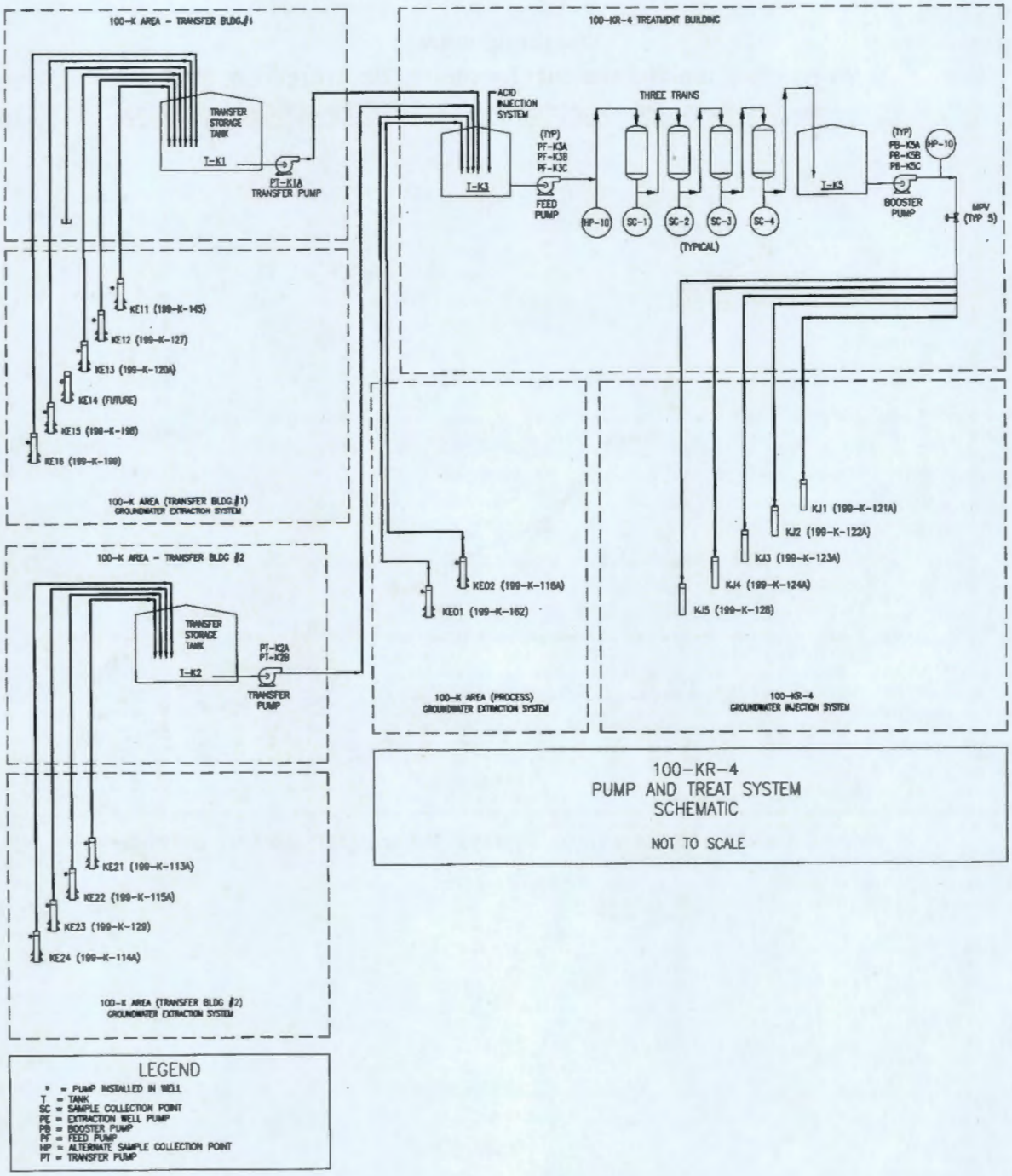


Figure 3-6. KR4 P&T System Schematic

Since the changeover to ResinTech SIR-700 resin in 2012, no resin changeouts have been required at the KR4 P&T system. Process stream pH is measured near the inlet to the IX vessels and before the treated process effluent is discharged. The average influent pH for the KR4 P&T system during 2016 was 6.72 units; the average effluent pH for this system was 6.94 units. No changes in treatment process chemistry were implemented during 2016.

3.2.1.2 KR4 Pump and Treat System Performance

Table 3-2 presents an overview of the operational parameters and total system performance for the KR4 P&T system during 2016. Groundwater was processed at an annual average pumping rate of 1,116 L/min (295 gal/min) during 2016. The average Cr(VI) concentration in the P&T system influent for 2016 was 4.8 µg/L (Figure 3-5) compared to 6.4 µg/L and 9.5 µg/L in 2015 and 2014, respectively. The influent concentration ranged from a minimum of 1 µg/L to a maximum of 10 µg/L (Figure 3-7). The maximum Cr(VI) concentration observed in the system effluent during 2016 was 4 µg/L, and the average concentration for the reporting period was less than 2 µg/L. Additional operational and system characteristics of the KR4 P&T system for 2016 are summarized as follows:

- A total of 580 million L (153 million gal) of groundwater was treated, and approximately 2.5 kg (5.6 lb) of Cr(VI) were removed.
- Mass removal efficiency was 77 percent, which is less than the 83 percent reported in 2015. The decrease in process removal of chromium is related to the decreasing concentration in extracted groundwater and not IX resin effectiveness. The effluent concentrations were at or below detection for all process samples. Since startup, the effluent has met the discharge criterion. Since 1997, average annual influent concentrations have been decreasing over time (Figure 3-5).
- Total treatment system run-time was 98.6 percent.

Only one KR4 P&T extraction well, 199-K-144, exhibited Cr(VI) concentrations above the interim remedial action groundwater target concentration of 20 µg/L during 2016. Prior to being realigned to the KX P&T system, the maximum measured Cr(VI) concentration was 25 µg/L; post realignment, the maximum measured concentration was 32 µg/L. In SGW-58986, *FY2016 Plume Containment and Remediation Utilization Plan*, well 199-K-144 was identified for realignment to the KX P&T system. As indicated in Section 3.2.1.1, this modification reduced the average influent Cr(VI) concentration from 5.7 to 3.8 µg/L allowing the KR4 system to operate for hydraulic containment only.

Table 3-3 presents the pumping flow rates and total run-time percentage (total flow hours divided by total possible run-time) for each extraction and injection well currently in use for the KR4 P&T system. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. During 2016, some wells were subject to downtime due to equipment repair and/or maintenance.

The downtime is reflected in the yearly average flow-rate calculations and the total run-time percentages for each extraction well. Figure 3-8 shows the monthly online availability for the KR4 P&T system for 2016.

Other contaminants of potential concern (COPCs) were detected in the effluent from the KR4 P&T system during 2016, including average concentrations of tritium at 3,560 pCi/L, nitrate at 10,200 µg/L, strontium-90 at 2.3 pCi/L, and carbon-14 at 8.5 pCi/L. Total chromium was detected at an average concentration of 3.1 µg/L. All of these effluent contaminant concentrations were less than their respective DWSs. TCE was not analyzed at the KR4 P&T system. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system.

Table 3-2. KR4 P&T System Operational Parameters and System Performance

Total Processed Groundwater	2015	2016
Total amount of groundwater treated (since September 1997 startup) (million L)	7,904	8,484
Total amount of groundwater treated during CY (million L)	655.5	580.0
Mass of Hexavalent Chromium Removed		
Total amount of Cr(VI) removed since September 1997 startup (kg)	375.3	377.8
Total amount of Cr(VI) removed in CY (kg)	3.9	2.5
Summary of Operational Parameters		
Average pumping rate (L/min)	1,249	1,116
Average hexavalent chromium influent concentration (µg/L)	6.4	4.8
Average hexavalent chromium effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	82.9	77.1[a]
Waste generation (m^3)	0	0
Regenerated resin installed (m^3)	0	0
New resin installed (m^3)	0	0
Number of resin vessel changeouts	0	0
Summary of Other COCs Detected in Effluent		
Average tritium concentration (pCi/L)	5,775	3,560
Average nitrate concentration (µg/L)	10,850	10,200
Average strontium-90 concentration (pCi/L)	2.6	2.3
Average carbon-14 concentration (pCi/L)	17.3	8.5
Average total chromium concentration (µg/L)	1.2	3.1
Summary of System Availability		
Total possible run-time (hours)	8,760	8,784
Total time online (hours)	8,719	8,659
Total availability (%)[b]	99.5	98.6

a. The lower removal efficiency in 2016 compared to 2015 is because of the lower influent concentration.

b. [(total time online) ÷ (total possible run-time)].

COC = contaminant of concern

Cr(VI) = hexavalent chromium

CY = calendar year

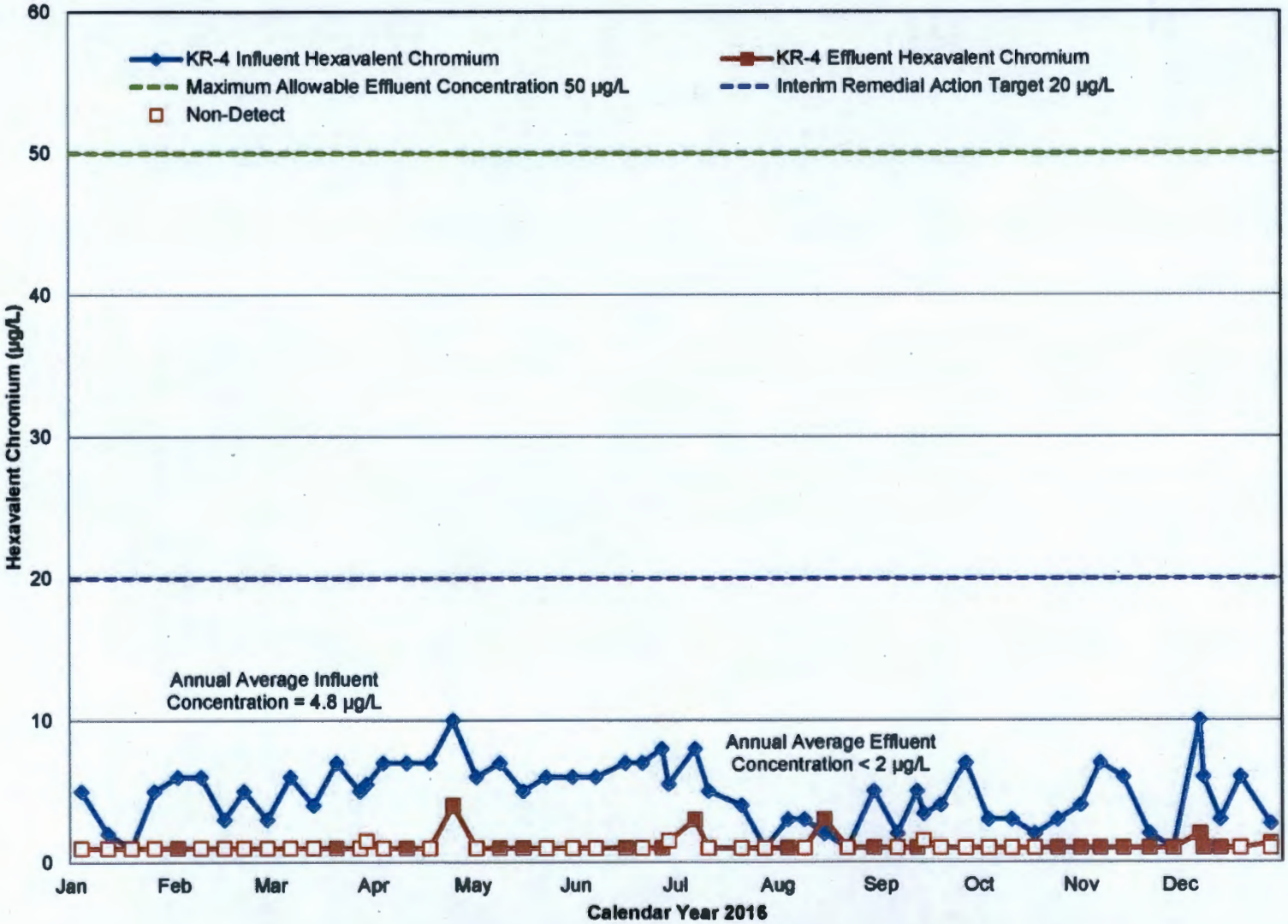


Figure 3-7. KR4 P&T System Trends of Influent and Effluent Cr(VI) Concentrations, 2016

Table 3-3. Flow Rates and Total Run-Times for KR4 P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Yearly Average Flow Rate, L/min (gal/min)	Total Flow Hours in 2016	Total Run-Time[a] (%)	Purpose
C5940	199-K-162	KE01	170.6 (45.1)	8,280	94.3	Extraction
B2803	199-K-116A	KE02	138.5 (36.6)	8,352	95.1	Extraction
C5361	199-K-145	KE11	110.2 (29.1)	8,664	98.6	Extraction
C3662	199-K-127	KE12	72.7 (19.2)	7,896	89.9	Extraction
B2807	199-K-120A	KE13	89.1 (23.5)	8,592	97.8	Extraction
C5360	199-K-144	KE14	154.6 (40.8)	4,488[b]	85.0[b]	Extraction
C7698	199-K-198	KE15	75.8 (20)	8,424	95.9	Extraction
C7699	199-K-199	KE16	75.2 (19.9)	8,448	96.2	Extraction
B2800	199-K-113A	KE21	43.9 (11.6)	8,712	99.2	Extraction
B2802	199-K-115A	KE22	58.2 (15.4)	8,712	99.2	Extraction
C4117	199-K-129	KE23	33.4 (8.8)	7,800	88.8	Extraction
B2801	199-K-114A	KE24	143.6 (37.9)	8,712	99.2	Extraction
B2808	199-K-121A	KJ1	171.3 (45.3)	8,640	98.4	Injection
B2809	199-K-122A	KJ2	339.3 (89.6)	8,712	99.2	Injection
B2810/ B2811	199-K-123A/ 199-K-124A	KJ3A/ KJ3B	195.4 (51.6)	3,888[c]	90.5[c]	Injection
B2810	199-K-123A	KJ3	187.2 (49.5)	4,488	100	Injection
B2811	199-K-124A	KJ4	156.9 (41.5)	4,488	100%	Injection
C7150	199-K-179	KJ4	158.7 (41.9)	3,816[d]	85.5[d]	Injection
C3663	199-K-128	KJ5	206.3 (54.5	8,712	99.2	Injection

a. Percentage total run-time is calculated by [(days well in operation) ÷ (number of days in the CY)].

b. 199-K-144 - disconnected from the system on 7/8/2016. Well was available for 187 days of the year at KR4. Total Run-Time includes the number of days connected to the system + the days it took to realign well to KX P&T system.

c. 199-K-123A/199-K-124A – disconnected from the system on 6/10/2016. Well was available for 162 days in this configuration. Total Run-Time includes the number of days connected to the system + the days it took to realign well to KX P&T system.

d. 199-K-179 – disconnected from the system on 6/7/2016. Well was available for 159 days of the year at KR4. Total Run-Time includes the number of days connected to the system + the days it took to realign well to KX P&T system.

COC = contaminant of concern
CY = calendar year
ID = identification
P&T = pump and treat
PLC = programmable logic controller

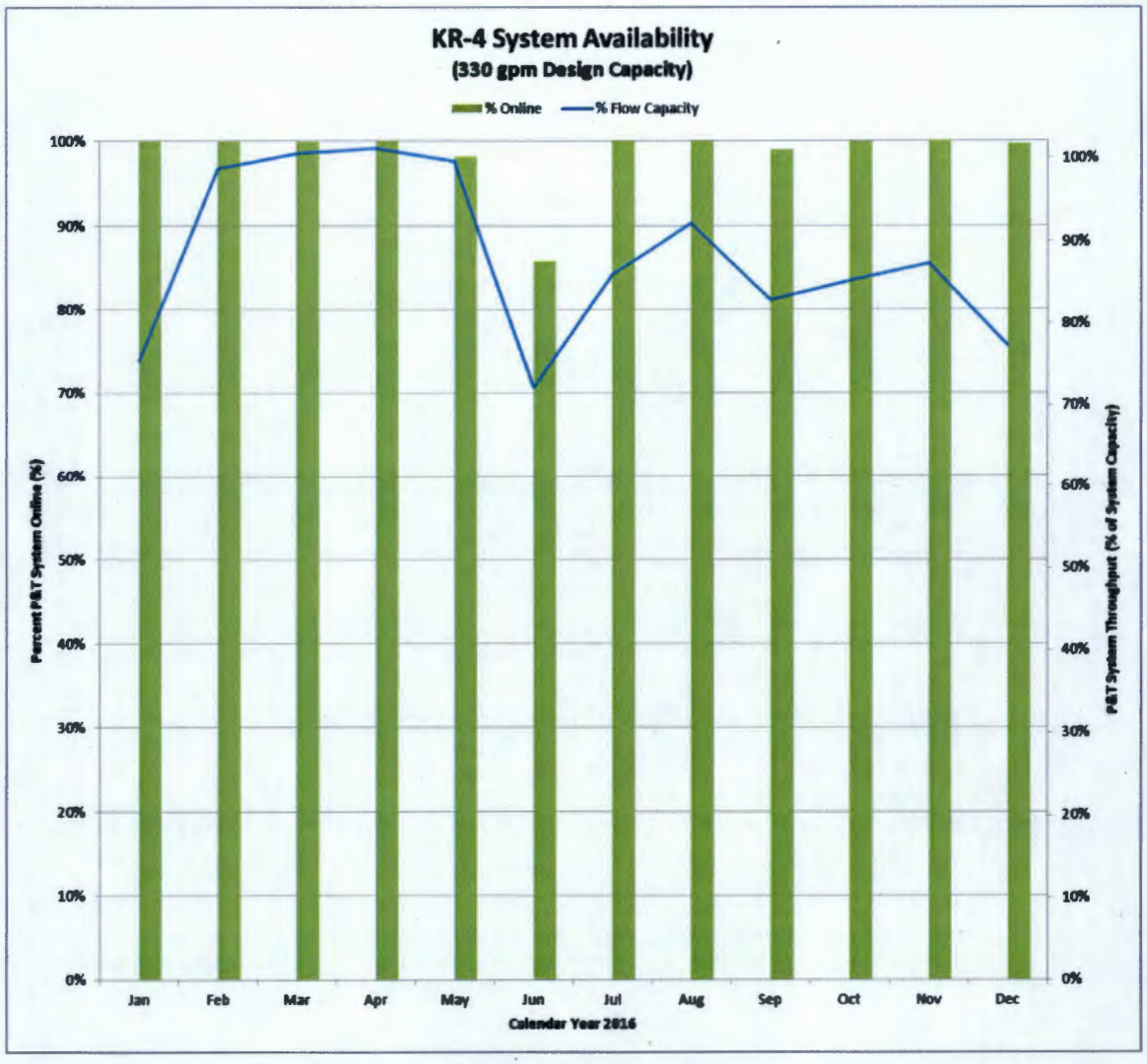


Figure 3-8. Monthly Online Availability for the KR4 P&T System, 2016

3.2.2 KW Pump and Treat System

The KW P&T system was installed to address Cr(VI) groundwater contamination in the 105-KW Reactor area vicinity (Figure 3-2). The KW P&T system became operational on January 29, 2007, and has treated over 3,807 million L (1,006 million gal) of groundwater and removed 241 kg (531 lb) of Cr(VI). The sources of Cr(VI) in the groundwater are historically intentional and unplanned release (UPRs) of water treatment chemicals near the 183-KW Head House chemical storage tank farm. Possible UPRs from the pipeline that transferred sodium dichromate solution from the tank farm to the injection point at the clear wells may have contributed to the condition.

3.2.2.1 KW Pump and Treat System Configuration and Changes

The KW P&T system was originally designed to receive and process up to 757 L/min (200 gal/min). Over the past several years, optimization activities have increase the operational capacity of the system to 1,249 L/min (330 gal/min). The KW P&T system includes 11 groundwater extraction wells and four injection wells (Figure 3-9).

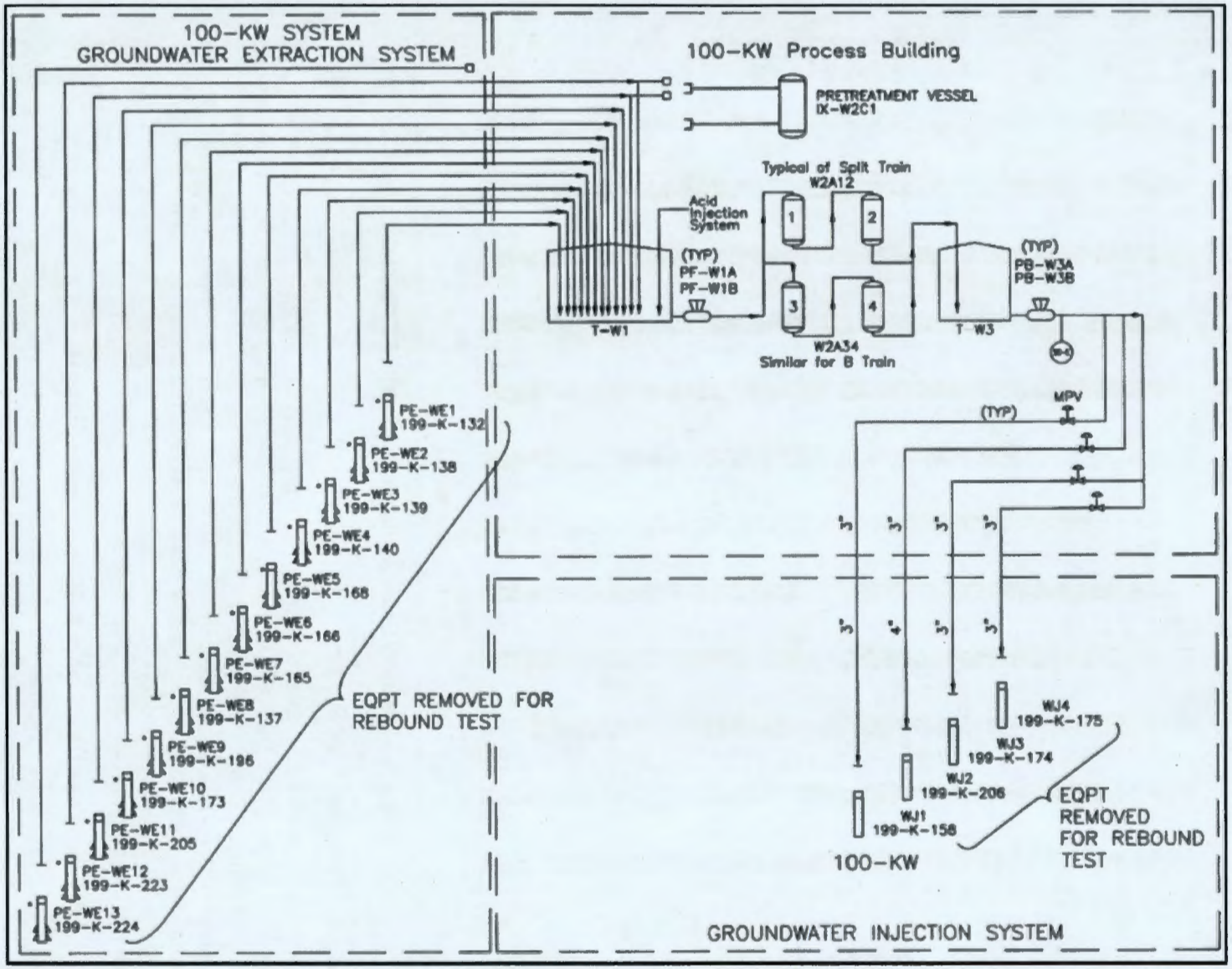


Figure 3-9. KW Reactor Area P&T System Schematic

From January 1 through May 16, the KW P&T system operated using the two-vessel train configuration and SIR-700 resin. The system was shut down on May 16, 2016 to initiate a rebound study.

Before the KW P&T system was shut down, it continued to operate under the 2015 focused pumping strategy of using six extraction wells at higher pumping rates to remove groundwater along the axis of the Cr(VI) plume generally perpendicular to the river. The two wells located in the highest concentration portion of the plume (i.e., 199-K-173 and 199-K-205) were operated at the highest pumping rates (i.e., 50 and 120 gal/min, respectively).

Process stream pH is measured near the inlet to the IX vessels and before the treated process effluent is discharged from the plant. Prior to the shutdown, the average influent pH for the KW P&T system during 2016 was 6.75 units and ranged from 6.69 to 6.80; the average effluent pH for this system was 6.73 units and ranged from 6.68 to 6.80. No changes in treatment process chemistry were implemented during 2016.

3.2.2.2 KW Pump and Treat System Performance

Table 3-4 presents the operational parameters and total system performance overview for the operational period of 2016 for the KW P&T system. The system processed groundwater at an annual average pumping rate of 1,229 L/min (325 gal/min) and operated at overall 99 percent run-time prior to the initiation of the rebound study on May 16, 2016.

The KW P&T system influent Cr(VI) concentration continued a downward trend over the operational period of 2016. The average influent Cr(VI) concentration for 2016 was 12.4 µg/L, about half of the 2015 average (22 µg/L) (Figure 3-10). Between January 1 and May 16, Cr(VI) concentrations dropped from 16 µg/L to 8 µg/L (Figure 3-11).

The Cr(VI) concentration in the KW P&T system effluent remained consistently below the 10 µg/L remedial action objective for river protection during 2016 with an average concentration of less than 2 µg/L. The maximum detected Cr(VI) concentration in the KW P&T effluent samples in 2016 was 3 µg/L (Figure 3-11). Due to the initiation of the rebound study, only one effluent sample was collected for laboratory analysis during the year, and it was below detection limits (less than 1.5 µg/L). This result is consistent with the in-plant measurements taken on a weekly basis. Resin replacement has not been required at the KW P&T system since SIR-700 resin was placed in service in September 2011.

Selected operational and system characteristics of the KW P&T system for 2016 are summarized as follows:

- Overall total system run-time (calculated as the fraction of time the P&T system was in operation) was greater than 99 percent. The monthly online percentages are shown in Figure 3-12.
- A total of 241 million L (63.8 million gal) of groundwater was treated 2016, and approximately 2.9 kg (6.4 lb) of Cr(VI) was removed.
- The average mass removal efficiency was 90.8 percent, a slight decrease from 2015 (Table 3-4).

Table 3-4. KW P&T System Operational Parameters and System Performance

Total Processed Groundwater	2015	2016[a]
Total groundwater treated since January 2007 startup (million L)	3,568	3,807
Total groundwater treated in CY (million L)	651.1	241.5
Mass of Hexavalent Chromium Removed		
Total Cr(VI) removed since January 2007 startup (kg)	238.2	241.1
Total Cr(VI) removed in CY (kg)	17.6	2.9
Summary of Operational Parameters		
Average pumping rate (L/min)	1,241	1,229
Average Cr(VI) influent concentration (µg/L)	22	12.4
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	94.5	90.8
Waste generation (m^3)	0	0
Regenerated resin installed (m^3)	0	0
New resin installed (m^3)	0	0
Number of resin vessel changeouts	0	0
Summary of Other COCs Detected in Effluent[b]		
Average tritium concentration (pCi/L)	1,373	--
Average nitrate concentration (µg/L)	23,033	--
Average strontium-90 concentration (pCi/L)	2.0	--
Average carbon-14 concentration (pCi/L)	450	--
Average TCE concentration (µg/L)	3.0	--
Average total chromium concentration (µg/L)	2.7	--
Summary of System Availability[a]		
Total possible run-time (hours)	8,760	3,288
Total time online (hours)	8,712.8	3,272.5
Total availability (%)[c]	99.5	99.5

a. 2016 system parameter calculated based on the operational period between January 1 and May 16, 2016.

b. Influent and effluent samples for other COCs where not collected due the rebound study and the scheduled sampling events occurring in June and December.

c. Total availability [(total time online) ÷ (total possible run-time)].

COC = contaminant of concern

Cr(VI) = hexavalent chromium

CY = calendar year

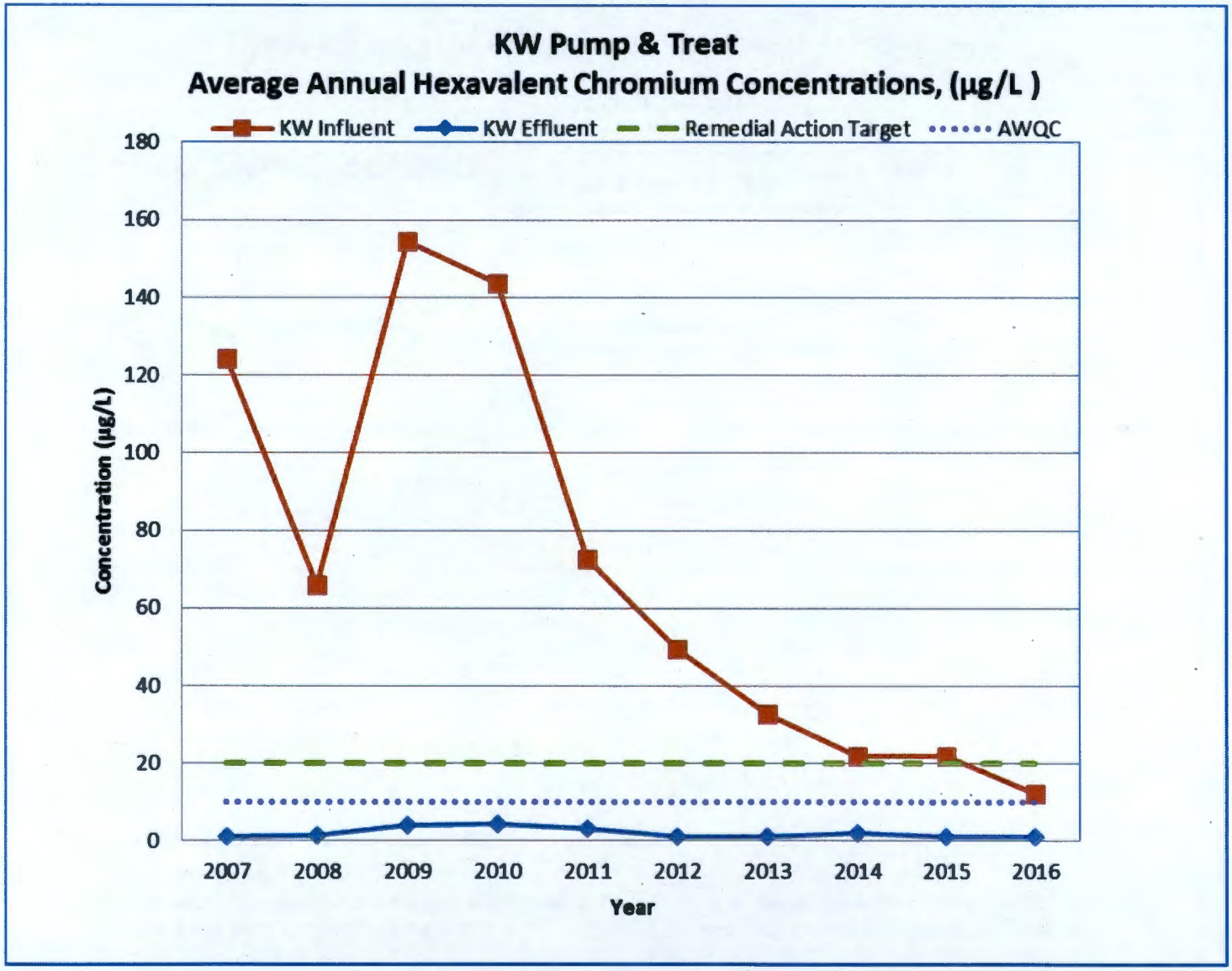


Figure 3-10. KW P&T System Annual Average Influent and Effluent Concentrations

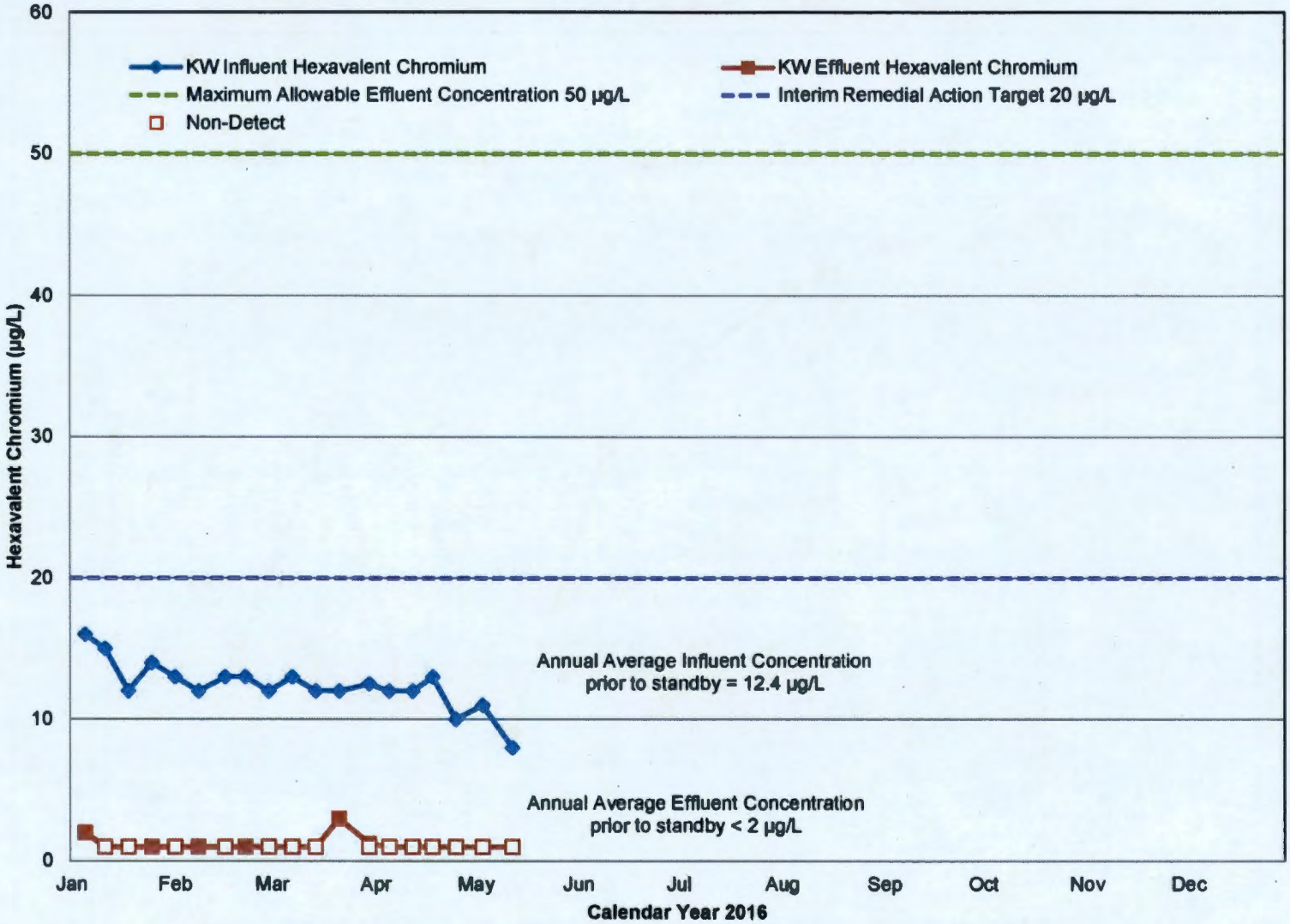


Figure 3-11. KW P&T Trends for Influent and Effluent Cr(VI) Concentrations, 2016

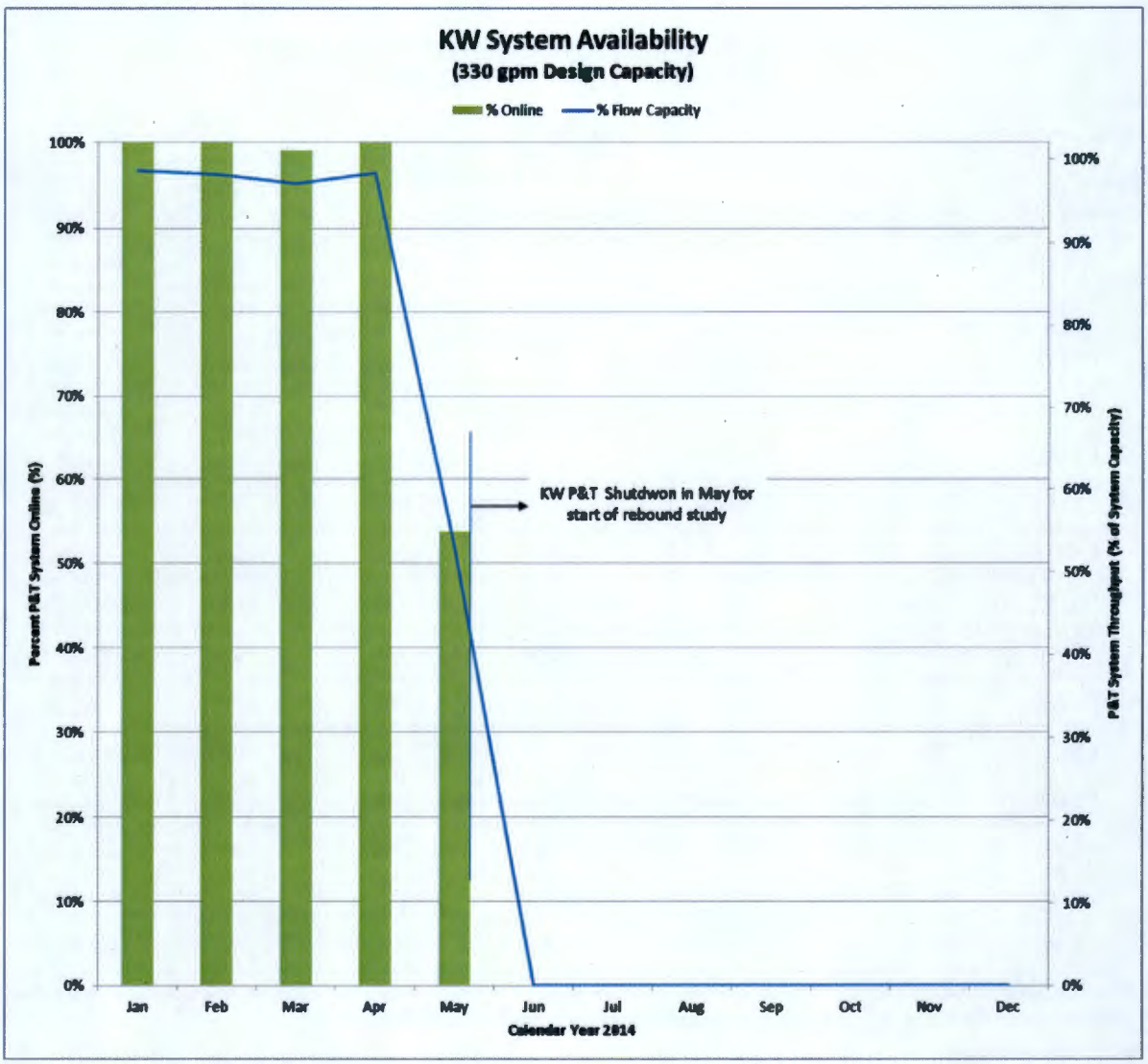


Figure 3-12. Monthly Online Availability for the KW P&T System, 2016

Table 3-5 presents the pumping flow rates and total run-time percentage (total flow hours divided by total possible run-time) for the extraction and injection wells active in the KW P&T system for 2016. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. All wells were subject to downtime for repair 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.

Influent and effluent samples typically collected in June and December and analyzed for other COCs where not collected in 2016 due to the initiation of the rebound study. However, based on analytical results from KW P&T extraction wells and associated monitoring wells, it is unlikely the effluent concentration would have varied much from the December 2015 effluent concentrations. At that time, all effluent contaminant concentrations were less than their respective DWSs. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system.

Table 3-5. Flow Rates and Total Run-Times for KW P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2016	Total Run-Time* (%)	Purpose
C4670	199-K-132	WE1	1.8 (0.5)	192	6	Extraction
C5113	199-K-138	WE2	45.4 (12)	3,288	100	Extraction
C5114	199-K-139	WE3	1.8 (0.5)	192	6	Extraction
C5115	199-K-140	WE4	37.8 (10)	3,288	100	Extraction
C6454	199-K-168	WE5	151.4 (40)	3,288	100	Extraction
C6452	199-K-166	WE6	3.7 (1.0)	216	7	Extraction
C6451	199-K-165	WE7	149.6 (39.5)	3,288	100	Extraction
C5112	199-K-137	WE8	86.1 (22.7)	3,288	100	Extraction
C7696	199-K-196	WE9	113.6 (30)	3,288	100	Extraction
C7016	199-K-173	WE10	189.3 (50)	3,288	100	Extraction
C8292	199-K-205	WE11	448.8 (118.6)	3,288	100	Extraction
C5484	199-K-158	WJ1	353.4 (93.3)	3,288	100	Injection
C8293	199-K-206	WJ2	387.0 (102.2)	3,288	100	Injection
C7061	199-K-174	WJ3	241.6 (63.8)	3,288	100	Injection
C7062	199-K-175	WJ4	241.5 (63.8)	3,288	100	Injection

*Percentage total run-time is calculated by [(days well in operation) ÷ (number of days in the CY)]. Before the initiation of the rebound study on May 16, 2016, the total number of available days in the CY 2016 was 137.

CY = calendar year

ID = identification

PLC = programmable logic controller

3.2.3 KX Pump and Treat System

The KX P&T system was primarily designed to treat the Cr(VI) located between the northern end of the 116-K-2 Trench and the N Reactor fence line (also known as the K North plume). However, in its current well configuration, the KX P&T system is responsible for remediating the inland portions of the remaining Cr(VI) outside the influence of the KW P&T system. This includes the commingled Cr(VI) contamination from the 116-K-1 Crib, 116-K-2 Trench, and the 183-KE Head House, the central plume segment from the 116-K-2 Trench, and the northeastern portion of the 116-K-2 Trench which extend into 100-NR-2. This system began partial operation in November 2008 and was fully operational in early February 2009. Since startup, the system has treated more than 8,992 million L (2,375 million gal) of water and removed approximately 248.5 kg (547.8 lb) of Cr(VI).

3.2.3.1 KX Pump and Treat System Configuration and Changes

The KX P&T system was originally designed to receive and process groundwater at a rate of up to 2,300 L/min (600 gal/min). Over the past several years, optimization activities have increased the operational capacity of the system to 3,407 L/min (900 gal/min). At the end of 2016, the KX P&T system included 21 extraction wells and 10 injection wells (Figure 3-13). The following highlights modification to the KX P&T system during 2016:

- Operating KX extraction well 199-K-182, was taken offline in the early part of 2016 to install a large capacity pump. This increased potential flow rates at this well from 45 gal/min to 75 gal/min.
- KR4 injection well 199-K-179 was realigned to the KX P&T system to increase injection capacity.
- KR4 extraction well 199-K-144 was realigned to the KX P&T system to reduce the KR4 average influent Cr(VI) concentration, allowing the KR4 system to operate for hydraulic containment only.
- Well 199-K-225, which was drilled in 2016 and is located downgradient of the 183-KE Head house and operating extraction well 199-K-220, was aligned to the KX P&T system for mass removal downgradient of the head house. Well 199-K-225 and well 199-K-220 are set up to run only one at a time. The current plan is to switch between these wells every 3 to 6 months depending on the Cr(VI) concentrations exhibited at each location.

During 2016, the KX P&T system continued to operate using the SIR-700 IX resin in the treatment process. The average influent pH for KX P&T system in 2016 was 6.63 units; the average effluent pH (i.e., treated water returned to the aquifer) was 7.01 units. No changes in treatment process chemistry were implemented during 2016.

3.2.3.2 KX Pump and Treat System Performance

Table 3-6 presents an overview of the operational parameters and total system performance for the KX P&T system during 2016. Groundwater was processed at an annual average pumping rate of 3,121 L/min (825 gal/min) and operated 99 percent of the time during 2016.

The average Cr(VI) concentration in the P&T system influent for 2016 was 16.9 µg/L, about 10 percent lower than 2015 (Table 3-6; Figure 3-14). The influent concentrations varied from 14 to 21 µg/L (Figure 3-15).

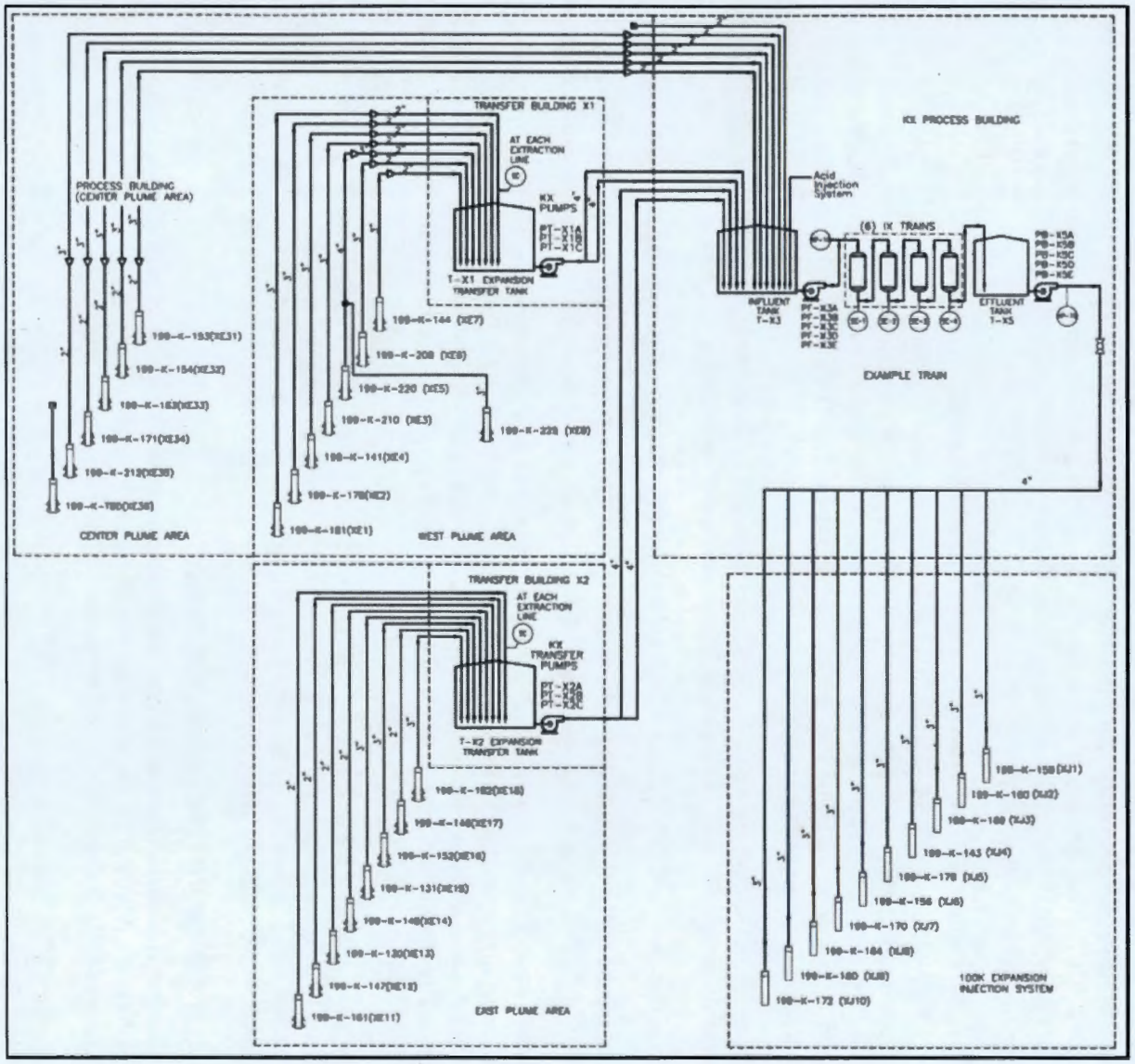


Figure 3-13. KX P&T System Schematic

Table 3-6. KX P&T System Operational Parameters and System Performance

Total Processed Groundwater	2015	2016
Total groundwater treated since November 2008 startup (million L)	7,361.4	8,991.9
Total groundwater treated in CY (million L)	1,587.5	1,636.1
Mass of Hexavalent Chromium Removed		
Total Cr(VI) removed since November 2008 startup (kg)	222.9	248.5
Total Cr(VI) removed in CY (kg)	28.6	25.6
Summary of Operational Parameters		
Average pumping rate (L/min)	3,038	3,121
Average Cr(VI) influent concentration (µg/L)	18.4	16.9
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	93.2	90.6
Waste generation (m^3)	3.6	7.46
Regenerated resin installed (m^3)	0	0
New resin installed (m^3)	0	0
Number of resin vessel changeouts	0	0
Summary of Other COCs Detected in Effluent		
Average tritium concentration (pCi/L)	2,487	3,543
Average nitrate concentration (µg/L)	14,967	15,767
Average strontium-90 concentration (pCi/L)	2.5	1.9
Average carbon-14 concentration (pCi/L)	65.6	62.5
Average total chromium concentration (µg/L)	3.5	5.6
Summary of System Availability		
Total possible run-time (hours)	8,760	8,784
Total time online (hours)	8,693.6	8,707.5
Total availability (%)*	99.2	99.1

*Total availability [(total time online) ÷ (total possible run-time)].

COC = contaminant of concern

Cr(VI) = hexavalent chromium

CY = calendar year

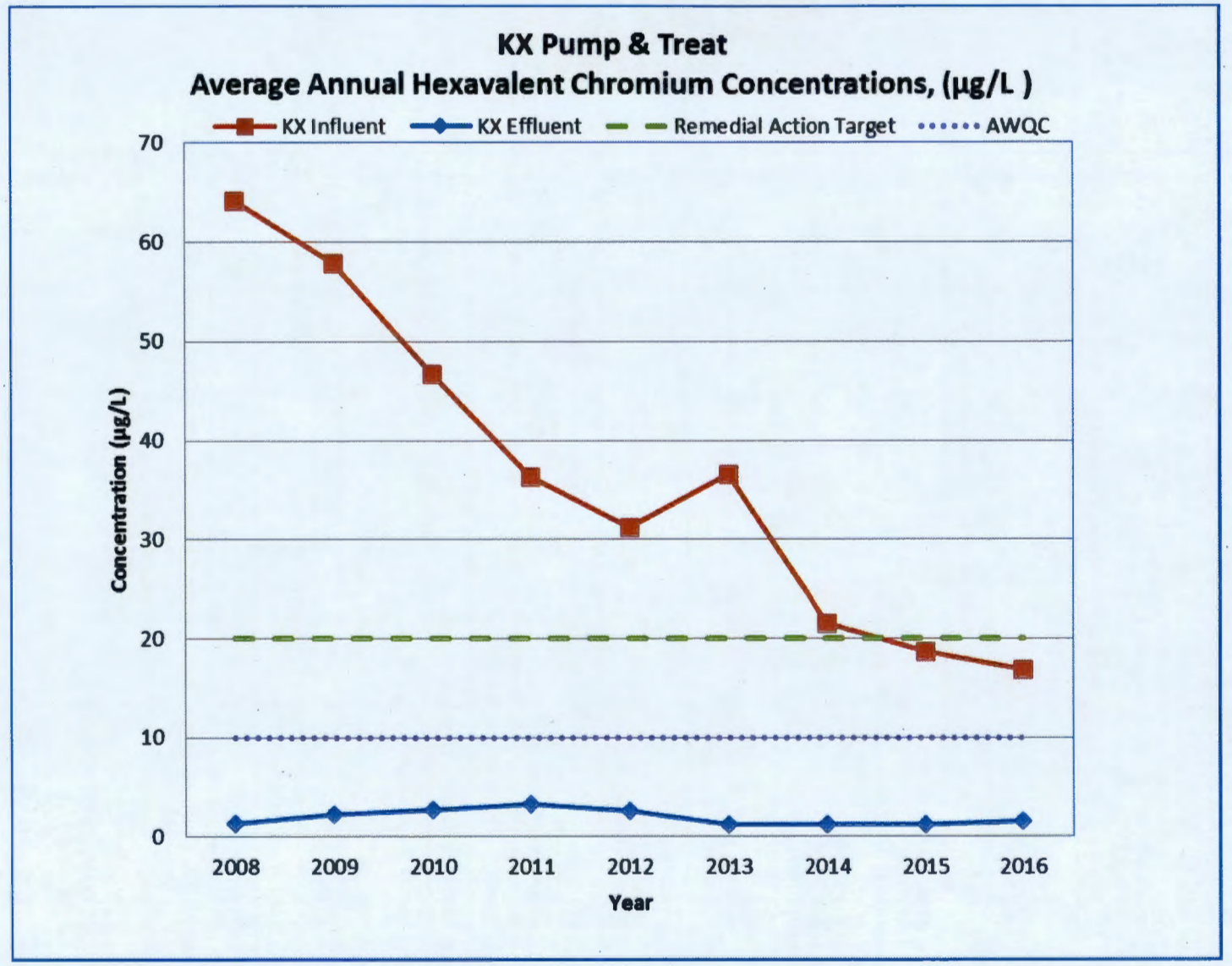
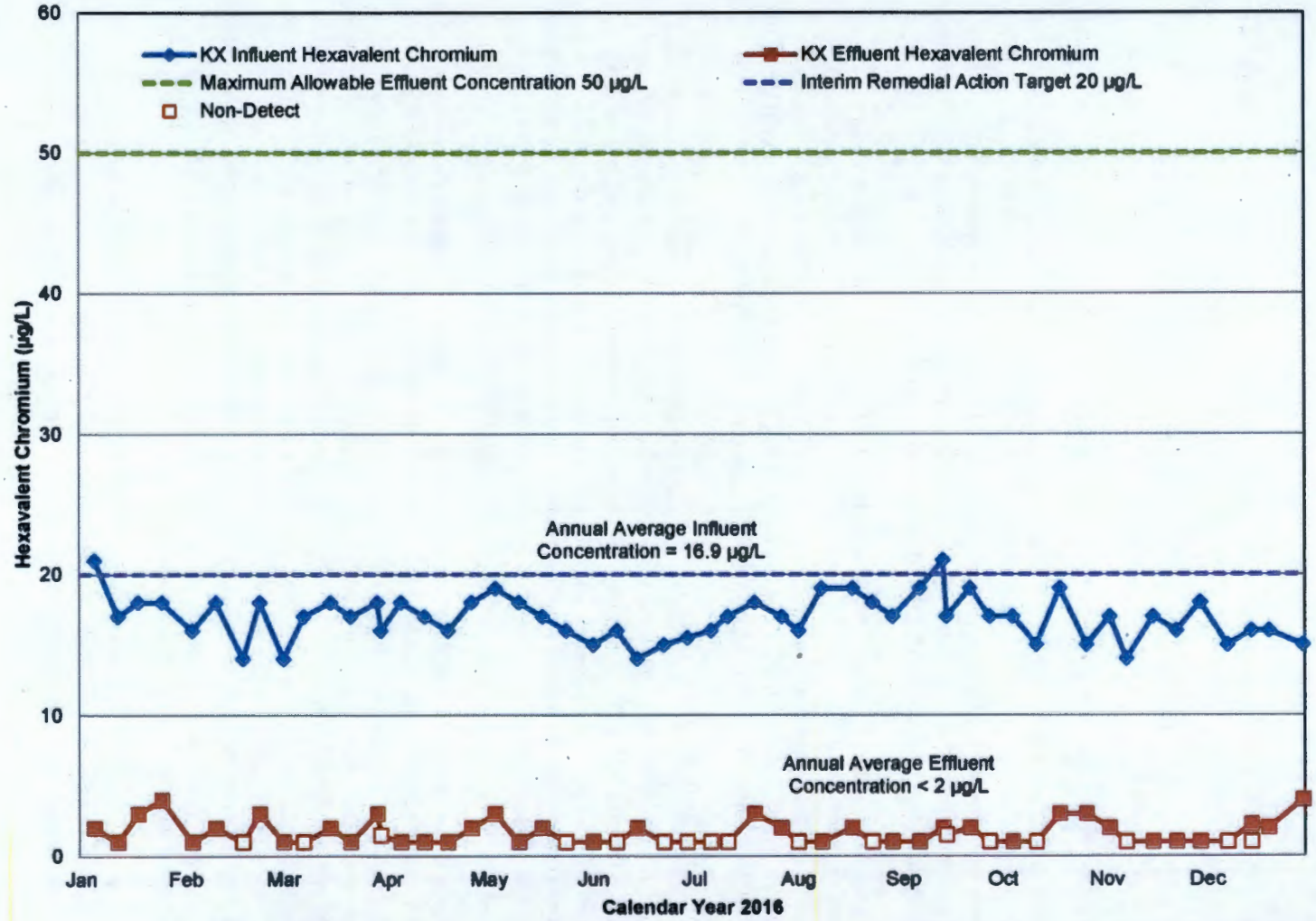


Figure 3-14. KX P&T System Annual Average Influent and Effluent Concentrations



Note: These trends reflect a combination of laboratory and in-plant measurements.

Figure 3-15. KX P&T System Trends of Influent and Effluent Cr(VI) Concentrations, 2016

The maximum reported concentration of Cr(VI) in the KX P&T system effluent during 2016 was 4 µg/L. Effluent concentrations were below detection for most of the year and averaged below the estimated 2 µg/L detection limit (i.e., most of the measurements indicated "0"). Additional operational and system parameters for the KX P&T system for 2016 are as follows:

- Overall total system run-time (calculated as the fraction of time the P&T system was in operation) was greater than 99 percent. Figure 3-16 shows the monthly online percentages.
- A total of 1,636 million L (431.9 million gal) of groundwater was treated, and 25.6 kg (56.4 lb) of Cr(VI) was removed.
- The annual average mass removal efficiency was 90.6 percent (Table 3-6).
- Table 3-7 presents the 2016 pumping flow rates and total run-time for the extraction and injection wells currently active in the KX P&T system. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. During 2016, each well was subject to downtime due to repair and/or maintenance. The downtime is reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction and injection well.
- Other COPCs were detected in the effluent from the KX P&T system, including average concentrations of tritium at 3,543 pCi/L, nitrate at 15,767 µg/L, strontium-90 at 1.9 pCi/L, carbon-14 at 62.5 pCi/L, and total chromium at 5.6 µg/L. As with the other two P&T systems, these concentrations were all less than their corresponding DWSs. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system.

3.2.4 Performance Monitoring

Control of Cr(VI) in groundwater remains the principal objective of the active groundwater interim remedial action at 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 part of the remedial action. The ROD acknowledges that the interim action remedy does not treat other non-chromium groundwater contaminants. The groundwater COCs identified in the RI/FS report (DOE/RL-2010-97, Draft A) are chromium (total and hexavalent), nitrate, carbon-14, strontium-90, tritium, and TCE.

Contaminant concentration data are collected each year from 100-KR-4 OU compliance wells, other monitoring and extraction wells, and aquifer tubes. The data are used to update the nature and extent of groundwater contamination 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 toward the river is highest. Tables 3-8 through 3-10 show the maximum 2016 concentrations for Cr(VI), tritium, strontium-90, carbon-14, nitrate, and TCE for the KW Reactor area, the KE Reactor area, and 116-K-2 Trench (K North) area, respectively, which are described in the following subsections. This report focuses on evaluating the analytical results for Cr(VI) being remediated through the interim action P&T systems. Further summary and analysis of the other COPCs and are presented in the annual groundwater monitoring report (DOE/RL-2016-67).

Tables 3-11 and 3-12 present the 2016 maximum concentration for Cr(VI) in the 100-KR-4 OU plume areas at high and low river stages. CERCLA system performance assessment addresses longer term changes in Cr(VI) concentrations at selected monitoring and extraction wells in the 100-KR-4 OU.

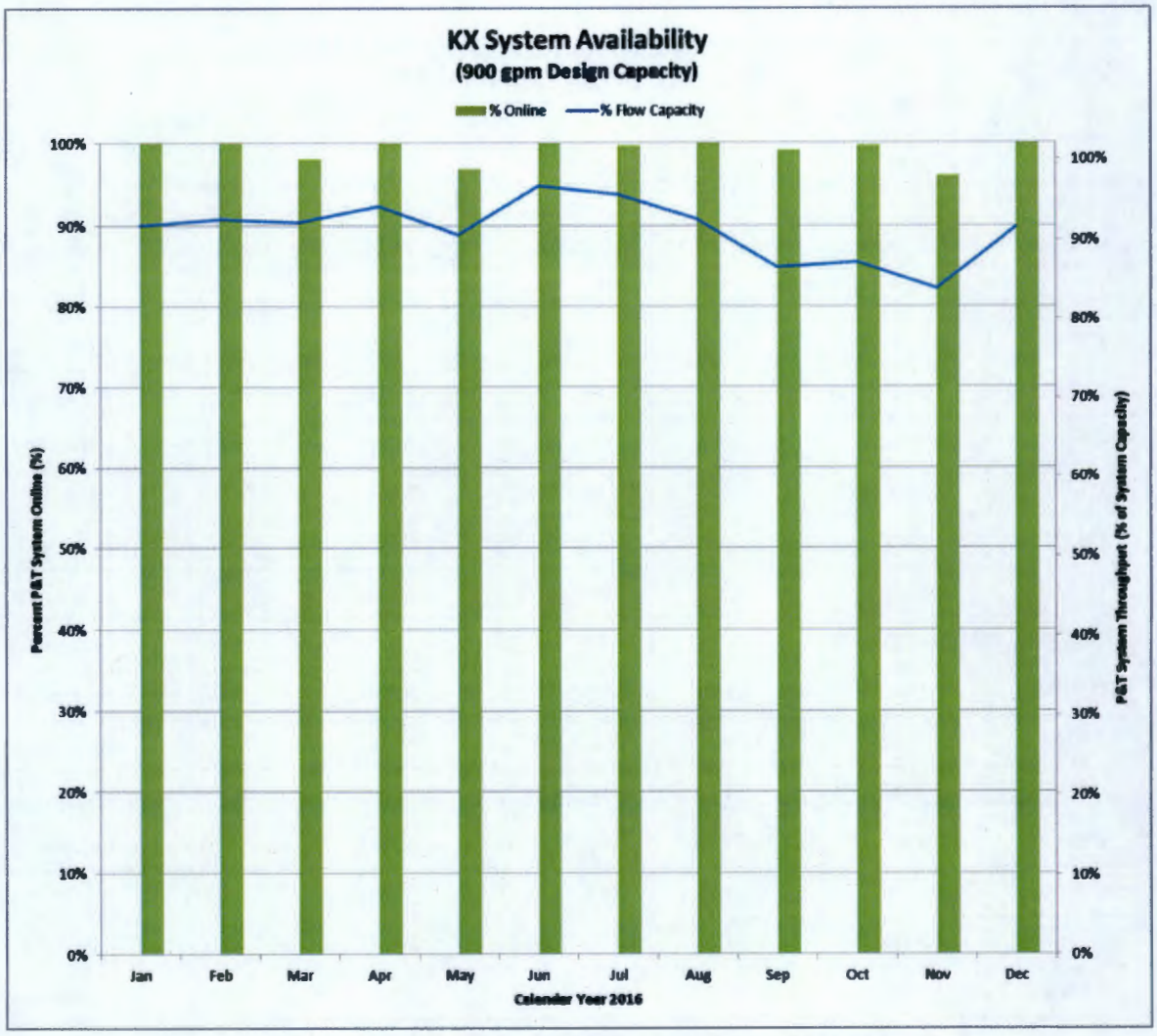


Figure 3-16. Monthly KX P&T System Availability, 2016

Table 3-7. Flow Rates and Total Run-Times for KX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Yearly Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2016	Total Run-Time (%)[a]	Purpose
C7464	199-K-181	XE1	216.6 (57.2)	8,760	99.7	Extraction
C7149	199-K-178	XE2	138.4 (36.6)	8,136	92.6	Extraction
C8297	199-K-210	XE3	283.5 (74.9)	8,760	99.7	Extraction
C5303	199-K-141	XE4	65.7 (17.4)	8,760	99.7	Extraction
C8795	199-K-220	XE5	176.1 (46.5)	5,904	67.2	Extraction
C8295	199-K-208	XE6	249.6 (67.4)	8,760	99.7	Extraction
C5360	199-K-144[b]	XE7	255 (67.4)	3,480	99.3	Extraction
C9597	199-K-225[c]	XE8	227.2 (60)	1,848	93.9	Extraction
C5939	199-K-161	XE11	61.2 (16.2)	8,760	99.7	Extraction
C5363	199-K-147	XE12	61.5 (16.2)	8,760	99.7	Extraction
C4120	199-K-130	XE13	104.7 (27.7)	8,760	99.7	Extraction
C5364	199-K-148	XE14	105.5 (27.9)	8,760	99.7	Extraction
C4561	199-K-131	XE15	115.5 (30.5)	8,760	99.7	Extraction
C5368	199-K-152	XE16	168.7 (44.6)	8,712	99.2	Extraction
C5362	199-K-146	XE17	23.5 (6.2)	6,840	77.9	Extraction
C7476	199-K-182	XE18	263.3 (69.5)	8,520	97	Extraction
C5369	199-K-153	XE31	215.5 (56.9)	8,304	94.5	Extraction
C5370	199-K-154	XE32	234.2 (61.9)	8,760	99.7	Extraction
C6172	199-K-163	XE33	121.2 (32)	7,824	89.1	Extraction
C6746	199-K-171	XE34	204.7 (54.1)	8,208	93.4	Extraction
C8299	199-K-212	XE35	166.4 (43.9)	8,040	91.5	Extraction
C5937	199-K-159	XJ1	243.1 (64.2)	8,760	99.7	Injection
C5938	199-K-160	XJ2	238.9 (63.1)	8,592	97.8	Injection
C6744	199-K-169	XJ3	530.2 (140.1)	8,760	99.7	Injection
C5305	199-K-143	XJ4	205.6 (54.3)	8,760	99.7	Injection
C7150	199-K-179[d]	XJ5	309.9 (81.9)	4,296	99.4	Injection
C5372	199-K-156	XJ6	427.8 (113)	8,760	99.7	Injection

Table 3-7. Flow Rates and Total Run-Times for KX P&T System Extraction and Injection Wells, 2016

Well ID	Well Name	PLC ID	Yearly Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2016	Total Run-Time (%)[a]	Purpose
C6745	199-K-170	XJ7	543.2 (143.5)	8,760	99.7	Injection
C6386	199-K-164	XJ8	250.8 (66.2)	8,760	99.7	Injection
C7151	199-K-180	XJ9	241.5 (63.8)	8,760	99.7	Injection
C6747	199-K-172	XJ10	285.4 (75.4)	8,760	99.7	Injection

a. Percentage total run-time is calculated by [(days well in operation) ÷ (number of days in the CY)].

b. 199-K-144 – Connected to KX P&T on 8/8/2016.

c. 199-K-225 – Connected to KX P&T on 10/11/2016.

d. 199-K-179 – Connected to KX P&T on 7/5/2016.

CY = calendar year

ID = identification

PLC = programmable logic controller

Table 3-8. Maximum Contaminant and Co-Contaminant Concentrations for KW Reactor Area, 2015 and 2016

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well Name
2015				
Hexavalent chromium	183	F	1/15/2015	199-K-205
Hexavalent chromium	195	UF	1/6/2015	199-K-205
Strontium-90	33.8	UF	11/6/2015	199-K-34
Tritium	11,700	UF	10/21/2015	199-K-132
Carbon-14	14,200	UF	11/6/2015	199-K-106A
Nitrate	75,300	UF	8/27/2015	199-K-132
Trichloroethene	8.7	UF	5/7/2015	199-K-185
2016				
Hexavalent chromium	450	F	12/7/2016	199-K-224*
Hexavalent chromium	470	UF	12/7/2016	199-K-224*
Strontium-90	41.5	UF	6/10/2016	199-K-34
Tritium	91,900	UF	8/18/2016	199-K-106A

Table 3-8. Maximum Contaminant and Co-Contaminant Concentrations for KW Reactor Area, 2015 and 2016

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well Name
Carbon-14	40,100	UF	7/8/2016	199-K-106A
Nitrate	75,300	UF	9/9/2016	199-K-185
Trichloroethene	9.48	UF	2/1/2016	199-K-185

*Well 199-K-224 was installed in 2016; sample collected from the bottom of the screened interval.

Table 3-9. Maximum Contaminant and Co-Contaminant Concentrations for KE Reactor Area, 2015 and 2016

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well Name
2015				
Hexavalent chromium	250	F	11/3/2015	199-K-111A
Hexavalent chromium	348	UF	2/9/2015	199-K-111A
Strontium-90	4,000	UF	9/23/2015	199-K-222[a]
Tritium	64,500	UF	11/3/2015	199-K-111A
Carbon-14	4,830	UF	8/26/2015	199-K-222[a]
Nitrate	57,100	UF	5/12/2015	199-K-23
Trichloroethene	6.49	UF	11/11/2015	199-K-190
2016				
Hexavalent chromium	350	F	5/2/2016	199-K-111A
Hexavalent chromium	330	UF	2/1/2016	199-K-111A/ 199-K-226[b]
Strontium-90	75	UF	7/28/2016	199-K-141
Tritium	730,000	UF	1/22/2016	199-K-207
Carbon-14	2,480	UF	2/1/2016	199-K-189
Nitrate	48,700	UF	10/20/2016	199-K-207
Trichloroethene	5.92	UF	5/9/2016	199-K-190

a. Well 199-K-222 was installed in 2015; samples collected during drilling.

b. Well 199-K-226 was installed in 2016; sample collected during well development.

Table 3-10. Maximum Contaminant and Co-Contaminant Concentrations for 116-K-2 Trench Area (K North Plume), 2016

Constituent	Maximum Value Detected (µg/L or pCi/L)	Filtered (F) or Unfiltered (UF)	Date Sampled	Well Name
2016				
Hexavalent chromium	81	UF	2/5/2016	199-K-201
Hexavalent chromium	81	F	2/5/2016	199-K-201
Strontium-90	164	UF	11/30/2016	199-K-200
Tritium	9,030	UF	11/13/2016	199-K-149
Carbon-14	73.2	UF	11/9/2016	699-78-62
Nitrate	28,800	UF	5/9/2016	199-K-201
Trichloroethene	0.3 (U)	UF	8/3/2016	199-K-201

Table 3-11. Cr(VI) 2016 Maximum Concentrations KW Reactor Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	KW Operational[a] Maximum Cr(VI)		KW Rebound[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-106A	M	4/29/2016	3.1	6/17/2016	4.4	6/17/2016	4.4
199-K-107A	M	4/20/2016	7.8	12/9/2016	8.7	12/9/2016	8.7
199-K-108A	M	4/19/2016	3.3	9/30/2016	7	9/30/2016	7
199-K-132	E/M	4/27/2016	14.5	9/20/2016	19	9/20/2016	19
199-K-137	E/M	1/5/2016	18	12/9/2016	40	12/9/2016	40
199-K-138	E/M	1/19/2016	10	6/29/2016	10	1/19/2016	10
199-K-139	E/M	4/27/2016	10	12/12/2016	8.3	4/27/2016	10
199-K-140	E/M	1/5/2016	11	12/4/2016	11	1/5/2016	11
199-K-158	I/M	—	—	11/3/2016	3.5	11/3/2016	3.5
199-K-165	E/M	4/14/2016	10.8	9/8/2016	20	9/8/2016	20
199-K-166	E/M	3/13/2016	4	12/28/2016	23	12/28/2016	23
199-K-168	E/M	1/5/2016	14	11/29/2016	19.6	11/29/2016	19.6
199-K-173	E/M	1/5/2016	13	11/21/2016	98	11/21/2016	98
199-K-174	I/M	—	—	8/31/2016	8	8/31/2016	8
199-K-175	I/M	—	—	6/23/2016	7.4	6/23/2016	7.4
199-K-184	M	2/5/2016	6.2	12/28/2016	8.5	12/28/2016	8.5
199-K-185	M	2/27/2016	5.3	8/25/2016	25.6	8/25/2016	11
199-K-196	E/M	2/21/2016	10	6/29/2016	7.5	2/21/2016	10

Table 3-11. Cr(VI) 2016 Maximum Concentrations KW Reactor Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	KW Operational[a] Maximum Cr(VI)		KW Rebound[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-204	M	3/11/2016	4.3	6/9/2016	7.7	6/9/2016	7.7
199-K-205	E/M	1/16/2016	17	11/10/2016	180	11/10/2016	180
199-K-206	I/M	—	—	12/28/2016	4.8	12/28/2016	4.8
199-K-223	M	—	—	9/28/2016	168	9/28/2016	168
199-K-224	M	—	—	12/7/2016	470	12/7/2016	470
199-K-34	M	4/29/2016	8.5	8/5/2016	9.6	8/5/2016	9.6
17-D	AT	—	—	9/22/2016	2.5	9/22/2016	2.5
17-M	AT	—	—	10/21/2016	1.5(U)	10/21/2016	1.5(U)
AT-K-1-D	AT	—	—	6/24/2016	2.2	6/24/2016	2.2
AT-K-1-M	AT	—	—	9/28/2016	1.5(U)	9/28/2016	1.5(U)
AT-K-1-S	AT	—	—	9/28/2016	1.5(U)	9/28/2016	1.5(U)
C6239	AT	—	—	9/13/2016	3(U)	9/13/2016	3(U)
C6240	AT	—	—	9/13/2016	1.5(U)	9/13/2016	1.5(U)
C6241	AT	—	—	9/13/2016	3.2	9/13/2016	3.2
C7641	AT	1/19/2016	1.5(U)	9/20/2016	1.5(U)	1/19/2016	1.5(U)
C7642	AT	1/19/2016	1.7	7/29/2016	3(U)	7/29/2016	3(U)

Table 3-11. Cr(VI) 2016 Maximum Concentrations KW Reactor Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	KW Operational[a] Maximum Cr(VI)		KW Rebound[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
C7643	AT	1/19/2016	3(U)	9/5/2016	1.5(U)	1/19/2016	3(U)

The average results for injection wells are Cr(VI) concentrations from treated effluent.

Laboratory qualifiers: U = nondetect (shown with detection limit).

a. KW P&T operated through May 16, 2016 and then shut down for rebound study.

b. Well use: E = extraction, I = injection, M = monitoring, AT = aquifer tube

— = sample was not collected or analysis was not performed

Cr(VI) = hexavalent chromium

P&T = pump and treat

RI/FS = remedial investigation/feasibility study

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-11	M	—	—	11/30/2016	4.8	11/30/2016	4.8
199-K-110A	M	5/3/2016	4.5	11/13/2016	6	11/13/2016	6
199-K-111A	M	5/2/2016	350	11/11/2016	290	5/2/2016	350
199-K-112A	M	—	—	11/9/2016	3.1	11/9/2016	3.1
199-K-113A	E - KR4	5/3/2016	3	12/7/2016	40	12/7/2016	40
199-K-114A	E - KR4	4/5/2016	5	12/7/2016	41	12/7/2016	41

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-115A	E - KR4	5/3/2016	3	12/7/2016	39	12/7/2016	39
199-K-116A	E - KR4	7/21/2016	7	11/1/2016	5	7/21/2016	7
199-K-117A	M	6/6/2016	1.5(U)	10/13/2016	2.7	10/13/2016	2.7
199-K-118A	M	—	—	11/11/2016	1.5(U)	11/11/2016	1.5(U)
199-K-119A	M	5/3/2016	1.5(U)	11/11/2016	1.8	11/11/2016	1.8
199-K-120A	E - KR4	7/21/2016	5	12/7/2016	3	7/21/2016	5
199-K-125A	M	5/9/2016	1.7	11/15/2016	3(U)	11/15/2016	3(U)
199-K-126	M	4/21/2016	10.1			4/21/2016	10.1
199-K-127	E - KR4	4/5/2016	3	12/7/2016	3	8/6/2016	3
199-K-129	E - KR4	6/11/2016	4	12/7/2016	34	12/7/2016	34
199-K-13	M	5/2/2016	10	12/2/2016	1.5(U)	5/2/2016	10
199-K-130	E - KX	4/18/2016	9	9/1/2016	8	3/15/2016	9
199-K-133	M	5/26/2016	1.5(U)	11/17/2016	1.5(U)	8/22/2016	1.5(U)
199-K-134	M	—	—	11/17/2016	1.5(U)	11/17/2016	1.5(U)
199-K-135	M	—	—	11/17/2016	1.5(U)	11/17/2016	1.5(U)
199-K-136	M	5/26/2016	1.5(U)	11/17/2016	1.5(U)	8/21/2016	1.5(U)
199-K-141	E - KX	5/13/2016	22	12/7/2016	25	7/21/2016	25
199-K-142	M	—	—	11/15/2016	14	11/15/2016	14

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-144	E - KR4	5/3/2016	25	12/7/2016	32	12/7/2016	32
199-K-145	E - KR4	4/5/2016	8	9/1/2016	6	4/5/2016	8
199-K-146	E - KX	6/7/2016	6	10/12/2016	9	10/12/2016	9
199-K-147	E - KX	4/18/2016	14	11/21/2016	17	11/21/2016	17
199-K-148	E - KX	6/7/2016	7	10/12/2016	8	2/11/2016	9
199-K-152	E - KX	6/7/2016	31	12/7/2016	32	7/10/2016	32
199-K-153	E - KX	5/2/2016	18	12/7/2016	22	12/7/2016	22
199-K-154	E - KX	4/18/2016	28	11/21/2016	31	3/3/2016	39
199-K-157	M	5/3/2016	1.7	11/14/2016	2.5	11/14/2016	2.5
199-K-161	E - KX	5/25/2016	3	10/12/2016	19	10/12/2016	19
199-K-162	E - KR4	7/21/2016	8	12/7/2016	4	7/21/2016	8
199-K-163	E - KX	4/18/2016	4	11/21/2016	4.2	2/21/2016	6
199-K-171	E - KX	5/25/2016	16.4	12/7/2016	16	3/3/2016	19
199-K-178	E - KX	4/18/2016	21	12/7/2016	24	12/7/2016	24
199-K-18	M	4/6/2016	2.7	10/13/2016	2.5	1/15/2016	3.7
199-K-181	E - KX	5/5/2016	10	12/7/2016	17	10/8/2016	17
199-K-182	E - KX	6/7/2016	30	9/1/2016	29	2/11/2016	31
199-K-186	M	5/5/2016	30	11/13/2016	27	5/5/2016	30

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-187	M	4/29/2016	4	11/13/2016	4.3	11/13/2016	4.3
199-K-188	M	—	—	11/30/2016	15	11/30/2016	15
199-K-189	M	5/2/2016	28	11/18/2016	2.3	5/2/2016	28
199-K-19	M	4/29/2016	3.5	11/9/2016	2.6	4/29/2016	3.5
199-K-190	M	5/9/2016	8.7	11/13/2016	7.6	2/1/2016	9.4
199-K-191	M	4/29/2016	2.6	11/13/2016	3.6	2/1/2016	6.6
199-K-192	M	5/5/2016	6.1	11/13/2016	6	4/10/2016	6.1
199-K-193	M	4/29/2016	13	11/14/2016	30	11/14/2016	30
199-K-194	M	4/29/2016	7.3	11/14/2016	6.3	2/2/2016	8
199-K-197	M	—	—	11/30/2016	7.12	11/30/2016	7.12
199-K-198	E - KR4	5/3/2016	6	12/7/2016	4	5/3/2016	6
199-K-199	E - KR4	4/5/2016	5	11/1/2016	8	11/1/2016	8
199-K-20	M	7/28/2016	4.58	10/24/2016	1.5(U)	7/28/2016	4.58
199-K-200	M	5/9/2016	2	11/30/2016	6.29	11/30/2016	6.29
199-K-201	M	5/9/2016	59.6	11/13/2016	30	2/5/2016	81
199-K-202	M	7/28/2016	7.6	10/27/2016	5.8	7/28/2016	7.6
199-K-203	M	7/5/2016	20	12/9/2016	24	7/26/2016	24
199-K-207	M	4/6/2016	110	10/20/2016	79	4/6/2016	110

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
199-K-208	E - KX	5/25/2016	11.5	10/12/2016	19	10/12/2016	19
199-K-209	M	4/29/2016	3.3	11/15/2016	3.6	2/2/2016	3.8
199-K-21	M	4/6/2016	15	10/13/2016	1.7	4/6/2016	15
199-K-210	E - KX	6/20/2016	24	12/7/2016	28	12/7/2016	28
199-K-212	E - KX	6/7/2016	11	12/7/2016	15	12/7/2016	15
199-K-22	M	5/3/2016	34	11/9/2016	12	5/3/2016	34
199-K-220	E - KX	4/18/2016	16	9/1/2016	18	9/1/2016	18
199-K-221	M	4/6/2016	28	10/27/2016	11	1/15/2016	32
199-K-222	M	4/6/2016	20	10/20/2016	5.8	4/6/2016	20
199-K-225	E - KX	6/7/2016	2	12/7/2016	19	12/7/2016	19
199-K-226	M	7/18/2016	193	11/6/2016	330	11/6/2016	330
199-K-23	M	5/9/2016	1.5(U)	12/2/2016	1.5(U)	2/9/2016	2.2
199-K-32A	M	6/12/2016	14	11/11/2016	13	6/12/2016	14
199-K-32B	M	7/22/2016	7.2	—	—	7/22/2016	7.2
199-K-36	M	—	—	11/30/2016	45	11/30/2016	45
199-K-37	M	5/5/2016	22	11/18/2016	32	11/18/2016	32
699-78-62	M	5/26/2016	1.5(U)	11/9/2016	1.5(U)	2/5/2016	1.6
18-S	AT	—	—	10/10/2016	1.5(U)	10/10/2016	1.5(U)

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
19-D	AT	—	—	9/7/2016	1.5(U)	9/7/2016	1.5(U)
19-M	AT	—	—	9/7/2016	1.5(U)	9/7/2016	1.5(U)
21-M	AT	—	—	10/26/2016	1.5(U)	10/26/2016	1.5(U)
21-S	AT	—	—	9/8/2016	1.5(U)	9/8/2016	1.5(U)
22-D	AT	—	—	9/12/2016	43	9/12/2016	43
22-M	AT	—	—	9/12/2016	1.5(U)	9/12/2016	1.5(U)
23-M	AT	—	—	9/12/2016	1.5(U)	9/12/2016	1.5(U)
AT-K-2-D	AT	—	—	9/8/2016	1.5(U)	9/8/2016	1.5(U)
AT-K-3-D	AT	—	—	9/7/2016	44	9/7/2016	44
AT-K-3-M	AT	—	—	9/7/2016	44	9/7/2016	44
AT-K-3-S	AT	—	—	9/7/2016	13	9/7/2016	13
AT-K-4-M	AT	—	—	9/12/2016	1.5(U)	9/12/2016	1.5(U)
AT-K-4-S	AT	—	—	9/12/2016	1.5(U)	9/12/2016	1.5(U)
AT-K-5-D	AT	—	—	9/12/2016	3.6	9/12/2016	3.6
AT-K-5-M	AT	—	—	9/12/2016	1.9	9/12/2016	1.9
AT-K-5-S	AT	—	—	9/12/2016	1.5(U)	9/12/2016	1.5(U)
C6242	AT	—	—	9/14/2016	1.7	9/14/2016	1.7
C6243	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
C6244	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)
C6245	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)
C6246	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)
C6247	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)
C6248	AT	—	—	9/14/2016	1.5(U)	9/14/2016	1.5(U)
C6249	AT	—	—	9/14/2016	1.8	9/14/2016	1.8
C6250	AT	—	—	9/14/2016	1.7	9/14/2016	1.7
C6251	AT	—	—	9/19/2016	2.1	9/19/2016	2.1
C6252	AT	—	—	9/19/2016	3.5	9/19/2016	3.5
C6253	AT	—	—	9/19/2016	4.7	9/19/2016	4.7
C6254	AT	—	—	9/19/2016	1.5(U)	9/19/2016	1.5(U)
C6255	AT	—	—	9/19/2016	6.3	9/19/2016	6.3
C6256	AT	—	—	9/19/2016	14	9/19/2016	14
C6257	AT	—	—	10/26/2016	1.5(U)	10/26/2016	1.5(U)
C6258	AT	—	—	9/19/2016	1.5(U)	9/19/2016	1.5(U)
C6259	AT	—	—	9/19/2016	1.5(U)	9/19/2016	1.5(U)
C6260	AT	—	—	9/20/2016	1.5(U)	9/20/2016	1.5(U)

Table 3-12. Cr(VI) 2016 Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume

Well or Aquifer Tube Name	Current Well Use and P&T System[b]	High River Stage[a] Maximum Cr(VI)		Low River Stage[a] Maximum Cr(VI)		Annual Maximum Cr(VI)	
		Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)	Date Collected	Concentration (µg/L)
C6261	AT	—	—	9/20/2016	2.1	9/20/2016	2.1

The average results for injection wells are Cr(VI) concentrations from treated effluent.

Laboratory qualifiers: U = nondetect (shown with detection limit).

a. High river stage represents the period from April 1 to July 30. Low river stage represents the period from August 14 to December 4.

b. Well use: C = compliance, E = extraction, M = monitoring, AT = aquifer tube, E-KR4 = KR4 extraction, E-KX = KX extraction

— = sample was not collected or analysis was not performed

Cr(VI) = hexavalent chromium

P&T = pump and treat

Figures 3-3 and 3-4 present Cr(VI) plume maps for 2016 low river stage and high river stage, respectively. Contaminant plume maps in this report are based on average results for samples collected either during the low- or high-river period in 2016 for each well shown. The exception for 2016 is the K West Cr(VI) plumes. For 2016, the high river stage plume is based on the average Cr(VI) data collected prior to the shutdown of the KW P&T system on May 16, 2016. The low river stage is based on the maximum Cr(VI) concentration collected over the course of the rebound study (May 31 through December 31). The plume maps, data summary tables, and a summary of notable data observations are presented in the following subsections. Contaminant plume maps were generated as described in Chapter 2.

3.2.4.1 River-Stage Effects

Columbia River stage in the Hanford Reach varies daily with controlled release of water from the upstream Priest Rapids Dam and seasonally in response to annual snowmelt in the mountains of the upstream drainage. High river stage in the Hanford Reach of the Columbia River typically occurs in June or July at the peak of the annual freshet. A hydrograph of river stage at 100-K Area is shown in Figure 3-17. The highest river stage period in 2016 was observed in mid-April to early May, with the maximum on April 22, 2016 at an elevation of 121.08 m (397.23 ft). After the peak in April, the river stage was mostly declining due to the drought conditions experienced in the region and the typical distinct peak river stage conditions were not exhibited during June and July. During the period of low river stage (generally during fall, winter, and early spring), groundwater beneath the 100-K Area flows readily toward the Columbia River. Low river stage at 100-K was observed starting at the end of August, which is consistent with previous years. In 2016, the lowest river stage observed was 116.6 m (382.5 ft) which occurred in early September.

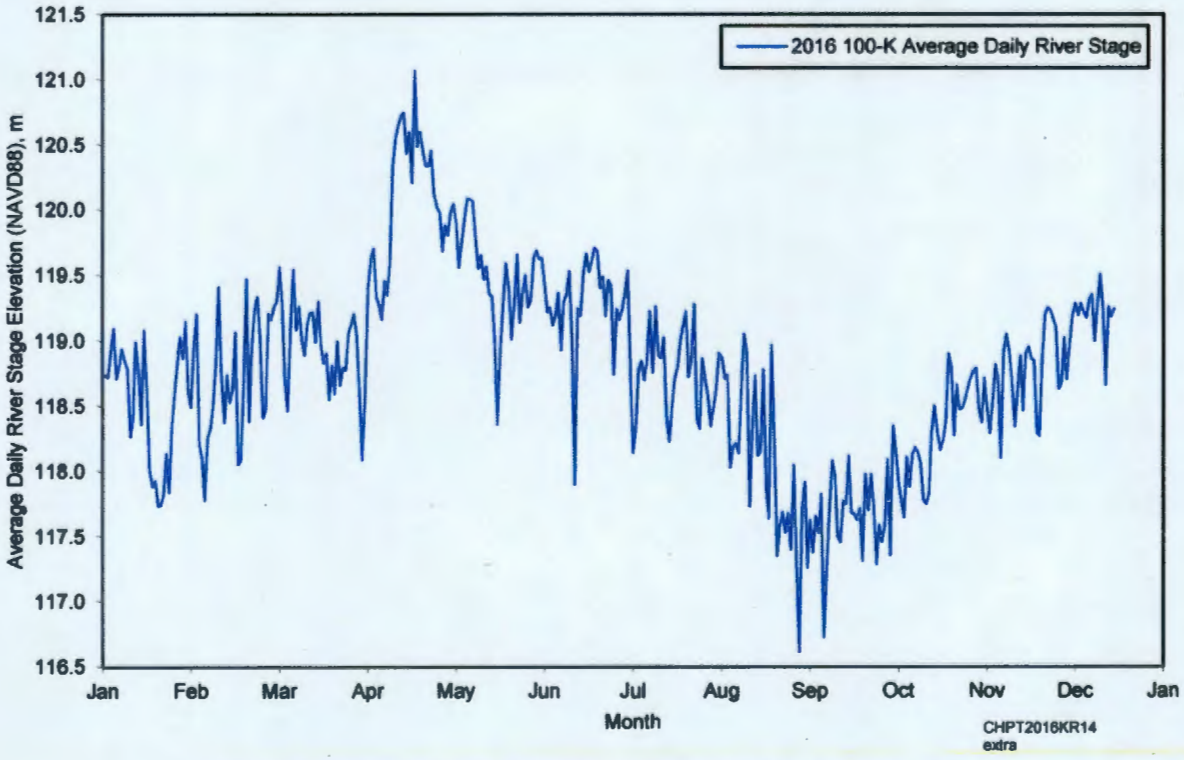


Figure 3-17. Columbia River-Stage Elevation at the 100-K Area, 2016

During high river stage, river water may intrude into the aquifer and cause displacement and/or dilution of the aquifer water in the near-shore environment. The March 2016 water table map (Figure 3-18) represents moderately high river stage conditions. Increased pumping at groundwater extraction wells, particularly those riverward of the distal portion of the 116-K-2 Trench, creates a cone of depression and gradient reversal near the river. Groundwater specific conductance was mapped to evaluate the potential for migration of river water into the aquifer due to capture by extraction wells (Figure 3-19). Several wells exhibited specific conductance measurements consistently below 200 µS/cm during 2016, indicating the samples were primarily river water (the Columbia River exhibits low specific conductance). Specific conductance of 300 µS/cm (or greater) is typical of groundwater in the former industrial operating area of the 100-KR-4 OU. Thus, a specific conductance of 200 to 300 µS/cm indicates a likely mixing of groundwater with river water.

3.2.4.2 Hexavalent Chromium Plumes

Several separate Cr(VI) plumes are differentiated by geographic distribution and by the location and nature of probable source areas. The plumes are associated with three general areas: a plume originating at or near the 183-KW Head House and extending toward the river, a plume originating at or near the 183-KE Head House and extending toward the river, and a plume originating at the 116-K-1 Crib and 116-K-2 Trench and extending radially away from those sites. Conditions observed in groundwater at the 183-KE and 183-KW Head Houses (where historical releases included high-concentration sodium dichromate-dihydrate solution) are likely related to continuing contributions from secondary sources remaining in the vadose zone and/or the periodically rewetted zone in those areas. The 116-K-2 Trench received primarily spent reactor cooling water, containing a substantially lower concentration of sodium dichromate. The potential also remains for continuing contributions from secondary source(s) in the vadose zone and periodically rewetted zone associated with the trench area.

These plumes have been reshaped and/or dissected by operation of the 100-KR-4 OU groundwater P&T systems. The P&T operations have also reduced the groundwater Cr(VI) concentrations at many locations. The plume near the KW Reactor is remediated by the KW P&T system. The plume at the KE Reactor is being remediated primarily by the KX P&T system. The Cr(VI) plume associated with the 116-K-1 Crib and 116-K-2 Trench is being remediated by the KX and KR4 P&T systems. Injection wells for the KX and KR4 P&T systems are located inland and to the northeast of the 116-K-1 Crib and 116-K-2 Trench plume. Figures 3-3 and 3-4 show the inferred Cr(VI) plume distribution for 2016 at low and high river stage, respectively.

KW Reactor Area. This plume is located near the KW Reactor, supporting water treatment facilities, and associated waste sites (Figures 3-3 and 3-4) and originated from releases of concentrated sodium dichromate solutions near the 183-KW Head House and chemical storage tank farm. 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, initially consisting of four extraction wells and two injection wells, began operating in January 2007 after elevated Cr(VI) concentrations were detected in aquifer tube AT-K-1-D. The upgradient edge of the plume is controlled by injection wells 199-K-175, 199-K-174, 199-K-158, and 199-K-206. The plume does not extend inland past well 199-K-175, which exhibited concentrations below 10 µg/L when the well was sampled before conversion to an injection well.

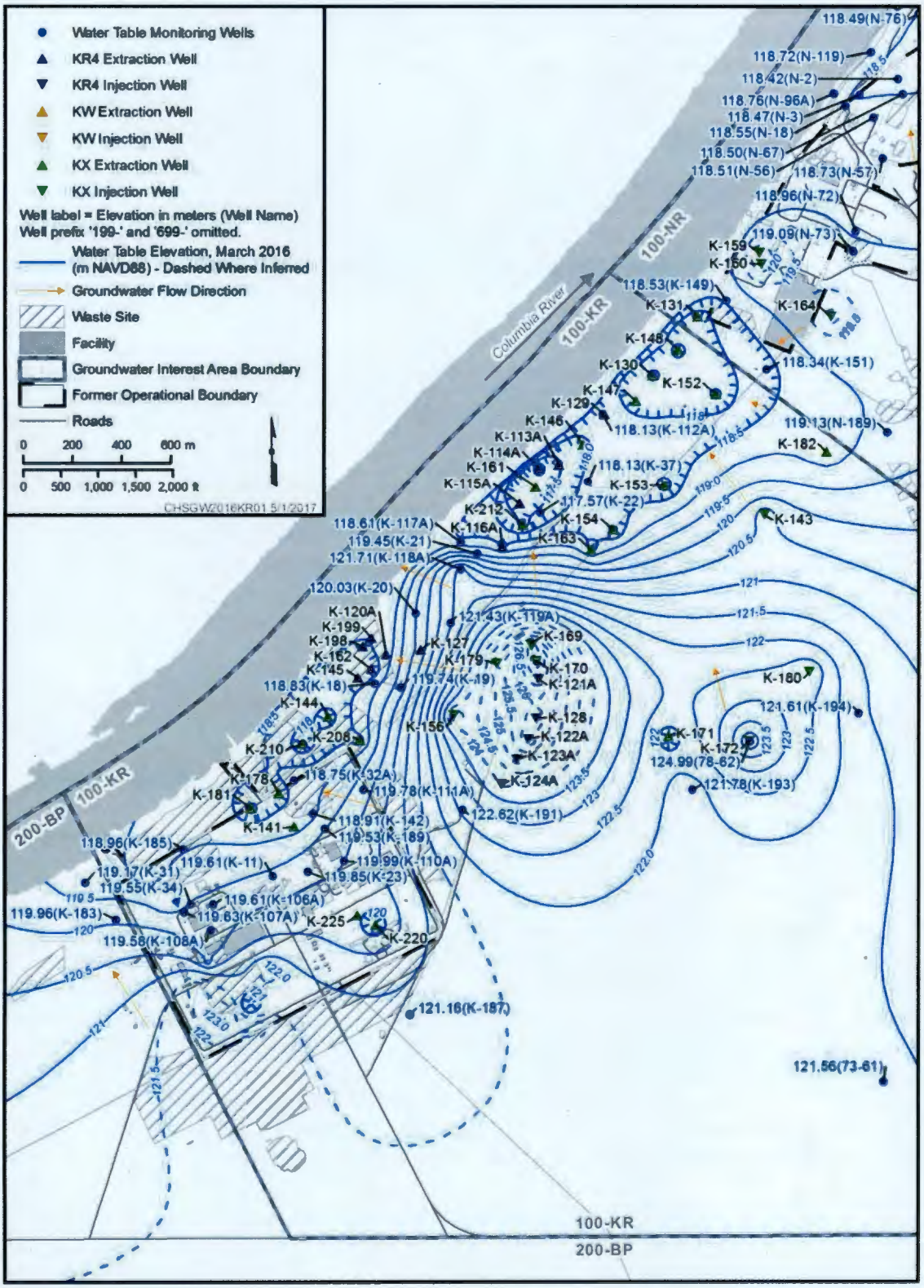


Figure 3-18. Groundwater Elevation Contour Map, March 2016

Figure 3-19. Plot of Groundwater Specific Conductance Relative to the Columbia River, 2016

Since 2013, river stage effects have had less influence on plume geometry than in earlier years. Instead, changes between high and low river stage appear to reflect P&T progress made over the calendar year. At the end of calendar year 2015, all groundwater wells (including extraction and monitoring wells) in the vicinity of the KW P&T system exhibited concentrations below the interim remedial action groundwater remediation target of 20 µg/L. From January through May 2016, the KW P&T extraction wells continued to exhibit Cr(VI) concentrations below 20 µg/L, with the maximum concentration of 18 µg/L in early January at extraction well 199-K-137.

In May 2016, the KW P&T was shut off for a rebound study to evaluate the completion of the interim action, as defined in the RD/RAWP (DOE/RL-2013-33, *Remedial Design/Remedial Action Work Plan for the 100-KR-4 Groundwater Operable Unit Interim Action*). As discussed in Section 3.1.3, a rebound study SAP (DOE/RL-2016-42) was written to determine whether contaminant concentrations will remain below cleanup levels when the aquifer is no longer under the influence of active remediation. The results of the study through the end of 2016 are discussed in Sections 5.2 through 5.8 of DOE/RL-2016-67.

Table 3-11 presents the Cr(VI) concentrations for wells and aquifer tubes monitoring the KW Reactor area plume during 2016, and includes the maximum concentration before and after the shutdown of the KW P&T system. Table 3-8 presents the highest Cr(VI) concentrations, as well as other co-contaminants, from these locations in 2016. The findings and observations are summarized below:

- Cr(VI) concentrations remained low over the course of the rebound study in extraction wells and monitoring wells downgradient of the KW Reactor. The extent of the concentrations less than 10 µg/L downgradient of the reactor is attributed to migration of Cr(VI) that existed between operating P&T wells. The highest concentration downgradient of the reactor was 19.4 µg/L at well 199-K-132.
- Cr(VI) concentrations between the 105-KW Reactor to the former 183-KW Head House (Figure 3-3), exhibited varying degrees of rebound and plume migration. At wells 199-K-173 and 199-K-205, concentrations increased from approximately 10 µg/L to greater the 50 µg/L over a four-month period. When compared to other monitoring wells in this area, this suggest that these wells are at or near sources of continuing groundwater contamination.
- The aquifer between the 105-KW Reactor and the 183-KW Head House is contaminated at variable concentrations with depth. Vertical profiles samples were collected at several locations in this area. At well 199-K-205, the maximum Cr(VI) concentrations were exhibited at the water table, suggesting that contamination continues to leach from the periodically rewetted zone (PRZ). However, samples collected at the middle and bottom of the screened interval continued to show Cr(VI) concentrations ranging from 30 to 50 µg/L. At well 199-K-224, the maximum Cr(VI) concentrations were observed at the bottom of the screened interval, with concentration greater than 100 µg/L at the top and middle of the aquifer.

The remedial performance of the KW P&T system has been evaluated using Cr(VI) data from 2016 and the long-term concentration trends for selected KW P&T system monitoring locations (Figure 3-20). Based on observations and measurements made in the early part of calendar year 2017, it is likely the KW P&T system will restart in 2017 to continue groundwater remediation of Cr(VI). Alternatives for dealing with the secondary source material in the area between the 105-KW reactor and the 183-KW Head House are being evaluated.

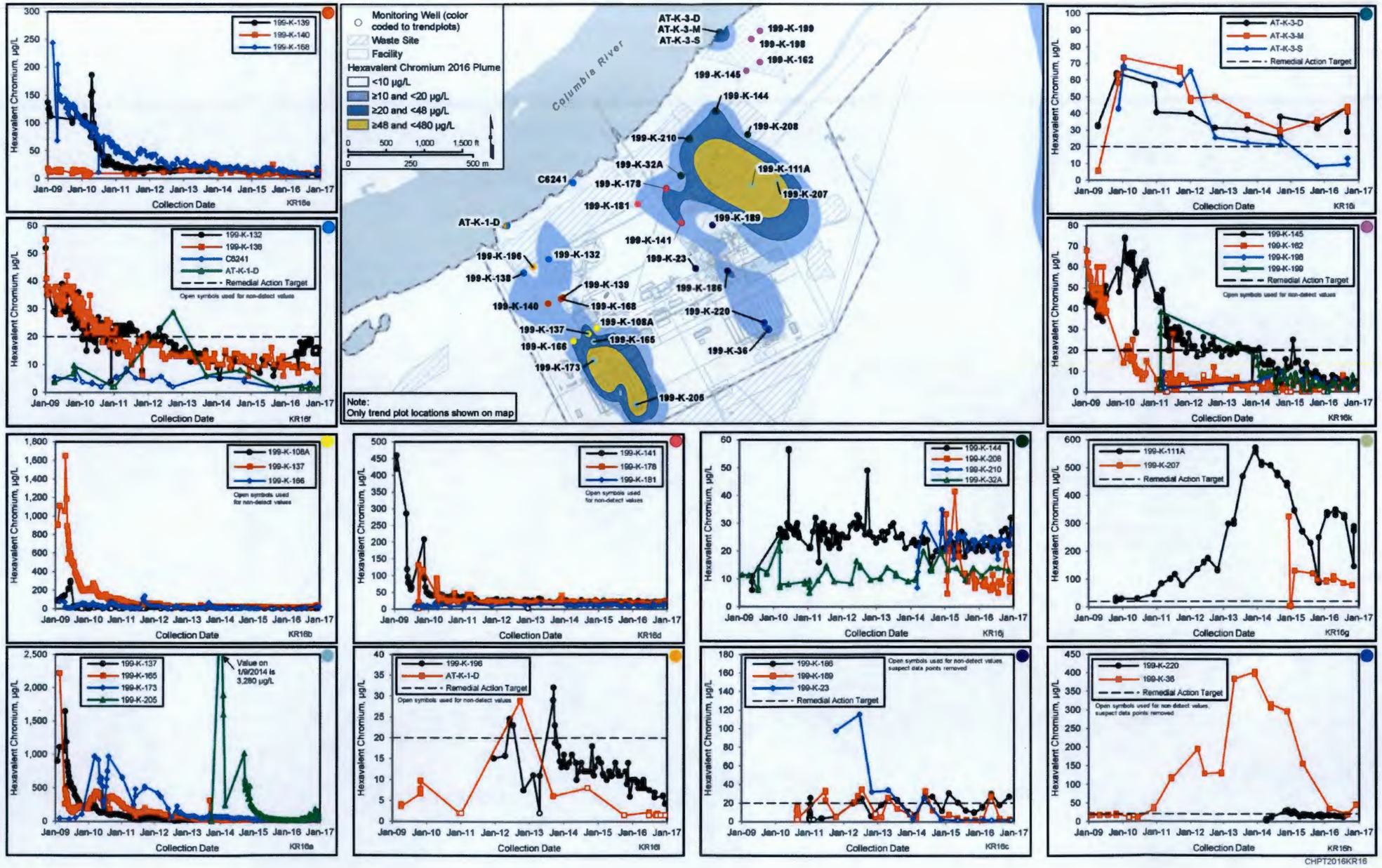


Figure 3-20. 2016 Cr(VI) Groundwater Concentration Time-Series Plots for Selected Wells near the KE and KW Reactors

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KE Reactor Area. By the end of 2016, the 105-KE Reactor Area Cr(VI) plume was remediated entirely by the KX P&T system. Part of the fiscal year 2016 Optimization scope was to realign KR4 P&T extraction well 199-K-144 to the KX P&T system to reduce the average influent Cr(VI) concentration at KR4, allowing that system to operate for hydraulic containment only. The plume has been monitored since the early 1990s, when several CERCLA monitoring wells were installed to characterize potential groundwater contamination in the area. The source of the Cr(VI) plume near the KE Reactor is attributed to the commingling of Cr(VI) contamination from the 116-K-1 Crib, 116-K-2 Trench, and the 183-KE Head house. These sources of contamination are from localized spills or leaks of highly concentrated sodium dichromate solution associated with the KE Reactor water treatment facilities (i.e., 183-KE Head house area) and the large plume created by mounding around the 116-K-2 Trench (caused by historical release of cooling water to the trench). Based on examination of inferred groundwater gradients in this area and the geochemical characteristics of groundwater at selected wells, the current chromium plume near the KE Reactor appears to represent releases from these sites.

Well 199-K-36 (located near the former 183-KE Head House) has historically exhibited Cr(VI) concentrations as high as 1,332 µg/L. Between 2011 and 2015, concentrations ranged from 115 to 403 µg/L. Over the course of 2016, concentration dropped as low as 18 µg/L, before increasing to 45 µg/L by the end of 2016. This area was subject to active soil remediation activities that started at the end of calendar year 2015 and carried into 2016. Downgradient extraction wells 199-K-220 and 199-K-225 exhibited Cr(VI) concentrations between 10 and 20 µg/L in 2016. Well 199-K-188, located just upgradient of well 199-K-36, exhibited concentrations of 20 µg/L or less, suggesting that the plume does not extend far inland of that location. KX P&T system extraction well 199-K-220, located near and downgradient of 199-K-36, exhibited Cr(VI) concentrations ranging from 12 to 27 µg/L in 2016.

Table 3-12 presents the Cr(VI) concentrations for wells and aquifer tubes associated with plume segments outside of the KW P&T system during 2016 and includes the maximum concentration for high and low river stage. Table 3-9 presents the highest Cr(VI) concentrations, as well as other co-contaminants, from these locations in 2016. Figure 3-20 provides trend charts for Cr(VI) concentrations for monitoring and extraction wells for the KR4 and KX P&T systems in the plume area. The remedial performance of the KX and KR4 P&T systems for the KE Reactor area plume (i.e., extent and effectiveness of plume capture and reduction in Cr[VI] concentration in groundwater) have been evaluated using Cr(VI) data from 2016.

Although aquifer tubes are not compliance points for treatment system performance, samples collected from these tubes are helpful to locate areas where Cr(VI) may be discharging to the Columbia River. Aquifer tube cluster AT-K-3-S/M/D is located downgradient of monitoring well 199-K-18 and extraction wells 199-K-162, 199-K-145, 199-K-198, and 199-K-199. This aquifer tube group has had concentrations as high as 85 µg/L since it was first sampled in 2004 (Figure 3-20). During 2016, these three aquifer tubes exhibited Cr(VI) concentrations between 9.4 and 44 µg/L. It is currently not clear what is causing the persistence of Cr(VI) in these aquifer tubes when all upgradient extraction wells have decreased below 10 µg/L. Other notable observations from the 2016 including the following:

- The maximum Cr(VI) concentration in the KE Reactor plume was 350 µg/L in well 199-K-111A, apparently related to migration of chromium from the vicinity of the 116-K-2 Trench and/or the 118-K-1 Burial Ground. Concentrations at cross-gradient monitoring well 199-K-207 had Cr(VI) ranged 73 to 110 µg/L in 2016.
- New monitoring well and future KX extraction well 199-K-226, which is located downgradient of well 199-K-111A, exhibited a post development maximum concentration of 330 µg/L.

- Operation of extraction well 199-K-210, located inland of aquifer tubes C6246 and C6247, continues to capture Cr(VI) that has caused persistent exceedances at these aquifer tubes since 2011.
- Cr(VI) concentrations have decreased in the core of the plume downgradient of the KE Reactor. However, in 2016 the upgradient plume around well 199-K-36 has been connected to the main KE Reactor plume. This apparent change is caused by the addition of KX P&T extraction well 199-K-225, with an average concentration of 16.7 µg/L and the increase in concentration at well 199-K-186.
- Concentrations ranged between 16 and 25 µg/L in well 199-K-141, a KX extraction well downgradient of the 105-KE Reactor, but continued to exhibit elevated strontium-90 concentration during 2016. This well is located on the downgradient edge of the inferred high-concentration strontium-90 plume originating at the 116-KE-3 FSB crib and is apparently capturing part of that plume. Strontium-90 in 199-K-141 was variable during 2016 (between 61.7 and 75 pCi/L).

116-K-2 Trench Area (K North). The current Cr(VI) groundwater plume associated with the 116-K-2 Trench occurs in multiple, isolated plume segments at the 10 µg/L contour (Figure 3-3 and 3-4). This plume, which was initially inferred in the mid-1990s (e.g., PNNL-12086, *Hanford Site Groundwater Monitoring for Fiscal Year 1998*) as being continuous over the length of the 116-K-2 Trench, has been dissected by operation of the P&T systems. The Cr(VI) plume associated with the head end (southwest end) of the 116-K-2 Trench (e.g., wells 199-K-111A and 199-K-226) may be continuous with chromium originating at the 183-KE head house area and is discussed above.

The central plume segment of the 116-K-2 Trench continues to exhibit concentrations greater than 10 µg/L extending from Trench inland to well 199-K-193 (Figure 3-3 and 3-4). The maximum concentrations in this plume segment occurs at well 199-K-201, located inside the footprint of the 116-K-2 Trench. At the beginning of 2016, the maximum concentration at this well was 83.6 µg/L in a filtered total chromium sample. By the end of 2016, concentrations were as low as 28.5 µg/L. This change was most likely caused by the pumping scheme at KX P&T extraction well 199-K-163. This well operated at reduced flows (95 to 114 L/min [25 to 30 gal/min] instead of the potential 208 to 227 L/min [55 to 60 gal/min) for 75 percent of calendar 2016. This allowed an inferred stagnation zone between well 199-K-163 and downgradient KR4 and KX P&T extraction wells 199-K-115A, 199-K-161, and 199-K-212 to be drawn downgradient. Well 199-K-154, which is located upgradient from the 116-K-2 Trench and is an extraction well for the KX P&T system, continued to exhibit decreasing Cr(VI) concentrations, ranging from 21 to 39 µg/L in 2016. In 2015 Cr(VI) concentrations ranged from 34 to 40 µg/L.

Cr(VI) concentrations were less than 10 µg/L in KR4 and KX extraction wells 199-K-116A through downriver well 199-K-146. In aquifer tubes along the similar stretch of river, concentrations were at or below detection limits in 2016, at all but one location. This observation along with the induced depression in the water table (Figure 3-18), indicate the KR4 and KX P&T extraction wells located inland are providing capture of the Cr(VI). However, there is an area of potential shoreline concern in the central Cr(VI) plume segment. In aquifer tube 22-D, located downgradient of KR4 P&T extraction well 199-K-114A, concentrations increased sharply in 2015 and 2016 (Figure 3-21). This observation along with a specific conductance greater than 200 µS/cm, higher than the typical river specific conductance, suggests that groundwater is continuing to discharge at this location.

Cr(VI) concentrations continued to decline at inland KX extraction wells 199-K-153, 199-K-154, and 199-K-163. Well 199-K-163 exhibited Cr(VI) concentrations below 10 µg/L in 2016 and the annual averages at wells 199-K-153 and 199-K-154 were 16.8 and 27.9, respectively. The 2016 annual average at 199-K-154 was about 35 percent lower than 2015 (43 µg/L).

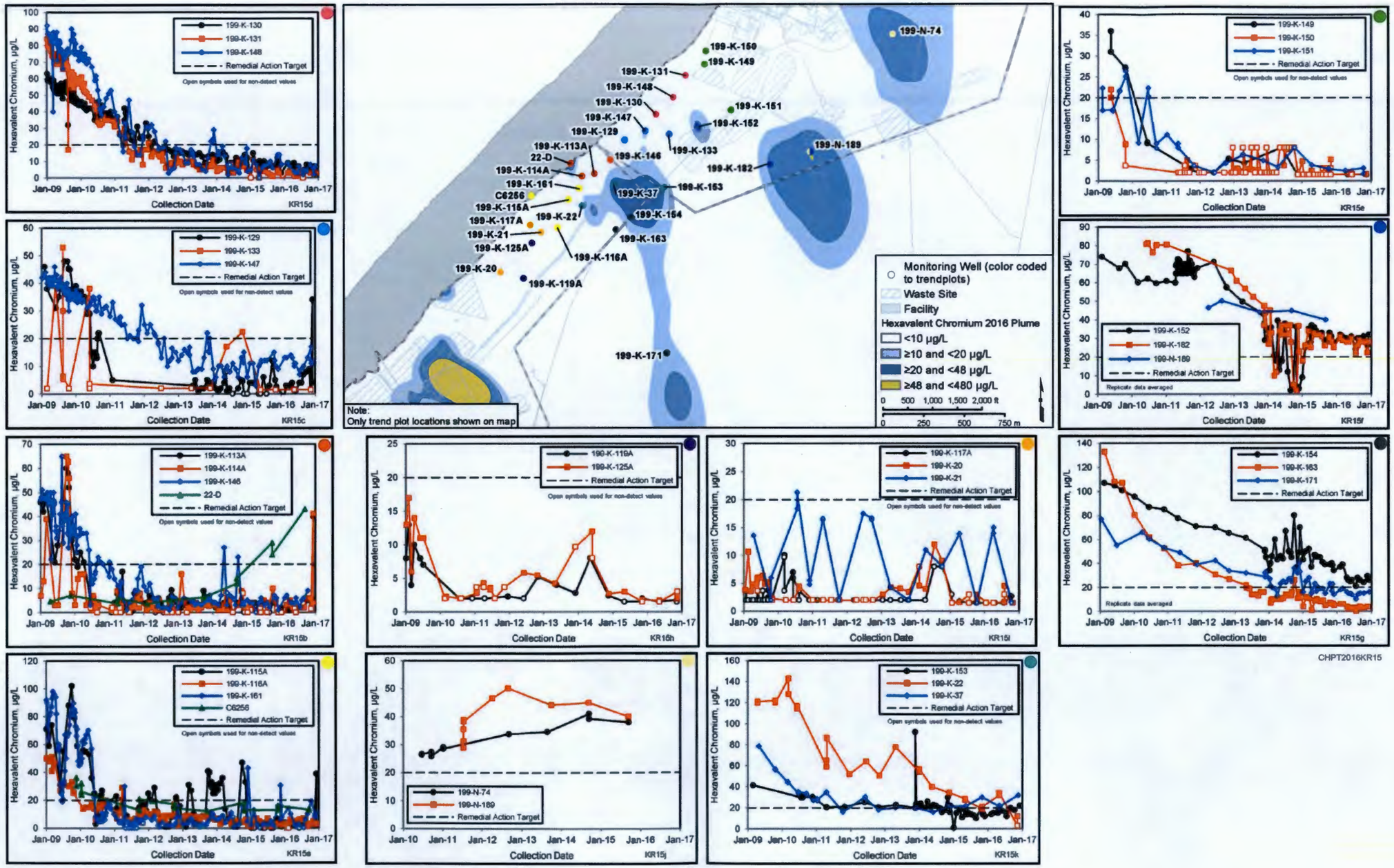

Figure 3-21. 2016 Cr(VI) Groundwater Concentration Time-Series Plots for Selected Wells near the 116-K-2 Trench Source Area

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Extraction wells 199-K-147, 199-K-130, 199-K-148, and 199-K-131 are located progressively farther to the northeast. These well locations are 152 to 183 m (500 to 600 ft) upgradient from, and roughly parallel to, the Columbia River shoreline (Figure 3-21). The concentrations in these wells have steadily decreased since system startup. During 2016, most of the concentrations in these wells were below 10 µg/L.

Inland extraction well 199-K-152 and monitoring well 199-K-151, similar to previous years, continue to demonstrate very different concentration trends. In 2016, well 199-K-152 exhibited concentrations ranging from 24 to 32 µg/L (Figure 3-21). Monitoring well 199-K-151, located 230 m (755 ft) northeast/cross-gradient of extraction well 199-K-152, continue to bound this plume segment upgradient with an annual maximum concentration of 3.1 µg/L. In the FY2017 optimization scope (SGW-59936, *FY2017 Plume Containment and Remediation Utilization Plan*), well 199-K-151 and monitoring well 199-K-149, are proposed to be realigned as injection wells for the KX P&T system. This change will shorten the injection lines to current KX injection wells 199-K-159 and 199-K-160, which will reduce head loss and potentially increase injection capacity of the KX P&T system.

The most northeastern portion of the 116-K-2 Trench plume extends into the 100-NR-2 OU (Figures 3-3 and 3-4). Groundwater sampling during drilling of well 199-N-189, located east of KX extraction well 199-K-182, detected Cr(VI) over the full thickness of the unconfined aquifer, at concentrations ranging from 29 to 39 µg/L in 2011. Well 199-N-189 was not sampled in 2016; therefore, the 2015 value of 49.2 µg/L was used for the plume depictions. Well 199-N-74, located 2 km (1.2 mi) from the end of the trench and farther north than 199-N-189, had an average Cr(VI) concentration of 44.7 µg/L in 2016. The contamination in both locations likely resulted from migration of the plume at the 116-K-2 Trench during the historical discharge period, when the large discharge mound at the trench moved contaminated water radially to the surrounding area. The Cr(VI) concentrations in these 100-N Area wells are consistent with the historical measurement of total chromium in filtered samples (a confident indication of Cr[VI]) in wells in that area over the past 20 years). Management and ultimate disposal of sodium dichromate solutions to wastewater cribs and trenches at the 100-N Area likely contributed to some of the Cr(VI) observed near the 100-N Area; migration of hexavalent chromium away from the 116-K-2 Trench also likely accounts for some of the Cr(VI) observed near the 100-N Area. Operation of the current P&T systems at the 100-K Area does not appear to be affecting the portions of the Cr(VI) plume(s) inland of the 100-N Area.

The overall pumping strategy used in this area is being evaluated to determine if the center of mass for each of these higher concentration plume zones should be more directly targeted for remediation. Part of the FY17 optimization scope is to realign well 199-N-189 as a KX P&T extraction well. This well would replace current KX extraction well 199-K-131, which has exhibited Cr(VI) concentrations ranging from less than detection to 11 µg/L since July 2012. This and other planned modifications should provide adequate capture along the river and increase the amount of Cr(VI) being removed from the aquifer in this area. The 116-K-2 Trench Cr(VI) plume is being remediated by the KR4 and KX P&T systems. However, KR4 continues to run primarily for hydraulic containment, while KX provides larger mass removal. Based on evaluation of groundwater elevation contours inland of the 100-K Area, groundwater appears to flow north-northeast, away from the 100-K Area under natural gradients.

Table 3-10 presents the highest Cr(VI) concentrations, as well as other co-contaminants, from locations associated with the 116-K-2 Trench K North plume area in 2016. Figure 3-21 provides trend charts for Cr(VI) concentrations for monitoring and extraction wells for the KR4 and KX P&T systems in the 116-K-2 Trench K North area.

3.2.4.3 Other Contaminants of Potential Concern

The interim remedial action for groundwater contamination at the 100-KR-4 OU is directed toward control of Cr(VI). Other constituents present in groundwater within this OU identified as COPCs include the following:

- Nitrate
- TCE
- Strontium-90
- Carbon-14
- Tritium
- Chromium (as total chromium)

These COPCs are present in the groundwater being treated for Cr(VI) at varying concentrations and are not subject to a remedial action decision at this time. The releases that caused the contamination by these COCs are generally not coincidental with the sources for the Cr(VI) (except for total chromium, which is present as Cr(VI)). The concentrations of COPCs in groundwater range from slightly greater than DWSs (e.g., TCE at concentrations less than 9 µg/L versus the DWS of 5 µg/L), to substantially exceeding the standards (e.g., carbon-14 at over 40,100 pCi/L compared to the single-nuclide DWS equivalent of 2,000 pCi/L, and strontium-90 at greater than 12,000 pCi/L compared to the single-nuclide DWS equivalent of 8 pCi/L). The occurrence and distribution of COCs in groundwater at the 100-KR-4 OU are described in detail in DOE/RL-2016-67.

The non-chromium COPC plumes are variably captured by the Cr(VI) P&T systems, pass untreated through the P&T systems, and are returned to the aquifer at the injection wells below DWS which is consistent with the interim action ROD requirements. This results in the potential relocation of COPCs into portions of the aquifer where they did not originally exist.

Four of the additional COPCs (i.e., TCE, strontium-90, carbon-14, and tritium) are currently found in at concentrations that may ultimately affect the interim action P&T operations, as described in the following discussion.

Trichloroethene. By the end of CY 2016, TCE exceeded the 5 µg/L DWS in seven wells near the KW Reactor. The maximum concentrations were at wells 199-K-11, 199-K-185, and 199-K-190 (6, 9.48, and 5.92 µg/L, respectively). The historical maximum was about 40 µg/L, although the monitoring history is short and a specific source of TCE contamination has not been identified. The TCE plume is poorly defined by the available measurements, and there are relatively few wells in the vicinity of the exceedances. Unlike previous years, where the KW effluent concentration was applied at injection wells, groundwater samples were collected and analyzed for TCE over the course of the KW rebound study. The measured concentrations are consistent with previous observations that the KW P&T has been injecting TCE at levels below the 5 µg/L DWS. This has created a relatively dispersed TCE plume in groundwater near the KW Reactor with TCE ranging just below the DWS at concentrations between 3.2 and 4.8 µg/L, extending from the three inland KW injection wells to the monitoring locations near the river. This condition will continue to be monitored.

Strontium-90. Strontium-90 is present in groundwater at concentrations exceeding the 8 pCi/L DWS at several locations within the 100-KR-4 OU. The primary locations of concern are downgradient of the 116-KW-2 FSB crib/reverse well, downgradient of the former 105-KE FSB and 116-KE-3 FSB crib/reverse well, and at multiple locations beneath and downgradient of the 116-K-2 Trench. Of particular interest for the P&T systems is the high-concentration strontium-90 plume located

downgradient of the former 105-KE FSB and 116-KE-3 FSB crib, near the 105-KE Reactor. The maximum strontium-90 concentration in groundwater in this area is estimated at greater than 10,000 pCi/L. KX P&T extraction well 199-K-141 has continued to exhibit increasing strontium-90 concentrations. Between 2015 and 2016, the concentration increased from a low of 45.7 pCi/L in early 2015 to a maximum of 75 pCi/L in 2016. This well location is inferred to be on the leading edge of the strontium-90 plume migrating riverward from the area of the former 105-KE FSB. Strontium-90 extracted by well 199-K-141 provides a measurable contribution of strontium-90 to the KX process stream, with an effluent concentration of 1.9 pCi/L in 2016. The concentrations in this area will be monitored for potential effects on P&T operation, which is currently focused on Cr(VI) removal.

Carbon-14. Carbon-14 in groundwater in 100-KR-4 OU originated from historical discharges of reactor gas dryer regeneration condensate to the 116-KE-1 and 116-KW-1 Gas Condensate Cribs. Four wells in the KW Reactor area had concentrations above 2,000 pCi/L in 2016 over the course of the rebound study (199-K-106A, 199-K-139, 199-K-132, and 199-K-204). These wells are located downgradient of the historical release site at the 116-KW-1 Crib. Well 199-K-106A, located 32 m (105 ft) downgradient of 116-KW-1 Crib, had a maximum concentration of 40,100 pCi/L, similar to the historic maximum in 1997. This release indicates a continuing source of carbon-14 below the 116-KW-1 Crib. The increase in carbon-14 was accompanied by increases in nitrate (to 70.8 mg/L) and tritium (to 91,900 pCi/L), indicating the apparent migration of contamination originating at the 116-KW-1 Gas Condensate Crib. Carbon-14 contamination in groundwater continued to be observed as widely distributed over the KW Reactor vicinity at concentrations below 1,000 pCi/L.

A lower concentration carbon-14 plume exists in the 105-KE Reactor area. The plume was formerly defined by wells 199-K-29 and 199-K-30, which have been decommissioned. In 2010, 199-K-29 and 199-K-30 had maximum concentrations of 3,120 and 6,900 pCi/L, respectively, which are above the DWS. These wells monitored conditions downgradient of the 116-KE-1 Crib waste site. As with conditions near the KW Reactor, the carbon-14 plume at the KE Reactor area appears to be migrating downgradient away from the source area. The carbon-14 plume at 105-KE Reactor area may not lie completely within the capture zone of the operating KX extraction wells. Well 199-K-202 had a carbon-14 concentration of about 2,000 pCi/L in 2016. Well 199-K-189, located between wells 199-K-202 and 199-K-203, exhibited a wide range in carbon-14 concentrations from 163 to 2,480 pCi/L during 2016, a decline from 2015.

Tritium. Tritium is found in groundwater at multiple locations in the 100-K Area, with the primary source areas at the 116-KE-1 Crib, 116-KW-1 Crib, and 118-K-1 Burial Ground. The highest concentrations are currently observed in wells downgradient of these source areas. During 2016, tritium concentrations in well 199-K-111A increased to 379,000 pCi/L and subsequently declined to 216,000 pCi/L by the end of 2016. Tritium concentrations declined in well 199-K-207, located upgradient of 199-K-111A and within the footprint of the former 118-K-1 Burial Ground from 935,000 pCi/L in 2015 to 400,000 pCi/L in October 2016. The KR4 and KX P&T system effluent exhibited 2016 average concentrations of tritium at 3,560 and 3,543 pCi/L, respectively. At KW, tritium in monitoring well 199-K-106A increased to 91,900 pCi/L in 2016. Tritium concentrations will continue to be monitored.

3.2.5 Hydraulic Monitoring

Hydraulic monitoring (i.e., water-level monitoring) is performed to evaluate the effect of the P&T systems on the water table and to evaluate groundwater flow direction and gradient. The hydraulic effects of the P&T systems are superimposed on seasonal fluctuations in the river levels and inland groundwater elevation to evaluate the effectiveness of providing hydraulic containment and capture of Cr(VI) plumes.

Groundwater elevation is measured manually during regularly scheduled groundwater sampling events, during focused events to collect elevation measurements from many wells over a short period of time, and in selected wells by automated data-logging pressure transducers placed in the wells (AWLN). The 100-K Area AWLN system includes 24 stations that were operating in and around the 100-KR-4 OU as of the end of CY 2016. Additional localized dynamic water level data are collected at each of the P&T extraction and injection wells operating within the 100-K Area. Reported water-level data from AWLN wells and manual depth-to-water measurements are reviewed and reduced, and a final dataset is compiled to assemble the groundwater elevation maps (Figures 3-3 and 3-4).

Under natural gradient conditions, regional groundwater generally flows to the north and northwest toward the Columbia River beneath the 100-KR-4 OU. Hydraulic effects of the P&T systems at the 100-KR-4 OU (i.e., the formation of depressions at extraction wells and mounds at injection locations) are superimposed onto these regional flow patterns. As shown in Figure 3-18, a substantial water table depression was observed during 2016 from the near-river area of 105-KE Reactor and extending to the distal end of the 116-K-2 Trench. This depression is interrupted near the mid-point of the 116-K-2 Trench by the inferred extension of the recharge mound associated with the 100-KR-4 and 100-KX P&T system injection mounds. The inferred water table is consistent with the observation that operation of the P&T systems is providing groundwater capture and resulting in river protection, along the 100-K Area river shore environs.

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 3.2.6. River stage behavior was, unlike 2015, somewhat more typical during 2016, with the absolute peak river stage observed in April 2016. The river stage then remained slightly elevated through the summer before declining to typical seasonal low levels in September (Figure 3-17).

Under natural flow conditions, and in areas away from the cone of depression caused by the operation of extraction wells, during high river-stage periods, the local groundwater gradient magnitude is reduced near the river; the area very near the river may actually exhibit a flow direction reversal, with river water migrating into the aquifer (i.e., seasonal bank storage). In addition, this change (i.e., increased elevation) of the boundary condition causes the groundwater inland of the river to back up during high river stage, thus creating the seasonal increase in groundwater elevation typically observed inland of the river. As the river stage declines following the seasonal freshet, the boundary condition again adjusts, the groundwater gradient steepens toward the river, and velocity increases. This condition continues until the groundwater head again equilibrates with the low river-stage condition. In areas of substantial groundwater extraction (e.g., the area between 116-K-2 Trench and the river), an inland flow from the river is maintained. Seasonal groundwater elevation transients are observed up to several kilometers from the river as the water table and river stage equilibrate, although the magnitude of the increase progressively decreases with distance from the river. Figure 3-18 presents a groundwater contour map of the area, which was developed using concurrent measurements collected in March 2016 (near the 2016 maximum river-stage period).

3.2.6 Hydraulic Containment

Hydraulic containment of the contaminant plumes is an essential element of the performance of P&T remediation in the 100-KR-4 OU. In general, hydraulic containment of the Cr(VI) plume segments in the 100-KR-4 OU is effective. This section presents a comparison of the estimated extent of hydraulic containment for the three 100-KR-4 OU P&T systems with the estimated extent of chromium contamination in groundwater. The assessment is based upon a joint evaluation of groundwater level, pumping rate (extraction and injection), and water quality data. The extent of hydraulic containment is estimated using two methods:

- Water-level mapping using an extension of the hybrid universal kriging/analytic element method technique (detailed in SGW-42305).
- Groundwater modeling using the 100 Area groundwater model (documented in SGW-46279).

In each case, the estimated extent of hydraulic containment is depicted using a CFM. The CFM constructed using the water-level mapping technique is referred to as an ICFM, whereas the CFM constructed using the 100 Area groundwater model is referred to as an SCFM. In each case, the CFM depicts the frequency with which particles representing mobile groundwater and contaminants are moving toward extraction wells, calculated over a series of mapped or simulated groundwater levels that represent conditions throughout the year. A frequency of 1.0 indicates that groundwater in the area is hydraulically contained under all conditions encountered during the period (i.e., groundwater is always moving toward extraction wells). A frequency of zero indicates that groundwater in the area was not hydraulically contained under any conditions encountered during the period (i.e., was at no time during the period moving toward extraction wells). Intermediate frequencies indicate that the groundwater was contained under some, but not all, conditions.

Water-level mapping using the ICFM approach was completed using monthly averaged groundwater elevations, pumping rates, and stage of the Columbia River, which resulted in 12 water-level maps encompassing the River Corridor, and correspondingly, 12 individual depictions of the extent of hydraulic containment for use in constructing an ICFM. Groundwater modeling using the 100 Area groundwater model was completed using monthly average pumping rates, stage of the Columbia River, and other time-varying boundary conditions. This resulted in 12 simulated groundwater level and flow fields, and correspondingly 12 individual depictions of the extent of hydraulic containment for use in constructing an SCFM.

The ICFM and SCFM are collective estimates for the monitoring period. Emphasis is placed on regions of high frequency and on comparing areas where the ICFM and SCFM are similar or where they differ. Where the ICFM and SCFM are similar, confidence is relatively high that containment is being achieved (where both maps suggest that containment is achieved); or that it is either weak or it is not being achieved (where both maps suggest that containment is not achieved or, in most cases, where capture frequencies are very low). Where the ICFM and SCFM differ substantially, confidence is lower in the assessment of containment because one method suggests that containment is being achieved whereas the other method suggests either that containment is not being achieved or that it is weak.

The extent of chromium contamination in groundwater during high and low river stage conditions is estimated using a systematic approach to develop contaminant plume maps using an integrated numerical interpolation methodology, as detailed in ECF-Hanford-16-0138.

Figures 3-22 to 3-27 compare the estimated extent of hydraulic containment and the estimated extent of chromium contamination in groundwater for both high and low river-stage conditions for the 100-K Area as follows:

- Figure 3-22 and Figure 3-23 depict chromium contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 3-24 and Figure 3-25 depict chromium contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 3-26 depicts the groundwater flow lines from particle tracking to estimate the aquifer capture zone of the 100-KR-4 OU P&T systems over a 10-year period.
- Figure 3-27 overlays the capture flow lines with the chromium plume contours for low river-stage conditions.

ECF-HANFORD-17-0028 presents details on the specific calculations used to produce these figures, including updates to and implementation of the 100 Area groundwater model, the methodology for water-level mapping, and the development of the ICFM and SCFM.

3.2.7 River Protection Evaluation

The river protection status of conditions at 100-KR-4 OU is based on assessment of the hydraulic effects of operation of the remedial action systems, along with evaluation of changes in the discharge boundary head conditions associated with the Columbia River and the inferred distribution of Cr(VI) in groundwater. Both a quantitative and a qualitative approach are used for this assessment. The assessment indicates that, in general, the river protection status improved in 2016 over the assessment for 2015. However, in 100-KW, the scheduled system shutdown in May 2016 resulted in ambient flow conditions with an average gradient direction toward the northeast.

This subsection describes the river protection evaluation process and presents the results of the 2016 analysis. SGW-54209 describes a method for evaluating progress toward attaining RAO #1, referred to as the "river protection objective." Since RAO #1 emphasizes protection of aquatic receptors, the river protection objective focuses on the performance of P&T (and other remedies) to protect the Columbia River from further discharges of dissolved chromium from inland at concentrations above 10 µg/L. Use of this standard is consistent with Tri-Party Agreement (Ecology et al., 1989) Milestone M-016-110-T01. ECF-HANFORD-12-0078 demonstrates the methods described in SGW-54209 for evaluating the progress toward attainment of the river protection objective using data obtained during (or prior to) 2011.

Figure 3-22. 2016 100-K Area Interpolated CFM and High River-Stage Chromium Contamination

Figure 3-23. 2016 100-K Area Simulated CFM and High River-Stage Chromium Contamination

Figure 3-24. 2016 100-K Area Interpolated CFM and Low River-Stage Chromium Contamination

Figure 3-25. 2016 100-K Area Simulated CFM and Low River-Stage Chromium Contamination

Figure 3-26. 100-K Area Groundwater Flow Lines of Capture Zone for 2016 Flow Field

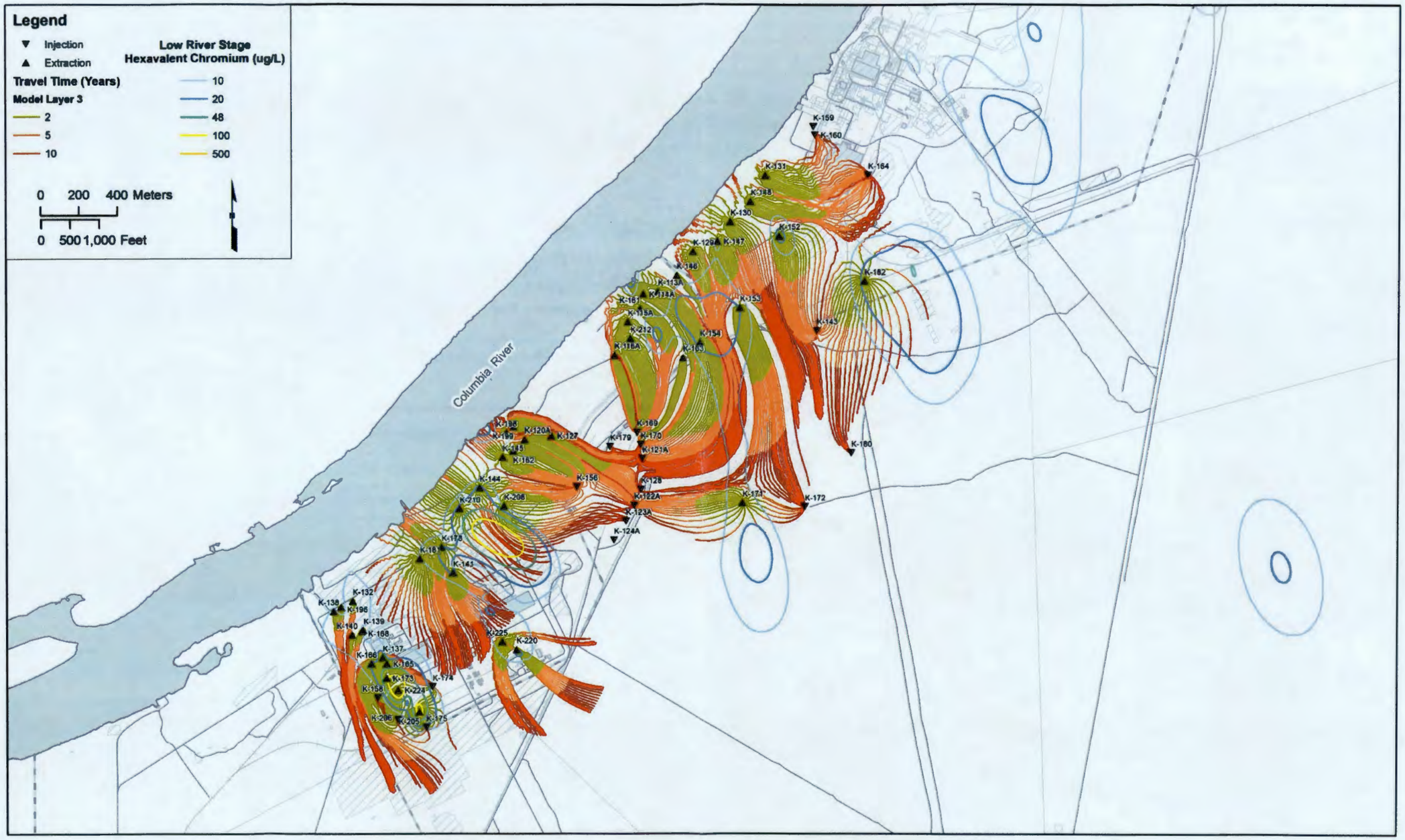

Figure 3-27. 2016 100-K Area Groundwater Flow Lines of Capture Zone Overlay with Low River Stage Chromium Plume Contours

Figures 3-28 and 3-29 present an assessment of progress toward attaining the river protection objective for 2016. The technical methods and process that were used to complete the calculations necessary to prepare this figure are detailed in SGW-54209. ECF-HANFORD-17-0028 presents details on the specific calculations that produced the figures for 2016. The results of contaminant standard and trend tests described in SGW-54209 to identify low-, moderate-, and high-concern wells are presented in Figures 3-28 and 3-29 using the symbols in Table 3-13.

Table 3-13. Standard and Trend Test Symbology for Wells

Low Concern Wells			High Concern Wells			Moderate Concern Wells		
Symbol	Standard	Trend	Symbol	Standard	Trend	Symbol	Standard	Trend
▼	Less than	Down	▲	Exceed	Up	△	Less than	Up
■	Less than	None	■	Exceed	None	▽	Exceed	Down
●	Less than	NSD	●	Exceed	NSD			

NSD = not sufficient data to calculate trend

Shoreline lengths are calculated and reported in increments of 100 m (328 ft); the results of the assessment are presented in these figures as color-filled circles of diameter equal to 100 m (328 ft). The color fill of each circle indicates the relative river protection objective status (i.e., green = protected; yellow = protected, but action may be required to ensure long-term protectiveness; and red = not protected). Table 3-14 presents the symbols depicting the results of the river protection evaluation.

Table 3-14. Symbology for Status of River Protection Objective

Symbol	Explanation
●	Protected
●	Protected (Action May Be Required)
●	Not Protected

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Figure 3-28. 100-K Area Quantitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River-Stage Chromium Contamination Above 10 µg/L and Results of Standard Test and Trend Test

Figure 3-29. 100-K Area Qualitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, together with Mapped Extent of Low River-Stage Chromium Contamination Above 10 µg/L and Results of Standard Test and Trend Test

Figures 3-28 and 3-29 depict the results of assessing progress toward attaining the river protection objective for chromium in the 100-K Area. Figure 3-28 depicts the results of the quantitative evaluation of the objective, which is determined based upon overlay and quantitative comparison of the extent of chromium contamination and the extent of hydraulic containment. Figure 3-29 depicts the results of the qualitative evaluation of the objective, which is based upon the quantitative evaluation but also considers more qualitative considerations (e.g., the duration and magnitude of hydraulic gradients along the shoreline). Based on these calculations, the river protection evaluation for the 100-K Area is as follows (note that all lengths are rounded to the nearest 5 m [or 5 ft]):

- Total length of shoreline adjacent to the 100-K Area: 4,000 m (13,120 ft)
- Length identified as protected: 3,500 m (11,480 ft)
- Length identified as protected (action may be required): 500 m (1,640 ft)
- Length identified as not protected: 0 m (0 ft)

The results of the qualitative river protection evaluations for the 100-K Area for 2016 are compared to those presented for 2015 in DOE/RL-2016-19. Table 3-15 provides a comparison of the river protection evaluation for 2015 and 2016.

Table 3-15. Comparison of River Protection Assessment Results

Assessed Shoreline Lengths, 100-K	2015	2016	Change from 2015 to 2016*
Total length of shoreline adjacent to 100-K Area	4,000 m (13,120 ft)		
Length identified as "protected" Percent of shoreline "protected"	3,600 m (11,810 ft) 90% of shoreline	3,500 m (11,480 ft) 88% of shoreline	200 m (660 ft) previously identified as "protected (action may be required)" now identified as "protected" 300 m (985 ft) previously identified as "protected" now identified as "protected (action may be required)"
Length identified as "protected (action may be required)" Percent of shoreline "protected (action may be required)"	300 m (980 ft) 7.5% of shoreline	500 m (1,640 ft) 13% of shoreline	200 m (660 ft) previously identified as "protected (action may be required)" now identified as "protected" 300 m (985 ft) previously identified as "protected" now identified as "protected (action may be required)" 100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)"
Length identified as "not protected" Percent of shoreline "not protected"	100 m (330 ft) 2.5% of shoreline	0 m (0 ft) 0% of shoreline	100 m (330 ft) of shoreline previously identified as "not protected" now identified as "protected (action may be required)".

*Details on year-to-year changes are provided in ECF-HANFORD-17-0028, *Columbia River Stage Correlation for the Hanford Area.*

The effect of river-stage fluctuations on groundwater flow, combined with the aquifer response to pumping, resulted in qualitative evaluations of the river protection objective for 2016 that the system performance is consistent over the last few years with effective river protection. The scheduled system shutdown in KW, which occurred in May 2016, resulted in reduced hydraulic containment downgradient. Although post-shutdown average hydraulic gradients in KW are toward the northeast, where extraction wells are located near the shoreline in KE, the qualitative river-protection evaluation indicates that it is possible for ambient flow conditions over a prolonged period to cause plume migration toward the river, resulting in further discharges of dissolved chromium to the river. However, system restart is expected in spring 2017. At that time, P&T well configurations will be evaluated to determine future river protection and hydraulic containment assessments. Monitoring near the shoreline will allow for assessing plume migration patterns during the shutdown period and post restart.

Quantitative evaluations of the river protection objective provide conservative assessment of shoreline protection; qualitative evaluations for 2016 incorporate the transient effects of hydraulic capture. The CFMs describe the aggregate fate of particles, under an ensemble of steady-state conditions, each reflecting a snapshot of hydraulic gradient magnitude and direction due to pumping and river stage. As a result, CFMs only indicate the relative strength of hydraulic containment and not a depiction of the actual transient hydraulic capture patterns. CFMs provide an effective metric to evaluate the relative strength of the capture zone, but they should not be considered an absolute indicator of hydraulic containment success or failure. Even during months of steeper hydraulic gradients, groundwater flow velocities result in actual plume migration expected to occur over very short distances. Relative dissipation of hydraulic gradient magnitude in subsequent months results in even slower plume migration and transient hydraulic containment. Capture can, and does, occur in areas where the CFMs indicate relatively low capture frequency. Comparison of the chromium plume depictions for 2015 and 2016 indicates a consistent number of shoreline segments where chromium concentrations are below the aquatic standard despite the prolonged periods of low river stage. Acknowledgement of these processes is reflected on the qualitative evaluation results.

3.2.8 Comparison of Simulated to Measured Contaminant Mass Recovery

Comparison of the ICFM and SCFM provides comparative depiction of the hydraulic simulation capabilities of the flow component of the 100 Area groundwater model. A similar qualitative comparison can be made for the transport component of the 100 Area groundwater model by comparing simulated and measured rates of contaminant mass recovery.

Figure 3-30 presents a comparison of monthly and cumulative mass of chromium recovered throughout the 100-K Area at each of the KX, KW, and KR4 P&T systems for 2016, as determined using actual influent concentrations and flow rates, versus the mass recovery simulated using the 100 Area groundwater model. For this simulation, the initial distribution of chromium in groundwater was assumed to be the low river-stage depiction of chromium for 2015, as presented in ECF-HANFORD-16-0061.

The pattern of correspondence between the model and the measured data, which varies by system, is fairly well reflected in the model results presented in ECF-HANFORD-17-0028. In each case, there are system-specific and systematic conditions that might lead to differences between the simulated and measured values. ECF-HANFORD-17-0028 presents graphs comparing the simulated and measured mass recovery at each individual extraction well for each P&T system.

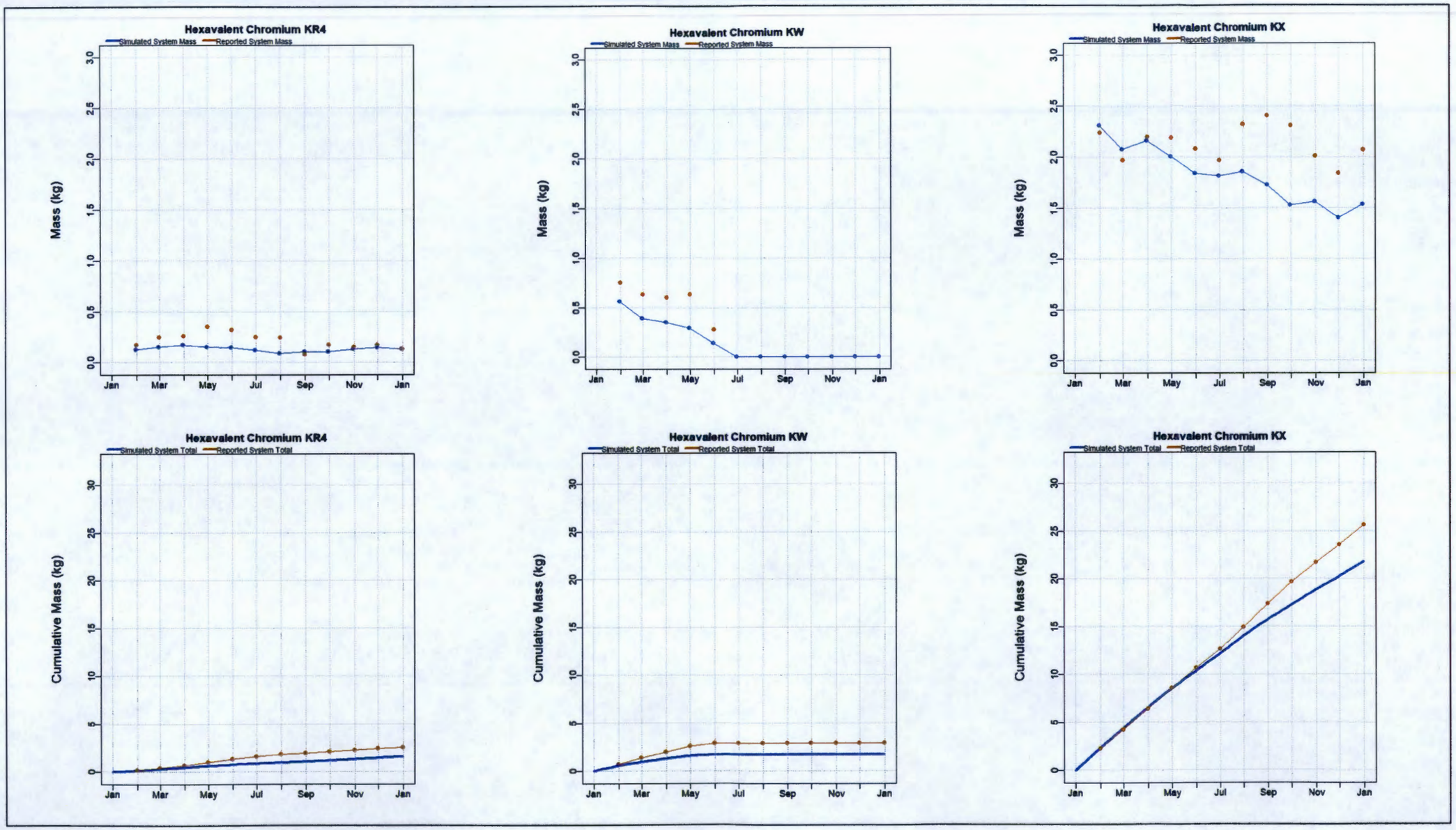

Figure 3-30. Comparison of Observed to Calculated Cr(VI) Mass Removal (Top Row = Monthly Mass Removal; Bottom Row = Cumulative Mass Removal)

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For the KW P&T system, the model predicted mass recovery prior to system shutdown in May 2016 is well correlated to the measured mass recovery, although the model slightly under-predicts mass recovery during that period. Influent concentrations at well 199-K-205 suggest that the extent of the high-concentration zone near that well, as well as the high-concentration distribution in the same area, were underestimated in the Fall 2015 plume, which was used as the initial condition in the simulation. In addition, the concentration distribution downgradient of 199-K-205 also appears to be underestimated in that plume, given that mass recovery at extraction wells 199-K-173, 199-K-137, and 199-K-168/199-K-140 is greater than what the simulated results suggest. However, post-shutdown rebound effects observed in KW monitoring wells, after May 2016, also suggest the presence of continuing sources and mass loading conditions that are impacted by lowering the water table as a result of the operation of the extraction wells.

The model simulated mass recovery tracks well the measured mass recovery in the KR4 P&T system. Differences on a monthly basis are rather small and reflect the cumulative effect of influent concentrations at the extraction wells of about and mostly below 10 μg/L. Only at well 199-K-144 are concentrations consistently above 20 μg/L and the model under-predicts these concentrations, suggesting that the interpolated chromium distribution in that area is underestimated.

The measured and simulated mass recovery in the KX P&T system are in general agreement, although discrepancies are observed during the second part of the year. Model predicted concentrations at wells 199-K-144 and 199-K-210, as well as 199-K-141, indicate that the interpolated chromium distribution underestimates the extent and magnitude of chromium concentrations in the aquifer, upgradient of those wells, due to the separation distance between monitoring wells and also, the potential presence of continuing sources in that area. Similarly, the model under-predicts concentrations at recovery wells 199-K-152 and 199-K-182, where the initial conditions, represented by the interpolated chromium distribution for Fall 2015, clearly underestimate the chromium concentration distribution in the aquifer in the vicinity of those wells.

From a systematic perspective, the differences between the simulated and measured mass recovery could result from using estimated hydraulic and/or contaminant transport parameters in the transport model that do not accurately reflect actual conditions encountered at specific locations in the subsurface. The simulated mass recovery estimate, however, presents a useful tool for estimating the system performance over time and developing estimates of time to remediation.

3.2.9 Remedial Process Optimization Activities

Contractors have developed a pumping optimization model and interface, based on the 100 Area groundwater model that will be used by OU scientists to evaluate the relative performance of alternative well configurations. The OU scientists will evaluate pumping configurations throughout the year and provide recommended adjustments to flow rates and recommendations for well realignment and/or the installation of new wells. Specific RPO activities performed at the 100-KR-4 OU during 2016 included the following:

- Increased the pump size at well 199-K-182 to increase extraction capacity.
- Realigned KR4 P&T extraction well 199-K-144 and injection well 199-K-179 to the KX P&T system.
- Reconfigured KR4 P&T injection well 199-K-124A to operate independent of 199-K-123A.
- Designed and constructed three new extraction wells, two downgradient of the 183-KW Head house, and one downgradient of the 183-KE Head house (199-K-223, 199-K-224, and 199-K-225).
- Completed realignment designs for a well impacted by the Traditional Cultural Property.

3.3 Radiological Dose and Drinking Water Standard Analysis of 100-K Area Pump and Treat Effluent

Effluent water from the three P&T systems located in 100-K area (i.e., 100-KR, 100-KW, and 100-KX) was evaluated for compliance with the requirements for radiological protection of human health and the environment. This evaluation includes calculation of the TED produced by radioisotopes present in the effluent water following treatment of extracted groundwater to remove identified contaminants. The resultant dose was compared to the target cumulative dose limit of 100 mrem/yr to the public established by DOE O 458.1. The cumulative TED is based on use of the DCS defined in DOE-STD-1196-2011. In addition to evaluation of the effluent constituents, selected monitoring wells in 100-K area have been identified for additional evaluation of potential dose contribution in areas down gradient of effluent injection wells.

Additional guidance for screening of radiological dose related to discharge of liquid effluents at DOE facilities is provided in DOE-HDBK-1216-2015. The Handbook provides recommended criteria for radiological effluent monitoring based on the DCS to ensure effective effluent monitoring that identifies problematic effluent conditions before they exceed target metrics.

This evaluation further compares the radioisotopes present in effluent water to the following radiological drinking water standards: 1) the 4 mrem/yr MCL dose for beta/photon emitters and 2) the 30 µg/L uranium mass concentration MCL.

Table 3-16 summarizes the recommended criteria described in the Handbook.

Table 3-16. Recommended Criteria for Liquid Radiological Effluent Monitoring

Criterion Number	DCS Sum-of-fractions	And	Potential Annual Dose from Exposure to a Likely Receptor (mrem)	Minimum Criteria for Liquid Radiological Effluent Monitoring
1	>/= 1		--	1. Apply BAT to reduce effluent releases (except H-3) 2. Use continuous monitoring/sampling, but where effluent streams are low flow and potential public dose is very low, (<<1mrem in a year) alternative sampling approaches may be appropriate.
2	>/= 0.01 to 1		>1	1. Continuously monitor or sample 2. Identify radionuclides contributing >/= 10 percent of the dose 3. Determine accuracy of results (+/- accuracy and percent confidence level).

Table 3-16. Recommended Criteria for Liquid Radiological Effluent Monitoring

Criterion Number	DCS Sum-of-fractions	And	Potential Annual Dose from Exposure to a Likely Receptor (mrem)	Minimum Criteria for Liquid Radiological Effluent Monitoring
3	>/= 0.001 to 0.01		<1	1. Monitor using a graded approach to select the appropriate method and duration 2. Identify radionuclides contributing >/= 10 percent or more of the dose 3. Assess annually the facility inventory and potential for radiological effluent release
4	<0.001		--	1. No monitoring required 2. Evaluate annually the potential for liquid radiological effluent release

Source: Table 3-1 of DOE-HDBK-1216-2015, *Environmental Radiological Effluent Monitoring and Environmental Surveillance.*

-- = not applicable

BAT = best available technology

3.3.1 Evaluation of Effluent Water Total Effective Dose for 100-K Area Pump and Treat for Calendar Year 2016

Effluent monitoring at the three 100-K Area P&T systems was performed using sampling and analysis of the stream exiting the plant prior to pumping effluent to the injection well fields. Sampling and analysis was performed on a quarterly basis for target radionuclides identified as contaminants of interest for the groundwater remedial actions supported by the treatment system. The radionuclides of interest for the 100-K Area P&T systems are:

- Tritium
- Strontium-90
- Carbon-14
- Technetium-99

Table 3-17 summaries the results of periodic sampling and analysis of effluent from 100-KR and 100-KX P&T systems. Where multiple measurements were determined for an analyte during a single sampling and analysis event, the maximum value was selected for use in this evaluation. No radiological effluent samples were collected from 100-KW system because the scheduled events were to occur during the period of time when the system was out of service to implement the KW rebound study (i.e., May through December 2016).

Individual radioisotope activity concentrations were subsequently converted to estimated effective dose using the DCS values in Table 3-18.

Table 3-17. Summary of Effluent Radioisotope Sampling and Analysis Results for CY 2016 at 100-KR and 100-KX Pump and Treat

Sample Location	Sample Date	Tritium (pCi/L)	Sr-90 (pCi/L)	C-14 (pCi/L)	Tc-99 (pCi/L)
100-KR P&T					
Effluent Tank – T-K5	12/28/2016	4,020	2.61	(24.9)	(17.1)
100-KX P&T					
Effluent Tank – T-X5	6/29/2016	3,100	-NM-	52.2	(9.2)
Effluent Tank – T-X5	9/14/2016	3,590	2.39	67.9	(8.7)
Effluent Tank – T-X5	12/14/2016	3,940	2.74	67.3	(16.6)

Note: Values in parentheses were reported as not detected; the value is the reported minimum detectable activity.

-NM- = Isotope not measured in this sample event.

Table 3-18. Derived Concentration Standards for Radioisotopes Evaluated in 100-KR and 100-KX Pump and Treat Effluent

DCS	Tritium	Sr-90	C-14	Tc-99
DCS (μCi/mL)[a]	1.90E-03	3.30E-07	6.20E-05	4.40E-05
DCS (pCi/L)[b]	1.90E+06	3.30E+02	6.20E+04	4.40E+04

a. DCS from Table 5 of DOE-STD-1196-2011, *Derived Concentration Technical Standard.*

b. DCS converted to pCi/L for direct comparison to measurement results.

DCS = Derived Concentration Standard

Table 3-19 shows the individual radioisotope dose contributions for each effluent sampling event at 200W P&T and the cumulative TED estimates for calendar year 2016. The TED was calculated using two approaches. The first a conservative approach incorporating the minimum detectable activity (MDA) for non-detect measurements as a value; the second includes no value for non-detect measurements. The resultant TED and DCS fractions were then compared to the criteria presented in Table 3-16, above.

The cumulative TED and DCS fraction values shown in Table 3-19 indicated that results of effluent sampling events during CY 2016 at 100-KR and 100-KX P&T systems met monitoring Criterion #2, with the exception of a single sample from 100-KX analyzed on 6/29/2016. This sample, however, was not analyzed for strontium-90; the other samples from this system exhibited detectable strontium-90. This indicates that the calculated TED and DCS fraction for the sample collected and analyzed on 6/29/2016 may not be completely representative of the effluent.

Guidance from the Handbook indicates that observed conditions meeting Criterion #2 should be further evaluated, including identifying isotopes contributing 10 percent, or more, of the calculated dose and examining the accuracy and uncertainty associated with the measurements. The Handbook guidance further recommends increased sampling and analysis frequency for effluents meeting Criterion #2. Table 3-20 summarizes the fractional dose contributions and relative total analytical error for the effluent isotopic measurements for CY 2016 from 100-KR and 100-KX P&T systems.

Table 3-19. Calculated Individual Radioisotope Dose Contributions and TED for 100-KR and 100-KX Pump and Treat Effluent in CY 2016.

Sample Location	Sample Date	Individual Isotope Effective Dose Contribution				TED Cumulative (mrem/yr)	DCS Fraction Cumulative (Fraction)	TED–Detects Only (mrem/yr)	DCS Fraction–Detects Only (Fraction)
		Tritium (mrem/yr)	Sr-90 (mrem/yr)	C-14 (mrem/yr)	Tc-99 (mrem/yr)				
100-KR P&T									
Effluent Tank-T-K5	12/28/2016	2.1E-01	7.9E-01	(4.0E-02)[a]	(3.9E-02)[a]	1.082[b]	0.0108[b]	1.002[b]	0.0100[b]
100 KX P&T									
Effluent Tank-T-X5	6/29/2016	1.6E-01	-NM-[c]	8.4E-02	(2.1E-02)[a]	-NR-[d]	-NR-[d]	-NR-[d]	-NR-[d]
Effluent Tank-T-X5	9/14/2016	1.9E-01	7.2E-01	1.1E-01	(2.0E-02)[a]	1.042[b]	0.0104[b]	1.023[b]	0.0102[b]
Effluent Tank-T-X5	12/14/2016	2.1E-01	8.3E-01	1.1E-01	(3.8E-02)[a]	1.184[b]	0.0118[b]	1.146[b]	0.0115[b]

a. Values in parentheses were reported as not-detected. Value presented is dose contribution based on MDA concentration for samples reported as analyzed but not detected.

b. Shaded cells: Cumulative TED and DCS Fraction values meet Criterion #2 in Table 3-16.

c. -NM- Analyte not measured in this sampling event.

d. -NR- = Not Representative. The absence of a measured value for strontium-90 indicates non-representative underestimation of the sum-of-fractions and the resultant dose.

DCS = Derived Concentration Standard

MDA = minimum detectable activity

P&T = pump and treat

TED = total effective dose

Table 3-20. Summary of Effluent Radioisotope Sampling and Analysis Results for CY 2016 at 100-KR and 100-KX Pump and Treat Indicating Relative Dose Contribution and Measurement Uncertainty/Error

Sample Location	Sample Date	Tritium pCi/L (+/- Total Analytical Error)	Fractional Dose Contribution (%)	Sr-90 pCi/L (+/- Total Analytical Error)	Fractional Dose Contribution (%)	C-14 pCi/L[a] (+/- Total Analytical Error)	Fractional Dose Contribution (%)	Tc-99 pCi/L* (+/- Total Analytical Error)	Fractional Dose Contribution (%)
100-KR P&T									
Effluent Tank – T-K5	12/28/2016	4,020 +/- 450	21	2.61 +/- 1	79	(24.9) +/- 12	Not included	(17.1) +/- 7.5	Not included
100-KX P&T									
Effluent Tank – T-X5	6/29/2016	3,100 +/- 260	65	-NM-	Not included	52.2 +/- 11	34	(9.2) +/- 4.4	Not included
Effluent Tank – T-X5	9/14/2016	3,590 +/- 340	18	2.39 +/- 0.94	70	67.9 +/- 8.3	11	(8.7) +/- 4.4	Not included
Effluent Tank – T-X5	12/14/2016	3,940 +/- 420	18	2.74 +/- 1	72	67.3 +/- 15	10	(16.6) +/- 7.4	Not included

*Values in parentheses were reported as not detected; the value is the reported minimum detectable activity (MDA).

-NM- = Isotope not measured in this sample event.

Evaluation of the fractional dose confirms that tritium, strontium-90 and carbon-14 each contribute 10% or more of the TED, with strontium-90 providing the largest fractional contribution at both 100-KR and 100-KX P&T systems. This is consistent with the observations of the groundwater plume distribution in 100-K Area. Evaluation of the effects of the analytical counting error for each of these isotopes on the calculated TED for 100-KX indicates that the activity concentration at the upper level of uncertainty (i.e., reported value + total analytical error) increases, however, the resultant TED and DCS fraction at the upper level of uncertainty does not change interpretation of the results relative to the monitoring criteria in Table 3-16. The upper level of uncertainty at 100-KX results in an average calculated TED of 1.4 mrem/yr and a DCS fraction of 0.014 that still fall within the level identified for Criterion #2. Addition of the total analytical error values to the monitoring results for 100-KR P&T system, however, does change the interpretation of the monitoring criteria; the TED increases to 1.3 mrem/yr and the DCS fraction increases to 0.013. These calculated values would meet the levels identified for Criterion #2.

3.3.2 Comparison of 100-KR and 100-KX Pump and Treat Effluent Water Radiological Constituents to Drinking Water Standards for Beta/Photon Emitters and Uranium for Calendar Year 2016

The radioisotopes measured in P&T effluent from 100-KR and 100-KX systems were also evaluated against the 4 mrem/yr drinking water maximum contaminant level for beta and photon emitters. Individual and average values for beta/photon emitters measured in the effluent at these two systems do not exceed the MCL. Table 3-21 shows the summary of this evaluation.

3.4 100-KR-4 Operable Unit Pump and Treat Systems Costs

This section summarizes the actual costs for the 100-KR-4 OU P&T systems for 2016. The primary categories of expenditures are described as follows:

- **Capital design:** Includes design activities to construct the P&T systems, including wells, 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.
- **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-KR-4 OU interim action work plan (DOE/RL-2013-33).
- **Waste management:** Includes the cost for the management of spent resin at the 100-KR-4 OU 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.

Table 3-21. Summary of Drinking Water Beta/Photon Emitter MCL Comparison for 100-KR and 100-KX Pump and Treat Effluent for CY 2016

Sample Location	Sample Date	Contributing Radioisotopes				Sum of Fractions[a]	Drinking Water β/ϒ Dose (mrem/yr)[a]	Sum of Fractions Detects Only[b]	Drinking Water β/ϒ Dose from Detects Only (mrem/yr)[b]
		Tritium	Strontium-90	Carbon-14	Technetium-99				
		Derived Concentrations (pCi/L)							
		20,000	8	2,000	900				
		Beta/Photon MCL Fraction							
100-KR P&T									
Effluent Tank T-K5	12/28/2016	0.201	0.326	(0.012)[c]	(0.019)[c]	0.559	2.2	0.50	2.1
100 KX P&T									
Effluent Tank T-X5	6/29/2016	0.155	-NM-[d]	0.026	(0.010)[c]	-NR-[e]	-NR-[e]	-NR-[e]	-NR-[e]
Effluent Tank T-X5	9/14/2016	0.180	0.299	0.034	(0.010)[c]	0.522	2.1	0.51	2.0
Effluent Tank T-X5	12/14/2016	0.197	0.343	0.034	(0.018)[c]	0.592	2.4	0.57	2.3

a. Sum of MCL fractional derived concentration values and calculated MCL dose, including non-detect values using the MDA as a value.

b. Sum of MCL fractional derived concentration values and calculated MCL dose, excluding non-detect measurements.

c. Values in parentheses were reported as non-detects; the value is the reported value of the MDA.

d. -NM- = Not Measured

e. NR- = Not Representative. The absence of a measured value for strontium-90 indicates non-representative underestimation of the sum-of-fractions and the resultant dose.

MCL = maximum contaminant level

MDA = minimum detectable activity

P&T = pump and treat

The costs include all activities associated with the interim remedial actions, including the construction of new wells and interim action performance monitoring. The 100-KR-4 OU costs for 2016 are associated with three P&T systems (KR4, KX, and KW). The total cost breakdown includes nonrecurring costs related to the installation of new wells and the P&T system modifications described in Section 3.2. Tables 3-22 through 3-24 show the yearly cost breakdowns for each of the three 100-KR-4 OU P&T systems. Costs are burdened and are based on actual operating costs incurred during 2016.

Summaries of the costs for each P&T system are presented in the following subsections.

3.4.1 KR4 Pump and Treat System

Table 3-22 shows the total cost for the KR4 P&T system during 2016 was $1.10 million, which consists of the sum of the categories. The percentage that each category comprises of the total cost for the KR4 P&T system (Figure 3-31) is as follows, in decreasing order:

- O&M – 56.3 percent ($616,100)
- Treatment system capital construction – 23.0 percent ($252,300)
- Performance monitoring – 12.6 percent ($137,500)
- Project support – 5.5 percent ($60,700)
- Waste management – 2.6 percent ($28,400)
- Design and field studies costs were negligible in 2016

Based on the total 2016 cost of $1,095,000, the yearly production rate of 580 million L (153 million gal), and 2.53 kg (5.6 lb) of Cr(VI) removed, the annual treatment costs equate to $0.0019/L, or $432/g of Cr(VI) removed.

3.4.2 KX Pump and Treat System

The total cost for the KX P&T system for 2016 was $3.19 million (Table 3-23). The increase in operations and maintenance costs compared to 2015 is associated with the KX P&T system configuration changes described in section 3.2.3.1. The percentage that each category comprises of the total cost for the KX P&T system (Figure 3-32) is as follows, in decreasing order:

- O&M – 86.0 percent ($2,745,100)
- Treatment system capital construction – 7.9 percent ($252,300)
- Performance monitoring – 3.2 percent ($103,700)
- Project support – 1.9 percent ($60,700)
- Waste management – 1.0 percent ($31,700)
- Design and field studies costs were negligible in 2016

Based on the total 2016 cost of $3,193,000, the yearly production rate of 1,636 million L (432 million gal), and 25.6 kg (56.3 lb) of Cr(VI) removed, the annual treatment costs equate to $0.0074/L, or $125/g of Cr(VI) removed.

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Table 3-22. Breakdown of KR4 P&T System Construction and Operation Costs

Description	Actual Costs (Dollars × 1,000)																
	2000	2001[a]	2002[b]	2003	2004	2005	2006	2007	2008	2009[c,d]	2010[e]	2011	2012	2013	2014	2015	2016
Design	—	96.5	55.2	70.8	163.9	190.8	97.8	187[f]	63.1	157.7	25.4	52.2	(1.7)	0.9	3.3	47.1	0.0
Treatment system capital construction	109.1	(0.1)	860.1	379.9	94.2	273.8	1,505.8	2,114.1[g]	8,368.5	6,651.0[g]	3,556.2	1,860.8	350.8[h]	30.7	78.8	123.0	252.3
Project support	143.0	188.2	257.8	171.0	211.8	851.9	530.5	489.8	963.0	174.1	77.6	94.3	58.0	109.8	83.9	75.4	60.7
Operations and maintenance	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	1,032.9	1,096.0	1,210.0	866.8	616.1
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	324.4	156.9	161.0	78.2	137.5
Waste management	481.8	367.5	343.3	684.7	475.8	198.3	230.2	458.9[i]	438.2	599.8	266.7	110.6	17.3	0.0	0.0	3.4	28.4
Field studies	—	—	—	—	—	—	—	—	—	25.0	653.1	3.0	0.2	(0.0)	0.0	0.0	0.0
Totals	**$1,383**	**$1,353**	**$2,413**	**$2,216**	**$2,147**	**$2,840**	**$4,264**	**$4,450**	**$11,384**	**$9,796**	**$6,925**	**$3,931**	**$1,782**	**$1,394**	**$1,537**	**$1,194**	**$1,095**

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. KX P&T system costs prior to startup are included in with 2009.

e. 2010 accrual costs were corrected. The KR4 and KX expense calculations were incorrectly grouped together.

f. Additional design costs were associated with pump and treat expansion.

g. Additional treatment system capital construction costs were associated with new wells and buildings to support pump and treat system expansion.

h. Includes costs for facility modifications to change ion exchange resin from Dowex 21K to ResinTech SIR-700.

i. Additional costs were associated with drilling wastes and resin cleared for shipment and handling.

— = not available

P&T = pump and treat

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Table 3-23. Breakdown of KX P&T System Costs

Description	Actual Costs (Dollars × 1,000)						
	2010	2011	2012	2013	2014	2015	2016
Design	31.4	21.4	2.8	9.5	46.0	51.5	0.0
Treatment system capital construction	22.9	(1.7)	639.9[a]	62.5	462.6	122.9	252.3
Project support	77.6	94.3	58.0	161.3	221.8	75.4	60.7
Operations and maintenance	1,224.4	1,647.8	1,340.4[b]	1,875.0	1,530.6	1907.1	2745.1
Performance monitoring	528.9	674.9	324.4	152.0	158.4	76.6	103.7
Waste management	579.6	219.1	2.1	0.0	0.0	3.3	31.7
Field studies	—	—	—	—	0.0	0.0	0.0
Totals	**$2,465**	**$2,656**	**$2,368**	**$2,260**	**$2,419**	**$2,237**	**$3,193**

a. Includes costs for facility modifications to change ion exchange resin from Dowex 21K to ResinTech SIR-700.

b. Includes costs for connecting extraction well 199-K-182 to the KX pump and treat system.

— = not available

Table 3-24. Breakdown of KW P&T System Costs

Description	Actual Costs (Dollars × 1,000)									
	2007	2008	2009[a]	2010	2011	2012	2013	2014	2015	2016
Design	13.0	27.7	78.1	11.6	20.0	8.6	20.6	32.4	47.1	0.0
Treatment system capital construction	2,187.8	1,088.3	2,301.8	324.3	794.8[b]	(0.4)	30.9	421.7	123.0	252.3
Project support	118.9	155.3	174.1	77.6[c]	94.3	58.0	121.0	240.9	75.4	60.7
Operations and maintenance	402.4	599.6	758.6	1,149.6[c]	1,041.3	1,055.9[d]	1,217.4	1,251.0	778.7	518.1
Performance monitoring	9.7	126.6	215.9	528.9[c]	674.9	324.4	160.0	156.9	78.4	475.0
Waste management	405.4	164.3	95.4	207.5[c]	84.0	84.6	0.0	0.0	3.5	27.7
Field studies	—	—	—	—	—	—	—	0.0	0.0	0.0
Totals	**$3,137**	**$2,162**	**$3,624**	**$2,300**	**$2,709**	**$1,531**	**$1,550**	**$2,103**	**$1,106**	**$1,334**

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. Includes costs for facility modifications to change ion exchange resin from Dowex 21K to ResinTech SIR-700.

c. Values were incorrectly calculated and later corrected.

d. Includes costs for converting to split train operation and connecting extraction well 199-K-173 to the KW pump and treat system.

— = not available

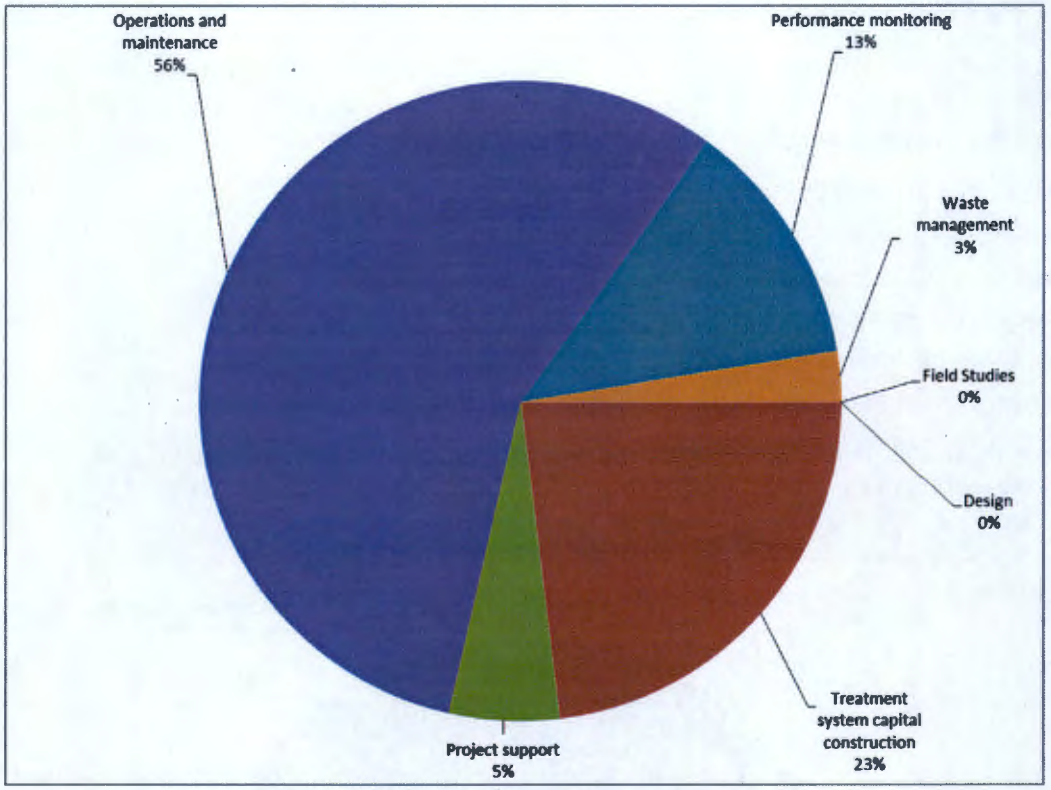


Figure 3-31. KR4 P&T System, 2016 ($1.10 million) Cost Breakdown (by Percentage)

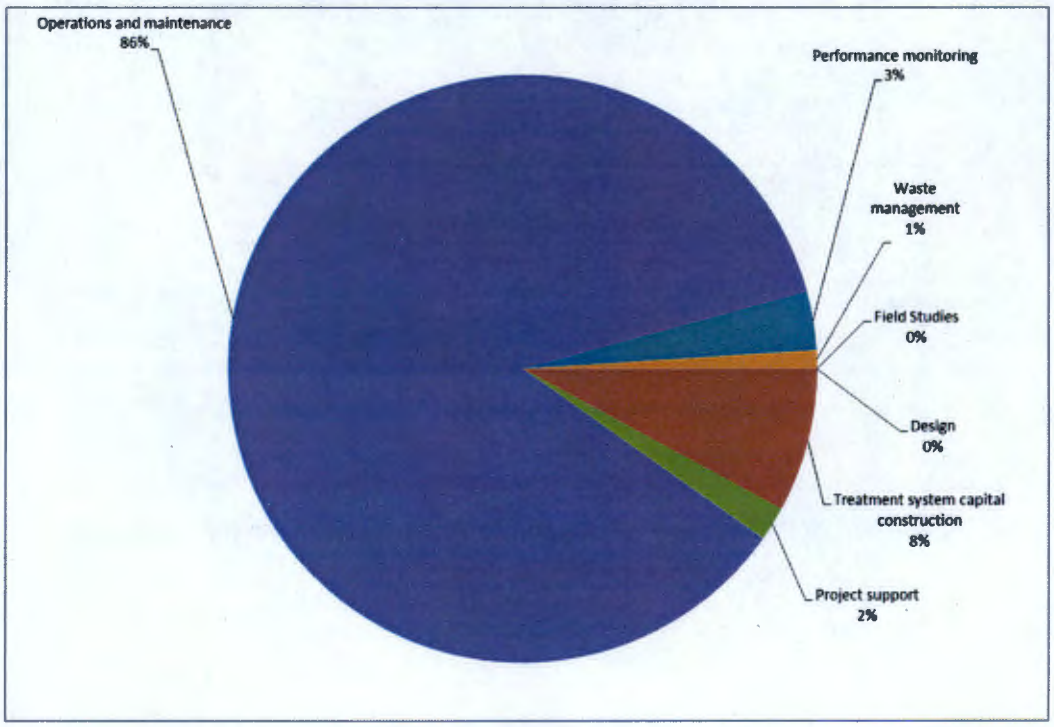


Figure 3-32. KX P&T System, 2016 ($3.19 million) Cost Breakdown (by Percentage)

3.4.3 KW Pump and Treat System

The total cost for the KW P&T system during 2016 was $1.33 million, which consists of the sum of the categories shown in Table 3-24. The percentage that each category comprises of the total cost for the KW P&T system (Figure 3-33) is as follows, in decreasing order:

- O&M: 38.8 percent ($518,100)
- Performance monitoring: 35.6 percent ($475,000)
- Treatment system capital construction: 18.9 percent ($252,300)
- Project support: 4.6 percent ($60,700)
- Waste management: 2.1 percent ($27,700)
- Design and field studies costs were negligible in 2016

Based on the total 2016 cost of $1,334,000, the yearly production rate of 242 million L (64 million gal), and 2.9 kg (6.3 lb) of Cr(VI) removed, the annual treatment costs equate to $0.021/L, or $462/g of Cr(VI) removed.

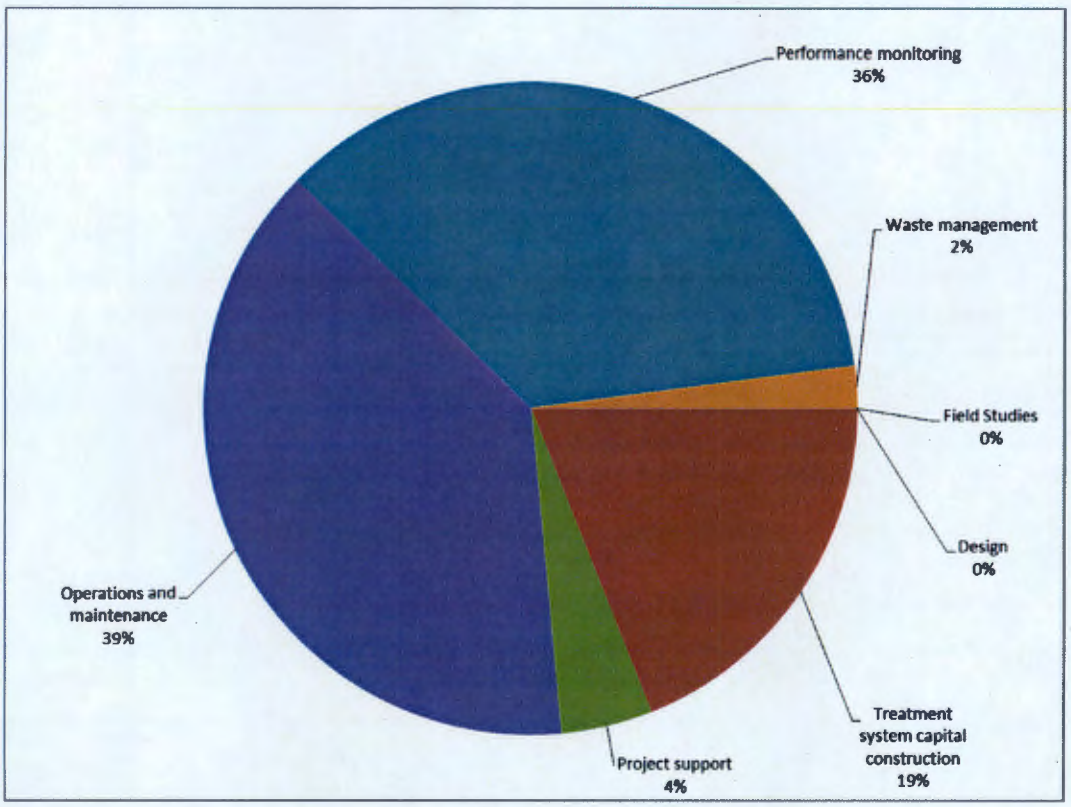


Figure 3-33. KW P&T System, 2016 ($1.33 million) Cost Breakdown (by Percentage)

3.5 Conclusions

Remedial progress has been achieved for the plume areas associated with each of the three P&T systems currently active within the 100-KR-4 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 indicates that operation of the KX, KW, and KR4 P&T systems has resulted in a capture efficiency of 74 to 94 percent over most of the 100-KR-4 OU Cr(VI) plumes above 10 µg/L.

  The combined hydraulic and water quality data evaluation indicates that the extent of hydraulic containment developed by the KX, KW, and KR4 P&T systems during 2016 improved compared to 2015. This improvement is consistent with expectations from well locations and planned extraction rates implemented in 2016. Calculations indicate that the river protection objective is being achieved along most of the 100-KR-4 OU shoreline. The performance of remedial action systems currently in place in the 100-KR-4 OU confirms that DOE has taken necessary measures to control the discharge of Cr(VI) into the Columbia River. Five locations along the 100-KR-4 OU river shore were identified as "protected (action may be required)" during 2016. Three of these locations are associated with the KW Rebound study area. The other two are associated with zones of potential aquifer stagnation generated due to high pumping at inland extraction wells; alternatively, a secondary source may be present in these areas. Further evaluations of these conditions are needed and may require adjustments to pumping rates.

  Based on the aquifer tube data for 2016, the general extent and concentration of Cr(VI) discharged to the Columbia River within the 100-KR-4 OU has decreased in response to P&T activities. The exception is the localized area at the downgradient edge of the plume at the head and distal ends of the 116-K-2 Trench.

  The 100-KR-4 OU P&T systems have removed substantial amounts of Cr(VI) from the unconfined aquifer. In total, the 100-KR-4 OU P&T systems have removed an estimated 867 kg (1,911 lb) of Cr(VI) from the unconfined aquifer.

  - Between September 1997 and December 31, 2016, the KR4 P&T system extracted and treated 8,484 million L (2,241 million gal) of groundwater, removing 378 kg (833 lb) of Cr(VI) from the aquifer near the 116-K-2 Trench. As a result of remediation activities, Cr(VI) concentrations have been reduced in most wells.
  - The KR4 P&T system has attained the RAO for river protection along the central portion of the 116-K-2 Trench area.
  - The KW P&T system started operating in January 2007. As of December 31, 2016, the system had extracted 3,807 L (1,006 million gal) of groundwater and removed 241 kg (531 lb) of Cr(VI). Prior to the shutdown of the KW P&T system in May 2016 to initiate a rebound study, all wells associated with the KW P&T system exhibited Cr(VI) concentration below 20 µg/L.
  - The KX P&T system in its current configuration, is providing the majority of the Cr(VI) mass removal for plumes outside the influence of the KW P&T system. Since system startup in February 2009, more than 8,992 million L (2,375 million gal) of water has been treated, and 248.5 kg (547.8 lb) of Cr(VI) has been removed.

The observed concentrations of Cr(VI) in groundwater at all three of the 100-KR-4 OU P&T systems are declining as remediation progresses.

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

  Results: 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. ICs remain in operation in 100-KR-4 OU.

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

  Results: Additional information on the groundwater contamination at the 100-KR-4 OU continues to be gathered. Ongoing groundwater monitoring activities provide information on the changes in contaminant concentrations, as well as the spatial distribution of the groundwater plumes. Assessment of information collected during source remediation actions provides details regarding the sources of groundwater contamination and the potential for continuing contributions from secondary sources within the vadose zone for hexavalent chromium as well as other contaminants of concern in this OU.

  An evaluation of information from multiple activities indicates that while the interim groundwater remedial actions at the 100-K Area have reduced Cr(VI) concentrations and plume sizes across the OU, residual secondary sources likely remain at multiple locations. A final remedy will need to address ongoing contributions from vadose zone sources, as well as high contaminant concentrations in groundwater at or near source release areas. During 2016, the KW P&T system was shut down to evaluate the potential for secondary source material in the PRZ. Based on the data collected through the end of 2016, secondary source material in the PRZ upgradient of the 105-KW Reactor were validated. These conditions will be further evaluated and the information incorporated into the final 100-K Area RI/FS report.

3.5.1 Conclusions of Evaluation of Radiological Constituents in 100-KR and 100-KX Pump and Treat Effluent Water for Calendar Year 2016

Evaluation of radiological dose of the 100-KR and 100-KX P&T effluent water during CY 2016 indicates that the effluent met the following standards and criteria:

- The calculated DCS-based TED of the effluent for both 100-KR and 100-KX was slightly over 1 mrem/yr, substantially below the 100 mrem/yr public dose limit.

- The calculated DCS-based sum-of-fractions and resultant TED of the effluent for both 100-KR and 100-KX P&T systems were consistent with recommended monitoring criteria indicating that increased effluent sampling frequency is appropriate (i.e., continuous sampling with frequent analysis).

- The calculated MCL-based beta/photon emitter drinking water dose was below the 4 mrem/yr MCL dose for both 100-KR and 100-KX P&T systems.

4 100-NR-2 Operable Unit Remediation

This chapter provides the annual performance report for 100-NR-2 OU groundwater remediation, as required by DOE/RL-2001-27, *Remedial Design/Remedial Action Work Plan for the 100-NR-2 Operable Unit*. The performance of the apatite PRB is discussed, and an update on the remediation of total petroleum hydrocarbon (TPH)-diesel range (TPH-D) contamination is provided. Groundwater monitoring data collected during 2016 that are pertinent to the interim remedial action are also provided. Discussion in this chapter includes the following:

- Section 4.1 provides a summary of the 100-NR-2 OU groundwater remedial activities during 2016.
- Section 4.2 describes water-level monitoring and hydrogeologic conditions for the remedial activities.
- Section 4.3 discusses the remediation of strontium-90 contamination.
- Section 4.4 discusses the remediation of TPH-D contamination.
- Section 4.5 discusses demolition of the 100-NR-2 P&T system.
- Section 4.6 presents the 2016 costs for the apatite PRB.
- Section 4.7 presents conclusions on remedy performance for 2016.

The 100-NR-2 OU is located along the Columbia River, between the 100-KR-4 and the 100-HR-3 OUs (Figure 4-1). The 100-NR-2 OU consists of the groundwater affected by contaminant releases from waste sites and facilities in the 100-N Area. The CERCLA interim action for remediation of groundwater is identified in the interim action ROD (EPA/ROD/R10-99/112). When the interim ROD was issued in 1995, the interim action for remediation of strontium-90 in groundwater was P&T. The 100-NR-2 P&T system operated from 1995 to 2006, when the system was placed into cold-standby status to facilitate a treatability test for construction of an apatite PRB along the 100-N Area shoreline. The authorization for the P&T status change in the 100-NR-2 interim action is documented in Tri-Party Agreement (Ecology et al., 1989) Change Number M-16-06-01, dated February 15, 2006.

The initial apatite PRB was constructed from 2006 through 2008 for the treatability test that placed a 91 m (300 ft) long apatite PRB along the 100-N Area shoreline in accordance with the strontium-90 treatability test plan for the 100-NR-2 OU (DOE/RL-2005-96). The barrier was created by injecting apatite-forming solutions into 16 wells located adjacent to the shoreline, downgradient of the highest strontium-90 groundwater plume contamination. The treatability test results were documented in PNNL-17429, *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization* and PNNL-SA-70033, *100-NR-2 Apatite Treatability Test FY09 Status: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization*).

Based on the treatability test results, the apatite technology showed promise as a remediation option. The Tri-Parties amended the interim action ROD in 2010 to allow for permanent decommissioning of the 100-NR-2 OU P&T system and expansion of the existing PRB from approximately 91 m (300 ft) long to 760 m (2,500 ft) long (EPA, 2010).

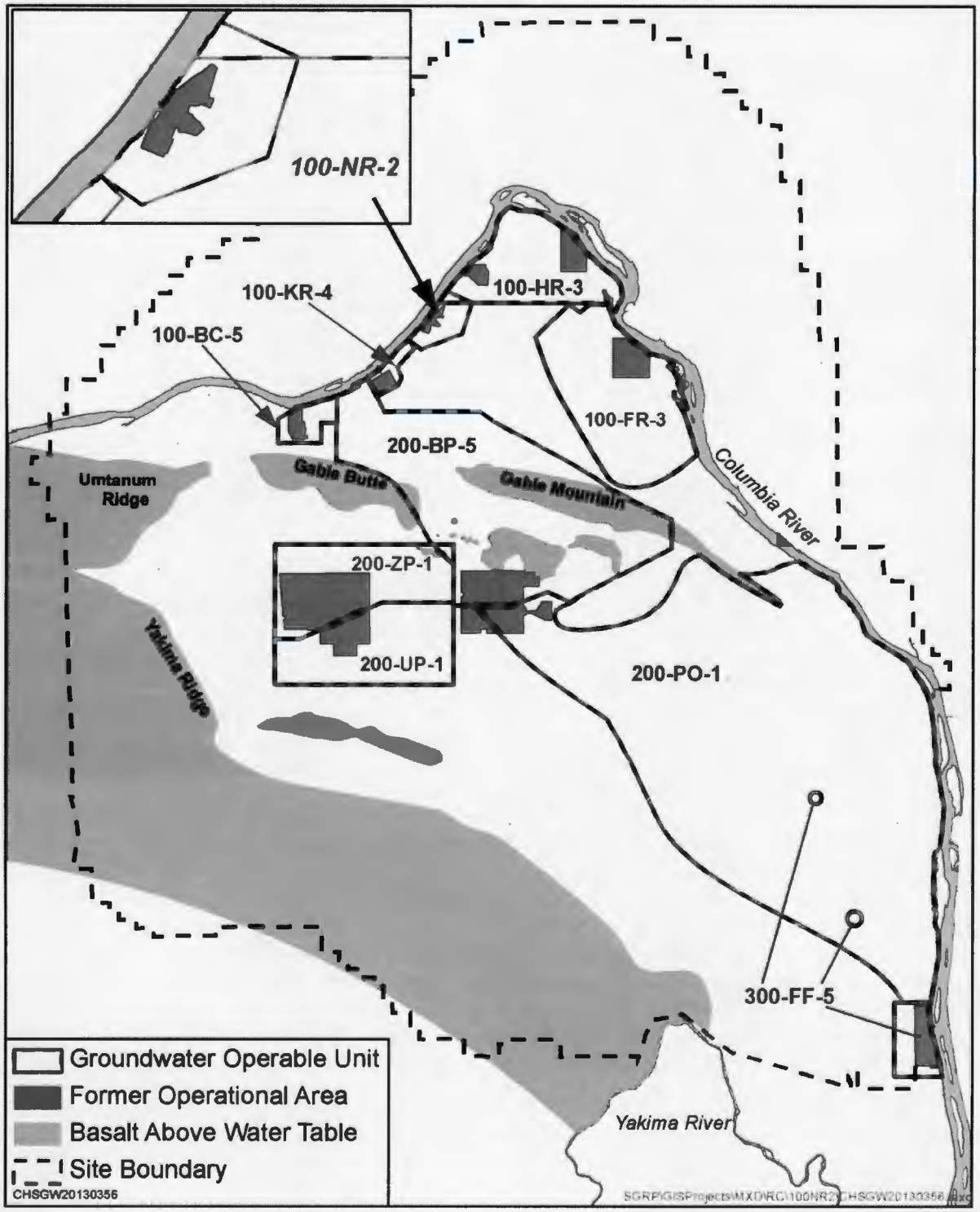


Figure 4-1. Location of the 100-NR-2 OU

4.1 Summary of Operable Unit Activities

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

- Extend the length of the apatite PRB from 91 m (300 ft) to approximately 760 m (2,500 ft).

  Status: The well network for future apatite-forming solution injections to expand the PRB to 760 m (2,500 ft) was installed and completed in 2010, which included the addition of 146 injection wells and 25 monitoring wells along the 100-N Area shoreline. The wells were installed both upriver and downriver adjacent to the original 16 well 91 m (300 ft) long PRB.

  Future injection of apatite solutions will extend the apatite PRB throughout this network along the 100-N shoreline to intercept the strontium-90 groundwater plume before it reaches the river. Section 4.4 discusses the performance on treated portions of the PRB and future injections.

- Inject apatite-forming solutions into two 90 m (300 ft) long segments of the expanded barrier well network in accordance with two design optimization studies (DOE/RL-2010-29, *Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit* and DOE/RL-2010-68, *Jet Injection Design Optimization Study for 100-NR-2 Groundwater Operable Unit*).

  Status: Apatite solutions were injected into 24 wells located southwest and upriver of the original barrier, and into 24 wells located northeast and downriver of the original barrier in 2011 in accordance with DOE/RL-2010-29. The se injections extended the apatite barrier by 110 m (360 ft) upriver and 110 m (360 ft) downriver. Performance monitoring was conducted for all three barrier segments (upriver, central [original], and downriver) during 2016 (SGW-56970, *Performance Report for the 2011 Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit*).

  Figure 4-2 shows the locations of the 100-NR-2 OU groundwater monitoring wells for 2016 and the location of the apatite PRB in relation to these wells (shown in the inset of the figure). Figures 4-3, 4-4, and 4-5 show the details for the three segments of the apatite PRB that have received apatite treatment to date.

  Jet injection of apatite into the vadose zone along the PRB well network to enhance the existing PRB treated interval has not been conducted.

- Apply one additional round of apatite injections within 5 years of completion of all first-round apatite injections.

  Status: No additional rounds of injections were performed in 2016. Not all first-round apatite injections have been completed. Injection of the remainder of the apatite barrier network wells with apatite forming solutions is not anticipated to be completed until after 2018.

- Use monitored natural attenuation.

  Status: Strontium-90 moves very slowly through the aquifer and naturally attenuates through radioactive decay. Groundwater monitoring wells are periodically sampled in accordance with Appendix A of DOE/RL-2001-27 to assess the ongoing decline in contaminant concentrations within the OU.

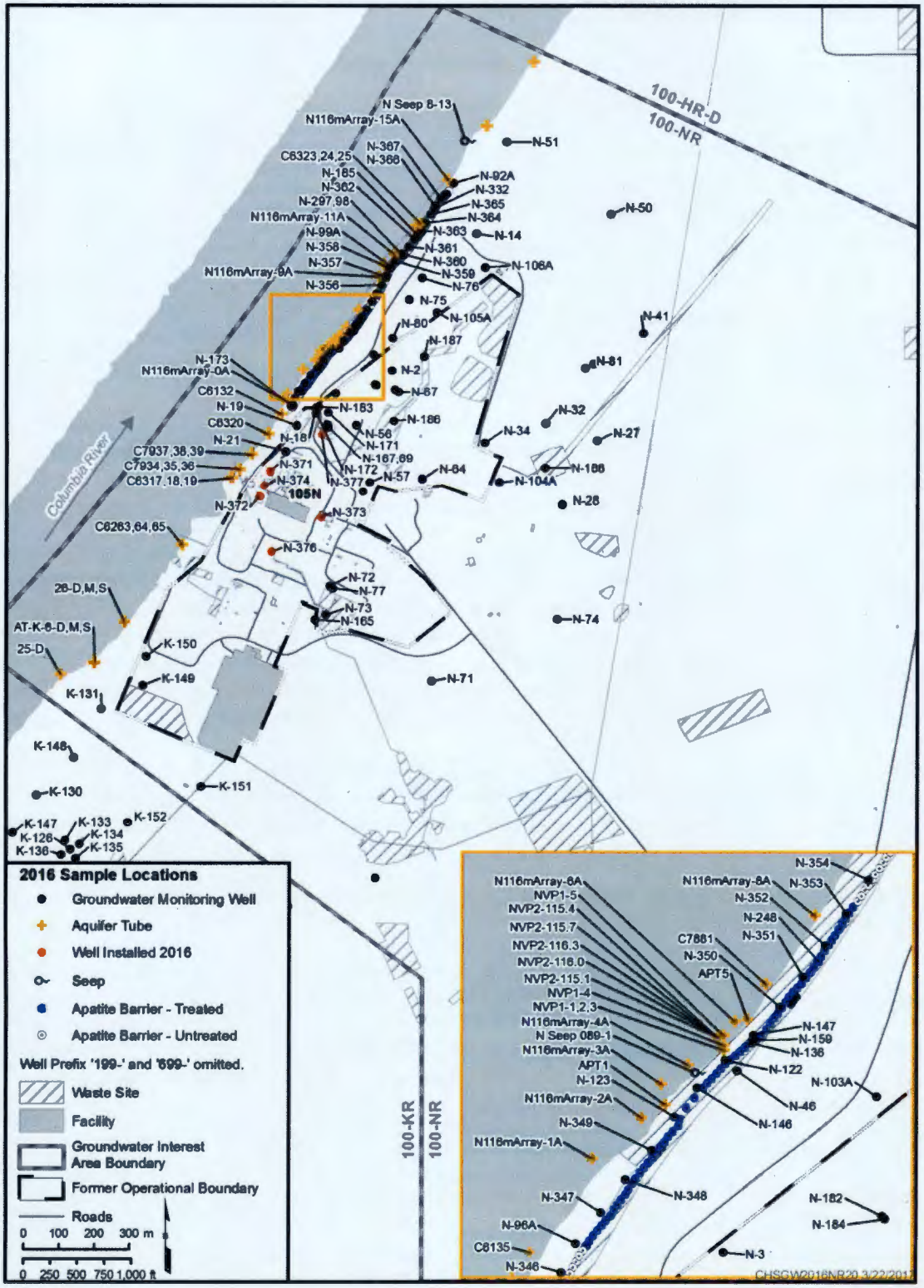


Figure 4-2. Locations of Wells in the 100-N Area

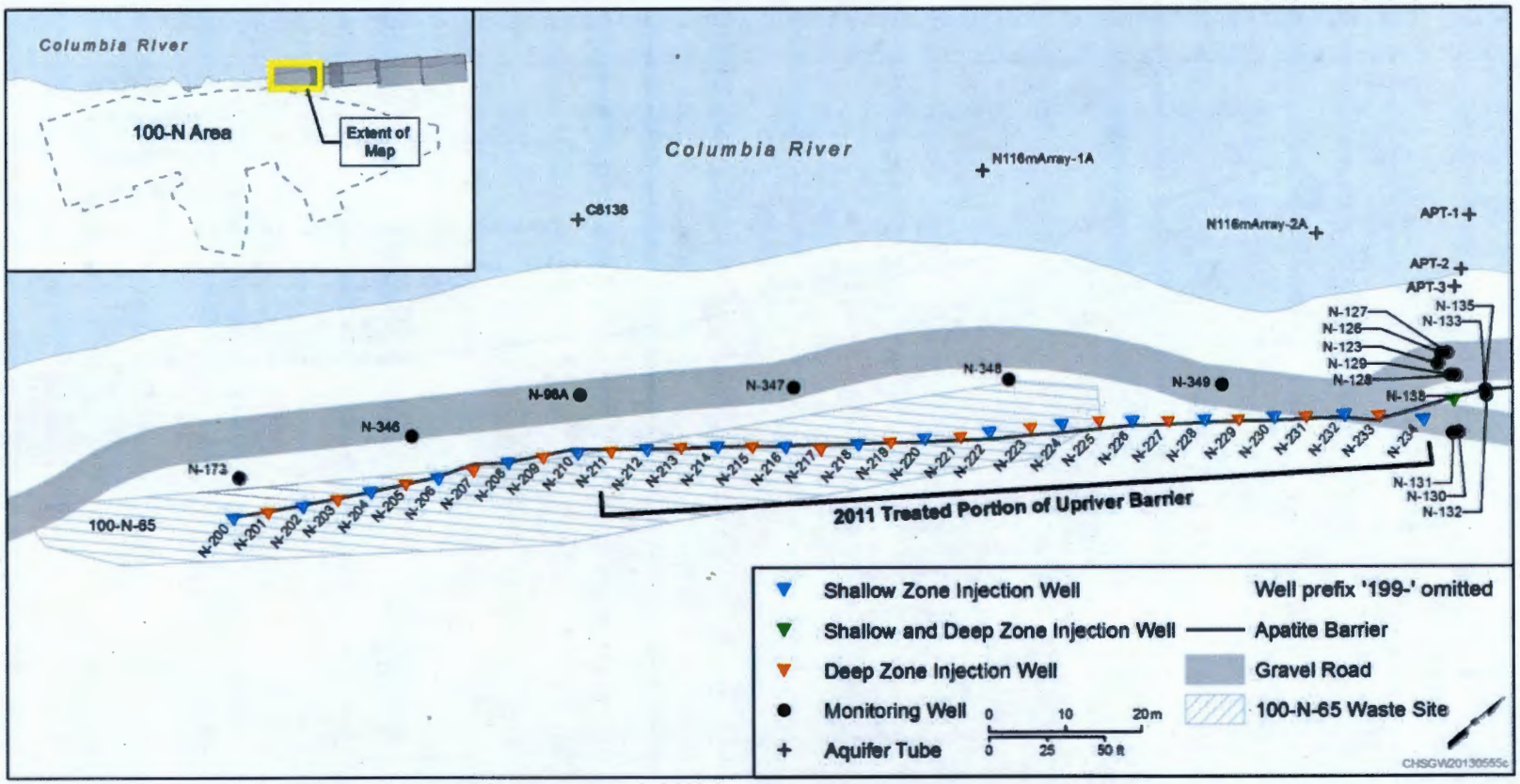


Figure 4-3. Upriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline

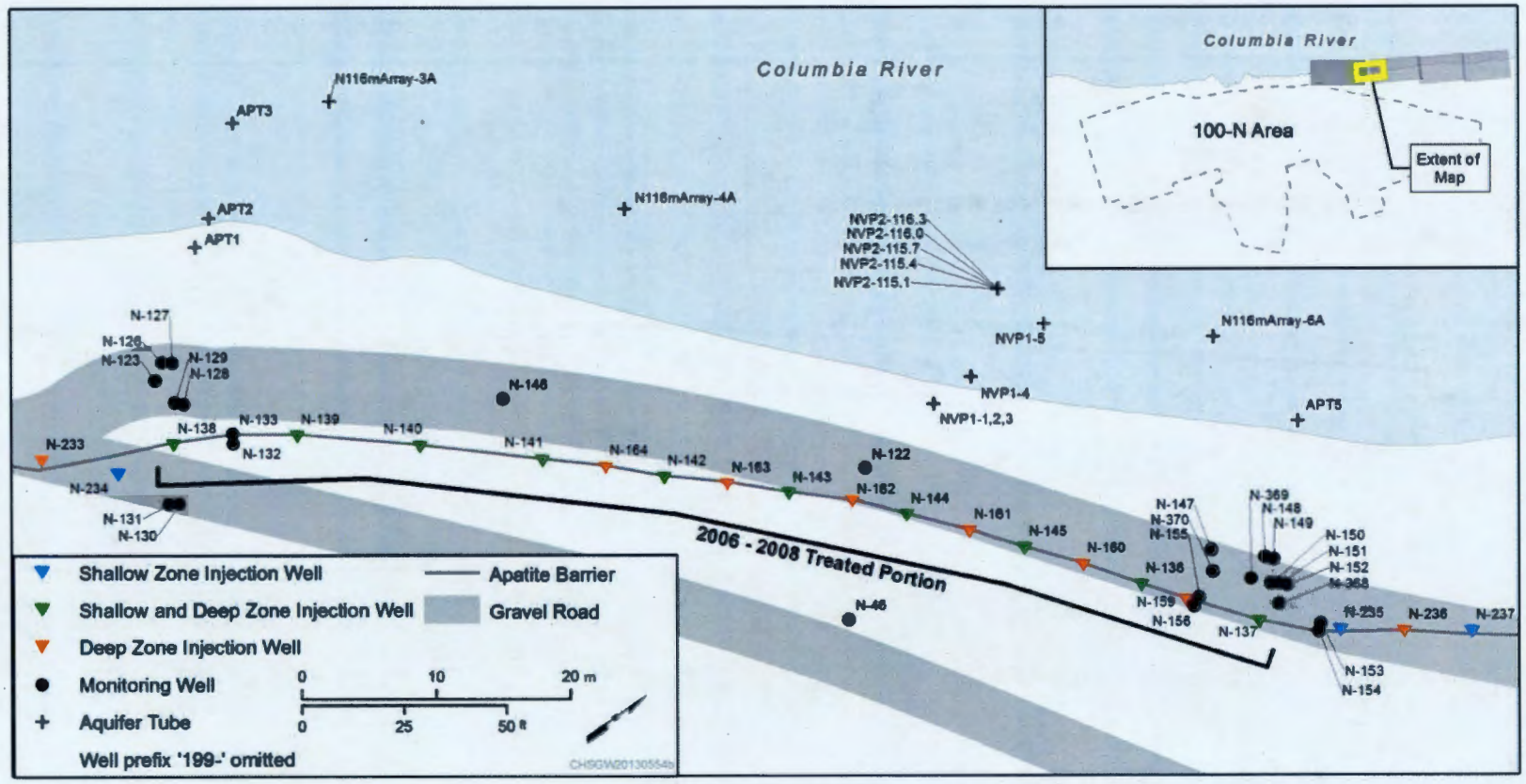


Figure 4-4. Central (Original) Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline

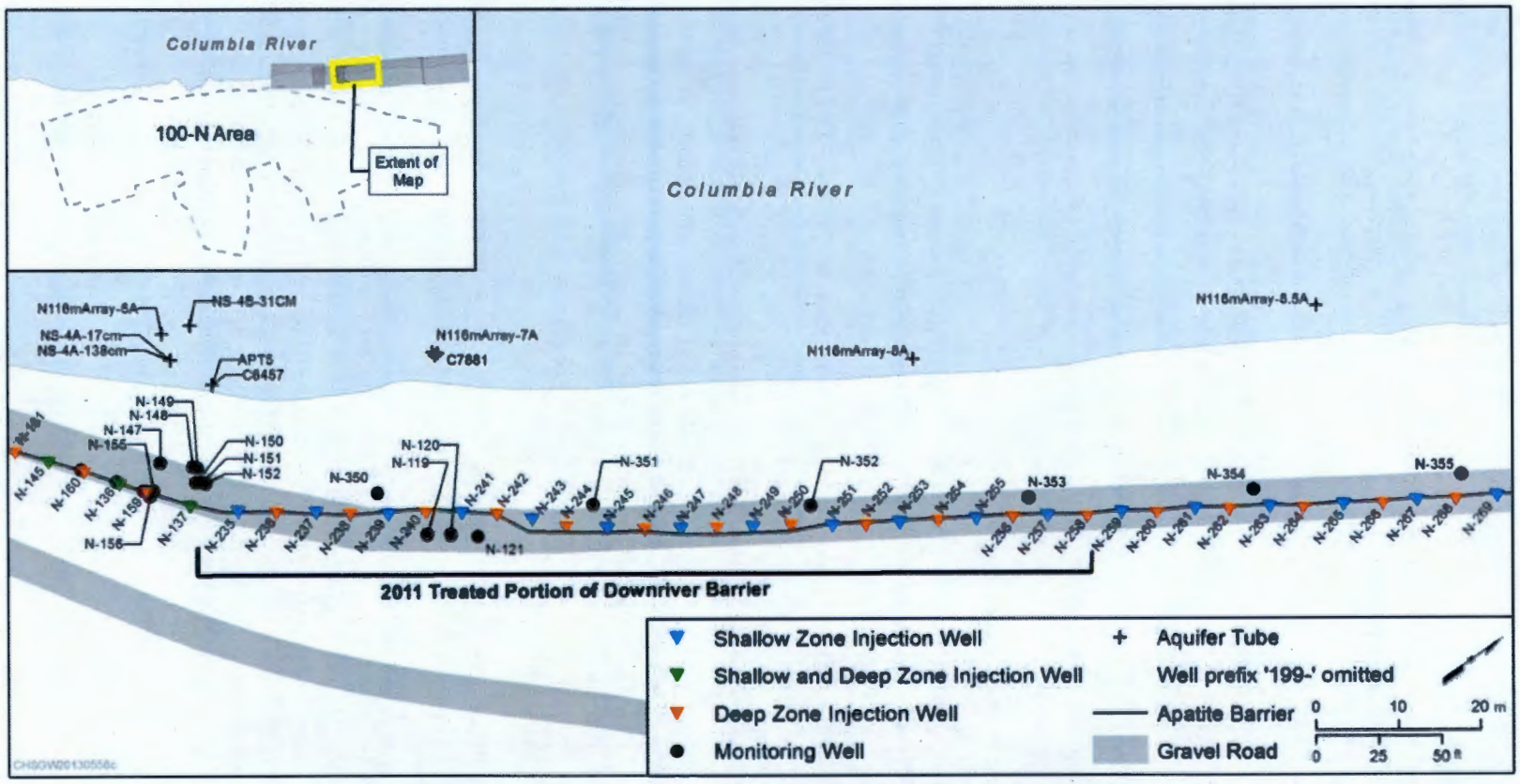


Figure 4-5. Downriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes along the Columbia River Shoreline

- Decommission the existing 100-NR-2 OU groundwater P&T system building and components. The P&T system has not been operated since March 2006.

  Status: The 100-NR-2 P&T system was demolished, excavated, and removed in 2016. Demolition debris was disposed of at ERDF. The former pump and treat extraction wells were converted to support groundwater monitoring prior to the start of demolition. Piping was removed from the former injection wells in January 2017.

- Maintain existing ICs.

  Status: Existing ICs include entry restrictions (security), escorts and badging of site visitors, excavation permits, surveillance, posted signs, deed notifications to restrict land and groundwater use (DOE/RL-2001-27). Existing ICs are being maintained.

- Maintain the riprap cover along the shoreline.

  Status: The riprap cover was placed over the groundwater seeps and springs along the shoreline. The existing riprap cover is being maintained.

- Perform periodic groundwater monitoring.

  Status: Performance monitoring of the expanded 311 m (1,020 ft) long PRB continued through 2016. Periodic groundwater monitoring is performed in accordance with Appendix A of DOE/RL-2001-27 (Section 4.3).

The selected interim action remedy to address TPH contamination in 100-NR-2 OU groundwater (EPA/ROD/R10-99/112) consists of the following:

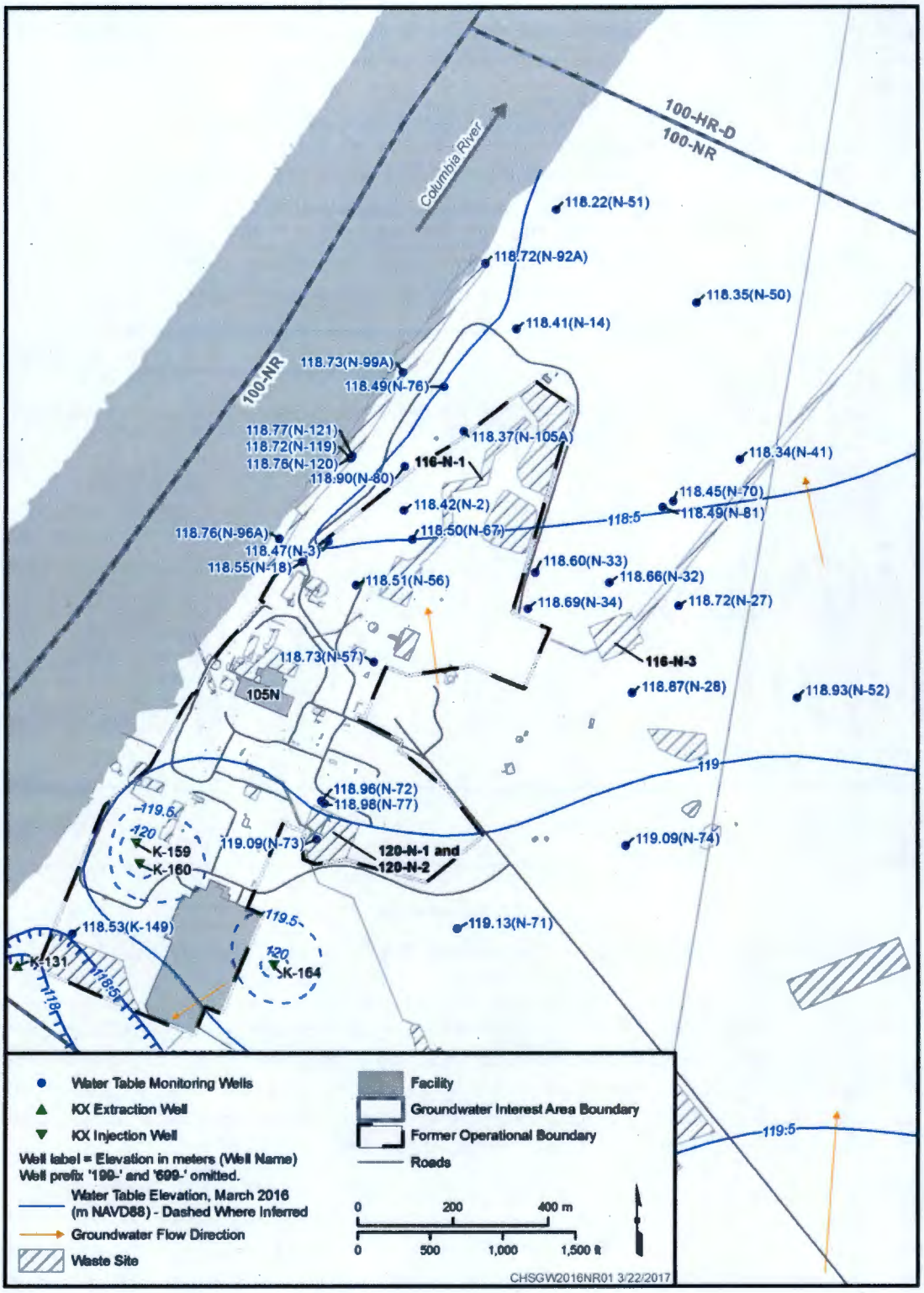
- Remove petroleum hydrocarbon (free-floating product) from any groundwater monitoring well.

  Status: Petroleum hydrocarbon contamination as free product was occasionally observed at wells 199-N-17 and 199-N-18. Well 199-N-17 went dry and was taken out of service and decommissioned in 2002. Removal of petroleum hydrocarbon light nonaqueous-phase liquid (LNAPL) from well 199-N-18 continued in 2016.

4.2 Water-Level Monitoring

Groundwater monitoring is conducted at the 100-N Area to assess the direction of migration of the Sr-90 and TPH-D contaminant plumes relative to the Columbia River and influences from the neighboring 100-K P&T operations.

Groundwater generally flows northwest toward the Columbia River beneath the 100-N Area. The magnitude of the difference in groundwater hydraulic head across the 100-N Area in March 2016 was about 1 m (3.3 ft) (Figure 4-6). Groundwater flow in 2016 continued to be influenced by groundwater extraction and injection through wells installed in the southwestern portion of the 100-N Area as part of the KX P&T remediation system for the 100-KR-4 OU (Chapter 3). A groundwater mound approximately 1 m (3.3 ft) high surrounding the KX P&T system injection wells creates local radial flow.



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

Figure 4-6. 100-N Area Water Table Map, March 2016

Groundwater flow in the 100-NR-2 OU is influenced by the Columbia River stage. The river stage can change daily (±1.5 m [5 ft]) and seasonally (±2.4 m [7.8 ft]) for sustained periods, which affects the saturated zone thickness and may create temporal 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*). The river is controlled by releases of water at Priest Rapids Dam upstream from the 100-N Area. A regression model as described in ECF-Hanford-13-0028, *Columbia River Stage Correlation for the Hanford Area*, calculates the estimated river stage at the 100-N Area derived from water elevation data from Priest Rapids Dam. The calculated 100-N river stage from the regression analysis is shown in Figure 4-7. The high river stage period in 2016 occurred in April through mid-July with highest elevation in April at 122.0 m (400.2 ft). The low river stage period was from mid-August through early December with a low of 116.3 m (381.5 ft) in September.

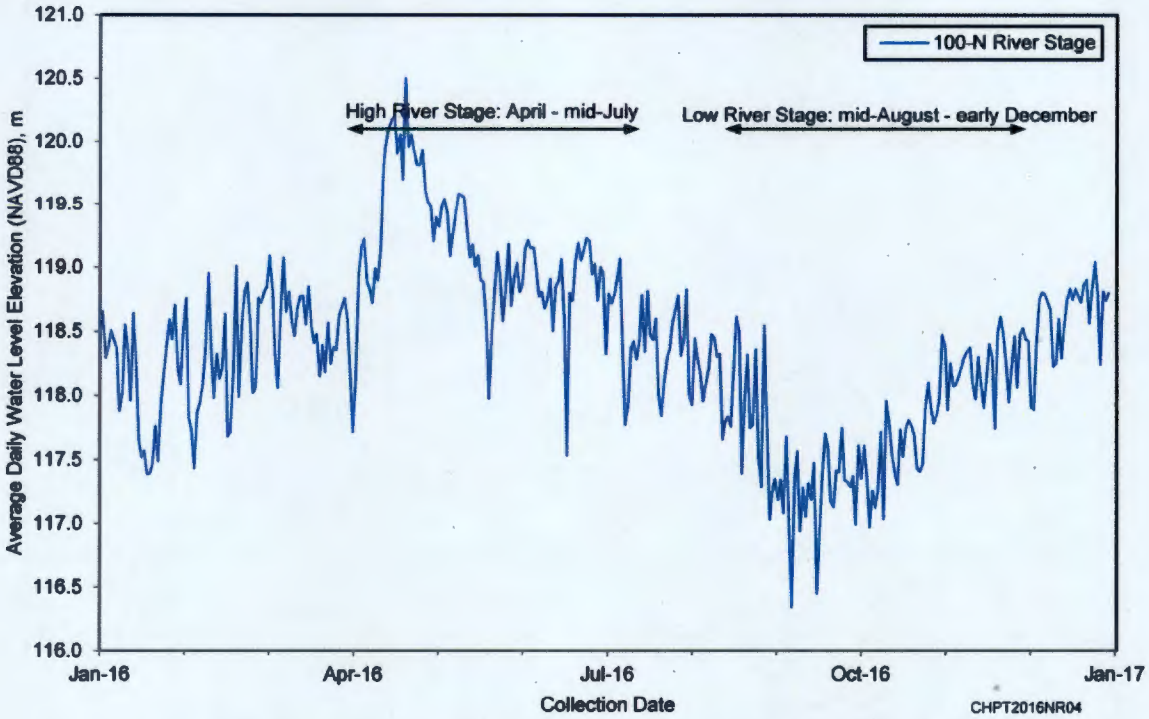


Figure 4-7. 100-N Area River Stage Derived from Priest Rapids Dam Data, 2016

Wells on the river shoreline respond very quickly to changes in river levels, and 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; however, unless the river level remains high or low for several days or more in a row, the effect may not have propagated inland to a distance that would be noticeable at inland locations. This effect is due to the relatively low permeability of the saturated Ringold Formation sediment that comprises the unconfined aquifer beneath most of the 100-N Area.

The 2016 hydrographs for river stage comparison to wells 199-N-3 and 199-N-72 is provided in Figure 4-8; the locations of the wells are shown in Figure 4-2. Wells 199-N-3 and 199-N-72 (approximately 107 and 762 m [351 and 2,500 ft], respectively, from the river) have much smoother hydrographs than the river. The effects of high and low river-stage influences to the inland wells are visible in Figure 4-8. Table 4-1 provides the average river elevation at 100-N (derived from Priest Rapids Dam [PRD] data) and water levels in wells 199-N-3 and 19-N-72 for days representing low and high river stage.

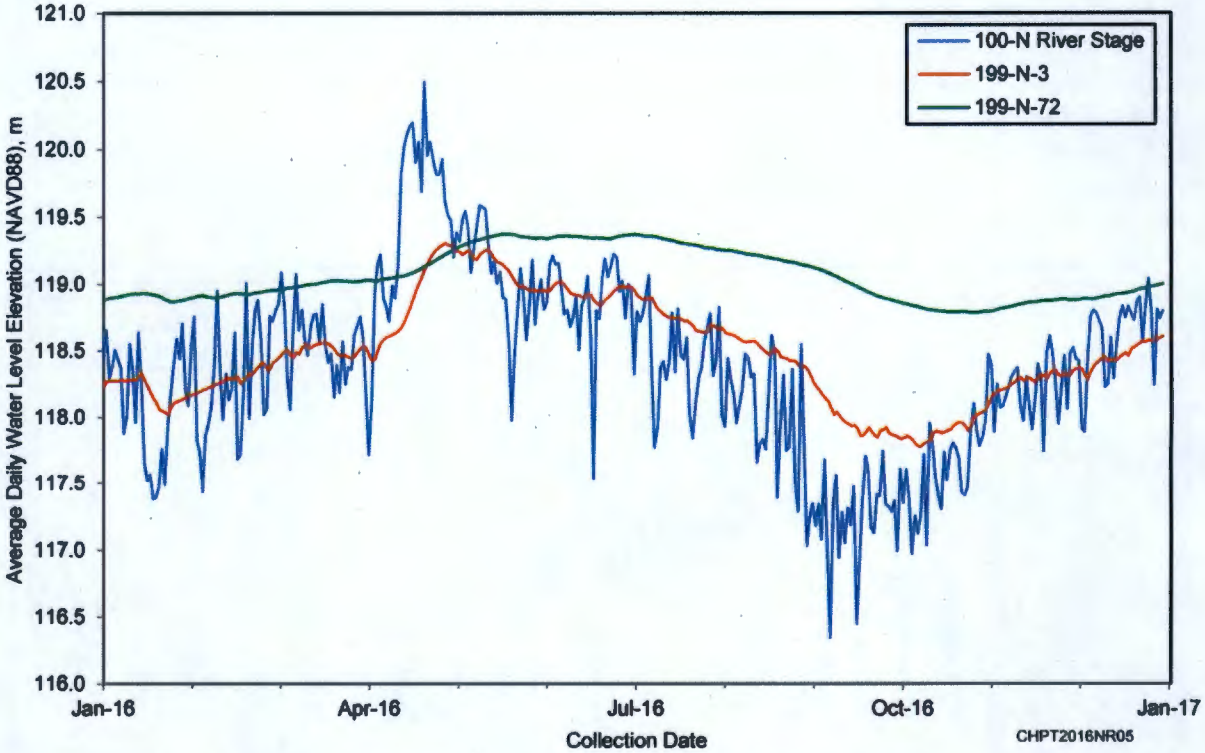


Figure 4-8. Daily Average Water Level for Wells 199-N-3 and 199-N-72 Compared to River Stage, 2016

Table 4-1. Well Water-Level Response to Changes in River Stage

100-N River Elevation		199-N-3		199-N-72	
Date	Average Elevationa (m)	Date	Average Elevationb (m)	Date	Average Elevationb (m)
Late Winter Low					
1/21/2016	117.39	1/25/2016	118.02	2/11/2016	118.90
Early Summer High					
4/22/2016	120.50	4/29/2016	119.31	5/20/2016	119.38
Late Fall/Early Winter Low					
10/6/2016	116.97	10/9/2016	117.78	10/27/2016	118.78

a. Derived from PRD water elevation data.

b. Based on hourly water-level elevation data.

PRD = Priest Rapids Dam

In April 2016, the PRD-derived river stage increased by 1.9 m (6.3 ft). Water levels in well 199-N-2, 170 m (557.7 ft) from the river, increased 0.71 m (2.3 ft), with a lag time of approximately 24 days (Figure 4-9). Water levels in well 199-N-50, 425 m (1,394.4 ft) from the river, increased 0.59 m (1.9 ft) and had a shorter lag time than well 199-N-2. The water table at well 199-N-50 appears to respond more quickly than at well 199-N-2, which is located closer to the river. This suggests that the saturated formation between the river and well 199-N-50 is more permeable than between the river and well 199-N-2.

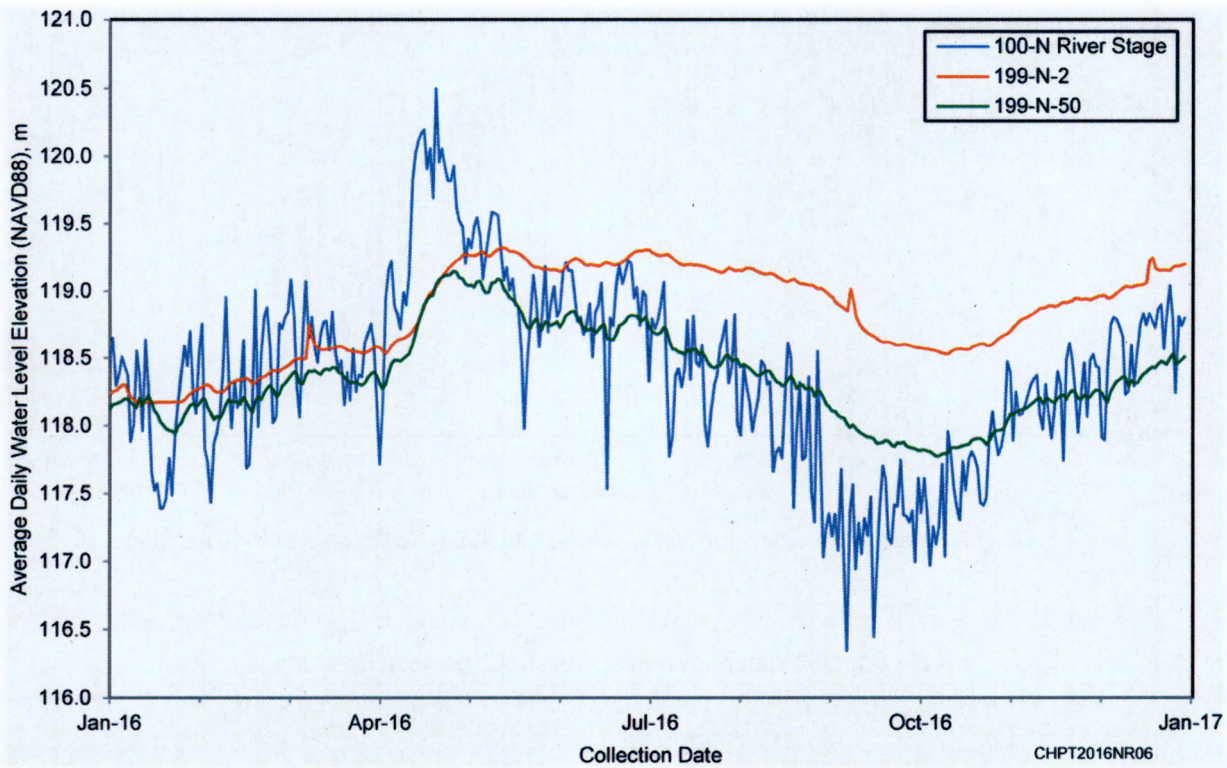


Figure 4-9. Daily Average Water Level for Wells 199-N-2 and 199-N-50 Compared to River Stage, 2016

Vertical hydraulic gradients in the 100-NR-2 OU vary from consistently upward gradient at inland well pair 199-N-81/199-N-70 to variably upward/downward at the well pair closest to the river (199-N-119/199-N-121). The strongest vertical gradient in 2016 was 8.3×10^{-3} m/m upward in 199-N-81/199-N-70.

4.2.1 Strontium-90

The primary source of the strontium-90 contamination in the subsurface of the 100-N Area was liquid waste disposal to the 116-N-1 and 116-N-3 waste sites. The size and shape of the strontium-90 plume changes very little from year to year, except near the apatite PRB. The plume extends from beneath the 116-N-1 and 116-N-3 waste sites to the Columbia River at concentrations above the DWS (8 pCi/L) (Figure 4-10). The highest concentration portion of the strontium-90 groundwater plume (i.e., the area with concentrations exceeding 800 pCi/L) primarily underlies the 116-N-1 Trench and extends northwest to near the Columbia River shoreline. Concentrations also exceed 800 pCi/L in one well beneath the 116-N-3 Crib. The lateral distribution of the groundwater plume with concentrations between 8 and 800 pCi/L is consistent with historical radial flow away from the two waste sites (areas of highest original concentration) and elongated toward the river parallel to the 116-N-1 waste site (Figure 4-10).

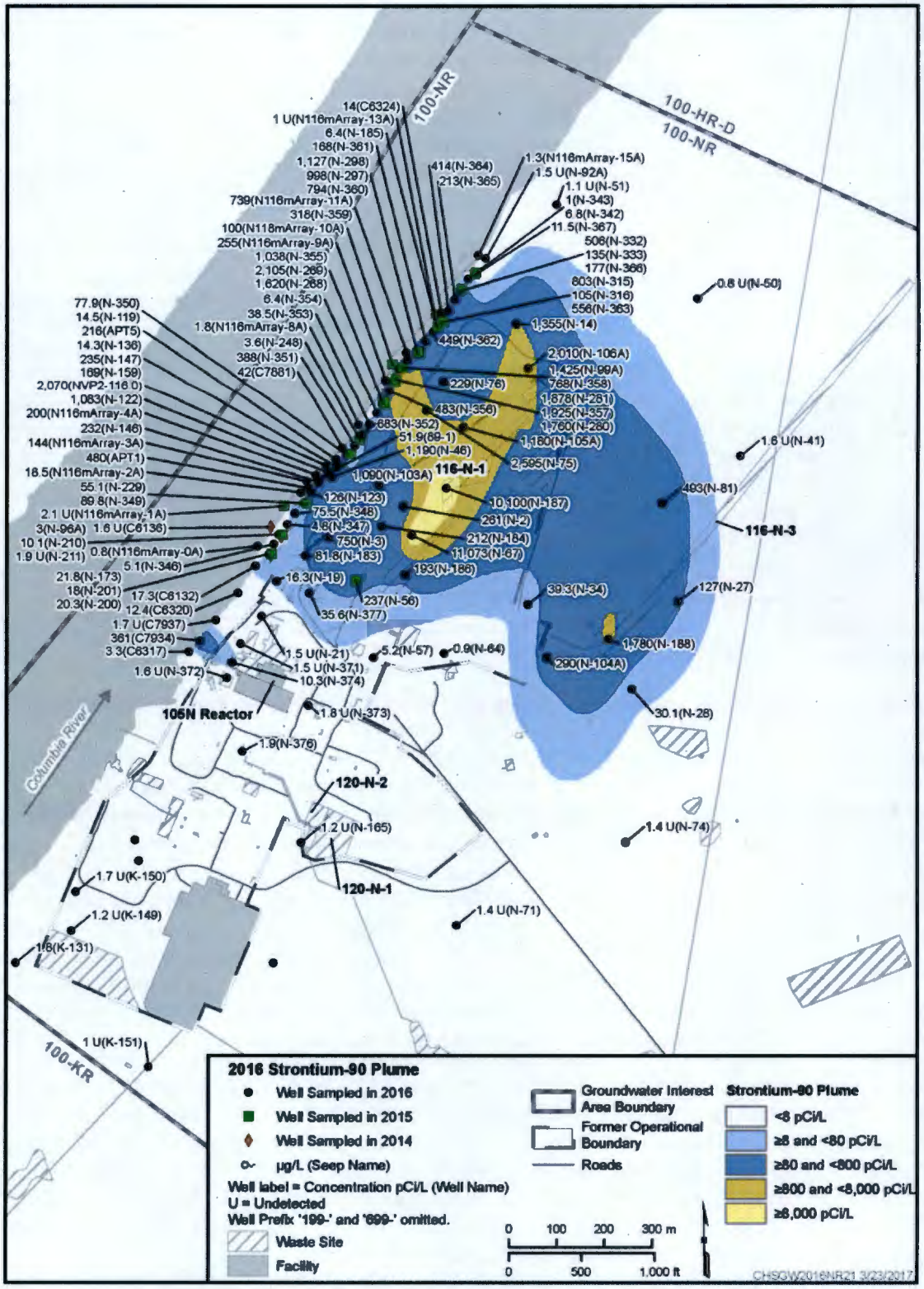


Figure 4-10. Strontium-90 Plume Map for the 100-N Area, 2016

Because strontium-90 adsorbs strongly to sediment grains, the majority of the strontium-90 remaining in the subsurface in the 100-N Area is in the lower vadose zone above the aquifer and upper portion of the unconfined aquifer. Approximately 99 percent of the strontium-90 in the subsurface within the 100-NR-2 OU is adsorbed, and 1 percent remains in solution in the groundwater (DOE/RL-2008-46-ADD5, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units*). Although primarily adsorbed, some strontium-90 is remobilized by seasonal water-level increases that release strontium-90 from sediments within the lower vadose zone not usually in contact with groundwater (PNNL-16891).

The high sorption (i.e., a high distribution coefficient) of strontium-90 also causes its rate of transport in groundwater toward the Columbia River to be approximately 100 times slower than the groundwater flow rate (PNNL-19572). Table 4-2 provides the strontium-90 concentrations in selected monitoring wells and aquifer tubes.

The highest strontium-90 groundwater concentration detected at 100-NR in 2016 was 12,600 pCi/L in a sample from 199-N-67, which is downgradient of the 116-N-1 Trench. Because of the low mobility of strontium-90 in groundwater, high strontium-90 concentrations (greater than 150 pCi/L) are limited to the upper portion of the aquifer. The seasonally low water table elevation in this area ranges from 116.8 m (383.1 ft) to 117.8 m (386.4 ft). Strontium-90 was measured at 83.9 pCi/L in 2015 at well 199-N-182, which monitors the lower portion of the unconfined aquifer. The top of the well screen is at 114.8 m (176.5 ft), which is 2 to 3 m (6.5 to 9.8 ft) below the low water table. Strontium-90 concentrations in monitoring wells screened deeper than well 199-N-182 range from non-detect to less than 8 pCi/L (with one measurement of 12 pCi/L at well 199-N-69 in 2012). This demonstrates that high strontium-90 contamination above 150 pCi/L in the unconfined aquifer is likely not lower than 3 m (9.8 ft) below the low water elevation of the periodically rewetted zone.

Strontium-90 concentration trends in monitoring wells near the 116-N-1 waste site show no obvious long-term decline but do show significant variability related to water levels. Figure 4-11 shows strontium-90 concentrations and water levels in well 199-N-67 (located just downgradient of the liquid waste disposal end of the 116-N-1 Trench). When the water table rises, some of the residual strontium-90 adsorbed to sediment in the deep vadose zone is released to groundwater, and concentrations in the groundwater increase. When the water table decreases, strontium-90 resorbs to sediment, and concentrations in the groundwater decrease. Annual concentration peaks are correlated with periods when the water table was higher and saturated the lower vadose zone (Ringold Formation) containing residual strontium-90 contamination. Figure 4-12 shows strontium-90 concentrations and water levels in former extraction well 199-N-105A. From 1996 until 2007, groundwater extraction lowered the water table to a deeper part of the aquifer where strontium-90 concentrations are lower. After extraction ceased, water levels increased to normal levels and strontium-90 concentration in well 199-N-105A increased as the periodically rewetted zone with strontium-90 adsorbed on the sediments became re-saturated.

Strontium-90 concentrations, as well as the water table elevation in well 199-N-81 (downgradient of the 116-N-3 Trench), have declined since the late 1990s (Figure 4-13). High water table elevations in 2011 and 2012 caused a slight increase in the strontium-90 concentration that continued into the fall 2015 sampling. The water table elevation returned to more normal elevations from the high-water table elevations observed in 2011 and 2012 and strontium-90 concentrations in well 199-N-81 have stabilized in 2016. The positive correlation of strontium-90 concentration with water-level changes may be more pronounced at wells nearer to the 116-N-1 waste site because it received a much larger mass of strontium-90 than the 116-N-3 waste site and presumably has more residual strontium-90 in the lower vadose zone.

Table 4-2. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes

Well/Tube Name	1994 (pCi/L)	2005 (pCi/L)	2008 (pCi/L)	2009 (pCi/L)	2010 (pCi/L)	2011 (pCi/L)	2012 (pCi/L)	2013 (pCi/L)	2014 (pCi/L)	2015 (pCi/L)	2016 (pCi/L)	Percent Change, 1994 to 2016	Percent Change 2005 to 2016
Monitoring Wells													
199-N-2	121	80.7	1,100	160	NS	NS	3,300	1,040	777	164	261	116	223
199-N-3	927	1,330	1,200	1,060	870	1,200	1,300	960	938	859	768	-17	-42
199-N-14	1,210	1,070	1,300	1,360	1,400	1,730	960	1,200	1,120	1,380	1,360	12	27
199-N-16	0.34	-0.08 (U)	0.06 (U)	-0.04 (U)	-2.70 (U)	-0.12 (U)	0.11 (U)	Decom. 12/18/2012	Decom. 12/18/2012	Decom. 12/18/2012	Decom. 12/18/2012	NC	NC
199-N-18	392	NS	290	-12 (U)	260	203	In use for TPH-D remediation	In use for TPH-D remediation	In use for TPH-D remediation	In use for TPH-D remediation	In use for TPH-D remediation	NC	NC
199-N-19	43.6	28.2	NS	NS	23	26.4	23	22	23[a]	17.1	16.3	-63	-42
199-N-21	1.50	NS	NS	-2.60 (U)	-7.6 (U)	1.22	1.2	1.8	0.31 (U)	-0.193 (U)	0.944 (U)	NC	NC
199-N-27	171	167	160	130	125	194	200	130	129	126	127	-26	-24
199-N-28	120	25.1	21	25	20	34.9	35	24	33	32.5	30.1	-75	20
199-N-32	1.27	0.358 (U)	-1.40 (U)	-1.60 (U)	-4.8 (U)	0.15 (U)	0.36 (U)	0.77 (U)	0.37 (U)	0.06 (U)	-0.606 (U)	NC	NC
199-N-34	69.3	53.5	67	44	37	57.4	45	42	42	35.9	39.3	-43	-27
199-N-41	0.004 (U)	-0.10 (U)	-0.41 (U)	-1.20 (U)	-1.80 (U)	0.50 (U)	1	NS	0.48 (U)	0.50 (U)	0.26 (U)	NC	NC
199-N-46	5,850	2,690	630	580	530	1,220	1,035	1,400	1,570	1,730	1,190[i]	-80	-56
199-N-50	-0.02 (U)	NS	NS	NS	-0.20 (U)	-0.13 (U)	0.23 (U)	0.8 (U)	0.17 (U)	0.73	0.348	NC	NC
199-N-51	0.254 (U)	0.11 (U)	NS	N	-5.30 (U)	0.52 (U)	0.26 (U)	0.78 (U)	0.16 (U)	-0.54 (U)	0.972 (U)	NC	NC
199-N-56	164[b]	317	170	140	-7.5 (U)	490	560	380	338	246	NS	NC	NC
199-N-57	26	9.71	8.51	2.90	5.80	15.2	15.5	12	10	6.86	5.18	-80	-47
199-N-64	0.185 (U)	0.785 (U)	0.256 (U)	-5.30 (U)	-4.60 (U)	0.48 (U)	3	0.49 (U)	1.2 (U)	0.35 (U)	0.857	NC	NC

Table 4-2. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes

Well/Tube Name	1994 (pCi/L)	2005 (pCi/L)	2008 (pCi/L)	2009 (pCi/L)	2010 (pCi/L)	2011 (pCi/L)	2012 (pCi/L)	2013 (pCi/L)	2014 (pCi/L)	2015 (pCi/L)	2016 (pCi/L)	Percent Change, 1994 to 2016	Percent Change 2005 to 2016
199-N-67	3,680	9,710	10,000	9,000	9,800	13,500	11,550	14,000	15,500	13,600	12,600	242	30
199-N-69[c]	-0.09 (U)	0.21 (U)	NS	NS	-3.20 (U)	2.96	12	4.8	3	0.57 (U)	NS	NC	NC
199-N-70[c]	0.321 (U)	0.156 (U)	-2.60 (U)	-2.40 (U)	-3.80 (U)	0.79	1.2	1.2	0.54 (U)	-0.27 (U)	NS	NC	NC
199-N-71	0.55	NS	0.38 (U)	-0.05 (U)	-2.80 (U)	-3.90 (U)	0.29 (U); 1.1	0.65 (U)	0.60 (U)	0.27 (U)	0.21 (U)	NC	NC
199-N-72	2.59[d]	NS	-1.00 (U)	NS	-1.70 (U)	-2.60 (U)	NS	NS	NS	NS	1.475[d]	-43	NC
199-N-73	0.53	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.83[d]	57	NC
199-N-74	0.415	-0.08 (U)	2.3[d]	405[d]	-2.0 (U)	-3.60 (U)	NS	NS	NS	NS	-0.54 (U)	NC	NC
199-N-75[e]	2,110	307	2,500	3,000	2,400	NS	3,200	2,500	2,540	3,200	3,050	45	893
199-N-76	84.9	216	180	180	120	387	1,120	690	440	177	302	256	40
199-N-77	0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.225[d]	394	NC
199-N-80[c]	0.734 (Q)	-0.154 (U)	0.82 (U)	-0.07 (U)	-5.9 (U)	0.22 (U)	0.77 (U)	1.5	2	0.06 (U)	0.502 (U)	NC	NC
199-N-81	746	734	970	400	320	395	450	490	475	513	493	-34	-33
199-N-92A	0.59 (U)	0.92	1.22	3.50	-9 (U)	0.60	0.47 (U)	0.69 (U)	1	-0.05 (U)	0.487 (U)	NC	NC
199-N-96A	4.90[f]	5.74	1.65	-1.30 (U)	3.94	9.90	2.04	5.9	2	4.36	7.15	46	25
199-N-99A	2,860[f]	1,270	1,200	1,400	1,500	1,020	666.5	1,230	1,600	1,540	NS	NC	NC
199-N-103A[e,g]	4.08[f]	422	1,200	1,200	1,400	1,360	1,600	1,300	1,420	1,560	1,090	NC	158
199-N-104A	5.68[f]	NS	NS	NS	NS	NS	380	260	NS	NS	290	NC	NC
199-N-105A[e,g]	112[f]	1,360	1,900	1,500	1,600	6,580	6,100	1,900	2,210	1,150	1,180	NC	-13
199-N-106A[e,g]	2,890[f]	3,260	2,200	1,800	NS	2,370	3,035	2,200	2,240	1,580	2,010	-30	-38
199-N-119	—	280	250	210	220	274	56	41	29	14.5	NS	NC	NC

Table 4-2. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes

Well/Tube Name	1994 (pCi/L)	2005 (pCi/L)	2008 (pCi/L)	2009 (pCi/L)	2010 (pCi/L)	2011 (pCi/L)	2012 (pCi/L)	2013 (pCi/L)	2014 (pCi/L)	2015 (pCi/L)	2016 (pCi/L)	Percent Change, 1994 to 2016	Percent Change 2005 to 2016
199-N-120[c]	—	10.1	6.55	NS	1.40 (U)	6.93	58	5.7	4	1.93	NS	NC	NC
199-N-121[c]	—	0.272 (U)	0.0169 (U)	NS	-2.00 (U)	-0.02 (U)	0.23 (U)	-0.21 (U)	0.33 (U)	0.52 (U)	NS	NC	NC
199-N-122	—	730	1,160	260	800	740	656	560	907	1,100	1,580	NC	116
199-N-123	—	871	255	-1.60 (U)	280	1,770	204	140	120	55.8	133	NC	-85
199-N-146	—	318[h]	412	260	300	328	215	270	256	200	286	NC	-10
199-N-147	—	522[h]	791	250	250	478	250	120	231	157	244	NC	-53
199-N-165	—	—	—	-1.90 (U)	-6.60 (U)	0.14 (U)	0.57 (U)	1.6	-0.39 (U)	0.24 (U)	-0.166 (U)	NC	NC
199-N-173	—	—	—	16	23	19	14.5	22	25	21.5	23.6	NC	NC
199-N-182	—	—	—	—	—	—	110	140	144	83.9	NS	NC	NC
199-N-183	--	--	--	—	—	—	120	100	82	81.2	89.3	NC	NC
199-N-184	—	—	—	—	—	—	5,000	1,100	1,150	320	212	NC	NC
199-N-185	—	—	—	—	—	—	3.9	7.6	8	6.43	NS	NC	NC
199-N-186	—	—	—	—	—	—	810	390	420	207	193	NC	NC
199-N-187	—	—	—	—	—	—	8,600	11,400	12,800	9,860	10,100	NC	NC
199-N-188	—	—	—	—	—	—	1,500	2,500	2,280	1,520	1,780	NC	NC
199-N-189	—	—	—	—	—	—	0.02 (U)	0.39 (U)	0.85 (U)	0.27 (U)	NS	NC	NC
Aquifer Tubes													
C7934	—	—	—	—	300	NS	93	310	321	344	361	NC	NC
C7935	—	—	—	—	300	NS	190	280	356	331	320	NC	NC
C7936	--	—	—	—	69	NS	55	96	83	80.4	85.6	NC	NC

Table 4-2. Strontium-90 Concentrations in Monitoring Wells and Aquifer Tubes

Well/Tube Name	1994 (pCi/L)	2005 (pCi/L)	2008 (pCi/L)	2009 (pCi/L)	2010 (pCi/L)	2011 (pCi/L)	2012 (pCi/L)	2013 (pCi/L)	2014 (pCi/L)	2015 (pCi/L)	2016 (pCi/L)	Percent Change, 1994 to 2016	Percent Change 2005 to 2016
APT-1	—	3,400[h]	NS	NS	500	530	840	270	211	331	480	NC	-86
APT-5	—	2,100[h]	NS	NS	450	420	270	120	184	238	216	NC	-90
N116mArray-3A	—	379	1,750[d]	500	110	248	240	170	190	120	144	NC	-62
N116mArray-4A	—	1,260	7,000[d]	340	270	226	250	280	342	186	200	NC	-84
NVP2-116.0	—	3,200	2,550[d]	1,100	1,200	1,100	733	700	845	1,680	2,070	NC	-35
N116mArray-6A	—	477	370[d]	95[d]	110	170	190	130	251	75.2	155	NC	-68

Notes: Data are maximum values reported from the fall of the year, unless otherwise noted.

Cells with "—" indicate the well or aquifer tube was constructed after this date.

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

a. Sampled on 1/20/2015.

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

c. Screened at depth in Ringold Formation.

d. Value calculated from gross-beta data (no strontium-90 data available); value listed is one-half of the gross-beta value measured.

e. Former P&T extraction well.

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

g. A P&T system was operated from 1995 through 2006.

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

i. Sampled on 7/1/2016.

NC = not calculated

NS = not sampled

P&T = pump and treat

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

TPH = total petroleum hydrocarbon-diesel

U = nondetect

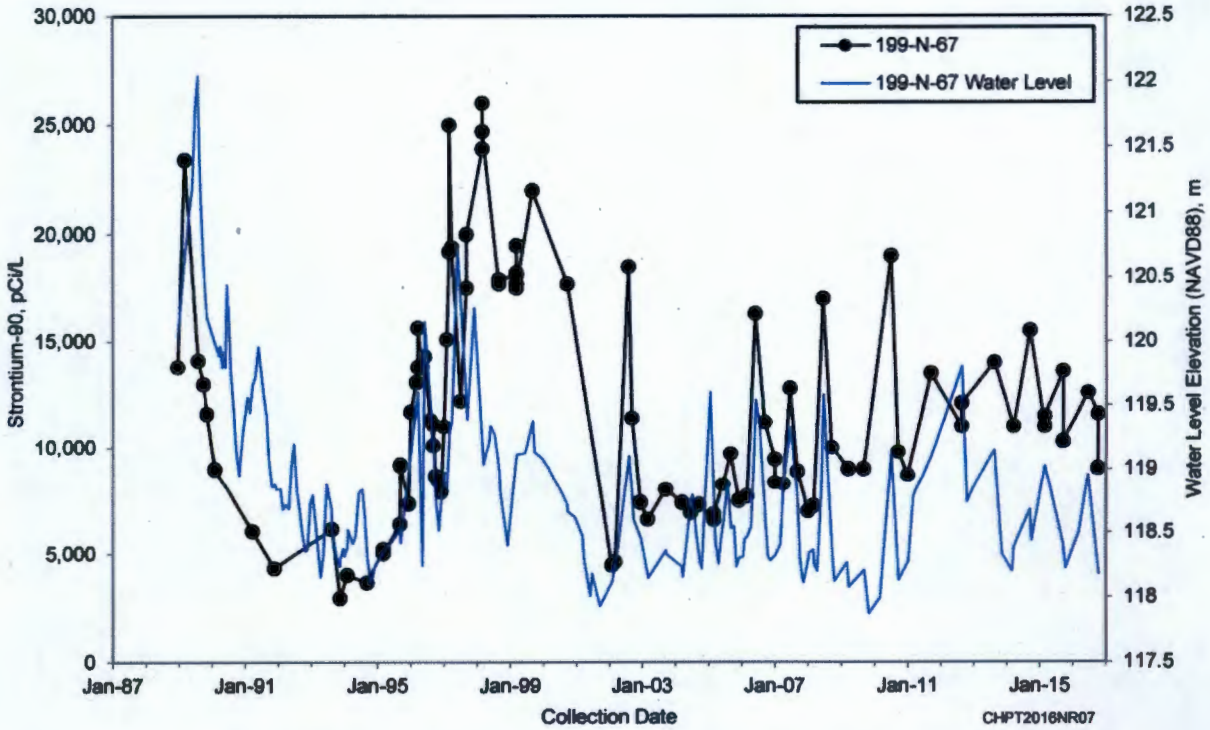
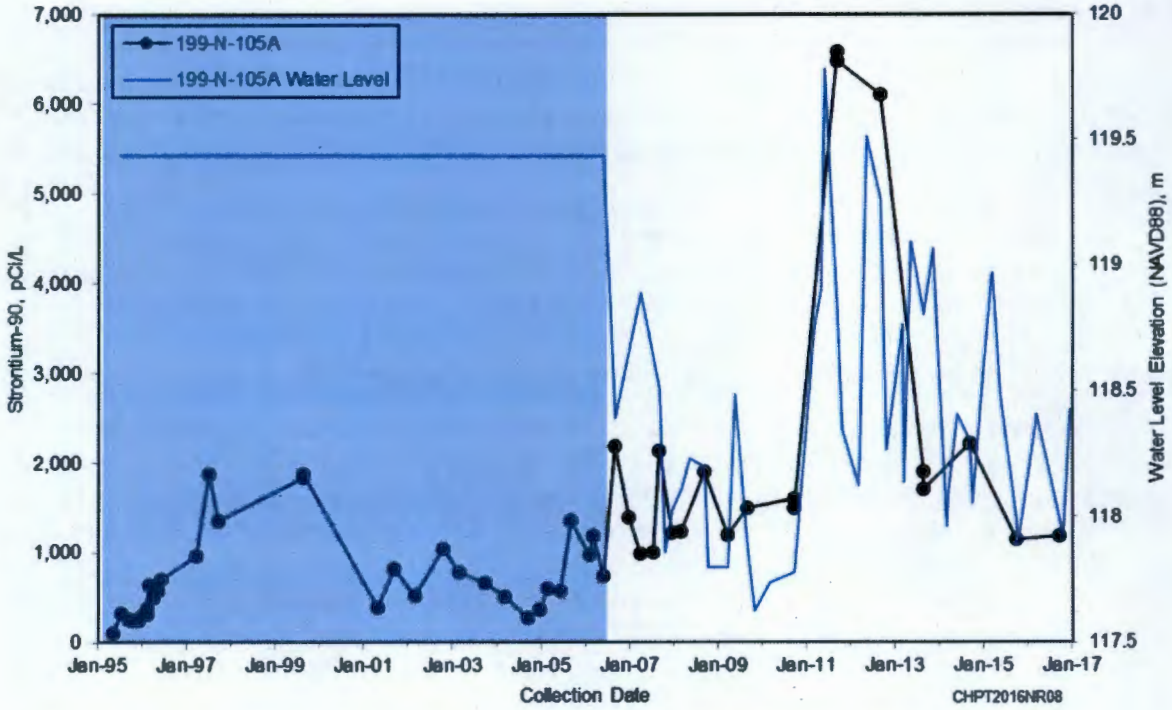


Figure 4-11. Strontium-90 Trend Plot and Water Levels for Well 199-N-67



Note: Well was former pump and treat extraction well from 1995-2006 (shaded band area).

Figure 4-12. Strontium-90 Trend Plot and Water Levels for Well 199-N-105A

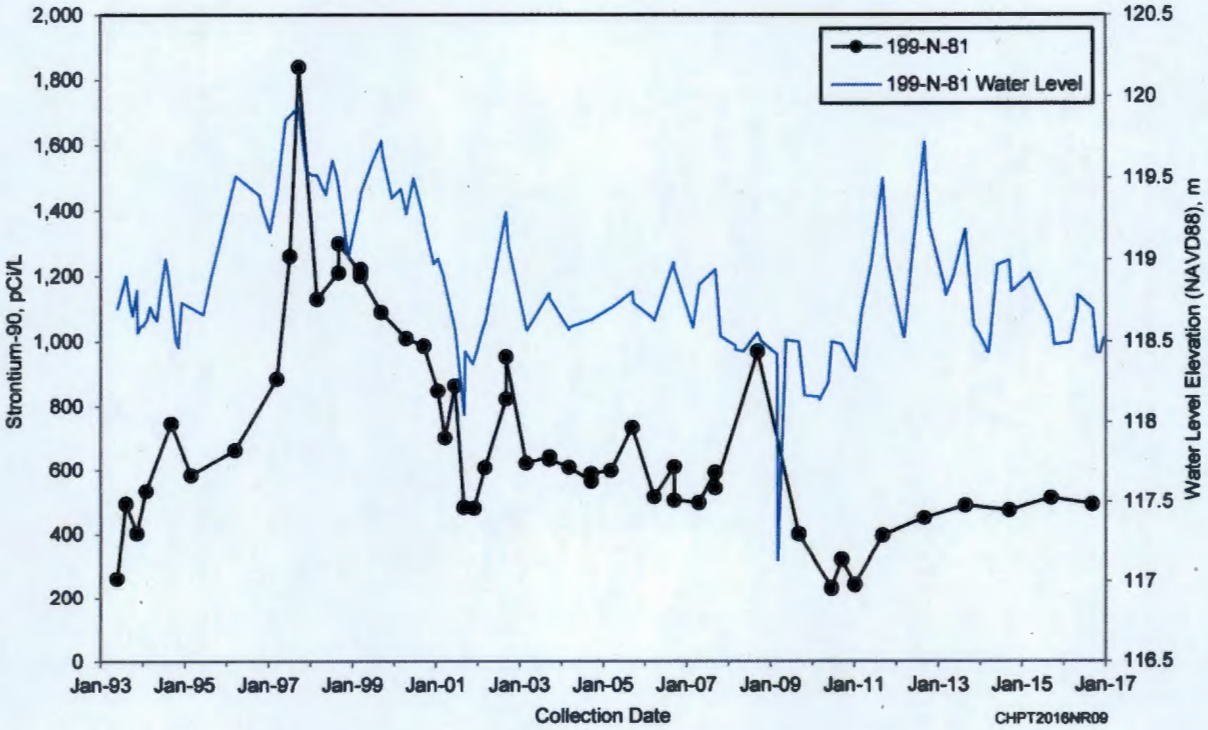


Figure 4-13. Strontium-90 Trend Plot and Water Levels for Well 199-N-81

The highest strontium-90 concentrations in groundwater in the near-shore area along the Columbia River were found near the original segment of the apatite PRB and downriver to the northeast (Figure 4-10). This region of the 100-N Area river shore was impacted by highly contaminated effluent during operations of the 116-N-1 waste site. Effluent discharged to the 116-N-1 waste site emerged at the steeply sloping near-shore surface as springs along the shoreline because of the artificially elevated water table (also known as N Springs). This contaminated area has been the focus of increased monitoring and remediation.

Strontium-90 concentrations in aquifer tubes are consistent with those seen in monitoring wells. Concentrations greater than the DWS are present only above approximately 115 m (377 ft) (i.e., the top 2 to 3 m [6.5 to 9.8 ft] of the aquifer); thus, most of the aquifer tubes are screened at this elevation. Table 4-2 shows the maximum concentrations in the aquifer tubes during 2016. The maximum strontium-90 concentration during 2016 was 2,070 pCi/L in aquifer tube NVP2-116.0.

The only strontium-90 detections in aquifer tubes outside of the area where the main strontium-90 plume intersects the Columbia River are found upriver at aquifer tube cluster C7934/C7935/C7936 (Figure 4-10). The highest detected strontium-90 concentration at this aquifer tube cluster was 361 pCi/L at C7934. These aquifer tubes are located near the engineered fill around the 1908-N Outfall, on the back side of the 105N Reactor building. The outfall construction may have created a preferential pathway in the fill for contaminant migration. Potential sources of strontium-90 contamination at this location include the 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*). Leaks from the FSB and associated facilities and pipelines between the 105N Reactor and the river are likely sources of the elevated strontium-90 concentrations at this location.

Three documented UPRs (UPR-100-N-3, UPR-100-N-7 and UPR-100-N-12) may be the sources of the strontium-90 contamination at aquifer tube cluster C7934/C7935/C7936. Collectively, over 4.22 million L (1.11 million gal) of radioactive liquid effluent was released to the soil between the reactor and river. Waste site UPR-100-N-7 is the largest of the radioactive liquid effluent spills. The spill occurred in April 1985 from a radioactive drain return pipe between the 109-N Bldg. and 1909-N valve pit. Approximately 1,910,000 L (504,000 gal) of effluent water were released from a rupture in the 25.4-cm (10-in.), radioactive drain-return line containing mixed fission products. Waste site UPR-100-N-3 was an unplanned release of radioactively contaminated fuel storage basin water discovered north of the fuel storage basin in 1978. The leak reported as UPR-100-N-12 occurred in 1979 at the same location. An estimated 1,363,000 L (360,000 gal) and 946,000 L (250,000 gal) of storage-basin water were released to the soil during 1978 and 1979, respectively. The estimated stronium-90 inventory released from UPR-100-N-3 was 0.8 Ci (DOE/RL-95-111, *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units*). Based on the estimated release volume and inventory, the release concentration would calculate to be 5.86E+5 pCi/L.

In 2016, wells 199-N-371, 199-N-372, and 199-N-374 were installed between the 105N reactor and the river (Figure 4-2) to evaluate the source of the strontium-90 contamination detected at the aquifer tube cluster C7934/C7935/C7936. Soil samples collected during drilling showed contamination at the water table, which supports the conceptual model that the source of contamination is from unplanned releases from the FSB and associated facilities and pipelines. Strontium-90 contamination was detected at 1.29 pCi/g in a soil sample at the water table at well 199-N-374. Groundwater samples at the water table had strontium-90 concentration of 18.4 pCi/L at well 199-N-374. Soil and groundwater samples collected in the 199-N-371 and 199-N-372 boreholes were non-detect and below the 8 pCi/L DWS for strontium-90, respectively. The low strontium-90 concentrations at 199-N-374 and non-detect at 199-N-371 and 199-N-372 indicate a narrow contamination plume from the unplanned release sites to the aquifer tube cluster C7934/7935/7936 as depicted in Figure 4-10.

Two river shore seeps (100 N SPRINGS 8-13 and 089-1) were sampled in September 2016 (Figure 4-2). The 100 N SPRINGS 8-13 sample location is north of the strontium-90 plume extent and concentrations in the sample were below the minimum detectable activity for strontium-90. 100 N SPRINGS 089-1 is located on the shoreline near aquifer tube N116mArray-4A, and strontium-90 concentration in the seep sample was 51.9 pCi/L.

4.2.2 Total Petroleum Hydrocarbon-Diesel

The primary source of the TPH-D groundwater contamination was a 1966 diesel fuel tank spill (UPR-100-N-17) (Figure 4-14). A small, relatively narrow groundwater plume persists downgradient from the spill location to the river. The two highest concentrations of TPH-D in 2016 were detected in wells 199-N-18 and 199-N-172 at concentrations of 17,200 µg/L and 16,600 µg/L, respectively. The current highest detected TPH-D concentrations at 100-N is lower than the 2011 and 2010 maximum concentrations (well 199-N-18) of 48,000 and 420,000 µg/L, respectively. Well 199-N-18 is being used for removal of TPH-D free product (Section 4.4.2) and was last sampled in 2011 after installation of the replacement well 199-N-183. Grab samples were collected from well 199-N-18 in 2016 to observe if TPH-D concentrations had substantially decreased as a result of product removal from the well.

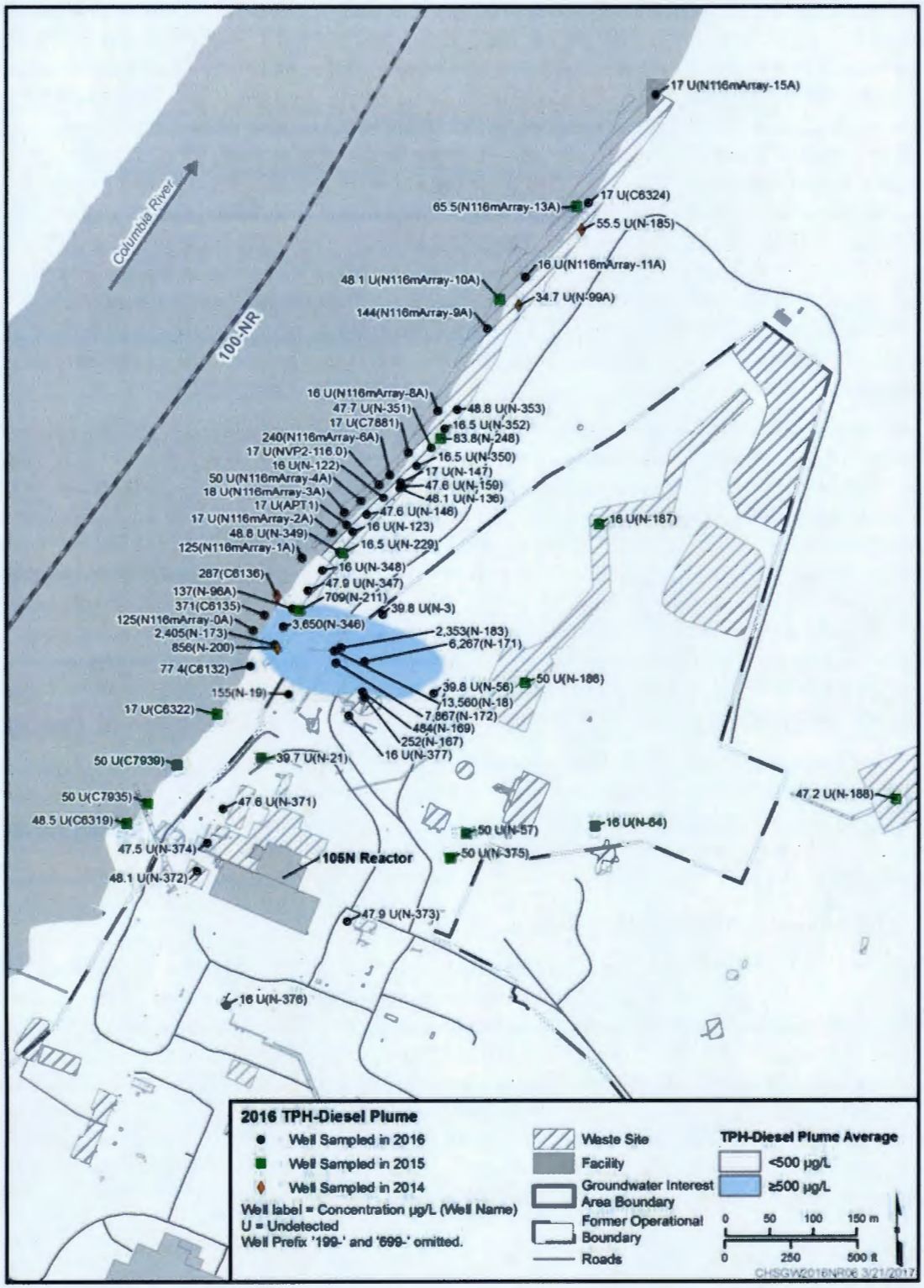


Figure 4-14. TPH-D Plume Map for the 100-N Area, 2016

The overall reduction in TPH-D concentrations in 2012 through 2016 is attributed primarily to the bioventing remediation being conducted for remediation of diesel in the deep vadose zone at UPR-100-N-17. The bioventing pilot test was conducted in 2010 and 2011 (WCH-490, *UPR-100-N-17; Bioventing Pilot Plant Performance Report*), and the full-scale bioventing remediation was initiated in 2012 (Appendix H of DOE/RL-2005-93, *Remedial Design Report/Remedial Action Work Plan for the 100-N Area*) (Section 4.4.1). Introduction of large amounts of air into the vadose zone injection wells contributes to an increased rate of diesel biodegradation and possible reduction in the residual flux to the aquifer. Continued monitoring will indicate whether a long-term groundwater concentration decrease has occurred.

TPH-D is also detected in three aquifer tubes located on the river shore immediately adjacent and downgradient of the TPH-D plume in groundwater. In 2016, a maximum concentration of 371 µg/L was detected in aquifer tube C6135. This is a decrease from the 2015 maximum concentration (800 µg/L at N116mArray-0A). River shore seep 100 N SPRINGS 089-1 was sampled in September 2016 for TPH. The TPH concentration was less than 100 µg/L in this seep sample.

The data used to prepare the 2016 TPH plume map include routine groundwater monitoring data and monitoring data for the in situ bioventing project. In 2016, the in situ bioventing project collected groundwater performance monitoring data in February 2016 and July 2016, at high and low water table.

The performance monitoring results quantified petroleum contamination in the diesel to motor oil range (C10 through C36). Routine groundwater samples for TPH-D monitoring were also collected in September. The routine monitoring program analyzes diesel/Bunker C range only (C10 through C28). The extent of the petroleum plumes using April to July and September to December performance monitoring results are shown in Figures 4-15 and 4-16 and are similar in extent to the annual average TPH-D plume (Figure 4-14).

4.3 Strontium-90 Remediation

During 2016, the 311 m (1,020 ft) long apatite PRB continued to reduce the flux of strontium-90 contamination in the 100-NR-2 OU groundwater along the majority of the apatite PRB in accordance with the amended interim action ROD (EPA, 2010). Performance monitoring indicated two locations in the apatite PRB with decreased performance that started in 2015 and continued in 2016 (Section 4.3.1).

The apatite PRB was formed by injecting a high-concentration calcium-citrate-phosphate solution into the aquifer through a network of vertical wells (i.e., the barrier well network). After the solution is injected, biodegradation of the citrate results in formation of apatite, a calcium phosphate mineral ($Ca_5[PO_4]_3[F, Cl, OH]$). Strontium ions (including strontium-90) in groundwater substitute for calcium ions in apatite via cation exchange and eventually become trapped as part of the mineral matrix during apatite crystallization (PNNL-16891, Section 1.3). The strontium-90 is sequestered within the apatite PRB as contaminant-laden groundwater flows through the barrier. The sequestered strontium-90 continues to decay in place within the barrier.

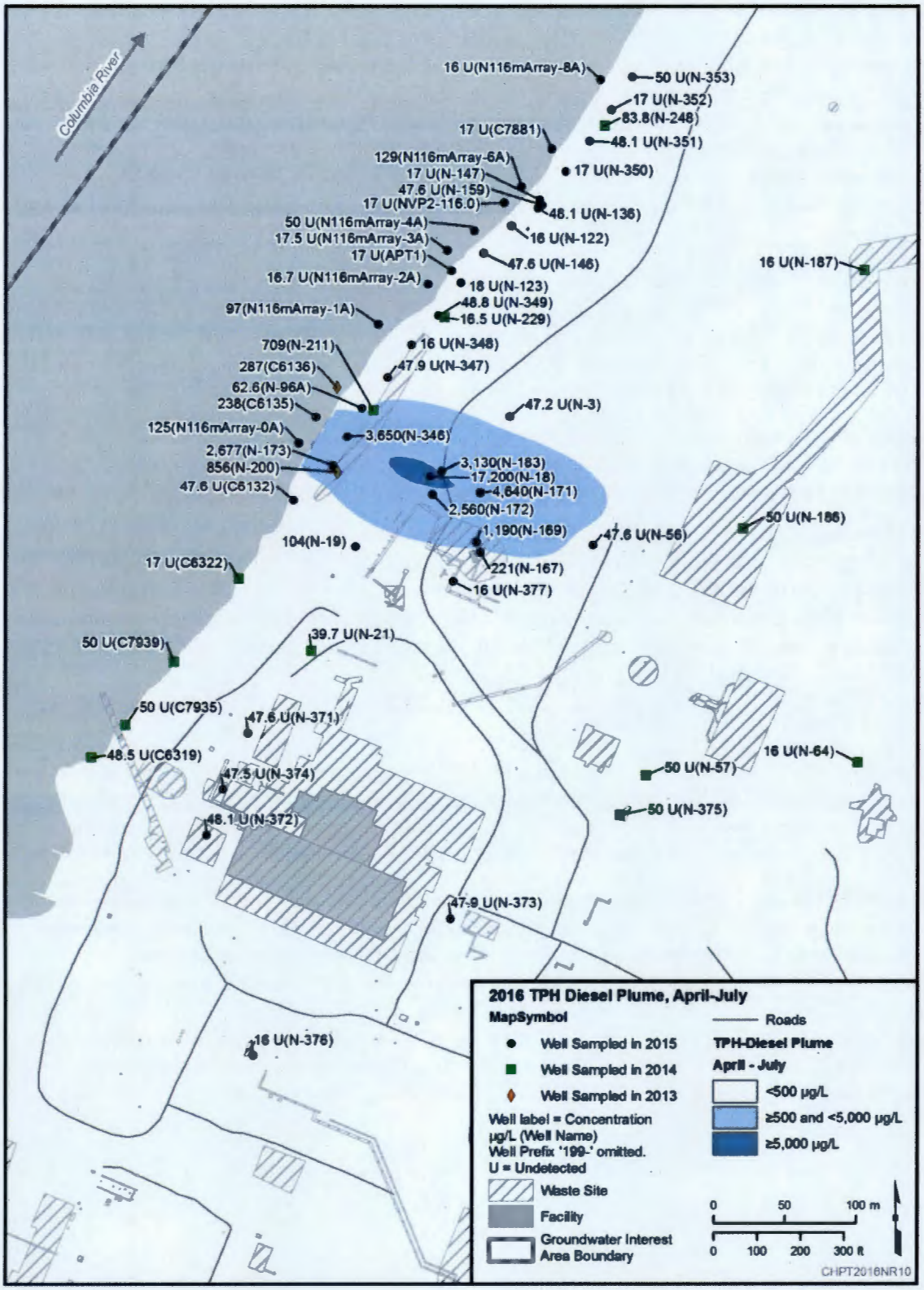


Figure 4-15. TPH-D and TPH Motor Oil Plume Map, Spring/Summer 2016

Figure 4-16. TPH-D and TPH Motor Oil Plume Map, Fall 2016

4.3.1 Permeable Reactive Barrier Performance Evaluation

Groundwater samples were collected from performance monitoring wells and aquifer tubes during moderately high river stage in June and during low river stage in September. Table 4-3 compares spring and fall 2016 data to pre-treatment baseline conditions. Table 4-4 lists the monitoring points for the 760 m (2,500 ft) long apatite barrier and indicates which points are being used to monitor the three treated segments of the barrier. Table 4-5 lists the injection wells for the 760 m (2,500 ft) long barrier and indicates which sections have been treated as of 2016.

The central (original) segment of the apatite PRB extends 91 m (300 ft) along the Columbia River shoreline (Figure 4-4). Sixteen injection wells comprise the PRB well network in the central segment, and four performance monitoring wells are located between the river and the barrier wells (Table 4-5). Apatite-forming solutions were injected into the Hanford formation and Ringold Formation over a period of 3 years (from 2006 through 2008).

The 110 m (360 ft) long upriver and downriver segments of the apatite barrier were injected with apatite solutions in fall 2011 (Figures 4-3 and 4-5). The barrier well networks in each of these segments consist of 24 injection wells (Table 4-5). The apatite barrier extensions increased the length of 100-N Area shoreline treated to sequester strontium-90 from 91 to 311 m (300 to 1,020 ft) (SGW-56970). The barrier was expanded in accordance with the design optimization study (DOE/RL-2010-29), which had seven objectives for evaluating barrier implementation and effectiveness. Data from the injections and subsequent performance monitoring are used to evaluate these objectives in SGW-56970.

The original apatite PRB segment has been in place for 8 years, and the upriver and downriver extensions have been in place for 5 years. The objective of the treatability test plan was a 90 percent reduction in strontium-90 groundwater concentrations in the performance monitoring wells (DOE/RL-2005-96, Section 4.4.3).

The interim action RDR/RAWP presents a decision flow diagram (included as Figure 4-17 in this report) for evaluating if reinjection of apatite-forming chemicals should be considered based on PRB performance. The PRB performance is based on measurements collected from the PRB monitoring wells listed in Table 4-4. The aquifer tubes listed in Table 4-4 are used to support evaluating PRB performance trends, but are not used in assessing PRB performance to achieve the remedial objective target since they are not constructed as resource protection wells (as specified in WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells"). Based on the decision flow logic presented in Figure 4-17, a qualitative assessment for performance of the treated PRB segments are displayed in figures in Sections 4.3.1.1 through 4.3.1.3, using colored circles at each injection well location. The color fill of each circle represents the design injection radius (9 m [30 ft]) to depict the following assessment:

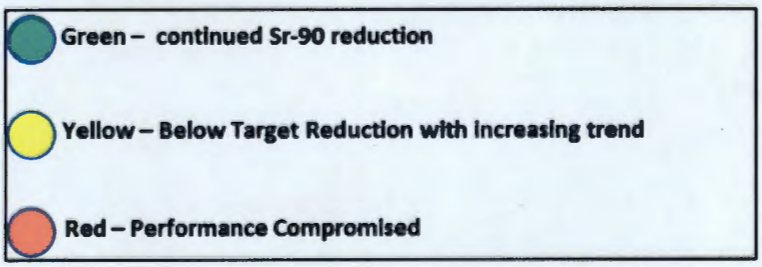


Table 4-3. Performance Monitoring at the Apatite PRB, 100-NR-2 OU

Well Name	Number of Baseline Samples	Number of Baseline Nondetects	Strontium-90 Concentration (pCi/L)				Percent Reduction in Strontium-90 (Baseline Maximum to 2016)[c]	
			Minimum Detected Baseline	Maximum Baseline	Spring 2016[a]	Fall 2016[b]		
Upriver Apatite Permeable Reactive Barrier								
			04/06/10		June 2016	Sept 2016	Spring	Fall
199-N-96A	56	8	1.54[d]	37.9[d]	1.02	7.15	97	81
199-N-347	1	1	7[e]	7[e]	4.99	4.59	29	34
199-N-348	1	0	1,800	1,800	57.8	93.2	97	95
199-N-349	2	0	220	230	61.6	118	73	49
Central (Original) Apatite Permeable Reactive Barrier								
(See footnote f)			(See footnote g)		June 2016	Sept 2016	Spring	Fall
199-N-122	10	0	657	4,630	585	1,580	87	66
199-N-146	4	0	318	985	177	286	82	71
199-N-147	3	0	522	1,842	177	226	87	88
199-N-123	6	0	689	1,180	133	119	89	90
Downriver Apatite Permeable Reactive Barrier								
			07/28/10 and 07/29/10		June 2016	Sept 2016	Spring	Fall
199-N-350	1	0	240	240	72.8	82.9	70	65
199-N-351	1	0	350	350	221	555	37	0
199-N-352	1	0	580	580	165	1,200	72	0

Table 4-3. Performance Monitoring at the Apatite PRB, 100-NR-2 OU

Well Name	Number of Baseline Samples	Number of Baseline Nondetects	Strontium-90 Concentration (pCi/L)				Percent Reduction in Strontium-90 (Baseline Maximum to 2016)[c]	
			Minimum Detected Baseline	Maximum Baseline	Spring 2016[a]	Fall 2016[b]		
199-N-353	1	0	83	83	3.34	73.7	96	11

a. Spring 2016 samples were collected from June 19 through July 5.

b. Fall 2016 samples were collected from September 16 through September 26.

c. The percentage reduction in strontium-90 concentration is calculated as: (([baseline value] – [2016 value])/[baseline value]) × 100. Maximum baseline value used for comparison.

d. Between 1995 and 2011, the maximum baseline was measured on 12/06/1995; the minimum detected baseline was measured on 06/13/2006 and 06/22/2007.

e. Strontium-90 is a beta emitter. Gross beta concentrations are approximately two times the strontium-90 concentrations (PNNL-17429, *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization*). The strontium-90 concentration was 1.1 U pCi/L. The gross beta concentration, 14 pCi/L, was divided by two to approximate the strontium-90 concentration of 7 pCi/L.

f. From Table 8.1 in PNNL-17429.

g. From Table 4.1 in PNNL-19572, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization*.

Table 4-4. Apatite PRB Performance Monitoring Wells and Aquifer Tubes

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			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

Table 4-4. Apatite PRB Performance Monitoring Wells and Aquifer Tubes

Well Name/ID	Well Type	Well Name/ID	Well Type	Well Name/ID	Well Type
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		

Note: Yellow shading indicates locations currently being monitored for treated portion of barrier.

*Aquifer tube N116mArray-7A was monitored from June 2006 through September 2009. The aquifer tube became unusable in 2009 and was replaced with C7881at the same location.

AT = aquifer tube
ID = identification
MW = monitoring well (6 in.)

Table 4-5. Apatite PRB Injection Wells

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

Table 4-5. Apatite PRB Injection Wells

Well Name/ID	Depth	Well Name/ID	Depth	Well ID	Depth	Well Name/ID	Depth
199-N-219/C7308	Deep; core	199-N-163/C6181	Deep	199-N-247/C7340	Shallow	199-N-269/C7362	Shallow
199-N-220/C7307	Shallow; core	199-N-143/C5049	Shallow, deep	199-N-248/C7341	Deep	199-N-270/C7363	Deep
199-N-221/C7306	Deep	199-N-162/C6180	Deep	199-N-249/C7342	Shallow	199-N-271/C7364	Shallow
199-N-272/C7365	Deep	199-N-291/C7384	Shallow	199-N-310/C7403	Deep	199-N-329/C7422	Shallow
199-N-273/C7366	Shallow	199-N-292/C7385	Deep	199-N-311/C7404	Shallow	199-N-330/C7423	Deep
199-N-274/C7367	Deep	199-N-293/C7386	Shallow	199-N-312/C7405	Deep	199-N-331/C7424	Shallow
199-N-275/C7368	Shallow	199-N-294/C7387	Deep	199-N-313/C7406	Shallow	199-N-332/C7425	Deep
199-N-276/C7369	Deep	199-N-295/C7388	Shallow	199-N-314/C7407	Deep	199-N-333/C7426	Shallow
199-N-277/C7370	Shallow	199-N-296/C7389	Deep	199-N-315/C7408	Shallow	199-N-334/C7427	Deep
199-N-278/C7371	Deep	199-N-297/C7390	Shallow	199-N-316/C7409	Deep	199-N-335/C7428	Shallow
199-N-279/C7372	Shallow	199-N-298/C7391	Deep	199-N-317/C7410	Shallow	199-N-336/C7429	Deep
199-N-280/C7373	Deep	199-N-299/C7392	Shallow	199-N-318/C7411	Deep	199-N-337/C7430	Shallow
199-N-281/C7374	Shallow	199-N-300/C7393	Deep	199-N-319/C7412	Shallow	199-N-338/C7431	Deep
199-N-282/C7375	Deep	199-N-301/C7394	Shallow	199-N-320/C7413	Deep	199-N-339/C7432	Shallow
199-N-283/C7376	Shallow	199-N-302/C7395	Deep	199-N-321/C7414	Shallow	199-N-340/C7433	Deep
199-N-284/C7377	Deep	199-N-303/C7396	Shallow	199-N-322/C7415	Deep	199-N-341/C7434	Shallow
199-N-285/C7378	Shallow	199-N-304/C7397	Deep	199-N-323/C7416	Shallow	199-N-342/C7435	Deep
199-N-286/C7379	Deep	199-N-305/C7398	Shallow	199-N-324/C7417	Deep	199-N-343/C7436	Shallow
199-N-287/C7380	Shallow	199-N-306/C7399	Deep	199-N-325/C7418	Shallow	199-N-344/C7437	Deep

Table 4-5. Apatite PRB Injection Wells

Well Name/ID	Depth	Well Name/ID	Depth	Well ID	Depth	Well Name/ID	Depth
199-N-288/C7381	Deep	199-N-307/C7400	Shallow	199-N-326/C7419	Deep	199-N-345/C7438	Shallow
199-N-289/C7382	Shallow	199-N-308/C7401	Deep	199-N-327/C7420	Shallow		
199-N-290/C7383	Deep	199-N-309/C7402	Shallow	199-N-328/C7421	Deep		

Notes: "Core" indicates that a core was taken at this well for jet injection study (2010).

Blue shading indicates downriver barrier extension wells treated in September 2011.

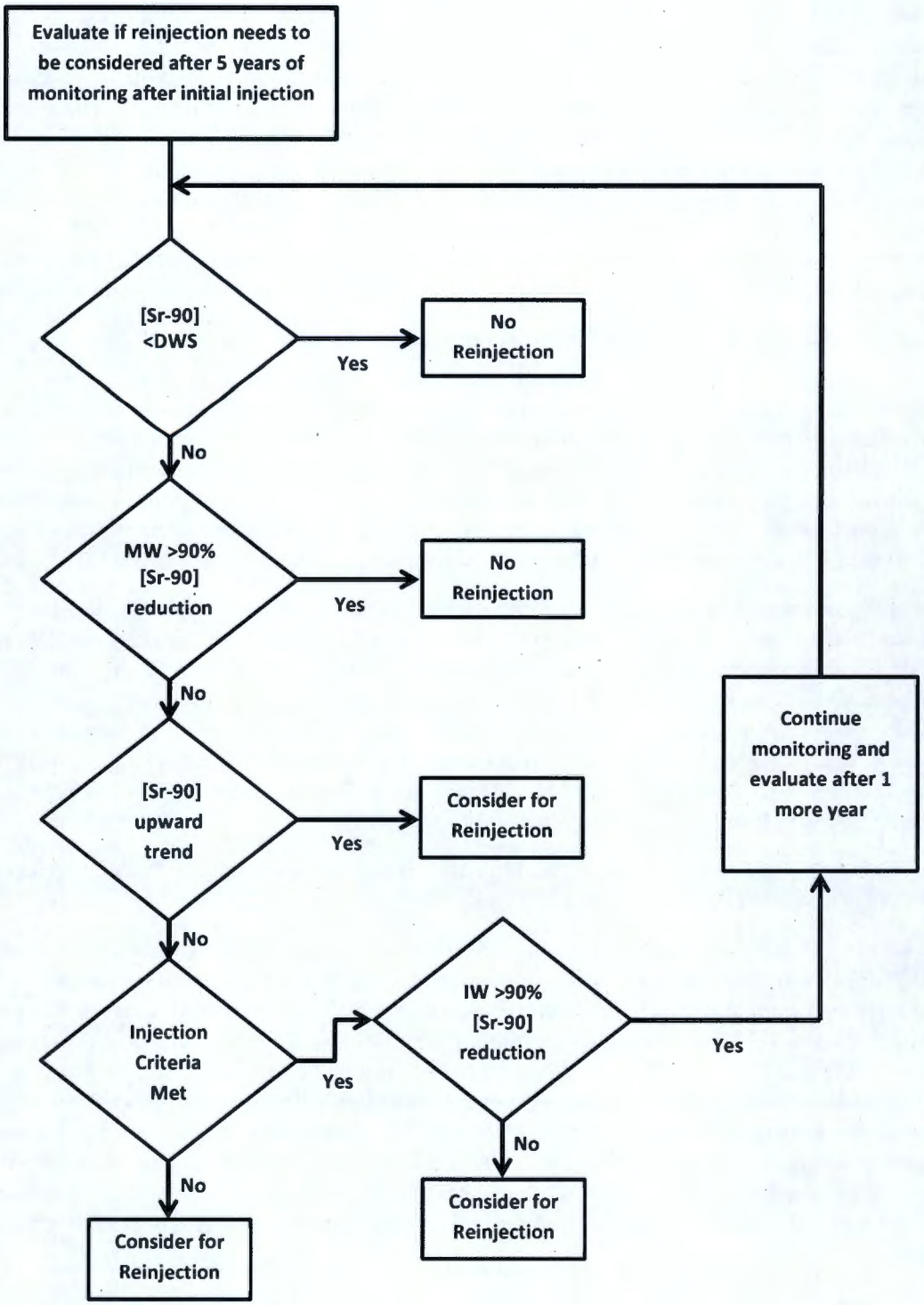
Green shading indicates original barrier wells treated in 2006 through 2008.

Pink shading indicates upriver barrier extension wells treated in September 2011.

No shading indicates that wells are not treated yet.

Wells identified with Shallow depth are screened in the upper region (typically about 2 m [6 ft]) of the unconfined aquifer; wells identified with Deep depth are screened below the shallow wells (typical screen length of 2.5 m (8 ft) about 0.6 m (2 ft) below the depth of shallow screened wells; wells identified with Shallow, deep depths are screened across both the shallow and deep depths.

ID = identification



DWS = drinking water standard
IW = injection well
MW = monitoring well

Figure 4-17. Reinjection Decision Flow Diagram

Green color fill indicates strontium-90 concentrations at the monitoring well meets the target strontium-90 reduction, is less that the DWS, or that continued strontium-90 reduction is observed with stable or decreasing trend. Yellow color fill indicates the calculated strontium-90 reduction does not meet the target strontium-90 reduction and there is an increasing strontium-90 concentration trend at the monitoring well. Red color fill indicates the calculated strontium-90 reduction does not meet the target strontium-90 reduction, there is an increasing strontium-90 concentration trend at the monitoring well, and the injection criteria were not met. Injection criteria includes meeting target injection volumes and phosphate concentrations, and radial distribution of amendment identified in DOE/RL-2010-29. Performance evaluation will continue with ongoing semiannual performance monitoring (high and low river stages) to assess the continued effectiveness of the apatite treatment along the expanded barrier.

4.3.1.1 Original Permeable Reactive Barrier Segment Performance

Following the apatite injections in 2008 in wells in the central (original) segment of the barrier, strontium-90 concentrations declined in the performance monitoring wells (Figure 4-18). The wells showed temporary, higher strontium-90 concentrations immediately following injection of the apatite solution, which had a higher ionic strength than groundwater and temporarily mobilized cations and anions, causing their concentrations in groundwater to increase. Strontium-90 concentrations in performance monitoring well 199-N-123, which are near the upriver end of the central barrier segment, temporarily increased again following injections into the nearby upriver barrier extension wells in 2011 (Figure 4-18).

Strontium-90 concentrations at well 199-N-122 have been trending upwards (Figure 4-18). The fluctuation in strontium-90 concentration depicted in Figure 4-18 is associated with high and low river sampling periods where concentration tend to be lower during high river stage, indicating some dilution from river water with the samples. As of fall 2016, the strontium-90 concentrations were still considerably lower in the performance monitoring wells along the central segment of the barrier than before the injections started in 2006. The percent reduction in strontium-90 concentrations ranged from 82 percent (199-N-146) to 89 percent (199-N-123) in spring 2016 and 66 percent (199-N-122) to 90 percent (199-N-123) in fall 2016 (Table 4-3 and Figure 4-19).

Aquifer tubes monitored downgradient of the original PRB segment also continue to show decreased concentrations from pre-injection strontium-90 concentrations (Figure 4-20).

Tables 4-6 and 4-7 provide the percent reduction in strontium-90 concentrations since 2011 for the original PRB segment monitoring wells and aquifer tubes, respectively. Concentrations in three of the original PRB segment monitoring wells continue to be near the 90 percent reduction target. The percent reduction in strontium-90 concentration at monitoring well 199-N-122 was 87 percent in the spring and 66 percent in the fall. This monitoring well has the highest baseline strontium-90 concentration of the PRB monitoring wells at 4,630 pCi/L. Three injection wells (199-N-161, 199-N-144, and 199-N-163) did not meet one or more of the injection criteria (PNNL-19572). The assessment indicates that the portion of the original PRB segment near monitoring well 199-N-122 is colored yellow (i.e., below target reduction with an increasing trend) in Figure 4-21 and should continue to be monitored to determine if this area should be reinjected. The remaining length of the upriver PRB segment continues to provide strontium-90 reduction.

The aquifer tubes downgradient from the original PRB segment continue to show strontium-90 reduction and stable trends, except for NVP2-116.0 which is trending upward. Aquifer tube NVP2-116.0 is located downgradient of monitoring well 199-N-122. The assessment indicates the original PRB segment continues to provide strontium-90 reduction, but trends at 199-N-122 and NVP2-116.0 indicate performance of the PRB in this area may declining. (Figure 4-21).

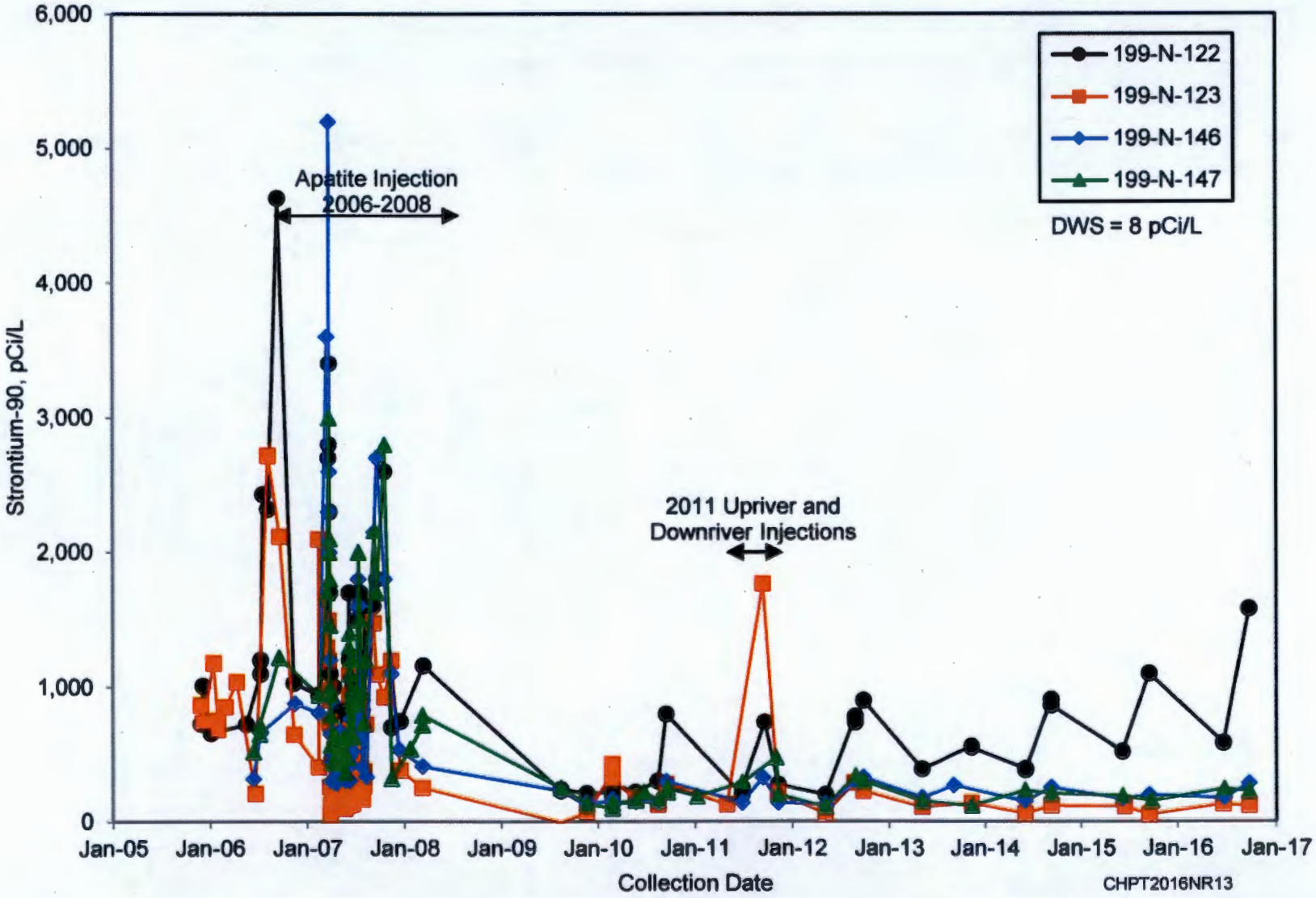


Figure 4-18. Strontium-90 Data for Performance Monitoring Wells along the Central Segment of the Apatite PRB

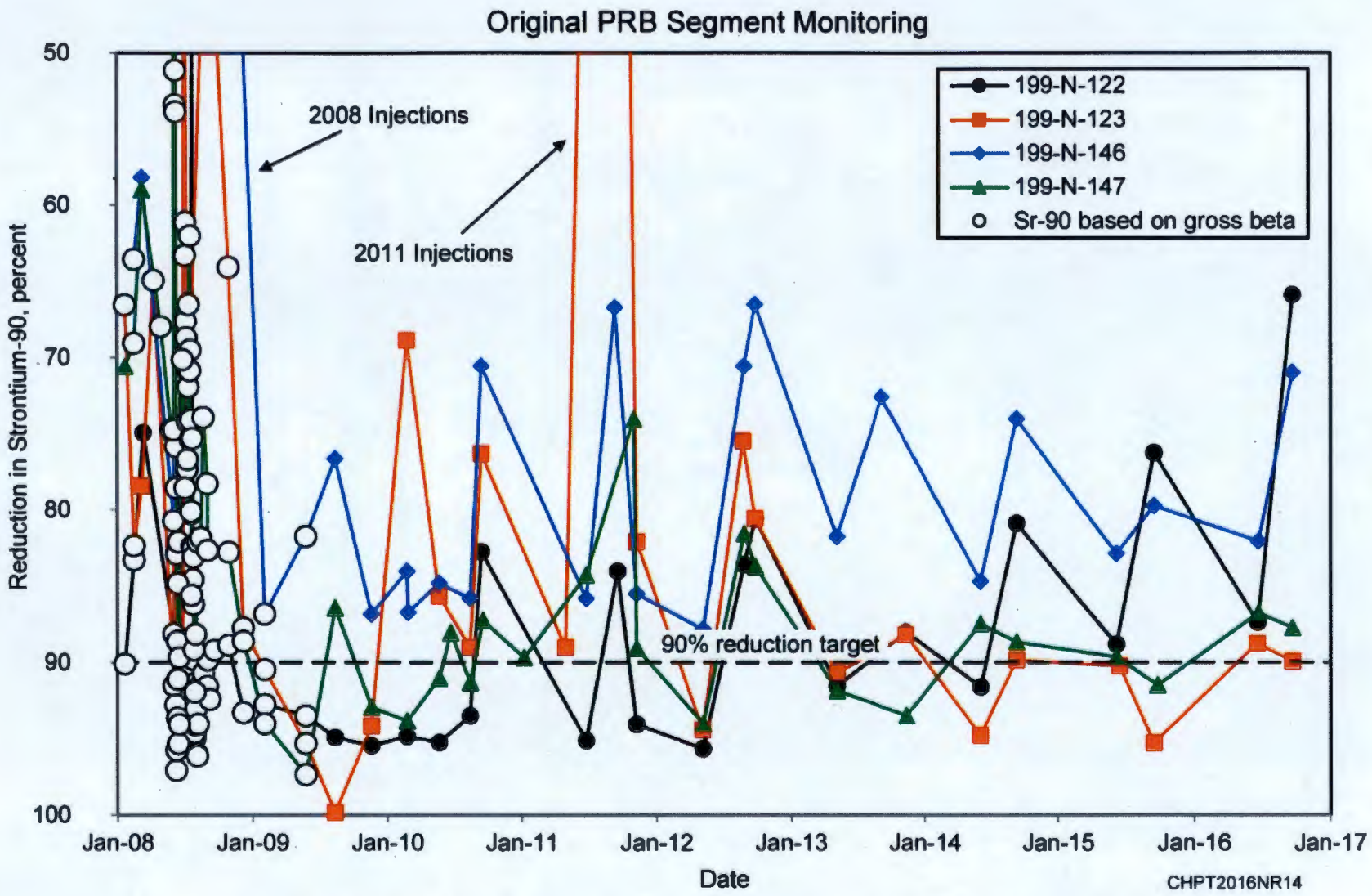


Figure 4-19. Original Apatite Performance Monitoring Wells Percent Strontium-90 Reductions, 2016

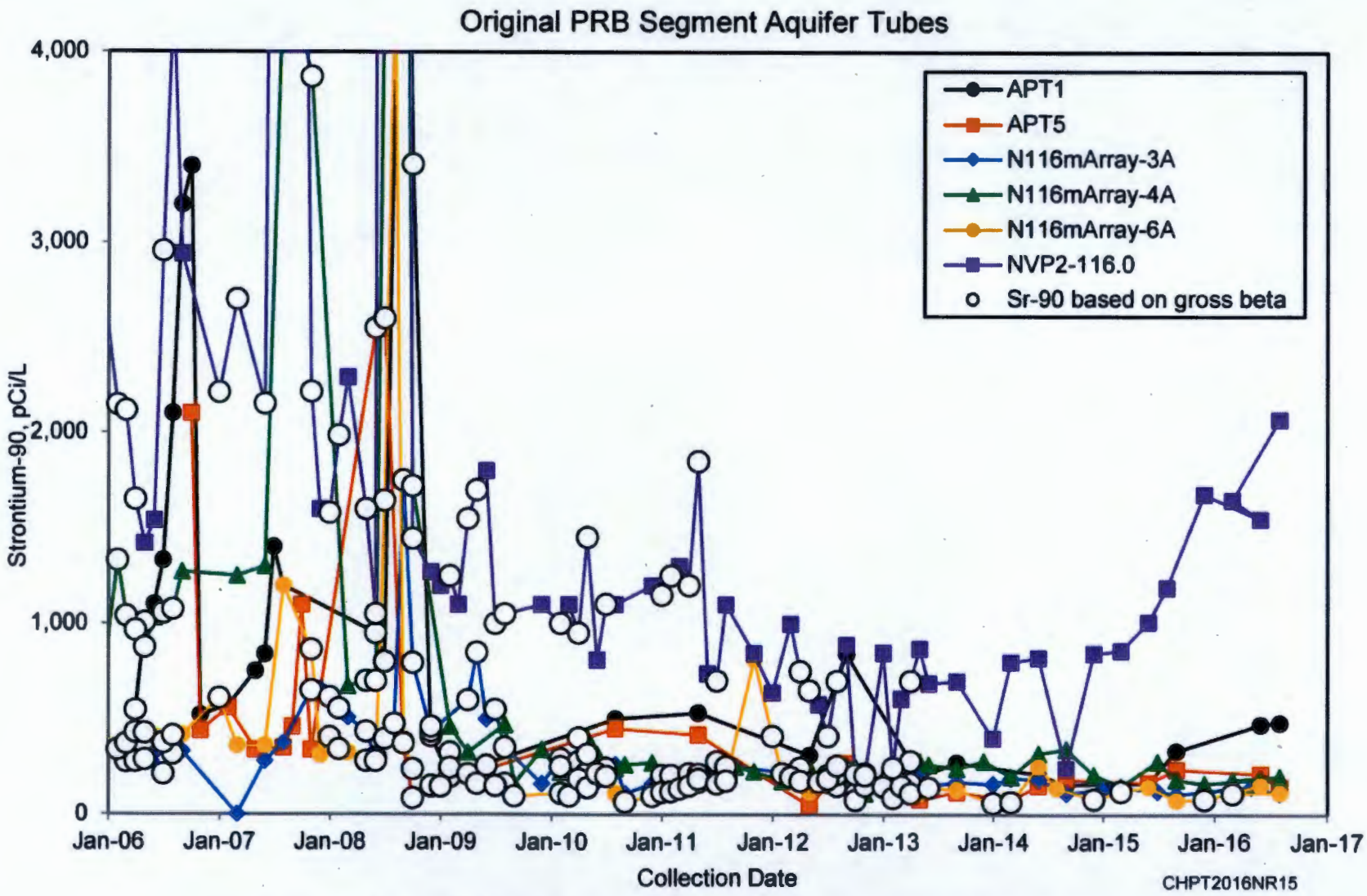


Figure 4-20. Strontium-90 Data for Aquifer Tubes along the Central Segment of the Apatite PRB

Table 4-6. PRB Monitoring Well 2011 - 2016 Performance Summary

Monitoring Well	Pre-injection Baseline[a]	Mo-Yr Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])					
			2011	2012	2013	2014	2015	2016
Upriver Apatite Permeable Reactive Barrier (Treated 2011)								
199-N-96A	37.9	Sep 2011	--[c]	2.3 (94%)	4.1 (89%)	1.6 (96%)	3.8 (90%)	3.04 (92%)
199-N-347	7[d]	Sep 2011	--[c]	7.8 (-12%)	6.9 (1.4%)	5.1 (27%)	4.7 (33%)	4.8 (32%)
199-N-348	1,800	Sep 2011	--[c]	54 (97%)	34 (98%)	35 (98%)	71 (96%)	76 (96%)
199-N-349	230	Sep 2011	--[c]	37 (84%)	46 (80%)	87 (62%)	111 (52%)	90 (61%)
Central (Original) Apatite Permeable Reactive Barrier (Treated 2006-2008)								
199-N-122	4,630	Jul 2008	366 (93%)	656 (86%)	472 (90%)	637 (86%)	809 (82%)	1,083 (77%)
199-N-146	985	Jul 2008	204 (79%)	215 (78%)	225 (77%)	204 (79%)	184 (81%)	232 (77%)
199-N-147	1,842	Jul 2008	272 (85%)	250 (86%)	135 (93%)	230 (88%)	174 (90%)	235 (87%)
199-N-123	1,180	Jul 2008	704 (40%)[e]	204 (83%)	125 (89%)	91 (92%)	96 (92%)	126 (89%)
Downriver Apatite Permeable Reactive Barrier (Treated 2011)								
199-N-350	240	Sep 2011	--[c]	34 (86%)	21 (91%)	27 (89%)	76 (68%)	78 (68%)
199-N-351	350	Sep 2011	--[c]	26 (93%)	39 (89%)	95 (73%)	376 (-7%)	388 (-11%)
199-N-352	580	Sep 2011	--[c]	30 (95%)	29 (95%)	42 (93%)	368 (37%)	683 (-17%)
199-N-353	83	Sep 2011	--[c]	5.0 (94%)	3.2 (96%)	4.0 (95%)	7.3 (91%)	39 (54%)

a. Pre-injection baseline concentrations for the upriver and downriver PRB monitoring wells area based on samples collected in 2010. Pre-injection baseline concentrations for the central PRB monitoring wells are from Table 4.1 in PNNL-19572, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization*.

b. The percentage reduction in strontium-90 concentration is calculated as ([pre-injection value] – [average value for the year] / [pre-injection value]) × 100.

c. Injections were performed in September 2011 so no performance calculated for this year.

d. Strontium-90 is a beta emitter. Gross-beta concentrations are approximately two times the strontium-90 concentrations. The strontium-90 concentration was 1.1 pCi/L (U). The gross beta concentration, 14 pCi/L, was divided by two to approximate the strontium-90 concentration of 7 pCi/L.

e. Increase in strontium-90 concentrations observed at monitoring well 199-N-123 in 2011 is attributed to injection treatment of the upriver segment in September 2011.

PRB = permeable reactive barrier

Table 4-7. PRB Aquifer Tube 2011 - 2016 Performance Summary

Aquifer Tube	Pre-injection Baseline[a]	Mo-Yr Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])					
			2011	2012	2013	2014	2015	2016
Upriver Apatite Permeable Reactive Barrier (Treated 2011)								
C6135[c]	2.3	Sep 2011	1.5 (33%)	2.8 (0%)	--[d]	--[d]	--[d]	--[d]
N116mArray-1A	34	Sep 2011	94 (0)[e]	162 (0)[e]	50 (0%)[e]	2.1 (94%)	1.9 (94%)	2.2[g] (87%)
N116mArray-2A	199	Sep 2011	244 (0%)[e]	29 (85%)	16 (92%)	16 (92%)	17 (92%)	18 (93%)
Central (Original) Apatite Permeable Reactive Barrier (Treated 2006-2008)								
APT-1	1,454	Jul 2008	530 (64%)	575 (60%)	235 (84%)	184 (87%)	276 (81%)	476 (67%)
APT-5	420	Jul 2008	420 (3%)	196 (55%)	97 (78%)	149 (66%)	202 (53%)	182 (57%)
N116mArray-3A	379	Jul 2008	185 (52%)	202 (47%)	185 (52%)	162 (58%)	125 (67%)	132 (65%)
N116mArray-4A	1,220	Jul 2008	230 (81%)	207 (83%)	215 (82%)	245 (80%)	202 (83%)	180 (85%)
N116mArray-6A	445	Jul 2008	203 (54%)	205 (54%)	126 (72%)	119 (73%)	106 (76%)	135 (72%)
NVP2-116.0	3,466	Jul 2008	1,078 (69%)	588 (83%)	633 (82%)	639 (82%)	1,146 (67%)	1,733 (50%)
Downriver Apatite Permeable Reactive Barrier (Treated 2011)								
N116mArray-7A/C7881[f]	336	Sep 2011	755 (0%)[e]	73 (78%)	32 (91%)	23 (93%)	27 (92%)	36 (89%)
N116mArray-8A	7.8	Sep 2011	8.9 (0%)[e]	2.4 (68%)	1.7 (78%)	1.3 (83%)	1.7 (78%)	1.3 (79%)
N116mArray-8.5A	81	Sep 2011	75 (4%)[e]	85 (0%)	98 (0%)	--[d]	--[d]	--[d]

Table 4-7. PRB Aquifer Tube 2011 - 2016 Performance Summary

Aquifer Tube	Pre-injection Baseline[a]	Mo-Yr Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])					
			2011	2012	2013	2014	2015	2016

a. Pre-injection baseline concentrations are based 95 upper confidence limit of pre-injection strontium-90 and gross beta measurements. Strontium-90 is a beta emitter. Gross-beta concentrations are approximately two times the strontium-90 concentrations. The gross beta concentrations were divided by two to approximate the strontium-90 concentration in determining pre-injection baseline concentrations.

b. The percentage reduction in strontium-90 concentration is calculated as ([pre-injection value] – [average value for the year] / [pre-injection value]) × 100.

c. Concentrations at C6135 are below the DWS (8 pCi/L).

d. Aquifer tube is missing and/or in need of repair and could not be sampled.

e. Increased concentrations at aquifer tube attribute to residual spike from injection treatment.

f. Aquifer tube C7881 is a replacement for N16mArray-7A installed in the same location.

g. Value calculated from gross-beta data (no strontium-90 data available); value listed is one-half of the gross-beta value measured.

DWS = drinking water standard

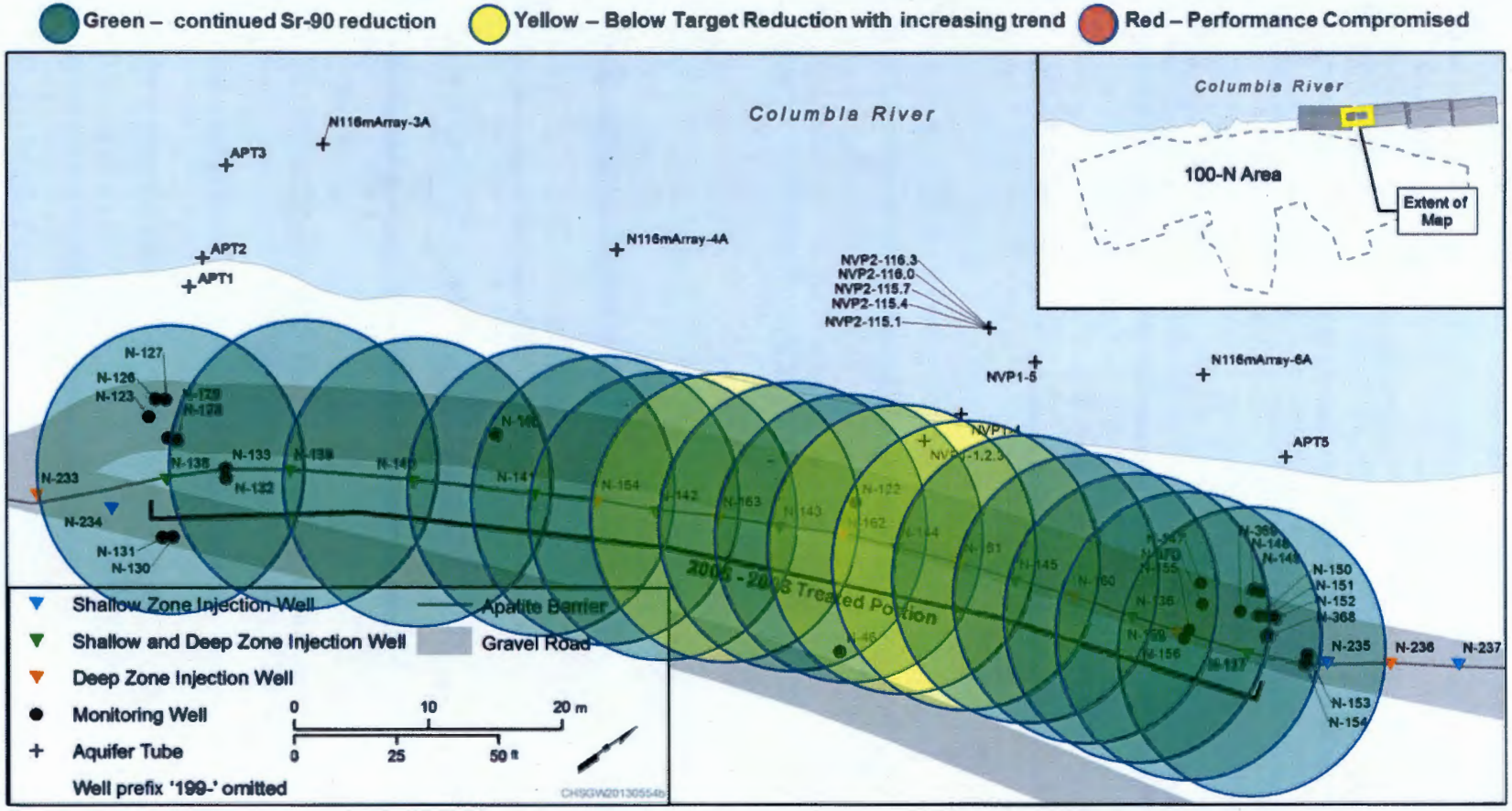


Figure 4-21. Original PRB Segment Performance Assessment for 2016

4.3.1.2 Upriver Permeable Reactive Barrier Segment Performance

In the performance monitoring wells along the upriver barrier extension, the percentage reduction in strontium-90 concentrations in 2016 (the fifth year following the injections) ranged from 34 percent (well 199-N-347) to 95 percent (199-N-348) (Table 4-3 and Figure 4-22) in the fall, and 29 percent (199-N-347) to 97 percent (199-N-96A, and 199-N-348) in the spring. This segment of the barrier forms the furthest upriver portion of the barrier near the outside edge of the strontium-90 groundwater plume. The relatively low percent reduction in 199-N-347 reflects comparison of the low baseline strontium-90 concentration in this well (the strontium-90 concentration was nondetect, and the strontium-90 concentration estimated from gross beta was 7.0 pCi/L) to the low strontium-90 concentration measured during September 2016 performance monitoring (4.6 pCi/L). Both the baseline and the September 2016 sample concentrations are below the DWS (8 pCi/L). Because concentrations in well 199-N-347 are below the DWS, the percent reduction in strontium-90 concentration at this well is not plotted in Figure 4-22. The percentage reduction in strontium-90 concentrations from 2016 low river-stage monitoring for well 199-N-349 was 49 percent (Table 4-3).

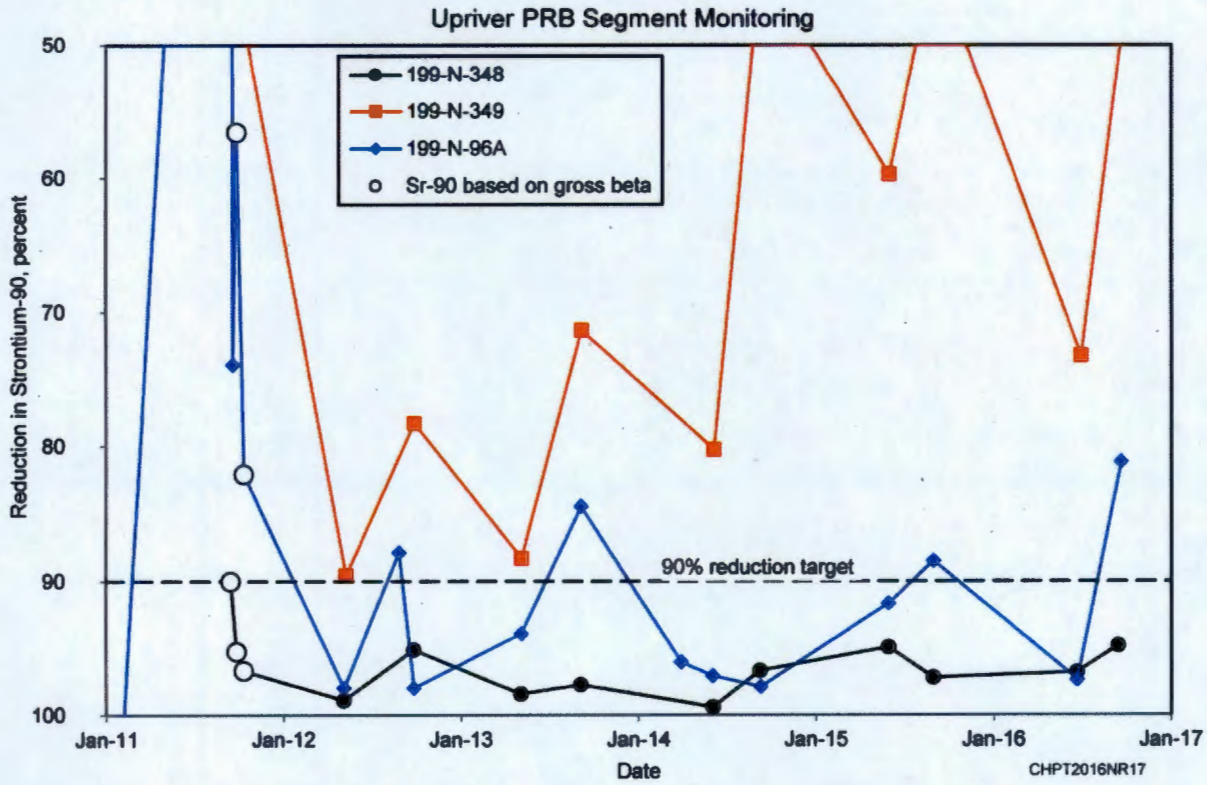


Figure 4-22. Upriver Apatite Barrier Extension Performance Monitoring Wells Percent Strontium-90 Reductions, 2016

The injection volume of apatite chemicals into the injection wells near monitoring well 199-N-349 is provided in Table 4-8. The injection flow rate was not controlled for even flow distribution in all injection wells (SGW-56970) so some wells received greater than 150 percent the target injection volume of 227,000 L (60,000 gal) and others received only about 50 percent of the target injection volume. The large amendment volumes injected in wells upgradient of well 199-N-349 may be an indication of areas of limited radial amendment distribution due to high injection rates.

Table 4-8. Injection Volume in Upriver Injection Wells Near Well 199-N-349

Injection Well	Screen/Formation	Injected Volume (L [gal]) (Percent of Target Volume*)
199-N-225	Deep/Backfill	327,693 (86,511) (144%)
199-N-226	Shallow/Backfill	320,655 (84,653) (141%)
199-N-227	Deep/Backfill	368,818 (97,368) (162%)
199-N-228	Shallow/Ringold	348,163 (91,915) (153%)
199-N-229	Deep/Hanford	567,508 (149,822) (250%)
199-N-230	Shallow/Ringold	90,496 (23,891) (40%)
199-N-231	Deep/Ringold	122,814 (32,423) (54%)

*Target injection volume is 227,000 L (60,000 gal).

Strontium-90 concentration trends for the upriver PRB segment are presented in Figure 4-23. Table 4-6 shows the percentage reduction in strontium-90 concentrations since 2011 for the upriver PRB segment monitoring wells. An increasing strontium-90 concentration trend was observed in 2015 at monitoring well 199-N-349, but has stabilized in 2016. Downgradient aquifer tubes (Figure 4-24) continue to show decreased strontium-90 concentrations (Table 4-7).

Strontium-90 concentrations are below the DWS at monitoring well 199-N-347, and the target strontium-90 reduction is being met at the remaining two monitoring wells. The assessment indicates that the portion of the upriver PRB segment near monitoring well 199-N-349 is colored yellow (i.e., below target reduction with an increasing trend) in Figure 4-25 and should continue to be monitored to determine if this area should be reinjected. The remaining length of the upriver PRB segment continues to provide strontium-90 reduction.

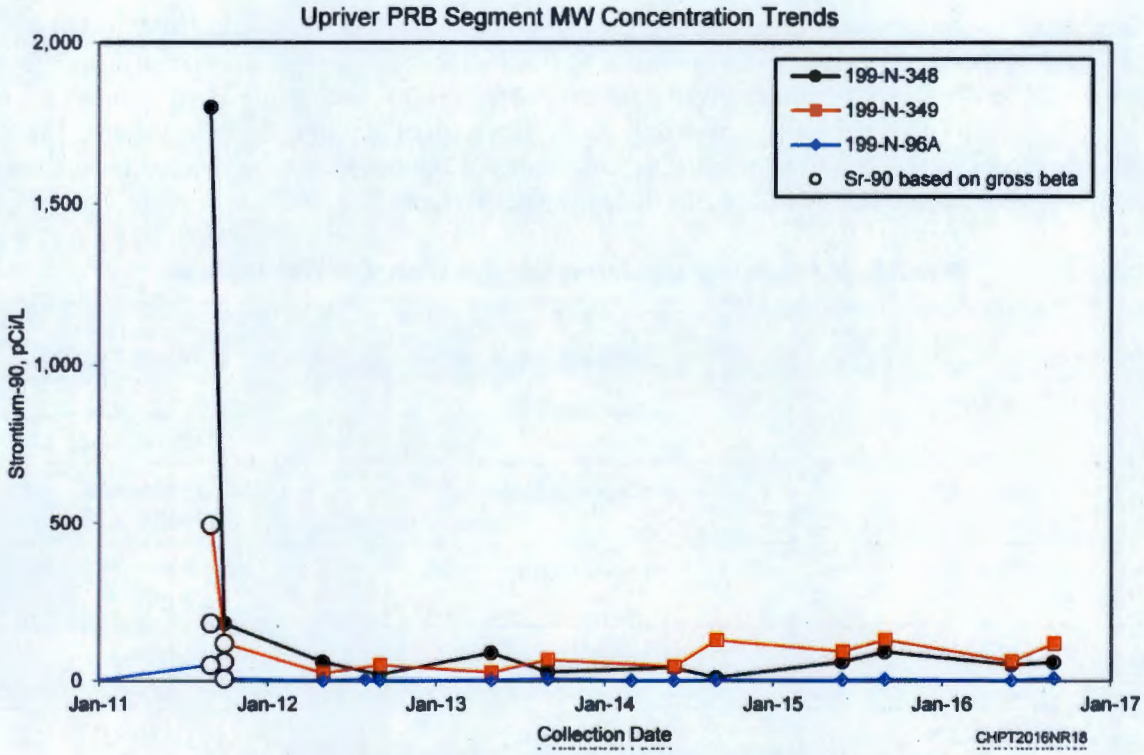


Figure 4-23. Strontium-90 Data for Performance Monitoring Wells along the Upriver Segment of the Apatite PRB

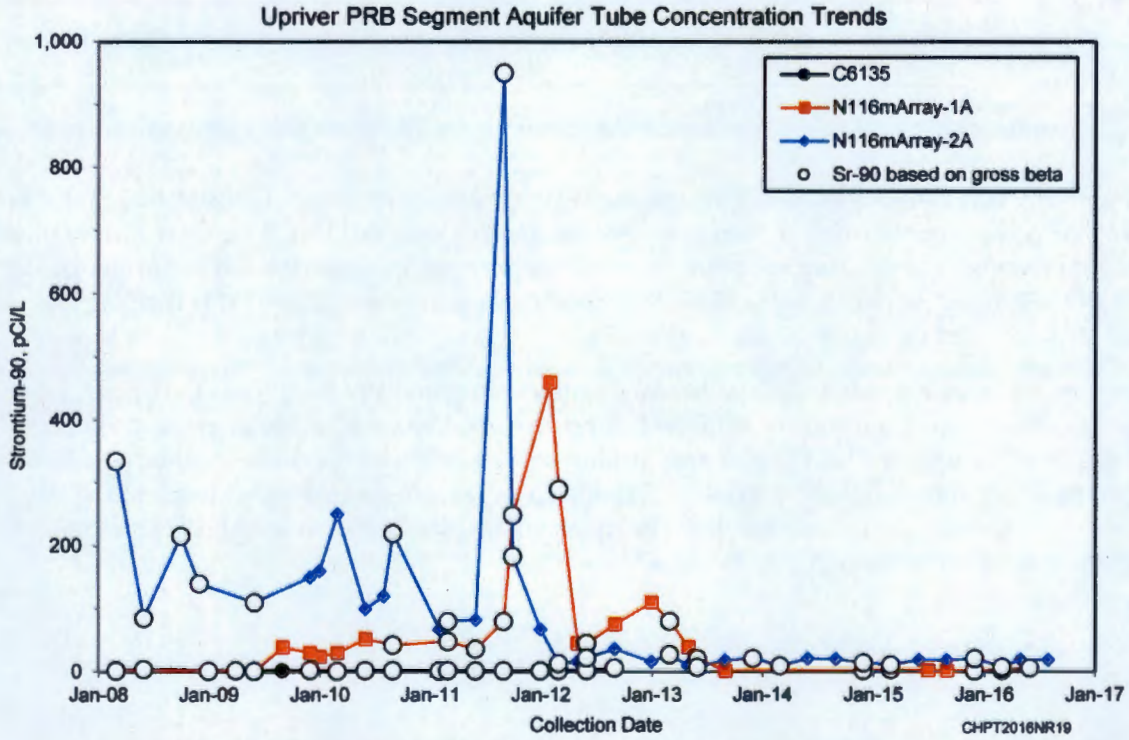


Figure 4-24. Strontium-90 Data for Aquifer Tubes along the Upriver Segment of the Apatite PRB

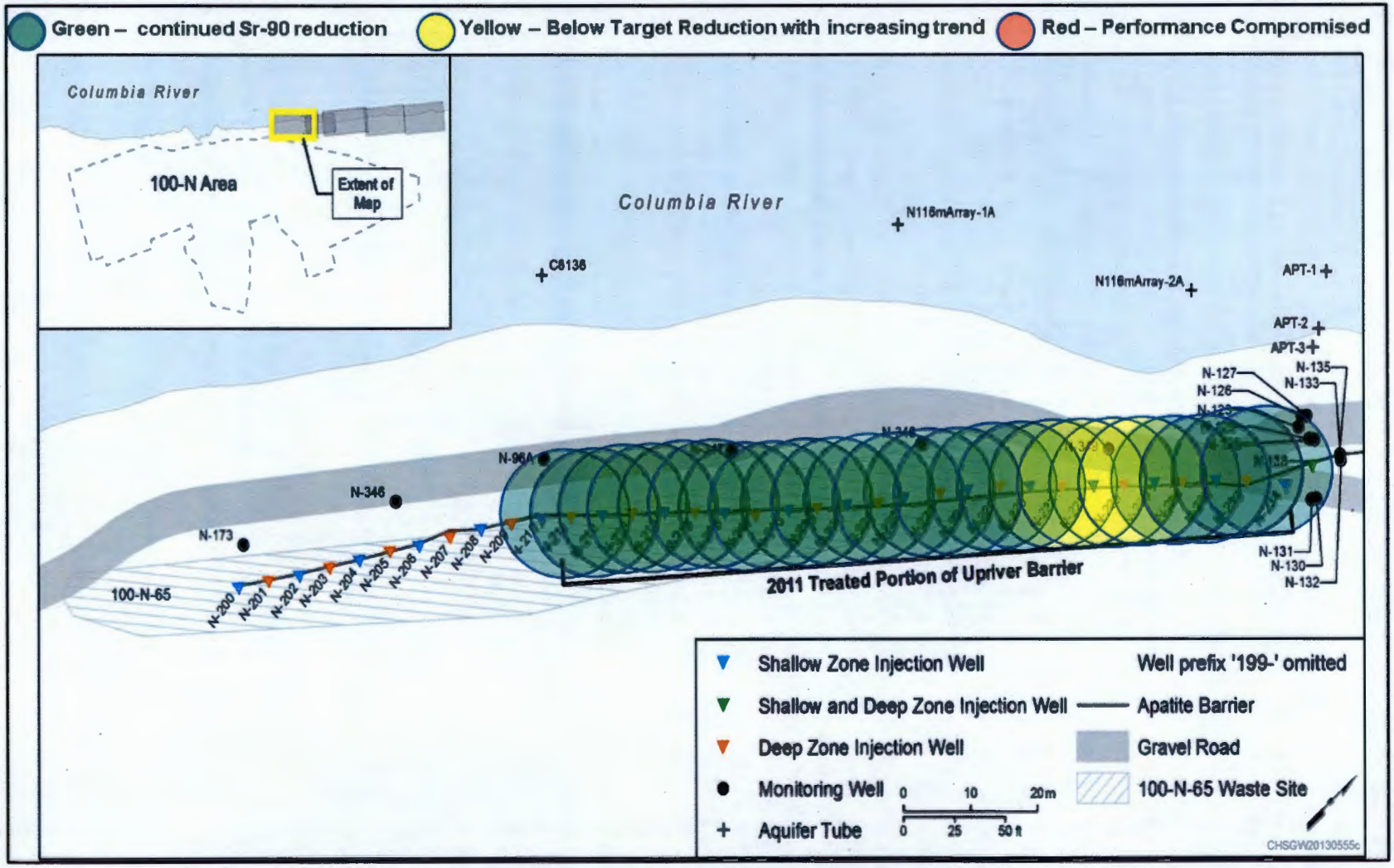


Figure 4-25. Upriver PRB Segment Performance Assessment for 2016

4.3.1.3 Downriver Permeable Reactive Barrier Segment Performance

The downriver extension intercepts higher strontium-90 groundwater concentrations than the upriver extension and had indicated initial successful barrier performance. The percentage reduction in strontium-90 concentrations in 2016 at the performance monitoring wells along the downriver barrier extension ranged from 0 percent (199-N-351 and 199-N-352) to 65 percent (199-N-350) (Table 4-3; Figure 4-26) in the fall, and 37 percent (199-N-351) to 96 percent (199-N-353) in the spring.

Strontium-90 concentration trends for the downriver PRB segment monitoring wells (Figure 4-27) show that strontium-90 concentrations at wells 199-N-351 and 199-N-352 have increased to pre-injection concentrations in 2016 and are increasing at well 199-N-350. Table 4-6 shows the percentage reduction in strontium-90 concentrations since 2011 for the downriver PRB segment monitoring wells. The injection volume of apatite chemicals into the injection wells near the monitoring wells with increasing trends is provided in Table 4-9, and several wells have received less than 30 percent of the target injection volume. Other injection wells received target injection volumes of more than 50 percent above the target injection volumes. The injection flow rate was not controlled for even flow distribution in all injection wells (SGW-56970), contributing to the large contrast in injection volumes that may have resulted in limited radial amendment distribution in these areas of the downriver PRB segment.

Downgradient aquifer tubes for the downriver PRB segment continue to show significant strontium-90 reduction (Table 4-7; Figure 4-28). The assessment indicates that the injection wells treating the portion of the downriver PRB segment monitored by wells 199-N-351 and 199-N-352 and injection wells that received less than 30 percent of the target amendment volume should be considered for reinjection (colored red in Figure 4-29). Other portions of the downriver PRB near well 199-N-350 should continue to be monitored to evaluate if this area should be reinjected. The decrease in strontium-90 reduction between the spring and fall measurements in 2016 at well 199-N-353 (95 percent and 11 percent, respectively, in Table 4-3) is out of trend from prior year measurements. Ongoing monitoring will determine PRB effectiveness at this location.

4.3.1.4 Summary of PRB Performance Evaluation

Table 4-10 summarizes the qualitative PRB performance evaluation for each treated PRB segment. The PRB performance evaluation for 2016 is:

- Total length of treated PRB: 311 m (1,020 ft)
- Green: Continued Sr-90 reduction: 169 m (555 ft)
- Yellow: Below target reduction with increasing trend: 92 m (300 ft)
- Red: Performance compromised: 50 m (165 ft)

4.3.2 Permeable Reactive Barrier Extensions

No additional treatment to expand the PRB occurred in 2016. Activities to expand the treated portion of the PRB by 305 m (1,000 ft) were initiated in 2014, which included refurbishing the injection skids, procuring piping and injection amendment monitoring instrumentation, procuring chemicals and storage tanks, and preparing internal contractor injection plans and work documents. Activities were conducted in 2014 to procure services to emplace apatite within the vadose zone overlapping the treated saturated portion of the PRB.

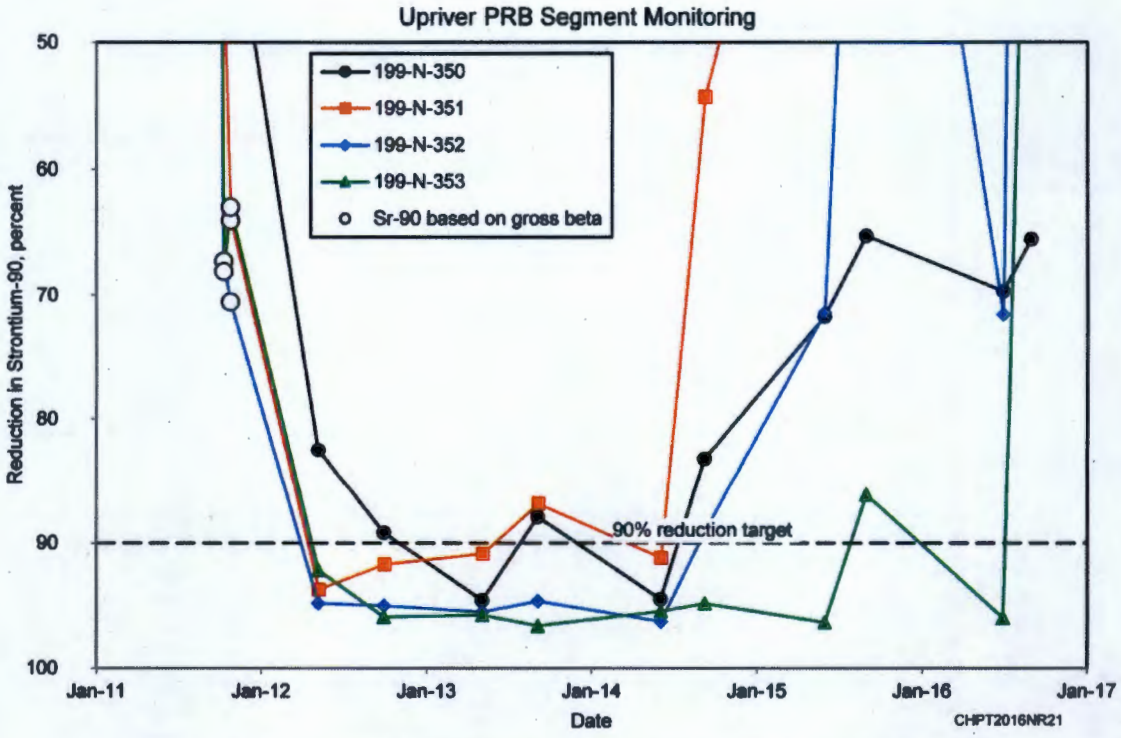


Figure 4-26. Downriver Apatite Barrier Extension Performance Monitoring Wells Percent Strontium-90 Reductions, 2016

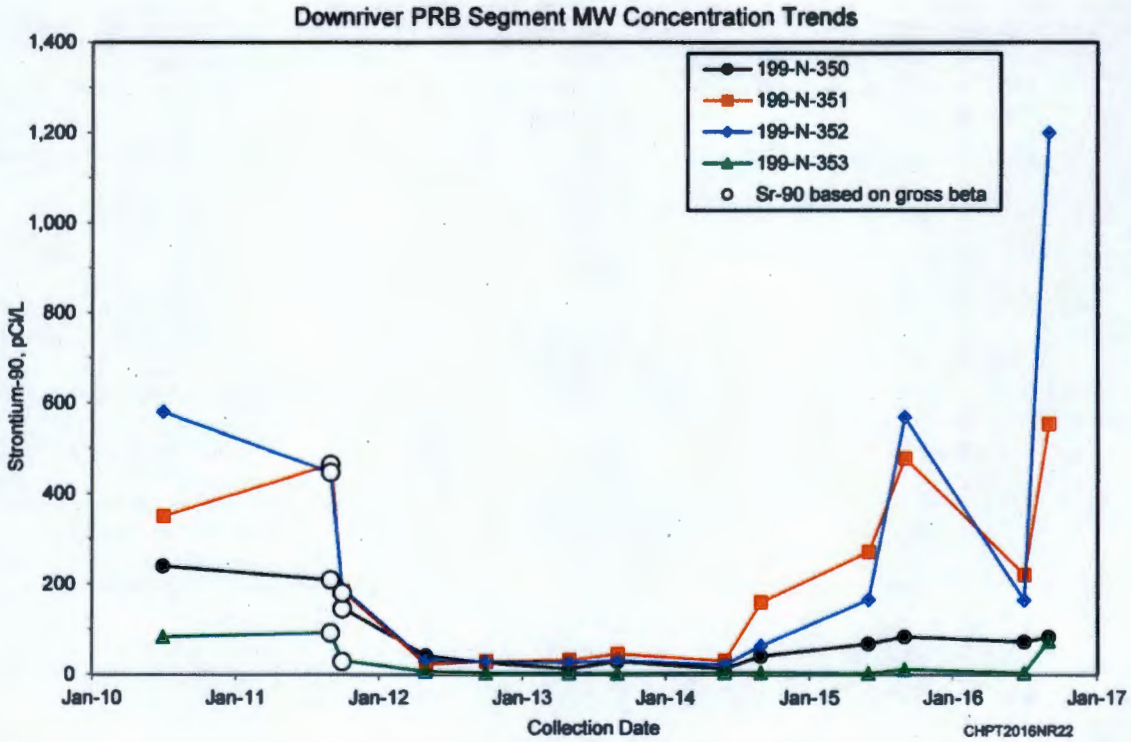


Figure 4-27. Strontium-90 Data for Performance Monitoring Wells along the Downriver Segment of the Apatite PRB

Table 4-9. Injection Volume in Downriver Injection Wells near Wells 199-N-350, 199-N-351, and 199-N-352

Injection Well	Screen/Formation	Injected Volume (L[gal]) (percent of target volume*)
199-N-237	Shallow/Ringold	79,739 (21,051) (35%)
199-N-238	Deep/Ringold	351,576 (92,816) (155%)
199-N-239	Shallow/Ringold	5,678 (1,499) (2%)
199-N-240	Deep/Ringold	85,648 (22,611) (38%)
199-N-241	Shallow/Ringold	112,553 (29,714) (50%)
199-N-242	Deep/Ringold	51,803 (13,676) (23%)
199-N-243	Shallow/Ringold	87,920 (23,211) (39%)
199-N-244	Deep/Ringold	58,610 (15,473) (26%)
199-N-245	Shallow/Ringold	247,591 (65,364) (109%)
199-N-246	Deep/Ringold	265,019 (69,965) (117%)
199-N-247	Shallow/Ringold	23,348 (6,164) (10%)
199-N-248	Deep/Ringold	236,216 (62,361) (104%)
199-N-249	Shallow/Ringold	231,879 (61,216) (102%)
199-N-250	Deep/Ringold	256,856 (67,810) (113%)
199-N-251	Shallow/Ringold	437,163 (115,411) (192%)
199-N-252	Deep/Ringold	219,333 (57,904) (97%)

*Target injection volume is 227,000 L (60,000 gal).

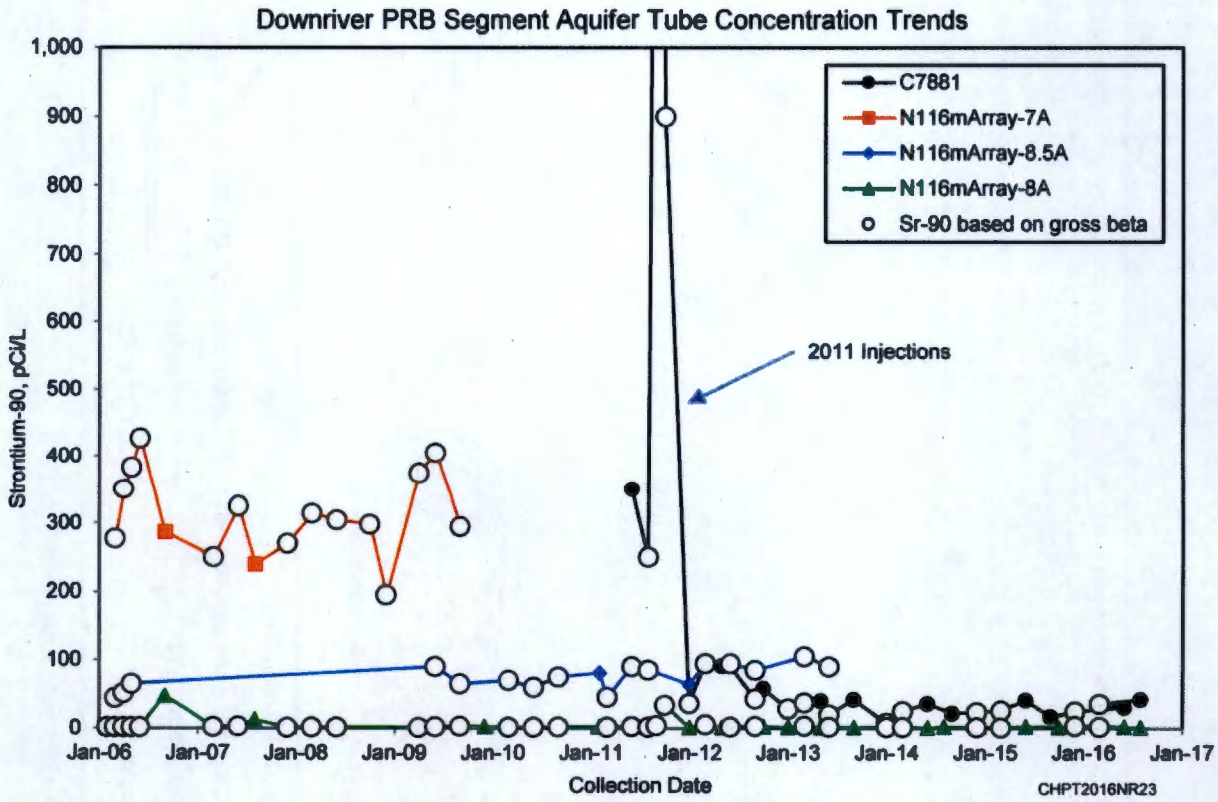


Figure 4-28. Strontium-90 Data for Aquifer Tubes Along the Downriver Segment of the Apatite PRB

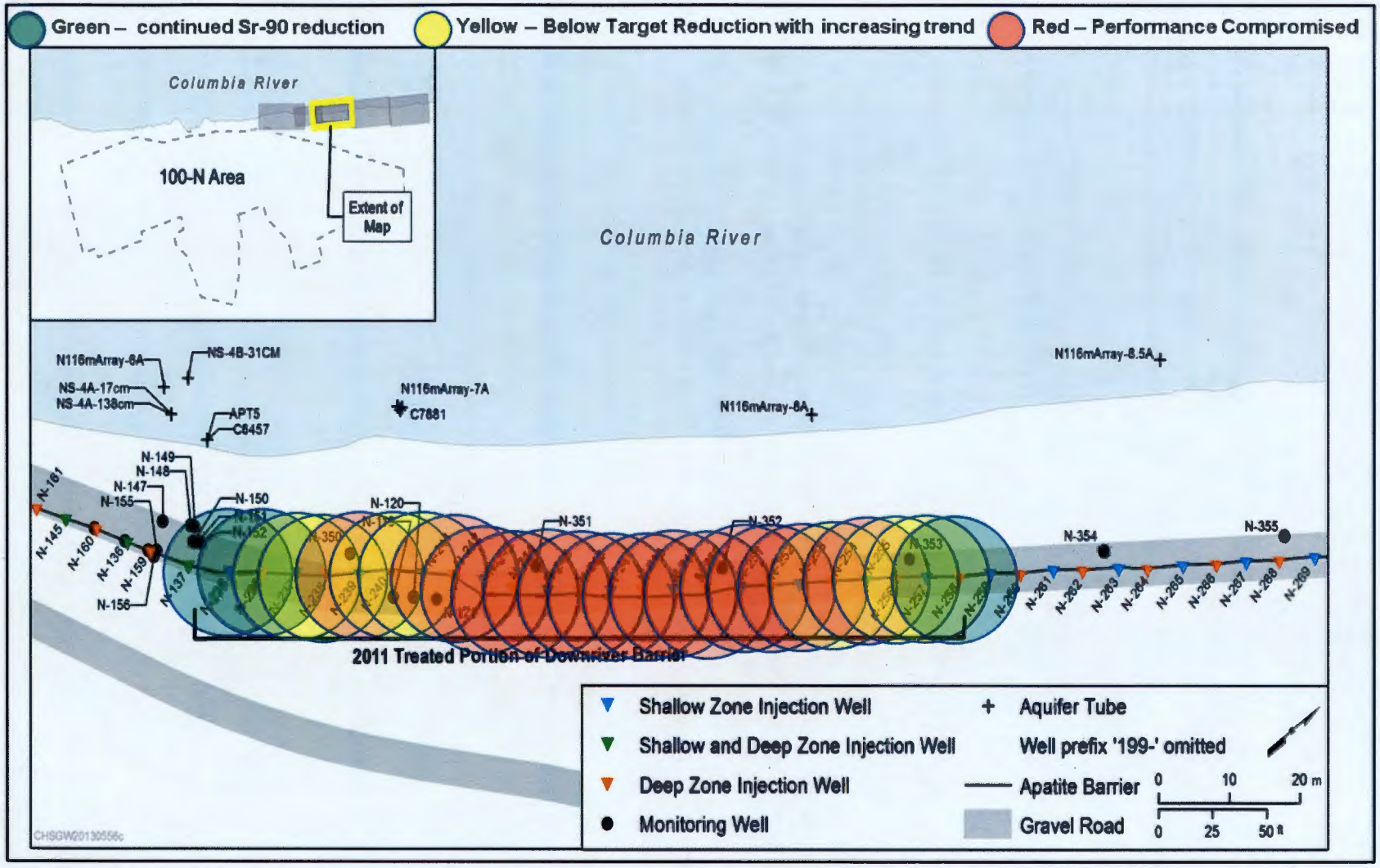


Figure 4-29. Downriver PRB Segment Performance Assessment for 2016

4-50

Table 4-10. PRB Performance Evaluation Summary

Assessed Treated PRB Length		Treated PRB		Upriver Segment		Original Segment		Downriver Segment	
		2015	2016	2015	2016	2015	2016	2015	2016
Total length of Treated PRB	m	311	311	110	110	91	91	110	110
	ft	1,020	1,020	360	360	300	300	360	360
Length identified as "Green – continued Sr-90 reduction"	m	206	169	87	87	91	68	28	14
	ft	675	555	285	285	300	225	90	45
	% Green	66	54	79	79	100	75	25	13
Length identified as "Yellow – Below Target Reduction with increasing trend"	m	55	92	23	23	0	23	32	46
	ft	180	300	75	75	0	75	105	150
	% Yellow	18	30	21	21	0	25	29	41
Length identified as "Red – Performance Compromised"	m	50	50	0	0	0	0	50	50
	ft	165	165	0	0	0	0	165	165
	% Red	16	16	0	0	0	0	46	46

PRB = permeable reactive barrier

Revision 1 of the RDR/RAWP for the 100-NR-2 OU (DOE/RL-2001-27, Rev. 1) was issued in September 2014 to carry out the barrier expansion, both in the saturated zone by chemical injection and in the vadose zone by jet injection, and reinjection of previously treated portions of the barrier, if needed. The schedule for the PRB extension in 2014 was based on working within previously disturbed locations outside of any traditional cultural property. However, a boundary revision to an existing traditional cultural property boundary became effective in January 2014, and the boundary revision encompasses the project area. A cultural review of the project activities addressing the requirements of the *National Historic Preservation Act of 1966*, Section 106 process (specifically, 36 CFR 800.3 through 800.5, "Protection of Historic Properties") has deemed the project to have an "adverse effect" on the traditional cultural property, as defined in 36 CFR 800.5(b). As such, work to complete the barrier is dependent upon completion of the *National Historic Preservation Act of 1966*, Section 106 reviews and is subject to schedule delays pending establishment of a memorandum of agreement for the project activities that are deemed to have an adverse effect on the traditional cultural property. Efforts to establish a memorandum of agreement for expansion of the PRB were initiated in 2015 and will continue during 2017.

Any activities to perform reinjection of the PRB sections with decreased performance are also subject to the establishing a memorandum of agreement for expansion of the PRB.

4.4 Total Petroleum Hydrocarbon–Diesel Remediation

Throughout its operational history, the 105N Reactor and support facilities had unplanned releases of petroleum products. The types of releases included corrosion failure of diesel and fuel oil piping systems, overfill at storage facilities, and spills during fuel transfers. Two of the releases resulted in petroleum hydrocarbon contamination through the vadose zone and into the 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 other isolated areas, and the releases were divided in three groups based on their occurrences. Table 4-11 shows these three groups and the associated releases:

- **Group 1**: Includes releases (UPR-100-N-17) near the 1715-N storage tanks and 166-N transfer areas (166-N Tank Farm). Figures 4-14 and 4-30 show the locations, as well as the location of nearby monitoring well 199-N-183 (replacement for well 199-N-18).
- **Group 2**: Includes releases (UPR-100-N-42) around the 184-N day tank storage facility. Well 199-N-16 was used to monitor this location; however, this well has been decommissioned and a new groundwater monitoring well 199-N-373 (Figure 4-14) was installed in 2016 near this location. Groundwater samples results for TPH-D from well 199-N-373 were less than detection.
- **Group 3**: Includes miscellaneous other sites.

Only the releases from Group 1 have resulted in persistent groundwater contamination. Remediation continued in 2016 for the residual petroleum hydrocarbon contamination in the vadose zone and groundwater in the 100-N Area.

4.4.1 Vadose Zone

DOE is using in situ bioventing to remediate TPH-D contamination identified in the deep vadose zone beneath the UPR-100-N-17 release at the 100-N Area. Oxygen is introduced into the deep vadose zone to promote microbial activity to enhance hydrocarbon degradation. The oxygen stimulates natural, in situ aerobic biodegradation of the TPH-D in the deep vadose zone to carbon dioxide and water.

Table 4-11. Petroleum Hydrocarbon Releases in the 100-N Area

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 3 – 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 (UNI-228).
	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).

Table 4-11. Petroleum Hydrocarbon Releases in the 100-N Area

Group	WIDS Number	Location	Description
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 m by 18 m (130 ft 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/Bonneville Power Administration 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).
	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).

References: 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 (April 26, 1989).*

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

WIDS = Waste Information Data System

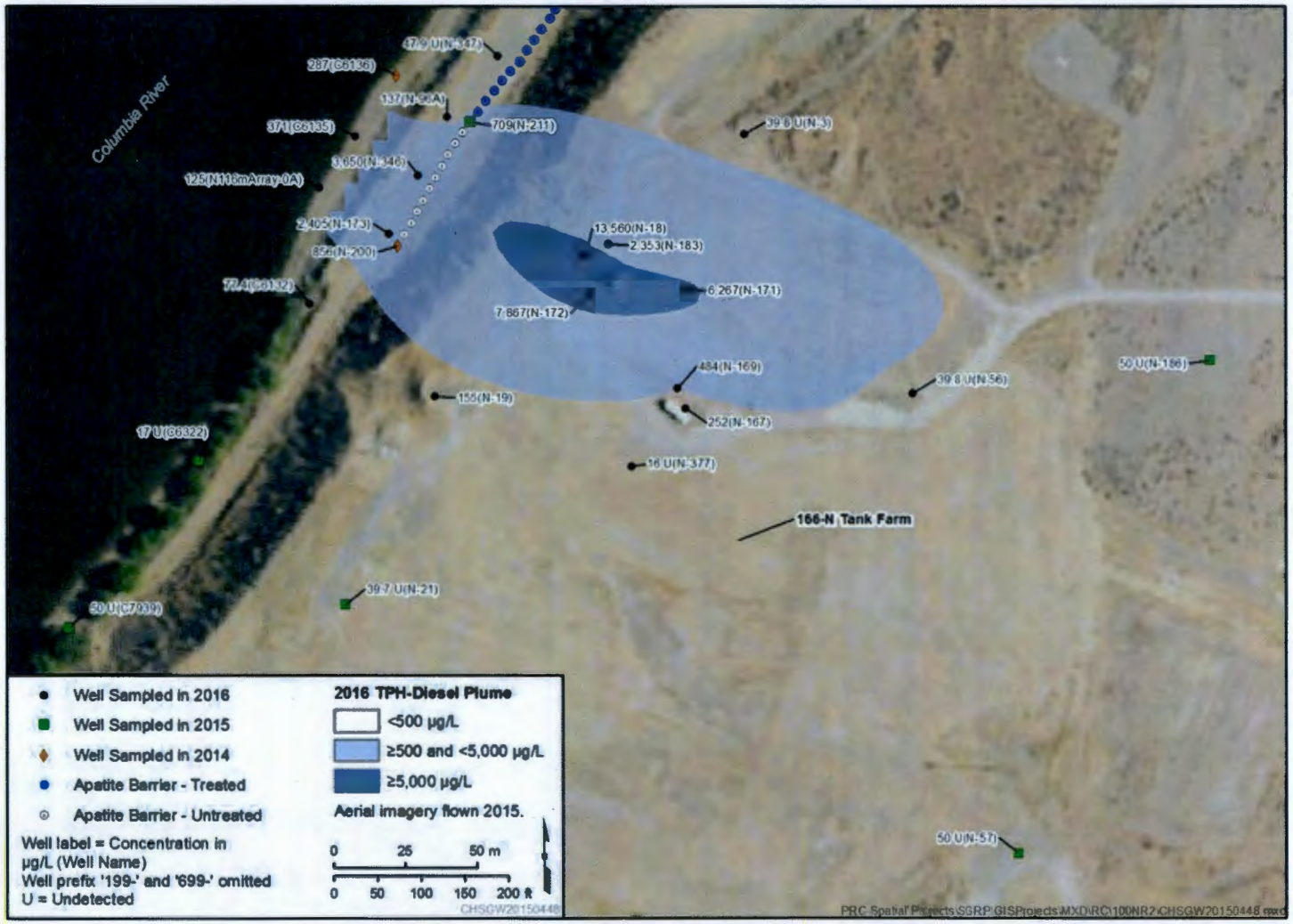


Figure 4-30. 166-N Tank Farm Facility, Location of Well 199-N-183 and 2016 TPH Groundwater Plume

A pilot test for bioventing was conducted from February 2010 through May 2011 to evaluate contaminant removal rates and the distribution of airflow within the vadose contaminated zone. All results of the pilot test are provided in WCH-490.

Data from the bioventing pilot test were used to support the design of a full-scale bioventing system. Full-scale bioventing system operations began at UPR-100-N-17 in December 2012 using two injection wells (199-N-167 and 199-N-172), two vadose zone vapor monitoring wells (199-N-169 and 199-N-171), and eight groundwater monitoring wells (199-N-3, 199-N-19, 199-N-56, 199-N-96A, 199-N-169, 199-N-171, 199-N-173, and 199-N-183) (Appendix H of DOE/RL-2005-93). Groundwater monitoring samples from the eight performance monitoring wells and three aquifer tubes (N116mArray-0A, C6132, and C6135) were collected in February and July 2016.

Table 4-12 provides the TPH-D groundwater concentrations for the eight performance monitoring wells (Figure 4-14). The performance of the full-scale bioventing system during 2016 is provided in DOE/RL-2016-34, *Annual Operations and Monitoring Report for UPR-100-N-17: March 2015-February 2016* and DOE/RL-2017-29, *Annual Operations and Monitoring Report for UPR-100-N-17: March 2016 – February 2017.*

Semiannual performance monitoring (high and low river stages) was conducted for the bioventing system in 2016. Ongoing monitoring will determine the continued effectiveness of the bioventing remediation for the TPH-D plume. In 2016, a new well (199-N-377 on Figure 4-14) was installed to evaluate the lateral upriver boundary of the TPH plume. TPH contamination was observed in the soil from 5.5 m (18 ft) below ground surface to the top of the Ringold Formation (13.7 m [45 ft] below ground surface). The maximum detected soil concentration was 2,880 mg/kg at 5.5 to 6.4 m (18 to 21 ft) below ground surface. TPH concentrations were near or below detection in soil samples collected below the Hanford/Ringold contact. Groundwater samples from 199-N-377 did not detect TPH-D.

4.4.2 Groundwater

The groundwater containing the TPH-D plume, also associated with the UPR-100-N-17 release, is being remediated to remove remaining petroleum free product. The CERCLA interim action for remediation of TPH-D in groundwater is identified in the interim action ROD (EPA/ROD/R10-99/112). The interim action ROD specifies that petroleum hydrocarbons (free-floating product) will be removed if observed in a monitoring well.

If present as LNAPL (or free product), the TPH-D in groundwater is found in the shallowest portion 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*, Rev. 1). Removal of free product from well 199-N-18 continued in 2016 in accordance with the interim action ROD (EPA/ROD/R10-99/112). The diesel is removed using a polymer "smart sponge" that selectively absorbs petroleum products from the groundwater within the well. Approximately every 2 months, two sponges are lowered to the surface of the aquifer in well 199-N-18 and left to soak up the diesel. The sponges are weighed prior to placement in the well and again after removal. The weight difference between the two measurements is the amount of diesel fuel removed from the well. In 2016, 950 g of diesel were removed from 199-N-18 (Table 4-13). Removal of petroleum product from this well will continue in 2017.

Table 4-14 provides the TPH-D concentrations in the known area of the diesel plume for TPH-D monitoring wells identified in the 100-NR-2 SAP (DOE/RL-2001-27, Rev. 2, Appendix A) (Figure 4-14). Table 4-15 provides the TPH-D concentrations for the adjacent upriver apatite barrier extension injection and performance monitoring wells.

Table 4-12. TPH-D Concentrations (C10-C20) (µg/L) for Bioventing Performance Monitoring Wells and Aquifer Tubes

Date	Bioventing Air Injection Wells		Bioventing Monitoring Wells							Upgradient Well	Aquifer Tubes		
	199-N-167	199-N-172	199-N-3	199-N-19	199-N-96A	199-N-169	199-N-171	199-N-173	199-N-183	199-N-56	C6132	N116mArray-0A	C6135
February 2016	459	4,440 (D)	47.6 (U)	2,780a	260	373	11,900 (D)	1,210 (D)	121 (J)	47.6 (U)	70.1 (J)	125 (J)	[a]
July 2016	234 (T)	2,560 (T)	47.2 (TU)	104 (JT)	62.6 (JT)	1,190 (T)	4,640 (T)	1,130 (T)	3,130 (DT)	47.6 (TU)	47.6 (TU)	[b]	238 (T)

a. Unable to sample C6135 in February because aquifer tube needed repairs.

b. Unable to sample N116mArray-0A in July because aquifer tube needed repairs.

D = analyte was identified in an analysis at a secondary dilution factor

J = estimated

T = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for but not detected above reporting limit

Table 4-13. Petroleum Hydrocarbon Removal from Well 199-N-18

Year	Product Removed (g)	Notes
2003[a]	~1,200[b]	Estimate provided per information given in table note; data records lost when original work package was lost in the field.
2004	3,475	Changed out twice per month.
2005	780	Changed approximately every 2 months.
2006	1,370	Changed every 2 months.
2007	1,294	Changed every 2 months.
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 apart in well. No removal for second half of 2010.
2011	500	Changed every 2 months.
2012	600	Changed in January, April, June, and August 2012.
2013	750	Changed in January, March, May, July, September, and November 2013.
2014	550	Changed in February, April, June, August, and October 2014.
2015	1,050	Changed in January (twice), April, June, July, September, and December (twice) 2015.
2016	950	Changed in June, July, October, and December 2016.
	Total	**15,044.5 g (approximately 15 kg) removed through end of 2016**

a. DOE/RL-2004-21, *Calendar Year 2003 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit (OU) Pump & Treat Operations*, reports that product removal began in October 2003.

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

4.5 Demolition of the 100-NR-2 Pump and Treat System

The documents EPA, 2010 and DOE/RL-2001-27 require the decommissioning, demolition, and removal of the 100-NR-2 P&T system. These documents required removing the residual resin and disposing this material at the ERDF, dismantling all noncontact treatment system hardware and salvaging reusable components, and cutting the high-density polyethylene conveyance piping into short lengths for transportation and disposal at ERDF. Continued use and reconfiguration of the existing wells for monitoring purposes was also a part of the decommissioning plan.

The 100-NR-2 P&T system was demolished, excavated, and removed during August through November of 2016. Surface and subsurface features associated with the system, including permanent and temporary structures, concrete slab, vaults and culverts beneath roads and three 100-NR-2 pump and treat signs were removed from the site and disposed of at the ERDF. Approximately 308 m^3 (10,875 ft^3) of concrete, soil, piping, conduit, and miscellaneous debris and equipment, weighing 430,913 kg (475 tons), was removed and disposed of at ERDF. Excavated areas were backfilled and contoured to match the surrounding terrain. A revegetation and site contouring plan will be prepared in consultation with the Tribal nation as required in MSA-1601100 to complete environmental restoration.

The only components of the P&T system remaining are the former extraction wells and injection wells. Extraction wells were converted to support groundwater monitoring prior to the start of demolition and piping was removed from injection wells in January 2017.

4.6 100-NR-2 Apatite Permeable Reactive Barrier System Costs

This section summarizes the burdened costs for the 100-NR-2 groundwater remediation for 2016. The primary categories of expenditures are described as follows:

- **Capital design**: Includes design activities to construct the PRB and designs for system expansion.
- **Capital construction**: Includes oversight labor, material, and subcontractor fees for capital equipment, initial construction, construction of new wells, well injections, and modifications to the PRB. Decontamination and decommissioning (D&D) of the 100-NR-2 P&T system are included in this category.
- **Project support**: Includes project coordination-related activities and technical consultation, as required, during the course of the system design, construction, acceptance testing, and operation.
- **O&M**: Represents facility supplies, labor, and craft supervision costs associated with maintaining the former P&T system.
- **Performance monitoring**: Includes system and groundwater sampling and sample analysis.
- **Waste management**: Includes the cost for the management at the 100-NR-2 OU in accordance with applicable laws for suspect hazardous, toxic, and regulated wastes.
- **Barrier maintenance**: Includes costs for maintenance of the PRB, including well injections and modifications to the PRB.

The 2016 cost breakdown for the 100 NR-2 groundwater remediation systems is presented in Table 4-16 and Figure 4-31. The total 2016 remedial action costs were $1,489,000. Costs for D&D of the 100-NR-2 P&T facility accounted for 53 percent of the total 2016 costs. The remaining 2016 costs were for performance monitoring (42 percent) and project support (5 percent).

Table 4-14. TPH Monitoring Wells Maximum TPH-D Concentrations

Date	199-N-3	199-N-16/ 199-N-373	199-N-18	199-N-183	199-N-56	199-N-96A	199-N-173	199-N-169	199-N-171	199-N-346
1992	NR	200 (U)	NR	N/A	1,000 (U)	NR	NR	N/A	N/A	N/A
1993	1,000 (U)	67 (J)	NR	N/A	NR	NR	NR	N/A	N/A	N/A
1994	1,000	4,000	NR	N/A	NR	NR	NR	N/A	N/A	N/A
1995 to 1998	NR	NR	NR	N/A	NR	NR	NR	N/A	N/A	N/A
1999	NR	NR	16,000 (D)	N/A	NR	NR	NR	N/A	N/A	N/A
2000	92 (U)	NR	23,000 (D,N)	N/A	NR	NR	NR	N/A	N/A	N/A
2001	92 (U)	NR	6,800,000 (D,N)	N/A	NR	50 (U)	NR	N/A	N/A	N/A
2002	50 (U)	NR	440,000 (D,N)	N/A	NR	1,500	NR	N/A	N/A	N/A
2003	50 (U)	6,500 (N)	630,000,000 (D)	N/A	NR	900	NR	N/A	N/A	N/A
2004	50 (U)	6,100 (N)	340,000 (D,N)	N/A	60 (U)	750 (N)	NR	N/A	N/A	N/A
2005	50 (U)	11,000 (N)	69,000 (D,N)	N/A	50 (U)	610	NR	N/A	N/A	N/A
2006	50 (U)	50 (U)	23,000 (D)	N/A	50 (U)	50 (U)	NR	N/A	N/A	N/A
2007	50 (U)	33 (U,D,N)	190,000	N/A	50 (U)	50 (U)	NR	N/A	N/A	N/A
2008	33 (U)	NR	809,000 (D)	N/A	NR	71 (U)	NR	N/A	N/A	N/A
2009	17 (U)	70 (U)	67,000 (D)	N/A	70 (U)	260	2,100	N/A	N/A	N/A

Table 4-14. TPH Monitoring Wells Maximum TPH-D Concentrations

Date	199-N-3	199-N-16/ 199-N-373	199-N-18	199-N-183	199-N-56	199-N-96A	199-N-173	199-N-169	199-N-171	199-N-346
2010	70 (U)	79 (J)	420,000 (D)	N/A	70 (U)	200	2,100	1,100 (N)	2,800 (N)	3,700
2011	70 (U)	70 (U)	48,000 (H)	N/A	70 (U)	70 (U)	70 (U)	760	70 (U,N)	NR
2012	70 (U)	70 (U)	Not sampled[a]	2,100	70 (U)	140	1,900	1,150	4,620	NR
2013[b]	70 (U)	—[c]	Not sampled[a]	3,350	70 (U)	70 (U)	410	1,370	9,450 (D)	NR
2014	51 (U)	—[c]	Not sampled[a]	2,600 (T)	112 (J,T)	446 (T)	4,700 (T)	1,920	4,680 (D)	18,000 (D)
2015	48 (U)	—[c]	Not sampled[a]	2,180 (T)	233 (T)	161 (J,T)	1,280 (T)	576	4,360 (D,T)	6,400 (D)
2016	47.6 (U)	—[c]	17200 (DT)	3300	48.1 (U)	420 (J)	3600	1,190 (T)	11,900 (D)	3,800 (N)

Note: Highest detected result or lowest nondetectable result for a calendar year are reported in this table.

a. Well 199-N-18 was replaced by 199-N-183 for groundwater sampling

b. Does not include results in WCH-600, *Annual Operations and Monitoring Report for UPR-100-N-17: November 2012 – February 2014*, for performance monitoring of bioventing.

c. Decommissioned on December 18, 2012.

d. Aquifer tube was broken and could not be sampled.

e. Wells 199-N-21 and 199-N-57 are no longer sampled for TPH-D because of the long period of nondetected TPH-D at the wells.

Data flags:

B = The analyte was detected in both the associated QC blank and in the sample
D = sample was diluted for analysis
H = laboratory holding time exceeded before sample was analyzed
J = concentration is estimated
N = spike sample outside limits
N/A = not applicable
NR = not reported
Q = associated with out-of-limit quality control data
T = spike and/or spike duplicate sample recovery is outside control limits
U = undetected

Table 4-15. TPH-D Concentrations for Upriver 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	—	3,200	—	3,000	—	2,700	—	1,400	—
6/4/2014	856	2,800	—	—	—	—	—	—	—	—
6/7/2015	—	17 (U)	—	—	—	—	—	—	—	—
9/15/2015	—	15 (U)	—	—	—	—	—	—	—	—
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)	—
3/31/2014	70 (U)	—	—	—	—	—	—	—	—	—
6/4/2014	49.5 (U)	—	—	—	—	—	—	—	—	—
7/29/2015	—	590)	—	—	—	—	—	—	—	—
9/15/2015	—	827	—	—	—	—	—	—	—	—
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)	—
7/29/2015	—	—	—	—	—	—	—	—	—	16 (U)
9/18/2015	—	—	—	—	—	—	—	—	—	17 (U)

Table 4-15. TPH-D Concentrations for Upriver Apatite Barrier Injection and Monitoring Wells

Date	N-230	N-231	N-232	N-233	N-234	N-96A	N-347	N-348	N-349
3/31/2010	—	70 (U)	—	70 (U)	—	—	—	—	—
4/6/2010	—	—	—	—	—	—	17 (U)	3,800	17 (U)
6/25/2010	70 (U)	—	70 (U)	—	70 (U)	—	—	—	—
11/14/2010	—	—	—	—	—	200)	—	—	—
1/18/2011	—	—	—	—	—	70 (U)	—	—	—
9/16/2011	—	—	—	—	—	70 (U)	80 (U)	80 (U)	70 (U)
9/20/2011	—	—	—	—	—	70 (U)	—	—	—
9/28/2011	—	—	—	—	—	—	80 (U)	80 (U)	80 (U)
10/13/2011	—	—	—	—	—	—	85 (U)	85 (U)	85 (U)
5/6/2012	—	—	—	—	—	—	70 (U)	70 (U)	—
8/27/2012	—	—	—	—	—	140	—	—	—
5/9/2012	—	—	—	—	—	—	—	—	91 J
5/6/2013	—	—	—	—	—	70 (U)	70 (U)		70 (U)
9/6/2013	—	—	—	—	—	70 (U)	70 (U)	70 (U)	70 (U)
6/5/2014	—	—	—	—	—	—	17 (U)	48.5 (U)	17 (U)
9/10/2014	—	—	—	—	—	—	140 (J)	65.5 (J,T)	—
9/11/2014	—	—	—	—	—	446 (T)	—	—	16 (U)
1/20/2015	—	—	—	—	—	52.1 (U)	—	—	—
6/7/2015	—	—	—	—	—	18 (U)	50 (T,U)	17 (U)	48.1 (T,U)
7/29/2015	—	—	—	—	—	161 (J,T)	—	—	—

Table 4-15. TPH-D Concentrations for Upriver Apatite Barrier Injection and Monitoring Wells

Date	N-230	N-231	N-232	N-233	N-234	N-96A	N-347	N-348	N-349
9/22-28/2015	—	—	—	—	—	17 (U)	89.1 (J)	16 (U)	47.6 (U)
2/17/2016	—	—	—	—	—	260	—	—	—
6/23/2016 6/30/2016	—	—	—	—	—	17 (U)	48.1 (U)	16 (U)	50 (U)
7/27/2016	—	—	—	—	—	62.6 (JT)	—	—	—
9/16/2016 9/22/2016 9/23/2016	—	—	—	—	—	420 (J)	47.6 (U)	16 (UN)	47.6 (TU)
9/22/2016	—	—	—	—	—		—	—	—
12/27/2017	—	—	—	—	—	47.2 (U)	—	—	—

Notes: Highest detected result or lowest nondetectable result for a calendar year is reported in this table.

Orange shading indicates barrier injection well (deep).

Pink shading indicates barrier monitoring well (deep).

Yellow shading indicates barrier injection well (shallow).

— = entry indicate well was not sampled for TPH-D on the identified date

J = estimated value

T = spike and/or spike duplicate sample recovery is outside control limits

TPH-diesel = TPH-D

U = undetected

Table 4-16. Breakdown of 100-NR-2 Remediation System Construction and Operation Costs

Description	Actual Costs (Dollars × 1,000)										
	1995 – 2006	2007	2008	2009	2010	2011	2012	2013	2014[c]	2015	2016
Design	3,872	—	—	20.5	31.0	—	0.6	0.0	0.0	0.0	0.0
Treatment system capital construction	9,303	—	—	316.2	(0.1)	(32.1)	0.0	0.0	0.0	0.0	796.4[d]
Project support	2,031	79.8	10.7	278.5	276.5	178.9	133.3	284.2	173.9	170.8	68.1
Operations and maintenance	9,104	199.9	107.4	50.2	23.6	30.4	0.4	0.0	0.0	0.0	0.0
Performance monitoring	960	62.7	36.2	466.2	956.3	1,069.0	1,801.1	769.3	1,077.1	967.7	624.1
Waste management	438	43.4	8.9	3.6	0.5	2.3	0.0	0.0	0.0	0.0	0.0
Field studies	--	—	—	874.1	1,228.3	119.5	(2.2)	68.0	0.0	0.0	0.0
Barrier maintenance	--	—	—	634.3	1,468.0	1,844.4	15.9	46.4	1,079.8	0.0	0.0
Totals	**$25,708**	**$386**	**$163**	**$2,644**	**$3,984**	**$3,212**	**$1,949**	**$1,168**	**$2,331**	**$1,139**	**$1,489**

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.

c. Barrier maintenance costs for 2014 were associated with preparation and procurement of chemicals for injections to extend the barrier but an adverse impact determination to a traditional cultural property has put further injections on hold until a memorandum of agreement is established for expansion of the PRB.

d. Treatment system capital construction costs for 2016 are associated with D&D of the 100-NR-2 Pump and Treat facility.

— = not available

D&D = decontamination and decommissioning.

PRB = permeable reactive barrier

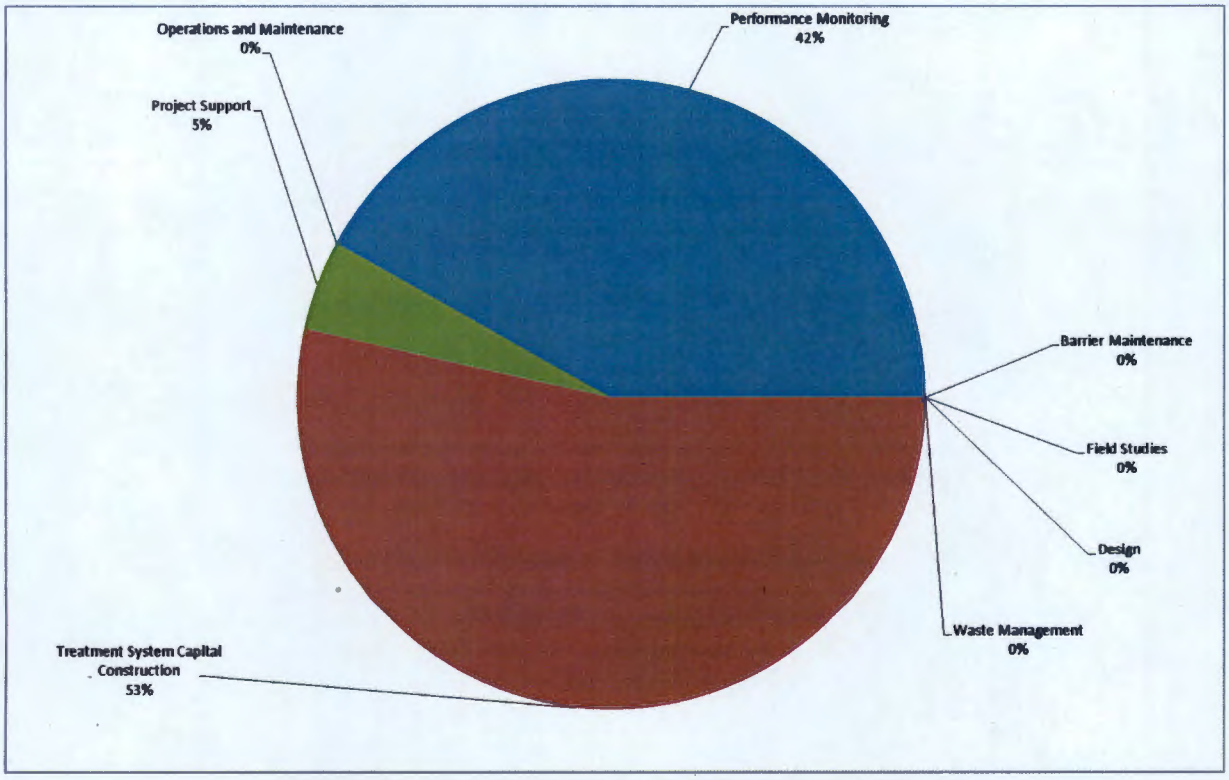


Figure 4-31. 100-NR-2 Apatite Barrier 2016 Cost Breakdown (by Percentage)

4.7 Conclusions

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

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

  Results: The PRB captures strontium-90 contamination moving in groundwater along the section of the 100-N Area shoreline with the highest historical groundwater contamination. Apatite solutions were injected in wells of the central (original) barrier segment from 2006 to 2008 and in wells of the upriver and downriver segments in 2011. Strontium-90 concentrations in some monitoring wells near the apatite PRB temporarily increased in response to the apatite injections. The concentrations in the majority of the monitoring wells in 2016 were lower than pre-injection levels. The concentrations in most of the monitoring wells in 2016 had declined from pre-injection levels by 54 percent to 96 percent. However, in 2015 concentrations of strontium-90 have increased in some of the monitoring wells and remained elevated in 2016 with concentrations in two monitoring wells at pre-injection levels. DOE plans to reinject poor performing sections of the PRB and expand the PRB in the future.

  The TPH-D plume bioremediation and free-product removal continues to reduce the contaminant mass in groundwater and the lower vadose zone that could eventually affect the river.

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

Results: The P&T system was not effective at removing strontium-90 from the groundwater because strontium-90 strongly adsorbs to sediment grains; therefore, the P&T system was placed in cold-standby status on March 9, 2006. The P&T facility was demolished and removed in 2016. The only components of the P&T system remaining are the former extraction wells and injection wells. Piping was removed from injection wells in January 2017.

The apatite PRB was installed along the section of the 100-N Area shoreline with the highest historical groundwater contamination. The injection design provides emplacement of sufficient apatite in the PRB to sequester the strontium-90 flux to the river for the duration needed for the upland strontium-90 groundwater contamination to naturally decay.

Smart sponges deployed in well 199-N-18 removed 950 g of TPH-D free product in 2016.

A full-scale bioventing system for remediation of TPH-D in the deep vadose zone near waste site UPR-100-N-17 was implemented in December 2012 and continued to operate in 2016. The performance evaluation for 2016 is documented in separate reports (DOE/RL-2016-34 and DOE/RL-2017-29.

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

  Results: A 311 m (1,020 ft) long apatite PRB is installed near the Columbia River shoreline. The remainder of the planned PRB extension to approximately 760 m (2,500 ft) will be performed in the future.

  Three other types of strontium-90 remediation technologies were tested for potential use in the 100-NR-2 OU in addition to the apatite PRB. Passive infiltration did not prove to be a viable method for emplacement of apatite-forming chemicals along the 100-N Area shoreline. Jet injection tests showed that the technology could effectively place apatite or apatite-forming chemicals into the upper vadose zone with good coverage. Phytoextraction has the potential to remove strontium-90 from the shoreline area, as demonstrated by greenhouse and laboratory (growth chamber) studies of strontium-90 uptake, and field studies in a contaminant-free location at the 100-K Area. No additional work on these technologies occurred in 2016.

  Technologies for remediation of strontium-90 are being evaluated in the RI/FS report for the 100-NR-1 and 100-NR-2 OUs (DOE/RL-2012-15, *Remedial Investigation/Feasibility Study for the 100-NR-1 and 100-NR-2 Operable Units*, Draft A).

- **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 ICs that must be implemented and maintained throughout the interim action period. These provisions include the following:

  - Access control and visitor escorting requirements
  - Maintain signs prohibiting public access (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

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