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CALENDAR YEAR 2019 ANNUAL SUMMARY REPORT FOR THE 100-HR-3 AND 100-KR-4 PUMP AND TREAT OPERATIONS, AND 100-NR-2 GROUNDWATER REMEDIATION

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

U.S. Department of Energy Richland Operations Office

P.O. Box 550
Richland, Washington 99352

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Executive Summary

This annual report presents the 2019 performance summary for groundwater remedial actions at the Hanford Site 100-HR-3, 100-KR-4, and 100-NR-2 Groundwater Operable Units (OUs), including details on the volume of water treated, contaminant mass removed, efficiency, effectiveness of the interim remedial actions, and the resulting effect on groundwater concentrations. Hexavalent chromium (Cr(VI)), the primary contaminant of concern (COC) in the 100-HR-3 and 100-KR-4 OUs, is being addressed by several pump and treat (P&T) systems. 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. Strontium-90 is the primary COC in the 100-NR-2 OU, and contamination flux to the river is addressed by strontium sequestration through a permeable reactive barrier (PRB).

100-HR-3

In July 2018, a final Record of Decision (ROD)[1] (hereinafter referred to as the 100-D/100-H Areas ROD) was issued that selected a final remedy of P&T for Cr(VI) and total chromium for the 100-HR-3 Groundwater OU. The 100-D/100-H Areas ROD established a cleanup level of 10 µg/L for Cr(VI) where groundwater discharges to surface water and 48 µg/L inland. The cleanup levels for total chromium are 65 µg/L where groundwater discharges to surface water and 100 µg/L inland. The remedy authorized continued use of the DX and HX P&T systems for groundwater treatment. With issuance of the 100-D/100-H Areas ROD, a new remedial design/remedial action work plan[2] was prepared to ensure that the P&T systems are operating with the goal of meeting the remedial action objectives (RAOs) identified in the 100-D/100-H Areas ROD. The remedial design/remedial action work plan is currently being reviewed by the regulatory agencies.

[1] EPA, Ecology, and DOE, 2018, *Record of Decision Hanford 100 Area Superfund Site 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: https://pdw.hanford.gov/document/0065047H.

[2] DOE/RL-2017-13, 2019, *Remedial Design/Remedial Action Work Plan for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://pdw.hanford.gov/document/0063897H.

Operations of the DX and HX P&T systems in the 100-HR-3 OU are making progress toward the RAOs for groundwater specified in the 100-D/100-H Areas ROD[1]:

- **RAO #1:** Prevent unacceptable risk to human health from ingestion of and incidental exposure to groundwater containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #2:** Prevent unacceptable risk to human health and ecological receptors from groundwater discharges to surface water containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #7:** Restore groundwater in the 100-HR-3 OU to cleanup levels, which include drinking water standards, within a timeframe that is reasonable given the particular circumstances of the site.

At the 100-HR-3 OU, the combined DX and HX P&T systems processed 2,289 million L (604 million gal) of groundwater and removed 54.7 kg of Cr(VI) in 2019. Since startup, the 100-HR-3 OU P&T systems have treated 26,182 million L (6,912 million gal) of groundwater and removed 2,601 kg of Cr(VI).

The Cr(VI) concentrations in 100-D Area groundwater in the unconfined aquifer have decreased since 2010 due to DX P&T system operations and source area removal of waste sites (e.g., the 100-D-100 waste site and the combined 100-D-30/100-D-104 waste sites). The maximum Cr(VI) concentrations decreased to 263 µg/L compared to 69,700 µg/L in 2010. The areal extent of the inland plume at the 48 µg/L cleanup level declined between 2018 and 2019. The extent of the high-concentration portions of the plume was also reduced.

The surface of the Ringold upper mud unit (RUM) forms the base of the unconfined aquifer in 100-HR-3 OU. Within the RUM, thin sand to gravel layers with variable hydraulic conductivities act as confined or semiconfined leaky aquifers.[3]. Multiple water-bearing zones are known to be present in the 100-HR-3 OU. These zones are

[3] DOE/RL-2010-95, 2014, *Remedial Investigation/Feasibility Study for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at:
https://pdw.hanford.gov/document/0083383H.
https://pdw.hanford.gov/document/0083382H.
https://pdw.hanford.gov/document/0083381H.
https://pdw.hanford.gov/document/0083380H.

present at different depths, and the number and connectivity of these various water-bearing zones have not been determined. However, the uppermost water-bearing zone (termed the RUM aquifer) is contaminated and is the focus of ongoing characterization and remediation efforts.

The P&T remedies continue to provide protection of the Columbia River from discharges of chromium-contaminated groundwater. River protection is assessed against conditions that may result in groundwater Cr(VI) discharges at concentrations >10 µg/L to surface water.

During 2019, 600 m (1,970 ft) of the 3,300 m (10,825 ft) shoreline affected by the Cr(VI) plume in the 100-D Area were identified as not adequately protected. This represents a decline in protected shoreline (from 100 m [330 ft] in 2018 to 600 m [1,970 ft] in 2019 of unprotected shoreline). The decline in protection was primarily in the shoreline length north of the 100-D Area and toward the Horn, beyond the field of P&T hydraulic containment. Conditions will continue to be monitored and evaluated for river protection.

During 2019 in the 100-H Area, 100 m (330 ft) of the 4,400 m (14,430 ft) of shoreline affected by the Cr(VI) plume were identified as not adequately protected. This represents an improvement from 2018 (200 m [660 ft] in 2018 to 100 m [330 ft] in 2019 of unprotected shoreline). The unprotected shoreline areas are evaluated for additional actions during annual remedy optimization activities. The remainder of the affected 100-D and 100-H Area shoreline was identified as either "protected," or as "protected, but additional action may be required."

100-KR-4

The P&T operations at the 100-KR-4 OU are ongoing in accordance with the interim action ROD.[4] Operation of the KX, KW, and KR4 P&T systems in the 100-KR-4 OU continue to provide progress toward meeting the objectives identified in the interim action ROD:

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

[4] EPA/ROD/R10-96/134, 1996, *Declaration of the Record of Decision, USDOE Hanford 100 Area, 100-HR-3 and 100-KR-4 Operable Units, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: https://pdw.hanford.gov/document/D196097243.

- **RAO #2:** Protect human health by preventing exposure to contaminants in groundwater.
- **RAO #3:** Provide information that will lead to a final remedy.

The combined KX, KW, and KR4 P&T systems treated 2,828 million L (747 million gal) of groundwater and removed 48.6 kg of Cr(VI) during 2019. Since startup, the KX, KW, and KR4 P&T systems have treated 29,188 million L (7,706 million gal) of groundwater and removed 988 kg of Cr(VI). Increased extraction rates resulting from the installation of new wells and realignment of existing wells during the previous 3 years are providing enhanced plume control in near-river regions of the 100-KR-4 OU.

In response to the results of the rebound study conducted between May 2016 and April 2017,[5] a soil flushing treatability test[6] and a sampling and analysis plan[7] were approved by the U.S Department of Energy (DOE) and the U.S. Environmental Protection Agency to address the secondary source location near the 183.1KW Headhouse. The goal of soil flushing is to remove Cr(VI) from the deep portions of the vadose zone by flushing the contaminant material into the groundwater, and then capturing and treating the Cr(VI) with the active P&T system to remove it from the groundwater. The treatability test was initiated in May 2019 using effluent from the KW P&T system to saturate the vadose zone beneath the former 183.1KW Headhouse area. Increased Cr(VI) concentrations were observed at the KW P&T system as a result of soil flushing. A treatability test report will be published in 2020. Based on the test results, DOE is evaluating whether additional soil flushing of secondary sources of Cr(VI) is appropriate to meet cleanup timeframes in the 100-KR-4 OU or in the other River Corridor groundwater OUs.

The river protection evaluation for the 100-K Area for 2019 identified that all 4,000 m (13,120 ft) of shoreline affected by chromium-contaminated groundwater were deemed either “protected” or “protected, but additional action may be required.” In both the

[5] SGW-62061, 2018, *KW Rebound Study Summary Report and Assessment*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/document/0064574H.

[6] DOE/RL-2017-30, 2018, *KW Soil Flushing/Infiltration Treatability Test Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://pdw.hanford.gov/document/0065840H.

[7] DOE/RL-2018-10, 2018, *KW Soil Flushing/Infiltration Treatability Test Plan Sampling and Analysis Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://pdw.hanford.gov/document/0064445H.

100-HR-3 and 100-KR-4 OUs, achieving river protection is the direct result of ongoing improvements in the capture and treatment of contaminated groundwater by the P&T systems through well realignments, increased extraction rates, and placement of new extraction wells at locations selected to intercept targeted plume segments.

100-NR-2

In the 100-NR-2 OU, interim remedial actions are implemented for strontium-90 and total petroleum hydrocarbons as groundwater COCs in accordance with the interim action ROD.[8] The RAOs identified in the interim action ROD are as follows:

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

A PRB was installed along the shoreline to intercept and treat the migrating groundwater contaminated with strontium-90 in situ using a mineral apatite, as described in the ROD amendment.[9] The treated length of the PRB is 311 m (1,020 ft), with 91 m (300 ft) treated in 2008 and extended to 311 m (1,020 ft) in 2011. The installed PRB targets the shoreline downgradient of the highest strontium-90 concentration areas. Groundwater samples at the PRB monitoring wells located between the PRB and river show that concentrations in most of the monitoring wells in 2019 continued to be lower than pre-PRB levels by nearly 90%. However, strontium-90 concentrations have been

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[8] EPA/ROD/R10-99/112, 1999, *Interim Remedial Action Record of Decision, U.S. Department of Energy / Hanford 100 Area, 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, Washington. Available at: https://pdw.hanford.gov/document/D9177845.

[9] 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, Region 10, Olympia, Washington. Available at: https://pdw.hanford.gov/document/0084198.

increasing in several monitoring wells since 2015, indicating that strontium-90 breakthrough and additional apatite treatment may be necessary at these PRB locations.

Removal of total petroleum hydrocarbons free-floating product (primarily diesel range) from wells 199-N-18 and 199-N-183 continued in 2019. The diesel is removed using a polymer "smart sponge" that selectively absorbs petroleum products from the groundwater in the wells. In 2019, a total of 1.23 kg of diesel was removed from these two wells.

Conclusions

Remedial action operations should continue, as well as monitoring activities and remedial process optimization activities. The remedial actions for the 100-HR-3, 100-KR-4, and 100-NR-2 OUs continue to be effective and demonstrate improvement in reducing groundwater contaminant concentrations and, in turn, protecting the Columbia River.

Remedy optimization and routine monitoring activities will include the following:

- 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 will include modifying the P&T facilities in the 100-K Area to expand treatment capacity by reducing the number of resin vessels in each treatment train to more effectively use the ion-exchange resin.
- Evaluating results from analytical samples collected from wells, aquifer tubes, and treatment process locations
- Evaluating the 100-NR-2 apatite PRB performance for possible additional injection of apatite chemicals.

Contents

Figures

Tables

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Terms

AEA	*Atomic Energy Act of 1954*
AFD	adjustable-frequency drive
AWLN	automated water-level network
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFM	capture frequency map
COC	contaminant of concern
Cr(VI)	hexavalent chromium
CSM	conceptual site model
DCS	derived concentration standard
DOE	U.S. Department of Energy
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FS	feasibility study
FSB	fuel storage basin
FY	fiscal year
IC	institutional control
ICFM	interpolated capture frequency map
IX	ion exchange
LWDF	liquid waste disposal facilities
MCL	maximum contaminant level
MDA	minimum detectable activity
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
O&M	operations and maintenance
OU	operable unit
P&T	pump and treat

PRB	permeable reactive barrier
PRZ	periodically rewetted zone
PVC	polyvinyl chloride
RAO	remedial action objective
RD/RAWP	remedial design report/remedial action work plan
RI	remedial investigation
ROD	Record of Decision
RPO	remedial process optimization
RUM	Ringold upper mud unit
SAP	sampling and analysis plan
SCFM	simulated capture frequency map
TCE	trichloroethene
TED	total effective dose
TPH	total petroleum hydrocarbons
TPH-D	total petroleum hydrocarbons-diesel
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
UCL	upper confidence limit

1 Introduction

This report presents the 2019 performance summary for groundwater remedial actions at the 100-HR-3, 100-KR-4, and 100-NR-2 Groundwater Operable Units (OUs). The report has been prepared in accordance with annual remedy reporting identified in the remedial design/remedial action work plans (RD/RAWPs) for each of the respective OUs:

- DOE/RL-2013-31, *100-HR-3 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*
- DOE/RL-2013-33, *Remedial Design/Remedial Action Work Plan for the 100-KR-4 Groundwater Operable Unit Interim Action*
- DOE/RL-2001-27, *Remedial Design/Remedial Action Work Plan for the 100-NR-2 Operable Unit*

The U.S. Department of Energy (DOE) has implemented actions along the Columbia River corridor of the Hanford Site to remediate contaminated groundwater in the 100-HR-3, 100-KR-4, and 100-NR-2 OUs (Figure 1-1). DOE has defined informal groundwater interest areas (Figure 1-1) that include the groundwater OUs and the intervening regions. The designation of groundwater interest areas allows for more efficient scheduling, data review, and data interpretation of groundwater monitoring data to evaluate the groundwater OU remedial actions. DOE currently operates and maintains five pump and treat (P&T) systems in these areas: two P&T systems within the 100-HR-3 OU and three P&T systems within the 100-KR-4 OU. The primary contaminant of concern (COC) in the 100-HR-3 and 100-KR-4 OUs is hexavalent chromium (Cr(VI)). The 100-D and 100-H Areas have two P&T systems, DX and HX, to remediate groundwater in the 100-HR-3 OU. Cr(VI) is removed by the KR4, KX, and KW P&T systems to remediate groundwater in the 100-KR-4 OU. Table 1-1 provides a performance summary for the five P&T systems for 2019.

The primary COCs in the 100-NR-2 OU are strontium-90 and petroleum/diesel products. DOE maintains a permeable reactive barrier (PRB) remedy along the 100-N Area shoreline to reduce the flux of strontium-90 entering the river and a petroleum free-floating product remedy to remove diesel contaminants from the groundwater.

In July 2018, a Record of Decision (ROD) was issued (EPA et al., 2018, *Record of Decision Hanford 100 Area Superfund Site 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units* [hereinafter referred to as the 100-D/100-H Areas ROD]) that selected a final remedy of P&T for Cr(VI) and total chromium. The remedy included continued use of the DX and HX P&T systems for groundwater treatment. The DX and HX P&T systems operated throughout 2019 to remediate Cr(VI) in the 100-HR-3 OU, which includes the combined 100-D and 100-H Areas and the Horn area.

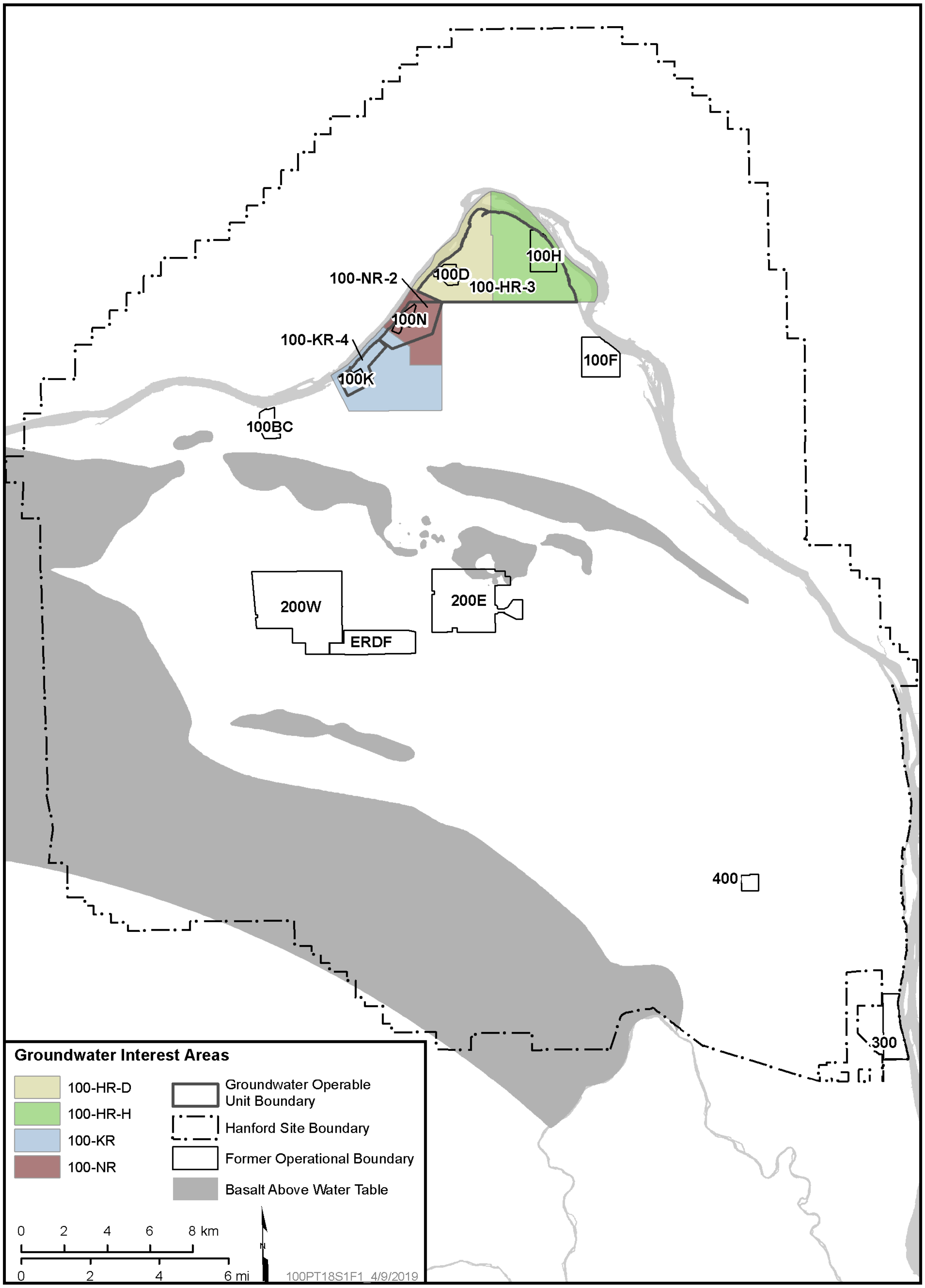

Figure 1-1. Locations of Groundwater OUs and Interest Areas Along the Columbia River

Table 1-1. P&T Performance Summary, 2019

Groundwater Operable Unit P&T System	100-HR-3		100-KR-4		
	DX	HX	KW	KR4	KX
Design capacity (L/min [gal/min])	2,936 (775)	3,407 (900)	1,250 (330)	1,250 (330)	3,410 (900)
Extraction wells[a]	46	43	6[b]	11	22
Injection wells[a]	13	19	4[c]	5	10
Average flow rate (L/min [gal/min])	2,450 (647)	1,954 (516)	1,023 (270)	965 (255)	3,405 (899)
Volume treated (million L [million gal])	1,276 (337)	1,013 (268)	537 (142)	504 (133)	1,786 (472)
Cr(VI) mass removed (kg)	24.1	30.6	19.6	1.7	27.3
Average Cr(VI) influent concentration (µg/L)	18.5	31.2	28.8	4.5	16.2
Average Cr(VI) effluent concentration (µg/L)	<2	<2	<2	<2	<2

a. The number of extraction and injection wells includes those that are not in service but are still connected to the system as of December 31, 2019.

b. Extraction wells connected to the KW P&T system target pumping efforts between the KW Reactor and the 183.1KW Headhouse.

c. Treated water can be valved to flow into injection wells or into the infiltration gallery.

Cr(VI) = hexavalent chromium

P&T = pump and treat

The P&T systems in the 100-HR-3 OU are making progress toward meeting the remedial action objectives (RAOs) for groundwater, as specified in the 100-D/100-H Areas ROD (EPA et al., 2018):

- **RAO #1:** Prevent unacceptable risk to human health from ingestion of and incidental exposure to groundwater containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #2:** Prevent unacceptable risk to human health and ecological receptors from groundwater discharges to surface water containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #7:** Restore groundwater in the 100-HR-3 OU to cleanup levels, which include drinking water standards (DWSs), within a timeframe that is reasonable given the particular circumstances of the site.

Groundwater remediation at the 100-KR-4 OU continued in 2019 in accordance with EPA/ROD/R10-96/134, *Declaration of the Record of Decision, USDOE Hanford 100 Area, 100-HR-3 and 100-KR-4 Operable Units, Hanford Site, Benton County, Washington* (hereinafter referred to as the 100-HR-3 and 100-KR-4 OU interim action ROD). The explanation of significant differences 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 a revised surface water quality criterion of 10 µg/L based on the assumption that contaminated groundwater (prior to discharging to the Columbia River) is mixed on a 1:1 basis with relatively uncontaminated water within a nearshore mixing zone along the river. Consequently, a remediation target of 20 µg/L for Cr(VI) in groundwater is currently applied to nearshore and compliance wells along the Columbia River.

Interim actions at the 100-KR-4 OU are part of the effort to achieve the following interim RAOs, as identified in the 100-HR-3 and 100-KR-4 OU interim action ROD (EPA/ROD/R10-96/134):

- **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 selected and constructed 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 after 10 years of operation, P&T was deemed ineffective in reducing the strontium-90 flux to the Columbia River. In accordance with Ecology et al., 1989, *Hanford Federal Facility Agreement and Consent Order Action Plan* (hereinafter referred to as the Tri-Party Agreement Action Plan), 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. Demolition and decommissioning of the 100-NR-2 P&T system was completed in 2017. 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 chemicals as a reactive material to sequester strontium-90 in situ in the groundwater.

The following four RAOs for the 100-NR-2 OU are identified in the interim action 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 100-NR-2 OU 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 Action Plan (Ecology et al., 1989) milestone target dates 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 Tri-Party Agreement milestone is directly applicable to the 100-HR-3, 100-KR-4, and 100-NR-2 OUs:

- ***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 operation and enhancement of Cr(VI) groundwater remedies in the 100-HR-3 and 100-KR-4 OUs continue to reduce overall groundwater chromium concentrations. Plume areas exceeding DWSs continue to decrease in the 100-HR-3 and 100-KR-4 OUs.

DOE continues to optimize P&T remedies in the 100-HR-3 and 100-KR-4 OUs. DOE reviews remedial action progress regularly and annually evaluates recommendations for changes to the remedial action systems to improve performance and shorten the remedy completion timeframe. Remedial process optimization (RPO) activities for 2019 at the 100-HR-3 and 100-KR-4 OU remedial systems focused on the following:

- **Assessing extraction and injection well performance:** Includes evaluating individual well performance and identifying wells needing 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, or along the leading edge of plumes).
- **Evaluating well network performance:** Includes evaluating the placement and pumping rates of wells with respect to contaminant plume distribution and monitoring. Modeling tools were used to evaluate anticipated well field performance under selected pumping scenarios. Based on these assessments, additional monitoring and extraction capability was added to the P&T systems. Selected existing wells were realigned as extraction wells, and new wells were drilled and constructed. This effort is focused on enhancing plume monitoring, enhancing contaminant capture and mass removal in source areas, and protecting the Columbia 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 using the current ResinTech® SIR-700 IX resin. In 2019, the resin continued to provide highly efficient Cr(VI) removal from extracted groundwater.
- **Soil flushing effectiveness:** Based on the soil flushing test results at the KW P&T system, DOE is evaluating whether additional soil flushing of secondary sources of Cr(VI) is appropriate to meet cleanup timeframes in the 100-KR-4 OU or in the other River Corridor groundwater OUs.

Groundwater P&T systems in the 100-HR-3 OU continue to show progress in river protection. However, during 2019, 600 m (1,970 ft) of the 3,300 m (10,825 ft) shoreline affected by the Cr(VI) plume in the 100-D Area were identified as not being adequately protected compared to 100 m (330 ft) in 2018. The affected shoreline is primarily north of the 100-D Area and toward the Horn. In the 100-H Area, 200 m (660 ft) of shoreline length identified as not adequately protected in 2018 was reduced in 2019 to 100 m (330 ft). The remainder of the affected shoreline in the 100-D and 100-H Areas was identified as either “protected,” or as “protected but additional action may be required.”

The river protection evaluation for the 100-K Area in 2019 identified that all 4,000 m (13,120 ft) of shoreline affected by chromium-contaminated groundwater were “protected” or “protected but additional action may be required.”

The P&T remedial actions are not yet complete, but current estimates indicate that the P&T approach is capable of remediating the Cr(VI) groundwater contamination. Annual assessments of river protection status (presented in Chapter 2 for the 100-HR-3 OU and in Chapter 3 for the 100-KR-4 OU) indicate ongoing progress for river protection for the two OUs.

ResinTech® is a registered trademark of ResinTech, Inc., West Berlin, New Jersey.

Groundwater samples at the 100-NR-2 OU PRB monitoring points show that concentrations in many of the monitoring wells during 2019 continued to be lower than pre-barrier levels by nearly 90%. However, In 2015, concentrations of strontium-90 increased in some of the monitoring wells and remained elevated throughout 2019.

This annual summary report discusses groundwater remedial actions conducted during 2019 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 respective chapters. Chapter 5 provides the references cited in this report.

1.1 100-HR-3 Operable Unit Activities

The DX and HX P&T systems operated throughout 2019, with several wells realigned to improve capture and remove contaminant mass from the aquifer. The methodology for evaluating river protection was initially presented in 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*, where areas along the Columbia River were classified as “protected,” “not protected,” or “action may be required.” Those areas considered at risk for contamination impacts were evaluated, and actions were initiated to improve river protection in those areas.

Figure 1-2 shows the 2019 P&T system layout for the 100-HR-3 OU, and Figure 1-3 highlights the well changes to the P&T system configuration. In 2019, two monitoring wells were converted to injection wells connected to the DX P&T system for hydraulic plume control. The HX P&T system changes included connecting two additional wells for extraction. Two new injection wells were connected to the HX P&T system for hydraulic plume control in 2019. Section 2.2 provides further details on the changes to the DX and HX P&T systems.

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 OU P&T systems. Table 1-1 presents the amount of water treated and mass removed by each system during 2019. The amount of mass removed by the systems each year began to decrease after the main source areas were remediated, and the areas of high concentrations have been reduced in size. As shown in Figure 1-5, this trend continued in 2019.

Multiple water-bearing zones are known to be present within the Ringold upper mud unit (RUM) in the 100-HR-3 OU. These zones are present at different depths, and the number and connectivity of these various water-bearing zones have not been determined. However, the uppermost water-bearing zone (termed the RUM aquifer) is contaminated and is the focus of ongoing characterization and remediation efforts. In 2019, water was extracted from the RUM aquifer from seven extraction wells for treatment at the 100-HR-3 P&T systems. New wells drilled during fiscal year (FY) 2019 and planned in FY 2020 will allow for delineation of the RUM aquifer Cr(VI) plume at 10 µg/L in the Horn. Section 2.2.3 provides further details on Cr(VI) monitoring of the RUM aquifer.

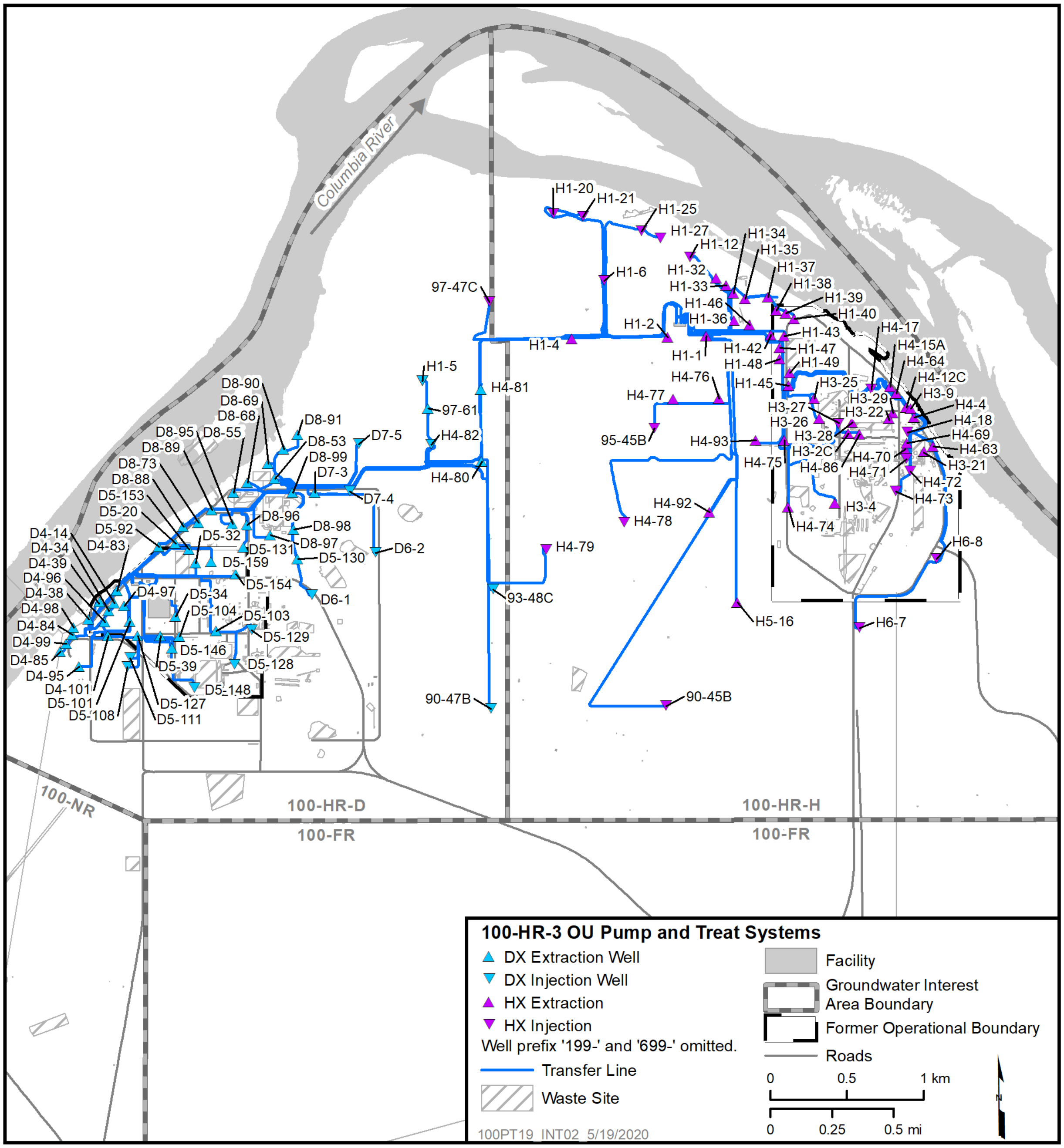

Figure 1-2. Layout of the 100-HR-3 OU P&T Systems (as of December 31, 2019)

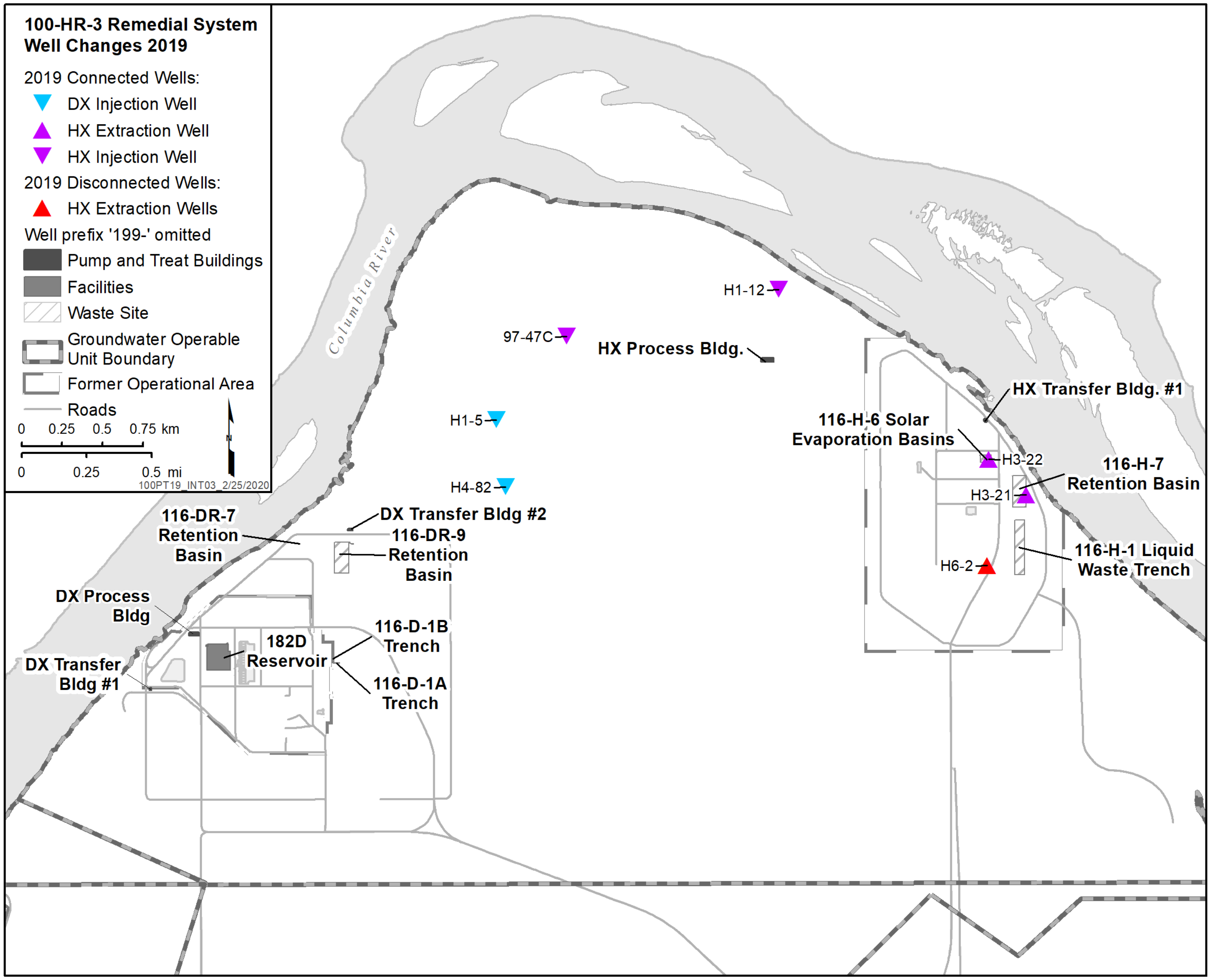

Figure 1-3. Well Changes Completed to the 100-HR-3 OU P&T Systems

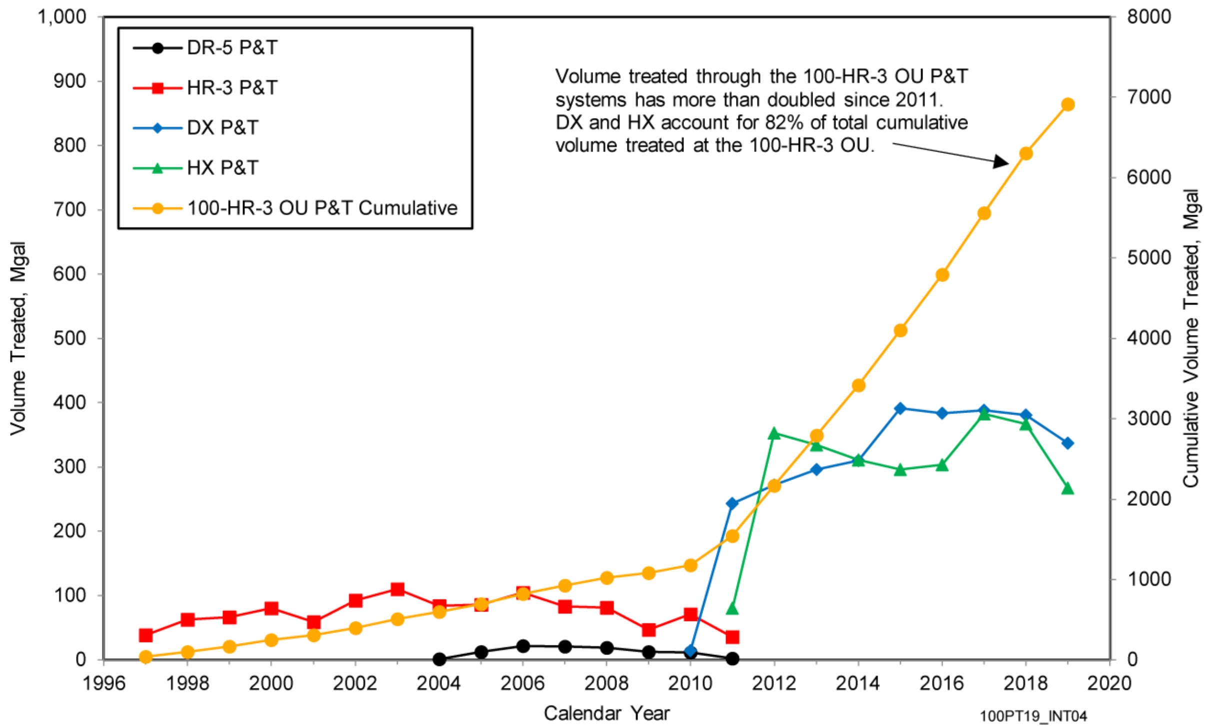

Figure 1-4. Volume Treated at the 100-HR-3 OU P&T Systems

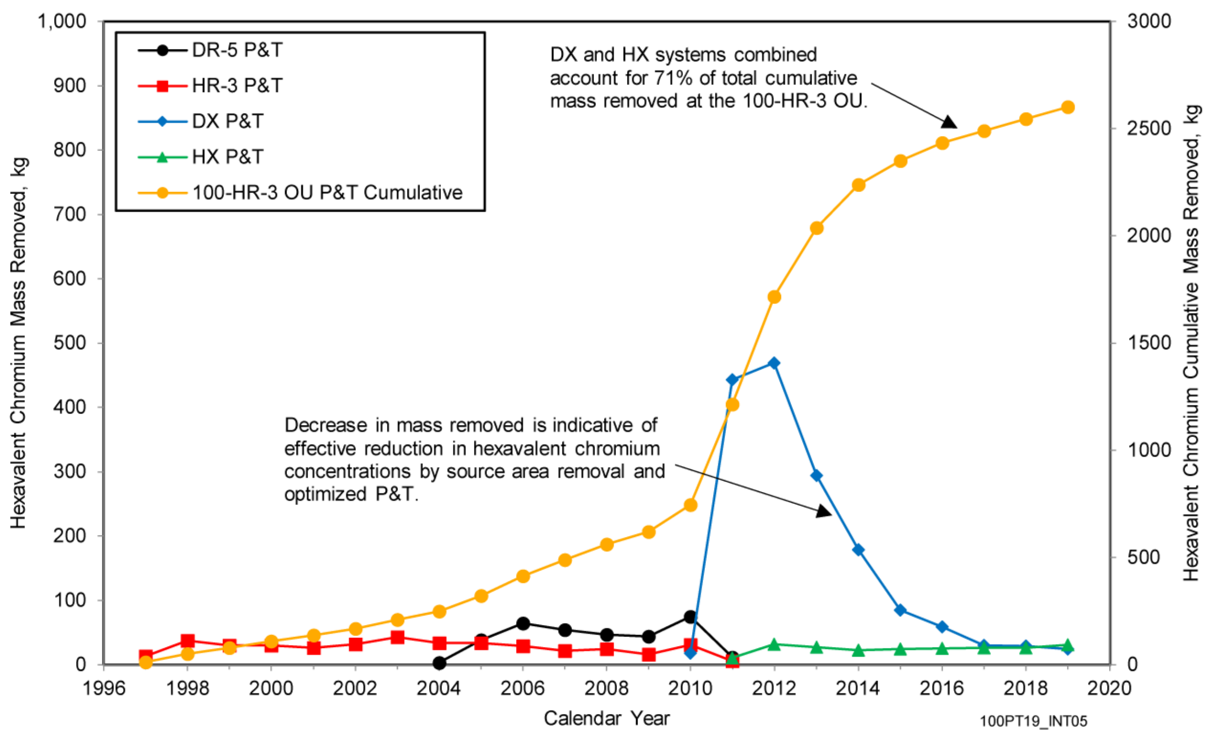

Figure 1-5. Cr(VI) Mass Removed by the 100-HR-3 OU P&T Systems

1.2 100-KR-4 Operable Unit Activities

In 2019, three active P&T systems continued operating in the 100-KR-4 OU. The KR4 P&T system treats groundwater downgradient from the 116-K-2 Trench. The KX P&T system treats groundwater between the 116-K-2 Trench and the N Reactor area, as well as in the vicinity of the KE Reactor. The KW P&T system extracts and treats groundwater near the KW Reactor. In total, the three P&T systems are capable of treating up to 5,900 L/min (1,560 gal/min). Figure 1-6 shows the layout of the 100-KR-4 OU P&T systems, and Figure 1-7 highlights the changes to the 100-KR-4 OU P&T system configuration implemented in 2019.

A soil flushing treatability test was conducted at the KW P&T system in 2019, and the initial results are discussed in Chapter 3. In 2018, DOE and the U.S. Environmental Protection Agency (EPA) approved a soil flushing treatability test plan (DOE/RL-2017-30, *KW Soil Flushing/Infiltration Treatability Test Plan*) and a sampling and analysis plan (SAP) (DOE/RL-2018-10, *KW Soil Flushing/Infiltration Treatability Test Plan Sampling and Analysis Plan*). The treatability test was designed to target a source of Cr(VI) contamination located in the deep vadose zone near KW extraction well 199-K-205. This source continues to produce Cr(VI) groundwater contamination above the Model Toxics Control Act (MTCA) (WAC 173-340, "Model Toxics Control Act—Cleanup") standard of 48 µg/L near the 183.1KW Headhouse.

Figures 1-8 and 1-9 show the annual and cumulative volume treated and mass removed by the 100-KR-4 P&T systems. Changeover to SIR-700 IX resin in 2012 at the 100-KR-4 P&T facilities, increased the treatment capacity of each system (Figure 1-8). Table 1-1 presents the amount of water treated and mass removed by each system during 2019.

1.3 100-NR-2 Operable Unit Activities

This section summarizes the activities at the 100-NR-2 OU for 2019.

1.3.1 100-NR-2 Operable Unit Permeable Reactive Barrier

Performance monitoring is ongoing along the entire treated portion of the PRB and is discussed further in Chapter 4. Figure 1-10 shows the location of the original PRB and the upstream and downstream extensions. Additional injections were not conducted in 2019. Wells and aquifer tubes downgradient of the treated segments of the PRB continued to be monitored. Groundwater monitoring of the upriver and downriver PRB extensions indicates that concentrations in the majority of the monitoring wells during 2019 were lower than the pre-injection levels. However, since 2016, strontium-90 concentrations at two of the downriver PRB monitoring wells have increased to pre-injection concentrations. Chapter 4 provides further discussion on PRB performance.

1.3.2 Total Petroleum Hydrocarbons Removal

Removal of total petroleum hydrocarbons (TPH) free-floating product from wells 199-N-18 and 199-N-183 continued in 2019 using a polymer "smart sponge" that selectively absorbs petroleum products from the groundwater within the well. In 2019, at total of 1.23 kg of diesel was removed. Chapter 4 provides further discussion on TPH remediation.

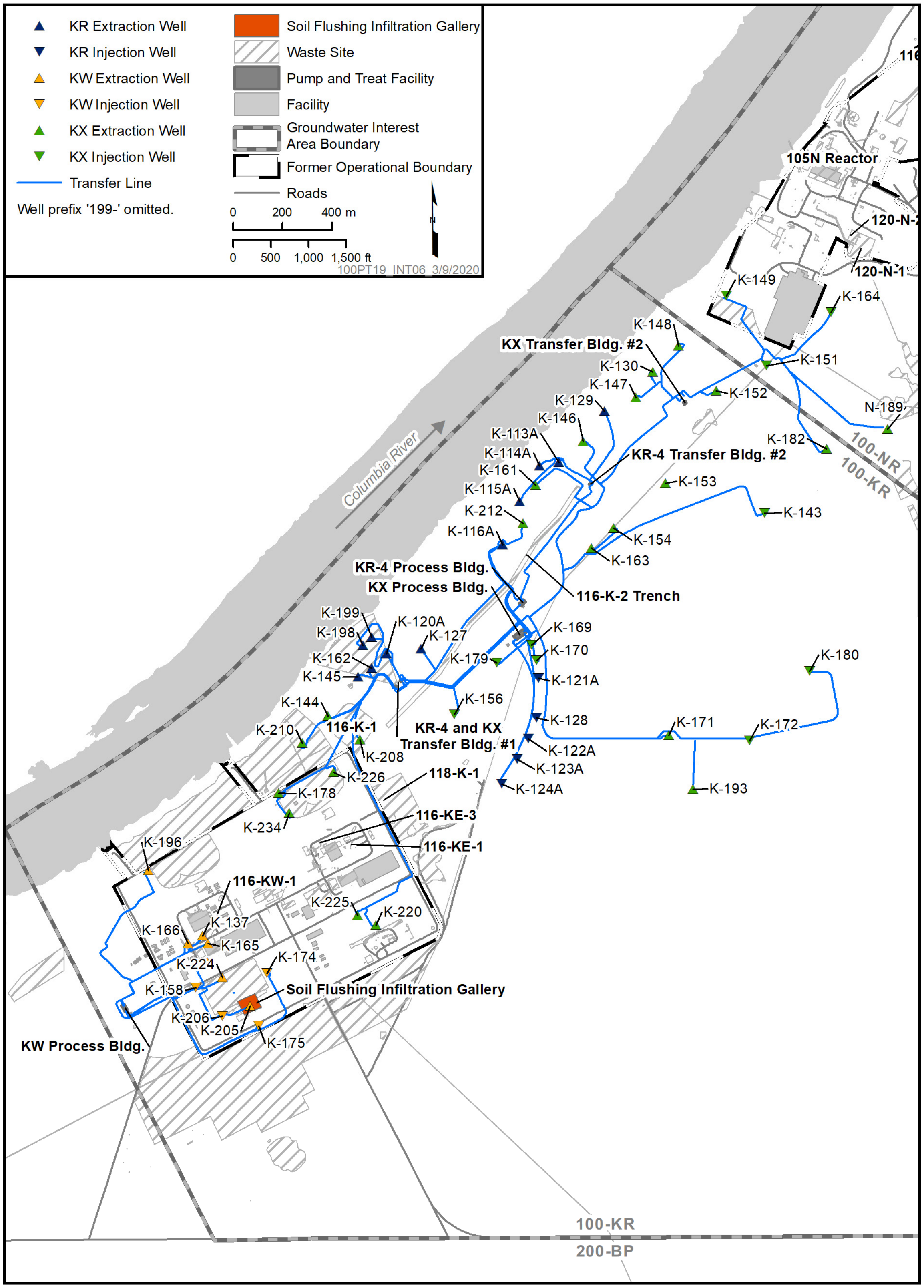

Figure 1-6. Layout of 100-KR-4 OU P&T Systems

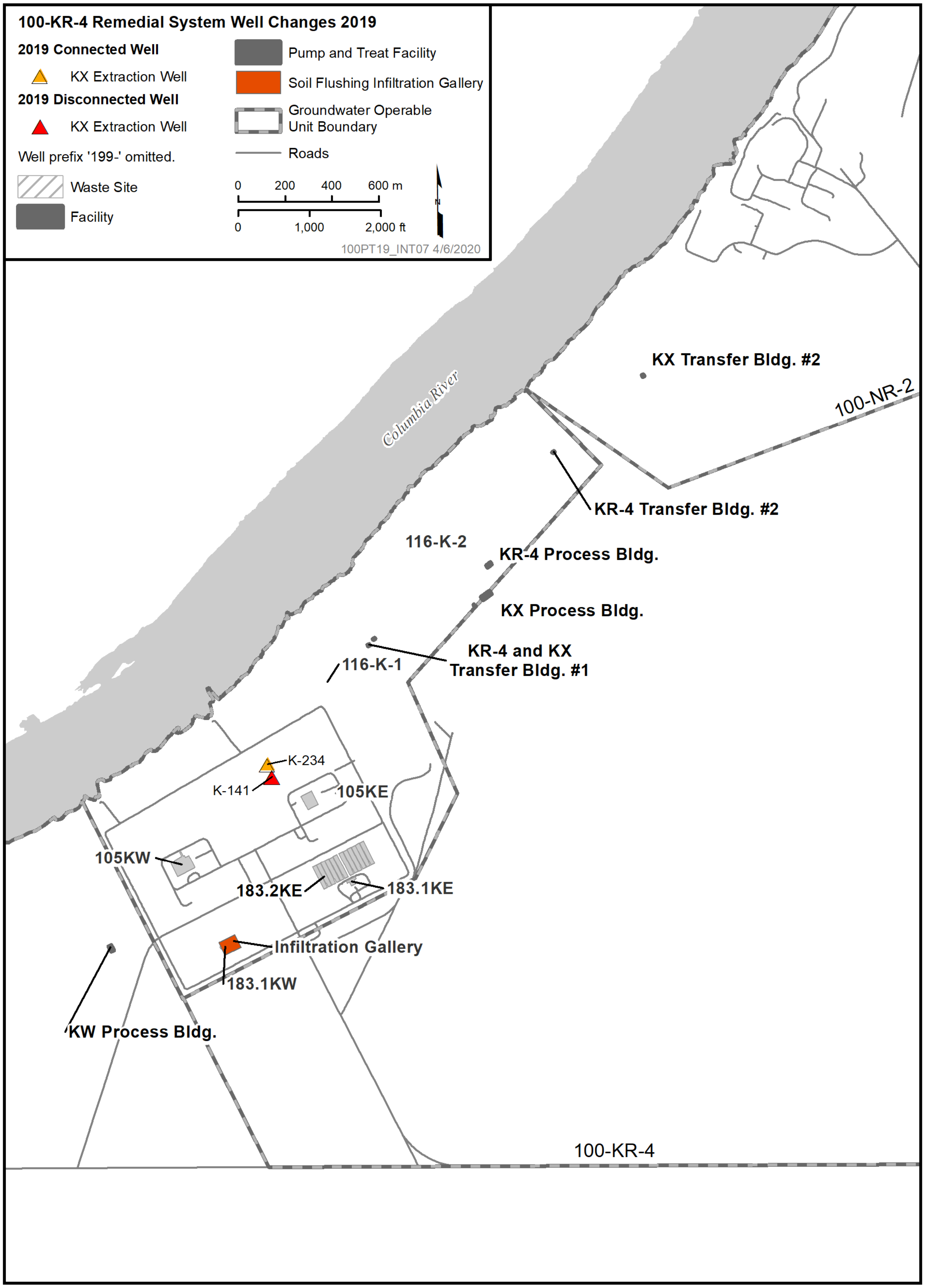

Figure 1-7. Well Changes Completed to the 100-KR-4 OU Well Network, 2019

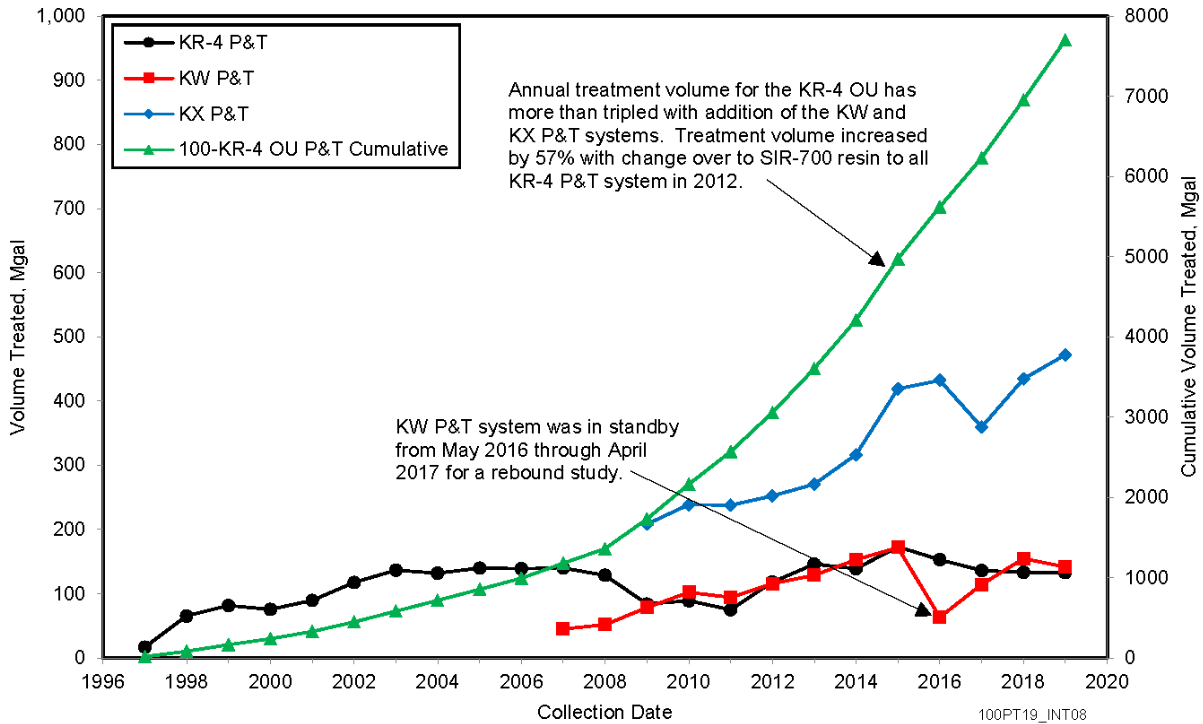

Figure 1-8. Volume Treated at the 100-KR-4 OU P&T Systems

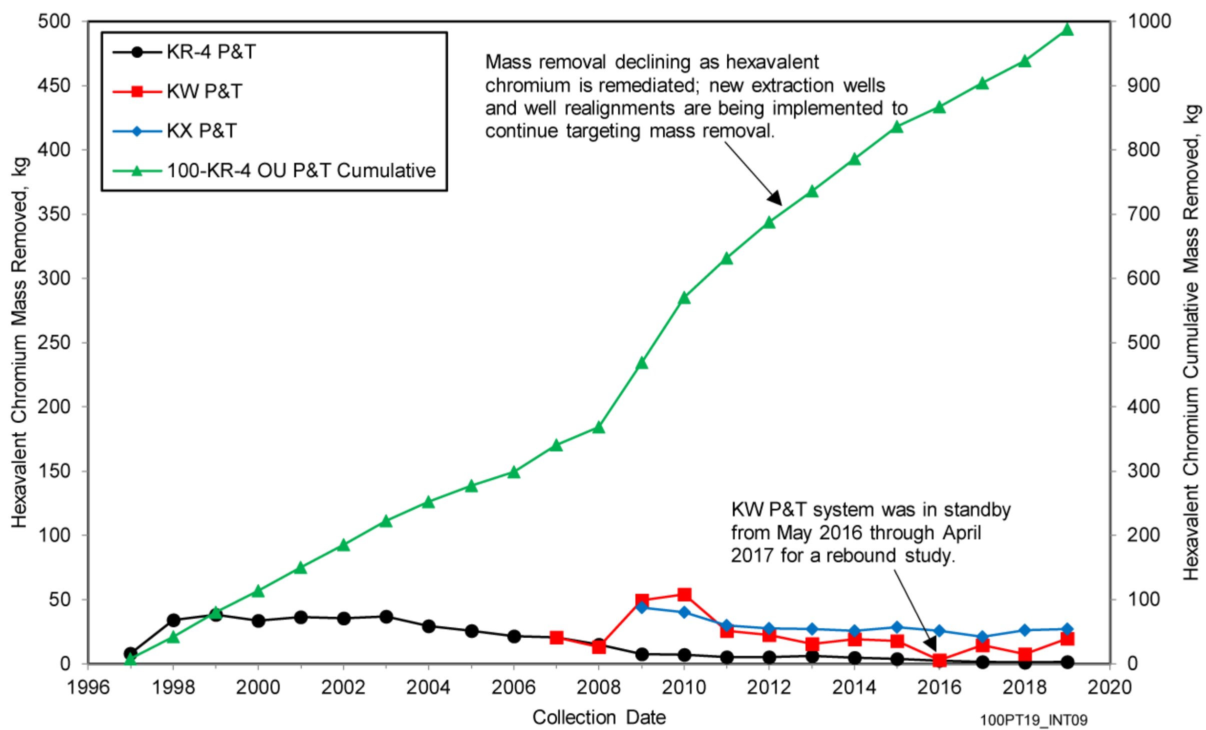

Figure 1-9. Cr(VI) Mass Removed by the 100-KR-4 OU P&T Systems

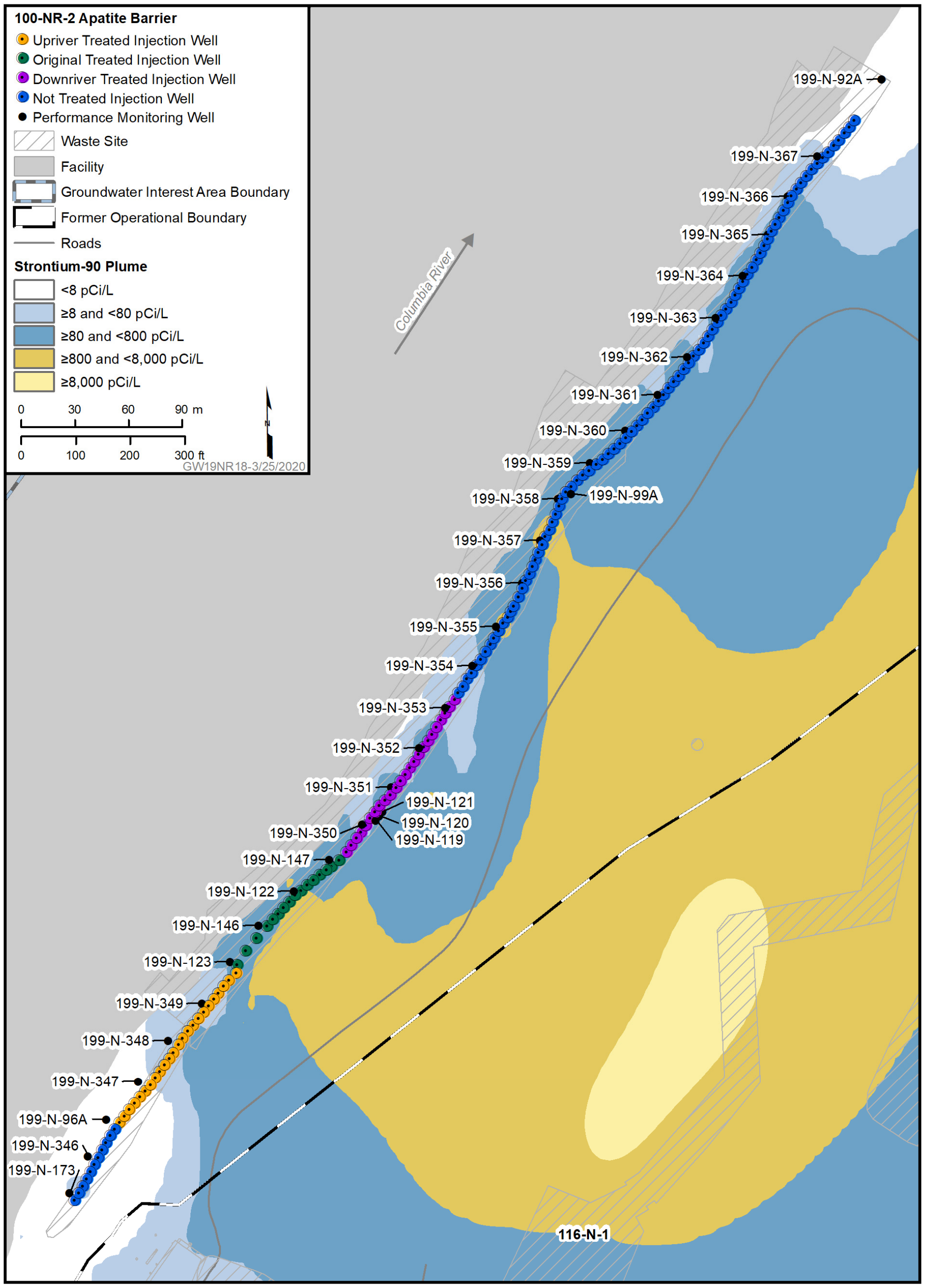

Figure 1-10. Treated Segments of the 100-NR-2 OU Apatite PRB

1.4 CERCLA Decision Document Activities

In July 2018, the 100-D/100-H Areas ROD (EPA et al., 2018) was issued, which selected a final remedy of P&T for Cr(VI) and total chromium. The remedy included continued use of the DX and HX P&T systems to treat groundwater. Nitrate and strontium-90 were identified as groundwater COCs, with monitored natural attenuation (MNA) selected as the remedy for both contaminants and institutional controls (ICs) restricting groundwater use for all COCs. With the issuance of the 100-D/100-H Areas ROD, a new RD/RAWP (DOE/RL-2017-13, Draft A, *Remedial Design/Remedial Action Work Plan for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*) was developed.

The RD/RAWP, which is currently being reviewed by the regulatory agencies, was developed to ensure that the remedial actions are operating with the goal of meeting the RAOs described in the 100-D/100-H Areas ROD. The new RD/RAWP will supersede the interim action RD/RAWP (DOE/RL-2013-31) upon signature approval.

DOE/RL-2010-97, Draft B, *Remedial Investigation for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*, was submitted for regulatory review in May 2019. Draft B included additional characterization data collected beneath the former KE Reactor fuel storage basin (FSB) and the former 116-KE-3 Crib/reverse well to fill a data gap regarding the nature and extent of vadose zone contamination near the reactor structure before issuing Rev. 0 of the remedial investigation (RI)/feasibility study (FS) report. This data gap was filled and documented in SGW-60149, *Report for Soil Borings and Well Installations in the UPR-100-K-1 and 116-KE-3 Waste Sites*. In 2018, the decision was made to separate the RI and FS into two separate documents. Once both documents are completed, they will provide the framework for a proposed plan, which will evaluate alternatives and recommend a preferred alternative. DOE and EPA will issue a ROD that incorporates stakeholder input and identifies the selected alternatives for waste site and groundwater cleanup. Interim remedial actions will continue until the ROD is issued. The FS is anticipated to be completed in 2020.

In November 2019, DOE/RL-2012-15, Draft B, *Remedial Investigation/Feasibility Study for the 100-NR-1 and 100-NR-2 Operable Units*, was submitted to the Washington State Department of Ecology (Ecology) (the lead regulatory agency for the 100-NR-1 and 100-NR-2 OUs) for review.

1.5 Atomic Energy Act Groundwater Monitoring Evaluation of Liquid Effluent

The *Atomic Energy Act of 1954* (AEA) groundwater monitoring plan establishes the plan for sitewide monitoring at the Hanford Site (DOE/RL-2015-56, *Hanford Atomic Energy Act Sitewide Groundwater Monitoring Plan*). The AEA groundwater monitoring and evaluation of liquid effluents are required for P&T systems in accordance with DOE O 458.1 Chg 3 (Admin Chg), *Radiation Protection of the Public and the Environment*. This DOE order requires effluent monitoring to prevent unacceptable exposure of the public and ecological receptors to radiation and for managing discharges that could result in new or increased plumes that would require mitigation action or remediation.

Evaluating effluent water from the P&T systems in the 100 Areas includes calculating the total effective dose (TED) produced by radioisotopes present in the effluent water following treatment of extracted groundwater to remove identified contaminants. The resulting dose is compared to the target cumulative dose limit of 100 mrem/yr to the public, as established by DOE O 458.1. The cumulative TED is based on use of the derived concentration standard (DCS), as defined in DOE-STD-1196-2011, *Derived Concentration Technical Standard*. In addition to evaluating the effluent constituents, selected monitoring wells in the 100-K Area have been identified for additional evaluation of potential dose contribution in areas downgradient of effluent injection wells.

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

This evaluation further compares the radioisotopes in effluent water to the following radiological DWSs: (1) the 4 mrem/yr maximum contaminant level (MCL) dose for beta/photon emitters, and (2) the 30 µg/L MCL for uranium. Sections 2.3 and 3.3 provide details on the radiological dose and DWS analysis for the 100-HR-3 and 100-KR-4 OU P&T systems effluent, respectively.

1.6 Quality Assurance/Quality Control

Appendix E of the annual Hanford Sitewide groundwater monitoring report for 2019 (DOE/RL-2019-66, *Hanford Site Groundwater Monitoring Report for 2019*) discusses quality assurance and quality control for groundwater sampling and analysis of wells. The annual report also includes information on quality assurance/quality control issues that may affect groundwater data interpretation.

2 100-HR-3 Operable Unit Remediation

This chapter provides the status of the final remedy and *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) activities for the 100-HR-3 Groundwater OU. The following discussion includes the final remedy P&T system performance for 2019 and a summary of progress made toward remediating the suprabasalt aquifer since the start of P&T operations.

2.1 Overview of Operable Unit Activities

The 100-HR-3 OU consists of groundwater contaminated by releases from facilities and waste sites associated with past operations at the D, DR, and H Reactors. Contamination from the releases migrated through the soil column to the groundwater and now underlies 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 groundwater COC and target of remedial action.

Initial remedial actions began at the 100-HR-3 OU in 1997 with installation of a small P&T system, HR3, under an interim action ROD (EPA/ROD/R10-96/134) and in accordance with 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*. A second P&T system, DR5, was installed in 2004. In 2010 and 2011, the two original systems were replaced with the larger DX and HX P&T systems.

The selected final remedy in the 100-D/100-H Areas ROD (EPA et al., 2018) authorized continued use of the DX and HX P&T systems for groundwater treatment. The ROD established a cleanup level of 10 µg/L for Cr(VI) where groundwater discharges to surface water and 48 µg/L inland (Table 6 in the ROD). The cleanup levels for total chromium are 65 µg/L where groundwater discharges to surface water and 100 µg/L inland. Other groundwater contaminants were identified as nitrate and strontium-90, with a selected final remedy of MNA for both.

With the issuance of the 100-D/100-H Areas ROD (EPA et al., 2018), a new RD/RAWP (DOE/RL-2017-13, Draft A) was prepared. The new RD/RAWP was developed to ensure that the P&T systems are operated with the goal of meeting the RAOs described in the ROD. The new RD/RAWP it is currently being reviewed by the regulatory agencies. In accordance with the ROD, work shall continue to be performed in accordance with the existing approved RD/RAWP until the new RD/RAWP is approved.

DOE/RL-2013-30, *Sampling and Analysis Plan for 100-HR-3 Groundwater Operable Unit Monitoring*, was 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 (EPA/ROD/R10-96/134). A new SAP is being prepared to meet the performance and monitoring criteria identified in the 100-D/100-H Areas ROD (EPA et al., 2018) and the new RD/RAWP (DOE/RL-2017-13, Draft A).

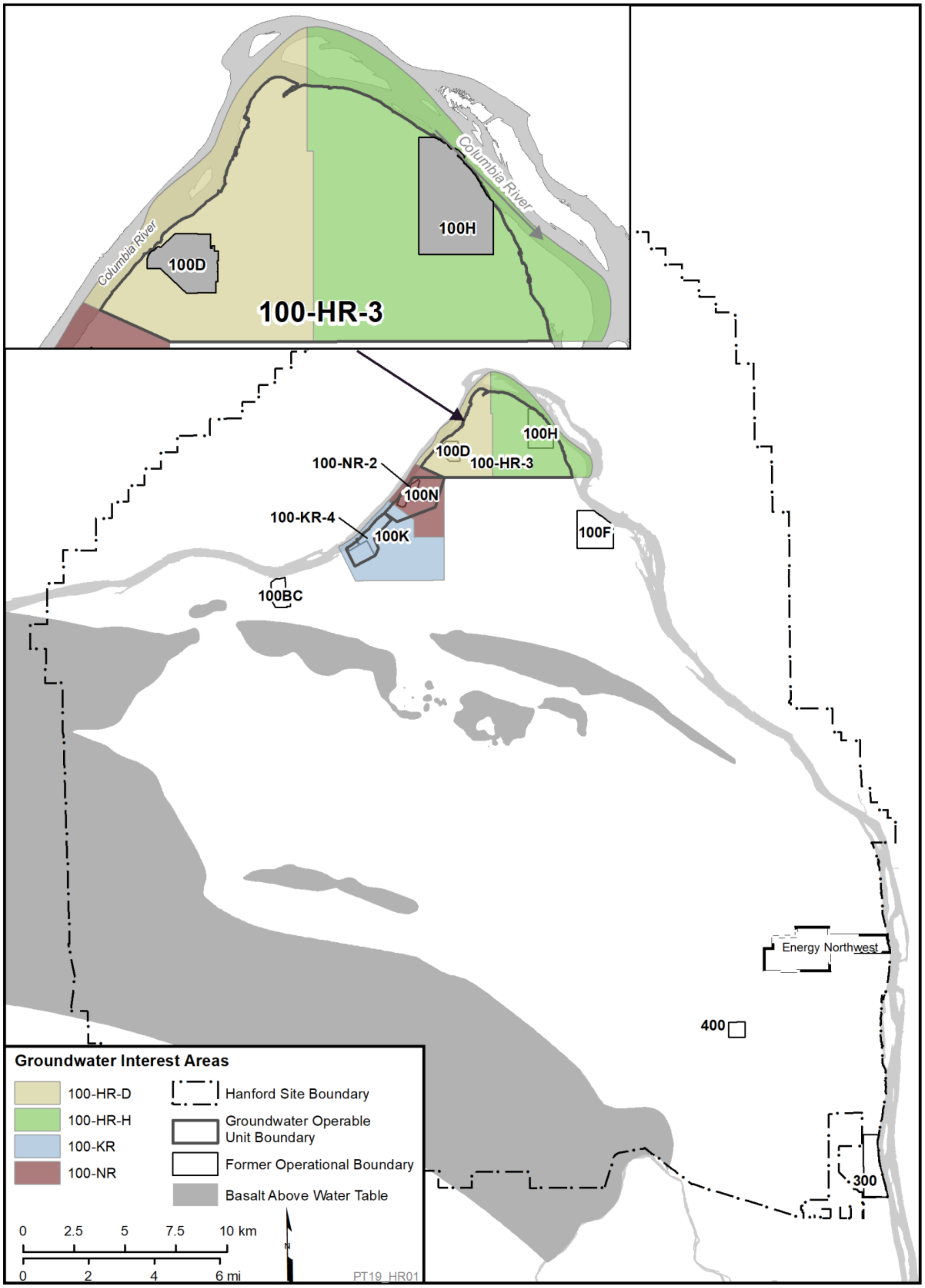

Figure 2-1. Location of the 100-HR-3 OU and Groundwater Interest Area

Monitoring, data evaluation, and site characterization activities are conducted to evaluate performance of the 100-HR-3 OU P&T systems compared to design criteria, to determine if system design modifications or operating parameters will further optimize performance, and to assess the measurable progress toward achieving plume cleanup and river protection RAOs:

- **RAO #1:** Prevent unacceptable risk to human health from ingestion of and incidental exposure to groundwater containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #2:** Prevent unacceptable risk to human health and ecological receptors from groundwater discharges to surface water containing contaminant concentrations above federal and state standards and risk-based thresholds.
- **RAO #7:** Restore groundwater in 100-HR-3 to cleanup levels, which include DWSs, within a timeframe that is reasonable given the particular circumstances of the site.

This chapter discusses the results of the 100-HR-3 OU P&T evaluation for 2019:

- Section 2.2 discusses the groundwater remediation activities.
- Section 2.3 discusses the radiological dose analysis of the system effluent.
- Section 2.4 provides the remedial action cost summary.
- Section 2.5 presents the conclusions regarding 2019 remedy performance.

2.2 100-HR-3 Operable Unit Remedial Action Activities

This section discusses the CERCLA activities for the 100-HR-3 OU for 2019, including activities related to operation and performance monitoring of the DX and HX P&T systems and contaminant monitoring in the RUM aquifer. Specific activities and operational performance details for the P&T 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.

Table 2-1 lists the changes completed for the 100-HR-3 OU remedial system wells during 2019. The changes were intended to increase system efficiency, enhance hydraulic plume capture, and reduce Cr(VI) plume concentrations. Table 2-1 summarizes the changes to the remedial systems, and Sections 2.2.1 and 2.2.2 provide further details for the DX and HX P&T systems, respectively.

Table 2-1. 100-HR-3 OU Remedial System Well Changes Completed in 2019

System	Well	Action	Purpose	Status as of December 31, 2019
DX	199-H1-5	Connect injection well	Plume control	Operational
	199-H4-82	Connect injection well	Plume control	Operational
HX	199-H6-2	Disconnect extraction well	System performance	Disconnection from HX P&T complete
	199-H3-22	Connect RUM aquifer extraction well	Mass removal	Operational
	199-H3-21	Connect extraction well	Mass removal	Operational
	699-97-47C	Connect injection well	Plume control	Operational
	199-H1-12	Connect injection well	Plume control	Operational

Table 2-1. 100-HR-3 OU Remedial System Well Changes Completed in 2019

System	Well	Action	Purpose	Status as of December 31, 2019

P&T = pump and treat
RUM = Ringold upper mud unit

Figures 2-2 and 2-3 present the 2019 extraction, injection, and monitoring well and aquifer tube locations for the 100-D Area and the 100-H Area, respectively. The figures also identify which aquifer is monitored. Figure 1-2 shows the layouts of the two P&T systems, and Figure 1-3 shows the locations of the new wells and realigned wells (i.e., wells with a change in use) in 2019.

2.2.1 DX Pump and Treat System

The DX P&T system improved the groundwater treatment capacity along the Columbia River and is a key component in DOE's strategy for keeping Cr(VI) from entering the river. Section 2.2.3 discusses the changes in concentrations and the overall trends. The DX P&T system was designed to capture and treat the Cr(VI) plume in the 100-D Area and was originally designed to extract and process up to 2,270 L/min (600 gal/min). Optimization activities have increased the system operational capacity to 2,940 L/min (775 gal/min) and expanded the well network to include the western Horn area. No changes to system treatment capacity were made during 2019. Figure 2-4 provides a schematic of the DX P&T system, which was current as of the end of 2019. Figures 1-4 and 1-5 and Table 2-2 show the cumulative amount of water treated and Cr(VI) removed since startup of the DX P&T system. The number of extraction and injection wells listed for each system includes those that are out of service but are still physically connected to the system. Wells that are out of service include those wells that are scheduled for disconnection from the system but still have piping and other equipment in place, in addition to wells that are in standby mode and are available for use if needed to manage system capacity.

The DX P&T system uses SIR-700 resin to bind Cr(VI) as influent groundwater flows through resin beds in the treatment facility. The SIR-700 resin is a high-capacity, single-use resin that does not require regeneration. No resin replacement was performed in 2019 at the DX P&T system.

2.2.1.1 DX Pump and Treat System Configuration and Changes

The annual plume capture evaluation from 2018 (Section 2.2 in DOE/RL-2018-67, *Calendar Year 2018 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater*) was used to identify areas along the Columbia River where additional plume capture was needed or where mass removal could be improved. The evaluation also identified Cr(VI) concentration trends (increasing, decreasing, stable, or indeterminant) at monitoring locations. The DX P&T system changes completed in 2019 (Figure 1-3) included connecting wells 199-H1-5 and 199-H4-82 to the DX P&T system as injection wells. The two wells (199-H1-5 and 199-H4-82) north of the 100-D Area were determined to be needed for Cr(VI) plume containment in that region of the Horn. Well 699-97-47C (connected to the HX P&T system) was also added for Cr(VI) plume containment in the area north of the 100-D Area.

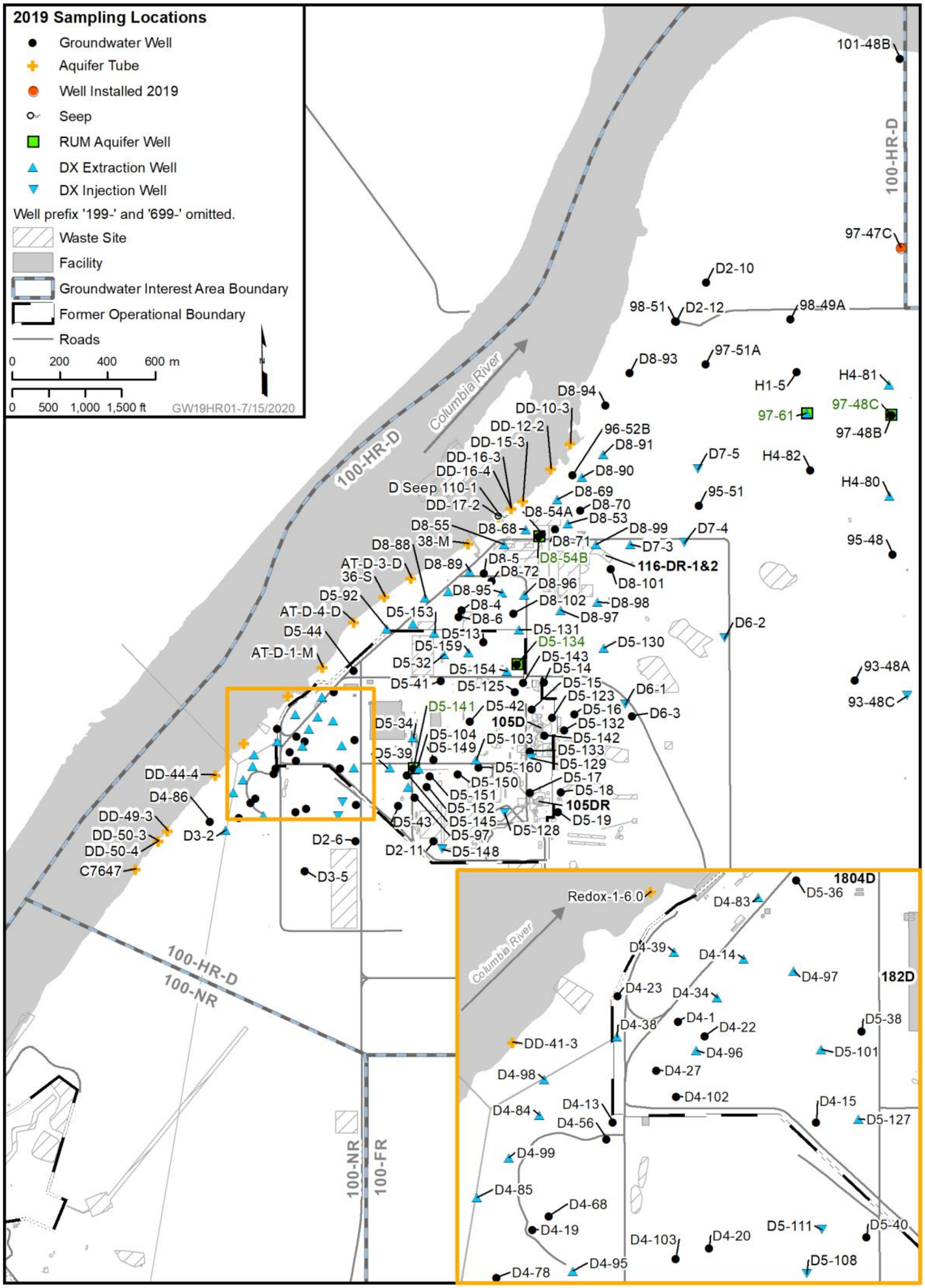

Figure 2-2. 100-D Area Wells and Aquifer Tubes

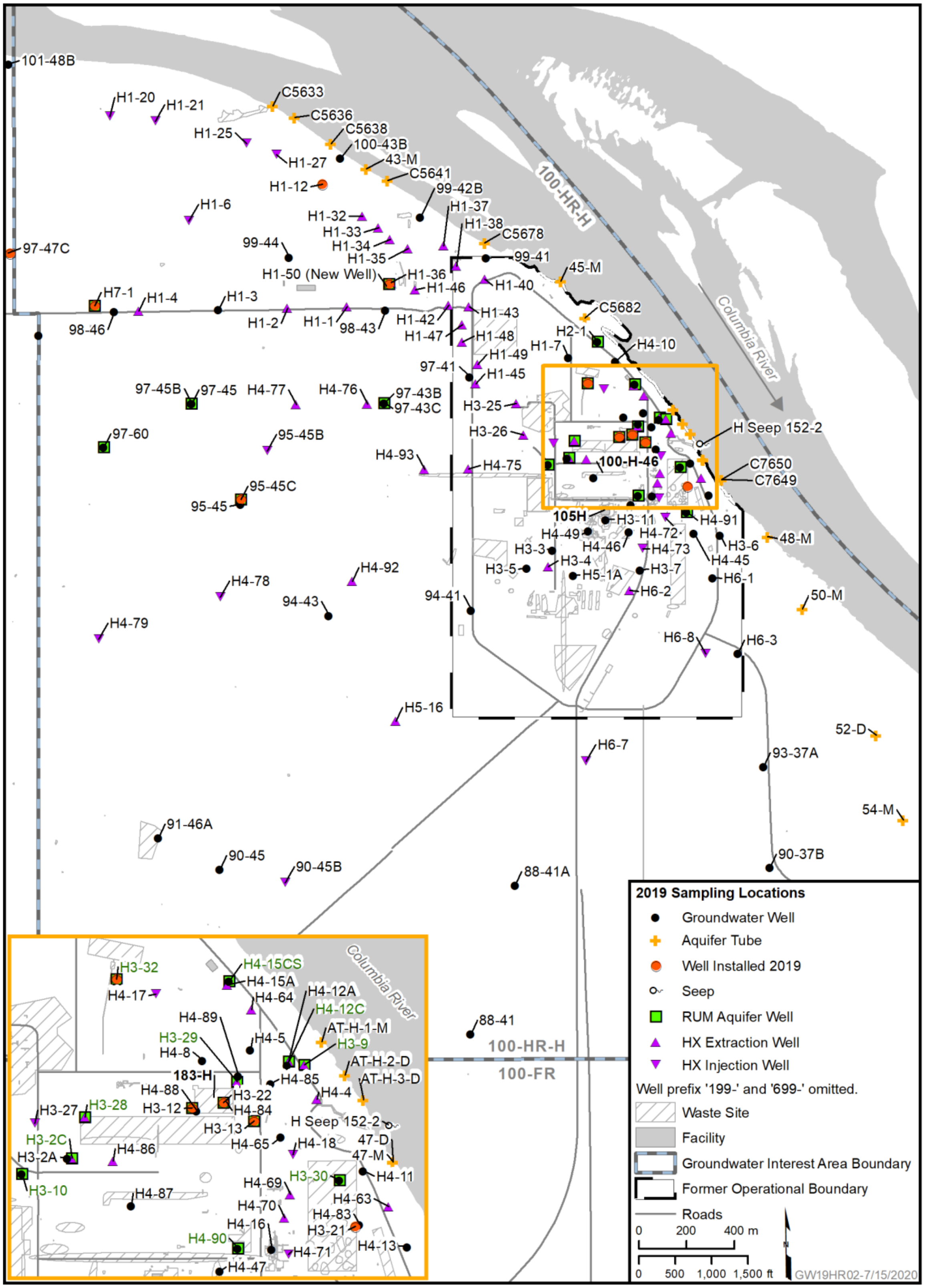

Figure 2-3. 100-H Area Wells and Aquifer Tubes

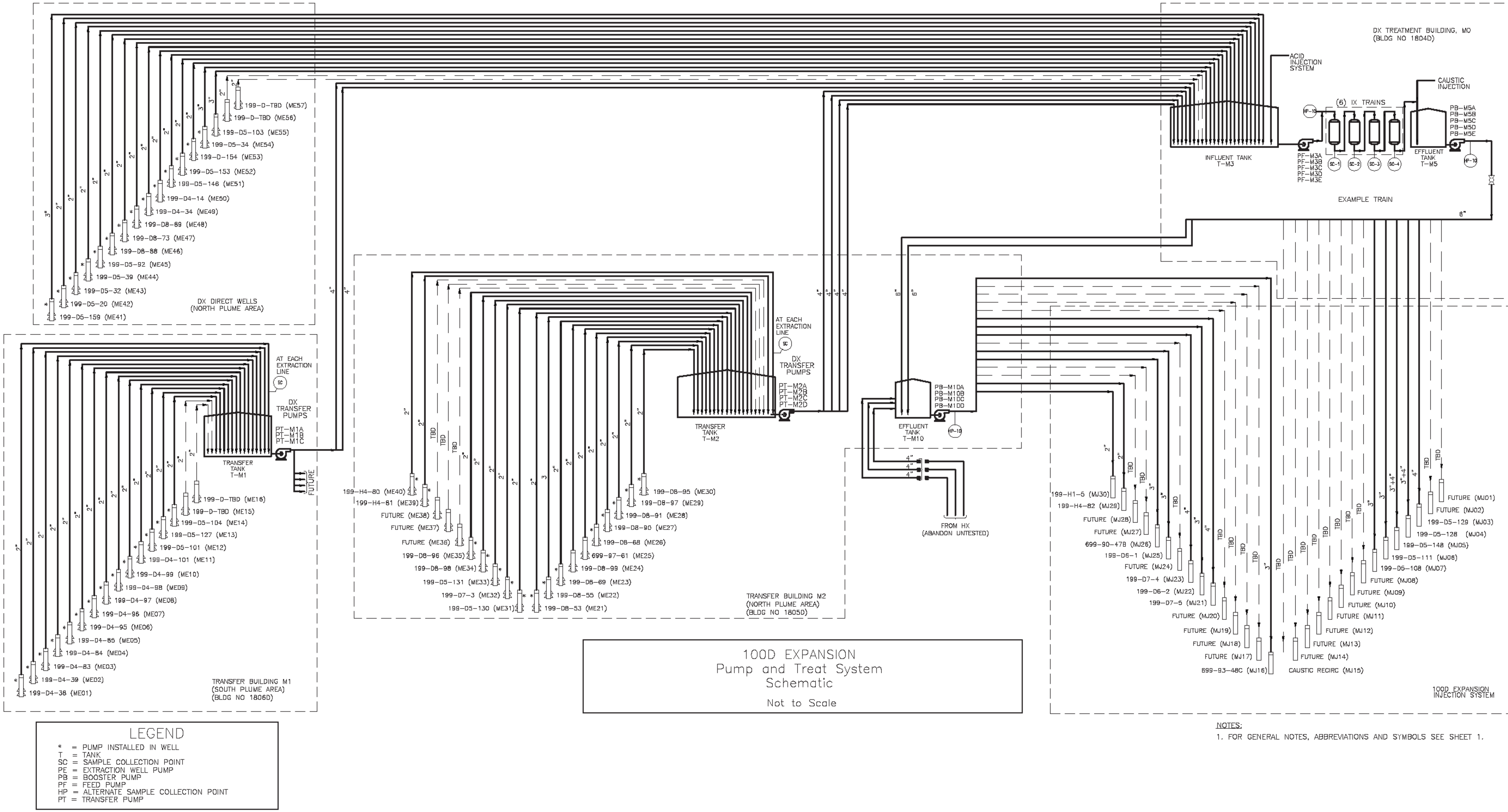

Figure 2-4. DX P&T System Schematic (as of December 2019)

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Table 2-2. Cumulative 100-HR-3 OU P&T Performance Summary

P&T System	DX[a]	HX[b]
Extraction wells[c]	45 unconfined 1 RUM	37 unconfined 6 RUM
Injection wells[c]	13 (all unconfined)	23 (all unconfined)
Cumulative volume treated (million L [million gal]) since startup[d]	11,420 (3,015)	10,202 (2,693)
Cumulative hexavalent chromium mass removed (kg) since startup[d]	1,631	227

a. The DX P&T system was started in 2010.

b. The HX P&T system was started in 2011.

c. The number of extraction and injection wells includes those that are not in service but still connected to the system as of December 31, 2019.

d. Data through December 31, 2019.

P&T = pump and treat

RUM = Ringold upper mud unit

The DX P&T system will continue to be optimized using 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 99% of the time throughout 2019. Figure 2-5 shows the system availability for the reporting period. The total flow rate through the DX P&T system (in terms of percentage of system capacity) was reduced slightly during periods of system and well maintenance. Table 2-3 presents an overview of groundwater extracted, mass removed, and system performance. About the same volume of water was treated in 2019 as in 2018. In general, the mass removed each year has been declining due to remediation of high-concentration contamination areas.

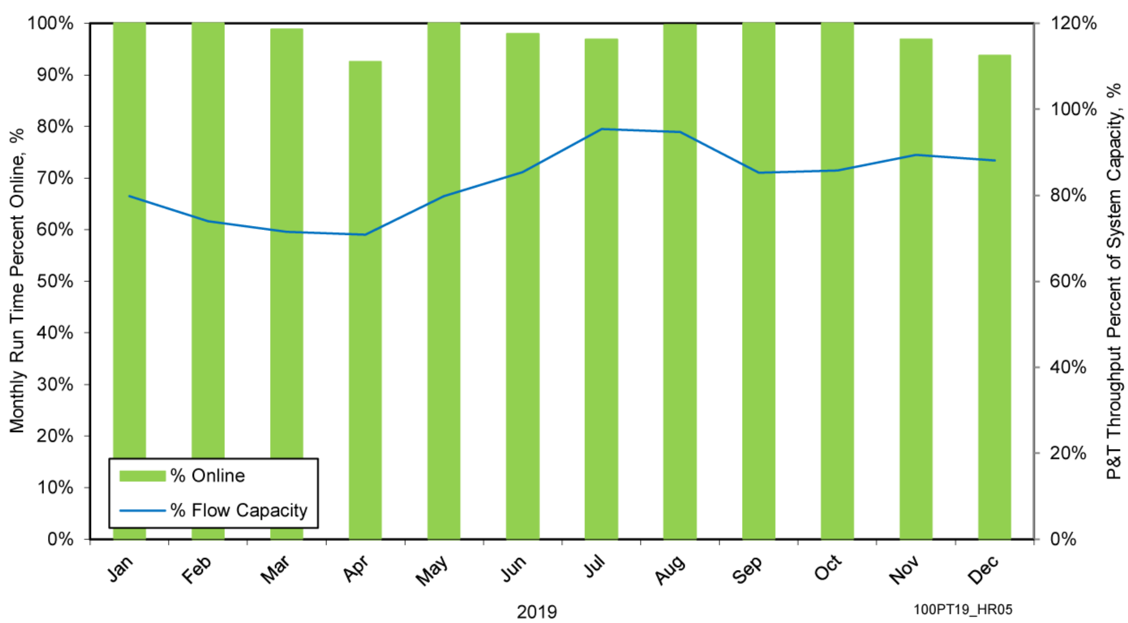

Figure 2-5. Monthly DX P&T System Availability, 2019

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

Total DX P&T System Processed Groundwater	2018	2019
Cumulative volume of groundwater treated (since December 2010 startup) (million L)	10,137	11,420
Total volume of groundwater treated during calendar year (million L)	1,442	1,276
Mass of Cr(VI) Removed	**2018**	**2019**
Cumulative mass of Cr(VI) removed (since December 2010 startup) (kg)	1,607	1,631
Total mass of Cr(VI) removed in calendar year (kg)	29.3	24.1
Summary of Operational Parameters	**2018**	**2019**
Average system process rate (L/min)	3,070	2,448
Average Cr(VI) influent concentration (µg/L)	21.7	18.4
Average Cr(VI) effluent concentration (µg/L)	<2.1	<2.0
Removal efficiency (% by mass)	90.4	89.5
Waste generation (m^3)	42.8	3.63
Spent resin disposed (m^3)	3.63	0
New resin installed (m^3)	0	0
Number of resin vessel change-outs	0	0
Summary of Co-Contaminants Detected in Effluent	**2018**	**2019**
Average nitrate concentration (µg/L)	19,940	18,775
Average strontium-90 concentration (pCi/L)	1.0	<1.3
Average total filtered chromium concentration (µg/L)	4.4	<4.65
Summary of Operational and System Availability	**2018**	**2019**
Total possible run time (hours)	8,760	8,760
Total time online (hours)	8,692	8,657
Total availability (%)*	99.2	98.8

Note: Table 4-1 in DOE/RL-2019-66, *Hanford Site Groundwater Monitoring Report for 2019*, lists key facts for the 100-HR groundwater interest area, including cleanup levels, plume areas, and measured maximum contaminant concentrations.

*Total availability [(total time online) ÷ (total possible run time)] × 100.

Cr(VI) = hexavalent chromium

P&T = pump and treat

Figure 2-6 shows the influent and effluent concentrations for the DX P&T system. The average influent Cr(VI) concentration in 2019 was 18.5 µg/L, a decline from 2018 that is likely due to overall reductions in plume concentrations. This trend is expected to continue as the remediation continues to operate. The average reported effluent concentration was <2.0 µg/L, which is below the detection limit. Overall, >48% of the results were below the detection limit. The maximum reported effluent result was 6 µg/L.

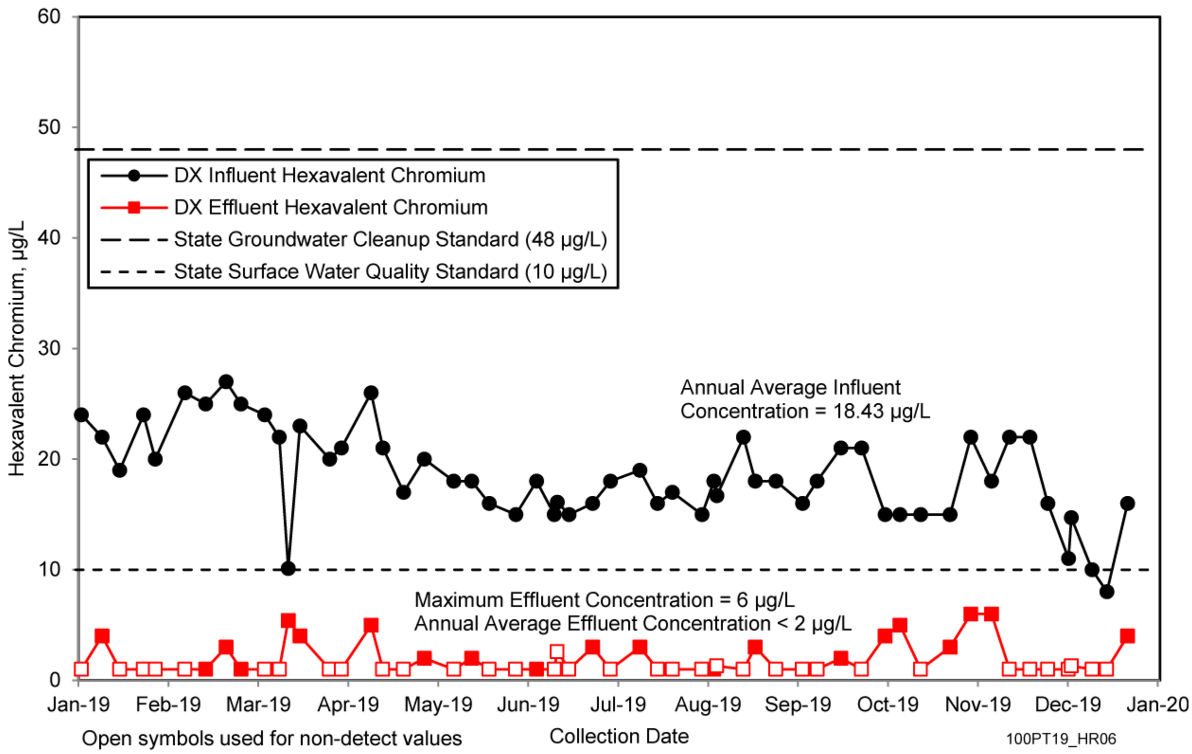

Figure 2-6. Influent/Effluent Concentrations for the DX P&T System

Table 2-4 presents the pumping flow rates and total run time for the extraction and injection wells active for the DX P&T system during 2019. The flow rates were calculated by dividing the total volume extracted for the period by the hours of pumping. Low river-stage periods resulted in longer downtimes for near-river wells lacking sufficient water levels for pumping. Figure 2-7 provides hydrographs for the Columbia River at the 100-D and 100-H Areas. Variations in extraction and injection rates due to downtime (e.g., low water in wells during low river stage, repair, and/or maintenance) are reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction well.

Extraction wells with low operational run-time percentages in 2019 are primarily located near the shoreline and are affected by low river stage. Twelve wells had an operational run time of <70% during 2019. Rationale for wells with low run times is included in Table 2-4.

2.2.2 HX Pump and Treat System

The HX P&T system became fully operational in 2011. The system design 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 3,400 L/min (900 gal/min). Figure 2-8 provides a schematic of the HX P&T system, which was current at the end of 2019. Overall, the water available in the aquifer limits the system throughput volume. The design and operational philosophy optimize the containment along the river and the containment and contaminant mass removal in areas with higher contamination. Figures 1-4 and 1-5 and Table 2-2 provide the cumulative volume of water treated and Cr(VI) removed since startup of the HX P&T system.
The number of extraction and injection wells listed for each system includes those wells that are out of service but are still physically connected to the system. Both the unconfined and RUM aquifers have extraction wells. The RUM aquifer extraction wells have high run-time percentages because of the constant availability of water in the semiconfined aquifer.

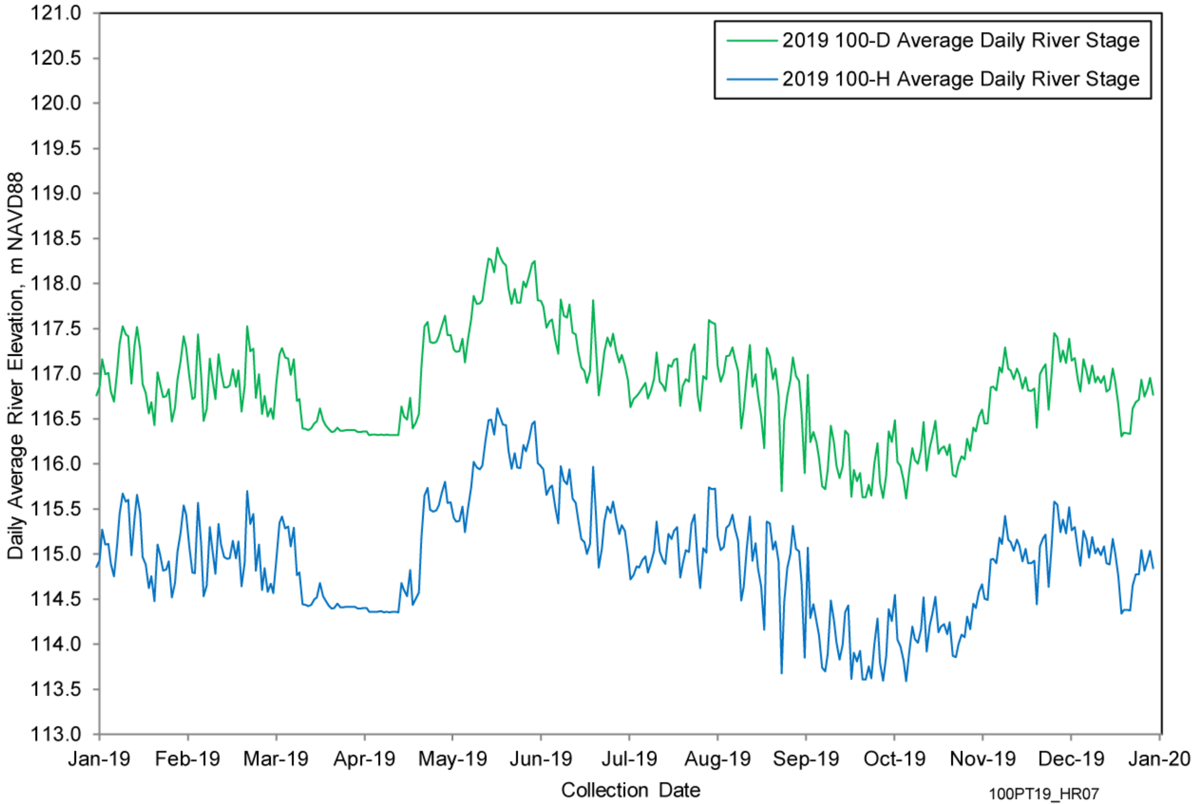

Figure 2-7. River-Stage Hydrograph for the 100-D and 100-H Areas (Derived from Priest Rapids Dam Water Elevation)

Similar to the DX P&T system, SIR-700 resin is used to treat Cr(VI) as it flows through resin beds in the HX P&T system. In 2019, all of the lead vessels for the HX P&T system were repaired, and the resin was replaced with a combination of new and old resin.

2.2.2.1 HX Pump and Treat System Configuration and Changes

The HX P&T system capture analysis for the previous year was used to identify areas along the Columbia River where additional plume capture was needed. The evaluation also identified Cr(VI) concentration trends (increasing, decreasing, stable, or indeterminant) at monitoring locations. These assessments were also used to determine the system modifications needed. The HX P&T system changes completed in 2019 (shown in Figure 1-3) included connecting unconfined aquifer extraction wells 199-H3-21, RUM aquifer extraction well 199-H3-22, and injection wells 199-H1-12 and 699-97-47C.

System infrastructure changes included a stainless-steel upgrade on the feed pump discharge header, repairs to nine IX vessels, and several resin exchanges. Resin from the #1 vessels was removed as waste. Resin from the #2 vessels was split in half and loaded into the #1 and #2 vessels, and one drum of new resin was added. A similar process was used to put resin in the last two empty vessels.

Table 2-4. Flow Rates and Total Run Times for DX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2019	Total Run Time[a] (%)	Rationale for Low Run Time	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average				
B8989	199-D4-38	ME01	17.8 (4.7)	27.3 (7.2)	6,921	79		Extraction
B8990	199-D4-39	ME02	31.3 (8.3)	40.7 (10.7)	5,527	63	Pump is nonoperational during low river stage.	Extraction
C3315	199-D4-83	ME03	20.4 (5.4)	20.8 (5.5)	3,861	44	Well maintenance reasons (will provide specifics when information is available).	Extraction
C3316	199-D4-84	ME04	15.9 (4.2)	18.9 (5)	6,117	70	Well maintenance reasons (will provide specifics when information is available).	Extraction
C3317	199-D4-85	ME05	69.4 (18.3)	58.5 (15.5)	6,742	77		Extraction
C7083	199-D4-95	ME06	73.3 (19.4)	64.5 (17)	7,438	85		Extraction
C7084	199-D4-96	ME07	35.6 (9.4)	43.8 (11.6)	7,824	89		Extraction[b]
C7085	199-D4-97	ME08	47.2 (12.5)	43.5 (11.5)	4,248	48	Pump issues from February to May. Pump serviced in June.	Extraction[b]
C7086	199-D4-98	ME09	49.2 (13)	43.2 (11.4)	6,982	80		Extraction
C7087	199-D4-99	ME10	73.7 (19.5)	65.4 (17.3)	7,380	84		Extraction
C7580	199-D4-101[c]	ME11	0 (0)	0 (0)	48	0.55	Minimal operation in 2019 due to filters fouling regularly.	Extraction
C7583	199-D5-101	ME12	47.6 (12.6)	49.6 (13.1)	6,997	80		Extraction
C7591	199-D5-127	ME13	69.3 (18.3)	70.1 (18.5)	8,712	99		Extraction
C5400	199-D5-104	ME14	95.9 (25.3)	96.8 (25.5)	8,701	99		Extraction
A4581	199-D8-53	ME21	69.6 (18.4)	81.1 (21.4)	8,543	98		Extraction
A4584	199-D8-55	ME22	13.2 (3.5)	16 (4.2)	1,704	19	Pump is nonoperational during low river stage.	Extraction
B2773	199-D8-69	ME23	83.6 (22.1)	80.2 (21.2)	6,096	70	Pump issues from January to March. Pump serviced in April.	Extraction[b]

Table 2-4. Flow Rates and Total Run Times for DX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2019	Total Run Time[a] (%)	Rationale for Low Run Time	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average				
C7593	199-D8-99	ME24	74.3 (19.6)	81.5 (21.5)	8,712	99		Extraction
C8794	699-97-61	ME25	59.2 (15.6)	59.4 (15.7)	8,687	99		RUM aquifer extraction
B2772	199-D8-68	ME26	218.4 (57.7)	210.1 (55.5)	8,687	99		Extraction
C7092	199-D8-90	ME27	80.4 (21.2)	79 (20.9)	8,495	97		Extraction
C7093	199-D8-91	ME28	85.2 (22.5)	84.7 (22.4)	8,567	98		Extraction
C7582	199-D8-97	ME29	44.4 (11.7)	50.1 (13.2)	8,711	99		Extraction
C7589	199-D8-95	ME30	20.5 (5.4)	26.2 (6.9)	8,255	94		Extraction
C7590	199-D5-130	ME31	2.9 (0.8)	16.1 (4.3)	792	9	Pump is nonoperational during low river stage.	Extraction
C7599	199-D7-3	ME32	82.8 (21.9)	79.1 (20.9)	8,628	98		Extraction
C7601	199-D5-131	ME33	72.4 (19.1)	72.9 (19.2)	8,687	99		Extraction
C7602	199-D8-98	ME34	84.3 (22.2)	81.9 (21.6)	6,216	71	Pump issues from January to March. Pump serviced in April.	Extraction[b]
C7603	199-D8-96	ME35	60 (15.8)	73.4 (19.4)	8,351	95		Extraction
C7596	199-H4-81	ME39	66.8 (17.6)	35.3 (9.3)	6,301	72	Pump issues in May and June. Pump serviced in July.	Extraction[b]
C7595	199-H4-80	ME40	70.9 (18.7)	70.3 (18.6)	8,087	92		Extraction
C9377	199-D5-159	ME41	111.4 (29.4)	134.1 (35.4)	8,160	93		Extraction
A4577	199-D5-20	ME42	0 (0)	0 (0)	0	0	Pump is nonoperational during low river stage.	Extraction
C4185	199-D5-32	ME43	71 (18.7)	72.1 (19)	8,736	100		Extraction
B8748	199-D5-39	ME44	30 (7.9)	42.1 (11.1)	3,936	45	Pump was nonoperational January through May. Pump was serviced in June.	Extraction[b]

Table 2-4. Flow Rates and Total Run Times for DX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2019	Total Run Time[a] (%)	Rationale for Low Run Time	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average				
C4583	199-D5-92	ME45	16.4 (4.3)	28.4 (7.5)	8,701	99		Extraction
C4536	199-D8-88	ME46	10.1 (2.7)	12.2 (3.2)	1,449	17	Well maintenance reasons (will provide specifics when information is available).	Extraction
C4474	199-D8-73	ME47	0.4 (0.1)	0.3 (0.1)	456	5.2	Pump is nonoperational during low river stage.	Extraction
C7091	199-D8-89	ME48	50.5 (13.3)	63.6 (16.8)	8,653	99		Extraction
B8985	199-D4-34	ME49	26 (6.9)	27.2 (7.2)	8,688	99		Extraction
B8072	199-D4-14	ME50	51.9 (13.7)	46.2 (12.2)	7,213	82	Well was nonoperational in October. Serviced in November.	Extraction[b]
C8726	199-D5-146	ME51	111.4 (29.4)	112.3 (29.6)	8,736	100		Extraction
C8789	199-D5-153	ME52	88.6 (23.4)	78.5 (20.7)	8,448	96		Extraction
C8790	199-D5-154	ME53	123.6 (32.6)	134.8 (35.6)	6,576	75	Well was down in May and June. Serviced in July.	Extraction[b]
C4187	199-D5-34	ME54	149.3 (39.4)	149.4 (39.4)	8,736	100		Extraction
C5399	199-D5-103	ME55	128.1 (33.8)	130.1 (34.4)	8,736	100		Extraction
C7600	199-D5-129	MJ03	432 (114)	421.3 (111.2)	8,700	99		Injection
C7612	199-D5-128	MJ04	237.7 (62.8)	230.6 (60.9)	8,700	99		Injection
C8728	199-D5-148	MJ05	335.3 (88.5)	324.4 (85.6)	8,735	100		Injection
C5581	199-D5-111	MJ06	30.7 (8.1)	30.7 (8.1)	8,735	100		Injection
C5578	199-D5-108	MJ07	69.8 (18.4)	69.4 (18.3)	8,735	100		Injection
C8929	699-93-48C	MJ16	189.5 (50)	189.2 (50)	8,653	99		Injection
C7608	199-D7-5	MJ21	213.2 (56.3)	199.8 (52.8)	8,701	99		Injection
C7607	199-D6-2	MJ22	281 (74.2)	265.8 (70.2)	8,701	99		Injection

Table 2-4. Flow Rates and Total Run Times for DX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate, L/min (gal/min)		Total Flow Hours in 2019	Total Run Time[a] (%)	Rationale for Low Run Time	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average				
C7594	199-D7-4	MJ23	451.6 (119.2)	421.9 (111.4)	8,701	99		Injection
C7592	199-D6-1	MJ25	85.2 (22.5)	79.2 (20.9)	8,700	99		Injection
C9584	699-90-47B	MJ26	200.8 (53)	194.4 (51.3)	8,700	99		Injection
C7609	199-H4-82	MJ29	68 (18)	61.1 (16.1)	5,496	63[d]	Injection well connected in May 2019. Operated 99% of the time after placed in operation.	Injection
C7610	199-H1-5	MJ30	99.9 (26.4)	87.5 (23.1)	5,520	63[d]	Injection well connected in May 2019. Operated 99% of the time after placed in operation.	Injection

Note: For purposes of deriving average flow rates for low 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 stage.

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

b. Well pump and motor replaced.

c. Well is planned to be disconnected due to low flow rates.

d. Connected as injection wells in May 2019; percent of run time after wells were put in operation is 99%.

ID = identification

PLC = programmable logic controller

RUM = Ringold upper mud unit

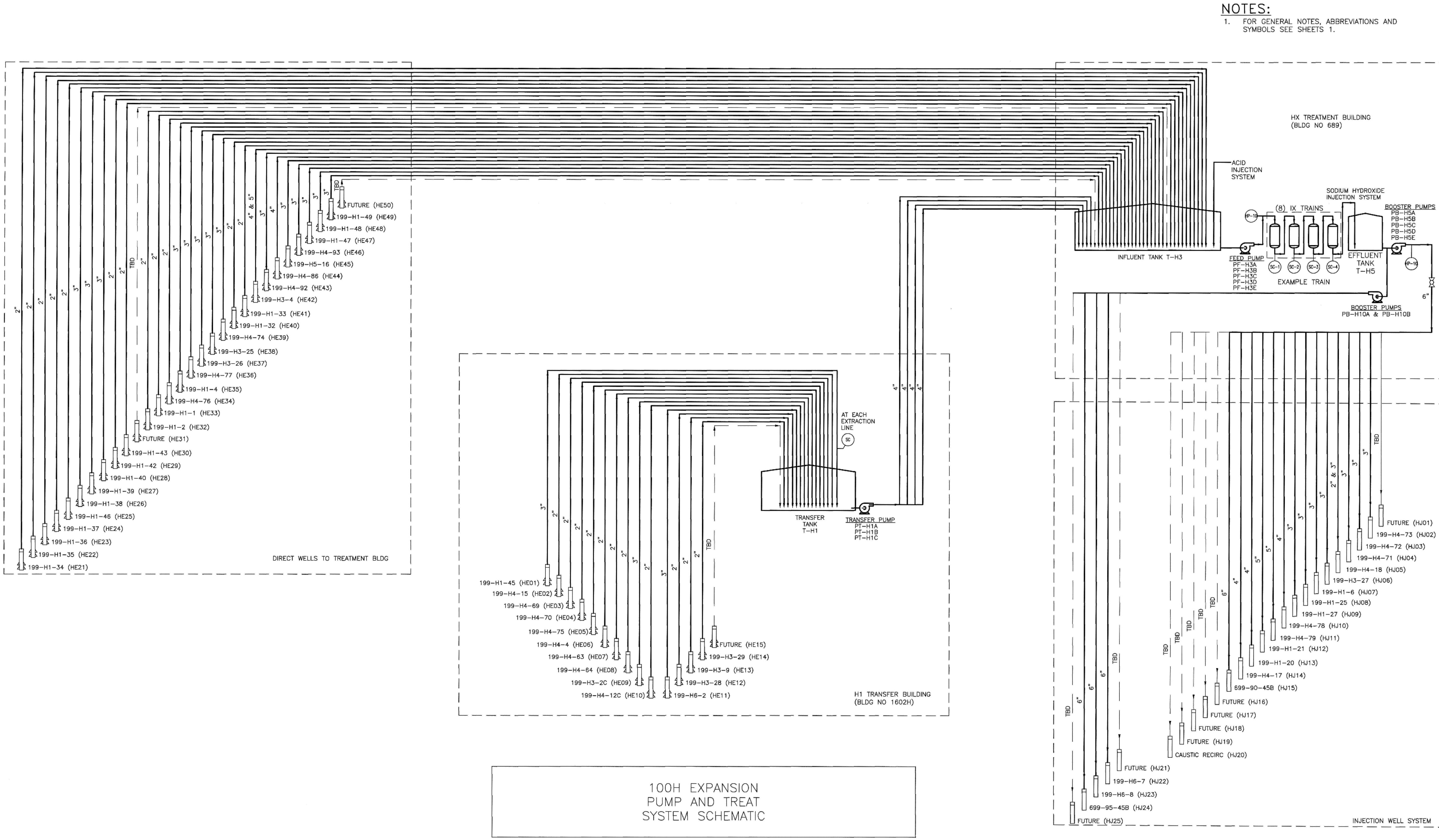

Figure 2-8. HX P&T System Schematic (as of December 2019)

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2.2.2.2 Treatment System Performance

The HX P&T system operated 98% of the time throughout 2019. Two expected short downtimes due to planned corrective maintenance occurred during the 98% operational period. Table 2-5 presents an overview of groundwater extracted, mass removed, and system performance.

Table 2-5. HX P&T System Operational Parameters and System Performance, 2019

Total HX P&T System Processed Groundwater	**2018**	**2019**
Cumulative volume of groundwater treated (since September 2011 startup) (million L)	9,189	11,421
Total volume of groundwater treated in calendar year (million L)	1,388	1,013
Mass of Cr(VI) Removed	**2018**	**2019**
Cumulative mass of Cr(VI) removed (since September 2011 startup) (kg)	196.3	226.9
Total mass of Cr(VI) removed in calendar year (kg)	26.6	30.6
Summary of Operational Parameters	**2018**	**2019**
Average treatment process rate (L/min)	2,720	1,953
Average Cr(VI) influent concentration (µg/L)	20.7	31.2
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	93.2	95.0
Waste generation (m^3)	59.6	3.63
Spent resin disposed (m^3)	14.5	32.63
New resin installed (m^3)	0	6.67
Number of resin vessel changeouts	0	32
Summary of Co-Contaminants Detected in Effluent	**2018**	**2019**
Average nitrate concentration (µg/L)	17,614	18,870
Average strontium-90 concentration (pCi/L)	1.6	<1.3
Average total filtered chromium concentration (µg/L)	5.0	7.5
Summary of Operational and System Availability	**2018**	**2019**
Total possible run time (hours)	8,784	8,760
Total time online (hours)	8,510	8,595
Total availability (%)*	96.9%	98.1%

*Total availability is calculated as [(total time online) ÷ (total possible run time)].

Cr(VI) = hexavalent chromium

P&T = pump and treat

Figure 2-9 shows the influent and effluent concentrations for the HX P&T system. The average influent Cr(VI) concentration for the system in 2019 was 31.0 µg/L, which was higher than the 2018 concentration of 20.7 µg/L. The increase in system influent concentrations is related to the new, high-concentration RUM aquifer extraction well 199-H3-22 coming online during 2019. The Cr(VI) concentrations from well 199-H3-22 were as high as 300 µg/L after the well was connected in July 2019. The average reported effluent concentration was <2 µg/L, with a maximum of 6 µg/L. The average removal efficiency for 2019 was 95%, and the system operated at an average rate of 1,953 L/min (516 gal/min).

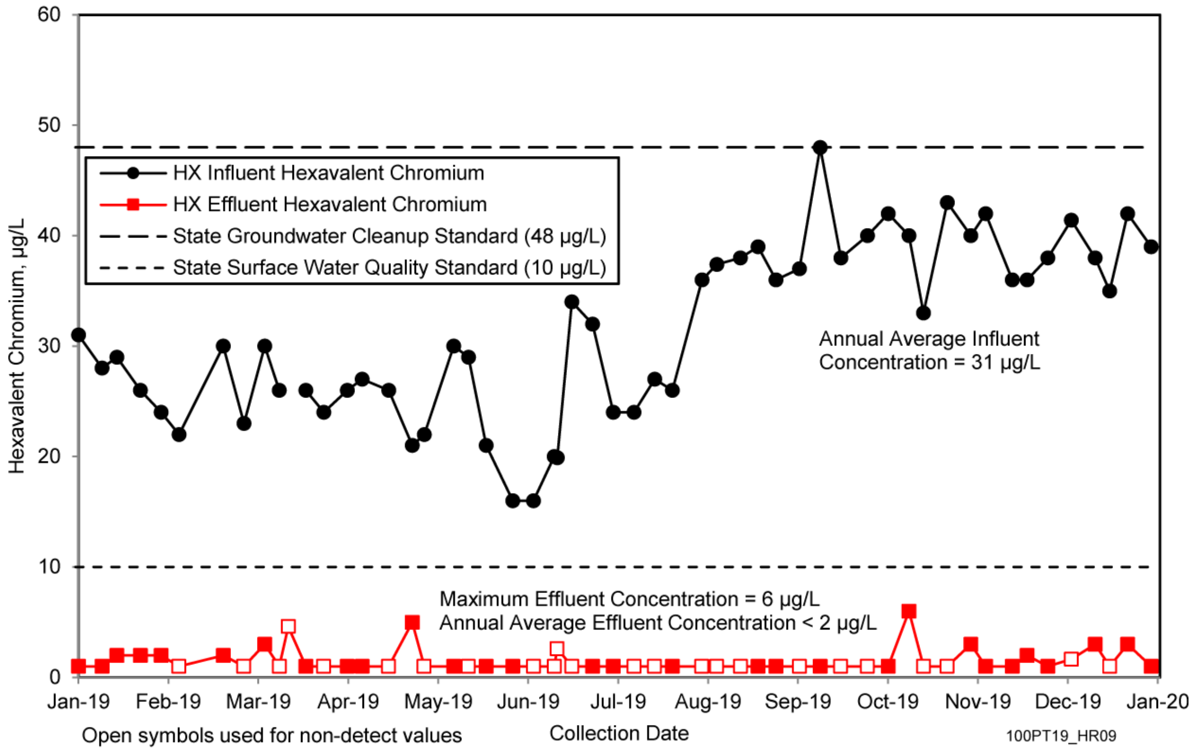

Figure 2-9. Influent/Effluent Concentrations for the HX P&T System

Slightly higher influent concentrations were observed during the winter and fall. This is a typical trend and is reflective of seasonal fluctuation, with decreased pumping rates at unconfined aquifer extraction wells closer to the river shoreline as water levels in the wells decline, and continued pumping from wells completed in the first water-bearing unit of the RUM with generally higher Cr(VI) concentrations. The RUM aquifer extraction wells 199-H3-2C, 199-H3-9, and 199-H4-12C had relatively constant pumping rates throughout 2019 and exhibited high (but declining) Cr(VI) concentrations.
Wells 199-H3-21 and 199-H3-22 were connected to the HX P&T system in July 2019. Well 199-H3-21 extracts groundwater from the unconfined aquifer, and well 199-H3-22 extracts from the first water-bearing unit of the RUM. Monitoring well 199-H3-13 (installed in April 2019), located downgradient of wells 199-H3-21 and 199-H3-22, had the highest Cr(VI) concentrations measured in 2019. During 2019, influent concentrations were also higher in the late summer. The RUM aquifer extraction wells 199-H3-28 and 199-H3-29 have high Cr(VI) concentrations that exhibited a slight downward trend in 2019. These wells contribute considerably to the Cr(VI) mass removed for the HX P&T system.

Figure 2-10 shows the system availability for 2019. The total flow rate through the HX P&T system (in terms of percentage of system capacity) was reduced during low river-stage times because extraction wells need a minimum of 0.6 m (2 ft) of water above the pump intake to operate. Across the Horn and in the northern portion of the 100-H Area, the aquifer is <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, even when pump flows are set as low as practicable, insufficient water may be available for pump operation.

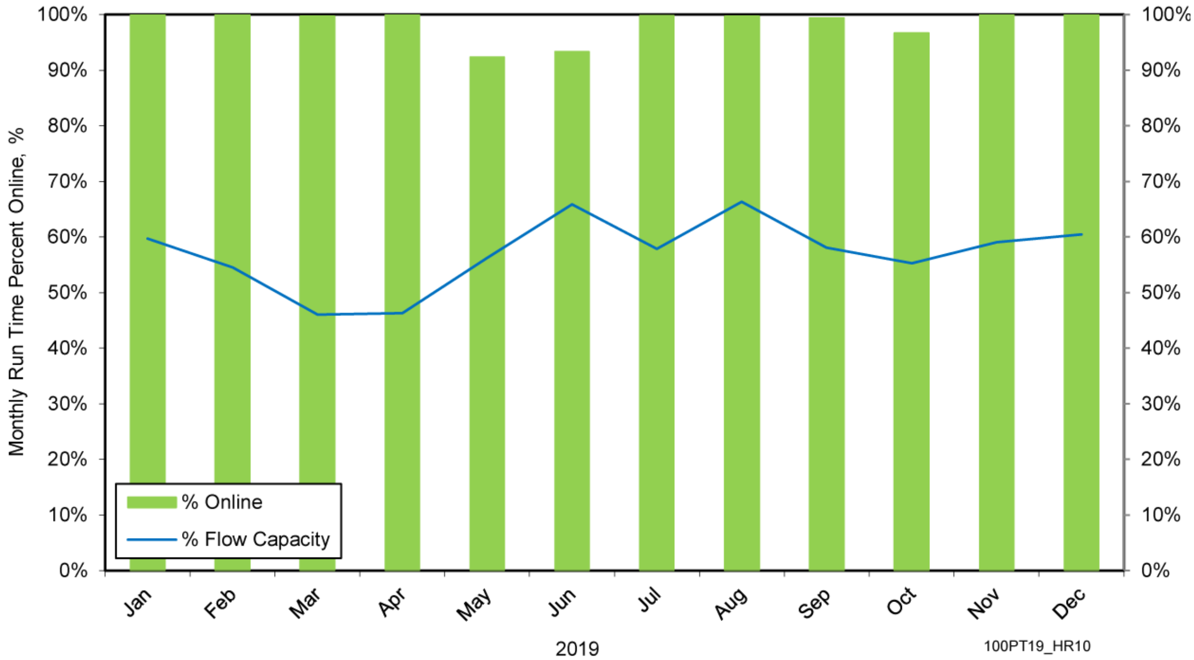

Figure 2-10. Monthly HX P&T System Availability, 2019

Table 2-6 shows the pumping flow rates and total run times for the extraction and injection wells currently active in the HX P&T system. Flow rates were calculated by dividing the total volume pumped by the hours of pumping. Operational downtime for 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 total run-time percentage is the percentage of actual pumping time in an extraction or injection well over the past year (2019) and calculated by [(days well in operation) ÷ (number of days in the calendar year)].

Extraction wells with low operational run-time percentages in 2019 are primarily located near the shoreline in areas of very thin saturated aquifer thicknesses and are affected by low river stage. Thirty-two wells had <70% operational run times at the HX P&T system during 2019. Table 2-7 lists the wells with low run times and the rationale. Eight of the wells with low operational run times are located in the northern 100-H Area near the river. These wells are identified as being under river influence, which means that the pump is inoperable during low river stage due to the lack of water above the pump. As a result, there is less plume capture in that area during the winter months (Section 2.2.5), which results in breakthrough of the plume to the river in that area. Remedial P&T system realignments (switching from extraction to injection) are scheduled for FY 2021 that are anticipated to change the migration path for the plume south and away from the river.

Table 2-6. Flow Rates and Total Run Times for HX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average			
C7477	199-H1-45	HE01	209.8 (55.4)	212.5 (56.1)	8,736	100	Extraction
A4621	199-H4-15A	HE02	56.7 (15)	70.6 (18.6)	8,304	95	Extraction
C7485	199-H4-69	HE03	34.4 (9.1)	54.5 (14.4)	8,112	93	Extraction
C7483	199-H4-70	HE04	16.2 (4.3)	25 (6.6)	7,728	88	Extraction[b]
C7597	199-H4-75	HE05	25.4 (6.7)	49.1 (13)	8,592	98	Extraction
A4630	199-H4-4	HE06	8.2 (2.2)	24 (6.3)	2,040	23	Extraction
B2776	199-H4-63	HE07	101.5 (26.8)	100.2 (26.4)	8,568	98	Extraction
B2777	199-H4-64	HE08	18.8 (5)	44.7 (11.8)	3,752	43	Extraction
A4613	199-H3-2C	HE09	67.2 (17.7)	79.8 (21.1)	8,520	97	RUM aquifer extraction
A4618	199-H4-12C	HE10	114.7 (30.3)	143.7 (37.9)	6,360	73	RUM aquifer extraction[b]
C9924	199-H3-22[c]	HE11	124.7 (32.9)	0 (0)	3,768	43	RUM aquifer extraction
C9715	199-H3-28	HE12	167.3 (44.2)	153.5 (40.5)	8,232	94	RUM aquifer extraction
C7639	199-H3-9	HE13	37.6 (9.9)	37.6 (9.9)	5,232	60	RUM aquifer extraction[b]
C9716	199-H3-29	HE14	46.6 (12.3)	56.9 (15)	8,568	98	RUM aquifer extraction
C9923	199-H3-21[d]	HE15	18.1 (4.8)	8.4 (2.2)	920	11	Extraction
C7108	199-H1-34	HE21	31 (8.2)	60.8 (16)	4,488	51	Extraction
C7106	199-H1-35	HE22	42.8 (11.3)	60.2 (15.9)	8,232	94	Extraction
C7102	199-H1-36	HE23	12.5 (3.3)	18.7 (4.9)	5,304	61	Extraction
C7099	199-H1-37	HE24	18.1 (4.8)	57.6 (15.2)	2,928	33	Extraction
C9486	199-H1-46	HE25	13.5 (3.6)	0 (0)	3,608	41	Extraction[b]
C7098	199-H1-38	HE26	7.5 (2)	23.3 (6.2)	1,320	15	Extraction
C7109	199-H1-39	HE27	0 (0)	45.8 (12.1)	528	6	Extraction
C7104	199-H1-40	HE28	0 (0)	13.1 (3.4)	576	6.6	Extraction
C7107	199-H1-42	HE29	23 (6.1)	45.2 (11.9)	4,176	48	Extraction
C7492	199-H1-43	HE30	39.4 (10.4)	67.8 (17.9)	8,664	99	Extraction
C7581	199-H1-3	HE31	0 (0)	0 (0)	—	0	Extraction

Table 2-6. Flow Rates and Total Run Times for HX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min])		Total Flow Hours 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
			Low River-Stage Average	High River-Stage Average			
C7584	199-H1-2	HE32	8.3 (2.2)	9 (2.4)	6,552	75	Extraction
C7585	199-H1-1	HE33	153.2 (40.4)	90.6 (23.9)	8,448	96	Extraction[b]
C7587	199-H4-76	HE34	19.6 (5.2)	16.9 (4.5)	3,792	43	Extraction
C7604	199-H1-4	HE35	5.3 (1.4)	5.6 (1.5)	2,688	31	Extraction
C7605	199-H4-77	HE36	33 (8.7)	41.9 (11.1)	8,304	95	Extraction
C7115	199-H3-26	HE37	0 (0)	82.2 (21.7)	4,728	54	Extraction
C7110	199-H3-25	HE38	258.4 (68.2)	0 (0)	4,848	55	Extraction[b]
C7598	199-H4-74	HE39	0 (0)	0 (0)	—	0	Extraction
C7100	199-H1-32	HE40	6.9 (1.8)	20 (5.3)	1,104	13	Extraction
C7105	199-H1-33	HE41	32.7 (8.6)	47.4 (12.5)	1,992	23	Extraction
B2779	199-H3-4	HE42	183.1 (48.3)	238.6 (63)	8,544	98	Extraction
C8792	199-H4-92	HE43	80.4 (21.2)	84.8 (22.4)	8,736	100	Extraction
C8724	199-H4-86	HE44	10.9 (2.9)	55.7 (14.7)	4,872	56	Extraction
C8948	199-H5-16	HE45	152.9 (40.4)	173.6 (45.8)	6,792	78	Extraction[b]
C8949	199-H4-93	HE46	22.5 (5.9)	32.5 (8.6)	4,656	53	Extraction
C9637	199-H1-47	HE47	17.3 (4.6)	24.7 (6.5)	5,280	60	Extraction
C9638	199-H1-48	HE48	22.6 (6)	13.7 (3.6)	1,224	14	Extraction[b]
C9639	199-H1-49	HE49	20.6 (5.4)	29.2 (7.7)	6,672	76	Extraction[b]
C7484	199-H4-73	HJ02	0 (0)	0 (0)	—	0	Injection
C7488	199-H4-72	HJ03	0 (0)	0 (0)	—	0	Injection
C7487	199-H4-71	HJ04	0 (0)	0 (0)	—	0	Injection
A4628	199-H4-18	HJ05	0 (0)	0 (0)	—	0	Injection
C7114	199-H3-27	HJ06	131.7 (34.8)	108.7 (28.7)	8,736	100	Injection
C7606	199-H1-6	HJ07	203.5 (53.7)	167.8 (44.3)	8,736	100	Injection
C7478	199-H1-25	HJ08	90.7 (24)	73.3 (19.4)	6,600	75	Injection
C7480	199-H1-27	HJ09	155.5 (41.1)	128.7 (34)	8,736	100	Injection

Table 2-6. Flow Rates and Total Run Times for HX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Flow Rate (L/min [gal/min]) Low River-Stage Average	Flow Rate (L/min [gal/min]) High River-Stage Average	Total Flow Hours 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
C7588	199-H4-78	HJ10	203.7 (53.8)	163.6 (43.2)	8,736	100	Injection
C7586	199-H4-79	HJ11	203.5 (53.7)	161.7 (42.7)	6,888	79	Injection[e]
C7111	199-H1-21	HJ12	84.3 (22.3)	157.7 (41.6)	7,032	80	Injection[e]
C7113	199-H1-20	HJ13	95.8 (25.3)	84.9 (22.4)	8,688	99	Injection
A4627	199-H4-17	HJ14	70.1 (18.5)	61.7 (16.3)	8,568	98	Injection
C9585	699-90-45B	HJ15	285.9 (75.5)	230.1 (60.8)	8,616	98	Injection
C9545	699-97-47C[f]	HJ16	106 (28)	0 (0)	2,880	33	Injection
C9926	199-H1-12[f]	HJ17	106.3 (28.1)	0 (0)	2,856	33	Injection
C8947	199-H6-7	HJ22	200.1 (52.8)	224.3 (59.2)	5,568	64	Injection[e]
C8951	199-H6-8	HJ23	118.9 (31.4)	107.7 (28.4)	6,744	77	Injection[e]
C8950	699-95-45B	HJ24	266.7 (70.4)	297.9 (78.7)	8,688	99	Injection

Note: For purposes of deriving average flow rates for low and high river stages, 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 stage.

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

b. Well pump and motor replaced.

c. Well 199-H6-2 was disconnected due to low flows, and well 199-H3-22 was connected in its place to the HX P&T system and began operation in July 2019.

d. New extraction well connected to the HX P&T system and began operation in July 2019.

e. Well maintenance activities performed on the well in 2019.

f. New injection well connected to the HX P&T system and began operation in September 2019.

ID = identification
P&T = pump and treat
PLC = programmable logic controller
RUM = Ringold upper mud unit

Table 2-7. HX P&T System Wells with Low Total Run-Time Percentage and Rationale

Well Name	PLC ID	Total Run-Time Percentage[a]	Rationale for Low Run Time
199-H4-4	HE06	23	Pump is nonoperational during low river stage.
199-H4-64	HE08	43	Low water level restricts pumping consistently.
199-H3-22	HE11	43	New connection.
199-H3-9	HE13	60	Down between March and June for repairs.
199-H3-21	HE15	11	New connection.
199-H1-34	HE21	51	Down in January, February and October.
199-H1-36	HE23	61	Down in October and November.
199-H1-37	HE24	33	Pump is nonoperational during low river stage.
199-H1-46	HE25	41	Pump was nonoperational from March through June. Pump was serviced in July.
199-H1-38	HE26	15	Pump is nonoperational during low river stage.
199-H1-39	HE27	6	Pump is nonoperational during low river stage.
199-H1-40	HE28	6.6	Pump is nonoperational during low river stage.
199-H1-42	HE29	48	Pump is nonoperational during low river stage.
199-H1-3	HE31	0	Low well water level restricts pumping consistently.
199-H4-76	HE34	43	Pump is nonoperational during low river stage.
199-H1-4	HE35	31	Low well water level restricts pumping consistently.
199-H3-26	HE37	54	Pump is nonoperational during low river stage.
199-H3-25	HE38	55	Pump was nonoperational from March through June. Pump was serviced in July.
199-H4-74	HE39	0	Low well water level restricts pumping consistently.
199-H1-32	HE40	13	Pump is nonoperational during low river stage.
199-H1-33	HE41	23	Pump is nonoperational during low river stage.
199-H4-86	HE44	56	Pump is nonoperational during low river stage.
199-H4-93	HE46	53	Pump is nonoperational during low river stage.
199-H1-47	HE47	60	Pump is nonoperational during low river stage.
199-H1-48	HE48	14	Pump operational July through September only. Pump was serviced in July.
199-H4-73	HJ02	0	Well use is minimized to allow for rebound at the 100-H Area.[b]
199-H4-72	HJ03	0	Well use is minimized to allow for rebound at the 100-H Area.[b]
199-H4-71	HJ04	0	Well use is minimized to allow for rebound at the 100-H Area.[b]
199-H4-18	HJ05	0	Well use is minimized to allow for rebound at the 100-H Area.[b]
199-H1-12	HJ17	33	New connection; operation began in September 2019.

Table 2-7. HX P&T System Wells with Low Total Run-Time Percentage and Rationale

Well Name	PLC ID	Total Run-Time Percentage[a]	Rationale for Low Run Time
699-97-47C	HJ16	33	New connection; operation began in September 2019.
199-H6-7	HJ22	64	Very low injection rates from January through March.

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

b. The volume of water injected into wells 199-H4-18, 199-H4-71, 199-H4-72, and 199-H4-73 was minimized starting in 2018 and continued through 2019 to evaluate if secondary contamination sources are present in the vadose zone in the 100-H Area as discussed in DOE/RL-2018-67, *Calendar Year 2018 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater*.

ID = identification

PLC = programmable logic controller

2.2.3 Performance Monitoring

The principal objective of the 100-HR-3 OU interim remedial action was controlling and removing Cr(VI) in groundwater, primarily through intercepting the Cr(VI) plumes at ≥10 µg/L and keeping contaminated groundwater from entering the Columbia River. With issuance of the 100-D/100-H Areas ROD (EPA et al., 2018), the goals related to remediation are stated as preventing unacceptable risk from groundwater discharges to surface water and restoring groundwater to cleanup levels. The means for accomplishing these goals for Cr(VI) remains P&T, plume control, and mass removal.

Other COCs identified in the 100-D/100-H Areas ROD (EPA et al., 2018) are nitrate and strontium-90, which have a selected remedy of MNA. Tritium, uranium, and technetium-99 were listed in the interim action ROD (EPA/ROD/R10-96/134) as potential co-contaminants. A new SAP is being developed based on the requirements of the new RD/RAWP (DOE/RL-2017-13, Draft A) and 100-D/100-H Areas ROD. Previously monitored contaminants such as uranium, technetium-99, and byproducts of the remediation system (e.g., sulfate) are being evaluated for monitoring.

Contaminant concentration data are collected each year from the monitoring wells, extraction wells, and aquifer tubes within the OU. Monitoring results are discussed in the annual groundwater monitoring report (e.g., Chapter 4 in DOE/RL-2019-66). Sampling data are used to update plume maps and to evaluate the effectiveness of ongoing remedial activities. Particular emphasis is given to Cr(VI) data collected during the fall of each year, when river levels are low and natural groundwater flow is directed toward the Columbia River.

Tables 2-8 through 2-10 present the high and low river-stage Cr(VI) monitoring results for 2019. Tables 2-8 and 2-9 present the results for the unconfined aquifer in the 100-D Area (including the DX P&T wells) and the 100-H Area (including the HX P&T wells) of the 100-HR-3 OU, respectively. Table 2-10 presents the RUM well results within the 100-HR-3 OU. Performance assessments for the P&T systems address changes in Cr(VI) concentrations in the 100-HR-3 OU. Figures 2-11 and 2-12 show the Cr(VI) plumes during periods of low river stage and high river stage during 2019 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 during low or high river stage during 2019 for each well shown. During high river-stage periods, many of the aquifer tubes become submerged and cannot be sampled; therefore, aquifer tubes in the 100-HR-3 OU are only sampled during low river stage.

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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-D2-10	M	5/14/2019	8.14	10/28/2019	13.1	10/28/2019	13.1
	199-D2-11	M	—	—	10/25/2019	3	10/25/2019	3
	199-D2-12	M	5/9/2019	7.71	10/28/2019	6.76	5/9/2019	7.71
	199-D2-6	M	—	—	10/25/2019	1.61	10/25/2019	1.61
	199-D3-2	M	—	—	10/28/2019	7.82	10/28/2019	7.82
	199-D3-5	M	—	—	10/25/2019	11.1	10/25/2019	11.1
	199-D4-1	M	—	—	10/28/2019	14.9	10/28/2019	14.9
DX	199-D4-101	E	—	—	—	—	—	—
	199-D4-102	M	5/17/2019	2.13	10/25/2019	1.3(U)	5/17/2019	2.13
	199-D4-103	M	5/17/2019	3.72	11/1/2019	4.28	11/1/2019	4.28
	199-D4-13	M	—	—	10/25/2019	1.83	10/25/2019	1.83
DX	199-D4-14	E	4/1/2019	16	11/21/2019	12.1	1/10/2019	18
	199-D4-15	M	5/17/2019	4.52	11/1/2019	2.57	5/17/2019	4.52
	199-D4-19	M	—	—	10/25/2019	1.73	10/25/2019	1.73
	199-D4-20	M	—	—	10/25/2019	1.3(U)	10/25/2019	1.3(U)
	199-D4-22	M	—	—	10/25/2019	10.6	10/25/2019	10.6
	199-D4-23	M	—	—	11/5/2019	2.76	11/5/2019	2.76
	199-D4-27	M	—	—	12/11/2019	8.17	12/11/2019	8.17
	199-D4-31	M	—	—	—	—	—	—
DX	199-D4-34	E	4/1/2019	21	11/7/2019	22	1/10/2019	25
DX	199-D4-38	E	4/1/2019	10	9/9/2019	13	9/9/2019	13
DX	199-D4-39	E	4/1/2019	8	10/14/2019	15	10/14/2019	15

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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-D4-48	M	—	—	—	—	—	—
	199-D4-50	M	—	—	—	—	—	—
	199-D4-56	M	—	—	12/3/2019	11.2	12/3/2019	11.2
	199-D4-60	M	—	—	—	—	—	—
	199-D4-68	M	—	—	12/3/2019	10.1	12/3/2019	10.1
	199-D4-78	M	—	—	12/11/2019	7.83	12/11/2019	7.83
DX	199-D4-83	E	5/23/2019	2.5	8/19/2019	2	1/16/2019	4
DX	199-D4-84	E	7/11/2019	11	9/9/2019	10	7/11/2019	11
DX	199-D4-85	E	7/11/2019	12	9/9/2019	15	9/9/2019	15
	199-D4-86	M	—	—	10/17/2019	8.76	10/17/2019	8.76
DX	199-D4-95	E	4/1/2019	18	10/30/2019	17.21	4/1/2019	18
DX	199-D4-96	E	7/11/2019	23	8/19/2019	16	7/11/2019	23
DX	199-D4-97	E	7/11/2019	9	9/9/2019	8	7/11/2019	9
DX	199-D4-98	E	7/11/2019	6	9/9/2019	12	9/9/2019	12
DX	199-D4-99	E	7/11/2019	8	9/9/2019	11	9/9/2019	11
DX	199-D5-101	E	4/1/2019	7	9/9/2019	13	9/9/2019	13
DX	199-D5-103	E	4/1/2019	104	8/5/2019	38	1/24/2019	129
DX	199-D5-104	E	4/1/2019	46	9/9/2019	47	9/9/2019	47
	199-D5-123	M	—	—	12/3/2019	5.78	12/3/2019	5.78
	199-D5-125	M	—	—	12/3/2019	10.3	12/3/2019	10.3
DX	199-D5-127	E	5/21/2019	7	9/9/2019	11	9/9/2019	11
	199-D5-13	M	—	—	10/17/2019	12.9	10/17/2019	12.9

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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)
DX	199-D5-130	E	6/25/2019	11.8	12/18/2019	16	12/18/2019	16
DX	199-D5-131	E	4/1/2019	18	11/13/2019	26	11/13/2019	26
	199-D5-132	M	—	—	11/5/2019	4.51	11/5/2019	4.51
	199-D5-133	M	5/21/2019	4.13	11/4/2019	2.61	5/21/2019	4.13
	199-D5-14	M	—	—	11/1/2019	7.3	11/1/2019	7.3
	199-D5-142	M	—	—	11/4/2019	4.71	11/4/2019	4.71
	199-D5-143	M	—	—	11/4/2019	22.1	11/4/2019	22.1
	199-D5-145	M	5/21/2019	38.8	11/4/2019	12.1	2/21/2019	41
DX	199-D5-146	E	4/1/2019	17	11/7/2019	13	1/10/2019	20
	199-D5-149	M	5/21/2019	16.9	11/4/2019	21.2	2/21/2019	22
	199-D5-15	M	—	—	—	—	—	—
	199-D5-150	M	5/21/2019	3.23	11/5/2019	3.22	3/6/2019	5
	199-D5-151	M	5/21/2019	45.3	10/31/2019	58.5	10/31/2019	58.5
	199-D5-152	M	5/21/2019	9.67	10/31/2019	7.16	2/27/2019	9.7
DX	199-D5-153	E	4/1/2019	28	10/7/2019	22	1/10/2019	29
DX	199-D5-154	E	4/1/2019	34	11/7/2019	31	4/1/2019	34
DX	199-D5-159	E	4/1/2019	27	8/5/2019	21	1/10/2019	34
	199-D5-16	M	—	—	12/3/2019	9.07	12/3/2019	9.07
	199-D5-160	M	5/10/2019	263	10/31/2019	175	5/10/2019	263
	199-D5-17	M	—	—	10/17/2019	6.72	10/17/2019	6.72
	199-D5-18	M	—	—	11/1/2019	4.48	11/1/2019	4.48
	199-D5-19	M	—	—	10/17/2019	4.29	10/17/2019	4.29

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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)
DX	199-D5-20	E	—	—	—	—	—	—
DX	199-D5-32	E	7/1/2019	42	8/5/2019	42	8/5/2019	42
	199-D5-33	M	—	—	—	—	—	—
DX	199-D5-34	E	6/17/2019	47	8/5/2019	42	1/10/2019	50
	199-D5-36	M	—	—	10/18/2019	4.19	10/18/2019	4.19
	199-D5-37	M	—	—	—	—	—	—
	199-D5-38	M	—	—	12/3/2019	6.83	12/3/2019	6.83
DX	199-D5-39	E	6/25/2019	6.81	11/7/2019	13	11/7/2019	13
	199-D5-40	M	—	—	10/25/2019	1.49	10/25/2019	1.49
	199-D5-41	M	—	—	11/1/2019	1.3(U)	11/1/2019	1.3(U)
	199-D5-42	M	5/17/2019	1.59	11/1/2019	1.39	5/17/2019	1.59
	199-D5-43	M	—	—	10/25/2019	3.27	10/25/2019	3.27
	199-D5-44	M	—	—	11/5/2019	11.5	11/5/2019	11.5
DX	199-D5-92	E	4/1/2019	21	11/7/2019	13	4/1/2019	21
	199-D5-97	M	5/21/2019	3.3	10/25/2019	3.1	5/21/2019	3.3
	199-D6-3	M	—	—	10/31/2019	3.01	10/31/2019	3.01
DX	199-D7-3	E	5/23/2019	3.78	9/17/2019	13	9/17/2019	13
	199-D7-6	M	—	—	—	—	—	—
	199-D8-101	M	—	—	10/18/2019	4.87	10/18/2019	4.87
	199-D8-102	M	5/10/2019	22.9	10/25/2019	21.5	5/10/2019	22.9
	199-D8-4	M	5/9/2019	5.99	10/28/2019	4.88	3/6/2019	6.11
	199-D8-5	M	—	—	12/3/2019	3.37	12/3/2019	3.37

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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)
DX	199-D8-53	E	4/1/2019	8	9/17/2019	17	9/17/2019	17
	199-D8-54A	M	—	—	12/9/2019	13.8	12/9/2019	13.8
DX	199-D8-55	E	6/25/2019	12	—	—	6/25/2019	12
	199-D8-6	M	5/9/2019	6.72	10/28/2019	6.71	2/27/2019	8.5
DX	199-D8-68	E	4/1/2019	21	11/13/2019	20	4/1/2019	21
DX	199-D8-69	E	5/23/2019	4.13	11/13/2019	21	11/13/2019	21
	199-D8-70	M	—	—	12/9/2019	2.94	12/9/2019	2.94
	199-D8-71	M	—	—	10/25/2019	18	10/25/2019	18
	199-D8-72	M	—	—	10/25/2019	9.75	10/25/2019	9.75
DX	199-D8-73	E	—	—	—	—	—	—
DX	199-D8-88	E	6/25/2019	4.29	9/30/2019	2.34	6/25/2019	4.29
CDX	199-D8-89	E	4/1/2019	16	11/7/2019	31	11/7/2019	31
DX	199-D8-90	E	4/1/2019	9	9/17/2019	10	9/17/2019	10
DX	199-D8-91	E	4/1/2019	12	11/13/2019	25	11/13/2019	25
	199-D8-93	M	5/10/2019	15.6	11/4/2019	13.9	5/10/2019	15.6
	199-D8-94	M	5/10/2019	38.4	10/25/2019	15.1	5/10/2019	38.4
DX	199-D8-95	E	4/16/2019	34.1	9/17/2019	38	9/17/2019	38
DX	199-D8-96	E	6/17/2019	31	10/31/2019	34	10/31/2019	34
DX	199-D8-97	E	4/1/2019	27	11/13/2019	23	7/22/2019	30
DX	199-D8-98	E	5/21/2019	18	10/31/2019	19	10/31/2019	19
DX	199-D8-99	E	6/25/2019	7.56	11/13/2019	16	11/13/2019	16
DX	199-H1-5	M/I[b]	—	—	—	—	2/4/2019	10

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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)
DX	199-H4-80	E	5/21/2019	15	11/13/2019	18	11/13/2019	18
DX	199-H4-81	E	4/1/2019	14	11/13/2019	32	11/13/2019	32
DX	199-H4-82	M/I[b]	—	—	—	—	3/11/2019	10.4
	699-101-48B	M	—	—	10/21/2019	1.3(U)	10/21/2019	1.3(U)
	699-93-48A	M	—	—	10/22/2019	10.5	10/22/2019	10.5
	699-95-48	M	—	—	10/24/2019	9.72	10/24/2019	9.72
	699-95-51	M	—	—	10/21/2019	1.3(U)	10/21/2019	1.3(U)
	699-96-52B	M	—	—	10/24/2019	4.46	10/24/2019	4.46
	699-97-47C	M	5/7/2019	12.1	—	—	5/7/2019	12.1
	699-97-48B	M	—	—	10/21/2019	14.7	10/21/2019	14.7
	699-97-51A	M	—	—	10/21/2019	6.16	10/21/2019	6.16
	699-98-49A	M	—	—	10/21/2019	1.3(U)	10/21/2019	1.3(U)
Aquifer Sampling Tubes								
	36-S[c]	AT	—	—	10/16/2019	3.6(B)	—	—
	38-M	AT	—	—	10/16/2019	3.99	10/16/2019	3.99
	AT-D-1-M	AT	—	—	10/16/2019	1.3(U)	10/16/2019	1.3(U)
	AT-D-3-D	AT	—	—	10/16/2019	2.25	10/16/2019	2.25
	AT-D-4-D	AT	—	—	10/16/2019	1.3(U)	10/16/2019	1.3(U)
	C6278[d]	AT	—	—	—	—	—	—
	C7647	AT	—	—	10/16/2019	10.6	10/16/2019	10.6
	DD-10-3	AT	—	—	10/17/2019	1.93	10/17/2019	1.93
	DD-12-2	AT	—	—	10/17/2019	3.09	10/17/2019	3.09

Table 2-8. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-D Area and DX P&T Systems, 2019

System	Well or Aquifer Tube Name	Well Use	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)
	DD-15-3	AT	—	—	10/17/2019	4.11	10/17/2019	4.11
	DD-16-4	AT	—	—	10/17/2019	11.4	10/17/2019	11.4
	DD-17-2	AT	—	—	10/22/2019	5.64	10/22/2019	5.64
	DD-41-3	AT	—	—	10/16/2019	1.3(U)	10/16/2019	1.3(U)
	DD-44-4	AT	—	—	10/16/2019	5.2	10/16/2019	5.2
	DD-49-3	AT	—	—	10/16/2019	11.4	10/16/2019	11.4
	DD-50-3	AT	—	—	10/16/2019	13	10/16/2019	13
	DD-50-4	AT	—	—	10/16/2019	14.5	10/16/2019	14.5
	Redox-1-6.0	AT	—	—	10/16/2019	1.8	10/16/2019	1.8
	Redox-3-3.3[d]	AT	—	—	—	—	—	—

Notes:

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

Blank cells in the "System" column indicate that the well/aquifer tube is not tied directly to a pump and treat system.

a. High river stage represents the period from mid-April through the end of June. Low river stage represents the period from August through December.

b. Wells 199-H1-5 and 199-H4-82 were converted from monitoring wells to injection wells in May 2019.

c. Aquifer 36-M could not be sampled in 2019, so aquifer tube 36-S (at the same location) was sampled instead.

d. Aquifer tubes were unable to be sampled in 2019 because tubes were broken.

— = indicates that 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

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

Table 2-9. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-H Area and HX P&T Systems, 2019

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	4/17/2019	27	12/4/2019	26	4/17/2019	27
HX	199-H1-2	E	4/17/2019	42	12/4/2019	37	4/17/2019	42
HX	199-H1-3	E	—	—	11/1/2019	33	11/1/2019	33
HX	199-H1-32	E	5/22/2019	17.7	12/11/2019	20.2	12/11/2019	20.2
HX	199-H1-33	E	7/11/2019	20	8/20/2019	19.2	7/11/2019	20
HX	199-H1-34	E	7/11/2019	16	12/11/2019	18	3/28/2019	19.3
HX	199-H1-35	E	4/17/2019	11	11/5/2019	11	11/5/2019	11
HX	199-H1-36	E	7/11/2019	20	8/26/2019	19	3/7/2019	21.9
HX	199-H1-37	E	7/11/2019	3	12/5/2019	7	12/5/2019	7
HX	199-H1-38	E	5/22/2019	5.12	12/5/2019	5	5/22/2019	5.12
HX	199-H1-39	E	—	—	—	—	—	—
HX	199-H1-4	E	6/12/2019	28	12/5/2019	29	12/5/2019	29
HX	199-H1-40	E	5/22/2019	5.1	—	—	5/22/2019	5.1
HX	199-H1-42	E	5/20/2019	20	12/5/2019	42	12/5/2019	42
HX	199-H1-43	E	4/17/2019	16	12/4/2019	17	12/4/2019	17
HX	199-H1-45	E	7/11/2019	13	12/4/2019	13	12/4/2019	13
HX	199-H1-46	E	—	—	11/5/2019	28	½/2019	29
HX	199-H1-47	E	7/11/2019	32	9/11/2019	28.3	7/11/2019	32
HX	199-H1-48	E	—	—	8/26/2019	29	8/26/2019	29
HX	199-H1-49	E	6/12/2019	17	12/30/2019	22.6	12/30/2019	22.6
	199-H1-7	M	5/10/2019	9.11	11/1/2019	5.1	5/10/2019	9.11
	199-H3-11	M	—	—	11/7/2019	4.22	11/7/2019	4.22
HX	199-H3-21	E	7/11/2019	25	12/10/2019	28.1	12/10/2019	28.1

Table 2-9. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-H Area and HX P&T Systems, 2019

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	—	—	12/11/2019	8.12	½/2019	9
HX	199-H3-26	E	5/20/2019	6	—	—	3/7/2019	8.4
	199-H3-2A	M	—	—	11/1/2019	1.3(U)	11/1/2019	1.3(U)
	199-H3-3	M	—	—	11/1/2019	3.96	11/1/2019	3.96
HX	199-H3-4	E	5/22/2019	13.5	12/4/2019	13	5/22/2019	13.5
	199-H3-5	M	—	—	11/7/2019	10	11/7/2019	10
	199-H3-6	M	—	—	11/7/2019	3.82	11/7/2019	3.82
	199-H3-7	M	—	—	11/7/2019	1.3(U)	11/7/2019	1.3(U)
	199-H4-10	M	—	—	12/3/2019	1.3(U)	12/3/2019	1.3(U)
	199-H4-11	M	—	—	11/12/2019	3.77	11/12/2019	3.77
	199-H4-12A	M	5/13/2019	3.15	11/12/2019	3.31	11/12/2019	3.31
	199-H4-13	M	—	—	11/12/2019	14.2	11/12/2019	14.2
HX	199-H4-15A	E	5/22/2019	3.99	8/20/2019	3.45	5/22/2019	3.99
HX	199-H4-4	E	5/22/2019	3.44	12/10/2019	3.36	5/22/2019	3.44
	199-H4-45	M	—	—	12/3/2019	5.85	12/3/2019	5.85
	199-H4-46	M	—	—	11/12/2019	5.2	11/12/2019	5.2
	199-H4-49	M	—	—	11/15/2019	4.29	11/15/2019	4.29
	199-H4-5	M	—	—	12/3/2019	3.69	12/3/2019	3.69
HX	199-H4-63	E	4/17/2019	13	10/10/2019	11	4/17/2019	13
HX	199-H4-64	E	5/22/2019	3.09	12/10/2019	2.57	5/22/2019	3.09
	199-H4-65	M	—	—	11/18/2019	6.01	11/18/2019	6.01
HX	199-H4-69	E	7/11/2019	13	12/10/2019	12.4	7/11/2019	13
HX	199-H4-70	E	6/12/2019	11	12/4/2019	11	12/4/2019	11

Table 2-9. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-H Area and HX P&T Systems, 2019

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-H4-74	E	—	—	—	—	—	—
HX	199-H4-75	E	7/11/2019	20	8/26/2019	14	2/27/2019	25
HX	199-H4-76	E	4/17/2019	3	9/11/2019	2.78	4/17/2019	3
HX	199-H4-77	E	6/19/2019	3.01	12/5/2019	3	3/7/2019	3.9
	199-H4-8	M	5/1/2019	2.18	—	—	5/1/2019	2.18
	199-H4-83	M	—	—	11/15/2019	18.8	11/15/2019	18.8
RCRA	199-H4-84	M	5/1/2019	29.3	8/5/2019	44.9	8/5/2019	44.9
RCRA	199-H4-85	M	5/1/2019	1.7	12/30/2019	3.65	3/7/2019	5
HX	199-H4-86	E	5/22/2019	6.26	—	—	3/11/2019	7
	199-H4-87	M	5/14/2019	4.09	8/6/2019	4.76	3/11/2019	6.41
RCRA	199-H4-88	M	5/1/2019	9.35	11/8/2019	9.87	3/7/2019	13.5
RCRA	199-H4-89	M	5/2/2019	4.35	8/5/2019	3.42	5/2/2019	4.35
HX	199-H4-92	E	6/12/2019	13	10/30/2019	5.18	6/12/2019	13
HX	199-H4-93	E	4/17/2019	14	12/5/2019	8	4/17/2019	14
HX	199-H5-16	E	5/20/2019	11	12/11/2019	12.3	12/11/2019	12.3
	199-H5-1A	M	—	—	11/8/2019	3.8	11/8/2019	3.8
	199-H6-1	M	—	—	11/8/2019	3.48	11/8/2019	3.48
	199-H6-2	M	—	—	11/18/2019	3.22	11/18/2019	3.22
	199-H6-3	M	—	—	11/18/2019	2.99	11/18/2019	2.99
	699-100-43B	M	—	—	10/21/2019	11.2	10/21/2019	11.2
	699-88-41	M	—	—	10/15/2019	14.4	10/15/2019	14.4
	699-88-41A	M	—	—	11/1/2019	7.23	11/1/2019	7.23
	699-89-35	M	—	—	10/15/2019	13.9	10/15/2019	13.9

Table 2-9. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-H Area and HX P&T Systems, 2019

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)
	699-90-37B	M	—	—	10/22/2019	1.3(U)	10/22/2019	1.3(U)
	699-90-45	M	—	—	10/22/2019	3.6	10/22/2019	3.6
	699-91-46A	M	—	—	10/22/2019	7.49	10/22/2019	7.49
	699-93-37A	M	—	—	10/22/2019	14.6	10/22/2019	14.6
	699-94-41	M	—	—	10/22/2019	12.9	10/22/2019	12.9
	699-94-43	M	—	—	10/22/2019	3.32	10/22/2019	3.32
	699-95-45	M	—	—	10/22/2019	3.49	10/22/2019	3.49
	699-97-41	M	—	—	10/24/2019	11.3	10/24/2019	11.3
	699-97-43B	M	—	—	11/1/2019	1.91	11/1/2019	1.91
	699-97-45	M	—	—	10/24/2019	21.9	10/24/2019	21.9
	699-97-47B	M	—	—	11/4/2019	16.6	11/4/2019	16.6
	699-98-43	M	—	—	10/23/2019	12.4	10/23/2019	12.4
	699-98-46	M	—	—	10/31/2019	27.8	10/31/2019	27.8
	699-99-41	M	—	—	10/21/2019	6.48	10/21/2019	6.48
	699-99-42B	M	—	—	10/31/2019	3.81	10/31/2019	3.81
	699-99-44	M	—	—	10/21/2019	20	10/21/2019	20
Aquifer Sampling Tubes								
	43-M	AT	—	—	10/23/2019	7.64	10/23/2019	7.64
	45-M	AT	—	—	10/23/2019	1.3(U)	10/23/2019	1.3(U)
	47-D	AT	—	—	10/24/2019	4.96	10/24/2019	4.96
	47-M	AT	—	—	10/24/2019	4.95	10/24/2019	4.95
	48-M	AT	—	—	11/6/2019	5.74	11/6/2019	5.74
	50-M	AT	—	—	12/16/2019	2.99	12/16/2019	2.99

Table 2-9. Maximum Cr(VI) Concentrations for Wells and Aquifer Tubes Monitoring the 100-H Area and HX P&T Systems, 2019

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)
	51-D	AT	—	—	—	—	—	—
	52-D	AT	—	—	12/23/2019	1.3(U)	12/23/2019	1.3(U)
	54-M	AT	—	—	12/16/2019	2.68	12/16/2019	2.68
	AT-H-1-M	AT	—	—	10/24/2019	4.95	10/24/2019	4.95
	AT-H-2-D	AT	—	—	10/24/2019	3.63	10/24/2019	3.63
	AT-H-3-D	AT	—	—	10/24/2019	9.4	10/24/2019	9.4
	C5633	AT	—	—	10/23/2019	10.6	10/23/2019	10.6
	C5636	AT	—	—	10/23/2019	8.02	10/23/2019	8.02
	C5638	AT	—	—	10/23/2019	16.7	10/23/2019	16.7
	C5641	AT	—	—	10/23/2019	20.3	10/23/2019	20.3
	C5678	AT	—	—	10/23/2019	2.68	10/23/2019	2.68
	C5682	AT	—	—	10/24/2019	1.46	10/24/2019	1.46
	C6293	AT	—	—	—	—	—	—
	C6301	AT	—	—	—	—	—	—
	C7649	AT			11/6/2019	2.89	11/6/2019	2.89
	C7650	AT	—	—	11/6/2019	11.6	11/6/2019	11.6

Notes:

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

Blank cells in the "System" column indicate that the well/aquifer tube is not tied directly to a pump and treat system.

*High river stage represents the period from mid-April through the end of June. Low river stage represents the period from August through December.

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

AT = aquifer tube

Cr(VI) = hexavalent chromium

E = extraction well

M = monitoring well

RCRA = *Resource Conservation and Recovery Act of 1976*

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

Table 2-10. Maximum Cr(VI) Concentrations for the 100-H Area and 100-D Area RUM Wells, 2019

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	—	—	10/25/2019	1.3(U)	10/25/2019	1.3(U)
	199-D5-141	M	—	—	10/18/2019	1.3(U)	10/18/2019	1.3(U)
	199-D8-54B	M	—	—	10/25/2019	10.1	10/25/2019	10.1
	199-H1-50	M	4/16/2019	16.7	11/1/2019	2.35	4/16/2019	16.7
	199-H2-1	M	5/10/2019	16	11/1/2019	12.9	2/6/2019	17
	199-H3-10	M	—	—	11/7/2019	4.06	11/7/2019	4.06
	199-H3-12	M	—	—	11/8/2019	313	3/6/2019	426
	199-H3-13	M	—	—	11/8/2019	544	3/7/2019	802
HX	199-H3-22	E	5/20/2019	178	8/26/2019	300	8/26/2019	300
HX	199-H3-28	E	4/17/2019	72	8/26/2019	63	½/2019	80
HX	199-H3-29	E	4/17/2019	237	8/26/2019	191	3/7/2019	264
HX	199-H3-2C	E	5/20/2019	29	11/5/2019	27	3/7/2019	29.6
	199-H3-30	M	7/9/2019	43.4	10/15/2019	92.9	10/15/2019	92.9
	199-H3-32	M	5/20/2019	110	11/12/2019	160	2/25/2019	200
HX	199-H3-9	E	7/11/2019	27	8/26/2019	30	½/2019	38
HX	199-H4-12C	E	7/11/2019	66	8/26/2019	63	½/2019	85
	199-H4-15CS	M	—	—	11/19/2019	124	11/19/2019	124
	199-H4-90	M	5/14/2019	10.8	11/15/2019	11	3/11/2019	11.6
	199-H4-91	M	5/13/2019	39.4	11/19/2019	45.06	11/19/2019	45.06
	199-H7-1	M	4/10/2019	18.3	8/6/2019	2.08	4/10/2019	18.3
	699-95-45C	M	5/1/2019	2.07	10/18/2019	1.3(U)	3/13/2019	2.42
	699-97-43C	M	5/29/2019	2.39	11/4/2019	3.11	11/4/2019	3.11

Table 2-10. Maximum Cr(VI) Concentrations for the 100-H Area and 100-D Area RUM Wells, 2019

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)
	699-97-45B	M	—	—	11/4/2019	5.4	11/4/2019	5.4
	699-97-48C	M	—	—	10/31/2019	147	10/31/2019	147
	699-97-60	M	—	—	10/31/2019	55	3/11/2019	73.7
DX	699-97-61	E	5/21/2019	80	9/17/2019	81	9/17/2019	81

Notes:

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

Blank cells in the "System" column indicate that the well/aquifer tube is not tied directly to a pump and treat system.

*High river stage represents the period from April through the end of June. Low river stage represents the period from August through December.

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

Cr(VI) = hexavalent chromium

E = extraction well

M = monitoring well

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

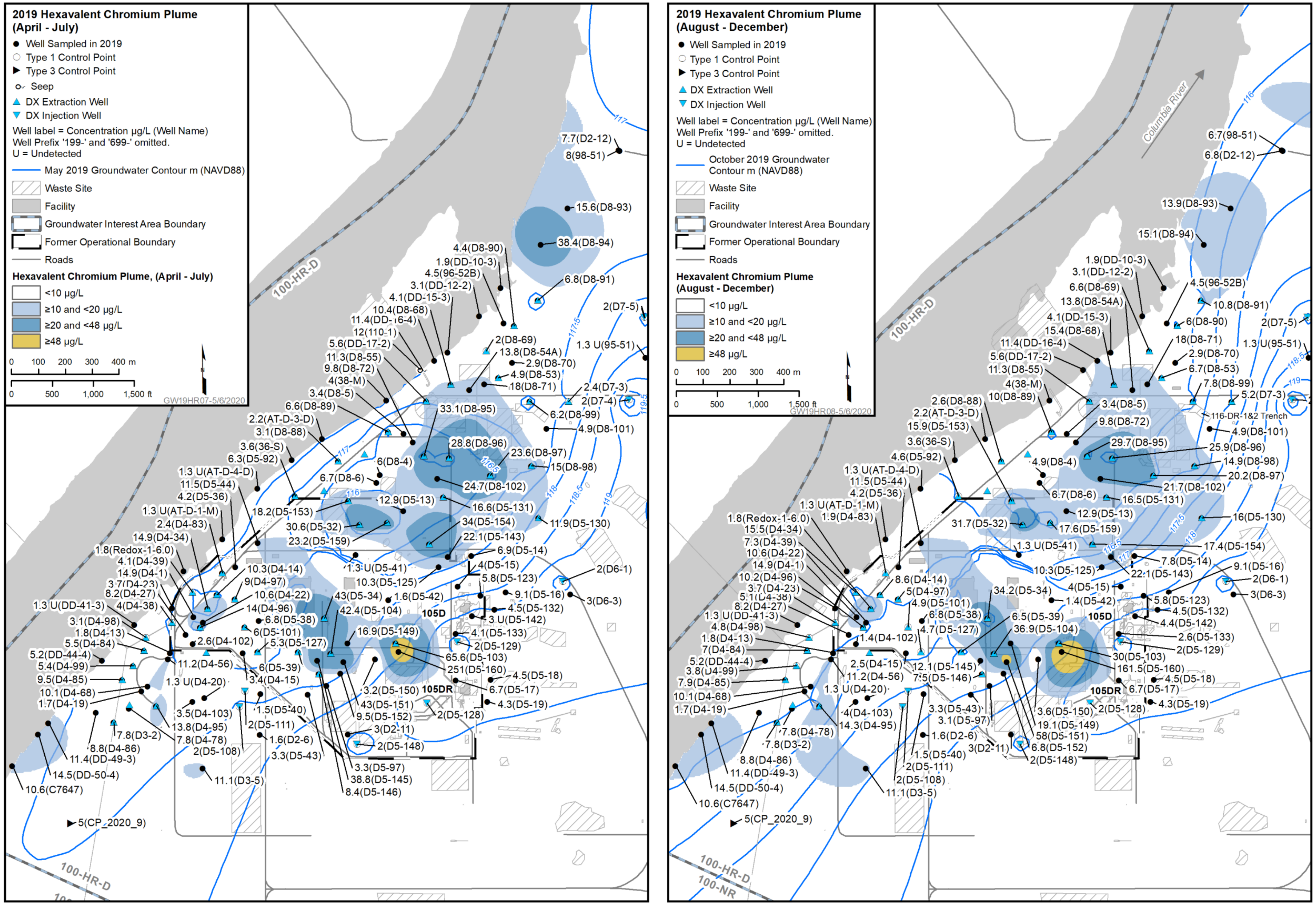

Figure 2-11. 100-HR-3 OU (100-D Area) Cr(VI) High River-Stage to Low River-Stage Comparison in Unconfined Aquifer, 2019

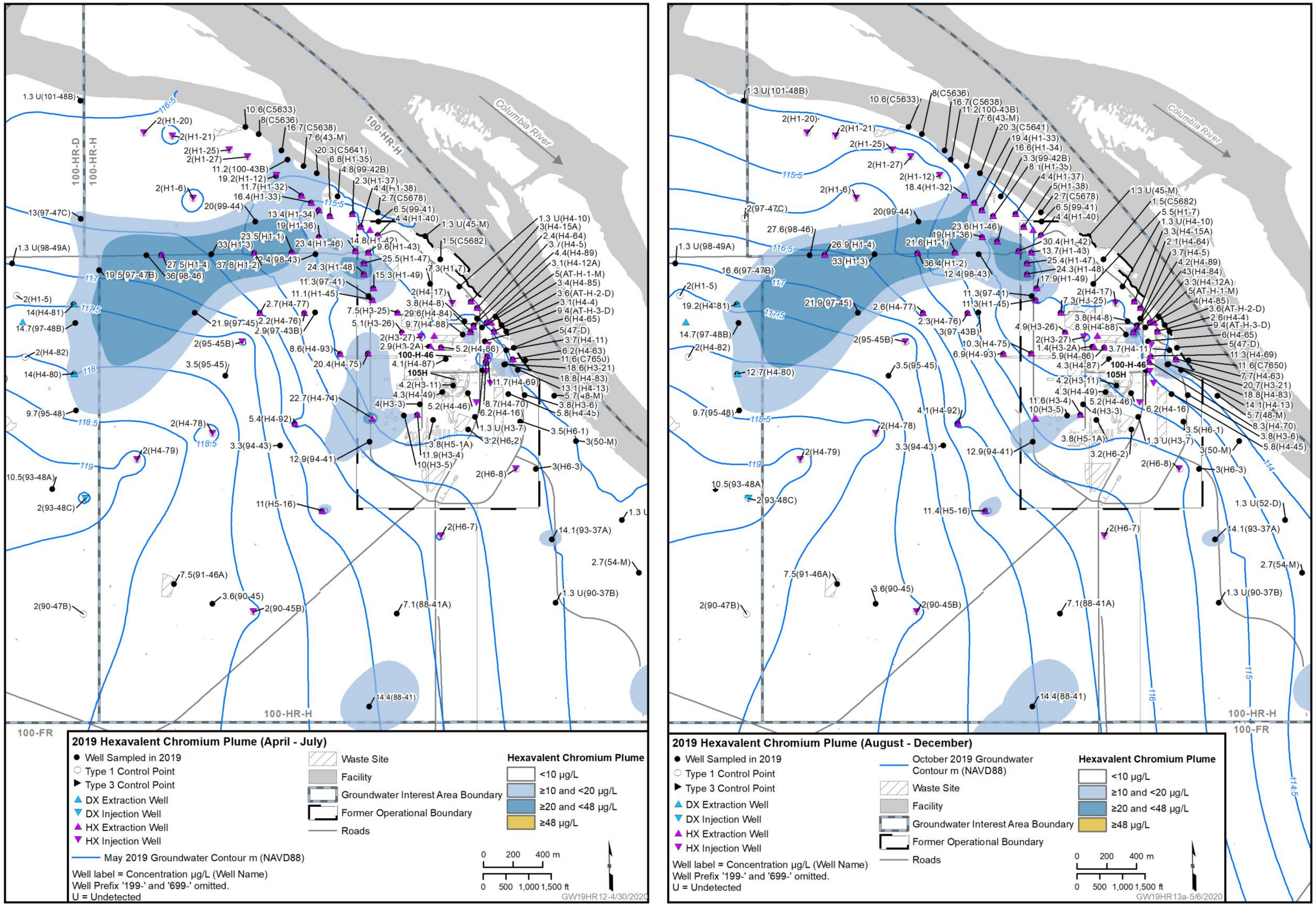

Figure 2-12. 100-HR-3 OU (100-H Area) Cr(VI) High River-Stage to Low River-Stage Comparison in Unconfined Aquifer, 2019

ECF-HANFORD-20-0018, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2019 Hanford Site Groundwater Monitoring Report*, describes the methods for generating contaminant plume representations. The following sections discuss the contaminant monitoring results. The annual groundwater monitoring report (Chapter 4 in DOE/RL-2019-66) provides further discussion of contaminants.

2.2.3.1 River-Stage Effects

The Columbia River is the discharge boundary for groundwater in the unconfined aquifer beneath the Hanford Site. The rise and fall of the Columbia River creates an interaction zone of surface water and groundwater. The 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. High river stage during 2019 was lower than normal and occurred from late April to early July, with the highest river levels occurring from mid-May to late June. Low river stage in 2019 occurred from September through early November, with the lowest river levels in September and October, which is typical. River stage affects both the unconfined and semiconfined RUM aquifers. The semiconfined aquifer in the RUM has been shown to be in communication with the Columbia River. However, it is uncertain whether (and to what extent) the river acts as a RUM discharge boundary, and additional studies are planned to help address this issue.

Groundwater elevation in the unconfined aquifer adjacent to the river increases in response to increased river-stage elevation. In locations near the river, some quantity of river water may actually enter the aquifer under conditions of rapid river-stage increases, resulting in what is known as bank storage. In the 100-D Area where the aquifer adjacent to the river consists of the relatively finer-grained Ringold unit E (as opposed to the Hanford formation), bank storage is limited to the aquifer volume very close to the river. In portions of the 100-H Area where the aquifer consists of the coarse-grained Hanford formation, river water intrusion and resulting bank storage may extend inland for many meters.

Contaminant concentrations vary as groundwater elevation changes seasonally. At locations near historical source release areas, contaminant concentrations are frequently observed to increase when the water table rises and comes into contact with residual contamination in the deep vadose zone/periodically rewetted zone (PRZ). In contrast, locations downgradient of source areas frequently exhibit decreased concentrations at high groundwater elevation due to mixing with river water.

Groundwater specific conductance was mapped using low river-stage data to evaluate river water migration into the unconfined aquifer as affected by seasonal elevation changes and due to capture by pumping at extraction wells (Figure 2-13). A specific conductance level of <200 µS/cm is indicative of river water (i.e., the Columbia River exhibits a relatively low dissolved solids load, thus, a low specific conductance). Specific conductance of 400 µS/cm (or greater) is typical for inland groundwater. Specific conductance of 200 to 400 µS/cm indicates likely mixing of groundwater with river water to varying degrees.

Most of the wells in the 100-D Area exhibited specific conductance >400 µS/cm (Figure 2-13), with some inland wells having specific conductance >600 µS/cm. Along the shoreline, wells and aquifer tubes in some areas had specific conductance values that represented more river water (e.g., 142 µS/cm at AT-D-4-D); other areas had values that represented a higher amount of groundwater (e.g., 408 µS/cm at DD-15-3). In the 100-H Area, the specific conductance was <200 µS/cm along most of river shoreline. South of the 100-H Area, the specific conductance values were higher and more typical of groundwater, which is consistent with the current plume configuration. 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), which is discussed in Section 2.2.4.

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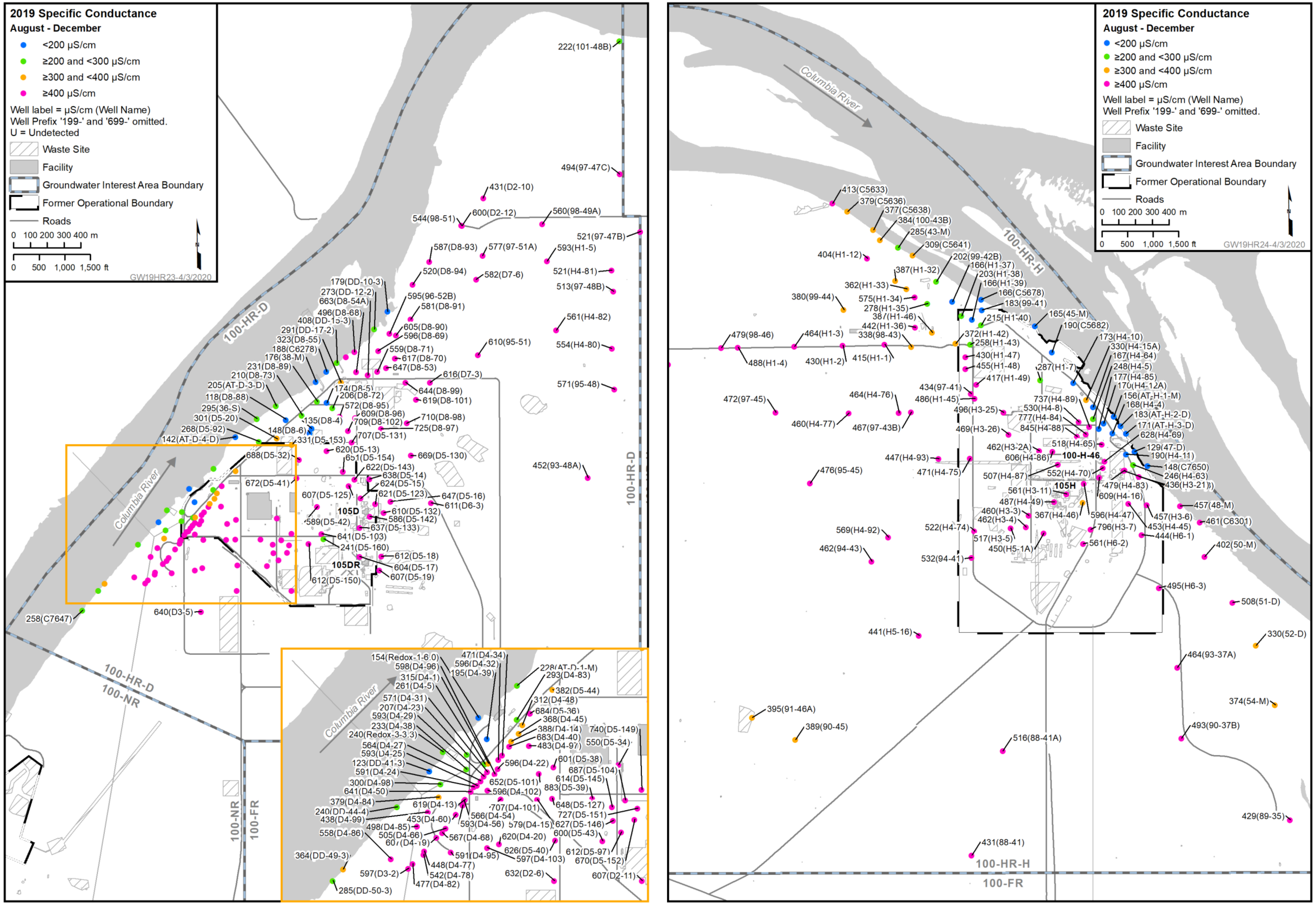

Figure 2-13. Specific Conductance at the 100-HR-3 OU, Fall 2019

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2.2.3.2 Hexavalent Chromium

The Cr(VI) concentrations are monitored in wells and aquifer tubes in the 100-HR-3 OU. The following sections discuss the monitoring results for the unconfined aquifer in the 100-D and 100-H Areas (Sections 2.2.3.2.1 and 2.2.3.2.2, respectively), as well as the RUM aquifer (Section 2.2.3.2.3). Figures 2-11 and 2-12 show the 2019 spring and fall Cr(VI) distribution in the unconfined aquifer in the 100-D and 100-H Areas, respectively. In wells near the Columbia River, maximum Cr(VI) concentrations generally coincide with low river conditions. Because the P&T system has become more robust and optimized over time with the addition of wells in key locations, the effect of the river stage on plume configuration has lessened. Plume changes are now primarily controlled by modifications made to P&T systems during the year.

2.2.3.2.1 Hexavalent Chromium in the 100-D Area

The portion of the plume with Cr(VI) concentrations >48 µg/L decreased in size in 2019 as a result of ongoing remediation activities and is now limited to a small area in the southern portion of the 100-D Area, near the former 100-D-100 and 100-D-30/100-D-104 waste sites (Figure 2-11).

Excavations of waste sites 100-D-100 (staining near the former sodium dichromate/acid railcar and truck unloading station), 100-D-30 (sodium dichromate trench and sump), and 100-D-104 (sodium dichromate storage tank and acid neutralization french drain) (Figure 2-14) were completed in 2014. The excavations at 100-D-30 and 100-D-104 were combined. Following excavation of the waste sites, Cr(VI) concentrations declined in downgradient well 199-D5-104 from >5,000 µg/L in 2012 to 156 µg/L by the end of 2015. Concentrations in wells 199-D5-104 and 199-D5-34 (both located downgradient) continue to show a decreasing trend, but concentrations in both wells began to approach an asymptote of 30 µg/L. The slowing rate of concentration decline continued during 2019 (Figure 2-15).

While the waste sites excavations extended to groundwater, some visibly contaminated soil near the water table remained in the northeastern corner of the 100-D-100 excavation. As a result, several wells near the excavation areas continue to exhibit concentrations >48 µg/L. The highest concentrations in the southern 100-D Area plume are in wells 199-D5-103 and 199-D5-160 (Figure 2-16), which are located between the two excavation areas.

Well 199-D5-103, which exhibited a strong correlation between the river stage and Cr(VI) concentrations between the end of 2016 and 2018, did not show a similar pattern in 2019 after it was connected to the DX P&T system in late 2018 (Figure 2-15). Cr(VI) concentrations decreased from 122 µg/L in January 2019 to 16 µg/L in December 2019. Adjacent well 199-D5-160 had a similar response to nearby pumping in 2017 and 2018 but followed the trend of well 199-D5-103 in 2019. Concentrations in well 199-D5-160 decreased from 263 to 175 µg/L between May and October 2019.

In the northern portion of the 100-D Area, the highest concentrations are near the 120-D-1 (100-D Pond) waste site (southwest of the 116-DR-1&2 Trenches). Elevated Cr(VI) concentrations remain in wells 199-D8-95 and 199-D8-96 (Figure 2-17); however, concentrations are slowly declining. Due to ongoing remediation, concentrations in that area remained <48 µg/L in 2019.

2.2.3.2.2 Hexavalent Chromium in the Horn and 100-H Area

Discharges to the basins and trenches during operations resulted in an unconfined aquifer Cr(VI) plume that extends across the Horn from the 100-D Area to the 100-H Area (Figures 2-11 and 2-12). This plume encompasses the largest portion of the 100-HR groundwater interest area. Cr(VI) concentrations in the unconfined aquifer in the Horn consistently remain <100 µg/L and were below the 48 µg/L cleanup level specified in the 100-D/100-H Areas ROD (EPA et al., 2018) for the second consecutive year.

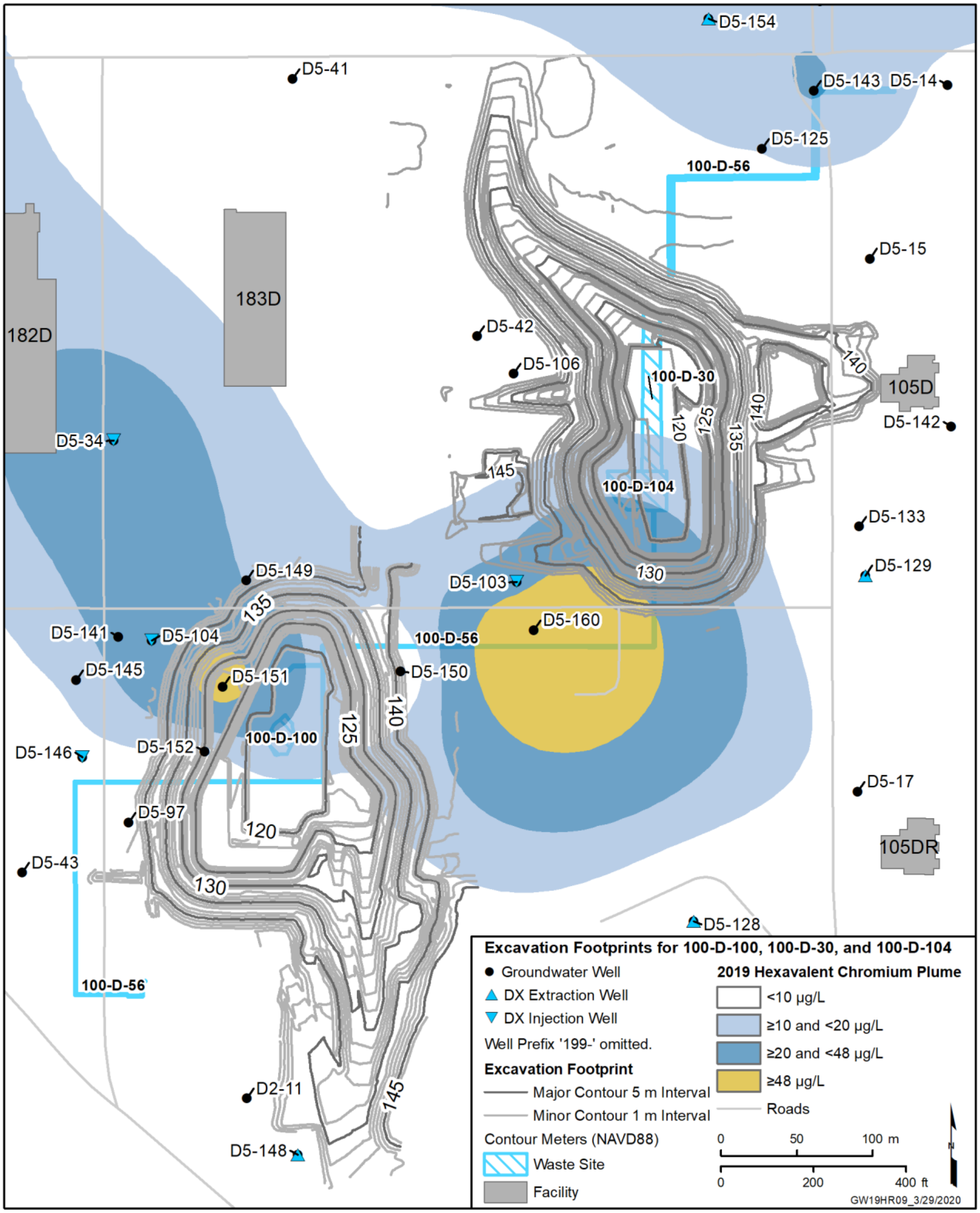

Figure 2-14. Excavation Footprints for Waste Sites 100-D-100 and 100-D-30/104

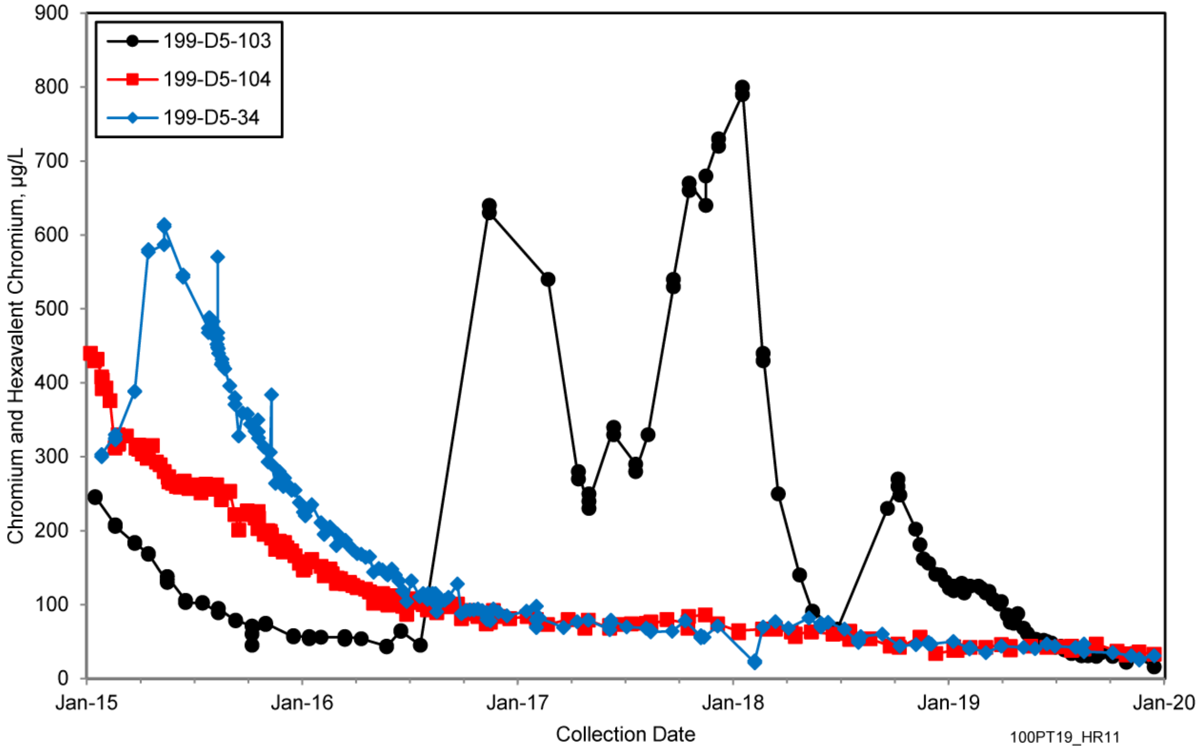

Figure 2-15. Chromium Data for Wells 199-D5-103, 199-D5-104, and 199-D5-34

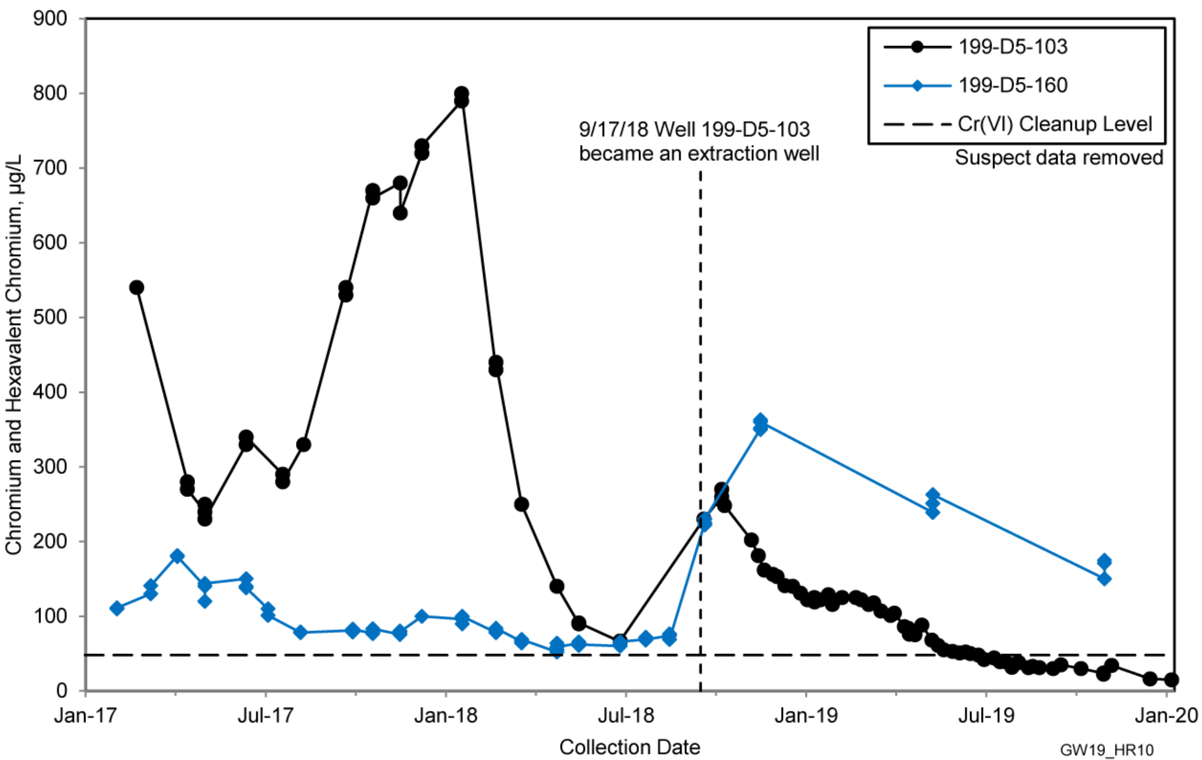

Figure 2-16. Chromium Data for Wells 199-D5-103 and 199-D5-160

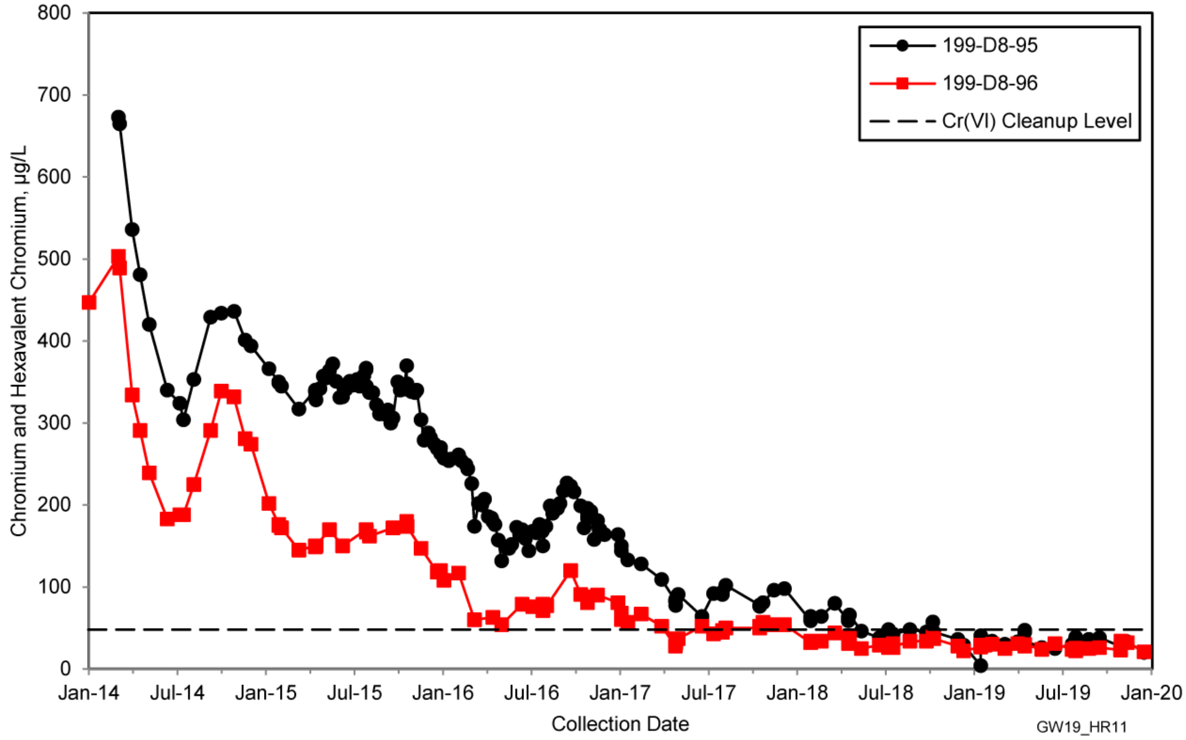

Figure 2-17. Chromium Data for Wells 199-D8-95 and 199-D8-96

Areas of Cr(VI) concentrations between 20 and 48 µg/L remain in the Horn in a plume that runs from west to east and in a small area to the south of the 100-H Area. Extraction wells in this area have low flow rates, with well 199-H1-4 extracting at only 10.5 L/min (2.8 gal/min) during low river stage. In addition, several wells in this area exhibit low water levels that restrict or preclude pumping for long periods (Table 2-6), therefore reducing plume capture.

Because of low extraction rates, Cr(VI) concentrations continue to remain between 20 and 48 µg/L in some wells across the Horn. For example, concentrations in wells 199-H1-4 and 199-H1-2 (located in the middle of the Horn) had concentrations of 31 and 45 µg/L in April 2014, respectively. Concentrations in these wells declined to 30 and 24 µg/L in December 2019, respectively. These concentrations are typical across the Horn.

The amount of injected water within the 100-H operational area has been reduced in the last few years to determine if continuing sources remain. The reduced amount of injection water (which tends to dilute contaminant concentrations) and the very high river stage in 2018 resulted in higher concentrations in areas with source material in the lower vadose zone. In 2019, concentration trends remained stable near the 183-H Solar Evaporation Basins and the 107H Retention Basin, and a continuing source in the lower vadose zone is suspected at both locations. At the 183-H Solar Evaporation Basins, Cr(VI) concentrations increase during periods of higher water levels, which is typical for areas with source material remaining in the vadose zone. Figure 2-18 shows an example of the correlation of Cr(VI) concentrations over time for well 199-H4-88 and river stage.

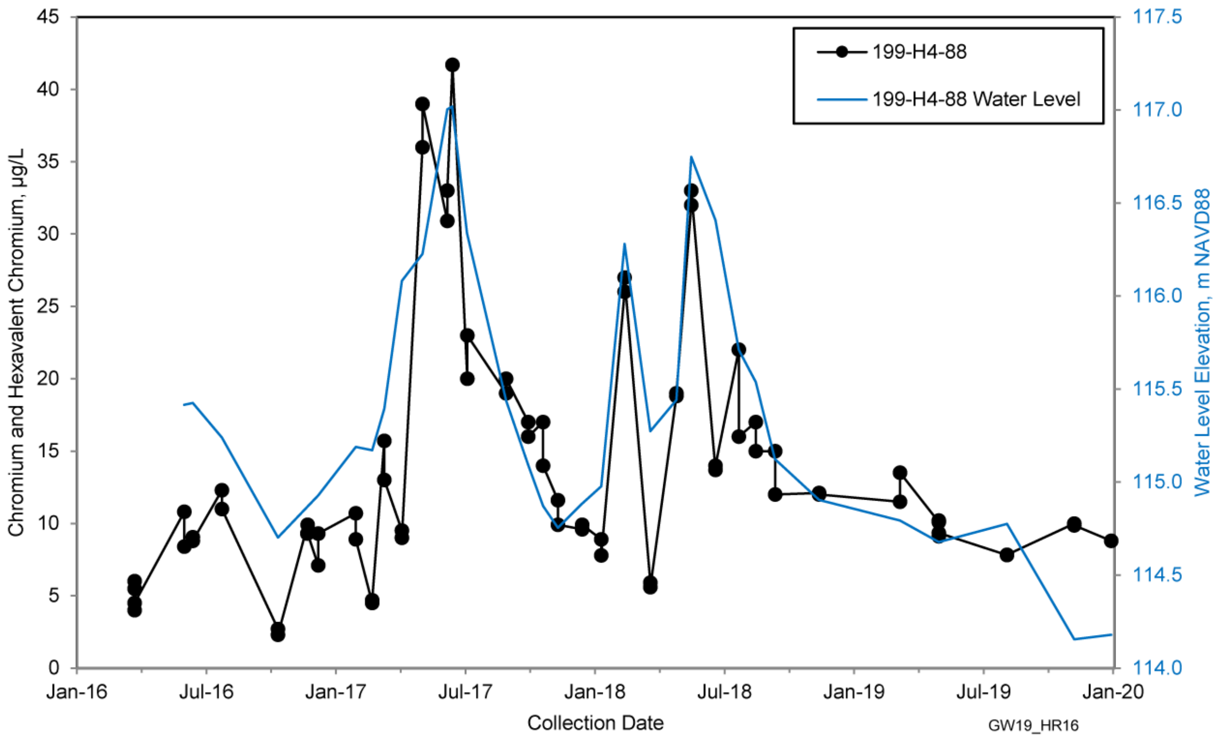

Figure 2-18. Chromium Data and Water Levels for Well 199-H4-88

At the 107H Retention Basin (waste site 116-H-7), Cr(VI) concentrations are >10 µg/L in monitoring wells 199-H4-83, 199-H4-63, and 199-H4-13 and in aquifer tube C7650 downgradient of the basin. Located on the edge of the basin, well 199-H4-83 exhibited decreased concentrations, from 41 µg/L in November 2018 to 19 µg/L in November 2019. Similarly, well 199-H4-13 exhibited decreased concentrations from 22 µg/L in 2018 to 14 µg/L in 2019. The decreased Cr(VI) concentrations in wells 199-H4-83 and 199-H4-13 are likely related to low river stage causing the water table to not come into contact with source material in the lower vadose zone. Concentrations in extraction well 199-H4-63, which has a pumping rate of 105 L/min (28 gal/min), continued to fluctuate above and below the cleanup level of 10 µg/L (consistent with previous years). New extraction well 199-H3-21 was installed in 2019 near the retention basin to address the area of persistent Cr(VI). The well began pumping in July 2019, and additional time is needed before an accurate estimate can be made regarding its impacts.

2.2.3.2.3 Hexavalent Chromium in the Ringold Upper Mud Unit Aquifer

Three wells in the 100-D Area monitor the first water-bearing unit of the RUM: 199-D5-134, 199-D5-141, and 199-D8-54B. Well 199-D5-141 is located southeast of the 182D reservoir, well 199-D8-54B is located near the 116-DR-1&2 Trenches, and well 199-D5-134 is located north of D Reactor (Figure 2-19). The Cr(VI) concentrations in wells 199-D5-141 and 199-D5-134 remained <10 µg/L in filtered samples and are typically below the detection limit. Concentrations in well 199-D8-54B have been trending slowly upward, with a maximum concentration in October 2019 of 10.1 µg/L (filtered sample). These wells will continue to be monitored to track concentrations.

Across the Horn, five RUM wells run from west to east (Figure 2-19). Cr(VI) concentrations are slowly declining in extraction well 699-97-61 but are stable or increasing in the next two wells to the east (699-97-48C and 699-97-60) (Figure 2-19). Further east, concentrations were <10 µg/L in well 699-97-45B and were below detection limits in well 699-97-43C in early 2019. In May and November 2019, concentrations increased to 2.4 and 3.1 µg/L, respectively.

Analytical results indicate that the plume is migrating to the east in the RUM aquifer, with well 699-97-61 representing the tailing end at 10 µg/L and well 699-97-45B just beyond the leading edge. New wells drilled during FY 2019 and FY 2020 will allow for delineation of the RUM aquifer Cr(VI) plume at 10 µg/L in the Horn. The RUM wells installed in FY 2019 included 199-D5-141, 199-H1-50, 199-H3-12, 199-H3-13, 199-H3-22, 199-H3-32, 199-H7-1, and 699-95-45C.

In the 100-H Area, the contamination levels and extent in the RUM are better defined than elsewhere in the 100-HR-3 OU due to a higher density of wells completed in that unit (Figure 2-19). The RUM wells near the 183-H Solar Evaporation Basins exhibit the highest Cr(VI) levels in the 100-H Area in both the unconfined and RUM aquifers. Well 199-H3-13, downgradient of the 183H clearwells/disposal pit, had the highest concentration of any location (802 µg/L in March 2019). In response to the continued high levels of Cr(VI) at RUM aquifer extraction wells downgradient from the basins, two RUM wells (199-H3-28 and 199-H3-29) were connected to the HX P&T system as extraction wells in 2018. In 2019, Cr(VI) concentrations in well 199-H3-29 declined from 269 µg/L in November 2018 to 176 µg/L in December 2019. Assuming a hydraulic connection, well 199-H3-29 is located just upgradient of RUM aquifer extraction wells 199-H4-12C and 199-H3-9. The results of the 2016 RUM aquifer test (SGW-60571, *Aquifer Testing of the First Water-Bearing Unit in the RUM at 100-H*) showed a hydraulic connection between extraction wells 199-H3-9 and 199-H4-12C. Well 199-H3-29 had not yet been installed at the time of the test, but it is presumed to be connected hydraulically to the other two extraction wells.

Extraction wells 199-H3-2C, 199-H4-12C, and 199-H3-9 combined for an average extraction rate of 76.2 L/min (20.2 gal/min) during 2019 (excludes well downtimes when pumping is zero). Well 199-H4-12C averaged 116 L/min (30.7 gal/min) despite no pumping between March 17 and June 18, 2019, because the pump was being exchanged for one of higher capacity. Extraction wells 199-H4-12C and 199-H3-9 (downgradient from the basins) and extraction well 199-H3-2C (upgradient) continue to have elevated Cr(VI) concentrations. Well 199-H4-12C had Cr(VI) concentrations consistently >100 µg/L from the startup of extraction in 2009 until the beginning of 2018. Concentrations continued to decline in 2019 and have been steadily declining for several years (Figure 2-19). Concentrations in well 199-H3-9 have declined from 170 µg/L in February 2012 to 27 µg/L in December 2019 (Figure 2-19, top inset chart).

It should be noted that RUM well 199-H4-12C has been operating since 2009, and four wells are currently extracting from the RUM aquifer in the 100-H Area. The pumping rate at well 199-H4-12C was limited by the previous pump size. Pumping rates increased after startup with the new, higher capacity pump. Long-term pumping has not dewatered the RUM aquifer, which provides further evidence that the RUM aquifer is connected to the unconfined aquifer, the river, or both (SGW-60571). Water is not currently being injected into this aquifer.

Other wells completed in the RUM at the 100-H Area are located along the river in the northern portion of the 100-H Area (wells 199-H2-1 and 199-H4-15CS) and south of the 183-H Solar Evaporation Basins (wells 199-H3-30, 199-H4-90, and 199-H4-91). Concentrations in well 199-H2-1 remained relatively stable, ranging from 17 to 13 µg/L in 2019. Well 199-H4-15CS is showing an increasing trend, with concentrations at 78 µg/L in November 2018 and 124 µg/L in November 2019. The contaminant source area for these wells has not been determined but may be hydraulically connected to the other 100-H Area RUM wells.

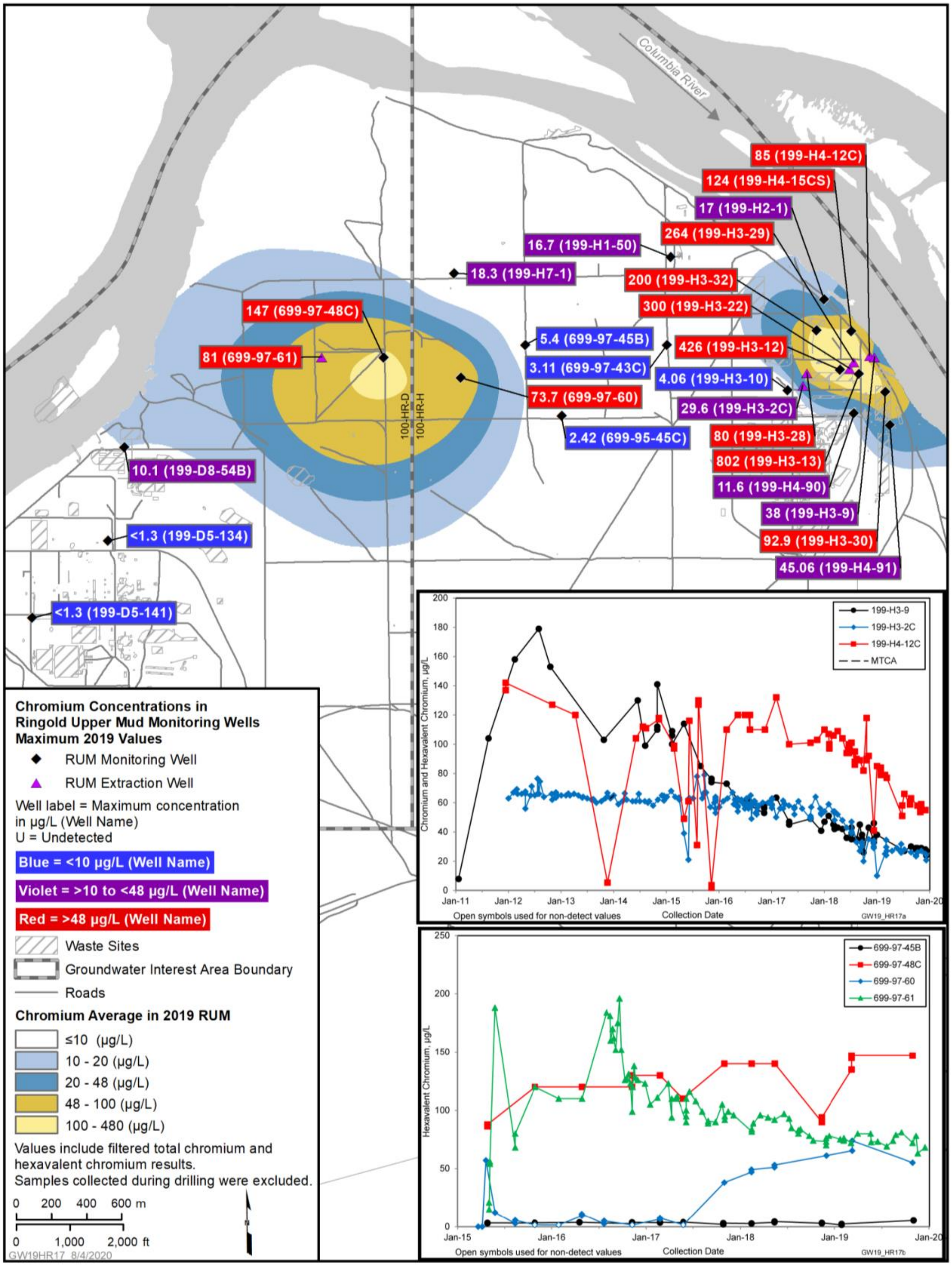

Figure 2-19. 100-H Area and Horn, Cr(VI) in the First Water-Bearing Unit of the RUM, 2019

Other wells completed in the RUM at the 100-H Area are located along the river in the northern portion of the 100-H Area (wells 199-H2-1 and 199-H4-15CS) and south of the 183-H Solar Evaporation Basins (wells 199-H3-30, 199-H4-90, and 199-H4-91). Concentrations in well 199-H2-1 remained relatively stable, ranging from 17 to 13 µg/L in 2019. Well 199-H4-15CS is showing an increasing trend, with concentrations at 78 µg/L in November 2018 and 124 µg/L in November 2019. The contaminant source area for these wells has not been determined but may be hydraulically connected to the other 100-H Area RUM wells.

In the southern part of the 100-H Area, RUM well 199-H3-30 was installed in late 2017. This well is located within the footprint of the former 107H Retention Basin (waste site 116-H-7). Cr(VI) concentrations in this well were as high as 88 µg/L in the post-development sample collected in December 2017. Concentrations decreased throughout 2018 but exhibited an increasing trend for all of 2019, from 16 µg/L in January to 93 µg/L in October (Figure 2-20). The increasing trend at this location could be due to the lower-than-normal river stage in 2019 not allowing for concentration dilution. For example, when the aquifer receives recharge from the river, uncontaminated water enters the system and dilutes the contaminant concentrations.

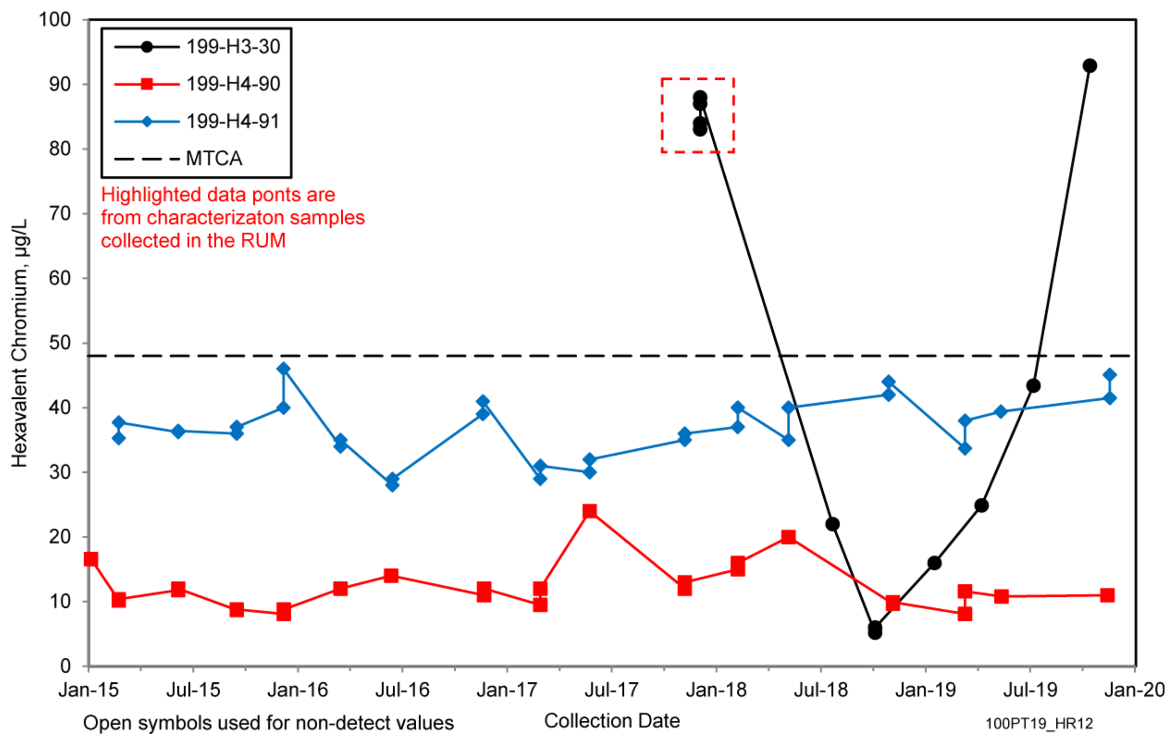

Figure 2-20. Hexavalent Chromium Data for RUM Wells 199-H3-30, 199-H4-90, and 199-H4-91

The presence of Cr(VI) near the 107H Retention Basin is consistent with the current conceptual site model (CSM) for the area, that contaminants migrated into the lower aquifer during operations as a response to downward vertical gradients.

South of the 107H Retention Basin (waste site 116-H-7), concentrations at RUM well 199-H4-91 have been stable at about 30 to 40 µg/L since 2014. The contamination source at well 199-H4-91 is suspected to be the 107H Retention Basin. Slightly inland and presumptively upgradient from the retention basin at well 199-H4-90, Cr(VI) levels remained around 11 µg/L in 2019 (Figure 2-20). In general, Cr(VI) concentrations in the RUM are higher than in the unconfined aquifer.

2.2.3.3 Sulfate

Sulfate concentrations tend to increase in wells located near P&T injection wells. Groundwater treated at the P&T systems is affected by the addition of sulfuric acid, which is used to lower the pH in the influent groundwater because the SIR-700 IX resin treatment technology is more efficient at a lower pH. The amount of acid has been reduced over the last few years since the influent Cr(VI) concentrations have declined. 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. Sulfate concentrations in the effluent during 2019 averaged 158 mg/L at the DX P&T system and 79 mg/L at the HX P&T system, which is below the secondary MCL of 250 mg/L. The maximum sulfate concentration in 100-HR-3 OU groundwater in 2019 was 200 mg/L in well 199-D5-149, which is typical for the well.

2.2.4 Hydraulic Monitoring

Hydraulic monitoring (i.e., water-level monitoring) is performed to evaluate the effect of P&T systems on groundwater levels 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.

Water levels 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 (automated water-level network [AWLN]). Figure 2-21 presents the March 2019 inferred groundwater elevation contour map, including inferred groundwater flow direction vectors. A greater number of monitoring wells with AWLN data providing good spatial distribution improve the confidence in the hydraulic monitoring system and, therefore, the ability to determine hydraulic capture with that data. SGW-53543, *Automated Water Level Network Functional Requirements*, discusses system improvements and identifies the AWLN configurations necessary to provide sufficient data to calculate gradients and to delineate capture zones in areas within the OU where a P&T system is implemented. The 100-HR-3 OU AWLN configuration (based on SGW-53543) consists of 74 AWLN stations, along with the 100-D and 100-H Area river gauges, which record water-level measurements on an hourly basis. It is anticipated that additional stations will be installed to monitor water levels in the RUM as new wells are installed since the groundwater flow direction in the RUM aquifer is currently not well understood. Localized, dynamic water-level data are also collected at each P&T extraction and injection well. Reported water-level data from AWLN wells and manual depth-to-water measurements are reviewed and reduced, and a final data set is compiled to prepare the groundwater elevation maps. ECF-HANFORD-20-0047, *Description of Groundwater Calculations and Assessments for the Calendar Year 2019 (CY2019) 100 Areas Pump-and-Treat Report*, presents an overview of the procedure for developing the water-level data set.

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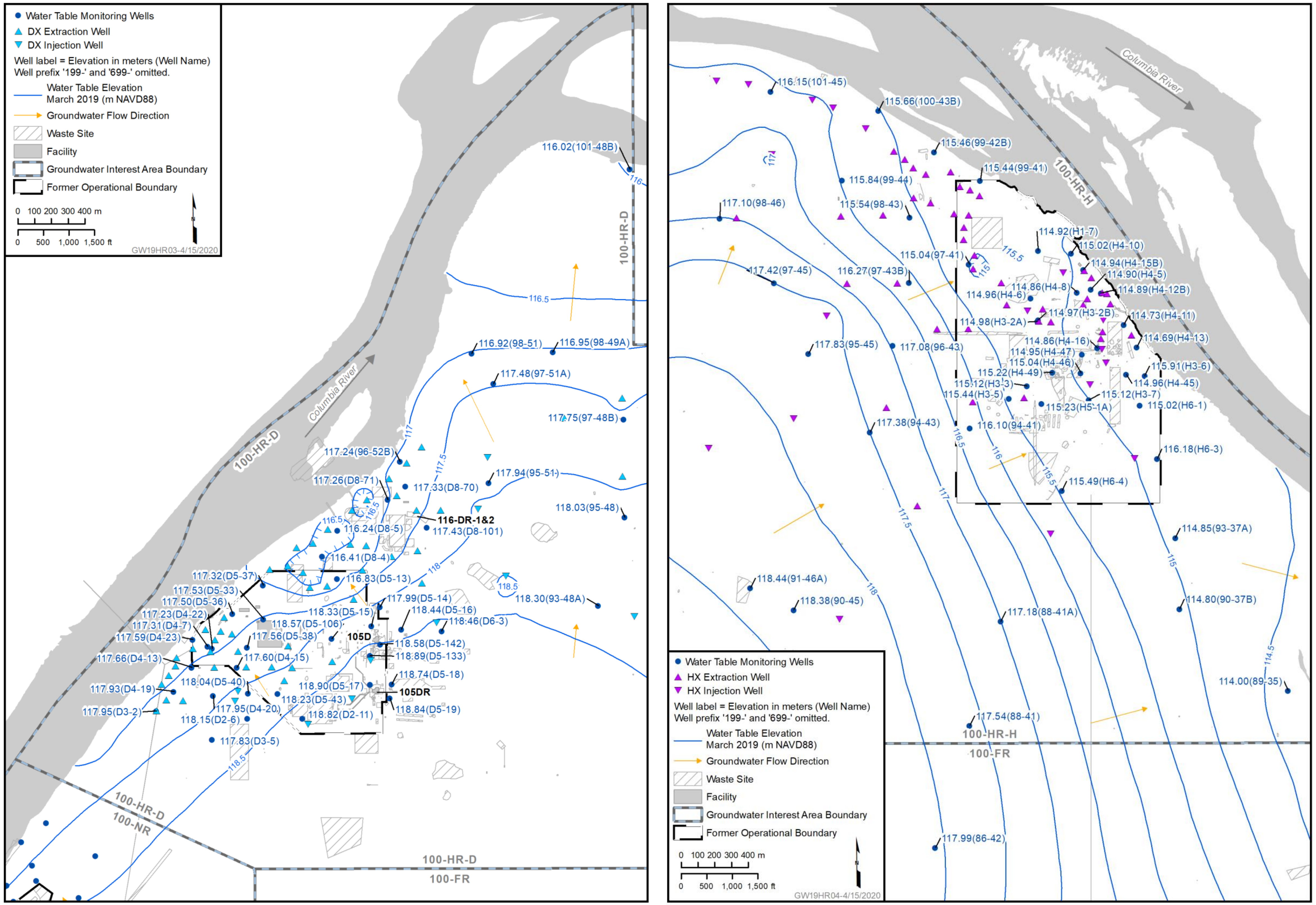

Source: ECF-HANFORD-19-0114, *Preparation of the March 2019 Hanford Site Water Table Map*.

Figure 2-21. 100-HR-3 OU Water Table Elevation Map, March 2019

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In the 100-HR-3 OU, the natural groundwater gradient of the unconfined aquifer is toward the Columbia River, with seasonal hydraulic gradient reversal near the shoreline during high river-stage conditions. However, the hydraulic effects of the P&T systems (i.e., the formation of depressions at extraction wells and mounds at injection locations) are superimposed onto the seasonal fluctuations. In the 100-D and 100-H Areas, groundwater mounds are formed due to reinjecting treated groundwater from the P&T system at inland injection wells, causing outward flows from those locations and increasing the magnitude of hydraulic gradients toward downgradient extraction wells and the river. Groundwater flow in the southern 100-D Area is toward the northwest (toward the river). In the remaining regions of the 100-D Area, groundwater flow is to the north and northwest, with groundwater flow inland being more eastward, moving across the Horn and toward the 100-H Area. In the 100-H Area, the natural groundwater gradient is toward the east and the Columbia River. Extraction and injection well operations cause groundwater to flow from inland injection wells, toward the downgradient extraction wells near the shoreline.

Groundwater in the RUM aquifer flows to the north and northwest in the 100-D Area in locations nearer to the river but flows to the northeast in more inland areas (Figure 2-22). Across the Horn, groundwater in the RUM aquifer flows to the east toward the 100-H Area where a depression in the potentiometric surface occurs around RUM aquifer extraction wells 199-H3-28 and 199-H3-2C. In the 100-H Area, the depression caused flow to the west from the direction of the river at the time of mapping in May 2019.

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 Cr(VI) contamination in the unconfined aquifer. The assessment is based on 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). The CFM depicts the frequency that particles representing groundwater and mobile contaminants move 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., at no time during the period was groundwater moving toward extraction wells, if each "condition" is considered separately, which is further explained in the following discussion). Intermediate frequencies indicate that groundwater was contained under some, but not all, conditions.

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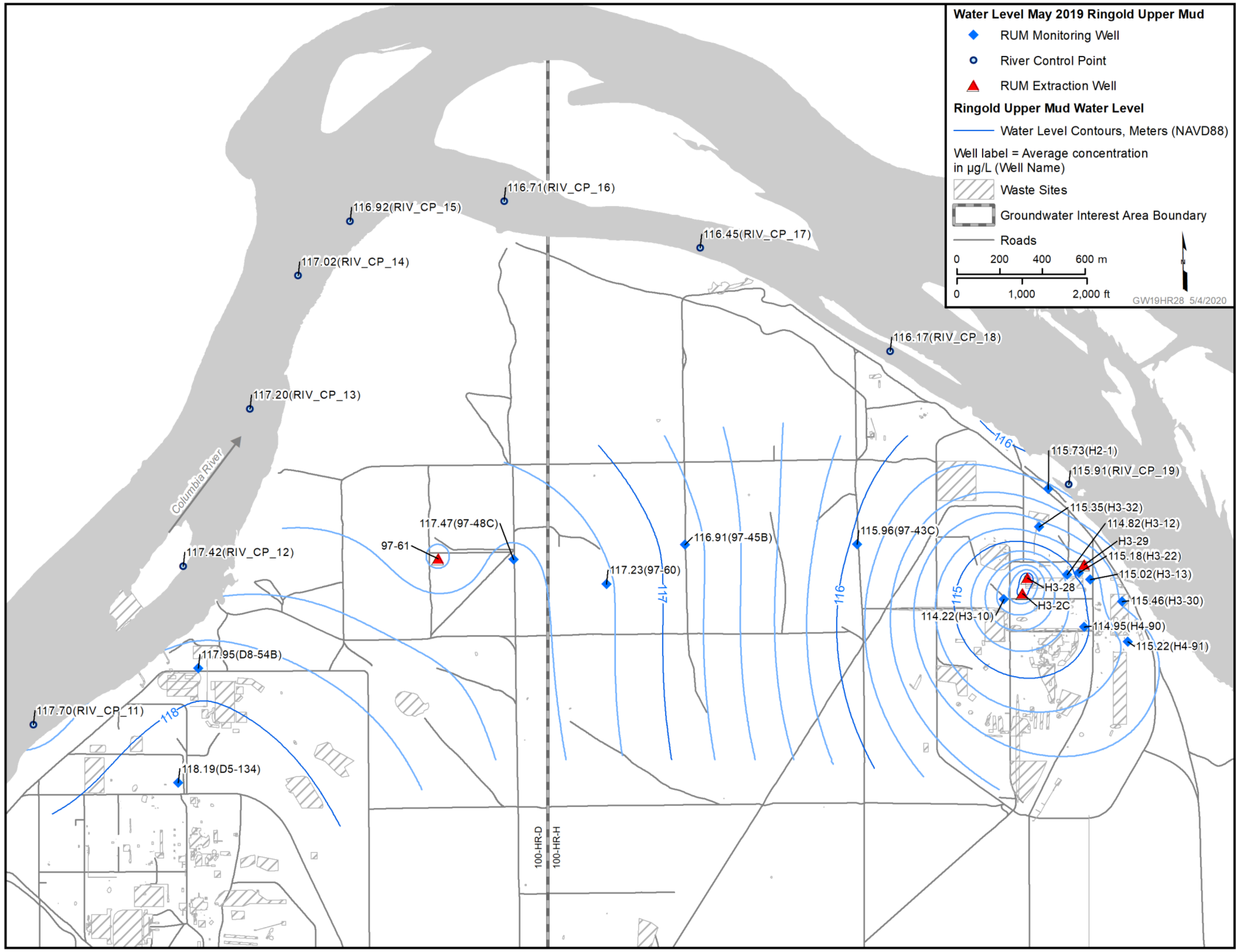

Source: ECF-HANFORD-20-0018, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2019 Hanford Site Groundwater Monitoring Report*.

Figure 2-22. 100-HR RUM Potentiometric Surface Map, May 2019

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Water-level mapping using the ICFM approach was completed using monthly average groundwater elevations, pumping rates, and Columbia River stage, 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, Columbia River stage, and other time-varying boundary conditions. This resulted in 12 simulated groundwater level and flow fields and, correspondingly, 12 individual depictions of the hydraulic containment extent for use in constructing an SCFM. Therefore, each groundwater-level depiction reflects a steady-state flow field that results from the operation of P&T wells and the average river stage for a particular month. Compilation of groundwater-level fields is not meant to reflect transient flow conditions during the year. As a result, compilation of monthly hydraulic containment depictions into CFMs does not directly translate to actual transient capture over time. Rather, CFMs are meant to illustrate the relative strength of hydraulic containment over the year, indicating areas where the effectiveness of the actual transient capture may require further attention over time.

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 containment is either weak or 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 containment assessment because one method suggests that containment is being achieved whereas the other method suggests either that containment is not achieved or, as it should be interpreted, is weak.

The Cr(VI) contamination extent 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-20-0018. Figures 2-23 through 2-28 compare the estimated extent of hydraulic containment and the estimated Cr(VI) contamination extent in groundwater for both high and low river-stage conditions for the 100-D Area as follows:

- Figures 2-23 and 2-24 depict Cr(VI) contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figures 2-25 and 2-26 depict Cr(VI) contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-27 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 (2020 through 2029). Flow rates for extraction and injection wells correspond to the July flow rates for the DX P&T system during 2019, which were representative of the system operation during this year, and repeated annually.
- Figure 2-28 overlays the capture zone flow lines on the Cr(VI) plume contours under low river-stage conditions.

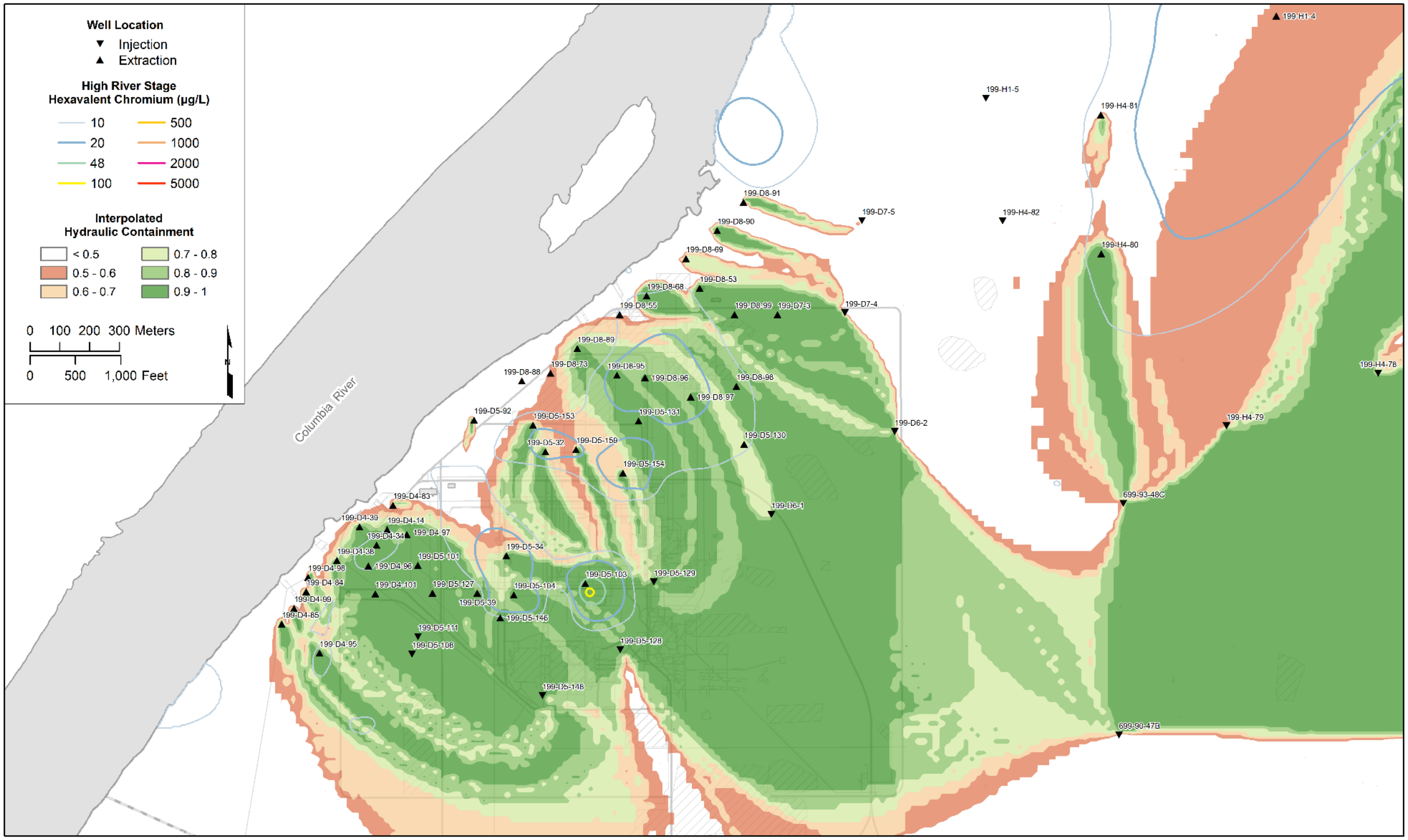

Figure 2-23. 100-D Area Interpolated CFM and High River-Stage Cr(VI) Contamination

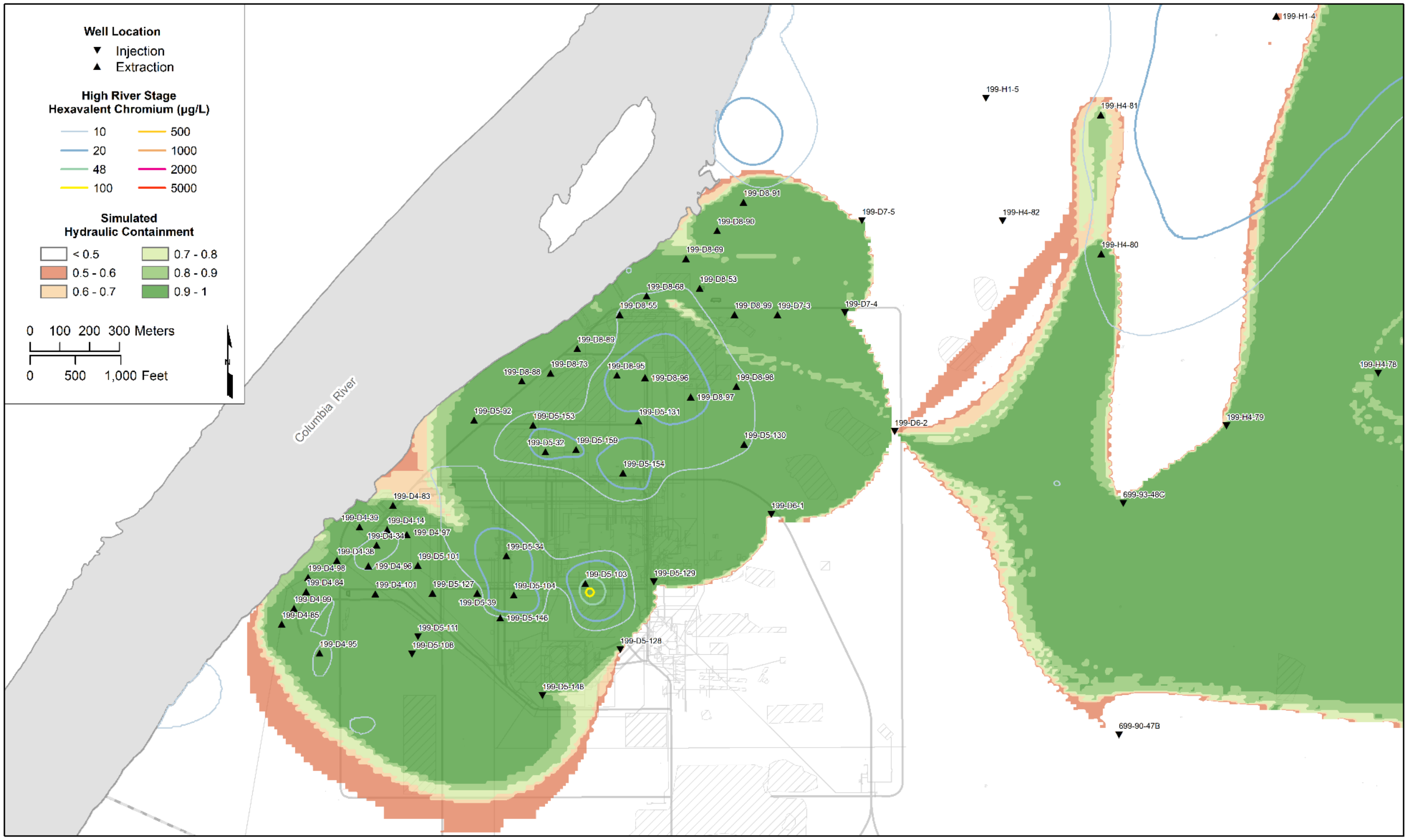

Figure 2-24. 100-D Area Simulated CFM and High River-Stage Cr(VI) Contamination, 2019

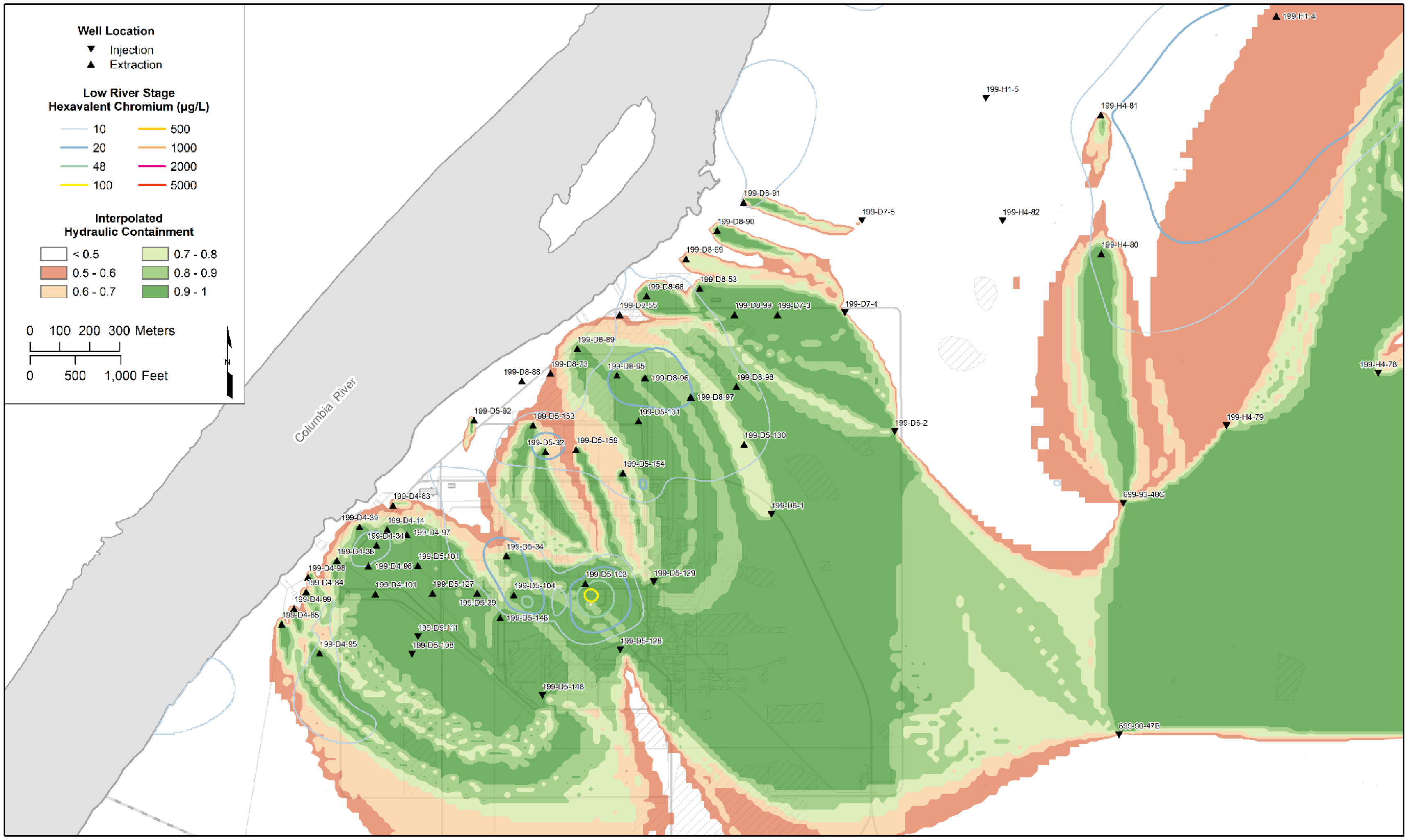

Figure 2-25. 100-D Area Interpolated CFM and Low River-Stage Cr(VI) Contamination, 2019

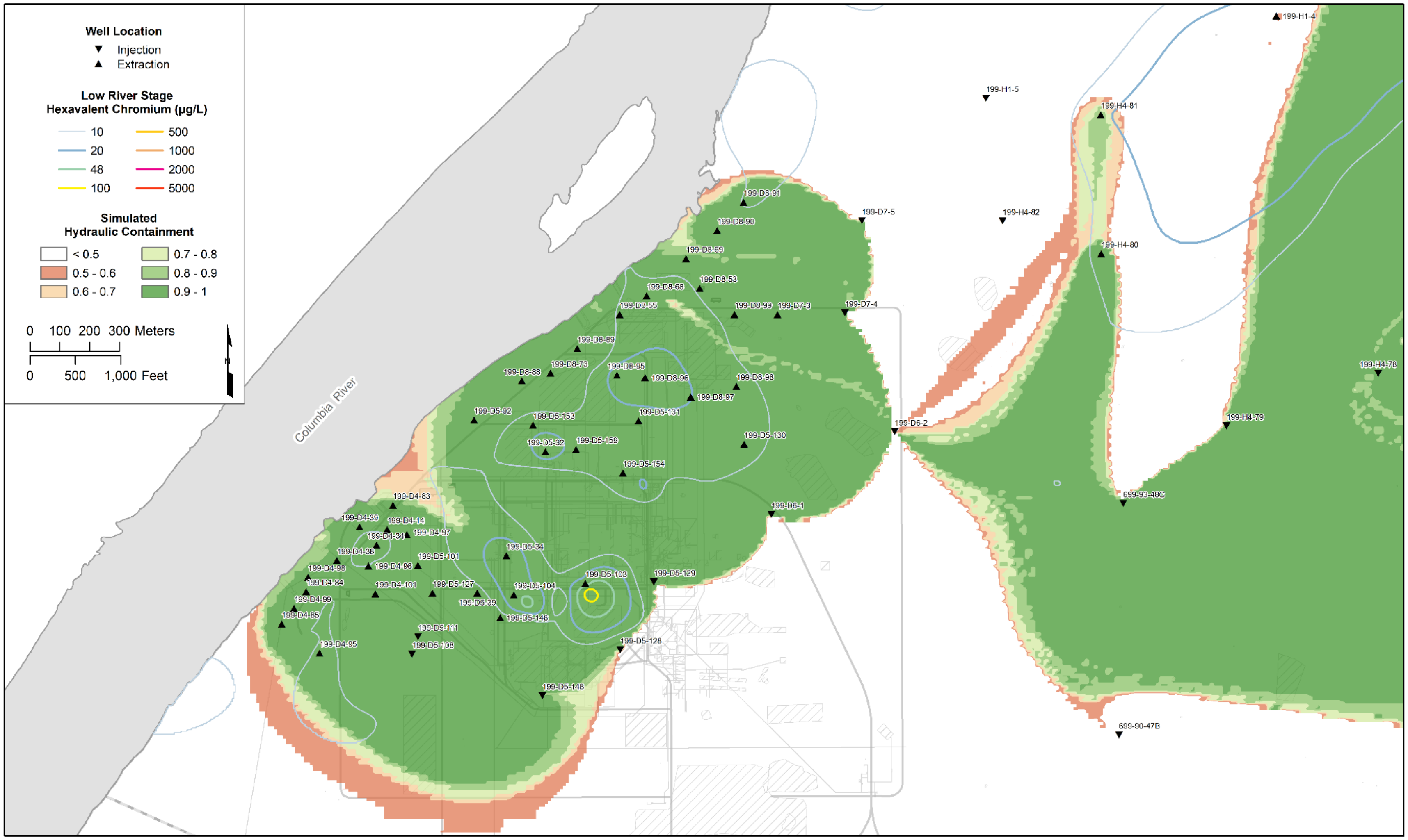

Figure 2-26. 100-D Area Simulated CFM and Low River-Stage Cr(VI) Contamination, 2019

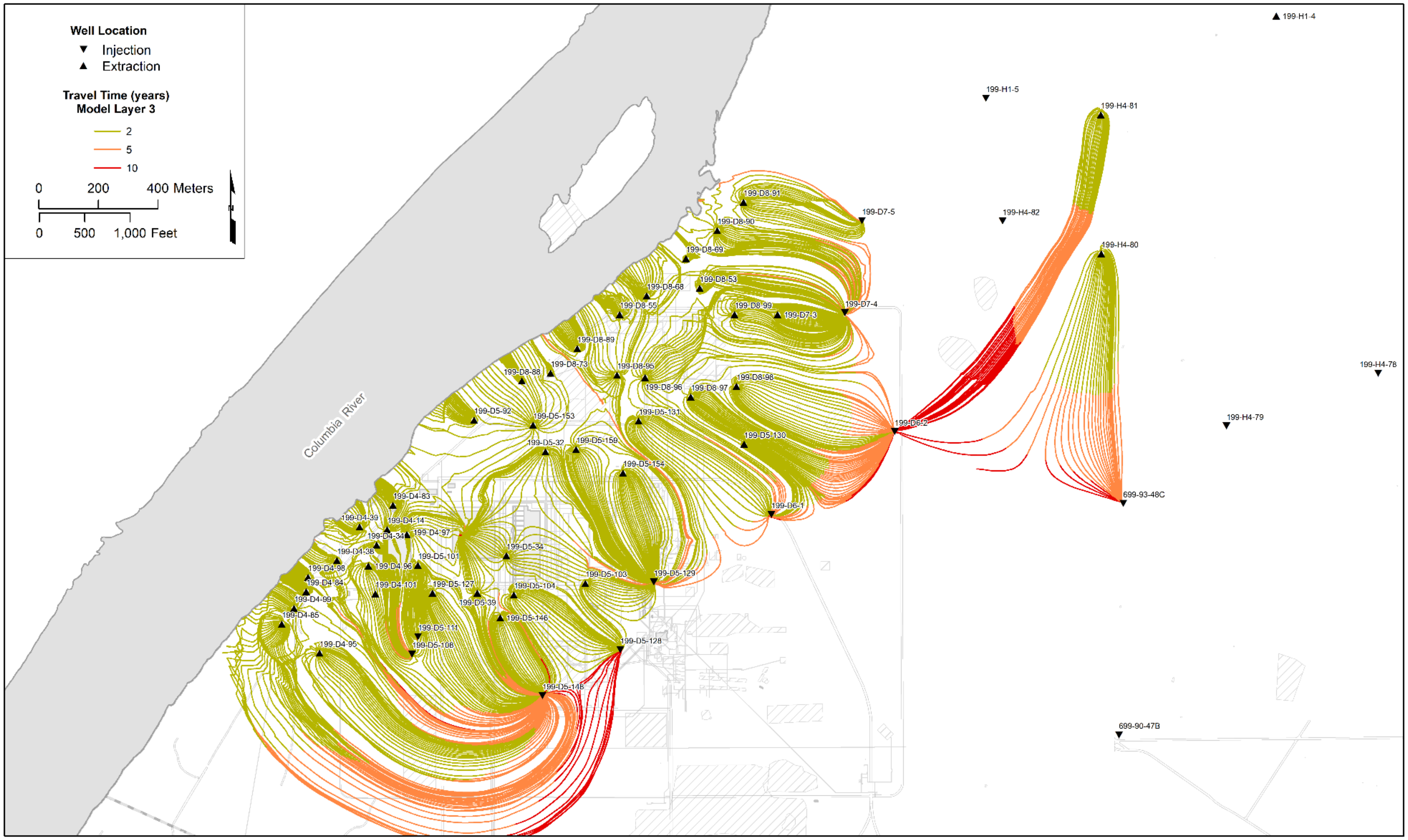

Figure 2-27. 100-D Area Groundwater Flow Lines of Capture Zone Flow Field, 2019

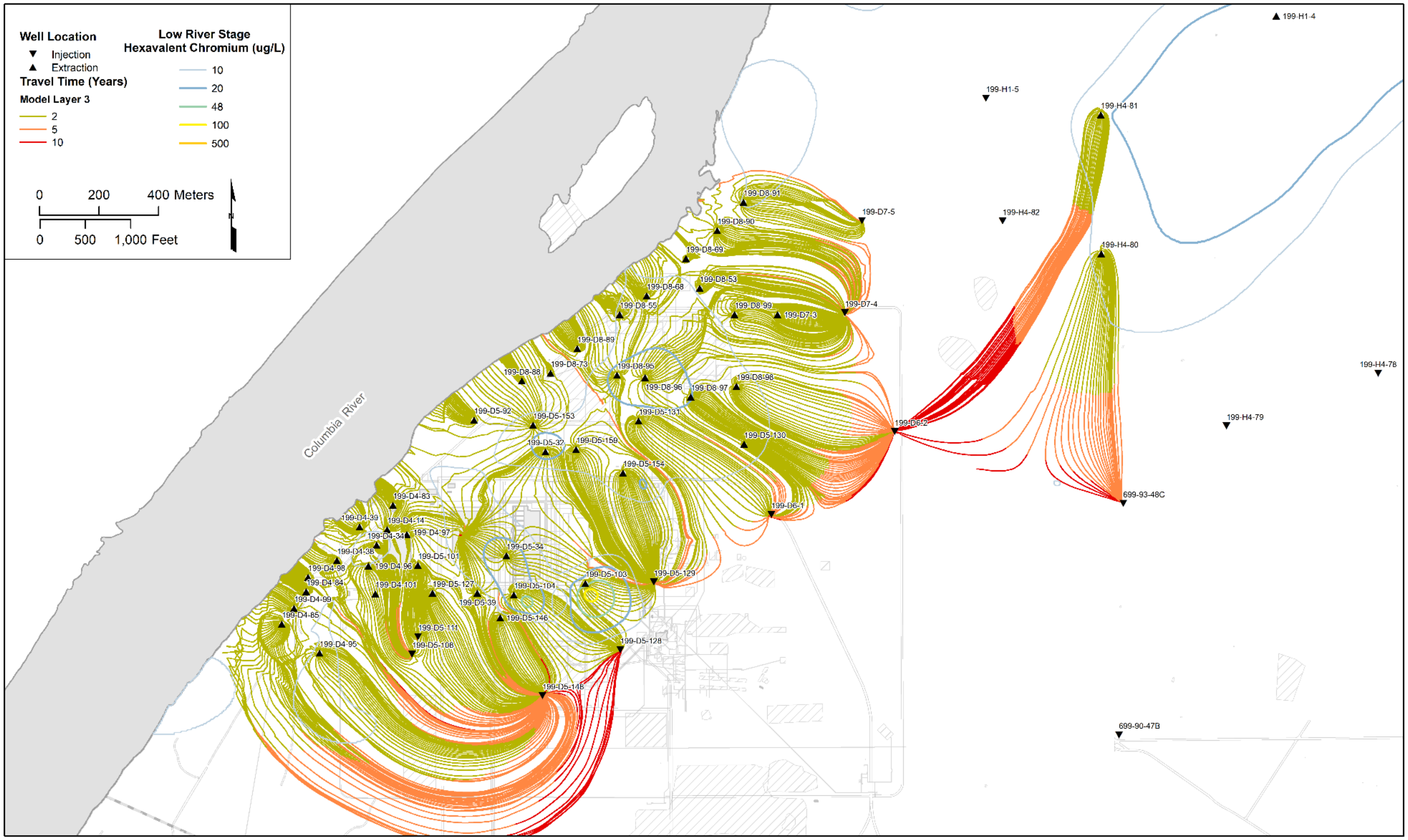

Figure 2-28. 100-D Area Groundwater Flow Lines of Capture Zone Overlay with Low River-Stage Cr(VI) Plume Contours, 2019

Figures 2-29 through 2-34 compare the estimated extent of hydraulic containment and the estimated Cr(VI) contamination extent in groundwater for both high and low river-stage conditions for the 100-H Area, as follows:

- Figures 2-29 and 2-30 depict Cr(VI) contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figures 2-31 and 2-32 depict Cr(VI) contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 2-33 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 (2020 through 2029). Flow rates for extraction and injection wells correspond to a composite set of monthly flow rates for the HX P&T system during 2019. This composite set of flow rates comprised representative rates for all wells during 2019 to ensure that wells that did not operate during several months of the year or came on late in the year would be included in the 10-year simulation. The composite set of flow rates was then repeated annually during the simulation timeframe.
- Figure 2-34 overlays the capture zone flow lines on the Cr(VI) plume contours under low river-stage conditions.

In 2019, the river stage was at its lowest in recent years, and its effect of river-stage fluctuations on groundwater flow, combined with the aquifer response to pumping, resulted in slightly reduced hydraulic containment compared to previous years. The SCFM in 2019 indicated stronger hydraulic containment than reflected in the ICFM, mainly in the 100-D Area. This is because model-simulated aquifer response to high river-stage conditions slightly underestimates water levels in the aquifer compared to river-stage elevation, resulting in lower magnitude of hydraulic gradients and, therefore, stronger hydraulic containment. Compared to the 100-D and 100-H Areas, hydraulic capture frequency appears to be weaker in the Horn (where saturated thickness remained low in 2019) and several extraction wells operated for a limited time. However, as explained below, hydraulic capture from the majority of the extraction wells is largely expected.

The capture flow lines in some areas illustrate how groundwater may follow a more indirect path to an extraction well (particularly as shown in Figures 2-33 and 2-34), which reflects the effects of river-stage fluctuations and aquifer hydraulic conditions on a particle flow path. When comparing those tortuous flow paths to CFMs, 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 capture may take longer to occur.

ECF-HANFORD-20-0047 presents details on the specific calculations used to produce the figures herein depicting capture, including updates to and implementation of the 100 Area Groundwater Model, the methodology for water-level mapping, and development of the ICFM and SCFM. Although advanced interpolation techniques are used to develop water-level maps, confidence in these maps is heavily dependent on the density of the monitoring well network and the quality of available data. During 2019, the quality of available AWLN data continued to improve in comparison to previous years due to station technology improvements and maintenance. Maintenance and data checks are conducted on a regular basis to improve system reliability and data quality.

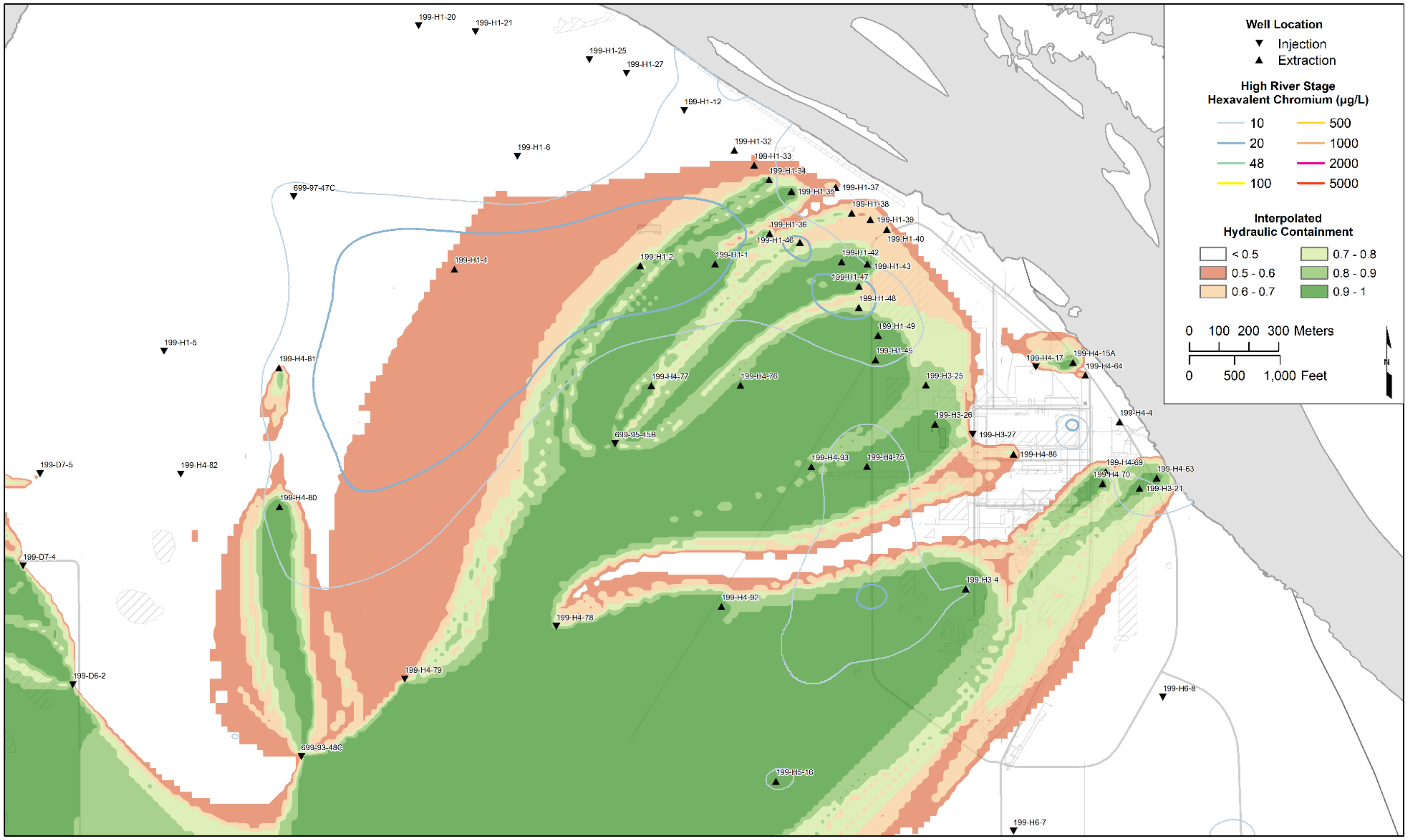

Figure 2-29. 100-H Area Interpolated CFM and High River-Stage Cr(VI) Contamination, 2019

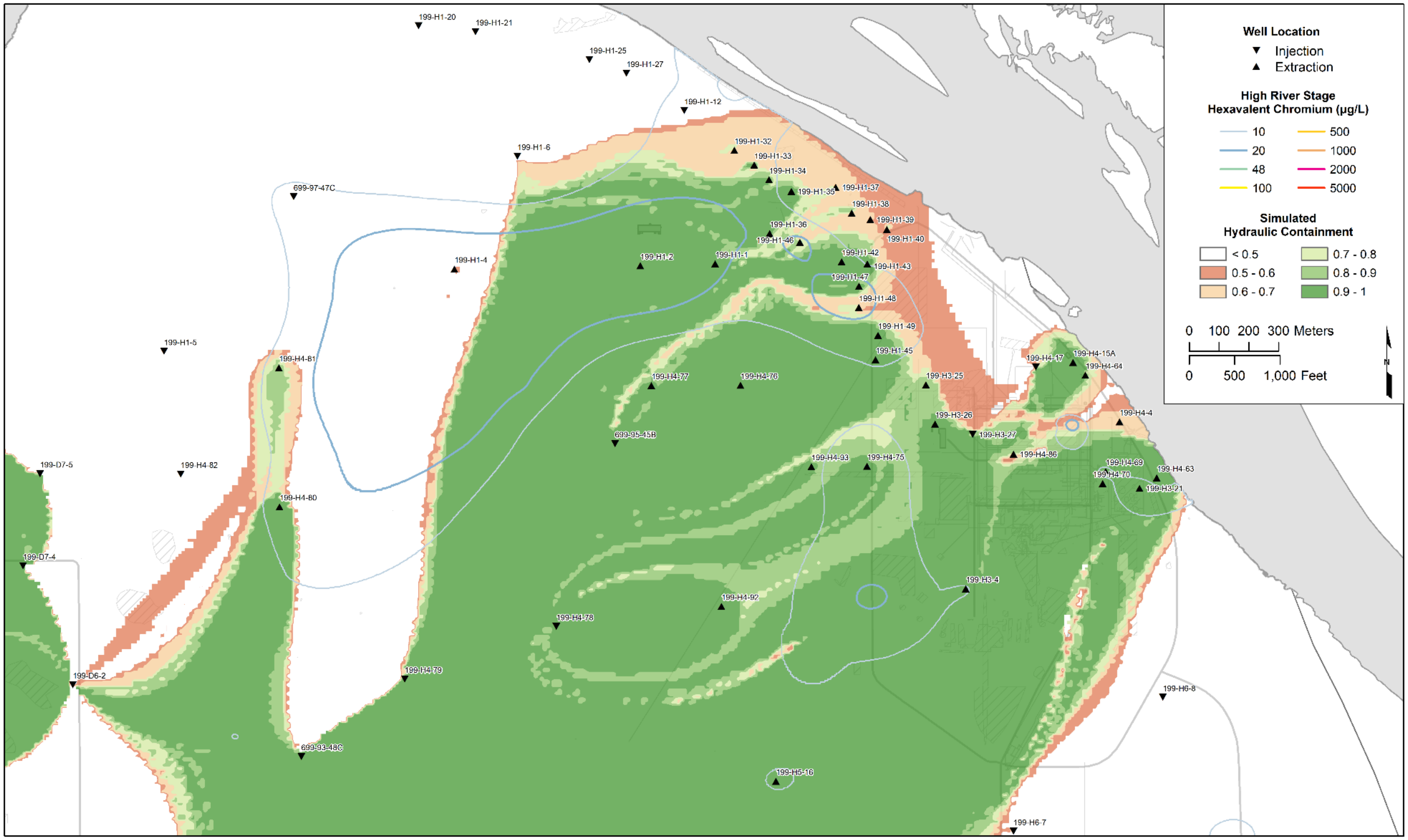

Figure 2-30. 100-H Area Simulated CFM and High River-Stage Cr(VI) Contamination, 2019

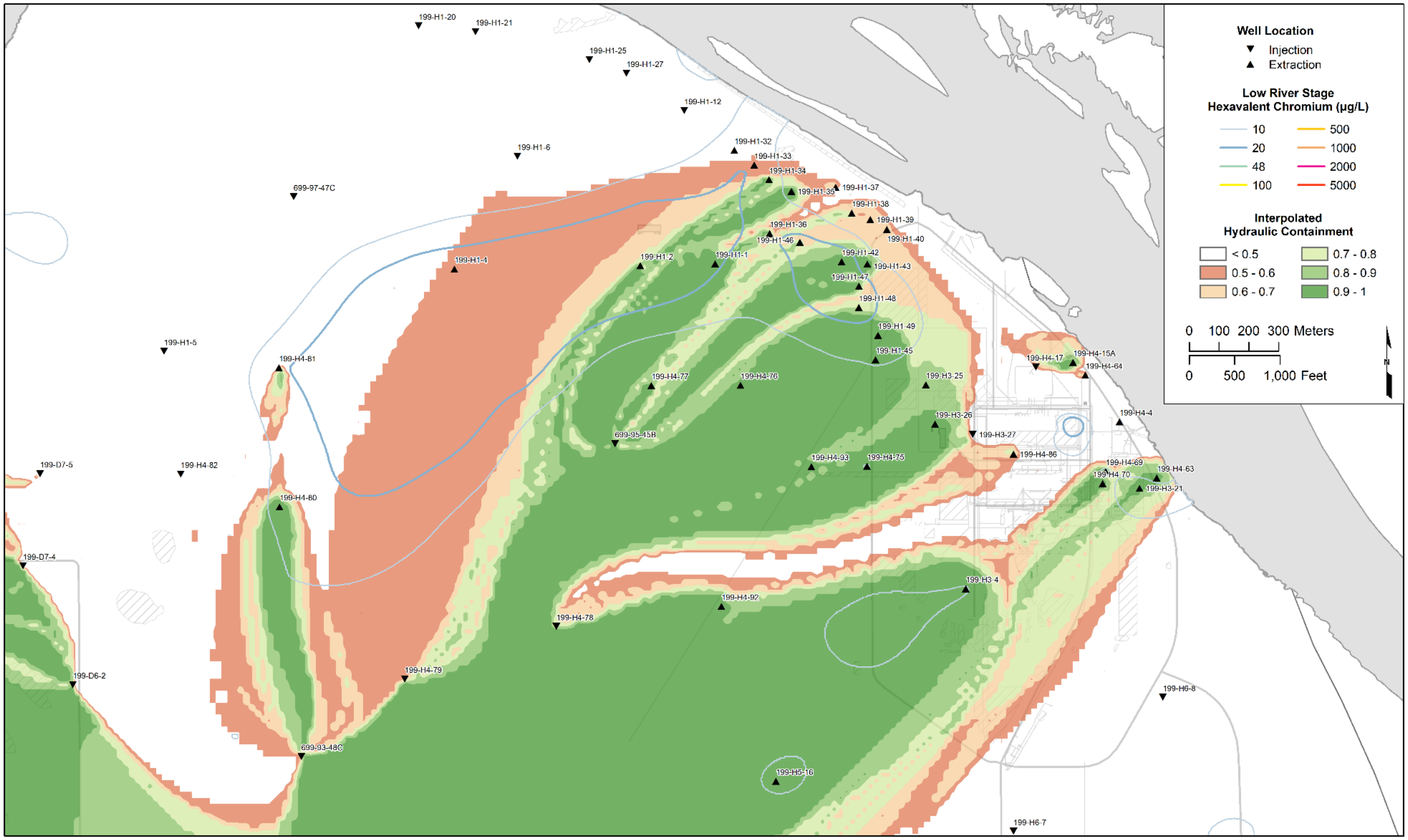

Figure 2-31. 100-H Area Interpolated CFM and Low River-Stage Cr(VI) Contamination, 2019

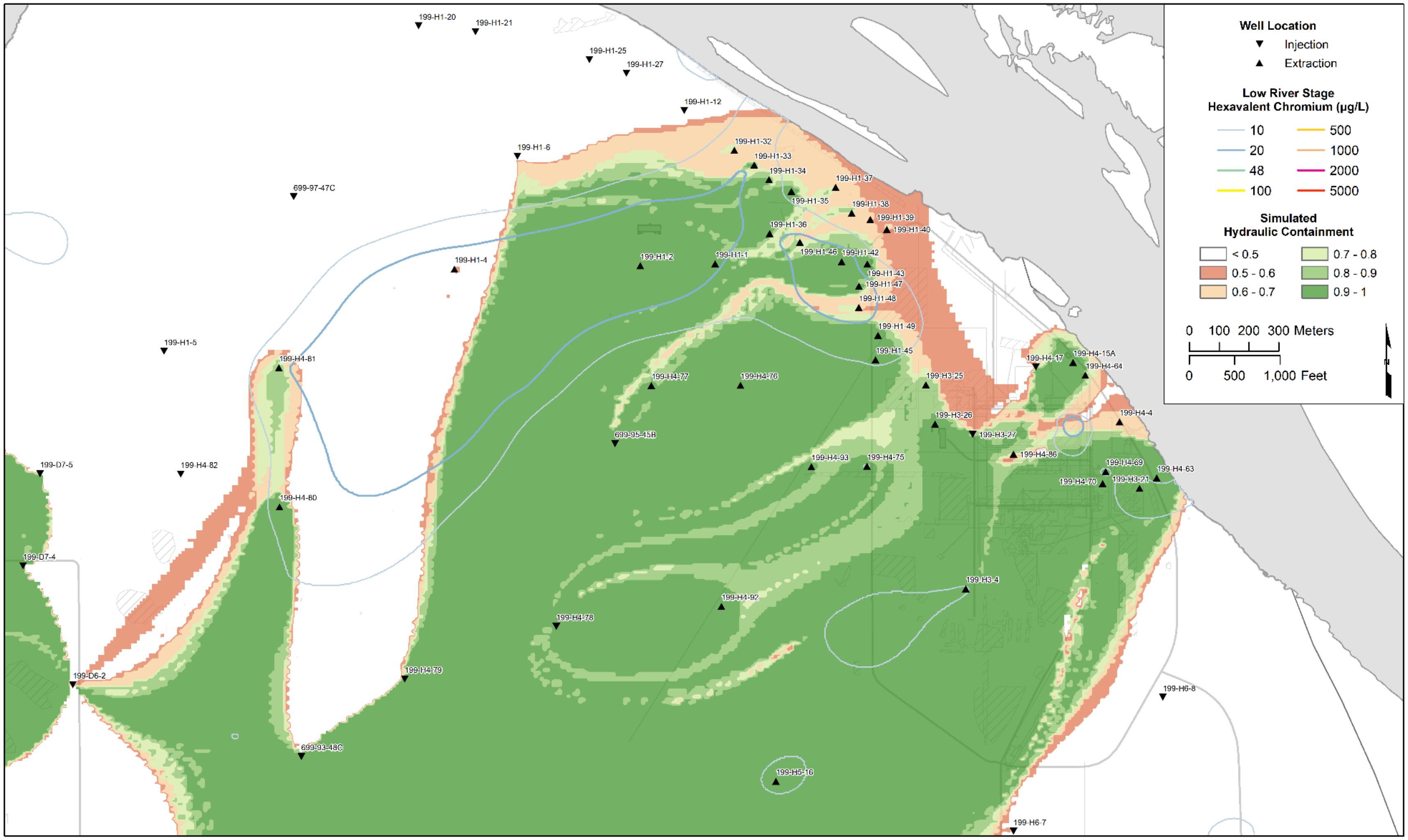

Figure 2-32. 100-H Area Simulated CFM and Low River-Stage Cr(VI) Contamination, 2019

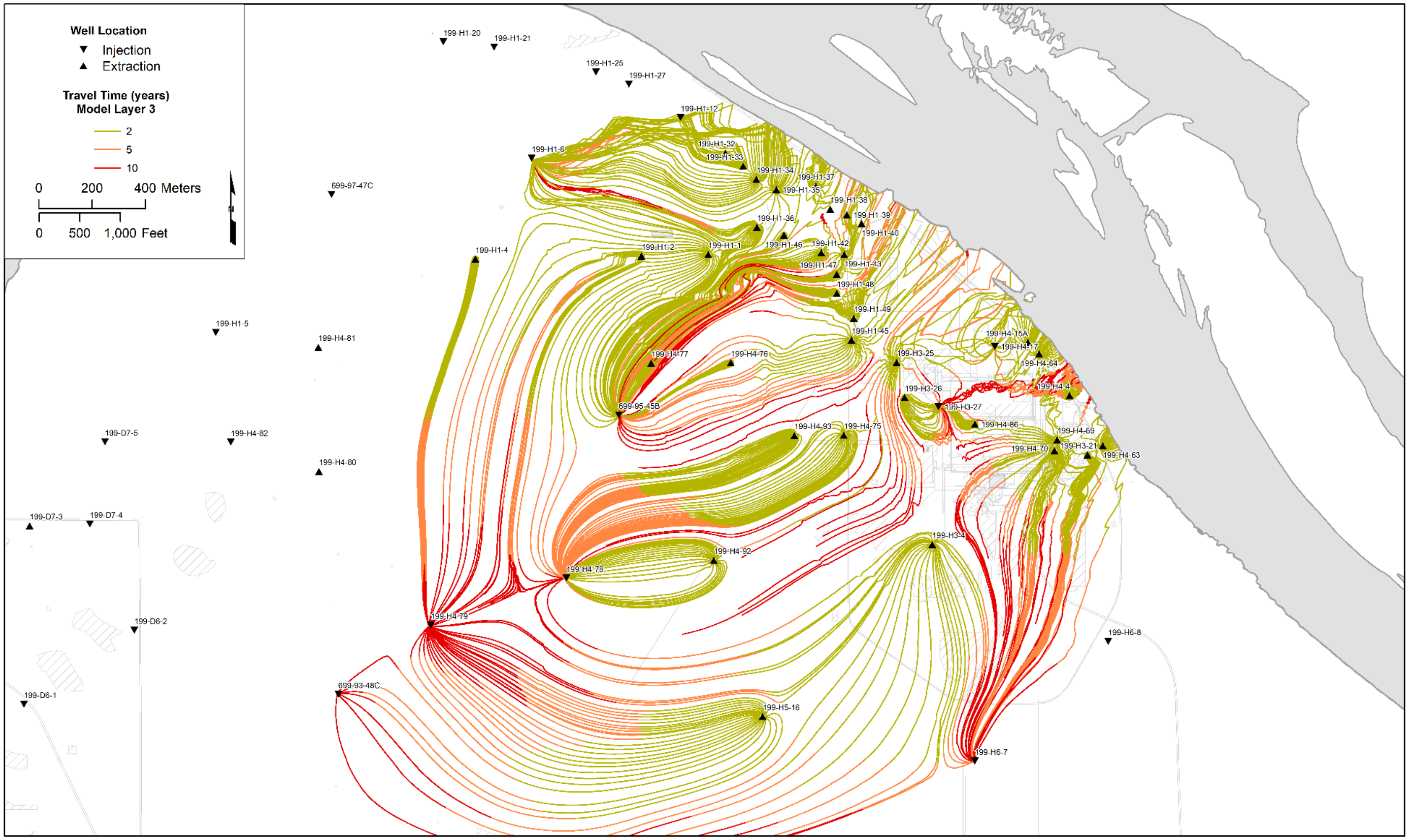

Figure 2-33. 100-H Area Groundwater Flow Lines of Capture Zone Flow Field, 2019

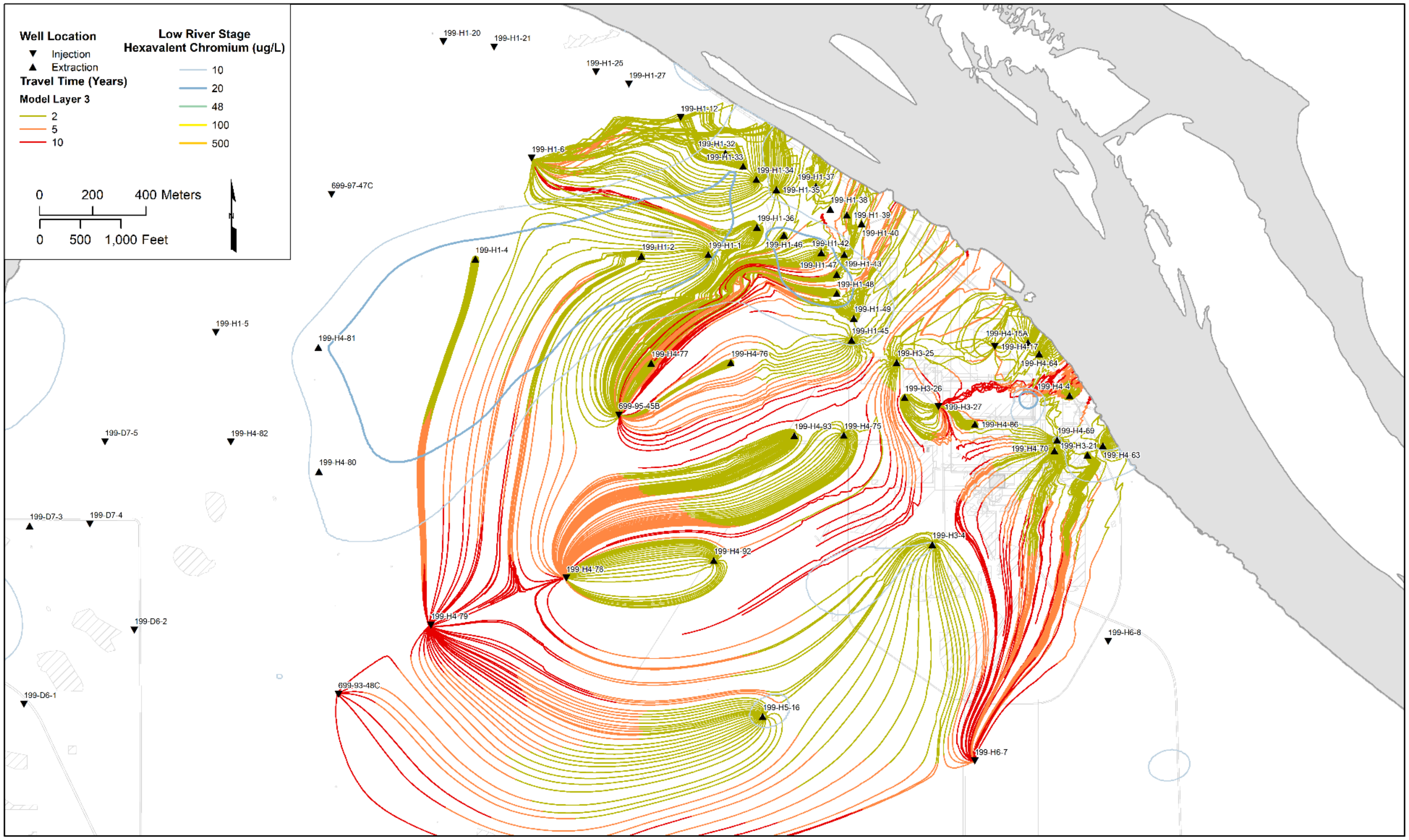

Figure 2-34. 100-H Area Groundwater Flow Lines of Capture Zone Overlay with Low River-Stage Cr(VI) Plume Contours, 2019

2.2.6 River Protection Evaluation

The river protection evaluation for the 100-HR-3 OU is based on assessing the hydraulic effects of remedial action system operations, as well as evaluating changes in the discharge boundary head conditions associated with the Columbia River and the inferred Cr(VI) distribution in groundwater. Both quantitative and qualitative approaches are used for this assessment.

This section describes the river protection evaluation process and presents the results of the 2019 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 the river protection objective. Since the river protection objective emphasizes protection of aquatic receptors, it focuses on the performance of P&T (and other remedies) in protecting the Columbia River from further discharges of Cr(VI) at concentrations >10 µg/L (Table 6 in the 100-D/100-H Areas ROD [EPA et al., 2018]).

An assessment of progress toward attaining the river protection objective for 2019 is presented in Figures 2-35 through 2-38. SGW-54209 discusses the technical methods and process used to complete the calculations to prepare these figures. ECF-HANFORD-20-0047 presents details for the specific calculations used to produce the figures for 2019. The contaminant standard and trend test results described in SGW-54209 to identify low-, moderate-, and high-concern wells are presented in these figures using the symbols identified in Table 2-11.

Shoreline lengths are calculated and reported in increments of 100 m (330 ft); the results of the assessment are presented in these figures as color-filled circles of diameter equal to 100 m (330 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 2-12 shows the symbols depicting the results of the river protection evaluation.

Figures 2-35 and 2-36 show the assessment of progress toward attaining the river protection objective for Cr(VI) in the 100-D Area. Figure 2-35 shows the results of the quantitative evaluation of the objective, which is determined based on overlay and quantitative comparison of the Cr(VI) contamination extent with the hydraulic containment extent. Figure 2-36 shows the results of the qualitative evaluation of the objective, which is based on 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).

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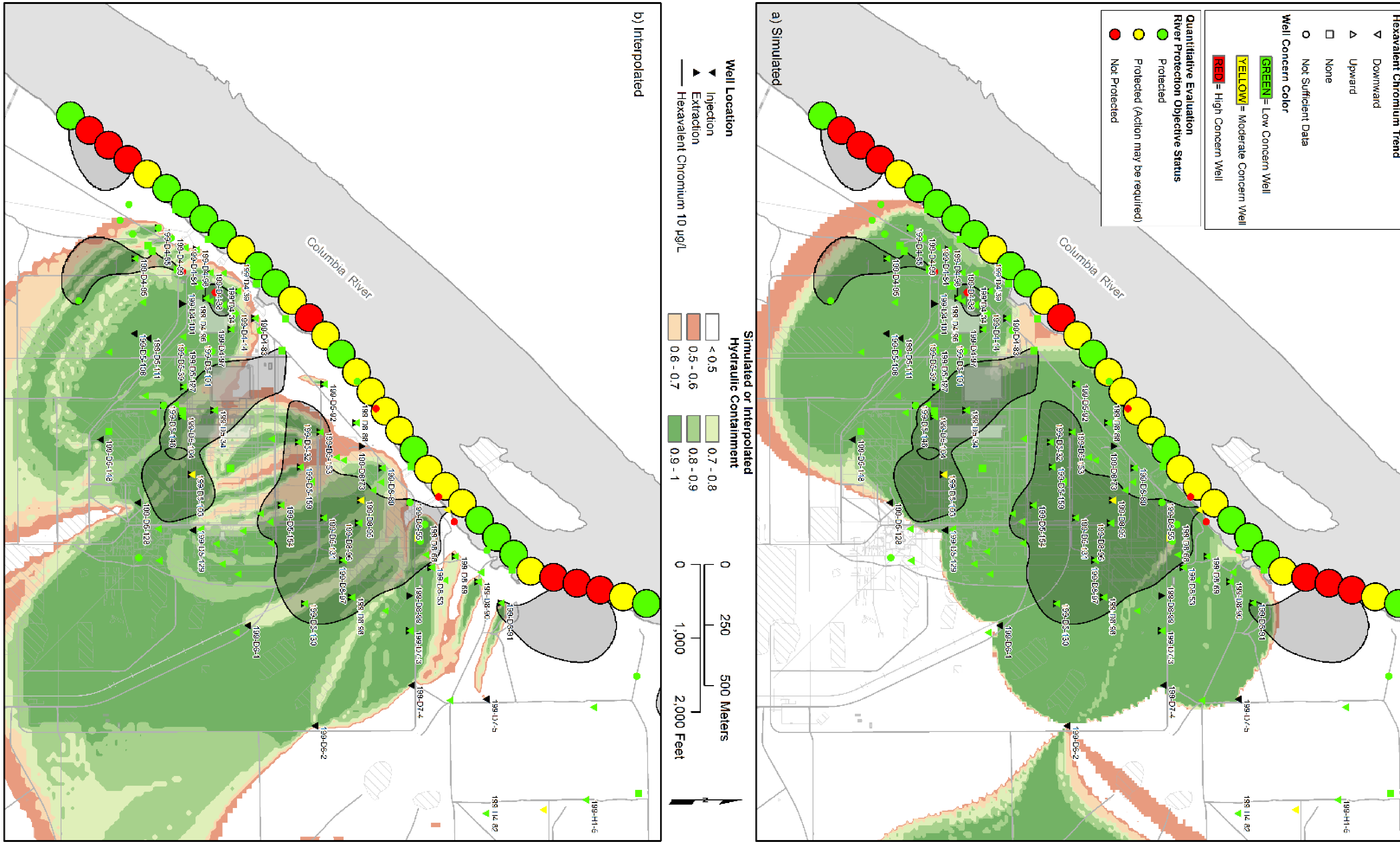


Figure 2-35. 100-D Area Quantitative Assessment of Shoreline Protection for 2019 with (a) Simulated and (b) Interpolated CFM, Together with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 µg/L and Results of Standard Test and Trend Test

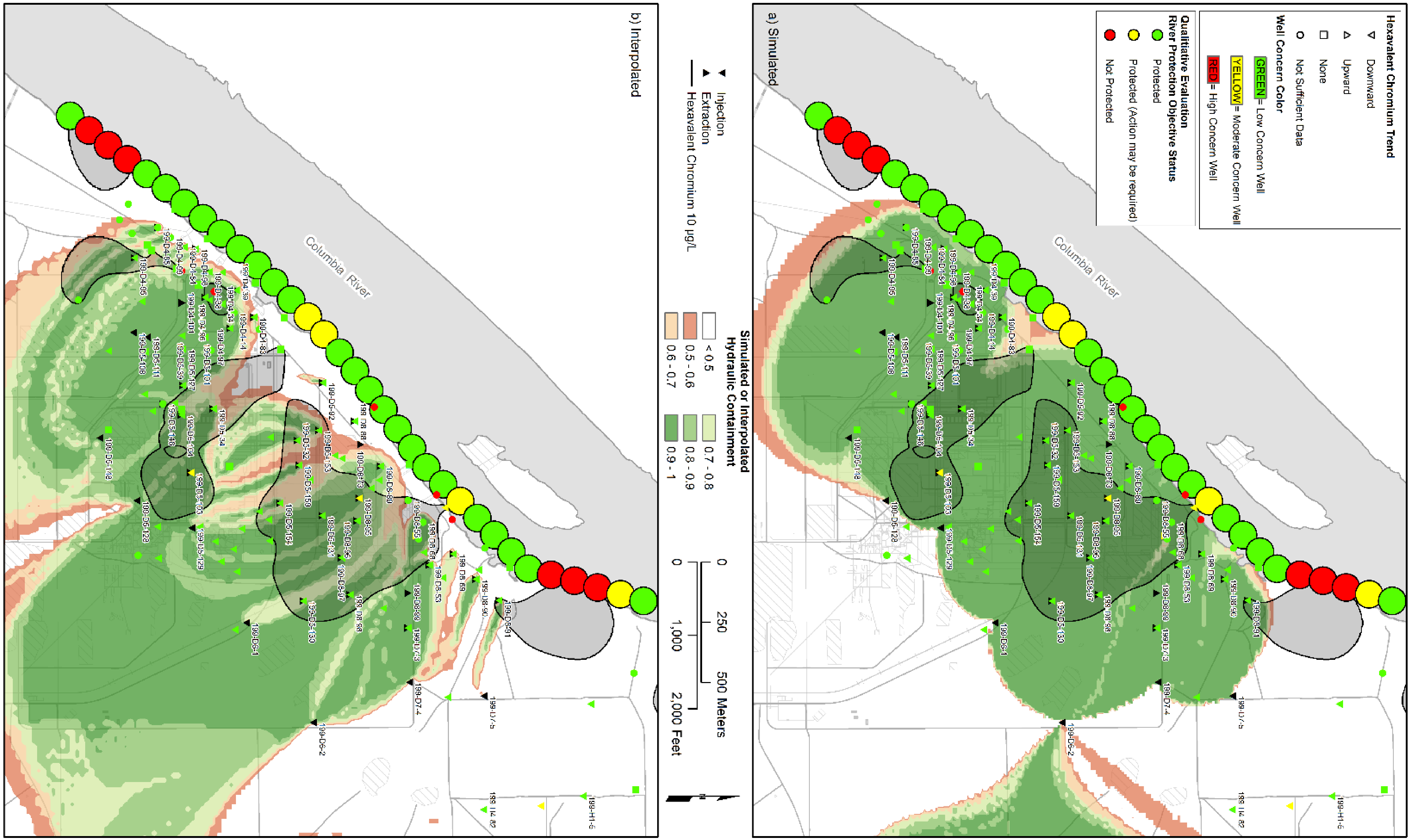
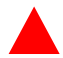
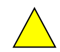
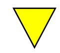
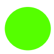
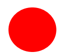


Figure 2-36. 100-D Area Qualitative Assessment of Shoreline Protection for 2019 with (a) Simulated and (b) Interpolated CFM, Together with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 µg/L and Results of Standard Test and Trend Test

Table 2-11. 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

Table 2-12. Symbology for Status of River Protection Objective

Symbol	Explanation
	Protected
	Protected (action may be required)
	Not protected

Conservative criteria for capture frequency are applied in determining river protection status based on the quantitative evaluation procedure (i.e., capture frequency >90% required to establish river protection). For 2019, the quantitative evaluation for the 100-D Area suggests that large stretches of the shoreline appear to be protected but will possibly require additional action in the future. However, with the exception of Cr(VI) at the 116-DR-5 outfall at concentrations >10 μg/L in 2019 (as was also the case in 2018), hydraulic containment was not compromised in 2019. This is evident when considering the location and operation of the P&T wells, the decreasing concentration trends at the monitoring locations along the shoreline, and the receding interpolated plume extents. However, for the shoreline length considered north of the DX P&T well network and toward the Horn, the presence of a Cr(VI) plume delineated to extend to the shoreline at concentrations >10 μg/L near monitoring wells 199-D8-91, 199-D8-93, and 199-D8-94 suggests that river protection was not attained in 2019 in that area. Similarly, for the area southwest of the 100-D Area, the presence of Cr(VI) at concentrations >10 μg/L in aquifer tubes indicates plume discharge to the river. As a result, river protection is characterized as weaker in 2019 compared to 2018, although this is mainly due to areas of elevated concentrations at the shoreline outside the hydraulic containment zone developed by the P&T well operation.

For the 100-H Area in 2019, the quantitative river protection evaluation is similar to that observed in 2018, reflecting the conservative approach to assessing hydraulic containment quantitatively. Hydraulic capture frequency within the portion of the Cr(VI) plume in the Horn remains relatively weak, with limited mass recovery from the extraction wells located in that area, which operated for a limited period of time in 2019 due to consistently low river-stage conditions throughout the year and the resulting reduced saturated thickness. However, qualitative evaluation of the river protection status reflects the same considerations implemented in the 100-D Area, including plume extents, concentration trends, and well operations near the shoreline, resulting in a qualitative assessment similar to 2018.

Based on these qualitative calculations, the river protection evaluation for the 100-D Area is as follows, (conversions from meters are rounded to the nearest 5 ft):

- **Total length of affected shoreline adjacent to the 100-D Area:** 3,300 m (10,825 ft)
- **Length identified as protected:** 2,300 m (7,545 ft)
- **Length identified as protected (action may be required):** 400 m (1,310 ft)
- **Length identified as not protected:** 600 m (1,970 ft)

Figures 2-37 and 2-38 depict the assessment of progress toward attaining the river protection objective for Cr(VI) in the 100-HR-3 OU/100-H Area. Figure 2-37 shows the results of the quantitative evaluation of the objective, which are determined based on an overlay and quantitative comparison of the extent of Cr(VI) contamination with the extent of hydraulic containment. Figure 2-38 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:** 4,100 m (13,445 ft)
- **Length identified as protected (action may be required):** 200 m (655 ft)
- **Length identified as not protected:** 100 m (330 ft)

Table 2-13 compares the results of the qualitative evaluations for the 100-D and 100-H Areas for 2019 and 2018 based on the comparable shoreline lengths for those 2 years.

Quantitative evaluations of the river protection objective provide a conservative assessment of shoreline protection. The 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 river-stage fluctuations. As a result, CFMs only indicate the relative strength of hydraulic containment and are 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 mostly does, occur in areas where CFMs indicate relatively low capture frequency.

2.2.7 Comparison of Simulated to Measured Contaminant Mass Recovery

Figure 2-39 compares the monthly and cumulative Cr(VI) mass recovered at the DX and HX P&T systems during 2019 (as determined using actual influent concentrations and flow rates) compared to 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 well excluded from the measured recovery plot since the current groundwater model addresses the presence of Cr(VI) in the unconfined aquifer only. As shown in Figure 2-39, more than half of the mass recovered at the HX P&T system originates in the RUM aquifer. For the model simulation of Cr(VI) migration in the unconfined aquifer, the initial distribution of Cr(VI) in groundwater for 2019 was assumed to be the low river-stage depiction of Cr(VI) for 2018, reflecting data collected from August 1 through December 31, 2018, as presented in ECF-HANFORD-19-0010, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2018 Hanford Site Groundwater Monitoring Report*.

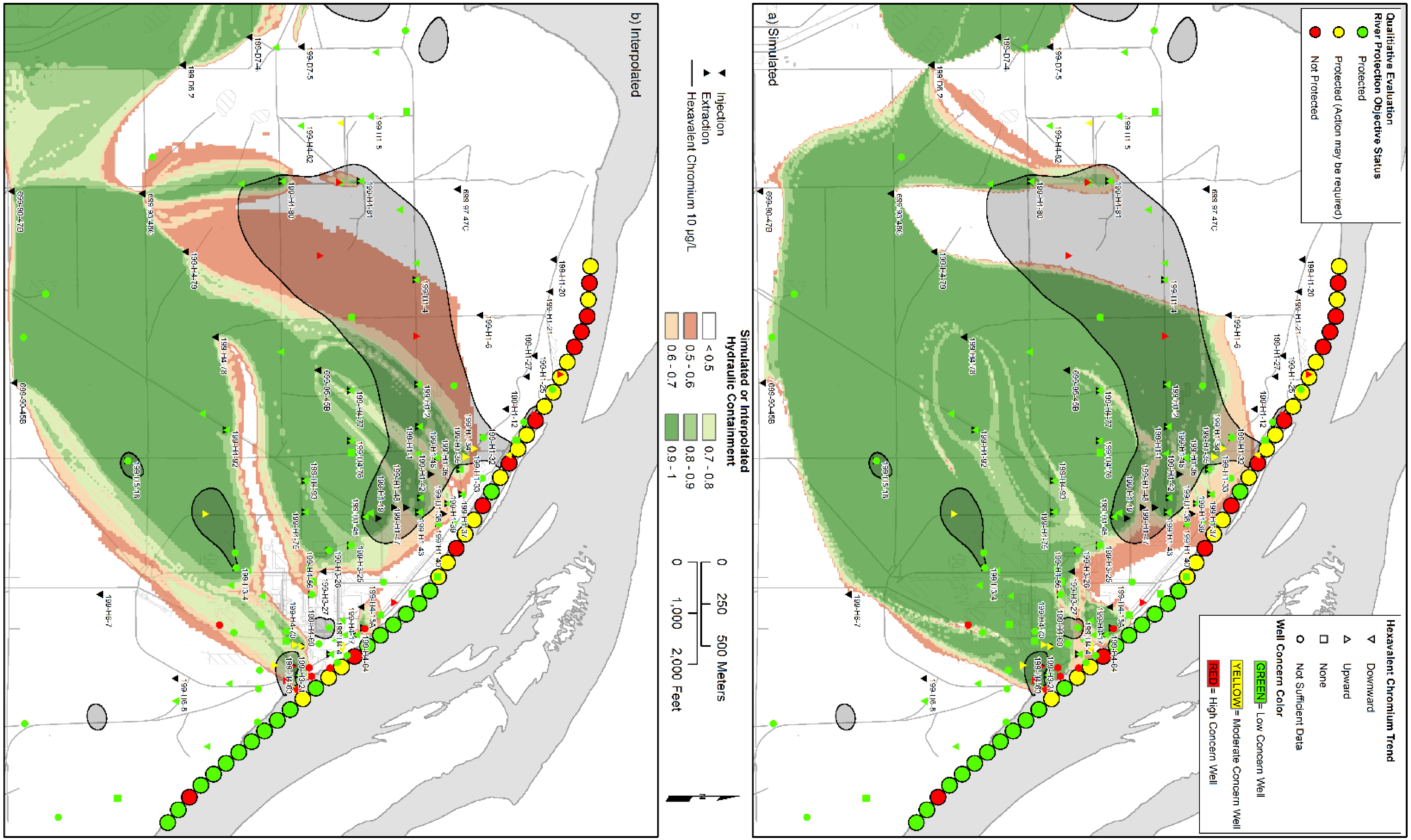


Figure 2-37. 100-H Area Quantitative Assessment of Shoreline Protection for 2019 with (a) Simulated and (b) Interpolated CFM, Together with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 µg/L and Results of Standard Test and Trend Test

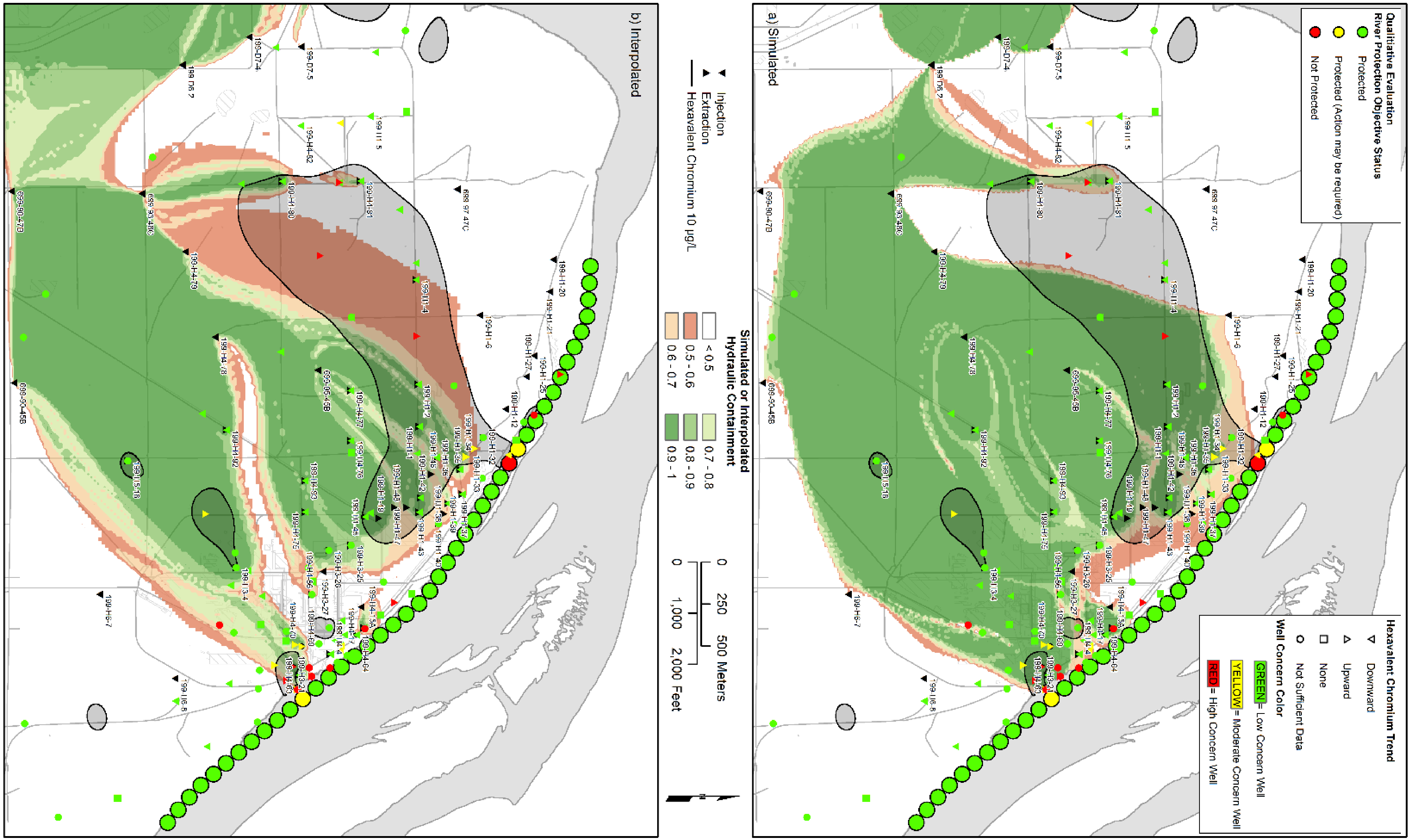


Figure 2-38. 100-H Area Qualitative Assessment of Shoreline Protection for 2019 with (a) Simulated and (b) Interpolated CFM, Together with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 µg/L and Results of Standard Test and Trend Test

Table 2-13. Comparison of River Protection Assessment Results

Assessed Shoreline Lengths for 100-HR-3/100-D	2018	2019	Change from 2018 to 2019*
Total length of shoreline adjacent to the 100-D Area	3,300 m (10,825 ft)		
Length identified as "protected" Percent of shoreline "protected"	3,100 m (10,230 ft) 94% of shoreline	2,300 m (7,545 ft) 70% of shoreline	500 m (1,640 ft) of shoreline identified as "protected" now identified as "not protected" 300 m (990 ft) of shoreline 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)"	100 m (330 ft) 3% of shoreline	400 m (1,310 ft) 12% of shoreline	300 m (985 ft) of shoreline identified as "protected" now identified as "protected (action may be required)"
Length identified as "not protected" Percent of shoreline "not protected"	100 m (330 ft) 3% of shoreline	600 m (1,970 ft) 18% of shoreline	500 m (1,640 ft) of shoreline identified as "protected" now identified as "not protected"
Total length of shoreline adjacent to the 100-H Area	4,400 m (14,430 ft)		
Length identified as "protected" Percent of shoreline "protected"	3,800 m (12,540 ft) 86% of shoreline	4,100 m (13,345 ft) 93% of shoreline	300 m (985 ft) of shoreline previously 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)"	400 m (1,320 ft) 9% of shoreline	200 m (655 ft) 5% of shoreline	300 m (985 ft) of shoreline previously 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"	200 m (660 ft) 5% of shoreline	100 m (330 ft) 2% 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-20-0047, *Description of Groundwater Calculations and Assessments for the Calendar Year 2019 (CY2019) 100 Areas Pump-and-Treat Report*.

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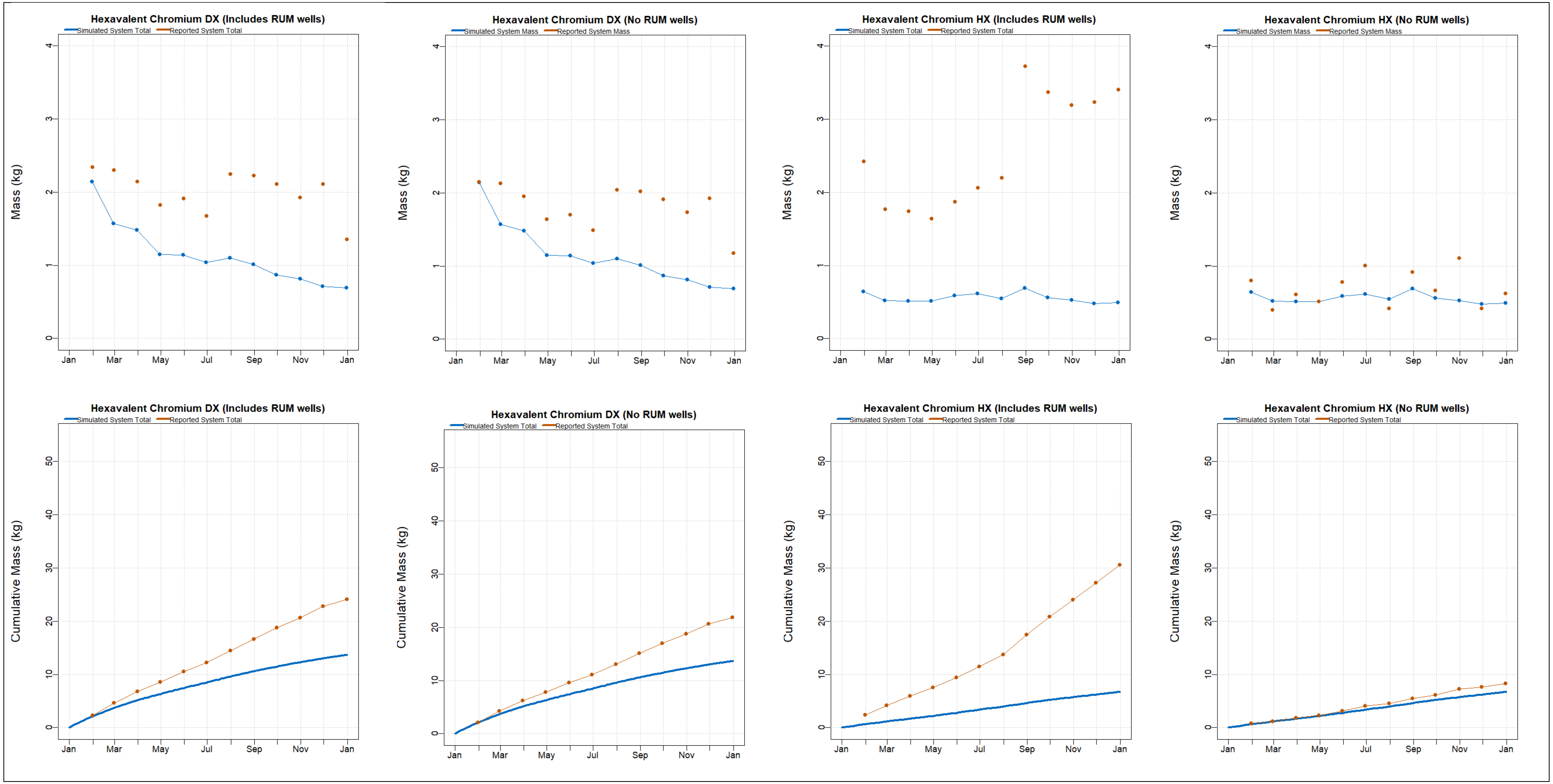

Figure 2-39. Comparison of Observed to Calculated Cr(VI) Mass Removal for 2019 (Top Row = Monthly Mass Removal; Bottom Row = Cumulative Mass Removal)

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ECF-HANFORD-20-0047 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 2-39. 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 continuing sources are not present.

At the DX P&T system, Cr(VI) mass immediately downgradient of the 100-D-100 waste site and near well 199-D5-103 is under-represented in the initial conditions of the numerical model, as it corresponds to mean conditions during the low river-stage period in 2018. Mass recovery at wells 199-D5-103, 199-D5-104, and 199-D5-34 suggests that higher Cr(VI) concentrations are 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, *Persistent Source Investigation at 100-D Area*) indicated that chromate-substituted calcite remaining in the PRZ soil and aquifer sediment provides a source of ongoing Cr(VI) release into groundwater. The simulated mass recovery does not correlate well in locations near/downgradient from a source since the simulated mass recovery reflects only the Cr(VI) distribution and does not include any contribution from continuing sources (similar to observations made in 2018). These discrepancies are consistent throughout the year, suggesting the presence of increased mass in the aquifer downgradient of the continuing source.

Recovery data from extraction wells 199-D4-96 and 199-D4-97 are in excellent agreement with simulated concentrations, indicating improved delineation of the Cr(VI) plume in that area. However, the persistent presence of concentrations >10 μg/L near the in situ redox manipulation barrier and in aquifer tubes southwest (outside the hydraulic containment zone of the DX P&T system) will continue to be monitored in 2020.

Simulated and measured mass recovery for wells located in the northern 100-D Area are generally in very good agreement. The difference between simulated and measured mass recovery observed at well 199-D5-32 indicates a larger extent of the actual plume distribution in that area and possibly a zone of lower transmissivity; measured concentration levels at the well remained between 21 and 42 μg/L throughout the year. This could also suggest arrival of higher concentrations from south, indicating capture by wells 199-D5-32 and 199-D5-153, because concentrations at downgradient monitoring locations remain low.

The Cr(VI) distribution further north in the 100-D Area is well defined (especially in the zone of higher concentrations), as suggested by the agreement between measured and simulated mass recovery at wells 199-D8-95, 199-D8-96, and 199-D8-97. However, the model initial conditions may be slightly underestimating concentrations upgradient of well 199-D8-95.

Well 699-97-61 is connected to the DX P&T system and is extracting Cr(VI)-contaminated groundwater from the RUM aquifer. In 2019, the DX P&T system recovered a total of 2.3 kg of Cr(VI) from this RUM well, or approximately 9.5% of the total Cr(VI) mass recovered in 2019 by the DX P&T system.

The HX P&T system removed 30.6 kg of Cr(VI) during 2019 (Figure 2-39). Approximately 22.3 kg, or about 73% of the total mass removed, was recovered by the HX P&T system wells completed within the RUM (i.e., 199-H3-2C, 199-H4-12C, 199-H3-9, 199-H3-22, 199-H3-28, and 199-H3-29), which are not included in the 100 Area Groundwater Model. Well 199-H3-22 became operational in July 2019, ramping up its flow rate in August/September, resulting in increased mass recovery. The remaining mass of approximately 8.3 kg originated from the unconfined aquifer, which is simulated by the 100 Area Groundwater Model. Comparing the observed mass removed from the unconfined aquifer to the mass recovery simulated by the 100 Area Groundwater Model (6.1 kg), it appears that dissolved Cr(VI) mass in the 100-H Area was underestimated in the model initial conditions (Figure 2-39).

ECF-HANFORD-20-0047 provides a detailed comparison between simulated and measured concentrations in the unconfined aquifer for the DX and HX P&T system extraction wells. Measured concentrations in the HX P&T system are much lower than those measured in the DX P&T system and in recent years have been consistently <48 μg/L. The HX P&T system Cr(VI) plume is contained and has been shrinking over time; however, the presence of continuing sources results in additional mass introduced in the system. In addition, the plume extent and the limited saturated thickness (mainly in the Horn) may impair the ability of the extraction wells to remove large masses of Cr(VI) during portions of the year. System operation is effective and aquifer restoration has progressed, but mass recovery in the Horn is limited.

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. However, simulated mass recovery estimates provide a useful tool for estimating system performance over time and developing estimates of the timeframe to complete remediation. However, these estimates will tend to underestimate remediation timeframes where a continuing source is present.

Sample summary statistics calculated for Cr(VI) in the 100-D and 100-H Areas and the Horn for the previous 5 years were used to prepare Figure 2-40. The data set comprised average Cr(VI) concentrations during the low river-stage period for each year, as used in the interpolation of the corresponding plumes. Concentration frequency distributions were calculated for each area, with outliers (concentrations >1.5 times the interquartile range [i.e., ranging from 25^{th} to 75^{th} percentile]) considered separately. For each graph for each year, the "box-and-whisker" style plots show the maximum and minimum values (top and bottom of the "whiskers"), 25^{th} and 75^{th} percentile values (top and bottom of the "box"), median (horizontal line within the "box" with a connecting dashed line), average (with connecting blue dashed line), and upper concentration limit (UCL) on the average (the latter is calculated using a Student's t-test distribution). Outliers are noted separately on the plots with their count and associated minimum and maximum values.

The plots (Figure 2-40) indicate a steady decline in unconfined aquifer concentrations over time at all monitoring locations to below the aquifer cleanup level and approaching the aquatic standard, with a small number of outliers exhibiting a similar downward trend. As previously discussed, elevated concentrations above the DWS are found in the 100-D Area only, in areas where the presence of continuing sources is suspected. In the 100-H Area and the Horn, concentrations are below the DWS, with the average and median concentration at or about the aquatic cleanup level for Cr(VI) where groundwater discharges to surface water.

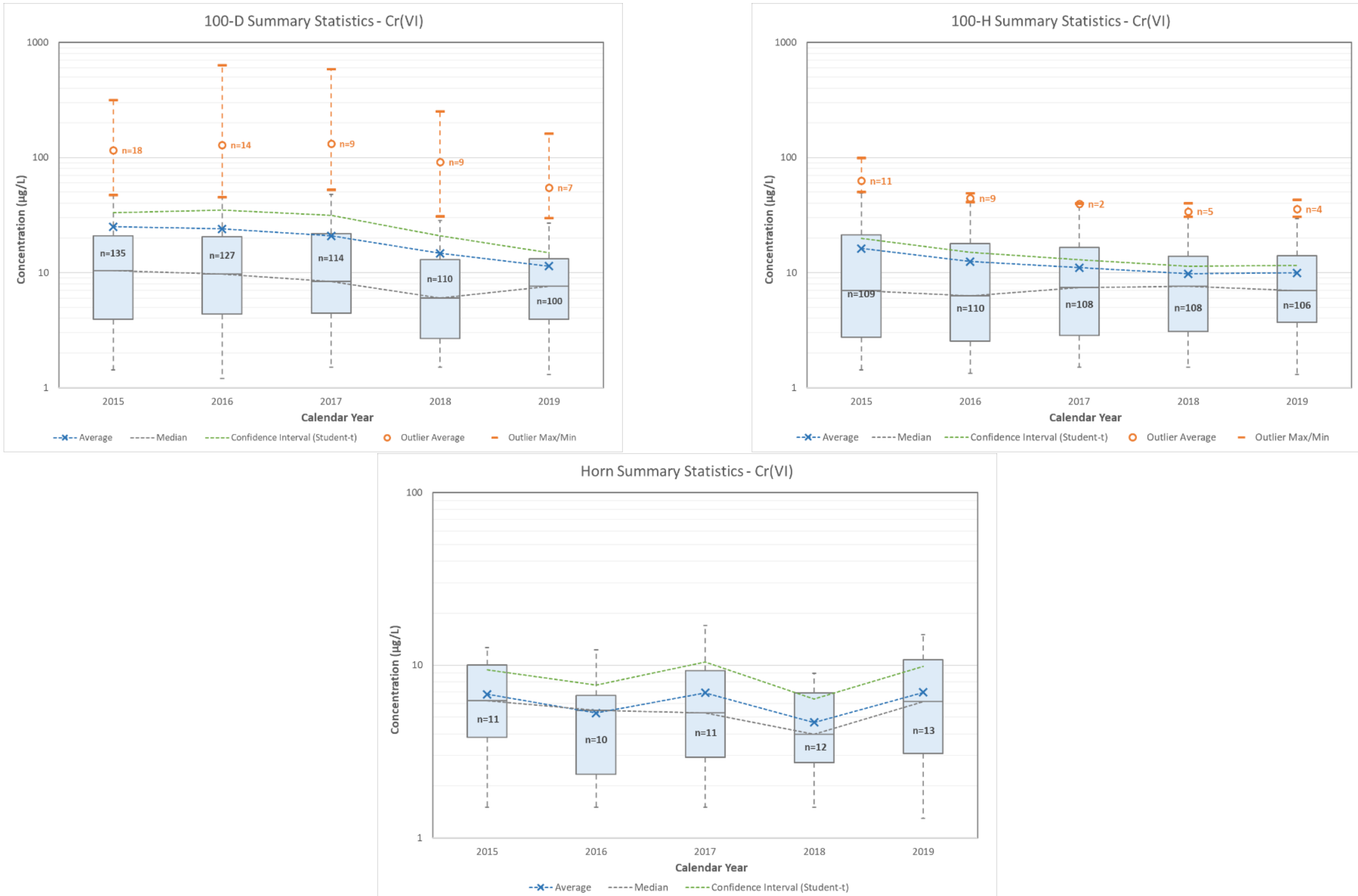

Figure 2-40. Summary Statistics for Cr(VI) in the 100-HR-3 OU (Logarithmic Scale)

2.2.8 Remedial Process Optimization Activities

A pumping optimization model and interface (based on the 100 Area Groundwater Model) has been developed that is used by OU scientists to evaluate the relative performance of alternative well configurations. The OU scientists evaluate pumping configurations throughout the year and provide recommended adjustments to flow rates, as well as recommendations for well realignment and/or installation of new wells. Specific remedial process activities performed at the 100-HR-3 OU during 2019 included the following:

- Identifying locations for new wells based on previous years' evaluations of plume capture and river protection analyses for use as extraction or monitoring locations
- Realigning monitoring wells for use as extraction wells and to enhance plume capture
- Maintaining the AWLN system to 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
- 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 DX and HX Pump and Treat Systems Effluent

The AEA groundwater monitoring plan was established for sitewide monitoring of groundwater at the Hanford Site in 2015 (DOE/RL-2015-56). The AEA groundwater monitoring and evaluation of liquid effluents are required at P&T systems in accordance with DOE O 458.1. This DOE order requires monitoring of effluents to prevent unacceptable exposure of public and ecological receptors to radiation and managing discharges that could result in new or increased plumes that would require mitigation action or remediation.

This section discusses the results of the radiological dose and DWS evaluation of the DX and HX P&T systems' effluent for 2019 against the requirements of DOE O 458.1 and DOE-STD-1196-2011 under the AEA groundwater monitoring plan (DOE/RL-2015-56). This evaluation included calculating the TED produced by radioisotopes in the effluent following treatment of extracted groundwater to remove identified contaminants. The resulting dose was compared to the target dose limit of 100 mrem/yr to the public established in DOE O 458.1. The cumulative TED is based on using the DCSs defined in DOE-STD-1196-2011. Additional guidance is provided in DOE-HDBK-1216-2015 and summarized in Table 2-14 for evaluating radiological effluent monitoring based on the DCS to ensure that mitigating steps are implemented before conditions exceed target metrics. These criteria are applied to the DX and HX P&T systems and are evaluated each year for adequacy and updated as necessary.

This evaluation further compares the radioisotopes in the effluent to the following radiological DWSs: 4 mrem/yr MCL dose for beta/photon emitters and 30 µg/L uranium mass concentration MCL.

Table 2-14. 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		—	Apply best available technology to reduce effluent releases (except tritium). Use continuous monitoring/sampling, but where effluent streams are low flow and potential public dose is very low (<1 mrem in a year); alternative sampling approaches may be appropriate.
2	≥0.01 to 1	and	>1	Continuously monitor or sample. Identify radionuclides contributing >/=10% of the dose. Determine accuracy of results (± accuracy and percent confidence level).
3	≥0.001 to 0.01	and	<1	Monitor using a graded approach to select the appropriate method and duration. Identify radionuclides contributing >/= 10% 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.

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

*To further clarify, the potential annual dose from exposure is the calculated cumulative total effective dose value.

— = not applicable

DCS = derived concentration standard

2.3.1 Evaluation of Effluent Water Total Effective Dose for DX and HX Pump and Treat Systems for 2019

Effluent monitoring at the DX and HX P&T systems was performed by sampling and analyzing the stream exiting the facilities prior to pumping effluent to the injection well fields. Sampling and analysis were performed periodically for target radionuclides identified as contaminants of interest for the groundwater remedial actions supported by the treatment systems. The radionuclides of interest under the AEA (Table A-35 in Appendix A of DOE/RL-2015-56) for the DX and HX P&T systems are tritium, technetium-99, strontium-90, and uranium. Table 2-15 summarizes the results of the periodic sampling and analysis of effluent from the DX and HX P&T systems in 2019. Where multiple measurements were determined for an analyte during a single sampling and analysis event, the maximum value was used in this evaluation.

Table 2-15. Summary of Effluent Radioisotope Sampling and Analysis Results at the DX and HX P&T Systems, 2019

Sample Location	Sample Date	Tritium (pCi/L)	Technetium-99[a] (pCi/L)	Strontium-90 (pCi/L)[a]	Uranium (µg/L)[a]	Uranium-234[b] (pCi/L)	Uranium-235[b] (pCi/L)	Uranium-238[b] (pCi/L)
DX P&T								
Effluent tank –M5	3/14/2019	1.27E+03	(40.5)	(1.14)	(0.4)	(0.15)	(0.0061)	(0.13)
Effluent tank –M5	6/13/2019	1.37E+03	(18.6)	(0.888)	(0.4)	(0.15)	(0.0061)	(0.13)
Effluent tank –M5	8/6/2019	1.59E+03	(39.4)	(1.38)	(0.067)	(0.03)	(0.0010)	(0.02)
Effluent tank –M5	12/4/2019	1.05E+03	(41.9)	(1.21)	(0.067)	(0.03)	(0.0010)	(0.02)
HX P&T								
Effluent tank – H5	3/14/2019	673	(38.7)	(1.18)	(0.4)	(0.15)	(0.01)	(0.13)
Effluent tank – H5	6/13/2019	556	20.2	(1.29)	(0.4)	(0.15)	(0.01)	(0.13)
Effluent tank – H5	8/6/2019	684	(41.3)	(1.53)	0.124	(0.05)	(0.00)	(0.04)
Effluent tank – H5	12/4/2019	447	(41.7)	(1.1)	(0.067)	(0.03)	(0.00)	(0.02)

a. Values in parentheses were reported as not detected. The value presented is the reported minimum detectable activity concentration for samples reported as analyzed but not detected.

b. Uranium isotope (i.e., uranium-234, uranium-235, and uranium-238) activity concentrations are derived from uranium mass concentration values assuming the mass distribution and specific activity of isotopes in natural uranium.

P&T = pump and treat

Individual radioisotope activity concentrations were subsequently converted to estimated effective dose using the DCS values in Table 2-16.

Table 2-16. Derived Concentration Standards for Radioisotopes Evaluated in DX and HX P&T System Effluent

DCS	Tritium	Technetium-99	Strontium-90	Uranium[a]	Uranium-234	Uranium-235	Uranium-238
DCS (µCi/ml)[b]	1.90E-03	4.40E-05	1.10E-06	—	6.80E-07	7.20E-07	7.50E-07
DCS (pCi/L)[c]	1.90E+06	4.40E+04	1.10E+03	—	6.80E+02	7.20E+02	7.50E+02

a. Uranium in mass concentration is not assigned a DCS value.

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

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

DCS = derived concentration standard

Table 2-17 shows the individual radioisotope dose contributions for each effluent sampling event at the DX and HX P&T systems and the cumulative TED estimates for 2019. The TED was calculated using two approaches: (1) a conservative approach was used to incorporate the minimum detectable activity (MDA) for nondetect measurements as a value, and (2) an approach assuming a value of zero for nondetect measurements and using only the reported detected values for calculations. The resulting TED and DCS fractions were then compared to the criteria presented in Table 2-14.

For the conservative approach to calculate cumulative TED and DCS fraction values, the results shown in Table 2-17 indicate that effluent sampling events during 2019 at the DX and HX P&T systems met monitoring criterion #3 on March 14, June 13, August 6, and December 4. Results were driven mainly by the nondetect values. The nonconservative approach yielded results that met criterion #3 for all dates at the DX P&T system and for one date (March 14, 2019) at the HX P&T system. The results from the June 13, August 6, and December 4 sampling event (at the HX P&T system) calculations met monitoring criterion #3.

2.3.2 Comparison of DX and HX Pump and Treat System Effluent Water Radiological Constituents to Drinking Water Standards for Beta/Photon Emitters and Uranium for 2019

The radioisotopes measured in effluent from the DX and HX P&T systems were also evaluated against the 4 mrem/yr drinking water MCL for beta and photon emitters. The cumulative beta/photon dose MCL is based on a sum-of-fractions calculation (similar to the AEA, DCS, and TED) using the derived concentration values published by EPA. The beta/photon MCL dose analysis was performed in two ways: (1) using the reported MDA as a value for measurements reported as nondetects, and (2) assuming a value of zero for nondetect measurements and using only the reported detected values for calculations. The first approach is a conservative screen used to assess potential dose contributions. For both the conservative and nonconservative approaches, individual and average values for beta/photon emitters measured in the effluent at these two systems do not exceed the dose MCL of 4 mrem/yr. Total uranium (metal) mass concentration for both systems does not exceed the 30 µg/L MCL. Table 2-18 summarizes the evaluation results.

Table 2-17. Calculated Individual Radioisotope Dose Contributions and TED for DX and HX P&T System Effluent, 2019

Sample Location	Sample Date	Individual Isotope Effective Dose Contribution						TED Cumulative (mrem/yr)[c]	DCS Fraction Cumulative (Fraction)[c]	TED Detects Only (mrem/yr)[c]	DCS Fraction Detects Only (Fraction)[c]
		Tritium (mrem/yr)	Technetium-99 (mrem/yr)[a]	Strontium-90 (mrem/yr)[a]	Uranium-234[a, b] (mrem/yr)	Uranium-235[a, b] (mrem/yr)	Uranium-238[a, b] (mrem/yr)				
DX P&T System											
Effluent tank –M5	3/14/2019	6.7E-02	(9.2E-02)	(1.0E-01)	(2.2E-02)	(8.4E-04)	(1.8E-02)	0.303	0.003	0.067	0.001
Effluent tank –M5	6/13/2019	7.2E-02	(4.2E-02)	(8.1E-02)	(2.2E-02)	(8.4E-04)	(1.8E-02)	0.236	0.002	0.072	0.001
Effluent tank –M5	8/6/2019	8.4E-02	(9.0E-02)	(1.3E-01)	(3.7E-03)	(1.4E-04)	(3.0E-03)	0.305	0.003	0.084	0.001
Effluent tank –M5	12/4/2019	5.5E-02	(9.5E-02)	(1.1E-01)	(3.7E-03)	(1.4E-04)	(3.0E-03)	0.267	0.003	0.055	0.001
HX P&T System											
Effluent tank – H5	3/14/2019	3.54E-02	(8.80E-02)	(1.07E-01)	(2.21E-02)	(8.41E-04)	(1.77E-02)	0.271	0.003	0.107	0.001
Effluent tank – H5	6/13/2019	2.93E-02	4.59E-02	(1.17E-01)	(2.21E-02)	(8.41E-04)	(1.77E-02)	0.233	0.002	0.029	0.0003
Effluent tank – H5	8/6/2019	3.60E-02	(9.39E-02)	(1.39E-01)	6.84E-03	2.61E-04	5.50E-03	0.282	0.003	0.049	0.0005
Effluent tank – H5	12/4/2019	2.35E-02	(9.48E-02)	(1.00E-01)	(3.69E-03)	(1.41E-04)	(2.97E-03)	0.225	0.002	0.024	0.0002

Note: Yellow-shaded cells indicate that cumulative TED and DCS fraction values meet criterion #3, and unshaded table cells met criterion #4 in Table 2-14.

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

b. Uranium isotope activity concentrations were derived from total uranium mass concentration for use in calculation of dose contribution.

c. The absence of a measured value for strontium-90, tritium, and uranium indicates nonrepresentative underestimation of the TED and DCS fraction.

DCS = derived concentration standard

P&T = pump and treat

TED = total effective dose

Table 2-18. Summary of Drinking Water Beta/Photon Emitter MCL Comparison for DX and HX P&T System Effluent, 2019

Sample Location	Sample Date	Contributing Radioisotopes			Sum of Fractions[b]	Drinking Water β/ϒ Dose (mrem/yr)[b]	Sum of Fractions Detects Only[c, d]	Drinking Water β/ϒ Dose from Detects Only (mrem/yr)[c, d]
		Tritium	Tc-99	Sr-90				
		Derived Concentrations (pCi/L)						
		20,000	900	8				
		Beta/Photon MCL Fraction[a]						
DX P&T System								
Effluent tank –M5	3/14/2019	0.064	(0.045)	(0.14)	0.25	1.00	0.06	0.25
Effluent tank –M5	6/13/2019	0.069	(0.021)	(0.11)	0.20	0.80	0.07	0.27
Effluent tank –M5	8/6/2019	0.080	(0.044)	(0.17)	0.30	1.18	0.08	0.32
Effluent tank –M5	12/4/2019	0.053	(0.047)	(0.15)	0.25	1.00	0.05	0.21
HX P&T System								
Effluent tank – H5	3/14/2019	0.034	(0.043)	(0.15)	0.22	0.90	0.18	0.72
Effluent tank – H5	6/13/2019	0.028	0.022	(0.16)	0.21	0.85	0.03	0.11
Effluent tank – H5	8/6/2019	0.034	(0.046)	(0.19)	0.27	1.09	0.03	0.14
Effluent tank – H5	12/4/2019	0.022	(0.046)	(0.14)	0.21	0.82	0.02	0.09

a. Values in parentheses were reported as nondetects. Value presented is MCL fraction based on MDA concentration for samples reported as analyzed but not detected.

b. Sum of MCL fractional derived concentration values and calculated MCL dose, including nondetect values using the MDA as a value.

c. Sum of MCL fractional derived concentration values and calculated MCL dose, excluding nondetect measurements.

d. The absence of a measured value for tritium and strontium indicates nonrepresentative underestimation of the sum of fractions and the resultant dose.

MCL = maximum contaminant level

MDA = minimum detectable activity

P&T = pump and treat

2.3.3 Conclusions of Evaluation of Radiological Constituents in DX and HX Pump and Treat System Effluent Water for 2019

The radiological dose evaluation for the DX and HX P&T effluent water during 2019 indicates that the effluent met the following standards and criteria:

- The calculated DCS-based TED of the effluent for the DX and HX P&T systems was <1 mrem/yr, substantially below the 100 mrem/yr public dose limit.
- The calculated DCS-based sum of fractions and resulting TED of the effluent for the DX and HX P&T systems on March 14, June 13, August 6, and December 4, 2019, were consistent with criterion #3 for a majority of the conservative and nonconservative results, except for three sampling events at the HX P&T system that met criterion #4. The TED values that met criterion #3 were likely driven by nondetect values used in the conservative method.
- The calculated MCL-based beta/photon-emitter drinking water dose was below the 4 mrem/yr MCL dose for the DX and HX P&T systems.
- Total uranium (metal) mass concentration in effluent for both systems was below the 30 µg/L MCL. Uranium was not detected in any samples at the DX P&T system. Uranium was detected in one sampling event at the HX P&T system.

No changes in the standard effluent monitoring sampling and analysis frequency or analytical suite are indicated for 2020.

2.4 100-HR-3 Operable Unit Pump and Treat System Cost

This section summarizes the actual costs for the 100-HR-3 OU P&T systems for 2019. 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 the 100-HR-3 OU SAP (DOE/RL-2013-30). Sampling activities for routine groundwater monitoring are integrated for all groundwater OUs to reduce overall labor with sample trips and analytical costs. These costs have been pooled in a separate project account and have not been included in the 100-HR-3 OU performance monitoring costs. To account for all performance monitoring costs associated with implementing remedial actions for the 100-HR-3 OU, a portion of the pooled costs based on sample

trips and analyses performed for the 100-HR-3 OU have been included with the performance monitoring costs in this year's report.

- **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 disposal, and new resin purchase.
- **Field studies:** Includes costs for conducting field tests (e.g., step tests, pumping tests, and 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 for the P&T facilities. Costs include fabricating and installing/modifying equipment and systems for well conversions, as well as installing piping runs and electrical cables from the P&T facilities to the wells.

The costs include all activities associated with the interim remedial actions, including construction of new wells and interim action performance monitoring. The cost breakdowns for the DX and HX P&T systems are shown in Tables 2-19 and 2-20, respectively. Costs are burdened and are based on actual operating costs incurred during 2019. Summaries of the costs for the DX and HX P&T systems are presented in the following sections.

2.4.1 DX Pump and Treat System

The total cost for the DX P&T system during 2019 was approximately $3.53 million, which consists of the sum of the categories shown in Table 2-19. The increase in cost compared to 2018 is primarily from installation of new wells to implement the final remedy in the 100-D/100-H Areas ROD (EPA et al., 2018). The 2011 through 2018 performance monitoring costs reported in previous P&T reports (e.g., DOE/RL-2018-67) in Table 2-19 have been adjusted to include the percentage of pooled groundwater monitoring cost associated with the 100-D Area portion of the 100-HR-3 OU since DX P&T system startup in 2011. The 2019 cost breakdown percentage for the DX P&T system (Figure 2-41) is as follows, in decreasing order:

- **O&M:** 34.7% ($1,227,200)
- **Performance monitoring:** 22.5% ($796,300; $561,000 apportioned from pooled groundwater monitoring cost)
- **Treatment system capital construction:** 17.7% ($626,400)
- **Well realignments:** 13.4% ($472,800)
- **Project support:** 6.4% ($225,600)
- **Waste management:** 4.0% ($139,900)
- **Design:** 1.3% ($44,900)
- **Field studies costs:** negligible costs in 2019

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Table 2-19. 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	2017	2018	2019
Design	2,115.2	1,287.8	100.7	34.3	28.9	5.7	44.4	11.0	188.8	150.8	44.9
Treatment system capital construction	5,759.8	16,266.3	—	(3.1)	244.2	565.7	851.4	714.1	736.8	269.5	626.4
Project support	495.1	1,236.9	45.7	71.3	186.0	132.4	14.3	118.7	165.1	86.4	225.6
Operations and maintenance	—	—	2,979.3	1,566.3	2,186.4	1,857.9 [c]	1,618.4 [c]	1,931.5	1,480.7	1,285.6	1,227.2
Performance monitoring[c]	—	—	924.7	1,792.9	1,270.3	1,495.3	991.7	1,010.8	977.0	739.3	796.3
Waste management	7.4	9.2	—	0.8	0.0	0.6	114.7	44.1	72.2	155.1	139.9
Field studies	—	—	—	—	—	0.4	—	—	10.7	0.3	—
Well realignments[d]	—	—	—	—	—	171.9	2,750.4	2,224.8	1,365.0	385.6	472.8
Totals	**$8,377**	**$18,800**	**$4,050**	**$3,462**	**$3,916**	**$4,230**	**$6,385**	**$6,055**	**$4,996**	**$3,073**	**$3,533**

a. Annual reporting 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 system construction was completed in December 2010 and began acceptance test procedures. It became fully operational in January 2011.

c. Performance monitoring costs have been adjusted back through 2011 to include pooled sampling costs for groundwater monitoring proportioned to the DX P&T.

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

— = not available

P&T = pump and treat

Table 2-20. Breakdown of HX P&T System Construction Costs

Description	Actual Costs (Dollars × 1,000)										
	2009[a]	2010	2011[b]	2012	2013	2014	2015	2016	2017	2018	2019
Design	896.4	1,047.5	1,079.8	35.9	3.6	6.0	37.8	9.4	161.0	156.1	47.2
Treatment system capital construction	214.1	9,354.2	11,316.2	(2.3)	220.0	566.9	725.8	608.7	628.1	279.0	658.3
Project support	—	400.2	1,981.4	53.2	179.4	128.7	10.9	101.2	123.2	70.6	244.7
Operations and maintenance	—	—	321.2	1,187.4	1,727.6	1,792.7[c]	1,586.4[c]	1,905.0	1,391.2	1,907.7	2,045.9
Performance monitoring[c]	—	—	520.4	1,440.1	994.9	885.4	737.4	813.2	883.4	793.2	804.4
Waste management	—	0.1	—	1.0	—	—	103.3	31.3	66.9	121.8	129.6
Field studies	—	—	—	—	—	0.4	—	446.4	81.5	0.0	—
Well realignments[d]	—	—	—	—	—	171.9	2,344.6	1,896.5	691.3	398.6	496.9
Totals	**$1,111**	**$10,802**	**$15,219**	**$2,715**	**$3,125**	**$3,552**	**$5,546**	**$5,812**	**$4,027**	**$3,727**	**$4,427**

a. Annual reporting 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 and began acceptance test procedures. It became fully operational in October 2011.

c. Performance monitoring costs have been adjusted back through 2011 to include pooled sampling costs for groundwater monitoring proportioned to the HX P&T.

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

— = not available

P&T = pump and treat

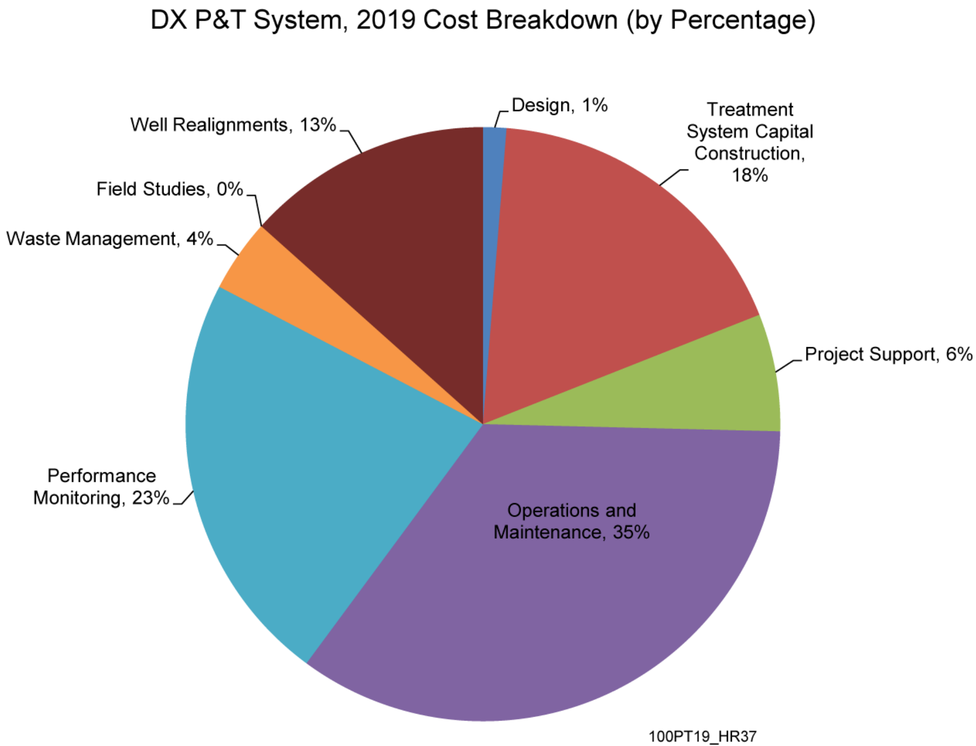

Figure 2-41. DX P&T System, 2019 Cost Breakdown (by Percentage)

Based on the total 2019 cost of $3,533,000, the yearly production rate of 1,276 million L (337 million gal), and 24.1 kg of Cr(VI) removed, the annual treatment cost is $0.0028/L, or $146.43/g of Cr(VI) removed.

2.4.2 HX Pump and Treat System

The total cost for the HX P&T system during 2019 was approximately $4.43 million, which consists of the sum of the categories shown in Table 2-20. The increase in cost compared to 2018 is primarily from installation of new wells to implement the final remedy in the 100-D/100-H Areas ROD (EPA et al., 2018). The 2011 through 2018 performance monitoring costs reported in previous P&T reports (e.g., DOE/RL-2018-67) in Table 2-20 have been adjusted to include the percentage of pooled groundwater monitoring cost associated with the 100-H Area portion of the 100-HR-3 OU since HX P&T system startup. The cost breakdown for the HX P&T system for 2019 (Figure 2-42) is as follows, in decreasing order:

- **O&M:** 46.2% ($2,045,900)
- **Performance monitoring:** 18.2% ($804,400; $605,000 apportioned from pooled groundwater monitoring cost)
- **Treatment system capital construction:** 14.9% ($658,300)
- **Well realignments:** 11.2% ($496,900)
- **Project support:** 5.5% ($244,700)

- **Waste management:** 2.9% ($129,600)
- **Design:** 1.1% ($47,200)
- **Field studies:** negligible in 2019

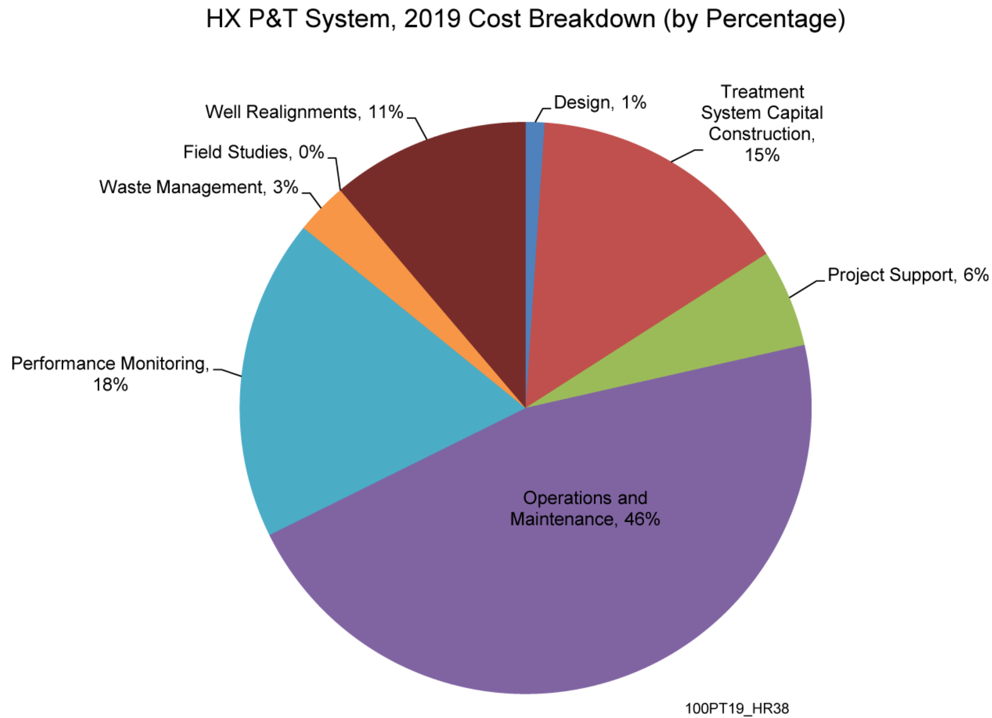

Figure 2-42. HX P&T System, 2019 Cost Breakdown (by Percentage)

Based on the total 2019 cost of $4,427,000, the yearly production rate of 1,013 million L (268 million gal), and 30.6 kg of Cr(VI) removed, the annual treatment cost is $0.0044/L, or $144.66/g of Cr(VI) removed.

2.5 Conclusions

Remediation of the Cr(VI) plume continued to progress in 2019 at the 100-HR-3 OU, as shown by reduced plume size and concentrations. The unconfined aquifer areas with concentrations >48 µg/L are now limited to a few locations. The DX and HX P&T systems removed a substantial mass of Cr(VI) from the aquifer in 2019 (54.7 kg). The amount of mass removed each year continues to decrease as areas with high Cr(VI) concentrations are remediated. About one-third of the mass removed is from the RUM aquifer due to the addition of new RUM aquifer extraction wells and declining concentrations in the unconfined aquifer. High concentrations in RUM wells 199-H3-13, 199-H3-28, and 199-H3-29 illustrate the need for continued remediation of the semiconfined aquifer in the 100-H Area. 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 indicates that the hydraulic containment extent developed by the DX and HX P&T systems during 2019 is consistent with the design of the systems and within expectations. Calculations indicate that the river protection objective is being achieved along the majority of the 100-HR-3 OU shoreline. However, the 100-D Area had areas of elevated Cr(VI) concentrations at the shoreline because these areas are outside the hydraulic containment zone developed by the P&T well operations.

The following conclusions for the 100-HR-3 OU are based on each of the RAOs related to groundwater from the 100-D/100-H Areas ROD (EPA et al., 2018).

- **RAO #1:** Prevent unacceptable risk to human health from ingestion of and incidental exposure to groundwater containing contaminant concentrations above federal and state standards and risk-based thresholds.

  Results: ICs are used to protect the integrity of a response action and/or to restrict exposure to contamination in soil and groundwater until such contamination is at levels that allow for unlimited use/unrestricted exposure. Required ICs include excavation and use restrictions to prevent inadvertent exposure to contamination in soil and ICs to restrict groundwater use until cleanup levels are achieved. Excavation and ICs are the selected remedy for a number of shallow and deep waste sites with radiological contamination exceeding unlimited use/unrestricted exposure levels (Table 1 in the 100-D/100-H Areas ROD [EPA et al., 2018]). In accordance with the ROD, ICs shall be implemented, maintained, reported on, and enforced.

  Access restrictions 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 MSA-1105355.6, *FY2017 Sitewide Institutional Control Assessment*. The findings of this report indicate that ICs were maintained to prevent public access, as required.

- **RAO #2:** Prevent unacceptable risk to human health and ecological receptors from groundwater discharges to surface water containing contaminant concentrations above federal and state standards and risk-based thresholds.

  Results: The effect of river-stage fluctuations on groundwater flow, combined with the aquifer response to pumping, resulted in less hydraulic containment in 2019 compared to previous years. The SCFM in 2019 indicated stronger hydraulic containment than reflected in the ICFM, mainly in the 100-D Area. This is because model-simulated aquifer response to high river-stage conditions underestimates water levels in the aquifer, resulting in stronger hydraulic containment. Hydraulic capture frequency appears to be weaker in the Horn, where there is limited saturated thickness, which causes reduced flow rates at extraction wells and results in slow plume migration in that area. However, as explained below, capture from downgradient extraction wells is expected.

  The capture flow lines in some areas are affected by river-stage fluctuations and aquifer hydraulic conditions and follow a more indirect path to an extraction well, as shown in Figures 2-33 and 2-34. When comparing the flow paths to CFMs (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 capture may take longer to occur.

For 2019, the quantitative evaluation for the 100-D Area suggests relatively weak hydraulic containment, as shown mainly in the ICFM. However, with the exception of the presence of Cr(VI) at the 116-DR-5 outfall at concentrations >10 μg/L (as was also the case in 2017 and 2018), hydraulic containment was sustained in 2019. This is evident when considering the location and operation of the P&T wells, the decreasing concentration trends at the monitoring locations along the shoreline, and the decreasing interpolated plume extents. Conditions will continue to be monitored and evaluated for river protection during 2020 and if further attention is required.

In the 100-H Area during 2019, the quantitative river protection evaluation reflects improved containment compared to 2018, as reflected by 100 m (330 ft) less of shoreline identified to be unprotected (Table 2-13). Hydraulic capture frequency within the portion of the Cr(VI) plume in the Horn remains weak, with limited mass recovery from the extraction wells located in that area and hydraulic gradients resulting in slow plume migration. Qualitative evaluation of the river protection status indicates protection along most of the 100-H Area shoreline, taking into consideration plume extents, concentration trends, and well operations near the shoreline.

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 observed Cr(VI) concentrations in groundwater at the DX and HX P&T systems are declining as remediation progresses. Discharge to the river from the RUM was not included in this evaluation.

- **RAO #7:** Restore groundwater in the 100-HR-3 OU to cleanup levels, which include DWSs, within a timeframe that is reasonable given the particular circumstances of the site.

  Results: The 100-HR-3 OU P&T systems have removed substantial amounts of Cr(VI) from groundwater. Since startup of the DX and HX P&T systems, an estimated total of 1,858 kg of Cr(VI) has been removed from the shallow unconfined aquifer and RUM, with the DX P&T system alone removing 1,831 kg of that total. In 2019, a total of 24.1 kg of Cr(VI) was removed by the DX P&T system, and a total of 30.6 kg of Cr(VI) was removed by the HX P&T system.

  Figure 2-39 compares the monthly and cumulative Cr(VI) mass recovered by the DX and HX P&T systems during 2019, as determined using actual influent concentrations and flow rates versus the mass recovery simulated with 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 well included in the plot and with the mass from the RUM well excluded from the measured recovery plot (since the groundwater model addresses the presence of Cr(VI) in the unconfined aquifer only). As shown in Figure 2-39, about one-third of the mass recovered at the HX P&T system originates in the RUM aquifer. The single RUM well (699-97-61) connected to DX P&T recovered a total of 2.5 kg of Cr(VI), or approximately 9% of the total Cr(VI) mass recovered in 2019 by the DX P&T system.

  The radiological dose evaluation for the DX and HX P&T effluent water during 2019 indicates that the calculated DCS-based TED was below the 100 mrem/yr standard, and the calculated MCL-based beta/photon-emitter drinking water dose was below the 4 mrem/yr drinking water MCL.

3 100-KR-4 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 2019 and a summary of progress made toward 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 KE and 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 100-HR-3 and 100-KR-4 interim action ROD (EPA/ROD/R10-96/134) as the primary groundwater COC in the 100-KR-4 OU. Groundwater co-contaminants identified in the interim action ROD are nitrate, tritium, strontium-90, carbon-14, and trichloroethene (TCE).

The interim action ROD for the 100-KR-4 OU (EPA/ROD/R10-96/134) 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-river mixing zone along the river, attaining <22 µg/L of Cr(VI) in the compliance monitoring well network is consistent with achieving this RAO. The explanation of significant differences 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 remediation target of 20 µg/L for Cr(VI) in groundwater is currently applied to nearshore and compliance wells along the river. The DWS for total chromium remains at 100 µg/L. Ecology has established a MTCA 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 in 2019. The KR4 P&T system was the first system installed and began operating 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. 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 high and low river-stage periods during 2019, are shown in Figures 3-3 and 3-4, respectively.

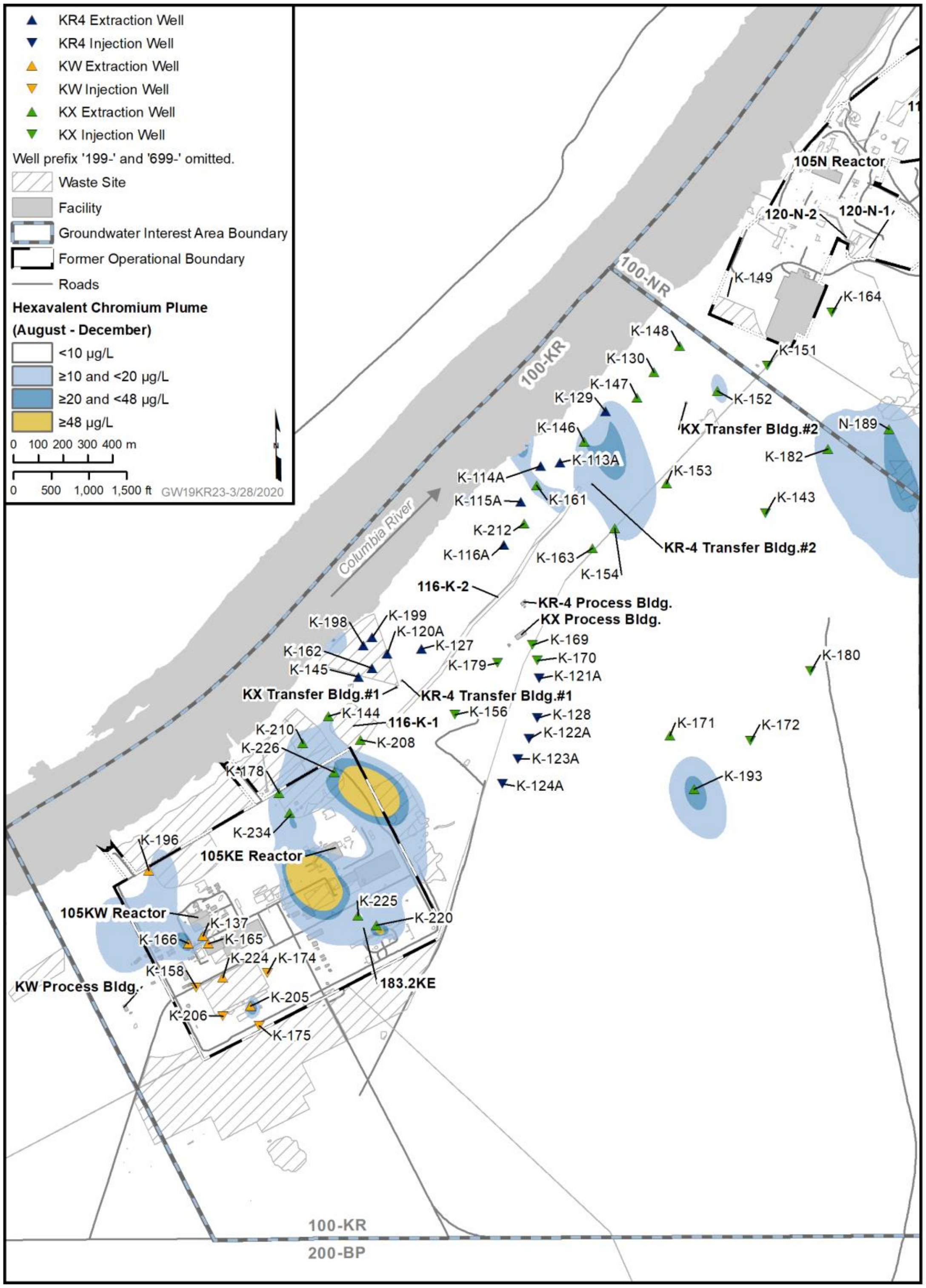

Figure 3-1. Layout of the 100-KR-4 OU P&T Systems (as of December 31, 2019) and Key Waste Sites and Facilities

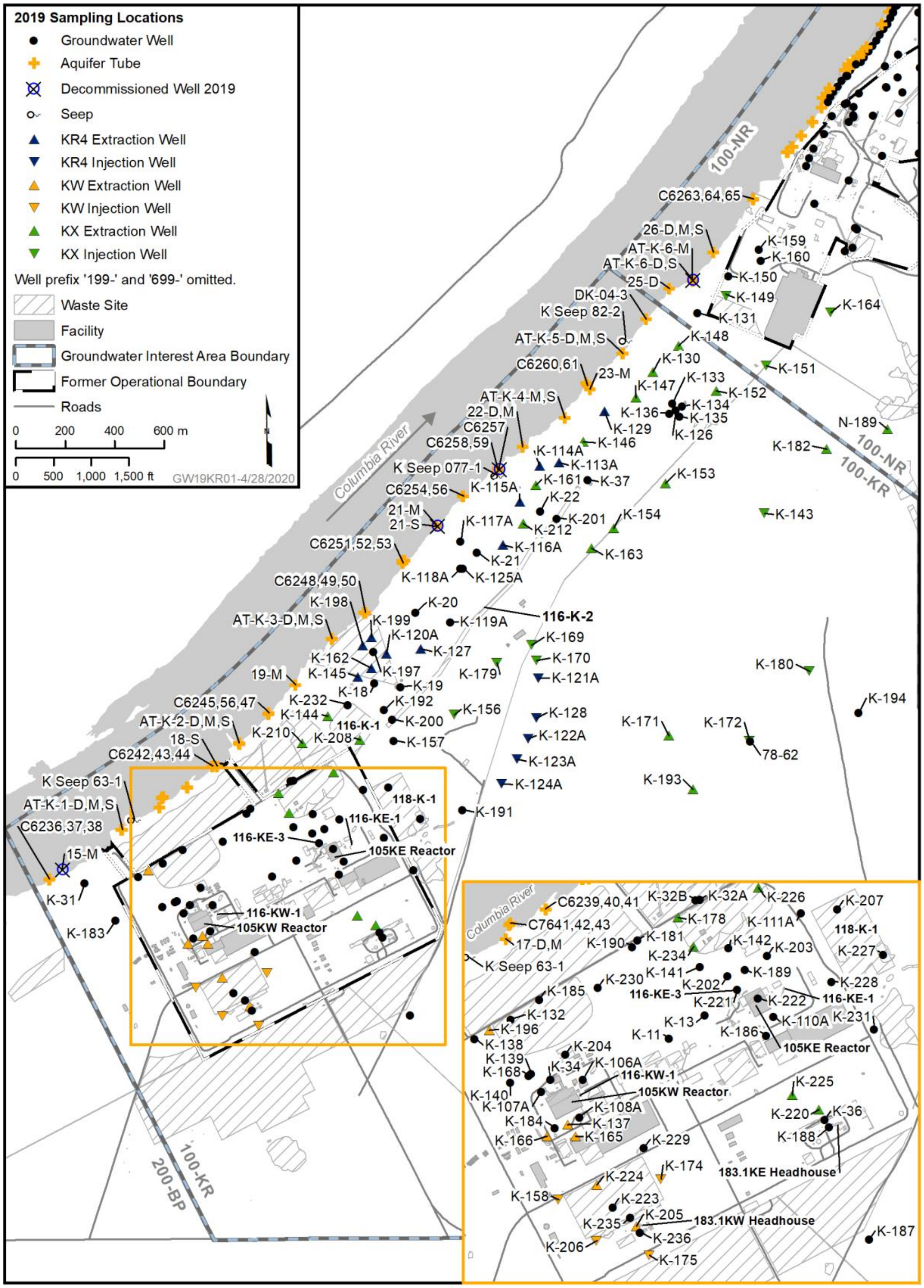

Figure 3-2. 100-KR-4 OU Remedial System Wells, Monitoring Wells, and Aquifer Sampling Tubes, 2019

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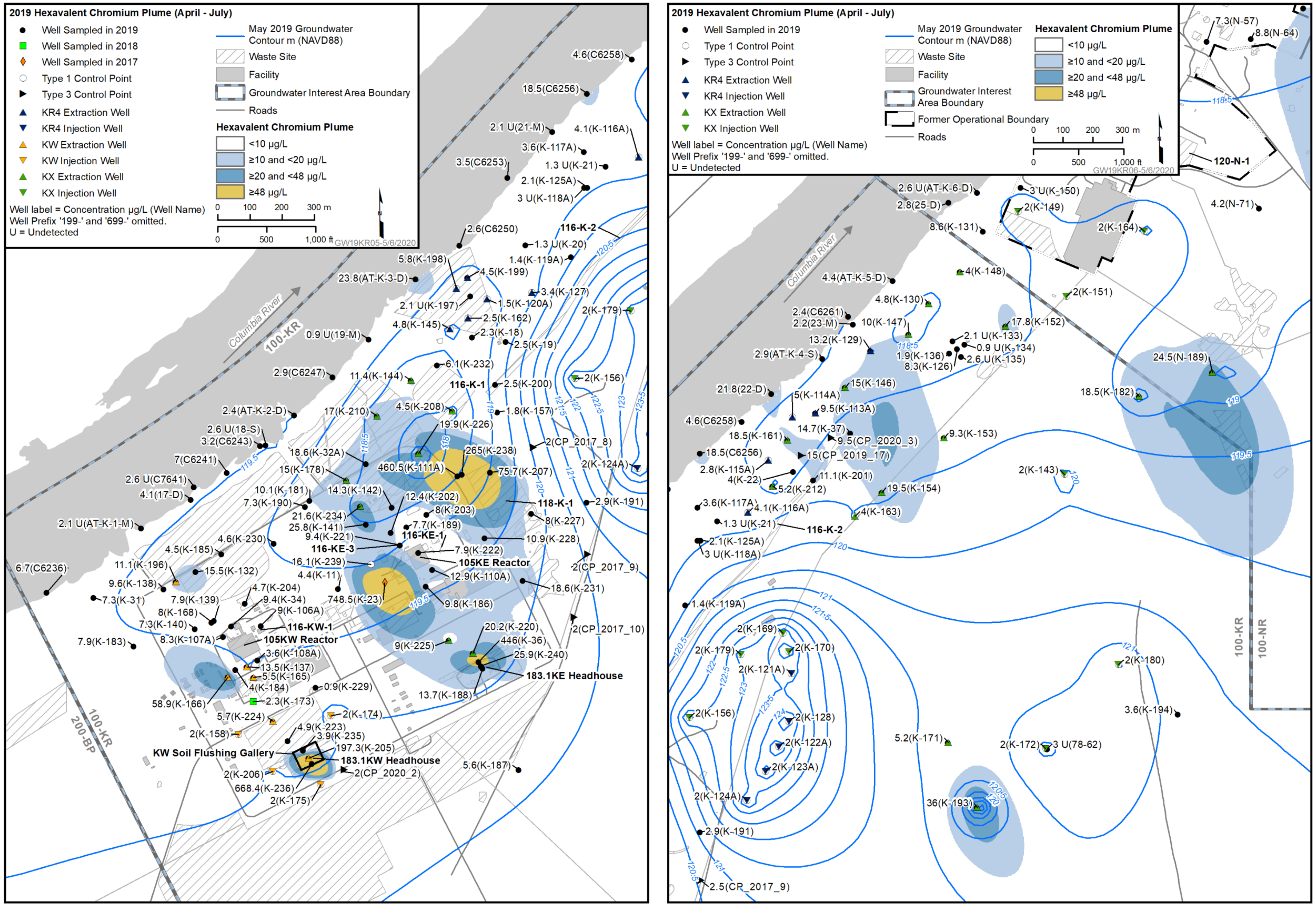


Figure 3-3. Cr(VI) Distribution in Groundwater at the 100-KR-4 OU (High River Stage, 2019)

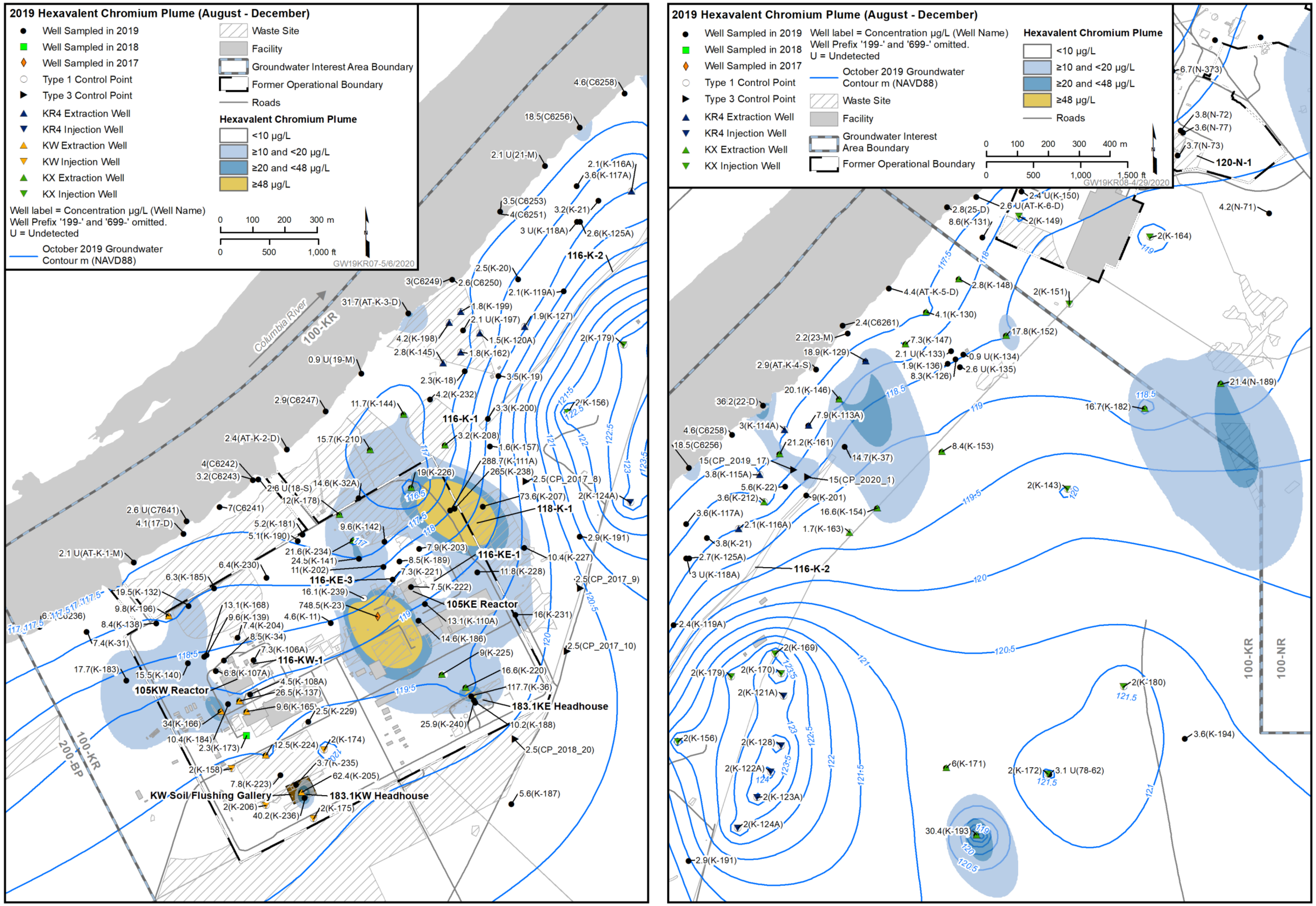


Figure 3-4. Cr(VI) Plume Distribution in Groundwater at the 100-KR-4 OU (Low River Stage, 2019)

Monitoring, data evaluation, and site characterization activities are conducted each year in an ongoing effort to determine performance of the 100-KR-4 OU P&T systems compared to the design criteria, whether system design modifications or operating parameters will further optimize performance, and progress toward achieving plume cleanup and river protection RAOs. This chapter discusses the results of the 100-KR-4 OU P&T evaluation for 2019, including 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.
- Section 3.5 presents conclusions on 2019 remedy performance for the 100-KR-4 OU.

3.1.1 Remedial Investigation/Feasibility Study Activities

In 2017, DOE began revising the 100-K Area RI/FS (DOE/RL-2010-97, Draft B). The revision incorporates supplemental data associated with the KE Reactor FSB and the 116-KE-3 Crib and reverse well, as well as data collected to support soil and groundwater interim remedial actions. In 2018, the decision was made to separate the RI and FS into two separate documents. When both documents are completed, they will provide the framework for a proposed plan, which will evaluate alternatives and recommend a preferred alternative. DOE and EPA will issue a ROD that incorporates stakeholder input and identifies the selected alternatives for waste site and groundwater cleanup. Interim remedial actions will continue until the ROD is completed. Completion of the RI report is anticipated in 2020, while the FS is anticipated to be completed in 2021.

3.1.2 Other CERCLA Document and Plans

TPA-CN-0857, *Tri-Party Agreement Change Notice Form: DOE/RL-2013-29, Sampling and Analysis Plan for the 100-KR-4 Groundwater Operable Unit Monitoring, Rev. 0*, was signed in 2019 to modify DOE/RL-2013-29, *Sampling and Analysis Plan for the 100-KR-4 Groundwater Operable Unit Monitoring*. The change notice updated the 100-KR-4 OU SAP to include newly installed wells and updated the sampling requirements for wells that may have been realigned or decommissioned.

In 2019, a soil flushing treatability test plan (DOE/RL-2017-30) and a related SAP (DOE/RL-2018-10) were implemented. The goal of soil flushing is to mobilize Cr(VI) from the deep portions of the vadose zone into groundwater, and then capture the contaminant with the active P&T system to remove it from the groundwater. The treatability test, which began on May 28, 2019, and continued into early calendar year 2020, used effluent from the KW P&T system to saturate the vadose zone beneath the former 183.1KW Headhouse area and flush residual Cr(VI) into groundwater, where it was extracted and treated by the KW P&T system. An effectiveness assessment of the treatability test is documented in SGW-63885, *KW Soil Flushing Treatability Test Effectiveness Assessment and Recommendation*. The results of the treatability test through December 31, 2019, are documented in DOE/RL-2019-66. A treatability test report (DOE/RL-2019-77, *KW Soil Flushing Treatability Test Report*) will be published in 2020.

3.2 100-KR-4 Operable Unit Interim Remedial Action Activities

This section summarizes the activities related to operation and performance monitoring of the KR4, KW, and KX P&T systems during 2019. Specific activities and operational performance details for the P&T systems include system configuration changes and availability, contaminant mass removed during operation, contaminant removal efficiencies, quantity and quality of extracted and disposed groundwater, hydraulic monitoring, and waste generation.

Changes to the 100-KR-4 OU interim action P&T systems during 2019 are summarized in Table 3-1 and are discussed in Sections 3.2.1 through 3.2.3. Well installation and realignment were intended to enhance hydraulic plume capture, reduce Cr(VI) plume concentrations, and remove mass from source areas. Figure 1-7 shows the locations of the new and realigned wells for 2019.

Table 3-1. 100-KR-4 Groundwater OU Remedial System Well Changes Initiated in 2019

System	Well	Action	Purpose	Status as of December 31, 2019
KR4	None	No realignments in 2019	—	—
KW	Infiltration gallery	Install underground infiltration system near the 183.1KW Headhouse	Infiltration gallery designed to support the KW soil flushing treatability test.	Completed in April 2019.
	199-K-205	Disconnect and reconnect extraction well	Well was disconnected from the KW P&T system to support infiltration gallery construction. Once construction was complete, well 199-K-205 was reconnected.	Between February and May 2019.
KX	199-K-141	Realign KX extraction well to monitoring well	Well was disconnected from the KX P&T system and replaced by well 199-K-234.	Completed in February 2019.
	199-K-234	Realigned monitoring well as KX extraction well	Connect high-capacity extraction well to increase mass removal and enhance river protection along the west side of the K East Cr(VI) plume.	Completed in April 2019.
	199-K-238	Install dual-purpose extraction well	Enhanced mass removal in the K East Cr(VI) groundwater plume.	Well construction completed December 3, 2019. Well will be connected to the KX P&T system in 2020.

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

3.2.1 KR4 Pump and Treat System

The KR4 P&T system was designed to capture and treat Cr(VI) associated with the 116-K-2 Trench (Figure 3-1). 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 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 10 billion L (2.6 billion gal) of groundwater and has removed 382 kg of Cr(VI). The KR4 P&T system has remediated much of the original Cr(VI) plume along the central 116-K-2 Trench to concentrations <20 µg/L. Contamination >20 µg/L remains in the groundwater at both ends of the trench and inland areas. The contaminant mass reduction near the central 116-K-2 Trench is reflected in the overall decline in system influent concentrations (Figure 3-5).

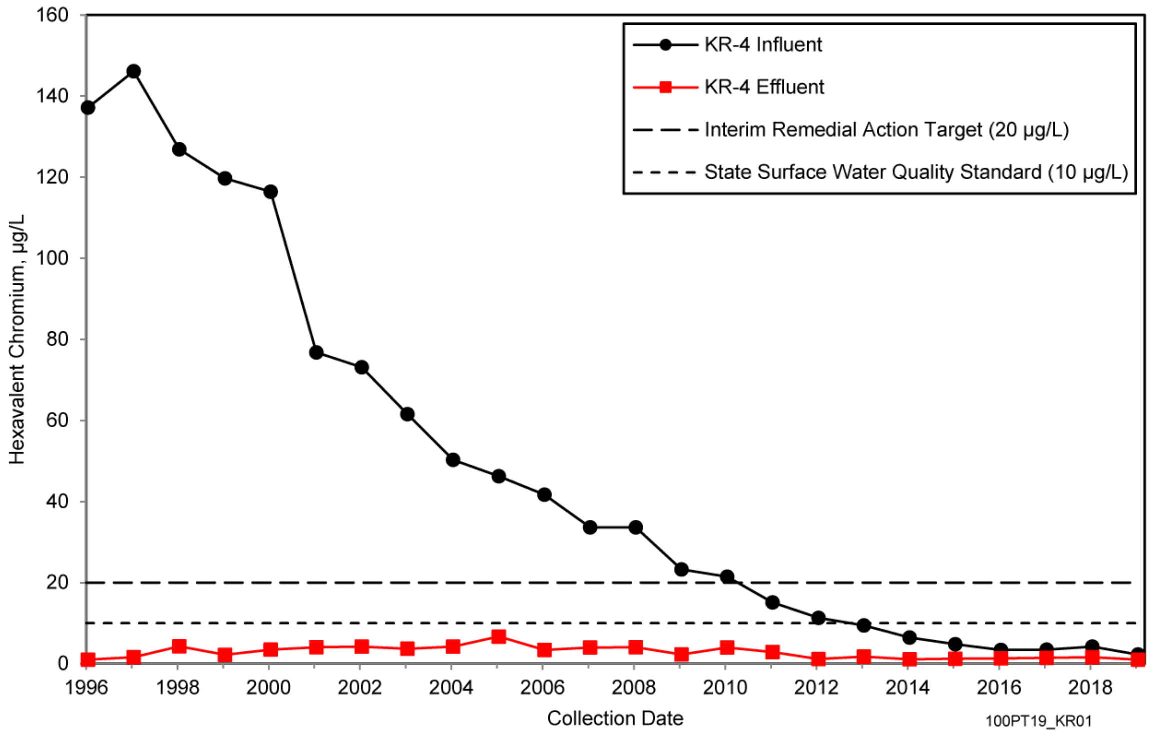


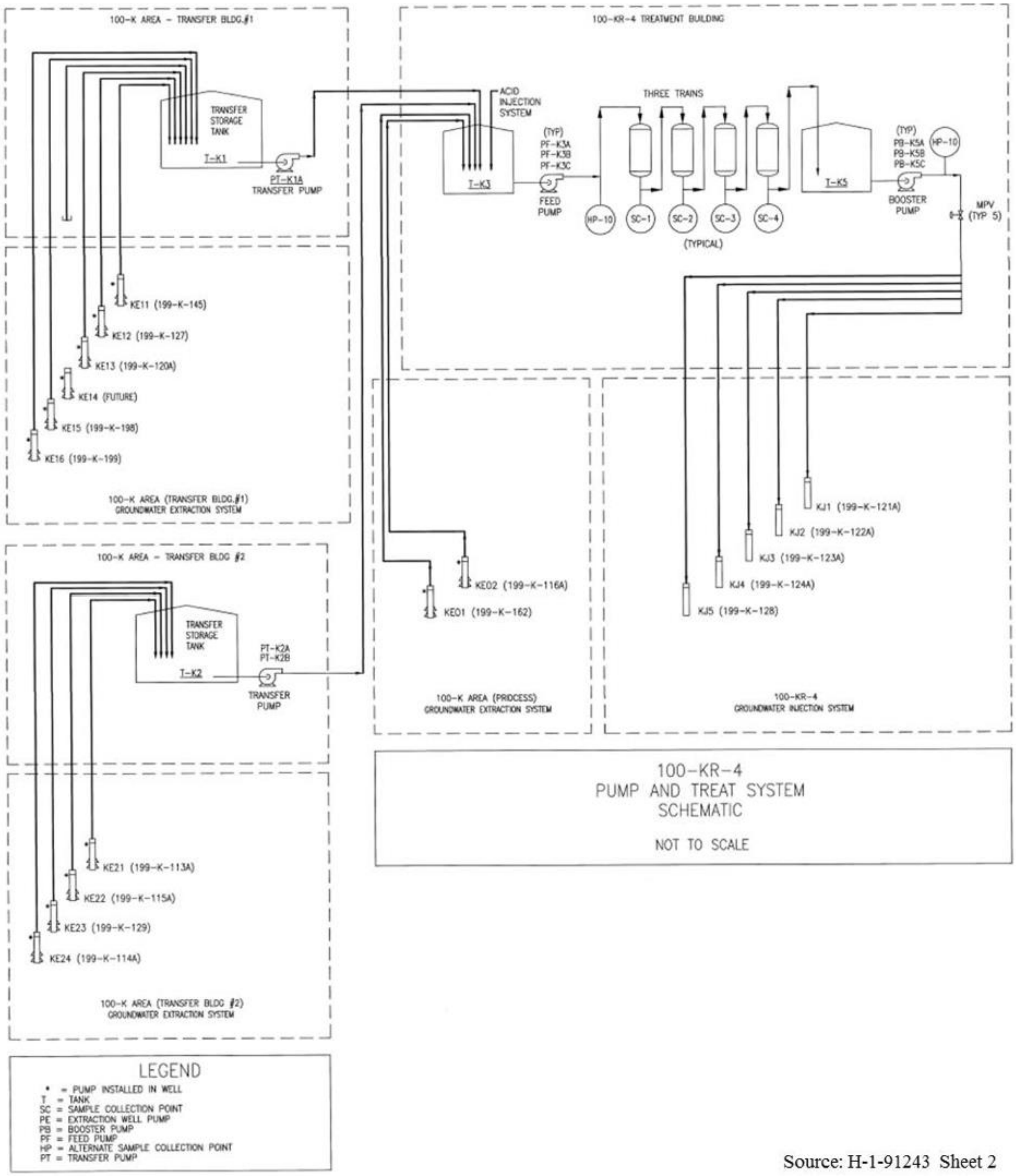
Figure 3-5. KR4 P&T System Annual Average Influent and Effluent Concentrations

During 2019, several KR4 P&T extraction wells along the distal end of the 116-K-2 Trench exhibited Cr(VI) concentrations >10 µg/L; however, well 199-K-129 was the only extraction well with average Cr(VI) concentrations of >10 µg/L during both high and low river stages. 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 (discussed in Section 3.2.6).

3.2.1.1 KR4 Pump and Treat System Configuration and Changes

The KR4 P&T system was originally designed to receive and process about 1,140 L/min (300 gal/min). Over the past several years, optimization activities have increased the system's operational capacity to 1,250 L/min (330 gal/min). As of December 31, 2019, the system design included 11 extraction wells and 5 injection wells (Figure 3-6). No modifications were made to the KR4 P&T system operating parameters or well field during 2019.

In December 2018, the adjustable-frequency drive (AFD) that supported the newly installed booster pump at the KR4 P&T facility failed. At that time, it was determined that all three AFDs supporting booster pump operations had become obsolete and required replacement. Between September and October 2019, the AFDs were upgraded, and plant operations returned to normal. However, because the repair was made during low river stage and many of the extraction wells are river-stage impacted, the average flow through the plant continued at <1,136 L/min (300 gal/min).



Source: H-1-91243 Sheet 2

Figure 3-6. KR4 P&T System Schematic (December 31, 2019)

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 2019. As discussed in Section 3.2.1.1, the average flow rate through the KR4 P&T system was reduced in 2019. Groundwater was processed at an annual average pumping rate of 1,003.5 L/min (265.1 gal/min) during 2019, and the overall run time was 95.2%. The average Cr(VI) concentration in the P&T system influent for 2019 was 4.4 µg/L (Figure 3-5). The influent concentrations ranged from <2 µg/L to a maximum of 14 µg/L (Figure 3-7). The maximum Cr(VI) concentration observed in system effluent during 2019 was 9 µg/L, and the average concentration was <2 µg/L.

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

Total Processed Groundwater	2018	2019
Total amount of groundwater treated (since September 1997 startup) (million L)	9,512	10,010
Total amount of groundwater treated during calendar year (million L)	506	504
Mass of Cr(VI) Removed		
Total amount of Cr(VI) removed since September 1997 startup (kg)	380.4	382
Total amount of Cr(VI) removed in calendar year (kg)	1.2	1.7
Summary of Operational Parameters		
Average pumping rate (L/min)	964.5	1,003.5
Average Cr(VI) influent concentration (µg/L)	3.5	4.4
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	57.8[a]	61.2[a]
Waste generation (m^3)	18.8	0
Spent resin disposed (m^3)	18.1	0
New resin installed (m^3)	4.8	0
Number of resin vessel changeouts	8	0
Summary of Co-Contaminants Detected in Effluent		
Average tritium concentration (pCi/L)	2,376	3,230
Average nitrate concentration (µg/L)	11,868	12,325
Average strontium-90 concentration (pCi/L)	1.9	<1.4
Average carbon-14 concentration (pCi/L)	32.3	<40.4
Average total chromium concentration (µg/L)	3.6	<1.5
Summary of System Availability		
Total possible run time (hours)	8,760	8,760
Total time online (hours)	8,721	8,339
Total availability (%)[b]	99.6	95.2

a. The low removal efficiency is because of the low influent concentration.

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

Cr(VI) = hexavalent chromium

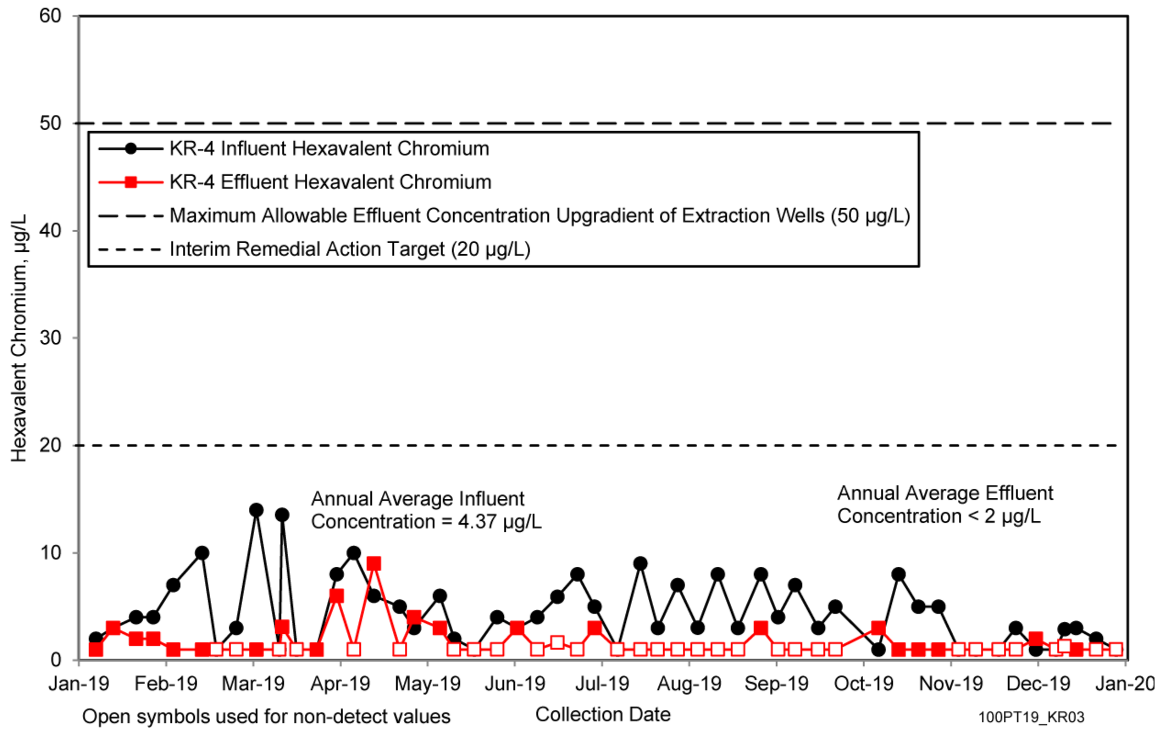


Figure 3-7. KR4 P&T System Trends of Influent and Effluent Cr(VI) Concentrations, 2019

The mass removal efficiency for the KR4 P&T system was 61% in 2019. The low removal efficiency continues to be related to the lower concentrations in extracted groundwater and not due to IX resin effectiveness. The average annual influent concentrations have been decreasing over time (Figure 3-5).

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 connected to the KR4 P&T system during 2019. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. Well 199-K-129 was subject to downtime due to equipment repairs.

Table 3-3. Flow Rates and Total Run Times for KR4 P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Yearly Average Flow Rate, L/min (gal/min)	Total Flow Hours in 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
C5940	199-K-162	KE01	139.3 (36.8)	8,432	96	Extraction
B2803	199-K-116A	KE02	129.8 (34.3)	8,456	97	Extraction
C5361	199-K-145	KE11	127 (33.5)	8,376	96	Extraction
C3662	199-K-127	KE12	89.5 (23.6)	8,456	97	Extraction
B2807	199-K-120A	KE13	116.6 (30.8)	8,360	95	Extraction
C7698	199-K-198	KE15	107.5 (28.4)	8,448	96	Extraction
C7699	199-K-199	KE16	120 (31.7)	8,448	96	Extraction
B2800	199-K-113A	KE21	34 (9)	8,456	97	Extraction
B2802	199-K-115A	KE22	46.3 (12.2)	8,456	97	Extraction

Table 3-3. Flow Rates and Total Run Times for KR4 P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Yearly Average Flow Rate, L/min (gal/min)	Total Flow Hours in 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
C4117	199-K-129	KE23	39.3 (10.4)	6,360	73	Extraction[b]
B2801	199-K-114A	KE24	67.1 (17.7)	8,408	96	Extraction
B2808	199-K-121A	KJ1	134 (35.4)	8,456	97	Injection
B2809	199-K-122A	KJ2	250.6 (66.2)	8,456	97	Injection
B2810	199-K-123A	KJ3	143.9 (38)	8,456	97	Injection
B2811	199-K-124A	KJ4	130.7 (34.5)	8,456	97	Injection
C3663	199-K-128	KJ5	321.2 (84.8)	8,432	96	Injection

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

b. Well extraction pump was replaced.

ID = identification

PLC = programmable logic controller

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 2019. From January through August, the average flow rate through the KR4 P&T system was reduced due to the failed AFD on the newly installed booster pump. The reduced run time and flow capacity observed in September and October 2019 resulted from the repair of the three AFDs that supported booster pump operations. The flow capacity started to increase after the repair, and river stage began to transition from low to high.

Co-contaminants including carbon-14, nitrate, strontium-90, and tritium were detected in KR4 P&T system effluent during 2019. Table 3-2 lists the annual average concentrations for each co-contaminant. In 2019, the annual average concentrations of co-contaminants were similar to those observed in 2018. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system. All effluent concentrations were less than their respective DWSs. TCE was analyzed for but was not detected at the KR4 P&T system.

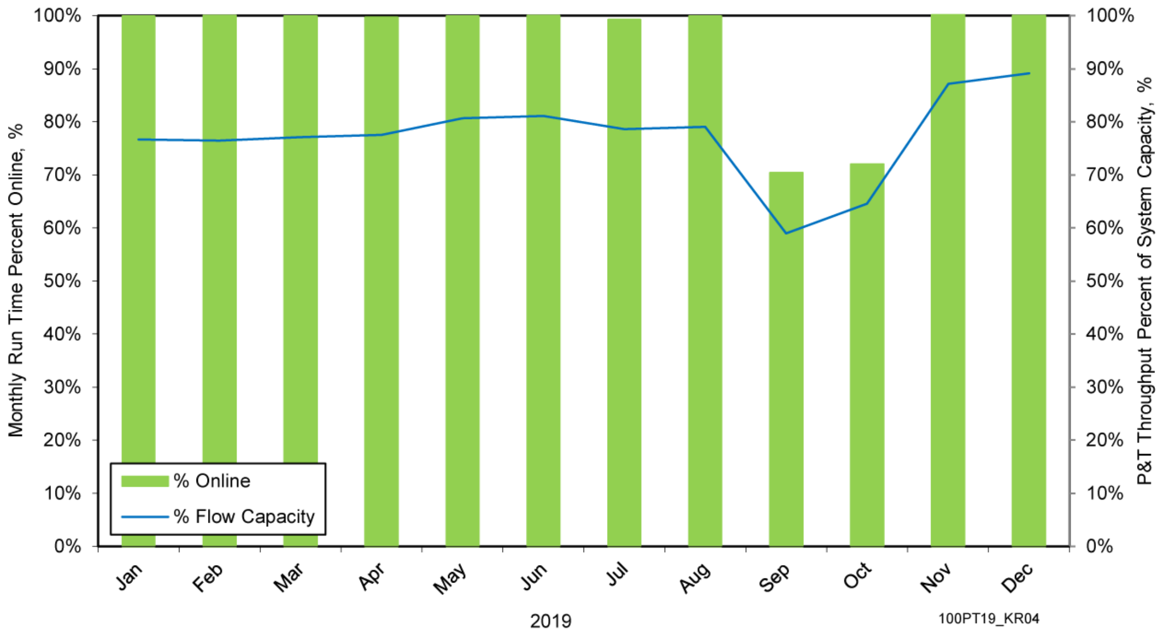


Figure 3-8. Monthly KR4 P&T System Availability, 2019

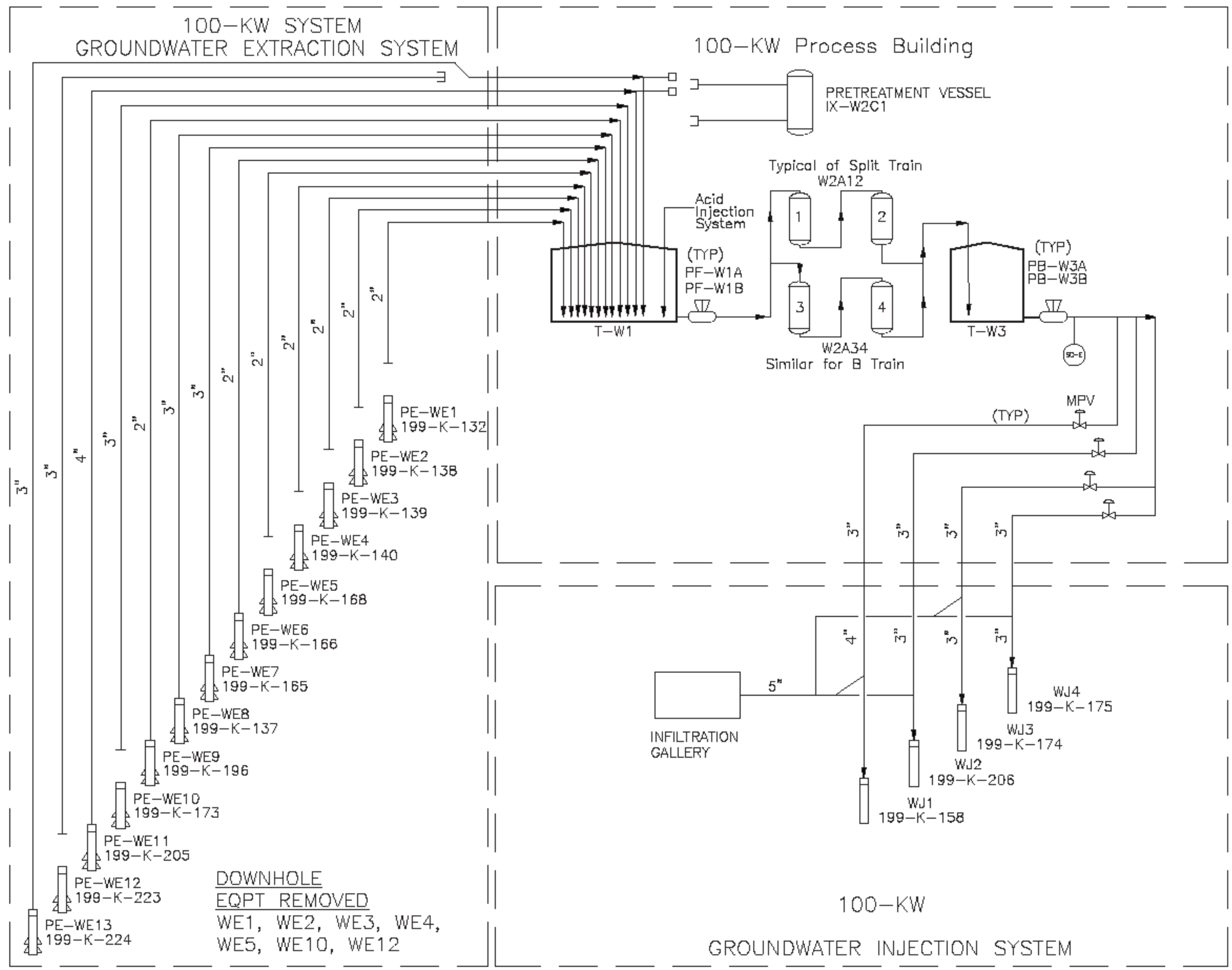
3.2.2 KW Pump and Treat System

The KW P&T system was installed to address Cr(VI) groundwater contamination in the KW Reactor vicinity (Figure 3-1). The system began operating on January 29, 2007, and has treated about 5.5 billion L (1.4 billion gal) of groundwater and removed about 283 kg of Cr(VI) since startup. Figure 3-9 provides a schematic for this P&T system.

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 760 L/min (200 gal/min). Optimization activities have increased the operational capacity of the system to 1,250 L/min (330 gal/min). In 2019, to support the KW soil flushing treatability test (DOE/RL-2017-30), an underground infiltration gallery was installed near the 183.1KW Headhouse (Figure 3-4). The infiltration gallery was designed to distribute KW P&T system effluent over an area of about 3,400 m^2 (0.85 ac) at rates up to 1,250 L/min (330 gal/min). Other configuration changes include the following:

- Reconnection of the pre-treatment vessel to accept water directly from extraction well 199-K-205. This was a temporary modification in case Cr(VI) concentrations were >5,000 µg/L during the treatability test.
- An injection well manifold was designed and installed that combined the four injection well conveyance lines into a single conveyance line out to the infiltration gallery. This manifold also allows for simultaneous operation of the gallery along with select injection wells later during the treatability test.



Source: Hanford drawing H-1-89139, sheet 1.

Figure 3-9. KW P&T System Schematic (as of December 31, 2019)

3.2.2.2 KW Pump and Treat System Performance

Table 3-4 presents an overview of the operational parameters and total system performance for the KW P&T system during 2019. Groundwater was processed at an annual average pumping rate of 1,024 L/min (270 gal/min) during 2019, and the overall run time was 99.5%. Overall, the flow rates through the KW P&T were reduced to support soil flushing treatability testing. The Cr(VI) concentration in the P&T system influent averaged 38.95 µg/L (Figure 3-10). This increase is a result of the soil flushing treatability test, where Cr(VI) reached a maximum concentration of 882 µg/L at extraction well 199-K-205. Prior to implementing the treatability test on May 28, 2019, influent concentrations ranged from 5 to 17 µg/L (Figure 3-11). Once the test was implemented, influent concentrations ranged from 17 to 295 µg/L. The Cr(VI) concentrations observed in system effluent during 2019 ranged from below detection to a maximum of 6 µg/L. Additional operation and system characteristics of the KW P&T system for 2019 are summarized as follows:

- A total of 537 million L (142 million gal) of groundwater was treated in 2019, and approximately 19.6 kg of Cr(VI) were removed.
- The average mass removal efficiency increased from 89.7% to 95.9% between 2018 and 2019 (Table 3-4). On a monthly basis in 2019, the KW P&T system removed an average of 1.6 kg of Cr(VI) compared to 0.6 kg in 2018.

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

Total Processed Groundwater	2018	2019
Total groundwater treated since January 2007 startup (million L)	4,844	5,381
Total groundwater treated in calendar year (million L)	601	537
Mass of Cr(VI) Removed		
Total Cr(VI) removed since January 2007 startup (kg)	263.1	282.6
Total Cr(VI) removed in calendar year (kg)	7.6	19.6
Summary of Operational Parameters		
Average pumping rate (L/min)	1,127.9	1,023.8
Average Cr(VI) influent concentration (µg/L)	12.7	28.8
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	89.7	95.5
Waste generation (m^3)	32.8	0
Spent resin disposed (m^3)	0	0
New resin installed (m^3)	0	0
Number of resin vessel changeouts	0	0

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

Summary of Co-Contaminants Detected in Effluent		
Average tritium concentration (pCi/L)	1,210	1,308
Average nitrate concentration (µg/L)	24,475	22,888
Average strontium-90 concentration (pCi/L)	1.8	<1.6
Average carbon-14 concentration (pCi/L)	270	241.7
Average trichloroethene concentration (µg/L)	3.0	3.0
Average total chromium concentration (µg/L)	3.8	3.4
Summary of System Availability		
Total possible run time (hours)	8,760	8,760
Total time online (hours)	8,632	8,714
Total availability (%)*	98.5	99.5

*Total availability is calculated as [(total time online) ÷ (total possible run time)].

Cr(VI) = hexavalent chromium

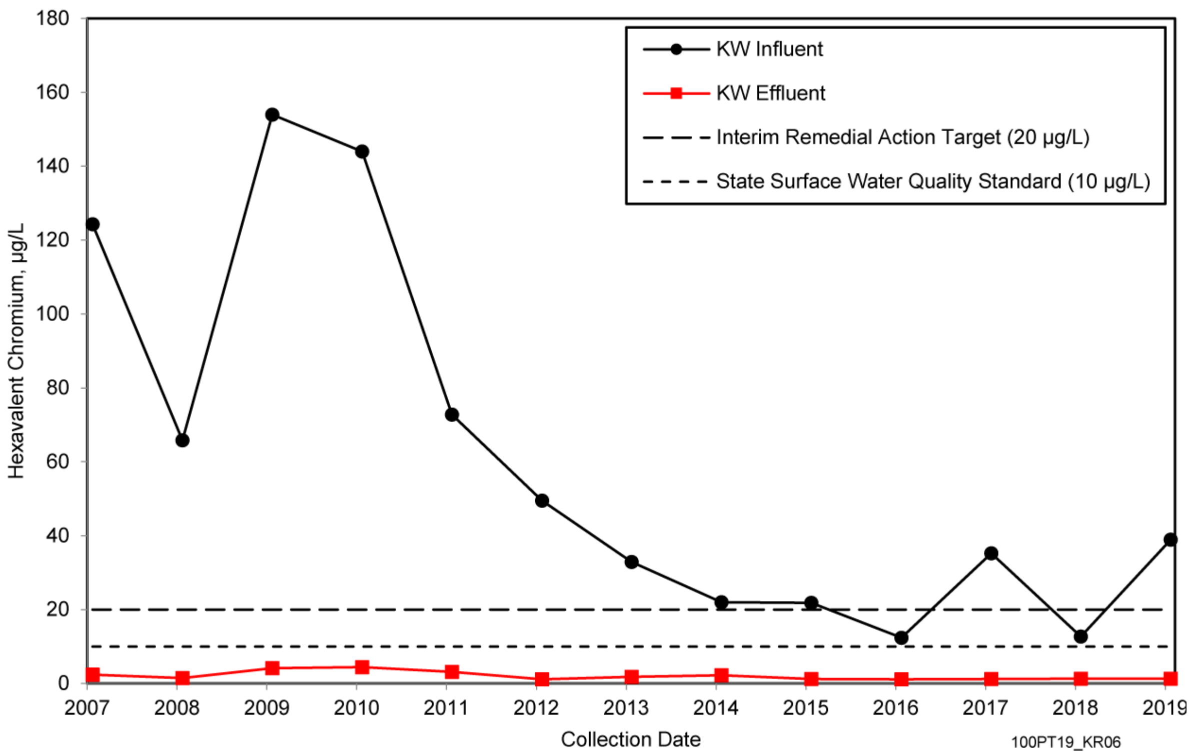


Figure 3-10. KW P&T System Annual Average Influent and Effluent Concentrations

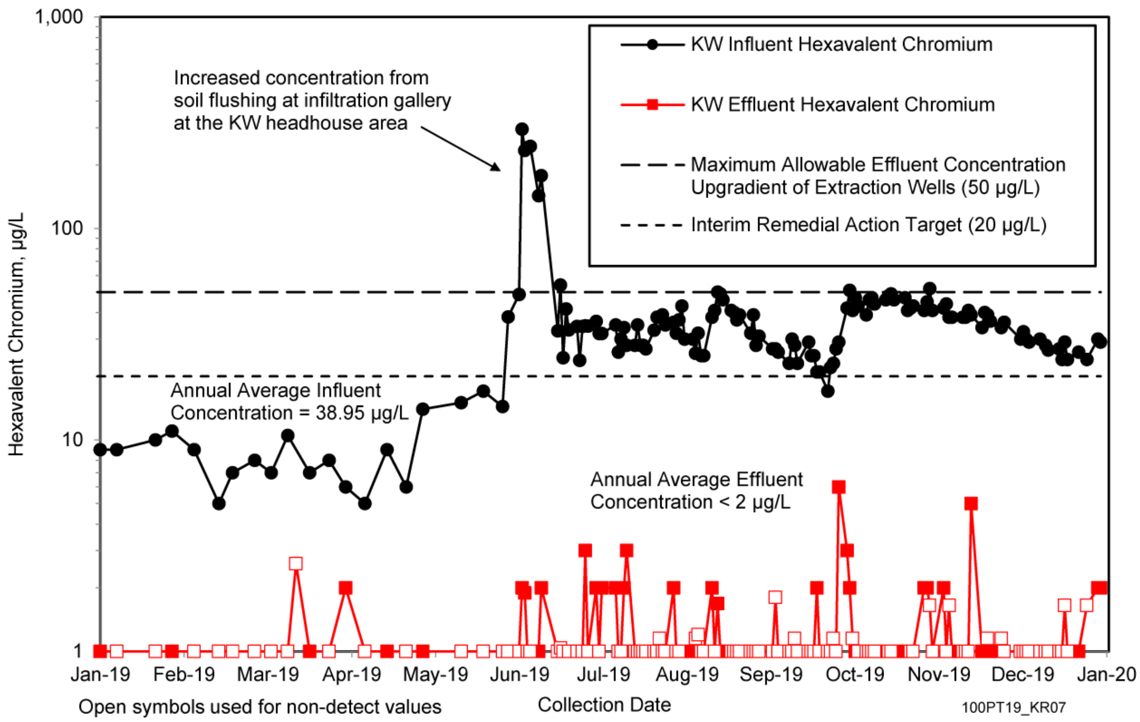


Figure 3-11. KW P&T System Trends for Influent and Effluent Cr(VI) Concentrations, 2019

Table 3-5 presents the pumping flow rates and total run-time percentage for each extraction and injection well connected to the KW P&T system during 2019. Wells that supported the KW soil flushing treatability test were subject to downtime in 2019. Well 199-K-205 was disconnected from the P&T system when construction and installation of the infiltration gallery occurred between February and April. The KW P&T system injection wells were all offline as planned when the infiltration gallery was in use. Beginning in September 2019, injection wells 199-K-174 and 199-K-206 were used in conjunction with the infiltration to control the flow of water and potentially increase the amount of Cr(VI) captured at well 199-K-205. Figure 3-12 shows the monthly online availability for the KW P&T system for 2019. Overall, the KW P&T system remained operational throughout the 2019.

Table 3-5. Flow Rates and Total Run Times for KW P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
C6452	199-K-166	WE6	175.4 (46.3)	8,760	100	Extraction
C6451	199-K-165	WE7	171.3 (45.2)	8,760	100	Extraction
C5112	199-K-137	WE8	64.3 (17)	8,760	100	Extraction
C7696	199-K-196	WE9	102.4 (27)	8,232	94[b]	Extraction
C8292	199-K-205	WE11	372 (98.2)	6,720	77[c]	Extraction
C9596	199-K-224	WE13	232.6 (61.4)	8,664	99	Extraction
C5484	199-K-158	WJ1	342.2 (90.4)	4,392	50[d]	Injection
C8293	199-K-206	WJ2	362.6 (95.7)	6,960	79[d]	Injection

Table 3-5. Flow Rates and Total Run Times for KW P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2019	Total Run Time[a] (%)	Purpose (Well Maintenance Footnotes)
C7061	199-K-174	WJ3	185.3 (48.9)	6,960	79[d]	Injection
C7062	199-K-175	WJ4	187.5 (49.5)	4,416	50[d]	Injection

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

b. Well had reduced run times due to communication issues.

c. Well 199-K-205 was disconnected between February and April 2019 to support construction activities associated with the KW infiltration gallery.

d. Reduced run time in support of the KW soil flushing treatability test.

ID = identification

PLC = programmable logic controller

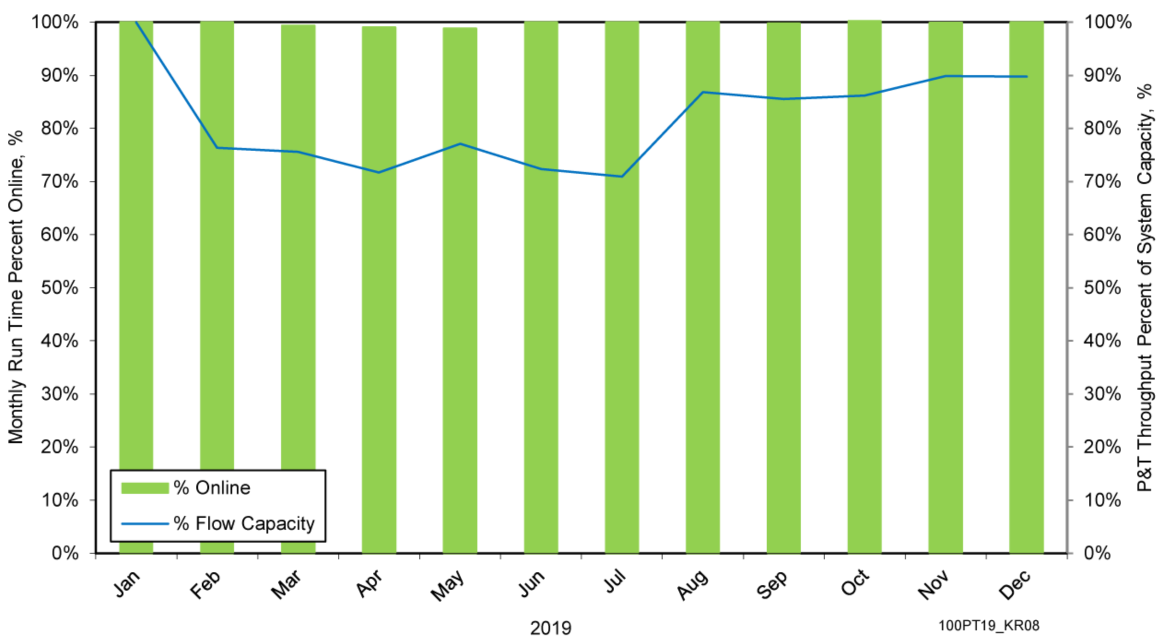


Figure 3-12. Monthly KW P&T System Availability, 2019

Co-contaminants including carbon-14, nitrate, strontium-90, tritium, and TCE were detected in the effluent from the KW P&T system during 2019. Table 3-4 lists the annual average concentrations for each co-contaminant. In 2019, the annual average co-contaminant concentrations were similar to those observed in 2018. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system. All effluent concentrations were less than their respective DWSs.

3.2.3 KX Pump and Treat System

The KX P&T system was primarily designed to treat Cr(VI) between the northern end of the 116-K-2 Trench and the N Reactor fence line (also known as the K North plume) (Figure 3-1). However, in its current well configuration, the KX P&T system is used to remediate the inland portions of the remaining Cr(VI) that are 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 183.1KE Headhouse; the central plume segment from the 116-K-2 Trench; and the northeastern portion of the 116-K-2 Trench, which extends into the 100-N Area. This system began partial operation in November 2008 and was fully operational in early February 2009. Since startup, the KX P&T system has treated >14 billion L (3.7 billion gal) of water and removed about 323 kg 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 3,400 L/min (900 gal/min). At the end of 2019, the KX P&T system included 22 extraction wells and 10 injection wells (Figure 3-13). Modifications to the KX P&T system during 2019 include the following:

- KX extraction well 199-K-141 was disconnected, and well 199-K-234 was connected.
- At KX P&T system transfer building #2, selected polyvinyl chloride (PVC) components were replaced with stainless steel. The modifications were designed to enhance system performance and reliability.

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 2019. Groundwater was processed at an annual average pumping rate of 3,405 L/min (899 gal/min) during 2019, and the overall run time was 99.6%.

Similar to 2018, the average Cr(VI) concentration in KX P&T system influent for 2019 was 16.2 µg/L, ranging from 10 to 26 µg/L (Figures 3-14 and 3-15). The maximum Cr(VI) concentration observed in system effluent during 2019 was 5 µg/L, and the average was <2 µg/L. Additional operational and system parameters for the KX P&T system for 2019 are as follows:

- A total of 1,786 million L (472 million gal) of groundwater was treated, and 27 kg of Cr(VI) were removed.
- The average mass removal efficiency was 89.3%, which is a slight decrease from 2018 (Table 3-6).

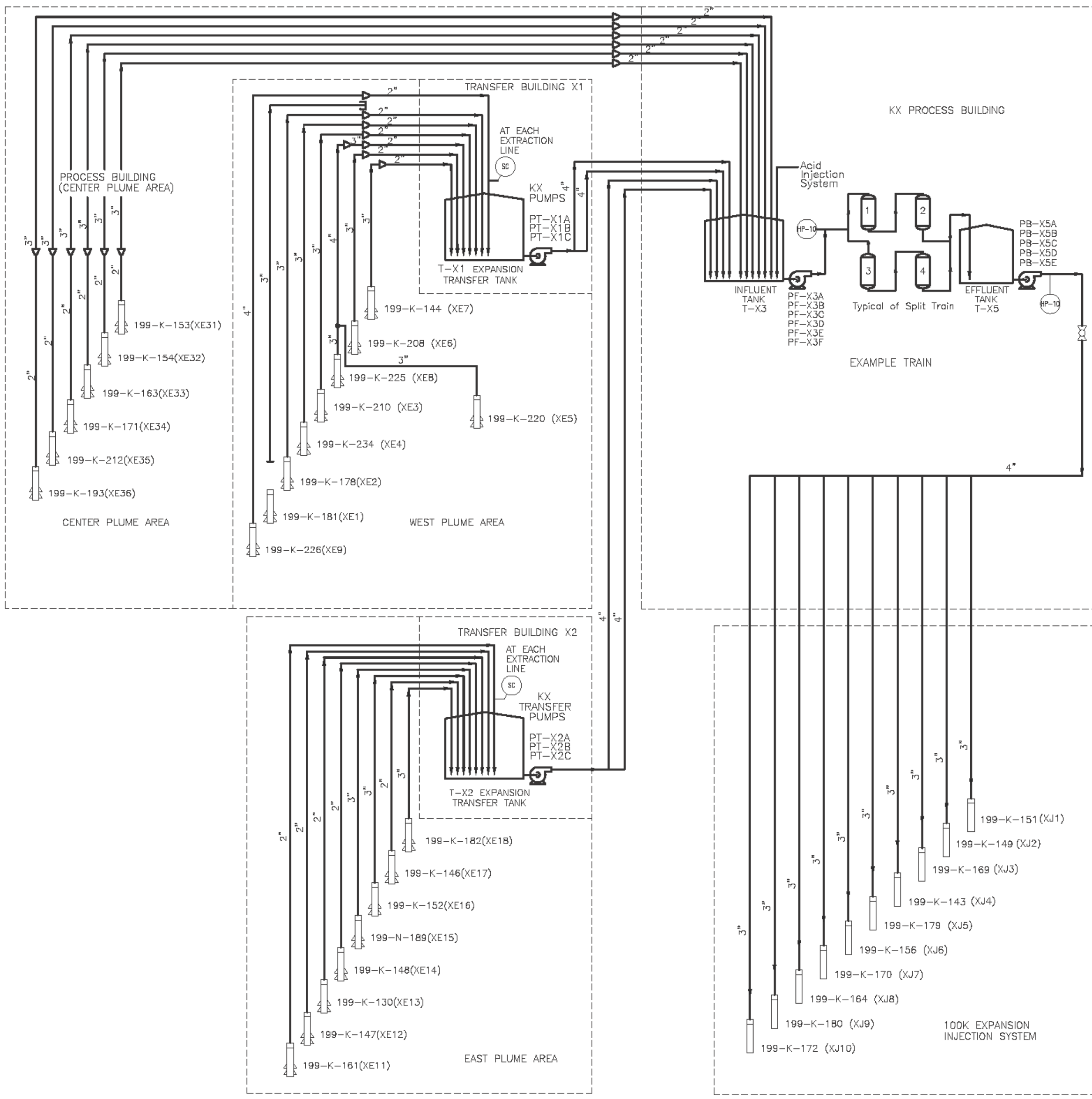


Figure 3-13. KX P&T System Schematic (as of December 31, 2019)

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

Total Processed Groundwater	2018	2019
Total groundwater treated since November 2008 startup (million L)	12,004	14,064
Total groundwater treated in calendar year (million L)	1,646	1,786
Mass of Cr(VI) Removed		
Total Cr(VI) removed since November 2008 startup (kg)	295.6	322.9
Total Cr(VI) removed in calendar year (kg)	26.1	27.3
Summary of Operational Parameters		
Average pumping rate (L/min)	3,142	3,405
Average Cr(VI) influent concentration (µg/L)	16.6	16.2
Average Cr(VI) effluent concentration (µg/L)	<2	<2
Removal efficiency (% by mass)	92.4	89.3
Waste generation (m^3)	22.6	24.9
Spent resin disposed (m^3)	14.5	0
New resin installed (m^3)	2.4	0
Number of resin vessel changeouts	4	0
Summary of Co-Contaminants Detected in Effluent		
Average tritium concentration (pCi/L)	4,960	3,905
Average nitrate concentration (µg/L)	15,525	14,300
Average strontium-90 concentration (pCi/L)	1.8	<1.4
Average carbon-14 concentration (pCi/L)	41.8	54.4
Average trichloroethene concentrations (µg/L)	<0.27	<0.3
Average total chromium concentration (µg/L)	4.2	<2.5
Summary of System Availability		
Total possible run time (hours)	8,760	8,760
Total time online (hours)	8,658.8	8,721.2
Total availability (%)*	98.8	99.6

*Total availability is calculated by [(total time online) ÷ (total possible run time)].

Cr(VI) = hexavalent chromium

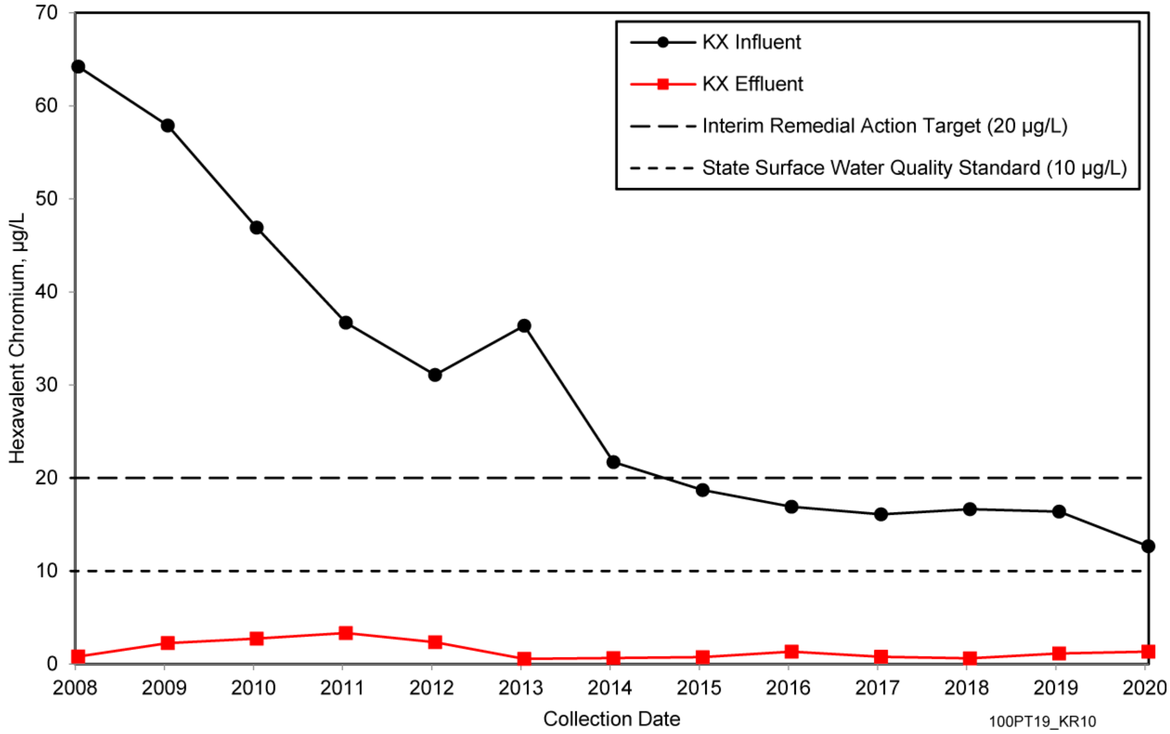
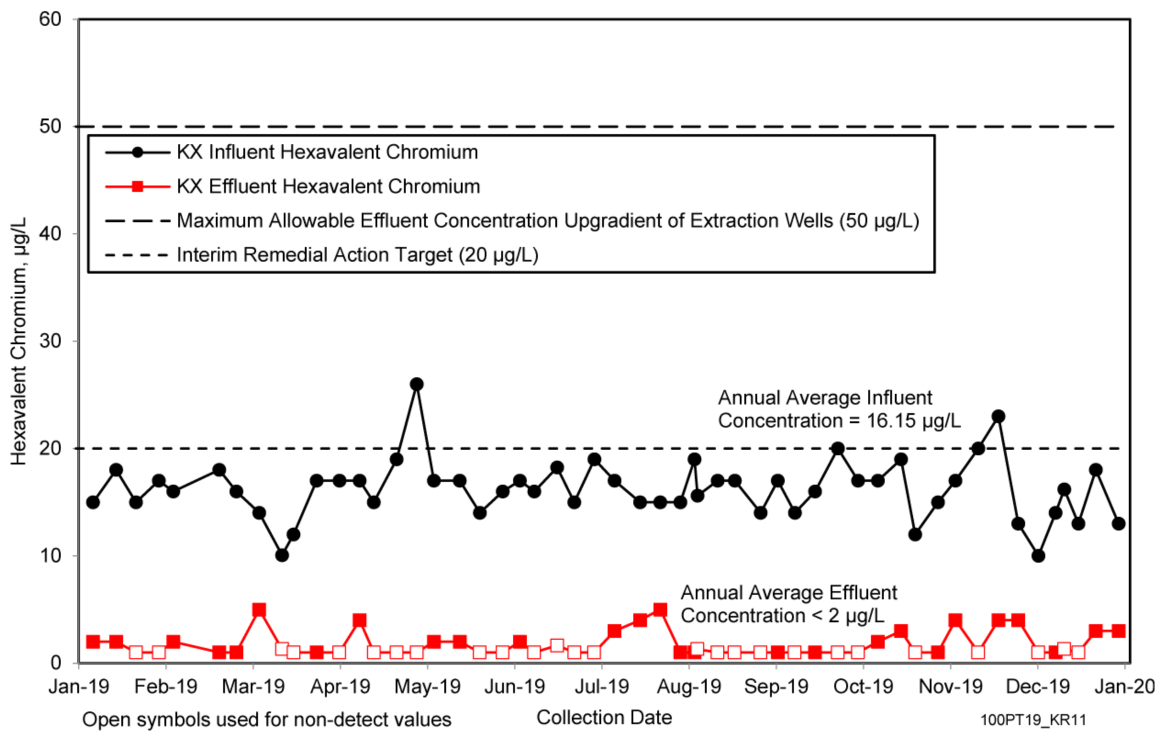


Figure 3-14. KX P&T System Annual Average Influent and Effluent Concentrations



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, 2019

Table 3-7 presents the pumping flow rates and total run-time percentage for each extraction and injection well connected to the KX P&T system during 2019. The average flow rate was calculated by dividing the total volume extracted by the hours of pumping. For the KX P&T system, all wells were subject to downtime for facility repair and/or maintenance activities during the year. The downtime is reflected in the yearly average flow rate calculations and the total run-time percentages for each extraction well.

Table 3-7. Flow Rates and Total Run Times for KX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Yearly Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2019	Total Run Time (%)[a]	Purpose (Well Maintenance Footnotes)
C7149	199-K-178	XE2	94.1 (24.8)	5,376	61.4	Extraction[b]
C8297	199-K-210	XE3	217.7 (57.5)	8,760	100	Extraction
C5303	199-K-141[c]	XE4	58.5 (15.5)	1,200	100	Extraction
C9922	199-K-234[c]	XE4	223.3 (59.0)	6,543	99.5	Extraction
C8795	199-K-220	XE5	242.6 (64)	7,200	82.2[d]	Extraction
C8295	199-K-208	XE6	142.9 (37.7)	8,760	100	Extraction
C5360	199-K-144	XE7	216.9 (57.3)	8,760	100	Extraction
C9597	199-K-225	XE8	222.6 (58.8)	552	6.3[d]	Extraction
C9598	199-K-226	XE9	428 (113)	8,760	100	Extraction
C5939	199-K-161	XE11	78.7 (20.8)	8,712	99.5	Extraction
C5363	199-K-147	XE12	68.9 (18.2)	8,712	99.5	Extraction
C4120	199-K-130	XE13	79.7 (21)	8,712	99.5	Extraction
C5364	199-K-148	XE14	105.4 (27.8)	6,000	68.5	Extraction[b]
C7689	199-N-189	XE15	119.2 (31.5)	8,688	99.2	Extraction
C5368	199-K-152	XE16	137.5 (36.3)	8,712	99.5	Extraction
C5362	199-K-146	XE17	31 (8.2)	8,712	99.5	Extraction
C7476	199-K-182	XE18	226.6 (59.8)	8,688	99.2	Extraction
C5369	199-K-153	XE31	154.2 (40.7)	8,136	92.9	Extraction
C5370	199-K-154	XE32	196.3 (51.8)	8,760	100	Extraction
C6172	199-K-163	XE33	173.6 (45.8)	8,448	96.4	Extraction
C6746	199-K-171	XE34	174.1 (46)	8,760	100	Extraction
C8299	199-K-212	XE35	172.7 (45.6)	8,760	100	Extraction
C7693	199-K-193	XE36	284.1 (75)	8,760	100	Extraction
C5367	199-K-151	XJ1	244.8 (64.6)	8,760	100	Injection
C5365	199-K-149	XJ2	244.8 (64.6)	8,760	100	Injection
C6744	199-K-169	XJ3	574.4 (151.6)	8,760	100	Injection
C5305	199-K-143	XJ4	283.1 (74.7)	8,760	100	Injection
C7150	199-K-179	XJ5	339.8 (89.7)	8,760	100	Injection
C5372	199-K-156	XJ6	382.9 (101.1)	8,760	100	Injection

Table 3-7. Flow Rates and Total Run Times for KX P&T System Extraction and Injection Wells, 2019

Well ID	Well Name	PLC ID	Yearly Average Flow Rate (L/min [gal/min])	Total Flow Hours in 2019	Total Run Time (%)[a]	Purpose (Well Maintenance Footnotes)
C6745	199-K-170	XJ7	542.1 (143.1)	8,760	100	Injection
C6386	199-K-164	XJ8	244.8 (64.6)	8,760	100	Injection
C7151	199-K-180	XJ9	245.2 (64.7)	8,760	100	Injection
C6747	199-K-172	XJ10	278 (73.4)	8,760	100	Injection

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

b. Well pump replaced.

c. The flow rate and run time are based on the amount of time the well was available for operation; well 199-K-141 operated between January 1, 2019, and February 20, 2019. Well 199-K-234 began operating on April 2, 2019, and continued through the end of 2019.

d. Run time was impacted by realignment activities at wells 199-K-141 and 199-K-234.

ID = identification

PLC = programmable logic controller

Figure 3-16 shows the monthly online availability for the KX P&T system for 2019. As discussed in Section 3.2.3.1, to support facility maintenance and repair activities, flows to various injection and extraction wells were reduced, but the overall system remained online. Maintenance and repair activities were primarily planned events. The most notable event, not part of normal facility maintenance checks, was the stainless-steel upgrade to various components at transfer building #2.

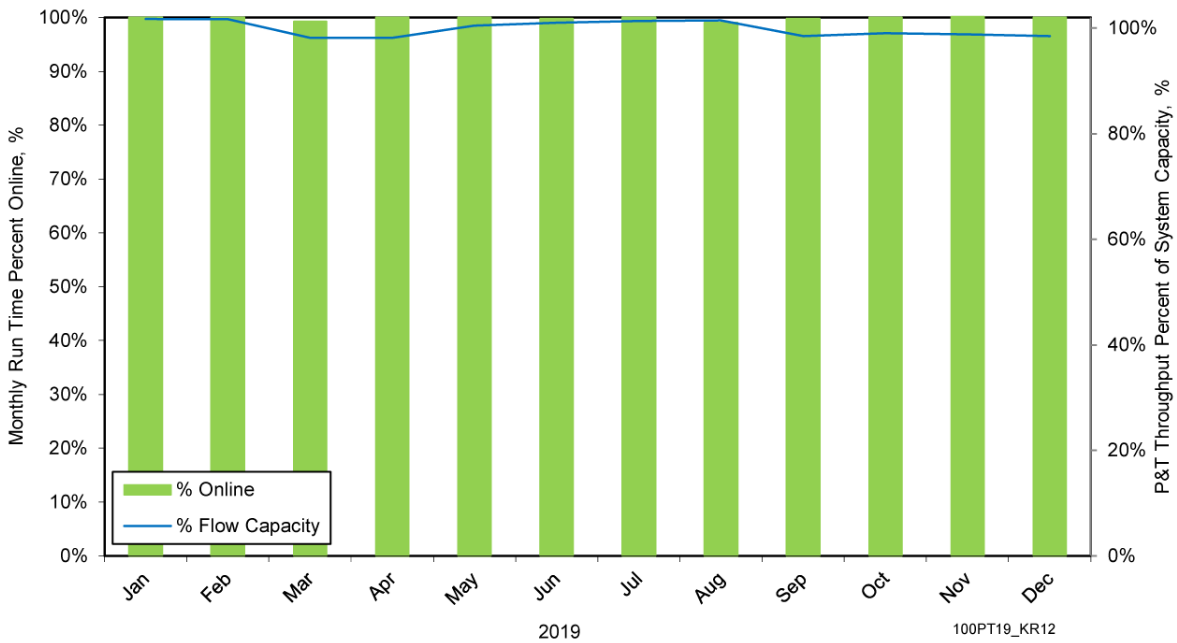


Figure 3-16. Monthly KX P&T System Availability, 2019

Co-contaminants including carbon-14, nitrate, strontium-90, tritium, and TCE were detected in the effluent from the KX P&T system during 2019. Table 3-6 lists the annual average concentrations for each co-contaminant. In 2019, the annual average co-contaminant concentrations were similar to those observed in 2018. These contaminants are unaffected by the SIR-700 resin treatment system and, therefore, pass through the system. All effluent concentrations were less than their respective DWSs.

3.2.4 Performance Monitoring

Removal of Cr(VI) and protection of the river are the principal objectives for the 100-KR-4 OU interim remedial action. Strontium-90 and tritium are listed as co-contaminants in the 100-KR-4 OU interim action ROD (EPA/ROD/R10-96/134) and are monitored as part of the remedial action. The ROD acknowledges that the interim action remedy does not treat co-contaminants. The groundwater COCs identified in the 100-K Area FS (DOE/RL-2018-22, Draft B) are chromium (total and Cr(VI)), 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 to evaluate the effectiveness of ongoing remedial activities. Particular emphasis is given to data collected during the fall of each year when the river stage is low, leading to steeper groundwater gradients toward the river and higher contaminant flux toward the river. The focus is on evaluating the analytical results for Cr(VI) being remediated through the interim action P&T systems. Chapter 5 in the 2019 annual groundwater report (DOE/RL-2019-66) presents summary and analysis information for the other contaminants of potential concern.

Tables 3-8 and 3-9 present the high and low river-stage monitoring results for Cr(VI) during 2019. Figures 3-3 and 3-4 show the Cr(VI) plumes during periods of high and low river stages during 2019 for the 100-KR-4 OU. The contaminant plume maps presented herein are based on average results for samples collected either during the low or high river stage during 2019 for each well shown on the maps. The plume maps, data summary tables, and a summary of notable data observations are presented in the following sections. Methods for generating contaminant plume representations are described in ECF-HANFORD-20-0018.

3.2.4.1 River-Stage Effects

The Columbia River is the discharge boundary for groundwater in the unconfined aquifer underlying the Hanford Site. Groundwater flows toward the river at a rate defined by the hydraulic gradient, which varies in response to seasonal and diurnal changes in river stage and P&T operations. The 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 during 2019 was from mid-April to the end of June (Figure 3-17). This pattern is typical for the Hanford Site; however, the high river stage in 2019 at the peak in May was about 2.5 m (8.2 ft) lower than the high river stage observed in 2018. Low river stage in 2019 occurred in August through late December, which is typical. In 2019, the lowest river stage observed in 100-K Area was 116.6 m (382.5 ft), occurring in late September and early October. The March 2019 water table map (Figure 3-18) represents transitional and moderate river-stage conditions. Figures 3-3 and 3-4 include representative water table contours for both high and low river stages.

Table 3-8. Cr(VI) Maximum Concentrations in the KW Reactor Area Plume, 2019

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-106A	M	—	—	11/22/2019	6.43	11/22/2019	6.43
199-K-107A	M	5/3/2019	9.34	8/16/2019	7.85	5/3/2019	9.34
199-K-108A	M	—	—	11/15/2019	3.71	11/15/2019	3.71
199-K-132	M, C	4/29/2019	16	8/14/2019	21.9	8/14/2019	21.9
199-K-137	E-KW	6/3/2019	19	9/11/2019	33	9/11/2019	33
199-K-138	M, C	4/29/2019	10.2	8/14/2019	11.4	8/14/2019	11.4
199-K-139	M	4/29/2019	8.88	11/22/2019	10.4	11/22/2019	10.4
199-K-140	M	4/29/2019	8.01	11/21/2019	38.7	11/21/2019	38.7
199-K-165	E-KW	7/1/2019	6	12/18/2019	13	12/18/2019	13
199-K-166	E-KW	7/11/2019	76	8/7/2019	99	8/7/2019	99
199-K-168	M	4/29/2019	8.51	11/22/2019	16.2	11/22/2019	16.2
199-K-183	M	4/24/2019	6.42	11/15/2019	25.2	11/15/2019	25.2
199-K-184	M	—	—	11/15/2019	10.3	11/15/2019	10.3
199-K-185	M	4/29/2019	4.68	8/14/2019	9.46	8/14/2019	9.46
199-K-196	E-KW	6/3/2019	15	8/7/2019	14	4/1/2019	15
199-K-204	M	4/29/2019	5.05	8/14/2019	7.83	8/14/2019	7.83
199-K-205[c]	E-KW	6/4/2019	882	8/14/2019	111	6/4/2019	882
199-K-223	M	6/12/2019	10.3	8/14/2019	31.3	8/14/2019	31.3
199-K-224	E-KW	7/1/2019	9	12/18/2019	16	12/18/2019	16
199-K-229	M	4/30/2019	1.3(U)	8/23/2019	2.32	8/23/2019	2.32
199-K-230	M	4/30/2019	5.02	8/23/2019	9.21	8/23/2019	9.21
199-K-235	M	6/3/2019	14.1	8/23/2019	12	6/3/2019	14.1
199-K-236[c]	M	5/31/2019	1,700	12/3/2019	82	5/31/2019	1,700

Table 3-8. Cr(VI) Maximum Concentrations in the KW Reactor Area Plume, 2019

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-31	M	4/24/2019	7.04	8/12/2019	8.95	8/12/2019	8.95
199-K-34	M	5/3/2019	10.7	8/16/2019	10.4	5/3/2019	10.7
Aquifer Tube Sampling							
17-D	M	—	—	9/12/2019	4.32	9/12/2019	4.32
17-M	M	—	—	9/12/2019	1.3(U)	9/12/2019	1.3(U)
AT-K-1-D	M	—	—	9/11/2019	1.3(U)	9/11/2019	1.3(U)
AT-K-1-M	M	—	—	9/11/2019	1.3(U)	9/11/2019	1.3(U)
AT-K-1-S	M	—	—	9/11/2019	1.3(U)	9/11/2019	1.3(U)
C6236	M	—	—	9/11/2019	7.91	9/11/2019	7.91
C6237	M	—	—	9/11/2019	5.41	9/11/2019	5.41
C6238	M	—	—	9/11/2019	5.26	9/11/2019	5.26
C6239	M	—	—	9/16/2019	1.3(U)	9/16/2019	1.3(U)
C6240	M	—	—	9/16/2019	1.76	9/16/2019	1.76
C6241	M	—	—	9/16/2019	7.08	9/16/2019	7.08
C7641	M	—	—	9/12/2019	1.3(U)	9/12/2019	1.3(U)
C7642	M	—	—	9/12/2019	2.48	9/12/2019	2.48
C7643	M	—	—	9/12/2019	1.48	9/12/2019	1.48

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

a. High river stage represents the period from April 1 to July 15. Low river stage represents the period from August 15 to December 31.

b. Well use: C = compliance, E-KW = KW extraction, and M = monitoring.

c. Identified wells are located near the soil flushing treatability test area. Elevated Cr(VI) concentrations were observed during the test..

— = sample was not collected or analysis was not performed

Cr(VI) = hexavalent chromium

P&T = pump and treat

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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	—	—	11/19/2019	4.8	11/19/2019	4.8
199-K-110A	M	4/25/2019	12.4	11/15/2019	12.8	11/15/2019	12.8
199-K-111A	M	5/1/2019	368	8/16/2019	326	5/1/2019	368
199-K-113A	E-KR4, C	6/13/2019	13	10/10/2019	16	10/10/2019	16
199-K-114A	E-KR4, C	4/2/2019	16	10/10/2019	11	4/2/2019	16
199-K-115A	E-KR4, C	6/13/2019	4	10/10/2019	14	10/10/2019	14
199-K-116A	M, C	6/13/2019	6	12/3/2019	3	3/5/2019	7
199-K-117A	M, C	—	—	11/19/2019	3.22	11/19/2019	3.22
199-K-119A	M, C	4/24/2019	1.3(U)	8/15/2019	4.03	8/15/2019	4.03
199-K-120A	E-KR4, C	7/9/2019	3	10/10/2019	5	1/9/2019	6
199-K-125A	M, C	5/3/2019	2.1	8/15/2019	4.62	8/15/2019	4.62
199-K-126	M	—	—	11/22/2019	7.8	11/22/2019	7.8
199-K-127	E-KR4, C	6/13/2019	9	10/10/2019	4	6/13/2019	9
199-K-129	E-KR4, C	7/9/2019	21	12/17/2019	22.8	12/17/2019	22.8
199-K-13	M	6/25/2019	4.89	9/19/2019	5.08	9/19/2019	5.08
199-K-130	E-KX, C	4/8/2019	6	10/10/2019	7	1/3/2019	8
199-K-133	M	—	—	11/22/2019	1.3(U)	11/22/2019	1.3(U)
199-K-134	M	—	—	11/22/2019	1.3(U)	11/22/2019	1.3(U)
199-K-135	M	—	—	11/22/2019	1.3(U)	11/22/2019	1.3(U)
199-K-136	M	—	—	11/22/2019	1.3(U)	11/22/2019	1.3(U)
199-K-141	M, C	—	—	11/22/2019	24.7	1/3/2019	29
199-K-142	M	—	—	11/22/2019	9.84	11/22/2019	9.84

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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-KX, C	5/22/2019	14.1	10/10/2019	18	1/3/2019	21
199-K-145	E-KR4, C	4/2/2019	8	10/10/2019	6	3/5/2019	11
199-K-146	E-KX, C	5/1/2019	16	12/9/2019	24	12/9/2019	24
199-K-147	E-KX, C	6/11/2019	16	11/19/2019	9	6/11/2019	16
199-K-148	E-KX, C	5/1/2019	6	11/14/2019	3.13	5/1/2019	6
199-K-152	E-KX, C	6/11/2019	19	10/10/2019	23	1/3/2019	25
199-K-153	E-KX	6/11/2019	12	10/10/2019	12	10/10/2019	12
199-K-154	E-KX	7/3/2019	21	10/10/2019	18	7/3/2019	21
199-K-157	M	—	—	11/25/2019	1.39	11/25/2019	1.39
199-K-161	E-KX, C	4/8/2019	28	10/10/2019	27	4/8/2019	28
199-K-162	E-KR4, C	6/13/2019	5	10/10/2019	4	6/13/2019	5
199-K-163	E-KX	5/1/2019	9	11/14/2019	2.76	5/1/2019	9
199-K-171	E-KX, C	7/3/2019	6	11/19/2019	12	11/19/2019	12
199-K-178	E-KX, C	7/3/2019	17	8/8/2019	17	8/8/2019	17
199-K-18	M, C	—	—	11/13/2019	2.4	11/13/2019	2.4
199-K-181	M, C	5/3/2019	10.1	8/16/2019	6.04	5/3/2019	10.1
199-K-182	E-KX, C	4/8/2019	20	9/10/2019	21	9/10/2019	21
199-K-186	M	4/25/2019	9.78	11/15/2019	18.1	11/15/2019	18.1
199-K-187	M	—	—	11/13/2019	5.72	11/13/2019	5.72
199-K-188	M	4/25/2019	15.4	11/18/2019	10.9	4/25/2019	15.4
199-K-189	M	5/3/2019	7.72	8/23/2019	8.96	8/23/2019	8.96
199-K-19	M, C	4/24/2019	1.82	8/12/2019	5.26	8/12/2019	5.26

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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-190	M	5/3/2019	7.32	8/16/2019	6.14	5/3/2019	7.32
199-K-191	M	—	—	11/13/2019	2.7	11/13/2019	2.7
199-K-192	M	—	—	11/13/2019	7.12	11/13/2019	7.12
199-K-193	E-KX	4/8/2019	37	10/10/2019	32	1/3/2019	47
199-K-194	M	—	—	11/25/2019	3.14	11/25/2019	3.14
199-K-197	M	—	—	11/25/2019	1.3(U)	11/25/2019	1.3(U)
199-K-198	E-KR4, C	4/2/2019	18	10/10/2019	9	4/2/2019	18
199-K-199	E-KR4, C	5/28/2019	7	11/13/2019	3.09	5/28/2019	7
199-K-20	M, C	4/24/2019	1.3(U)	8/12/2019	2.64	8/12/2019	2.64
199-K-200	M	4/24/2019	1.85	8/15/2019	5.21	8/15/2019	5.21
199-K-201	M	5/3/2019	11.1	8/20/2019	12.2	8/20/2019	12.2
199-K-202	M	4/30/2019	13	8/23/2019	12.4	4/30/2019	13
199-K-203	M	4/30/2019	9.15	11/15/2019	10.5	11/15/2019	10.5
199-K-207	M	5/1/2019	73.8	8/14/2019	80.5	8/14/2019	80.5
199-K-208	E-KX, C	4/8/2019	9	10/10/2019	9	10/10/2019	9
199-K-209	M	—	—	11/26/2019	3.96	11/26/2019	3.96
199-K-21	M	5/1/2019	1.3(U)	8/13/2019	8	8/13/2019	8
199-K-210	E-KX, C	4/8/2019	19	10/10/2019	19	10/10/2019	19
199-K-212	E-KX, C	5/1/2019	8	11/14/2019	5.67	5/1/2019	8
199-K-22	M	5/1/2019	3.95	8/13/2019	7.44	8/13/2019	7.44
199-K-220	E-KX	4/8/2019	24	10/10/2019	20	1/3/2019	25
199-K-221	M	5/3/2019	9.38	8/23/2019	7.53	5/3/2019	9.38

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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-222	M	5/3/2019	7.86	8/23/2019	7.88	8/23/2019	7.88
199-K-225	E-KX	—	—	12/19/2019	12	12/19/2019	12
199-K-226	E-KX	5/22/2019	20.7	10/10/2019	25	10/10/2019	25
199-K-227	M	4/30/2019	7.82	8/13/2019	12.7	8/13/2019	12.7
199-K-228	M	4/30/2019	10.6	11/26/2019	15.3	11/26/2019	15.3
199-K-231	M	4/24/2019	15.2	8/13/2019	17.7	8/13/2019	17.7
199-K-232	M	5/3/2019	5.63	8/20/2019	4	5/3/2019	5.63
199-K-234	E-KX	7/3/2019	24	10/10/2019	29	10/10/2019	29
199-K-32A	M, C	—	—	11/22/2019	11.8	11/22/2019	11.8
199-K-32B	M	—	—	11/22/2019	6.59	11/22/2019	6.59
199-K-36	M	4/25/2019	446	8/13/2019	196	4/25/2019	446
199-K-37	M	—	—	11/13/2019	15.2	11/13/2019	15.2
699-73-61	M	—	—	10/31/2019	3.09	10/31/2019	3.09
699-78-62	M	—	—	11/1/2019	1.3(U)	11/1/2019	1.3(U)
Aquifer Tube Sampling							
18-S	M	—	—	11/4/2019	1.3(U)	11/4/2019	1.3(U)
19-M	M	—	—	9/17/2019	1.3(U)	9/17/2019	1.3(U)
21-M	M	—	—	9/18/2019	1.3(U)	9/18/2019	1.3(U)
22-D	M	4/29/2019	22.4	11/7/2019	36	11/7/2019	36
22-M	M	4/29/2019	1.45	11/7/2019	1.3(U)	3/25/2019	3
23-M	M	—	—	11/5/2019	1.47	11/5/2019	1.47
AT-K-2-D	M	—	—	9/17/2019	1.83	9/17/2019	1.83

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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)
AT-K-2-M	M	—	—	9/17/2019	1.54	9/17/2019	1.54
AT-K-2-S	M	—	—	9/17/2019	1.63	9/17/2019	1.63
AT-K-3-D	M	4/15/2019	30.3	10/21/2019	31.2	10/21/2019	31.2
AT-K-3-M	M	4/15/2019	20.5	10/21/2019	17.6	4/15/2019	20.5
AT-K-3-S	M	4/15/2019	4.04	10/21/2019	3.42	4/15/2019	4.04
AT-K-4-M	M	—	—	9/19/2019	1.37	9/19/2019	1.37
AT-K-4-S	M	—	—	9/19/2019	1.82	9/19/2019	1.82
AT-K-5-D	M	—	—	9/24/2019	4.6	9/24/2019	4.6
AT-K-5-M	M	—	—	9/24/2019	3.7	9/24/2019	3.7
AT-K-5-S	M	—	—	9/24/2019	2.59	9/24/2019	2.59
C6242	M	—	—	9/16/2019	2.23	9/16/2019	2.23
C6243	M	—	—	9/16/2019	2.35	9/16/2019	2.35
C6244	M	—	—	9/16/2019	2.44	9/16/2019	2.44
C6245	M	—	—	9/19/2019	1.92	9/19/2019	1.92
C6246	M	—	—	9/19/2019	2.59	9/19/2019	2.59
C6247	M	—	—	9/19/2019	1.79	9/19/2019	1.79
C6248	M	—	—	9/17/2019	1.3(U)	9/17/2019	1.3(U)
C6249	M	—	—	9/17/2019	2.14	9/17/2019	2.14
C6250	M	—	—	9/17/2019	2.28	9/17/2019	2.28
C6251	M	—	—	9/18/2019	2.89	9/18/2019	2.89
C6252	M	—	—	9/18/2019	3.28	9/18/2019	3.28
C6253	M	—	—	9/18/2019	3.91	9/18/2019	3.91

Table 3-9. Cr(VI) Maximum Concentrations in the KE Reactor Area and 116-K-2 Trench Area Plume, 2019

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)
C6254	M	—	—	9/18/2019	2.24	9/18/2019	2.24
C6255	M	—	—	9/18/2019	6.68	9/18/2019	6.68
C6256	M	—	—	9/18/2019	20	9/18/2019	20
C6258	M	—	—	9/19/2019	5.19	9/19/2019	5.19
C6259	M	—	—	9/19/2019	1.47	9/19/2019	1.47
C6260	M	—	—	9/24/2019	1.78	9/24/2019	1.78
C6261	M	—	—	9/24/2019	1.74	9/24/2019	1.74
DK-04-3	M	—	—	—	—	—	—

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

a. High river stage represents the period from April 1 through July 15. Low river stage represents the period from August 15 through December 31.

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

— = sample was not collected or analysis was not performed

Cr(VI) = hexavalent chromium

P&T = pump and treat

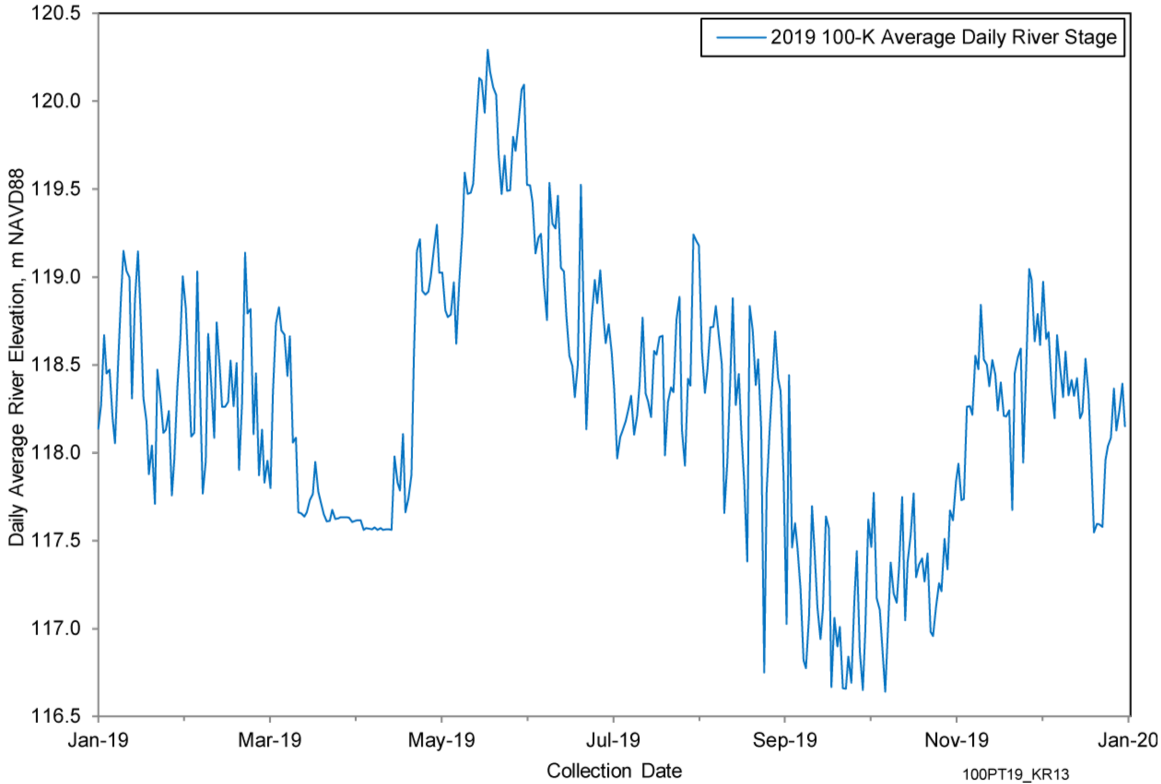


Figure 3-17. Columbia River-Stage Elevation at the 100-KR-4 OU, 2019 (Derived from Priest Rapids Dam Water Elevation Data)

During high river stage, river water may intrude into the aquifer and cause displacement and/or dilution of the aquifer water in the nearshore environment. 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 migration of river water into the aquifer due to capture by extraction wells (Figure 3-19). During 2019, well 199-K-114A exhibited specific conductance measurements consistently <200 µS/cm, indicating that the samples were primarily river water (the Columbia River exhibits low specific conductance). Specific conductance of 400 µS/cm (or greater) is typical for groundwater. Thus, specific conductance of 200 to 400 µS/cm likely indicates mixing of groundwater with river water to varying degrees. In 2019, extraction wells 199-K-113A, 199-K-115A, and 199-K-146 had specific conductance <300 µS/cm, suggesting that these wells were extracting an increased fraction of river water versus groundwater. In contrast, the specific conductance in all K East nearshore extraction wells (i.e., 199-K-144 and 199-K-210) exhibited specific conductance >300 µS/cm, which suggests that a higher fraction of groundwater is being extracted.

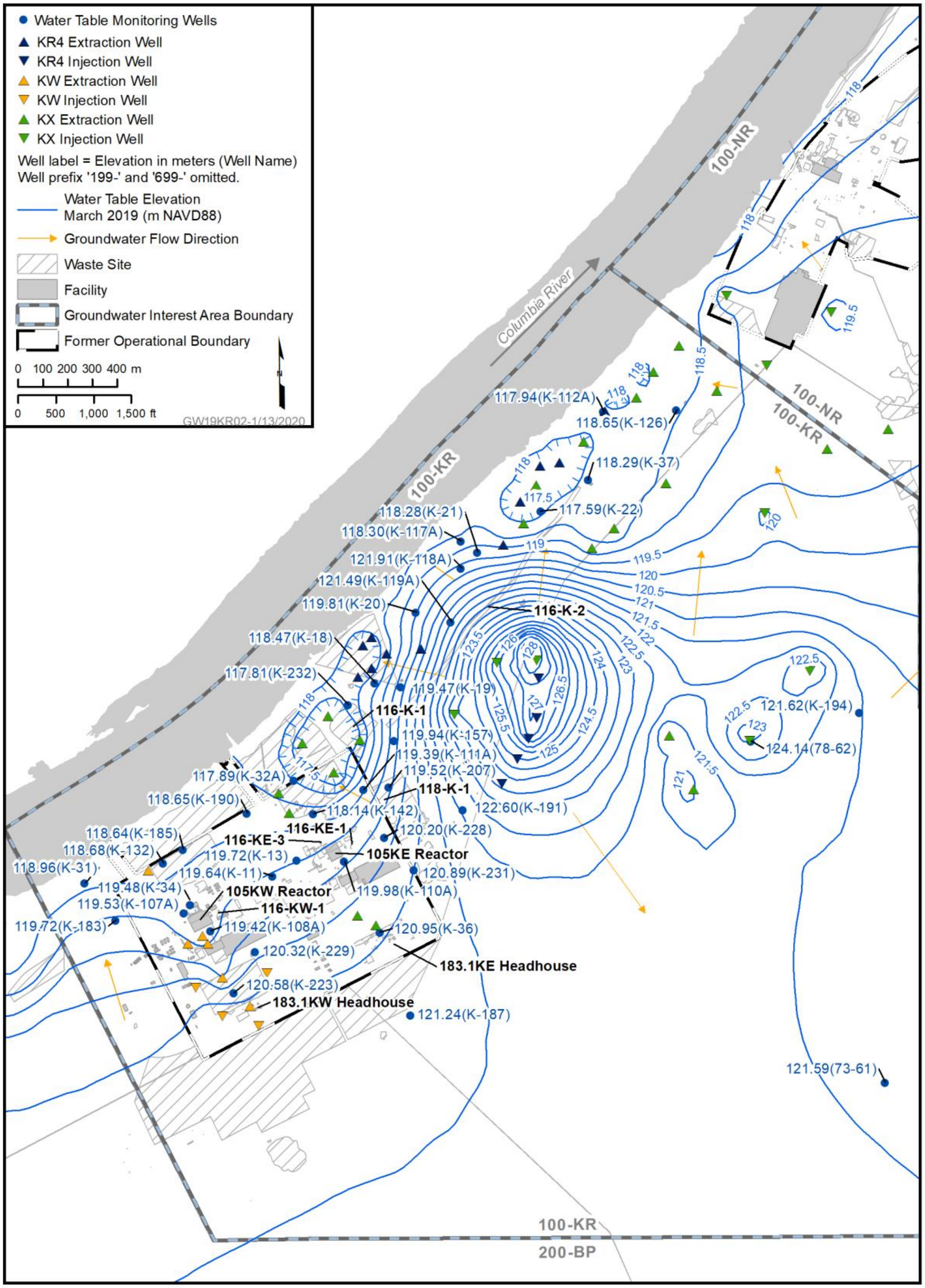


Figure 3-18. Groundwater Elevation Contour Map, March 2019

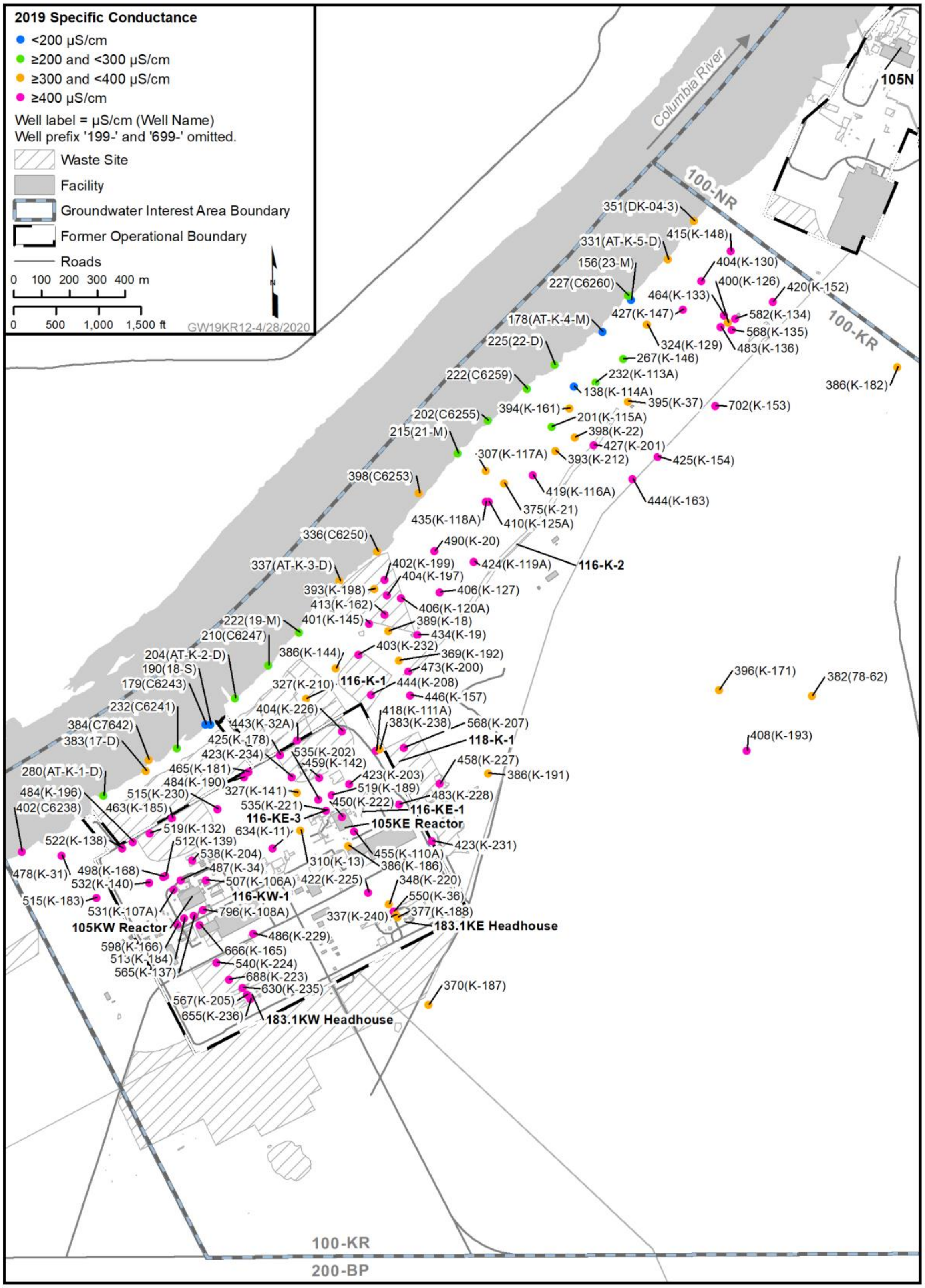


Figure 3-19. Plot of Groundwater Specific Conductance Relative to the Columbia River, 2019

3.2.4.2 Hexavalent Chromium Plumes

This section presents the 100-K Cr(VI) plumes for geographic areas designated as K West, K East, K North, and K-N Boundary based on the groundwater distribution (Figure 3-1). The Cr(VI) plume designations (as discussed in the following sections) were modified from the 2018 P&T report (DOE/RL-2018-67) to align with the current 100-K Area RI (DOE/RL-2010-97) and FS (DOE/RL-2018-22). In general, the K West plume originates near the 183.1KW Headhouse an extends downgradient toward the Columbia River. The K East plume originates near the 183.1KE Headhouse and extends downgradient toward the Columbia River. One part of the K East plume is downgradient and west of the process facilities centerline, while another part diverges to the northeast and combines with the Cr(VI) at the southwestern end of the 116-K-2 Trench. The K North and the K-N Boundary plumes encompass the northern portion of the 116-K-2 Trench and inland areas between the 100-KR-4 and 100-NR-2 OUs.

The 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 in K West is remediated by the KW P&T system. The plume in K East is being remediated primarily by the KX P&T system (Figure 3-1). The Cr(VI) plumes located in the K North and the K-N Boundary are 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 2019 at high and low river stages, respectively.

3.2.4.2.1 K West Area

The Cr(VI) plume in K West originates from operation of the KW Reactor, supporting water treatment facilities, and associated waste sites. Historically, the K West Cr(VI) plume has been depicted as a narrow band with relatively high concentration, starting near the 183.1KW Headhouse and extending toward the Columbia River. However, P&T activities have reduced the Cr(VI) plume in size and concentration. In 2019, a soil flushing treatability test was implemented in accordance with DOE/RL-2017-30 at the 183.1KW Headhouse area to address a continuing source of groundwater contamination. The goal of soil flushing is to remove Cr(VI) from the deep portions of the vadose zone by flushing contaminant material into the groundwater, and then capturing the material with the active P&T system to remove it from the groundwater. This residual Cr(VI) contamination, which was confirmed during the rebound study performed between 2016 and 2017, continued to produce groundwater contamination above the MTCA standard of 48 µg/L (WAC 173-340) near the 183.1KW Headhouse and well 199-K-205. To support the treatability test, a near surface infiltration system was installed in an area of about 3,400 m^2 (0.85 ac) at the former 183.1KW Headhouse to evaluate the effectiveness of using soil flushing to address the continuing source of Cr(VI) in the deep vadose zone. A treatability test report (DOE/RL-2019-77) will be prepared in 2020 to document the results of the treatability test and provide recommendation for future soil flushing operations.

The treatability test was designed to be implemented in phases, as detailed in DOE/RL-2017-30. Each phase of the test operated based on the observed Cr(VI) concentrations in monitoring wells at and downgradient of the test site. Infiltration for Phase 1 of the treatability test began on May 28, 2019, with infiltration of 1,000 L/min (265 gal/min) of treated KW P&T effluent and continued until mid-August. Within 24 hours of initial startup, the effects of infiltration through the vadose zone were observed by increasing water levels at nearby monitoring wells 199-K-235 and 199-K-236. The Cr(VI) concentrations in extraction well 199-K-205 also started to increase within the first 24 hours. Within 2 to 5 days, Cr(VI) concentrations in monitoring well 199-K-236 and extraction well 199-K-205 increased from <48 µg/L to peak concentrations of 1,700 µg/L and 882 µg/L, respectively (Figure 3-20). Observed Cr(VI) concentrations declined to <48 µg/L between mid-June and August as the infiltration gallery continued to flush contaminants out of the soil column. During Phase 1, extraction well 199-K-205 operated at an average flow rate of 310 L/min (82 gal/min) due to additional fine material being flushing through the vadose zone and clogging the extraction wells filter. At the reduced rate, this clogging occurred less frequently. On August 12, 2019, the infiltration gallery was shut down, and the resulting groundwater mound created during operation dispersed. This shutdown period was used to evaluate the effectiveness of soil flushing on the residual source. Shortly after the infiltration gallery was shut down, Cr(VI) concentrations in nearby wells temporarily increased to a maximum concentration of 111 µg/L in extraction well 199-K-205 (Figure 3-20). Between August and September, Cr(VI) had again declined to concentrations <48 µg/L. This increase and then gradual decrease as water levels declined indicated that the secondary source of Cr(VI) in the vadose zone continued to contaminate groundwater at concentrations near the DWS.

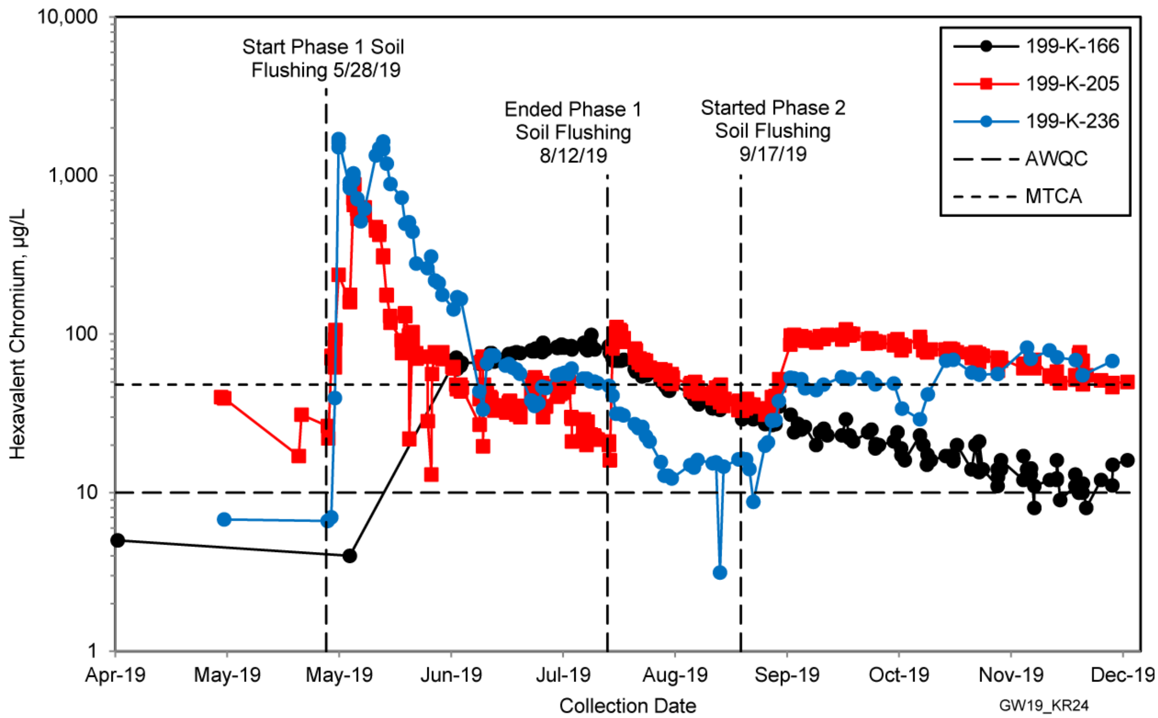


Figure 3-20. Cr(VI) Data for Key Soil Flushing Observation Wells

Infiltration for Phase 2 of the treatability test began on September 17, 2019, and continued into early 2020. Infiltration rates during Phase 2 ranged from 161 to 446 L/min (42 to 118 gal/min). In addition, injection wells 199-K-174 and 199-K-206, which were offline during Phase 1, were restarted during Phase 2 to enhance hydraulic control and increase mass removal. This change was in response to the observed increases at well 199-K-166. Further downgradient from the treatability test site, extraction well 199-K-166 exhibited a peak Cr(VI) concentration of 111 µg/L in August; however, concentrations declined to <20 µg/L by November. It is likely that the initial flushing activity caused some Cr(VI) to pass the capture zone of well 199-K-205 and migrate downgradient to the next line of K West extraction wells. As previously observed, Cr(VI) concentrations increased quickly as water infiltrated the soil column, with concentrations increasing to around 100 µg/L in extraction well 199-K-205. After the initial increase, Cr(VI) concentrations in wells 199-K-205 and 199-K-236 gradually decreased to around 48 µg/L. At wells 199-K-235 and 199-K-223 and extraction well 199-K-224, located progressively downgradient of the treatability test site, the average Cr(VI) concentration remained <20 µg/L throughout all phases of the test (Figures 3-3 and 3-4).

In wells between the KW Reactor and the Columbia River, Cr(VI) concentrations fluctuated, but the averaged concentration remained near or below the groundwater remediation target of 20 µg/L (Figures 3-3 and 3-4). Well 199-K-132 had the highest average concentration in this area during 2019 at 21.9 µg/L. At monitoring well 199-K-140, the annual average Cr(VI) was 15.5 µg/L, but the concentration increased sharply in November 2019 to 38.7 µg/L. Based on the associated sulfate measurement, this increase is likely similar to what was observed at well 199-K-166, indicating observed impacts from soil flushing. Sulfate concentrations in groundwater in K West are typically <80 mg/L. However, during Phase 1 of the treatability test, additional sulfuric acid was added to the process stream (in accordance with DOE/RL-2017-30) to lower the effluent pH and attempt to increase the solubility of Cr(VI) in the soil column. The result was an increase in overall sulfate concentrations in groundwater to >100 mg/L. This process was later determined to be unnecessary and was not performed during Phase 2.

The remedial performance of the KW P&T system was evaluated using Cr(VI) data from 2019 and the long-term concentration trends for selected KW P&T system monitoring locations (Figure 3-21). Of the six extraction wells connected to the KW P&T system, wells 199-K-137, 199-K-166, and 199-K-205 were the only wells with average Cr(VI) concentrations above the groundwater remediation target of 20 µg/L in 2019. Wells 199-K-166 and 199-K-205 were both impacted by the soil flushing treatability test (Figure 3-21). Downgradient extraction well 199-K-196, which was reconnected in July 2018 to increase river protection along the K West shoreline, exhibited Cr(VI) concentrations ranging from 7.0 to 14 µg/L in 2019.

3.2.4.2.2 K East Area

The K East Cr(VI) plume has been monitored since the early 1990s, when several monitoring wells were installed to characterize potential groundwater contamination in the area. The Cr(VI) plume source near KE Reactor is attributed to the contamination commingling from the 116-K-1 Crib, 116-K-2 Trench, and 183.1KE Headhouse. The contamination originated from spills or leaks of highly concentrated sodium dichromate solution associated with the KE Reactor water treatment facilities (i.e., 183.1KE Headhouse area) and the large plume created by mounding around the 116-K-2 Trench (caused by historical release of cooling water to the trench).

In the 183.1KE Headhouse area, well 199-K-36 continued to exhibit the highest Cr(VI) concentration, with a maximum of 446 µg/L in April 2019 that declined to 77.2 µg/L in November. Downgradient KX P&T system extraction well 199-K-220 exhibited Cr(VI) concentrations ranging between 15 and 25 µg/L in 2019. In well 199-K-188, Cr(VI) concentrations decreased from a maximum of 49.9 µg/L (in a filtered total chromium aliquot) in 2018 to a maximum of 15.4 µg/L in 2019. Based on observed Cr(VI) trends in wells 199-K-36 and 199-K-188 (located near the 183.1KE Headhouse area), it is likely that residual Cr(VI) contamination remains in the deep vadose zone (SGW-64284, *100-K Area Continuing Hexavalent Chromium Sources*) and is expected to continue to cause groundwater contamination above cleanup levels.

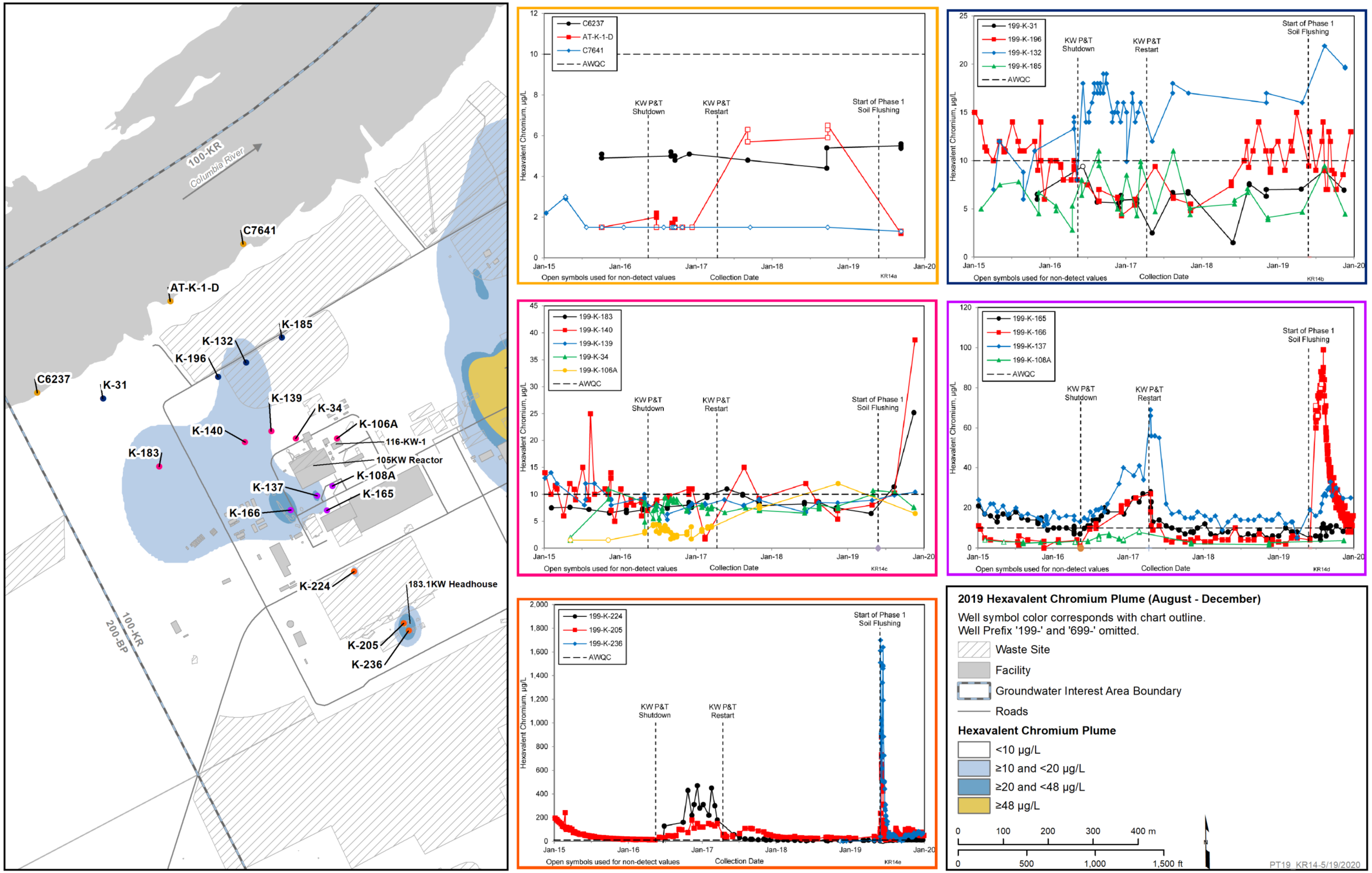


Figure 3-21. Cr(VI) Groundwater Concentration Time-Series Plots for Selected KW Reactor Wells, 2019

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West of the KE Reactor, elevated Cr(VI) concentrations observed at well 199-K-23 (with an annual average concentration of 748.5 µg/L 2017) continue to drive the general shape of this plume. Well 199-K-23 was decommissioned to support ongoing waste site remediation activities in the 100-K Area. However, the observed high concentrations at well 199-K-23 were not observed at monitoring well 199-K-13, which is located downgradient (Figure 3-3). Based on a downhole camera inspection of well 199-K-13, it is unclear which portion of the unconfined aquifer is being sampled. It is likely that the elevated Cr(VI) concentrations observed in well 199-K-23 originated near the sedimentation basin, downgradient of any previous monitoring locations. In January 2020, new monitoring well 199-K-239, which was installed to replace well 199-K-13, exhibited a Cr(VI) concentration at 16.1 µg/L. This new data allowed the interpreted Cr(VI) plume to connect downgradient at well 199-K-141 in both the high and low river-stage plumes (Figures 3-3 and 3-4, respectively) in 2019 compared to 2018.

The Cr(VI) plume on the northeast side and downgradient of KE Reactor remained consistent between 2018 and 2019. Cr(VI) concentrations in operating extraction wells remained relatively stable or declined slightly (Figure 3-22). In monitoring wells 199-K-111A and 199-K-207, Cr(VI) concentrations declined between 2018 and 2019. In late 2019, new monitoring well 199-K-238 (to be connected to the KX P&T system in 2020) exhibited a maximum Cr(VI) concentration of 265 µg/L, similar to neighboring monitoring well 199-K-111A (288.7 µg/L).

Table 3-9 presents the Cr(VI) concentrations for wells and aquifer tubes associated with plume segments outside of the KW P&T system during 2019 and includes the annual maximum concentration, as well as the maximum for high and low river stages. Figure 3-22 provides Cr(VI) concentration trend charts for the KR4 and KX P&T system monitoring and extraction wells in the plume area. The remedial performance of the KX and KR4 P&T systems for the K East Cr(VI) plume (i.e., extent and effectiveness of plume capture and reduction in Cr(VI) concentration in groundwater) is discussed in Sections 3.2.6 through 3.2.8 and was evaluated using Cr(VI) data from 2019.

Although aquifer tubes are not compliance points for treatment system performance, samples collected from the 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 extraction wells 199-K-145, 199-K-198, and 199-K-199. This aquifer tube cluster was extended in 2018 to allow for high river-stage sampling. In 2019, Cr(VI) concentrations in aquifer tube AT-K-3-D increased to 31.2 µg/L during low river stage compared to 21.5 µg/L in 2018. At inland extraction wells 199-K-145, 199-K-198, and 199-K-199, Cr(VI) concentrations continued to be <10 µg/L. It may be possible that the Cr(VI) concentrations >10 µg/L at aquifer tube AT-K-3-D may indicate a minor source of Cr(VI) along the shoreline since all inland wells continue to exhibit Cr(VI) concentrations <10 µg/L. At well 199-K-232, which is located between extraction wells 199-K-144 and 199-K-145, Cr(VI) concentrations are <10 µg/L. It is unlikely that the 116-K-1 Crib is the potential source of the elevated Cr(VI) at aquifer tube AT-K-3-D.

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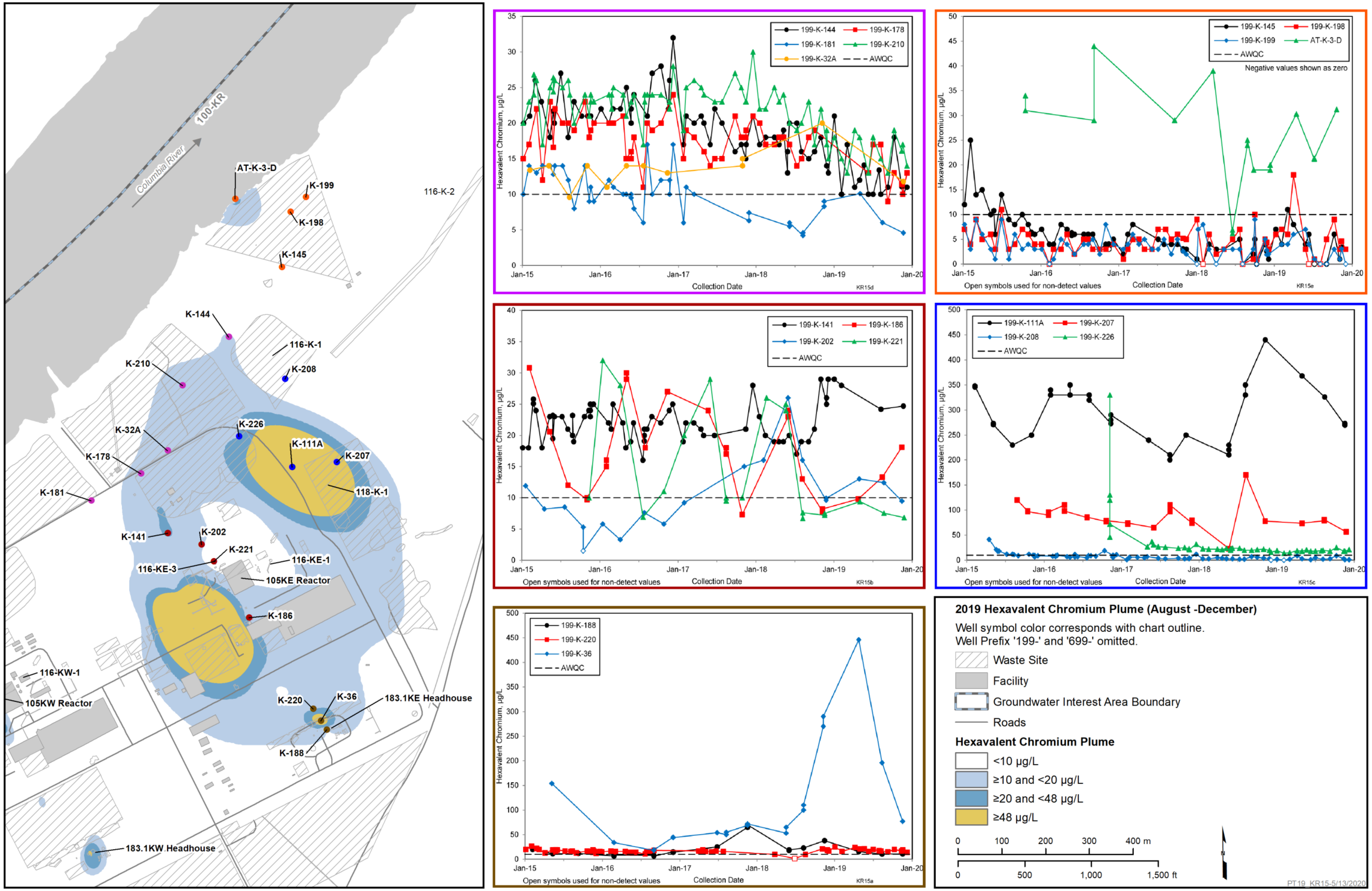

Figure 3-22. Cr(VI) Groundwater Concentration Time-Series Plots for Selected KE Reactor Wells, 2019

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3.2.4.2.3 K North and 100-K/N Boundary Area

The Cr(VI) groundwater plume located in the K North and 100-K/N Boundary areas is associated with the 116-K-2 Trench and occurs in multiple isolated plume segments at or above the 10 µg/L contour (Figure 3-3 and 3-4). The plume, which was once continuous over the length of the 116-K-2 Trench, has been dissected as a result of ongoing P&T operations, including injection in upgradient areas. Near the southwestern end of the trench (the proximal end) in wells 199-K-111A and 199-K-226, the Cr(VI) plume appears to be commingled with contamination originating from the 183.1KE Headhouse area and/or the 118-K-1 Burial Ground (as discussed in Section 3.2.4.2.2).

At the northern end of the former 116-K-2 Trench, the Cr(VI) plume was historically interpreted to extend from the trench to well 199-K-193. Starting in fall 2017, this plume became two isolated plumes with Cr(VI) concentrations >10 µg/L: the first defined by inland extraction wells 199-K-171 and 199-K-193, and the second remains focused around wells located at the northern end of the former 116-K-2 Trench. At well 199-K-193, Cr(VI) concentrations continued to decline in 2019 (Figure 3-23). At extraction well 199-K-171, average Cr(VI) concentrations remained ≤10 µg/L, which caused the interpreted separation. However, due to the presence of only a few wells between well 199-K-193 and the trench, the isolation of Cr(VI) in that area is not conclusive. At extraction well 199-K-154, Cr(VI) concentrations ranged from 17 to 24 µg/L, suggesting that an inland mass continues to migrate toward this extraction well.

Figure 3-23 provides Cr(VI) concentration trend charts for the KR4 and KX P&T system monitoring wells and extraction wells in the 116-K-2 Trench area (K North). On the Columbia River side of the 116-K-2 Trench, Cr(VI) concentrations continue to fluctuate with river stage. At KR4 P&T system extraction wells 199-K-113A and 199-K-114A, Cr(VI) concentrations increased above the 10 µg/L surface water standard in several sampling events (Figure 3-23). However, the average concentrations during the high and low river-stage periods averaged below the surface water standard. At KX P&T system extraction well 199-K-161, Cr(VI) concentrations ranged from 4 to 28 µg/L in 2019, similar to 2018. The Cr(VI) plume in this area was interpolated to reach the Columbia River in 2019 (Figure 3-4), which is consistent with observations over the past few years. However, Cr(VI) concentrations continue to decline at surrounding monitoring wells 199-K-22, 199-K-37, and 199-K-201, which causes the Cr(VI) plume in this area to become separated. Given the sustained Cr(VI) concentrations at extraction well 199-K-161, it is likely that a secondary source of Cr(VI) contamination exists in the deep vadose zone near the 116-K-2 Trench. At inland KX P&T system extraction wells 199-K-153 and 199-K-154, Cr(VI) concentrations continued to decline compared to 2018.

At aquifer tube 22-D, which is located downgradient from extraction wells 199-K-114A and 199-K-161, Cr(VI) concentrations increased in 2019 from 22.4 µg/L in April to 36 µg/L in November. The specific conductance in the aquifer tube remained >200 µS/cm, suggesting that groundwater is continuing to discharge at this location (Figure 3-19); however, the expected decrease in specific conductance due to high river stage in April and July was not observed. This seems to indicate that the aquifer tube is sampling from a lower permeable zone within the aquifer and that the observed Cr(VI) is from historical use of the 116-K-2 Trench and not from breakthrough in the current P&T system.

Extraction wells 199-K-146, 199-K-129, 199-K-147, 199-K-130, and 199-K-148 are located progressively farther upgradient from (and roughly parallel to) the Columbia River shoreline (Figure 3-23). In 2019, wells 199-K-146, 199-K-129, and 199-K-147 each exhibited Cr(VI) concentrations >10 µg/L. At wells 199-K-146 and 199-K-129, Cr(VI) concentration increased between 2018 and 2019 (Figure 3-23). The low river-stage average Cr(VI) concentrations for wells 199-K-146 and 199-K-129 increased from 9.4 and 11.7 µg/L to 20.1 to 18.9 µg/L, respectively. Based on the

October 2019 water table (Figure 3-4), it is likely that these increases are related to inland contaminant plume migration similar to well 199-K-154. Inland extraction well 199-K-152 exhibited stable concentrations, with concentrations ranging from 12 to 25 µg/L (Figure 3-23).

The most northeastern portion of the 116-K-2 Trench plume extends into the 100-NR-2 OU (Figures 3-3 and 3-4). During 2019, extraction wells 199-K-182 and 199-N-189 pumped at average rates of 226.6 and 119.2 L/min (59.8 and 31.5 gal/min), respectively. Between 2018 and 2019, Cr(VI) concentrations declined in both wells (Figure 3-23). The low river-stage average Cr(VI) concentrations at wells 199-K-182 and 199-N-189 declined between 2018 and 2019, from 19.3 and 26.9 µg/L to 16.7 to 21.4 µg/L, respectively.

The overall pumping strategy used for the 100-KR-4 P&T systems continues to focus on protecting the Columbia River from discharges of Cr(VI)-contaminated groundwater to the Columbia River and removing Cr(VI) mass from the unconfined aquifer. In 2020, newly installed monitoring well 199-K-238 will be connected to the KX P&T system to target the high Cr(VI) concentration northeast of KE Reactor. Given the success observed with soil flushing at the 183.1KW Headhouse area, the 183.1KE Headhouse will be evaluated as a potential target for future soil flushing activities. Part of FY 2021 optimization efforts will be to align newly installed monitoring wells as extraction wells to increase mass removal within the 100-KR-4 OU, as well as to evaluate the continuing source of groundwater contamination near the 116-K-2 Trench.

3.2.4.3 Other Contaminants

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 in the 100-KR-4 OU were identified as COCs in the RI (DOE/RL-2010-97, Draft B) and include nitrate, TCE, strontium-90, carbon-14, tritium, and total chromium. These constituents are present in the groundwater at varying concentrations. The co-contaminants generally had different sources compared to the Cr(VI) sources (except for total chromium, which is present as Cr(VI)). Chapter 5 in the annual groundwater monitoring report for 2019 (DOE/RL-2019-66) discusses the occurrence and distribution of these constituents in groundwater at the 100-KR-4 OU.

Non-chromium contaminants collocated with the chromium plumes are captured and blended with Cr(VI)-contaminated groundwater extracted by the P&T extraction wells, passed untreated through the P&T systems, and then returned to the aquifer at the injection wells. The non-chromium contaminants in the blended groundwater are at concentrations below their respective DWSs, which is consistent with interim action ROD requirements (EPA/ROD/R10-96/134). This results in the potential relocation of contaminants into portions of the aquifer where the contaminants did not originally exist.

Four of the constituents (TCE, strontium-90, carbon-14, and tritium) are currently found in groundwater and treatment system effluent at concentrations that may ultimately affect interim action P&T operations, as described in the following discussion.

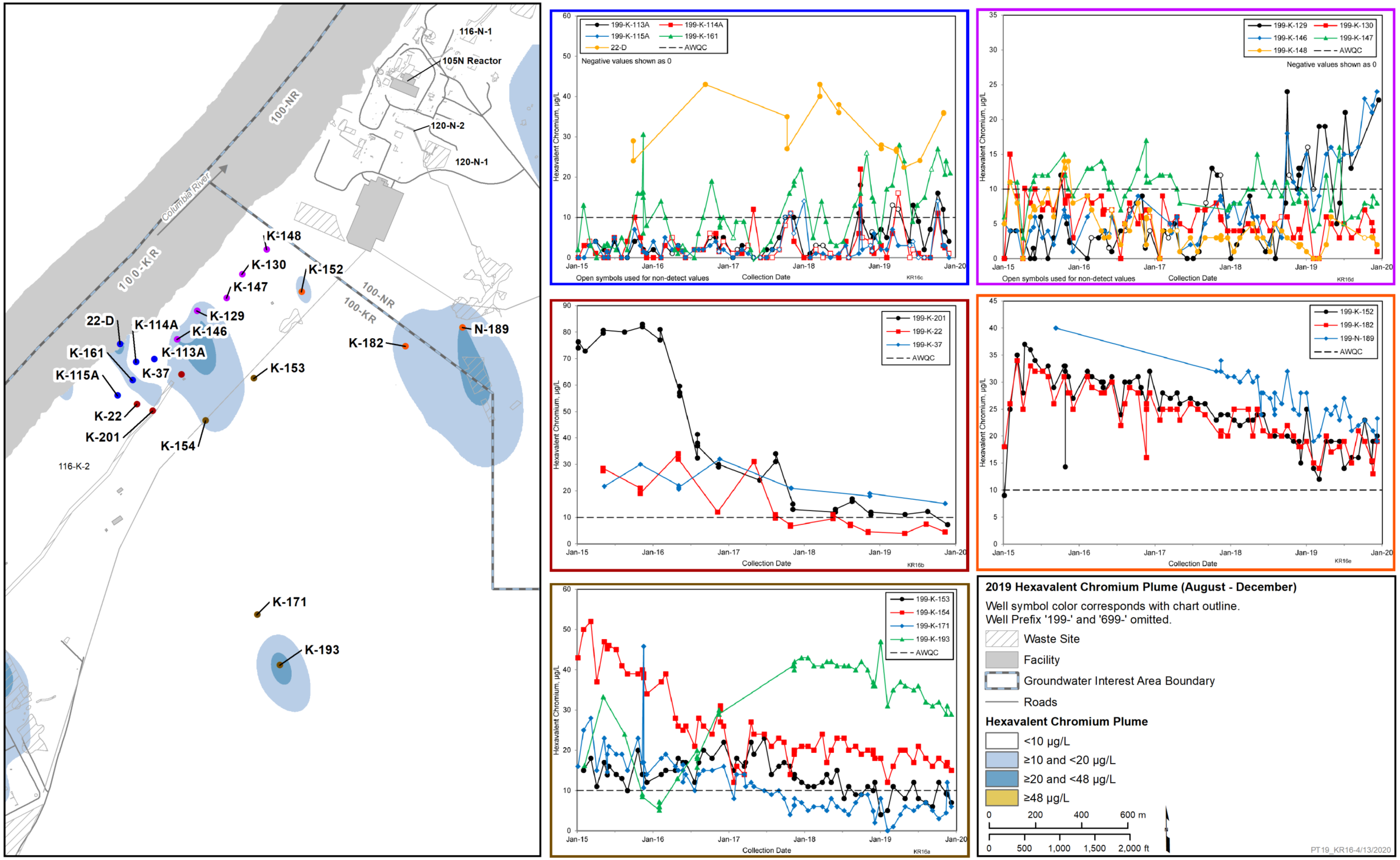

Figure 3-23. Cr(VI) Groundwater Concentration Time-Series Plots for Selected 116-K-2 Trench Area (K North) Wells, 2019

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3.2.4.3.1 Trichloroethene

The sources of TCE in the 100-KR-4 OU are likely related to the use of solvents during equipment maintenance activities, but specific release points have not been identified. The ongoing injection of TCE at levels below the 5 µg/L DWS through KW P&T system injection wells has resulted in a dispersed TCE plume near the KW Reactor. Figure 5-18 in DOE/RL-2019-66 shows the TCE plume using the maximum concentration observed throughout the KW Reactor area.

By the end of 2019, TCE concentrations exceeded the 5 µg/L DWS in four wells near the KW Reactor. Monitoring wells 199-K-11 and 199-K-185 exhibited the highest observed TCE concentrations of 7 and 7.6 µg/L, respectively, in routine samples.

3.2.4.3.2 Strontium-90

Strontium-90 is present in groundwater at concentrations exceeding the 8 pCi/L DWS at several locations in the 100-KR-4 OU. These locations are primarily downgradient of the 116-KW-2 Crib/reverse well, downgradient of the former KE Reactor FSB and 116-KE-3 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 KE Reactor FSB and 116-KE-3 Crib. The 2019 maximum strontium-90 concentration in groundwater in this area was observed in well 199-K-222 at 1,230 pCi/L. At former KX P&T system extraction well 199-K-141, which was disconnected in February 2019, strontium-90 concentrations declined from 117 pCi/L in August to 45.4 pCi/L in November. While well 199-K-141 continues to be inferred on the leading edge of the strontium-90 plume, which is migrating riverward from near the former KE Reactor FSB, it is likely the strontium-90 concentration will start to decline due to lack of pumping at this well. In 2018, strontium-90 extracted by well 199-K-141 provided a measurable contribution of strontium-90 to the KX P&T system process stream, with an average effluent concentration of 1.8 pCi/L. However, after well 199-K-141 was disconnected, measured concentrations of strontium-90 in the KX P&T system influent tank were less than detection. Strontium-90 concentrations near well 199-K-141 will be monitored for potential effects on P&T operations. At extraction well 199-K-234, which is located downgradient of and a replacement for well 199-K-141, reported strontium-90 concentrations were less than detection.

3.2.4.3.3 Carbon-14

Carbon-14 present in groundwater at the 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. The 2019 carbon-14 plumes exhibited little change in extent from 2017 and 2018. Concentrations remained consistent with previous years in the majority of the K West area. At well 199-K-106A, located downgradient of the 116-KW-1 gas condensate crib, the maximum concentration increased to 42,600 pCi/L in 2019 compared to 15,700 pCi/L in 2018. At well 199-K-204, the maximum concentration increased slightly to 35,100 pCi/L in 2019 compared to 32,900 pCi/L in 2018. These trends continue to indicate ongoing downgradient migration away from the 116-KW-1 Crib. Carbon-14 has historically been captured by the KW P&T system and distributed to the injection wells. Contamination in groundwater continued to be observed as widely distributed over the K West area at concentrations <1,000 pCi/L.

A lower concentration carbon-14 plume exists in the KE Reactor area. The plume was formerly defined by wells 199-K-29 and 199-K-30, which have been decommissioned. These wells monitored conditions downgradient of the 116-KE-1 Crib waste site. As with conditions near the KW Reactor, the carbon-14 plume in the KE Reactor area appears to be migrating downgradient, away from the source area.

3.2.4.3.4 Tritium

Tritium concentrations exceed the DWS 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 found in wells downgradient of these source areas. During 2019, tritium concentrations in well 199-K-111A continued to decline, reaching a low of 22,100 pCi/L. Concentrations in well 199-K-207 increased in 2019, ranging from 314,000 to 405,000 pCi/L. Well 199-K-227, which was installed at the southern end of the 118-K-1 Burial Ground to investigate tritium concentrations in this area, had concentrations ranging from 22,300 to 86,400 pCi/L in 2019.

3.2.5 Hydraulic Monitoring

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

Water levels area 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 as part of the AWLN. The 100-K Area AWLN includes 38 stations that were operating in and around the 100-KR-4 OU as of the end of 2019. The AWLN configuration is based on the proposed AWLN configuration in SGW-53543 to provide sufficient data to calculate gradients and to delineate capture zones from the 100-KR-4 OU P&T systems. Additional dynamic water-level measurements are collected from transducers at each of the P&T extraction and injection wells (separate from the AWLN). Reported water-level data from AWLN wells and manual depth-to-water measurements are reviewed and reduced, and a final data set is compiled to prepare the groundwater elevation maps for high and low river-stage conditions (Figures 3-3 and 3-4).

Under natural gradient conditions, regional groundwater generally flows to the north and northwest, generally toward the Columbia River in the 100-KR-4 OU. Hydraulic effects of the P&T systems (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, extensive water table depressions were present during 2019 from the near-river area of 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 KR4 and KX P&T system injection wells. The inferred water table is consistent with the observation that the P&T systems are providing groundwater containment, resulting in river protection along the 100-K Area river shoreline.

Section 3.2.6 discusses the effects of seasonal river-stage changes (and corresponding water table elevation response) on contaminant concentrations in the aquifer and treatment system performance. The river stage in 2019 exhibited a typical river-stage pattern, with the seasonal high during May and June and seasonal low in September and October. However, the seasonal high river stage recorded its lowest levels in recent years, with the absolute peak river stage observed in May. The river stage then continued to decline through the summer before reaching typical seasonal low levels in September and October (Figure 3-17).

Under natural, high river-stage flow conditions, the local groundwater gradient has a reduced magnitude near the river and is flattened, although in 2019 this effect was not as pronounced as in previous years. Along the River Corridor, the very near-river area may exhibit a flow direction reversal, with river water intruding into the aquifer as seasonal bank storage. This change at the river boundary causes the inland groundwater to slow its riverward migration, resulting in a flatter water table gradient and creating the seasonal increase in groundwater elevation typically observed inland from the river.

As the river stage declines following the seasonal freshet, the groundwater gradient steepens toward the river and velocity increases 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), inland flow from the river is maintained throughout the year. Seasonal groundwater elevation changes are usually 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 100-K Area that was developed using concurrent measurements collected in early March 2019 when the river level was moderate.

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 Cr(VI) contamination in groundwater. The assessment is based on 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 hydraulic containment extent 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. The CFM depicts the frequency that particles representing groundwater and mobile 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., groundwater was not moving toward extraction wells at any time during the period, if each condition is considered separately). Intermediate frequencies indicate that groundwater was contained under some, but not all, conditions.

Water-level mapping using the ICFM approach was completed using monthly average groundwater elevations, pumping rates, and Columbia River stage, 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, Columbia River stage, and other time-varying boundary conditions. This resulted in 12 simulated groundwater level and flow fields, and, correspondingly, 12 individual depictions of the hydraulic containment extent for use in constructing an SCFM. Therefore, each groundwater-level depiction reflects a steady-state flow field that results from the operation of P&T wells and the average river stage for a particular month. Compilation of groundwater-level fields is not meant to reflect transient flow conditions over the year. As a result, compilation of monthly hydraulic containment depictions into CFMs does not directly translate to actual transient capture over time. Rather, CFMs are meant to illustrate the relative strength of hydraulic containment over the year, indicating areas where the effectiveness of the actual transient capture may require further attention over time.

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 containment is either weak or 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 containment assessment because one method suggests that containment is being achieved whereas the other method suggests either that containment is not achieved or, as it should be interpreted, is weak.

The Cr(VI) contamination extent 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-20-0018. Figures 3-24 through 3-29 compare the estimated extent of hydraulic containment and the estimated Cr(VI) contamination extent in groundwater for both high and low river-stage conditions for the 100-KR-4 OU as follows:

- Figures 3-24 and 3-25 depict Cr(VI) contamination under high river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figures 3-26 and 3-27 depict Cr(VI) contamination under low river-stage conditions, with an ICFM and SCFM illustrating hydraulic containment, respectively.
- Figure 3-28 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 3-29 overlays the capture flow lines with the Cr(VI) plume contours for low river-stage conditions.

ECF-HANFORD-20-0047 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 for the 100-KR-4 OU is based on assessing hydraulic containment along the shoreline considering the effects of the remedial action systems, the 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, river protection status in 2019 is similar to 2018. In the K West area, the seasonal operation of well 199-K-196 continued to result in a relatively weak hydraulic containment at the K West shoreline throughout 2019, even though concentrations in aquifer tubes remained <10 µg/L. Cr(VI) migration caused by the infiltration test at the 183.1KW Headhouse was well contained, except for a portion of the plume that was pushed farther west and through a paleochannel, migrating faster than the remainder of the plume toward the shoreline and at the edge of the containment zone.

SGW-54209 describes a method for evaluating progress toward attaining the river protection objective, which emphasizes protection of aquatic receptors. Therefore, the river protection objective focuses on the performance of P&T (and other remedies) to protect the Columbia River from further discharges of Cr(VI) from inland at concentrations >10 µg/L.

Figure 3-24. 100-K Area Interpolated CFM and High River-Stage Cr(VI) Contamination, 2019

Figure 3-25. 100-K Area Simulated CFM and High River-Stage Cr(VI) Contamination, 2019

Figure 3-26. 100-K Area Interpolated CFM and Low River-Stage Cr(VI) Contamination, 2019

Figure 3-27. 100-K Area Simulated CFM and Low River-Stage Cr(VI) Contamination, 2019

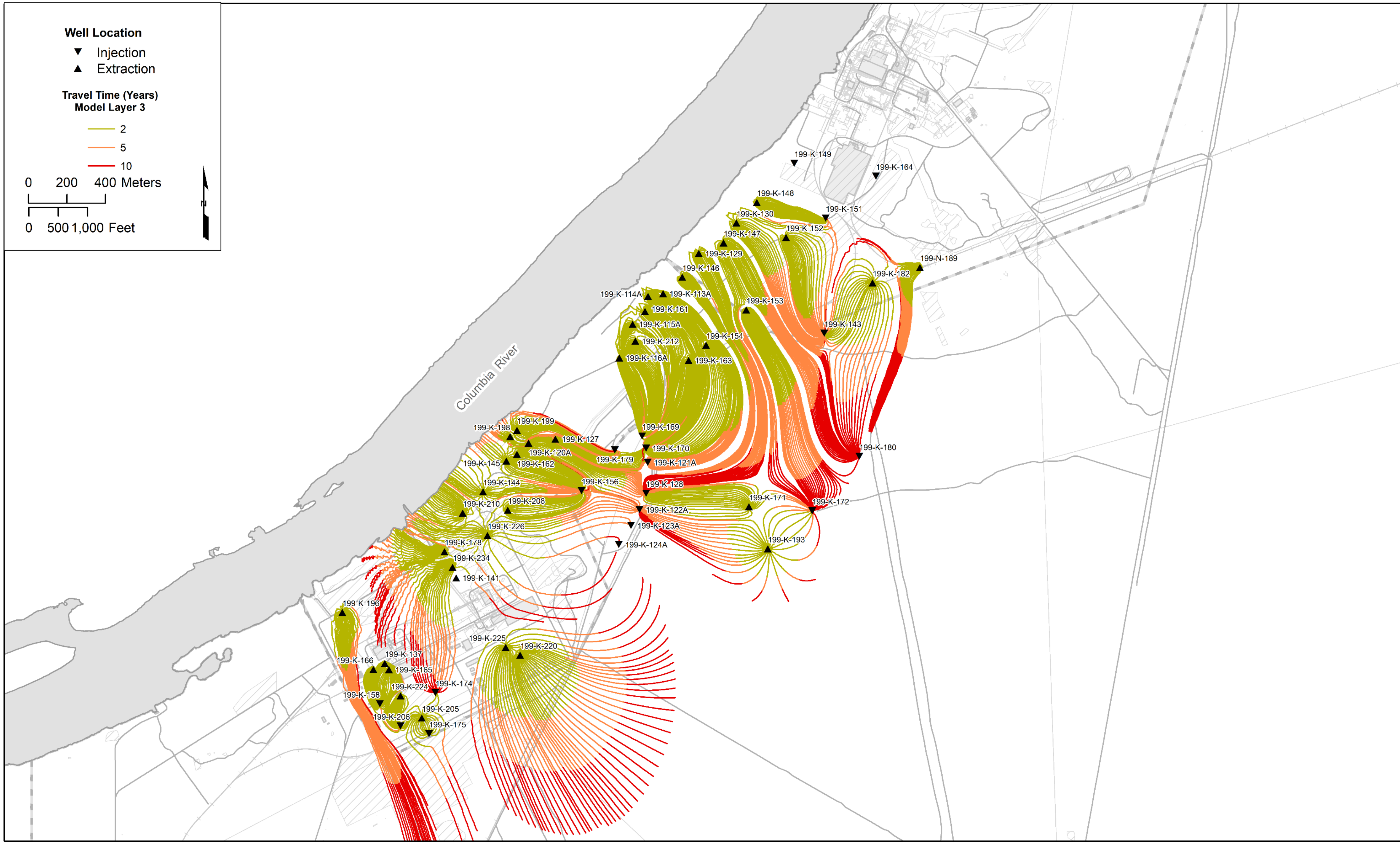

Figure 3-28. 100-K Area Groundwater Flow Lines of Capture Zone Flow Field, 2019

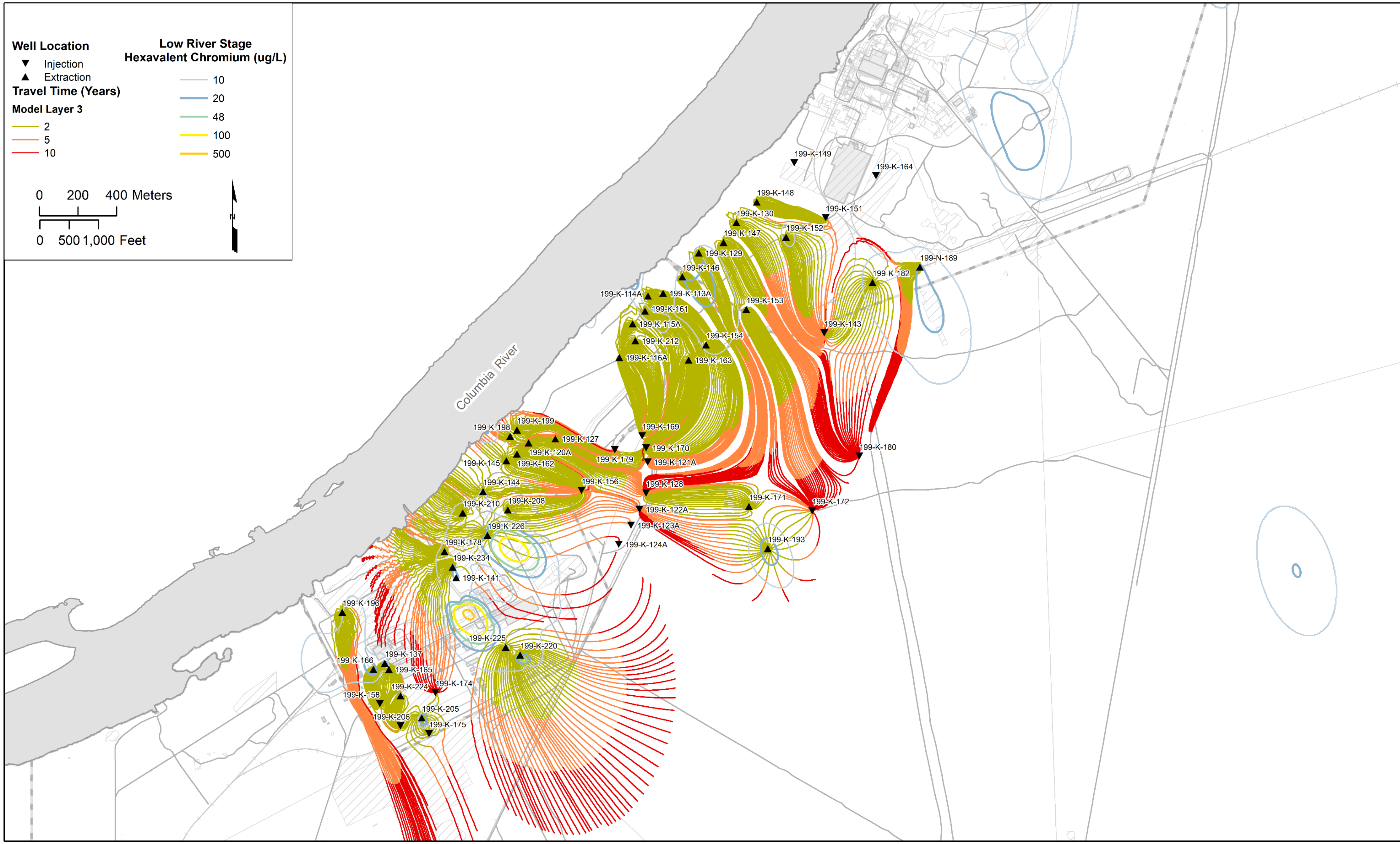

Figure 3-29. 100-K Area Groundwater Flow Lines of Capture Zone Overlay with Low River-Stage Cr(VI) Plume Contours, 2019

Figures 3-30 and 3-31 present the qualitative and quantitative assessment of progress during 2019 toward attaining the river protection objective. The technical methods and process used to complete the calculations necessary to prepare these figures are detailed in SGW-54209. ECF-HANFORD-20-0047 presents details on the specific calculations used to produce the figures for 2019. The results of contaminant standard and trend tests (described in SGW-54209) to identify low-, moderate-, and high-concern wells are presented in Figures 3-30 and 3-31 using the symbols shown in Table 3-10.

Shoreline lengths are calculated and reported in increments of 100 m (330 ft); the results of the assessment are presented in these figures as color-filled circles of diameter equal to 100 m (330 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 3-11 presents the symbols depicting the results of the river protection evaluation.

Figures 3-30 and 3-31 show the results of assessing progress toward attaining the river protection objective for Cr(VI) in the 100-K Area. Figure 3-30 shows the results of the quantitative evaluation, which is determined based on overlay and quantitative comparison of the extent of Cr(VI) contamination and the extent of hydraulic containment. Figure 3-31 shows the results of the qualitative evaluation, which is based on the quantitative evaluation but also relies on qualitative considerations (e.g., the duration, magnitude and direction of hydraulic gradients along the shoreline, location of the P&T wells, and concentration trends). Based on these calculations, the river protection evaluation for the 100-K Area is as follows (conversion from meters are rounded to the nearest 5 ft):

- **Total length of shoreline adjacent to the 100-K Area:** 4,000 m (13,120 ft)
- **Length identified as protected:** 3,100 m (10,170 ft)
- **Length identified as protected (action may be required):** 900 m (2,950 ft)
- **Length identified as not protected:** 0 m (0 ft)

Table 3-12 provides a comparison of the results of the qualitative river protection evaluations for the 100-K Area for 2019 to those from 2018 (DOE/RL-2018-67).

The KW P&T system was fully operational during the first half of 2019, re-establishing strong hydraulic containment in this area. Seasonal operation of well 199-K-196 resulted in relatively weak hydraulic containment at the K West shoreline in 2019, although water quality samples collected from wells and aquifer tubes near the shoreline showed only a minor increase in Cr(VI) concentrations, confirming the slow, transient nature of plume migration toward the shoreline, even under weaker hydraulic containment conditions. The infiltration test that started in May 2019 at the 183.1KW Headhouse resulted in significant Cr(VI) mass loading in the aquifer from flushing the continuing source in that area. A portion of the resulting Cr(VI) plume traveled along the western edge of the 100-KR-4 OU and, due to limited hydraulic containment in that area, reached shoreline well 199-K-196 within a short timeframe. The presence of Cr(VI) in that area can be noted on the interpolated hydraulic containment map under low river-stage conditions (Figure 3-26).

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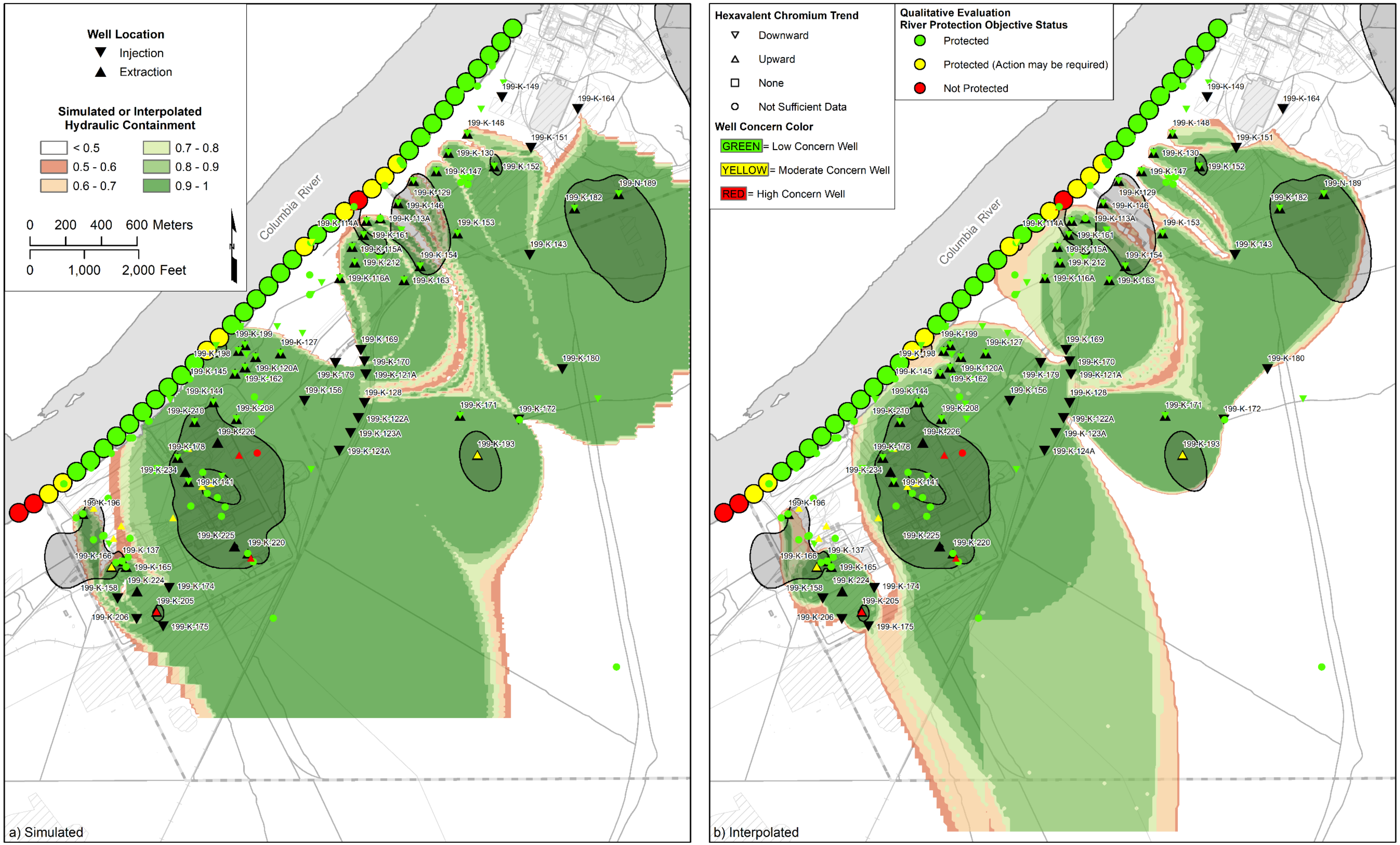

Figure 3-30. 100-K Area Quantitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 µg/L and Results of Standard Test and Trend Test

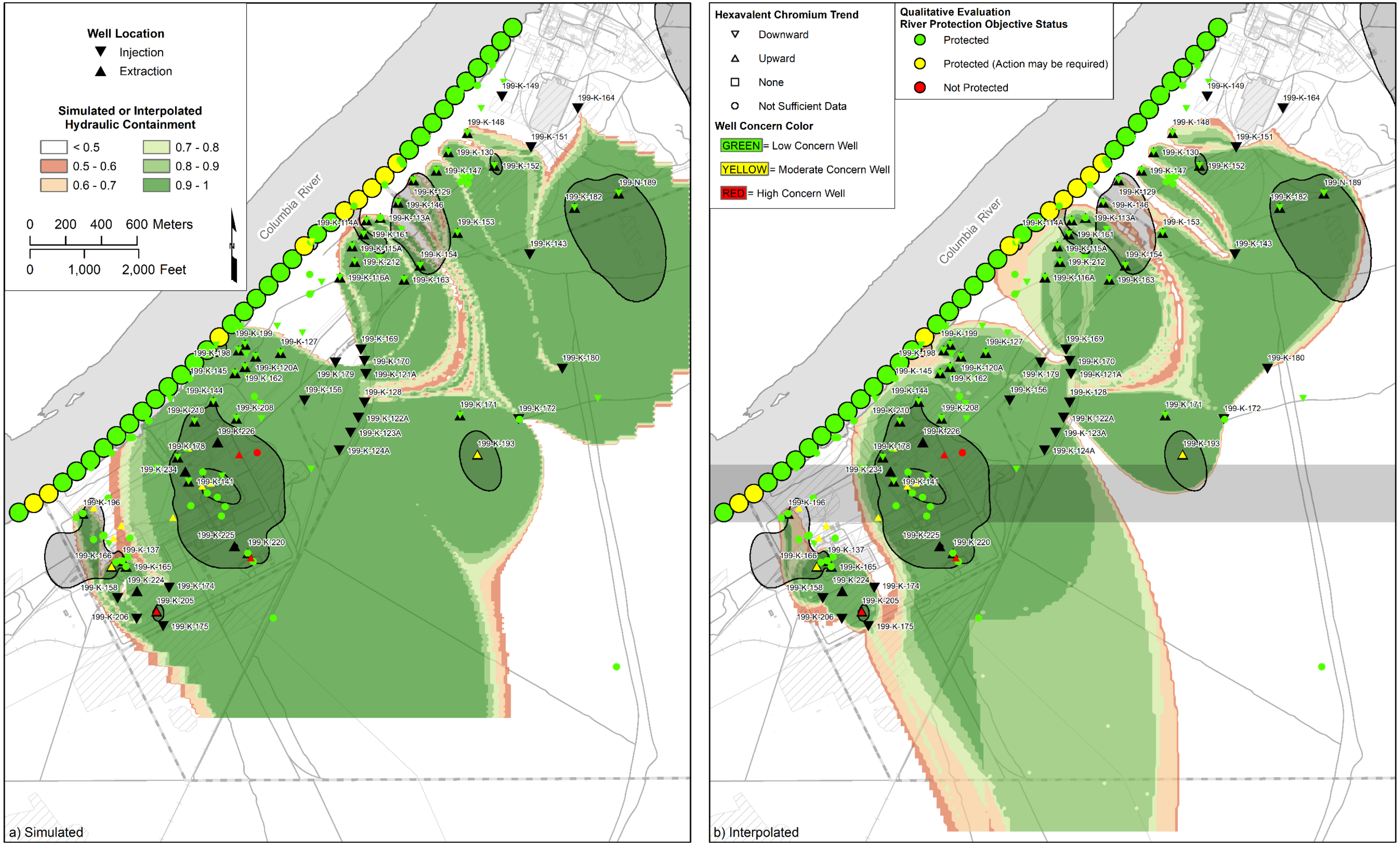

Figure 3-31. 100-K Area Qualitative Assessment of Shoreline Protection with (a) Simulated and (b) Interpolated CFM, with Mapped Extent of Low River-Stage Cr(VI) Contamination >10 μg/L and Results of Standard Test and Trend Test

Table 3-10. 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

Table 3-11. Symbology for Status of River Protection Objective

Symbol	Explanation
●	Protected
●	Protected (action may be required)
●	Not protected

Table 3-12. Comparison of River Protection Assessment Results

Assessed Shoreline Lengths for 100-K	2018	2019	Change from 2018 to 2019*
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	3,100 m (10,170 ft) 78% of shoreline	500 m (1,640 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)"	400 m (1,310 ft) 10% of shoreline	900 m (2,950 ft) 22% of shoreline	500 m (1,640 ft) previously identified as "protected" now identified as "protected (action may be required)"
Length identified as "not protected" Percent of shoreline "not protected"	0 m (0 ft) 0% of shoreline	0 m (0 ft) 0% of shoreline	

*Details on year-to-year changes are provided in ECF-HANFORD-20-0047, *Description of Groundwater Calculations and Assessments for the Calendar Year 2019 (CY2019) 100 Areas Pump-and-Treat Report*.

Plume extents in 2019 were similar to those in 2018 in the K East and K North areas, with elevated Cr(VI) concentrations at the same three locations at the shoreline. Cr(VI) at aquifer tubes AT-K-3-D and C6256 remained >10 µg/L, exhibiting a long-term insignificant or decreasing trend. However, hydraulic containment due to the operation of a series of extraction wells inland from the aquifer tubes and the measured concentrations at those extraction wells suggest that the aquifer tubes possibly monitor a low-permeability zone with residual contamination.

The Cr(VI) in aquifer tube 22-D remained at similar levels to those observed in 2018, with a minor increase during the second half of the year. At extremely low river-stage conditions (e.g., those observed in 2019), it is possible that hydraulic containment, especially around well 199-K-161, may be somewhat reduced from previous years and allow some mass to migrate closer to the shoreline. However, Cr(VI) trends at inland extraction wells 199-K-114A, 199-K-115A, and 199-K-161 suggest that operation of the P&T wells remains effective, preventing further discharges of the inland plume to the river. Therefore, it is more plausible that aquifer tube 22-D monitors a low-permeability zone at the shoreline with residual contamination.

Quantitative evaluations of the river protection objective provide a conservative assessment of shoreline protection where qualitative evaluations for 2019 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 do not depict 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 Cr(VI) plume depictions for 2018 and 2019 indicates a consistent number of shoreline segments where Cr(VI) concentrations are below the aquatic standard, despite the impact of low river-stage periods. Acknowledgement of these processes is reflected in the qualitative evaluation results.

3.2.8 Comparison of Simulated to Measured Contaminant Mass Recovery

Comparison of the ICFM and SCFM provides a depiction of the hydraulic simulation capabilities of the 100 Area Groundwater Model flow component. 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 3-32 shows a comparison of monthly and cumulative Cr(VI) mass recovered throughout the 100-K Area at each of the KX, KW, and KR4 P&T systems for 2019, 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 Cr(VI) distribution in groundwater was assumed to be the low river-stage depiction of Cr(VI) for 2018, as presented in ECF-HANFORD-19-0010.

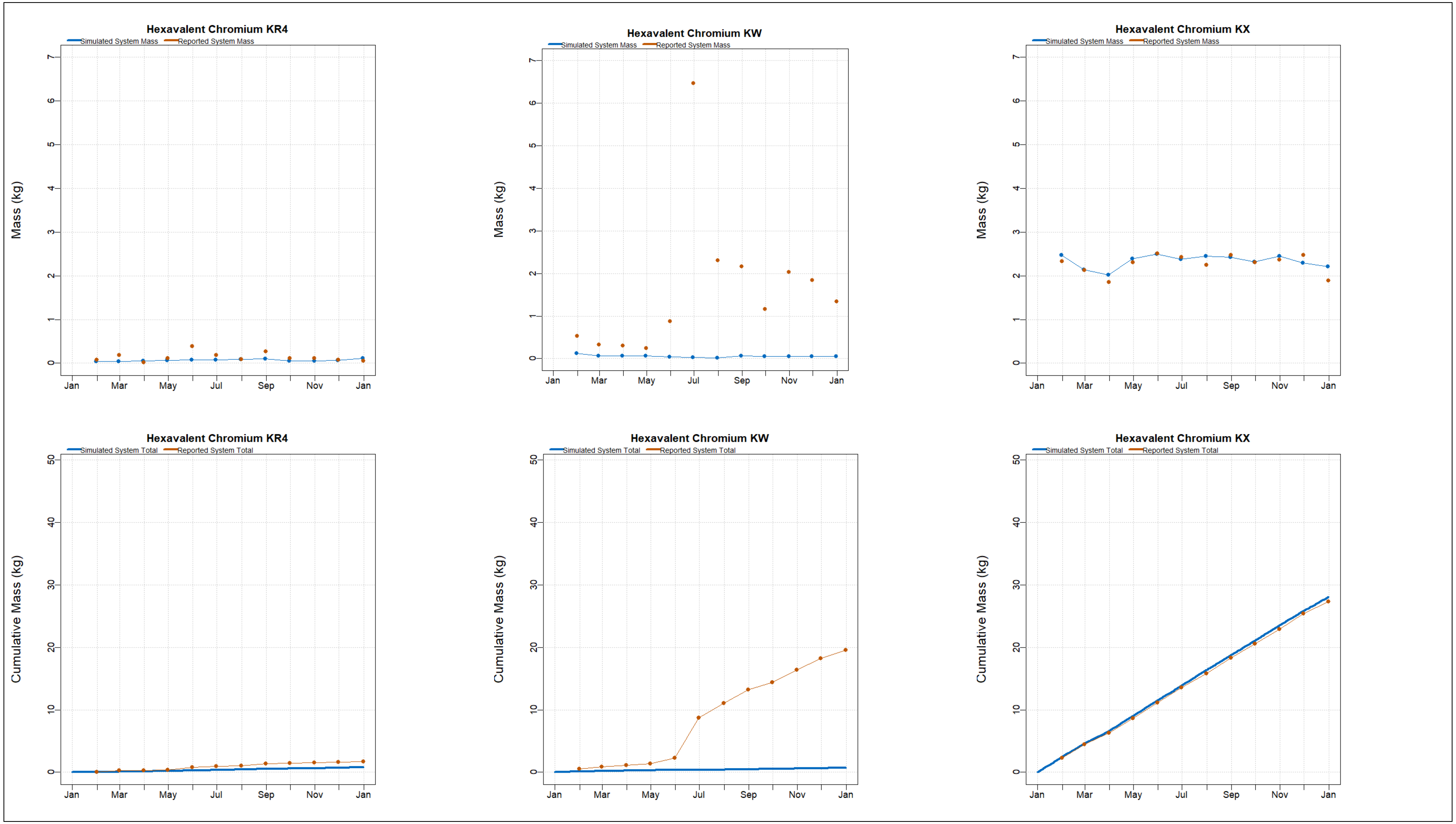

Figure 3-32. Comparison of Observed to Calculated Cr(VI) Mass Removal for 2019 (Top Row = Monthly Mass Removal; Bottom Row = Cumulative Mass Removal)

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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 detail in ECF-HANFORD-20-0047). In each case, there are system-specific and systematic conditions that might lead to differences between the simulated and measured values. ECF-HANFORD-20-0047 presents graphs comparing the simulated and measured mass recovery at each individual extraction well for each P&T system.

For the KW P&T system, the model underpredicts mass recovery for 2019. Comparison of measured to simulated concentrations at the KW P&T system extraction wells illustrates the impact of the presence of a continuing source at the 183.1KW Headhouse and the resulting mass loading due to the infiltration test conducted in that area in the second half of the year. Simulated concentrations at the recovery wells did not reflect the observed data (mostly evident at well 199-K-205), as the model did not include the mass loading from this continuing source, resulting in underpredicting the total mass recovery, with a significant departure in measured values starting in June.

The model-simulated mass recovery tracks well for measured mass recovery in the KR4 P&T system. Only minor differences between measured and simulated concentrations are observed on a monthly basis at the extraction wells, but simulated concentrations do not significantly overpredict or underpredict the measured concentrations.

Measured and simulated concentrations in the KX P&T system are in excellent agreement. Simulated concentrations at the extraction wells matched almost perfectly the measured concentration values and recovery patterns, suggesting that the initial conditions in the model reflected the actual Cr(VI) distribution in the aquifer. A discrepancy observed at well 199-K-226 suggests that the initial condition may be overestimating Cr(VI) in the aquifer in that area; however, based on the sampling data from near the well, this discrepancy is rather localized.

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. However, the simulated mass recovery estimate presents a useful tool for estimating system performance over time and developing estimates of the timeframe for remediation.

Figure 3-33 depicts Cr(VI) sample summary statistics calculated for the last 5 years in monitoring locations in each of the subareas encompassing K West, K East, and the area east of K East (noted as "KN" in this figure). The data set comprised average Cr(VI) concentrations at each well during the low river-stage period for each year (as used in the interpolation of the corresponding plumes). Concentration frequency distributions were calculated for each area, with outliers (concentrations >1.5 times the interquartile range [i.e., the range from 25th to 75th percentile]) considered separately. For each graph for each year, the "box-and-whisker" style plots show the maximum and minimum values (top and bottom of the "whiskers"), 25th and 75th percentile values (top and bottom of the "box"), median (horizontal line within the "box" with a connecting dashed line), average (with connecting blue dashed line), and UCL on the average (the latter is calculated using a Student's t-test distribution). Outliers are noted separately on the plots with their count and associated minimum and maximum values.

The plots reflect the observed concentration variations under low river-stage conditions for the last 5 years. As a result, the plot for K West does not convey in detail the elevated Cr(VI) concentration patterns observed during the system shutdown in 2016–2017, the subsequent rebound as concentrations in the aquifer decreased toward the second half of 2018, or the increased concentrations due to the infiltration test in 2019. The plot for K East shows the higher concentration levels observed downgradient of the reactor area, while the decreasing trends observed in the K North wells are shown in the corresponding plot.

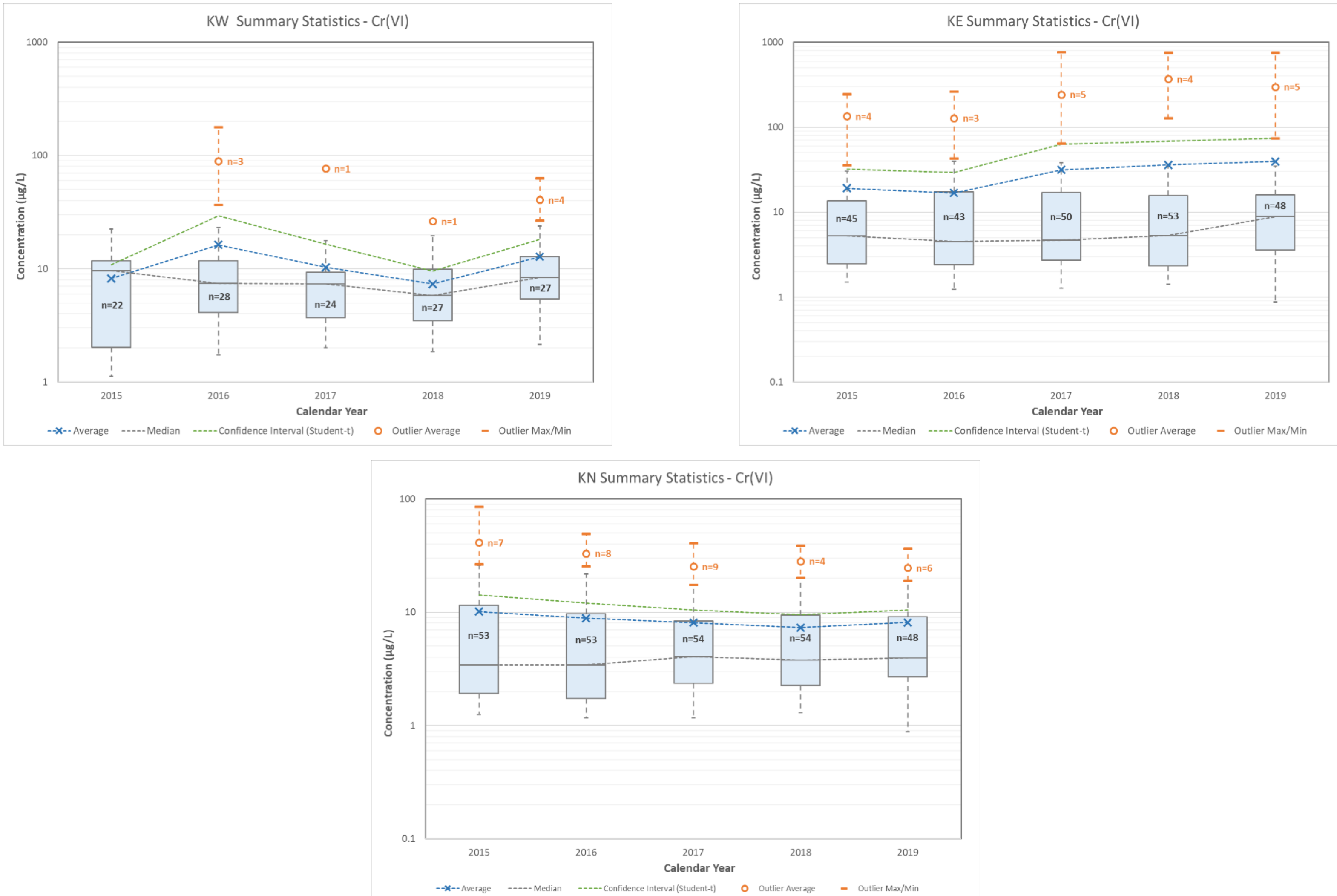

Figure 3-33. Summary Statistics for Cr(VI) in the 100-KR-4 OU (Logarithmic Scale)

3.2.9 Remedial Process Optimization Activities

A pumping optimization model and interface (based on the 100 Area Groundwater Model) was developed to evaluate the relative performance of alternative well configurations. Pumping configurations are evaluated throughout the year, and recommendations for flow rate adjustments, well realignments, and/or installation of new wells are provided. Specific RPO activities performed at the 100-KR-4 OU during 2019 included the following:

- Installed, operated, and monitored the KW P&T system soil flushing infiltration gallery in accordance with DOE/RL-2017-30 and DOE/RL-2018-10.
- Disconnected KX P&T system extraction well 199-K-141 from the KX P&T system and connected and operated monitoring well 199-K-234 as an extraction well.

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

This section discusses the results of radiological dose and DWS evaluations of the 100-KR-4 OU P&T system for 2019 against the requirements of DOE O 458.1 and DOE-STD-1196-2011. Additional guidance to proactively evaluate radiological effluent monitoring based on the DCS to ensure that mitigating steps are implemented before conditions exceed target metrics is described in DOE-HDBK-1216-2015 and summarized in Table 3-13. These criteria are applied to the 100-KR-4 OU P&T systems and are evaluated each year for adequacy and updated as necessary.

Table 3-13. 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		—	Apply best available technology to reduce effluent releases (except tritium). Use continuous monitoring/sampling, but where effluent streams are low flow and potential public dose is very low (<1 mrem/yr), alternative sampling approaches may be appropriate.
2	≥0.01 to 1	and	>1	Continuously monitor or sample. Identify radionuclides contributing >/= 10% of the dose. Determine accuracy of results (± accuracy and percent confidence level).
3	≥0.001 to 0.01	and	<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.

Table 3-13. 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

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

*To further clarify, the potential annual dose from exposure is the calculated cumulative total equivalent dose value.

— = not applicable

DCS = derived concentration standard

3.3.1 Evaluation of Effluent Water Total Effective Dose for 100-K Area Pump and Treat Systems for 2019

Effluent monitoring at the three 100-KR-4 OU P&T systems was performed by sampling and analyzing the stream exiting the P&T systems prior to pumping effluent to the injection well fields. Sampling and analysis were performed on a quarterly basis for target radionuclides identified as contaminants of interest under the AEA (Table A-35 in Appendix A of DOE/RL-2015-56) for the groundwater remedial actions supported by the treatment systems. The radionuclides of interest for the 100-KR-4 OU P&T systems are tritium, strontium-90, carbon-14, and technetium-99.

Table 3-14 summarizes the results of periodic sampling and analysis of effluent from the KR4, KW, and 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 this evaluation.

Individual radioisotope activity concentrations were subsequently converted to estimated effective dose using the DCS values in Table 3-15.

Table 3-16 shows the individual radioisotope dose contributions for each effluent sampling event for the 100-KR-4 OU P&T systems and the cumulative TED estimates for 2019. The TED was calculated using two approaches: (1) a conservative approach incorporating the MDA for nondetect measurements as a value, and (2) an approach assuming a value of zero for nondetect measurements and using only the reported detected values for calculations. The resulting TED and DCS fractions were then compared to the criteria presented in Table 3-13.

The cumulative TED and DCS fraction values shown in Table 3-16 indicate that the results of effluent sampling events during 2019 at the KR4, KW, and KX P&T systems met monitoring criterion #3, with the exception of the March 14 sampling event at the KW P&T system. Only the conservative approach (likely driven by the combination of higher tritium, carbon-14, and nondetect strontium-90) resulted in the cumulative TED and DCS fraction values to meet monitoring criterion #2 for March 14.
The nonconservative approach for TED and DCS fraction value of March 14 for the KW P&T system met monitoring criterion #3.

Table 3-14. Summary of Effluent Radioisotope Sampling and Analysis Results for the KR4, KW, and KX P&T Systems, 2019

Sample Location	Sample Date	Tritium (pCi/L)	Strontium90* (pCi/L)	Carbon-14* (pCi/L)	Technetium-99* (pCi/L)
KR4 P&T System					
Effluent tank – T-K5	3/14/2019	3,120	(1.43)	40.9	(38.5)
Effluent tank – T-K5	6/18/2019	3,100	1.31	(34.1)	(43.3)
Effluent tank – T-K5	8/6/2019	2,950	1.41	(32.6)	104
Effluent tank – T-K5	12/12/2019	3,750	1.59	54	(20.4)
KW P&T System					
Effluent tank – T-W3	3/14/2019	1,230	(1.7)	412	52.9
Effluent tank – T-W3	6/18/2019	1,140	(1.11)	155	(45.3)
Effluent tank – T-W3	8/6/2019	1,470	(1.59)	134	55.3
Effluent tank – T-W3	12/19/2019	1,560	(1.86)	307	77.2
KX P&T System					
Effluent tank – T-X5	3/14/2019	4,610	(1.42)	54.2	(41.1)
Effluent tank – T-X5	6/18/2019	3,670	(1.12)	39.2	(48.1)
Effluent tank – T-X5	8/6/2019	3,570	(1.19)	63.2	(46.2)
Effluent tank – T-X5	12/19/2019	3,770	(1.44)	60.8	(43)

*Values in parentheses were reported as not detected. Values presented is the reported minimum detectable activity concentration for samples reported as analyzed but not detected.

P&T = pump and treat

Table 3-15. Derived Concentration Standards for Radioisotopes Evaluated in KR4, KW, and KX P&T System Effluent

DCS	Tritium	Strontium-90	Carbon-14	Technetium-99
DCS (µCi/mL)[a]	1.90E-03	1.10E-06	6.20E-05	4.40E-05
DCS (pCi/L)[b]	1.90E+06	1.10E+03	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 3-16. Calculated Individual Radioisotope Dose Contributions and TED for KR4, KW, and KX P&T System Effluent, 2019

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)	Strontium-90* (mrem/yr)	Carbon-14* (mrem/yr)	Technetium-99* (mrem/yr)				
KR4 P&T System									
Effluent tank – T-K5	3/14/2019	1.64E-01	(1.30E-01)	6.60E-02	(8.75E-02)	0.448	0.004	0.230	0.002
Effluent tank – T-K5	6/18/2019	1.63E-01	1.19E-01	(5.50E-02)	(9.84E-02)	0.436	0.004	0.282	0.003
Effluent tank – T-K5	8/6/2019	1.55E-01	1.28E-01	(5.26E-02)	2.36E-01	0.572	0.006	0.392	0.004
Effluent tank – T-K5	12/12/2019	1.97E-01	1.45E-01	8.71E-02	(4.64E-02)	0.475	0.005	0.284	0.003
KW P&T System									
Effluent tank – T-W3	3/14/2019	6.47E-02	(1.55E-01)	6.65E-01	1.20E-01	1.004	0.010	0.849	0.008
Effluent tank – T-W3	6/18/2019	6.00E-02	(1.01E-01)	2.50E-01	(1.03E-01)	0.514	0.005	0.310	0.003
Effluent tank – T-W3	8/6/2019	7.74E-02	(1.45E-01)	2.16E-01	1.26E-01	0.564	0.006	0.419	0.004
Effluent tank – T-W3	12/19/2019	8.21E-02	(1.69E-01)	4.95E-01	1.75E-01	0.922	0.009	0.753	0.008
KX P&T System									
Effluent tank – T-X5	3/14/2019	2.43E-01	(1.29E-01)	8.74E-02	(9.34E-02)	0.553	0.006	0.330	0.003
Effluent tank – T-X5	6/18/2019	1.93E-01	(1.02E-01)	6.32E-02	(1.09E-01)	0.468	0.005	0.256	0.003
Effluent tank – T-X5	8/6/2019	1.88E-01	(1.08E-01)	1.02E-01	(1.05E-01)	0.503	0.005	0.290	0.003
Effluent tank – T-X5	12/19/2019	1.98E-01	(1.31E-01)	9.81E-02	(9.77E-02)	0.525	0.005	0.296	0.003

Note: Yellow-shaded cells indicate that cumulative TED and DCS fraction values meet criterion #2 in Table 3-13. Unshaded cells indicate that cumulative TED and DCS fraction values meet criterion #3 in Table 3-13.

*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.

DCS = derived concentration standard

P&T = pump and treat

TED = total effective dose

3.3.2 Comparison of KR4, KW, and KX Pump and Treat System Effluent Water Radiological Constituents to Drinking Water Standards for Beta/Photon Emitters and Uranium for 2019

The radioisotopes measured in P&T effluent from the KR4, KW, and KX P&T systems were evaluated against the 4 mrem/yr drinking water MCL for beta and photon emitters. The cumulative beta/photon dose MCL is based on a sum-of-fractions calculation using the derived concentration values published by EPA. The beta/photon MCL dose analysis was performed in two ways: (1) using the reported MDA as a value for measurements reported as nondetects, and (2) an approach assuming a value of zero for nondetect measurements and using only the reported detected values for calculations. The first approach is a conservative screen used to assess potential dose contributions. With both methods, the effluent evaluated at the KR4, KW, and KX P&T systems consistently remained below the 4 mrem/yr drinking water MCL. Table 3-17 summarizes this evaluation.

3.3.3 Conclusions of Evaluation of Radiological Constituents in KR4, KW, and KX Pump and Treat Effluent Water for 2019

Evaluation of radiological dose of the KR4, KW, and KX P&T systems' effluent water during 2019 indicates that the effluent met the following standards and criteria:

- The calculated DCS-based TED of the effluent for KR, KW, and KX P&T systems was <1 mrem/yr, substantially below the 100 mrem/yr public dose limit using the conservative and nonconservative approach for all sampling events except for the March 14 event at the KW P&T system. The conservative approach from March 14 met criterion #2, but the nonconservative approach still meets criterion #3.

- The calculated DCS-based sum of fractions and resulting TED of the effluent for the KR4, KW, and KX P&T systems were consistent with recommended monitoring criteria, indicating that monthly sampling and analysis with annual review remains at an appropriate frequency.

- The calculated MCL-based beta/photon-emitter drinking water dose was below the 4 mrem/yr MCL dose for all three of the P&T systems.

No changes in the effluent monitoring sampling and analysis frequency or analytical suite are indicated for 2020.

Table 3-17. Summary of Drinking Water Beta/Photon Emitter MCL Comparison for KR4, KW, and KX P&T System Effluent, 2019

Sample Location	Sample Date	Contributing Radioisotopes				Sum of Fractions[b]	Drinking Water β/ϒ Dose (mrem/yr)[b]	Sum of Fractions Detects Only[c]	Drinking Water β/ϒ Dose from Detects Only (mrem/yr)[c]
		Tritium	Strontium-90[a]	Carbon-14[a]	Technetium-99[a]				
		Derived Concentrations (pCi/L)							
		20,000	8	2,000	900				
		Beta/Photon MCL Fraction							
KR4 P&T System									
Effluent tank – T-K5	3/14/2019	0.156	(0.179)	0.020	(0.043)	0.40	1.59	0.18	0.71
Effluent tank – T-K5	6/18/2019	0.155	0.164	(0.017)	(0.048)	0.38	1.54	0.32	1.28
Effluent tank – T-K5	8/6/2019	0.148	0.176	(0.016)	0.116	0.46	1.82	0.44	1.76
Effluent tank – T-K5	12/12/2019	0.188	0.199	0.027	(0.023)	0.44	1.74	0.41	1.65
KW P&T System									
Effluent tank – T-W3	3/14/2019	0.0615	(0.2125)	0.2060	0.0588	0.54	2.16	0.33	1.31
Effluent tank – T-W3	6/18/2019	0.0570	(0.1388)	0.0775	(0.0503)	0.32	1.29	0.13	0.54
Effluent tank – T-W3	8/6/2019	0.0735	(0.1988)	0.0670	0.0614	0.40	1.60	0.20	0.81
Effluent tank – T-W3	12/19/2019	0.0780	(0.2325)	0.1535	0.0858	0.55	2.20	0.32	1.27
KX P&T System									
Effluent tank – T-X5	3/14/2019	0.2305	(0.1775)	0.0271	(0.0457)	0.48	1.92	0.26	1.03
Effluent tank – T-X5	6/18/2019	0.1835	(0.1400)	0.0196	(0.0534)	0.40	1.59	0.20	0.81
Effluent tank – T-X5	8/6/2019	0.1785	(0.1488)	0.0316	(0.0513)	0.41	1.64	0.21	0.84
Effluent tank – T-X5	12/19/2019	0.1885	(0.1800)	0.0304	(0.0478)	0.45	1.79	0.22	0.88

a. Values in parentheses were reported as nondetects; the value is the reported value of the minimum detectable activity.

b. Sum of MCL fractional derived concentration values and calculated MCL dose, including nondetect values using the minimum detectable activity as a value.

c. Sum of MCL fractional derived concentration values and calculated MCL dose, excluding nondetect measurements.

MCL = maximum contaminant level

P&T = pump and treat

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 2019. 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 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 P&T operations and periodic maintenance.
- **Performance monitoring:** Includes system and groundwater sampling and sample analysis as required in accordance with the 100-KR-4 OU RD/RAWP (DOE/RL-2013-33) for the interim action. Sampling activities for routine groundwater monitoring are integrated for all groundwater OUs to reduce overall labor with sample trips and analytical costs. These costs have been pooled in a separate project account and have not been included in the 100-KR-4 OU performance monitoring costs. To account for all performance monitoring costs associated with implementation of remedial actions for the 100-KR-4 OU, a portion of the pooled costs based on sample trips and analyses performed for the 100-KR-4 OU have been included to the performance monitoring costs in this year's report.
- **Waste management:** Includes the cost for managing spent resin at the 100-KR-4 OU in accordance with applicable laws for suspect hazardous, toxic, and regulated wastes. Costs includes waste designation sampling and analysis, resin regeneration, and new resin purchase.

The costs include all activities associated with the interim remedial actions, including construction of new wells and interim action performance monitoring. The 100-KR-4 OU costs for 2019 are associated with three P&T systems (KR4, KW, and KX). The total cost breakdown includes nonrecurring costs related to installing new wells and the P&T system modifications described in Section 3.2. Tables 3-18 through 3-20 provide the yearly cost breakdowns for each of the KR4, KW, and KX P&T systems, respectively. The costs are burdened and are based on actual operating costs incurred during 2019.

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

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Table 3-18. 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	2017	2018	2019
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	91.2	0.0	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	435.1	291.5	122.4
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	96.3	45.5	179.7
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	862.0	1,004.3	663.5
Performance monitoring[i]	111.2	122.6	124.6	119.7	83.3	446.3	548.8	395.7	634.9	569.1	928.1	1,243.8	758.1	550.0	462.7	337.5	523.8	371.1	288.0	499.8
Waste management	481.8	367.5	343.3	684.7	475.8	198.3	230.2	458.9[j]	438.2	599.8	266.7	110.6	17.3	0.0	0.0	3.4	28.4	48.7	97.1	43.4
Field studies	—	—	—	—	—	—	—	—	—	25.0	653.1	3.0	0.2	(0.0)	0.0	0.0	0.0	55.5	52.0	9.2
Well realignment[k]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.0	38.6	29.7
Totals	**$1,383**	**$1,353**	**$2,413**	**$2,216**	**$2,147**	**$2,840**	**$4,264**	**$4,450**	**$11,384**	**$9,796**	**$6,925**	**$4,277**	**$1,865**	**$1,787**	**$2,218**	**$1,453**	**$1,481**	**$1,960**	**$1,817**	**$1,548**

a. The 2001 costs were corrected for project support and waste management. Initial expense calculations for 2001 were not properly categorized.

b. The 2002 accrual costs were corrected for appropriate split between Bechtel Hanford, Inc. and Fluor Hanford, Inc.

c. Annual report 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 KX P&T system costs prior to startup are included in 2009.

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

f. Additional design costs were associated with P&T expansion.

g. Additional treatment system capital construction costs were associated with new wells and buildings to support P&T system expansion.

h. Includes costs for facility modifications to change ion-exchange resin from Dowex® 21K (a registered trademark of Dow Chemical Company, Midland, Michigan) to ResinTech® SIR-700 (a registered trademark of ResinTech, Inc., West Berlin, New Jersey).

i. Performance monitoring costs have been adjusted back through 2011 to include pooled sampling costs for groundwater monitoring proportioned to the KR4 P&T system.

j. Additional costs were associated with drilling waste and resin cleared for shipment and handling.

k. Well realignment costs were provided separately beginning in 2017.

— = not available

P&T = pump and treat

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Table 3-19. Breakdown of KW P&T System Costs

Description	Actual Costs (Dollars × 1,000)												
	2007	**2008**	**2009[a]**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Design	13.0	27.7	78.1	11.6	20.0	8.6	20.6	32.4	47.1	0.0	91.2	173.2	0.2
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	435.1	694.7	97.0
Project support	118.9	155.3	174.1	77.6[c]	94.3	58.0	121.0	240.9	75.4	60.7	92.8	79.4	131.5
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	695.2	836.1	671.1
Performance monitoring[e]	9.7	126.6	215.9	528.9[c]	1,020.8	758.1	553.2	460.8	337.7	861.3	373.8	274.8	506.1
Waste management	405.4	164.3	95.4	207.5 [c]	84.0	84.6	0.0	0.0	3.5	27.7	42.8	65.4	89.8
Field studies	—	—	—	—	—	—	—	0.0	0.0	0.0	263.3	381.9	1,631.1
Well realignment[f]	—	—	—	—	—	—	—	—	—	—	284.8	24.1	18.6
Totals	**$3,137**	**$2,162**	**$3,624**	**$2,300**	**$2,260**	**$909**	**$1,943**	**$2,240**	**$1,365**	**$1,720**	**$2,279**	**$2,530**	**$3,145**

a. Annual report 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 (a registered trademark of Dow Chemical Company, Midland, Michigan) to ResinTech® SIR-700 (a registered trademark of ResinTech, Inc., West Berlin, New Jersey).

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 P&T system.

e. Performance monitoring costs have been adjusted back through 2011 to include pooled sampling costs for groundwater monitoring proportioned to the KW P&T system.

f. Well realignment costs were provided separately beginning in 2017.

— = not available

P&T = pump and treat

Table 3-20. Breakdown of KX P&T System Costs

Description	Actual Costs (Dollars × 1,000)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Design	31.4	21.4	2.8	9.5	46.0	51.5	0.0	91.2	0.0	0.0
Treatment system capital construction	22.9	(1.7)	639.9[a]	62.5	462.6	122.9	252.3	435.1	583.0	244.9
Project support	77.6	94.3	58.0	161.3	221.8	75.4	60.7	125.8	90.0	411.7
Operations and maintenance	1,224.4	1,647.8	1,340.4[b]	1,875.0	1,530.6	1,907.1	2,745.1	1,945.9	1,693.2	1,029.7
Performance monitoring[c]	528.9	1020.8	758.1	545.1	459.2	335.9	490.0	387.4	333.7	512.5
Waste management	579.6	219.1	2.1	0.0	0.0	3.3	31.7	409.9	313.3	194.2
Field studies	—	—	—	—	0.0	0.0	0.0	4.7	0.4	0.0
Well realignment[d]	—	—	—	—	—	—	—	634.5	85.4	59.7
Totals	**$2,465**	**$3,002**	**$821**	**$2,653**	**$2,521**	**$2,496**	**$3,580**	**$4,035**	**$3,099**	**$2,453**

a. Includes costs for facility modifications to change ion-exchange resin from Dowex® 21K (a registered trademark of Dow Chemical Company, Midland, Michigan to ResinTech® SIR-700 (a registered trademark of ResinTech, Inc., West Berlin, New Jersey).

b. Includes costs for connecting extraction well 199-K-182 to the KX P&T system.

c. Performance monitoring costs have been adjusted back through 2011 to include pooled sampling costs for groundwater monitoring proportioned to the KX P&T system.

d. Well realignment costs were provided separately from operations and maintenance costs beginning in 2017.

— = not available

P&T = pump and treat

3.4.1 KR4 Pump and Treat System

Table 3-18 shows the total cost for the KR4 P&T system during 2019 was $1.55 million, which consists of the sum of the categories. Previous performance monitoring costs for 2011 through 2018 reported in previous annual P&T reports (e.g., DOE/RL-2018-67) shown in Table 3-18 have been adjusted to include the percentage of pooled groundwater monitoring cost apportioned to the 100-KR-4 OU following continuous operations of all the 100-KR-4 OU P&T systems. The percentage that each category comprises of the total cost for the KR4 P&T system (Figure 3-34) is as follows, in decreasing order:

- **O&M:** 42.9% ($663,500)
- **Performance monitoring:** 32.3% ($499,800; $467,000 apportioned from pooled groundwater monitoring cost)
- **Project support:** 11.6% ($179,700)
- **Treatment system capital construction:** 7.9% ($122,400)
- **Waste management:** 2.8% ($43,400)
- **Well Realignments:** 1.9% ($29,700)
- **Field studies:** 0.6% ($9,200)
- **Design:** negligible in 2018

Based on the total 2019 cost of $1,548,000, the yearly production rate of 504 million L (133 million gal), and 1.69 kg of Cr(VI) removed, the annual treatment cost is $0.0031/L, or $916/g of Cr(VI) removed.

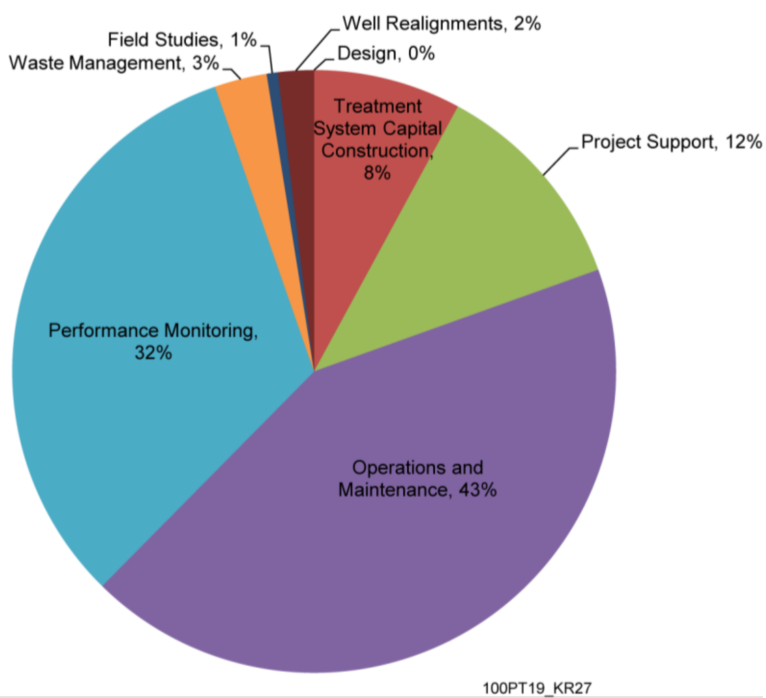

Figure 3-34. KR4 P&T System, 2019 Cost Breakdown (by Percentage)

3.4.2 KW Pump and Treat System

The total cost for the KW P&T system during 2019 was $3.15 million, which consists of the sum of the categories shown in Table 3-19. The increased cost from 2018 is associated with the soil flush treatability test conducted at the 183.1KW Headhouse area as reflected in the increased field studies costs. Performance monitoring costs for 2011 through 2018 reported in previous P&T reports (e.g., DOE/RL-2018-67) shown in Table 3-19 have been adjusted to include the percentage of pooled groundwater monitoring cost apportioned to the 100-KR-4 OU following continuous operations of all the 100-KR-4 OU P&T systems. The percentage that each category comprises of the total cost for the KW P&T system (Figure 3-35) is as follows, in decreasing order:

- **Field studies:** 51.9% ($1,631,100)
- **O&M:** 21.3% ($671,100)
- **Performance monitoring:** 16.1% ($506,100; $467,000 apportioned from pooled groundwater monitoring cost)
- **Project support:** 4.2% ($131,500)
- **Treatment system capital construction:** 3.1% ($97,000)
- **Waste management:** 2.9% ($89,800)
- **Well realignment:** 0.6% ($18,600)
- **Design:** negligible costs in 2019

Based on the total 2019 cost of $3,145,000, the yearly production rate of 537 million L (142 million gal), and 19.6 kg of Cr(VI) removed, the annual treatment costs are $0.0059/L, or $160/g of Cr(VI) removed.

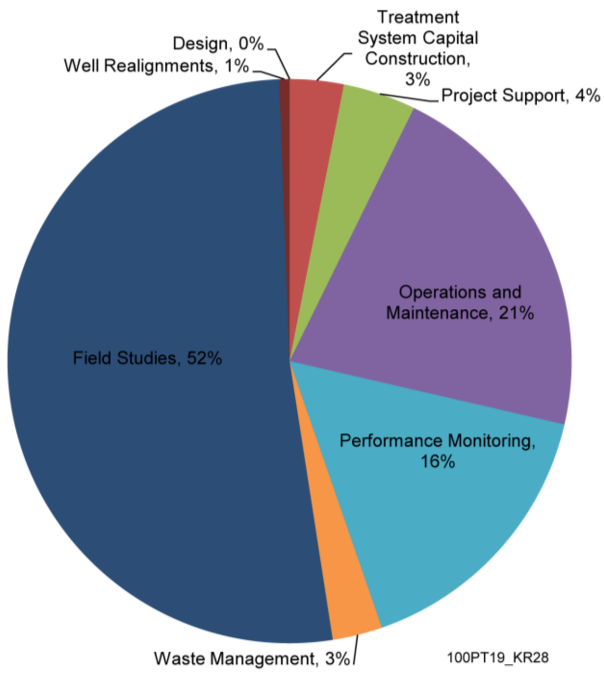

Figure 3-35. KW P&T System, 2019 Cost Breakdown (by Percentage)

3.4.3 KX Pump and Treat System

The total cost for the KX P&T system for 2019 was $2.45 million (Table 3-20). Performance monitoring costs for 2011 through 2018 reported in previous P&T reports (e.g., DOE/RL-2018-67) shown in Table 3-19 have been adjusted to include the percentage of pooled groundwater monitoring cost apportioned to the 100-KR-4 OU following continuous operations of all the 100-KR-4 OU P&T systems. The percentage that each category comprises of the total cost for the KX P&T system (Figure 3-36) is as follows, in decreasing order:

- **O&M:** 42.0% ($1,029,700)
- **Performance monitoring:** 20.9% ($512,500)
- **Project support:** 16.8% ($411,700)
- **Treatment system capital construction:** 10.0% ($244,900)
- **Waste management:** 7.9% ($194,200)
- **Well realignment:** 2.4% ($59,700)
- **Design and field studies:** negligible costs in 2019

Based on the total 2019 cost of $2,453,000, the yearly production rate of 1,786 million L (472 million gal), and 27.3 kg of Cr(VI) removed, the annual treatment costs are $0.0014/L, or $89.87/g of Cr(VI) removed.

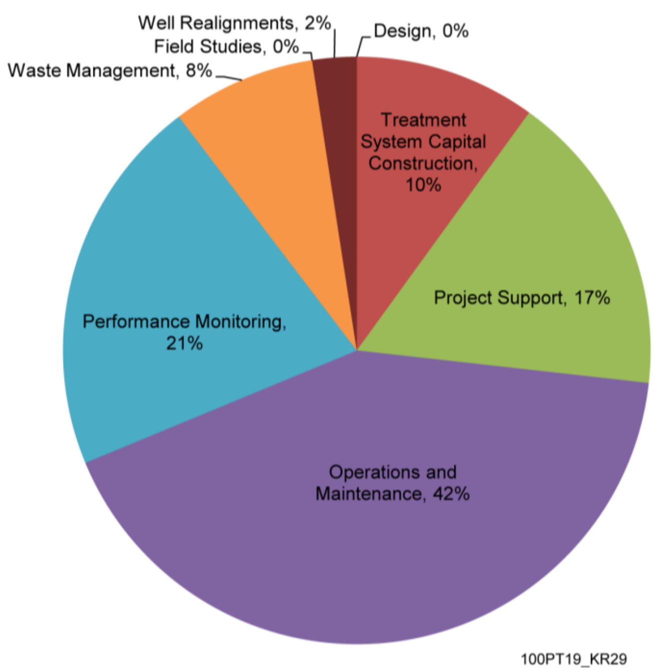

Figure 3-36. KX P&T System, 2019 Cost Breakdown (by Percentage)

3.5 Conclusions

Remedial progress has been achieved for 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 interim action RAOs:

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

  Results: 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 2019 that are consistent with the previous few years of effective river protection. The assessment indicates that, in general, river protection status in 2019 was similar to that in 2018. In K West, the seasonal operation of well 199-K-196 continued to result in a relatively weak hydraulic containment at the K West shoreline throughout 2019, even though concentrations in aquifer tubes remained <10 µg/L. Cr(VI) migration caused by the infiltration test at the 183.1KW Headhouse area was well contained, except for a portion of the plume that was pushed farther west and through a paleochannel, migrating faster than the remainder of the plume, toward the shoreline and at the edge of the containment zone.

  The effectiveness on river protection for the extraction wells operating near the shoreline will continue to be evaluated, and priority will be given to maintaining primary river protection wells during facility maintenance activities. Aquifer tubes AT-K-3-D, AT-K-3-M, AT-K-3-S, 22-D, and 22-M (which were extended to allow sampling during high river-stage conditions) will continue to be monitored to help determine if Cr(VI) is migrating to the shoreline from inland or if it is present in low-transmissivity zones leaching slowly into the aquifer.

  As conditions change, the P&T systems will continue to be evaluated through RPO, as defined in DOE/RL-2013-33.

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

  Results: The interim 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 MSA-1105355.6. ICs remain in operation in the 100-KR-4 OU.

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

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

An evaluation of information from multiple activities indicates that while interim groundwater remedial actions in 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. In 2019, a soil flushing treatability test (in accordance with DOE/RL-2017-30) was implemented in the 183.1KW Headhouse area. The goal of soil flushing is to remove Cr(VI) from the deep portions of the vadose zone by flushing the contaminant material into the groundwater and then capturing it with the active P&T system to remove the contaminant from groundwater. As a result of the test, the total mass of Cr(VI) removed increase from 7.6 to 19.6 kg between 2018 and 2019. The results of the treatability test will be evaluated and the information considered in the development of the final 100-K Area FS report.

In addition to information regarding Cr(VI) distribution and behavior, the interim remedial action and its associated monitoring activities have provided additional information regarding the nature and extent of groundwater plumes for other contaminants present in the 100-KR-4 OU (i.e., strontium-90, tritium, nitrate, carbon-14, and TCE).

The evaluation of radiological doses of KR4, KW, and KX P&T system effluent during 2019 indicates that the calculated DCS-based TED was below the 100 mrem/yr standard, and the calculated MCL-based beta/photon-emitter drinking water dose was below the 4 mrem/yr drinking water MCL.

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4 100-NR-2 Operable Unit Remediation

This chapter provides the annual performance summary for 100-NR-2 OU groundwater remediation, as required by the RD/RAWP (DOE/RL-2001-27). The apatite PRB performance is discussed, and an update is provided on the remediation of petroleum hydrocarbon contamination. Groundwater monitoring data collected during 2019 that are pertinent to the interim remedial action are also provided.

4.1 Overview of Operable Unit Activities

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 CERCLA interim action for remediation of strontium-90 and petroleum hydrocarbon contamination in groundwater for the 100-NR-2 OU is identified in the 1999 interim action ROD (EPA/ROD/R10-99/112, *Interim Remedial Action Record of Decision, U.S. Department of Energy / Hanford 100 Area, 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*, as amended (EPA, 2010).

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

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

  Status: Wells for future apatite chemical injection were installed and completed in 2010 to enable expansion of the PRB to 760 m (2,500 ft). This included installing 146 injection wells and 25 monitoring wells along the 100-N Area shoreline. Wells were installed both upriver and downriver, adjacent to the original 16-well (91 m [300 ft] long) PRB.

  Future apatite solution injections will extend the apatite PRB along the 100-N Area shoreline to intercept the strontium-90 groundwater plume before it reaches the Columbia River. Section 4.4 discusses the performance for 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*; 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. These injections extended the apatite barrier by 110 m (360 ft) upriver and 110 m (360 ft) downriver (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 sampled in 2019 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 details for the three segments of the apatite PRB that have received apatite treatment to date.

  Jet injection of apatite into the vadose zone (in accordance with DOE/RL-2010-68) along the PRB well network to enhance the existing PRB treated interval has not been conducted.

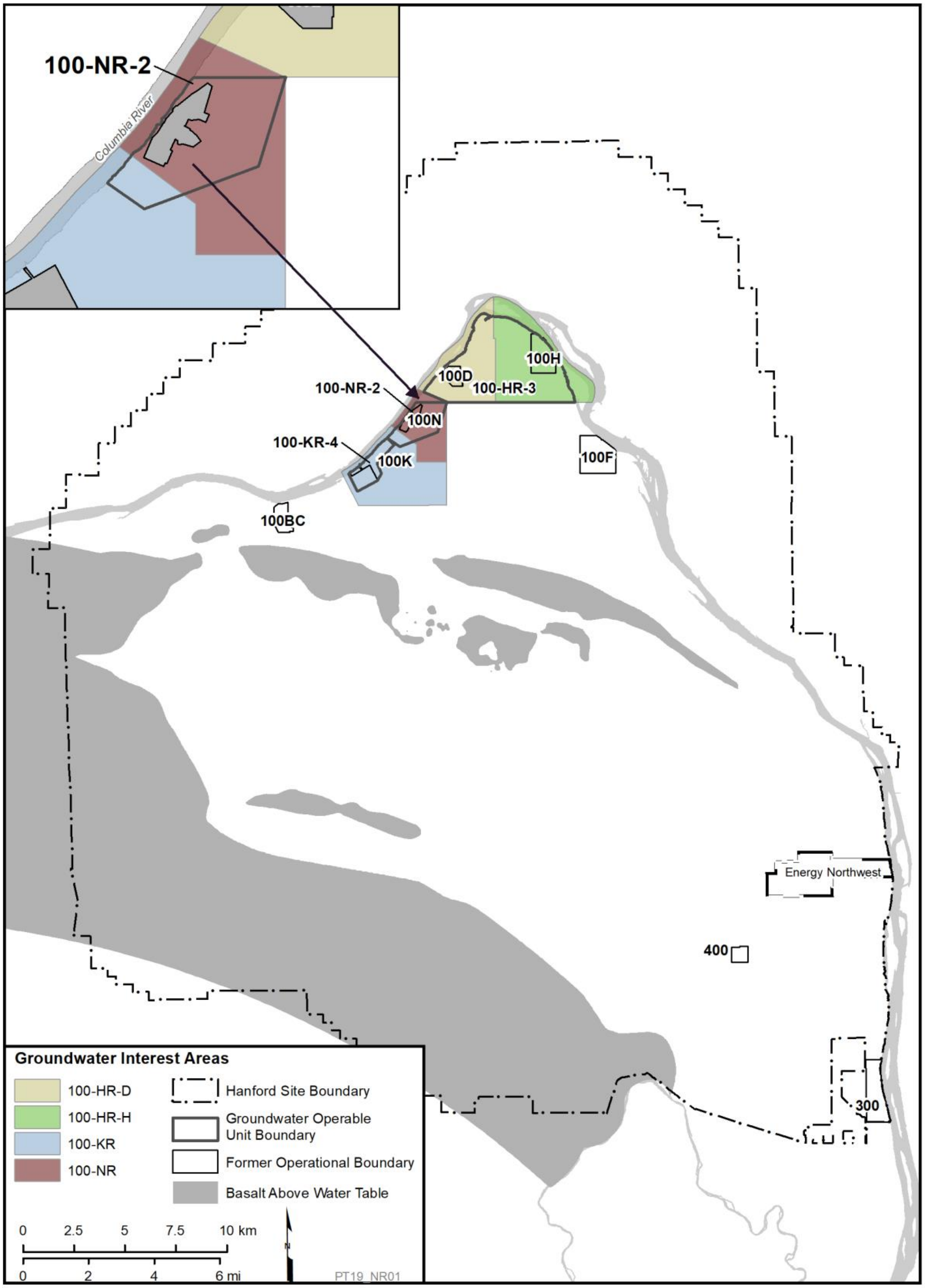


Figure 4-1. Location of the 100-NR-2 OU

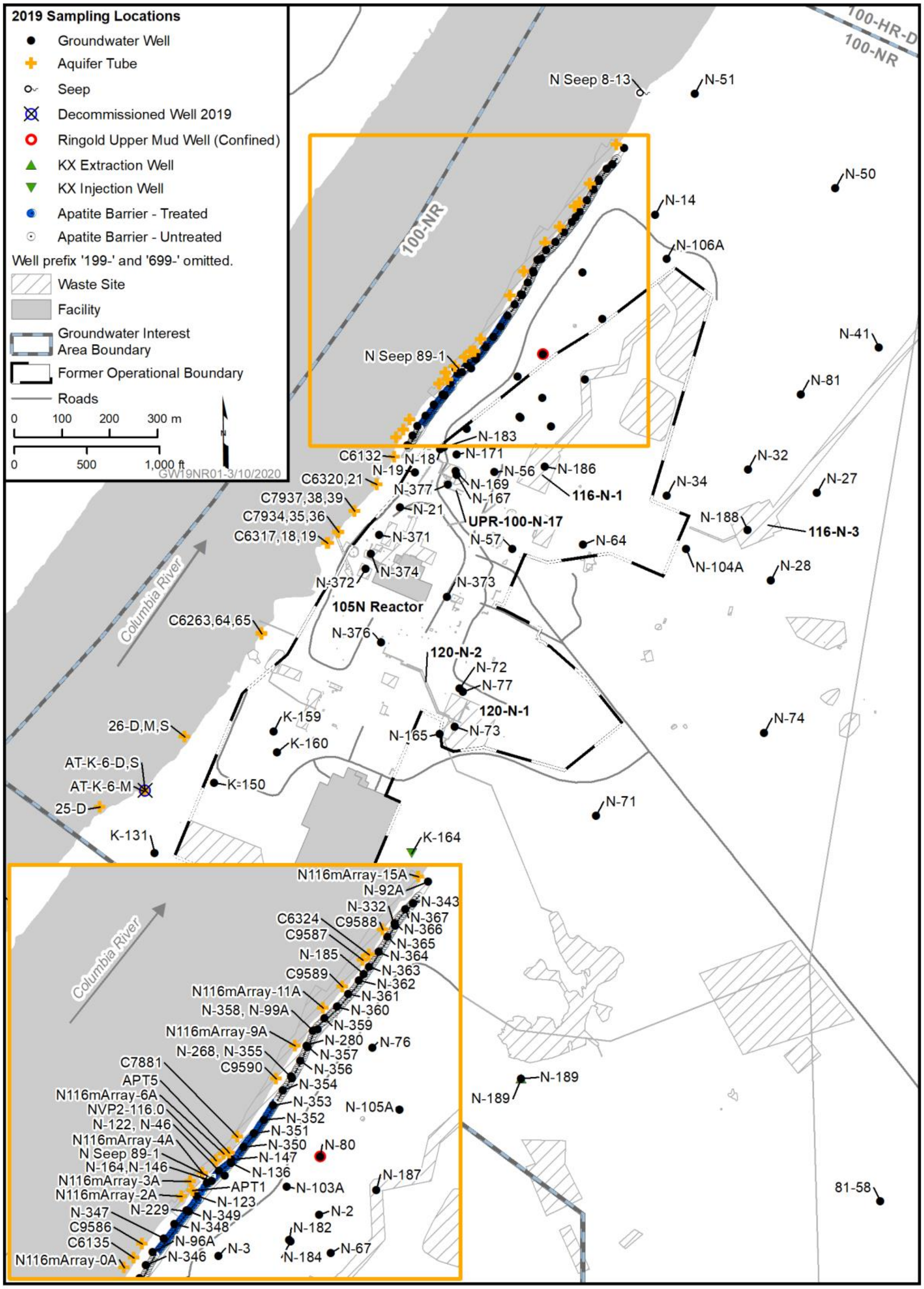


Figure 4-2. Groundwater Sampling Locations in the 100-N Area

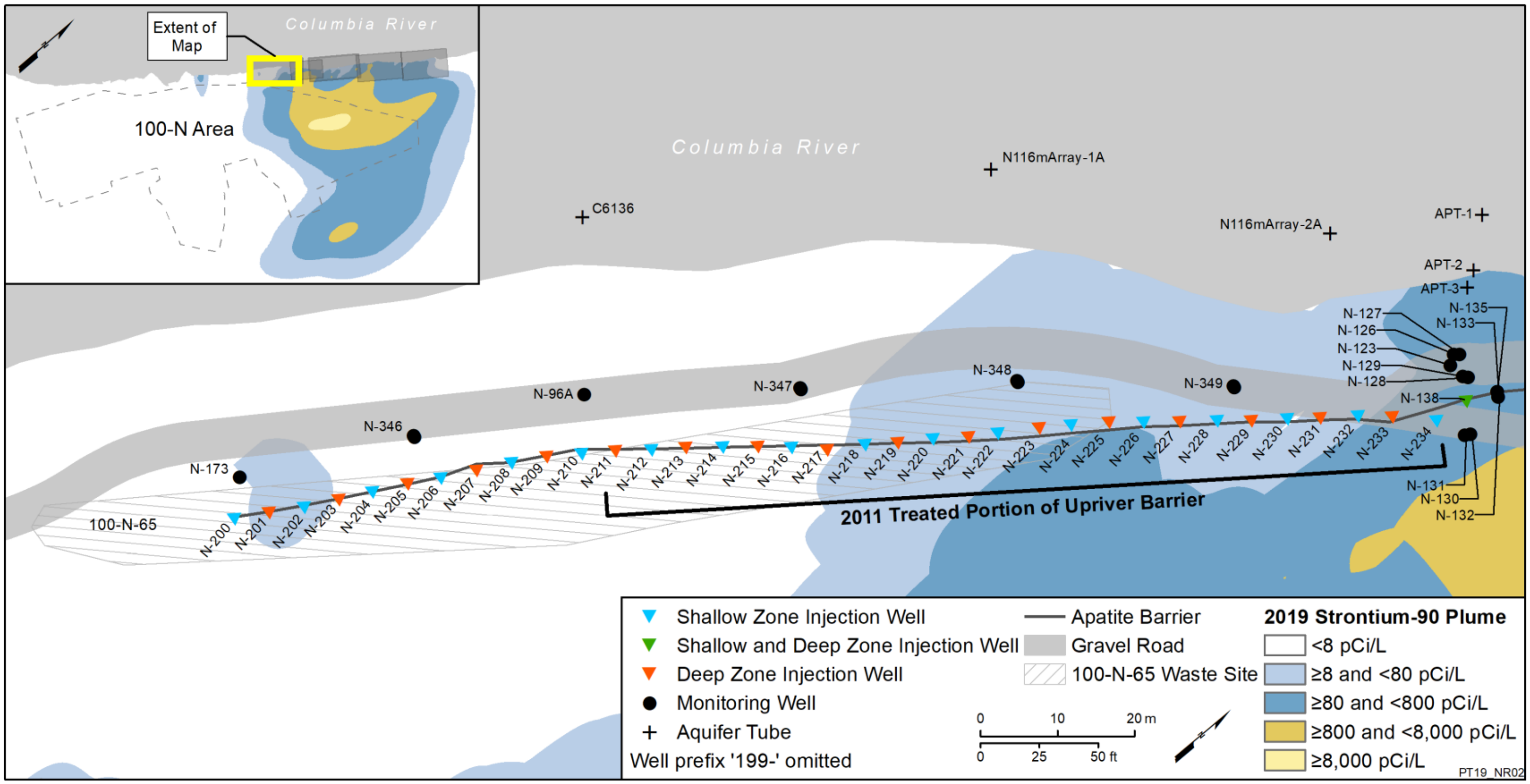


Figure 4-3. Upriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes Along the Columbia River Shoreline

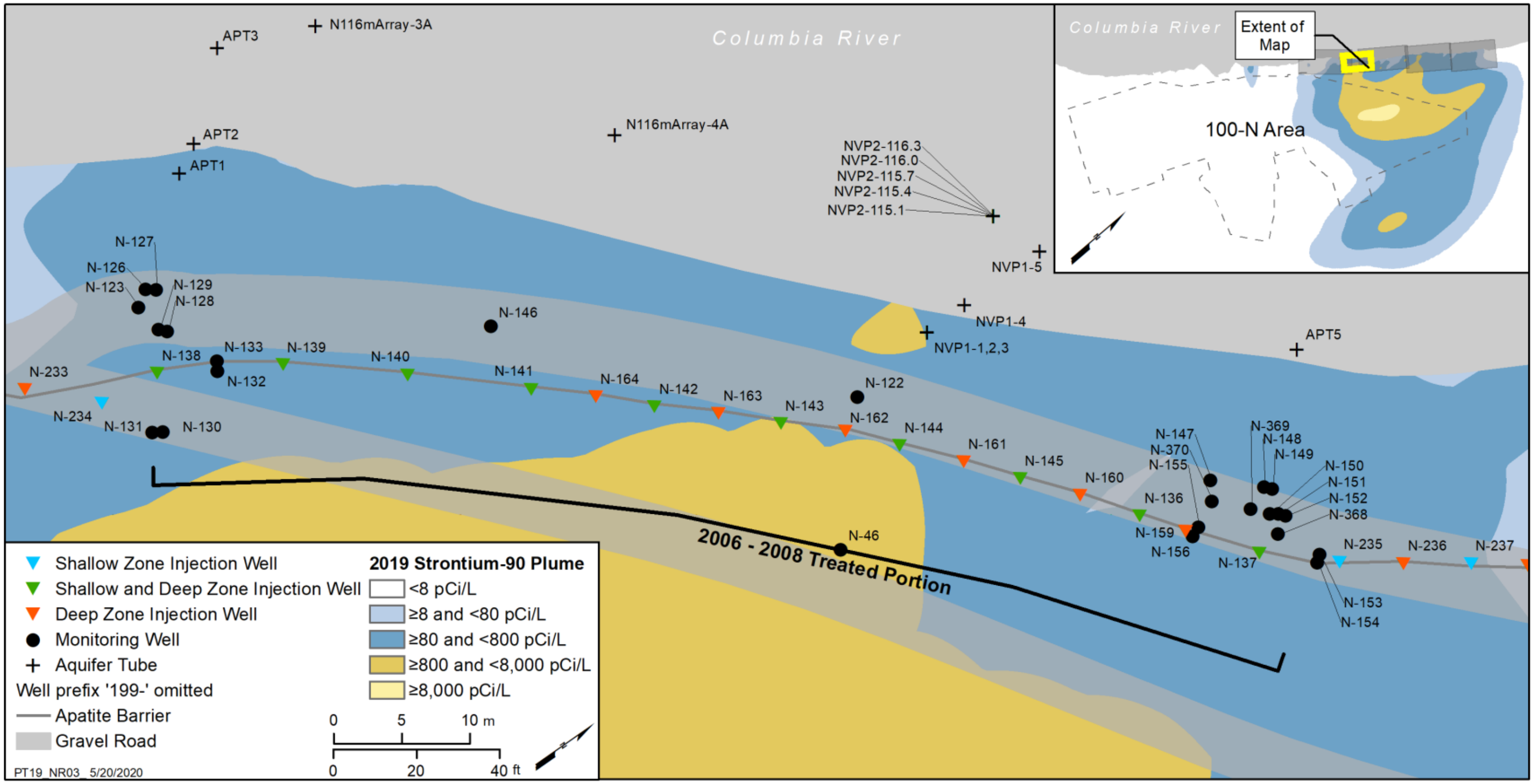


Figure 4-4. Central (Original) Apatite Barrier Monitoring Wells and Aquifer Tubes Along the Columbia River Shoreline

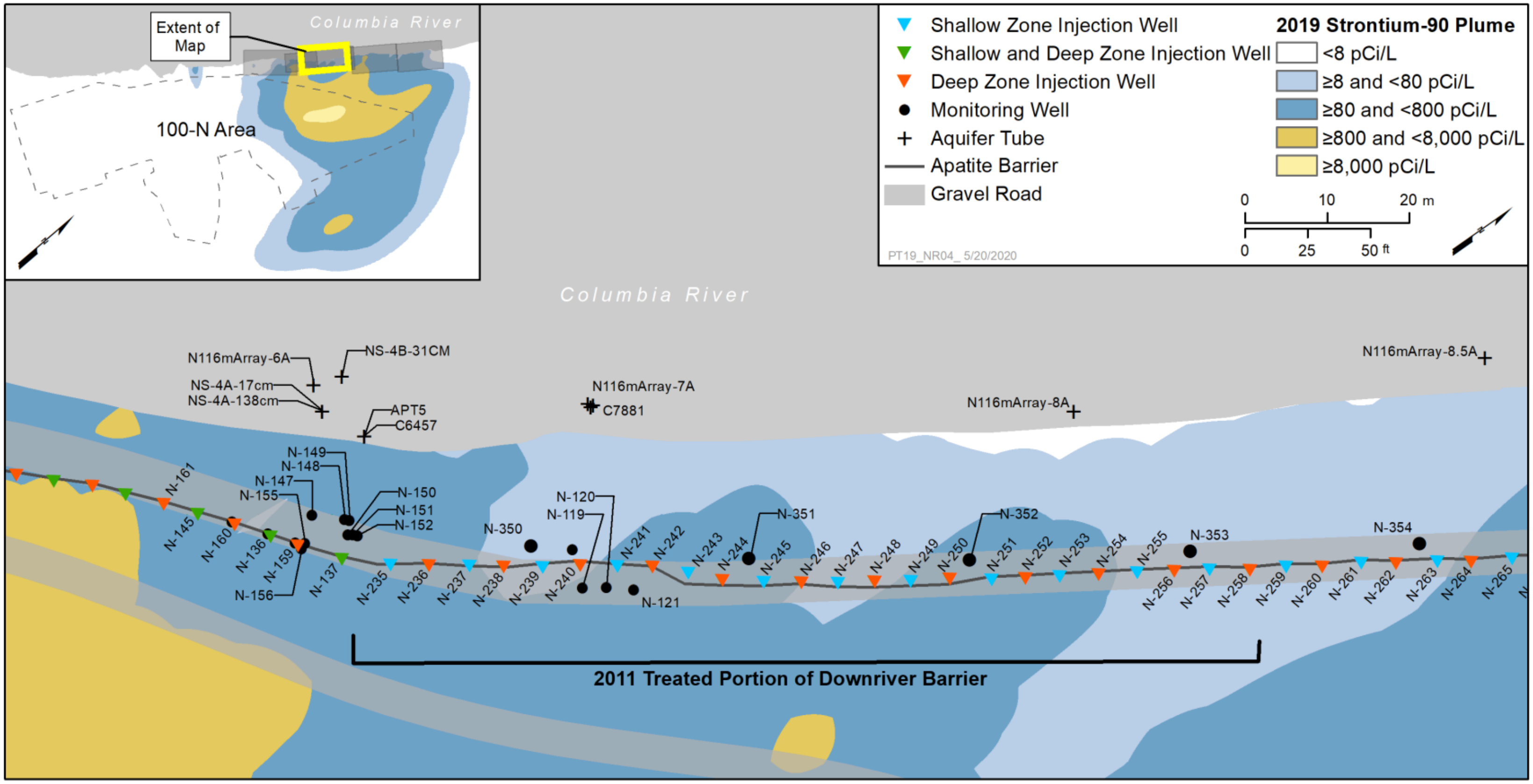


Figure 4-5. Downriver Extension Apatite Barrier Monitoring Wells and Aquifer Tubes Along the Columbia River Shoreline

- Apply one additional round of apatite injections within 5 years of completing all first-round apatite injections.
- **Status:** Additional rounds of injections were not performed in 2019 because all first-round apatite injections have not been completed. Injections have not been completed since the work involved in completing the barrier will be conducted within a traditional cultural property boundary and has been delayed pending establishment of a memorandum of agreement to conduct the project activities deemed to have an adverse effect on the traditional cultural property. Efforts to establish a memorandum of agreement to expand the PRB were initiated in 2014 and will continue during 2020.
- Use MNA.

  Status: Strontium-90 moves very slowly through the aquifer and naturally attenuates by radioactive decay. Groundwater monitoring wells are periodically sampled in accordance with Appendix A of the RD/RAWP (DOE/RL-2001-27) to assess the ongoing decline in contaminant concentrations in the 100-NR-2 OU.
- Decommission the existing 100-NR-2 OU groundwater P&T system building and components. The P&T system has not operated since March 2006.

  Status: The P&T system was demolished, excavated, and removed in 2016. Demolition debris was disposed at the Environmental Restoration Disposal Facility (ERDF). The former P&T extraction wells were converted to support groundwater monitoring prior to starting demolition. Demolition and decommissioning were completed in 2017 to remove piping from the former injection wells and to demolish the 1323N sample shack (located near the Columbia River shoreline).
- Maintain existing ICs.

  Status: Existing ICs include entry restrictions (security), escorts and badging of site visitors, excavation permits, surveillance, posted signs, and 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 during 2019. Periodic groundwater monitoring is performed in accordance with Appendix A of the RD/RAWP (DOE/RL-2001-27). Further discussion is provided in Section 4.3.

The selected interim action remedy to address petroleum hydrocarbon 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 present as light nonaqueous-phase liquid (or 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. Smart sponge assemblies were used to absorb and remove petroleum hydrocarbons from well 199-N-18.

In 2017, smart sponge assemblies were also installed in well 199-N-183, which was drilled near well 199-N-18 as a replacement well. Diesel odor and an oil sheen have periodically been observed in the new well during sampling. Removal of petroleum hydrocarbon light nonaqueous-phase liquid from wells 199-N-18 and 199-N-183 continued during 2019 (see Section 4.5.2).

Other contaminants identified in the interim action ROD (EPA/ROD/R10-99/112) include nitrate, chromium (total), Cr(VI), tritium, manganese, and sulfate. Monitoring information for these groundwater contaminants is provided in Chapter 6 of the 2019 annual groundwater report (DOE/RL-2019-66).

4.2 Water-Level Monitoring

Water-level monitoring is conducted in the 100-N Area to assess groundwater flow direction. Groundwater generally flows north and 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 2019 was about 1.1 m (3.6 ft) (Figure 4-6).

Groundwater flow in the 100-NR-2 OU is influenced by Columbia River stage. The river stage can change daily (±1.5 m [5 ft]) and seasonally (±2.4 m [7.8 ft]), which affects the saturated thickness of the aquifer and may create temporal flow reversals (Section 1.1 in 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 stage is controlled by releases of water at Priest Rapids Dam, upstream from the Hanford Site. Figure 4-7 provides a hydrograph of 100-N Area river stage. The daily average river elevation in March ranged from 117.1 to 118.1 m (384.3 to 387.5 ft). The high river-stage period in 2019 occurred from April through mid-July, with the highest elevation recorded in May at 119.34 m (391.4 ft). The low river-stage period was from mid-August through November, with a low of 116.3 m (381.4 ft) in October. The river elevation in 2019 for the high river-stage period was lower than that observed in 2017 and 2018.

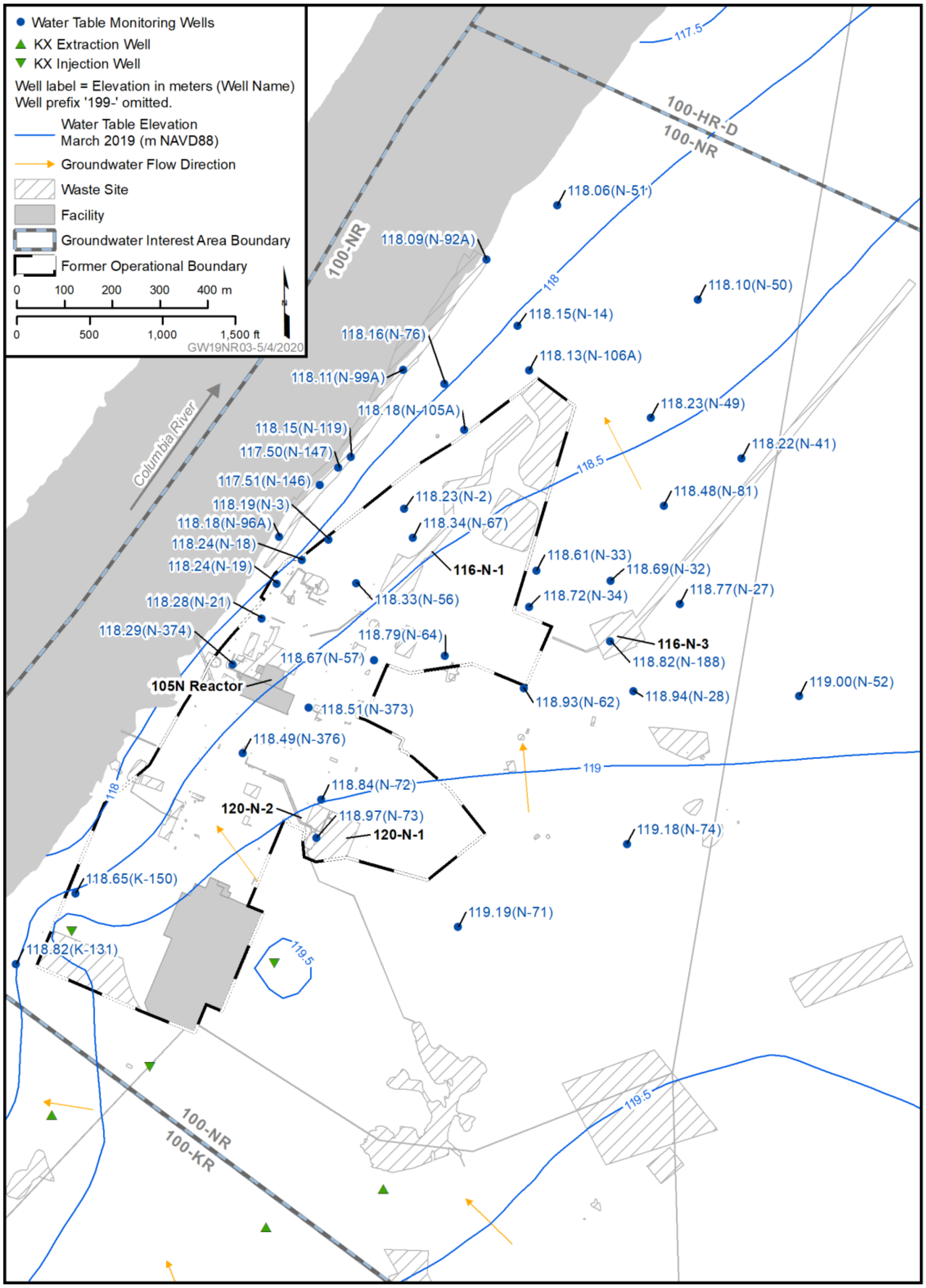
Groundwater flow in the southwestern portion of the 100-N Area is also influenced by groundwater extraction and injection through wells installed as part of the KX P&T remediation system for the 100-KR-4 OU (Chapter 3). A groundwater mound approximately 1 m (3.3 ft) high surrounding the KX P&T system injection wells in the southwestern portion of the 100-N Area creates local radial flow. A water table depression is also present around 100-KR-4 OU groundwater extraction wells along the 100-NR-2 OU/100-KR-4 OU boundary.

4.3 Groundwater Contaminant Sources and Monitoring

This section describes strontium-90 and petroleum hydrocarbon sources and groundwater monitoring performed in 2019.

4.3.1 Strontium-90

The primary source of strontium-90 in groundwater at the 100-N area was liquid waste disposed to two liquid waste disposal facilities (LWDFs) from N Reactor: the 116-N-1 Crib and Trench, and the 116-N-3 Crib and Trench (Figure 4-2). Concentrations in groundwater vary with fluctuating water levels and due to installation of the PRB along the shoreline. However, the size and shape of the strontium-90 plume (Figure 4-8) changes very little from year to year because of the low mobility of strontium-90 in groundwater.



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

Figure 4-6. 100-N Area Water Table Map, March 2019

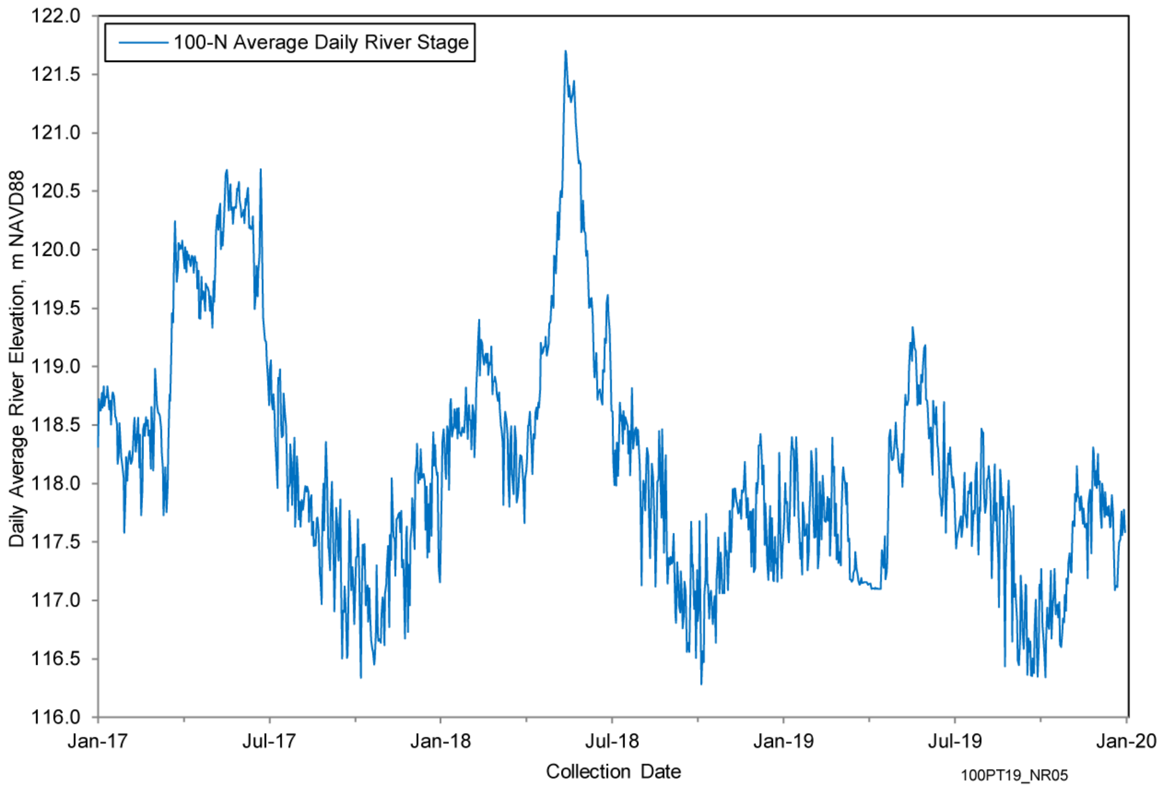


Figure 4-7. 100-N Area River Stage Derived from Priest Rapids Dam Data, 2017–2019 (Derived from Priest Rapids Dam Water Elevation)

The plume extends beneath the LWDFs to the Columbia River at concentrations above the DWS (8 pCi/L) (Figure 4-8). The highest concentration portion of the strontium-90 groundwater plume (i.e., the area with concentrations >800 pCi/L) primarily underlies the 116-N-1 Trench and extends northwest to near the Columbia River shoreline. The highest strontium-90 concentration in 100-NR-2 OU groundwater in 2019 was 11,400 pCi/L at well 199-N-67, located in the main body of the plume beneath the 116-N-1 Trench. Concentrations were also >800 pCi/L in well 199-N-188 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 LWDFs (areas of the highest original concentrations) and elongated toward the river parallel to the 116-N-1 waste site. Additional details on development of the strontium-90 plume interpretation are provided in Chapter 6 of the 2019 annual groundwater report (DOE/RL-2019-66).

Because strontium-90 adsorbs strongly to sediment grains, the majority of the strontium-90 remaining in the subsurface at the 100-N Area is in the lower vadose zone and upper portion of the unconfined aquifer sediments. Approximately 99% of the strontium-90 in the subsurface is adsorbed to the soil particles, and 1% 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*). Some strontium-90 is remobilized by seasonal water-level increases that release strontium-90 from sediments within the lower vadose zone that are not usually in contact with groundwater (PNNL-16891).

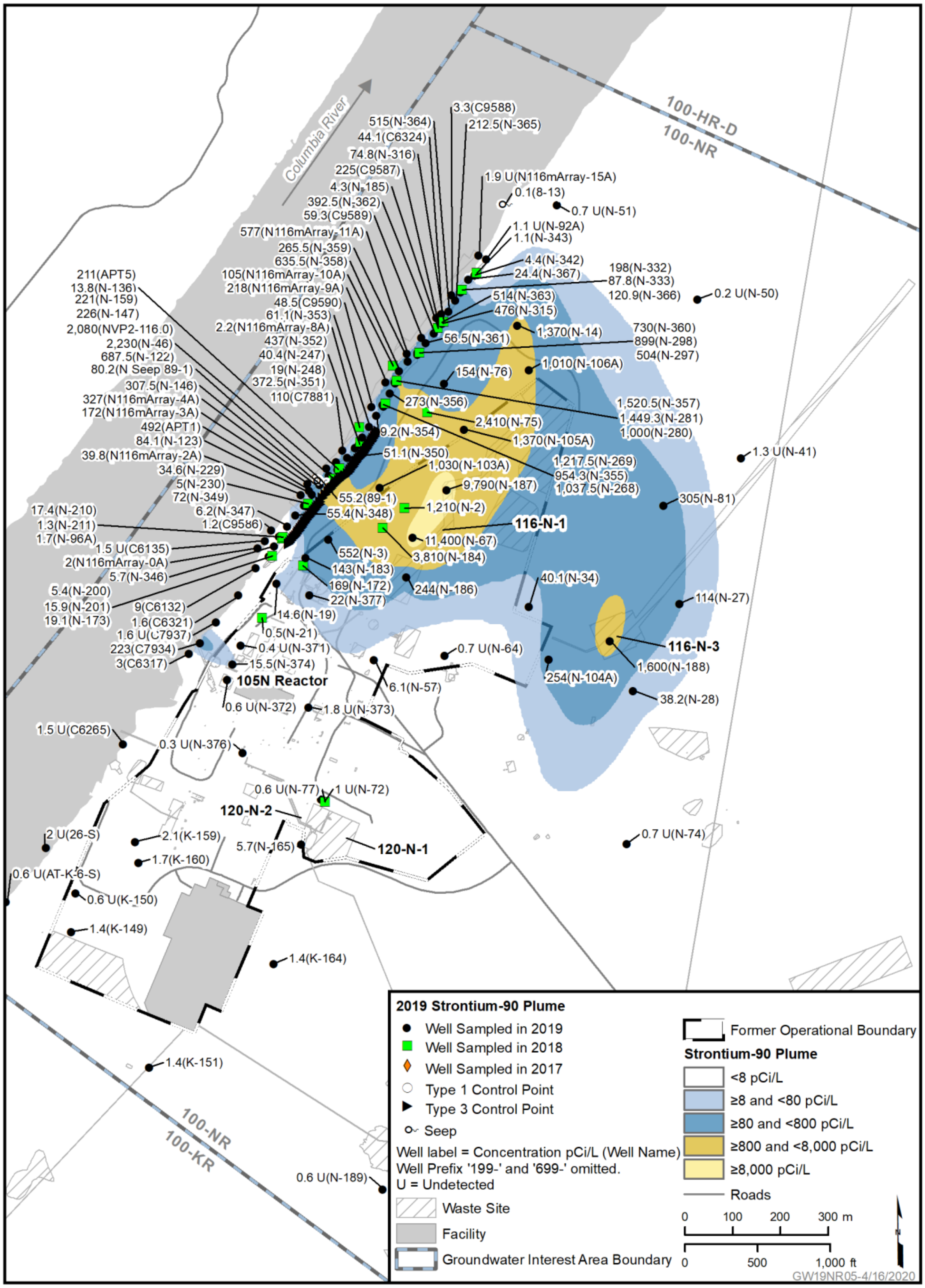


Figure 4-8. Strontium-90 Plume Map for the 100-N Area, 2019

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, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization, Final Report*). As a result of the low mobility of strontium-90 in groundwater, high strontium-90 concentrations (>150 pCi/L) are limited to the upper portion of the aquifer, binding to the soil in that area instead of migrating vertically through the aquifer thickness (DOE/RL-2019-66).

Table 4-1 lists the strontium-90 concentrations in selected monitoring wells and aquifer tubes, as well as information on how concentrations have changed between 1994 (pre-interim remedy P&T) and 2019.

Strontium-90 concentration trends in monitoring wells near the 116-N-1 waste site increase during higher water-level periods and decrease as water levels decline. 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. As the water table decreases, strontium-90 resorbs to sediment and concentrations in the groundwater decrease. Figure 4-9 shows strontium-90 concentration and water-level trends in well 199-N-67 (located downgradient of the liquid waste disposal end of the 116-N-1 Trench). 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 4-10 shows the 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 returned to pre-pumping levels, and strontium-90 concentrations in well 199-N-105A increased. The increase in groundwater concentrations at this well is due to the resaturation of strontium-90-contaminated sediments.

High water table elevations in 2011 and 2012 caused an increase in strontium-90 concentrations that continued through 2015 and then stabilized in 2016. The high river stage was higher in 2017 and over a longer period compared to that observed in 2016. The river stage was again higher in 2018 (Figure 4-7), resulting in an increase in strontium-90 concentrations measured in wells downgradient of the 116-N-1 Trench and 116-N-3 Crib (see information for wells 199-N-2, 199-N-105A, 199-N-184, and 199-N-188 in Table 4-1). The positive correlation of strontium-90 concentrations with water-level changes is more evident near the 116-N-1 and 116-N-3 waste sites, which presumably have more residual strontium-90 in the lower vadose zone than locations farther from the waste sites. Strontium-90 concentrations, as well as the water table elevation in well 199-N-81 (monitoring downgradient of the 116-N-3 Trench), have declined since the late 1990s (Figure 4-11). Strontium-90 concentrations in well 199-N-81 do not fluctuate as much with changing water elevations as wells near and downgradient of 116-N-1 (Figures 4-9 and 4-10).

The highest strontium-90 concentrations in groundwater in the nearshore area along the Columbia River are found near well 199-N-122, which is used to monitor the original segment of the apatite PRB and downriver to the northeast (Figure 4-8). This region of the 100-N Area river shoreline was impacted by highly contaminated effluent during 116-N-1 waste site operations. Effluent discharged to the 116-N-1 waste site emerged at the steeply sloping, nearshore surface as springs along the shoreline (also known as N Springs) because of the artificially elevated water table. The N Springs are no longer present because the artificially elevated water table has returned to ambient conditions. This contaminated area has been the focus of increased monitoring and remediation.

Table 4-1. 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)	2017 (pCi/L)	2018 (pCi/L)	2019 (pCi/L)	Percent Change, Earliest Data Date to 2018
Monitoring Wells															
199-N-2	121	80.7	1,100	160	NS	NS	3,300	1,040	777	164	261	1,630	1,210	274	126
199-N-3	927	1,330	1,200	1,060	870	1,200	1,300	960	938	859	768	863	675	552	-40
199-N-14	1,210	1,070	1,300	1,360	1,400	1,730	960	1,200	1,120	1,380	1,360	1,380	1,350	1,370	13
199-N-16	0.34	-0.08 (U)	0.06 (U)	-0.04 (U)	-2.70 (U)	-0.12 (U)	0.11 (U)	Decommissioned 12/18/2012							NC
199-N-18	392	NS	290	-12 (U)	260	203	In use for TPH-D remediation								NC
199-N-19	43.6	28.2	NS	NS	23	26.4	23	22	23[a]	17.1	16.3	11.9	17	15	-67
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)	0.278 (U)	0.49	NS	NC
199-N-27	171	167	160	130	125	194	200	130	129	126	127	184	145	114	-33
199-N-28	120	25.1	21	25	20	34.9	35	24	33	32.5	30.1	27.4	26	38	-68
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)	-0.494 (U)	0.581 (U)	0.896 (U)	-29
199-N-34	69.3	53.5	67	44	37	57.4	45	42	42	35.9	39.3	51.9	47	40	-42
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)	-0.519 (U)	0.204 (U)	1.52 (U)	NC
199-N-46	5,850	2,690	630	580	530	1,220	1,035	1,400	1,570	1,730	1,190[b]	NS	2,230	NS	NC
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	NS	0.131 (U)	0.219 (U)	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)	-0.869	0.123 (U)	0.659 (U)	NC
199-N-56	164[c]	317	170	140	-7.5 (U)	490	560	380	338	246	NS	NS	NS	NS	NC
199-N-57	26	9.71	8.51	2.90	5.80	15.2	15.5	12	10	6.86	5.18	10.7	11	6	-76
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	0.016	2	0.67 (U)	NC
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	10,400	11,600	11,400	210
199-N-69[d]	-0.09 (U)	0.21 (U)	NS	NS	-3.20 (U)	2.96	12	4.8	3	0.57 (U)	NS	NS	NS	NS	NC
199-N-70[d]	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	NS	NS	NS	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)	NS	NS	NS	NC
199-N-72	2.59[e]	NS	-1.00 (U)	NS	-1.70 (U)	-2.60 (U)	NS	NS	NS	NS	1.475[e]	NS	NS	0.999 (U)	-61
199-N-73	0.53	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.83[e]	NS	NS	NS	NC
199-N-74	0.415	-0.08 (U)	2.3[e]	405[e]	-2.0 (U)	-3.60 (U)	NS	NS	NS	NS	-0.54 (U)	0.611 (U)	0.191 (U)	0.679 (U)	64
199-N-75[f]	2,110	307	2,500	3,000	2,400	NS	3,200	2,500	2,540	3,200	3,050	2,420	2,410	NS	NC
199-N-76	84.9	216	180	180	120	387	1,120	690	440	177	302	222	295	154	81
199-N-77	0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.225[e]	1.55[e]	0.614 (U)	NS	NC
199-N-80[d]	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)	0.63 (U)	0.132 (U)	0.688 (U)	NC
199-N-81	746	734	970	400	320	395	450	490	475	513	493	473	523	305	-59
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)	0.209	1.34 (U)	0.264 (U)	NC

Table 4-1. 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)	2017 (pCi/L)	2018 (pCi/L)	2019 (pCi/L)	Percent Change, Earliest Data Date to 2018
199-N-96A	4.90[g]	5.74	1.65	-1.30 (U)	3.94	9.90	2.04	5.9	2	4.36	7.15	1.62	1	2	-66
199-N-99A	2,860[g]	1,270	1,200	1,400	1,500	1,020	666.5	1,230	1,600	1,540	NS	NS	NS	NS	NC
199-N-103A[f, h]	4.08[g]	422	1,200	1,200	1,400	1,360	1,600	1,300	1,420	1,560	1,090	916	824	1,030	25,145
199-N-104A	5.68[g]	NS	NS	NS	NS	NS	380	260	NS	NS	290	NS	NS	254	4,372
199-N-105A[f, h]	112[g]	1,360	1,900	1,500	1,600	6,580	6,100	1,900	2,210	1,150	1,180	2,280	2,760	1,370	1,123
199-N-106A[f, h]	2,890[g]	3,260	2,200	1,800	NS	2,370	3,035	2,200	2,240	1,580	2,010	2,320	2,300	1,010	-65
199-N-119	—	280	250	210	220	274	56	41	29	14.5	NS	NS	NS	NS	NC
199-N-120[d]	—	10.1	6.55	NS	1.40 (U)	6.93	58	5.7	4	1.93	NS	NS	NS	NS	NC
199-N-121[d]	—	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	NS	NS	NS	NC
199-N-122	—	730	1,160	260	800	740	656	560	907	1,100	1,580	1,120	961	972	33
199-N-123	—	871	255	-1.60 (U)	280	1,770	204	140	120	55.8	133	162	221	87	-90
199-N-146	—	318[i]	412	260	300	328	215	270	256	200	286	503	307	437	37
199-N-147	—	522[i]	791	250	250	478	250	120	231	157	244	238	190	226	-57
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)	1.92[e]	NS	6	399
199-N-173	—	—	—	16	23	19	14.5	22	25	21.5	23.6	20.8	23	20	22
199-N-182	—	—	—	—	—	—	110	140	144	83.9	NS	NS	NS	NS	NC
199-N-183	—	—	—	—	—	—	120	100	82	81.2	89.3	80	112	143	19
199-N-184	—	—	—	—	—	—	5,000	1,100	1,150	320	212	1,590	3,810	454	-91
199-N-185	—	—	—	—	—	—	3.9	7.6	8	6.43	NS	NS	4	NS	NC
199-N-186	—	—	—	—	—	—	810	390	420	207	193	433	860	244	-70
199-N-187	—	—	—	—	—	—	8,600	11,400	12,800	9,860	10,100	14,200	11,300	9,790	14
199-N-188	—	—	—	—	—	—	1,500	2,500	2,280	1,520	1,780	3,230	2,110	1,600	7
199-N-189	—	—	—	—	—	—	0.02 (U)	0.39 (U)	0.85 (U)	0.27 (U)	NS	NS	1.22 (U)	0.634 (U)	NC
199-N-371	—	—	—	—	—	—	—	—	—	—	1.76 (U)	1.59 (U)	0.267 (U)	0.257 (U)	NC
199-N-372	—	—	—	—	—	—	—	—	—	—	1.85 (U)	1.5 (U)	0.6 (U)	0.662 (U)	NC
199-N-374	—	—	—	—	—	—	—	—	—	—	14	33	29	18	28
Aquifer Tubes															
C7934	—	—	—	—	300	NS	93	310	321	344	361	260	189	220	-27
C7935	—	—	—	—	300	NS	190	280	356	331	320	275	161	189	-37
C7936	—	—	—	—	69	NS	55	96	83	80.4	85.6	59.7	51	40	-41
APT-1	—	3,400[i]	NS	NS	500	530	840	270	211	331	480	699	651	414	-88
APT-5	—	2,100[i]	NS	NS	450	420	270	120	184	238	216	181	173	211	-90

Table 4-1. 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)	2017 (pCi/L)	2018 (pCi/L)	2019 (pCi/L)	Percent Change, Earliest Data Date to 2018
N116mArray-3A	—	379	1,750[e]	500	110	248	240	170	190	120	144	202	146	172	-55
N116mArray-4A	—	1,260	7,000[e]	340	270	226	250	280	342	186	200	209	237	287	-77
NVP2-116.0	—	3,200	2,550[e]	1,100	1,200	1,100	733	700	845	1,680	2,070	2,390	2,740	2,080	-35
N116mArray-6A	—	477	370[e]	95[e]	110	170	190	130	251	75.2	155	183	142	145	-70

Notes:

Data are maximum values reported from the fall of the year, unless otherwise noted.

Cells with "—" indicate that 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 January 20, 2015.

b. Sampled on July 1, 2016.

c. Not sampled in 1994. Value from 1993 is used for this table.

d. Screened at depth in the Ringold Formation.

e. Value calculated from gross-beta data (no strontium-90 data available). Value listed is one-half of the gross-beta value measured.

f. Former P&T extraction well.

g. Not sampled in 1994. Value from 1995 is used for this table.

h. P&T system was operated from 1995 through 2006.

i. Not sampled in 2005. Value from 2006 is used for this table.

NC = not calculated

NS = not sampled for strontium-90 or gross beta

P&T = pump and treat

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

TPH-D = total petroleum hydrocarbons-diesel

U = nondetect

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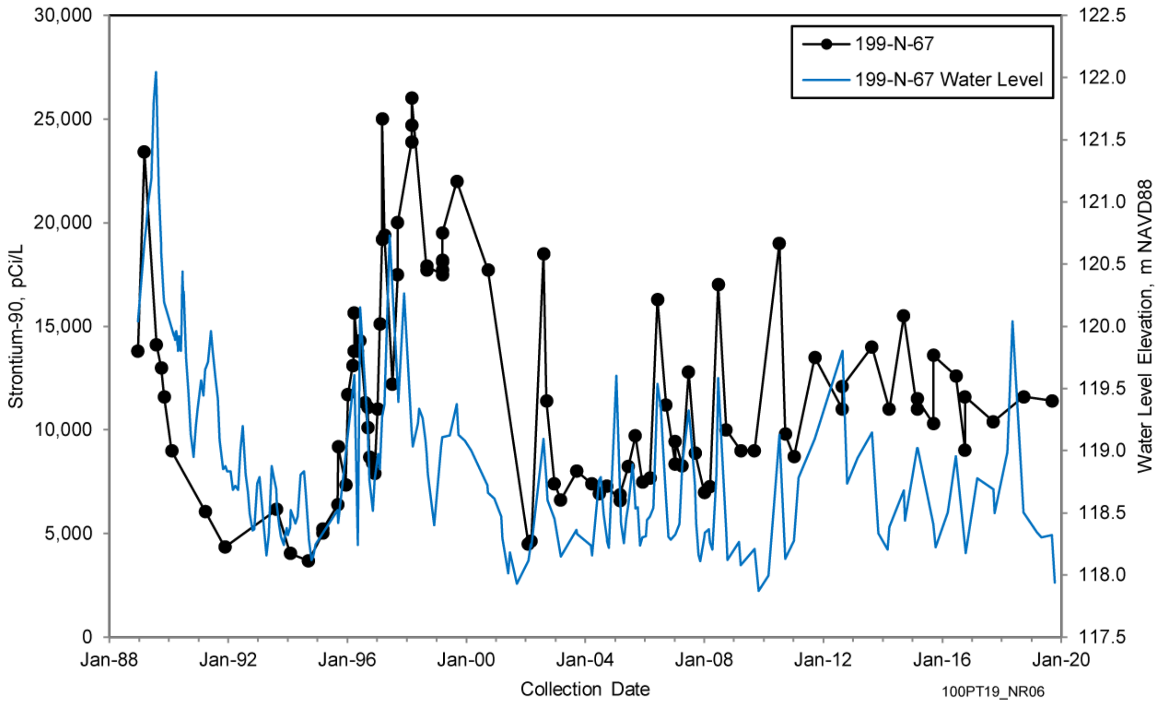
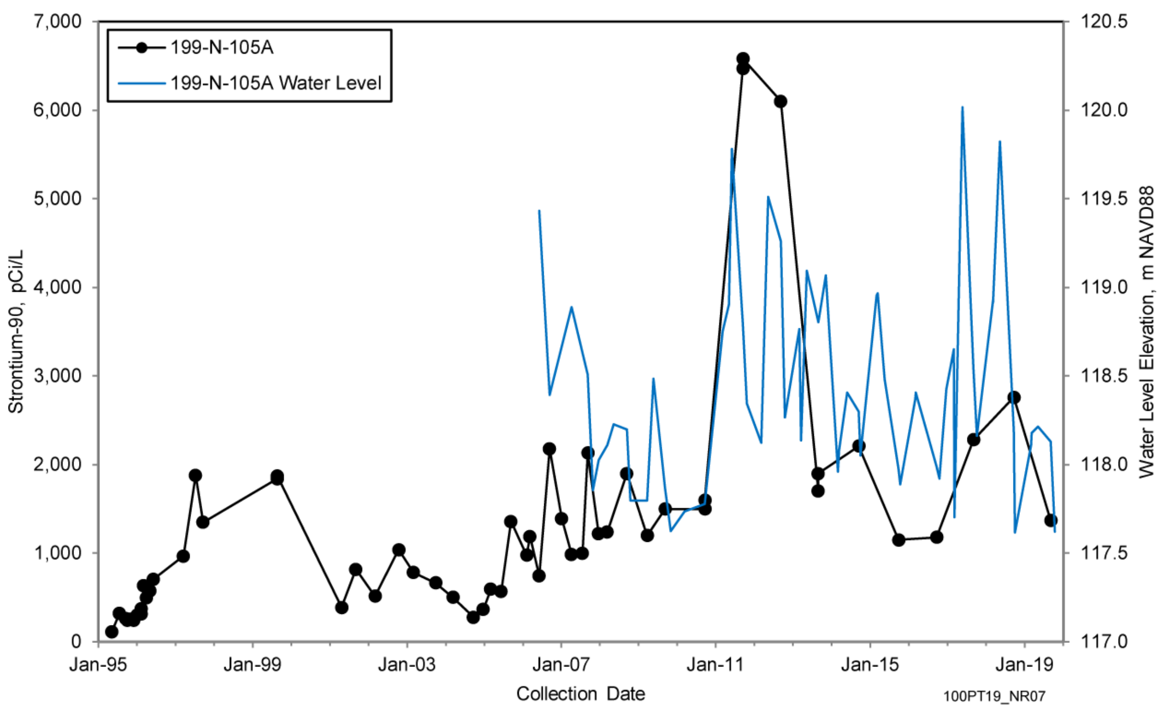


Figure 4-9. Strontium-90 Trend Plot and Water Levels for Well 199-N-67



Note: Well was a former pump and treat extraction well from 1995 through 2006.

Figure 4-10. Strontium-90 Trend Plot and Water Levels for Well 199-N-105A

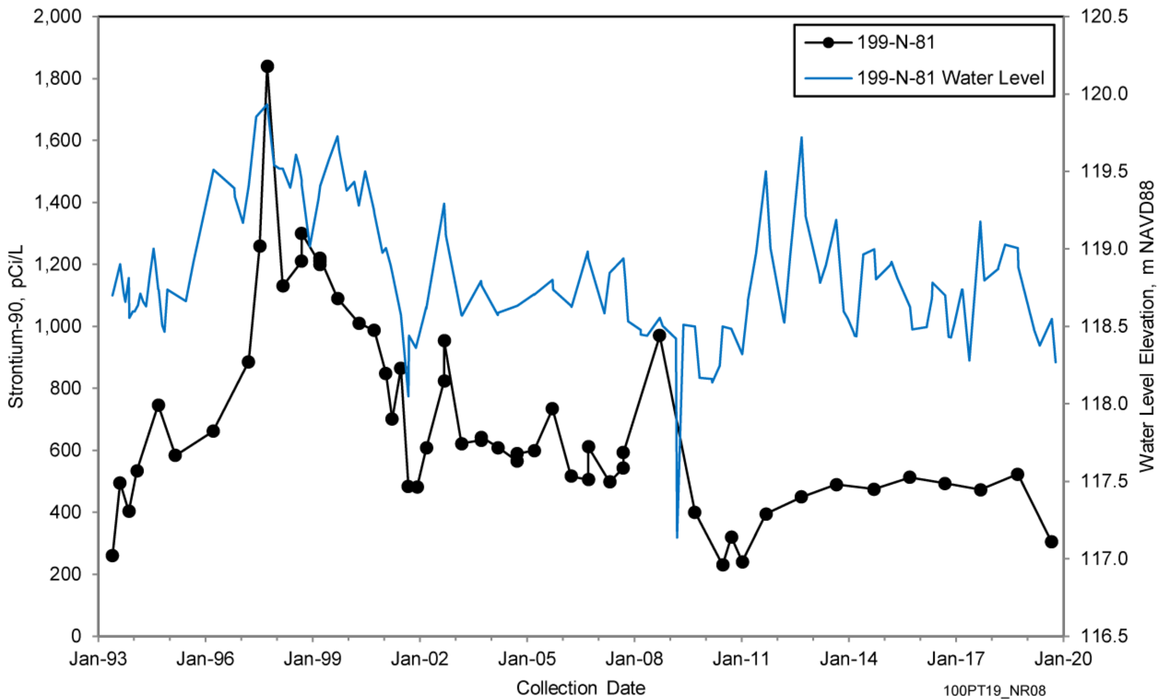


Figure 4-11. Strontium-90 Trend Plot and Water Levels for Well 199-N-81

Strontium-90 concentrations in aquifer tubes are consistent with concentrations in monitoring wells. Concentrations greater than the DWS are present only above approximately 115 m (377 ft) in elevation (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 4-1 provides the maximum concentrations observed in the aquifer tubes during 2019. The maximum concentration in an aquifer tube in 2019 was detected in NVP2-116.0 at 2,080 pCi/L. A general increase in strontium-90 concentrations has been observed in this aquifer tube since 2010.

The only strontium-90 concentrations above the DWS outside of the main plume (described above) are defined by well 199-N-374 and aquifer tube cluster C7934/C7935/C7936, downgradient of N Reactor (Figure 4-8). In 2019, the maximum concentrations in this plume ranged from 22.2 pCi/L at well 199-N-374 to 223 pCi/L at the aquifer tube cluster. Concentrations at well 199-N-374 and aquifer tube cluster C7934/C7935/C7936 fluctuate with changes in river elevation, but concentration trends are generally stable or decreasing. The presumed strontium-90 sources were unplanned releases from the N Reactor FSB and associated facilities and pipelines (UPR-100-N-3, UPR-100-N-7, and UPR-100-N-12). The aquifer tubes are located near the engineered fill around the 1908-N outfall, which suggests that outfall construction created a preferential pathway for contaminated groundwater migrating to the river (Section 4.2 in SGW-49370, *Columbia River Pore Water Sampling in 100-N Area, December 2010*).

Two seeps along the 100-N shoreline were sampled in 2019: N Seep 89-1 (located near well 199-N-123 in the main strontium-90 plume) and N Seep 8-13 (located north of well 199-N-92A, downriver from the main strontium-90 plume) (Figure 4-2). Strontium-90 concentrations were 55.2 pCi/L in N Seep 89-1 and below detection in N Seep 8-13.

4.3.2 Total Petroleum Hydrocarbons-Diesel

The primary source of the total petroleum hydrocarbons-diesel (TPH-D) groundwater contamination was a 1966 diesel fuel tank spill (UPR-100-N-17). A small, relatively narrow groundwater plume persists downgradient from the spill location to the river (Figure 4-12). The data used to prepare the TPH plume map for 2019 included routine groundwater monitoring data and monitoring data for the in situ bioventing project (Section 4.5.1). Groundwater samples for in situ bioventing performance monitoring were collected twice in 2019 (June and November). The 2019 high- and low-water TPH-D plumes (Figures 4-13 and 4-14) were similar in extent to the annual average TPH-D plumes (Figure 4-12).

The two highest concentrations in 2019 were in wells 199-N-18 and 199-N-171 (81.9 and 29.0 mg/L, respectively). In 2019, the maximum aquifer tube concentration was in C6135 (0.8 mg/L). The concentration of TPH-D in shoreline seep N Seep 89-1 was less than detection.

The TPH concentrations in groundwater generally decreased from 2012 through 2016, presumably due to in situ bioventing in the vadose zone. However, TPH-D concentrations in most groundwater monitoring wells downgradient of the UPR-100-N-17 spill have increased since 2017. Increasing TPH-D concentrations at wells 199-N-169 and 199-N-171 and corresponding depletion of dissolved oxygen are an indicator of a continuing source deep within the vadose zone and are likely related to the high water table in 2017 and 2018 remobilizing petroleum hydrocarbon contamination in the vadose zone (Figures 4-15 and 4-16, respectively). Manganese and sulfate concentrations have also increased in the TPH plume area corresponding with the reducing conditions created by the depletion of dissolved oxygen in the TPH plume (Figures 4-17 and 4-18).

4.4 Strontium-90 Remediation

During 2019, the 311 m (1,020 ft) long treated portion of the apatite PRB continued to reduce the flux of strontium-90 contamination in groundwater along the majority of the apatite PRB. Performance monitoring indicates that there are two locations in the apatite PRB with decreased performance since 2015.

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 was 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 isomorphic substitution and eventually become trapped as part of the mineral matrix during apatite crystallization (PNNL-16891). The strontium-90 is sequestered within the apatite PRB as contaminated groundwater flows through the barrier. The sequestered strontium-90 continues to decay in place within the barrier.

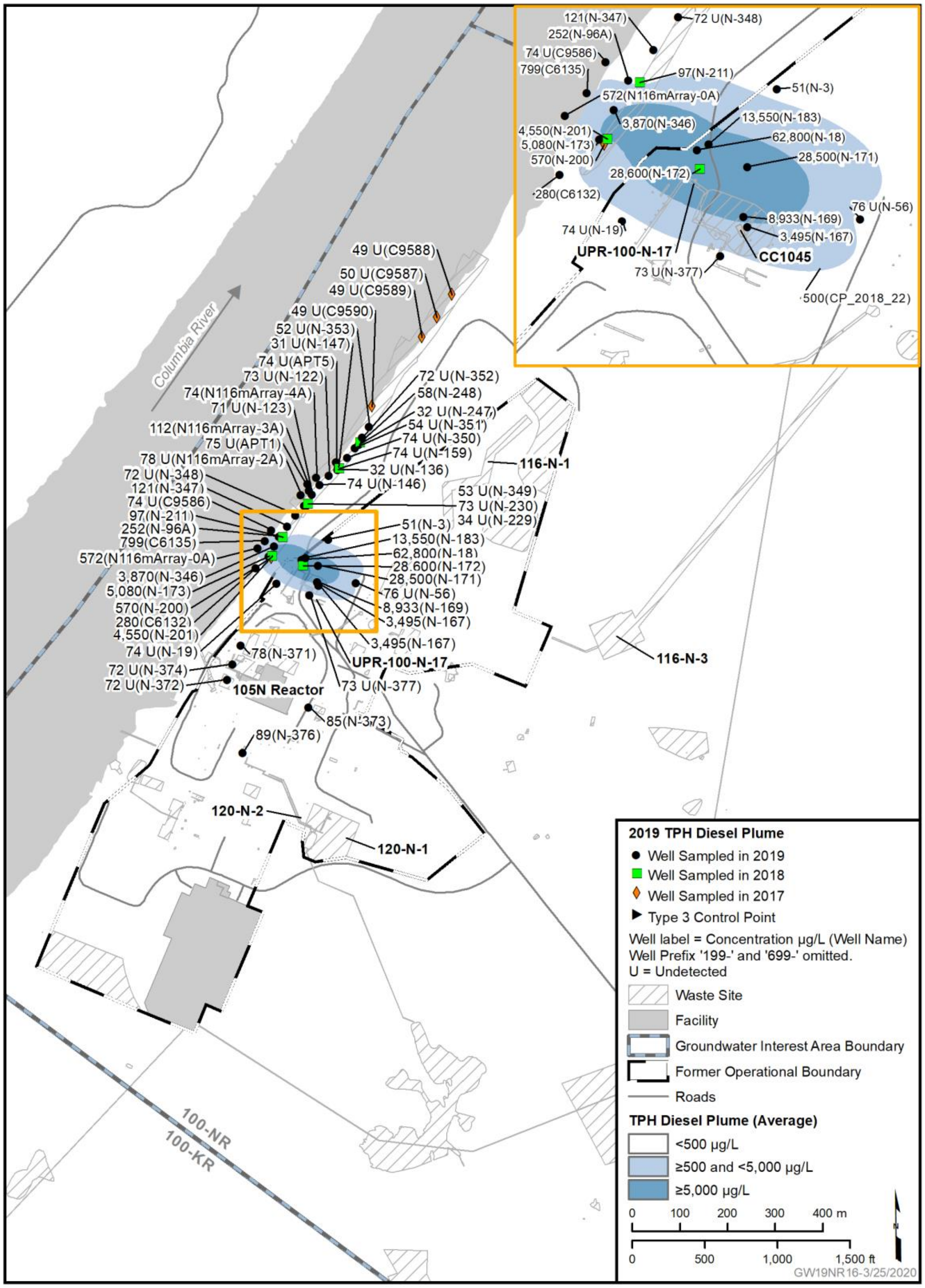


Figure 4-12. TPH-D Plume Map for the 100-N Area, 2019

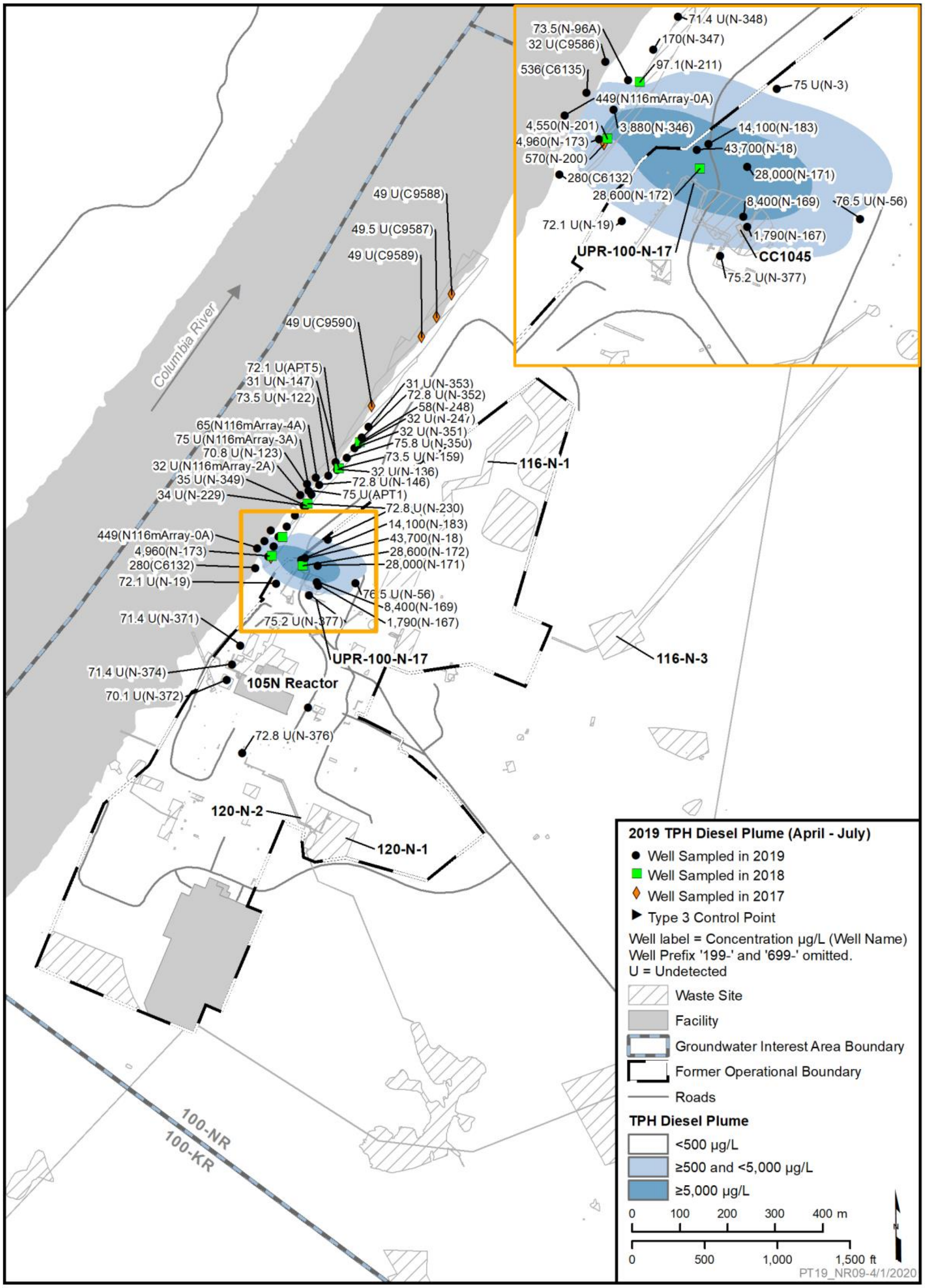


Figure 4-13. TPH-D Plume Map, Spring/Summer 2019

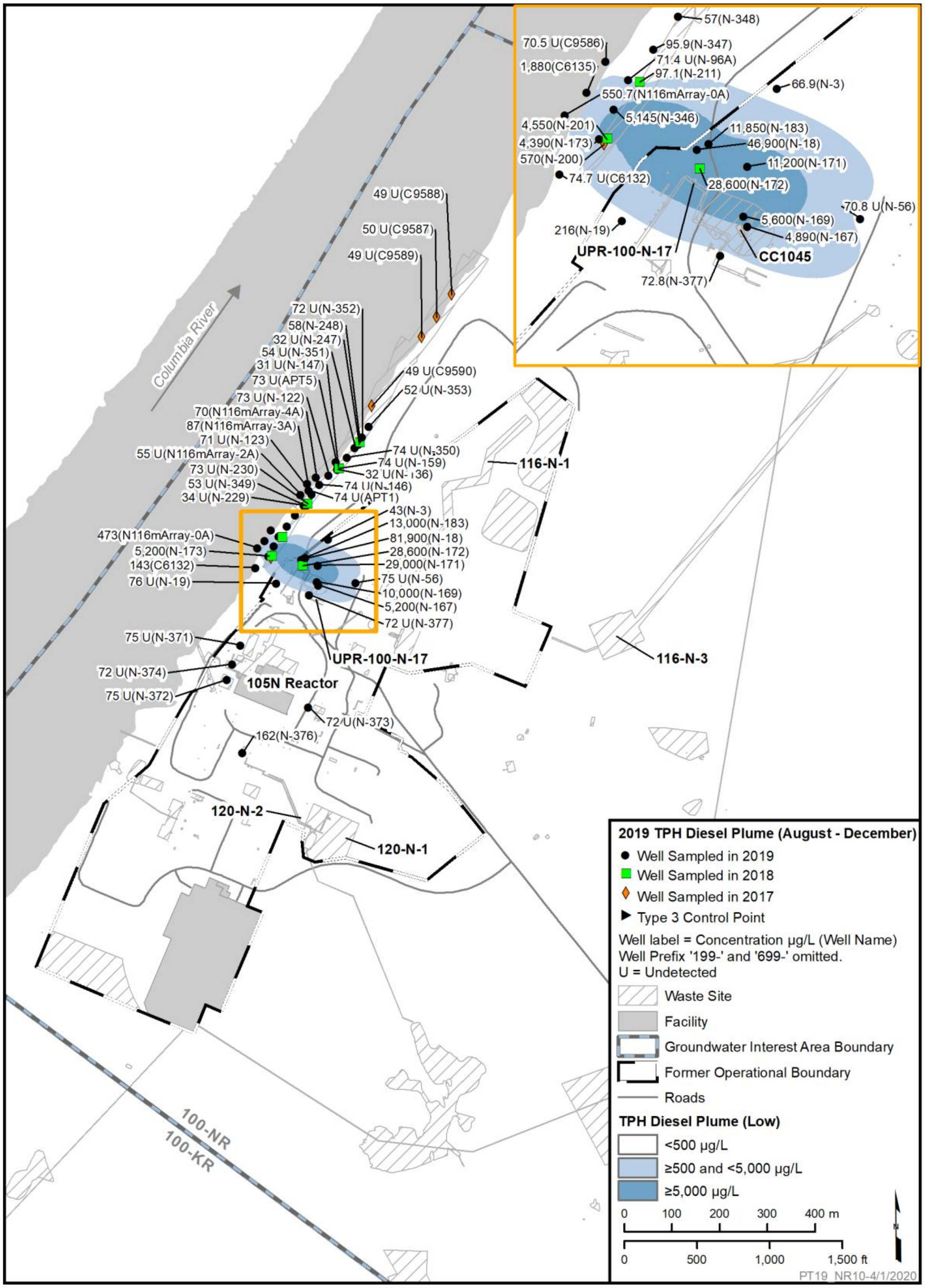


Figure 4-14. TPH-D Plume Map, Fall 2019

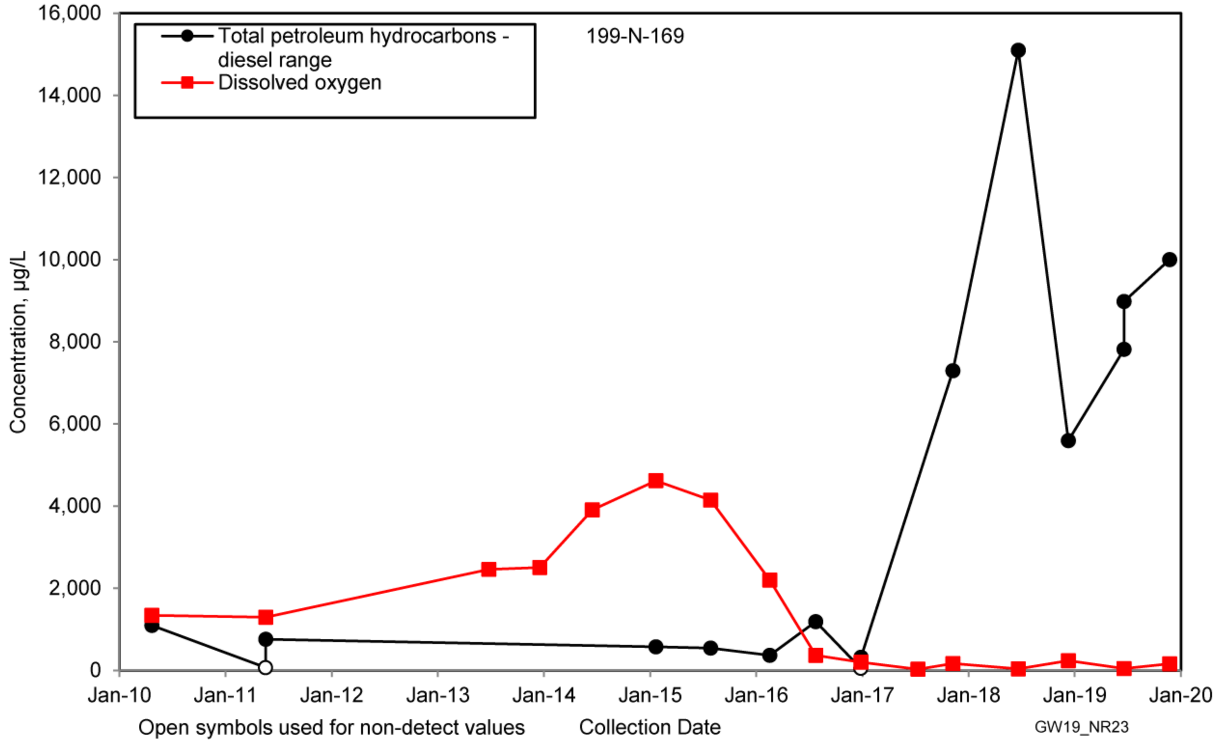


Figure 4-15. Dissolved Oxygen and TPH-D Data at Well 199-N-169

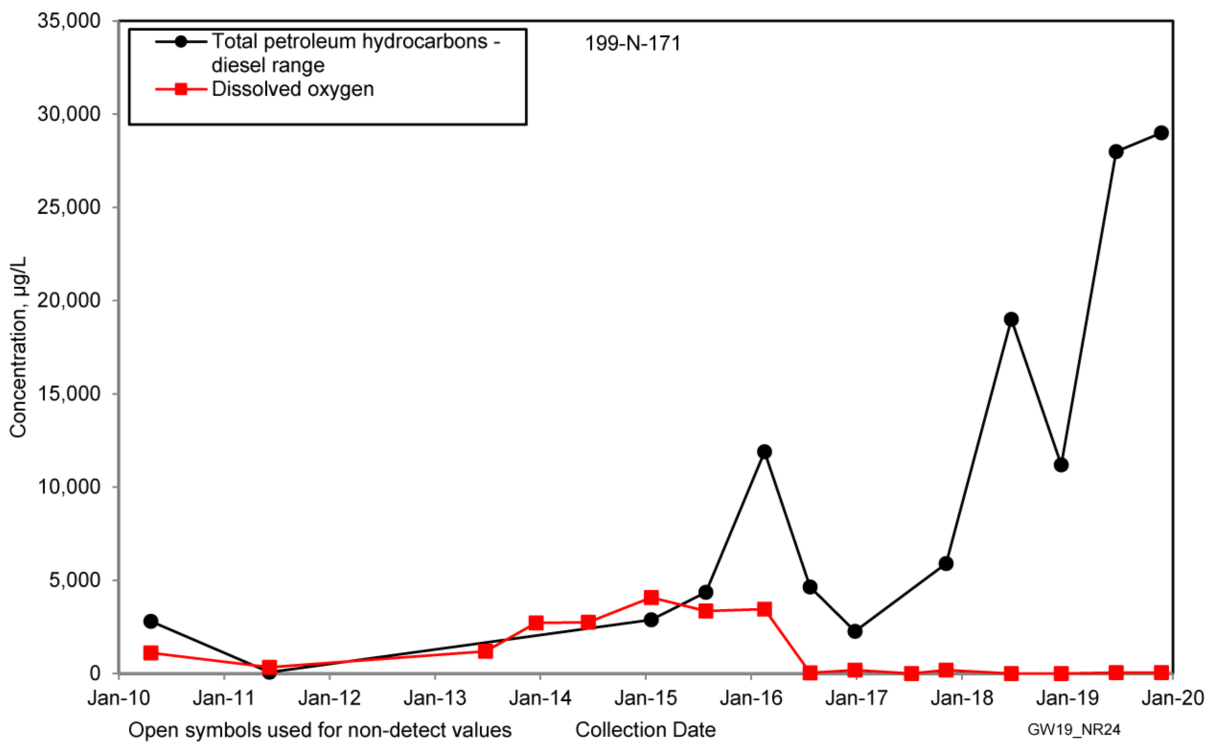


Figure 4-16. Dissolved Oxygen and TPH-D Data at Well 199-N-171

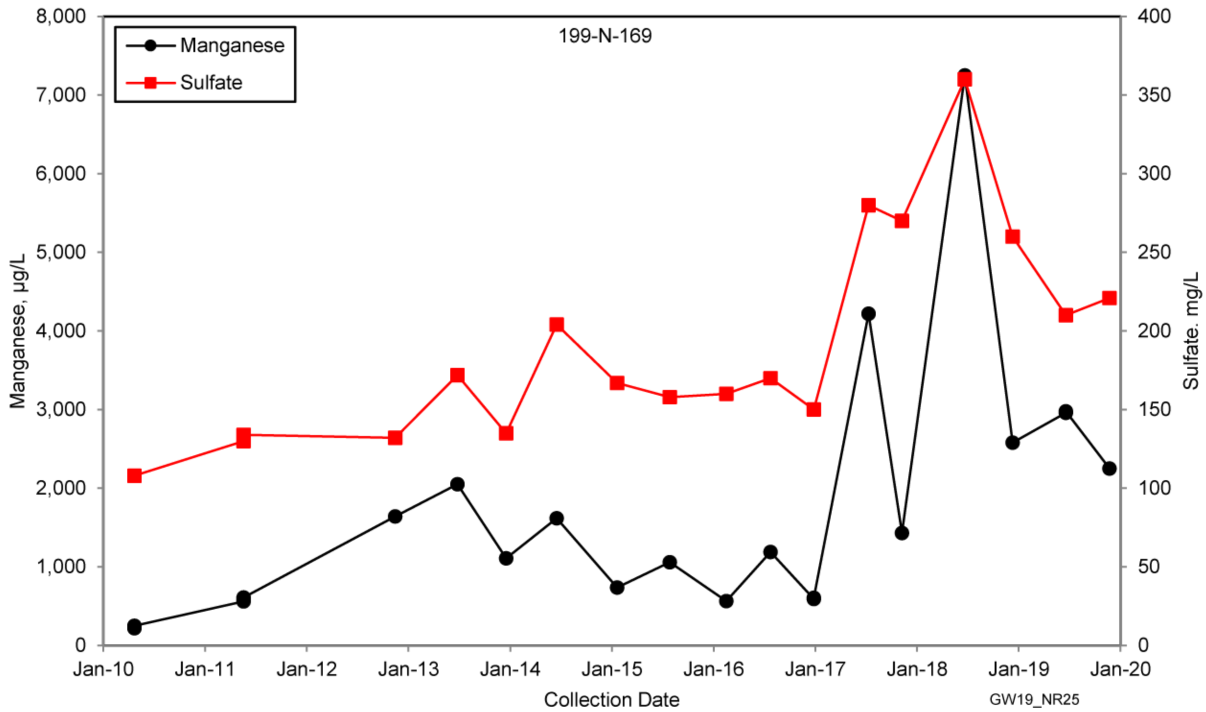


Figure 4-17. Manganese and Sulfate Data at Well 199-N-169

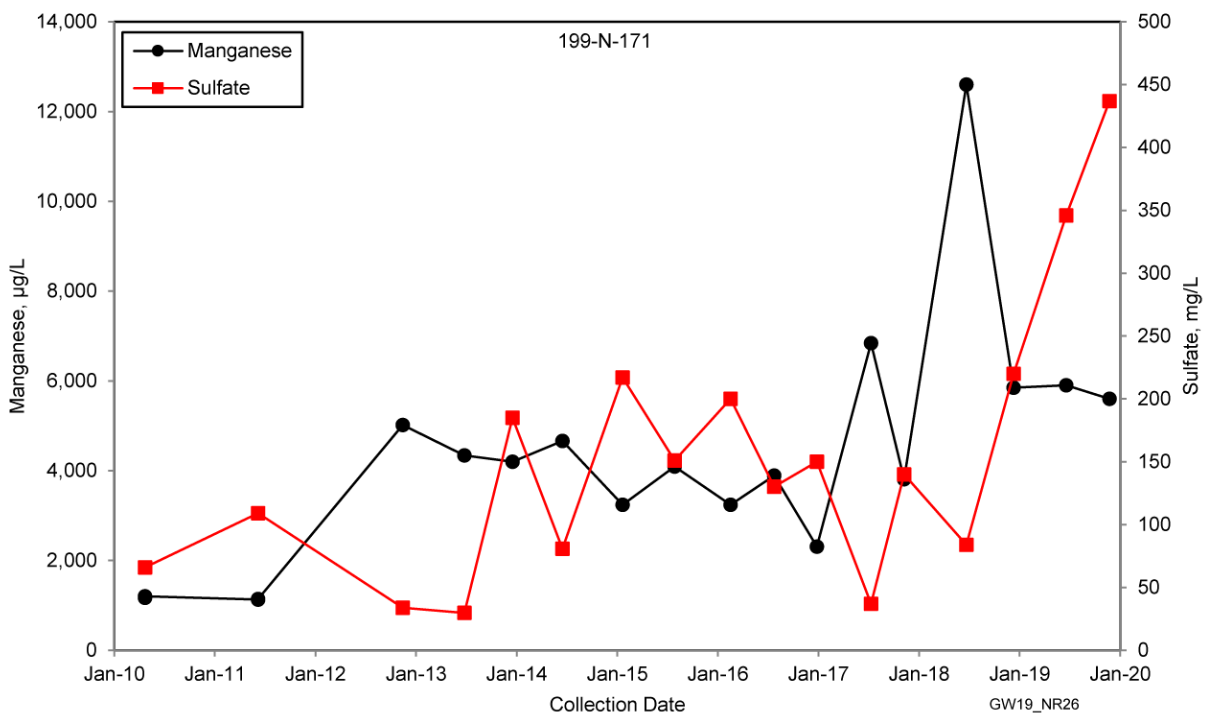


Figure 4-18. Manganese and Sulfate Data at Well 199-N-171

4.4.1 Permeable Reactive Barrier Performance Evaluation

In 2019, groundwater samples were collected from performance monitoring wells and aquifer tubes during high river stage in June and low river stage in September. Table 4-2 compares the spring and fall 2019 data to the pre-treatment baseline conditions. Table 4-3 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 barrier segments. Table 4-4 lists the injection wells for the 760 m (2,500 ft) long barrier and indicates which sections have been treated as of 2019.

The treated central (original) segment of the apatite PRB extends 91 m (300 ft) along the Columbia River shoreline (Figure 4-4). Sixteen injection wells form the PRB well network in the central segment, and four performance monitoring wells are located between the river and the barrier wells (Table 4-4). Apatite-forming solutions were injected into the Hanford formation and Ringold Formation over a period of 3 years (from 2006 through 2008).

The treated 110 m (360 ft) long upriver and 110 m (360 ft) 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 4-4). The apatite barrier extensions increased the length of treated 100-N Area shoreline 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 the objectives identified in SGW-56970.

The original apatite PRB segment has been in place for 11 years, and the upriver and downriver extensions have been in place for 8 years. The objective of the treatability test plan was a 90% reduction in strontium-90 groundwater concentrations in the performance monitoring wells (Section 4.4.3 in DOE/RL-2005-96).

Qualitative assessments for performance of treated PRB segments are shown in figures presented in Sections 4.4.1.1 through 4.4.1.3 using colored circles at each injection well location to represent the 9 m (30 ft) design injection radius:

- **Green color fill:** Indicates that strontium-90 concentrations at the monitoring well meet the target strontium-90 reduction, are less than the DWS, or continued strontium-90 reduction is observed with stable or decreasing trend.
- **Yellow color fill:** Indicates that 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 that 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 include meeting target injection volumes and phosphate concentrations, and radial distribution of amendment (identified in DOE/RL-2010-29).

Table 4-2. 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 2019)[c]	
			Minimum Detected Baseline	Maximum Baseline	Spring 2019[a]	Fall 2019[b]		
Upriver Apatite PRB								
			4/6/2010		Spring 2019	Fall 2019	Spring	Fall
199-N-96A	56	8	1.54[d]	37.9[d]	1.8	1.7[h]	95	96
199-N-347	1	1	7[e]	7[e]	4.9	7.5	30	0
199-N-348	1	0	1,800	1,800	44	67	98	96
199-N-349	2	0	220	230	81	63	65	73
Central (Original) Apatite PRB								
(See footnote f)			(See footnote g)		Spring 2019	Fall 2019	Spring	Fall
199-N-122	10	0	657	4,630	403	972	91	79
199-N-146	4	0	318	985	178	437	82	56
199-N-147	3	0	522	1,842	226	215	88	88
199-N-123	6	0	689	1,180	82	87	93	93
Downriver Apatite PRB								
			7/28/2010 and 7/29/2010		Spring 2019	Fall 2019	Spring	Fall
199-N-350	1	0	240	240	46	56	81	77
199-N-351	1	0	350	350	199	546	43	0
199-N-352	1	0	580	580	256	618	56	0
199-N-353	1	0	83	83	34	88	59	0

Table 4-2. 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 2019)[c]
			Minimum Detected Baseline	Maximum Baseline	Spring 2019[a]	Fall 2019[b]	

a. Spring 2019 samples were collected from June 5 through June 20.

b. Fall 2019 samples were collected from September 4 through September 10, except well 199-N-96A (which was sampled November 21).

c. The percentage reduction in strontium-90 concentration is calculated as ([baseline value] – [2019 value])/[baseline value]) × 100. The maximum baseline value was used for comparison.

d. Between 1995 and 2011, the maximum baseline was measured on December 6, 1995. The minimum detected baseline was measured on June 13, 2006, and June 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, Final Report*.

h. Water levels were too low in this well to sample in September. The fall sample for this well was collected on November 21.

PRB = permeable reactive barrier

Table 4-3. 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	199-N-359/C7452	MW
199-N-173/C7038	MW	N116mArray-6A/C5259	AT	N116mArray-11A/C5265	AT
N116mArray-0A/C5514	AT	199-N-147/C5116	MW	199-N-360/C7453	MW
199-N-346/C7442	MW	APT-5/C5386	AT	N116mArray-12A/C9589	AT
C6135	AT	199-N-350/C7443	MW	199-N-361/C7454	MW
199-N-96A/A9882	MW	C7881*	AT	199-N-362/C7455	MW
C6136/C9586	AT	199-N-351/C7444	MW	199-N-363/C7456	MW
199-N-347/C7441	MW	199-N-352/C7445	MW	N116mArray-13A/C9587	AT
N116mArray-1A/C5255	AT	199-N-353/C7446	MW	199-N-364/C7457	MW
199-N-348/C7440	MW	N116mArray-8A/C5261	AT	199-N-365/C7458	MW
N116mArray-2A/C5256	AT	199-N-354/C7447	MW	N116mArray-14A/C9588	AT
199-N-349/C7439	MW	N116mArray-8.5A/C9590	AT	199-N-366/C7459	MW
199-N-123/C4955	MW	199-N-355/C7448	MW	199-N-367/C7463	MW
APT-1/C5269	AT	199-N-356/C7449	MW	199-N-92A/A8878	MW
N116mArray-3A/C5257	AT	199-N-357/C7450	MW	N116mArray-15A/C5512	AT
199-N-146/C5052	MW	N116mArray-9A/C5263	AT		
N116mArray-4A/C5258	AT	199-N-358/C7451	MW		
199-N-122/C4954	MW	N116mArray-10A/C5264	AT		

Note: Yellow-shaded cells indicate locations currently being monitored for the 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 aquifer tube C7881 at the same location.

AT = aquifer tube

ID = identification

MW = monitoring well (6 in.)

Table 4-4. 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 4-4. 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

Table 4-4. Apatite PRB Injection Wells

Well Name/ID	Depth	Well Name/ID	Depth	Well ID	Depth	Well Name/ID	Depth
199-N-287/C7380	Shallow	199-N-306/C7399	Deep	199-N-325/C7418	Shallow	199-N-344/C7437	Deep
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 yet treated.

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

4.4.1.1 Original Permeable Reactive Barrier Segment Performance

Following apatite injections in wells in the central (original) segment of the barrier in 2008, strontium-90 concentrations declined in the performance monitoring wells (Figure 4-19). The wells showed temporary, higher strontium-90 concentrations immediately following apatite solution injection, which had a higher ionic strength than groundwater and displaced cations and anions from the sediments, causing the concentrations in groundwater to increase. Strontium-90 concentrations in performance monitoring well 199-N-123 (near the upriver end of the central barrier segment) temporarily increased following injections into the nearby upriver barrier extension wells in 2011 (Figure 4-19). The injection effects were temporary, as concentrations declined following the injections when strontium-90 was incorporated through initial precipitation and adsorption/slow incorporation into the apatite and as the reagent plume dissipated.

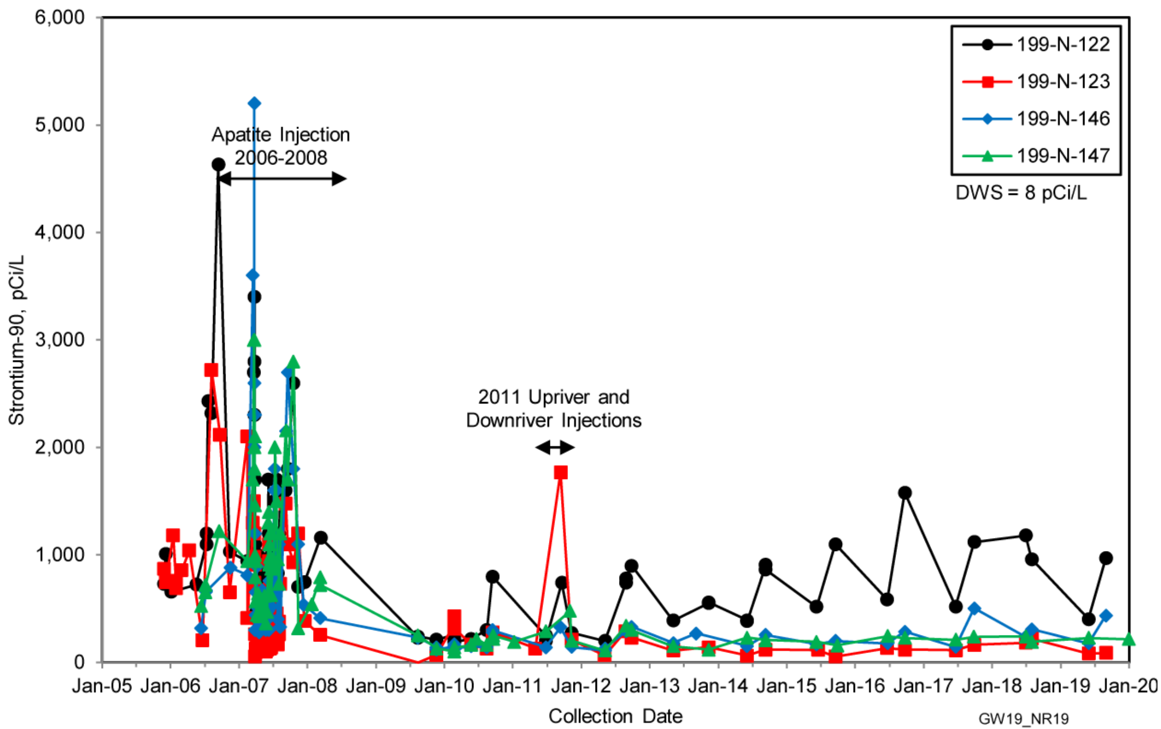


Figure 4-19. Strontium-90 Data for Performance Monitoring Wells Along the Central Segment of the Apatite PRB

The strontium-90 concentration fluctuation (Figure 4-19) is associated with high and low river sampling periods, where concentrations tend to be lower during high river stage, indicating some dilution from river water. Strontium-90 concentrations at well 199-N-122 have been trending upward (Figure 4-19) but remain lower than the pre-injection baseline concentration of 4,630 pCi/L. The percent reduction in 2019 from baseline strontium-90 concentrations ranged from 82% (well 199-N-146) to 93% (well 199-N-123) in the spring, and 56% (well 199-N-146) to 93% (well 199-N-123) in the fall (Table 4-2; Figure 4-20).

Aquifer tubes monitored downgradient of the original PRB segment also continue to show decreased concentrations compared to the pre-injection strontium-90 concentrations (Figure 4-21).

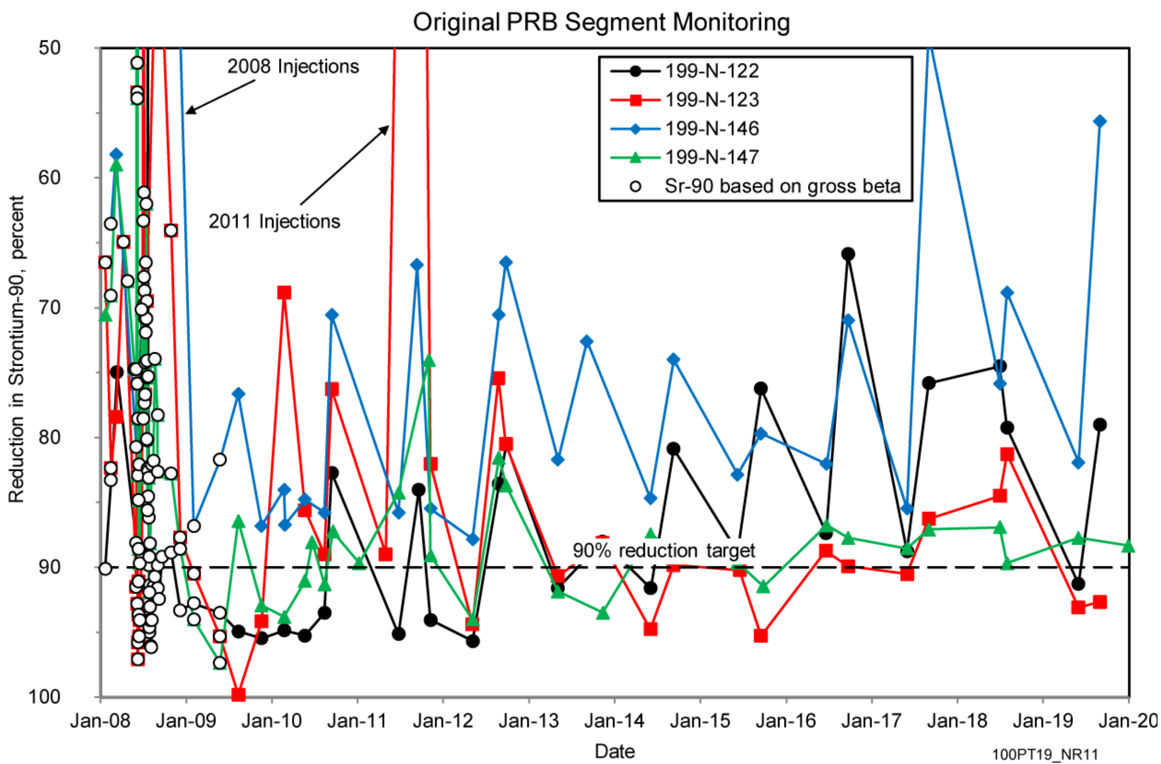


Figure 4-20. Original Apatite Performance Monitoring Wells Percent Strontium-90 Reductions

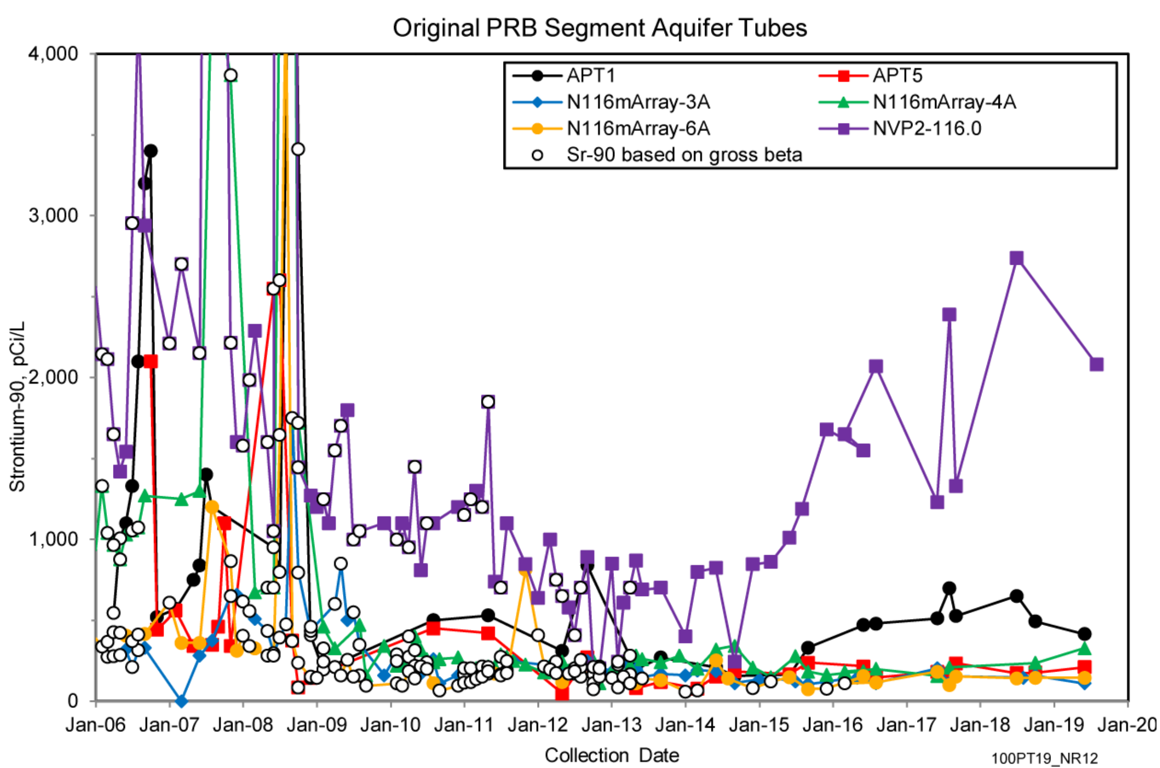


Figure 4-21. Strontium-90 Data for Aquifer Tubes Along the Central Segment of the Apatite PRB

Tables 4-5 and 4-6 list the percent reduction in strontium-90 concentrations since 2011 for the original PRB segment monitoring wells and aquifer tubes, respectively. Well 199-N-147 continues to show reduced strontium-90 concentrations near the 90% reduction target. The percent reduction in strontium-90 concentrations at monitoring well 199-N-122 was 91% in the spring and 79% in fall 2019. This monitoring well had 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 in Figure 4-22 (i.e., below target reduction with an increasing trend) and should continue to be monitored to determine if this area should be reinjected. Strontium-90 concentrations are trending upward in well 199-N-146, and the percent reduction in fall 2019 was 56%. The overall concentration reduction for 2019 at well 199-N-146 was 69%. Injection wells in this area (199-N-140 and 199-N-141) are among the farthest apart of PRB injection wells. Injections in well 199-N-141 did not meet the target radial extent of amendment distribution, and the results were inclusive for injections to well 199-N-140 (PNNL-19572). The assessment indicates that the portion of the original PRB segment near monitoring well 199-N-146 is below target reduction with an increasing trend (i.e., colored yellow in Figure 4-22) and should continue to be monitored to determine if the area should be reinjected. The remaining length of the original PRB segment continues to provide strontium-90 reduction.

The aquifer tubes downgradient from the original PRB segment continue to show strontium-90 reductions 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 that the original PRB segment continues to provide strontium-90 reduction, but trends for wells 199-N-122 and 199-N-146 and for aquifer tube NVP2-116.0 indicate that PRB performance in this area may be declining (Figure 4-22).

4.4.1.2 Upriver Permeable Reactive Barrier Segment Performance

The upriver PRB segment forms the upriver portion of the barrier, near the outside edge of the strontium-90 groundwater plume. Strontium-90 concentrations are below the DWS at performance monitoring wells 199-N-96A and 199-N-347, and the target strontium-90 reduction is being met at well 199-N-348. However, these goals have not been achieved near well 199-N-349.

In the performance monitoring wells along this PRB extension, the percentage reduction in strontium-90 concentrations for 2019 ranged from no reduction (well 199-N-347) to 96% (wells 199-N-95A and 199-N-348) in the fall and 30% (well 199-N-347) to 98% (well 199-N-348) in the spring (Table 4-2; Figure 4-23). The relatively low percentage reduction at well 199-N-347 reflects a low baseline strontium-90 concentration in this well (strontium-90 was nondetect, and the strontium-90 concentration estimated from gross beta was 7.0 pCi/L) and the low concentrations detected in 2019 (4.9 and 7.5 pCi/L). Both the baseline and the 2019 sample concentrations in well 199-N-347 are below the DWS (8 pCi/L), while concentrations in well 199-N-96A have been below the DWS since 2012. Because concentrations in well 199-N-347 are below the DWS, the percent reduction in strontium-90 concentration is not plotted in Figure 4-23. In groundwater monitoring well 199-N-349, 73% and 65% reductions in strontium-90 concentrations were observed in fall and spring 2019, respectively (Table 4-2; Figure 4-23). The percent reduction in well 199-N-349 may be an indication of areas with limited radial amendment distribution due to high injection rates. Table 4-7 lists the volume of apatite chemicals injected into the injection wells near monitoring well 199-N-349. The injection flow rate was not controlled for even flow distribution in all of the injection wells (SGW-56970), so some wells received >150% of the target injection volume of 227,000 L (60,000 gal) and other wells received only about 50% of the target injection volume.

Table 4-5. PRB Monitoring Well Performance Summary, 2011–2019

Monitoring Well	Pre-Injection Baseline[a]	Month/Year Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])								
			2011	2012	2013	2014	2015	2016	2017	2018	2019
Upriver Apatite PRB (Treated in 2011)											
199-N-96A	37.9	September 2011	—[c]	2.3 (94%)	4.1 (89%)	1.6 (96%)	3.8 (90%)	3.04 (92%)	1.6 (96%)	1.1 (97%)	1.7 (95%)
199-N-347	7[d]	September 2011	—[c]	7.8 (-12%)	6.9 (1.4%)	5.1 (27%)	4.7 (33%)	4.8 (32%)	6.0 (14%)	6.4 (8.6%)	6.2 (12%)
199-N-348	1,800	September 2011	—[c]	54 (97%)	34 (98%)	35 (98%)	71 (96%)	7 (96%)	37 (98%)	57 (97%)	55 (97%)
199-N-349	230	September 2011	—[c]	37 (84%)	46 (80%)	87 (62%)	111 (52%)	90 (61%)	67 (66%)	129 (44%)	72 (69%)
Central (Original) Apatite PRB (Treated 2006–2008)											
199-N-122	4,630	July 2008	366 (93%)	656 (86%)	472 (90%)	637 (86%)	809 (82%)	1,083 (77%)	821 (82%)	1,070 (77%)	688 (85%)
199-N-146	985	July 2008	204 (79%)	215 (78%)	225 (77%)	204 (79%)	184 (81%)	232 (77%)	323 (67%)	273 (72%)	308 (69%)
199-N-147	1,842	July 2008	272 (85%)	250 (86%)	135 (93%)	230 (88%)	174 (90%)	235 (87%)	225 (88%)	216 (88%)	221 (88%)
199-N-123	1,180	July 2008	704 (40%)[e]	204 (83%)	125 (89%)	91 (92%)	96 (92%)	126 (89%)	137 (88%)	202 (83%)	84 (93%)

Table 4-5. PRB Monitoring Well Performance Summary, 2011–2019

Monitoring Well	Pre-Injection Baseline[a]	Month/Year Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])								
			2011	2012	2013	2014	2015	2016	2017	2018	2019
Downriver Apatite PRB (Treated in 2011)											
199-N-350	240	September 2011	—[c]	34 (86%)	21 (91%)	27 (89%)	76 (68%)	78 (68%)	75 (69%)	74 (69%)	51 (79%)
199-N-351	350	September 2011	—[c]	26 (93%)	39 (89%)	95 (73%)	376 (-7%)	388 (-11%)	258 (27%)	276 (21%)	372 (-6%)
199-N-352	580	September 2011	—[c]	30 (95%)	29 (95%)	42 (93%)	368 (37%)	683 (-17%)	494 (15%)	487 (16%)	437 (25%)
199-N-353	83	September 2011	—[c]	5.0 (94%)	3.2 (96%)	4.0 (95%)	7.3 (91%)	39 (54%)	31 (63%)	23 (72%)	61 (26%)

a. Pre-injection baseline concentrations for the upriver and downriver PRB monitoring wells are 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, Final Report*.

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 performance was not 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 4-6. PRB Aquifer Tube Performance Summary, 2011–2019

Aquifer Tube	Pre-Injection Baseline[a]	Month/Year Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])								
			2011	2012	2013	2014	2015	2016	2017	2018	2019
Upriver Apatite PRB (Treated in 2011)											
C6135[c]	2.3	September 2011	1.5 (33%)	2.8 (0%)	—[d]	—[d]	—[d]	—[d]	—[d]	0.3 (89%)	1.4 (46%)
N116mArray-1A	34	September 2011	94 (0)[e]	162 (0)[e]	50 (0%)[e]	2.1 (94%)	1.9 (94%)	4.4[f] (87%)	—[g]	—[g]	—[g]
N116mArray-2A	199	September 2011	244 (0%)[e]	29 (85%)	16 (92%)	16 (92%)	17 (92%)	15 (93%)	22 (89%)	37 (82%)	40 (80%)
Central (Original) Apatite PRB (Treated from 2006–2008)											
APT-1	1,454	July 2008	530 (64%)	575 (60%)	235 (84%)	184 (87%)	276 (81%)	476 (67%)	605 (58%)	589 (61%)	453 (69%)
APT-5	420	July 2008	420 (3%)	196 (55%)	97 (78%)	149 (66%)	202 (53%)	182 (57%)	176 (58%)	204 (52%)	194 (54%)
N116mArray-3A	379	July 2008	185 (52%)	202 (47%)	185 (52%)	162 (58%)	125 (67%)	132 (65%)	157 (59%)	149 (61%)	146 (62%)
N116mArray-4A	1,220	July 2008	230 (81%)	207 (83%)	215 (82%)	245 (80%)	202 (83%)	180 (85%)	209 (83%)	237 (82%)	307 (75%)
N116mArray-6A	445	July 2008	203 (54%)	205 (54%)	126 (72%)	119 (73%)	106 (76%)	135 (72%)	142 (68%)	148 (67%)	145 (67%)
NVP2-116.0	3,466	July 2008	1,078 (69%)	588 (83%)	633 (82%)	639 (82%)	1,146 (67%)	1,733 (50%)	1,810 (49%)	2,035 (35%)	2,080 (41%)

Table 4-6. PRB Aquifer Tube Performance Summary, 2011–2019

Aquifer Tube	Pre-Injection Baseline[a]	Month/ Year Treated	Concentration (pCi/L) (Percent Reduction from Baseline[b])								
			2011	2012	2013	2014	2015	2016	2017	2018	2019
Downriver Apatite PRB (Treated in 2011)											
N116mArray-7A/ C7881[h]	336	September 2011	755 (0%)[e]	73 (78%)	32 (91%)	23 (93%)	27 (92%)	36 (89%)	65 (81%)	121 (64%)	121 (70%)
N116mArray-8A	7.8	September 2011	8.9 (0%)[e]	2.4 (68%)	1.7 (78%)	1.3 (83%)	1.7 (78%)	1.6 (79%)	1.3 (84%)	1.9 (74%)	—[d]

a. Pre-injection baseline concentrations are based on a 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 drinking water standard (8 pCi/L).

d. Aquifer tube is missing and/or in need of repair and could not be sampled.

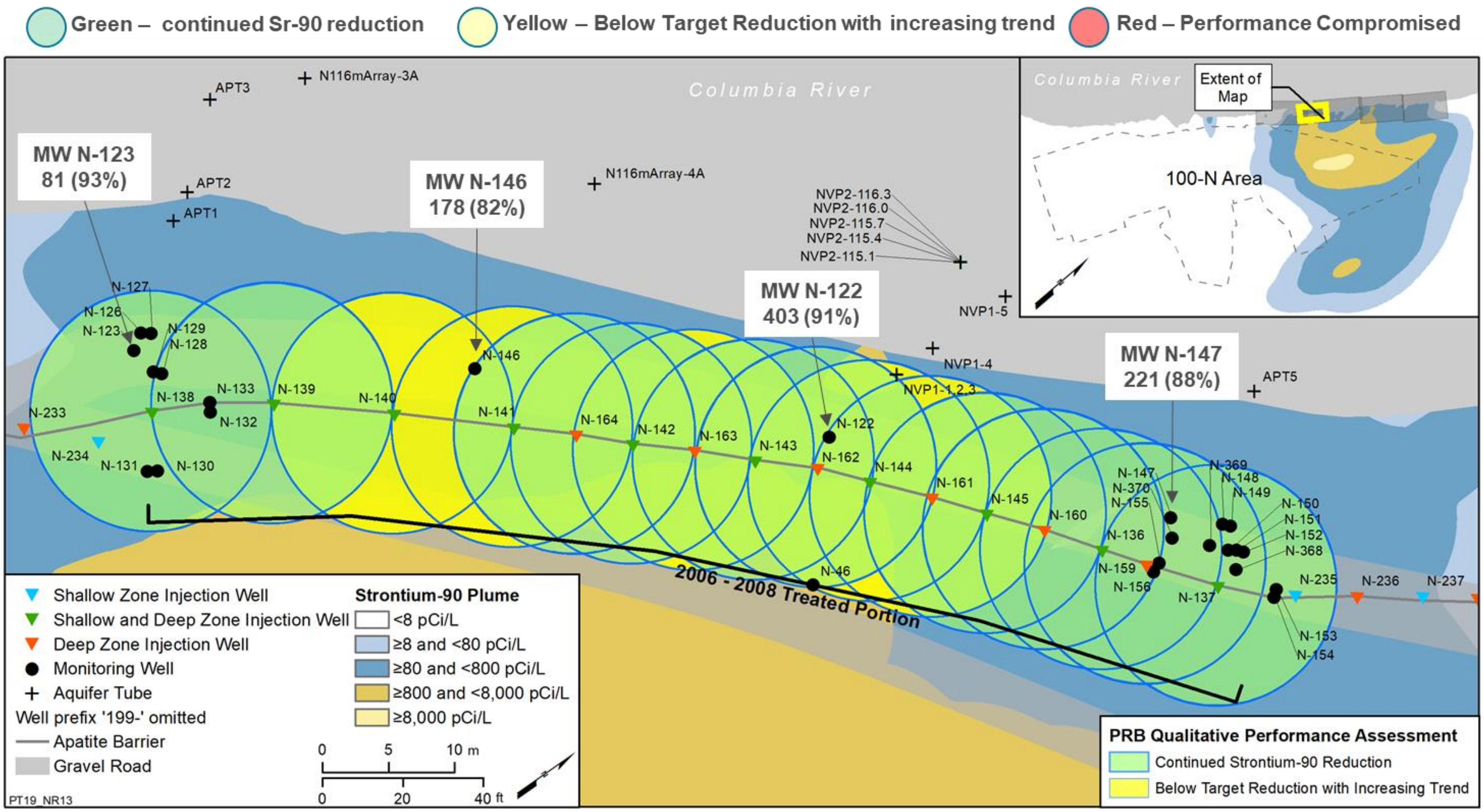
e. Increased concentrations at aquifer tube attribute to residual spike from injection treatment.

f. Value calculated from gross-beta data (no strontium-90 data available); value listed is one-half of the gross-beta value measured.

g. Concentrations at N116mArrary-1A were below the drinking water standard (8 pCi/L) before the aquifer tube became damaged and could no longer be sampled.

h. Aquifer tube C7881 is a replacement for N16mArray-7A, which was installed in the same location.

PRB = permeable reactive barrier



Note: Text boxes in the figure show the 2019 yearly average strontium-90 concentrations and percent reduction (in parentheses) from baseline concentration for permeable reactive barrier monitoring wells.

Figure 4-22. Original PRB Segment Performance Assessment for 2019

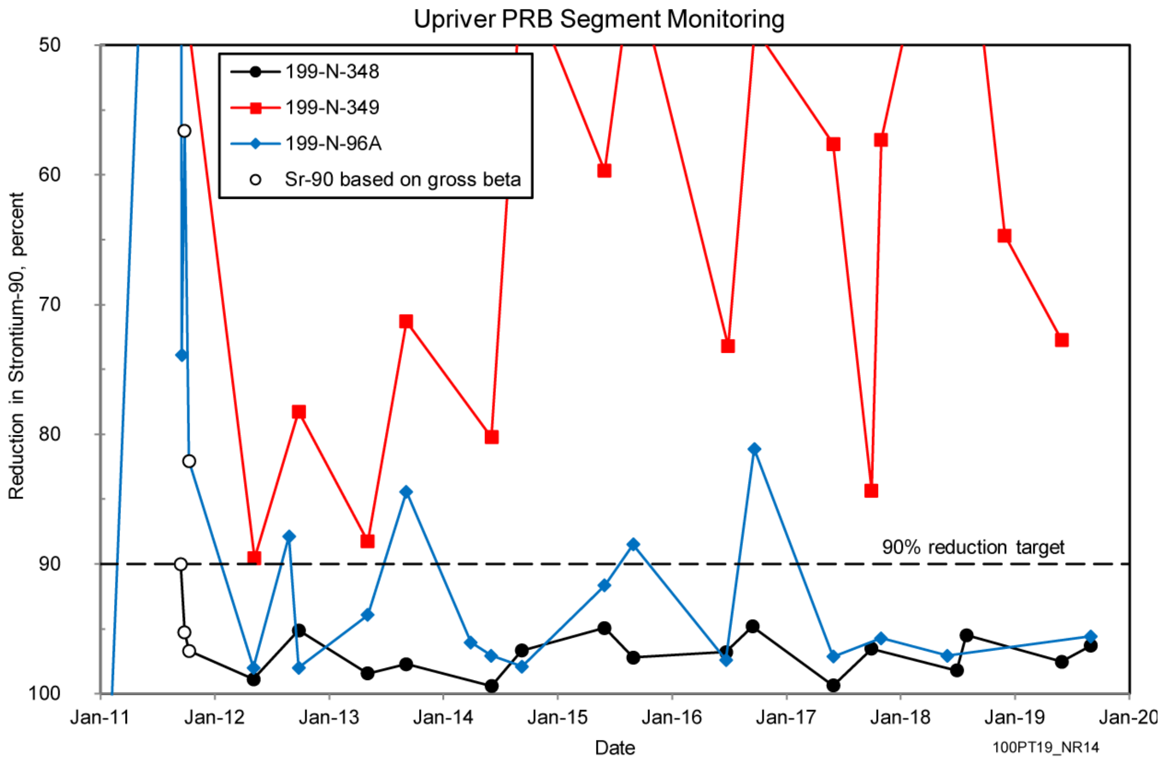


Figure 4-23. Upriver Apatite Barrier Extension Performance Monitoring Wells Percent Strontium-90 Reductions, 2019

Table 4-7. 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).

Figure 4-24 shows the strontium-90 concentration trends for the upriver PRB wells. Table 4-5 shows the percentage reduction in strontium-90 concentrations each year since 2011. Downgradient aquifer tubes continue to show decreased strontium-90 concentrations (Figure 4-25; Table 4-6).

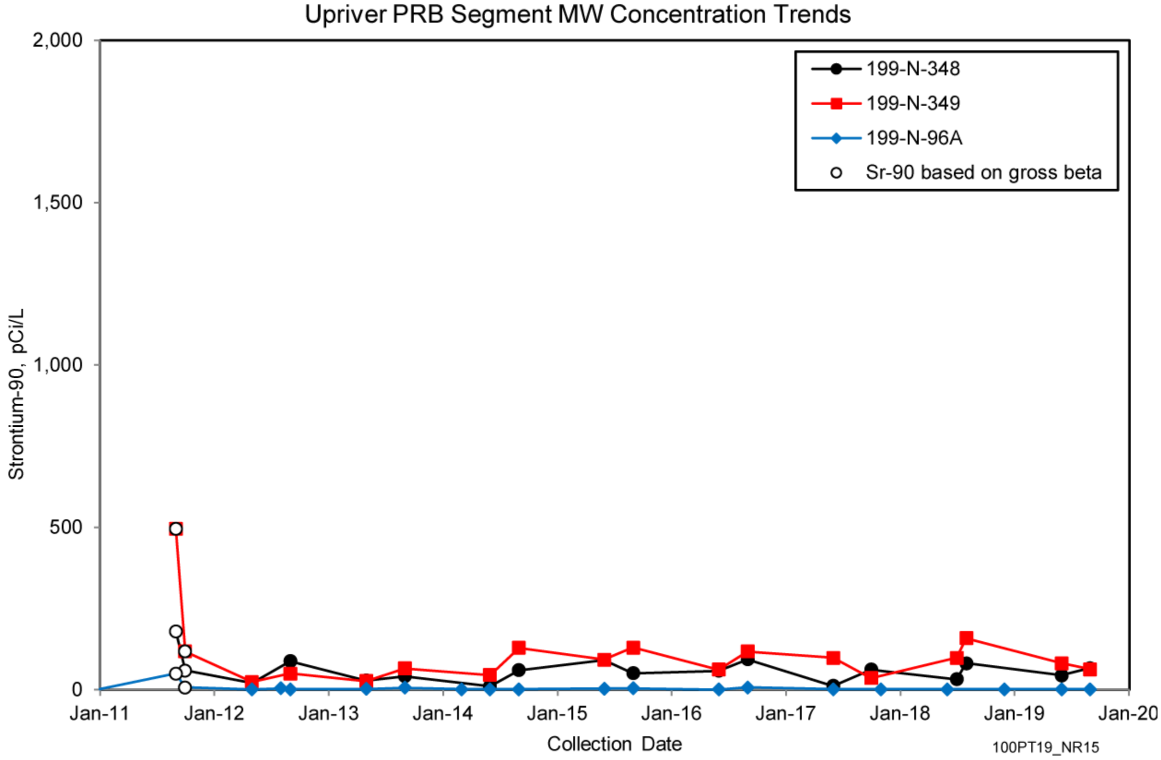


Figure 4-24. Strontium-90 Data for Performance Monitoring Wells Along the Upriver Segment of the Apatite PRB

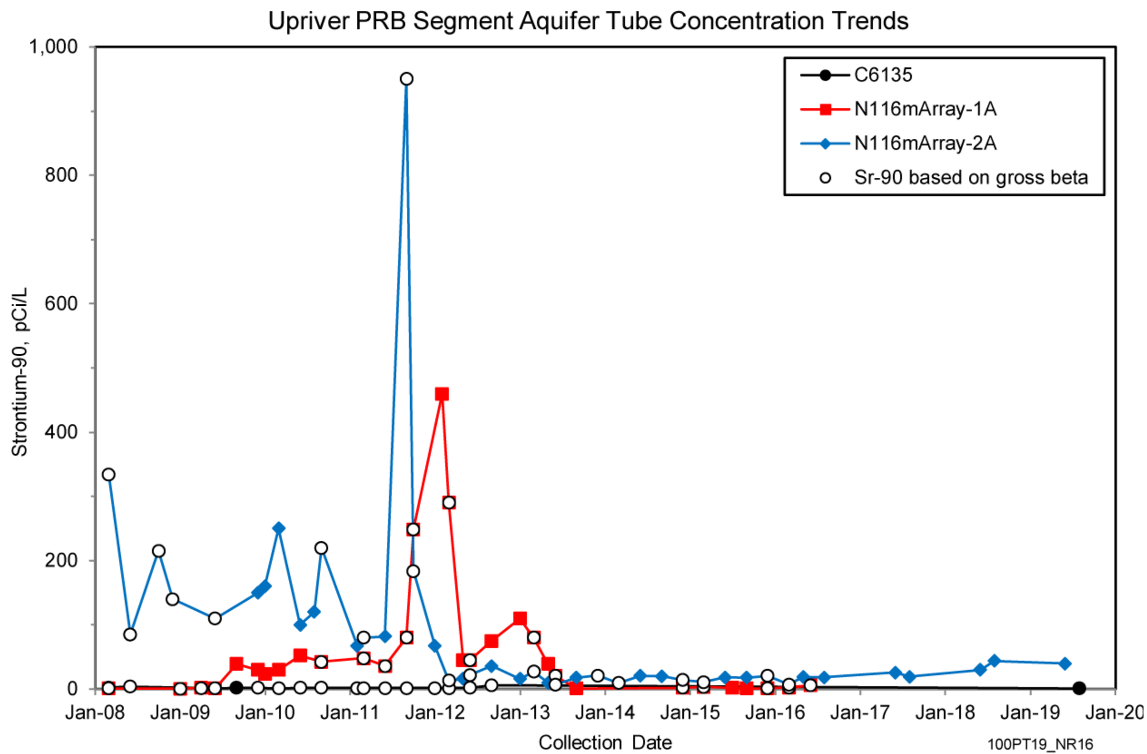


Figure 4-25. Strontium-90 Data for Aquifer Tubes Along the Upriver Segment of the Apatite PRB

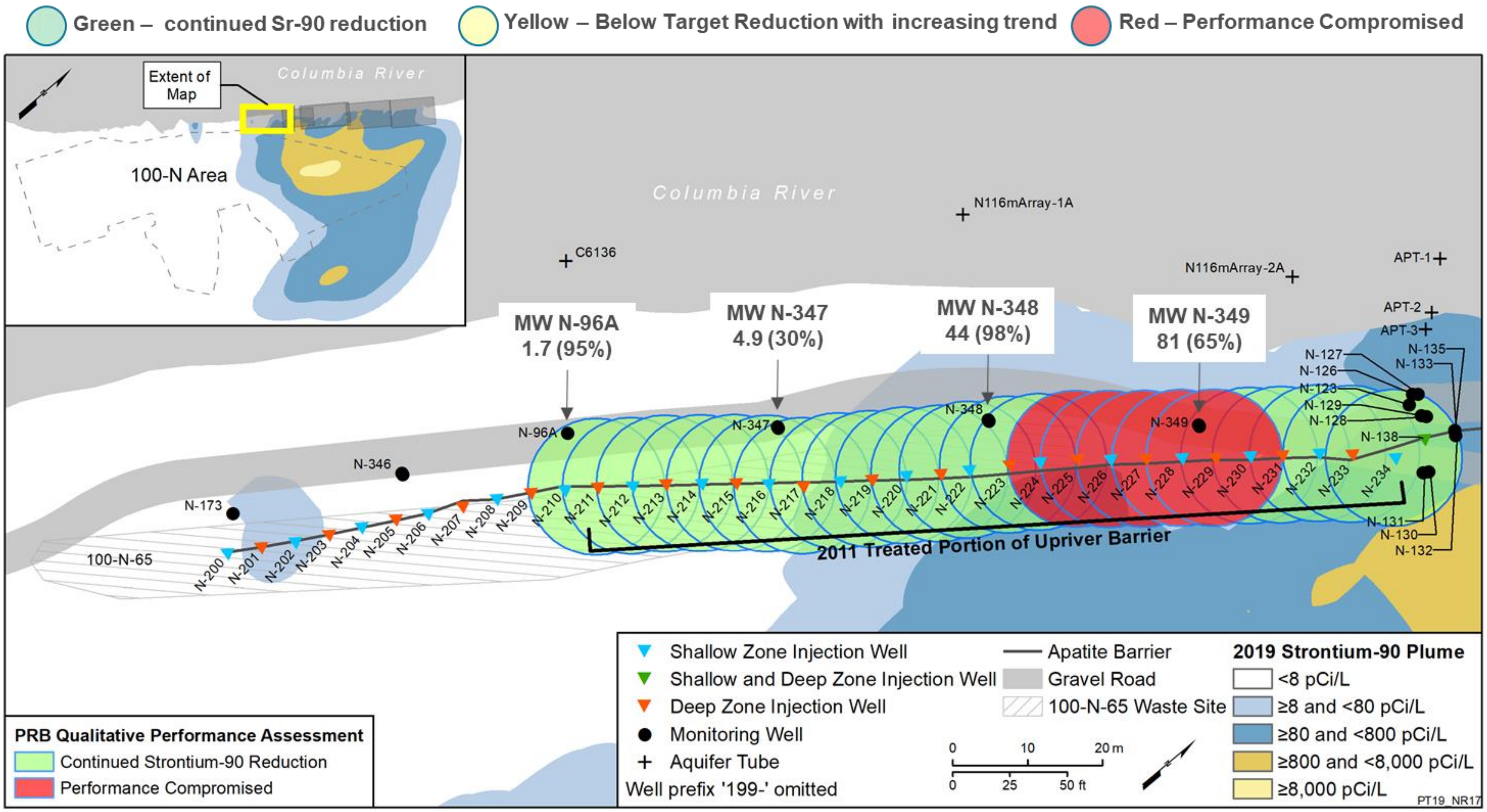
Strontium-90 concentrations are below the DWS at monitoring well 199-N-347, and the target strontium-90 reduction is being met at the remaining two monitoring wells. The assessment indicates that the portion of the upriver PRB segment near monitoring well 199-N-349 is below target reduction and is colored red in Figure 4-26 because of the increased concentrations in 2018 and 2019 and decrease in strontium-90 concentration reduction, although concentrations were lower in 2019. This area should continue to be monitored to determine if reinjection is warranted. The remaining length of the upriver PRB segment continues to provide strontium-90 reduction.

4.4.1.3 Downriver Permeable Reactive Barrier Segment Performance

The downriver extension intercepts higher strontium-90 groundwater concentrations than the upriver extension and indicated initial successful barrier performance. The percentage reduction in strontium-90 concentrations in 2019 at performance monitoring wells along the downriver barrier extension ranged from no reduction (wells 199-N-351, 199-N-352, and 199-N-353) to 77% (well 199-N-350) (Table 4-2; Figure 4-27) in the fall and 43% (well 199-N-351) to 81% (well 199-N-350) in the spring. The data indicate that performance in this segment of the PRB has declined since 2014, as shown by generally increasing concentrations over time (Table 4-5; Figure 4-27).

Strontium-90 concentration trends for the downriver PRB segment monitoring wells (Figure 4-28) show that concentrations at wells 199-N-351 and 199-N-352 have increased to pre-injection levels since 2016. In 2019, the strontium-90 concentration at well 199-N-353 increased to pre-injection levels in the fall and were higher in the spring compared to the 2018 value. Concentrations at well 199-N-350 showed increasing trends in 2013 through 2015 but have since stabilized. Table 4-5 shows the percentage reduction in strontium-90 concentrations since 2012 for the downriver PRB segment monitoring wells. Decreased performance along the PRB and increasing strontium-90 concentrations may be associated with inconsistent volume of apatite-forming chemicals received in each injection well. Table 4-8 provides the volume of apatite chemicals injected into the injection wells near the monitoring wells. Several wells received <30% of the target injection volume; other injection wells received target injection volumes of >50% above the target injection volumes. The injection flow rate was not controlled for even flow distribution in all injection wells (SGW-56970), which contributed to the large contrast in injection volumes. This likely 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 >70% strontium-90 reductions (Table 4-6; Figure 4-29).

The assessment indicates that the portion of the downriver PRB segment monitored by wells 199-N-351, 199-N-352, and 199-N-353 where injection wells received <30% of the target amendment volume should be considered for reinjection (colored red in Figure 4-30). Portions of the downriver PRB near well 199-N-350 should continue to be monitored to evaluate if these areas should be reinjected.



Note: Text boxes in the figure show the 2019 yearly average strontium-90 concentrations and percent reduction (in parentheses) from baseline concentration for permeable reactive barrier monitoring wells.

Figure 4-26. Upriver PRB Segment Performance Assessment, 2019

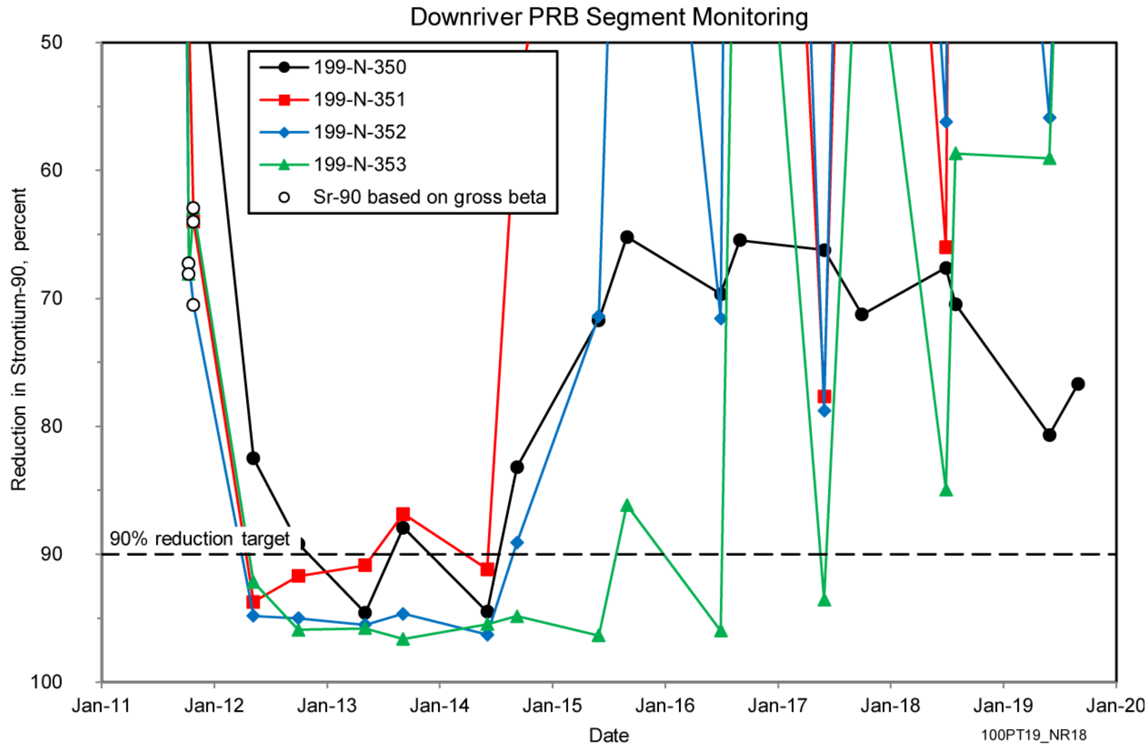


Figure 4-27. Downriver Apatite Barrier Extension Performance Monitoring Wells Percent Strontium-90 Reductions, 2019

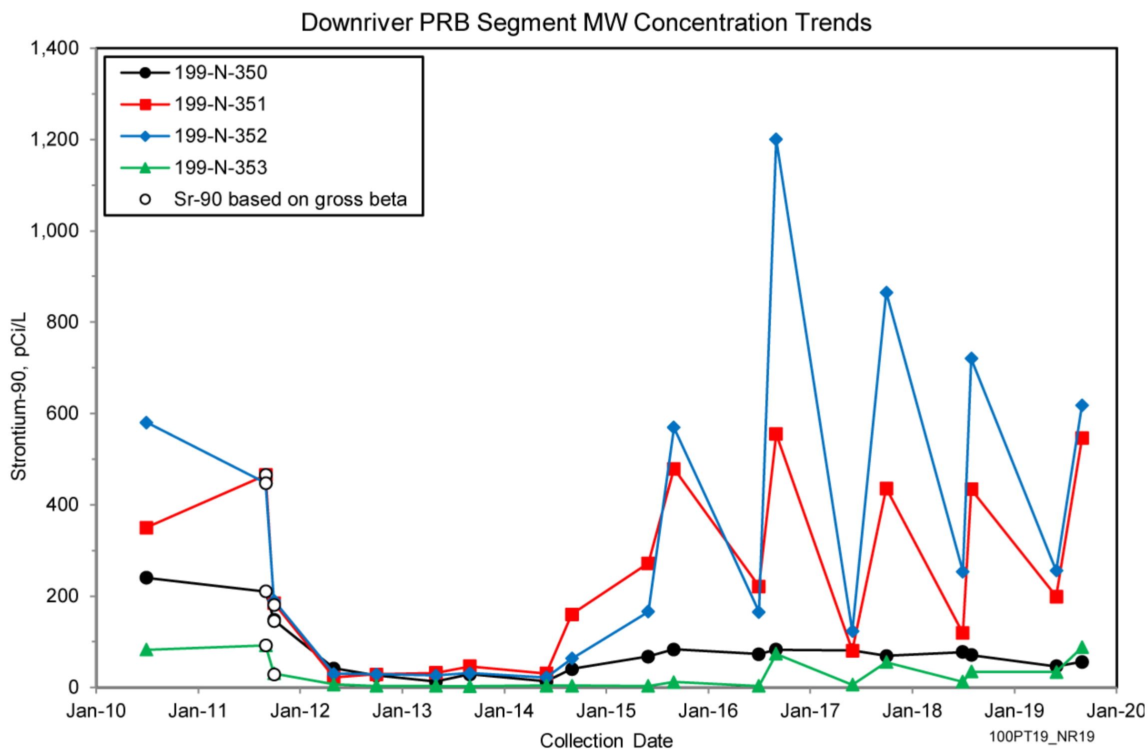


Figure 4-28. Strontium-90 Data for Performance Monitoring Wells Along the Downriver Segment of the Apatite PRB

Table 4-8. 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).

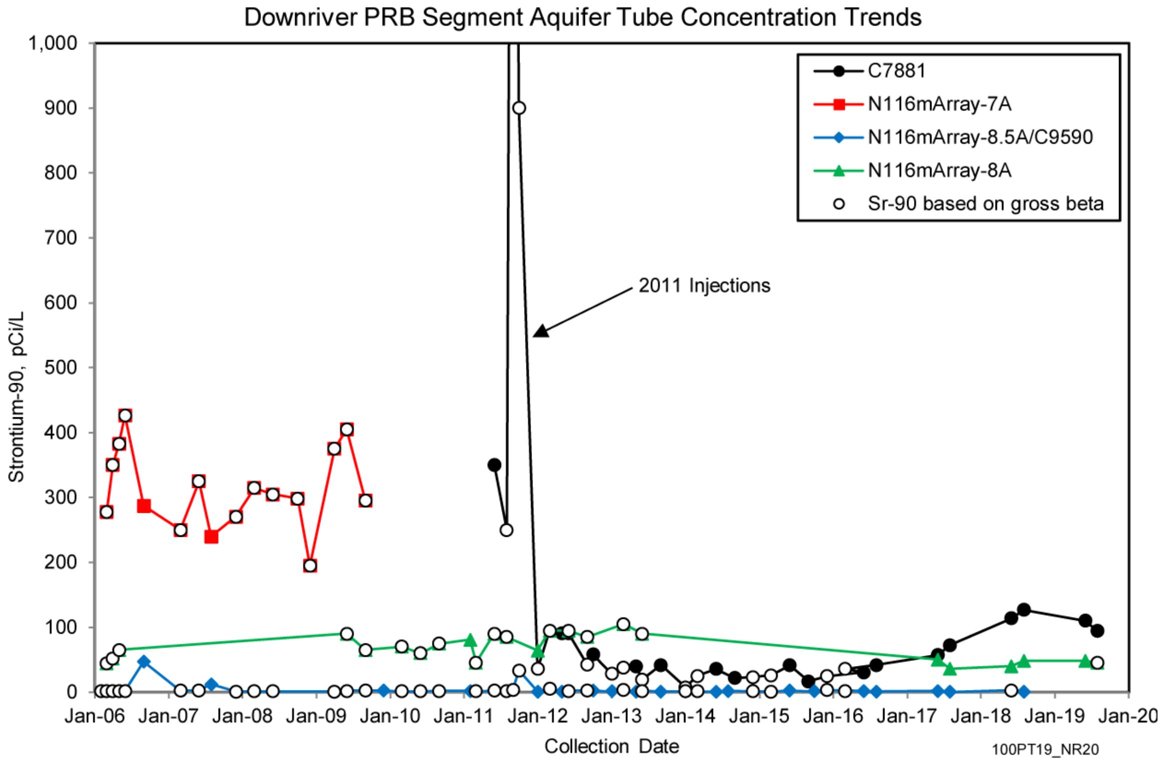
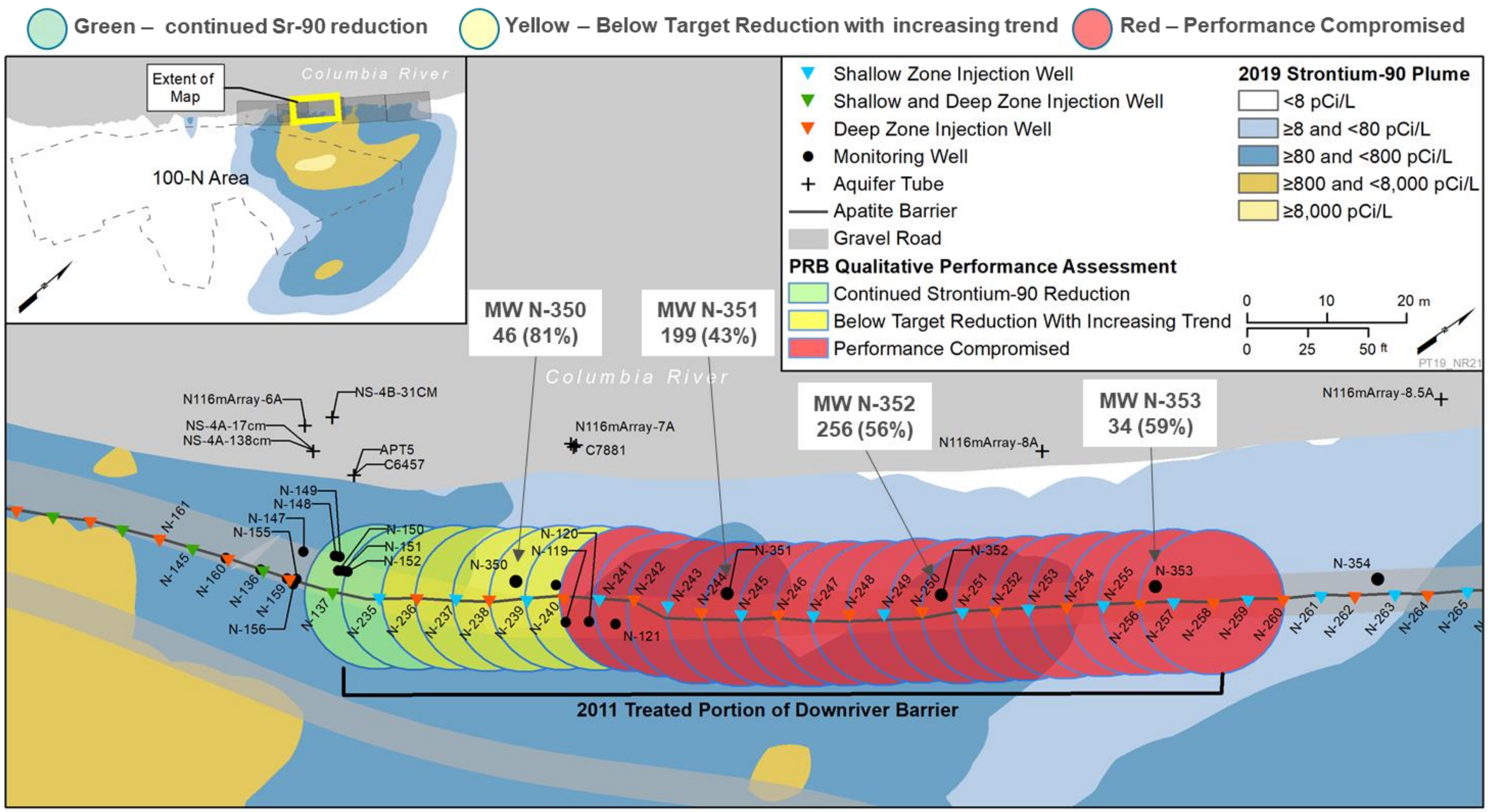


Figure 4-29. Strontium-90 Data for Aquifer Tubes Along the Downriver Segment of the Apatite PRB

4.4.1.4 Summary of Permeable Reactive Barrier Performance Evaluation

Table 4-9 summarizes the qualitative PRB performance evaluation for each treated PRB segment. The PRB performance evaluation for 2019 is summarized as follows:

- **Total length of treated PRB:** 311 m (1,020 ft)
- **Green:** continued strontium-90 reduction; 151 m (495 ft)
- **Yellow:** below target reduction with increasing trend; 60 m (195 ft)
- **Red:** performance compromised; 100 m (330 ft)



Note: Text boxes in the figure show the 2019 yearly average strontium-90 concentrations and percent reduction (in parenthesis) from baseline concentration for permeable reactive barrier monitoring wells.

Figure 4-30. Downriver PRB Segment Performance Assessment, 2019

Table 4-9. PRB Performance Evaluation Summary

Year	Treated PRB Segment	Total Length of Treated PRB		Length Identified as "Green – Continued Sr-90 Reduction"			Length Identified as "Yellow – Below Target Reduction with Increasing Trend"			Length Identified as "Red – Performance Compromised"		
		m	ft	m	ft	% Green	m	ft	% Yellow	m	ft	% Red
2015	Upriver segment	110	360	87	285	79	23	75	21	0	0	0
	Original segment	91	300	91	300	100	0	0	0	0	0	0
	Downriver segment	110	360	28	90	25	32	105	29	50	165	46
	Total treated	**311**	**1,020**	**169**	**555**	**54**	**92**	**300**	**30**	**50**	**165**	**16**
2016	Upriver segment	110	360	87	285	79	23	75	21	0	0	0
	Original segment	91	300	68	225	75	23	75	25	0	0	0
	Downriver segment	110	360	14	45	13	46	150	41	50	165	46
	Total treated	**311**	**1,020**	**169**	**555**	**54**	**92**	**300**	**30**	**50**	**165**	**16**
2017	Upriver segment	110	360	87	285	79	23	75	21	0	0	0
	Original segment	91	300	55	180	60	36	120	40	0	0	0
	Downriver segment	110	360	14	45	13	46	150	41	50	165	46
	Total treated	**311**	**1,020**	**156**	**510**	**50**	**105**	**345**	**34**	**50**	**165**	**16**
2018	Upriver segment	110	360	87	285	79	0	0	0	23	75	21
	Original segment	91	300	55	180	60	36	120	40	0	0	0
	Downriver segment	110	360	14	45	13	46	150	41	50	165	46
	Total treated	**311**	**1,020**	**156**	**510**	**50**	**82**	**270**	**26**	**73**	**240**	**24**
2019	Upriver segment	110	360	87	285	79	0	0	0	23	75	21
	Original segment	91	300	55	180	60	37	120	40	0	0	0
	Downriver segment	110	360	9	30	8	23	75	21	77	255	71
	Total treated	**311**	**1,020**	**151**	**495**	**49**	**60**	**195**	**19**	**100**	**330**	**32**

PRB = permeable reactive barrier

4.4.2 Permeable Reactive Barrier Extensions

Additional treatment to expand the PRB did not occur in 2019. Work to complete the barrier is dependent upon completion of *National Historic Preservation Act of 1966*, Section 106 reviews. Extension of the PRB 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 encompassing the PRB area. Efforts to establish a memorandum of agreement to expand the PRB were initiated in 2015 and will continue during 2020.

4.5 Total Petroleum Hydrocarbons–Diesel Remediation

The primary source of petroleum hydrocarbon contamination to groundwater was a 1966 diesel fuel spill release (UPR-100-N-17) near the former 1715-N storage tanks and 166-N transfer areas (166-N Tank Farm) (Figure 4-31). Residual petroleum hydrocarbons in the vadose zone remain a source of groundwater contamination. Remediation continued in 2019 for the residual petroleum hydrocarbon contamination in the vadose zone and groundwater in the 100-N Area.

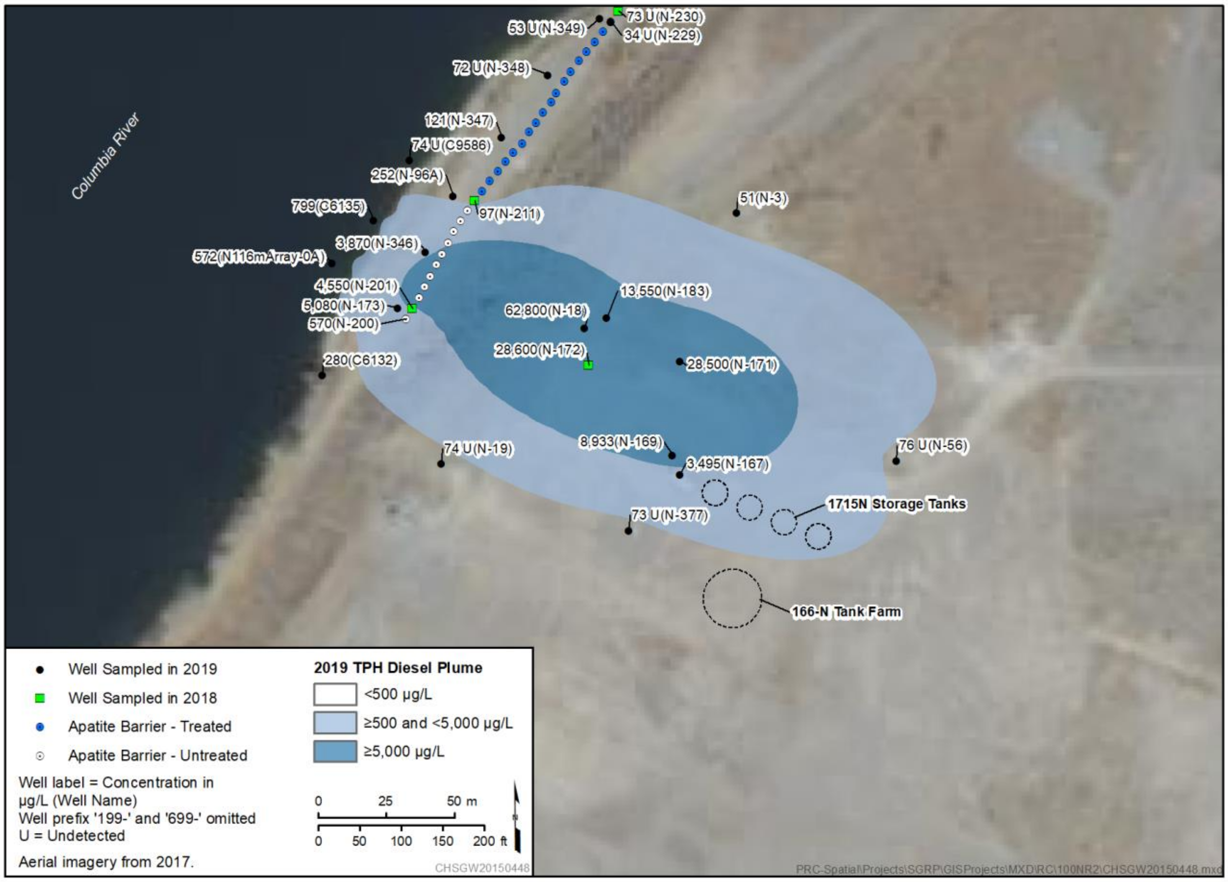


Figure 4-31. 1715-N Storage Tanks and 166-N Tank Farm Facility Locations and TPH Groundwater Plume

4.5.1 Vadose Zone

DOE is using in situ bioventing to remediate TPH-D contamination identified in the deep vadose zone beneath UPR-100-N-17 in the 100-N Area. Oxygen is introduced into the deep vadose zone to promote microbial activity and 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.

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, *Remedial Design Report/Remedial Action Work Plan for the 100-N Area*). Groundwater monitoring samples from the eight performance monitoring wells and three aquifer tubes (N116mArray-0A, C6132, and C6135) were collected in June and November 2019.

Ongoing monitoring will determine the continued effectiveness of bioventing remediation for the TPH-D plume. Table 4-10 shows the TPH-D groundwater concentrations for the eight performance monitoring wells (Figure 4-12). The performance of the full-scale bioventing system is discussed in CHPRC-03726, *Summary of Calendar Year 2017 Bioremediation at the UPR-100-N-17 Waste Site*.

4.5.2 Groundwater

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 interim action ROD (EPA/ROD/R10-99/112) specifies that petroleum hydrocarbons (free-floating product) will be removed if observed in a monitoring well. The Draft B RI/FS (DOE/RL-2012-15) includes an evaluation of remedial alternatives to remediate groundwater petroleum hydrocarbon contamination.

If present as free product, TPH-D in groundwater is found in the shallowest portion of the aquifer or floating on top of the water table (Section 4.4 in 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*). Removal of free product from wells 199-N-18 and 199-N-183 continued during 2019 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, sponges are placed into wells 199-N-18 and 199-N-183 and left to absorb and remediate the diesel. The sponges are weighed prior to placement in each well and again after removal. The weight difference between the first and second measurements is the amount of diesel fuel removed from each well.

Smart sponge assembly use in well 199-N-183 began in 2017 since diesel odor and an oil sheen have periodically been observed in the well during sampling. In 2019, a total of 0.59 kg and 0.64 kg of product were removed from wells 199-N-18 and 199-N-183, respectively (Table 4-11). Diesel removal from wells 199-N-18 and 199-N-183 will continue during 2020.

Table 4-12 provides the TPH-D concentrations in the known diesel plume area for TPH-D monitoring wells identified in the 100-NR-2 OU RD/RAWP (Appendix A of DOE/RL-2001-27) (Figure 4-12). Apatite barrier injections have the potential to displace and dilute the dissolved-phase TPH mass located downgradient of the apatite barrier injection wells. Table 4-13 provides the TPH-D concentrations for the adjacent upriver apatite barrier extension injection and performance monitoring wells and aquifer tubes.

Table 4-10. TPH-D Concentrations (C10–C20) (in 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-377	199-N-56	C6132	N116mArray-0A	C6135
June 2019	1,790	—*	75 (U)	72.1 (TU)	74.3 (J)	8,980 (D)	28,000 (D)	4,960 (D)	14,100 (D)	78.9 (U)	76.5 (U)	280 (N)	449	536
November 2019	5,200 (N)	—*	43 (JN)	76.4 (U)	610	10,000 (N)	29,000 (DN)	5,200 (N)	13,000	72.8 (TU)	75.3 (U)	75 (TU)	572	799

*Well could not be sampled because the well screen split, causing filter pack material to fall in the well above the water level. Repairs will be attempted.

TPH-D = total petroleum hydrocarbons-diesel

Data flags:

D = analyte was identified in an analysis at a secondary dilution factor

J = estimated

N = spike sample outside limits

T = spike and/or spike duplicate sample recovery is outside control limits

U = analyzed for but not detected above reporting limit

Table 4-11. Petroleum Hydrocarbon Removal from Wells 199-N-18 and 199-N-183

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 the 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.
2017	1,500	Sponges were changed out in well 199-N-18 in February, April, July, September, and November, removing a total of 900 g of product in 2017. Installed sponges in well 199-N-183 beginning February 2017 and were changed out in April, July, September, and November, removing a total of 600 g of product in 2017.
2018	2,050	Sponges were changed out in wells 199-N-18 and 199-N-183 in January, March, May, June, August, November, and December. A total of 1,110 g and 940 g of product were removed from 199-N-18 and 199-N-183, respectively, in 2018.
2019	1,230	Sponges were changed out in wells 199-N-18 and 199-N-183 in May, June, August, October, and December. A total of 590 g and 640 g of product were removed from 199-N-18 and 199-N-183, respectively, in 2019.
	Total	**19.8 kg removed through the end of 2019**

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.

Table 4-12. Maximum TPH-D Concentrations in Monitoring Wells

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	199-N-377[a]
1992	NR	200 (U)	NR	N/A	1,000 (U)	NR	NR	N/A	N/A	N/A	N/A
1993	1,000 (U)	67 (J)	NR	N/A	NR	NR	NR	N/A	N/A	N/A	N/A
1994	1,000	4,000	NR	N/A	NR	NR	NR	N/A	N/A	N/A	N/A
1995 to 1998	NR	NR	NR	N/A	NR	NR	NR	N/A	N/A	N/A	N/A
1999	NR	NR	16,000 (D)	N/A	NR	NR	NR	N/A	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	N/A
2001	92 (U)	NR	6,800,000 (D,N)	N/A	NR	50 (U)	NR	N/A	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	N/A
2003	50 (U)	6,500 (N)	630,000,000 (D)	N/A	NR	900	NR	N/A	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	N/A
2005	50 (U)	11,000 (N)	69,000 (D,N)	N/A	50 (U)	610	NR	N/A	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	N/A
2007	50 (U)	33 (U,D,N)	190,000	N/A	50 (U)	50 (U)	NR	N/A	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	N/A
2009	17 (U)	70 (U)	67,000 (D)	N/A	70 (U)	260	2,100	N/A	N/A	N/A	N/A
2010	70 (U)	79 (J)	420,000 (D)	N/A	70 (U)	200	2,100	1,100 (N)	2,800 (N)	3,700	N/A
2011	70 (U)	70 (U)	48,000 (H)	N/A	70 (U)	70 (U)	70 (U)	760	70 (U,N)	NR	N/A

Table 4-12. Maximum TPH-D Concentrations in Monitoring Wells

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	199-N-377[a]
2012	70 (U)	70 (U)	Not sampled[b]	2,100	70 (U)	140	1,900	1,150	4,620	NR	N/A
2013[c]	70 (U)	—[d]	Not sampled[b]	3,350	70 (U)	70 (U)	410	1,370	9,450 (D)	NR	N/A
2014	51 (U)	—[d]	Not sampled[b]	2,600 (T)	112 (J,T)	446 (T)	4,700 (T)	1,920	4,680 (D)	18,000 (D)	N/A
2015	48 (U)	—[d]	Not sampled[b]	2,180 (T)	233 (T)	161 (J,T)	1,280 (T)	576	4,360 (D,T)	6,400 (D)	N/A
2016	47.6 (U)	—[d]	17,200 (DT)	3,300	48.1 (U)	420 (J)	3,600	1,190 (T)	11,900 (D)	3,800 (N)	N/A
2017	48.1 (U)	289[e]	16,600 (D)	7,300 (B)	73 (JB)	1,800 (B)	11,000 (B)	10,000 (DT)	7,280 (DT)	5,300 (D)	1,500 (B)
2018	63 (J)	710	46,900 (D)	13,000 (BDT)	35 (J)	101 (J)	4,800 (BDT)	5,600 (BDT)	19,000	8,000	2,600
2019	75 (U)	102 (JT)	81,900 (D)	14,100 (D)	76.5 (U)	610	5,200 (N)	10,000 (N)	29,000 (DN)	3,880	78.9 (U)

Note: The highest detected result or lowest nondetectable result for the calendar year is reported in this table.

a. Well 199-N-377 was installed in August 2016.

b. Well 199-N-18 was replaced by well 199-N-183 for groundwater sampling.

c. 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.

d. Well 199-N-16 was decommissioned on December 18, 2012.

e. Well 199-N-373 was installed in August 2016 as replacement for well 199-N-16.

N/A = not applicable

NR = not reported

<u>Data flags</u>:

B = analyte was detected in both the associated quality control 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

T = spike and/or spike duplicate sample recovery is outside control limits

U = undetected

Table 4-13. TPH-D Concentrations for Upriver Apatite PRB Injection and Monitoring Wells and Aquifer Tubes

Well	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
199-N-200	2,100	—	—	—	859	—	—	570	—	—
199-N-201	3,500	—	—	—	2,800	17 (U)	—	600	6,900	—
199-N-202	3,200	—	—	—	—	—	—	—	—	—
199-N-203	3,600	—	—	—	—	—	—	—	—	—
199-N-204	3,000	—	—	—	—	—	—	—	—	—
199-N-205	3,200	—	—	—	—	—	—	—	—	—
199-N-206	2,700	—	—	—	—	—	—	—	—	—
199-N-207	17 (U)	—	—	—	—	—	—	—	—	—
199-N-208	1,400	—	—	—	—	—	—	—	—	—
199-N-209	2,200	—	—	—	—	—	—	—	—	—
199-N-210	70 (U)	—	—	—	70 (U)	—	—	50 (U)	2,500	—
199-N-211	17 (U)	—	—	—	—	827	—	166 (J)	118 (J)	—
199-N-212	70 (U)	—	—	—	—	—	—	—	—	—
199-N-213	17 (U)	—	—	—	—	—	—	—	—	—
199-N-214	70 (U)	—	—	—	—	—	—	—	—	—
199-N-215	17 (U)	—	—	—	—	—	—	—	—	—
199-N-216	70 (U)	—	—	—	—	—	—	—	—	—
199-N-217	17 (U)	—	—	—	—	—	—	—	—	—
199-N-218	70 (U)	—	—	—	—	—	—	—	—	—
199-N-219	17 (U)	—	—	—	—	—	—	—	—	—
199-N-220	90 (U)	—	—	—	—	—	—	—	—	—
199-N-221	17 (U)	—	—	—	—	—	—	—	—	—
199-N-222	100 (U)	—	—	—	—	—	—	—	—	—
199-N-223	17 (U)	—	—	—	—	—	—	—	—	—
199-N-224	70 (U)	—	—	—	—	—	—	—	—	—
199-N-225	70 (U)	—	—	—	—	—	—	—	—	—
199-N-226	70 (U)	—	—	—	—	—	—	—	—	—
199-N-227	70 (U)	—	—	—	—	—	—	—	—	—
199-N-228	70 (U)	—	—	—	—	—	—	—	—	—
199-N-229	70 (U)	—	—	—	—	17 (U)	—	48 (U)	—	34 (U)
199-N-230	70 (U)	—	—	—	—	—	—	—	72.8 (U)	—
199-N-231	70 (U)	—	—	—	—	—	—	—	—	—
199-N-232	70 (U)	—	—	—	—	—	—	—	—	—
199-N-233	70 (U)	—	—	—	—	—	—	—	—	—

Table 4-13. TPH-D Concentrations for Upriver Apatite PRB Injection and Monitoring Wells and Aquifer Tubes

Well	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
199-N-234	70 (U)	—	—	—	—	—	—	—	—	—
199-N-96A	200	70 (U)	140	70 (U)	446 (T)	161 (JT)	420 (J)	1,800 (B)	101 (J)	610
199-N-123	—	—	70 (U)	70 (U)	17 (U)	17 (U)	16 (U)	50 (U)	70 (U)	72 (U)
199-N-173	2,100	70 (U)	1,900	410	4,700 (D)	1,280 (T)	3,600	11,000 (B)	4,800 (BDT)	5,200 (N)
199-N-346	3,700	—	—	—	18,000 (D)	6,400 (D)	3,800 (N)	5,300 (D)	8,000	3,880
199-N-347	17 (U)	85 (U)	70 (U)	70 (U)	140 (J)	89.1 (J)	48.1 (U)	50 (TU)	119 (J)	170 (J)
199-N-348	3,800	85 (U)	70 (U)	70 (U)	65.5 (JT)	17 (U)	16 (U)	51 (U)	68 (U)	72.4 (U)
199-N-349	17 (U)	85 (U)	91 (J)	70 (U)	17 (U)	48.1 (TU)	50 (U)	50 (U)	72.8 (U)	71.9 (U)
N116mArray-0A	570	700 (N)	360	880	2,200 (T)	800	126	1,010	754	572
N116mArray-2A	200	85 (U)	70 (U)	80 (U)	120 (J)	17 (U)	17 (U)	50 (U)	69 (U)	77.9 (TU)

Notes:

The highest detected result or the lowest nondetectable result for the 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).

— = well was not sampled for total petroleum hydrocarbons-diesel in the identified year

Data flags:

B = analyte was detected in both the associated quality control blank and in the sample

D = sample was diluted for analysis

J = estimated value

N = spike sample outside limits

T = spike and/or spike duplicate sample recovery is outside control limits

U = undetected

4.6 Demolition of the 100-NR-2 Operable Unit Pump and Treat System

The interim action ROD (EPA, 2010) and the RD/RAWP (DOE/RL-2001-27) included decommissioning, demolition, and removal of the 100-NR-2 P&T system. The 100-NR-2 P&T system was demolished, excavated, and removed from 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 at ERDF. Demolition and decommissioning were completed in 2017 to remove piping from the former injection wells and to demolish the 1323N sample shack (located near the shore of the Columbia River). Extraction wells were converted to support groundwater monitoring prior to the start of demolition, and piping was removed from the injection wells in January 2017. Revegetation and site contouring were completed in December 2019.

4.7 100-NR-2 Operable Unit Remedial Action Costs

This section summarizes the burdened costs for 100-NR-2 OU groundwater remediation for 2019. 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 of the 100-NR-2 OU 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 100-NR-2 OU P&T system.
- **Performance monitoring:** Includes system and groundwater sampling and sample analysis. Sampling activities for routine groundwater monitoring are integrated for all groundwater OUs to reduce overall labor with sample trips and analytical costs. The performance monitoring costs includes an apportionment of the pooled costs based on sample trips and analyses performed for the 100-NR-2 OU.
- **Waste management:** Includes the cost for waste 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 2019 cost breakdown for the 100-NR-2 OU groundwater remediation systems is presented in Table 4-14 and Figure 4-32. The total 2019 remedial action cost was $939,000, with performance monitoring accounting for 80% of the total 2019 cost. Percentages of the 2019 cost for the remaining categories include treatment system capital construction (14%), and project support (6%). Treatment system capital construction costs are associated with revegetation of the 100-N P&T system.

Table 4-14. Breakdown of 100-NR-2 Remediation System Construction and Operation Costs

Description	Actual Costs (Dollars × 1,000)											
	1995–2008	2009	2010	2011	2012	2013	2014[a]	2015	2016	2017	2018	2019
Design	3,872.2	20.5	31.0	—	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Treatment system capital construction	9,302.5	316.2	(0.1)	(32.1)	0.0	0.0	0.0	0.0	796.4[b]	189.0[b]	0.0	128.9[c]
Project support	2,121.8	278.5	276.5	178.9	133.3	284.2	173.9	170.8	68.1	113.7	158.3	54.0
Operations and maintenance	9,411.7	50.2	23.6	30.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Performance monitoring	1,059.1	466.2	956.3	1,069.0	1,801.1	769.3	1,077.1	967.7	624.1	966.1	1,028.0	756.0
Waste management	489.8	3.6	0.5	2.3	0.0	0.0	0.0	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	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	30.1	8.4	0.0
Totals	**$10,632**	**$2,644**	**$3,984**	**$3,212**	**$1,949**	**$1,168**	**$2,331**	**$1,139**	**$1,489**	**$1,299**	**$1,195**	**$939**

a. Barrier maintenance costs for 2014 were associated with preparing and procuring 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 permeable reactive barrier.

b. Treatment system capital construction costs for 2016 and 2017 are associated with decontamination and decommissioning of the 100-NR-2 Operable Unit pump and treat facility.

c. Treatment system capital construction costs for 2019 are associated with revegetation of the former 100-NR-2 Operable Unit pump and treat facility site.

— = not available

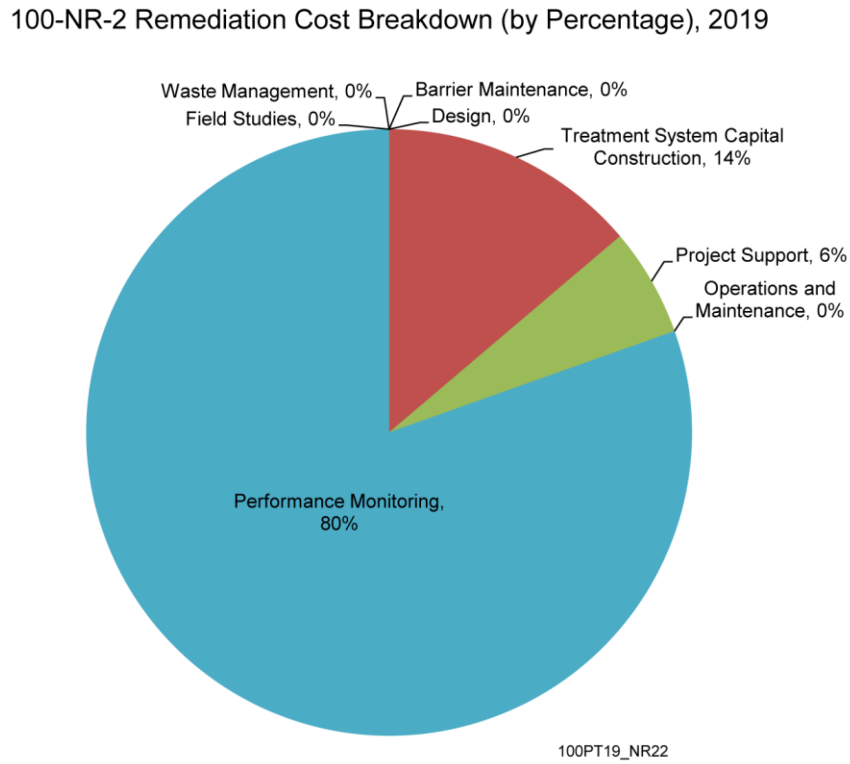


Figure 4-32. 100-NR-2 OU Remediation Cost Breakdown (by Percentage), 2019

4.8 Conclusions

The conclusions for the 100-NR-2 OU interim actions toward achieving the RAOs specified in the interim action ROD (EPA, 2010) are as follows:

- **RAO #1:** Protect the Columbia River from adverse impacts from 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 treated section of the shoreline with the highest historical groundwater contamination. Strontium-90 concentrations in some monitoring wells near the apatite PRB temporarily increased in response to the apatite injections, as was expected. Concentrations in the majority of the monitoring wells during 2019 were lower than pre-injection levels, declining from pre-injection levels by 69% to 97%. However, in 2015, strontium-90 concentrations increased in some monitoring wells and remained elevated, with concentrations in three monitoring wells at pre-injection levels in 2019. DOE plans to reinject apatite into poor-performing sections of the PRB and to expand the PRB in the future once the final action ROD is approved.

  Free product removal and bioremediation continue to reduce TPH contaminant mass in groundwater and the lower vadose zone.

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

  Results: The apatite PRB was installed along the section of the 100-N Area shoreline with the highest historical groundwater contamination. The injection design emplaces sufficient apatite in the PRB to sequester strontium-90 flux to the river for the duration needed for the upland strontium-90 groundwater contamination to naturally decay.

  Smart sponges used in wells 199-N-18 and 199-N-183 removed a total of 1,230 g of TPH-D free product in 2019.

  A full-scale bioventing system for remediating TPH-D in the deep vadose zone near waste site UPR-100-N-17 was implemented in December 2012, and the system continued operating in 2019.

- **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 additional 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 emplacing 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 in the 100-K Area. Additional work regarding these technologies did not occur in 2019.

  Technologies evaluated for remediating strontium-90 are identified in the Draft B RI/FS report for the 100-NR-1 and 100-NR-2 OUs. The Draft B RI/FS (DOE/RL-2012-15) was submitted for review in November 2019 to Ecology (the lead regulatory agency for the 100-NR-1 and 100-NR-2 OUs). The RI/FS will be used to support future cleanup decisions and to prepare a proposed plan and ROD.

- **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 action ROD (EPA/ROD/R10-99/112) established 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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